International Workshop on Radiation Imaging Detectors iWoRID 2014

Sunday 22 June 2014 - Thursday 26 June 2014

Trieste - Italy

Book of Abstracts

Welcome to Trieste!

The Local Organizing Committee is delighted to welcome you to the 16th International Workshop on Radiation Imaging Detectors, iWoRiD 2014, in Trieste, Italy. Despite of the Soccer FIFA World Cup and many other interesting contemporaneous conferences we are pleased that also this year more than 200 scientists have chosen iWoRiD to share their results, exchange ideas and knowledge on position sensitive detectors for radiation imaging.

We have done our best to promote fruitful discussions and a maximum of interactions between attendees: the Scientific Committee has selected state-of-the-art contributions for oral and poster presentations, and our invited speakers were chosen for their significant contributions to their field. Industrial sponsors and exhibitors, who have contributed to detector research or benefited from it, gave us their support and will present their innovative products or services. And finally, we have set up a convivial Triestino social program to foster connections among delegates.

We hope that you will enjoy your participation to this exciting scientific event, and we thank you for your presence!

Renata Longo & Ralf Hendrik Menk

Benvenuti a Trieste!

Il Comitato Organizzatore Locale ha il piacere di darvi il benvenuto al 16° Workshop Internazionale sui rivelatori di radiazione per imaging, iWoRiD 2014, a Trieste. Nonostante il Campionato del Mondo di Calcio e molte altre interessanti conferenze contemporanee siamo lieti che anche quest'anno più di 200 partecipanti hanno scelto questo workshop per condividere i loro risultati, scambiare idee e conoscenze sui rivelatori di radiazione per l'imaging.

Noi abbiamo fatto del nostro meglio creare un evento adatto a promuovere discussioni fruttuose e occasioni di conoscenza e scambio tra i partecipanti. Il comitato scientifico ha selezionato per le presentazioni orali e per i poster le ricerche piu' innovative ed i nostri relatori su invito sono stati scelti per i loro significativi contributi nei rispettivi ambiti di ricerca. Gli sponsor e gli espositori industriali, che hanno contribuito alla ricerca sui rivelatori o ne hanno beneficiato, ci hanno dato il loro sostegno e presenteranno i loro prodotti o servizi innovativi. E, infine, abbiamo organizzato un programma sociale "Triestino" per favorire una frequentazione anche conviviale tra i delegati.

Ci auguriamo la vostra partecipazione a questo entusiasmante evento scientifico sia all'altezza delle vostre aspettative e vi ringraziamo per la vostra presenza!

Renata Longo & Ralf Hendrik Menk

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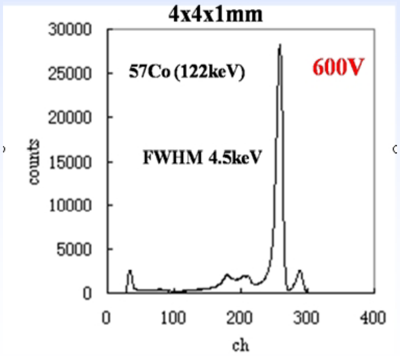
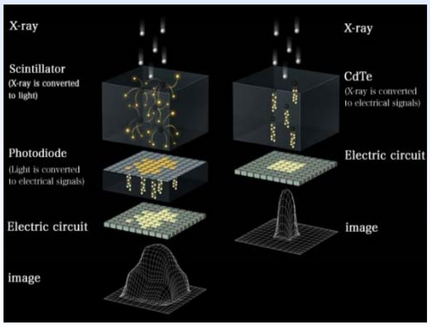
Characteristics of CdTe detector:

High energy resolution
Room temperature operation
Direct conversion from radiation to electric signal
Very sharp image (X-ray imager)

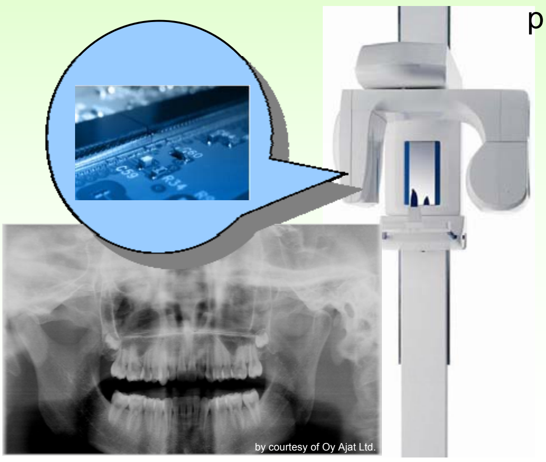




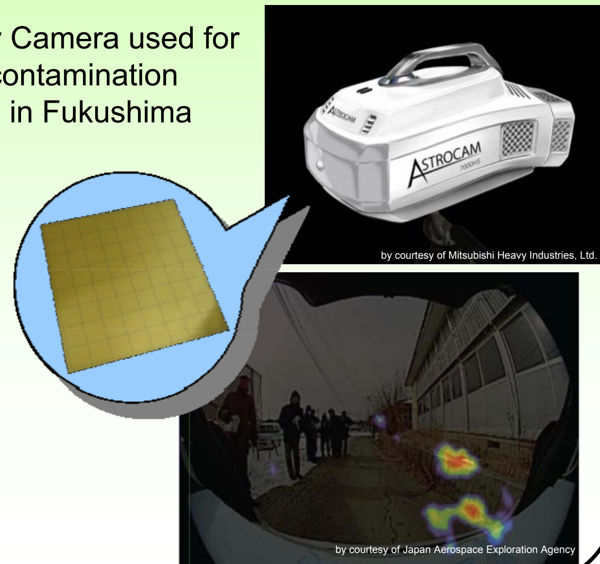
Application examples of Acrorad's CdTe detectors:

Medical: Dental Panorama System, Bone densitometer, PET
Industry: Non-Destructive Testing, Gamma-ray camera for decontamination
Security: Luggage Inspection System
Science: Astrophysics (Gamma-ray telescope), X-ray diffractometer

Dental Panorama System



Gamma-ray Camera used for the decontamination program in Fukushima



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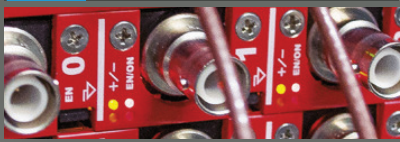

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- Infrastructure for management of Rear Transition Module (RTM) boards
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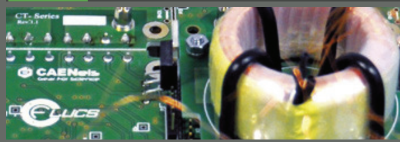

- Precision current measuring transducers with closed-loop current transformer technology (Zero Flux technology)
- Galvanic isolation between primary and secondary conductor
- Current-Output and Voltage-Output versions available

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- TURN-KEY Solutions for Photon Beam Position Monitors and Power Supply Systems for Optics
- Low Noise and High Resolution
- Ethernet Connectivity
- Firmware Remote Update

Magnet Power Supply Systems

- Digital Current Regulation Loop: easiness to adapt to any load condition
- High Modularity and Extreme Configurability
- Ethernet Connectivity
- Firmware Remote Update

CAEN ELS d.o.o.

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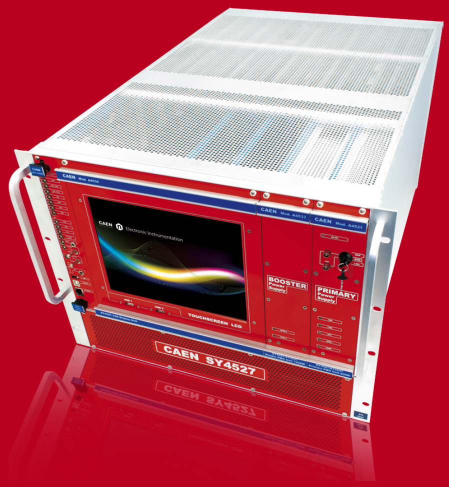

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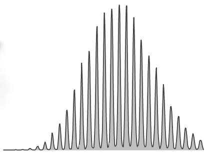
KETEK SiPM News

Silicon Photomultipliers for
Low Level Light Applications



High Performance SiPM

with best-in-class blue light sensitivity

KETEK is further expanding its SiPM portfolio with very high photon detection efficiency, especially in the blue range:

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- Low temperature coefficient of the gain (< 1 % / K)
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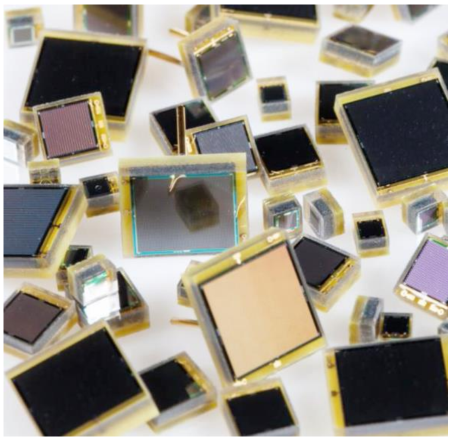
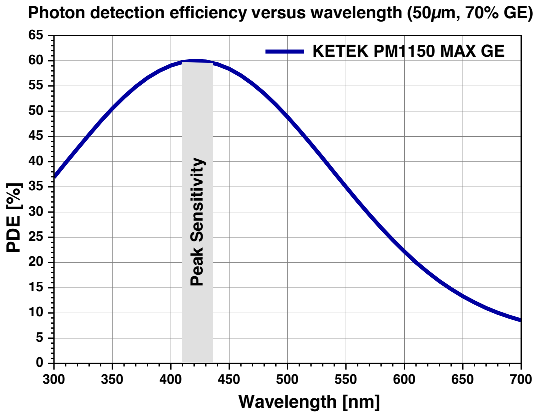
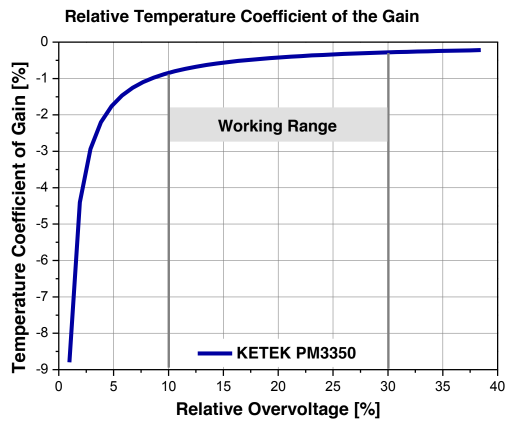
- Active areas from 1.4 mm^2 to 36.0 mm^2 in
- Pin- and SMD packages







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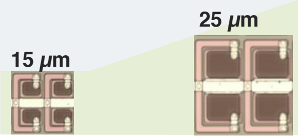

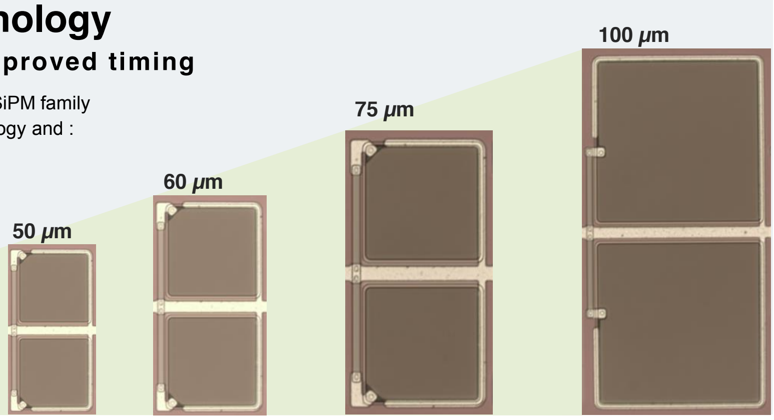

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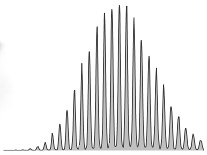
KETEK SiPM News

Silicon Photomultipliers for
Low Level Light Applications



Type	Active Area [mm²]	Cell Pitch [µm]	Geometrical Efficiency [%]	PDE @ 420 nm [%]	Dark Rate @ 20% OV [MHz]	Package Size [mm²]	Connection	Order Code
KETEK Standard SiPM Modules								
PM11	1.2 x 1.2	25	48	≥ 30	< 0.18	2.0 x 2.5	SMD	PM1125NS-SB0
	1.2 x 1.2	50	70	≥ 54	< 0.4	2.0 x 2.5	SMD	PM1150NS-SB0
PM22	2.0 x 2.0	50	70	≥ 45	< 2.0	2.8 x 3.3	SMD	PM2250NS-SB0
PM33	3.0 x 3.0	50	70	≥ 50	< 4.5	3.8 x 4.3	SMD* Pin	PM3350NS-SB0 PM3350NP-SB0
KETEK SiPM Modules with Optical Trench Isolation								
PM11	1.2 x 1.2	50	63	≥ 50	< 0.4	2.0 x 2.5	SMD	PM1150TS-SB0
	1.2 x 1.2	75	72	≥ 60	< 0.8 [1]	2.0 x 2.5	SMD	PM1175TS-SB0
	1.2 x 1.2	100	80	≥ 63	< 0.6 [2]	2.0 x 2.5	SMD	PM11100TS-SB0
PM22	2.0 x 2.0	50	63	≥ 48	< 2.0	2.8 x 3.3	SMD	PM2250TS-SB0
	2.0 x 2.0	100	81	≥ 50	< 2.0	2.8 x 3.3	SMD	PM22100TS-SB0
PM33	3.0 x 3.0	50	63	≥ 48	< 0.5	3.8 x 4.3	SMD Pin	PM3350TS-SB0 PM3350TP-SB0
	3.0 x 3.0	60	68	≥ 60	< 0.5 [3]	3.8 x 4.3	SMD* Pin	PM3360TS-SB0 PM3360TP-SB0
	3.0 x 3.0	75	72	≥ 62	< 0.5 [1]	3.8 x 4.3	SMD Pin	PM3375TS-SB0 PM3375TP-SB0
PM66	6.0 x 6.0	60	66	≥ 42	< 18	6.8 x 7.8	SMD Pin	PM6660TS-SB0 PM6660TP-SB0

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Kyma was established in 2007 as a joint venture between Elettra Sincrotrone Trieste S.C.p.A. and the industrial companies Cosylab d.d. (Ljubljana) and Euromisure Sas (Cremona). More than twenty years of experience in design, assembling, characterization and operation of insertion devices at Elettra Synchrotron met the manufacturing capabilities of industrial partners to build up a world class company for insertion devices design and manufacturing.

The Kyma head office is located in the premises of the Elettra Laboratory, Area Science Park, Trieste, while a fully equipped temperature controlled laboratory for assembling and magnetic characterization is situated in the Technology Park of Sežana, a town just 10 km from Elettra.

A further lab for mechanical design, assembly and characterization is operating at Euromisure.
The competencies and resources available at Kyma allow the realization of top performing insertion devices at competitive prices and unexpectedly short delivery times.

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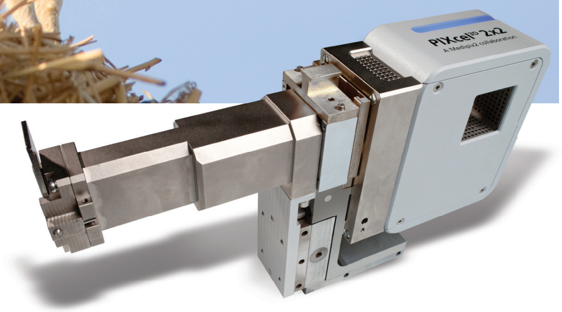

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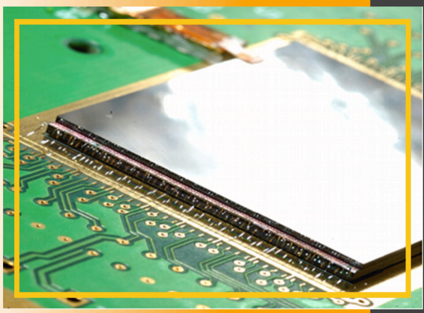

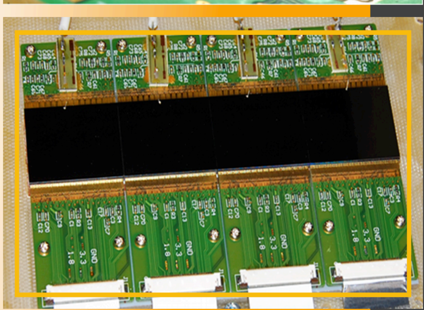

PIXIRAD is a **INFN Spin-off** introducing an **innovative**, **high quality X-ray imaging sensor** based on **Chromatic Photon Counting technology.**

It represents a radical leap forward compared to the standard methods currently available on the market.

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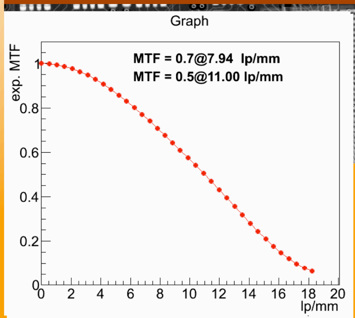
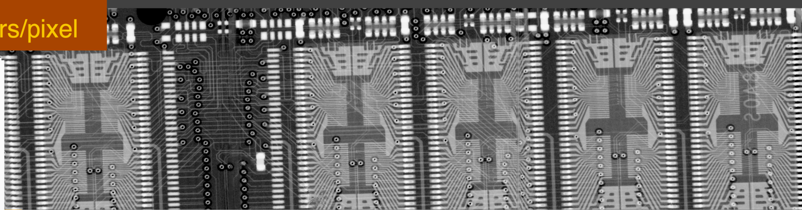
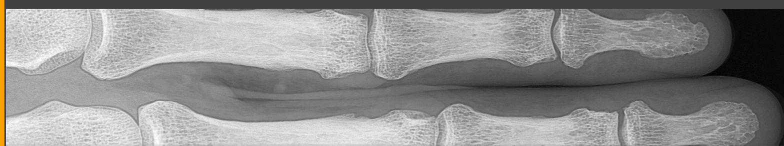
The individual **PIXIRAD block** is a two-side buttable semiconductor radiation detector made of a thin pixellated CdTe crystal coupled to a large area VLSI CMOS pixel ASIC (512×476 pixels).

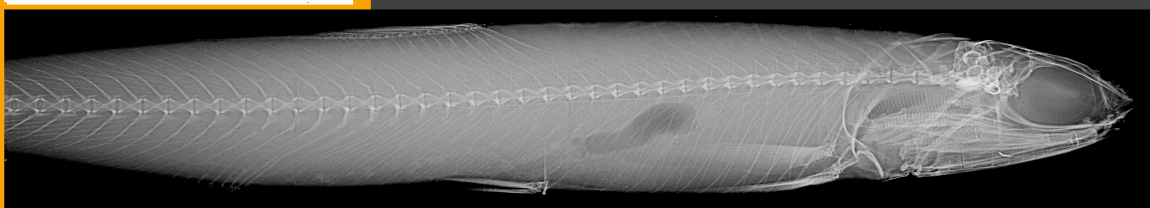
Characteristics (4 tiles):

12.3 × 2.5 cm^2 image area, 1 Mpixels
60 μm pixel pitch (hexagonal pattern)
2.5 pixels dead space
> 150 frames/s, two 15 bits ctrs/pixel





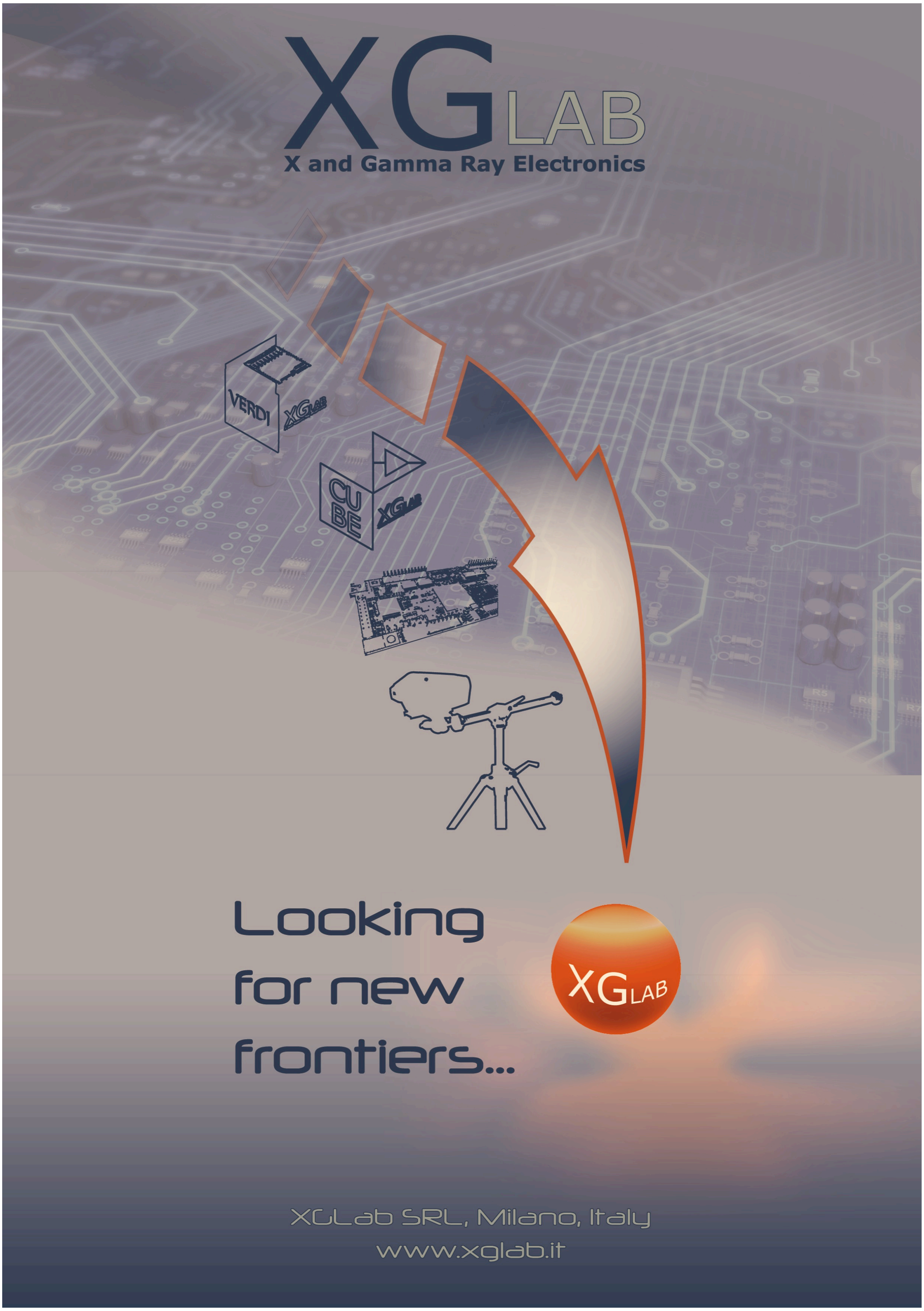




PIXIRAD is able to deliver extremely clear and highly detailed images for medical, biological, industrial and scientific applications. 1,2,4,8 tile units are available.

(Contacts:pixirad1@gmail.com, see more at http://pixirad.pi.infn.it

INFN Spin-off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Honorary talk / 183

Sensors and Electronics Integration Frontier: From Photographic to Electronic Bubble Chambers and Beyond

RADEKA, Veljko [1]

[1] *Brookhaven National Lab*

Corresponding Author: radeka@bnl.gov

Developments of particle and photon detectors have paralleled developments in electronics over the last half century. I will provide a brief glimpse on the origin of some detectors which are likely to continue playing an important role in the next few decades. understand detectors as being comprised of sensors and electronics. The technologies of the two have become increasingly intertwined over the last two decades, and it is this close integration that has made possible all the most productive detectors in science. Among sensor and electronics technologies I will address silicon detectors and vertically integrated microelectronics, monolithic active pixel sensors, silicon photo multipliers (SiPMs), gas and noble liquid time projection chambers (TPCs), including cryogenic electronics. A question often asked these days is about the future of microelectronics technology: "Beyond CMOS?". There is a considerable activity in industry and at universities in exploring different device principles, increasingly in the domain of nanotechnology, in the quest for smaller and faster devices with lower power. I will illustrate some of these in the context of the requirements such new devices will have to satisfy if they are to replace fully CMOS technology. I will conclude with suggesting how the sciences based on radiation detectors might make use of developments in microelectronics technology.

Invited talk / 175

Neutron Detectors for the European Spallation Source

HALL-WILTON, Richard [1]

[1] *European Spallation Source ESS AB*

Corresponding Author: richard.hall-wilton@esss.se

The European Spallation Source (ESS) in Lund, Sweden will become the world's leading neutron source for the study of materials by 2025. First neutrons will be produced in 2019. It will be a long pulse source, with an average beam power of 5 MW delivered to the target station. The ESS is just entering the construction phase, which started in 2013 with the completion of the Technical Design Report (TDR). The instruments are being selected in yearly rounds selected from conceptual proposals submitted by groups from around Europe. These instruments present numerous challenges for detector technology in the absence of the availability of Helium-3, which is the default choice for detectors for instruments built until today and due to the extreme rates expected across the ESS instrument suite. Additionally a new generation of source requires a new generation of detector technologies to fully exploit the opportunities that this source provides. To meet this challenge at a green-field site, the detectors will be sourced from partners across Europe through numerous in-kind partners. This contribution presents briefly the current status of detectors for the ESS, and outlines the timeline to completion. For a conjectured full instrument suite, which has been chosen for demonstration purposes for the TDR, and updated based upon chosen instruments and submitted instrument concepts, a recently updated snapshot of the current expected detector requirements is presented. A strategy outline as to how these requirements might be tackled by novel detector developments is shown, with a focus on applications with higher resolution requirements.

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Road to Direct Electron Detectors for near-Atomic Resolution Electron Cryo-Microscopy

Author: FARUQI, Wasi Faruqi [1]

Co-Authors: MCMULLAN, Greg [2]; HENDERSON, Richard [2]

[1] *MRC Laboratory of Molecular Biology, Cambridge, UK*

[2] *MRC Laboratory of Molecular Biology*

Corresponding Author: arf@mrc-lmb.cam.ac.uk

The quest for direct detectors for electron microscopy was initiated in our laboratory shortly before the 2nd iWoRID in Freiburg (2000). It was clear by that time that 'indirect' detection methods, such as are used in phosphor fibre optics coupled CCDs could not attain the highest values of DQE at all spatial frequencies, essential for high resolution imaging using 300keV electrons. Encouraged by developments in semiconductor detectors, particularly in CERN, we started investigations into their suitability for electron microscopy as 'direct detectors'. I will give a brief overview of some of the stages in the design of electron detectors initially with Medipix1 followed closely by Medipix2 and finally CMOS based monolithic active pixel sensors (MAPS)[1]. There were a number of fundamental limitations in the design of hybrid technology, such as the inability to carry out backthinning, necessary for optimum performance at 200 – 300 keV. Theoretical considerations and preliminary tests indicated that CMOS based monolithic active pixel sensors may have the necessary properties. This has indeed proven to be the case but several improvements, in hardware design and processing software, were essential to obtain the dramatic improvements in performance reported here [2, 3]; results were obtained with Falcon II, a backthinned detector from FEI[4]. Two main factors, which contributed to the improvements were the high DQE and the minimising of effects due to specimen movement during imaging by recording in a 'movie-mode' [5]. Some of the most recent structures include the yeast mitochondrial ribosome at 3.2 Å and the F420-reducing [NiFe] hydrogenase at 3.36 Å, reviewed recently [6].

1) A.R. Faruqi, G. McMullan, Electronic detectors for electron microscopy, Q. Rev. Biophys., 44 (2011) 357-390
2) A.R.Faruqi, R.Henderson., G.McMullan, Recent Developments in Direct Electron Detectors for Electron Cryo-Microscopy, in: Proceedings of Science (Vertex 2013), http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=198, 2013, pp. 1-11
3) N. Guerrini, R. Turchetta, G. Van Hoften, R. Henderson, G. McMullan, A.R. Faruqi, A high frame rate, 16 million pixels, radiation hard CMOS sensor, JINST, 6 C03003 (2011).
4) http://www.fei.com/
5) X.-c. Bai, I. Fernandez, G. McMullan, S. Scheres, Ribosome structures to near-atomic resolution from thirty thousand cryo-EM particles, eLife, 2 (2013)
6) W. Kühlbrandt, The Resolution Revolution, Science, 343 (2014) 1443-1444

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Direct electron imaging of EBSD patterns using a Timepix detector

Author: VESPUCCI, Stefano [1]

Co-Authors: NARESH-KUMAR, Gunasekar [2]; EDWARDS, Paul R. [2]; MANEUSKI, Dima [3]; O'SHEA, Val [4]; DAY, Austin P. [5]; MINGARD, Ken P. [6]; WINKELMANN, Aimo [7]; TRAGER-COWAN, Carol [2]

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[4] *University of Glasgow*

[5] *Aunt Daisy Scientific Ltd, Claremont House, High St, Lydney, GL15 5DX, UK*

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Electron backscatter diffraction (EBSD) is a scanning electron microscope (SEM) technique used to obtain accurate crystallographic information from bulk materials, thin films and nanoparticles, ranging from metals, to rocks, to ceramics, to semiconductors, on the nanometer scale [1]. An EBSD detector typically consists of a high sensitivity CCD camera, lens and phosphor screen [1]. The detector is placed in front of the specimen, which is tilted at ≈ 70 degrees. When a focused electron beam strikes a point on the specimen surface, an EBSP, consisting of overlapping Kikuchi bands (diffraction cones from different crystal planes), is produced. The phosphor converts the EBSP signal into light, which is then imaged by the camera. These electrons to light (phosphor) and light to electron (camera) conversions are very inefficient and limit the sensitivity of EBSD detectors. Direct electron detection methods are the next logical step.
Our current understanding of EBSD is that the predominant contribution to the EBSP formation comes from electrons within a narrow energy range. Work based on the use of an electrostatic energy filter in EBSD imaging has shown that the largest contribution to the EBSD pattern may be attributed to electrons having an energy within 10% of the energy of the primary electron beam [2]. The contrast in the diffraction features reaches a maximum when the energy of the filter is set at around 3% below the energy of the primary electron beam [2].
In this presentation we will report the progress made in using a Timepix detector [3] installed in an FEI Sirion field emission SEM for the direct, energy filtered acquisition of EBSPs. Energy filtered EBSPs show an increase in the contrast and detail contained in the pattern, which is not visible using the conventional existing technologies. Improved contrast may enable the application of the EBSD technique to a wider range of materials for which the conventional EBSD analysis is currently problematic.

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Diamond particle detectors systems in high energy physics

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With the first three years of the LHC running complete, ATLAS and CMS are planning to upgrade their innermost tracking layers with more radiation hard technologies. Chemical Vapor Deposition (CVD) diamond is one such technology. CVD diamond has been used extensively in beam condition monitors as the innermost detectors in the highest radiation areas of BaBar, Belle, CDF and all LHC experiments. This talk will describe the lessons learned in constructing the ATLAS Beam Conditions Monitor (BCM), Diamond Beam Monitor (DBM) and the CMS Pixel Luminosity Telescope (PLT) all of which are based on CVD diamond with the goal of elucidating the issues that should be addressed for future diamond based detector systems. The talk will also present the first beam test results of prototype diamond devices with 3D detector geometry that should further enhance the radiation tolerance of this material.

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PIXIE III: a very large area photon-counting CMOS pixel ASIC for sharp X-ray spectral imaging

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PIXIE III is the third generation of very large area (32x25 mm2) pixel ASICs developed by PiXirad Imaging Counters srl to be used in combination with suitable X-ray sensor materials (Silicon, CdTe, GaAs) in hybrid assemblies using flip-chip bonding. The chip, fabricated in 0.16 micron CMOS technology, is organized as a matrix of 512x402 square pixels at 62 microns pitch. Each pixel incorporates an octagonal electrode (top layer of metal) connected to a charge-sensitive shaping amplifier feeding two discriminators and two 15-bit counter/registers allowing to collect two color images in a single exposure.
The ASIC can be configured in several modalities, the most important being:
1)Pixel mode (PM)
In this modality each pixel counts independently from the others.
The pixel works in windowed counting mode and each counter can be read-out in less than 1 ms, allowing for very high frame rates. PM is the modality showing the highest count rate capability (higher than 1 MHz input rate per pixel) but it could suffer for some multiple counts effect when working at very low thresholds with polychromatic beams. The sharpness of the color separation is limited by the tail of the pixel charge collection efficiency due to charge leak to neighbor pixels because of diffusion.
2)Neighbor Pixel Inhibit mode (NPI)
In this modality only one counter per event is allowed to count. This is accomplished exploiting the duration (Time-Over-Threshold) of the discriminator output pulse. In case of an event spreading over several pixels, the hit is allocated to the pixel receiving the highest fraction of the total charge.This modality has the highest position resolution and the lowest possible noise,but the problem of the sharpness of the color separation is not completely solved yet.
3) Pixel Summing Mode (PSM)
In PSM mode the signals of 4 neighbor pixels are summed together in each pixel to correctly evaluate the total energy of any event involving up to 4 pixels. Because this evaluation is performed in each pixel, i.e. at the same pitch of 62µm in both X directions, the PSM mode, when used in combination with NPI, ensures that both the spatial accuracy and energy resolution are finally preserved. A factor 2 increase of the pixel noise and a factor 4 increase of pulse pile-up is the unavoidable trade-off.
In this presentation we will discuss results obtained with PIXIE III both in a test bench set-up as well in X-ray imaging applications with real detectors.

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Looking at single photons using hybrid detectors

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The single photon counting detectors developed by the SLS Detectors group MYTHEN, PILATUS and more recently EIGER operate at synchrotron facilities all over the world. They provide a high data quality and allow reliable operation for the users. Since the only source of noise in the images comes from the Poisson fluctuations on the number of X-rays and their dynamic range is virtually infinite, photon counters are optimal for experiments where a small signal must be detected over a large background. However they present some limitations which can only be partially overcome by technological improvements i.e. the count loss at high impinging intensities, due to the shaping time of the frontend electronics, and the restrictions on the minimum pixel size, due to the charge diffusion in the sensor.

In the last few years, charge integrating detectors with single photon sensitivity and large dynamic range have also been developed, mainly motivated by XFEL applications. With low fluxes and high frame rates, detectors as GOTTHARD, JUNGFRAU and MOENCH can be operated in single photon regime i.e. with less than one photon per pixel detected on average. The analog information read out for each single X-ray can then be exploited to mimic the photon counting behavior and to improve the data quality. The spectrum of the detected radiation can be measured with an energy resolution limited by the electronic noise. Moreover, in the case of small pitches, the charge sharing can be exploited to enhance the spatial resolution by means of interpolation.
As an example, with an energy resolution better than 130 eV, MOENCH can be used in energy dispersive spectroscopy. Micrometric resolution is also achieved using GOTTHARD or MOENCH for imaging.

An overview of the detectors developed by the SLS Detectors group will be given. In particular, the performances of charge integrating detectors operated in single photons regime will be compared to those of photon counters. The new possibilities opened by analog detectors will be discussed together with the challenges given by the huge data throughput and by the precise calibration required.

