International Workshop on Radiation Imaging Detectors

28 June – 2 July 2015

Hamburg, Germany

Book of Abstracts

DESY

European XFEL

UHH

Dear Participants of the 2015 IWORID

We are happy and honored to welcome you in what the Hamburgers proudly call: “die schönste Stadt der Welt”, and we have done our best to try to meet the high standards set by the previous IWORID conferences, both scientifically and culturally.

From the excellent scientific contributions received, the local organizing committee, with the help of the Scientific Committee, has put together, what we hope is an exciting program, which will stimulate many discussions, and maybe even some new collaborations. We invite you all to make this conference as lively as possible.

We wish you all a successful and enjoyable conference, and if there is anything we can do to help, please don’t hesitate to contact anyone from the local team.

Sincerely,

Erika Garutti (University Hamburg)

Andreas Koch (European XFEL)

Heinz Graafsma (DESY)

Matthias Kreuzeder (DESY)

iWorid 2015
28. 6. - 2.7. 2015
Draft programme

Sunday, 28th 2015

17:00 - 20:00	Registration	
18:00 - 20:00	**Welcome cocktail**	

Monday, 29th June 2015

8:00 - 9:00	Registration	
9:00 - 9:15	Opening and welcome	
9:15 - 10:00	From Hybrid to CMOS pixels at the LHC? *Honorary speaker - Norbert Wermes (University of Bonn)*	Chair Heinz Graafsma
10:00 - 10:30	New trends in ASICs development for Photon Science Invited talk - Carlo Fiorini (Politecnico di Milano)	
10:30 - 11:00	Coffee break	
Oral session 1	**FEL Detectors**	Chair Ralf Menk
11:00	The Development of the DSSC Camera for the European XFEL. Latest results and prospects. Dr. TURCATO Monica (European XFEL)	
11:20	JUNGFRAU: A Gain Switching Pixel Detector for Photon Science Dr. JUNGMANN-SMITH, Julia (Paul Scherrer Insitut)	
11:40	The Percival Soft X-ray Imager Dr. CORREA, Jonathan (DESY)	
12:00	The Adaptive Gain Integrated Pixel Detector at the European XFEL Dr. Allahgholi, Aschkan (DESY)	
12:20 - 14:00	Lunch	
Oral session 2	**Detector development I**	Chair Stephanie Hustache
14:00	High Speed X-ray Imaging and Spectroscopy with novel direct detection CMOS based Active Pixel Sensors Prof. STRUEDER, Lothar (PNSensor)	
14:20	The LAMBDA pixel detector and hard X-ray experiments at synchrotrons Dr. PENNICARD, David (DESY)	
14:40	The Digital Silicon Photomultiplier Imager Prof. D'ASCENZO, Nicola (Huazhong University of Science and Technology)	
15:00	A CMOS SPAD Array Chip with fast Full Frame Readout Prof. FISCHER, Peter (Institute for Computer Engineering, University of Heidelberg, Mannheim, Germany)	

15:20 - 15:50	Coffee break		
Oral session 3	**Detector Concepts**		Chair Christer Fröjdh
15:50	Towards a new generation of pixel detector readout chips CAMPBELL, Michael (CERN)		
16:10	XFEL-based imaging using photon energies above 40 keV: the detector challenges and a new possibility Dr. WANG, Zhehui (Los Alamos National Laboratory)		
16:30	Utilization of novel Silicon Photomultipliers with bulk integrated quench resistors in tracking applications for particle physics. PETROVICS, Stefan (Semiconductor Laboratory of the Max-Planck Society)		
16:50 - 18:00		**Poster session 1**	
19:30 - 20:30	**Boat trip**		

Tuesday, 30th June 2015

Industrial exhibition - all day		
8:30 - 9:00	Organic semiconducting crystals for a novel generation of thin, flexible, large-area, room temperature ionizing radiation detectors Invited talk - Beatrice Fraboni (University of Bologna)	
9:00 - 9:30	Current and future directions of R activities in the field of GaAs:Cr radiation sensors Invited talk - Anton Tyazhev (Tomsk State University)	
Oral session 4	**Sensor Materials**	Chair Seppo Nenonen
09:30	Characterisation and Optimisation of Chromium Compensated Gallium Arsenide Detectors for High Frame Rate X-Ray Imaging Detectors Dr. VEALE, Matthew (STFC Rutherford Appleton Laboratory)	
09:50	Characterization of PILATUS3 CdTe and CdZnTe Large-Area Detectors Dr. ZAMBON, Pietro (DECTRIS Ltd.)	
10:10	A large surface X--ray camera based on XPAD3--CdTe single chip hybrids Dr. CASSOL, Franca (Aix Marseille Université, CNRS/IN2P3, CPPM UMR 7346 – Marseille France)	
10:30 - 11:00	Coffee break	
Oral session 5	**Astronomy**	Chair Val O'Shea
11:00	CMOS sensors for energy resolved X-ray imaging Doering, Dennis (Goethe University Frankfurt)	
11:20	Emulation of an x-ray DEPFET detector for verification of the ATHENA WFI camera system OTT, Sabine (Max-Planck-Institut für extraterrestrische Physik)	
11:40	Hard-X and gamma-ray imaging detector for astrophysics based on pixelated CdTe semiconductors GáLVEZ, José-Luis (Institut de Ciències de l'Espai (CSIC-IEEC)	

12:00	Self-healing in semiconductors for radiation hardness Prof. SCHMITZ, Jurriaan (University of Twente)	
13:30 - 15:00	**Poster session 2**	
15:30 - 18:30	**Visit PETRA III, FLASH, XFEL**	
20:00 - 22:00	**Meeting - Local organising committee**	

Wednesday, 1st July 2015

Industrial exhibition - all day		
8:30 - 9:00	Future needs in Protein Crystallography *Invited talk - Alke Meents (DESY)*	
9:00 - 9:30	Current and future directions in the field of Medical Imaging *Invited talk - Walter Ruetten (Philips Electronics Nederland)*	
Oral session 6	**Medical I**	Chair Andreas Koch
09:30	Spectral response measurements of a multi-bin photon counting CZT detector using synchrotron radiation DAERR, Heiner (Philips research)	
09:50	High resolution and fast micro-CT of low attenuating material using photon counting detectors KUMPOVA, Ivana (The Institute of Theoretical and Applied Mechanics AS CR, v. v.i, Centre of Excellence Telč)	
10:10	Visualization of inhomogeneities in carbon ion radiotherapy Dr. MARTISIKOVA, Maria (Heidelberg University Hospital, Germany)	
10:30 - 11:00	Coffee break	
Oral session 7	**Detector development II**	Chair Wasi Faruqi
11:00	HIGH-PERFORMANCE SILICON DRIFT DETECTORS FOR HIGH THROUGHPUT X-RAY SPECTROSCOPY Dr. HOFMANN, Martin (Ketek GmbH)	
11:20	The LHCb VELO Upgrade Paula Collins (CERN)	
11:40	Two-dimensional diffraction X-ray measurement with monolithic SOI pixel detector Dr. MITSUI, Shingo (Kanazawa University)	
12:00	DEPFET detectors for future electron-positron colliders Dr. MARINAS, Carlos (University of Bonn)	
12:20 - 13:30	Lunch	
Oral session 8	**Detector development III**	Chair Heinz Graafsma
13:30	Characterization of MÖNCH, a 25 µm pitch hybrid pixel detector Dr. RAMILLI, Marco (Paul Scherrer Institut)	
13:50	GOTTHARD based spectrometer for shot-to-shot photon energy characterization at FLASH PALUTKE, Steffen (DESY/University of Hamburg)	

14:10	Results from Timepix Onboard the First Test of the New Orion Spacecraft Prof. PINSKY, Lawrence (University of Houston)	
Oral session 9	**Front-end electronics I**	Chair Joacqim dos Santos
14:30	SPIDR; a 10 Gigabit per second read-out system for Timepix3 & Medipix3 quads Dr. VISSER, Jan (Nikhef)	
14:50	Charge Collection Properties of a Depleted Monolithic Active Pixel Sensor using a HV-SOI process BACKHAUS, Malte (CERN)	
15:10	FITPix COMBO - Timepix detector with integrated analog signal spectroscopic readout HOLIK, Michael (University of West Bohemia in Pilsen, Faculty of Electrical Engineering)	
15:30 - 16:00	Coffee break	
16:00 - 17:00	**Poster session 3**	
Oral session 10	**Medical II**	Chair Valeria Rosso
17:00	Integrated ultrasound and gamma imaging probe for medical diagnosis Dr. POLITO, Claudia (SAIMLAL Department, Sapienza University of Rome, Rome, Italy)	
17:20	Proton radiography system to improve proton therapy treatment Dr. BIEGUN, Aleksandra (KVI-Center for Advanced Radiation Technology, University of Groningen)	
17:40	A four-dimensional gamma detector for PET application MORROCCHI, Matteo (University of Pisa and INFN, sezione di Pisa, Italy)	
19:30 - 22:00	**Conference dinner,** *Ehemaliges Hauptzollamt, Hafen Hamburg*	

Thursday, 2nd July 2015

9:00 - 9:30	Development of X-ray diffraction imaging (XDi) systems and the required detector technology *Invited talk - Jens-Peter Schlomka (Morpho Systems)*	
Oral session 11	**Industrial and other applications**	Chair Erika Garutti
09:30	A New Generation of Detectors for Scanning X-ray Beam Imaging Systems Dr. ROMMEL, J. Martin (American Science and Engineering)	
09:50	Development of a Timepix based detector for the NanoXCT project NACHTRAB, Frank (Fraunhofer Development Center X-ray Technology EZRT)	
10:10	Characterization and measurements of silicon based pixel array detectors for the neutron detection at ESS BANSAL, Yashika (ESS)	
10:30	N.N.	
10:50 - 11:30	Coffee break	
Oral session 12	**Medical III & Front-end electronics II**	Chair Renata Longo

11:30	DEVELOPMENT OF A HIGH RATE PROTON COMPUTED TOMOGRAPHY DETECTOR SYSTEM Dr. NAIMUDDIN, Md (University of Delhi)
11:50	Development of a novel gamma probe for detecting radiation direction Dr. LONGO, Mariaconcetta (Post Graduate School of Medical Physics, Sapienza University of Rome, Rome, Italy)
12:10	Simulations of a silicon pixel based on MOS Deep Trapping Gate principle Dr. FOURCHES, Nicolas (CEA/IRFU)
12:30 - 13:00	**Concluding remarks on conference**
13:00 - 14:00	Lunch
End of conference	

General information

Conference venue	**DESY Campus, Hamburg Bahrenfeld** **Main entrance** - Notkestr. 85, 22607 Hamburg, Germany **Side entrance -** Luruper Chaussee 149, 22761 Hamburg, Germany The Side entrance is opened for motorists from Monday to Friday 06:00 to 19:00, and closed on weekends. It is opened for pedestrians and cyclists constantly. (It is recommended to ring the bell next to the gate after 19:00 and indicate your destination to the guard-duty).
DESY WLAN	We have set up a wireless network for this conference. Name: iWorid2015 WPA/WPA2-PSK: ndPXJXd7
Registration	Attendees can register onsite from 17.00 – 20.00h on Sunday 28 June during the reception in the tent next to building 7. From Monday 29 June you may register at the conference desk in the foyer of the auditorium (Bldg. 5).
Special events	Sunday 28. June, 18.00h: Welcome Reception Tent next Bldg. 7 Monday 29 June, 19:30h, Boat trip throught the Hamburg harbor starting at “Teufelsbrück” Transfer from DESY at 19:00h Wednesday 2 July, 19:30h, Conference Dinner at “Ehemaliges Hauptzollamt Hafen Hamburg” Transfer from DESY at 19:00h
Meals	*Breakfast* Breakfast will be served at the DESY cafeteria (opens at 07:00, building 9) at your own expenses. *Lunch* Lunch will be served in the tent next to Bldg.7.
Supermarkets	Supermarkets in the vicinity LIDL From the main gate at Notkestrasse turn right and follow the street (700 – 800m). LIDL will be clearly visible on the left side of the street at the next junction. PENNY Form the main gate at Notkestrasse walk straight down the street “Zum Hünengrab”. On the right side, at the end of the street you will find the supermarket.

