ATTRACT TWD Symposium: Trends, Wishes and Dreams in Detection and Imaging Technologies

Thursday 30 June 2016 - Friday 01 July 2016

Other Institutes

Book of Abstracts

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Fast, scalable, low-dose phase-based x-ray imaging with conventional sources

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There is wide agreement on the transformative potential of phase-based approaches to X-ray imaging (X-Ray Phase Contrast Imaging - XPCI). The use of phase was proven to enable the visualization of features classically considered “x-ray invisible”, and to enhance the visibility of all details in an x-ray image. This has huge implications in a variety of fields, from the earlier detection of life-threatening diseases in medicine to industrial and security inspection, through materials science, biology, archeology and many other areas.

So far, however, the translation of these advances outside physics labs and into the real world has proven problematic. The main roadblock is XPCI’s requirements for source coherence: outside synchrotron facilities, this is obtained either by using microfocal sources, or by strongly collimating the output of a conventional source to make it sufficiently coherent.

In both cases this leads to systems that are suitable for proof-of-concept experiments, but very hard to translate – the limits being low flux leading to excessively long exposure times, delicate and difficult to align optical elements, small field of views, high delivered doses, etc.

We have developed a solution to this problem in the form of the first incoherent XPCI method. The main observation is that illuminating a sharp absorbing edge, also with a weakly collimated beam, makes a system extremely sensitive to small refraction angles. Since refraction is proportional to the first derivative of phase changes, this is sufficient to perform phase retrieval. Preliminary results indicate the potential to resolve refraction angles of 200 nanoradians and below using an uncollimated, divergent and polychromatic rotating anode x-ray source, which matches what much more complex, proof-of-concept systems based on coherent methods are capable of achieving outside synchrotrons.

Unlike those methods, we obtain this high phase sensitivity by means of low aspect ratio x-ray masks that are cheap, easy to fabricate, highly scalable. Indeed, a first prototype with 20 cm coverage (> 3 times over other existing system) has been built and is under test with our industrial collaborator Nikon Metrology UK. The presentation will briefly describe the way the method works, show examples of preliminary applications, and discuss possible strategies for prototype development and scaling up in various areas.

Summary:

X-ray imaging methods based on phase have been explored that can completely transform all applications of x-ray imaging, in medicine and beyond. So far, attempts at translating these methods outside specialized facilities like synchrotrons proved problematic and suffered from – among others - long exposure times, excessive delivered doses, extreme sensitivity to vibrations and other environmental factors, small fields of view. We have taken a radical approach to the problem by eliminating the main source of the above limitations: the requirement for high source coherence. This led to a phase-based method that can be implemented with conventional, commercially available x-ray equipment and readily translated to robust, easily scalable, fast and low-dose imaging systems.

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STAX. Axion-like particle searches with sub-THz photons

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We discuss an improved detection scheme for a light-shining-through-wall (LSW) experiment for axion-like particle searches [Capparelli, Cavoto, Ferretti, Giazotto, Polosa and Spagnolo, arXiv: 1510.06892]. We propose to use: extremely intense photon fluxes (from 100 kW to 1MW) from gyrotron sources at frequencies around 30 GHz; single photon detectors in this frequency domain, with efficiency ≈ 1, based on transition-edge-sensors (TES); high quality factor Fabry-Perot cavities in the microwave domain (Q $\approx 10^4 - 10^5$), both on the photon-axion conversion and photon regeneration sides.
We compute that present laboratory exclusion limits on axion-like particles might be improved by at least four orders of magnitude for axion masses ≤ 0.01 meV.

Summary:

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"4H" X-ray Camera

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Fast X-ray imaging using 30 keV and above X-ray photons is highly desirable for studies of dynamic material evolution and discovery of new materials. The state-of-the-art single-line-of-sight X-ray camera technology, which is mostly based on silicon sensors and silicon Application Specific Integrated Circuits (ASICs), cannot meet the requirements because the atomic number of silicon is only 14 ("Low-Z"), and the highest speed achieved so far is less than 10 MHz frame-rate in X-ray Free Electron Laser (XFEL) environment. Fast readout chips with an equivalent frame rate above 100 MHz do exist through on-board data storage. Therefore, it is possible to construct "4H" X-ray cameras for high-energy XFELs. "4H" stands for high-Z (Z>30) sensor, high-resolution (less than 300 micron pixel pitch), high-speed (above 100 MHz), and high-energy (above 30 keV in photon energy).

Summary:

We discuss progress and plans to realize such a technology.

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Core-shell diode array for high performance particle detectors & imaging sensors

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We propose a novel high performance radiation detector & imaging sensor by a ground-breaking core-shell diode array design1. This novel detector avoids the performance limitations of the conventional planar silicon drift detectors (SDDs) in respect to radiation hardness, spatial resolution, power consumption and slow signal response, and will perform far beyond state-of-the-art.

This kind of detectors will provide solutions for various fundamental research fields currently limited by instrumentation such as high energy physics (HEP), astronomy and x-ray based protein crystallography measurements at extreme count rate.
The core-shell particle detectors are expected to have the following properties which are highly promising for the requirements at CERN for the upgraded LHC or next generation high luminosity particle accelerators.

• Ultrahigh radiation hardness beyond state-of-the-art

• High spatial resolution (high granularity)

• Fast signal response (for measurements at high count rate)

• Low power consumption (cooling of detectors might be omitted)

• High sensitivity

These properties can be integrated into a single detector, and so that a series of new applications in HEP, astrophysics, and protein crystallography will be enabled.
A prototype has been developed by using state-of-the-art nanotechnology and device processing2, and the functionality has been tested by electron beam induced current (EBIC).

IPHT has patented this concept (DE 10 2014 104 602 (granted on 07.Jan.2015), Hartpartikeldetektor mit einem Kern-Schale-Aufbau und Array dieser Hartpartikeldetektoren) for the application of high performance particle detectors, however, these diode array can be widely used in other spectral range as high performance photodiodes and imaging sensors.

Reference:

1. G. Jia, J. Plentz, I. Höger, J. Dellith, A. Dellith and F. Falk, Core-Shell Diodes for Particle Detectors, J. Phys. D: Appl. Phys. 49, 065106 (2016).

2. G. Jia, J. Westphalen, J. Drexler, J. Plentz, J. Dellith, A. Dellith, G. Andrä and F. Falk, Ordered Silicon Nanowire Arrays Prepared by an Improved Nanospheres Self-Assembly in Combination with Ag-Assisted Wet Chemical Etching, Photonics and Nanostructures-Fundamentals and Applications, in press (2016).

Summary:

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Pixel-individually auto-sampling image sensors

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The mode of operation of state-of-the-art image sensors is useful for one thing: photography, i.e. for taking an image of a still scene. Exposing an array of pixels for a defined amount of time to the light coming from a static scene is an adequate procedure for capturing its visual content. However, as soon as change or motion is involved, the paradigm of visual frame acquisition becomes fundamentally flawed. If a camera observes a dynamic scene, no matter where you set your frame rate to, it will always be wrong. Because there is no relation between scene dynamics and the chosen frame rate, over-sampling or under-sampling will occur, and both will usually happen at the same time. As different parts of a scene have different dynamic contents, a single sampling rate governing the exposure of all pixels in an imaging array will naturally fail to yield adequate acquisition of these different scene dynamics present at the same time. The solution is an image sensor that samples parts of the scene that contain fast motion and changes at high sampling rates and slow changing parts at low rates - with the sampling rate going to zero if nothing changes. Unfortunately, the information about where in a scene, and at which speed, things change and move is usually not known beforehand. A way to solve this problem is to let each individual pixel adapt and optimize its own sampling rate to the visual input it receives by autonomously reacting to the temporal evolution of light incident to its photosensor. As a consequence, (a) the image sampling process is no longer governed by a fixed timing source but by the signal to be sampled itself and (b) image information is not acquired and transmitted frame-wise but continuously and conditionally only from parts of the scene containing relevant information. These sensors are able to combine ultra-high-speed operation at wide dynamic range with low data rates, outperforming conventional image sensors in many areas of machine vision.

Summary:

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Runtime Monitoring for the Diagnosis and Recovery of Complex Physical Systems

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Runtime verification focuses on techniques to check the dynamic (runtime) behaviour of a system typically with the aim of ensuring that the system is working correctly. Inlining property checks via assertions or similar techniques has been standard practice since the dawn of programmable machines. Such inlined approaches result in the interweaving of the executable system specification (the program) with the specification of properties which it should satisfy. Separation of concerns has long been identified as an important principle, and the possibility of separating these two aspects of a system is one of the objectives of most modern runtime verification approaches — allowing for (i) having different teams working on the different aspects i.e. development and quality assurance; (ii) the use of the specification across different versions, instances or even systems. Another issue with inlined assertion checking arises as the complexity of the properties increases. Although inlining a property such as 'The gas leak variable should be low when the induceSpark method is called' is straightforward, a property such as 'The openValve method should have been called before induceSpark is called' results with the developer having to introduce additional state to remember whether openValve was called in the past. More complex properties, such as 'The gas leak variable may not have been true for more than 1 minute in the last 30 minutes just before induceSpark is called', results in more complex additional state and logic to handle it, which may, in turn result in more new errors being introduced into the system.

The role of the runtime verification tool is twofold: (i) it modifies the system instrumenting code to be able to capture points of interest during its execution which are of interest with respect to the specification; and (ii) it converts the specification into a monitor, which reacts whenever a point of interest is reached, checking that the behaviour of the system does not violate the specification. Using such an approach, a specialised language can be used to write the specifications, which allows the adoption of domain specific languages which can be used to describe the behaviour more succinctly and precisely.

Runtime verification would lend itself well to complex and critical environments such as detector and accelerator control systems, where loss of detector sub-systems could hinder it from data-taking, or errors in control systems of high-energy particle accelerators with highly-destructive beams such as LHC could damage the machine, leading to months of costly downtime.

Summary:

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Positron emission tomography without image reconstruction

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Time-of-flight positron emission tomography (TOF-PET) has been a main driver for the steady improvement, in recent years, of the timing performance of scintillation-based gamma-ray detectors. PET image quality will benefit from improvements in coincidence resolving time (CRT) down to a value of about 20 ps. At this point, tomographic image reconstruction as is presently needed will actually become obsolete. Presently, commercially available PET scanners achieve a CRT of about 350 ps FWHM, while CRT values somewhat below 100 ps have been achieved for small detectors in the laboratory.

Basically, detector timing improves if more photons are detected very soon after the gamma-ray interaction. An especially interesting idea is to use Cherenkov light for fast timing as it is the fastest light response of a material to the interaction of gamma rays. However, the number of Cherenkov photons is very small, causing other detector properties such as energy resolution, and potentially position resolution, to suffer. A combination of the use of Cherenkov light for timing and scintillation light for other purposes was therefore proposed [1]: improved PET imaging performance may be obtained by decoupling the timing from other information, e.g. allowing TOF-PET using slow scintillators. In recent years, steady progress in the investigation of Cherenkov light for TOF-PET has been reported [2-4]. The full realisation of this idea will require improvements in different aspects: scintillators modified for maximum production of Cherenkov photons, very fast and efficient UV-sensitive photosensors and the coupling of the two. An important requirement in these developments is that the detector efficiency does not suffer.

The improved technology will be useful in any application where ultrafast and efficient detectors for gamma-ray detection and imaging are needed.

[1] Dendooven P.G., "Time-of-flight positron emission tomography using Cerenkov radiation", patent no. WO/2010/085139, filed 26 January 2009, issued 29 July 2010

[2] Lecoq P. et al. "Factors influencing time resolution of scintillators and ways to improve them" IEEE Trans. Nucl. Sci. 57(2010)2411-2416

[3] Brunner S.E. et al. "Studies on the Cherenkov effect for improved time resolution of TOF-PET" IEEE Trans. Nucl. Sci. 61(2014)443-447

[4] Dolenec R. et al. "Cherenkov TOF PET with silicon photomultipliers" Nucl. Instrum. Meth. Phys. Res. A 804(2015)127-131

Summary:

TOF-PET, Cherenkov, scintillator, timing

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The ToF CMOS Visual Cortex Project

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Different thermal neutron detection techniques exist and many of them are based upon individual particle detection techniques, while others are using "integrating" or "continuous" flux measurements, such as imaging cameras combined with scintillators. Each class of techniques has its advantages and proper limits. Thermal neutron detection moreover has a very specific application, which is "time of flight" measurements of which the time resolution needed is of the order of a few microseconds. It is a very accurate, and often the only, way of determining the low energies of thermal neutrons with high resolution. If we could have CMOS type cameras with an acquisition rate of 100

000 fps or more, continuously, with on-system image analysis in order to turn each image on-line into a “neutron count histogram”, we would have the best of both worlds (counting and integrating). In order to achieve this, one would need to speed up the current CMOS column-parallel readout about a 1000-fold, which is possible if we replace the current, slow Wilkinson-type on-chip ADCs by potentially off-chip ADCs, which transmit their data stream directly into a matrix of FPGA and/or GPU still to be defined, to do the front line image treatment. A camera which has a continuous frame rate of 100 000 fps or more, with on-board image treatment and extraction of useful information, can have potentially a lot of spin off applications beyond the original neutron detection goal. Cameras with much higher frame rates exist today, but they can only handle a few hundred frames in a “one shot” or in a “stroboscopic” application, and are read out at a much slower pace. To our knowledge, no camera exists which can sustain a 100 000 fps rate, and without accumulating very large amounts of raw image data which have to be analyzed off-line. The challenges will be on the CMOS sensor fabric itself and its noise behavior, the analogue connectics, the development of massively parallel ADC systems, and the feeding of the converter data flow in suited image treatment systems.

Summary:

We propose the development of a CMOS camera with 100000 fps sustained frame rate and online image processing for ToF thermal neutron detection.

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CUBIX - Highly sensitive radiation imaging detector with fully 3D segmentation

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CUBIX is a concept of innovative radiation imaging/tracking detector with high 3D granularity and high absorption for common radiation types. The basic hybrid sensor module is of a cubic shape of roughly 3 cm3 consisting of 128x128x128 voxels (2 Mega voxels). Good absorption for penetrating radiation is achieved by large detector volume (1.5 cm thickness or more, sensitivity of 25-50% for 511 keV gamma can be achieved with silicon). Thanks to its 3D segmentation the detector maintains good spatial resolution regardless of the total thickness. The whole detector device can be of hand-held size operated at room temperature.

The proposed detector records a complete information for every event. This way the undesired influences of undesired radiation background or e.g Compton scattering can be greatly reduced or even further exploited (directional sensitivity, polarization sensitivity, Compton camera …).

There are many applications of such ultimate imaging detector and hand-held tracker: Medical imaging (scintigraphy, SPECT, PET) and Non-destructive-testing with isotopes or low power X-ray sources, radiation monitoring and security, environmental and geological research, exploration and mining, scientific experiments, education etc. Many other applications would be probably enabled by this technology in future.

The proposed detector combines latest CERN technology of imaging/tracking readout chips such as Timepix3 with unique technology of thin silicon sensors with active edges (sometimes called edgeless sensors). The edgeless technology allows to bring sensor electrodes over the sensor edge (e.g. strips, or double sided crossed strips). Therefore even when many of such sensor layers are stacked their contacts are still accessible for connection of readout electronics. This way the fully 3D sensitive structure can be made and flip-chip bonded e.g. to pair of Timepix3 redout chips. The basic detector structure is shown in the image here.

> The proposed CUBIX structure presents a next level in 3D integration of sensors. This technology of imaging detector can be a significant technological breakthrough in field of radiation imaging and radiation protection. It combines and extents cutting-edge purely European technologies of particle counting detectors Medipix/Timepix developed in CERN with technology of edgeless sensors developed in VTT Finland.

Summary:

CUBIX is a concept of innovative radiation imaging/tracking detector with high 3D granularity and high absorption for common radiation types. The basic hybrid sensor module is of a cube shape of roughly 3 cm3 consisting of 128x128x128 voxels (2 Mega voxels). The ultimate configuration which (probably beyond current technological limits) would allow even 16 Mega voxels. Such detector unit is 3 sides buttable. 4 sides buttability could be also achieved with small gap of about 250 microns among modules. The proposed sensor material is silicon. Good absorption for penetrating radiation is achieved by large detector volume (1.5 cm thickness or more => even sensitivity of 25-50% for 511 keV gamma can be achieved). Thanks to its 3D segmentation the detector maintains good spatial resolution regardless of the total thickness. The whole detector device can be of hand-held size operated at room temperature with low biasing voltage.

The proposed detector concept allows recording of up to 80 million hits per second. The detector would be operated in list mode providing the 3D coordinates, energy and time-stamp for every hit. The complete information recorded for every event allows for reconstruction of full chain of interactions for every particle (tracking mode). This way the undesired influences of radiation background or e.g Compton scattering can be greatly reduced or even further exploited (directional sensitivity, polarization sensitivity, Compton camera …).

There are many applications of such ultimate imaging detector and hand-held tracker: Medical imaging (scintigraphy, SPECT, PET) and Non-destructive-testing with isotopes or low power X-ray sources, radiation monitoring and security, environmental and geological research, exploration and mining, scientific experiments, education and many others.

The proposed detector combines latest CERN technology of imaging/tracking readout chips such as Timepix3 with unique technology of thin silicon sensors with active edges (sometimes called edgeless sensors). The edgeless technology allows to avoid need of guard rings and bring sensor electrodes over the sensor edge (e.g. strips, or double sided crossed strips). Therefore even when many of such sensor layers are stacked on top of each other their contacts are still accessible on sides for connection of readout electronics. This way the fully 3D sensitive structure can be made and flip-chip bonded e.g. to pair of Timepix3 redout chips.

The proposed CUBIX structure presents a next level in 3D integration of sensors. This technology of imaging detector can be a significant technological breakthrough in field of radiation imaging and radiation protection. It combines and extents cutting-edge purely European technologies of particle counting detectors Medipix/Timepix developed in CERN with technology of edgeless sensors developed in VTT Finland.

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Towards a high-precision ”weightless” charged particle tracker: ultra-thin and fast position-sensitive-detectors with wireless data transmission.

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The tracking performance of the current generation of charged-particle tracker systems is often limited by the use of the present bulky sensing
technologies and wired links for transmitting the detector's data. We will present here a road-map towards a light-weight, high-resolution post-LHC
tracking system based on the emerging Low Gain Avalanche Detectors (LGAD detectors) a promising position-sensitive-detector (PSD) technology with intrinsic
signal gain proposed a few years ago by the IMB-CNM radiation detection group (one of the participating institution of this contribution). This enabling technology should allow the manufacturing of very thin PSD sensors while preserving a high Signal-to-Noise ratio; moreover, high-resolution time stamping of the tracking information is possible.The intrinsic characteristics of these detectors may be also applied to develop new electron detection schemes at x-ray free electron lasers and other pulsed sources.

Additionally, we will tackle the wireless transmission of the acquired data and, the more challenging, wireless power distribution to avoid the material burden created by the now existing wired links. Coping with this ambitious challenge will require of the emerging know-how from outside of the academic sector provided by ERZIA Technologies expertise on dedicated wireless datalinks as well as engineering research institutes such as ITAINNOVA, expert on EMC and complex power systems.