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Measurement of the Spatial resolution of the MÖNCH 25 micron hybrid pixel detector

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MÖNCH is a 25 μm pitch hybrid silicon pixel detector with a charge integrating analog read-out front-end within each pixel. Its low-noise read-out chain allows spatial interpolation with high resolution. The small pixel size brings new challenges in bump-bonding technique, in power consumption and chip-design in general.
The MÖNCH02 a prototype ASIC, manufactured in UMC 110nm technology with a field of view (FOV) of 4x4mm^2 and 160x160^2 pixels, has been characterized in single photon regime i.e. with less than a photon acquired on average on a 3x3 pixel cluster.
The low noise and small pixel size allow allows spatial interpolation with high resolution.

In the present study, the spatial resolution of the MOENCH detector has been measured by acquiring images of a sharp edge at the SYRMEP beamline of Elettra.
The performance of the detector has been characterized as a function of the X-ray energy (from which depend the SNR and the average photon absorption depth) and of the sensor bias (on which depend the charge collection time). Different position-finding algorithm approaches are also investigated. In particular the issues arising from 2D image reconstruction will be discussed, compared to the experiments performed previously in 1D using GOTTHARD.

To further characterize the charge collection of the detector, the sensor was illuminated with a 20 keV photon beam in edge-on configuration.
By vertically slicing the beam by means of a 5 mu slit and scanning through the 320um silicon sensor depth, the charge collection is characterized as a function of the photon-absorption depth for different bias voltages.

The results obtained using the present prototype in terms of noise and spatial resolution, motivate the development of a larger detector (MÖNCH03) with a FOV of 1x1cm^2 (160k pixels) for energy dispersive spectroscopy and high resolution imaging.

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HyPix-3000 - A large area single-photon counting detector with two discriminator thresholds

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We present a newly developed large area, single photon counting X-ray camera for in-house XRD named HyPix-3000. The active area of 77.5 mm x 38.5 mm (approx. 3000 mm^2) consists of 298375 pixels. High spatial resolution is achieved by 100 μm pitch square-shaped pixels. Each pixel comprises two independent discriminators followed by two independent 16-bit-long counters. The pixels support three different operation modes: differential (two independent images), ultra-high dynamic range (single 31-bit-long counter) or zero dead time (single 16-bit-long counter with memory). They allow effective background noise suppression and measurements of very strong reflections. The readout time is 3.7 ms in differential and ultra-high dynamic range modes, and 0 ms in zero dead time mode. HyPix-3000 can handle more than 2.9x10^11 cps per active area (more than 1x10^6 cps/pixel) and has 99% efficiency with Cr, Fe, Co and Cu characteristic x-ray energies with resolution better than 25% at Cu Kα. The camera also works in Time Delay and Integration (TDI) mode, and can be used for conventional scanning with 0D or 1D detector mode.
High-resolution two-dimensional measurement of rocking curve profiles of InGaN/GaN using no attenuator was performed with HyPix-3000 and conventional scintillation counter. With ultra-high dynamic range mode, HyPix-3000 shows no saturation of the counter with the intensity of more than 1x10^6 cps/pixel. By introducing the shutterless operation in the zero dead time mode, in which no photon is essentially lost, in situ and time resolved measurement can be easily performed. In situ exposure of ceramic in zero dead time mode was performed. The phase transition with intermediate phase images was successfully captured. We also performed a measurement of reciprocal space map of a (Pb, La)TiO_3 (PLT) oriented film on a Pt based layer and Si substrate, where the data collection of the map was done in only 10 minutes.

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Energy Resolving Imaging with Large Area Pixel Detector WIDEPIX

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The recently introduced particle counting pixel detector WIDEPIX 10x10 with resolution of 2560 x 2560 pixels (6.5 Mpixels) and continuously sensitive area is composed of a matrix of sensitive detector tiles. Each tile consists of single Timepix hybrid detector (256 x 256 pixels) with edgeless silicon sensor. Every pixel has integrated discriminator and digital counter which counts number of particles (e.g. X-ray photons) with energy over certain preselected threshold level. The particle counting principle assures noiseless registration of particles without added noise. The intrinsic energy sensitivity of the device can be applied in field of X-ray radiography for material sensitive imaging such as K-edge imaging technique.

The effective usage of WIDEPIX device for energy sensitive imaging requires optimization of the detector and system parameters. Assuring homogenous settings of the energy threshold level in the whole detector area is of special importance. Each Timepix device has integrated DAC for common threshold settings. Furthermore, each pixel allows local adjustment of the threshold value using 4-bit DAC. Thus, the whole WIDEPIX detector has in total 100 threshold DACs for all its tiles and 6.5 millions of local adjustments for individual pixels. The optimal settings of all these parameters has to be determined for certain target energy threshold (e.g. K-edge energy). The process searching for optimal setting of local threshold adjustments is usually called a “threshold equalization”. It presents very complex task especially when several target threshold levels are needed in color radiography.

Current equalization techniques use signal of (i) noise, (ii) analog test pulses or (iii) monochromatic irradiation. The common problem of these methods is difficult settings of arbitrary target energy.

In this work we present a very fast and flexible routine allowing to perform full optimization of the large multidetector system such as WIDEPIX device for any target energy threshold. This procedure is very general and it can be used for other similar detectors such as Medipic2 or Medipx3. It doesn’t require any radiation source other than X-ray tube. The optimized energy spectra recorded with WIDEPIX device and few other and several energy sensitive radiograms will be shown in the presentation.

This work is carried out in frame of the Medipix Collaboration.

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Foil-based X-ray detector with amorphous oxide TFTs and organic photodiodes

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Currently nearly all large area X-ray detectors in the medical field are using amorphous silicon (a-Si) large area electronics on a glass plate. We investigated the possibility of a 'glass-less' X-ray detector made on plastic foil substrate. Instead of using glass a foil-based detector could enable an extremely light weight, robust, and finally even flexible portable detector with many expected benefits in terms of workflow and patient comfort.

We demonstrate a device using an array of high-mobility amorphous oxide thin-film transistors (AOS-TFTs) integrated with organic photodiodes (OPD). To our knowledge this is the first X-ray detector combining these two large area electronics technologies. Both processes can be run at temperatures below 150°C and are therefore compatible with plastic foil. Optical images and, using a scintillator, also X-ray images are shown with a PEN-foil based device of QQVGA-format having 120 x 160 pixels of 126 µm size. The heterojunction OPDs are made by coating a specific polymer-fullerene blend that exhibits a very low dark current of only 1 pA/mm2. In contrast to earlier work featuring a-Si or organic TFTs (OTFTs) on foil, we used amorphous oxide (Indium Gallium Zinc Oxide, IGZO) TFTs, which can be made with much higher mobility. Dynamic imaging with several frames per second could be demonstrated. The IGZO TFTs are currently made by sputtering techniques, but in future also solution processing will become possible. The radiation hardness of our integrated arrays was tested up to the expected lifetime dose of a radiographic X-ray detector.

The final goal is to realize a full size detector of more than 30 x 40 cm2. Although still work has to be done to achieve this goal, we do not see any severe roadblocks in upscaling the used processes to this size, so that we envision a cost efficient production of future foil-based X-ray detectors.

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The MAPS based PXL vertex detector for the STAR experiment

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The Heavy Flavor Tracker (HFT) was installed in the STAR experiment for the 2014 heavy ion run of RHIC. Designed to improve the vertex resolution and extend the measurement capabilities in the heavy flavor domain, the HFT is composed of three different silicon detectors based on CMOS monolithic active pixels (MAPS), pads and strips respectively, arranged in four concentric cylinders close to the STAR interaction point.

The two innermost HFT layers are placed at a radius of 2.7 and 8 cm from the beam line, respectively, and accommodate 400 ultra-thin (50 um) high resolution MAPS sensors arranged in 10-sensor ladders to cover a total silicon area of 0.16 m2. Each sensor includes a pixel array of 928 rows and 960 columns with a 20.7 µm pixel pitch, providing a sensitive area of ~ 3.8 cm2. The architecture is based on a column parallel readout with amplification and correlated double sampling inside each pixel. Each column is terminated with a high precision discriminator, is read out in a rolling shutter mode and the output is processed through an integrated zero suppression logic. The results are stored in two SRAM with ping-pong arrangement for a continuous readout. The sensor features 185.6 µs readout time and 170 mW/cm2 power dissipation.

The detector is air-cooled, allowing a global material budget of 0.50% radiation length per layer. A novel mechanical approach to detector insertion enables effective installation and integration of the pixel layers within an 8 hour shift during the on-going STAR Run.

After a detailed description of the detector characteristics, the experience of the first months of data taking will be presented in this talk, with a particular focus on sensor threshold calibration, latch-up protection procedures and general system operations aimed at stabilizing the running conditions. Issues faced during the 2014 run will be discussed together with the implemented solutions. A preliminary estimation of the detector performance meeting the design requirements will be reported.

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The ALPIDE pixel chip development for the upgrade of the ALICE Inner Tracking System

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The ALICE experiment at CERN will undergo a major upgrade in the second Long LHC Shutdown in the years 2018-2019; this upgrade includes the replacement of the Inner Tracking System (ITS), deploying seven layers of Monolithic Active Pixel Sensors (MAPS).
For the development of the new ALICE ITS, the TowerJazz 180nm CMOS imaging sensor process has been chosen as it is possible to use full CMOS in the pixel and different starting materials (including high resistivity epitaxial layers).
The ALPIDE (ALice PIxel DEtector) pixel chip is one of the candidate sensors to instrument the new ITS. This development is carried out by a collaboration formed by CCNU (Wuhan, China), CERN, INFN (Italy), and Yonsei (South Korea). Its readout architecture is based on an in-pixel binary front-end combined with a hit-driven architecture, which aims to reduce power consumption and integration time to fulfil the ALICE specifications.
First prototype chips have been fabricated to study charge collection and diode layouts, as well as the effect of back-biasing and the influence of different epi-layer thicknesses and resistivity. These prototype chips have been tested with X-ray sources and high momentum particles (4GeV/c to 6GeV/c positrons), before and after irradiation up to 1013 1 MeV neq. Charge collection efficiency has been measured with 55Fe sources; its dependence on irradiation level, back bias voltage, epi-layer thickness and pixel layout will be discussed. Signal-to-noise ratio with high momentum particles shows a decrease after irradiation, mainly due to the increase of noise, while the signal amplitude is not substantially affected.
The pALPIDE chip, the first small-scale prototype matrix of the ALPIDE, was designed to address the feasibility of both the analog front-end and the readout scheme. It was characterized with 4GeV/c to 6GeV/c positrons at DESY. First results show a detection efficiency reaching 99.7% at Vbb = 0V. In February 2014 a full scale chip (pALPIDEfs) has been submitted, which contains a matrix of 512×1024 pixels, whose cell dimensions are 28×28um2. The overall size of the pALPIDEfs is 15.3×30mm2. Its purpose is mainly to explore microelectronics and system aspects related to the integration of a large scale MAPS chip and to the physical and electrical interconnection of such a chip on flex printed circuits.
The design of the pALPIDEfs will be presented in this contribution, including the test results from the first available prototypes

poster session I / 155

Characterization of Silicon Micro-strip Sensors and Micro-Vertex Detectors with a pulsed infra-red laser system for the CBM experiment

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The Compressed Baryonic Matter (CBM) experiment at FAIR is composed of 8 tracking stations consisting of 1292 double sided silicon micro-strip sensors. For the the quality assurance of produced prototype sensors a laser test system has been built up. The aim of the sensor scans with the pulsed infra-red laser system is to determine the charge sharing between strips and to measure the uniformity of the sensor response over the whole active area. The prototype sensors tested with the laser system so far have 256 strips with a pitch of 50 micro meter on each side. They are read out by the self-triggering n-XYTER prototype read-out electronics. The laser system measures the sensor response in an automatized procedure at several thousand positions across the sensor with focused infra-red laser light (spot size ≈15 micro meter, wavelength = 1060 nm). The duration (~ 10 ns) and power (< 5 mW) of the laser pulses is selected such, that the absorption of the laser light in the 300 micro meter thick silicon sensors produces a number of about 24000 electrons, which is similar to the charge created by minimum ionizing particles in these sensors. Results from the characterization of micro-vertex detectors for understanding the spot-size of the laser and laser scans for different sensors will be presented.

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poster session I / 117

Bidimensional Polycrystalline CVD diamond detector for Intensity Modulated Radiation Therapy pre-treatment verifications

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Aim of the work. This study aims at investigating the dosimetric properties of a polycrystalline Chemical Vapour Deposited (pCVD) diamond bidimensional detector and its possible employment for pre-treatment verifications in Intensity Modulated Radiation Therapy (IMRT). In modern radiotherapy, dose delivery to the target volume is carried out with high conformation, to spare surrounding organs at risk. During a IMRT treatment, dose gradients are generally high, with variations in space and time of both dose rate and beam energy spectrum. Pre-treatment verifications and machine Quality Assurance (QA) are valuable tools, necessary to measure the efficiency and accuracy of the delivery process. Here we present a novel device for pre-treatment QA, based on a monolithic matrix of pixels made on a polycrystalline synthetic diamond film, with a high spatial resolution and no energy dependence, potentially low costs and larger areas.
Methods & techniques:
A bidimensional pCVD diamond sample (thickness:300µm,area:2.5x2.5cm^2) produced by Diamond Detectors Ltd, has been equipped with house-made Cr/Au contacts at the University of Florence. The sample's upper contact, consists of a squared matrix of 12x12 pixels (pixel size:1.8x1.8mm^2,pitch:2mm), the back contact is a square pad of about the dimension of the diamond film. Such a device was previously tested with different beam qualities, and its dosimetric pivotal properties, such as response velocity and dose rate dependence, have been studied at the Radiotherapy Unit of Florence University. In this work, the pCVD response to a 10MVRX prostatic IMRT field were investigated. Dose maps measured with the device under study were compared with the ones obtained with a commercial bidimensional detector (SunNuclear Mapcheck, matrix of diodes) and with Treatment Planning System calculations.
Results:
The first measurement with a matrix of pixels of pCVD diamond has provided promising results on a map of 1.8x12.6cm^2. Absorbed doses measured along IMRT profiles by pCVD and Mapcheck are consistent and an overall good agreement with respect to the TPS was found for the diamond dosimeter. The results demonstrate that the pCVD diamond device is a suitable detector for dosimetric pre-treatment verification analysis in IMRT and conformal beams, when used with low bias operation. This allows for the development of a large area monolithic device with relatively low effective costs.

poster session I / 116

Novel structure design for hard particle detectors: ultrahigh hardness, low power, and high spatial resolution

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Ultrahigh hardness particle detectors are needed in future particle accelerators for high energy physics. The Large Hardron Collider (LHC) in CERN can be operated at a designed luminosity of 1034 cm-2s-1, and a planned upgrade of the LHC, the super- LHC, will reach a luminosity of 1035 cm-2s-1. At the inner core of the Collider, silicon detectors face directly the inferno surrounding, will experience unimaginable irradiation by the high energetic particles, and should have ultrahigh radiation hardness. Irradiation damage was found to be the main origin of the failure of the particle detectors after reaching a certain radiation dose.

We have analyzed the main issues of conventional silicon drift detectors, and propose a novel core-shell diode design. The novel structure allows for a high homogenous electric field in the bulk even without additional reverse bias, for short collection length <50 μm, and high spatial resolution down to sub-μm range. Conventional radiation detectors are made of pn-junction diodes that have been fabricated on high resistive FZ-Si wafers, which can be reverse biased up to several hundreds volts, so that the whole volume is depleted. An electric field is present in the entire volume, thus the motion of the carriers is merely a drift process driven by the electrical field.

A dilemma in the conventional detectors is that a higher doping level in the volume is preferred for higher electric field, which promotes the carrier collection. However, diodes made on Si-wafers with high doping level will need a depletion voltage more than thousand volts. A compromise was found to stay at low doping level while using a reverse bias in the order of hundreds volts, while scarifying the high electric field needed for the carrier collection.

The novel core-shell structure tolerates much more to the high doping level, a very high electric field can be reached even without additional reverse bias. This high electric field introduces a strong band bending, which can empty the deep level traps in the bulk, suppressing significantly the carrier recombination. Such structure is expected to have ultrahigh hardness against high energetic particle radiation, fast signal response, low power consumption, and high spatial resolution down to sub-μm range, which will probably meet the requirement of the hard particle detector for the SLHC in the future, and opens many possibilities in high resolution imaging, for example, bioimaging and astrophysics.

poster session I / 64

Design and characterization of a YAG:Ce calorimeter for proton Computed Tomography application

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Aim of the work presented

A YAG:Ce calorimeter has been designed and characterized to measure the residual energy in a proton Computed Tomography (pCT) apparatus. The calorimeter has a 6x6cm^2 active area, to fully cover the tracker area of pCT system, it is able to stop up to 200MeV protons and sustain 1MHz particle rate. The YAG:Ce scintillator crystal is promising for charged particle detection applications where high-count rate, good energy resolution and compact photodiode readout, not influenced by magnetic fields, are of importance. Aim of the work is to show data acquired with proton beam energy up to 170MeV and to discuss the performances of this calorimeter.

Methods and techniques employed

A severe constraint of the pCT apparatus is the acquisition rate of 1MHz. In order to achieve this aim, the calorimeter has been divided into four optically separated crystals assembled in the same housing. Each crystal was optically coupled with commercial photodiode. The electronic front-end has been designed using hybrid electronic components. The proprieties investigated are: light yield and energy resolution for different energy values, spatial homogeneity. Each electronic front-end channel has been calibrated in order to have the same gain. Then, the calorimeter has been characterized at Laboratori Nazionali del Sud, Catania Italy, with proton beam energy up to 60MeV and a The Svedberg Laboratory, Uppsala Sweden, up to 170MeV. Moreover, using a silicon tracker, the spatial response homogeneity of each crystal has been studied.

Results

Crystals show different light yields (about 50% between four crystals) and thus, a calibration procedure is proposed in order to use this instrument for the pCT application. No optical crosstalk effects are observed between four crystals. The energy resolution of a single crystal at 170MeV has been measured to be about 1% rms. The spatial response is not homogeneous over the whole crystal area: results obtained will be discussed.

Comparison with other work and future prospects

Results presented are significant in research field of scintillation crystals: in literature, data about the performances of the YAG:Ce at high energy protons are not present. This work permits to confirm the YAG:Ce as pCT calorimeter and to fix the calibration procedure necessary for this specific application. Moreover, the results presented open prospects of other application of this crystal.

poster session I / 65

Study and characterisation of different electrode materials for INO-ICAL Resistive Plate Chamber and detector performance

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The India-based Neutrino Observatory (INO) is a proposed underground laboratory in southern India. INO will house a large magnetised Iron Calorimeter (ICAL) detector to study the mass mixing and oscillation parameters of atmospheric neutrinos. About 28000 of 2m x 2m Resistive Plate Chambers (RPCs) detectors will be used as active element for ICAL. In view of the large number of RPC detectors required for ICAL, it is very important to perform a panoramic study of all the properties of these detectors before finalising its material and design. In this paper, we present an extensive study of optical, structural and electrical properties of different materials as appropriate electrode for RPC detector. Various types of Glass and Bakelite electrode materials are characterized for morphology, topography, composition, orderness and reflectance studies using different techniques like Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), Energy Dissipative X-ray (EDX), X-ray Diffraction Spectroscopy (XRD) and Ultraviolet Visible Spectroscopy (UV-vis) respectively. Small prototypes 30*30 cm2 RPC have been fabricated using different types of glasses and Bakelite as electrode materials. Various characterization and performance studies were performed to select the electrode and detector. We then correlate the performance studies with the characterization study to choose the best detector. On the basis of studies like efficiency, noise rate, time resolution and charge spectra, we have chosen the best electrode material for the ICAL RPC detectors. Various concerns such as RPC ageing effects, optimization of gases and choice of different oil coatings are being pursued at the moment.

poster session I / 179

Status of the ATLAS Upgrade Planar Pixel Sensors R Project

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To extend the physics reach of the LHC, upgrades to the accelerator are planned to increase the peak luminosity by a factor 5 to 10 which will enable the experiments to collect up to 3000 fb-1 of data. This, however, will lead to increased occupancy and radiation damage of the inner trackers, approaching fluences of a 2-3e16 neq/cm2 at the innermost layer and still ~3e15 neq/cm2 at the outer pixel layers.

The ATLAS experiment plans to introduce an all-silicon inner tracker with the HL-LHC upgrade to cope with the elevated occupancy. With silicon, the occupancy can be adjusted by using the unit size (pixel, strip or short strip sensors) appropriate for the radiation environment. For radiation damage reasons, only electron-collecting sensors designs are considered (n-in-p and n-in-n): Beyond a fluence of about 1e15 neq/cm2, trapping becomes the dominant radiation effect and electrons are trapped significantly less than holes.

To investigate the suitability of pixel sensors using the proven planar technology for the upgraded tracker, the ATLAS Planar Pixel Sensor R Project was established comprising 19 institutes and more than 90 scientists. Main areas of research are
– performance assessment and improvement of planar pixel sensors at HL-LHC fluences
– the achievement of slim or active edges to provide low geometric inefficiencies without the need for shingling of modules
– establishment of reliable device simulations for severely radiation-damaged pixel detectors
– the exploration of possibilities for cost reduction to enable the instrumentation of large areas with pixel detectors

The presentation will give an overview of the R project and highlight its recent accomplishments, among them
– beam test and laboratory measurement results with planar sensors up to innermost layer fluences
– measurements obtained with irradiated thin edgeless n-in-p pixel assemblies
– characterization of large-area ("quad") module prototypes after irradiation to realistic outer layer fluences
– prototyping efforts for large areas: sensor design improvements, 6" wafer production experience, 8" wafer production possibilities, concepts for low-cost hybridisation

Together, these results will allow an assessment of the state-of-the-art with respect to radiation-hard position-sensitive tracking detectors suited for the instrumentation of large areas.

poster session I / 68

Development of Large Dynamic Range Silicon Photomultipliers for High Energy Particle Calorimetry

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Silicon Photomultipliers (SiPM) are very promising devices for high energy physics (HEP) experiments due to their high photon detection efficiency, miniaturized device size and insensitivity to high magnetic fields. Most often detectors are exposed to a high radiation dose for which reason the performance should degrade only minor under the applied radiation load. Decreasing the active depth of a SiPM microcell should help to strengthen the radiation hardness. Additionally for high energy particle physics experiments a large dynamic range is mandatory. This was a further driving reason at KETEK to scale down the microcell pitch and thereby losing only small amount in geometrical efficiency. With these large dynamic range SiPMs a photon detection efficiency in blue spectral range of 32% for 2500 microcells/mm² and 22% for 4400 microcells/mm² was achieved. With an improved manufacturing technology the dark noise level was decreased to about 250 kHz/mm² at 20% overvoltage (measured at 20°C), while the gain variation was still less than 1%/K. Further optimization of the depleted region increased the sensitivity in the output wavelength range of common scintillators (515 nm) by 20% compared to the standard devices. The round shaped active area of 1.0 mm², 6.16 mm² and 8.55 mm² enables optimal coupling to a fiber bundle. The recovery time constant of the tested devices was 12 ns for the 1.0 mm² device and 20 ns for the devices with 6.16 mm² and 8.55 mm².

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A Geant4 based framework for pixel detector simulation

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The output from a radiation detector depends on the interaction of the photons or particles with the sensor material, the transport of the resulting charge in the sensor, the pulse
processing in the readout circuit and processing of the resulting signal. In order to understand the full behaviour of the device and to predict the performance of future devices it is important to have a framework that can simulate the entire process in the detector.
Geant4 is a Monte Carlo based toolkit for simulation of charge interaction with matter which is developed and actively used for CERN experiments and detector development [1].
By extending the Monte Carlo code in Geant4 with a charge carrier transport model of the sensor material and basic amplifier functionality as well as read out logic, it allows for
simulating the behaviour of a complete detector system. The MEDIPIX readout chip is a state of the art hybrid pixel detector that allows bonding of a wide range of sensor materials
[2, 3]. It is of growing interest and currently used for several studies [4]. Simulation models have been developed and tested for different chips from the MEDIPIX family.
The simulation is defined using configuration files to set the geometry, sensor material properties, number of pixels, pixel pitch and chip properties. Source properties as well
as filters and objects in the beam can be added for different experimental set-ups. The
interaction of radiation with the sensor is taken into account in the transport of the charge
carriers in the sensor material and a current induced in the pixel electrode that triggers an
amplifier response.
Simulation results have been verified with X-ray fluorescence and radioactive sources using MEDIPIX family chips. In this paper we present the developed simulation framework and first results.

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[4] A. Korn, M. Firsching, G. Anton, M. Hoheisel, and T. Michel. Investigation of charge carrier
transport and charge sharing in X-ray semiconductor pixel detectors such as Medipix2

poster session I / 174

A novel approach to dark matter search based on nanometric emulsions

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The most convincing candidate as main constituent of the Dark Matter in the Universe consists of weakly interacting massive particles (WIMP). WIMPs must be electrically neutral and interact with a very low cross-section (σ < 10^(-40) cm2) which makes them detectable in direct searches only through the observation of recoiled nuclei induced by the WIMP rare scatterings. In the experiments carried out so far, recoiled nuclei are searched for as a signal over a background produced by Compton electrons and neutron scatterings.
Signal found by some experiments have not been confirmed by other techniques. None of these experiments is able to detect the track, typically less than one micron long, of the recoiled nucleus and therefore none is able to directly detect the incoming direction of WIMPs. This proposal explores a very innovative method to observe the incoming apparent direction of WIMPs, which would provide a new and unambiguous signature. We propose an R program for a new experimental method able to observe the track of the scattered nucleus based on new developments in the nuclear emulsion technique: films with nanometric silver grains, expansion of emulsions and very fast completely automated scanning systems. Nuclear emulsions would act both as the WIMP target and as the tracking detector able to reconstruct the direction of the recoiled nucleus.
This unique characteristic allows to achieve an unprecedented sensitivity in the search for WIMPs. Experiments using gaseous targets may see the track of the recoiled nucleus, but they are limited in mass by the extremely low density of gases and therefore cannot compete in sensitivity with our approach.

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In Situ calibration of a PMT inside a scintillation detector by means of primary scintillation detection

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PMTs are widely used as scintillation detector photosensors in γ-ray spectrometry, high-energy physics and rare event detection. PMT gain knowledge allows determining the number of photoelectrons released by the photocathode, after measuring the total number of collected electrons. The absolute energy dissipated in the scintillators is related to the number of photons produced, which is related to the number of photoelectrons emitted by the PMT. An effective method for gain determination is obtained by the PMT response to single photoelectron (SER). Usually, a PMT is illuminated with a LED at very low intensity inducing single photoelectron response. Upon photocathode illumination the peak distribution associated to events resulting from a given number of photoelectrons reaching the first dynode can be approximated to a Gaussian which centroid position relative to the noise peak presents a linear increase with the number of photoelectrons hitting the first dynode; the Gaussian area related with the probability for that event obeys a Poisson distribution. Therefore, either the SER is deconvoluted to determine the position of the peak of events with a single photoelectron emission, or the amount of LED light hitting the PMT is reduced so that the probability of multiple photoelectron emission is less than few percent. In this case the SER pulse-height distribution fits well a single Gaussian. In many experiments, the PMT gain is measured before assembling or by placing LEDs and/or optical fibres inside the detector, to allowing PMT gain monitoring with time along the experiment. However, in many cases the PMT is inside a sealed chamber inaccessible to LED light, like in most scintillation detectors, or the electronic noise is high, being impossible to use this method.

We propose a calibration method that uses primary scintillation from the radiation interaction in the scintillator. If this scintillation induces single photoelectron response of the PMT that could be approximated to an exponential function in the high-energy region of this response, the PMT average gain can be determined from the inverse of the exponent of the exponential fit. Our studies show PMT gain calibration by fitting an exponential to the high-energy tail of the SER pulse-height distributions to be a valid procedure for PMT illumination within suitable levels, inducing on average 1.0 photoelectron per scintillation pulse.

poster session I / 24

Laser mapping of the interstrip response in double sided silicon strip detectors for particle identification

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Silicon microstrips are used in nuclear physics experiments when high granularity and high resolution is required (e.g. particle-particle correlation). In addition microstrip detectors are used in the field of X-ray detection for position resolved X-ray spectroscopy.

In the framework of the construction of a novel Femtoscope Array for Correlation and Spectroscopy, named FARCOS, and aiming to perform the identification in charge and mass even of particles stopping in the first detection layer, we are performing a thorough characterizations of the silicon detector layers in terms of the efficiency and collection properties as a function of the point of incidence. We have experimental evidence – as previously observed also in the literature for other strip detectors – that interstrip incidence alters the signal shape not only for the trivial charge division but also affecting the shape of the induced signal on neighbor strips. The phenomenon can be more or less pronounced depending on the energy and ion type but is always present.

In order to surgically probe the response of the interstrip region we tested the detector response matrix both in back and in front injection with an infrared pulsed laser at two different wavelengths (705 nm and 904 nm) in order to probe different ionization profiles. The laser spot size below 10 um FWHM is well suited to probe the interstrip. Thanks to the digital data acquisition we sample at high frequency (100 MS/s) the preamplifier output waveform that are stored on disk for further investigation of the impact of the incidence in the interstrip region with high precision. Depending on the side of interaction, on the position of incidence and on the absorption length, the shapes of the induced signals are significantly altered and signals of opposite polarity or bipolar signals arise. This phenomenon was already observed in the literature for other microstrip detectors but not analyzed in detail and no detailed laser mapping has been performed yet.

In order to get a complete picture of the physical phenomena at the basis of the aforementioned behavior we performed detailed device simulations with a custom semi-analytical code and compared the experimental results with 3D simulations. The presentation will focus on the description of the experimental measurements, their exhaustive interpretation on the basis of the device physics and of the 3D simulation and their relevance in the use of the detectors on-beam.

poster session I / 81

Commercial CMOS image sensors as X-ray imagers and particle beam monitors.

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CMOS image sensors are widely used in several applications such as mobile handsets webcams and digital cameras among others. Furthermore they are available across a wide range of resolutions with excellent spectral and chromatic responses.
In order to fulfill the need of cheap systems as beam monitors and high resolution image sensors we exploited the possibility of using commercial CMOS image sensors as X-rays and proton detectors.
Two different sensors have been mounted and tested. An Aptina MT9v034, featuring 752 × 480 pixels, 6 μm × 6 μm pixel size has been mounted and successfully tested as bi-dimensional beam profile monitor, able to take pictures of the incoming proton bunches at the DeFEL beamline (1-6 MeV pulsed proton beam) of the LaBeC of INFN in Florence. The naked sensor is able to successfully detect the interactions of the single protons. The sensor point-spread-function (PSF) has been qualified with 1MeV protons and is equal to one pixel (6 μm r.m.s) in both directions.
A second sensor MT9M032, featuring 1472 x 1096 pixels, 2.2 × 2.2 μm pixel size has been mounted on a dedicated board as high-resolution X-ray imager to be used in X-ray imaging experiments with table-top generators. In order to ease and simplify the data transfer and the image acquisition the system is controlled by a board embedding a digital media processor (DM3730 1 GHz ARM Cortex-A8) on which a modified LINUX kernel has been implemented.
The presentation will focus on the description of the architecture of the sensor system and on the results of the experimental measurements.

poster session I / 22

Performance of the EIGER single photon counting detector

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EIGER is a single photon counting hybrid pixel detector being developed at Paul Scherrer Institute (PSI), Switzerland, for applications at synchrotron light sources in an energy range from a few to 25 keV. EIGER is characterized by a small pixel size (75x75 um^2), a frame rate up to 22 kHz and a small dead time between frames (4 us).

An EIGER module is a hybrid detector composed of approximately 8x4 cm^2 silicon sensor bump bonded to 4x2 readout chips, for a total of 500 kpixels. Custom designed module electronics reads out the signals and processes the data in the module before transferring it. A large dynamic range (32 bits) for the pixel counter can be obtained through on-board image summation. Rate corrections can be applied on-board to compensate for inefficiencies when the pixel counting rates approach pile-up levels around a million counts per second.

The EIGER modules are the building blocks of large area detectors: a 1.5 and a 9 Mpixel systems are under development for the cSAXS beamline at the Swiss Light Source at PSI. The very high frame rate capabilities are equally fast for multi-module systems due to the fully parallel data processing.

We will address the steps for the module construction, qualification and characterization. The module calibration will be discussed, with emphasis on the choice of the optimal operation settings as a function of photon energy. The performance regarding threshold dispersion and minimum achievable threshold will be presented. In addition, the progress towards the production of larger multi-module systems will be discussed.

poster session I / 23

A CMOS Readout Circuit for Microstrips Detector

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In this work, we present the design and the results of a CMOS analog channel for silicon microstrips detectors. The readout circuit was initially conceived for the outer layers of SuperB silicon vertex tracker (SVT), but can now serve more generally other microstrip-based detection systems. The strip detectors considered show a very high stray capacitance and high series resistance. Therefore, the noise optimization was the first priority design concern. A necessary compromise on the best peaking time to achieve an acceptable noise level together with efficiency and timing accuracy has been investigated. The ASIC is composed by a classical processing scheme, composed by a preamplifier, shaping amplifier and TOT for the digitalization of the signals. The chosen shaping function is the third-order semi-Gaussian function implemented with complex poles. An inverter stage is employed in the analog channel in order to operate with signals delivered from both p and n strips. The circuit visualizes the possibility to select the peaking time of the shaper output (250, 375, 500 and 750 ns). In this way, the noise performances and the signal occupancy can be optimized according to the real background during the experiment. The first prototype fabricated in the 130nm IBM technology which is considered intrinsically radiation hard. The results of the experimental characterization of a produced prototype are matched with simulation.

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Silicon Vertex Detector for Antihydrogen Detection and Measurement in the ALPHA experiment

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The aim of the ALPHA experiment at CERN is to trap cold atomic antihydrogen, study its properties, and ultimately to perform precision comparison between the hydrogen and antihydrogen atomic spectra. Recently the collaboration has reached important milestones beginning with demonstrating the ability to trap and confine neutral cold antihydrogen [1][2], performing the first spectroscopic measurements of antihydrogen [3] and of late through demonstrations of the first application of a new technique to measure the gravitational mass of antihydrogen [4].

The principal diagnostic tool for antihydrogen detection and measurement is a Silicon Vertex Detector (SVD). The detector consists of double-sided silicon strip hybrid modules. Surrounding the ALPHA neutral atom trap, its purpose is to monitor single annihilation events and collective antiproton plasma behavior. A description of the performance and characteristics of this detector [5] and its upgrade [6] will be given, along with methods and results, using spatial and timing data to perform precision measurements on antihydrogen.

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poster session I / 180

HV/HR-CMOS sensors for the ATLAS Upgrade - concepts and test chip results

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Deep-submicron HV-CMOS processes feature moderate bulk resistivity and HV capability and are therefore good candidates for drift-based radiation-hard monolithic active pixel sensors (MAPS). It is possible to apply 60-100V of bias voltage leading to a depletion depth of ~10-20 um. Thanks to the high electric field, charge collection is fast and nearly insensitive to radiation-induced trapping. CMOS Imaging Processes often feature high-resistive substrates, thinning, stitching and backside processing, which makes them also interesting to study.

We explore the concept of using such processes to produce active pixel sensors (APS) that contain simple circuits to amplify and discriminate the signal. A readout chip (ROC) is still needed to receive and organize the data from the active sensor and handle high-level functionality such as trigger management. This chip can follow the pixel chip concept with the readout circuits distributed over the area of the chip, or the strip concept with one or few rows of pads along one (or more) sides of the chip. The connection between APS and ROC can be made in a “traditional” way (wire/bump-bonding) or by capacitive coupling (e.g. gluing) which could lower the production cost significantly.