	BUDNIKOWSKY (Drug store) - Osdorfer Weg 106, 22607 Hamburg From the main gate at Notkestrasse walk straight down the street “Zum Hünengrab”, on the main crossing (with Osdorfer Landstrasse) turn left and follow the street “Osdorfer Weg” (550 m). The Drug Store is on the left side. •Pharmacy: APOTHEKE an der Osdorfer Landstrasse Osdorfer Landstr.112, 22607 Hamburg From the main gate at Notkestrasse turn right and follow the street, on the main crossing (with Osdorfer Landstrasse) turn right and follow the street “Osdorfer Landstrasse “ (1400 m). The Pharmacy is on the right side.
Cash machine/ATM	You will find a cash machine in the foyer of the DESY canteen (Building 9).

ABSTRACTS

Honorary talk:

From Hybrid to CMOS pixels at the LHC?

Norbert Wermes (University of Bonn)

Hybrid pixel detectors have been invented for the LHC to make tracking and vertexing at all possible in LHC's radiation intense environment. The LHC pixel detectors have meanwhile very successfully fulfilled their promises and R&D for the planned HL-LHC upgrade is in full swing targeting even higher ionising doses and non-ionising fluences.

In terms of rate and radiation tolerance hybrid pixels are unequalled. But they have disadvantages as well, most notably material thickness, production complexity, and cost.

Meanwhile also CMOS electronics and active pixel sensors (DEPFET, MAPS) have come to real detectors but they would in their present form not stand the rates and radiation faced from HL-LHC.

New, so-called DMAPS (depleted MAPS) which are full CMOS-pixel structures with charge collection in a depleted region have come in the R&D focus for pixels at high rate/radiation levels. This can perhaps be realised exploiting HV technologies, high ohmic substrates and/or SOI based technologies.

The talk will cover the main ideas and encouraging results from prototyping R&D, not hiding the difficulties.

Invited talk

New trends in ASICs development for Photon Science

CARLO FIORINI[1,2*]

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A continuous progress in the development of ASICs for Photon Science applications has been particularly stimulated in the recent years by the availability of synchrotron sources of increased intensity and X-ray Free Electron Lasers (XFELs) facilities. In the field of X-ray spectroscopy detectors, the main challenges are represented by the need of the detection systems to operate with high counting rates (e.g. 1Mcps/channel) still keeping an adequate energy resolution. In the field of X-ray imaging systems, the main challenges are represented by the need to operate at high frame rates (e.g. 4.5MHz for the European XFEL) with single photon detection capability (even at low energy) and with high dynamic range (10^4 and beyond). Several ASICs developments are ongoing to cope with such demanding requirements.
The purpose of this presentation is to review solutions recently proposed in ASICs development for Photon Science to face such challenges. After a brief review of the major ASIC families for Photon Science applications, the presentation will focus more to new solutions for the front-end (FE) stage of the ASICs, which plays a fundamental role in noise minimization both in high-resolution X-ray spectroscopy systems and in low-energy photon detection in X-ray imaging systems. Moreover, FE designs implementing compression techniques which are required to cope with the high-dynamic range necessary for XFEL detection systems will be reviewed. Finally, possible impacts of technology scaling on FE designs for the mentioned detector applications will be discussed.

The Development of the DSSC Camera for the European XFEL. Latest results and prospects.

Content:

We present the latest results of the development of the DSSC system. The aim of the development is to deliver a high-speed focal plane detector system for the European XFEL in Hamburg. In particular, the DSSC will be optimized for the Small Quantum System (SQS), the Spectroscopy and Coherent Scattering (SCS), and the Single Particles, Clusters, and Biomolecules (SPB) instruments.
The camera must be able to operate at a maximum frame rate of 4.5 MHz and to achieve very high dynamic range (~104 photons/pixel) and single photon detection capability at the same time. 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 DSSC is based on Si-sensors and is composed of 1024x1024 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 local data storage. In order to achieve high dynamic range and single photon detection simultaneously, a non-linear system response is required. The originally foreseen DSSC DEPFET provides dynamic range compression thanks to its intrinsic non-linear current/charge characteristic.
In parallel to the DEPFET, which at the moment requires a long production time, the consortium has started the development of a simplified sensor based on mini-SDD arrays. A dedicated front-end, placed on the readout ASICs in parallel with the DEPFET front-end, makes the sensor compatible with the rest of the DSSC system. Even if the mini-SDD sensor provides reduced performance, it will allow one to operate the DSSC camera for the day-zero of the European XFEL operation, covering part of the experiments. The ultimate performance is expected operating the DSSC camera with the DEPFETs.
The presentation will provide an overview of the whole DSSC system focusing on the sensors and the readout electronics with the latest measurements.
A noise below 20 el. rms has been measured with an 8x8 ASIC prototype coupled with an array of non-linear DEPFETs. An overview of the first 64x64 full size ASIC will be given together with the experimental characterization.
The mini-SDD sensor concept and design will be presented and critically compared with the DEPFET solution. For the first time we will show the results on the newly fabricated mini-SDD arrays coupled with the DSSC readout electronics.

Primary authors:
Dr. Turcato Monica (European XFEL)

JUNGFRAU: A Gain Switching Pixel Detector for Photon Science

Content:

The pixel detector JUNGFRAU (adJUstiNg Gain detector FoR the Aramis User station) is developed for the Aramis end-stations of SwissFEL currently under construction at the Paul Scherrer Institut, Switzerland. It provides optimal data quality for photon science applications at free electron lasers (FEL) and synchrotron light sources.
The readout chip of the JUNGFRAU detector is characterized by single photon sensitivity and a low noise performance over a dynamic range of 10^4 12 keV photons. These distinguishing characteristics are achieved by a three-stage, gain-switching preamplifier in each pixel, which dynamically adjusts its gain to the amount of charge deposited on the pixel (similar to AGIPD or GOTTHARD).
Geometrically, a JUNGFRAU chip consists of 256×256 pixels of 75×75 µm2 each. The chips are bump bonded to 320 µm silicon sensors. Arrays of 2×4 chips are tiled to form modules of 4×8 cm2. Several multi-module systems with up to 16 Mpixels per system will be delivered to the two end stations at SwissFEL. The anticipated readout rate of >2kHz is independent of the detector size and serves both the readout requirements of SwissFEL and enables high count rate synchrotron experiments with a dead time free, linear count rate capability of 20 MHz/pixel (50MHz/pixel) at 12 keV (at 5 keV).
The JUNGFRAU systems for SwissFEL are presented along with promising characterization results from the full-size JUNGFRAU 1.0 chip. Experiments from fluorescence X-ray, infrared laser and synchrotron irradiation are shown. The results include an electronic noise as low as 65 electrons r.m.s., which enables single photon detection down to X-ray energies of <2 keV. Noise well below the Poisson statistical limit is demonstrated over the entire dynamic range. The linearity of the pixel response is characterized to be below 1%. First successful imaging tests will be shown.
A prototype variation of JUNGFRAU specifically dedicated to low-noise performance (with a noise of 30 e- r.m.s. ~ 110 eV) will be introduced and the performance for spectroscopic X-ray science will be evaluated.
This contribution will highlight how JUNGFRAU’s specifications and performance characteristics make this charge-integrating readout chip one of the most advanced detection systems for efficient detection at both free electron lasers and synchrotron light sources, while providing the data quality the community is familiar with from single photon counting systems.

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The Percival Soft X-ray Imager

Content:

With the increased brilliance of Synchrotron radiation sources and Free Electron Lasers comes an urgent need for suitable photon imaging detectors. Requirements include high frame rates, large dynamic range, single-photon counting capability with low probability of false positives, and (multi)-mega-pixels.

PERCIVAL (“Pixelated Energy Resolving CMOS Imager, Versatile And Large”) is being developed by DESY, RAL, Elettra, DLS and PAL to address this need for the soft X-ray regime. PERCIVAL is a monolithic active pixel sensor (MAPS), 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%.

Small-scale back-illuminated prototype systems (160×210 pixels of 25 µm pitch) are undergoing detailed testing with X-rays and optical photons. In March 2015, a prototype sensor was tested at 400 eV at DLS’s I10 BLADE beamline. We will report on the status of the project and results from these recent experiments.

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The Adaptive Gain Integrated Pixel Detector at the European XFEL

Content:

The adaptive gain integrating pixel detector (AGIPD) is a hybrid pixel detector developed by DESY, PSI, and the Universities of Bonn and Hamburg. It is targeted for use at the European XFEL, a source with unique properties: a train of up to 2700 pulses is repeated at 10Hz rate. The pulses inside a train are separated by 220ns, where each is ≤100fs long and contains up to 10^{12} photons.

A detector designed for the European XFEL has to cope with both, the high dynamic range and the repetition rate of 4.5MHz within a train.
The AGIPD chip comprises 64x64 pixels of 200x200µm² each. The chips are coupled to 500µm silicon sensors. Arrays of 2x8 chips are tiled to form modules of ~3x11cm². (The final AGIPD 1Mpix system will consist of four independently movable quadrants each comprising four modules.)
Each pixel contains 352 analogue memory cells. This design allows signal storage of up to 352 images at a repetition rate of more than 4.5MHz out of one bunch train.
In order to cope with the dynamic range, the first stage of each bump-bond is a charge sensitive preamplifier with three gain stages. These stages are dynamically and allow single photon sensitivity for the first gain stage and a dynamic range of up to 10^4 12 keV photons in the third gain stage in the same image.

In this contribution we focus on the design of the AGIPD 1.0 ASIC along with results from the first modules from beam times at the PETRA III and APS synchrotron sources.