Summary:

The tracking performance of the current generation of charged-particle tracker systems is often limited by the use of the present bulky sensing
technologies and wired links for transmitting the detector's data. We will present here a road-map towards a light-weight, high-resolution post-LHC
tracking system based on the emerging Low Gain Avalanche Detectors (LGAD detectors) a promising position-sensitive-detector (PSD) technology with intrinsic
signal gain proposed a few years ago by the IMB-CNM radiation detection group (one of the participating institution of this contribution). This enabling technology should allow the manufacturing of very thin PSD sensors while preserving a high Signal-to-Noise ratio; moreover, high-resolution time stamping of the tracking information is possible.The intrinsic characteristics of these detectors may be also applied to develop new electron detection schemes at x-ray free electron lasers and other pulsed sources.

Additionally, we will tackle the wireless transmission of the acquired data and, the more challenging, wireless power distribution to avoid the material burden created by the now existing wired links. Coping with this ambitious challenge will require of the emerging know-how from outside of the academic sector provided by ERZIA Technologies expertise on dedicated wireless datalinks as well as engineering research institutes such as ITAINNOVA, expert on EMC and complex power systems.

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easyPET – a new approach for axial preclinical PET

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easyPET is a new concept of PET scanner using an innovative acquisition method based on two rotation axes for the movement of detector modules. The concept allows high position resolution and spatial uniformity over the whole field of view (FOV) due to its capacity to eliminate (when operating in 2D acquisition mode) the parallax error due to depth of interaction (DOI), characteristic of ring based PET systems.The immunity of easyPET to DOI effects does not impose limitations on the proximity of the detector elements to the FOV and thus favours the system sensitivity. Furthermore,

full axial imaging is possible with only a small number of detector elements, e.g. 256 scintillator crystal pairs.
A scaled up version of the easyPET concept for high resolution and good sensitivity for preclinical purposes will be presented and discussed. Patent pending by the Aveiro University, PCT/IB2016/051487

Summary:

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Development of 3D Associative Memory Chip

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Project idea:

the project will bring together high performance pattern recognition technologies and 3D chip integration. This allows to increase the number of pattern stored in the memory and a reduction of power dissipation.
The main goals of this project will be:

- Designing and producing of innovative cost effective and low energy associative memory chip to provide an integrated circuits with high performance in term of processing capability, efficiency and reliability.
- Using innovative 3D chip technologies to stack in one chip many layers of active silicon connected by Trough Silicon Vias (TGVs).

The main technological objectives will be:

- Development of a new Associative Memory chip in aggressive technology nodes (28 nm).
- Design associative memory core using ultra low power technology to reduce the power consumption.
- Design of novel computing architectures in the 3D domain.

The project will take advantage of the state of the art 3D asic design and will open to new breakthroughs in the design, implementation
and testing of new associative memory chip requiring the control of mixed
criticalities (i.e. power dissipation, clock and signal distribution) opening multifaceted applications in industry
(i.e. control of industrial processes), engineering (i.e. real-time context aware
vehicles), health-care (i.e. dynamic diagnostics), etc.

Direct Applications and Industrial end users:

- High energy physics: trigger system.
- Medical Industry: Real time analysis of medical imaging data.
- Robotics and computer vision.

Summary:

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Imaging in TPC detectors equipped with high granularity charge readout: transfering techology from rare event searches

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Imaging techniques are essential for medical diagnosis. The traditional scintillation detectors have limited efficiency and resolution, while new semiconductor detectors are expensive. Gas chamber detectors equipped with high granularity charge readout working with high pressure could be an attractive alternative that offers good energy resolution and excellent spatial resolution, a competitive efficiency, uniform response without dead zones, low cost and the ability to scan large areas, as it would include the entire body. These novel detectors are in the frontier of technology development and the more and more used in particle physics due to their high performance.

In the group of the University of Zaragoza, as part of the T-REX project, a number of R&D and prototyping activities have been carried out during the last years to explore the applicability of gaseous Time Projection Chambers (TPCs) with Micromesh Gas Structures (Micromegas) in rare event searches like double beta decay, axion research and low-mass WIMP searches where the pattern recognition of the signal is crucial. Microbulk Micromegas are able to image events with high quality measuring its energy deposition with an excellent resolution. The group has also developed as open source software, RESTSoft, suitable for simulations, analysis and event reconstruction. This technology and the software are ready to be transferred to medical diagnosis.

We will show here some examples of imaging in a quite large detector (TREX-BB) working up to 10 bars in a mixture of Xe and trimethylamine (TMA), which reduces diffusion and improves event reconstruction.

Summary:

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Pixelated ceramic scintillators for large-area high-resolution X-ray and gamma-ray detectors

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Current detector technology used in large equipment at CERN and other collider facilities concentrates either on low energy absorption with high spatial and energy resolution (Si-strip or Ge-detectors) or on strong energy absorption with limited spatial resolution (PWO, BGO, CsI:Tl). Equipment with properties in between, i.e. medium to high energy absorption combined with relatively high spatial and energy resolution seems to be less abundant.

We propose a technology that provides strong energy absorption and high spatial resolution for pixelated scintillator detectors at a moderate price. Up till now ceramic technology for gadolinium oxisulfides (GOS) and garnets (GGAG) have been developed at the Philips Generators, Tubes and Components (GTC) business group in cooperation with Philips Research. Garnet ceramics are produced as optically transparent sticks of up to 60 mm length, with the diameter adapted to the pixel size of current SiPM detectors. A major advantage compared to single crystal growth is the larger flexibility to tailor the material composition to meet scintillator requirements. Effective Z values up to 57, photon gain values approaching 50 - 60,000 photons/MeV, energy resolution on par with high-end PET scintillators such as LSO and LYSO, and decay times much shorter than known for single-crystalline garnets have been reached. Building large-area arrays of scintillator sticks for medical imaging applications (CT and PET), including optical reflectors, is by now an established technology for Philips.

Our current research is concentrating on a deep understanding of garnet properties. In cooperation with Peter the Great St. Petersburg Polytechnic University we are working on a further optimization of this material class. Determination of the nature of deep traps, quantitative evaluation of trapping parameters and emission time constants, development of counter measures for deep trapping, and band gap engineering will enable using garnets as scintillator material without secondary decay time constants, trapping or hysteresis effects.

We consider ceramic scintillator technology as a disruptive technology that will outperform single crystals in terms of the availability of fine-tuned material composition, advanced 3D shapes and pixel structures, and in cost price. Further effort should be put into the development of ceramics array technologies that are needed to enhance detection performance and reduce manufacturing costs. We are aiming at building prototypes of ceramic scintillator arrays, cooperating with various R&D partners in different scientific and engineering disciplines:

1. Ceramic scintillator material development
2. Additive manufacturing, e.g. 3D printing, of structured ceramic materials
3. Encapsulation and packaging of ceramic scintillator arrays
4. Detector assembly, i.e. integration of scintillator arrays with other components, including photosensors, read-out electronics and image data processing
5. X-ray and gamma-ray imaging in different applications domains, such as medical, high-energy physics, security, spectrometry, non-destructive testing, and astronomy

Summary:

In the past years Philips has developed ceramic scintillator materials and manufacturing processes for a first generation of pixelated scintillators in medical imaging equipment: gadolinium oxisulfides for CT and garnets for PET.
We consider ceramic scintillator technology as a disruptive technology that will outperform single crystals in terms of the availability of fine-tuned material composition, advanced 3D shapes and pixel structures, and in cost price. Further effort should be put into the development of ceramics array technologies that are needed to enhance detection performance and reduce manufacturing costs. We are aiming at building prototypes of ceramic scintillator arrays, cooperating with various R&D partners in different scientific and engineering disciplines such as ceramic scintillator material development, additive manufacturing of structured ceramic materials (e.g. 3D printing), encapsulation and packaging of ceramic scintillator arrays, detector assembly (i.e. integration of scintillator arrays with photo-detector / read-out electronics), and X-ray and gamma-ray imaging in different applications domains, such as medical, high-energy physics, security, spectrometry, non-destructive testing, and astronomy.

Two Photon Absorption Transient Current Technique for 3D field, time response and efficiency mapping of semiconductor detectors

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Conventional device characterization based on light-matter interaction uses the photoelectric effect and lasers as standard tools. The problem is that the photoelectric effect, even with collimated light beams, doesn't allow to resolve device structures in full 3D due to absorption and charge generation along the full penetration path.

In recent years new near infrared femtosecond pulsed lasers are revolutionizing the field, from basic characterization to high precision mapping. It is now possible to put ultrahigh power ultrashort pulsed laser light in micron voxels without disturbing the surrounding material because photon absorption operates in the non-linear regime. The key for that feat is low energy (mJ) but ultrashort wavelength-tunable pulsed (fs) laser light. This technology is now used into art and nanomanufacturing, as subsurface laser engraving and 3D litography, and make it possible nanosculptures and nanomachines.
For chemistry, multiple photon absorption (in short, Two Photon Absorption) permits precise spatial-temporal control of reactions in liquid media. For biomedicine, TPA induced fluorescence pinpoints structures in living cells without damage.

The TPA revolution now finds its way to semiconductor detectors, the origin of the photoelectric applications. As it's well known, the core of semiconductor detectors design is to locate a huge electric field by means of selectively doped pn junctions. The totally important electric field region needs an accurate experimental technique for characterization.

We present a new experimental method, TPA-TCT or Two Photon Absorption Transient Current Technique. TPA-TCT takes advantage of the non-linear photoelectrics in silicon associated to near infrared femtosecond laser pulses to generate eh pairs in a few cubic microns around the focal point, deep inside the device. Fast current amplifiers with state of the art DAQ electronics can resolve in time the current pulse shape generated in response to the laser pulse. Combining the 3D spatial pair generation volume and the DAQ timing, it is possible to determine the depletion volume in the semiconductor device, resolving the electric field distribution.

Spatially resolved electric field and efficiency characterization in semiconductor detectors opens the door to detector design optimization for highest performance in many fields. Other possible applications of TPA-TCT, specially by tuning the wavelength, are defect spectroscopy, application to diamond sensors or radiation tolerance characterization of depleted silicon sensors (bulk and HV-CMOS). Examples on High Energy Physics particle detectors will be given in the presentation including the monitoring of radiation damage.

Summary:

We present a new non-linear laser technique for 3D tracing of the electric field in semiconductor detector pn junctions. The precise knowledge of the electric field distribution is key to semiconductor design and operating life monitoring. Examples on High Energy Physics particle detectors will be given in the presentation including the monitoring of radiation damage.

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Neuromorphic image sensors for future particle detectors

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The idea behind this abstract was triggered by the article entitled „Giving Machines Humanlike Eyes" [http://dx.doi.org/10.1109/MSPEC.2015.7335800] in the December 2015 number of the IEEE Spectrum magazine. Of course, the idea of designing machine parts inspired by models existing in the nature is not new. However, the neuromorphic image sensors offer a completely new paradigm for computational imaging and open new doors to technological breakthroughs.

The concept of neuromorphic vision sensors exist since early 2000s. They continuously track the amplitude of each pixel and record changes of only those pixels that modify their brightness level by a pre-defined amount. This approach is called level-crossing sampling. This type of sensors is thus event-based, as opposed to the frame-based classical sensors with low and fixed sampling rate. Implementations are already commercially available at iniLabs, Switzerland [http://inilabs.com/].

The intrinsic parallelism of such sensors as well as the associated speed capabilities and extremely-low power consumption, make them interesting candidates for future particle detectors. We envisage the design and implementation of an acquisition system, using reconfigurable hardware (FPGA) and a dynamic vision sensor, allowing us to investigate the possibilities of using neuromorphic image sensors for future particle detectors.

Summary:

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The use of energetic heavy ions to produce nanometre resolution molecular images in ambient conditions

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Molecular imaging with a resolution approaching the size of an individual protein without sample preparation or the use of a vacuum chamber will be possible by 2025. The technology necessary to accomplish this analysis already exists in the form of swift heavy ion accelerators used in hadron therapy and ion beam irradiation facilities. Powerful magnets, electrostatic lenses or simple collimating capillaries can be used to confine the heavy ion beam in air to spot sizes of tens of nanometres. Impinging heavy ions focussed in this manner induce molecular desorption at the surface of a sample to produce a molecular ion signal that can be analysed at atmospheric pressure using a differentially-pumped mass spectrometer.

The development of this imaging technology in parallel with recent advancements in ambient mass spectrometry technologies that are being developed, for example, for use during surgical procedures will offer an unprecedented understanding of the underlying molecular distribution at a subcellular level.

Applications of this new technique are foreseen in the fields of biology, medicine, forensics, cultural heritage and materials science.

Summary:

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FLEXPIX - Flexible Pixel Detector

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Trying to reach new energy and luminescence frontiers with new collider experiments brings new challenges especially to the vertex detectors.
Essential are the minimalisation of the material budget and wish to have the first layer of the vertex detector as close as possible to the beam pipe. Ideally one would like to have the beam pipe wrapped up with the sensors as thin as possible to minimize multiple scattering. One of the main challenges is to have still high signal in such very thin sensor.
We propose a detector concept, which could solve all challenges at once.
DEPFET sensor with its all silicon module concept are already world leading in the minimalisation of the material budget and can still have high signal and low noise due to the internal amplification which is inherent in the DEPFETs 1. At present for the development of the BELLE II pixel detector all silicon module provides stability, mounting capability and interconnection to the outside world [2].
Idea of the new concept would be to incorporate thin DEPFET sensors into flexible wired 3D foil [3]. In this way the foil itself can provide all interconnection to the sensor as well as required stability/flexibility.
Proposed concept would give ideal 4pi coverage around the interaction region.
Combination of MEMS and micro-electronics, together with development of customized interconnect technologies (fine pitch, flexible) and further development of the features of new flavours of DEPFET readout cells (infinipix, rndr, quadpix..) would provide an ideal detector for the future colliders.

References:

1. Andricek, et al. Processing of ultra-thin silicon sensors for future e+e - linear collider experiments , 2004, IEEE Transactions on Nuclear Science, 51, pp. 1117-1120.
2. Andricek et al.,All-silicon multi-chip modules based on ultra-thin active pixel radiation sensors, International Conference and Exhibition on Device Packaging 2014, 2014, pp. 159-161
3. Bock, K. et al. Multifunctional system integration in flexible substrates,Proceedings - Electronic Components and Technology Conference 2014, pp. 1482-1487

Summary:

DEPFETs, MEMS, FINEPITCH, FLEXIBLE, VERTEX

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A tomography-inspired method for event reconstruction in Liquid Argon Time Projection Chamber

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The Liquid Argon Time Projection Chamber (LArTPC) has characteristics suitable for precise reconstruction of neutrino interaction including inividual tracks as well as for calorimetric measurements. In order to gain sensitivity to reactions with very small cross-sections, modern LArTPC devices are built at a considerable scale. Future experiments such as the Deep Underground Neutrino Experiment (DUNE) will include tens of kilotons of the cryogenic medium. To be able to utilize sensitive volume that large while staying within practical limits of power consumption and cost of the front-end electronics, it is instrumented with arrays of wire electrodes grouped in readout planes, arranged with a stereo angle. This leads to certain challenges for object reconstruction due to ambiguities inherent in such scheme. We present a novel reconstruction method inspired by principles used in tomography, which brings the LArTPC technology closer to its full potential.

Summary:

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3D diamond detectors for particle tracking and dosimetry

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3D diamond detectors for particle tracking and dosimetry

Advances in the laser assisted transformation of diamond into amorphous-carbon has enabled the production of a new type of particle detector - 3D diamond. Compared to conventional planar technologies, previous work has proven a 3D geometry to improve the radiation tolerance of detectors fabricated in silicon. First tests of single-crystal and polycrystalline CVD diamond 3D detectors in various particle beams and performance comparison with simulations demonstrate the viability of this concept.

Recent improvement in the fabrication methods, including the use of a spatial light modulator to produce conductive wires with ˜1um diameter allowed the fabrication of devices in both single-crystal and polycrystalline CVD diamond with lower resistivity of the wires, promising an improved performance. Furthermore the use of spatial light modulators open
up the possibility of arbitrary wire shapes and therefor new detector concepts.

Outside the field of high energy particle physics, a potential application for this technology includes medical dosimetry; where the high resilience to radiation damage, operation at low bias voltage with well defined active volume, in addition to high compatibility to human tissue, makes their use desirable. First tests with at an clinical irradiation facility show promising results.

Summary:

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The sixth sense: a new detector to observe the universe

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The first direct detection of gravitational waves 1 opens a new era in the observation of the universe. The kilometers long laser interferometers developed since the 1990's have now proven to be sensitive enough to measure the minuscule variations in displacements caused by massive astronomical bodies. This discovery will boost gravitational wave physics with interferometers and Europe is investigating two facilities to enhance the gravitational wave research infrastructure. In 2028 Einstein Telescope should be an operational facility with a ten-fold improved sensitivity and in 2034 eLISA will be the first gravitational wave observatory in space. To reach unprecedented precision both projects rely on further research and development of innovative detector technologies. We will discuss detector systems based on novel opto-electronics, (MEMS) accelerometers, and sensitive readout electronics to reduce limiting noise sources in laser interferometry, especially at low frequencies.

Future GW interferometers require seismic sensor networks for subtraction of gravity gradient noise, caused by direct gravitational coupling of mass density fluctuations to suspended components of the interferometer. Nikhef has started the development of a novel seismic sensor: an ultra-sensitive miniaturized accelerometer made in MEMS technology in combination with extremely low-noise low-power integrated readout electronics in CMOS technology. For this system, the signal bandwidth is in the 1-100 Hz frequency band where the typically dominant flicker noise has to be 'beaten' by several orders of magnitude with a limited power budget. Innovations in both the MEMS design and in the electronics system will target acceleration resolutions in the order of 1 ng/√Hz. Nanometer CMOS technologies provide better high frequency behavior for readout and actuating of MEMS devices. Since these sensors are part of a large area network they need to communicate and transmit data via wireless links.

Nikhef is also developing a monolithic accelerometer with interferometric readout, aiming at fm/√Hz to measure the residual motion of the optical components of GW interferometers since no (commercial) sensor with sufficient sensitivity is available. Another development is a novel Phase Camera for high resolution wave-front sensing to provide a measure of the transverse spatial profile of a laser field. This will allow to determine mirror aberrations at sub-nanometer level which may then be compensated using a thermal compensation system. These sensor systems are some examples that require further development and will benefit from future developments in MEMS technology in combination with integrated (photonic) circuits. The applications of these sensors are manifold: from monitoring and control of accelerator components (including FELs, synchrotrons, etc.) to consumer electronics and oil & gas exploration.

1 Observation of Gravitational Waves from a Binary Black Hole Merger, B.P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration), Phys. Rev. Lett. 116, 061102 – 11 February 2016

Summary:

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A pixelised detector for thermal neutrons

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For the European Spallation Source (ESS), now under construction, a new generation of neutron detectors will be
required with groundbreaking properties in terms of 2D spatial resolution, time resolution, efficiency, rate capability, gamma discrimination and radiation hardness.
We propose to deposit a 10B containing semiconducting layer directly onto a pixel chip with charge-sensitive pixel input pads.
This layer is coated with a thin metal contact: by applying a certain potential to this contact, a bias field is created in
the semiconducting layer volume. Thermal neutrons, interacting with a 10B nucleus will cause a nuclear reaction resulting
in the emission of an alfa-particle and a recoil 7Li ion. These to charged energetic particles will strongly ionise the semiconductor
material. The bias field will separate electrons and holes, and with just a few ns life time of these charge carriers, sufficient
charge is induced onto the pixel input pads to activate the pixel circuitry.
With the available TimePix-3 chip, a high performance neutron detector would be feasible if a B containing compound can
be created and deposited with charge carrier properties meeting specific requirements. These properties should not change
after the absorption of a certain amount of neutrons. The TimePix-3 chip itself is shielded from neutrons by the
active 10B contains layer. As layer material, BC, BNC, B4C are potential candidates.