The active sensor approach offers many advantages with respect to standard silicon sensors: fabrication in commercial CMOS processes costs less than traditional diode sensors, aggressive thinning is resulting in much lower mass, bias voltage and operation temperature requirements are favorable. From a practical perspective, maintaining the traditional separation between sensing and processing functions lowers development cost and makes use of existing infrastructure.

ATLAS-compatible test ASICs were produced in a variety of processes. Both strip-like or pixel-like readout could be selected on most devices. They were either capacitively coupled by gluing with less than about 10 µm of glue layer thickness or wirebonded to strip ROCs. First results of their characterization, partially also after irradiation to HL-LHC fluences (1e16 neq/cm2 or 1GRad), will be shown.

In addition, future strip readout concepts will be introduced which foresee a digital encoding of the z position along the virtual strip and require a modified ATLAS strip readout chip (ABC'/ACDC) for readout. This concept promises a very large reduction in the number of wirebonds which helps to lower both production cost and time.

poster session I / 5

Novel Polymer Thin Film Scintillator Device for Neutron Imaging and Detection

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Due to the recent shortage of He-3 production, the development of inexpensive and efficient thermal neutron detectors, effectively discriminating gamma radiation, is a critical requirement for international security. A second important use of neutron detectors is in the field of medical, scientific and industrial imaging. The large neutron scattering cross section of hydrogen imparts a unique feature to neutron imaging- A sharp contrast between metals, semiconductors and organic matter (solid chemicals, plastics and liquids) which generally contains hydrogen. A neutron imaging based interrogation technique can thus be effectively used to check terrorist threats, illegal immigration, smuggling etc. by detection of explosives, organic hazardous material and biological matter hidden in shielded dense cargo. Development of low cost, large area, polymer composite thin film scintillator for neutron imaging and detection aims at replacing expensive scintillator screens/films. The developed scintillator effectively discriminates gamma radiation.

Technology being pursued is based on tautomer science, photo induced electron transport, energy cascading, and photon up-conversion. The scientific and engineering design aspects, various fabrication procedure and characterization results are elucidated.

poster session I / 4

The OFFSET3 scintillation-fiber tracker for real-time particle imaging

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The OFFSET3 tracker (Optical Fiber Folded Scintillating Extended Tracker) are presented. It exploits a novel system for particle tracking. It's designed to achieve real-time particle imaging exploiting large detection areas and a high spatial resolution especially suitable for applications in medical diagnostics. The tracker consists of two 29x29 cm2 FOV position detectors stacked by 10 cm, made by 500 micron squared scintillating fibers ribbon for both directions. The track position information is extracted real-time in an using a reduced number of read-out channels, thank to which it's possible to obtain the large detection area with moderate costs and complexity. The architecture has been patented by the Istituto Nazionale di Fisica Nucleare (INFN). The performances of the tracker were investigated by beta sources, cosmic rays, 60 MeV- 250 MeV proton and 400 MeV/A carbon clinical beams.

poster session I / 6

Novel Surfactant Based Thermal Neutron Detector

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Helium-3 filled pressurized tubes are the current state of art in radiation portal monitors to detect illicit transport of special nuclear materials (SME). Due to the recent shortage of He-3 production, the development of inexpensive and efficient thermal neutron detectors, effectively discriminating gamma radiation, is a critical requirement for international security [1]. As a solution, a novel, ultra economic technology, based on specially designed surfactants, has been developed at the Institute of Polymers, Bulgarian Academy of Sciences.

Scientific design aspects and preliminary experimental results demonstrating the proof of concept is presented. The strengths of the novelty are compared over the existing technologies.

poster session I / 9

Development of compact radiation detectors based on MAPD photodiode and Lutetium Fine Silicate and Stilbene scintillators

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Performance of scintillation detector strongly depends on the quality of a scintillator and photo sensor. Scintillators with high light output in combination with photo sensors are used widely in different experiments. One of them is a radiation monitoring device. Radiation monitoring devices provide excellent tools for obtaining information on gamma emitters within a material. When ionizing radiation penetrates into the scintillator it deposits its entire energy. The deposited energy converts into scintillation light. The scintillation light is usually detected by the photo electron multiplier (PMT).Unfortunately features of PMT do not allow making compact high efficiency vibration insensitive and inexpensive scintillation detector with low operation voltage. Progress in the development of silicon micro-pixel photodiodes (MAPD) made it possible to use them as photo sensors instead of PMT in scintillation detectors.

In this work we investigated gamma-rays in energy range from 59.5 keV to 834 keV detection measurements performed using Lutetium Fine Silicate (LFS) scintillators with Micro-Pixel Avalanche Photodiode (MAPD) are presented. The linearity in energy response of gamma rays and the energy resolution vs. energy of gamma rays are obtained. Several measurements are done due to confirm the gamma ray sources identification performance of detector. Minimum detected activity in the experiments was 70 Bq from Sn-113 source. This activity is not the minimum detectable activity for this detector. We also investigated response of the LFS-8 scintillator to fast neutrons and no significant difference between counts due to background and fast neutrons was observed. Therefore, counts due to neutron do not significantly affect the gamma ray identification performance of the detector. Besides, intrinsic gamma spectrum of LFS-8 (Lu-176) scintillator is detected by HPGe detector and defined activity and mass of Lu-176 is 23.5±3 Bq and 12.5mg.

The alpha particle and neutron detection performance using LFS and stilbene scintillators with micro-pixel avalanche photodiode are discussed as well.

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Pulsed current signals in capacitor and junction type particle detectors

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Particle detectors, based on carrier drift and charge collection signal measurements, are designed referring to Ramo's theorem which describes the induced current flowing in the external circuit when the particle crosses the detector volume. This theorem was originally formulated for the linear medium in design of vacuum tubes and does not describe the current components caused by charge relaxation, generation and capture processes that are inherent for the radiation damaged volume of detectors. Therefore, these processes should be included within analysis of the registered current transients. Furthermore, the analysis of current transients becomes more complicated in partially depleted semiconductor detectors when variations of depletion boundary due to mentioned processes should be taken into account.

In this work, the peculiarities of the drifting charge induced currents are considered for analysis of pulsed operational characteristics in photo- and particle-detectors. The models of formation of the drifting charge domain induced pulsed currents are analyzed in capacitor-type and junction containing detectors assuming a plane-parallel geometry of the finite area electrodes. The drift regimes of small and large charge are discussed. The bipolar carrier drift transformation to a monopolar one is considered, after either electrons or holes, injected within detector volume, reach the external electrode. The role of the initial velocity of the injected charge domain, of its components and drift velocity saturation effects are clarified. The influence of the carrier drift, trapping, generation and diffusion on current waveforms is discussed. The models of the formation of the induced pulsed currents are analyzed for the regimes of partial and full depletion. Also, charge collection efficiency for bipolar and monopolar drift regimes is analyzed. The impact of the dynamic capacitance and load resistor within external circuit in formation of drift current transients is highlighted. Experimental results of the current pulse variations determined by either the rather small or large carrier density injected at various positions within cross-sectional boundary of non-irradiated and irradiated Si junction detectors are presented.

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Development of a Portable α-Particle Spectroscope

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A-particle spectrometry is used in the measurement of nuclear decay, safeguards verification, nuclear security, and environmental surveys and monitoring. Among these uses are the measurements involved in the verification of alpha emitters for safeguards application. These measurements are conducted mainly in laboratories. The α-particle measurement equipment used in a laboratory room is generally large and heavy. As a result, there are many difficulties in operating these instruments outside of the laboratory. In order to detect the diversion of nuclear materials in a timely manner, in-field detection are necessary. However, there have been few studies in the area of in-field portable alpha spectroscopic equipment. The objective of this study is to develop a portable α-particle instrument, which can be used on site during nuclear safeguards inspection. To increase the energy resolution of the α-particle detector, a collimator was utilized to guide the alpha particle straight into the detector. The alpha detector was designed to use the Monte Carlo simulation code (GEANT4). GEANT4 simulation showed that the α-particle collimator increases the energy resolution, but decreases the total detection efficiency. This portable alpha detector could be built up by minimizing optimally its electronics. The α-particle spectroscope under development consists largely of an α-particle detection device, a vacuum pump, a power supply device and an analysis computer. Peaks in spectral distribution measured by our portable alpha spectroscope were clear and separable from each other. The detection efficiency of our equipment was determined to be about 18%. Although the alpha-particle spectroscope discussed in this paper is small and light, its performance appears to be similar to those large-scale devices that are used in laboratories.

This work discussed the utilization of an α-particle spectroscope for safeguards application. In addition to the detection of nuclear materials, measurements from alpha-particle emitters in the environment are needed in order to formulate an emergency plan needed to respond to radiological or nuclear material-related accidents. Under such circumstances, the portable alpha detection device could help a decision-maker to establish an emergency plan by providing quick and reliable information on radioactivity in environmental.

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Purification and evaluation of thallium bromide crystals for gamma-ray detectors

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Thallium bromide (TlBr) crystal is a promising compound semiconductor for fabrication of gamma-ray detectors for applications in medical imaging and spectroscopy. In recent study, TlBr detectors with high charge transport properties have been fabricated from TlBr crystals purified by the multi-pass zone refining method. Although the multi-pass zone refining method is highly effective for obtaining high purity TlBr crystals, the purification process needs very long duration. Thus, various purification methods supporting the multi-pass zone refining method have been investigated to shorten the processing time of the purification. In this study, TlBr raw materials were purified by the vacuum distillation method using an originally fabricated Pyrex glass. After the purification, TlBr crystals were grown by the travelling molten zone method using the purified materials. TlBr gamma-ray detectors were fabricated from the grown crystals and 137Cs gamma-ray energy spectra were measured at room temperature in order to evaluate the effect of the vacuum distillation method on detector performance. TlBr detectors fabricated from a purified material by the vacuum distillation method exhibited full-energy peak corresponding to 662 keV gamma-rays from a 137Cs source, whereas TlBr detectors fabricated from a raw material exhibited no photo peak. Further progress on purification process of TlBr would be achieved by optimizing condition of the vacuum distillation process.

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LaBr3:Ce small FOV gamma camera with very high energy resolution for multiple gamma ray energies imaging

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Aim of the work

The simultaneous administration of different radiopharmaceuticals labeled with distinct radioisotopes is becoming increasingly interesting for animal experiments and clinical practice. To perform imaging of different radiopharmaceutical distributions, a gamma camera with very high energy resolution (ER) is required. The availability of scintillation crystals with high light yield, as for example LaBr3:Ce, is collecting particular interest in high ER gamma cameras. However, limitation on LaBr3:Ce crystal size and current elevated cost could still be the major obstacles to developing high ER gamma cameras. In this paper we present a new gamma camera based on a LaBr3:Ce crystal with round shape, with coating and surface treatment able to provide excellent ER results.

Methods and techniques

The LaBr3:Ce crystal has round shape and size proper of a small imager (50mm Ø and 6 mm thickness). The round shape improves light collection, and the reflective treatment of surfaces (MgO powder) ensures more than 98% of diffuse light. LaBr3:Ce is optically coupled with a Hamamatsu H10966 multi-anode PMT. A 64 independent channels readout electronics is used. Local ER and imaging results are achieved by scanning the crystal surface with a collimated source and overall ER by flood-field irradiations. To further improve ER, we propose the application of an anodic gain correction and the reduction of the diffuse contribution in the pulse height with an event selection in the spot image (region of interest ROI).

Results

At 140 keV photon energy, the proposed gamma camera shows excellent ER results: (6.9±0.2)% as best value for spot irradiation. The application of anodic gain correction and the ROI method allow to reach enhanced ER: (6.5±0.2)% at 140 keV for a spot irradiation and (5.1±0.2)% at 356 keV for a flood field irradiation. Also good intrinsic spatial resolution results are obtained, with a best value of (1.1±0.1)mm.

Conclusion

The characterization of a small FOV gamma camera based on a LaBr3:Ce scintillation crystal with reflective surfaces indicates improvements in ER results, compared with the ones extracted from other similar LaBr3:Ce detectors, aimed at multi isotope [1] applications or general purpose gamma ray imaging [2]. Furthermore the enhanced ER due to reflector material at all sides does not lead up to spatial resolution degradation.

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Calculation and study of operational scenario and test of radiation hardness for the micro-strip sensors for the tracking detectors at the CBM experiment

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The Silicon Tracking System (STS) is the central tracking detectors at the Compressed Baryonic Matter (CBM) experiment at FAIR Planned. The STS will operate with challenging conditions using the double-sided silicon micro-strip sensors as tracking detectors. The STS is Planned to use sensors with pitch of 58 micrometers, strip width of 18 micrometers and thickness of 300 micrometers. The sensor Has to be radiation hard as They Shall be operational at a radiation environment of 1 × 10 14 n / cm 2 . There is need to understand and prepare a running scenario for the sensor at the planned beam time in CBM experiment in 2017-19. The experiment conditions will induce radiation damage, which in turn will reduce the charge collection and operational ability of sensors. The operating scenario will be presented using the simulation of operational voltage range, age of detectors (replacement time. The study of annealing parameters for micro-strip detectors based on CBM prototype sensors will also be presented.

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Readout cross-talk for alpha-particle measurements in a pixelated sensor systems

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Crosstalk and charge sharing degrades the spatial and spectral resolution of single photon processing X-ray imaging systems. For typical medical imaging applications the process is dominated by charge sharing between the pixels in the sensor. This process depends on the bias voltage and the ratio between pixel size and detector thickness. For heavier particles each impact generates a larger amount of charge that can saturate the analogue amplifier and hence impose charge transport mechanisms in the sensor or in the readout circuitry substrate.

In this work the crosstalk in the analogue part of the pixilated amplifier is discussed. Simulations show the behavior of the charge transport mechanism for amplifiers both with and without Krummenacher scheme and how it is affected by interpixel capacitance and parasitic capacitance. The result is also related to the charge sharing in the sensor.

Measurements of the analogue pulse for different energies for a Medipix 2 system with 55 µm pixel size are achieved to verify the simulations. From this model and measurements, different aspects of the readout functionality can be explained.

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The Pixel Detector of the ATLAS experiment for the Run2 at the Large Hadron Collider

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The Pixel Detector of the ATLAS experiment has shown excellent performance during the whole Run-1 of LHC. Taking advantage of the long showdown, the detector was extracted from the experiment and brought to Surface, to equip it with new service quarter panels, to repair modules and to ease installation of the Insertable B-Layer (IBL). IBL is a fourth layer of pixel detectors, and will be installed in May 2014 between the existing Pixel Detector and a new smaller radius beam-pipe at a radius of 3.3 cm. To cope with the high radiation and pixel occupancy due to the proximity to the interaction point, a new read-out chip and two different silicon sensor technologies (planar and 3D) have been developed. Furthermore, the physics performance will be improved through the reduction of pixel size while, targeting for a low material budget, a new mechanical support using lightweight staves and a CO2 based cooling system have been adopted. IBL construction is now completed.

An overview of the IBL project as well as the experience in its construction will be presented, focusing on adopted technologies, module and staves production, qualification of assembly procedure, integration of staves around the beam pipe and commissioning of the detector.

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Software interface for high-speed readout of particle detectors based on the CoaXPress communication standard

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Present contribution is devoted to the software design and development of a high-speed readout application used for interfacing particle detectors via the CoaXPress communication standard. The CoaXPress provides an assy- metric high-speed serial communication over coaxial cable. It uses widely available 75 Ω BNC standard and can operate in various modes with a data throughput ranging from 1.25 Gbps up to 25 Gbps. Moreover, it supports a low speed uplink with a fixed bit rate of 20.833 Mbps which can be used to control and upload configuration data to the particle detector. The CoaX- Press interface is an upcoming standard in medical imaging, therefore its usage promises long-term compatibility and versatility. This work presents an example how to use the CoaXPress standard for DAQ of Medipix2 MXR Quad pixel detector. For this purpose, a flexible DAQ card was developed based on XILINX FPGA Spartan 6. At the PC side, FireBird CXP6 Quad was used, plugged in the PCI Express bus. The data transmission was performed between the FPGA and framegrabber card via the standard coaxial cable at communication mode with a bit rate of 3.125 Gbps. With Medipix2 Quad, the framerate of 100 fps was achieved. The front-end ap- plication makes use of the FireBird framegrabber software development kit and is able to perform the basic DAQ functionality as well as control of the detector through the registers implemented in the FPGA.

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Investigation of a Novel 6LiInSe2 Detector for Neutron Transmission Imaging

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Neutron imaging is an important technique for many material and systems investigations. In this investigative technique, high spatial resolution, large dynamic range, good gamma/neutron discrimination capability, and large intrinsic detection efficiency are highly desired traits of the detection system, especially when system temporal behaviors are sought, such as water flow in microchannels of PEM fuel cells. Current methods of neutron imaging use 6LiF:ZnS scintillation screens and a CCD camera. More recent advances use doped microchannel plates and an ASIC. However, at this point in time each detection system suffers in at least one of these desired attributes.

Semiconductor materials have shown promise as ionizing radiation detection devices; however, to be used as a neutron detector, these materials require the addition of a nucleus with a large neutron absorption cross section to capture thermal neutrons and convert them into directly detectable particles. A semiconducting material that contains the neutron absorber within its regular stoichiometry has the potential to be more efficient than a layered or heterogeneous device at transferring the kinetic energy of the charged particle into the semiconducting material. Ternary Li chalcogenides have band gaps (2-3.5 eV) appropriate for room-temperature detection of thermal neutrons and would be the first detection material that is simultaneously, exquisitely sensitive to thermal neutrons and acts as a direct conversion device. Recent developments in the growth of 6LiInSe2 (LISe) semiconducting crystals have enabled the successful detection of thermal neutrons. 100 percent detection efficiency s possible in only 5 mm. This feature provides an opportunity to create a neutron transmission imaging detector that has a fast response, minimal dead time, and potential gamma/neutron discrimination capability. Development of a multi-channel, spatially sensitive LISe gross neutron detector for neutron transmission imaging applications will be presented that outlines first efforts and experimental results. Investigations into the crystal response, packaging, front end electronics, signal processing, image reconstruction, and modeling are considered. Device fabrication, from pixel design, fabrication, and packaging is considered. The front end electronics are being developed from off-the-shelf components and are coupled to CAEN digitizers.

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Fast neutron detector with a surface-barrier VPE GaAs sensor

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Nowadays neutron methods are widely adopted. For some applications detectors based on semiconductor materials are used. Generally the operation principle of such detectors is based on the detection of the secondary particles produced by neutrons in converter material with semiconductor sensors. Depending on the neutron energy (n,α)-reactions are used for the thermal neutron detection and the recoil proton method are used for the fast neutron detection [1].

This work was aimed on the development of a fast neutron detector using high-purity GaAs layers grown by vapor-phase epitaxy. The using of the high-purity GaAs epilayers allows to reduce the operating bias of a sensor in comparison with bulk GaAs material [2,3] and makes it possible to use detectors without external bias. This could be the determining factor, e.g. for the development of detectors for neutron personal dosimetry.

The fast neutron detection with the fabricated detector is based on the recoil proton method. Polyethylene is used as the converter layer and the recoil protons are detected with the surface barrier GaAs sensor. The sensor was fabricated using 50μm high-purity n-GaAs epilayers with a carrier concentration of 3·1011cm-3. A Schottky contact with a large area of 5×5mm2 was fabricated using Pt/TiN/Au metallization system proposed in [4]. The used technology has allowed to obtain low dark currents: the leakage currents were 0.7nA and 1.2nA at the reverse bias of 50V and 100V, respectively. It should be noted that the operation voltage of the sensor is significantly lower than these values. The charge collection efficiency of the sensor measured using the 238Pu α-source at the zero bias is 60% and reaches a value close to 100% at the reverse bias of 10V.

Electro-physical characteristics of the used high-purity GaAs epilayers are presented, electrical characteristics of the fabricated large-area Schottky contact are discussed, as well as test results of the fabricated fast neutron detector using the 241Am-Be source are shown.

The future work will be focused on increasing the active region of the GaAs sensor with increasing the rectifying contact area (>50mm2) and with increasing the epitaxial layer thickness up to 100–150μm.

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Pixelated Single-crystal Diamond Detector for fast neutron measurements

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Diamond Detectors, due to their high radiation hardness, fast response time and small size, are good candidates as fast neutron detectors in environment where the high neutron flux is an issue, such as spallation neutron sources. Single-crystal Diamond Detectors (SDDs) are of particular interest also for fast neutron spectroscopy for diagnosing the next generation thermonuclear fusion plasmas, i.e. the ITER experiment [1]. Neutron detection in SDDs is based on the collection of electron-hole pairs produced by charged particles generated by neutron interaction on 12C. Measurements performed on prototype SDD in the past determined: i) the spatial profile of the fast neutron flux, with a spatial resolution of 4.5 mm [2]; ii) the good energy resolution (<4% at 14 MeV neutron energy), of the SDD coupled to a fast digital spectroscopic electronic chain; iii) the possibility to measure the neutron flux at high rates (>1 MHz).
In this work the design and construction of a new 12-pixel SDD matrix is presented. The fast charge preamplifier and 1Gs/s waveform digitizer readout will be described together with the most important results obtained during the SDD matrix calibration procedure. The measurement reproducibility in terms of energy resolution and time stability, of each single pixel will be evaluated. The measurements were performed irradiating with a 241Am alpha source each SDD pixel.

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Measurements and Analysis of Charge Sharing Effect with Hybrid Pixel Detectors

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When going into new deep sub-micron technologies many new possibilities show up while designing a readout electronics for hybrid pixel detectors. For one – the pixels can be smaller, what is desirable for medical applications but also in diffactometry as the distance from the measured sample to the detector can be shorter. However one disadvantage that rises while going into smaller pixel sizes is the charge sharing effect, which starts to be an important issue in new designs of hybrid pixel detectors working in single photon counting mode. It produces three main types of inaccuracy in the measuring system, namely:

- in determining the incident photon energy, as the charge deposited in the detector is shared between neighbouring channels,
- in determining precise photon hit position, as the hit at the border of two pixels will be assigned to one of them,
- in determining the precise time of photon arrival, as the shared charge will result in smaller amplitude pulse after shaping generating so called time walk effect.

For precise estimation of the pixel area that is affected by the charge sharing effect, we have made measurements at Spring-8 facility using different prototype modules with different detector geometries. The sensors were illuminated with a very narrow X-ray beam, which has the diameter not wider than 10 μm. With this setup we have made precise movements of the detector with very small step. The detailed analysis of the results will be presented together with mathematical calculation of the charge sharing effect and its' influence on the noise and gain estimation from the measurement.

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Neutron Beam Imaging with GEM detectors

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Neutron GEM-based detectors represent a new frontier of devices in neutron physics applications where a very high neutron flux must be measured such as future fusion experiments (e.g. ITER Neutral beam Injector) and spallation sources (e.g. the European Spallation source). This kind of detectors could be used both as beam monitors but also as neutron diffraction detectors since they may represent a valid alternative for the 3He detectors replacement. Fast neutron GEM detectors (nGEM) feature a cathode composed by two layers of polyethylene + aluminium (neutron scattering on hydrogen generate protons that are detected in the gas) while thermal neutron GEM detectors (bGEM) are equipped with a borated aluminium cathode (charged particles are generated through the 10B + n → 7Li + α reaction). GEM detectors can be realized in large area (1 m2) and their readout can be pixelated. Three different prototypes of nGEM and one prototype of bGEM detectors of different areas and equipped with different types of readout have been built and tested. All the detectors have been used to measure the fast and thermal neutron 2D beam image at the ISIS- VESUVIO beam line. The different kinds of readout patterns (different areas of the pixels) have been compared in similar conditions. All the detectors measured a width of the beam profile compatible with the expected one. The imaging property of each detector was then tested by inserting samples of different material and shape in the beam. All the samples were correctly reconstructed and the definition of the reconstruction depends on the type of readout anode. The fast neutron beam profile reconstruction was then compared to the one obtained by diamond detectors positioned on the same beam line while the thermal neutron one was compared to the imaged obtained by cadmium-coupled x-rays films. Finally also efficiency, the gamma background rejection and the counting stability have been determined. These prototypes represent the first step towards the realization of new high rate large area neutron detectors for fusion experiments and spallation sources.

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High resolution alpha particle detectors based on 4H-SiC epitaxial layer

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In this work we fabricated high-resolution alpha particle detectors based on 4H-SiC epitaxial layer. The detectors consist of 105 um thick 4H-SiC epitaxial layer grown on 350 um 4H-SiC substrate. The circular Schottky contacts with diameter of 1.4 mm using Au/Ni (9/5 nm) and Au/Pt (9/5 nm) double layer was evaporated on the Si face of the epilayer. The thin metallization were used to minimize diffusion and energy loss of impinging alpha particles. The detectors were characterized using current-voltage measurements and alpha spectroscopic measurements.

Current-voltage measurements at room temperature reveal leakage current about 1 pA at operating bias of 500 V. The break down voltage was found at 750 V. The capacitance-voltage measurements showed monotonous decreasing of effective doping concentration from 1.3×10E14 cm-3 closely below Schottky contact to 1.0×10E14cm-3 near the substrate.

The spectroscopic setup based on ORTEC was used for alpha particle energy measurements. As a source of alpha particles we utilized triple radioisotopes 239-Pu 241-Am 244-Cm which generates alpha particles with energies from 5106 keV up to 5806 keV. The best energy resolution of 13.8 keV for 5486 keV alpha particles was reached at operation bias of 200 V. The noise of the spectroscopic setup connected to the detector was about 4 keV calculated for SiC material. Using SRIM calculation and known Bragg curves we estimated absorbed energy in detector volume and calculate diffusion length of generated charge in the neutral region which we estimated to 5.5 um. The charge collection efficiency versus bias voltage rapidly increases and achieves 99 % at 50 V. Considering the doping concentration at the bias of 50 V the thickness of space charge region is equals to the range of detected alpha particles.

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A Method to Simulate the Observed Surface Properties of Proton Irradiated Silicon Strip Sensors

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During the scheduled high luminosity upgrade of LHC, the world's largest particle physics accelerator at CERN, the position sensitive silicon detectors installed in the vertex and tracking part of the CMS experiment will face more intense radiation environment than the present system was designed for. To upgrade the tracker to required performance level, extensive measurements and simulations studies have already been carried out.

A defect model of Synopsys TCAD package for the bulk properties of proton irradiated devices has been producing simulations closely matching with measurements. However, the model does not provide expected behavior due to the fluence increased surface damage. The solution requires an approach that does not affect the accurate bulk properties produced by the proton model, but only adds to it the required radiation induced properties close to the surface. These include the observed position dependency of the strip detector's charge collection efficiency (CCE). A procedure to find a defect model that reproduces the correct CCE loss will be presented.

When applied with CCE loss measurements at different fluences, this method may provide means to parametrizate the accumulation of oxide charge at the SiO2/Si interface as a function of dose.

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The CMS Silicon Pixel Detector Phase-1 Upgrade

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The silicon pixel detector is the innermost component of the CMS tracking system, providing high precision space point measurements of charged particle trajectories. The phase-1 upgrade of the CMS pixel detector includes changes in the front-end readout chip, the geometry of the detector and the cooling system to be installed in the year 2018. Each of these aspects will be summarized and the resulting improvements in physics performance discussed. The performance of the upgraded CMS pixel detector modules tested in the DESY positron test beam with and without proton irradiation and laboratory measurements to study the new digital read-out chip will be reported. A study of an in-house tin bump bonding process at DESY to connect the front-end read-out chips to the silicon substrate of the CMS pixel detector will also be presented.

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Comparison of Radiation Hardness Properties of p-in-n & n-in-p Si Strip Sensors Using Simulation Approach

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In order to address the problems caused by harsh radiation environment in high luminosity phase of the LHC, the Si micro-strip sensors based CMS tracker will undergo an upgrade. This requires development of Si sensor technology, which can guarantee a satisfying performance of the micro-strip detectors during the high luminosity LHC (HL-LHC) data tacking. Systematic studies based on micro-strip device measurements and performance simulations have been initiated, with a special focus on device design and material options for Silicon micro-strip sensors. One of the most important tasks is to compare the sustainability of p-in-n versus n-in-p Si strip sensors after different level of radiation damage. In the present work, comprehensive device simulations have been carried out for both types of sensors incorporating surface and bulk damage together. Simulations have been performed using commercially available TCAD tools, Silvaco and Synopsys. The surface damage is incorporated using different amount of surface oxide charge density at the Si-SiO2 interface, while introducing trap levels within the Si band gap includes the bulk damage. Various properties of p-in-n and n-in-p sensors like inter-strip capacitance, inter-strip resistance and electric field, have been simulated for different levels of radiation damage and compared with measurement campaign data. Systematic evaluation of critical electric field inside the devices provided also a plausible explanation for the observed higher rate of non-Gaussian noise in p-in-n compared to n-on-p sensors. The collection of simulation results indicate that n-in-p sensors are the most promising choice, in terms of performance after high radiation damage, compared top-in-n sensors for CMS tracker upgrade.

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Simulation of 4H-SiC Detectors for Ultra Fast Particles Spectroscopy

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Silicon carbide (SiC) has been studied as radiation detector in the last decades, many publications on SiC radiation detectors development and their performance on detection and spectroscopy have been come out . Compared with conventional semiconductors (Ge, Si, CdTe, CdZnTe, GaAs…), 4H-SiC has a higher carrier saturation velocity, higher breakdown field and wider bandgap. The high carrier velocity of SiC makes it suitable for high speed detection applications, in addition its high breakdown field (2 MV/cm) allows to operate under high operating bias voltage without junction breakdown, so achieving fast charge carrier collection. The extremely low current density, lower than 1 pA/cm2 at 300K due to its wide bandgap (3.2 eV), makes SiC detector extremely low noise even at high temperature.

We present a study on the high speed detection capability of Nichel/4H-SiC Schottky junctions to proton and alpha particles with different energies in the MeV range. The particle path and the distribution of the deposited energy were calculated by SRIM, the contribution of each e-h pair generated on the path to the total signal is dependent on the deposited energy distribution on the path, and then the current and voltage signals are calculated by adding the contributions of all generated and collected charge. The best time response of 5.5 MeV alpha particle has been achieved with a rise-time of 330 picoseconds and pulse width of 730 picoseconds, which are predicted in good agreement with experimental values. For 2 MeV proton, 300 ps rise-time and 700 ps pulse width have been obtained. The effect of SiC layer doping, detector geometry and bias condition have been studied, so establishing the criteria for designing ultra fast SiC devices for timing and time of flight detectors.

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Technology evolution of FBK SiPMs for imaging applications in nuclear medicine.

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In this presentation, we will give a comprehensive description of the main improvements achieved during the years in the performance of Silicon Photomultipliers (SiPMs) at FBK. First, we will focus our attention on the electric field shape optimization, correlating it to the improvement of the dark count rate (DCR), temperature stability, breakdown voltage uniformity, and photo-detection efficiency (PDE). Then, we will move our attention to the optimization of the micro-cell border structure. We reduced consistently the cell size while preserving a high fill factor, for improved linearity, reduced correlated noise and faster signal response. We produced SiPM prototypes featuring a cell size ranging from 30x30 down to 12x12 um2. With the first devices, we measure a PDE exceeding 50 % in the blue/green region of the light spectrum whereas, with the latter, the efficiency is higher than 25 %.

This technology evolution has a clear impact on the functional performance of the device in nuclear medicine applications such as Time-of-Flight Positron Emission Tomography (TOF-PET) and Single Photon Emission Tomography (SPECT). For the first application, timing performance is the most critical aspect. The PDE is the dominant parameter but DCR plays also an important role because it prevents from triggering at very low level. In this respect, we developed a pole-zero cancellation circuit that makes the effect of DCR much less detrimental especially for large area devices. With the latest technology, using a 4x4 mm2 device with 25x25 um2 cells coupled to a 3x3x5mm3 LYSO crystal, we obtained a coincidence resolving time of 145 ps FWHM at 20 C with an energy resolution better than 10 % FWHM at 511 keV. In case of SPECT, the critical parameter is the energy resolution. It depends on the ratio between the excess noise factor (ENF) and the PDE. Thus, reduction of the correlated noise is extremely important. With the same device mentioned before coupled to a 3x3x5mm3 CsI(Tl) crystal, we obtained an energy resolution close to 10 % at 122 keV. It is interesting to note that the best operating voltage for the two applications is very different because of the different impact of the SiPM parameters.

Finally, in this presentation, we will show a new development we are conducting on position-sensitive SiPMs. These sensors are very promising for high-resolution imaging with scintillators since they allow a drastic reduction of the number of read-out channels.

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Highly granular Positron Emission Tomography detector for a novel multimodal medical imaging tool

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This talk describes the characterisation of crystals and photodetectors for a new Positron Emission Tomography (PET) detector, namely the external plate of the EndoTOFPET-US detector.
The EndoTOFPET-US collaboration (FP7 project agreement No. 256984) aims to integrate Time-Of-Flight PET with ultrasound endoscopy in a novel multimodal device, capable to support the development of new biomarkers for prostate and pancreatic tumors.
The detector will consists in two parts: a PET head mounted on an ultrasound probe and an external PET plate. The challenging goal of 1 mm spatial resolution for the PET image requires a detector with high channel density: 4096 scintillator crystals individually readout by Silicon Photomultipliers (SiPM) make up the external plate. Morevover, a Coincidence Time Resolution (CTR) of 200 ps FWHM must be achieved for efficient background rejection. The quality and properties of the single components and the combined crystal+SiPM modules are evaluated before the detector assembly.
The SiPMs chosen for the external plate are arrays of 4x4 discrete MPPCs from Hamamatsu. For each channel, the single photo-electron spectrum is recorded for several voltage points, and then the gain, breakdown voltage, Dark Count Rate (DCR) and inter-pixel optical cross talk are extracted. In agreement with the SiPM producer, an acceptance limit of the DCR has been set in order to guarantee the time resolution requested. Results show that 98 % of the SiPMs meet this requirement, and the spread in the breakdown voltage in each array is compatible with the voltage bias tuning capability of the dedicated readout chip.
The scintillators are arrays of 4x4 LYSO:Ce crystals, each with a volume of 3.5x3.5x15 mm3. Using a conventional PMT, the average light yield and energy resolution is measured for every array.
After the crystals are glued to the SiPM arrays, the CTR of each channel is measured using an ultra-fast amplifier/discriminator. Results show an average value close to the demanding goal of 200 ps FWHM.
In order to perform a preliminary detector calibration, the light output for the 511 keV photon is measured for each channel. Finally, after the correction for the SiPM non-linear response, the average energy resolution for the 511 keV is found to be about 13 %, enough for Compton discrimination.
All the detector modules are now ready for the integration with the dedicated readout chip and the final mechanical assembly.

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Measurement of the energy and time resolution of the novel VIP CdTe detector for PET applications

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The Voxel Imaging PET (VIP) pathfinder project is developing a prototype scanner for positron emission tomography (PET) based on highly pixelated CdTe Schottky detectors.