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High Speed X-ray Imaging and Spectroscopy with novel direct detection CMOS based Active Pixel Sensors

Content:

High speed counting, imaging and spectroscopic measurements of X-rays at energies between 100 eV and 30 keV require detectors with challenging properties. A back-illuminated 450 µm thick active pixel sensor (APS) was developed and qualified for space operation. Matched to the resolution of the X-ray optics aboard it has 300 µm x 300 µm large pixels in a format of 64 x 64, resulting in a sensitive area of 2 x 2 cm2. It is operated at a frame rate of 7.000 Hz, still delivering Fano limited imaging X-ray spectroscopy. Because the readout is so fast (30 Megapixel per second), the cooling requirements are relaxed and operation is performed with thermoelectric cooler. The new device is based on the DePFET principle. The 4 cm2 large detector chip is controlled and operated with the help of two different ASICs. One (switcher) is responsible for the selection of the row to be read out and to select the row to be cleared from signal charge. The second one does the analogue signal processing and multiplexing (ASTEROID) of the signals into two fast 14 bit ADC channels. To speed up the readout, the sensor is subdivided in two hemispheres, which are read out in parallel. As the select row switcher can be programmed, areas with higher X-ray flux can be read out more frequently than areas with lower intensity. We have tested the detector system operated at full speed at the calibrated end stations SX700 and KMC of the PTB at the synchrotron BESSY in Berlin. The X-ray energies were ranging from 250 eV up to 10 keV. At 200 eV the energy resolution is 61 eV (FWHM) and it is 161 eV (FWHM) at 10 keV. Three different detector systems were tested, they are behaving very similarly. This concept allows shrinking the pixel size down to 20 µm. The DePFET is able to perform non-linear gain compression to increase the dynamic range up to 105. The detector can be operated in a gated way with a fast switching from sensitive to non-sensitive time intervals in time slices of less than 100 ns. A non-destructive repetitive readout was realized as well, leading to a readout noise floor of 0.2 electrons (rms) only, at the expense of readout time. All above listed properties have been verified experimentally. Beside X-ray imaging and spectroscopy the detector is equally suited for electron detection from 1 keV up to 400 keV. In this case the frame rate can be increased to approx. 15.000 frames per second because a higher readout noise can be tolerated.

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The LAMBDA pixel detector and hard X-ray experiments at synchrotrons

Content:

Photon-counting pixel detectors provide extremely high signal-to-noise ratios and high speed, which makes them the technology of choice for many X-ray scattering experiments at synchrotrons. The LAMBDA detector has been developed to improve on existing pixel detectors by providing a combination of small pixel size (55µm) and large area (tileable modules of 780k pixels) while operating at readout speeds of 2000 frames per second with no time gap between frames. LAMBDA systems have been used in a range of experiments at synchrotron sources.

Photon-counting detectors predominantly use silicon as a sensor material, but this makes them impractical for many experiments above 20 keV where their quantum efficiency becomes poor. In addition to silicon, LAMBDA systems have also been built with “high-Z” materials such as GaAs, CdTe and Ge, to allow high-speed experiments at hard X-ray beamlines. As an example, a GaAs LAMBDA module has been tested in a dynamic compression experiment at 30 keV, where a sample undergoes rapid changes in pressure while its structure is studied with X-rays. Useful data was obtained at a 1kHz frame rate, demonstrating that this technology can provide two orders of magnitude higher time resolution than the typical flat-panel detectors used for these experiments. Larger multi-module systems with GaAs or CdTe are now in development. Germanium sensors have also been developed and tested, which show higher image uniformity than typical high-Z sensors.

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The Digital Silicon Photomultiplier Imager

Content:

The Silicon Photomultiplier (SiPM) are the new step in the development of modern detection structures in the area of the low photon flux detection down to the single photon. The conventional SiPM consists of an array of photo-detectors, p-n junctions operated in avalanche-breakdown mode. Although being space-distributed, the sensors are connected in parallel and the output of the detector is proportional to the total number of detected photons. Thus, in conventional SiPMs the coordinate detection information is lost. The SiPM sensor technology is fully compatible with CMOS technology and could be produced at standard technology facilities. This observation gives a huge perspective in the possibility of a modern SiPM, which combines the sensors and front-end electronics on one chip, with a wide range of variation of the performance and compatibility to connection to standard data processing systems.
In this paper we will present the design of a novel fully Digital SiPM Imager, consisting of an array of independently addressed p-n junction sensors operated in Geiger mode. By integrating low-power CMOS electronics into the SiPM chip, a digital SiPM imager was developed in which each photon detected is converted directly into an ultrahigh speed digital pulse that can be directly used by on-chip intelligent processing circuits. In contrast to conventional SiPMs, the digital counting SiPM is therefore an all-digital device. As a result, it produces faster and more accurate photon counts with extremely well defined timing of the first photon detection, and digital information of addressing individually the triggered micro-cells, allowing for retrieving the coordinate information.
This digital design provides several advantages for the application of SiPM sensors: the pixel and the pixel controller are highly configurable. Individual breakdown avalanche micro cells can be switched on or off, depending on their dark count performance and validation and integration times as well as readout schemes can be set according to the application needs. In addition, the digital nature and independence from analogue effects such as gain or amplification reduces the temperature sensitivity of the device. Since only digital signals are provided, subsequent processing electronics are greatly simplified.
First results of the characterization of the prototypes of this novel imaging photo-detectors and possible application to X rays photon source will be discussed.

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Towards a new generation of pixel detector readout chips

Content:

The Medipix3 Collaboration has broken new ground in spectroscopic X-ray imaging and in single particle detection and tracking. This paper will review the performance and limitations of the present generation of pixel detector readout chips developed by the Collaboration. Through Silicon Via technology has the proven potential to provide a significant improvement in the tile-ability and the performance of such chips. The next generation of chips will provide improved spectroscopic imaging performance at rates compatible with human CT. It will also provide full spectroscopic images with unprecedented energy and spatial resolution. The opportunities and design challenges presented by the latest generation of CMOS (65nm) will be described in the context of a next generation of pixel detector readout chips.

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XFEL-based imaging using photon energies above 40 keV: the detector challenges and a new possibility

Content:

The invention of X-ray free-electron lasers (XFELs) has opened new vistas to material structures on micrometer and finer scales. Imaging using XFELs presents daunting detector challenges, in particular when the requirements of high efficiency for 40 keV and above photon energies, sub-ns inter-frame time for multiple frames, and massive data handling are combined. We discuss the technological gap between the state-of-the-art imagers and GHz-equivalent imagers, followed by a new multilayer-camera concept for such imaging applications.

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Utilization of novel Silicon Photomultipliers with bulk integrated quench resistors in tracking applications for particle physics.

Content:

Silicon Photomultipliers (SiPMs) are a promising candidate for replacing conventional photomultiplier tubes in many applications, thanks to ongoing developments and advances in their technology. A drawback of conventional SiPMs is their limited fill factor caused by the need for a high ohmic polysilicon quench resistor and its metal lines on the surface of the devices, which in turn limits the maximum photon detection efficiency. At the Semiconductor Laboratory of the Max-Planck Society (HLL) a novel detector concept was developed integrating the quench resistor directly into the silicon bulk of the device resulting in a free entrance window on the surface. The feasibility of the concept was already confirmed by simulation and extensive studies of first prototype productions. Recently SiPMs were also considered as an attractive alternative for tracking applications in vertex detectors. The requirements for a fast response, simple design and high fill factor can all be met by SiPMs. In addition the increased trigger probability for an avalanche by minimum ionizing particles allows device operations at lower overbias voltages, resulting in a decreased noise contribution. The concept can be evolved further towards an imaging photo-detector.
A new design for an application of these SiPM devices as vertex detectors with active quenching developed by HLL and DESY as well as first simulation results will be presented. Also, first measurements of the trigger efficiency as a function of the applied overbias voltage of SiPM devices will be shown.

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Invited talk

Organic semiconducting crystals for a novel generation of thin, flexible, large-area, room temperature ionizing radiation detectors

Prof. FRABONI, Beatrice (University of Bologna)

The light weight, simple processability, and mechanical flexibility of π-conjugated organic small molecules and polymers has recently led to remarkable research efforts towards the realization of new opto-electronic devices. Moreover, organic materials can be deposited and grown by means of easy, low temperature and low cost technologies as inkjet printing. In the field of ionizing radiation detection, organic semiconductors have been proposed so far mainly in the indirect conversion approach, i.e. as scintillators, which convert ionizing radiation into visible photons, or as photodiodes, which detect visible photons coming from a scintillator and convert them into an electrical signal.

Recent examples of organic devices used as direct photon detectors have been presented for operation in the UV-NIR range, with very interesting values for figures of merit such as photo-conversion efficiency, speed and minimum detectable signal level [1], and even though the simultaneous attainment of all these relevant parameters is demonstrated only in a limited number of papers, real applications are within reach for this technology, where the best reported photo-responsivity outperform amorphous silicon-based devices.

Organic semiconductors are very promising candidates also for the direct detection of higher energy photons (X- and gamma rays) [2] and we recently reported how organic semiconducting single crystals (OSSCs) provide a stable and linear electrical photo-response to increasing X-rays dose rates, at room temperature [3]. As organic materials are based on Carbon, their low effective atomic number is similar to the average human tissue-equivalent Z and makes them ideal candidates for medical applications We will report and discuss the different X-ray photo-response and sensitivity of different solution-grown OSSCs, based on molecules that impart quite different chemical and physical properties, from the crystal shape to its charge carrier mobility. The aim is twofold: i) to achieve a better understanding of the photo-conversion and charge transport processes within the organic semiconducting crystal; ii) to optimize and select the better performing molecules towards the implementation of a flexible 2D matrix of OSSCs pixel detectors, fabricated with ink-jet printing technologies (EU project i-FLEXIS; www.iflexis.eu)

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Current and future directions of R&D activities in the field of GaAs: Cr radiation sensors

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The report provides an overview of the current state of technology and scientific investigations in the field of GaAs: Cr X-ray sensors. The analysis of the test results of pixel GaAs: Cr sensors are demonstrated. It is shown that the sensors are promising for the development of modern X-ray imaging systems. The directions of further R&D dedicated to the technology optimization and the performance improvement of GaAs: Cr sensors are proposed.

The investigations were supported by Russian Federation Grant # RFMEFI58714X0003.

Characterisation and Optimisation of Chromium Compensated Gallium Arsenide Detectors for High Frame Rate X-Ray Imaging Detectors

Content:

Recent measurements by the HEXITEC and MEDIPIX collaborations have demonstrated that small pixel devices fabricated from chromium compensated gallium arsenide (GaAs:Cr) have excellent spectroscopic performance, radiation hardness and produce a linear response under high flux illumination with X-rays. These promising results mean this novel material is now of particular interest for the development of high frame rate X-ray imaging cameras for next generation light sources, like the European XFEL. At the STFC Rutherford Appleton Laboratory existing ASIC technology has been used to characterise and optimise the performance of this exciting new material. In this paper the HEXITEC spectroscopic imaging detector system has been used to investigate how the GaAs:Cr thickness and electrode fabrication process affect the performance of small pixel detectors with a pitch of 250 microns.

Measurements with an Am-241 gamma-ray source were used to measure the performance of the detectors in the energy range 14 – 60 keV. At a fixed electric field strength of -3000 V cm-1 and a temperature of 0C, the energy resolution (FWHM) varied from 0.7 – 2.7 keV for the 0.5 mm thick detectors and 0.9 – 3.4 keV for those with a 1.0 mm thickness. Under the same operating conditions a standard 1 mm thick HEXITEC CdTe detector achieves a FWHM of 0.7 – 1.5 keV across the same energy range. The spectroscopic data provided by the HEXITEC system will be used to study how phenomena such as charge trapping, sharing and loss contribute to the measured FWHM in the different thickness detectors.