Summary:

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Smart pixels for single photons

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In close collaboration with CERN, Nikhef has developed a strong record in the design and realisation of large detectors for particle physics. Key parts were silicon and gas filled sensors that are specialised in measuring charged particles with accurate position and energy information. Today our knowledge on design of both mechanical and electronic precision equipment has reached a level where we expect it to make impact on relevant non particle physics sience fields. In particular we foresee a large impact on single photon counting and spectral Xray imaging for medical and industrial tomography systems 1. Specifically we expect to realise a new generation of detectors for soft photons, electrons, neutrons and MIPs by combining CMOS pixel chips with MEMS-built structures. We want to push for imaging with time resolution down to the picosecond regime while reaching MHz readout speed, and spatial resolution defined by the granularity of the pixel chip. A concrete goal is the development of the Cherenkov PET scanner [2].

1 Prospects of spectral CT with Medipix detectors PoS TIPP2014 (2014) 246
[2] Potential applications of electron emission membranes in medicine. Advances in detectors and applications for medicine NIM A Vol 809, 11 February 2016, Pages 171–174

Summary:

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PYXGEN: A novel charge domain global shutter pixel platform for scientific imaging with automated generator

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B. Dupont, Pyxalis (in collaboration with ST Microelectronics)
In nowadays technology, most advanced features are developed for consumer grade application whereas some of those technologies could be very beneficial for scientific imaging. In particular for quite a vast range of applications, ultra-low noise global shutter pixels are becoming more and more interesting. High speed low noise imaging in biology application, or earth observation satellites are looking for such architecture. However, using advanced technology node (65nm and below) to achieve state of the art performances has a significant cost. In this project, we propose a way to offset the costs by creating a dynamically generated pixel array dedicated to scientific imaging.
We propose to develop a versatile pixel platform for scientific usage. The platform is meant to be scalable with the following targets:
• Noise floor: below 2e-
• Global shutter
• Pixel pitch: scalable, from 4,5um up to 100um
• Image sensor diagonal: from a few pixels to waferscale imager.
The goal of this development is not only to demonstrate such performances for scientific imaging but also to create a true platform, following the example of RAM block arrays: a generator will be design to quickly generate a pixel array with dedicated peripherals using simple parameters such as: number of pixels X and Y, pixel pitch, shutter types, Full-well, digital or analog sensor, etc. This will speed up design time and will benefit the entire scientific imaging community with a more affordable route to high performance imaging technologies.

Summary:

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Simultaneous x-ray transmission and fluorescence imaging.

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X-ray imaging exploits the differences in the complex x-ray refractive index of materials to obtain spatial information on electron density changes. This technique has been used for over 100 years and is a popular in many areas of research. The use of x-ray fluorescence from materials for imaging has taken a little longer to emerge, but is now a mainstream imaging technique for materials analysis, especially on synchrotron storage ring sources. If these two techniques are combined and information obtained simultaneously on electron density and elemental concentration, It would add greatly to the characterisation of the object.

We have been exploring methods of using coded illuminating beams during x-ray computed tomography. This is done in such a way that has little or no effect on the quality of the x-ray CT but the fluorescence emission from regions with the object is encoded. Encoding needs to be done in a way that provides a means of decoding the position of fluorescing regions within the object. A manifestation of compressed sensing has been trialled on the beamline with some encouraging results. The technology we are exploring is aimed at this particular problem, but the concept can be applied to other situations especially where multi-element detectors are difficult or expensive to develop.

Summary:

Coded beam x-ray imaging could be used for simultaneous computed tomography and x-ray fluorescence tomography.

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Magnetic field sensors for medical imaging: Wishes and potential

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Emerging approaches to image the structure and function of the human brain would drastically benefit from exquisitely sensitive yet robust and easy-to-use magnetic field sensors.

Magnetoencephalography (MEG) is about non-invasively measuring electric brain activity through the neurally-generated magnetic fields. While the SQUID-sensor-based MEG is already an established technique, overcoming its current performance and commercial limits calls for a breakthrough in sensor technology; the sensors should be more sensitive, they should be brought closer to the scalp to increase spatial resolution, the sensor array should be malleable to the head size and shape of the subject or patient, and the sensors should operate without cryogenics for low running costs and simple construction. With such improvements, MEG could be a future replacement of the invasive, surgically-implanted recording electrodes currently applied in patients suffering from epilepsy to localize the epileptogenic area.

Ultra-low-field magnetic resonance imaging (ULF–MRI) is a safe, potentially low-cost future imaging technology, which has uniquely high contrast e.g. for certain tumor types. In ULF–MRI, the low-frequency (< 20 kHz) NMR signals are detected magnetically, without using tuned RF coils as in conventional high-field MRI. Like MEG, ULF–MRI would greatly benefit from advancements in magnetic sensor technology; the performance of the current ULF–MRI systems is limited largely by the sensitivity of the sensors. Compared to the state of the art, an order-of-magnitude reduction in the sensor noise level (down to sub-fT level) would greatly improve image quality and shorten the measurement time, thus helping ULF–MRI to become a clinically viable technology.

Summary:

In this talk, I will briefly describe the current state of MEG and ULF-MRI as medical imaging modalities and illustrate how improvements in magnetic sensing technology could boost their performance as diagnostic tools and increase their commercial potential.

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PYX-XL: World largest resolution sensor for scientific applications

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In commercial, consumer grade sensors, the sensor size tends to decrease every years, optimizing costs in mobile applications. However, similar technologies can be used to create very large detectors that are required to make progress in scientific imaging. It is particularly the case in electron

beam microscopy, synchrotron or in earth observations with the possibility even to achieve by 2025 geostationary earth observation sensors. Furthermore, there are existing synergies with professional imaging.
Through this project, we propose to design and manufacture the world largest resolution sensor. It is also the largest monolithic sensor with a 29mm diagonal (8x10 optical format). To design such sensor, several challenges have to be overcome: first, the number of pixels is so high that a traditional matrix organization with readout on the edges will not work anymore. Thus, an organization in array of readout, scarifying optical columns and lines, has to be accommodated. To minimize the number of inactive cells, the sensor will have to be 3D stacked using through silicon via. The readout ASICs will be custom designed as well to handle the data output.

Summary:

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Efficient and time-encoded imaging detectors based on MPGDs

Authors: Dorothea Pfeiffer[1]; Eraldo Oliveri[1]; Filippo Resnati[1]; Florian Maximilian Brunbauer[2]; Leszek Ropelewski[1]; Patrik Thuiner[1]; Richard Hall-Wilton[3]

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Gaseous detectors and in particular MicroPattern Gaseous Detectors (MPGDs) are widespread devices in High Energy Physics experiments. Recent technology developments have resulted in successful demonstrations of their usability for x-ray fluoroscopy and 3D imaging, energy resolved photon counting, and various other applications.
In certain conditions, MPGDs behave like scintillator plates with extraordinary scintillation yields. Thus, combining a low noise optical readout with the signal amplification inherent to MPGDs allows for excellent image qualities.
The anticipated technological advances in commercially available cameras, chiefly the increase of the sensor sensitivity and the recorded frame rate, will make time-stamping in images obtained from MPGDs competitive, which will enable not only time-resolved images, but also the mitigation of pileup in photon counting mode. Moreover, a dedicated amplification scheme will make time encoding in images on a tens of nanoseconds scale feasible, transforming the detector into a versatile 3D imaging device: a time projection chamber (TPC) where the time information is contained in the images themselves.
The full development picture foresees an increase of sensitivity to neutral particles - namely gammas and neutrons - on the detector side. Solid converters which maximise the performance (efficiency, position resolution, point spread function, etc.) are under study. Secondary electron emitters with embedded converters coupled to MPGDs will allow for fast, sharp and efficient imaging devices.
While the time scale for all these fields of research is several years, and it depends on the technological advances on the sensor performance and material science, the impact of the results from such activities, though uncertain, can be of extraordinary impact.

Summary:

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Direct optical readout of ionisation tracks in gas-based TPCs

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In the fields of particle physics and radiation detection, gas-based time projection chambers (TPCs) are used as a versatile tool for particle detection and 3D track reconstruction. Their operation principle requires a reference time obtained from a primary signal, which allows the absolute placement of an ionisation track in space.
Owing to their excellent spatial resolution and intuitive readout, optically read out signal intensifiers, such as MicroPattern Gaseous Detectors (MPGDs), are a promising candidate technology for providing the 2D projection on the end planes of TPCs, realisations of which are already actively pursued and studied. However, the anticipated technological progress in digital imaging sensor technology in the coming years makes the optical readout of not only a strongly intensified signal at the end caps of a TPC but also the optical detection of primary ionisation signals in TPCs feasible. Highly sensitive imaging sensors which can be operated at high frame rates might allow for direct imaging of the scintillation produced by primary ionisation events of particles traversing a gas volume. In fact, this could lead to a novel generation of particle detectors based solely on a volume of scintillating gas, which is ionised by crossing particles and read out directly with capable cameras, effectively making conventional TPCs obsolete. Not only would this detector concept be much simpler than current technologies, but it could also be scaled up effectively and be adapted to arbitrary geometrical requirements. Thus, the direct optical readout of primary scintillation by highly sensitive imaging sensors may prove to be of exceptional significance for future radiation and tracking detectors.

Summary:

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Modules for an organ-specific personalized PET scanner

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In today's world early detection of cancer has proven to be the most crucial step for effective treatment. This is only possible by making the non-invasive imaging techniques more affordable and accessible for individuals. AvanTomography modules would achieve this goal by designing a module for positron emission tomography (PET) scanner. This module can enable the assembly of lower-cost PET scanners with more versatile designs.
A scanner comprising of AvanTomography modules would involve electronically and mechanically separated modules that could be combined together to create a scanner according to the desired area to be scanner, i.e. breast, arm, leg, small animal, full body etc. Mechanical connection between the modules would be a structure resembling Lego® pieces, where modules can be attached and detached easily depending on the desired gantry size and application. Since the scanner geometry can be arranged, patient could be scanned in different scanning positions, i.e. standing, sitting or lying down. As a full ring scanner wouldn't be needed for smaller areas of interest, it would be possible to make a low-cost scanner that only includes few modules. Such a personalized PET scanner would achieve a high sensitivity just by being close to the object. If necessary, the sensitivity of the scanner could be increased by stacking more modules around the object of interest. All of these are possible using the axial geometry of scintillator crystal positioning, which is referred as AX-PET. This technology is already made available and proven to work in an experimental setting by CERN.

Main property of Axial PET (AX-PET) technology is the scintillating crystals that are aligned in parallel with the axis of the scanner instead of the traditional radial orientation, stacked in several layers. Crystal layers are interleaved with an array of wavelength shifter (WLS) strips, placed orthogonal to the crystals.
AvanTomography modules could also be tailored according to the application. For example, if a breast scanner is desired, then the modules would be designed to be optimal in a square plate structure rather than a rectangular shape. With this geometrical configuration, it is possible to use crystals up to 30 cm in length and still achieve a good image quality thanks to the overlaid WLSs.

Summary:

The aim of these modules is to design a scanner that is tailored for the needs of the patient and the user. While providing a lower cost ans smaller sized solution to the PET scanners in the market, this scanner aims to achieve a good resolution and sensitivity by using a different crystal configuration, also called axial PET.

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Progress on simulation and first prototype results on a beam monitor based on MPGD detectors for hadron therapy

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Study and development of an innovative beam monitor based on MPGDs for the characterization of proton therapy beams.

Summary:

Remarkable scientific and technological progress during the last years has led to the construction of accelerator based facilities dedicated to hadron therapy. This kind of technology requires precise and continuous control of position, intensity and shape of the ions or protons used to irradiate cancers. Patient safety, accelerator operation and dose delivery should be optimized by a real time monitoring of beam intensity and profile before and during the treatment, by using non-destructive, high spatial resolution detectors. In the framework of AMIDERHA (AMIDERHA - Enhanced Radiotherapy with HAdron) project funded by the Italian Ministry of Education and Research the authors have studied and developed an innovative beam monitor based on Micro Pattern Gaseous Detectors (MPDGs) called TPC-GEM (TPG) detector, characterized by high spatial resolution and rate capability. Due to the low amount of material in the active volume, it is "not invasive", therefore the beam characteristics are preserved, so minimizing the uncertainties on beam position, intensity, energy and stability.

The aim of this talk is to give an overview of the Monte Carlo simulations of the beam monitor prototype carried out to optimize the geometrical set up and to predict the behavior of the detector. The experimental results of the beam monitor characterization using an X-ray tube will also be presented, as well as the future developments.

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Graphene-based Golay THz arrayed detectors

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Abstract:

TeraHertz (THz) is a non-ionizing, and thus safe, radiation, attracting a growing interest for its potentiality of non-destructive chemical imaging and sensing. Its application was hindered in the past for a dramatical lack of THz sources and detectors. Recently new technological approaches emerged in the field of THZ sources, while THz detector still rely on older approaches
THz imaging requires the development of miniaturized THz sensors built in dense arrays. Golay cells are formed by a gas chamber enclosed in flexible membranes: when the gas pressure is raised by IR or THz radiation absorption, the membrane curvature change may be detected by optical imaging. Since THz wavelength is larger than 30μm, the lateral resolution of the fabrication process is not a limiting factor. The critical component of a micron sized Golay cell is instead the flexible membrane, which must have both a high breaking strength and a low flexural rigidity. Graphene is the ideal material for this purpose because of its high strength and of its atomic thickness, in contrast with thicker polymeric membranes. Low flexural rigidity is critical to deflection sensitivity in response to temperature changes of the gas enclosed within a Golay cell scaled to the 10 μm to 100 μm scale. We recently develop a method to transfer clean graphene monolayers on micropatterned substrates. By graphene transfer in solution, we demonstrated that water remains trapped into micron sized graphene bubbles and that those bubbles are stable at temperatures much higher than 1000C.
Here we propose to develop arrays of graphene bubbles on transparent substrates as a THz detector. The bubbles will be filled with water-based solutions, to maximize absorbance in the THz region, and could be kept close to the liquid-vapor transition, in order to maximize the volume change upon THz absorption (i.e. the sensitivity).
For imaging purposes, spatially modulated THz radiation acts with different intensity on cells located at different positions locally so that the THz spatial distribution will be reflected in a pattern of cells curvature. The cells curvature patterns, properly demagnified, will be imaged through the transparent substrate with an ordinary CCD, providing THz spatially resolved images.
Just like color CCD are made color-filtering the nearest neighbors pixels, by filling nearest neighbors cells with water solution absorbing at different wavelength, we will produce a "color sensitive" THZ imaging detector.

Summary:

Keywords:

TeraHerz Golay sensors, Teraherts imaging, Grafene sensors

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Nanomechanical biosensors

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Abstract:

Medical analysis for prognostic and treatment follow up is evolving toward real-time, bed size, protein finger print and personalized medicine. Therefore the molecular sensors used to detect and quantify the molecular tergt of interest should be fast, to operate in real time, selective, to be insensitive to the so-called biological noise and detect the lowest analyte concentration and multiplexed to provide a comprehensive description of the overall biological activity of the patient.
Micro and nanomechanical sensors (NEMS) represent a promising new class of biosensors that may respond the requirements listed above. Because of their extreme sensitivity, fast response, low cost, and multiplicity they can be competitive in terms of analysis time and costs, compared with current diagnostic systems (i.e. ELISA test). The most common dynamic NEMS sensors, based on resonance frequency perturbation, are quartz microbalences, ring resonators and cantilevers. However, there a major limitation that need to be addressed: NEMS sensors, when operated in liquid, i.e. biological, environment, loose most of their extraordinary properties. As an evolution of cantilevers, we developed micro-pillars, columnar resonators that offers three key advantages on the current NEMS approach.
a) they can be arranged in dense arrays of several hundred thousand sensors in a squared cm, thus offering a promising approach to multiplexing, i.e. the detection of a full pool of markers within the same chip. To this purpose a strategy for decorating each sensor with a different functionalization and a parallel read-out should be developed. We already developed simple optical read-out optical method based on CCD imaging and software image analysis which allows the recording of the resonance frequency of hundreds of pillars in parallel that can provide information on tens of antigen in parallel.
b) they can be fabricated in superhydrophobic arrangement. In this way only the top of the pillar is in contact with the analyte while the structure oscillates in air. In this way real time analysis can be performed directly immersed in the analyte solution, whitout deteriorating the quality factor of the resonator.
c) they can be integrated as active elements into monolithic optical waveguides. Hundreds of pillar can be coupled to a single waveguide, each one modulation the optical signal at a different frequency thus offering the opportunity of a self-aligned full-optical simple read-out design suitable for integration on a lab-on-a-chip disposable device.
With the full development of the pillar approach, personalized medicine and early diagnosis of the most freighting diseases will become a reality.

Summary:

Keywords:

Nanoelectromechanical systems (NEMS), Fingerprint assays, Real time analysis, Point of care (POC) analysis

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Electron and Photon beam monitors

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A variety of beam position and diagnostic monitor (BPDM) technologies have been proposed for the aim of maintaining the beam focusing and alignment of accelerators and beamlines in Synchrotrons and FEL. Metal wires, Compton scattering from laser beams and image currents from the electron beam are the most applied methods to estimate the performance and quality of synchrotron radiation.
We can distinguish BPDM in two main categories: BPDMs: intercepting and non-intercepting methods. While non-intercepting (such as cavity electron) BPDMs, together with a beam-based alignment system, are the best solutions for the monitor purpose, intercepting wire monitors are valuable for rough alignment, for beam size and shape measurements, and for simultaneous measurement of electron and photon beam position by detecting bremsstrahlung radiation from electrons and diffracted x-rays from the photon beam.
Wire scanners require sequential measurements in orthogonal directions. They are used successfully at SLAC to measure micron, or smaller, beam sizes. The working principles consist of sliding a wire (generally metallic) across the beam using a linear motion stage, or by steering the beam across the wire, obtaining indirectly the profile of the beam. While the beam central position resolution is determined by the properties of the stage, the beam shape reconstruction depends on the wire size: the thinner the wire, the higher the accuracy.
By using a carbon wire, simultaneous characterization of electron and photon beams is possible. High energy electrons generates bremsstrahlung, radiation while the x-ray photons are diffracted from the wire crystal structure; however the photon wavelengths that produce a detectable diffraction patterns are limited to a narrow range around 1nm. Metallic wire BPDMs: have several drawbacks: the wire size cannot be reduced over the limit imposed by the material properties and the intensity of the acquired signal is generally too high, further limiting the beam measuring resolution.
To address these problems, we substituted the metal with a microfabricated Silicon Nitride device, eventually coated with thin metal film, which allows the reduction of the radiation emission to detectable values. We produced several microfabricated prototypes consisting in Si_3N_4 bridges as small as to 2x2 um in cross section and as long as 2 mm,. Thanks to the flexibility of the fabrication process, the geometry of the wire can be easily engineered according to beam size and energy. The bridges were successfully coated with different metals (Pt-Al-Cr-Ti) in order to make them conductive and tune the emission efficiency.
With the proposed approach the size and the shape of an high energy beam could be obtained in real time in a non interfering fashion with spatial resolution in the micrometer regime.