Optimized for human brain scans, the innovative design is expected to deliver images with unprecedented high quality and with up to 30 times less patient exposure with respect to the state-of-the-art PET scanners based on scintillating crystals [Mikhaylova E. et al., IEEE Trans. Med. Imaging 33:2 2014]. The full ring will be made of a stack of CdTe individual detectors with a 10x10 mm^2 surface and a 2 mm thickness.
Each detector is electronically pixelated and bump-bonded onto a dedicated 10x10 channels, low-noise, low-consumption ASIC with 1x1 mm^2 pitch [Macias-Montero J.-G. et al., IEEE Trans. Nucl. Science 60:4 2013]. Developed as part of the VIP project, the ASIC provides each channel with a fully integrated self-triggered front-end electronic for the processing of the detector signal and the digitization of the deposited energy and the impact time.

This work presents the measurement of the energy and time resolution of a single detector operated at room temperature with a 2000 V bias applied orthogonally to the detector surface for a total electrical field of 1000 V/mm. The spectroscopy of several radioactive sources is obtained to characterize the response across a wide energy spectrum, from few keV up to 1 MeV. The timing performance is studied by operating the detector in coincidence with a fast scintillator coupled to a PMT. The measurement of the coincidence time resolution of two VIP detectors in the simultaneous detection of 511 keV photon pairs is also provided. The values obtained in the laboratory are compared to those obtained with the simulation performed with both the COMSOL Multiphysics software and the GAMOS Geant4 toolkit.

To date, no pixelated CdTe detector with the capabilities of the VIP device has been developed and the measurements presented here are of crucial importance in the optimization of the design, both in terms of the geometry and the read-out electronic. Results confirm that, with a 1% energy resolution and a 10 ns coincidence time resolution for 511 keV photons, the VIP detectors behave as expected by the theoretical models and present ideal characteristics for the use in PET.

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Measurement of charged particle yields emitted during irradiation with therapeutic Carbon, Helium and Oxygen beams in view of the design of a new tool for the monitoring of hadrontherapy treatments

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The work presented in this contribution addresses one of the key issues related to hadrontherapy treatments: the lack of a common adopted clinical technology for the on-line dose release monitoring, that could be able to match the high precision achievable in the heavy ion dose release planning. The detailed knowledge of charged and neutral particles production in the interaction between the hadron beam and the target plays a crucial role in dose monitoring devices design and optimization, as well as in tuning Monte Carlo simulations. It has been demonstrated that it is possible to monitor the Bragg peak (BP) position and the dose release exploiting the secondary protons emitted at large angles (up to 90 degrees with respect to the beam incoming direction) [1].

The application of such monitoring technique, based on the back tracing of protons exiting from the target, to ion beams of therapeutical energy, heavily relies on the measured energy and angle production spectrum of outgoing secondary particles. Such spectra are needed to optimize the detector technology and geometry, as a function of the beam and treatment configurations.

In this work we present the results obtained studying the interactions of a 220 MeV/u 12C ion beam with a PMMA target (GSI, Darmstadt). The flux and energy spectra of secondary charged particles have been measured, and support the observation of a non negligible production of Z = 1 fragments at large angle. A clear correlation between the secondary charged particles production region in the target and the BP position has been observed: different observables, correlated with the BP position, have been defined and measured with a precision better than 1 cm.

The same study has been done studying the interactions of 4He and 16O ion beams with a PMMA target (HIT, Heidelberg): the data analysis just started and here we present some preliminary results. The performances obtained with He, C and O ion beams support the feasibility of a larger area detector, capable of a better final resolution, that could be employed as on-line monitor in hadrontherapy treatments. A dose profiler device, funded by the INSIDE PRIN italian project, designed to detect neutral and charged secondary particles accordingly to what observed in this work, is under construction in collaboration with the CNAO centre (Pavia).

[1] Agodi C et al 2012b Charged particle's flux measurement from PMMA irradiated by 80 MeV/u carbon ion beam Phys. Med. Biol. 57 5667

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The Dosepix detector – an energy-resolving photon-counting pixel detector for spectrometric measurements

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The Dosepix detector(1) is a hybrid photon-counting pixel detector based on ideas of the Medipix detector family(2). Included in the pixel electronics is a novel concept of energy binning allowing energy-resolved measurements within one acquisition. The possibilities of this detector concept range from applications in personal dosimetry(3) and energy-resolved imaging(4) to quality assurance of medical X-ray sources by analysis of the emitted photon spectrum. In this contribution the Dosepix detector, its response to X-rays as well as spectrum measurements with Si and CdTe sensor layer are presented.

The pixel matrix of the Dosepix detector consists of 16x16 square pixels with 220µm pixel pitch. The hybrid setup allows using the same ASIC-design with different sensor layers, in this case 1mm CdTe and 300µm Si. Besides integration and photon-counting mode, the energy-binning mode is provided. In this operational mode the deposited energy of an incident photon is acquired using Time-over-Threshold (ToT) – measurement. The ToT-values are then compared to 16 pixel wise set digital energy thresholds. Thereby it is possible to derive a binned spectrum of the deposited energy of impinging photons in each pixel and within a single acquisition. To obtain a finer sampling of the spectrum, shifted energy bins for different pixels of the matrix are applied. This technique can be used to characterize directly the emitted photon spectrum of an X-ray tube concerning, for example, applied electron acceleration potential (kVp) or anode material.

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Large Area Synchrotron X-Ray Fluorescence Mapping of Biological Samples

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Large area mapping of inorganic material in biological samples has suffered severely from prohibitively long acquisition times. With the advent of new detector technology we can now generate statistically relevant information for studying cell populations, inter-variability and bioinorganic chemistry in large specimen. We have been implementing ultrafast synchrotron-based XRF mapping afforded by the MAIA detector for large area mapping of biological material. For example, a 2.5 million pixel map can be acquired in 3 hours, compared to a typical synchrotron XRF set-up needing over 1 month of uninterrupted beamtime. Of particular focus to us is the fate of metals and nanoparticles in cells, 3D tissue models and animal tissues. The large area scanning has for the first time provided statistically significant information on sufficiently large numbers of cells to provide data on intercellular variability in uptake of nanoparticles. Techniques such as flow cytometry generally require analysis of thousands of cells for statistically meaningful comparison, due to the large degree of variability. Large area XRF now gives comparable information in a quantifiable manner. Furthermore, we can now image localised deposition of nanoparticles in tissues that would be highly improbable to 'find' by typical XRF imaging. In addition, the ultra fast nature also makes it viable to conduct 3D XRF tomography over large spans in Z.

This technology avails new opportunities in biomonitoring and understanding metal and nanoparticle fate ex-vivo. Following from this is extension to molecular imaging through specific anti-body targeted nanoparticles to label specific tissues and monitor cellular process or biological consequence.

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Edge-Illumination X-Ray Phase Contrast Imaging: matching the imaging method to the detector technology

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X-Ray Phase Contrast Imaging (XPCI) has been arguably the hottest topics in x-ray imaging research over the last two decades, due to the significant advantages it can bring to medicine, biology, material science and many other areas of application. Considerable progress has recently been achieved, in terms of the first in vivo implementations at synchrotrons (notably at Elettra in Trieste), and of new XPCI methods working with conventional sources. Among the latter, edge-illumination (EI) is arguably one of the most promising in terms of possible mainstream translation, due to set-up simplicity, scalability and flux efficiency compared to other approaches. EI is indeed the only method working with a completely incoherent source: however, it was recently demonstrated that neither the ability to perform quantitative phase retrieval, nor the method's phase sensitivity are affected by the source's incoherence.

Another key difference is that, while in most XPCI approaches a detector with the appropriate spatial resolution (and where possible efficiency) is simply placed e.g. at the output of an interferometer, in EI it forms part of the "phase sensing" mechanism itself. This is achieved via a variety of means, including "masking" the detector as in the "coded-aperture" approach typically used in lab-based implementations; alternatively, as commonly employed at synchrotrons, the physical edge of the detector itself, or the separation between pixels in direct conversion detection systems, may be used as the phase sensing mechanism.

After briefly reviewing the method's working principle, quantitative potential and phase sensitivity, this talk will delve into the detail of the detector's role in the image formation principles of the EI technique. Specifically, after discussing in general how signal sharing and cross-talk phenomena affect the phase signal in EI, we will present some results recently obtained by implementing EI XPCI with the PICASSO edge-on silicon microstrip detector at the SYRMEP synchrotron beamline in Trieste, and with the chromatic photon counting PIXIRAD hybrid CdTe detector with conventional x-ray sources in the UCL labs. To conclude, we will examine the enhancements that these implementations allow compared to the use of more generally used detector technology (e.g. Si and Se flat panels, CMOS), and discuss potential ways to bring these benefits into mainstream use.

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Quantitative phase contrast mammography at clinical doses with synchrotron radiation

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This work presents the first study of X-ray phase contrast imaging based on a simplified implementation of the edge illumination method (EIXPCi) with synchrotron radiation for application in mammography. Moreover, a novel phase retrieval (PR) algorithm, recently developed by Munro [1], was applied to a set of mammographic images. Differently from conventional radiography, based on absorption only, the application of this algorithm to EIXPCi images leads to quantitative maps of absorption and differential phase.

The study was carried out at the SYRMEP beamline of Elettra synchrotron radiation facility (Trieste, Italy), where a mastectomy specimen was investigated with the EIXPCi technique. For applying this method to mammographic examination, we propose a simplified set-up, which utilizes only one mask for shaping the beam, while the insensitive area of the detector pixel is created by using the pixel edge itself. Images were acquired by using a linear array silicon detector operating in single photon counting mode and in the edge-on configuration. The phase retrieval algorithm is based on the acquisition of a pair of images in two complementary EIXPCi configurations, by using two different edges of the linear detector. The sample was exposed at two different energies (17 and 23 keV) suitable for mammography with synchrotron radiation; the entrance air kerma was of about 1 mGy for each exposure.

Both differential phase and retrieved absorption images were obtained by applying the PR method. The retrieved absorption images represent maps of linear attenuation coefficients integrated over the sample. Mean values of ROIs selected in retrieved absorption images were compared with the expected ones. The quantitative data are in good agreement with the expected values of linear attenuation coefficients for the examined sample.

The PR algorithm was previously validated on images of differently absorbing wires using a synchrotron radiation source and a single photon counting detector. The present study demonstrates that it is possible to extract quantitative information on the composition of breast and to differentiate tissues. In order to evaluate the possible clinical impact of extracting quantitative information about the breast tissue, associated with maps of differential phase, extensive studies are necessary on ex vivo samples.

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Dose reduction in x-ray phase-contrast imaging with a multi energy-channel photon-counting detector

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Imaging the phase shift of x-rays in an object promises high sensitivity especially for low-Z materials. (1) To retrieve this phase information, a so-called Talbot-Lau interferometer can be used. Although the interferometer has a complex energy response, it can be operated using a conventional x-ray source. (2) This is essential for a wide application of the imaging method. However, a broad x-ray spectrum lowers image quality compared to monochromatic illumination. But it is known from attenuation-based imaging that the performance of an imaging chain can be enhanced if a photon-counting detector is used instead of an energy-integrating detector. (3) The image quality can be even further improved by energy weighting if a spectroscopic pixel detector is used. (4) In this contribution we demonstrate energy weighting for differential phase-contrast imaging. In order to increase phase-image quality SNR- optimized weighting factors were derived. These were verified in a benchmark experiment using the multi energy-channel pixel detector Dosepix (5). The detector has 12x16 pixels of 220µm pitch. Each of these pixels is equipped with 16 individually set energy bins. After measuring the Time-over-Threshold (ToT) value of an interacting photon, this value is compared to the 16 energy bins and the counter of the corresponding bin is increased. By this technique the spectral information of a radiation field can be measured in 16 bins by one single acquisition.
With this detector differential phase contrast images of a PMMA wedge were acquired. Using the energy information, energy weighting was performed. To quantify the image quality improvement contrast-to-noise ratios were determined. A dose reduction of 60% compared to an emulated integrating detector was achieved. The result of the measurement demonstrates the advantages of energy-resolved photon-counting in x-ray phase-contrast imaging.

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CZT Detector Technology for Medical Imaging and Security Applications

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II-VI semiconductors CdTe and CdZnTe (CZT) have emerged as the material of choice for room temperature detection of hard X-rays and soft γ-rays. The techniques of growing the crystals, the design of the detectors, and the electronics used for reading out the detectors have been considerably improved over the last few years. CdTe/CZT materials find now applications in astrophysics, medical imaging and security applications. The paper discusses recent progress in CZT detector technology and outlines possible new application opportunities.

CZT material originally started to be grown using various flavors of Bridgman technique. The introduction of large single crystal and high performance CZT grown by THM has defied conventional myths about the capability of this crystal growth method with respect to the production of spectroscopic grade CZT. In particular control of crystalline defects that challenge the thickness scalability of large volume CZT detectors was effectively addressed. Advances in THM CZT crystal growth include 100mm diameter ingot and state-of-the-art detector fabrication.

The cost of the CZT technology is significantly affected by required fabrication steps to convert CZT crystal into functional CZT detectors. These steps include wafer cutting, surface passivation, lithography and side polishing. Many of these operations are performed manually but future fab equipment automation will significantly reduce these costs. One new trend in commercial CZT manufacturing is movement towards silicon like wafer level processing. Due to high yield of THM it is now possible to process entire CZT wafer instead of traditional good detector “mining” process used in the past.

CZT technology has achieved maturity required for commercial deployment. CZT based SPECT machines, BMI cameras and bone densitometry DEXA devices have been shipping in volume for several years. Recent major improvements in crystal quality by implementing new growth and wafer annealing processes have enabled Wafer Level Fabrication (WLF). WLF in turn significantly improves yields, costs, capacity and product quality. CZT researchers have solved high flux polarization problem making future large volume commercial applications like dental, flat-panel X-ray or Computed Tomography within development reach. Further research efforts are required to address the most demanding application like baggage scanning and PET.

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Investigating the Suitability of GaAs:Cr Material for High Flux X-Ray Imaging

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Semi-insulating wafers of GaAs material with a thickness of 500 um have been compensated with chromium by Tomsk State University. Initial measurements have shown the material to have high resistivity (3 x 10[9] Ohm cm) and tests with pixel detectors on a 250 um pitch produced uniform spectroscopic performance across an 80 x 80 pixel array. The average FWHM at an energy of 60 keV was found to be 2.8 +/- 0.5 keV.

At present, there is a lack of detectors that are capable of operating at high X-ray fluxes (> 1 x 10[8] photons s-1 mm-2) in the energy range 5 - 50 keV. Under these conditions, the poor stopping power of silicon, as well as issues with radiation hardness, severely degrade the performance of traditional detectors. While high-Z materials such as CdTe and CdZnTe may have much greater stopping power, the formation of space charge within these detectors under high flux also degrades detector performance. Initial measurements made with GaAs:Cr detectors suggest that many of its material properties make it suitable for these challenging applications. In this paper the performance of the material for such high flux imaging applications will be assessed in terms of radiation hardness and imaging under irradiation.

The radiation hardness of the GaAs:Cr material has been measured on the B16 beam line at the Diamond Light Source Synchrotron. Small pixel detectors were bonded to the STFC Hexitec ASIC and were irradiated with 4 x 10[10] s-1 mm-2 monochromatic 12 keV X-rays up to a maximum dose of 3 MGy. Measurements of the spectroscopic performance before and after irradiation will be reported. GaAs:Cr micro-strip detectors with pitches of 100 um and 50 um (512 and 256 channels respectively) have also been fabricated by Tomsk and have been bonded to the STFC XCHIP (X2) readout ASIC. These detectors will be used to demonstrate the X-ray imaging performance during high flux irradiation and will compare the performance of electron and hole readout.

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Investigation of GaAs:Cr Timepix assemblies under high flux irradiation

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Gallium arsenide compensated by post-growth chromium diffusion (GaAs:Cr) has recently shown to be a promising sensor material for X-ray applications due to its high resistivity (1e9 Ohm*cm), leading to low leakage currents at room temperature. Additionally, its fully active volume, the good electron transport properties and an absorption of >95% for photon energies up to 30 keV at typical sensor thicknesses of several hundreds of microns make this material a favorable candidate for photon counting X-ray imaging detectors.
However, being a compound semiconductor, this material inevitably features crystal imperfections such as dislocation networks or small angle grain boundaries, which might reduce the detection performance or image quality. Also, temporal instabilities especially at high photon fluxes usually found at synchrotrons or in medical applications like computed tomography may occur.
In this work, we study the material properties and the performance of 500 µm thick GaAs:Cr sensors, bump-bonded to Timepix electronics. The image quality and the behavior under the irradiation with high X-ray fluxes using a monochromatic synchrotron beam are investigated. We find that the dislocation network typically present in melt-grown GaAs, which is used as the base material for the chromium compensation, indeed influences the detection properties due to local variations of the charge transport properties. However, it is also found that high image quality and signal-to-noise ratios can be obtained and that the high flux behavior can be substantially improved by optimized chip settings, i.e. by tuning the Timepix' leakage current compensation. By doing so, a stable performance of the material at fluxes as high as ~1e10 ph/s/mm² can be realized, which is already well beyond the point at which pileup becomes dominant due to the maximum pulse processing speed achievable with the Timepix chip.
Based on these promising results, the next steps will be to increase the active area as well as the frame rate by producing multi-chip assemblies and combining them with novel, fast (>=100 Hz) readout systems.

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Radiation detectors fabricated on high-purity GaAs epitaxial substrates

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Materials with high atomic numbers (GaAs/Ge/CdTe) have higher absorption efficiency than silicon for the high X-ray energy range. The CdTe remains a high absorption efficiency at 100 keV. However, its disadvantages are the limit of crystal size, material non-uniformity and the high cost. Germanium is available in 6-inch wafer with the high uniformity, but to decrease the high leakage current due to its narrow bandgap (0.67 eV) cooling is required, which increases the complexity of system.

The use of GaAs as an alternative to Si detector is attractive for many applications, e.g. X-ray dynamic defectoscopy and medical radiography, where the beam energy above 10 keV is needed. GaAs has high atomic numbers and is an ideal material to fill the moderate energy gap left by silicon and CdTe. There are two types of detector-grade GaAs: semi-insulating bulk and epitaxial material. The semi-insulating GaAs bulk suffers from non-uniform concentration of defects resulting in a short lifetime of minority carriers. High-purity epitaxial GaAs material, however, is a good candidate for X-ray detection at room temperature, due to its superiority in defect and doping control during growth of the epitaxial layer.

VTT and Aalto University have built a CVPE (Chloride Vapor Phase Epitaxy) reactor at Micronova to grow high-purity epitaxial GaAs layers. The new vertical flow reactor enables growth of uniform GaAs epitaxial layer on 2 to 6 inch substrates. The structure of the CVPE reactor and the preliminary result from the test run will be reported in the conference.

At the same time, two epitaxial GaAs wafers from Ioffe Physical Technical Institute were processed at the Micronova cleanroom. These epi-wafers have a p-i-n structure with a 2-3 µm p+ layer and a 150 µm intrinsic layer. The material has been characterized by synchrotron topography to evaluate defects of the material. Two Medipix sensors, one mini-strip sensors and many diodes were fabricated on each 2-inch GaAs epi-wafer. Some key process steps were carefully studied to improve the quality of flip-chip bonding and the reliability of sensors. The GaAs diodes were characterized with C-V, I-V and the device temperature dependency was investigated. Two GaAs sensors were assembled on Timepix chips at VTT and characterized with X-ray fluorescence and isotope sources. A semi-insulated GaAs detector was measured with the same setup as a comparison. All characterization results will be presented in the conference.

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First PILATUS3 200K-W CdTe detector: calibration and performance

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A large area CdTe single photon counting X-ray detector with 200k pixels on a sensitive area of 16.8cm x 3.4cm, was built with four CdTe sensors bump bonded to PILATUS3 CMOS readout ASICs. The detector was calibrated with fluorescent X-ray over a wide range of energies from 8keV to 60keV. The detector performance and characteristic parameters have been measured with an X-ray tube and at a synchrotron beamline (BAMline at BESSY II).

The CdTe sensors have ohmic contacts, a size of 4.2cm x 3.4cm and a thickness of 1mm.

The PILATUS3 ASIC with instant retrigger technology is configured for electron readout and high-energy operation.

The detector has been characterized in terms of energy resolution, quantum efficiency, Point Spread Function and count rate. The CdTe material behavior over time has been studied. Polarization, defects and non-uniformities, typically arranged in a network of lines, have been investigated under different irradiation fluxes and X-ray energies.

Measurements with the monochromatic beam at the beamline prove a wide range of operation from 8keV to 60keV and a quantum efficiency of 80-90%, a reduction to 80% is observed between 25-50keV due to the CdTe Ka escape photons.

The operation under long-term exposure at high X-ray flux has shown a reduction of the mean number of counts with time due to the polarization of the material and the formation of line structures. The count rate reduction and the increase of the contrast of the lines have been investigated in detail as a function of time and at different fluxes. Moreover it has been observed that higher operation temperature and higher negative bias voltage improve the stability of both parameters. The influence of the operation conditions on the detector performance will be presented.

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Large Area Medipix X-ray Pixel Detectors with Monolithic Si, CdTe and GaAs Sensors

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X-ray pixel detectors based on Medipix and Timepix ASICs process incoming X-ray photons as single events and offer advanced features [1] for different fields of detector applications. For example they provide adjustable energy thresholds with separate counters for multi-spectral X-ray imaging, a correction for charge sharing that improves the energy resolution and a small pixel pitch of 55 x 55 µm² for a high spatial resolution.

The Medipix ASICs can be paired with different semiconductor sensor materials. Silicon is the standard material here and provides a high detector and image quality due to its homogeneity and stability, but has a very low X-ray absorption efficiency at energies above 20 keV. For detector applications that require a high efficiency at X-ray energies up to several hundred keV the compound semiconductor sensor materials GaAs and CdTe are first choice [2].

Two read-out systems have been developed for large area arrays of Medipix ASICs. In the standard configuration both read-out systems use 3x2 tiling of Medipix ASICs providing an active area of 42 x 28 mm² and about 400k pixels. The “Hexa Box” is a compact plug-and-play system with USB-interface, low power consumption and it is compatible with the Pixelman software. On the other hand the “X-Kit” is a very flexible, high performance read-out system. It provides a frame rate of up to 120 fps, uses a network cable for data transfer via UDP and offers low-level interface library for scripting. Both systems are temperature stabilized and have a programmable high-voltage module onboard.

The performance of the Si, GaAs and CdTe sensors in terms of homogeneity, the signal-to-noise ratio (SNR), the spatial resolution (MTF) and the efficiency will be presented here as well as the performance of the two read-out systems.

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Dependence of X-ray sensitivity of GaAs:Cr sensors on material of contacts

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The investigation of the pulse height distribution and X-ray sensitivity depending on the contact material on high resistive chromium compensated gallium arsenide (HR GaAs:Cr) sensors is presented. Some samples had Cr/Ni contacts made using electron-beam deposition and some samples had In additionally alloyed into the contacts. Three different configuration of sensors were investigated: Ni/Cr - HR GaAs:Cr – Cr/Ni, In/Ni/Cr - HR GaAs:Cr – Cr/Ni/In and In/Ni/Cr - HR GaAs:Cr – Cr/Ni.

Depending on the type of sensor there are differences in both the X-ray sensitivity and pulse height distribution depending on X-ray intensity are observed. Ni/Cr - HR GaAs:Cr – Cr/Ni –structures have shown sublinear sensitivity dependence to intensity, while In/Ni/Cr - HR GaAs:Cr – Cr/Ni/In are characterized by superlinear dependence holding everything else constant. The results and possible causes are discussed in this paper.

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Reduction and investigation of the dark current in polycrystalline CdTe based digital X-ray imaging detectors

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In recent years, digital direct-conversion flat-panel X-ray detectors have been widely used in medical imaging and industrial application. These flat-panel detectors are based on the utilization of photoconductor such as amorphous-selenium (a-Se), polycrystalline Cd(Zn)Te and HgI2 and other compound semiconductors. Currently, a-Se based large-area detector with electric readout method in direct-conversion detectors has been widely utilized for chest radiography and mammography and digital tomosynthesis applications [1]. Polycrystalline CdTe conversion material is considered as a very promising candidate for high spatial resolution and low dose in X-ray imaging detectors field such as dental CT and fluoroscopy. However, this material has still high dark current in comparison with popular a-Se photoconductor for fluoroscopic imaging which is used in very low X-ray flux. Therefore, we need to method to reduce the dark current of polycrystalline CdTe films. In this work, we have fabricated and investigated polycrystalline CdTe films in order to utilize this photoconductor in direct-conversion X-ray detectors. The polycrystalline CdTe films with different thickness were fabricated on ITO glasses by physical vapor deposition (PVD) method in different deposition rate at 10-6 torr pressure condition. Different doping concentration With Zn material in polycrystalline CdTe implemented in order to increase the bulky resistivity. And also the ZnTe barrier layer with 5um thickness on ITO glass substrate was deposited to reduce the leakage current. Finally additional dielectric or charge block layer materials were formed on polycrystalline CdZnTe films [2]. Their microstructures and electrical characterizations of the fabricated polycrystalline CdZnTe films were investigated in terms of Zn concentration and additional barrier layer by measuring the dark current as a function of applied voltage. X-ray and alpha particle response of the fabricated films were measured in order to investigate the signal amplitude and electron or hole drift mobility at room temperature range.

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Energy characterization of PiXirad-1 photon counting detector system

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This work is focused on the characterization of the PiXirad-1 detector from the spectroscopic point of view. PiXirad-1 is the first commercial product of PiXirad Imaging Counters s.r.l., a recently constituted INFN spin-off company.
The core of x-ray imaging system is a new detector, based on chromatic photon counting, that has been realized coupling a pixelated large area ASIC (known as Pixie-II) to a matching pixelated cadmium telluride (CdTe) sensor by flip-chip bonding technique.
The sensor is a 650 micron thick Schottky type diode with electron collection on the pixels. It is characterized by a very low leakage current at 400V bias voltage.
The system has chromatic capabilities, i.e. is able to count incident x-ray photons according to their energy in order to produce two 'color' images from a single exposure. As expected, the color sensitivity is limited by some unavoidable charge sharing effects.
The energy calibration of the thresholds has been carried on using data acquired at the Elettra synchrotron with photons having energy between 8.1 and 44 keV. Few more points (at the lowest and the highest energies) were obtained using the Argon fluorescence line and radioactive sources.
Using the same sources and the fluorescence of other elements (V, Fe, Co, Cu, Mo, Ag, Cd, I) we acquired spectra on clusters of pixels and on a single pixel. We measured the energy resolution as a function of the energy. The results have been compared with the theoretical estimation.
Last, analyzing the acquired spectra, we estimated the amount of the charge sharing, exploiting the monochromatic synchrotron radiation source.

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THCOBRA detector operation in pure Kr for imaging purposes

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Photon counting detectors based on Micropattern Gaseous Detectors (MPGD) with energy and position discrimination capability have already conquered their place among radiation imaging detectors. Some general and important features of this kind of detectors include: possibility of electronic noise rejection; fair energy resolution; high count rate capability and absence of dead areas. [1]
For imaging purposes heavy noble gases, such as Xe or Kr are usually the best choice since they present higher absorption efficiency for the energy range required for example in mammography or small animal imaging.
In this work, a Thick-COBRA (THCOBRA) structure, for MPGD, was used. [2] The THCOBRA allows two charge amplification stages in a single structure, achieving high gains. Two resistive lines, orthogonal to each other, allow the determination of the interaction position and the energy of each single photon. [1]
In previous works [3], a 10×10 cm2 2D-THCOBRA was used in a detector filled with NeCH4. Pure Kr provides an X-ray absorption two orders of magnitude higher than NeCH4 for the photon energy range of 0 to 30 keV and higher than Xe between 15 and 30 keV.
The detector was filled with pure Kr, continuously purified by a getter, working in a sealed mode. The detector was characterized in terms of its counting curve, gain, energy resolution and spatial resolution. The results will be presented and the prospects of applying it for X-ray imaging (X-ray projection and Computed Tomography), will be discussed. The possibility to improve image quality, using energy weighting techniques, will be also discussed together with future developments.

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Biological Objects Recognition in μ-radiography Images

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In our work, there is presented a study of applicability of real-time microradiography to chestnut leafminer, Cameraria ohridella (Insecta: Lepidoptera, Gracillariidae), and following image processing focusing on image segmentation and objects recognition. The study of insects, such as chestnut leafminer can become very difficult when the aim is a non-invasive inspection that leaves the organisms alive. The requirement for this kind of study is a high spatial resolution (micrometer scale) radiographic system [1]. The system is based on a micro-focus X-ray tube and two types of imaging devices. The first device is a charge integrating detector, such as the Hamamatsu flat panel. The second device is a pixel semiconductor detector, such as the Medipix2 detector, allowing the detection of single quantum photon of ionizing radiation.
We obtained numerous chestnuts leafminers in several microradiography images which can be very well recognized automatically using image processing techniques. We implemented algorithm that is able to count a number of dead and alive chestnuts leafminers in images. The algorithm is mainly based on the two methods: 1) Noise reduction using Gaussian low-pass and mathematical morphology filters 2) Canny edge detection algorithm. The accuracy of algorithm is higher for Medipix2 than for flat panel. Therefore, we conclude that Medipix2 has lower noise and better displays contours (edges) of biological objects. Our method allows automatic selection and calculation of dead and alive chestnuts leafminers and thus it allows faster classification of the world´s major parasite.
Our results will be shown in the poster section.
This work was realized in the frame of the Medipix Collaboration.

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X-ray Imaging of High Velocity Moving Objects by Scanning Summation using a Single Photon Processing System

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Many products in process industry require classification and characterization where X-ray imaging can reveal a great amount of information about the manufactured product. In industrial processes involving moving webs, conveyor belts etc, there are methods for imaging moving objects or webs, either by illuminating the objects with a short burst of high level radiation to capture a pixel resolved image [1], or by irradiating a longer strip of the web and taking a mean value of the collected photons, thereby reducing the demand on high burst flux. Problems to acquire a pixel resolved image arise when the moving objects or webs have higher velocities, for example from 1 to 10 m/s, and the pixel resolution is in the 50 μm range. In this paper method of high velocity imaging is proposed that can reduce the demands on the X-ray source, and still achieve high quality pixel resolved images in high velocities.

The problem with X-ray imaging of high velocity objects is the high burst of radiation needed in a very short period of time, in order for the images not to be blurred. The proposed method involves a 2D pixel layout in a readout system such as, for instance, the MEDIPIX3 system [2]. Suppose that any given part of the object passes a column of pixels (one strip) at a given time period. In that time period a small number of photons can be collected from an X-ray source of reasonable flux, although not enough to resolve the object. If the intensity data of that column is stored, it can be added to the next adjacent column during the following time period it takes for the object to pass that column of pixels. The procedure is continued until the end of the pixel detector is reached, adding the intensity values of each new column to the summated column, enabling the acquisition of a full image. Enabling this summation for high velocities require hardware implementation resembling a shift register, where the memory banks for the columns are shifted to match the velocity of the moving object, thereby summing photons in real time.

This paper presents the method and the fundamental limitations of the method, simulations showing the level of image degradation from the movement, and low velocity real time imaging using the MEDIPIX platform.

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Fast, multi-wavelength, efficiency-enhanced pixelated device based on InGaAs/InAlAs quantum-well

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Several applications utilizing either synchrotron or conventional light sources require fast and efficient pixelated detectors. In order to cover a wide range of monitoring experiments, this work investigates the possibility to use InGaAs/InAlAs Quantum Well (QW) devices as photon detectors for a broad range of energies.
Owing to their direct, low-energy band gap and high electron mobility, such QW devices may be used also at Room Temperature (RT) as multi-wavelength sensors from visible light to hard X-rays. Furthermore, internal charge-amplification mechanism can be applied for very low signal levels, while the high carrier mobility allows the design of very fast photon detectors with sub-nanosecond response times.

Samples were grown by Molecular Beam Epitaxy (MBE) on 500-μm-thick, commercial semi-insulating (001) GaAs substrates. Metamorphic $In_{0.75}Ga_{0.25}As/In_{0.75}Al_{0.25}As$ heterostructures were obtained by relaxing the strain due to the lattice mismatch in the substrate by means of a composition-graded buffer layer. A two-dimensional electron gas (2DEG) forms in a 25-nm-thick $In_{0.75}Ga_{0.25}As$ QW. The carrier density and mobility at RT were 7.7×10^{11} cm^{-2} and 1.2×10^4 cm^2 V^{-1} s^{-1}, respectively.
These QW samples have been pixelated by using standard photolithographic techniques. In order to fit commercially available readout chips, a pixelated sensor with pixel size of 172x172 um^2 is currently under development.

A small-scale version of the pixelated QW sensor has been preliminary tested with 100-fs-wide laser pulses and X-ray synchrotron radiation. The reported results indicate that these sensors respond with 100-ps rise-times to ultra-fast laser pulses. Synchrotron X-ray tests show how these devices exhibit high charge collection efficiencies, which can be imputed to the charge-multiplication effect of the 2DEG gas inside the QW. Moreover, by analysing the crosstalk between pixels, different pixelation strategies have been compared in order to plan an optimal one.

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High Sensitivity Molecular Imaging for Targeted Cancer Therapy

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The proposed research focuses on the detection and visualization of the pharmacokinetics of tumor targeting substances specific for particular cancer sites using a newly developed camera for gamma-ray imaging of radiotracers with high spatial resolution and
sensitivity. The high resolution (< 0.5 mm) permits monitoring the pharmacokinetics of labeled gene constructs in vivo in small animals with a human tumor xenograft which is one of the first steps in evaluating the potential utility of a candidate gene. The additional benefit of high sensitivity detection will be improved cancer treatment strategies in patients based on the use of specific molecules binding to cancer sites for early detection of tumors and identifying metastasis, monitoring drug delivery and radionuclide therapy for optimum cell killing at the tumor site. This new technology can provide high resolution, high sensitivity imaging of a wide range of gamma energies which will significantly extend the range of radiotracers that can be investigated and used clinically. The small and compact construction of the camera allows flexible application which will be particularly useful for monitoring residual tumor around the resection site during surgery. It is also envisaged to test the performance of new drugs/gene-based therapies in vitro and in vivo for tumor targeting efficacy using automatic large scale screening approaches/methods.

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Bunch-by-Bunch Beam Transverse Diagnostics by HgCdTe Semiconductor Array

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An innovative mid-infrared detector, based on a HgCdTe semiconductor array, has been designed and assembled to study transverse beam instabilities in circular accelerators and it is presented in the following. The classic beam diagnostics for storage rings and circular colliders is mainly based on devices measuring the total beam current, the beam transverse (horizontal and vertical) average position and tunes, the beam transverse profile as an envelope of all the bunches. For example, commercial synchrotron light monitors based on a standard camera working with the visible light, are common and low cost devices. Gated camera are much more expensive tools but the sampling frequency is still too low respect to the bunch repetition rate. Innovative instruments, able to give bunch-by-bunch information about the beam behavior, are generally under study but, apart few exceptions, still in a phase of R At DAFNE, the e+/e- collider running at Frascati by INFN since 1997, the low energy beams are subjected to many different instabilities limiting the performance in terms of maximum beam currents and peak luminosity. In particular, parasitic electron clouds produced by the photons hitting the walls along the vacuum chamber are formed close to bending dipoles and wiggler magnets. These parasitic e- clouds affect mainly the positron beam that, having charge of opposite sign, is susceptible to forces of attraction that can made undesired effects. To study in depth the e+ beam behavior and to characterize the transverse beam dynamics, an innovative bunch-by-bunch instrument working in the mid-infrared has been developed at INFN-LNF. The detector, based on a HgCdTe multi-pixels array, has been designed and assembled by using compact 3-stage wide band amplifiers for each pixel of the detector. Furthermore a dedicated 8 channel bunch-by-bunch and turn-by-turn data acquisition system has been designed based on commercial FPGA evaluation boards remotely controlled by a personal computer. A timing system has been designed and built to control the skew of each pixel in the picosecond range. Moreover, a PC can drive eight clock delay registers used to de-skew the split sampling frequency by an USB interface connected to an Arduino-DUE board that loads in parallel the delay registers. The user interface to the FPGA real time system is made by a simple http web based protocol. Results, comparison with other works and tools and future prospects are presented and discussed.