The majority of results published on GaAs:Cr detectors, to date, have used devices where vanadium is the metal forming the anode pixel contact (Au/Ni/Cu/V/GaAs/Ni). This under-bump-metallisation (UBM) was chosen for its compatibility with existing MEDIPIX bonding techniques but involves multiple fabrication stages. A more desirable process, in terms of ease of fabrication, is the deposition of electroless nickel contacts Ni/GaAs/Ni. Am-241 spectroscopic measurements will be used to show that these devices at least match, if not out-perform, the performance of the traditional vanadium devices.

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Characterization of PILATUS3 CdTe and CdZnTe Large-Area Detectors

Content:

The improvement in quality of High Z materials over the last few years has led to the possibility of extending x-ray sensitivity of photon counting detectors up to energies unattainable with silicon sensors. CdTe of 1mm and CdZnTe of 1.5mm thickness were tested as sensor materials for the PILATUS3 hybrid photon-counting detectors. The PILATUS CMOS ASIC, originally developed for silicon sensors in hole collection mode, is compatible with the electron collection mode required by the High Z materials. A selectable ”reduced” gain was introduced in the front-end electronics to adjust for the increased energy range up to 100keV. Large-area detectors can be achieved by tiling together single modules of 84mm×34mm, each consisting of 100k pixels with size 172μm×172μm. Each pixel has a 20 bit counter and the instant retrigger technology allows for an incoming photon rate of up to more than 107photons/s/pixel.
Characterization in order to fully qualify the properties and the possible limitations of PILATUS3 High Z detectors was performed. Measurements were completed both in in-house laboratories and at the SLS beamlime at PSI and the BAM beamline at BESSY-II.
The energy calibration algorithm, adapted from the silicon case, extends the energy range from 8keV to 80keV while preserving uniformity and stability over the entire detector. The energy resolution is ≤1keVr.m.s. for energies below 30keV, which increases up to ~2keVr.m.s. for higher energies due to gain non-linearity.
The quantum efficiency (QE), measured in the energy range of 8-60keV, shows values close to 100% up to the cadmium Kedge at 26.7keV where it has sudden decrease, as well as at the tellurium Kedge at 31.8keV. The QE curves demonstrate a relative maximum of ~85% at 60keV and 68keV for CdTe and CdZnTe, respectively.
The incoming photon rate limit at low energies is the result of the chip itself and was found to be 6.5×106photons/s/pixel for CdTe and CdZnTe as measured with a 18keV photon beam. At high energies the main factor limiting the performances of CdTe and its possible applications is the well-known polarization effect. CdZnTe did not demonstrate any effect due to polarization.
The imaging properties of CdTe and CdZnTe were investigated including LSF and MTF measured with a polychromatic beam in the range of 25-100kV using the slanted-edge technique. The PSF was measured using a monochromatic beam at 22keV and raster-scanning with a 10μm pinhole in steps of 5μm, achieving comparable results.

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A large surface X--ray camera based on XPAD3--CdTe single chip hybrids

Content:

The XPAD3 chip bump-bonded to a Si sensor has already been widely used in pre-clinical micro-computed tomography and in synchrotron experiments [1, 2]. Although the XPAD3 chip is linear up to 60 keV, XPAD3-Si hybrid performance is limited to energies below 30 keV, for which detection efficiencies remain above 20%. To increase detection efficiency in order to access imaging at higher energies, we decided to develop a camera with XPAD3 single chips bump-bonded to high-Z CdTe sensors. This camera is composed of 7 x 8 independent single chip hybrids for a total surface of 7 x 12 cm2. In a first R phase, three types of hybrids were studied (ohmic vs. Schottky contacts or electrons vs. holes collection mode) [3]. The Schottky hybrids with hole collection, which appeared to be the best case out of three, were selected for the construction of this camera whose main challenge consists in the mechanical assembly of 56 independent hybrids with a precision better than 20 microns, while still granting the possibility to replace easily any single chip hybrid in case of failure.
The striking advantage of having a higher efficiency for K-edge imaging, for which a photon selection as a function of energy has to be done, is to provide access to a wider range of energies that permit to imaging a larger number of contrast agents.
We will first present the construction of the XPAD3-CdTe hybrid pixel camera developed within the CHiPSpeCT project, from the first tests of the hybrids to the actual mechanical assembly of single chip hybrids, and illustrate a direct comparison of the K-edge imaging performance achieved with the XPAD3 chip bump-bonded onto Si or CdTe sensors [4].

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CMOS sensors for energy resolved X-ray imaging

Content:

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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Emulation of an x-ray DEPFET detector for verification of the ATHENA WFI camera system

Content:

The Wide Field Imager is a spectroscopic camera for the future x-ray observatory ATHENA as the next ESA L-class mission. The key element of the WFI is the detector with its set of DEPFET sensors and front-end electronics, which is built up in a mixed signal technology with ASICs. Sequencing, data processing and transmission is performed by the detector electronics.
Up to now the readout chain is verified with measurements of real x-ray sources, thus only limited test scenarios are possible. To overcome this we present a new concept for verification of the readout chain of the WFI. For this purpose a programmable, real-time emulator of the DEPFET system including front-end electronics is designed. The system is based on mathematical models of the components of the signal processing chain. Different pixel structures are implemented making the detector emulator a modular instrument. Input of the emulator can be an astro-physical data stream, which is processed in a similar way to the real detector system. Furthermore it is possible to determine the signal at different stages of the emulator system supporting the development and debugging of the real system. Effects like noise, pile up, misfits, offset drift or disturbances can be generated.
With a reproducible variation of the astro-physical input data and characteristics of the single modules of the emulated detector system, the signal processing chain can be characterized from end-to-end. The detector emulator is not only an instrument for debugging but a system for analyzing and improving single components of the signal processing chain.
The emulator will be able to generate up to eight differential analog output signals in the range of ±1.7 V with a resolution of 16 bit and a multiplexing frequency up to 25 MHz. Thus it will be able to emulate DEPFET matrices of 64x64 pixel up to 512x512 pixel controlled by SWITCHER-S and read out by VERITAS 2 ASICs. Maximum frame rates of 780 fps up to 6250 fps can be reached depending on matrix size. In this way the emulator provides a flexible platform to test and verify the digitalization, data processing and telemetry.
Currently the models of the detector system are developed and verified with measurement results on DEPFET pixel devices. The results are used for continuous improvement of the emulation models. To prove the real-time emulator itself, it will be verified and compared with measurement data of real DEPFET systems.

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Hard-X and gamma-ray imaging detector for astrophysics based on pixelated CdTe semiconductors

Content:

Stellar explosions are astrophysical phenomena of great importance and interest. Since years we have been working on the characterization of novae and supernovae in X-rays and gamma-rays, with use of space missions as well as been involved on feasibility studies of future instruments in the energy range from several keV up to a few MeV, in collaboration with IFAE and IMB-CNM research institutes. High sensitivities are essential to perform detailed studies of cosmic explosions and cosmic accelerators. In order to achieve the needed performance, a hard-X and gamma-ray imaging detector with mm spatial resolution and large enough efficiency is required.
Our development of a Hard-X and gamma-ray detector tries to fulfil the combined requirement of high detection efficiency with good spatial and energy resolution. The basic detector module consists of a single CdTe crystal of 12.5x12.5 mm2 and 2 mm thick with a planar cathode and with the anode segmented in an 11x11 pixel array with a pixel pitch of 1 mm attached to the readout chip. Two possible detector module configurations have been studied: the so-called Planar Transverse Field (PTF) and the Parallel Planar Field (PPF). The study is complemented by the simulation of the CdTe module performance using the GEANT 4 and MEGALIB tools which will help us to optimise the detector design. We will report the main features such as the energy resolution of a pixel CdTe module in PTF and PPF arrangement tested at -1ºC, a bias voltage of -400V and different energy radiation sources.

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Self-healing in semiconductors for radiation hardness

Content:

Recently, important advances are reported on self-healing in solid-state materials after mechanical damage. Microdamage caused by stress loading would normally grow larger and larger, finally leading to destruction of the material. In case of self-healing, the microdamage disappears (dissolves) over time as the result of a room-temperature diffusion process. [1] Such phenomena are being studied in various classes of materials such as metals, polymers, ceramics and concrete.
Moving to semiconductors, the damage we care about has a somewhat different nature. We typically study damage after electrical stress or radiation exposure rather than mechanical stress; and this damage occurs at the atomic scale. The most prominent defects are interface states, bulk traps (in semiconductors and insulators) and defect clusters. Only limited recovery of this damage is seen (and sometimes the contrary [2,3]). In other words, the critical materials in the semiconductor are not self-healing at room temperature. The consequence is that stress-induced damage piles up, leading to a gradual deterioration of device performance.
But atomic-scale damage in silicon is readily annealed out at a few hundred degrees C, depending on the anneal ambient (see e.g. [3,4,5] and references therein). So one could argue that silicon is a self-healing semiconductor at elevated temperature.
Work on CIGS semiconductors (polycrystalline chalcopyrite materials with composition Cu(In,Ga)(S,Se)2) has however shown that after heavy radiation damage, its electrical properties can recover fully under normal operating conditions [6]. To be more precise, this has been shown for the specific mixture of CuInxGa1-xSe2 with x=0.2-0.3, the compound used for thin-film photovoltaics. In this paper we will make a case for radiation detection with CIGS based heterojunction diodes and show forecasts of detector performance.

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Invited talk:
Detector requirements for serial synchrotron crystallography
A. Meents (*DESY)*

Structure determinations from microcrystals at low emittance synchrotron sources and X-ray free electron lasers (XFELs) [1] have recently attracted a great deal of attention and have the potential to change the way X-ray crystallographic data is collected from macromolecular crystals in the future. At new low emittance synchrotron sources such as PETRA III and NSLS II it has become possible to focus a large amount of photons into a spot of a few μm^2 only and hence to perform structure determinations from multiple microcrystals in a similar way as current serial crystallography experiments at XFELs.

For room temperature serial crystallography at beamline P11 at PETRA III the typical protein crystal lifetime in beam is in the millisecond range. Here crystals are constantly delivered to the X-ray beam by flowing through a thin-walled capillary and diffraction pattern are continuously recorded (figure 1 left) [2]. Another approach is the use of a micro-fabricated sample holder from single crystalline silicon with micro-pores (figure 1 right) [3]. Here Data collection is performed by automatic raster-scanning of the chip at cryogenic temperatures with crystal life times of about one second. For current monochromatic experiments detector framing rates of up to 1 kHz are considered to be sufficient. To further improve the signal to noise ratio in-vacuum experiments are currently designed or already under construction at different facilities.

In future we plan to extend serial crystallography experiments to the time domain and to study irreversible biochemical reaction with pink beam micro-focus crystallography using exposure times in the microsecond range. Such an experiment will tremendously benefit from the latest detector developments such as the AGIPD providing frame rates of up to 5 MHz and thus being able to capture full diffraction patterns from single bunches.