Summary:

Beam position monitors, Beam Diagnosys, wire scanner, FEL, Synchrotron beam alignment

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Implemented Pixelated Phosphor Detector (PPD) for laser coupled FEL beam diagnosis

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Although the characterization of the beam quality is an essential prerequisite for a reliable application of pulsed high-power vacuum ultraviolet (VUV) and soft X-ray (SXR) beams (e.g. free-electron laser (FEL) light sources), the design of proper devices is still an open issue.
The approaches employed at the moment show severe limitations: direct monitoring with YAG scintillators or phosphors screens produces blurred images because of the light-spreading phenomenon; the ablative imprint over PMMA or silicon requires time-consuming ex-situ analysis; the wavefront reconstruction works only in a limited wavelength range.
We recently demonstrated an effective method to preserve the advantages of the scintillators (such as in situ and real-time detection), increasing their spatial resolution to achieve a reference technique for spatial quality diagnosis; in our Pixelated Phosphor Detector (PPD) devices, an array of micrometric phosphor pixels has been obtained by filling micrometric silicon pores arranged in a hexagonal geometry with suitable phosphor powders. The device is coupled with a CCD camera external to the experimental vacuum chamber through a telemicroscope. The design of our PPD guarantees high resolution, close to the beam size, of the order of a few micrometers. Thanks to the reduced pixels size (in the range of a few micrometers or lower), the focused beam can be traced through the simple detection of the illuminated pixel phosphors in each cavity. The VUV and SXR pulses of from FEL, as short as hundred femtoseconds, can be used to explore the temporal evolution of various processes: electronic motion, phase transitions, and chemical reactions. The measure of femtoseconds or picoseconds events however requires the so-called pump-and-probe technique: either an optical laser is used as pump and the X-ray beam as a probe beam or viceversa. In this way the temporal distance between the pump and the probe can be easily achieved by deviating the visible beam through a delay line. The conceptually simple but practically challenging precondition is to have a precise control of spatial and temporal alignment of pump and probe sources. With the available technology several days should be dedicated to the temporal tuning and the spatial alignment of the beams before starting an experiment that may last just a couple of hours. .
PPD technology represents a promising platform to design and develop a new family of beam position detectors able to monitor the spatial arrangement and the temporal delay between pump and probe beams. Taking advantage of the capability of some materials to change the transmittance at specific wavelength when they are exposed to the FEL beam, and developing a suitable micro- and nano-fabrication process, we will design a combined system of two different pixel arrays: one to monitor the FEL beam shape and the position, and another one to determine the temporal coincidence of FEL and visible beam. enabling a real time control of pump and probe experiments.

Summary:

Phosphor Detector, FEL, beam diagnosis, laser, real time, in situ

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Sensing the Universe in colour; Kinetic Inductance Detectors for optical and near-IR astronomy

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I will describe the ongoing work in the development of Microwave Kinetic Inductance Detectors (MKIDs) for optical and infra-red astronomy. These super-conducting devices represent an important step towards the development of the 'ultimate detector'; one that can measure the position, energy and arrival time of a photon. Currently, we have arrays of 20,000 MKIDs, where each pixel is capable of determining the arrival time of a photon to 1 microsecond and the energy of the photon to around 5%. I will describe the operating principles of the devices, their current status and the future promise of this disruptive technology. I will outline the areas of astronomical instrumentation where we have identified their potentially transformational impact.

Summary:

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Avalanche piselated sensors and dedicated front-end electronics as imaging detectors for time resolved experiments

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Novel fast imaging detectors are necessary for X-ray time resolved experiments. Diamond Light Source, the UK synchrotron radiation facility, approved recently a project to develop a large area imaging detector based on the Timepix3 ASIC for time resolved experiments. This detector will enable time resolved experiments to access comfortably time resolution from tens of nanoseconds to milliseconds and will reduce by order of magnitudes the time that it takes to collect a data set in pump and probe time resolved experiments.
Although this detector will be a major improvement with respect to the present detector technology it will still have limitations such as the dead time between two events mainly due to the duration of the analogue pulse. The development of pixelated avalanche sensors working in proportional regime and dedicated front-end electronics can overcome this limitation by shortening considerably the duration of the analogue pulse. This will require considerable R&D efforts. The Attract initiative is the ideal framework to pursue a long term development programme that is required to develop detectors that are pushing the boundary of the technology.
In this talk I will report the reasons why synchrotron facilities need fast imaging detectors, I will give an overview of Timepix3 and its capabilities, and I will put forward some ideas on how to build a more effective detector for time resolved experiments based on avalanche sensors.

Summary:

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Large area photon-counting X-ray or particle image sensor using pixelated scintillator

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Photon counting based X-ray imaging is known to be superior in performance as compared to the state of the art charge integration X-ray imaging. This is obvious at very low fluxes where photon counting yields quantum limited noise, yet also at high fluxes photon counting yields a DQE advantage over integration. A second advantage of photon counting is that it offers the possibility to extract spectral information from each photon separately, thus without multiple exposures or an increased X-ray dose.
Most, if not all of today's successful photon counting X-ray imagers are based on "direct detection". From pure detection performance standpoint this approach is ideal: the photo-electric conversion happens in a very limited volume, the energy quantum is deposited in a narrow trace or cloud of secondary electron-hole pairs, which are quickly and with little sideward dispersion collected by the electric drift field. The limiting factor for the widespread use of direct detection in photon counting imaging is the cost and manipulation of the semiconductor material.
The alternative route, indirect detection, i.e. detection of X-ray photons by absorbing them in a high-Z scintillator, then detecting the secondary, visible light radiation by a visible light image sensor, is a

much more economically viable. Many scintillators are inexpensive, easy to co-integrate, and CMOS visible light event counting is an easily scalable and mature technology.
However, the indirect detection has a few annoying disadvantages as compared to direct detection: the overall indirect process has a significantly lower photon to electron conversion, suffers from slow decay times, and especially suffers light dispersion and thus poor MTF, and poor reproducibility of charge packet sizes, making photon (and particle) energy measurements unreliable.
It was concluded earlier that a root-cause solution to these issues would be the use of "segmented" or "pixelated" scintillators 1. These could confine the secondary charges within the pixels, thereby challenging the MTF and particle/photon energy measurement capabilities of direct detectors, yet at an order of magnitude lower cost. In principle the cost per unit area of such photon counting array will approach that of the present state of the art CMOS based X-ray plates.
In this project we propose to develop a CMOS ROIC plus a pixel-matched pixelated scintillator in collaboration with Philips Medical (see abstract 75 referring to the pixelated scintillator itself).
The development will aim to realize a prototype with
• A CMOS photon packet counting arrays of at least 1cm2, yet aiming to wafer size, depending of budget, concepts working further on the prior experience.
• It will feature in-pixel sense-amplifications, multiple thresholds (or energy resolution), counting and multiplexing means.
• Although we are inspired by X-ray photon counting and energy discrimination, it is conceptually capable to do the same with HE particles, as these are also detected by scintillators.
• The fabrication of a corresponding pixelated scintillator
• The hybridization and packaging of a decent number of devices (ROIC + Scintillator)
• Experimental verification of such hybrid devices under the X-ray beam, with verification of DQE and compare to the state of the art
• Further experimental use and test in disciplines as medical X-ray, and interested partners in particle physics, NDT, etc.

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1. B.Dierickx, S. Vandewiele, B. Dupont, A. Defernez, N. Witvrouwen, D.Uwaerts, "Scintillator based color X-ray photon counting imager", Workshop on medical applications of spectroscopic X-ray detectors, CERN 22-25 April 2013 (slides available at www.caeleste.be)

Summary:

The purpose of the project is to design and manufacture a large 2D array of X-ray (and particle) counting pixels. The design include the CMOS ROIC as well as the pixelated scintillator.
Due to the segmentation of the scintillator one will overcome the weak point of scintillators: the pooir MTF due to sideward spreading of the light, and the Lubbert's effect that preclude an accurate particle/photon energy measurement.

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Internet of radiation Sensors (IoS)

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The recent availability of affordable solid-state radiation sensors, of reliable and cheap micro-controllers and memories, together with new developments in the fields of wireless communication, low power

microelectronics and efficient batteries, make possible building a practical, fully automated and remotely controlled network of radiation sensors. The development of a network of smart radiation sensors is perfectly aligned with powerful trends in the contemporary technological landscape, as the far-reaching concept of the "Internet of Things" (IoT). The goal of the Internet of radiation Sensors (IoS) project is to design, build, test and operate such a network, with applications in the fields of environmental monitoring, individual dosimetry on the workplace and for the general public, monitoring and tracking of radioactive materials. It responds to the urgent needs of a vast community of scientists and researchers: on the one hand, it makes radiation monitoring more reliable, more sensitive, and more easily applicable to a variety of different situations; on the other hand, it drastically increases the quality of the data collected by a radiation monitoring system.
The initial development of the IoS project is thought for the CERN environment: considering the availability of unique infrastructure, distributed over a large geographical area, the variety of skills and expertise, and the highly diversified testing ground for radiation applications, CERN is in a truly unique position to host this research.
The IoS project can branch out into many applications for hospitals, environmental protection, monitoring of nuclear infrastructures etc. It may as well provide a platform for monitoring elements of environmental risk beyond radiation.

Summary:

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Development of large-format IR detectors in Europe

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Detectors are a critical component in all astronomical research equipment. Infrared detectors, in particular, have become more and more important for both ground-based and space-based astronomy. Yet the technology, based on hybridized HgCdTe/silicon, remains difficult and highly specialized. Currently, the US dominates world large-format (2kx2k and larger) detector production, with only 1-2 companies able to provide the quality necessary for astronomy. This single supplier problem results in very high prices,and ultimately risks loss of production capability should the manufacturer change its business interests. In addition, military heritage in the technology results in difficulties due to ITAR restrictions, especially for European customers.

Yet Europe has a number of smaller manufacturers who are expert in IR technology for tactical, security, and other applications. In recent years, ESA has provided funding to encourage European development of science-quality devices. The ATTRACT initiative offers a rare opportunity to leverage the further funding required to continue this development and ultimately establish European competition in this area of production.

Summary:

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Innovative devices for amplification of ionisation charge in liquid Argon Time Projection Chamber detectors

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The groundbreaking idea we are proposing is the development of innovative devices to multiply and collect electron charge generated by ionising particles passing through liquid Argon (LAr) medium.

The primary motivation is to make single-phase Liquid Argon Time Projection Chamber detectors (LAr-TPCs) sensitive to events with energy deposition of the order of 10 keV or less, 100 times smaller than present state of the art. The concept is to seek the multiplication of ionisation electrons directly in LAr at the end of their drift path by dimensioning and realising a Micro Strip anodic plane capable of generating an electric field locally large enough (˜ 1 MV/cm) to trigger the proportional multiplication of charge carriers. The feasibility of the project is supported by the positive results of pioneering attempts to multiply charge in LAr in proximity of micrometric wires, yet too fragile to be exploited in TPC detectors.

The impact on Particle Physics of low energy rare events is potentially dramatic, mainly in searches for Dark Matter interactions and coherent neutrino scattering characterised by O(100 keV) experimental signature and a O(10E-40 cmˆ2) cross section. Beyond fundamental Physics researches, achievements of the project will have immediate and interdisciplinary applications in Gamma-ray telescopes for measuring polarization of Gamma-rays and in high resolution Compton spectrometers for medical imaging or identification of explosive devices.

Summary:

LIQUID ARGON;
ELECTRON MULTIPLICATION;
MICROPATTERN DETECTORS;
LOW ENERGY RARE EVENTS PHYSICS;
DARK MATTER;
COHERENT NEUTRINO SCATTERING;
MEDICAL IMAGING;
GAMMA RAY TELESCOPES.

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3Dˆ3: Simple, Reliable, Low Cost Particle Dosimetry for Cancer Therapy using 3D printing and Geant4 simulation

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WHY:
The precise knowledge of the correct dose distribution delivered to the patient during cancer treatment is essential for a correct radiation treatment planning. This is particularly true in PEDIATRIC TREATMENTS where dose deposition in healthy cells could be catastrophic for the life expectancy of the patient. This information needs to be FAST,RELIABLE, REDUNDANT and LOW COST. At the moment precise dosimetry is a key open question in particle therapy.

HOW:
CT scanning is the tool used to detect tumors. The CT outcome is a digitized file which can be fed AT THE SAME TIME into a 3D printer and a simulation tool like Geant4 producing a true, tissue equivalent 3-dimensional replica of the organ,the tumor and its simulation object.

For precise 3-dimensional energy deposition information, the 3D-printed tumor-replica and its neighborhood can be divided into "voxels" filled with tissue equivalent liquid scintillator each read out separately by transmission fibers and silicon-photo-multipliers and exposed to the treatment beam. The same can be done in the G4 object.

These combined "physical" and "simulated" energy deposition tests can help to get a precise definition of the beam energy required for effective treatment and the dosimetry on the tumoral and the neighbor healthy tissues regions in preparation to the treatment planning with moderate cost and time delay.

Repetition of the tests with a new tumor-replica and G4 simulation is possible at any stage due to the rapidity and moderate cost of the process.

Finally:
The use of liquid scintillators would allow also to easily study the effects of the inclusion of enhancing treatment media like GOLD nano-particles which are believed to enhance the cancer cell removal.

Summary:

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HgCdTe APDs for low photon number IR detection

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HgCdTe APDs have opened a new horizon in photon starved Infra-Red (IR) applications due to their exceptional performance in terms of high linear gain, low excess noise and high quantum efficiency which have enabled single photon detection with high efficiencies from the uv up to the mid-IR range 1. These properties, which enables the detection of a few number of photons, down to single photon detection, with an ultra-low loss of the information contained in the photon flux, equivalent to an effective quantum efficiency of 70 to 80 %, combined with a large linear dynamic range offers an unique observation window of low photon number temporal and/or spatial information in the IR range. The performances of HgCdTe APDs, such as quantum efficiency, gain, dark noise, excess noise, response time will be discussed as a function of the spectral sensitivity of the APD that can be tuned by varying the composition of the compound semi-conductor [2-4] in order to achieve down to single photon detection for wavelengths ranging from the uv up to cut-off wavelengths varying between 2.5 and 10 µm.
HgCdTe APD prototype detectors have been developed for applications such as time of flight 3D imaging, astrophysics, free space optical telecommunications, photoluminescence or fluorescence life time measurements, gas LIDAR and singe photon detection. The presently achievable detector performance will be illustrated through a number of such application demonstrations made with prototype imaging arrays and single element detectors dedicated to extract the spatial and/or temporal information low photon number IR flux.

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[3] J. Rothman et. al., Short-wave Infrared HgCdTe Avlanche Photodiodes, J. Electron. Mater., 41, 2928, 2012.
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Summary:

HgCdTe avalanche photodiode enables the detection of a low number of photons from the uv to the mid-IR range with a close to negligeable degradation in signal quality. In this communication we will detail the physical principels of HgCdTe APDs and present the performance of already developped detectors and the perspectives for imaging and/or temporal analysis of weak IR photon signals.

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Spectral Imaging using Hybrid Integrated, Large-Area High Resolution X-ray Detectors

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In the commercial market, digital radiography is largely "charge integration" based, which results in a read noise that is composed of the quantum-limited photon shot noise, but also of electronic read noise and excess noise due to the non-reproducible charge packet sizes per absorbed X-ray photon. In X-ray imaging, as in other imaging domains, the ultimate sensitivity and signal-to-noise ratio are obtained when each incoming photon is counted - the so called quantum limit.
By this technique, significantly better image contrast can be achieved due to enhanced signal to-noise ratio. Also, since one can discriminate between energies and weight the contribution of each individual energy or each energy range to a final image, significant enhancement in image quality while reducing the radiation dose is and has already been shown to be possible. Other important advantages of the photon counting technique include the improvement of spatial resolution, the reduction of noise for the same quantum efficiency, and the ability to yield reconstructions with reduced beam-hardening and reduced ghosting artifacts due to lag providing the potential for single-exposure multiple-energy imaging.
The technology has numerous societal benefits. For medical application, this means that patient examinations can be done quicker, sharper images can be obtained and lower doses can be used. By additionally measuring the energy of the incoming photons, the energy information will enable tissue or material identification: Applications range from medical diagnostics, bone densitometry and mammography. Also Security applications can benefit by additional means to identify dangerous or forbidden substances hidden in closed containers, suitcases and bags.

In the last decades a considerable effort in the scientific field has been devoted to the development of active pixel devices for the detection of X-rays. Examples of such devices are the Medipix2 and Timepix ASICs. The size of these detectors is still in the 1-2 cm2 range, with typical 256x256 pixels. These developments have benefited from the advance of the hybrid integration technologies developed for the IC industry.

In order for these devices to become commercially interesting for a wide range of applications and (currently unserved) markets, R&D needs to be devoted to the following basic elements:

1. **Increase detector Size**: Applications call for several tens of cm2 (detector size up to 8 and 12 inch), a considerable increase from current devices. At the same time, yield of the combined ASIC/pixel stack needs to be addressed, in order to reach the 80 to 90% for complete stacks. Alternative architectures (both for design as for assembly) need to be developed.
2. **Reduce Cost Considerably**. An issue directly linked to the size of the detector, as well as the yield. Furthermore, assembly technologies tailored for large areas and (new) hybrid device architectures need to be developed and optimized and processing cost needs to be reduced. 3D printing is also potentially beneficial for packaging elements.
3. **Improve Scintillators**. Large area scintillators need to be developed with a high light yield, small decay times and high stopping power.

Our expertise is in the design and development of active CMOS detectors for large area detectors. Also, we have expertise in hybrid wafer to wafer technologies. By cooperating with various R&D partners in the different fields, we want to use our capabilities to build prototypes of energy resolved X-ray imaging and evaluate them in clinical tests, as well as in security trials.

Summary:

Digital radiography will greatly benefit from a change from "charge integration" to phonton counting technology. The advantages are numerous:
Better image contrast can be achieved, significant enhancement in image quality while reducing the radiation dose, improvement of spatial resolution, reduction of noise for the same quantum efficiency, and the ability to yield reconstructions with reduced beam-hardening and reduced ghosting artifacts
For medical application, patient examinations can be done quicker, sharper images can be obtained and lower doses can be used. By additionally measuring the energy of the incoming photons, the energy information will enable tissue or material identification: Applications range from medical diagnostics, bone densitometry and mammography. Also Security applications can benefit by additional means to identify dangerous or forbidden substances hidden in closed containers, suitcases and bags.