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Evaluation of image quality for FPD based low dose mobile C-arm CT system

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The imaging quality associated with the extent of the angle of gantry rotation, the number of projection views, and the dose of X-ray radiation was investigated in flat-panel detector (FPD) based C-arm cone-beam computed tomography (CBCT) system for medical applications. A prototype CBCT system for the projection acquisition used the X-ray tube (A-132, Varian inc.) having rhenium-tungsten molybdenum target and flat panel a-Si X-ray detector (PaxScan 4030CB, Varian inc.) having a 397 x 298 mm active area with 388 μm pixel pitch and 1024 x 768 pixels in 2 by 2 binning mode. The performance comparison of X-ray imaging quality was carried out using the Feldkamp, Davis, and Kress (FDK) reconstruction algorithm between different conditions of projection acquisition.

In this work, head-and-dental (75kVp/20mA) and chest (90kVp/25mA) phantoms were used to evaluate the image quality. The 361 (30 fps × 12 s) projection data during 360° gantry rotation with 1° interval for the 3D reconstruction were acquired. Parke weighting function were applied to handle redundant data and improve the reconstructed image quality in a mobile C-arm system with limited rotation angles. The reconstructed 3D images were investigated for comparison of qualitative image quality in terms of scan protocols (projection views, rotation angles and exposure dose).

Furthermore, the performance evaluation in image quality will be investigated regarding X-ray dose and limited projection data for a FPD based mobile C-arm CBCT system.

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Iterative gradient total variation (IGTV)-based algorithm approach for beam hardening reduction in CBCT reconstruction

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Accurate beam hardening correction is required to produce high-quality reconstructions of X-ray cone-beam computed tomography (CBCT) system for medical and non-destructive testing (NDT) applications. This paper introduces the iterative gradient total variation (IGTV) for filtered-backprojection suffering from the serious beam hardening problems. Feldkamp, Davis, and Kress (FDK) reconstruction algorithm for CBCT system is most widely used reconstruction technique. The FDK reconstruction could be realized by generating the weighted projection data, filtering the projection images, and back-projecting the filtered projection data into the volume. However, FDK reconstruction suffers from the beam hardening artifact by X-ray attenuation coefficients. Recently, total variation (TV) method in compressed sensing (CS) has been particularly useful in exploiting the prior knowledge of minimal variation in the X-ray attenuation characteristics across object or human body. But a practical implementation of this method still remains a challenge. The main problem is the iterative nature of solving the TV-based CS formulation, which generally requires multiple iterations of forward and backward projections of a large dataset in clinically or industrially feasible time frame. In this paper, we propose IGTV method after FDK reconstruction for reducing the beam hardening artifact. The beam hardening problem is reduced by the IGTV method to promote sparsity inherent in the X-ray attenuation characteristics.

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Dynamics of Current Voltage Characteristics During the Polarization Effect in CdTe Detectors

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Polarization phenomena in a metal-semiconductor-metal (M-S-M) structure CdTe radiation detectors were studied. Two families of detectors were studied: (1) Au-CdTe:In-Au structure, manufactured at the Institute of Physics, Charles University, Prague and (2) Pt-CdTe:Cl-Pt structure, fabricated by Eurorad, Strassburg.
For this purpose, current-voltage characteristics were reconstructed from leakakge current evolution in time after detector buasing. For this purpose, we developed modified algorithm of detector leakage current measurement, utilizing the LabView envirnoment and the Keithley 6517 electrometer. Particular values of the leakage current were scanned in defined time range from 1 second to 360 seconds after the detector biasing.
Detectors (1) showed fast current transit with applied voltage and linear – ohmic character of the current-voltage characteristics at biast voltages higher than 10 V during the whole process of current transient. The slopes of the current-voltage characteristics in linear area were constant during the whole, polarization. Detectors (2) showed from applied bias voltage higher than 50 V strongly non-linear, injection-like characters. The injection-like character increased with time after biasing and is associated with the increase of the injection of minority carriers into the bulk of the crystals. In initial time of the polarization, the increase of leakage current with applied voltage was proportional to exponent of 1.3 with applied voltage. The exponent rise ended at the value of 2.1, when the dedectors currents became stable in time.
Resulting potential barrier fluctuations, built-in potential and the saturation current evolution in time, received from IV characteristics at low bias voltages during the polarization are presented and the effect of temperature is on the dynamics of the current-voltage characteristics is infestigated.

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Application of CdZnTe semiconductor detectors to the radioactivity analysis of a PWR reactor coolant system

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Radiation filed information in nuclear power plants should be provided for optimal job planning and workers dose management. It can be categorized with radiation type, incident direction, energy distribution and dose rate for external exposures. Survey meters and multiple personal dosimeters are used to obtain the information but the energy distribution analysis is not generally carried out. Photon energy distribution information can be used to design proper shielding for high dose jobs or to reconstruct workers specific organ doses. So, it is important to monitor the radiation source terms to analyze the radiation field.
Generally, portable scintillation(NaI) spectrometers or high purity germanium(HpGe) detectors with In-situ object counting system(ISOCS) can be used to measure the radioactivity directly for the assessment of photon energy field characteristics in the working places. However, both devices cannot be easily applied to the detection of source terms in reactor coolant systems because of the low energy resolution and the inconvenience with liquid nitrogen cooling respectively.
Radiation detectors using CdZnTe(CZT) can overcome these weak points. A CZT detector has much higher energy resolution than scintillation detectors and dose not need additional cooling devices. So recently, the CZT detectors are applied to radiation protection tool at several nuclear power plants and the reports show good results. CZT detection systems, however, still need the in-situ calibration process for proper measurement conditions before application like ISOCS or other in-situ devices.
In this study, CZT detection systems were used to analyze radionuclides inside the primary reactor coolant systems in pressurized water reactor type to estimate the possibility of application.
Three different sizes of CZT element (GBS SDP310, CZT 500, CZT 1500) and Multi-Channel Analyzer (MCA-166) were used for various dose rates during reactor shut down water chemistry process and then the photon energy spectrum were obtained directly from outside surface of major pipes.
From the results, CZT detection system shows the possibility of application to radiation source term analysis in RCS without the extraction of coolant samples. Also, it can be considered to be used to detect the radioactive CRUD inside the major pipes in RCS and give the proper information of major radiation source to workers for establishing pre-job dose planning.

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Spatial Resolution Limitations in CdTe

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The effects of K-edge fluorescence, Compton scattering and subsequent electrons on the inherent spatial resolution has been investigated in a number of publications in the context of amorphous-Selenium (a-Se) flat panel detectors [1,2].

Recently, these models were extended to CdTe-based pixel detectors working in photon counting mode [3], enabling an analytical calculation of the Point Spread Function, Modulated Transfer Function and the expected energy spectra. Experimental data collected from detectors tested at the Diamond Light Source are shown to validate the model.

Further investigation has used Geant4 to simulate the limitations on the spatial resolution due to the K-edge fluorescence and Compton scattering inside the CdTe sensors to determine optimal pixel sizes and sensor thicknesses for various photon energies used in X-ray diffraction experiments and medical X-ray imaging. The Geant4 data is coupled to a Finite-Elements package, Comsol, to incorporate the weighting potential, the electric potential and the charge carrier characteristics, including diffusion and repulsion.

The compromise between the energy resolution due to the small pixel effect and the spatial resolution due to photon scattering and fluorescence is presented.

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A critical comparison of the metal-semiconductor interface of gold contacts on CdZnTe radiation detectors formed by sputter and electroless deposition

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Fully spectroscopic X/γ-ray imaging is now possible thanks to advances in the growth of wide-bandgap semiconductors. One of the most advanced materials is cadmium zinc telluride (CdZnTe or CZT), which has been demonstrated in medical imaging, homeland security, industrial analysis and astrophysics applications. These applications have demanding energy and spatial resolution requirements that have not always been met by the metal contacts deposited on CdZnTe. The challenge now is to improve the quality of these metal contacts. The interface between semiconductor and metal formed during contact deposition is of fundamental importance to detector operation and the choice of deposition method is a key variable.

In this paper a multi-technique investigation and comparison of the metal-semiconductor interface resulting from sputter and electroless deposition of gold contacts onto CdZnTe is presented. Focused ion beam (FIB) cross section imaging, X-ray photoelectron spectroscopy (XPS) and temperature dependent current-voltage (IV) analysis have been used to characterize the structure, chemistry and electronic properties of the interface. The energy and spatial resolution of small pixel CdZnTe detectors (250 μm pitch) with sputtered and electroless gold contacts have been measured by bonding the detectors to the low noise 80x80 channel HEXITEC ASIC.

Significant differences were found between the interfaces formed by the two deposition methods. A model has been proposed to explain the relationship between structure and chemistry of each interface and its electronic response. The knowledge developed at the Rutherford Appleton Laboratory during this investigation has directly led to improvements in the fabrication and performance of small pixel CdZnTe X-ray imaging detectors.

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Characterization of the C-MOS Cd-Te Imager Pixirad for energy discriminated X-ray imaging

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Future burning plasma experiments for Magnetic Fusion will produce high radiative background (Neutrons, Gammas, Hard-X) posing severe limitations for the installation of Soft X-Ray (SXR) plasma diagnostics. Detectors will have to be radiation tolerant, compact to be easily shielded, and with low sensitivity to neutrons and gamma rays.

It is nowadays evident that imaging and/or tomographic X-ray diagnostics for fusion experiments will be based on photon counting mode, rather than on current or charge integration mode, because they are more sensitive, noise free and allow post-process digital treatment of the image at full speed without loss of information. In addition, proportional detectors in counting mode could allow for energy discrimination, which is very desirable especially in magnetic confined plasma experiments to investigate different regions of the plasma emitting in different X-ray spectral bands depending on electron temperature and impurity content.

The aim of the present work is to assess the operational characteristics of the PIXIRAD Imaging Counter for use in high-definition energy resolved X-ray imaging for slow control in magnetic fusion plasma experiments. This activity was undertaken at the ENEA- Frascati X-ray Laboratory in the context of fusion plasma diagnostics. The PIXIRAD imager was developed by an INFN-Pisa Spin-off; it works in photon counting mode in a wide energy range, soft and hard X-rays (2-100 keV), with pulse discrimination defined by two thresholds. The 650 μm thick CdTe X-ray sensor is interfaced with a CMOS VLSI chip organized on a 512×476 matrix of 55μm exagonal pixels (total active area of 30.7×24.8 mm²). The experimental characterization was carried out in the range 3-80 keV, to assess the energy discrimination capability, detection efficiency, spatial resolution and cluster size of the PIXIRAD. Energy discrimination in bands was investigated using calibrated monochromatic X-ray sources (fluorescence of KCl, Fe, Cu, Pb, Mo, Ta) and radioactive sources (Fe55, BaCs), with scans in threshold of the detector. Experimental data will be presented showing that the PIXIRAD energy response is linear up to 35 keV, after which saturation occurs, permitting a 30-40% energy resolution over the whole spectral range. As consequence energy discrimination is not sharp and a few criteria have been defined in order to treat it properly.

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Study of defect related luminescence in ZnSe scintillation crystals co-doped with oxygen and aluminum

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Zinc selenide scintillators are successfully employed for detection of low energy X-ray emission in industrial multi energy introscopy and medical computed tomography. ZnSe based detectors have a low atomic number allowing effective detection of low and moderate X Ray radiation (up to 160-200 keV). They have a low afterglow level, a high light yield and are nonhygroscopic.

Defect related luminescence band is utilized in the ZnSe based scintillator crystals. The crystal doping with isoelectronic impurities (Te, O, S) and annealing in Zn vapor improves efficiency of this emission. The conventional tellurium doped ZnSe scintillators have a high thermal stability and the highest light output reaching up to 80000 photons/MeV. Crystal doping by oxygen results in significantly faster response reaching 1-5 μs. However, it is quite complicated to perform the doping by oxygen due to its high chemical activity.

This study is aimed at comparative characterization of ZnSe crystals co-doped with O and Al and conventional ZnSe(Te) scintillator crystals. The comparative study of deep-level-related emission in the conventional ZnSe(Te) and ZnSe(O,Al) scintillators is accomplished using photo- and X-ray-luminescence in the temperature range from 8 to 300 K. The study of the absolute quantum yield and the photoluminescence has also been performed.

It is demonstrated, that ZnSe doping by Al2O3 enables formation of oxygen-related donor-acceptor pairs (DAP) acting as radiative recombination centers whose density exceeds that of tellurium-related DAPs in ZnSe(Te) with 1% tellurium concentration.

Under nominally identical photoexcitation conditions, ZnSe(O,Al) crystal exhibited a higher photoluminescence intensity, however, the X-ray luminescence intensity was by factor of 1.6 higher in the conventional ZnSe(Te) crystal. It is shown that the observed difference is caused by the peculiarities in X-ray and photoexcitation. The absolute quantum yield of ZnSe(O,Al) crystal was found to be lower than that of the conventional ZnSe(Te) scintillator. Since the introduction of Al2O3 into the melt ensures a high density of radiative donor-acceptor pairs, the low quantum yield of ZnSe(O,Al) is caused by strong nonradiative recombination and might be improved by optimizing growth and annealing technologies to decrease the density of nonradiative recombination centers.

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X-ray beam design for multi-energy imaging with charge-integrating detector: a simulation study

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Recently, there has been increasing demand in the X-ray imaging fields for semiconductor detectors. A major advance in X-ray imaging was accomplished by the development of using the semiconductor detector such as CdTe or CZT detector to improve the contrast with energy weighting [1]. Also, dose reduction could be expected by setting the image quality to be the same as that of the image obtained with charge-integrating detector acquired at a certain dose level [2]. However, the major problem of photon-counting detectors is low count rates due to the effects of pulse pile-up and dead-time at very high count rates [3]. To avoid spectral distortion, therefore, the operational count rates are usually around 1×106 cps/mm2 in photon-counting mode. The purpose of this study was to propose the design of X-ray beam with combinations of various tube voltages and filters based on charge-integrating detector to overcome low-count rate based on the photon-counting detector. We performed a simulation study of the direct conversion detector (DRtech, Korea) charge-integrating detector composed of thin-film transistor (TFT)-amorphous selenium (a-Se) by using a Geant4 Application for Tomographic Emission (GATE) simulation. The tube voltages were 50, 60, 70, 80, 90, 100, 110, and 120 kVp, respectively. The filter materials were nine (Z=13, 29, 42, 50, 56, 58, 64, 68, and 74). The quantity of filtered spectra was set to 1×108 cps/mm2. We evaluated the designed spectra and their beam hardening effects to determine the for the multi-energy X-ray imaging. The designed spectra were evaluated with comparison between Monte Carlo and empirical model. The beam hardening effects were quantified with pre- and post-transmitted spectra with PMMA and aluminum. The results show that the minimum and maximum normalized root-mean-square errors (NRMSE) were 3.0 % and 14.1 % at Monte Carlo model and empirical model, respectively. The quantity of beam hardening is unity at all combinations of tube voltages and filters. In beam hardening effect of aluminum, Z= 58, 64, and 68 is effective filter materials for 50, 60, and 70 kVp tube voltages, respectively. Z=74 is effective filter for 80 to 120 kVp, In conclusion, we successfully established designed of the X-ray beam with combinations of tube voltages and filters based on charge-integrating detector. The results could improve the low-count rate of photon-counting X-ray system.

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Study of irradiation side sampling X-ray flat panel detector for mammography

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In-direct X-ray imaging method have been widely used for conventional flat panel detector (FPD) system and used two different scintillators which are cesium iodide and gadolinium oxysulfate. The conventional FPD system is structured so that scintillators and photodiodes are arranged in front-and-back to the incident x-ray, respectively. An FDR D-EVO, which is based on an irradiation side sampling (ISS) FPD system, is presented by FUJIFILM. Contrary to an conventional FPD system, an ISS structure has a scintillator in the opposite direction of an incident X-ray. Because of the reduction in light attenuation and the blurring effect during photon transfer in a scintillator, an ISS FPD system has an advantage of having a better light yield and a better modulation transfer function (MTF) when compared to an conventional FPD system.
The FDR D-EVO is composed of scintillators, photodiode arrays on a glass with thin film transistors (TFT), and other electronic components. When using an ISS FPD system in mammography, the photodiode pitch has to be in the range from 50 to 80 μm. However, it is difficult to make a small photodiode pitch on a glass with a TFT. Thus, a crystal silicon based CMOS image sensor is better adapted for mammography. Since 25 to 35 KeV of soft X-rays, as instructed by RQA-M of IAEA for mammography, an x-ray absorption on crystal silicon is an important factor in determining a sensitivity and a signal to noise ratio.
We have calculated and simulated the quantum efficiency of conventional and ISS FPD systems for mammography over several x-ray energies. From these works, the ISS FPD system was found to have a better efficiency in converting X-rays to charged signals than the conventional FPD system by 162%. Moreover, we compared the energy conversion ratios of direct and indirect detection. Furthermore, we have prepared samples of actual chips fabricated with 1P3M 0.35um process to test and analyze the efficiency of the conventional and ISS FPD systems.

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PiXirad with PIXIE III: high speed, high resolution spectroscopic X-ray imaging from 2 to 100 keV

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Spectroscopic imaging is the new frontier in X-ray and γ-ray imaging applications. Spectral information adds a new, powerful dimension to the image. High speed photon counting with pixel detectors is the natural technology choice to try to implement this new modality. However, adding the color dimension to a very finely segmented pixel sensor is highly demanding in terms of complexity and transistor density of its read-out electronics. In this presentation we will discuss the results obtained with PIXIE III, the brand new ASIC generation utilized for the first time in PiXirad detectors. PiXirad detectors are based on the hybrid assembly of an advanced, thin, Cadmium Telluride pixel sensor to a very large area custom CMOS ASIC with 512 x 402 pixels at 62 microns pitch. Each pixel has two 15 bit counters fed by two independently settable energy discriminators to get two color images in a single exposure .

A PIXIE III based PiXirad unit shows several advances compared to what has been available up to now. It has a very broad dynamic range (up to 100 keV before pulse saturation, high speed (100ns peaking time),high frame rate (larger than 500 fps), dead-time-free operation, good energy resolution (around 2 keV at 20 keV), high photo-peak fraction and sharp spectral separation between the color images.

The last one is the most critical performance: it is obtained by allowing each microscopic pixel to 'know' and recover the charge (energy) shared with some of its neighbor pixels. The sharing is due to the finite size of the charge cloud and to the diffusion process occurring during its transport from the conversion point to the collecting pixel anode. The new ASIC's feature has been implemented by adding a third discriminator and a 'sum' amplifier in each pixel. The summing amplifier collects the 4 signal currents which are dispatched by the front-end amplifier (FE) of the pixel itself and by the FEs of 3 neighbor pixels and converts the sum back into a voltage. The latter is then discriminated against the 'windowed' energy thresholds to assign the hit to a unique color pixel counter. The additional discriminator is used to resolve the ambiguity which occurs when only one pixel collects the full charge. The trade-off with the electronics noise and dead-time is discussed.

We present results obtained by testing a PiXirad CdTe-PIXIE III assembly under high flux X-ray sources. First sharp color images obtained in a single shot will be presented.

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INVESTIGATION OF ENERGY DISSIPATION IN PROCESS ZONE USING ADVANCED RADIOGRAPHIC AND TOMOGRAPHIC TECHNIQUE

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During fracture of quasi-brittle and ductile materials, the energy dissipation takes place in an extensive area at the crack tip – a nonlinear fracture process zone. The aim of this work is evaluation of fracture process zone behavior during loading using advanced time lapse X-ray Dynamic Defectoscopy and computed tomography. The test specimens with various geometries were subjected to three-point bending in a special tabletop loading device [1]. Influence of the specimen parameters on the fracture process zone behavior were studied.
The modular tomographic system provides an experimental setup allowing positioning adjustment of the X-ray tube, motorized positioning of the detector and the operational movement of the observed object fixed on a motorized stage. The linear axis of this stage enables to set the projective magnification of the object. The rotation axis is used for tomographic data acquisition. The setup is equipped by the motorized revolver holder of the filters used for the fully automated acquisition of data needed for beam hardening correction, using the Signal to Equivalent Thickness (SET) method [2]. X-ray Works microspot tube is employed as X-ray source in the tomographic system. The pixelated Perkin Elme flat panel was utilized as X-ray imager in our work. This detector has active area 400 × 400 mm with 200 μm pixel size.
Highly stiff loading compressive device was used for the specimen loading. This device allows very low loading velocity while it's relatively low weight and dimensions enable time lapse X-ray observation of the specimen in the radiographic cabin. Loading device generally consists of the actuating part and of the chamber in which specimen is placed. This chamber was manufactured from the 0.6 mm thick carbon epoxy laminate, which is practically transparent for X-rays. This solution enables radiographic observation of the analyzed specimen without influence of the loading device for X-ray measurement. The radiograms were recorded continuously during loading to observe process zone evolution while CT measurement was done in several loading states.

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APPLICATION OF DUAL SOURCE X-RAY MICRO-TOMOGRAPHY SETUP FOR INSPECTION OF SEMI-DESTRUCTIVE TESTING METHOD OF WOODEN GIRDERS

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X-ray computed tomography (CT) is widely used as a method for inspection and visualization of inner structure of complex engineering and also natural materials. In medical imaging, the method has been significantly improved by introduction of dual-source X-ray computed tomography (DSCT) devices enabling less time-consuming measurements and higher temporal resolution (particularly in coronary imaging [1]). The main limitation of medical DSCT method for material science imaging is low spatial resolution (the lower limit approx. 0.5mm) of conventional DSCT devices with rotational movement of tubes and detectors caused by fixed tube-detector distance limiting measurement variability.
In this paper, novel dual-source/dual energy (DECT) micro-tomography device and results of high resolution DSCT reconstruction are presented. DSCT micro-tomography setup was designed as a multipurpose X-ray imaging device with orthogonal arrangement equipped with two pairs of X-ray detectors and tubes with independent control and voltage/current settings. Both pairs (tube-detector) are mounted on computer numerical control (CNC) positioning system and can be independently set up to different geometries (e.g. with different zoom of each pair). For DSCT measurement, XWT-160-CT and XWT-240 (X-ray Worx, Germany) X-ray tubes with minimal focal spot size 5 um and XRD1622 (Perkin Elmer, USA) large-area flat panel detectors with active area 41 cm x 41 cm, resolution 2048 x 2048 px were used for scanning of a part of wooden girder during and after semi-destructive test for assessment of wood quality. Prior to tomography measurements, setup geometry of both pairs was precisely calibrated using semi-automatic algorithms to match horizontal tube-specimen-detector axes, zoom and vertical axes. DSCT measurements were carried out in sequence (2 x 90 degrees for each tube) with resulting spatial resolution of reconstruction better than 50 um. To conclude, experimental setup and technique suitable to perform dual-source micro-tomography measurements has been developed and was successfully applied.

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Contrast Enhancement Utilizing Energy Sensitive Radiography

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Complex structures composed from materials with similar and/or significantly different X-ray attenuations leads to obstacles with their X-ray imaging. In the case of similar materials, one wants to achieve the highest possible contrast between individual material components while in the case of very different materials one wants to achieve the lowest possible contrast to suppress the unpleasant artefacts in the X-ray CT. The solution to this problem is the use of energy sensitive radiography. The Timepix detector technology allows setting of energy threshold. This feature enables obtaining of "colour" radiographs [1] where different materials are imaged in different colours and also allows suppression or enhancement of the particular material component in the image to achieve desired contrast. This feature requires getting of several (at least two) snapshot to be taken with different settings of energy threshold. However, the correct combination of the energy threshold for the given materials and their thicknesses is not known a priori. Therefore, the systematic measurement and study of the energy threshold combinations and its correct setting for the X-ray radiography is needed. In this work the energy sensitive radiography will be used for analysing of advanced composite material employed in the aircraft industry. An important class of such materials are composites that are made of carbon reinforced polymer (CFRP) and metal (often copper) grid. This material combination of low absorbing CFRP and high absorbing metal leads to unpleasant image artefacts in the X-ray CT method. On the other hand, similarity in the X-ray attenuation of carbon fibres and the polymer matrix makes difficult to distinguish these components in the images. Optimization of the energy threshold combination for X-ray radiography of such composite materials will be object of this work.

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Verification of Geant4 pixel detector simulation framework by measurements with MEDIPIX familiy detectors

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Monte Carlo simulations are a extensively used tool for developing and understanding radiation detector systems and show good agreement with measurement data [1]. Inthis work we used results of several and readout modes of the MEDIPIX detector family to validate a Geant4 based pixel detector framework which is capable of simulating various MEDIPIX and TIMEPIX chips from particle tracking to charge transport in the sensor material and different readout modes [2, 3].

MEDIPIX 3 is the most recent photon counting detector providing features like multiple thresholds, single pixel mode (SPM) and charge summing mode (CSM) which allows to allocate low energy depositions in adjacent pixels to the maximal deposition. The Timepix chip is commonly used for spectral imaging and offers features like time-over-threshold (ToT), time-of-arrival and photon counting mode.
We experimentally verified the simulation with different detector geometries in terms of pixel pitch and size as well as sensor material and sensor thickness. The SPM and CSM modes in MEDIPIX 3 have been evaluated with fluorescence and synchrotron radiation. The
integration of the charge sensitive amplifier functionality in the simulation framework allowed to simulate the time over threshold mode of the TIMEPIX chip. Simulation and measurement have been compared in terms of spectral resolution using threshold scans in photon counting mode (MEDIPIX) and time over threshold mode (TIMEPIX). Further comparisons were done using x-ray tube spectra and beta decay to cover a broad energy range. The results show good agreement between simulation and measurement.

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Comparison of three types of XPAD3.2 / CdTe single chip hybrids for hard X-ray applications in material science and biomedical imaging

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Two decades ago, new types of X-ray imagers based on photon counting instead of charge integration during exposure have been introduced for particle tracking in high energy physics experiments. This approach called quantum X-ray imaging is capable of discriminating and processing each single X-ray photon in addition to counting them. It also o□ers improved image quality and noise subtraction compared to the former devices while operating at room temperature. In this so-called hybrid approach where analytic electronic chain is physically bound to each pixel, the sensor material can be chosen according to the energy of the X-ray photons to be detected and its electronics custom-designed for specific applications. Sensor and electronics are assembled using bump-bonding and flip-chip technologies resulting in a hybrid-pixels photon counting detector.

Silicon based hybrids are now regularly used in X-ray detectors for material science and for the development of photon counting and spectral X-ray CT. However, the detective quantum eciency of thin (500 microns) silicon based hybrids is decreasing steadily from 90% at 12 keV to less than 40% at 20 keV. Therefore, a grown interest in studying new high-density and high-Z sensor materials for X-ray imaging at energies above 25 keV appeared (i.e. for third generation synchrotron sources or new generations of medical X-ray detectors). Thanks to its high resistivity at room temperature and its large linear attenuation coecient, cadmium-telluride (CdTe) appeared to be a good prospective material for room temperature semiconductor detectors.

We will report tests that have been performed both with radioactive sources and on synchrotron beamlines. We will determine the best suited configuration for the production of hybrids with CdTe sensors using either Schottky or Ohmic contacts in hole or electron collection modes, bump bonded to the di□erent flavors of the XPAD3.2 chip. Several single chip hybrids were assembled and evaluated, allowing for the selection of the detector type. Their linearity, stability robustness were evaluated in order to chose the most relevant technology for building a large detector composed of 56 single chip modules dedicated to material science and preclinical imaging.

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Treatment monitoring with in-beam PET at CNAO: can in-spill data contribute?

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Positron-Emission-Tomography (PET) is a non-invasive in-vivo method for monitoring the correctness of the dose delivery to patients undergoing particle therapy. By comparing pre-calculated PET activity profiles with measured profiles, it is possible to verify whether the dose was delivered correctly. In this work, we investigate this method for particle range verification in phantoms irradiated at the CNAO (Centro Nazionale di Adroterapia Oncologica) treatment center in Pavia, Italy, with a compact in-beam PET system. In particular, we test the capability of our system to determine particle range in various irradiation conditions and particle energies, including data acquisition during beam extraction (in-spill). The latter is very challenging due to high beam background and there are no experimental data in this condition.

Various homogeneous, inhomogeneous and anthropomorphic phantoms were irradiated at the CNAO treatment centre with protons and carbon ions with various energies. Irradiations were performed with mono-energetic beams, spread-out-bragg peaks, and real treatment plans. PET activity data were acquired with a 10x10 cm2 planar PET system and compared with predictions from the FLUKA MC generator. The PET system features a gating system in order to flag the data as in-spill, intra-spill and after-beam. Since simulations have shown that the number of real annihilations is considerable in-spill, we investigate whether it is possible to profit from in-spill data.

We will present results of various data acquisitions performed at CNAO with different types of phantoms under different irradiation conditions, including in-spill. In particular, we will perform a comparison of the measured and MC calculated activity profiles. Hereby the focus is on the quantity Δw50, i.e., the distance between the 50% rise and 50% fall-off position of the 1-D PET activity profiles. Also, we analyse how to profit optimally from the treatment plan for range verifications. Finally, we discuss the implication of the dose delivered in the phantom in term of statistics required for a significant capability of discrimination between measured and pre-calculated profiles.

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Positron Counting in PET Radiopharmaceutical Production and R&D

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A new way of measuring sample activity during the radio-pharmaceutical production process is presented. Instead of measuring annihilation gamma from 18F, it is proposed to count positrons. This technique shows incredible advantages in terms of linearity, sensitivity, dynamic range and enables spatial resolution measurement.
Current techniques for the measurement of radioactivity during PET radio-pharmaceutical production are based on the detection of the annihilation gamma rays. These inherently suffer from low detection efficiency, high background noise and very poor linearity. They are also unable to provide any reasonably useful position information. Conventionally these measurements are done by a scintillation detector coupled with PMT and read out by crate of electronics. Bulky shielding is essential for background suppression.
The detection system used for positron counting is a silicon hybrid pixel detector Medipix. It comprises of silicon sensor bump-bonded to a Medipix readout chip developed at CERN. The sensitive volume consists of a 300 um thick silicon detector pixellated into 256x256 elements, 55 um on each side with a surface area of 1.96 cm2.
It was successfully demonstrated that integration of pixel detector Medipix offers number of advantages over conventional gamma-detection techniques at two production facilities. Position resolution was achieved down to sub-mm, unprecedented dynamic range from 1 kBq up to 100 GBq was demonstrated, superb linearity between 1 kBq and 108 kBq, sensitivity down to 1 kBq was achieved. The system was demonstrated to be suitable for lab-on-a-chip applications.

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Measurement of mobility and lifetime of electrons and holes in a Schottky CdTe diode

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We report on the measurements of the mobility and lifetime of electrons/holes in a CdTe detector with Schottky electrodes. The dimensions of the CdTe detector are 10 mm x 10 mm x 2 mm and the anode is segmented into 99 pixels, each covers an area of 1 mm x 1 mm. Two charge sensitive preamplifiers type AMPTEK A250 were used for this measurement and were connected to the pixel electrodes in different configurations, such as one preamp connected to one pixel and the other one connected to the 8 pixels surrounding the first pixel, with the rest of the pixels shorted to ground. The detector was exposed to alpha particles (Am241) on both sides (anode and cathode) to obtain the contribution of either electrons or holes to the induced signals. The lifetime for each charge carrier has been measured by changing the bias voltage and comparing the effect on the total drift time. These measurements have been repeated at different temperatures to determine the dependency of the charge mobility on temperature. The measured drift properties of the charge carriers are used as input to the COMSOL software, which has been chosen as the platform for this simulation. This approach will allow us to have a realistic simulation of the signal induced at the electrodes of the pixel CdTe detector under study.

In a 2 mm thick coplanar CdTe detector with a bias voltage of 500V/mm, the typical drift time for the electron from the cathode to the anode is about 35 nsec which is relatively slow for the bandwidth of the Amptek250 which can achieve a rise time of 2.5nsec. This implies that by continuous sampling the output of the Amptek250, one can detect the kink of the output signal which shows the transition in the contribution to the induced signal, from electrons to holes. From the full signal collection and the position of the kink, on the time scale of the full charge collection, we measure the depth of interaction (DOI) insider the detector.

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Preliminary evaluation of a monolithic detector module for integrated PET/MR scanner with high efficiency and very high spatial resolution

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Aim of the work
On behalf of MindView collaboration (European project n. 603002), we propose a low-cost PET module, based on monolithic crystals, suitable to be integrated with a Magnetic Resonance. We aim to achieve high imaging performances: high efficiency, spatial resolution (SR) of about 1 mm and discrimination of Depth of Interaction (DoI) in order to reduce parallax error.
Methods
Since the pixelated crystals have many disadvantages, including poor energy resolution (ER) and SR bounded below of crystal pixel size, we propose PET modules based on monolithic crystals. To ensure a high efficiency, monolithic crystals for PET imaging have to be almost 15 mm thick; this involves a reduced field of view (FoV). Using a new position algorithm[1] we can considerably enlarge FoV, improving SR too. In addition, DoI was evaluated utilizing the method explained in [2].
A numerical simulation[3] was implemented, in order to optimize positioning and DoI evaluation.
Preliminary measurements were performed on a monolithic LYSO crystal of 12 mm thickness, 50x50 mm2 exit face and 40x40 mm2 entrance face. All sides are black painted. Crystal is optically coupled with 12x12 silicon photomultipliers, produced by SensL (Dublin). Na-22 sources of 1 mm3 are used, collimated with 24 mm of W with 1.2 mm drilled holes.
Results
The results of our positioning and DoI discrimination algorithms, on the simulated data, agree with requirements: RS is about 1 mm and DoI resolution less than 4 mm. These results are validated by preliminary experimental data.
Future prospects
The introduction of monolithic crystals module for PET imaging allows to achieve significant improvements compared to standard PET: first of all better ER, DoI discrimination and lower realization costs. Since the system is suitable to be integrated with a Magnetic Resonance, considerable imaging improvements are feasible, e.g. diagnosis of schizophrenia or other mental illness (MindView European project)

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Visualization of the delamination within aerospace composite material utilizing advanced phase contrast and high resolution computed tomography techniques

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This work is focused on development of instrumental radiographic methods for detection of delaminations in the layered Carbon Fiber Reinforced Plastic (CFRP) composites used in the aerospace industry. The delamination causing from CFRP layers disconnection during loading. We can distinguish closed and open delamination. The faces of the closed delamination are in contact. Therefore it almost does not contribute to the X-ray attenuation image. Innovative method for delamination detection using X-ray phase effects was developed. For which, the distance between delamination faces is not relevant. Nevertheless signal from delamination phase contrast effect can be similar to the signal caused by the inner layered structure. This ambiguity can be solved using energy sensitivity of the large area single photon counting WidePIX detector, composed from Timepixe devices. It is well known that absorption depends on energy as 1/E4 while refraction as 1/E2. The contribution of both effects can be resolved performing two measurements with two different energy thresholds. The calibrations of count rate on total absorption were measured for both thresholds using set of flat Aluminum sheets. Similarly, the two measurements of the angle bar specimen containing delaminations were performed and X-ray images were converted into equivalent thicknesses. If only absorption would be involved then both images should be identical. The difference between them indicates presence of the phase contrast effect caused by delaminations (and specimen boundaries). Results were confirmed using single grating phase contrast technique.