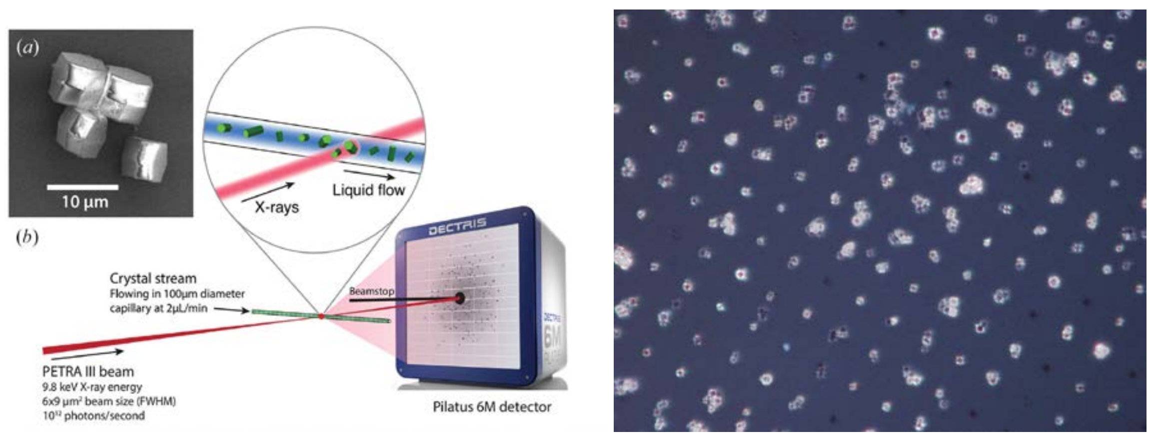

Figure 1: Experimental setup for serial synchrotron crystallography using a crystal suspension flowing in a capillary (left) and micro-crystals loaded onto a micro-patterned silicon chip (right).

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Invited talk

Current and future directions in the field of Medical Imaging

Dr. RUETTEN, Walter (Philips Research)

Medical imaging is one of the backbones of medical diagnosis. Next to ultrasound and magnetic resonance imaging (MRI), there is a number of imaging modalities relying on ionizing radiation like X-ray, Computed Tomography (CT), Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET). Each of them comes with specific system and detector concepts.

In this talk we will point out some of the trends for medical imaging on application, workflow, system and detector level. The topic of fast, high dynamic range CMOS X-ray detectors will be explored in more depth.

Spectral response measurements of a multi-bin photon counting CZT detector using synchrotron radiation

Content:

Spectral photon-counting Computed Tomography (CT) based on direct-converting materials like CdTe or CZT is considered to improve medical CT. Promising features of photon-counting CT besides lower patient dose due to the absence of electronic noise are reduced or eliminated beam-hardening artefacts, higher spatial resolution, material discrimination, quantitative imaging and K-edge imaging. Spectral features like K-edge imaging are enabled by applying multi-bin photon counting detectors and material decomposition [1]. A key ingredient for the material decomposition is the spectral response of the detector. Spectral response functions determine the spectral performance of any photon-counting, spectral CT scanner and a good understanding and knowledge thereof are paramount for the development of spectral CT.
We report on measurements of the detector spectral response function with mono-energetic X-rays over the entire energy range relevant for x-ray computed tomography from 25 keV to 135 keV conducted at the ESRF in September 2014. Furthermore, we performed measurements to characterize the amount of cross-talk between adjacent pixels. The main contribution to cross-talk was charge sharing. Cross-talk is a major contributing factor to the so-called low energy tail of the spectral response impeding material decomposition. A reduction of the low-energy tail of the spectral response is preferable as it will reduce the amount of noise in the resulting material images after decomposition.

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High resolution and fast micro-CT of low attenuating material using photon counting detectors

Content:

The Gellan Gum (GG) has been recently very popular for tissue engineering applications because of its tunable physical and mechanical properties. To expand its use in bone tissue regeneration bioactive glass (BG) particles (highly bioactive and osteogenic material) were added to the polymer matrix. Detail description of structural parameters and effective permeability is essential in terms of the clinical application.

Imaging of such thin and low attenuating material is very challenging using conventional X-ray imaging techniques. On the contrary utilization of microCT measurements with photon counting detectors provides promising improvement for microstructure imaging and X-ray dynamic defectoscopy.

A modular dual-source tomographic scanner equipped with unique large area photon counting detector WidePIX and modular pixelated detector system ModuPIX were employed for micro-CT scanning. The world largest pixel detector WidePIX is composed of a matrix of 10 × 10 tiles of silicon pixel detectors Timepix (each of 256 × 256 pixels with pitch of 55 microns) having fully sensitive area of 14.3 × 14.3 cm without any gaps between the tiles. ModuPIX is composed of four independent modules with edgeless Timepix detectors which can be used in different configurations. It has a smaller active area (8 cm square) however disposes with fast parallel readout up to 850 frames per second depending on occupancy of frames.

Results in the field of X-ray microtomography and dynamic defectoscopy utilizing photon counting detectors and comparison of results with common available flat panel detectors are presented in this article.

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Visualization of inhomogeneities in carbon ion radiotherapy

Content:

Ion beams are used for highly precise radiotherapy, which is employed for treatments of tumors close to critical organs like e.g. brain stem. Therefore an accurate dose deposition in tissue in the course of such therapy is crucial. However, this accuracy can be decreased by unpredictable anatomical changes of the patient, by tumor movement or beam delivery failures. Therefore an online monitoring of the beam within the patient is of large interest. However, there is a lack of detection systems capable to perform the relevant measurements in clinical conditions. The main challenge is, that the entire beam stops inside of the patient.

We investigate the possibility to collect the information about the beam extension in the patient by detecting light ions, which emerge from the treated patient as a by-product of the irradiation. Exploiting their kinematics, a method for visualization and quantification of the carbon ion beam profile in a homogeneous phantom was published in [Gwosch et al., PMB 58, 2013]. In this contribution, the capability of the method to detect cavities in an otherwise homogeneous phantom was investigated.

The experiments were performed at the Heidelberg Ion Beam Therapy Center (HIT) in Germany. A carbon ion beam of 226 MeV/u, which is a typical energy in therapy, was directed onto a homogneneous plastic phantom with a typical head size. The phantom was made up of 14 PMMA plates, each 1 cm thick, positioned perpendicularly to the beam. The stopping point of the beam was adjusted between the 10th and 11th plate. Secondary ions emerging from the phantom during the irradiation, were detected by a 3D-voxel detector [Soukup et al., JINST 6,2011], consisting of 3 Timepix detector layers [developed by the Medipix Collaboration at CERN, Llopart NIMA 581,2007]. Tracks of emerging secondary particles were measured in 3D. A comparison of the track distributions acquired with a full phantom were compared with cases when plates were missing at several positions.

Our experimental results demonstrate that this novel imaging modality enables clear visualization of 1 cm gaps in a head-sized phantom, under clinical irradiation conditions. Therefore, secondary ions, being a by-product of the irradiation, are an attractive source of information on the actual beam extension and stopping in the irradiated body. This work was performed within the Medipix Collaboration.

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HIGH-PERFORMANCE SILICON DRIFT DETECTORS FOR HIGH THROUGHPUT X-RAY SPECTROSCOPY

Content:

Silicon Drift Detectors (SDDs) are the state of art detectors for X-ray fluorescence analysis and SEM/TEM energy dispersive X-ray analysis. KETEK offers a large variety of SDDs with collimated areas starting at 7 mm² up to 150 mm². We will present the latest developments and improvements with regards to spectroscopic performance and high count-rate capability.

Recently, KETEK has introduced an ultra-low capacitive ASIC (CUBE) as replacement of the FET as charge sensitive pre-amplification stage. This opens up new possibilities with regards to count-rate capability, excellent spectroscopic performance, and operation even at high ambient temperatures.
CUBE-based SDDs achieve Mn-K_alpha FWHM down to 125 eV at digital peaking times of 1 µs, independent of the active area. This allows to operate the detector at very high input count rates without loss in performance. At shorter peaking times down to 100 ns the CUBE-based SDDs still achieve a FWHM of less than 140 eV and can handle up to 1 Mcps input count rate. Even operation at room temperature is possible with a FWHM of 155 eV. The CUBE technology will also be used in the new 7-Channel SDD Array, which will be topic of another KETEK presentation at this workshop.

All KETEK SDDs achieve a Peak-to-Background ratio of typically >20,000 and are equipped with a multilayer collimator suppressing any stray lines from the collimator.
For applications with high X-ray energy excitation KETEK also offers an SDD with an internal absorber layer that suppresses any stray lines from the integrated Peltier element. This allows the detection of materials like Sn, Sb, Te at very low concentration levels. New SDDs with a thickness of 775 µm increase the detection probability for X-rays at 15 keV to 80%, having the same spectroscopic properties as standard 450 µm SDDs.
For low-energy applications, KETEK also offers modules with an AP3.3 window, achieving a resolution as low as 35 eV for the Be-K_alpha line and allowing even the detection of Li (@ 52 eV).

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The LHCb VELO Upgrade

Content:

The upgrade of the LHCb experiment, planned for 2018, will transform the experiment to a trigger-less system reading out the full detector at 40 MHz event rate. All data reduction algorithms will be executed in a high-level software farm with access to the complete event information. This will enable the detector to run at luminosities of 2 x 10^33 /cm^2/s and probe physics beyond the Standard Model in the heavy flavour sector with unprecedented precision.

The Vertex Locator (VELO) is the silicon vertex detector surrounding the interaction region. The current detector will be replaced with a hybrid pixel system equipped with electronics capable of reading out at 40 MHz, designed to withstand the irradiation expected at an integrated luminosity of 50 fb-1 and beyond. The upgraded VELO will form an integral part of the software trigger, and must provide fast pattern recognition and track reconstruction while maintaining the exceptional resolution of the current detector. The detector will be composed of silicon pixel sensors with 55x55 um^2 pitch, read out by the VeloPix ASIC which is being developed based on the TimePix/MediPix family. The hottest region will have pixel hit rates of 900 Mhits/s yielding a total data rate more than 3 Tbit/s for the upgraded VELO.

The detector modules are located in a separate vacuum, separated from the beam vacuum by a thin custom made foil. The foil will be manufactured through milling and possibly thinned further by chemical etching. The detector halves are retracted when the beams are injected and closed at stable beams, positioning the first sensitive pixel at 5.1 mm from the beams. The high data rates require development of low-mass, high-speed, flexible electrical serial links bringing the data out of the vacuum where electrical-to-optical conversion is performed.

The material budget will be minimised by the use of evaporative CO_2 coolant circulating in microchannels within 400 um thick silicon substrates. Microchannel cooling brings many advantages: very efficient heat transfer with almost no temperature gradients across the module, no CTE mismatch with silicon components, and low material contribution. This is a breakthrough technology being developed for LHCb.

The current status of the VELO upgrade will be described together with a presentation of recent test results, including operation of irradiated sensor and ASIC assemblies in testbeam and lab environments.

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Two-dimensional diffraction X-ray measurement with monolithic SOI pixel detector

Content:

We are developing the two-dimensional diffraction X-ray measurement system with monolithic SOI (Silicon-on-Insulator) pixel detectors. We will present the performance of the system and the results of the measurements.

SOI detectors have been developed by High Energy Accelerator Research Organization (KEK) in Japan. They are fabricated in a 0.2 µm CMOS fully-depleted (FD-) SOI process of Lapis Semiconductor Co., Ltd. An SOI detector consists of a thick, high-resistivity Si substrate for the sensing part and a thin Si layer for CMOS circuits. An SOI detector has no bump bonding, and therefore the sensor has low capacitance, low noise, and high gain. There can be complex circuits included in each pixel.