In the last decades a considerable effort in the scientific field has been devoted to the development of active pixel devices for the detection of X-rays, like Medipix2 and Timepix ASICs. The size of these detectors is still in the 1-2 cm2 range, with typical 256x256 pixels. In order for these devices to become commercially interesting for a wide range of applications and markets, R&D needs to be devoted to *increase size* (large size detectors on 8 to 12 inch wafers while still obtaining large yields), *reduce cost* (related to size and yield) and *improvement of Scintillators*.
Our expertise is in the design and development of active CMOS detectors for large area detectors. Also, we have expertise in hybrid wafer to wafer technologies. By cooperating with various R&D partners in the different fields, we want to use our capabilities to build prototypes of energy resolved X-ray imaging and evaluate them in clinical tests, as well as in security trials.

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Infrared sensor at high sensitivity for large surface

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In this work we present a challenging idea for the realization of an infrared sensor with high photon quantum efficiency (of the order of 90%), based on an array of micro antenna.
The state of art and the technical problem for realization will be discussed. We will present possible applications suitable for large surface particle detection.

Summary:

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New Generation of UV, IR and y - ray sensors with Carbon NanoTubes (CNT)

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Many types of Ultra Violet (UV) and Infrared Radiation (IR)
detectors are used up to now, based on a variety of materials depending on
the wavelength being detected. UV spectrum is of particular interest not only
in particle physics where scintillators emit in this region but also in other fields

like agriculture where the maturity of a fruit can be detected in UV("so called bee eye"). Concerning Chemical, Biomedical applications the use of Medium Wavelength Infrared (MWIR) spectrum in the range 3-5 μm is significant for gas identification and skin tumor identification but these cameras require cooling for good resolution. On the other hand γ-ray detectors are gas filled or solid state sensors like scintillators, silicon based strip or pixel detectors or even CdTe and Diamond sensors.

The main idea of this proposal is to build low cost and low operating voltage UV, IR and γ- ray sensors based on arrays of well-aligned Carbon Nano Tubes (CNT) in the form of Single Wall CNT (SWNT) or Multi Wall CNT (MWNT).
For the UV, IR sensor the plan is to develop a CNT layer on a Silicon substrate and to use the hetero-junction created when CNT are grown on Si as a
photo-detecting sensor. The Silicon substrate will be already preprocessed with lithographic techniques to build pixels. The periphery of each pixel will be used as electrodes to bias the pixel and get the signal out.
The advantages are: i) they can operate at Room Temperature in a wide range of UV spectrum (200nm -400nm) and IR spectrum (from 0.8 μm to almost 5μm), because the layer of MWNT's covers a wide range of diameters ii) there is no need for HV power supply since a low voltage of the order of 20V between the electrodes of the CNT pixel is enough to operate iii) matrix arrays of CNTs can be easily grafted on a surface in a variety of scales (from mm down to nm) by lithographically patterning a precursor and v) they are very cheap in production. A CNT layer width of a few tenths of microns is good enough for a UV or IR detector.
On the other hand in the case of a γ-ray detector with radiation source localization capabilities (i.e. Compton Camera) the width of the CNT layer required should be much bigger. This is because the main absorption mechanism for 200KeV to 2MeV γ rays (typical range of most of the radioactive sources) in Carbon is Compton scattering. To improve the radiation source localization resolution it is important
to trace the recoil electron path coming from the Compton scattering in order to shrink the compton cone and estimate the source of the γ rays. Calculation show that scattered electrons of about 1MeV are expected to travel about 2mm in Carbon and thus this is a good detector dimension to have full charge collection. Thus the γ-ray detector will be a pixel CNT detector based on the same topology presented above for the UV, IR sensor of about 2mm depth and 500μm x 500μm pixel size or even less to have enough hits to reconstruct the electron path.
TRL level: This is quite a new area of CNT application and thus the starting will be the study of the essential characteristics and behaviours of the CNT-Si system followed by the development of the simulation tools (TRL1,2).
Preliminary work has shown that such kind of detectors in the UV and IR part of the spectrum are possible. The parameters involved are the thickness of the CNT layer, the use of a tunneling layer, the conductance of the substrate and the use of a capping layer. Then the construction of a prototyping will follow (TRL 3,4) and with the help of a company the extensive test of the prototype in realistic conditions could be performed (TRL 5,6).

Summary:

The main idea of this proposal is to build low cost and low operating voltage UV, IR and γ- ray sensors based on arrays of well-aligned Carbon Nano Tubes (CNT) in the form of Single Wall CNT (SWNT) or Multi Wall CNT (MWNT).

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Future requirements for detectors in Electron Cryo-microscopy

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Detectors have played a central role in the structure determination of biological macromolecules to near-atomic resolution using electron cryo-microscopy. Over the past two or three years progress has been so rapid that it has been called a 'revolution' by a leading structural biologist 1. Further progress in detector technology is essential for obtaining near-perfect detectors with a faster readout and to have a higher time resolution in imaging mode. It has been established that the highest DQE can only be obtained in the 'counting' mode with electron sub-pixel impact localization [2].
Advances have been possible due to developments of detectors based on backthinned CMOS technology; these detectors have a high detective quantum efficiency for 300 keV electrons at all spatial frequencies and can read out at a sufficiently high speed to enable movie-mode imaging [3]. The detector development can be divided into two related parts: the detector and the readout and processing electronics. Our present detectors use 180 nm lithography, which have been superseded by 65 nm or finer lithography, with superior performance. We also need larger detectors with 8k x 8k pixels and faster readout to collect data at 2000 frames/second. Since the detectors are exposed to the direct beam of 100 – 300 keV electrons in the microscope they need to be sufficiently resistant to radiation damage over several years operation. Data readout, pre-processing and storage are challenging issues. During image recording data output will be several hundreds of GBytes/second, which needs pre-processing for event localisation and disk storage.
We think that a detector with the proposed parameters would transform the field of electron cryo-microscopy by allowing considerably more macro-molecular structures to be solved, which are not accessible with present day detectors. For example, such structures could include many lower molecular weight membrane proteins, whose detailed structure is vital for intelligent drug design.

1 W. Kühlbrandt, The Resolution Revolution, Science, 343 (2014) 1443-1444.
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[3] G. McMullan, A.R. Faruqi, D. Clare, R. Henderson, Comparison of optimal performance at 300 keV of three direct electron detectors for use in low dose electron microscopy, Ultramicroscopy, 147 (2014) 156-163.

Summary:

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A Novel Radio-guided surgery for complete tumor resection

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Radio-guided surgery (RGS) is a technique adopted by the surgeon to perform a complete lesion resection, taking advantage from the uptake from the tumor of specific radiolabelled tracers. Established methods make use of γ emitting tracer and γ radiation detection probe, but the high attenuation lenght of this radiation prevents the use of RGS when there are newarby uptaking organs.
To extend the applicability of RGS, our team of physicists, nuclear physicians, bio-engineers and chemists is developing an innovative technique exploiting β- radiation 1. It penetrates only a few mm resulting both in a lower required radio-pharmaceutical activity and the possibility to apply the technique also to cases with a large uptake of nearby healthy organs. Low background rate is also correlated with low medical team exposure.
To this aim, We developed and tested several prototypes of intraoperative β- probe, the core made of para-terphenyl scintillator[2]. The readout electronics is portable and customized to match the surgeon needs, with wireless data transfer to the PC.
In the current prototypes the p-terphenil is directly copupled with SensL SiPMs (series C).
Feasibility studies have been performed on DICOM images for meningioma, glioma,and neuroendocrine tumors (NET) [3,4] showing that even when the tumor uptake is too low for therapeutical treatments, like in the case of glioma, the sensitivity of the probe can be sufficient.
Besides these feasibility studies, we have also validated the technique on "ex-vivo" specimen of patients affected by meningioma, confirming the predictive model[5].
The actual diffusion of such technique requires:
- to be able to certify the prototypes for clinical use, performing the risk assessment (or eventual mitigation). This will allow a broader range of clinical tests
- to make the detector more versatile to be sensitivity to more radio-nuclides and to be useable also in laparoscopy
- to identify more tumors of interest and to develop new radio-tracers to be used in this technique. From the physics point of view this also involves studies on the production of beta- emitting radioisotopes, typically using neutron irradiation.

References:
1 E. Solfaroli Camillocci et al, "A novel radioguided surgery technique exploiting β− decays", Sci. Rep. 4, 4401 (2014)
[2] Polycrystalline para-terphenyl scintillator adopted in a beta- detecting probe for radio-guided surgery, E Solfaroli Camillocci et al 2015 J. Phys.: Conf. Ser. 620 012009
[3] F. Collamati et al, "Toward Radioguided Surgery with Beta- Decays: Uptake of a Somatostatin Analogue, DOTATOC, in Meningioma and High-Grade Glioma" J. Nucl. Med. 56:3–8 (2015)
[4] F. Collamati et al, "Time evolution of DOTATOC uptake in Neuroendocrine Tumors in view of a possible application of Radio-guided Surgery with beta- Decays" J. Nucl. Med. 56:1501–6 (2015)
[5] E. Solfaroli Camillocci et al, "First Ex-Vivo Validation of a Radioguided Surgery Technique with $\beta-$ Radiation", Submitted to Cancer Research

Summary:

Radio-guided surgery(RGS) is a technique that helps the surgeon to perform a complete lesion resection. Currently, RGS uses γ emitting tracers, to mark the cancerous tissue form the healthy organs, and a γ radiation detection probe. To overcome the limitations due to the high penetration of γ radiation, a novel approach based on β- radiation has been patented and developed(Camillocci, Sci Rep.2014;4:4401), allowing to include cases with high uptake of nearby healthy organs, and to benefit of a low medical team exposure.

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Laser techniques for a new class of scintillators

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Our ideas point to the development of a new generation of radiation detectors exploiting the rich collection of optical processes in laser spectroscopy, in line with the flourishing trend of interdisciplinary application of specific techniques to branches of Physics other than the ones in which they are widespread. Through modification, new functions are found in a different branch, where ways to overcome inherent limitations in its traditional instruments are finally found. This innovative approach is certainly promising, as demonstrated, for example, by the improvements brought by the optical frequency comb in astronomical observation 1.

We select three possible mechanisms to be applied in the field of radiation detection:
1. rare-earth (RE) upconversion
2. via phonon upconversion
3. laser oscillation/amplification
In *upconversion*, low energy incident radiation (e.g. infrared light) is converted into higher energy emitted radiation (e.g. visible light). It is efficiently accomplished by incorporating rare-earth ions in inorganic matrices. In fact, the f-electron configurations of these ions, a three- or five-level energy cycle can be identified, in which energy is first absorbed by the ground level (0) to reach a metastable intermediate state (1), characterised by relatively long lifetimes $\sim$ ms. Subsequently, another excitation photon delivered by a pump laser tuned to the transition from level 1 to 2 promotes the ion to the state (2). A radiative transition from this latter excited state back to the ground state or some other lower-energy state, results in a higher energy photon emission. To date, this mechanism has been extensively applied for the development of lasers and optical devices, but it has not yet been applied to particle detection. In the envisaged detector, the active material is transparent to the pump radiation, until a particle excites low energy levels (hundreds to tens of meV) and triggers a fluorescence signal from a higher level, to be detected with conventional detectors.

A particle interaction in a material gives rise to *phonons* as well. Through a careful selection of the active material, the generated phonon energy can be converted to a photon via another photon, delivered by the pump laser, whose energy is smaller than that required for the selected transition. This idea follows the well known mechanism of laser cooling of solids (or optical refrigeration), an anti-Stokes process that has been demonstrated to allow cooling of solid state materials from room temperature through a net temperature drop of 190 K [2].

Finally, another key photonic process we envisage as applicable to the field of radiation detection is the coherent amplification of photons.
An OPO (optical parametric oscillator), a wave-mixing nonlinear device, might for example be approached as a particle detector, provided the nonlinear material in which wavelength conversion takes place is also a good scintillator. The particle interaction would trigger a coherent emission if the OPO cavity is operated just below threshold.

The great potential of these new, all-optical detection approaches lies in the possibility to lower the energy threshold in relatively large detector volumes, opening a window in experiments devoted to the search of particles that interact with matter only very weakly.
As sensors of ionizing radiation fields, in the shape of small RE-doped optical fibers, they might well be employed in medical dosimetry, to monitor remotely a real time dose radiation field with punctual evaluation.

1 Science \textbf{321}, 1335 (2008)

[2] Nature Photonics 4, 161 - 164 (2010)

Summary:

upconversion, laser, coherent scintillation, solid-state detectors, anti-Stokes

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PixFEL: high resolution, fast, multi-tier detectors for diffraction imaging at next generation X-ray FELs

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The use of large accelerator-driven X-ray sources, such as those available at the synchrotron light and X-ray free-electron lasers (FEL) facilities, continues to grow and expand to many scientific disciplines worldwide. These research centers are now driving the state of the art of X-ray science, therefore shaping the requirements for many types of X-ray detectors. X-ray FELs in particular can offer unprecedented capabilities in penetrating the microscopic structure of organic and inorganic systems, new materials and matter under extreme conditions and in recording and understanding the time evolution of fast biochemical phenomena at the nanoscale.
The aim of the PixFEL collaboration is to provide the X-ray FEL users community with a new, hybrid pixel detector for X-ray diffraction imaging applications compliant with the very challenging specifications set by fourth generation FELs in terms of input dynamic range, processing speed, amplitude measurement resolution and radiation hardness. The detector will have a multi-tier structure. The sensitive layer will consist of a slim edge silicon pixel detector to minimize the dead area at the sensor edge. The front-end chip will result from the vertical integration of two layers, one devoted to the analog front-end and the ADC, the second one to dedicated memories used to accumulate data in applications with high X-ray pulse rates. The analog processor is based on a time variant solution, including a charge preamplifier with a dynamic compression feature based on the non linear characteristic of a MOSFET capacitor. The converter relies on a 10 bit resolution, time interleaved, SAR architecture with split capacitor DAC. The power dissipation per channel, including dynamic power consumption in the SAR ADC, is about 230 uW. A 65 nm CMOS technology will be used to accommodate all the needed functions in a pixel pitch of 100 um. More scaled technologies may be employed in the memory layer to increase the storage capacity of the chip. Maximum flexibility will be pursued in the front-end design, to broaden the detectable photon energy range as much as possible and make the detector suitable for different beam structures and rates. Interconnection of the sensor to the front-end electronics will be accomplished through vertical integration techniques to minimize parasitic capacitances and optimize the system noise performance. The target of the project is the fabrication of an elementary tile based on a 64x64 cell array to compose a 20 cm x 20 cm, 4 Mpixel camera with less than 2% dead area, more than 5 MHz sampling rate and more than 1 ksample per cell storage capacity.

Summary:

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A new High-Rate and High-Resolution X-ray Spectroscopy Detector for Synchrotron XRF and XAFS Applications

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Despite the effort in developing suitable detectors for X-ray fluorescence measurements at synchrotron light sources, e.g. for XRF and XAFS experiments, in many applications the capability

of fluorescence spectroscopy detectors is rather limited. The high-rate performances of current detectors may be further challenged due to the ongoing machine upgrades or for the use in future sources where a factor between 10 and 100 of beam-on-sample fluxes may be increased with respect to the present conditions. Despite different commercial options for SDDs-based systems presently available, these are actually limited to single- or few-channel systems (4-7 units maximum). This motivates a new, sharp transition of this technology toward compact, multi-channels, high-density systems (hundreds of channels) to build high-resolution, high-rate and also versatile systems for synchrotron radiation applications. We propose a new detector development aimed to cope with this challenge in the following years. The detector is based on monolithic arrays of SDDs (e.g. 8x8 units of 1mm2 area each) bump bonded to a readout ASIC containing the full CMOS readout chain, from the charge preamplifier to the ADC. Although the detector-ASIC bump bonding architecture is rather popular in X-ray imaging detectors domain, it has not been significantly explored for X-ray spectroscopy-grade detectors and surely not for SDDs. The challenge here is to obtain a hybrid, monolithic detector based on SDDs with a high channel density but still keeping the adequate spectroscopy performances required by the target synchrotron applications. The readout chip will be composed by a CUBE preamplifier, a state-of-the-art CMOS preamplifier for SDDs for the first time integrated on the same chip with the remaining electronics analog chain, an analog shaping amplifier and an ADC for the on-chip data digitalization, a feature which allows to transmit data out of the detector with high robustness with respect to external pick-ups. At the shortest possible processing time, e.g. 100ns, an energy resolution better than 150eV at 5.9keV can be obtained, with an output counting rate larger than 1Mcps/channel, that, multiplied by the number of channels could allow to achieve several tens of Mcps/detector. The monolithic detector unit will be designed to allow a compact assembly of several units which could increase the count rate capability of the overall detection system up to few hundreds Mcps. This development could lead to a new generation of X-ray spectroscopy detectors for the next generation of high-brightness synchrotron experiments.

Summary:

• X-ray spectroscopy detectors
• X-ray fluorescence
• X-ray absorption fine structure
• CMOS readout ASIC

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A scalable gas pixel detector based on micro-Resistive-WELL technology for X-ray and neutron imaging

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The micro-Resistive-WELL (μ-RWELL) is a compact, spark-protected, single amplification stage Micro-Pattern Gas Detectors (MPGD).
The new micro-structure based on the resistive technology concept of a very efficient spark quenching is a high reliable device. In addition, since the detector does not require any complex as well as time-consuming assembly procedures (neither stretching nor gluing), it becomes extremely simple to be assembled. These features allow an easy engineering of the detector that could result in industrial applications.
The new detector is composed by only two elements, i.e. the readout-PCB embedded with the amplification stage (the core of the detector named μ-RWELL_PCB), and the cathode.

The amplification stage of the detector realized by photolithography as a matrix of wells (with a pitch of 140 µm and a diameter of 60-70 µm) on a 50 µm thick polyimide substrate is embedded through a resistive layer combined by the readout board.
The resistive layer can be prepared by different technologies, such as, for instance, DLC (Diamond Like Carbon) dry sputtering or screen printing. The required surface resistivity, typically ranging from few units to hundreds MΩ/square, is clearly a crucial parameter that must be optimized as a function of detector performance. A cathode electrode defining the gas conversion-drift gap completes the detector mechanics.
The proposed technology, suitable for large area tracking devices and compact digital hadron calorimetry in HEP experiments (it has been proposed for the phase-2 upgrades of CMS and LHCb muon apparatus and for the neutrino detector of the SHIP experiment), can be exploited for fine X-ray and thermal neutron (using suitable lithium-fluoride or Boro-10 coated cathode) imaging in industrial applications.
Neutron science, acting in a complementary way with respect to X-ray, gives us knowledge that improves our everyday lives, our health and our environment.
As an example neutron imaging is suitable to investigate DNA molecules and proteins that control aging and cancer, opening the way towards the development of new techniques and more effective treatments and medicines. Further examples of neutron science applications in the environmentally friendly materials and processes are: fuel cells driven by hydrogen, solar power, climate technology, new generation materials and life science.
For both X-ray and neutron imaging applications the detector must be designed with a multi-pixel anode (pitch of the order of 1 mm) that coupled with a suitable front-end electronics with charge readout will allow fine 2D-track reconstruction by charge centroid (about 50 µm image resolution). In addition using Time to Digital Converters (TDCs) to extract the arrival time of the ionization clusters, a full 3D-reconstruction of the event would be available (µ-TPC mode).