In some cases, open delamination is presented due to delamination faces sliding. Besides that the volume of the open delamination is relatively small also for open delamination, local density of the CFRP varies in the range of several hundreds of percent, therefore desired contrast and spatial resolution have to be relatively high. High resolution computed tomography measurement was performed on the same angle bar specimen as it was inspected by the phase contrast technique. Contrast between open delamination and surrounding CFRP material was two times improved using signal to equivalent thickness calibration technique applied on all CT projections. Open delamination shape was successfully identified and visualized although closed delaminations are not visible in the tomographic reconstruction.

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Hybrid Pixel Detectors Timepix with Thinned Read-Out Chip and Their Applications

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The hybrid pixel detector Timepix was already used in many applications (energy and phase sensitive X-ray radiography and tomography, radiography with heavy charged particles, neutron radiography, etc.). The Timepix device and especially its successor Timepix3 can be very effectively used also for particle tracking. For this purpose several detector layers are arranged to form a telescope.

The hybrid Timepix detector consists of sensitive sensor (usually 300 μm thick) chip bump-bonded to radiation insensitive chip of read-out electronics. The thickness of read-out chip is typically 750 μm. The presence of read-out chip in particle tracker composed of several layers is not desired since it limits the sensitivity and precision of the final system. With current technology it is very difficult to fabricate the hybrid pixel detector with read-out chip thinner than about 150-200 μm. The most difficult step is to perform bump-bonding of sensor to thinned read-out chip.

In this contribution we present our results in field of back-side thinning of read-out chip for Timepix detector. Our technology allows to fabricate the Timepix hybrid detector with 100 μm thick read-out chip with high yield. The technological limit is much lower.

The read-out chip thinning technology allowed construction of compact ion tracker or large area pixel detector WidePIX. The ongoing development of compact highly efficient voxel detector with 3D sensitivity composed of several layers of pixel detectors in tight geometry will be introduced. Such detector can be used e.g. for radiation monitoring with directional sensitivity.

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In situ variations of carrier recombination characteristics in polycrystalline CdS during 1.6 MeV proton irradiation

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Polycrystalline cadmium sulfide layers and hetero-junctions are promising material as particle sensors and X-ray imaging devices. Polycrystalline CdS can also be exploited as a cheap scintillating material for visualization of particle beams and for dosimetry. The combined charge collection and scintillating sensors could be suitable for synchronous detection of the optical and electrical responses. However, radiation hardness of the polycrystalline CdS is poorly investigated.

In this work, variations of the characteristics of the proton induced luminescence and of microwave probed photoconductivity transients have simultaneously been measured during 1.6 MeV proton irradiation and correlated, to evaluate the changes of the radiative and non-radiative recombination in polycrystalline CdS. In order to estimate the suitable range of the resolvable changes of scintillation signals, the efficiency of the optical and particle excitation of the luminescence signals has been studied. Moreover, the defect introduction rate has been evaluated by calibration of the luminescence intensity and the density of the generated excess carriers induced by laser irradiation and proton beam. The difference of a carrier pair generation mechanism inherent for light and for a proton beam has been revealed. Evolution of the obtained characteristics of the radiative and non-radiative recombination during exposure to proton irradiation up to fluence of 5E14 1/(cm*cm) and mechanisms inherent for carrier generation by photons and protons will be discussed.

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In situ changes of carrier decay and proton induced photoluminescence characteristics in MOCVD grown GaN

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Crystalline GaN is a promising material for creation of radiation hard particle detectors of different types capable to operate in harsh areas of particle accelerators. Moreover, GaN crystals show rather efficient luminescence properties in several spectral bands under excitation by UV radiation. Thereby, GaN material can be utilized for fabrication of the combined device which is able to operate both as scintillating and charge collecting detector. However, efficiency of such detectors and their functionality is investigated insufficiently.
This work is addressed to study of evolution of the efficiency of proton induced photoluminescence. To evaluate the density of the high energy proton induced excess carriers, a correlation between the microwave probed photoconductivity transients and the proton induced luminescence intensity has been examined. The proton energy range of 1.5 -1.8 MeV has been chosen to implement the nearly homogeneous and rather strong excitation of the 2.5 -5 um thick MOCVD grown GaN epi-layers. To estimate radiation hardness of such material, evolution of the photoconductivity transients and of the proton induced photoluminescence characteristics has been studied by the in situ measurements of the changes of luminescence intensity and photoconductivity decay rate during exposure to a proton beam reaching fluences up to 10e15 1/(cm*cm). Mechanisms inherent for carrier generation by photons and protons will be discussed.

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Gamma emission tomosynthesis based on an automated slant hole collimation system

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The imaging capabilities of radioisotope molecular imaging systems are limited by their ring geometry and by the object-to-detector distance, which impairs spatial resolution, efficiency and image quality. Information on image detection could be enhanced by performing acquisitions with dedicated small FoV gamma cameras placed in close proximity to the object. In this work a prototype of a new automated slant hole collimator, coupled to a small FoV gamma camera, is presented. Moreover, the traditional back projection tomographic reconstruction was compared with Shift And Add (SAA) method.

The device is based on a gamma camera with high spatial resolution, achieved with a planar NaI:Tl scintillation crystal, coupled with an array of position sensitive photomultipliers. The device is able to acquire a set of planar images by a static detector coupled to an automated slant hole collimator. The images acquired at different angles are utilized to perform a 3D reconstruction of the entire object through the use of the SAA method. It is a mathematical method to line up each image based on its shifting amount to generate reconstruction slices at specified depths [1]. In order to verify the effectiveness of the technique and to test the image reconstruction algorithm, a Monte Carlo simulation, based on the GEANT4 code, was implemented. The method was also validated by a set of experimental measurements.

The results of both simulation and experiments demonstrate that the technique leads to sub-centimetres coronal spatial resolution. A sub-optimal response in terms of sagittal spatial resolution, that is more than 1 cm, could be solved by eliminating reconstruction projections at small angles. The proposed device is demonstrated to have a high diagnostic sensitivity and specificity for sub-centimetre tumours bigger than 5 mm with an uptake ratio of 6:1 respect to healthy tissue.

The discussed device works in the proximity of the patient to detect objects placed at a distances ranged from 0 to 8 cm, thus allowing planar resolutions of about few millimetres and sagittal resolution of about 1 cm. The new collimation method implies high-resolution capabilities and increases contrast and SNR for sub-centimetre tumours. Compared with the traditional tomographic reconstruction, the SAA produces comparable spatial resolutions, while preserving the image counts.

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Simulation of Charge Transport in Pixelated CdTe and Comparison with Experimental Data

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The Voxel Imaging PET (VIP) Pathfinder project is proposing a novel design for Positron Emission Tomography (PET), which can be extended to Positron Emission Mammography (PEM) and Gamma Compton camera as well, to achieve an improved image reconstruction without efficiency loss. The design is based on the use of pixelated CdTe Schottky detector to have optimal energy resolution and spatial resolution. An individual read-out channel is dedicated for each detector voxel (1mm x 1mm x 2mm) using an application-specific integrated circuit (ASIC) which the VIP project has designed, developed and is currently evaluating experimentally.

The behaviour of the signal charge carriers in CdTe should be well understood because it has an impact on the performance of the readout channel. For this purpose the Finite Element Method (FEM) Multiphysics COMSOL software package has been used to simulate the behaviour of signal charge carriers in CdTe and extract values for the expected charge sharing depending on the impact point, bias voltage, temperature and anode size. The results on charge sharing obtained with COMSOL are combined with the Geant particle tracking Monte Carlo software package, to get a full evaluation of the amount of charge sharing in a pixelated CdTe set-up as a function of different gamma impact points.

The simulation results are compared to the experimental results obtained with a set-up using a pixellated CdTe detector coupled to the VIP ASIC chip.

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GaAs Detectors Irradiated by Electrons at Different Dose Rates

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In our previous research [1] we have investigated the radiation-hardness of Semi-Insulating (SI) GaAs detectors against high energy electrons. The large area SI GaAs detectors were irradiated by 5 MeV electrons up to a dose of 69 kGy and showed a very good detector radiation resistance within a dose up to 40 kGy followed by deterioration of some spectrometric and electric properties. However, the reverse current and the detector charge collection efficiency showed only slight changes with the overall applied dose. In this work we have extended the electron-radiation-hardness study of SI GaAs detectors. The influence of various dose rates on spectrometric and electric properties of small area detectors is presented.

A set of SI GaAs detectors prepared from 230 μm thick substrate was exposed to 5 MeV electrons from linear accelerator up to a dose of 25 kGy at different dose rates ranging from 25 to 100 kGy/h. In comparison to our previous study [1], the GaAs substrate was of higher quality. The galvanomagnetic measurements (at 300 K and 400 K) revealed electron Hall mobility of 7150 ± 150 cm2/Vs and resistivity of 2.0×10E7 ± 0.1 Ωcm at room temperature. Fabricated detectors have Ti/Pt/Au Schottky contact of a circular shape with 1 mm diameter and the whole area Ni/AuGe/Au ohmic contact at the back side. The forward and reverse current-voltage measurements show significant changes with applied dose and also used dose rate. The detector spectrometric properties (the charge collection efficiency, the detection efficiency) at different reverse biases (from 100 V to 300 V) were evaluated via measured spectra of 241-Am radionuclide gamma source before and after electron irradiation with various doses and various dose rates.

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A compact and portable X-ray Beam Position Monitor using Medipix3 sensors

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The present work reports on the design of a novel portable XBPM device. It comprises two parts: the electronics enclosure and the vacuum chamber with external dimensions of 120x88x66 mm and 75x75x50 mm, respectively. This system provides users with real-time beam characterisation without beam obstruction, in vacuum operation, and interfaces with up to four Medipix3 hybrid detectors.
The electronics readout consists of three custom six-layer printed circuit boards, a Medipix3 carrier board placed in the vacuum chamber side, a data acquisition board, and an embedded image data acquisition and processing system. In addition to all signal interconnections for four Medipix3 dies the carrier board includes the temperature on board and pressure in vacuum chamber monitoring. Data and control differential signals are driven on the data acquisition board; it also contains modules for power supplies, high voltage settings, cooling control, external triggering, and analogue outputs. The image-processing platform is based on an ARM CortexTM-A8 processor, which controls Medipix3 operations, through one Altera Cyclone FPGA, and data transfer throughout a network interface.
Communication between detector and processing unit is achieved through the FPGA, which interfaces with drivers and receivers providing adequate signal termination. The control and readout protocol for the Medipix3 is developed on the FPGA, offering with this a rapid, versatile, and scalable system.
For system performance measurement, one Medipix3 detector is mounted and tested at maximum permitted configuration values according to the capabilities of the Medipix3 chip and readout system. The system is capable of acquiring magnified images and profiles of synchrotron X-ray beams at a transfer rate through Ethernet of 27 frames/s.
Further improvement in hardware and software is being carried out to offer a more robust cooling system, lighter instrument, and faster readout controller. This work was made possible thanks to the support of the MEDIPIX collaboration, which provided Medipix3.0 chips to use in this XBPM prototype.

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Development of a Fast Multi-Line X-Ray CT Detector for Non-Destructive Testing

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Typical X-ray detectors for non-destructive testing (NDT) are line detectors or area detectors, like e.g. flat panel detectors. Multi-line detectors are currently only available in medical Computed Tomography (CT) scanners.
Compared to flat panel detectors, line and multi-line detectors can achieve much higher frame rates. This allows time-resolved 3D CT scans of an object under investigation. Also, an improved image quality can be achieved due to reduced scattering radiation from object and detector themselves. Another benefit of line and multi-line detectors is that very wide detectors can be assembled easily, while flat panel detectors are usually limited to an imaging field with a size of approx. 40 x 40 cm² at maximum. The big disadvantage of line detectors is the limited number of object slices that can be scanned simultaneously. This leads to long scan times for large objects. Volume scans with a multi-line detector are much faster, but with almost similar image quality. Due to the promising properties of multi-line detectors their application outside of medical CT would also be very interesting for NDT. However, medical CT multi-line detectors are optimized for the scanning of human bodies. Many non-medical applications require higher spatial resolutions and/or higher X-ray energies. For those non-medical applications we are developing a fast multi-line X-ray detector.
We are presenting the current state of development of our novel detector, which includes several outstanding properties like an adjustable curved design for variable focus-detector-distances, conserving nearly uniform perpendicular irradiation over the entire detector width. Basis of the detector is a specifically designed, radiation hard CMOS imaging sensor with a pixel pitch of 200 µm. Each pixel has an automatic in pixel gain adjustment, which allows for both: a very high sensitivity and a wide dynamic range. The final detector will have 256 lines of pixels. By using a modular assembly of the detector, the width can be chosen as multiples of 512 pixels. With a frame rate of up to 300 frames/s (full resolution) or 1200 frame/s (analog binned to 400 µm pixel pitch) time-resolved 3D CT applications become possible. Two versions of the detector are in development, one with a high resolution scintillator and one with a thick, structured and very efficient scintillator (pitch 400 µm). This way the detector can even work with X ray energies up to 450 keV.

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LOFT - Large Observatory for X-ray Timing

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LOFT (the Large Observatory for X-ray Timing), is a mission concept that was considered by ESA as a candidate for an M3 mission and has been studied during an extended 2-years long assessment phase.

The mission was specifically designed to perform fast X-ray timing and probe the status of the matter near black holes and neutron stars. The LOFT scientific payload is composed of a Large Area Detector (LAD) and a Wide Field Monitor (WFM). The LAD is a 10m2-class pointed instrument with 15 times the collecting area of the largest past timing missions (as RXTE) over the 2-30 keV range (30-80 keV expanded) combined with CCD-class spectral resolution, which holds the capability to revolutionise studies of X-ray variability down to the millisecond time scales.

Its ground-breaking characteristic is a mass per unit surface in the range of ~10 kg/m2, enabling an effective area of ~10 m2 (@10 keV) at a
reasonable weight. The development of such large but light experiment,
with low mass and power per unit area, is now made possible by the recent advancements in the field of large-area silicon drift detectors
and capillary-plate X-ray collimators.

In particular, the LOFT/LAD and WFM prototype detectors have been manifactured at FBK (Fondazione Bruno Kessler, Trento, Italy), and designed in collaboration with INFN, Trieste. They are based on the heritage of the detectors used in the Inner Tracking System of the ALICE experiment at the Large Hadron Collider at CERN (Rashevski et al. 2002, Beolè et al. 2007), for which INFN Trieste had and maintains the full knowledge of both design and process details.

Although the LOFT mission has not been finally down-selected in the M3 ESA programme (with launch in 2022-2024), during the assessment phase most of the trade off have been closed leading to a robust and well documented design which will be re-proposed in the future ESA calls.
In this talk, we will summarize the characteristics of the LAD instrument and briefly describe the status of the detectors design.

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Large-area linear Silicon Drift Detectors for X-ray imaging and spectroscopy

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The first extensive use of large-area, linear Silicon Drift Detectors (SDDs) for instruments of considerable surfaces has been implemented in the Inner Tracking System (ITS) in the ALICE experiment of the Large Hadron Collider (LHC) at CERN. The ALICE SDDs were optimized for high-resolution two-dimensional tracking of high-energy ionizing particles in a high-multiplicity environment, such as that produced in Pb-Pb collisions at the LHC.
Over the last years INFN (Ts), FBK (Tn) and INAF have conducted an intense and effective R activity aimed at exploiting the outstanding capability of the SDDs to read-out a large collecting area with a small set of low-capacitance anodes in X-ray astronomy from space missions.
This development, carried out by means of a number of detector prototypes, has been focused on the optimization of SDDs for X-ray spectroscopy, timing and imaging in the 2-30 keV energy band.
With a power consumption below 0.5 mW/cm^2, the demonstrated performance of the built prototypes features a 200 eV (FWHM) energy resolution, 10 us timing-resolution, and an anode-axis average spatial resolution of 20 um FWHM, which improves to ~10 um FWHM for photon energies greater than 8 keV. Moreover, using a 1-D read-out, the detector provides also a coarse position resolution better than 8 mm FWHM along the drift direction.
In the following we present the results of the detector R activity together with the foreseen application of the SDDs in both a collimated X-ray timing instrument and a coded-mask based Wide Field Monitor.

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A Silicon Drift Detector - CMOS Front-End System for High Resolution X-Ray Spectroscopy up to Room Temperature

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Silicon Drift Detectors (SDDs) for X-Ray Spectroscopy are able to operate at non cryogenic temperature with high energy resolution in 0.1-20 keV energy range. Presently, it is possible to reach spectral line widths approaching the Fano limit with SDD areas of the order of 10-30mm^2 operating at temperature in the -20°C to -50°C range. The best published values of energy resolution are 123eV at -20°C and 260eV at +25°C as FWHM of 5.9keV 55Fe line. These results are due to progresses in silicon cristal quality, in detector fabrication technology, in advances in low noise front-end electronics and system optimization [1-3]. The upper limit of the SDDs-based system operating temperature is determined by the detector current density at the anode, ranging from 1 nA/cm^2 down to 200 pA/cm^2 at room temperature for typical and best devices and by the noise of the Front-End Electronics at short shaping times.

Our group has made a significant effort for designing extremely low-noise CMOS ASICs and for developing a technology for fabricating SDDs with the lowest anode current [4-6]. We present here the results of our efforts: a CMOS charge preamplifier specifically designed for ultimate low noise has been coupled to a 12.8 mm^2 SDD manufactured by optimizing the production processes in order to reduce the anode current. The preamplifier has a noise level of less than 2 electrons r.m.s. and the SDD a current density at the anode of 28 pA/cm^2 at room temperature. A 55Fe spectrum acquired at +21°C shows 141 eV FWHM at 5.9 keV, the pulser line width is 74 eV FWHM and the noise lower threshold is only 170 eV. At the best of our knowledge this is the best result ever achieved at room temperature. At -30°C the line FWHM are 124 eV at 5.9 keV and 29 eV (3.3 electrons r.m.s.) on pulser line.

Both efforts in the design of low noise front-end electronics as in SDD technology allowed us to realize a system with high energy resolution even at room temperature: this result opens new perspectives taking advantage of system low power consumption and compactness as consequence of the reduction or even absence of the cooling system.

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Environmental Compton camera development: imaging radionuclide transport in soils and geomaterials

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Current research in the Nuclear Instrumentation group of the University of Liverpool focuses on the optimisation of the gamma ray Compton camera [1]. Such an imaging system can utilise two energy and position sensitive semiconductor detectors with the Compton scattering formula to gain position and energy information of gamma-ray emitting radioactive sources. This presents a significant improvement in efficiency and dynamic range over coded aperture systems currently used in industry [2]. We present the progress of a project funded by the Natural Environment Research Council, aiming to optimise a Compton camera system for environmental radioactivity measurements. The project will investigate the feasibility of a range of applications, from small scale imaging of radiation transport through soil and uptake in plants, to large scale monitoring of soil erosion and radioisotope retention in tree canopies. This will build upon previous work that developed the proof of concept of a fused radiometric and optical stereoscopic imaging system for use in nuclear decommissioning. This project employs a Compton camera that consists of two planar HPGe semiconductor detectors of dimensions 60x60x5 mm and 60x60x20 mm. The processes of radiometric image generation will be presented in the context of an experiment that imaged 20 MBq Cs-137 point sources at standoff distances of 0.8–1.5 m. Experiments will now focus on the ability of the system to image low activity sources and initial measurements will look to develop previous work by Corkhill et al [3] that produced time lapse images of Tc-99m transport using a gamma camera. This will be presented alongside GAMOS [4] simulations that investigate the limits of the system. The potential for fusion with optical stereoscopic images will be discussed alongside prospects for this project beyond the laboratory work.

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Simulations of the LUCID experiment in the Low Earth Orbit radiation environment

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The Langton Ultimate Cosmic ray Intensity Detector (LUCID) experiment [1] is a satellite-based device that uses five Timepix hybrid silicon pixel detectors [2] to make measurements of the radiation environment at an altitude of approximately 635km, i.e. in Low Earth Orbit (LEO).

The experiment is due to launch aboard Surrey Satellite Technology Limited's (SSTL's) TechDemoSat-1 in Q2 of 2014.

The Timepix detectors, developed by the Medipix Collaboration [3], are arranged to form the five sides of a cube enclosed by a 0.7 mm thick aluminium covering, and will be operated in Time-over-Threshold mode to allow the flux, energy and directionality of incident ionising radiation to be measured.

To understand the expected detector performance with respect to these measurements, the LUCID experiment has been modelled using the Allpix package, a generic simulation toolkit for silicon pixel detectors built upon the GEANT4 framework [4].

The work presented here summarises studies completed using the grid infrastructure provided by the GridPP Collaboration to both perform the simulations, store the resultant datasets, and share that data with the LUCID Collaboration.

The analysis of these datasets has given an indication of the experiment's expected performance in differing space radiation environments (for example, during polar passes or when over the South Atlantic Anomaly), and has allowed the LUCID Collaboration to prepare for when data is transmitted back to Earth later in 2014.

Keywords: LUCID Pixel detector Silicon detector Space radiation Timepix GEANT4 Grid computing GridPP

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Using Hybrid Pixel Radiation Imaging Detectors for Space Radiation Environmental and Dosimetric Applications

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While it may seem like a retro-application to use hybrid pixel detectors for applications that consist primarily of observing incident charged particles, given the provenance of these detectors in high energy physics, in actuality the challenges faced are surprisingly novel, at least for these devices. While the space radiation environment consists of mainly charged particles, the routinely seen charges of dosimetric interest range from protons through that of fully ionized iron nuclei, and with energies from stopping to very relativistic. In addition, while their fluxes are not necessarily isotropic, as a practical matter, locally they can appear to be incident from any direction with respect to the detectors. Furthermore, the fluences can vary by many orders of magnitude both in location and time. In the end, the ultimate goal is to characterize the charged particle radiation field as completely as possible in order to be prepared to calculate any potential dosimetric endpoint, and to do so with minimum power and external bandwidth requirements. While devices that enjoy access to spacecraft (or even spacesuit) power, detector stacks with multiple layers can be considered, however for portable battery-powered “film-badge” replacements one is pretty much relegated to a single detector device. Using pattern recognition and an thorough analysis of the pixel cluster created in pixel-based device like the Medipix2 Timepix technology, it is possible to measure the track length of an energetic penetrating charged particle as well as the energy deposited, which leads to knowledge of the Lineal Energy Transferred (LET) to the sensor. Further one can determine the polar and azimuthal angles of the track, and by analyzing the δ-rays for more energetic particle’s tracks the propagation direction can inferred. Likewise the δ-rays can give information about the energy (or more correctly the velocity), which when coupled with the LET can give a reasonable estimate of both the charge and kinetic energy of the particle. Some difficulties that need to be overcome include distinguishing crossing tracks, interactions, and stopping particles as well as having to deal with the huge range of potential input charge per pixel including accurate calibration. Results from 5 Timepix units with over a year and a half in orbit on the International Space Station will be presented.

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Timepix3: First measurements and characterization of a hybrid-pixel detector working in event driven mode

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In this paper we present the first measurements with the Timepix3 chip bump bonded to a 300µm thick Silicon sensor. Timepix3 is a unique ASIC developed to provide fast readout in a low to medium hit rate environment. The pixel matrix consists of 256x256 pixels with a pitch of 55µm. The chip can be configured in either data driven or frame-based modes. In data driven mode the chip sends out a 48-bit package every time a pixel is hit while the shutter is open . This packet contains Time-of-Arrival (TOA) and Time-over-Threshold (TOT) information from each hit pixel. In frame-based mode the pixels operate in Photon Counting (PC) and integral TOT (iTOT) mode and zero suppressed information is sent off chip after the shutter is closed. The chip is designed to handle a maximum hit rate of 40Mhits/s/cm2 in the data driven mode.

The chip is calibrated using radioactive sources and X-ray fluorescence from metal foils providing absolute measurements of the electronic noise, threshold dispersion and minimum threshold. The energy resolution in photon counting and time over threshold mode is measured for each pixel and compared under different operating points. A first assessment of the hit rate capabilities in the data driven mode is presented and compared to the design specifications. We also investigate the monotonicity of the preamplifier for high input charges using alpha particles.

Looking at these results the Timepix3 chip provides unique features when it comes to fast read-out and accurate time stamping and is foreseen to be used in many different applications from XRF to particle tracking and radiation monitoring. It builds on the successful Timepix chip and, with the data driven mode, it enables many new applications previously limited by read-out dead time and hit rate capabilities. Also having the time and energy information from each particle hit means that it will be a useful tool to study sensor properties and investigate new architectures for spectroscopic X-ray imaging.

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Development of 1D- and 2D-type X-ray detectors combined with a CdTe Schottky diode and photon-counting ASICs

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We have been developing 1D- and 2D-type high energy X-ray detectors combined with CdTe Schottky diode sensors and photon-counting readout ASICs in use for synchrotron radiation experiments [1-4]. On the CdTe sensor device the front side was deposited with aluminum to form pixelated electrodes and the back side was covered with a single platinum-electrode. This electrode configuration has the advantage of providing a high Schottky barrier formed on the Al/CdTe interface, and, hence, a benefit to operate the CdTe as an electron-collecting pixelated diode.

The first prototype of 2D-detector (SP8-01) was designed with a pixel size of 200 μm ×200 μm and a matrix of 16 × 16 [1-2]. This detector has an ASIC with a preamplifier, a shaper, a window-type discriminator and a 20-bits counter in each pixel. The detector successfully operated with a photon-counting mode selecting X-ray energy with the window comparator. Excellent energy linearity was achieved between 15 and 120 keV [2]. The second prototype (SP8-02) was redesigned to 20 × 50 pixels with the same architecture in the pixel circuit. The SP8-02 detector realized a long-term stability at 5 degrees C [3]. Then, the ASIC was improved as SP8-02B to suppress the dispersion of threshold energies of the discriminator [4]. In this talk, we will present the specification and performance of a large area detector having a CdTe sensor 8.2 mm × 40.2 mm in detective area and 2 × 4 SP8-02B ASICs.

The 1D-type CdTe sensor assembly was designed as it is compatible with the MYTHEN Si-strip sensor. While the silicon strip sensor could directly connect to an ASIC with wires, the CdTe strip sensor couldn't employ the wire-bonding technique because the CdTe crystal easily gave due to mechanical stress during the bonding procedure. In our technical choice the CdTe strip sensor was once bump-bonded to an interposer board with an In/Au-stud bonding method, and, then, the interposer board was wire-bonded to the ASIC. 638 strip-shaped electrodes formed 50 μm in pitch on the CdTe sensor and two sensors was adapted on one interposer board with 200 μm dead area in between two sensors. In this talk, we will present basic performance of this CdTe strip sensor assembly.

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The LAMBDA pixel detector and high-Z sensor development

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Many X-ray experiments at third-generation synchrotrons benefit from using single-photon-counting detectors, due to their high signal-to-noise ratio and potential for high-speed measurements. Furthermore, experiments with X-ray tubes can benefit from energy-binning photon counting detectors (colour imaging), for example to improve discrimination of different materials.

LAMBDA (Large Area Medipix3-Based Detector Array) is a pixel detector system based on the Medipix3 readout chip, with colour photon-counting capability. It combines the features of Medipix3 (such as a small pixel size of 55μm and flexible functionality) with a large tileable module design consisting of 12 chips (1536 x 512 pixels) and a high-speed readout system currently capable of running at 1000 frames per second. Recently, a series of LAMBDA systems have been produced, commissioned and used in experiments at synchrotrons.

To enable high-speed experiments with hard X-rays, the LAMBDA system has been combined with different high-Z sensor materials, in collaboration with other institutes and industry. Room-temperature systems using GaAs and CdTe systems have been assembled and tested at beamlines. These first systems provide an area of 768 x 512 pixels, and larger systems using multiple tiled high-Z sensors are in development.

While these sensors provide acceptable image quality after flat-field correction, hybrid pixel systems using Germanium are being developed to achieve a higher image quality. The first single-chip hybrid Ge sensors have been produced and bump bonded. These sensors have a layout of 256 x 256 pixels of 55μm, work successfully, and show good image uniformity. Larger germanium sensors with a 768 x 512 pixel layout are currently in production.

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High speed imaging and spectroscopy with X-rays

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Counting, imaging and spectroscopic measurements of X-rays at energies between 50 eV and 30 keV require detectors with challenging properties. As the penetration depth of low energy X-rays in the above energy range is only 100 nm, special attention must be given to the properties of the radiation entrance window. For the higher energies the depleted thickness must be large. As the number of generated electron-hole pairs is low (for X-rays of e.g. 100 eV about 27 signal charges) the detector systems must be operated with very low electronic noise, especially if not only imaging shall be performed but simultaneously spectroscopy. For experiments requiring spectroscopic information the "system energy resolution" should be Fano-limited, i.e. at 300 eV X-ray energy the system noise should be lower than 3.5 electrons (rms) and at 4 keV the requirement would be below 10 electrons. In case experiments are executed with a repetition rate of e.g. 120 Hz with a detector format of 1024 x 1024 pixels, the data rate is 2 Gigabit per second, i.e. 10 Terabit for one hour data taking. Efficient data reduction schemes are needed. As the photon intensities per unit area can be as high as 108 X-rays per second and pixel, long term stability, especially radiation hardness is an important requirement. In case of imaging experiments with analog signal integration the dynamic range, the charge handling capacity, plays a major role. As many experiments require the proper detection of single X-rays per pixel and readout frame, as well as more than 10.000 X-rays per pixel in the same image frame special mechanisms have to be implemented to keep the spatial and amplitude information intact. Recently tests have been performed showing that pnCCDs can cope with more than 100.000 X-rays per frame and pixel. This became possible through a controlled charge extraction during signal integration. For readout rates below 5 kHz charge coupled devices (CCDs) have proven their usefulness in experiments at X-ray Free Electron Laser sources and synchrotrons. Last not least, the physical limitations of the measurement precision will be discussed.
Finally, options for future CCD architectures will be touched.

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Monolithic arrays of SDDs and low noise CMOS readout for X-ray spectroscopy measurements in nuclear physics experiments

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This work deals with the developments of Silicon Drift Detectors (SDDs) of different sizes and low noise CMOS read-out preamplifiers in view of their use in nuclear physics experiments, like SIDDHARTA upgrade supported by INFN. The SIDDHARTA experiment used high precision X-ray spectroscopy of the kaonic atoms to determine the transition yields and the strong interaction induced shift and width of the lowest experimentally accessible level. In this work we report about the recent SDDs and CMOS preamplifiers development, with particular emphasis of X-ray measurements at cryogenic temperatures. The SDDs presented are designed as single square shaped units of different areas 64 mm2 (8 mm x 8 mm) or 144 mm2 (12 mm x 12 mm) and also as monolithic arrays of 9 elements (8 mm x 8 mm each, total area 26 mm x 26 mm) in a 3x3 format. Measurements with all the SDDs versions (64 mm2, 144 mm2 and 3x3 array) will be reported at cryogenic temperatures up to 50 K and with resolution below 125 eV FWHM on the MnKα line. Low temperatures operations are required to speed-up the drift time that is important for the timing of the experiment in order to reject the high background. The detectors have been designed and manufactured by the Fondazione Bruno Kessler (FBK) Semiconductor Laboratories. The read-out of the SDDs is based on new versions of the CMOS preamplifier (CUBE) for both the single unit and the 3x3 array. The CMOS technology is intrinsically more robust at lower temperatures with respect to the more conventional JFET transistor used in SDDs readout and it allows the use of these devices without penalties at these very low temperatures New preamplifiers versions have allowed to obtained relevant results with measured resolution of 123 eV on the MnKα line with the optimum shaping time and resolution of 126.4 eV with 250 ns shaping time with round shaped 10 mm2 SDDs detectors, allowing excellent spectroscopy performances even with very high input count rates. This last feature makes the SDD+CUBE combination very attractive also for synchrotron applications. The nine detectors array required in addition to the preamplifiers the use of a multichannel ASIC (Application Specific Integrated Circuit) for signal shaping and peak detection of all the units and of a custom Data Acquisition System. Also measurements of low energies lines will be reported in order to proof the possible extension of the soft X-ray range of the experiment and application in synchrotron beam lines.

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Medium-Format Photon-Integrating Pixel Array Detectors for Time-Resolved and High Dynamic Range Experiments

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Synchrotron radiation experiments place a diverse set of demands on x-ray area detectors. Desired qualities include fast readout, a high signal to noise ratio for single-photon detection, wide dynamic range, and the ability to handle high instantaneous flux. Photon-integrating detectors offer a particular advantage in that they can tolerate instantaneous hit rates exceeding those of photon-counting detectors, while still detecting single photons with a high signal to noise ratio. To this end, photon-integrating pixel array detectors (PADs) are being developed to meet the needs of light source users and to enable challenging experiments. Two photon-integrating PADs in an advanced stage of development will be described, and examples from recent experiments will be given to demonstrate the detector capabilities. Both detectors are based on ASIC/sensor hybrid modules tiled in a 2 x 3 configuration to produce medium-format units with 256 x 384 pixels. The Mixed-Mode PAD (MM-PAD) uses mixed analog and digital readout to achieve a pixel well depth of 4 x 10^7 8 keV photons while maintaining excellent single-photon sensitivity. The maximum frame rate is greater than 1 kHz and the detector can tolerate an instantaneous hit rate of 10^12 photons/pixel/s and a sustained hit rate of over 10^8 photons/pixel/s. The Keck PAD uses in-pixel frame storage to achieve time resolution better than 150 ns for successive frames, which would enable single-bunch imaging at many storage ring sources. Both detectors have been used in high-frame-rate time-resolved experiments at the Cornell High Energy Synchrotron Source. The MM-PAD has also been used in coherent diffractive imaging experiments at the Advanced Photon Source and PETRA III, and for tomographic reconstruction of a randomly-oriented 3-D object using sparse data (<10^-2 photons/pixel/frame) from a home-laboratory x-ray source.

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Latest Results In The Development Of The DSSC Camera For The European XFEL

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The DSSC camera under development for the European XFEL must be able to operate at a maximum frame rate of 4.5 MHz and to achieve high dynamic range (~10^4 photons/pixel) and single photon detection capability at the same time [1]. Among the developments for the European XFEL, the DSSC will be the only 2D, large-area, high-speed detector able to achieve single photon resolution even in the low energy range down to 0.25 keV. The camera is based on Si-sensors and is composed of 1024 x 1024 pixels for a total active area of 210x210 mm^2. 256 bump-bonded ASICs provide full parallel readout, comprising analog filtering, 8-bit digitization and data storage. In order to achieve simultaneously high dynamic range and single photon detection, a non-linear system response is required. The originally foreseen DEPFET provides dynamic range compression thanks to its intrinsic non-linear current/charge characteristic. The DEPFET fabrication requires a large number of process steps that, at the moment, turn out into a long production time and limit the availability of a large number of full format sensors. Therefore, the consortium has started, in parallel, the development of a sensor based on mini-SDD pixel arrays that require a considerably simplified technology. This sensor provides a linear output response, but a dedicated front-end [2], placed on the readout ASIC in parallel to the DEPFET front-end, implements the required signal compression and makes the sensor fully compatible with the rest of the DSSC system. Even if the mini-SDD sensor provides limited performance, especially at high speed and low-energy, it will allow one to operate the DSSC camera for the day-zero of the European XFEL operation, covering part of the foreseen experiments.
The ultimate performance is expected operating the DSSC camera with the DEPFETs. In the presentation an overview of the DSSC system comprising the sensor and the readout electronics with the latest measurements will be given. New experimental results on the DSSC DEPFETs will show that these devices are able to achieve single photon detection at low energy even at 4.5 MHz. The mini-SDD sensor concept will be presented and critically compared with the DEPFET solution.