For X-ray imaging, we developed the integration type pixel detector, INTPIX4. It has CDS circuit in each pixel for noise reduction. The pixel size is 17 µm squares, a number of pixels are 832 x 512, and a sensitive area is 14.1 x 8.7 mm2. The INTPIX4 is read out through an evaluation board, SEABAS2 (Soi EvAluation BoArd with Sitcp 2). The SEABAS2 is mounted FPGAs and operated with a Gigabit Ethernet. It can take images at 70 fps with the INTPIX4. We fabricated the two-dimensional diffraction X-ray measurement system with INTPIX4 and SEABAS2. We will show you the performance of this system.

When X-ray is irradiated to a material, the X-ray is diffracted, and they form a Debye-ring. These X-rays are diffracted in constant angle according to lattice spacing. The Debye-ring has a lot of information of the crystal surface state. Then we study the parameter of Debye-ring and usability of our system for industrial application. For example, we investigate a relation between the Vickers hardness and the width of Debye-ring. The Vickers hardness of a material is investigated by measuring a shape of impression induced by a sharpened diamond in the past. But the material is scratched due to the test. Therefore, we study the non-destructive method of Vickers hardness measurement by using our system.

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DEPFET detectors for future electron-positron colliders

Content:

The DEPFET Collaboration develops highly granular, ultra-thin pixel detectors for outstanding vertex reconstruction at future electron-positron collider experiments. A DEPFET sensor, by the integration of a field effect transistor on a fully depleted silicon bulk, provides simultaneous position sensitive detector capabilities and in-pixel amplification. The characterization of the latest DEPFET prototypes has proven that a comfortable signal-to-noise ratio and excellent single point resolution can be achieved for a sensor thickness of 50 micrometers. The close to final auxiliary ASICs have been produced and found to operate a DEPFET pixel detector of the latest generation with the required read-out speed. A complete detector concept is being developed for the Belle II experiment at the new Japanese super flavour factory. DEPFET is not only the technology of choice for the Belle II vertex detector, but also a solid candidate for the ILC. Therefore, in this contribution, the status of DEPFET R project is reviewed in the light of the requirements of the vertex detector at a future electron-positron collider.

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Front-end readout electronics considerations for Silicon Tracking System and Muon Chamber

Content:

Silicon Tracking System (STS) and Muon Chamber (MUCH) are components of the the Compressed Baryonic Matter (CBM) experiment at FAIR, Germany. STS will be built from 8 detector stations located in the aperture of the magnet. Each station will be built from double-sided silicon strip detectors and connected via kapton microcables to the readout electronics at the perimeter of each station. The challenging physics program of the CBM experiment requires from the detector systems very high performance. Design of readout ASICs requires finding optimal solution for interaction time and input charge measurement in the presence of tight area (channel pitch : 58 µm), noise (<1000 e- rms), power (<10 mW/channel), radiation hardness and speed requirements (average rate: 250 khit/s/channel).

This paper presents the front-end electronics' multi-objective analysis towards final ASIC implementation in the UMC 180 nm CMOS process and in-system performance with the emphasis on:

- Multimode operation of the analog front-end (AFE) (switchable shaping times, switchable gain for support of gas detectors in MUCH detector and silicon strip detectors in STS).
- Transistor sizing and biasing current selection in the AFE (charge sensitive amplifier CSA, two shaping amplifiers).
- Detector modeling together with the kapton microcable including 3-dimensional structure of these devices.
- The chip performance evaluation in the presence of noisy power supplies (based on low-dropout regulators' performance provided by manufacturers), external decoupling capacitors (including equivalent series resistance and inductance) and parasitic components of PCB traces, vias and wire-bonds.

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Characterization of M\"{O}NCH, a 25 µm pitch hybrid pixel detector

Content:

M\"{O}NCH is a novel hybrid silicon pixel detectors based on charge integration and with analog readout, featuring a pixel size of 25$\times$25 μm^2. Several prototypes have been commissioned, aimed at characterizing its performance and optimizing it for synchrotron applications.
M\"{O}NCH02 is a fully functional, small scale prototype of 4$\times$4 mm^2, containing an array of 160$\times$160 pixels. This array is subdivided in five blocks, each one featuring a different pixel architecture.
The first block features two statically selectable preamplifier gain values and, especially in the high gain mode, targets high position resolution for low flux synchrotron applications, as RIXS (resonant inelastic X-ray scattering) or X-ray tomography with X-ray tubes. In this case, the charge sharing effect between the small pixels of M\"{O}NCH can be exploited and interpolation algorithms are used to determine the hit position with a resolution that reaches the sub-micron level.
Three other architectures feature an automatic switching between two gains to increase the dynamic range for possible application in XFEL experiments, where the photon flux on the detector is expected to span several orders of magnitudes.
M\"{O}NCH03, with an active area of 10$\times$10 mm^2 and an array of 400$\times$400 identical pixels is a larger area version of the first pixel architecture of M\"{O}NCH02. Several improvements are implemented in the chip periphery and in the readout system, which will result in a final frame rate of 8 kHz.
The high bump-bonding yield, even for such a challenging pixel pitch and the extremely good noise performance, with an ENC of the order of 35 electrons RMS, make these hybrid detectors competitive with monolithic detectors and with CCDs in the fields of high resolution imaging and soft X-ray detection below the keV level.
Characterization results of M\"{O}NCH02 and M\"{O}NCH03 in terms of bump-bonding yield, linearity, dynamic range and energy resolution will be shown, together with preliminary measurements acquired using both prototypes. Finally, the perspective for the realization of a future low energy detector using 4$\times$3 cm^2 modules will be discussed.

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GOTTHARD based spectrometer for shot-to-shot photon energy characterization at FLASH

Content:

We present the setup and the commissioning of a spectrometer based on a modified Gain Optimizing microsTrip sysTem witH Analog ReaDout (GOTTHARD) detector [1]. It enables for the first time photo energy characterization on a shot-to-shot base at the Free Electron Laser Hamburg (FLASH).
Free Electron Lasers like FLASH generate short linear coherent light pulses of high peak brilliance and have given access to various new experiments focusing on the interaction of matter with extreme laser fields or dynamics. The light producing Self Amplifying Spontaneous Emission is a statistical process and causes fluctuations in all photon pulse parameters. For example, the pulse mean photon energy at FLASH varies around 1% in average from pulse to pulse which reduces the resolution in spectroscopic experiments. If a high flux is necessary and monochromators [2] are not desirable, the only way to enhance the experimental energy resolution is the parallel measurement of the pulse photon energies. But due to the unique property of FLASH and the upcoming European X-FEL of using superconducting linear accelerators the pulse frequency exceeds by far readout frequencies of commonly used detectors. FLASH produces pulse trains consisting of up to 800 soft X-ray pulses with a repetition frequency of up to 1MHz. The European X-FEL will generate up to 2700 pulses per pulse train and pulse frequencies of 5.4MHz. Detectors which provide these readout frequencies are currently under development.
One of these developments by the Paul Scherrer Institute and DESY is the GOTTHARD detector: a hard X-ray detector with a single line silicon sensor, which currently provides readout frequencies up to 1MHz. A modified version was integrated in a compact, movable soft X-ray grating spectrometer to serve as an end station behind transparent experiments at the FLASH BL-beamlines.
As we demonstrated, the spectrometer provides online display of the measured pulse spectra for machine studies and beam characterization and the ability to enhance the resolution of photoelectron spectra taken by an experiment which was performed in parallel.
The work was supported German Ministry of Education and Research (05K10HRB) within the framework of priority program: "301-FLASH: Matter in the light of ultrashort and extremely intense X-ray pulses” and the German Research Foundation (MA 2561/4-1).

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Results from Timepix Onboard the First Test of the New Orion Spacecraft

Content:

Radiation monitoring devices based on the Timepix radiation imaging detector technology from the European Organization for Nuclear Research (CERN)-based Medipix Collaboration have been successfully operating on the International Space Station (ISS) since October 2012. In addition, two such devices were flown as the only active radiation monitors in the first test of the new Orion manned spacecraft module on NASA's Exploration Flight Test-1 (EFT-1) mission this past December. Preliminary results will be shown from the EFT-1 measurements including data taken within the Orion capsule as it flew through regions of the trapped radiation field that have not been traversed by man-rated vehicles since the Apollo program. Comparisons of the Timepix-based measurements with the ISS data and with passive detectors flown on the Orion mission will also be shown.

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SPIDR; a 10 Gigabit per second read-out system for Timepix3 & Medipix3 quads

Content:

The realisation of the Timepix3 chip opened the way for new possibilities in research areas such as particle tracking with both semiconductor sensors and gas filled time projection chambers, electron microscopy and imaging mass spectrometry.
To exploit the full capability of the Timepix3 chip, Nikhef developed a compact read-out system, called SPIDR that can deal with the high data output of 80 Mhits per chip per second. The main read-out board connects to both 10 Gb Ethernet and 1 Gb Ethernet devices. The latter obviously at a reduced rate. The main board connects to individual chip-carrier boards via a standard FMC connector. The system is designed such that support for other readout chips is foreseen via reprogramming the FPGA. Besides the Timepix3 chip also the Medipix3 chip is currently supported.
Both the main board and the quad board are cooled, via the main housing and a fan to obtain a stable temperature of around 40 ± 0.2°C for the Timepix3 chips. We will present the system and the results obtained with the LHCb beam telescope at CERN and proton radiography data obtained with a time projection chamber based on GEM technology.

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Charge Collection Properties of a Depleted Monolithic Active Pixel Sensor using a HV-SOI process

Content:

Silicon-On-Insulator (SOI) technologies have been developed for applications, which require radiation hardness since many years. However, for its use as particle detector the Total Ionizing Dose (TID) response of SOI devices is more complex than bulk silicon devices due to the buried oxide (BOX). On one hand a significant influence of radiation damage in the BOX on the transistor characteristics due to the so-called back gate effect has been observed and published in SOI technologies, and on the other hand the charge collection on such a structure and a possible influence of the BOX needs to be analyzed in unirradiated and irradiated samples.

We have fabricated and tested a new 0.18 um SOI CMOS monolithic pixel sensor using the XFAB process. In contrast to most SOI technologies, this particular technology provides a double well structure, which shields the thin gate oxide transistors from the Buried Oxide (BOX). This in addition with the particular geometry between transistors and BOX makes the technology promising against back gate effects mentioned before. Furthermore, the process allows the use of high voltages (up to 200V), which are used to partially deplete the substrate. The process allows fabricating in higher resistivity, therefore a fully depleted substrate could be achieved after thinning. Thus the newly fabricated device in the XFAB process is especially interesting for applications in extremely high radiation environments, such as LHC experiments.

The TID radiation hardness and the lack of the back gate effect on this prototype have been published previously. Besides, we have carried out a program to analyze the charge collection properties in the silicon bulk below the BOX for this prototype and the possible BOX influence in unirradiated and irradiated samples.

The characterization program was performed on five samples: 1 unirradiated, 3 irradiated with neutrons (1x1013 neq/cm2, 5x1013 neq/cm2 , 5x104 neq/cm2) and 1 irradiated with protons 1x1013 neq/cm2 in a lab environment. A Fe55 source was used for the charge calibration of the samples and an Sr90 source to measure the charge collection properties such as collected charge and charge collection time.