The development of a dedicated ASIC solution for the read-out of the µ -RWELL, based on 130 nm process technology, is crucial in order to fully exploit the detector potentiality.
A typical read-out chain will consist of a high gain and low noise pre-amplifier stage, followed by a suitable shaping, tail-cancellation stage and a discriminator, to obtain a binary read-out. The discriminated signal is typically used for time measurements being the input to a Time to Digital Converter (TDC) circuit, having resolutions in the order of 1-2 ns (r.m.s.). The TDC can be integrated on the same circuit containing the amplifier, shaper and discriminator.
Thanks to new microelectronics technologies a very dense Front-End electronics characterized by low-power consumption, low-noise, selectable-gain and complying high rate and harsh radiation environments may be proposed satisfying charge and timing requirements.
Either a separate chain or a dedicated signal processing chain have to be foreseen for position and timing measurements together with an adequate digital pipeline length to account for trigger latency. Since the device is used in multi-disciplinary applications, where self-trigger capability is generally required, the architecture should be operated also in data-driven mode.

In conclusion the µ-RWELL detector with dedicated integrated electronics is a high performance, wide impact, scalable device suitable for both large area applications in HEP (as tracking device) and industrial and medical applications (as X-ray and neutron imaging gas pixel detector).

Summary:

The project aims in developing a new scalable gas pixel detector based on the micro-Resistive-WELL (µ-RWELL) technology with a dedicated front end electronics for X-ray and neutron imaging purposes. The novel architecture is a compact, spark-protected, single amplification stage Micro-Pattern Gas Detectors (MPGD). The micro-structure exploits several solutions and improvements achieved in the last years for MPGDs, in particular, for GEMs and Micromegas.

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Fastissimo ..or the ultimate design for ultra-high speed radiation sensors

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We propose to develop silicon sensors with excellent time (˜10 ps) and position (˜25 um) resolutions. This can be achieved by taking advantage of the fast response properties of MEMS based 3-Dimensional (3D) sensors with trench-electrodes processed throughout the silicon bulk rather than on the wafer's surface and a modified read-out electronics based on fast current amplifiers.
3D sensors are particularly favoured for timing applications due to their electrodes configuration, which allows strong and homogeneous electric fields, inter distance as close as 50 microns and large signals. The particle arrival time can be measured by using the rise time of the induced current signal with reduced fluctuations due to the fact that in 3D sensors all charges along the ionization track, including those from delta rays, are generated within similar, and at the same time shorter, distance from the collecting electrode. This is to be compared with planar sensors where each charge carrier from an impinging minimum ionising particle is generated at a different distance from the collecting electrode, inducing peak signals at different times.
So far the fast response characteristics of 3D sensors have not been fully exploited, because of both non-optimized sensor design and technology, and limits coming from the read-out electronics. However, a time resolution ranging from˜30 ps to ˜180 ps, depending on the signal amplitude, was already obtained1 giving hope to further improvements with a dedicated design of both sensor (in 1 year) and electronics (longer time).
Preliminary TCAD simulations also show that electric field values high enough for carrier velocity saturation can be obtained in most of the sensitive volume by adopting an hexagonal 3D cell, with current signal rise times of ˜10 ps, regardless of the particle impact position.
It should also be stressed that the proposed sensors also maintain all earlier features of 3D sensors such as extreme radiation hardness and sensitivity to the last few microns of the sensors's volume by the use of active edges.

1 S. Parker et al., "Increased speed: 3D silicon sensors; fast current amplifiers", IEEE Trans. Nucl. Sci. NS-58, 2, 404-417 (2011)

Summary:

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Radiation Detection Technique based on new Tunable Flux Array Device

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In a recent research, a nanometric pattern of niobium islands implemented as a controllable regular fluxon-array was used to investigate the phase transitions with stable and metastable states (vortex insulator-vortex metal state) in competing regular vortex configurations [Nicola Poccia, Tatyana I. Baturina, Francesco Coneri, Cor G. Molenaar, X. Renshaw Wang, Ginestra Bianconi, Alexander Brinkman, Hans Hilgenkamp, Alexander A. Golubov, Valerii M. Vinokur, Science , 349 (2015) 1202]. These structures (80μmx80μm) (300X300=90000 Nb islands) were produced at 'MESA Institute for Nanotechnology, University of Twente'. In detail, this device is realized on a silicon/silicon oxide substrate where is grown a metallic gold template with four contacts. On this 'template' an array of niobium superconducting islands is realized with a period around 270nm. The island diameter is 220nm, the separation is 47 nm and the island thickness is 45 nm. An applied magnetic field (0-100mT) can induce the localization of different magnetic-vortex arrays between the superconducting

islands, because of the weak superconductivity proximity effect. A simple I-V technique controls the dynamic state of the superconducting system.
Our idea is to use this new nanometric superconducting device as a radiation detector. In fact, it is possible to select a particular 'flux array configuration' with an applied magnetic field and to monitor the induced variations in the flux-array structures by incident radiation with a simple I-V measurement at 1.4-4.2K fixed temperature. The breaking of a cooper pair should trigger the transitions to a state with different flux configuration. Hence, the system should be sensitive to energy of the order of few meV.
Three analysis types are possible by monitoring: 1) the dynamic resistivity variation dV/dI between superconducting-normal state (bolometric effect); 2) the dynamic resistivity variation between two different competing stable flux-array configurations (non-bolometric effect); 3) the dynamic resistivity variation between vortex metallic-vortex insulator state in a fixed flux array (non-bolometric effect); the latter effect, should have a faster response. Moreover, this new superconducting device can be a promising new kind of single-photon detector. The technology to achieve this device is similar to that used for the well-known nanowire single-photon detectors that offer high efficiency, low dark counts, excellent timing resolution. In our case we also have an additional fine control on detectable energy through an additional control parameter: the magnetic field that fixes possible different array-configurations in the device.

Summary:

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Monitoring of hadrontherapy treatments with a novel tracking devise based on charged particle detection

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Protons and carbon ion beams are presently used in hadrontherapy to treat many different solid cancers. Compared to the standard X-rays treatments the main advantage of hadrontherapy technique is the better localization of the dose in the tumor region sparing healthy tissues and surrounding Organs At Risk (OAR).
The intrinsic precision due to the peculiar features of dose release at the end of the range in hadrontherapy with respect to photon radiotherapy is somewhat threatened by uncertainties (inhomogeneities, Computed Tomography (CT) artifacts, inter session anatomical/physiological changes and others) in the knowledge of actual primary particle range. Nowadays these uncertainties are managed by means of safety margins around the tumoral region but for quality assurance a dose deposition monitoring is necessary.

The interaction of the incoming beam radiation with the patient body in hadrontherapy treatments produces secondary charged and neutral particles, whose detection can be used for monitoring purposes and to perform an on-line check of beam particle range. Charged particles are potentially attractive since they can be easily tracked with a high efficiency, in presence of a relatively low background contamination. In order to verify the possibility of exploiting this approach for in-beam monitoring in hadrontherapy, and to guide the design of specific detectors, both simulations and experimental tests are being performed with ion beams impinging on simple homogeneous tissue-like targets (PMMA).
The results obtained so far show that the measurement of charged particles can be successfully implemented in a technology capable of monitoring the dose profile and the position of the Bragg peak inside the target and finally lead to the design of a novel profile detector.

We present a new tracking device, developed in the framework of the INSIDE project. Charged tracks are detected using 6 planes of scintillating fibers ($0.5 \times 0.5\ mm^2$) with orthogonal views, readout by Silicon PM, followed by a plastic scintillator and by a small calorimeter made of a pixellated LFS crystal. The achievable spatial resolution for single charged particle has been studied by means of a full simulation of the device, benchmarked against experimental data, and a dedicated reconstruction code. Charged particle yield as a function of primary energy, thickness of material and device positions with respect to the patient have been considered in order to establish a possible procedure for real-time comparison of measurements with expectations in the actual clinical operation.

Summary:

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The technological challenges for the EISCAT-3D radar system

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The radar system will be built in several stages as funding is provided. For the first stage, it will consist of three radar sites, each with 9919 crossed dipoles divided into 109 sub-arrays. On one of the sites, about half of the antenna will be equipped with transmitter units, giving about 5MW of total transmitter power. All of the sites will receive the scattered signal from the transmitted radio pulses, and at each of the antenna elements the signal will be digitised. This is done to be able to point the whole collective antenna into about 100 different directions simultaneously. This puts a large challenge onto the hardware and software.

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The data will go through several steps before it's ready as a scientific product, each of them demanding large resources: two stages of beam forming, a 1D profiling with first analysis results, a 3D profiling with a full analysis, and a selection process of what will be finally stored in the data archives. As with all environmental data, all data is unique, and the with the richness of the EISCAT data there will be a continuously reanalysis done by the users for studies of different aspects.

The first beam former is taking the digitised signal from each antenna element at about 100MHz speeds, delaying the signal at 10 ps resolutions to steer the beam (look direction), mixing the signal down to base band, and filter it and re-sample it. The delays are individual for each antenna and ten simultaneous look directions are formed. This process is done using FPGA technique and needs very accurate timing given by the White Rabbit protocol. This is done separately for each of the 109 subarrays, and the data is going with high speed network into a central site server. Here is the 2nd beam forming unit, based on a CPU cluster, where each of the 10 beams are divided into further 10 narrow ones, making a total of 100 look directions. After the beams are formed a first analysis of the data is done via decoding of the signals and computing spectral components.

The data from the radar sites will be processed online at the Operations Centre, estimated for 500 Tflop/s processing and 20PB buffer storage, and used to simultaneously direct the radar and search directions. The challenge for this Operations Centre computing is to combine the data online from multiple sources into three-dimensional data products using tightly-coupled high-throughput computing. These data products must then be used to control the radar direction and the search directions of the receive sites.

The EISCAT_3D scientific programme encompasses many areas of study, one of the key areas being the Geospace Environment, ranging from troposphere out to the topside ionosphere some at 2000 km altitude, along with Climate change, Near-Earth object studies, Radio astronomy and Micrometeors. The Operations Centre computing must be able to react and adapt between the science cases in real-time as natural phenomena occur randomly and are not repeatable.

Summary:

The EISCAT Scientific Association will establish a system of distributed phased array radars, EISCAT_3D, which is an environmental research infrastructure on the ESFRI (European Strategy Forum on Research Infrastructures) roadmap. Once assembled, it will be a world-leading international research infrastructure to study the atmosphere in the Fenno-Scandinavian Arctic and to investigate how the Earth's atmosphere is coupled to space. The use of new radar technology, combined with the latest digital signal processing, will achieve many times higher temporal and spatial resolution over larger volumes than obtained by present radars while offering continuous measurement capabilities.

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Silicon-based micro-dosimeters for advanced radiation therapies

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Radiotherapy is used for the treatment of cancer in almost 50% of the patients, both for curative or palliative aims. The introduction of advanced techniques such as hadrontherapy, based on the use of protons and heavier charged particles, i.e. carbon ions, is currently a growing modality of radiation therapy. These particles deposit a larger amount of energy per unit particle track length than conventional RT sources and they create a highly conformal high dose region with the possibility of covering the tumor volume with high accuracy, while at the same time delivering lower doses to the surrounding healthy tissue. In 2016, according to data from the Particle Therapy Co-Operative Group, there are 61 particle therapy centers in the world with 32 others under construction (19 and 10 in Europe, respectively).

Treatment planning systems are used to determine the dose distribution obtained for a certain beam arrangement to be applied to a tumor volume. In the case of hadrontherapy, this is challenged by the need to account for the different radiobiological efficiency (RBE) of the beam depending on its primary energy and depth in tissue. This RBE has to be modelled and used in the treatment to optimize the tumor control probability and minimize unintended side effects due to normal tissue irradiation. **Using radiation microsensors that can experimentally verify microdosimetric characteristics would have a fundamental impact on treatment planning. In fact no adequate biodosimeters are currently available for the routine verification of biological dose in hadrontherapy.** Existing methods are software-based using Monte-Carlo simulations, or based on gaseous chambers that have cm3 volumes, suffer from wall effects, require a gas supply, perturbate the fluence significantly and provide only single-point measurements.

Silicon-based device fabrication can produce tailor-made micrometer-scale micromachined structures. Additionally, silicon sensors are operated at low voltages, are small and portable with fast time response. The Spanish National Center of Microelectronics (IMB-CNM, CSIC), building on more than 15 years' experience of producing advanced silicon detectors for nuclear and high energy physics experiments, has developed a **silicon microsensor technology that can provide cell-like silicon sensitive volumes to allow for unprecedented spatial and dose resolution**. Proof-of-concept devices have already been used to characterize with high accuracy the radiation quality parameters of carbon and proton beams.

Our goal is the realization of a **complete microdosimetry system for the verification of the biological efectiveness of hadron treatment plans based on this novel silicon technology**. We propose to address this challenge with a well balanced multidisciplinary team with a strong combination of expertise including microelectronics technology, electronics, system integration, data processing, Monte-Carlo simulation, radiation therapy and radiobiology.

Summary:

Keywords: Radiation science and engineering, advanced radiation applications, hadrontherapy, dosimetry.

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Highly granular MAPS detectors with fully integrated data processing for particle detection and imaging

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The next generation of CMOS MAPS detectors for particle physics applications are driven by the need for optimal resolution, which requires high pixel granularity and minimal material. At the same time, the need for high-speed readout imply sophisticated in-pixel and on-sensor data processing, which is very difficult to achieve with current technologies. Hybrid solutions are prohibitive in terms of material and cost. A natural way forward is to move in the third dimension and to stack several CMOS layers on top of each other. This will allow all the necessary in-pixel electronics to be distributed over several CMOS layers and to separate analog front-end and digital back-end of each pixel. However, the technological advantages do not stop there as individual layers can now be optimized for a particular functionality which then allows us to take advantage of the best materials and processing for: sensing, digital and mixed mode applications. The availability of deep-submicron (65 nm or smaller) layers will enable us to integrate advanced digital data-processing like e.g. machine-learning-based clustering, or to provide precise sub-ns timing for pixel hits, providing a key ingredient for a 4D-Tracking approach. By combining the hits over several sensitive layers we can form tracklets within a sensor unit, which can further reduce the occupancy due to fake hits or extremely low-momentum tracks. In the next few years there will be a paradigm shift in the way we construct tracking detectors which will allow us to exploit flexible and adaptive technologies to optimize performance.

Summary:

MAPS, Stacking, deep sub-micron , CMOS, 3D Integration

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Plasma driven UV FEL test experiment

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This work will be performed in collaboration with DESY (Germany) and UCLA (USA)

Summary:

A high quality electron beams produced by a plasma accelerator module at SPARC_LAB could be injected in in a short period undulator of new type, for example a RF or Optical undulator, thus enabling the investigation of the performances of a compact UV FEL source, an extremely important contribution towards the V generation light sources development. INFN will contribute with its expertise in the characterization of the time duration and intensity of the pulses with cross correlation experiments. Benchmark experiments of non-linear optics in isolated samples and pump-probe measurements on nanoparticles and biological samples will be performed to compare the performances of the radiation produced with the typical ones of fs table-top lasers.

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Plasma Acceleration staging

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This work will be performed in collaboration with HU (Israel) and UCLA.

Summary:

The basic of Laser Wake field acceleration (LWFA) scheme is limited by the diffraction of the laser pulse, the de-phasing of the electron bunch and finally by laser energy depletion. To overcome these three limitations of LWFA schemes various solutions were proposed and demonstrated, except for laser energy depletion. Concatenating (staging) tens GeV-level acceleration units is a natural solution to drive X-FEL photon sources. This approach is taken by BELLA project at USA. However, employing conventional optics to couple the laser energy into the acceleration region sets the length of a single unit to more than one meter. We propose demonstration of employing the curved capillaries (developed in Hebrew University) to combine guided multiple high intensity laser pulses (from FLAME laser system at SPARC_LAB) into a single channel and accelerate the electrons injected by the SPARC_LAB high brightness photoinjector. The proposal is based on an initial demonstration by Hebrew University group of laser beam combining by the curved channels and the current development of external injection schemes (EXIN) at SPARC_LAB. This proof of principle experiment can lead to the compact multistage LWFA acceleration channel where the interaction with electron bunch takes place. In our scheme, the overall length of a basic accelerating unit that combines two high intensity beams unit is about 5 cm (not limited to) leading to a significant reduction in the overall length of the accelerator. The plasma channels in this experiment were created using ablative capillaries. It can be easy extended to other capillary channels were the discharge is mainly conducted by gas.

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Adiabatic plasma lenses

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This work will be performed in collaboration with UCLA (USA) and HU (Israel).

Summary:

One of the key elements of the plasma blowout regime is the strong, linear focusing provided by the ion density. This focusing provides highly effective transverse guiding of beams. One advantage of this focusing is its extraordinary strength, which has led to the underdense plasma lens to be proposed as an element of a plasma based radiation sources. Another advantage of underdense plasma focusing is its flexibility, the extreme strength of the focusing gradient is simply proportional to plasma density , which may be easily changed experimentally.
The adiabatic plasma lens is a potentially transformative technique for advanced radiation sources, and is based on this flexibility, relying on an adiabatic increase in focusing to funnel the beam size down to very small spots. As such, it may be used to mitigate the need for very long beam transport systems.
This idea can be paired with a related concept, that of plasma matching and beam transport between each plasma accelerating module stage, to diminish the ultra-strong beam-plasma transition forces that produce effects that notably damage the quality of the accelerated beam.

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Energy spread de-chirper

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This work will be performed in collaboration with DESY (Germany) and HU (Israel)

Summary:

We aim to show energy-chirp compensation of electron beams in a plasma, providing the basis for efficient beam transport and ultimately to allow the utilization of plasma accelerated beams for photon source application. The main reason is that although different injection schemes have been proposed for plasma acceleration modules, they all are expected to generate a significant monotonically changing, mostly linear, energy-chirp, with the energy increasing from the head of the beam to the tail. The proposed method relies on the fact that longitudinal fields as seen by a short driving beam are decelerating and thus, can be used to compensate an initially imposed energy-chirp. This offers the possibility to cancel the energy chirp of the accelerated beam by making him drive a plasma wave. The resulting wakefields will make the tail of the drive beam lose energy, while the head is unaffected. Since the accelerated beam is very shorter, the plasma density can be adjusted at the end of the acceleration module to bring the beam to drive a wake for "self-dechirping". To this end a dedicated design, production and test of the plasma module is required.

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Real time data analysis at the front end: enabling interactivity on complex and big data

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A device based on critical decision-making must evaluate data in a time scale short enough for the decision to be useful in the application context. Exemplary cases are the autonomous vehicles and robots, or medical robotic prosthetics, with the inherent needs to fast and meaningfully react to the environment. The very same need is also present in frontier science experiments, where sensors produce higher than manageable data flows, and data driven selective fast decision is needed, also known as either trigger or compressive sensing.

The above-mentioned problems are often combinatorial, because data produced by individual sensors assume a meaningful interpretation only in correlation with the other sensors, in a non-predictable way. Their computational complexity represents a limit to the present state of the art systems, when the tolerated latency prevents to use a distributed computing architecture (such as a cloud) or when the application dictates severe limitation in local weight, volume and power consumption. In facts, the classic approach is based on a rigid sequence: sensor-digitization-serialization-transmission-deserialization-computing. This scheme, where any intelligence is centralized far away from the sensor, is generally adopted due to the digital standardization advantages, but is in principle inefficient since it accumulates latency and concentrate the data before any processing, which is the opposite of what would suggest a divide and conquer strategy.