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3D Silicon Sensors with Variable Electrode Depth for Radiation Hard High Resolution Particle Tracking

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3D sensors, with electrodes micro-processed inside the silicon bulk using Micro-Electro-Mechanical System (MEMS) technology, were industrialized in 2012 and will be installed in the first detector upgrade at the LHC, the ATLAS IBL* in 2014. They are the radiation hardest sensors ever made.

A new idea is now being explored to enhance the three-dimensional nature of 3D sensors by processing collecting electrodes at different depths inside the silicon bulk as shown in figure 1. This technique uses the electric field strength to suppress the charge collection effectiveness of the regions outside the p-n electrodes' overlap. Evidence of this property is supported by test beam data of irradiated and non-irradiated devices bump-bonded with pixel readout electronics and simulations. Applications include High-Luminosity Tracking in the high multiplicity LHC forward regions. This paper will describe the technical advantages of this idea and the tracking application rationale.

note
* The Insertable B-Layer (IBL) in ATLAS will start taking data in 2015 and is composed of 14 staves to surround the beampipe's envelope at 3.2cm from the beam. 3D sensors compatible with the 2x2cm2 FE-I4 readout chip, will cover 25% of the total detector area. At the High Luminosity (HL) LHC more stringent requirements are imposed on the tracking detectors closest to the interaction points since as many as 200 primary vertexes are expected, radiation levels as high as 2x1016n1MeV /cm2 and the necessity to disentangle the enhanced track density at high angles.

ATLAS IBL collaboration, Prototype ATLAS IBL modules using the FE-I4A front-end readout chip, 2012 JINST 7 P11010

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Development of Edgeless TSV X-ray detectors

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Hybrid pixel detectors are the cutting-edge technology for many X-ray experiments at synchrotrons and free electron lasers. The span of the applications extends from material analysis and biomolecular screening to chemical dynamics monitoring.
However, these detectors suffer from a certain amount of dead space between modules, due to the need for guard rings in the sensor and wire bond connections to the readout chip. A possible solution is to use edgeless detectors with active-edge sensors and read-out chips (ROC) utilizing through-silicon-via (TSV) technology.
The current state of the art includes the CERN TSV Medipix3 chip and VTT (Advacam) edgeless X-ray sensor.
Here, we report about the activity and progress on the development of edgeless detectors at DESY.
Active-edge sensors have been simulated with Synopsys TCAD for different polarities including p-on-n, p-on-p, n-on-p and n-on-n with p-spray or p-stop for different thicknesses from 150um to 500um. Results show that the bending of electric field close to the active edge is leading to image distortion on the sensor edge. In addition, the current design of active-edge sensors shows very poor radiation hardness. We are currently in cooperation with industry partners for the development of a radiation hard active-edge sensor with optimized imaging quality.
Through-silicon-via (TSV) technology is a new concept of connecting read-out chip to the read-out electronics. Instead of wires and wire-bonding which introduces large dead area, TSV enables connection through ROC itself. We use Medipix3RX chips in this development. Due to the existence of wire bonding pads on the chip, it introduces about 3.5mm of dead space. By replacing wire bonding with TSV, dead space between detectors will be reduced to only 0.8mm. Technology partner in this development is IZM from Berlin, Germany. Thickness of the wafer is designed on 200um with the via diameter of 60um. Inside of the via a 5um thick copper layer will be used as a conducting layer. On the back side of the chip a Re-distribution Layer (RDL) will be deposited. For RDL structure, 5um thick copper with 40um wide conductive lines will be used. Bump bonding of the sensor plus ROC assembly to LTCC ceramics has to be optimized in terms of material and bonding temperature. We expect first test modules to be ready by the end of this year. Final goal of this development is to make Large Area Medipix Detector (LAMBDA) with TSV edgeless units.

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MARS: A new ASIC for X-ray fluorescence measurements

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Silicon photodiode detectors and Silicon drift detectors (SDDs) have widespread applications in astrophysics, high energy physics, crystallography and medical imaging. Maia, a scanning x-ray fluorescence microprobe was designed with a multi-element photodiode sensor with 384 pixels and two application specific integrated circuits (ASICs) [1]. The detector was wire-bonded to a front-end ASIC which provided low noise charge pre-amplification and shaping. The output of the shaper was wire-bonded to a precision peak and time detector ASIC with arbitration logic and analog memory. We present a new Multi-element Amplifier Readout System (MARS) ASIC that has been designed and fabricated in 250 nm CMOS to replace the ASICs currently used in the Maia x-ray microprobe system. The MARS ASIC can accept electron or hole signals, allowing its use with either simple photodiodes or SSDs. It combines the functions of the two chips currently used for Maia while significantly reducing the physical footprint, the electronic noise, and the power dissipation. The ASIC dissipates 127 mW and combines 32 channels. Each channel is comprised of low noise charge amplification, high order shaping with baseline stabilization, discrimination, pileup rejection, peak amplitude and time-over-threshold with analog memory. Each channel processes and stores the amplitude and corresponding timing for above threshold events. Any channel with a processed event can be read out independent of the other channels. The readout is sparse with the channel address and the channel is rearmed after readout is complete. The interface is analog differential and digital LVDS. Preliminary measurements for a 96-element silicon diode detector array will be presented.

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10 µm thin transmissive photodiode produced by CELLS + IMB-CNM-CSIC

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Transmission photodiodes are useful beam diagnostic devices in synchrotron beamlines, which allows beam intensity monitoring simultaneously with the experiment. Due to Si absorption, devices under 10 µm thick are needed to achieve transmission over 90% for energies over 10 KeV. With the aim of producing a 10x10 mm2 10 µm thin transmission photodiode, CELLS-ALBA and IMB-CNM-CSIC have produced the first prototype of thin photodiode and hereby we present our preliminary results. The fabrication process is based on a technique developed at the MPI to process large area thin detectors. Thinned wafers are produced, diced to single chips and mounted on a support at CNM. The support has a circular window of 8,5 mm in diameter and pin connectors. CELLS has designed a dedicated box that copes with the device mechanical fragility. A generic characterization has been performed to measure shunt resistivity (230 MΩ), dark noise (1.2 nA), terminal capacitance (0.17 nF) and diode capacitance vs voltage. A preliminary diode test under beam was also performed at CELLS. X-ray response characterization was done at ESRF. The laboratory setup was composed by a Genix Cu X-ray generator at 8 KeV aligned with the transmissive photodiode and a beam-viewer FAV2 1x. Diode current was measured with a Keithley k6485 electrometer. X-rays focused on the beam-viewer produce an spot which intensity was measured as the average intensity of the spot transverse section in ADUs. Photodiode transmission was calculated as the ratio of spot intensity with/without the photodiode. The same setup was used in beamline BM05 under a 8KeV beam, adding a 500 µm Si calibrated photodiode. Photodiode response homogeneity was measured reading photodiode current in steps of 0.2 mm for a mesh of 12x12 mm2. The same area was scanned in steps of 0.4 mm to measure the transmission homogeneity. Preliminary results at 8 KeV are a transmission of 80% and a sensitivity of 0.2097 A/W with a maximum deviation of 4% for an active area of 8.3 mm in diameter. In the near future further test are planned to be done in BL13 beamline at ALBA synchrotron. Some samples will be sent to PTB3 laboratory for further characterization. In addition, a funded program is being developed under the EDi program of FCRI4 to promote the availability of these devices to external institutes. We want to thank ESRF detector unit for their help and collaboration.

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FPGA-based optimized firmware designed for spatial resolution improvement for MSGC detector

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The presented work has been conducted for a 157Gd based Micro-Strip Gas Chamber (MSGC) aimed for the detection of thermal neutrons. The earlier developed prototype detector is characterized by a high 2D pixel resolution (635µm × 635µm) and a high count rate capability (up to 5*107 events/s). The subsequent DAQ-system is aimed to track the time and amplitude distribution of an electron avalanche initiated by conversion electrons after neutron capture. It comprises the developed ASIC circuit (performing time stamping), developed ADC board (for amplitude digitalization) and followed by a FPGA transmitting gathered data to a PC for post-processing. Due to low-pressure operation of the MSGC the electron avalanche creates signals on several neighbouring cathode strips of both coordinates. The developed FPGA firmware has been designed to improve the definition of position resolution of neutrons by the Center-of-Gravity (CoG) method.
The CoG calculation requires significant computational resources if any loss of data shall be avoided at the anticipated high counting rate. Preparatory experiments with a high end Aquiris DAQ-system, allowing 2 GHz sampling of 5 amplified analogue signals simultaneously, allowed us to determine the amplitude distribution in dependence on operating pressure and electrical field configuration of the MSGC. As result we found that a single event (i.e. a detected neutron) can create signals on up to 5 neighbouring cathode strips which we call a cluster.
A mixture of VHDL code and Simulink System Generator model was written allowing real-time read-out and processing of the data at high rate. The designed CoG calculation firmware introduce very strict requirements to computational and memory resources: in worst case 64 events at 128 input strips with extended time stamp (43 bits for one strip) and amplitude data (12 bits) have to be treated. One Kintex-7 FPGA is capable to cope with 128 strips of one coordinate. The preliminary design shows that 64 high capacity dividers could be implemented in chosen FPGA performing the most critical part of CoG calculation. The most resource demanding part responsible for clusters definition was significantly optimised with respect to memory and DSP utilization. In the presentation the cluster identification algorithm and the architecture of the firmware will be explained in detail.

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CMOS sensors for energy resolved X-ray imaging

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Due to their low noise, CMOS Monolithic Active Pixel Sensors are suited to sense X-rays with a few keV quantum energy, which is of interest for "colored" high resolution X-ray imagine. Moreover, the good energy resolution of the silicon sensors might potentially be used to sense this quantum energy. Combining both features with the good spatial resolution of CMOS sensors opens the potential to build X-rays sensitive cameras.
Taking those images is hampered by the need to operate the CMOS sensors in a single photon counting mode, which restricts the photon flux in reach of the sensors. More importantly, the charge sharing between the pixels smears the potentially good energy resolution of the sensors.
Based on our experience with CMOS sensors for charged particle tracking, we studied techniques to overcome the latter obstacle by means of an offline processing of the data obtained from the camera. We found that the energy resolution of the pixels can be recovered on expenses of reduced quantum efficiency.
We will introduce the results of our study and discuss the feasibility of taking "colored" X-ray pictures with CMOS sensors.

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SMARTPIX, a photon-counting pixel detector for synchrotron applications based on Medipix3RX readout chip and active edge pixel sensors.

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Photon-counting pixel detectors are now routinely used on synchrotron beamlines. Many applications benefit from their noiseless mode of operation, single-pixel point spread function, and high frame rates. These detectors are generally based on a modular architecture permitting an adaptation to various detection geometries. However the size of the elementary detector modules is sometimes too large for some applications, whereas the detection area of large multimodule systems show important interstitial dead gaps. This has motivated the development of SMARTPIX, a scalable pixel detector system built around the MEDIPIX3RX readout chip. In order to achieve nearly seamless detection areas, SMARTPIX relies on the through-silicon-via technology available on MEDIPIX3RX as well as on active edge pixel sensor technologies developed by ADVACAM. The SMARTPIX building block is a compact detector module with 30x30 mm2 detection area including four MEDIPIX3RX chips in 2x2 arrangement. Several of these modules can be tiled to form detection areas of arbitrary shape. A scalable acquisition electronics is developed to enable acquisition rates of 6000 fps for a 2-modules SMARTPIX system. In addition, SMARTPIX will provide the users with the improved spectroscopic capabilities of MEDIPIX3RX chip. The detector design and its main specifications will be presented.

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Light read-out of a 1 liter liquid argon scintillation chamber with Silicon PMs : light detection performance.

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We will show the results obtained with a liquid argon scintillation chamber with light read-out completely based on SiPM. We used a PTFE chamber containing 1l
of liquid argon lined with a reflective foil (VIKUITI) evaporated with a wavelength shifter (TetraPhenyl Butadiene - TPB).
The chamber is observed by a small array of 7 large area SiPM (Hamamatsu S11828-3344M, ~ 2 cm2 each) for a coverage of the internal surface of the order of 4%.
We obtain a light yield comparable with what we
obtain with a high efficiency 3" cryogenic photomultiplier (Hamamatsu R11065) that has a photo-catodic coverage 3 times higher.
This is an extremely important result that shows that at this moment SiPm represents a real alternative to standard photo-multipliers in liquid argon applications.

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A Real-time Auto-Detection Method of Random Telegraph Signal Noise in CMOS Active Pixel Sensors

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In the area of high energy physics experiment, compared with the hybrid pixel sensors and charge coupled device, CMOS Active pixel sensors can achieve an attractive tradeoff among the key performance parameters, such as granularity, material budget, power dissipation, readout speed and more function on the same substrate. However, CMOS APS can be greatly influenced by random telegraph signal (RTS) noise, making particle tracking or energy calculation failure, especially under radiation environment.
RTS noise is induced by the defects located in the pixels, making the dark signals fluctuating with two or more levels[1]. Pixels' RTS behavior can be explained by the variation of physical state of the defects, and two key parameters are used to describe RTS noise: time constant, transition amplitude. The parameters have relationship with the radiation source, radiation dose, working temperature as well as the process variables. In-depth research of pixels' RTS behavior stimulates interest of the methods of RTS noise detecting and parameter extracting.
Threshold based methods can be conveniently used to judge whether RTS occurs[2]. To do this, the standard variance of the dark signal is calculated and compared with a target transition amplitude. If the amplitude is higher than the standard variance, the corresponding transition is recognized as a RTS transition. The main drawback of this method is that, when the Gaussian noise or RTS noise degrades, RTS transitions with low amplitudes would not be detected successfully.
A real-time auto-detection method of RTS noise is proposed in this paper. Comparing with the previous reported RTS detection methods, the proposed method employs a real-time signal variance rather than the whole signal variance, to judge the RTS transition. Therefore, the RTS detection efficiency can be greatly improved by 20%. Moreover, even under the situation that the Gaussian and RTS noise degrades, the proposed methods keeps high detection efficiency.

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A Novel Multi-cell Silicon Drift Detector for Low Energy X-ray Fluorescence (LEXRF) Spectroscopy

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The TwinMic spectromicroscope at Elettra is a multipurpose experimental station for full-field and scanning imaging modes and simultaneous acquisition of X-ray fluorescence. Operating in the 400-2200 eV photon energy range, the beamline is particularly suited for bio-related research with low-Z elements[1]. The actual LEXRF detection setup consists of eight single-cell SDDs in an annular configuration[2]. Although they provide good performances in terms of both energy resolution and low-energy photon detection efficiency, they cover just about 4% of the whole photoemission solid angle. This is the main limitation of the present detection system, since large part of the emitted photons is lost and consequently a high acquisition time is required.

In order to increase the solid angle, a new LEXRF detection system is being developed within a collaboration of INFN, Elettra, Politecnico of Milan and FBK (Trento).

The system, composed of 4 trapezoidal multi-cell silicon drift detector, is configured as a 33 × 33 mm^2 square detector with a central hole and covers up to 40% of the photoemission hemisphere. This geometry provides a 10 times improvement over the present configuration. First measurements in the laboratory and on the TwinMic beamline have been performed in order to characterize a single trapezoidal detector, configured and controlled by means of two multichannel VEGA ASICs, which provide preamplification, shaping and peak-stretching, connected to acquisition electronics based on fast ADC and FPGA and working under vacuum.

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Spatial Resolution Studies for the PERCIVAL Sensor

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The PERCIVAL ("Pixelated Energy Resolving CMOS Imager, Versatile and Large") is an initiative of a collaboration of DESY, RAL, Elettra and DLS to develop a monolithic active pixel sensor (MAPS) to provide a suitable detector for photon science for the photon energy regime between 250 eV and 1 keV. An important performance parameter is the spatial resolution which can be inferred from the Modulation Transfer Function (MTF). The MTF measures the relative contrast of a pattern for a given spatial frequency in optical systems and the resolution is commonly quoted as the spatial frequency at which the MTF has a value of 0.1.

With a backthinned PERCIVAL prototype chip, dedicated MTF evaluation data were taken at Elettra's TwinMic beamline in March 2014 at a photon energy of ~ 535 eV. A knife edge with an angle of ca. 7 degrees with respect to one of the axes of the detector was mounted on a manipulator, which allowed to move the knife edge in front of the sensor at a distance of ~ 1 cm. Images of the beam were taken with and without the knife edge, together with dark images. Despite the uneven illumination from the attenuated direct beam, combining the 3 image types enabled us to derive an MTF for the system.

For the tested PERCIVAL chip the derived MTF for one pixel type of interest yields a value of 0.1 for a spatial frequency of 0.02 line pairs/µm, which corresponds to a line pairs period of 50 µm.

We will present our MTF derivation approach employed to correct for the uneven illumination of the edge, together with MTF results for 3 pixel types of the irradiated backthinned test sensor and a brief summary of selected other TwinMic-based results.

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Factors related to image quality in the lens-coupled X-ray detector

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Background: Scintillator, is the key section of the lens-coupled X-ray microscope detector for high spatial resolution X-ray imaging experiment at unfocused beamline of synchrotron radiation . The performance of Scintillator plays a significant role on the resolution and contrast of the image while the effective pixel size is close to 1microns. However, users of SSRF neglected this fact that scintillator could influence images' sharpness when they performed their X-ray imaging experiments. Purpose: Selecting a scintillator with suitable thickness can help us get excellent images to achieve outstanding experimental result. Methods: We obtain the optimal thickness of scintillator for every objective lens (1.25X, 2X, 4X, 10X and 20X) by the way of experiment and mathematical computations. Results: And both of the results are nearly in accordance. Conclusions: Users of SSRF will get an excellent result of X-ray imaging experiment when they chose the best scintillator of the objective lens.

Keywords X-Ray microscope detector, Scintillator, Contrast.

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Program status on the dynamic tomography at sub-second time scale

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With the availability of third generation Synchrotron Radiation (SR) sources, SR-μCT has evolved as an increasingly accepted and utilized technique for quantitative characterizing the 3D internal structure of samples in different research fields [1-3]. Generally, SR-μCT need a large number of projections that will no doubt decreasing the temporal resolution of SR-μCT thus handers its applications in some research fields, and increasing the dose delivered to the sample.

In order to overcome this problem, the imaging group at SSRF has launched a program that aiming to realize dynamic tomography at sub-second time scale. The program utilizes image reconstruction algorithm and detector reformation to speed up the SR-μCT. Firstly, the compressed sensing theory[4] is introduced in SR-μCT that can sharply reduce the required SR-μCT projections number thus increase the time resolution of SR-μCT. Secondly, a novel detector model, realizing by merging digital high-speed camera and scintillator reformation program, will be utilized to accelerate SR-μCT data collecting speed. Moreover, the GPU base parallel computing technique will be utilized to speed up the compressed sensing based SR-μCT reconstruction that is an iterative algorithm.

This program is founded by National Natural Science Foundation of China as a four years project starting from 2014. Our preliminary the results shown that the compressed sensing based SR-μCT reconstruction algorithm can obtain comparable results, comparing to FBP algorithm, when utilized about 1/5 of the FBP's projection number. This means reasonable results can be obtained, by utilizing about 100 projections, for a sample; moreover, 100 Hz frame rate with acceptable image quality is achievable for the novel detector model. With these, we believe dynamic tomography at sub-second time scale is feasible.

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The fiber-SiPMT beam monitor of the R484 experiment at RIKEN-RAL Muon Facility

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We report here the lay out and the read out structure as well as the very promising results of a scintillating fibers Silicon Photo-multiplier based beam hodoscope built for the R484 experiment. This instrument has been designed to deliver position, shape and timing of the low energy muon beam at the RIKEN-RAL Muon Facility at Rutherford Appleton Laboratory.

R484 is a project which will lead to the measurement of the hyperfine splitting in the ground state of the muonic hydrogen atom and the determination of the Zemach radius of the proton.

A recently published measurement of the proton root mean square charge radius, extracted from the experimental value of the Lamb shift in muonic hydrogen, differs by 7 standard deviations from previous determinations derived mostly from electronic hydrogen. The discussions about the correctness of the theory or experiments or even the adequacy of the proton models have not yet lead to a satisfactory explanation of this discrepancy. Resolving the proton charge radius puzzle therefore requires precise measurements of alternative proton characteristics in muonic hydrogen, the most appropriate of these being the proton Zemach radius considered an important parameter of the proton structure along with the proton charge radius, and among the few that reflect both its charge and magnetic structure. The proposed experiment will be sensing the Zemach proton radius in muonic hydrogen, furthermore this measurement will strengthen the experimental limits on the parameters of the proton structure.

An important component of the experimental set-up is a scintillating fiber SiPM based beam monitor detector, designed to deliver position, shape and timing of the low energy muon beam entering the hydrogen gas target. The very compact and reliable design has two arrays of square shaped scintillating fibers, along x and y coordinates, arranged in planes of dimensions 5 x 5 cm2 and a pitch of 3 mm. Each fiber is read at one end by a SiPMT, the hodoscope has been successfully tested on the electron beam at the Beam Test Facility (BTF) of the INFN LNF laboratory.

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Count Rate Characteristics of the PILATUS3 ASIC for Different Synchrotron Bunch Modes

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To improve the rate correction for PILATUS detectors the count rate characteristic of the PILATUS3 ASIC was investigated for different bunch modes at several synchrotrons. The instant retrigger technology enables non-paralyzed counting at high photon fluxes [1], which allows the detector systems to be operated up to photon rates of 15*106 counts per second (cps) and pixel. The experimental data is compared to the results of a Monte-Carlo simulation, which is able to predict the count behavior for different detector settings and arbitrary bunch modes. The simulation can be used to provide accurate rate corrections without repeating the intricate measurement of the count characteristic for the different bunch modes at synchrotrons around the world.

The experimental results presented in Figure 1 demonstrate the rate capability of the PILATUS3 ASIC with enabled and disabled retrigger mode to incoming rates of up to 108 cps and pixel for fast detector settings. Compared to the PILATUS2 ASIC the new readout chip can cope with four to five times higher photon fluxes. A closer look at intermediate count rates reveals that no significant count loss occurs up to an incoming rate of 106 cps even without applying any rate correction. Furthermore the PILATUS3 ASIC shows a higher global count rate limit and a reduced sensitivity to different bunch modes.

The Monte-Carlo simulation of the count rate behavior of the PILATUS3 ASIC is found to reproduce the acquired data up to 107 cps with a typical accuracy of below five percent for continuous-like bunch modes and below ten percent for highly structured bunch modes. By applying a bunch mode specific rate correction the accuracy of the data can improve by up to forty percent compared to a correction based on a continuous X-ray beam.

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DEVELOPMENT OF A TIMEPIX3 READOUT SYSTEM

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This contribution describes the development of a read-out system for the Timepix3 hybrid pixel ASIC, developed by CERN within the Medipix Collaboration.
Timepix3 chip provides information (individually for each pixel in the 256x256 matrix) about
- Time of Arrival (ToA), which provides information about the time at which the particle is detected, with a resolution of up to 1,56ns;
- Time over Threshold (ToT), which provides an indirect measure of the incoming particle's energy;
- Hit Count (PC), which provides information about the number of detected particles.

What makes it very attractive is the possibility of receive both ToA and ToT (i.e. energy) information together, packed with the coordinates of the active pixel.
Because of these characteristics, Timepix3 can be used in many applications where fast timing and energy information are needed, e.g. X-ray Photon Correlation Spectroscopy and particles tracking.
The development starts from the Medipix3 read-out system Merlin, developed in Diamond Light Source. The Merlin system is based on a National Instruments PXI/FlexRIO system running a Xilinx Virtex5 FPGA.
The National Instruments part of the hardware is general purpose and completely configurable, so it is exactly the same used for the Medipix3 read-out system. All the hardware modifications are in the custom adapter, which was developed ad hoc to interface the Medipix3 chip with the FPGA card contained in the PXI rack.
The two chips have a completely different management of their communication system, this requires completely new interface software. The main characteristics of the Timepix3 chip, for what concerns the communication are:
- Packet orientation;
- Clocks management;
- Independence of output lines;
- Encoding of output data.

The work necessary to adapt the Merlin system to the Timepix3 chip involves HDL coding, LabView programming and changes in the custom hardware.
To test functionality and efficiency of the developed read-out system, some characterization test for the Timepix3 chip have been carried out, initially using the built in test pulse feature.
The system is still under development, especially in the GUI part, optimization of the program. The final goal is develop an efficient read-out system which can be used with both Medipix3 and Timepix3 chips.
Timepix3 main characteristics, key parts of the new software (HDL and LabView) and results from the characterization tests will be presented during the conference.

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Operation and Applications of a Bunch-by-Bunch, Turn-by-Turn X-Ray Beam Size Monitor at CesrTA

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The Cornell Electron Storage Ring Test Accelerator (CesrTA) functions as a testbed for future e+/e- accelerators. In particular, the program is interested in collective effects where bunches earlier in a train will affect the beam dynamics and beam size of bunches later in the train. Traditional beam size monitors are time-averaged over many revolutions, and are not capable of resolving behavior of individual bunches in a train on a single pass, thus mandating the development of a new instrument.

The solution chosen for CesrTA which meets these requirements is an x-ray beam size monitor (xBSM), a one-dimensional InGaAs diode array with 50-micron pixel pitch and readout electronics designed in-house. The new monitor was required to be capable of bunch-by-bunch, turn-by-turn measurements for upwards of 30,000 bunch-turns and a bunch spacing down to 4 nS. The monitor is capable of resolving a vertical beam size below 15 microns, with the ability to resolve changes in beam size of one micron or less. Additionally, it is capable of measuring beam sizes over a wide energy reach, from 1.8-4 GeV, corresponding to x-ray energies approximately 1-10 keV. The xBSM is a peak-detection system, capable of timing in on the peak of a bunch passage to within 10 pS. Two classes of optic are available for imaging: a vertically-limiting variable-width tungsten aperture which acts as a one-dimensional pinhole, and a multi-slit pattern (coded aperture, or CA) which is printed in Au on a Si substrate.

In this poster, the design and operation of the xBSM and associated optics are briefly detailed. Example uses of the device and optics are presented for both single-bunch and multi-bunch configurations. Lessons from the first generation of coded aperture have led to the development of a new coded aperture with improved resolving power at low beam energy (1.8GeV), which has been demonstrated in machine studies in April 2014.

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SiPM based photon counting detector for scanning digital radiography

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In the present report, we summarize the results of our efforts to create a x-ray counting detector for digital scanning radiography based on the silicon photomultipliers (SiPM) in Budker Institute of Nuclear Physics during last year. We performed a comparative study of the possible candidates for scintillator: YAP, LFS-3, LGSO, LYSO and two types of SiPMs: old style HAMAMATSU MPPC and trench type one from MIFI. To measure real detector parameters we built detector prototype based on 32 channel Omega EASIROC front-end chip. The results obtained while this study demonstrate that at present moment the detector could reach quantum efficiency >95%, counting rate - 5MHz, energy resolution 35% (at 59.5 keV) and spatial resolution is defined by scintillator and SiPM size .

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Flexible DAQ card for detector systems utilizing the CoaXPress communication standard.

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This work concerns the design and construction of a flexible FPGA based data acquisition system aimed for particle detectors. The interface card as presented was designed for large area detectors with millions of individual readout channels. Flexibility was achieved by partitioning the design into multiple PCBs, creating a set of modular blocks, allowing the creation of a wide variety of configurations by simply stacking together functional PCBs. This way the user can easily toggle the polarity of the high voltage bias supply or switch the downstream interface from CoaXPress to PCIe or stream directly HDMI. We addressed issues of data throughput, data buffering, bias voltage generation, trigger timing and fine tuning of the whole readout chain enabling a smooth data transmission. On the current prototype, we have wire-bonded a MediPix2 MXR quad and connected it to a XILINX FPGA. For the downstream interface, we implemented the CoaXPress communication protocol, which enables us to stream data at 3.125 Gbps to a standard PC. This prototype is able to achieve frame rates of up to 700 fps. With the current MediPix2 Quad we achieved a frame rate of 100 fps. The main limiting factor here is the maximum speed at which we can clock the LVDS interface to the Medipix2 chips.

The readout system compares favourably to Ethernet based DAQs systems, mainly because CoaXPress is better suited than Ethernet for the transfer of image data. The data are protected against corruption while in transfer and the throughput is deterministic. The upper limit for the CoaXPress communication standard is currently 25 Gbps, of which at least half we intend to achieve in the following years. Such data rates might become necessary for larger detectors than the currently used MediPix2 MXR quad. Another area we are actively investigating is to harden the readout chain against radiation induced soft errors.

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Development of a CZT 3D spectrometer for high energy astronomy

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The development of new instrumentation for high energy astronomy, operating from ~60 keV up to 600 of keV, is particularly challenging. This type of instrument requires high performance detectors able to perform simultaneously measurements of several observational parameters as energy, incoming direction and polarization status of the impinging photons. We describe a three dimensional (3D) position sensitive detector prototype proposed as a basic module to build high efficiency Laue lens focal plane spectroscopic imager . The prototype is composed of 8 linear modules, each composed of one basic sensitive unit. Each unit is a drift strip detector based on a CZT crystal (20 mm x 8 mm x 2.4 mm), irradiated transversally to the electric field direction. The anode is segmented into 8 detection cells having a pitch of 2.4 mm, each comprising one collecting strip surrounded by 4 drift strips on each side. The strips are 0.15 mm wide with a gap of the same size. The drift strips are biased by a voltage divider in order to focused the electrons on the collecting strips. The cathode is divided into 4 strips orthogonal to the anode ones with a pitch of 2 mm for the reconstruction of the interaction position along the direction of the anodes. In this way the detector is equivalent to a stack of thinner CZT horizontal layers with the advantage of not having any passive material between each layer. The position of the incident photon in the inter-electrode distance can be obtained by using the ratio between the cathode and anode signals. This detector configuration is currently under study for use in a balloon payload dedicated to performing a high significance measurement of the polarization status of the Crab nebula/pulsar between 100 and 500 keV (see dedicated poster in this conference).

The detector readout electronics is based on three RENA-3 ASICs and the data handling system uses custom electronics based on an FPGA. We describe the components and the status of the ongoing activities for the assembling of the proposed 3D CZT prototype. As the operating temperature of the detection system composed of the AFEE and detector box is very important, a cooling system able to stabilize the temperature of the box, containing the detection system, below 25 °C has been realized. We report the results of the response characterization of the CZT modules.

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Use of XR-QA2 radiochromic films for quantitative imaging of a synchrotron radiation beam

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Purpose: This work investigates the use of GAFCHROMICTM XR-QA2 radiochromic films for quantitative imaging of a synchrotron radiation (SR) beam.

Materials and Methods: Pieces (200×30 mm^2) of GAFCHROMICTM XR-QA2 film (lot # A10071003A) were irradiated in a plane transverse to the beam axis, at the SYRMEP beamline at ELETTRA, with a monochromatic beam of size 170×3.94 mm2 (H×V) and energy of 28, 35, 38 or 40 keV. The response was calibrated (1-20 mGy) in terms of average air kerma rate (mGy s^-1), measured with a calibrated ionization chamber. Films were digitized in reflectance mode using a flatbed scanner. The 16-bit red channel was used. The netdR was then converted to photon fluence per unit ring current f/I (photons mm^-2 mA^-1). The SR beam profile was acquired also with the scintillator (GOS) based, fiberoptic coupled CCD camera.

Results: Horizontal profiles obtained with the two modalities were compared, evaluated in a ROI of 17.71×0.59 mm2, across the beam center. We observed a non-uniformity of the CCD response over the horizontal and vertical directions, attributed to the light collection geometry of the tapered fiberoptic coupling between the scintillator screen and the CCD chip. Once corrected for this detector response, the CCD profile was scaled in order to have the same average value as the normalized profile acquired with the Gafchromic film. The two profiles in the ROI 17.71×0.59 mm2 showed fluctuations within 2% for the CCD and 1% for the radiochromic detector, well within the statistical uncertainties evaluated for the radiochromic dose measurements (10%).

Conclusions: The Gafchromic images (in units of mm^-2 mGy^-1 s mA^-1) provide the normalized 2D distribution of the beam intensity. The comparison with images acquired with a CCD scintillator camera shows that the film is free of geometrical distorsion and provides information on the structure of the beam, though it necessitates of an offline processing with respect to the real time operation of other imaging detectors.

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X-ray Signal Evaluation Of A Photoconductor For The Application In Automatic Exposure Control Sensor

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Automic Exposure Controllers (AEC) are currently used in diagnostic radiation imaging to reduce the rate of re-imaging through exposing an appropriate amount of radiation in image acquisition areas while obtaining optimal diagnostic images. AEC devices use radiation transmitted through the subject and compared with a reference voltage to adjust the quantity before reaching the image detector. AEC Sensors mainly use silicon. However, silicon does not effectively handle changes in performance due to doping; furthermore, due to the complexity of the production process, prices of production units have become a problem. In this study, shortcomings in silicon sensors were supplemented and sensors using photoconduction materials to detect x-ray signals were created for use as AEC sensors. In sensor creation, powdered HgI2, PbI2, and PbO were mixed with binders for use as photoconductor materials. Indium tin oxide glass was used on the lower electrode, and 2cm2 each of HgI2 14um, PbI2 11um, and PbO 14um were deposited on the lower electrode using a screen printing method as photoconductor materials to maintain an x-ray transmittance of 90%. Due to the thinness of the deposited material, a coating of about 3μm of parylene was used as an insulating layer on the photoconductor materials to prevent latch-up. Next, Au was vacuum-deposited on the upper electrode to collect signals. To confirm feasibility as an AEC sensor, linearity, reproducibility, transmittance and shadow image tests were performed. Results of measuring linearity showed that collection amounts of all photoconductor materials increased linearly under each radiation condition. Reproducibility measurement results confirmed standard deviations of HgI2 0.72% and PbI2 1.07%, 0.93% when measured 10 times under the same conditions. Transmissivity was shown to be HgI2 92.9%, PbI2 91.1%, and PbO 84.7%. These results showed that only small quantities are lost when x-rays reach the imaging sensor. Shadow image recording results confirmed that the image densities were similar to those of the currently used AEC sensor. These results confirmed the feasibility of AEC sensors using photoconductors in the field of diagnostic radiation, and the characteristics of linearity, reproducibility and transmissivity of photoconductor materials used in this study can be used as examples in diagnostic radiation and in other fields as well.