The presentation explains and quantifies the drift and diffusion contribution of the collected charge observed in the unirradiated sample at different voltages. Results from the charge calibration, a bias voltage scan with an Sr90 source and an analysis regarding the depletion depth is p

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FITPix COMBO – Timepix detector with integrated analog signal spectroscopic readout

Content:

The hybrid semiconductor pixel detector Timepix [1] has proven a powerful tool in radiation detection and radiation imaging. Energy loss and directional sensitivity as well as particle type resolving power are possible by high resolution particle tracking and per-pixel energy and quantum-counting capability. The spectrometric resolving power of the detector can be further enhanced by analyzing the analog signal of the detector common sensor electrode (also called back-side pulse). In this work we present a new compact readout interface, based on the FITPix readout [2] architecture, equipped with integrated analog signal electronics. Integrating simultaneous operation of the digital per-pixel information with the back-side analog pulse processing circuitry [3] into one device enhances the detector capabilities and opens new applications. Thanks to noise suppression and built-in electromagnetic interference shielding the common hardware platform enables parallel analog signal spectroscopy on the back side pulse signal (spectrometric resolution around 100 keV for 5.5 MeV alpha particles). Self-triggering is implemented with delay of few tens of ns makes use of adjustable low-energy threshold of the particle analog signal amplitude. The digital pixelated full frame can be thus triggered and recorded within the common sensor analog signal. The waveform, which is sampled with frequency 100 MHz, can be recorded in adjustable time window including time back prior trigger level. An integrated software tool provides control, on-line display and read-out of both analog and digital channels. Both the pixelated digital record and the analog waveform are synchronized and written out by common time stamp.

Research carried out in frame of the Medipix Collaboration.

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Integrated ultrasound and gamma imaging probe for medical diagnosis

Content:

Aim
A new dual modality probe, based on an UltraSound (US) detector integrated with a small FoV single photon emission gamma camera, is presented. The device, dedicated to visualize small organs or tissues located at short depths, performs an US-gamma fused image permitting to correlate morphological and functional information, allowing the identification of pathological structures and greatly improving the accuracy of diagnosis.
Methods
The small FOV gamma camera consists of a continuous NaI:Tl crystal coupled with two Hamamatsu R7600M16 multi-anode PMTs. The electronics readout has 32 independent channels permitting to provide both 2D and 1D information. The gamma detector is equipped with a slit collimator (step 1.2mm, 0.2mm septum) that, thanks to its high efficiency, permits to obtain acquisition time close to US one. The US probe is a linear B-mode detector, 192 piezoelectric crystals, customized in order to reduce back-suppressor thicknesses. The US device is located in the system head in order to facilitate the contact with the analyzed region of body. The perfect alignment between US and gamma device is established through the alignment of the piezoelectric strip with inter-spaces of slit collimator. The active area has overall dimension of about 50x30mm^2. The gamma camera is characterized in terms of energy and spatial resolution and the overall detector is analyzed in order to optimize the correspondence between the US image and the gamma one. Finally, an images fusion is realized with a customized phantom.
Results
The gamma camera has showed an energy resolution close to 12%, with intrinsic spatial resolution of 1.1mm (@140keV). The slit efficiency is resulted 10^-3 at 5cm SCD, 10 times less than one from general purpose parallel hole. With the dedicated phantom, the US-gamma images fusion has allowed to individuate the spatial distribution of radiopharmaceutical with an uncertainty comparable with the US detector resolution, thanks to the perfect co-registration between US and gamma devices, in terms of geometry and image processing, as consequence of calibration procedures.
Conclusion
The great innovation of this probe is in its handheld configuration and in perfectly co-registration of dual images. This last feature is no observed in other similar devices that utilize gamma detector only as a counter [1]. In the near future the probe could be used for clinical trials (as thyroid, sentinel lymph node...).

[1]Anzai Medical,USPatent7094203B2

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Proton radiography system to improve proton therapy treatment

Content:

The quality of the cancer treatment with protons critically depends on accurate predictions of the proton stopping powers of traversed tissues. Today, proton treatment planning is based on stopping power information derived from X-ray Computed Tomography (CT) images. The conversion of Hounsfield Units (HU) from the CT to proton stopping powers has systematic uncertainties in the calculated proton range in a patient of approximately 3-4% and even up to 10% in regions containing bone. The inaccuracies may in certain cases lead to no dose at all in parts of the tumor or a very high dose in organs at risks and other normal tissues. A direct measurement of the proton stopping power by transmission radiography of high-energy protons will make it possible to significantly reduce these uncertainties and will thereby improve the quality of dose delivery. This is expected to have a positive impact on treatment outcome (higher tumor control, less serious complications).
Several theoretical studies showed that the best way to obtain a sufficiently accurate radiograph is by tracking individual protons traversing the phantom (patient). Our studies benefit from the novel gas-filled time projection chambers based on GridPix technology, being developed at the National Institute for Subatomic Physics (Nikhef) in The Netherlands, to track a single proton entering and exiting the phantom. A BaF2 calorimeter has been used to measure the proton’s residual energy. To obtain transmission radiographs, different phantom geometries and materials have been irradiated with a 3x3 cm2 scattered proton beam with the energy of 150 MeV, produced by the AGOR cyclotron facility of the University of Groningen. The experiment was simulated using the Geant4 simulation package.
First results for both energy and scattering angle radiographs, for different geometries and materials, show a good agreement between simulated and experimental energy radiographs. The multiple Coulomb scattering that affects the position resolution of the proton traversing different materials is being analyzed. Both energy and scattering angle radiographs will be discussed.

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A four-dimensional gamma detector for PET application

Content:

A PET detector module with 3 dimensional spatial and time resolution capability has been developed in the framework of the 4DM-PET (4Dimensions - Magnetic compatible PET Module) INFN collaboration. The detector concept is based on a monolithic scintillator crystal coupled on top and bottom sides to two SiPM arrays in order to provide the gamma interaction position in the crystal volume in 3D. Furthermore the time-tagging of the detected signals allows the off-line reconstruction of the annihilation events occurring in a PET examination.
The scintillator entrance surface is of 20 mm x 20 mm and the thickness is of 10 mm. The lateral faces are black painted to absorb the scattered light and improve the spatial resolution. The two photodetectors arrays are made of 8 x 8 SiPMs (RGB-type by AdvanSiD), 3 mm x 3 mm of active area and 3.6 mm x 3.6 mm pitch. To reduce the gap between adjacent pixels, the SiPMs signal are collected from the photosensor back-side while the bias is provided to the front-side through a micro-bonding daisy chain. Each matrix is coupled to a 64-channels ASIC that provides the time and time over threshold information for each triggered SiPM.
A region growing algorithm was used to select the cluster of SiPMs signals on each array generated to a valid event and that can be used to reconstruct the energy, position and time information. Only events that triggered at least one SiPM on each matrix and more than three pixels (total on the two sides) were used; this selection allowed to reconstruct correctly the 511 keV events, while low energy events were not validated. The distribution of the signals on the two sides was used to reconstruct the 3-dimensional position of the scintillation in the crystal. Two methods were used to reconstruct the depth of interaction: in the first method the number of SiPMs triggered on each side is compared, while in the second method the maximum energy collected on a single SiPM on each face is used. The center of gravity method was used to reconstruct the position on the other two directions.
A collimated beam of 511 keV photons (produced by Na22 radioactive source) was scanned over the frontal and lateral surfaces of the module to determine the spatial and depth of interaction resolution. A resolution of 1.5 mm (standard deviation) in depth of interaction was obtained at the center of the detector by using both methods, while the spatial resolution at the center of the detector was of 1.4 mm FWHM.

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Invited talk

Development of X-ray diffraction imaging (XDi) systems and the required detector technology

Jens-Peter Schlomka, Dirk Kosciesza, Stephan Olesinski, Dirk Strecker, Geoffrey Harding, and Helmut Strecker

(Morpho Detection, Heselstuecken 3, Hamburg, Germany)

X-ray diffraction imaging (XD*i*) is a novel modality for scanning the x-ray diffraction (XRD) properties of inhomogeneous objects with sufficient speed and spatial resolution for e.g. inspection of airport luggage. Morpho Detection has built a prototype system based on the Multi-Inverse Fan Beam (MIFB) topology, which is equipped with 17 pixelated room-temperature semiconductor (CZT or CdTe) detector modules for photon counting, a multi-focus X-ray source (MFXS), and conventional X-ray transmission imaging modules.

Requirements of the detector arrays are spectroscopy-quality spectra, calling for very good energy-resolution and efficiencies, which is why signal-corrections are performed on-board. Each module is an enclosed independent unit to ensure service-friendly modularity. It receives power, a trigger signal, and uses Ethernet for control and data-transfer.

We will explain the functional principle of XD*i* and the requirements of the main imaging components of the XD*i* –system with special focus on the detectors. Furthermore, we will present results on the detector and system performance and finish with an outlook towards future applications, markets and thus technical demands on X-ray diffraction imaging systems and detectors.

A New Generation of Detectors for Scanning X-ray Beam Imaging Systems

Content:

Scanning X-ray Beam Imaging Systems were first developed by AS in the early 1970s. Since then they have found a wide range of applications in security inspection and non-destructive testing. Most commonly large area detectors are used to collect the back-scattered radiation but smaller transmission detectors are also employed in selected applications. Until recently only two basic detector designs have been used: Large scintillator blocks with attached PMTs or large volume light-tight boxes, lined with scintillator screens and port windows for PMTs. In both cases the detectors have considerable depth to provide acceptable light collection efficiency.

A new design currently under development at AS relies on wave-shifting fibers for light collection. For the first time this approach enables the construction of thin large-area detectors. Stacking layers of wave-shifting fiber ribbons and scintillation screens in varying combinations allows optimizing the detection efficiency for different applications. Reading out different layers separately provides an energy sensitive signal combination. Energy sensitivity can be improved further by adding filtration between the signal channels.

Several prototype configurations have been built and characterized for both, back-scatter and transmission imaging. We report on the performance of these new detectors.

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Development of a Timepix based detector for the NanoXCT project

Content:

The NanoXCT EU FP7 project [1] aims at developing a laboratory, i.e. bench top sized nano-CT system with a large field-of-view (FOV) for non-destructive testing needs in the micro- and nano-technology sector. The targeted voxel size is 50 nm at 0.175 mm FOV, the maximum FOV is 1 mm at 285 nm voxel size. Within the project a suitable X-ray source, detector and manipulation system have been developed.

The system concept [2] omits the use of X-ray optics, to be able to provide a large FOV of up to 1 mm and to preserve the flexibility of state-of-the-art micro-CT systems. The targeted resolution will be reached via direct geometric magnification made possible by the development of a specialized high-flux nano-focus transmission X-ray tube. The end-user’s demand for elemental analysis will be covered by energy-resolved measurement techniques, in particular a K-edge imaging method.

Timepix [3] modules were chosen as the basis for the detector system, since a photon counting detector is advantageous for the long exposure times that come with very small focal spot sizes. Additional advantages are the small pixel size and adjustable energy threshold. To fulfill the requirements on field-of-view, a detector width > 3000 pixels was needed. The NanoXCT detector consists of four Hexa modules with 500 µm silicon sensors supplied by X-ray Imaging Europe. An adapter board was developed to connect all four modules to one Fitpix3 readout. The final detector has an active area of 3072 x 512 pixels or approximately 17 x 3 cm2.