A representative attempt to implement a fast decision process are the Associative Memories, content addressable memories that contain a set of precomputed solutions for a fixed set of inputs. These are very fast solutions to manage a big data flow, but their potential scalability is strongly limited by the fact that the address space grows with a factorial progression with dimension of the input parameter space.
Deep neural networks (DNN) are considered instead the mainstream approach to complex data. They

consist in a concatenation of simple neural network trained with data, behaving like tailored filters, as flexible as the number of layers of concatenated networks, each representing a possible degree of freedom for the data matching. DNN are more and more often optimized by running on GPUs and/or FPGAs, to increment their speed, at the expenses, though, of power consumption. The amount of flexibility is appreciable but limited by the fact that a DNN is essentially a black box, every time learning from scratch, thus not eligible for an engineering based on incremental knowledge trough problem modelling.

An attempt in overcoming these limitations, is the Weighting Resistive Matrix technique (WRM), conceived for discriminating vertices in real time in HEP experiments; by relying on an analog computing architecture it implements the equivalent of a probabilistic regression at nanosecond scale, without actually computing but exploiting the physics of a specific network. Thanks to this it extracts directly from data the most likely fit parameter values, using the energy of the input signal in a single clock cycle independently from the input. For this feature the WRM is an extremely fast and low power consumption device. A WRM chip has been already produced for HEP and adapted to artificial vision applications. The extensive studies performed in this application, from the full software simulation to the real demonstrator, have shown that WRM potential has never been fully exploited as it is essentially hindered by the digital design inheritance of the present WRM, and by the limited dimensionality of the matrix, constrained by the standard IC technology. The study finally revealed an impressive and very inspiring similarity between the WRM technique and the neural information processing, from the retina up to the visual cortex.

We propose to develop a new IC architecture, inspired to the WRM principles and overcoming its limits, integrating sensors, front end and data processing in the same device, to work ahead of the digitization so to achieve an extreme computing power intensity per electric power unit. This will be done by studying a fully analog neuro-inspired matrix, relying on a high level of internal connectivity, which can be dynamically configured through a memristors-like network. We intend to investigate how this technology can be employed to enable data driven decision at the front end, across successive levels of data abstraction, enabling the mobile things awareness concept. We envisage as realistically reachable target a new generation of reliable and lightweight self-driving vehicle and autonomous robots safely interacting with the environment.

Summary:

Seeing, not watching, feeling not sensing: smart sensors front end concept for awareness in complex environment.

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CMOS pixel sensors with on-chip Neural Network: A new horizon for embedded systems?

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Since the early 1990's, CMOS Pixels Sensors (CPS) have become the most successful member of the family of Monolithic Active Pixel Sensors (MAPS), consisting in an array of pixel sensors and on-the-chip circuitry (e.g. preamplifier and digitization) on the same silicon substrate. They are now widely used in a large panel of applications, from visible light detection in cell phone camera or digital single-lens reflex, X-rays detection and imaging, up to charged particles detection in high

energy physics. Besides integrating the sensor and the signal treatment in the same substrate, this technology offers several advantages: small achievable granularity, sensitivity to different type of radiations, possible thinning down to 50 μm to reduce material budget, and competitive radiation tolerance. Furthermore, CPS have been sustained by constant progress in the industry allowing to reduce costs.
Recently, new technologies have become available, reaching a deep sub-micronic feature size (from 180 nm down to 65 nm and even lower), offering various properties (e.g. high resistivity epitaxial layers) and various advanced features (e.g. quadruple-well implant). This allows to add more and more elaborated functionalities in a given area. Finally, integrating more signal treatment on the pixel itself and/or the chip periphery, allows to consider more complex operations both on the analog signal and on the digital output, in order to compactify the useful information in the output. This should translate into an output bandwidth reduction, a possible enhancement of the read-out speed and at last but not least a power consumption reduction.
In another domain belonging to Information Science, signal treatment and image analysis made very significant progress in the last decade thanks to algorithms based on bioinspired network models. Advanced techniques (e.g. deep learning, h-max algorithms) allow considering more and more applications for embedded systems in various applications (pattern recognition, face recognition, clustering, robotics to assist handicapped persons, etc.). However severe limitations still exist (robustness, adaptability to various environments, power consumption, maximum footprint, etc.). These constraints represent real technological obstacles.
One way to overcome these issues is to combine the progress of the two domains mentioned above (CPS and bio-inspired neural network). This leads to the concept of smart CMOS sensors using neural networks integrated on the chip. The expected added value is to allow both an advanced treatment of the data and a reduction of the bandwidth in the same time. At last but not least, this should enhance the adaptability of the technology counterbalancing the inherent rigidity of any very integrated system. One expects that this will open the door for a wide range of new applications. For instance, in particle physics, one could investigate how the vertex detector of the International Linear Collider (ILC) could use this feature to reject the hits generated by the beam background, taking advantage of their particular cluster shape they create on the matrix of the sensor.
One will give a short overview of the state of the art of CPS technology and describe the expected challenges of the described idea. Finally one will briefly explore the potential applications of CPS integrating neural networks in various fields.

Summary:

Continuous and recent progress in CMOS pixelated sensor technology allows to integrate more and more signal treatment and functionalities in the chip itself. Secondly, neural networks algorithms are extensively used in embedded systems but with some technical limitations in terms of integration. One will present the concept of smart CMOS sensors using neural networks integrated on the chip which could overcome these limitations.

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High resolution radiographic detector based on multi-channel-plate.

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The aim of this project is to increase the efficiency of the prototype of the imaging detector dedicated for NDT (non-destructive-testing) industrial radiography. This prototype was built in National Centre for Nuclear Research, Poland.
The main part of the detector is 10x10cm pixelized scintillator based on GEM foil, used as a multi-porous-material (and not as an electron amplifier). Dedicated GEM foil was produced with the holes

diameter 50um, while the distance between holes centers is 80um. Also, the holes in the GEM foil are not hourglass-shaped walls, but straight for bigger capacity.
In each hole the powdered GADOX scintillator has been placed and then locked by transparent cover. Flat distribution of the Gadox powder was achieved thanks to the use of ultrasonic densification and Gadox powder sedimentation.
Such pixelized scintillator converts X-rays into visible green light, reflected then by front-covered mirror and transported through optical elements to high-efficiency CMOS camera. Problem of dark-areas of the detector has been solved by fast movement of the pixelized scintillator in the detector, which covers all dead-areas.
Achieved image resolution is much better then commercially available industrial imaging detectors (so-called flat panels, for example from Perkin Elmer or GE).

In this project we need to develop more advanced technology to increase the efficiency of pixelized scintillator.
The following ideas has been proposed:

- to cover the inner part of 50um dia holes of the GEM foil by reflective Ni layer to increase the visible light transmission
- to make a light-guide within each hole by mixing the Gadox powder with some transparent resin
- to increase the thickness of the pixelized converter by precise multi-stacking of 10 GEM foils, thus to achieve 0.5mm scintillator thickness, still having 50um pixel size
- to decrease the distances between neighboring holes to minimize dark-areas. At the moment all dark areas are covered by fast movement of the pixelized scintillator during every exposition.

All developed techniques will be used to build the bigger, 40cm x 40cm imaging area detector, prototype no. 2.

It will be my pleasure to present already achieved results (images obtained on existing prototype in comparison to commercially available detectors) and to desribe the ideas for increasing the efficiency of the detector (thus, to get shorter time of industrial imaging and/or lower required X-ray dose).

Summary:

A prototype imaging detector based on multi-channel plate has been built. As a multi-channel plate, a dedicated GEM has been used, with more dense holes distribution and lowered holes diameter. Each hole was filled with powdered Gadox scintillator. Thus, in effect the pixelized scintillator has been created.
Achieved resolution based on the pixelized scintillator installed in fluoroscopic detector is 63 um. The aim is to use this detector in industrial radiography field. The advantages are: possible big imaging areas, high resolution, radiation resistivity. Observed disadvantages: poor efficiency. Technological R&D is required to increase the efficiency of pixelized scintillator.

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New 3D neutron sensors with high detection efficiency, high gamma rejection and reduced fabrication complexity

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We designed, simulated and fabricated new sensors with MEMS based high aspect-ratio trenches (3D) to be filled with ^{10}B neutron converter with a Geant4-predicted efficiency of ˜20%, to be compared with ˜4% of traditional deposition on a planar sensor's surface. Compared to sensors proposed by other groups 1[2], the fabrication complexity is strongly reduced, and is suitable for volume productions. High gamma-ray rejection can be achieved by minimizing the silicon active volume and/or by signal processing.
A prototype batch was recently fabricated at Fondazione Bruno Kessler (FBK) in Trento, Italy, showing excellent first results from electrical measurements. Tests on wafers indicated full depletion voltages between 80 and 100V (depending on the sensor's geometry) and breakdown voltages in excess of 500 V, with leakage currents as low as ˜5 nA/cm^2. Furthermore preliminary functional tests with an ^{241}Am α -source have shown full charge collection efficiency. Both electrical and functional test results are in good agreement with TCAD simulations, thus validating the design approach and the quality of the fabrication process.
While these initial results were obtained from diodes, which allow bump-bonding-free tests, the wafer layout includes also pixel detectors compatible with MEDIPIX read-out chip, with different geometrical options adopted for trenches. We plan to develop a full imaging system based on these sensors, which could achieve very good, spatial, time and energy resolution, thus opening many application opportunities.

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Summary:

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MONDO: a neutron tracker for Charged Particle Therapy secondary emission measurements

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The Charged Particle Therapy (CPT)
is a relatively recent and widely diffused technology
for which several additional treatment centers have recently been planned
or approved for (and are under) construction, that uses accelerated particles
and ions to perform tumor control. However, the neutron component of the secondary radiation is
still affected by large experimental uncertainties and is almost, yet,
unexplored˜\cite{uno, due}. Neutrons, characterized by a small attenuation length, are
contributing to a substantial dose deposition in body regions
not directly targeted or crossed by the beam, and are representing
the most abundant and harmful radiation exiting from the patient body.
Moreover, the risk of developing a radiogenic second malignant
neoplasm (SMN), years or decades after undergoing a treatment
is one of the main concerns in CPT administration
and planning˜\cite{uno}.

A complete characterization of the neutron production, and the related dose deposition, is of outmost importance in order to provide a better treatment plan to patients, maximizing the therapy effectiveness while reducing secondary effects. The MONDO (MOnitor for Neutron Dose in hadrOntherapy)~\cite{tre} project aims for the development of a compact, high-resolution tracking detector tailored for the observation and measurement of the secondary ultra-fast neutron production in CPT treatments.

The n-p events are the most useful for neutron detection since the elastic scattering correlates the neutron and proton momenta. If both proton recoils are measured, the neutron energy and direction can be reconstructed. In this latter case, the tracking and energy resolution achievable on the detection and reconstruction of the two recoiling protons will drive the final neutron energy and angular resolutions.

The tracker, composed of subsequent orthogonal layers of 0.250 mm square scintillating fibers. The geometrical parameters are mainly dictated by the neutrons interaction length in the fibers plastic scintillator, ranging from ~ 10 cm to ~ 60 cm in the $10-200$ MeV kinetic energy range. The choice of the final layout foresee a total tracker active volume of $10 \times 10 \times 20$ cm^3.

The technology that has been considered for the readout of the MONDO tracker is based on CMOS Single Photon Avalanche Diode (SPAD) arrays.
The SPAD matrix will have high spatial resolution (0.250 mm) and will implement the self trigger logic that matches the tracker readout requirements.
Currently, the evaluation kit of a sensor with similar features known as SPADnet-I~\cite{quattro,cinque} is being used to test the tracker's signal detection efficiency under the self triggering approach. The signal over background ratio is being characterized to assess the feasibility of a CMOS SPAD based readout of the fibers, without image intensification.

A preliminary MonteCarlo simulation of the detector has been performed using the FLUKA software, in order to finalize the detector layout while maximizing the expected efficiency and resolution of the detector.The results expected for MONDO project will improve the knowledge of the secondary neutron produced in particle therapy treatments measuring their flux as a function of the neutron energy and angle.
Those informations are essential in order to fully validate with data the MC simulations and analytical models used so far in particle therapy for the development of the Treatment Planning System (TPS); in particular, the estimation of the contribution to the total dose induced by neutrons in region away from the tumor volume is essential in pediatric TPS. The measurement of this dose contribution will significantly help the understanding and reduction of unwanted secondary effects related to the therapy.
Moreover, the neutrons back tracking up to their emission point allows to infer the Bragg peak position. It's worth to be stressed that such monitoring techniques have been already investigated using prompt photons and charged fragments as probes, but the neutrons study is still unexploited, namely because of the lack of neutron tracking device in the energy range of interest. The use of the neutrons as probe is of evident utility: the neutrons are produced with larger abundance than other secondary particles and their long interaction length can provide dose shape information even for deep-seated tumors. The tracking capability of the proposed device allows to exploit also the secondary charged particle component for dose profile monitoring, having a twofold and more reliable determination of the Bragg peak position in the patient.

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Summary:

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Ultra Fast Silicon Detectors

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We propose an ultra-fast silicon detector (UFSD) with time resolution a factor 10 better than what is possible today, which will establish a new paradigm for space-time particle tracking. Presently, precise tracking devices determine time quite poorly while good timing devices are too large for accurate position measurement. This fact is imposing severe limitations on the potential of many applications ranging from medical PET to mass spectroscopy or particle tracking. We plan to develop a single device able to concurrently measure with high precision the space (~10 μm) and time (~10 ps) coordinates of a particle.
This research is poised to open up a range of new opportunities for applications that benefit from the combination of position and timing information. For example, UFSD allows obtaining sharper PET images, 3D camera and robotic vision, monitoring more accurately the dose delivered in cancer treatment and improving particle tracking in High-Energy physics experiments.
Since UFSD are extremely thin, they will make use of the internal charge multiplication in silicon sensors; a recent very active field of investigations within the CERN based RD50 collaboration.
The core of our project is to design a thin sensor with an innovative doping profile that achieves charge multiplication without having electric breakdown. The silicon sensors will be based on the technology of Low Gain Avalanche Detectors (LGAD) developed by CNM-CSIC while the Application-Specific Integrated Circuits (ASIC) solution is the natural choice for the read-out electronics of the UFSD system. Such a solution will benefit from the performances of the most advanced technologies (based on the 65 nm node) both in terms of circuit density (for space resolution) and of circuit speed (for time resolution).

Summary:

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Thin Films for the Next Generation of Neutron Detectors

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Thin films can be seen as quasi-2D layers with a thickness within the nanometer to micrometer range. The trend to use them is steadily growing and they have a great impact as functional materials across a vast range of applications. This presentation touches on a vision of how thin films can revolutionize detector capability over the coming decade and beyond and shows how this vision is rooted in today's results from ongoing interdisciplinary collaborative work.

The helium-3-crisis has forced the detector community to search for alternative neutron detection methods for neutron scattering facilities like the European Spallation Source (ESS), for societal applications such as radiation scanners at, e.g., airports, or for measuring production in an industrial environment.

A synergy between expertise areas within material science and neutron/radiation detection has developed and proven that detectors based on boron-10-enriched boron carbide thin films are a competitive alternative to helium-3 gas based detectors. By using materials theory, advanced diagnostics techniques, and industrial production processes, the thin films do not only match the requirements of excellent adhesion and high purity of the active detector material as well as for low production costs, but are also ready to be mass produced by vapor deposition methods to fulfill the needs of large scale facilities like the ESS. For this purpose, the ESS has set up a detector coatings workshop adjacent to the Linköping University premises where main development work is also carried out. Compared to helium-3, the new boron-10 detector technology promises superior resolution in time, energy, and space and has the potential to replace most helium-3 containing detectors at the ESS. On a 10-year timescale, the development and use of thin films will allow a miniaturization of detector technologies, leading to a broadening of the range of potential applications for neutron detectors.

This interdisciplinary set of people have the vision to further develop the thin solid films to be used as detection materials, to merge them with the latest detector technologies, and to realize a complete set of neutron detectors for the next generation of neutron science. So far, the focus has been on neutron scattering science, but the technology can equally well be used in societally broader applications where neutrons need to be captured and provide information to users, like in radiation scanners, oil well logging, industrial production environments or in radiation monitors. Besides this, the potential of thin films exists generally for all detector types, not just the mentioned neutron detectors. Through our interdisciplinary synergies, functional thin films deposited onto a variety of base-component materials have the potential to solve technical problems for many types of sensor applications within the coming decades.

Summary:

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Slim-edge planar silicon sensors for large-area radiation imaging

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We are proposing the development of an improved technology for the fabrication of pixelated silicon planar sensors with slim edge, to minimize the dead area when tiling several sensors to build a large area detector.
Slim edges will be obtained through segmented trenches, fabricated with Deep Reactive Ion Etching technique and doped to be electrically active. On the one side, this approach ensures mechanical stability to the wafers, avoiding the need of a support wafer. The process is thus simplified and the fabrication costs are reduced. On the other side, the absence of a support wafer enables flexibility in the backside surface processing (e.g., the possibility of tuning the doping profile), thus offering an enhanced efficiency for low-energy x-rays.
At the same time, optimized guard ring structures will be designed to enable the application of a high voltage bias, necessary for fast and efficient charge collection. The sensors will be designed so that the required operating conditions are met also after accumulating a large dose of ionizing radiation, as high as 1 GGy.
Several photon and particle imaging applications will benefit from this technology, in particular synchrotron and X-ray Free Electron Laser spectroscopy and particle tracking in high-energy physics experiments.
Preliminary experimental results on p-on-n sensors, obtained from a pilot fabrication run developed in the framework of INFN project PixFEL, will be discussed.

Summary:

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Vertically integrated avalanche pixel sensors for charged particle detection

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In this work, the implementation of a new type of silicon sensor based on Geiger-mode avalanche detectors is proposed. The sensor consists in a two-tier pixel array, where each pixel is based on two vertically aligned avalanche detectors, and the coincidence between two simultaneous avalanche events is used to discriminate particle-triggered detections from dark counts.
Thanks to the large avalanche gain, the detector thickness can be much smaller than in conventional particle detectors and the electronics much more compact due to the digital nature of the Geiger-mode avalanche signal. Therefore, a detector with these characteristics can potentially offer a low material budget, a fine segmentation and a low power consumption, in addition to a timing resolution in the order of tens of picoseconds. These features are appealing for a set of applications as, for instance, tracking and vertex reconstruction in particle physics experiments and charged particle imaging in medicine and biology.
A first two-tier proof-of-concept sensor was designed and fabricated in a commercial 150nm CMOS process in the framework of the R&D project APiX2 funded by INFN in Italy. The sensor consists of a 48x16 pixel array, and includes avalanche diodes of different sizes to evaluate the detection efficiency for different fill factors. Each pixel, having a 50um x 75um area, includes detectors and electronics on both layers, with the top-layer signal transmitted to the bottom layer using a vertical interconnection per pixel.

Bump bonding has been used for 3D integration, due to the accessibility and high yield offered by this technique in small-volume prototyping. The first measurements on two separate layers and on vertically-integrated sensor assemblies have confirmed the complete functionality of first prototypes and experimentally validated the proposed approach. A measurement campaign is on-going to fully assess the characteristics of the produced sensors. The test results obtained on the vertically-integrated sensors will be presented and the possibilities for future improvements with respect to this first prototype will be discussed.