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First characterization results of the MÖNCH hybrid pixel detector

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MÖNCH is a novel hybrid silicon pixel detector based on charge integration and analog readout, featuring a challengingly small pixel size of 25x25 μm2. It is a research project which aims to push the development of hybrid pixel detectors to its limits in terms of photon flux, position resolution, energy information and low energy detection.
MÖNCH02 is a fully functional, small scale prototype of 4x4mm2, containing an array of 160x160 pixels, designed in UMC 110nm technology [1]. This array is subdivided in five sub blocks, each featuring a different pixel architecture. The first block targets high resolution, low flux synchrotron applications, as RIXS (resonant inelastic X-ray scattering) or X-ray tomography with X-ray tubes. In this case the charge sharing effect between pixels, together with the signal analog readout, can be exploited to interpolate the hit position with a precision that could reach the sub-μm resolution [2, talk by Sebastian Cartier].
The first characterization results of this sub block of MÖNCH02 in terms of bump-bonding yield, linearity, dynamic range and energy resolution will be shown. The noise performance will be presented in more detail, showing a total noise as low as <40 e-, as well as an overview of the noise contribution of the different blocks, from the amplifier to the off-chip buffer.
The encouraging results obtained lead to the design of a bigger size prototype, MÖNCH03. MÖNCH03 has an active area of 10x10mm2 and it contains an array of 400x400 identical pixels, based on the first block of MÖNCH02. Several improvements are implemented in the chip periphery and in the readout system, which should result in a final frame rate of ~8 kHz.

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The read-out ASIC for the space NUCLEON project

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The space NUCLEON project is designed to investigate a cosmic ray nuclei energy spectrum from 100 GeV to 1000 TeV as well as a cosmic ray electron spectrum from 20 GeV to 3 TeV. A method of energy determination by means of a silicon tracker for measuring the particle charge of space rays and calorimetric system were developed. The main parameters, that determine the quality of calorimetric systems are the dynamic range of input signals, which should reach tens thousands of single charge particles. Important parameters of read-out electronics are the consumed power, as well as the weight-size characteristics and reliability.
This paper summarizes the design results for the read-out ASIC as one of the core elements. The ASIC with a unique high dynamic range (1 – 40 000 mip) at low power consumption (< 1.5 mW per channel) has been developed. The ASIC allows to record signals of relativistic particles and nuclei with a charges from Z = 1 up to Z > 50 from silicon detectors, having capacitances up to 100 pF. The chip structure includes 32 analog channels, consisting of charge sensitive amplifier (CSA) with PMOS input transistor (W=8mm, L=0.5μm), shaper (peaking time of 2 us) and T circuit.
The ASIC showed a 120 pC dynamic range at a SNR of 2.5 for the minimal energy (1 mip) particles. The transfer function of CSA, having two subranges of different slopes (gains), allowed to reach a high dynamic range of the readout electronics. The splitting of the full dynamic range (from noise to saturation) into automatically switched subranges is considered as a specific feature of the designed circuit. An auxiliary class B amplifier is added to the CSA output. For small signals this amplifier is off and the CSA gain is determined by a relatively small feedback capacitance value and set to 0.15 V/pC. For higher amplitudes (~3 pC), the class B amplifier is dynamically switched on. In this case, an additional capacitor is added into the CSA feedback via the class B amplifier. That defines the equivalent feedback capacitance value of the CSA at level of 10 times higher, decreasing the CSA gain in the large amplitude region.
All analog chain outputs are collected by analog multiplexor with output current driver and supplemented by a calibration system. The chip area is 4.0 × 4.0 mm.sq. The ASIC was fabricated by the 0.35 um CMOS process via Europractice and tested both at lab conditions and in the SPS beam at CERN.

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Deformations in Single Crystal Copper Cantilevers revealed by a pnCCD in Energy-dispersive micro Laue diffraction

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Energy-dispersive µLaue diffraction is used to analyse morphology and energetic structure of circular and streaked Cu 711 and 511 reflections collected during a position-resolved experiment on a plastically deformed Cu micro-beam with a dimension of 6 x 6 x 30 µm. The synchrotron experiment was performed at the BM32 beam line of ESRF using polychromatic X-rays in the energy range between 5 and 25 keV and a beam size of 0.5 x 0.5 µm. The diffraction signal was recorded using an energy-dispersive three-dimensional detector (pnCCD), operated in the single photon counting mode and providing diffraction intensity as a function of photon energy for every detector pixel. Whereas the Laue spots obtained from undeformed sample regions remain sharp and occur at fixed X-ray energies, streaked reflections originating from plastically deformed regions possess an energy gradient which is interpreted by lattice rotation and lattice deformation caused by geometrically necessary dislocations stored in the crystal. This new approach in the structural analysis of materials will be used to analyse (i) strains in elastically deformed samples without the need of sample rotation and (ii) dislocation structures as well as local strains in plastically deformed metals.

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SiPM tracking in NEXT for background rejection and energy calibration

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NEXT is a high-pressure gas xenon TPC which has been designed to measure the ββ0v mode of Xe-136. The detector will use the electroluminescence of the gas to amplify the signal from deposited charge using a region of increased electric field in the last 0.5 cm before the anode. The light produced will be detected in a tracking plane made up of silicon photomultipliers positioned 2 mm behind the anode as well as in PMTs at the opposite end of the light tube. The tracking plane information will be used to reconstruct the topology of events allowing for the identification of muons, single electrons and, ultimately, double electrons indicative of a double beta event.

NEXT-NEW and NEXT-100 will be the first stages of NEXT used for measurement of double beta decay. We will present the design of the tracking plane, its electronics and methods for its calibration. Moreover, we will describe the development of reconstruction and background rejection algorithms using data from prototype detectors and Monte Carlo studies.

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X-Ray imaging detectors for the Imaging and Medical Beam Line at the Australian Synchrotron

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The Imaging and Medical Beam Line (IMBL) at the Australian Synchrotron is used for both radiography and radiotherapy research. It is highly versatile x-ray facility, primarily built for biomedical imaging but capable of materials radiography as well.
The beam line requires several x-ray imaging detectors to cover the full range of experimental requirements. Most of the detector are commercial. However one unit is a lens coupled phosphor system custom designed by IMBL staff in collaboration with Monash University Biological Engineering Department. The system is called 'Ruby' and consists of a 120 mm by 120 mm removable phosphor screen imaged through a mirror and a commercial macro camera lens, onto a scientific CMOS sensor. The CMOS sensor currently used is the PCO.edge which gives 5.5 megapixel images at rates up to 30 frames per second. The sensor is mounted on a motorised slide to permit the field of view to be altered to suit the experiment. The phosphor can be easily changed to suit the required resolution and efficiency providing a versatile and popular imaging unit.
This paper will briefly introduce the beam line and the detectors in the IMBL suite, then follow with a discussion of the design considerations and performance of the Ruby detector.

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Comparative Study on Two Guard Ring Structures of Silicon Photomultipliers

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The guard ring (GR) of silicon photomultipliers (SiPM) is the most essential structure to prevent the edge breakdown effectively. In previous study, several types of GRs were suggested such as diffused n-well GR (NGR), virtual GR (VGR), trench GR (TGR). The NGR was devised at the early stage of Geiger mode avalanche photodiodes (GAPDs). A low doped and deep diffused n-well is defined at the junction edge to obtain a wide junction curvature to increase the breakdown voltage higher than at the center of the junction. The area efficiency of NGR is not good because the active area was consumed by the wide n-well. The VGR was proposed to increase the area efficiency of a GAPD. A uniform and medium doped p-well is implanted inside the active area to decrease the breakdown voltage lower than at the edge of the junction. The space consumed by this method is smaller than by the NGR. The TGR was the most advanced technique with the highest area efficiency but it was impractical due to a significant high dark count rate (DCR) by defects which are introduced during the etching process. Therefore, the best GR for a GAPD was known as the virtual structure. However, the VGR is also not free from the defects during the p-well implantation. These defects located within high field region role as trap centers and cause high DCR by the trap assisted tunneling mechanism.

In this study, the SiPMs with two types of GRs which are the virtual and diffused n-well were designed, fabricated and will be compared in terms of the area efficiency and DCR. Both of the structures were designed with several widths and overlaps to find the optimum size. The widths of the GRs are varied from 0 to 3 um and overlaps between the NGR and the n+-well are varied from 0 to 1.5 um. The SiPMs were processed at National NanoFab center (NNFC) with 4 um thick p-type epitaxial layer wafers. The p-well for the VGR was implanted by boron with doses of 5e12 and 4.5e12 cm-2 at 80 keV. The different p-well doses were used to evaluate the effect of the trap assisted tunneling on the dose level. The NGR was defined by phosphorus with a dose of 5e12 cm-2 at 150 keV. The drive-in for the defect curing and dopant activation was processed in 1000 C for 165 min. The measurement of I-V characteristics was shown the breakdown voltages of 20 V and 27 V for etch VGRs and 71 V for the NGR. Moreover, the current of the NGR after the breakdown was significantly lower than VGR.

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Development of Silicon Photomultipliers for PET-MRI Application

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In recent years, silicon photomultipliers (SiPMs) have been highlighted as one of essential solid state photo-sensors for the embodiment of fusion image systems, such as positron emission tomography (PET) magnetic resonance imaging (MRI) and PET computed tomography (CT). Especially, its potential as a MR compatible PET detector was proven with its high gain, good energy/timing resolution, non-magnetic sensitivity, lower operation voltage, compactness as well as lower cost compare to PMTs.
The SiPMs were fabricated using customized CMOS process at the National NanoFab Center (NNFC) in Korea. (100) oriented 4 μm thick p-type epitaxial wafers were used. To maximize electric fields at the avalanche region, the N+/P/π/P+ layer structure and conditions were optimized using the device and process simulations. To enhance the sensitivity at short wavelengths, a low energy arsenic implantation and rapid thermal annealing processes were used to define shallow N+ cathode formation. Besides, to prevent early breakdown, a low dose N type implanted guard-ring was adopted. The SiPM was designed to have a size of 3×3 mm2 made up thousands of micro cells which is included passive quenching elements. The size of a micro cell was 65×65 μm2 which is optimized value using a trade-off relation between PDE and dynamic range.
We measured the photon detection efficiency (PDE) of SiPM with photon counting method using several wavelengths from 375 nm to 660 nm. The PDE was approximated 12% at 420 nm which is the peak wavelength of LYSO crystal. The dynamic range of SiPM was also measured using pico-second laser diode with intensities from low to saturation level. The pulse width is less than 100 ps which make possible to recognize as simultaneous photons to SiPM and escape from recovery time effect of micro-cells. The energy resolution was measured and certificated at Korea Research Institute of Standards and Science (KRISS). The energy resolution is the full width at half maximum (FWHM) of around 10% at 511 keV with 3×3×20 mm3 LYSO crystal coupling. With two opposite SiPM modules of 3×3×20 mm3 LYSO crystal and pre-amplifiers, time difference of two annihilation gamma rays from Na-22 was measured. The result shows the FWHM of 2.24 ns by constant fraction timing method. This result is also enough for fusion PET-MRI system.

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An ultra-low power self-timed column-level ADC for a CMOS pixel sensor based vertex detector

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The ILD vertex detector has driven stringent requirements on the CMOS pixel sensors. A sensor prototype (MIMOSA-31) integrated with column-level 4-bit ADC for the outer layers has been fabricated and tested. The ADC has demonstrated attractive performances while maintaining low power consumption and small area. In order to further reduce the power consumption, an ultra-low power self-timed ADC is proposed. This work is dedicated to the improved ADC for CMOS pixel sensors in the ILD vertex detector.

The ADC completes the conversion by using a multi-bit/step approximation. Due to the low hit density in the outer layers, it is designed to operate in two modes (active and idle) to save power, which employs a threshold voltage to trigger the conversion. If the pixel output signal is higher than the threshold, the ADC is triggered and does the conversion, and otherwise the ADC goes asleep until the next conversion.

The structure of the ADC consists of an improved sample-and-hold (S/H) circuit and a self-timed technique. The S/H is enhanced by using single correlated double sampling architecture to reduce the fixed pattern noise from the pixel and operational amplifier. This avoids an extra auto-zeroing capacitor, and therefore reducing the power consumption and area. The efficiency of the comparator is improved by using a self-timed bit-cycling, and the preamplifier settling time is relaxed, thus reducing the current. The total power consumption is significantly decreased compared with the ADC in MIMOSA-31. The post simulation results show that it is reduced by up to 53% in idle mode and 40% in active mode while all the parameters are kept identical.

The self-timed ADC is designed in a 0.35 μm CMOS process with a pixel pitch of 35 μm. The conversion time of the ADC is 80 ns at a sampling rate of 6.25 MS/s. The power consumption, for a 3-V supply, is 225 μW during idle time, which is by far the most frequent. This value rises to 425 μW in the case of the active mode. The DNL and INL are 0.11/-0.16 LSB and 0.10/-0.06 LSB, respectively. In order to reduce the effect of crosstalk and give enough space to transmission lines, the layout is drawn with a smaller width, slightly increasing the length. Its footprint amounts to 35 x 590 μm2.

This paper will describe the details of the circuit implementation of the improved ADC. Also the preliminary laboratory experimental results will be shown, complemented with an outlook on further design improvements.

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Multi-channel readout of structured detectors using CUBE preamplifiers and VERDI processing ASICs

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Position-sensitive detectors for X- and Gamma-rays photons is a matter of continuously growing interest, either in scientific research (e.g. at synchrotron beam lines) or in industrial applications. Applications are always pushing the performances towards higher photon-energy, higher count-rate, and better spectroscopy capability.
New detector requirements, with continuously increased number of channel, can be better addressed using customized ASICs. Acquisition systems (based on multichannel ASICs) have intrinsic advantages like compactness, power consumption, and cost to name a few.
We successfully used the CUBE preamplifier ASIC and the VERDI processing ASIC to readout one pixel element with good energy resolution. The ASICs are complementary in the implemented functions. The first ASIC (named CUBE), is a charge preamplifier, which is designed to be mounted close to the detector. VERDI, the second ASIC, implements 8 complete readout channels, each one is composed by the hybrid charge preamplifier, analog shaping amplifier, baseline holder, peak-stretcher and output buffer.
In our previous work, we demonstrated the possibility to achieve the best possible noise performance with the best possible count-rate with SDDs (Silicon Drift Detector) [1] and with pixelated Si(Li) (Silicon-Lithium) and HPGe (High Purity Germanium) detectors [2,3]. As an example, using a 1-mm2 HPGe pixel we were able to achieve an energy resolution as low as 88 eV with a pulser. This corresponds to 344 eV [FWHM] at 59 keV 241Am-peak [3].
Having demonstrated the best achievable performances, we present in this work the first readout of 1-D structured detectors with a complete system. We have designed a compact 8-channel module based on VERDI; the module is 6 x 10 cm in size and requires less than 2 W of power. It is controlled via USB link for VERDI configuration and data-taking, and it can also be powered directly from the PC USB. Each module is equivalent to an 8-channel adjustable shaper and 8-channel multi-channel analyzer. The design foresees the possibility to daisy chain several modules in order to readout strip detectors with 64 or more channels with spectroscopic capability. Measures will be presented like the simultaneous spectra acquisition with an HPGE strip detector.

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The Development of Quad Medipix3RX Detectors for use on Synchrotron Beamlines at Diamond Light Source.

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This contribution will describe the development, calibration, integration and commissioning of a Medipix3RX quad chip x-ray imaging system recently deployed on multiple beamlines at Diamond Light Source. It covers the development of the Merlin system to control four Medipix3RX chips simultaneously, the development of novel calibration techniques required to operate the chips effectively, beamline tests to characterise the detectors and the ongoing deployment and commissioning of quad systems on the I07, I13 and I20 beamlines at DLS.

Following the developments previously reported to this conference the Merlin system has been redesigned to drive multiple chips simultaneously to facilitate a larger active area. This has also required the development of new custom readout electronics and a new chip carrier PCB that incorporates integrated thermal management features to cope with the higher power consumption.

A significant part of the development process has been to implement robust calibration techniques and characterise the detectors performance. During early testing it was noted that the Medipix3RX chip suffers from a front end oscillation effect trigged by digital coupling. Up to now this has generally limited the calibration that can be performed with noise edges to the lower gain modes. The contribution will present a novel calibration technique that avoids this problem and allows Medipix3RX chips to be calibrated in all gain modes and circumstances. The calibration and compensation of gains between chips that share a sensor is also described. Tests were performed on B16 the test beamline at DLS, and with an x-ray tube, to characterise the performance of this detector system. The effect of the gain variation between pixels and between chips sharing a sensor was measured, and microfocus beam scans were performed to characterise the larger pixels at the centre of multi-chip sensors.

The ongoing deployment, commissioning and use of the Merlin system on five different beamlines at DLS is described. This includes the use on I16 for high resolution imaging of Bragg peaks, a multi function repositionable sensor in B16, a quad system deployed with a 10m cable extension on the goniometer on I07, a quad and a single chip sensors deployed in tandem on I13 and the development of a 4 by 1 chip sensor array to instrument a spectrometer on I20.

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Development of a radiation detector based on polymer dispersed liquid crystal

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The use of active matrix flat panel imager (AMFPI) in large area x-ray imaging systems have grown over time but are still severely limited by pixel resolution, complex fabrication processes and high cost. This study presents a radiation detector based on polymer dispersed liquid crystal to overcome such limits. A photoconductor and a polymer dispersed liquid crystal are combined to develop the radiation detector based on polymer dispersed liquid crystal, and an external light source and an optical sensor are used to investigate the light transmission of the polymer dispersed liquid crystal. Instead of regular liquid crystal, polymer dispersed liquid crystal was used in this paper because it does not need polarizers and it is self-adhesive so that the transmittance is very high in the transparent state, which allows linear x-ray response and sufficient dynamic range in digital radiography. To develop the detector, mercuric iodide film as a photoconductor was deposited using particle in binder method after polymer dispersed liquid crystal film was prepared by the polymerization induced phase separation process. The mercuric iodide film with 250 μm of thickness was prepared to stop 90% of x-rays normally used in digital radiography and 0.5 V/um of electric field was applied to the film to separate the generated electron hole pairs. The generated electron hole pairs cause liquid crystal molecules to rotate and therefore light transmission was determined as a function of x-ray dose. As a result, we obtained the transmission-voltage (T-V) curve and the x-ray response characteristics of the detector. The threshold value of bias voltage at 10% of transmittance was 3.78 V and the saturation value of bias voltage at 90% of transmittance was 7.48 V. Also, the measured spatial frequencies for 50% MTF were 6.8 lp/mm. The result of this study showed the use of polymer dispersed liquid crystal not only leads the improvement of x-ray detection properties but also facilitates the fabrication of x-ray detector in large area x-ray imaging systems.

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A Front-end Stage with Signal Compression Capability for XFEL Detectors

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The availability of high-intensity and high repetition rate X-ray sources, like XFEL facilities, imposes severe constraints for the detectors to be developed, in terms of high speed and high dynamic range. For the European XFEL, different detector developments are on the way to readout X-ray flashes with a repetition rate of 4.5MHz with a dynamic range up to 104. In this framework, different compression techniques [1-3], at the sensor level or at the electronics readout level, have been adopted to allow the detection system to cope with the required dynamic range, still keeping the noise low enough to provide single photon detection at low signal intensities. In this work, we propose a very simple front-end (FE) solution based on an input PMOS transistor placed on the CMOS readout chip connected to the pixel detector. The FE is optimized for low-noise readout of X-ray photons at low intensities and characterized by a compression of the gain when the signal intensity increases. The PMOSFET is operated in the triode regime and its current is fed into a current-readout filter through a resistor. Larger is the transistor signal, larger is the voltage drop on the resistor which pushes the transistor to operate more in triode regime at lower gain, producing a compression in the overall FE+filter response. The proof-of-principle of the technique has been verified in a first prototype realized in the IBM 130nm technology. Using the prototype with a test detector, X-ray measurements have been carried out to assess the electronics noise. To optimize the compression profile of the response of the FE, more stages can be used in parallel, each one implementing a NMOSFETs instead of the resistor, to have a variable resistance in the signal range. The principle of the proposed FE, the related experimental results on first prototypes and the optimized design will be presented in this work.

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Multi-element readout of structured HPGe-detectors for high-resolution X-ray spectroscopy using CUBE-preamplifiers

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Very recently we have shown that CUBE-preamplifiers developed by XGLab s.r.l. can be used for reading out single elements of thick structured planar HPGe- and Si(Li)-detectors made by SEMIKON. Depending on the size of the detector element and the shaping time an energy resolution between 344 eV (A_element = 1 mm^2) and 407 eV (A_element = 20 mm^2) is achieved for the 60 keV Americium-line [1]. The next step was the realization of a simultaneous multi-element readout of structured detectors using the same preamplifiers for high-energy X-rays (more than 100 keV) with a comparable energy resolution as for the single-element readout. Two single-sided HPGe-detectors have been used for the tests: one detector with 8 elements (3.75 mm x 10 mm each) and one detector with 32 strips (1 mm x 5 mm each).

In addition to that we have equipped an existing 16-pixel HPGe-polarimeter from GSI-Darmstadt [2] with the new readout. The detector elements (7 mm x 7 mm each, arranged in a 4x4 matrix) are connected to CUBE-preamplifiers. The improved energy resolution of this detector system will allow much more precise polarization measurements of x-rays emitted from atom-ion collisions which are part of the physics program of the SPARC collaboration at GSI and the future FAIR accelerator facility.

We will present the results of our laboratory tests as well as the tests of the modified detector system at GSI-Darmstadt.

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A 3D CZT polarimeter for a balloon borne payload

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In next decade high energy astronomy, the measurement of the polarization status of cosmic sources will be a key observational parameter in order to determine the physical processes and the respective source emission sites, as well as to establish more accurate emission sources' physical models. Polarization is expected to be observed in a wide variety of gamma-ray sources such as: pulsars, solar flares, active galactic nuclei, galactic black holes and gamma-ray bursts.

As hard X-ray polarization observations are very difficult to perform in low flux situations typical for many hard X ray cosmic sources, telescopes operating in this energy range should be optimized for this type of measurement. In this perspective, we present the concept of a high-performance CZT spectrometer designed to operate as a scattering polarimeter between 100 and 600 keV. The detector with 3D spatial resolution is made of CZT spectrometers in a highly segmented configuration in order to enhance as much as possible the sensitivity to the linear polarization of detected photons. We describe a design concept for a stratospheric balloon payload (CμSP - Cadmium telluride μ-Spectrometer Polarimeter) and the on-board required resources as well as future possible mission scenarios. As a balloon borne experiment, this instrument will be dedicated to obtain an accurate and reliable measurement of the polarization status of the Crab source. This payload can be seen as a pathfinder for a high performance detector for the next generation of hard X and soft gamma ray telescopes based on high energy focusing optics (e.g. Laue lenses).

Finally, we will present Monte Carlo evaluations of the achievable polarization sensitivity for typical balloon observation times compared with expected polarized flux from the Crab pulsar. The minimum detectable polarization will be calculated as a function of detector segmentation level (pixel size and depth), spectroscopic performance, and for different expected background conditions (diffuse cosmic X-rays, from galactic cosmic ray protons and delayed background noise due to material activation). Furthermore, systematic effects generated in polarization modulation pattern due to pixels geometry will also be evaluated.

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Direct-detection Monolithic sensors for X-ray Free-Electron Lasers and ultimate storage ring light sources

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Monolithic sensors have been traditionally used in in-direct X-ray detection scheme[1]. Recently, direct-detection monolithic sensors renewed attention in hard X-ray regime owing to their advantages in achieving small pixel, low readout noise, low power etc. At the SPring-8 site, the use of monolithic sensors has been started with off-the-shelf charge-coupled devices (CCD) for hard X-ray coherent X-ray diffraction experiments. These were succeeded by our multi-port CCD (MPCCD) development optimized for X-ray Free-Electron Laser (XFEL) experiments [2].

In this talk, we review the trade-off of CCD and direct-detection CMOS Image Sensor technologies from the viewpoint of XFEL experiments. Outlook of these technologies toward the ultimate storage ring light sources will be also given with an emphasis on the stacked sensor concept to achieve high quantum efficiency for the photon energy range from 5 to 30 keV.

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X-ray Imaging and its Detector Developments at SSRF

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X-ray imaging beamline (BL13W) at the Shanghai Synchrotron Radiation Facility(SSRF) is a beamline with wiggler source and photon energy range of 8-70keV, which is designed for full field X-ray imaging with field of view up to 5×45mm[1]. Up to now, this beamline has provided beam time for 2800 user times from 770 proposals. As a result, 180 research papers have been published. All kinds of X-ray imaging methods have been developed at BL13W and extensive applications have been found[2-17]. According to the user operation experiences in five years, methods related to dynamic imaging and fast micro-CT are highly desired. As a wiggler beamline, the flux density at BL13W is not high enough to meet simultaneously the need of high spatial and high temporal resolution. The development of high sensitivity, high frame rate detectors will be emphasized. Two new X-ray imaging beamlines named as "Fast X-ray imaging" and "X-ray nano-CT" for SSRF phase-II project are to be built and new detectors are required.

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The AGIPD Detector for the European XFEL: Characterization of the first full chip

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AGIPD (adaptive gain integrating pixel detector) is a hybrid detector system for the European XFEL (Eu-XFEL), which is currently being constructed in Hamburg, Germany. The detector system is developed by a consortium consisting of Deutsches Elektronen-Synchrotron (DESY), University of Hamburg, University of Bonn and the Paul-Scherrer-Institut (PSI).
The Eu-XFEL will operate with bunch trains at a repetition rate of 10 Hz. Each train consists of 2700 bunches with a temporal separation of 220 ns corresponding to a rate of 4.5 MHz. Each photon pulse has a duration of < 100 fs (rms) and contains up to 10^12 photons in an energy range between 0.25 and 25 keV. In order to cope with the large dynamic range, the first stage of each bump-bonded AGIPD ASIC is a charge sensitive preamplifier with three different gain settings that are dynamically switched during the charge integration. Dynamic gain switching allows single photon resolution in the high gain stage and can cover a dynamic range of 10^4·12.4 keV photons in the low gain stage. The burst structure of the bunch trains forces to have an intermediate in-pixel storage of the signals.
After an extensive prototype optimization process over 5 prototypes (AGIPD 0.1, 0.2, 0.3, 0.4, 0.5) the first full scale chip (AGIPD 1.0) was received at the end of last year. The full scale chip, AGIPD1.0, has 352 in-pixel storage cells inside the pixel area of 200 x 200 µm^2. The detector system will be organized in 4 quadrants with a total pixel count of 1 Megapixel.

In this contribution we focus on the measured performance characteristics of AGIPD1.0 (a noise of 285 el. has been measured), the layout of the full detector system and first results from full modules. A dynamic range enhancement feature (implemented in AGIPD0.5) and its impact on the noise and dynamic range will also be shown.

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Jungfrau: A Dynamic Gain Switching Detector for SwissFEL

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JUNGFRAU (adJUstiNg Gain detector FoR the Aramis User station) is a novel, dedicated two- dimensional pixel detector for high performance photon science applications at free electron lasers (FEL) and synchrotron light sources. It is developed for the SwissFEL [1] currently under construction at the Paul Scherrer Institute, Switzerland.
Distinguishing characteristics of this application-specific integrating circuit readout chip include single photon sensitivity and a low noise performance over a dynamic range of over four orders of magnitude of input signal. These characteristics are achieved by a three-stage, gain-switching preamplifier in each pixel, which automatically adjusts its gain to the amount of charge deposited on the pixel (similar to detectors as AGIPD [2] or GOTTHARD [3]).
Geometrically, the final JUNGFRAU chip comprises 256x256 pixels of 75x75 μm2 each. The chips are coupled to 320 μm silicon sensors. Arrays of 2x4 chips are tiled to form modules of 4x8 cm2. Multi-module systems up to 16M pixels are planned for the end stations at SwissFEL. A readout rate in excess of 2kHz is anticipated, which serves the readout requirements of SwissFEL and enables high count rate synchrotron experiments with a prodigious linear count rate capability of 25 MHz/pixel.
The systems for SwissFEL are presented along with promising characterization results from a 4x4mm2 prototype (JUNGFRAU 0.2). Experiments from fluorescence X-ray, infrared laser and synchrotron irradiation are shown. The results include an electronic noise as low as 100 electrons, which enables single photon detection down to X-ray energies of at least 4.5 keV. Noise well below the Poisson statistical limit is demonstrated over the entire dynamic range. The linearity of the pixel response is found to be below 1%. First imaging experiments successfully show automatic gain switching over four orders of magnitude for both laser and synchrotron beam irradiation. An according charge-to-photon number calibration is evaluated. Remarkably, the point spread function of the imaging system proves to be comparable in quality to single photon counting hybrid pixel detectors.

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Combined high spatial and temporal resolution Synchrotron Radiation Computed Tomography with a CdTe pixel detector

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Studying the hemodynamics in brain is of particular interest for the diagnosis, the understanding and the management of pathologies such as ischemia, tumors, and traumas. For malignant glioma, it has been shown that perfusion parameters are correlated to the tumor aggressivity, and can be used for the treatment outcome prognosis. Quantitative measurements have to be compared between various imaging days and between patients. Synchrotron Radiation Computed Tomography (SRCT) is the gold standard to measure in vivo contrast agent concentrations with high accuracy and precision owing to the characteristic of the beam and performances close to theoretical limits: high flux, nearly parallel and monochromatic x-ray beams. In addition to being quantitative, SRCT could be greatly improved with both high temporal and spatial resolution, which we assumed would be combined using the Maxipix-CdTe detector under development at ESRF. This detector features a monolithic 1 mm thick single crystal CdTe sensor (99.9% efficient at 33 keV) hybridised to a matrix of 3x1 Timepix chips, giving a total area of 768x256 pixels at 55 µm pitch (45 x 15 mm2). Its tomographic spatial resolution is of 0.06x0.06x0.06 mm3. It shows a linear single photon counting ability for fluxes up to 107 photons/mm2/s. The high efficiency of the detector as well as its background noise suppression enabled low dose imaging (200mGy/s). Monochromatic X-rays at 35 keV were used. 360° tomography images have been taken over 2s, 3s, 6s, and 60s. Reconstruction of the tomographic slices was conducted using PyHST package developed at ESRF. Preliminary software extension has been developed to correct for defective or unstable pixels. The results were compared to images acquired with the reference 1D germanium detector. We have successfully retrieved iodine contrast agent quantification for both steady-state protocol and dynamic contrast-enhanced perfusion imaging, with phantoms. The follow-up of the iodine concentration in a dynamic phantom was performed with one 6s image taken every minute for 9 minutes. However the in vivo SRCT perfusion imaging in rats bearing brain tumors requires images to be repeated without interruption to follow up the contrast agent concentration. An increased contrast to noise ratio is also needed. We thus foresee low dose high resolution volumic perfusion measurements, relying on enhanced frame rates and synchronization accuracy as well as improved image reconstruction techniques.

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Energy efficient high speed optical transmission for detector systems

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Future detectors, ranging from particle physics via nuclear and hadronic physics to materials research, will consist of up to a billion electrical signal channels. Together with sharply rising signaling rates of the individual channels, this will result in a massive increase of the amount of generated data well beyond many hundreds of GB/s. The handling of these data is one of the biggest challenges for future detector systems. An increased bandwidth to transfer the data is a key element to solve this challenge.

Even with massive local data reduction it will not be possible to transfer all raw data produced in a detector to the processing stages outside of the detector with electrical wires. Here optical fibers offer a 1000 times higher bandwidth (Tbit/s), lower signal attenuation, lower power consumption (pJ/bit), electrical insulation, and last but not least a considerably lower mass budget.

While optical data transmission with directly modulated laser diodes is the state-of-the-art for large-scale detector systems, this approach is limited in terms of channel density, power consumption and speed. Our new approach uses non-modulated light generated remotely to keep power dissipation outside of the detector. The light will be modulated inside the detector and routed back to a receiver outside the detector. Extremely power-efficient, electro-optical modulators are available in telecommunication research which are about to be adapted for use in advanced detector systems. In a further step the modulators could be integrated monolithically with amplifiers and other electronics. Such a scheme of data transfer is entirely novel to the field of complex detector systems and could revolutionize the approach for data acquisition and transport. With this technique, local power reductions and an increase of throughput per fiber by orders of magnitude are possible. The intended modulators are fabricated from silicon and are able to transmit data rates of 40 Gbit/s. With more sophisticated modulation schemes higher data rates and with wavelength division multiplexing a multitude of such channels can be transmitted through a single glass fiber. As a result, a considerable reduction of data cables and possibly power feeds and cooling pipes can be achieved. Consequently, less passive material is required inside the detector, thereby reducing the scattering of charged particles and improving the tracking resolution in particle and high-energy physics experiments.

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The Percival Soft X-Ray Imager

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With the increased brilliance of state-of-the-art Synchrotron radiation sources and the advent of Free Electron Lasers enabling revolutionary science with EUV to X-ray photons comes an urgent need for suitable photon imaging detectors. Requirements include high frame rates, very large dynamic range, single-photon counting capability with low probability of false positives, and (multi)-megapixels.

PERCIVAL ("Pixelated Energy Resolving CMOS Imager, Versatile and Large") is currently being developed by a collaboration of DESY, RAL, Elettra and DLS to address this need for the soft X-ray regime. PERCIVAL is a monolithic active pixel sensor (MAPS), i.e. based on CMOS technology. It will be back-thinned to access its primary energy range of 250 eV to 1 keV with target efficiencies above 90%. According to its preliminary specifications, the roughly 10 x 10cm2, 3.5k x 3.7k monolithic sensor will operate at frame rates up to 120 Hz (commensurate with most FELs) and use multiple gains within its 27 micron pixels to measure 1 to ~ 105 (500 eV) simultaneously-arriving photons.

Currently, small-scale back-illuminated prototype systems (160x210 pixels of 25 micron pitch) are undergoing detailed testing with X-rays and optical photons. In March 2014, a prototype sensor was tested at 350eV – 2keV at Elettra's twinmic beamline. The data recorded include diffraction patterns at 350eV and 400eV, knife edge and sub-pixel pinhole illuminations, and comparisons of different pixel types. We will present an overview of the Percival Project and system components, planned performance, and some prototype test results.

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A Hybrid CMOS Sensor with Multi-Frame Storage for High-Speed X-Ray and Optical Imaging of Inertial Confinement Fusion Experiments

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A large-aperture sensor has been developed to record multiple x-ray images with integration times as short as 1ns and interframe times as short as 2ns to measure the implosion and heating dynamics of Inertial Confinement Fusion experiments on the Z pulsed-power facility at Sandia National Laboratories. The sensor consists of a silicon photo-detector array directly bonded to a CMOS readout integrated circuit (ROIC). Both the silicon photo-detector array and the CMOS ROIC are fabricated at Sandia's Mesa Fabrication 0.35μm technology node. The 1024x448 pixel photo-detector array has a 25 micron pitch with nearly 100% fill factor, an active area of 25.6mm x 11.2mm, and is sensitive to x-rays between 0.7 - 10 keV with high efficiency. The corresponding 1024x448 pixel ROIC incorporates a global shutter with adjustable integration and interframe timing and 2-frame in-pixel analog storage with a maximum of more than 1 million electrons per frame. A pulsed laser-produced-plasma x-ray source was used to measure the sensor time-response, absolute sensitivity, dynamic range, spatial resolution, and frame-to-frame isolation. A camera has also been fabricated that is sensitive to visible light and used to record shadowgraphs of shock evolution in laser-heated gas-filled targets. A next-generation camera has been designed and is being fabricated that will provide 4-frames per pixel and increased integration and interframe timing flexibility. We are also developing alternative photo-detector arrays that have optimized sensitivity to higher and lower energy x-rays and to electrons with energies down to 1 keV.