In this contribution we present the development of the Timepix based NanoXCT detector, it’s application in the NanoXCT project for CT and material specific measurements and the current status of results.

[1] http://www.nanoxct.eu/

[2] Nachtrab, F., et al., Proc. SPIE 9212, Developments in X-Ray Tomography IX (2014), http://dx.doi.org/10.1117/12.2061752

[3] Llopart, X., et al., NIM A 581.1 (2007): 485-494, http://dx.doi.org/10.1016/j.nima.2007.08.079

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Characterization and measurements of silicon based pixel array detectors for the neutron detection at ESS

Content:

The European Spallation Source (ESS), situated in Lund, Sweden, is going to become the world's brightest and strongest source of neutrons by 2025. The purpose of this research is to expose silicon detector technology to the world of neutron scattering and to open up new avenues of possibilities for neutron instrument design. Silicon detector characterization is a collaborative ongoing project between European Spallation Source (ESS), Sweden, SINTEF in Oslo and University of Bergen (UiB) in Bergen, Norway. The silicon pixel array detectors are fabricated at SINTEF and coated with neutron converter material B4C at Linköping, Sweden. These detectors primarily aim for the needs and requirements of a highly innovative spectrometer named CAMEA – Continuous Angular and Multiple Energy Analyzer proposed by ESS. It is a cold-neutron inverse-geometry time-of-flight spectrometer. Combining indirect time-of flight with multiple consecutive analyzer arrays, this instrument will provide massive flux on the sample and strongly enhanced efficiency in detecting neutrons scattered in the horizontal scattering. The combination yields a spectrometer with completely unprecedented performance – with gains from 2 up to 4 orders of magnitude compared to current state of the art. The experimental work running at UiB includes electrical measurements on sensor level, investigation of different methods for deposition of neutron converter material, sensor response using alpha, proton and neutron source, radiation hardness and detector's lifetime. A systematic, reliable and reproducible characterization procedure is identified and will be discussed. Moreover, preliminary measurement results from the first prototypes will be presented. The work is supported by Norwegian Research Council.

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DEVELOPMENT OF A HIGH RATE PROTON COMPUTED TOMOGRAPHY DETECTOR SYSTEM

Content:

Proton computed tomography (pCT) offers an alternative to x-ray imaging with potential for three dimensional imaging, reduced radiation exposure, and in-situ imaging. The second generation pCT system being developed at Northern Illinois University in collaboration with Fermilab and Delhi University is comprised of a tracking system, a calorimeter or the range detector, data acquisition system, a computing farm, and software algorithms for image reconstruction. The proton beam encounters the upstream tracking detectors, the patient or phantom, the downstream tracking detectors, and a calorimeter. The tracking detectors are scintillating fibers and the calorimeter is made up of stacked scintillator plates. The data acquisition sends the proton scattering information to an offline computing farm. The pCT detector design allows for an increased data acquisition rate (up to 5 million proton tracks per second) and an improved imaging algorithm, which significantly reduced reconstruction times of three dimensional images.

In this presentation, we will present the current status of the pCT detector system, development of the complete detector simulation and reconstruction tools and their validation, and preliminary test beam data analysis with the full pCT detector system.

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Development of a novel gamma probe for detecting radiation direction

Content:

The present work refers to a scintigraphic goniometric probe to identify gamma radiation and its direction.
The scintigraphic probe consists of a tubular body divided in four sectors, each one constituted by a LYSO scintillation crystal. It has a whole diameter of 1.1 mm with a thickness of 3 mm and a height of 22 mm. This external component also acts as active shield of the lateral surface of a CsI(Na) scintillation crystal, 5 mm ∅ and 5 mm thick, housed inside the tubular body [1]. All the scintillation crystals are optically coupled to a Multi Anode PMT, which permits, by the Anger logic, to identify the crystals responses and to perform imaging.
This prototype was designed for clinical scintigraphic examinations, as for example the localization of the sentinel lymph node.
A specific procedure applied to the acquired images permits to retrieve the position of a source, providing an indication on radiation direction.
In order to verify the effectiveness of this technique, esperimental measurements were performed by moving a collimated 99mTc source, placed at fixed distance, around longitudinal and trasversal axis of the device. The main technical characteristics of the prototype gamma locator were also determined. In particular sensitivity, spatial resolution and detection efficiency of the protype were investigated operating a transverse scanning of an acrylic breats phantom containging a 57Co point source.
These tests have shown that the device is able to measure the gamma ray incident direction with an uncentain of 7 degrees. In comparison with existing systems [2], which do not provide information about the radiation direction, the presented apparatus allows to obtain similar counting rates (about 1 kHz). The spatial resolution, calculated as FWHM of counting rate distribution for the central element as function of source position, was about 7 mm. The system sensitivity was 17 counts/s/kBq. The overall detection efficiency at 122 keV, evaluated at the center of the probe, was 1.7x10-2.
The presented device showed a high sensitivity and efficiency to identify gamma radiation taking a short time (from 30 to 60 s). Even though it was designed for applications in radio-guided surgery, it could be used for other purposes, as for example home land security.

[1] Pani R. (2013) Scintigraphic goniometric probe. Patent US20130053686.
[2] Mariani G. et al. (2005) J. Nucl. Med., 46(3):388.

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SIMULATION OF A SILICON PIXEL BASED ON THE MOS DEEP TRAPPING GATE PRINCIPLE

Content:

To reduce the size of single pixels in megapixels arrays, the concept of deep trapping gate MOS device was introduced recently. In this vertical MOS structure the upper gate is used to switch from detection to readout mode. Its area is reduced comparing with classical (3T) CMOS pixel. Up to now classical-simulations with deep levels introduced in the structure to form the deep –trapping-gate have given the proof of concept for such a device, as shown in an earlier paper. This new device requires the development of sound semiconductor process, so the involvement of microelectronic and material science research institutions is necessary. However with TCAD codes, the number of trial and test steps can be reduced, allowing focusing on experimental issues such as deep impurity control within the DTG, which in turn can be treated using utmost work in solid state science. The simulation of the fabrication using SUPREM like computer codes is more straightforward with techniques such as epitaxy, than with high energy ion implantation, for which accurate electrically active defect modelling is still an open question. Recent work on Ge growth on Si opens the possibility to the use Ge quantum well as a DTG. This stems from the fact that the Ge layer should preferably retain holes than electrons. Many research teams have studied epitaxial growth of strained germanium on silicon for optoelectronics, the fabrication of a Si/Ge/Si /SiO2 seems realistic. We have then focused here on the 2D simulation of a Ge DTG device using Silvaco code. 3D simulations would then be simply used as a last step checking tool. The simulated fabrication of such a device leads to a pixel which has good static output characteristics. Transient transport simulations applied to the pixel structure with a buried Ge Gate and with the appropriate doping profiles are presented in this work. We will present Schrödinger-Poisson simulations of the structure that will help evaluating the role of the buried Ge internal quantum layer as a carrier localizing gate. The sensitivity of the pixel device to a simulated charge generated in the device will be studied. The quantum well gate as an alternative solution to a deep impurity trapping gate will be discussed in consideration of all fabrication constraints. The outcome of this study should allow the definition of first test vehicles that should be fabricated and evaluated.

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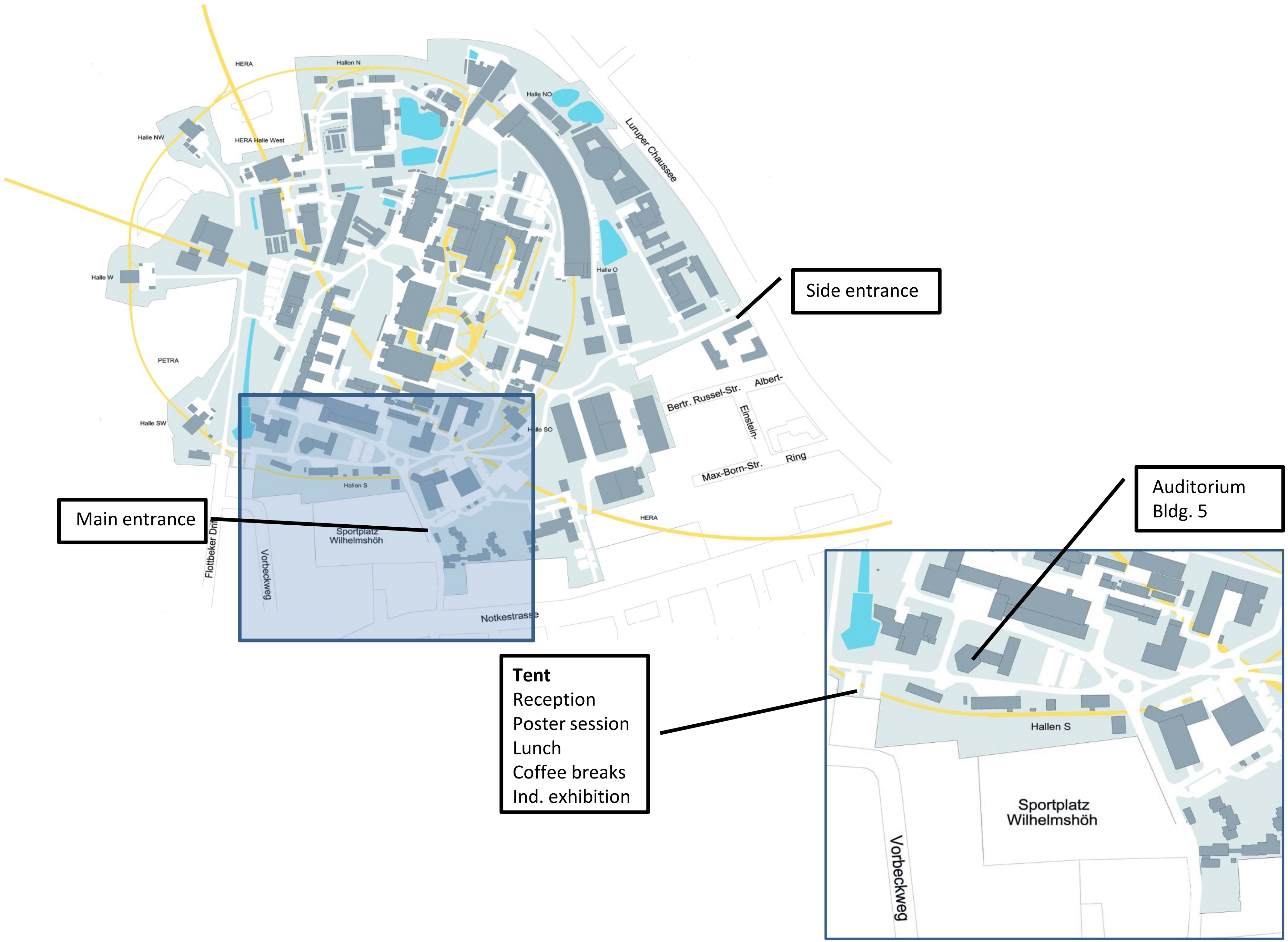

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