Summary:

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Silicon carbide/graphene – the neutron-sensitive semiconductor technology of the future

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Semiconductor detectors for ionizing radiation (X- and gamma-rays, electrons, protons, alpha particles, heavy ions) are employed extensively for spectrometry, dosimetry and imaging in many fields: from fundamental scientific research to medical applications, homeland security, material analysis and industrial applications. Many of these applications have increasingly demanding requirements on the detector devices, including high energy resolution, low power consumption, low-noise room temperature operation, structural stability, and radiation hardness to name only a few.

It is clear that the Si-based device technology of today cannot meet these criteria. This creates a desperate need for novel semiconductor materials, innovative device designs and advanced manufacturing processes across many applications.

A noticeable trend in functional materials is to turn towards 2D materials. A very promising concept are detectors based on silicon carbide/graphene. Compared to everyday silicon, silicon carbide (SiC) has lower noise levels at room temperature. Furthermore, it is intrinsically more resistant to radiation damage due to its stronger-bound cristal lattice. This physical strength of SiC also allows for ultra-thin membrane detectors that can be used in special applications such as living cell radiology and even intelligent vacuum windows. By depositing graphene layers into etched structures on the SiC, a monolithic material which combines the radiation resistance of SiC with the high electron conductivity of graphene may be created.

Further, SiC offers exciting possibilities in a field where the applications of semiconductor detectors are essentially unexplored: the detection of neutrons. Being uncharged, neutrons are detected only indirectly, e.g. via nuclear reactions in a converter material (for low-energy or "thermal" neutrons) or via recoil reactions (for high-energy or fast neutrons). In SiC, neutrons recoiling from the carbon nucleus yield a very distinct signature. By depositing moderator or converter materials such as polyethylene or 10B into structures on the SiC, this sensitivity can be increased and extended to thermal neutrons.

Thin, low-noise, radiation-hard, and mechanically stable semiconductor detectors capable of detecting a wide energy-range of neutrons as well as ionizing radiation are clearly invaluable for future scientific instruments, whether it is the final instrumentation suite of ESS or the next-generation of tracking detectors in particle physics experiments. With the existing experience and infrastructure for semiconductor development and neutron detection, and the established and ongoing collaboration with ESS and industrial partners of ACREO and Graphensic, the Physics Department at Lund University is the place where SiC can be established as the go-to semiconductor technology of 2025 in science.

Summary:

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A cheap and highly-available source-based testbed for novel neutron detectors

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Neutrons are important probes of matter and are crucial for an increasing number of applications in both scientific and industrial fields. A key element for such studies is the ability to reliably detect neutrons. One of the most common neutron detector technology in neutron imaging today are He-3 gas-based detectors. However, due to the increasing scarcity of He-3, alternative technologies are desperately needed.

It is vital for each of these new technologies and the resulting instrument prototypes to be tested at a dedicated facility offering neutron irradiation. This is typically done using either standard neutron-emitting radioactive sources or by going to a reactor beam line. However, the latter is both highly limited in available beam time and prohibitively cost intensive while the former typically only provides functional tests.

This is where a technique called "tagging" comes in. Tagging neutrons makes it possible to study the detector responses as function of neutron energy even with standard radioactive sources. This data is absolutely crucial to evaluate detector performance but is missing in "classical" irradiations of detectors with radioactive sources.

The method of tagging high-energy or "fast" neutrons has already been established and the corresponding setup is now located at the Source Testing Facility (STF) at Lund University. By extending this method to lower or "thermal" energies and by using different sources of neutrons, the full energy range of neutrons could be made available for in-depth tests of the neutron-response of detector prototypes – cheap, safely and available around the clock.

Summary:

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Smart imaging devices for bioimaging (SidBio)

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Project idea:

Modern imaging sensors, such as SCMOS cameras and SPAD-arrays, deliver unprecedented data rates. This opens new opportunities for the bioimaging field, but also poses challenges on image processing and quantification as well as data handling such as storage, sharing, streaming and visualization. This project aims to (i) implement on-chip spatio-temporal resolved imaging patterns in collaboration with camera manufactures, (ii) to establish a real-time data processing pipeline for bio-imaging data and (iii) develop real-time algorithms for lossless as well as "information less" compression and hereby reduce the amount of data to be stored over years significantly. In particular in the field of fluorescent 3D high-speed imaging with light-sheet microscopes, where single experiments can yield tens of terabytes of data per day, a tight integration of imaging sensors and processing is needed. In addition to FPGA- and GPU-based image processing of the camera data streams, the increase on-chip logic can be used to implement novel imaging modalities (see comments below).

Direct applications and Industrial end users:

We expect direct application in the field of fluorescent microscopy and adjacent applications such as drug discovery (high throughput and high content screening), flow cytometry or electron microscopy which will forester research across all scales in the life sciences from cell biological to the organismal scales and in the end translational medicine.
EMBL is at the forefront of research conducted in the areas described above and its recent Spin-off Luxendo explores the use of the above-mentioned technologies in light sheet microscopy.

Areas of technology spillover:

Similar concepts, algorithms as well as complete submodules are needed in applications where data handling is currently limiting general use. Such application include 3D cartography of buildings, cities and landscapes, 3D vision in robotics as well as automotive industry (driver assistance), medical data processing for CT and MRI images.

Comments:

Our collaboration with Hamamatsu Photonics Germany and Japan has lead to a sensor modification, which enables confocal line detection on latest SCMOS sensor without any addition optical components[for details see Medeiros et al, 2015 and Patent pending]. Although this work marks only the first steps, it has triggered similar approaches other camera manufactures (Andor Technologies and PCO GmbH Germany).

Reference:

Medeiros G, Norlin N, Günther S, Albert M, Panavaite L, Fiuza UM, Peri F, Hiiragi T, Krzic U, Hufnagel L. (2015)
Confocal multiview light-sheet microscopy.
Nat Commun 6 doi: 10.1038/ncomms9881

Summary:

3D bioimaging, smart sensors, large data handling, real-time image processing.

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Neuroscience beyond neurons

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The human brain displays amazing computing capacities. Unfortunately, it also often goes wrong with dramatic consequences. Diseases of the central nervous system cost each European € 5500 every year and represent one third of the financial burden of European public health systems 1. For historical and technological reasons, neuroscience has focused mostly on neurons and derives its name as a field from that specific cell type. However, the human cortex consists of numerous cell types, and neurons only represent 20% of that overall population [2]. In recent years, new imaging technologies have allowed us to investigate non-neuronal cell types, collectively called glial cells. Unlike neurons, glial cells are not electrically active but show tremendous activity when monitored via imaging techniques that assess fluctuations of their internal calcium concentration. These studies have revealed that glial cells play a key role in all aspects of brain function, both in health and disease. Because of the relative novelty of this line of inquiry, there is no algorithm to segment and analyse calcium-imaging data in glial cells, and there is no theory to make sense of the data.

Neuroscience is faced today with the challenge of developing new image-processing technologies and a new theoretical framework to go beyond mere neural networks, which we know do not represent the biological reality underlying our computing prowess and diseases [3].

To tackle this challenge, this project will bring together experimental neuroscientists, computer scientists, engineers and computational biologists to collect, store and share the data in an open fashion, to develop the necessary imaging and pattern recognition techniques, and to develop the missing theoretical framework. Through this transformative effort, we expect that neuroscience will mature into brain science. This project will have an impact on our understanding of brain function, paving the way for better machine intelligence algorithms, and it will have an impact on our understanding of the onset and progression of diseases of the central nervous system, opening new therapeutic avenues.

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Summary:

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Image content understanding in the future massive Liquid Argon Time Projection Chambers

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Liquid Argon Time Projection Chamber (LArTPC) detector technology is the tool for neutrino physics studies, with the ultimate and ambitious goal of building the 40kt DUNE detecor (Deep Underground Neutrino Detector), to be placed on the neutrino beam by 2026 (ref. 1). LArTPC is all about imaging the particle interactions in high resolution and large volumes.

LArTPC detector technology is present on the neutrino market for many decades, however the techniques of processing the LArTPC data are still under very active development and offer a large unexplored field of possible approaches. Today's jump in the availability of parallel processing hardware and the progress on the neural network processing open an obvious direction for the LArTPC data analysis development. Our team, after development one of the major currently used solutions in 3D reconstruction (ref. 2), is now convinced that research should be pushed in this direction and combine machine learning with algorithmic solutions that are already developed for LArTPC's.

The idea is far beyond simple application of the newly available machine learning toolkits. Any approach attempted in LArTPC realm needs many layers of pattern and context recognition in order to make the interpretation of images useful for physics analysis. Briefly summarizing: interesting interaction needs to be localized among tracks of background particles, large- and small-scale features have to be recognized in order to find the primary interaction point and understand species and energies of outgoing particles, all of that under the strict control of systematic uncertainties which are the priority for the DUNE experiment. Finally and the most importantly for the image processing challenge: events in the images do not follow regular shape templates; the interpretation has to be done on a high level of abstraction.
Challenge in the machine learning based approach to the analysis of LArTPC images comes also with the huge volume of data. Even though the expected experimental data amount for DUNE is manageable already today (order of PB), data sets larger by many orders of magnitude are foreseen in the R&D process towards formulation of efficient image content recognition. Today's technical limitations result with simplicity of algorithms for deep convolutional neural networks (CNN) training, while much more advanced algorithms do exists for the standard, multi-layer perceptrons; such methods should become available for CNN with the hardware developments.

The proposed research in our vision should become competitive in applications beyond the physics data analysis. The perfect example is the medical image recognition, such as reconstruction and interpretation of vascular trees or mammograms, often very similar to the LArTPC images in the signal to noise quality, resolution and even the object shapes. We also note an important synergy between medical and physics data processing: in both cases the understanding and control over systematic properties of algorithms are extremely important factors.

Let us close the abstract with two remarks about very distant in time events. We are now standing at the beginning of the exciting research, with the first proof of concept. However the future of LArTPC's is the 3D readout replacing multiple 2D projections, vastly improving the potential of the particle interactions imaging, and opening new challenges for analysis techniques.

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Fig.1. Neutrino event among cosmic muons in the MicroBooNE LArTPC detector (source: http://www-microboone.fnal.gov/first-neutrinos). Each event in LArTPC is to be reconstructed and interpreted from two or three such 2D projections made at different angles.

References:

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Summary:

Keywords: neutrino physics, liquid argon time projection chamber, computer vision, machine learning, image and pattern recognition, convolutional neural network, deep learning, medical imaging, vascular trees, mammograms

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A standardized approach to accessing identity information over decentralized connected device networks

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As the concept of Internet of Things slowly moves from a futuristic idea to a pervasive reality, a number of novel challenges start appearing. The hardware and software ecosystem for IoT applications is today fragmented and highly unstandardized and several different architectures, protocols and hardware platforms are being proposed by technology providers. The idea of decentralized architectures based on protocols and technologies like block chains is emerging as a possible, intrinsically more secure, scalable and user-centric model for the implementation of tamper-resilient, distributed, transactions-based architectures for IoT applications.

At the same time, the use of personal data, today already pervasive in a variety of applications from user profiling for e-commerce applications, to social networking, or electronic medical records, will only increase with the increased use of wearable or connected devices collecting and transmitting biometric data like fitness bands, connected scales, blood pressure readers. The use of fingerprints, retinal scans or heart rate patterns are also used as authentication factors in an increasing number of devices for applications ranging from unlocking phones or computers to opening doors and starting cars.

Most of the identity management challenges in decentralized networks of sensors and connected devices are still unexplored and unresolved. Concerns must be legitimately expressed about ownership, use, storage, sharing, and the risk of abuse of personal identity and biometric data in such highly distributed scenarios.
Work on defining a standard, open stack of technologies to implement decentralized architectures is being proposed as a way of starting the consolidation and standardization process in this domain. As part of this work, particular importance must be given to the specific aspect of standardizing the human-device interfaces when exchanging and using personal biometric information as a way of identifying and authorizing people and their access to devices and systems in decentralized, autonomous networks where such personal information is not and should not be centralized and stored in any specific place.

We propose to define, design, and implement a model, a reference architecture and a set of standard APIs to be used by sensors and connected devices to handle biometric identity information, with fine-grained user-defined permissions for use in autonomous, decentralized IoT scenarios.

Summary:

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Automated Multimodal Correlative Microscopy for high resolution in vivo imaging.

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Rational:
Modern research in Life Sciences is integrating diverse data from complex models to understand, at the molecular level, the mechanisms underlying the development, function and dysfunction of living organisms. For this, imaging technologies are playing a crucial role. Here, the aim is to record the living state (functional and dynamic) at the highest resolution possible (ultrastructural level). To achieve this, various imaging technologies can be correlated to study the same specimen. Correlative Light and Electron Microscopy (CLEM) is now an imaging field per se that covers a broad spectrum of applications on multiple biological domains and models. On animal models, correlating intravital imaging (by LM) to subcellular recordings (by EM) requires acute targeting precision in 3D with sufficient speed and robustness. In doing so, the enhanced experimental/imaging throughput is expected to enable quantitative analysis of biological phenomena.
We have recently demonstrated the power of multimodal correlative microscopy that greatly facilitates the correlation of intravital imaging to large volume electron microscopy of single metastatic cells (1). Reducing the CLEM workflow from 3-5 months to ˜14 days, it is now feasible to study the cellular mechanisms, e.g. of cancer metastasis, in relevant tissue models in vivo. Working closely with numerous laboratories, we are now establishing workflows for various applications in the fields of cell biology, development biology, neurobiology and physiology in normal or pathological conditions.
We aim to enable routine and high-throughput CLEM studies, allowing targeting rare and transient phenomena in vivo. Although our recently developed approach has already demonstrated unprecedented throughput, our aim is to make it faster and, importantly, to make the workflow more accessible to non-specialized laboratories. In doing so, we will answer to the growing needs from the scientific community to link structure to function in biologically relevant multicellular models. Achieving this goal will only be possible with key technological development to offer new instrumentation and automation in the areas of image processing (software), of sample preparation (control and mechanics), of the large volume imaging (microscopic x-ray computed tomography – 'microCT') and of the high resolution electron microscopy step itself.

Project:
Our correlation strategy (1) relies i) on 3D image acquisition and registration, ii) on precise shaping of the samples to reveal the region of interest (ROI), and iii) on intelligent acquisition of the ROI volume by EM. We propose to develop automated solutions that are generally applicable to a large range of biological samples and dramatically improve throughput of the experiment.
i) The multimodal workflow relies on mapping the EM-processed sample in 3D using microCT, and correlate this volume to the in vivo dataset in 3D. Following EM preparation, the ROI observed in vivo is no longer visible with LM and its location within the sample is therefore difficult to retrieve. MicroCT enables the visualization of structural landmarks within the EM-processed sample that can be correlated to landmarks visible in the in vivo dataset (LM). 3D registration of these features then enables to predict the position of the ROI inside the EM-processed sample. Currently, the correlation between LM and microCT is performed manually, which is a tedious and time-consuming (2-3 days) task within the workflow. We will develop a software solution to automate the registration task. In parallel, we intend to innovate in the imaging of the EM sample by developing compact, low-cost, accessible instrumentation for this step, which should allow easier implementation in any research laboratory. ii) When the precise mapping of the EM sample is achieved, it is trimmed in order to expose the volume of interest for the 3D EM acquisition. This process demands highly-accurate instruments (ultra-microtomes), and a skilled operator. Since the current ultramicrotomes are not designed to achieve the required accuracy, careful approach to the ROI is needed, which unnecessarily prolongs the workflow with ˜1-2 days. By developing a motorized solution, we intend to fully automate and further facilitate this process. Here, based on the 3D maps generated in i), the unwanted parts of the sample will be automatically removed and the progress to the ROI will be monitored by an automated feed-back loop. iii) Large volume imaging by EM is now made possible

by automated serial imaging technologies based on scanning EMs. To overcome the current slow acquisition time, we intend to further improve the SEM scanning procedures, detectors and acquisition schemes. For our correlative workflows, we will also develop a software solution to fully automate imaging of the correlated sub-volume of interest. Such "intelligent" acquisition will be controlled using the 3D maps built from the other imaging modalities registered as described in i).

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Summary:

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3D printed smart structures

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Large area support structures, containing sensors and fast, high density electronics requires effective cooling to be reliable. This is true for commercial gadgets, like computers, and even more so for XL scientific apparatuses like detector systems in accelerators, electron microscopy , synchrotron light sources , Xfels and more where outcomes could lead to fundamental discoveries and therefore require additional precision. At the moment cooling is either bulky, therefore potential source of secondary scattering and noise (Peltier cells), or not optimally effective in removing the local heat.

We propose to use recent advances in novel 3D printing materials to fabricate, SMART,low mass, low cost, silicon compatible and precise Ceramic support structures with embedded micro-channels for CO2 cooling. Aluminum Oxide and Aluminum Nitride, which can both be printed, have spectacular thermal propertied and are thermally compatible with silicon, are compatible with brazing and interconnect with either ceramic or metal pipe and have shown that details, like internal channels, can be as small as 200-500 microns respectively.
FAST fabrication makes this proposal particularly attractive since tests and design optimization would be possible in a fraction of the present time and cost.

Summary:

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Fast neutron micro-imaging by 2025?

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X-ray microtomography (i.e. tomography at the micrometer scale) is made possible nowadays by the availability of imaging detectors with adequate spatial resolution and suitable high brillance X-ray sources. Achieving the same spatial resolution in cold/thermal neutron tomography is more challenging but constant developments in the field suggest that micrometer-scale neutron imaging will soon be possible by careful optimization of existing technologies.
What about micro-imaging with fast neutrons? Is high resolution fast neutron imaging a realistic proposition for a dedicated detector development effort in the next decade? Here we propose a novel detection scheme where micropattern gaseous detectors are used for particle tracking to push fast neutron detection into the micrometer scale.
At the heart of any neutron detector is a suitable interaction mechanism that can be used to convert neutrons into a detectable particle - usually a charged particle. The range of the resulting charge particle in the detector is usually assumed to be the fundamental limit setting the order of magnitude of achievable spatial resolutions. By recording the full track of the charged particle the neutron interaction point can be inferred with an accuracy that is typically a small fraction of the charged particle range. Micro-Pattern Gaseous Detectors (MPGDs) are often used for charge particle tracking, as exemplified at the LHC experiments. In recent years, these devices found applications beyond high energy physics mainly due to their imaging capabilities. MPGDs (i.e. GEMs, Micromegas and their derivatives) coupled to suitable converter cathodes have proven in the recent years to be able to efficiently detect neutrons (with different energies) at high rates (> MHz/cm2), with a sub-mm space resolution and with a gamma background rejection <10-6. The technique used for fast neutron detection is the measurement of the recoil proton coming from an elastic scattering on a hydrogenated material composing the cathode (e.g. polyethylene).
A detailed measurement of the proton track using a Time Projection Chamber (TPC) based on MPGDs would give the possibility to significantly improve both the spatial and time resolution compared to the detectors developed so far, since the contribution of the track length could be reduced substantially. A high resolution fast neutron TPC-MPGD can be realized by coupling a single GEM (or Micromegas) with a plastic converter cathode to a high definition read-out chip like the Timepix2 that allows to reach space resolutions better that 100 μm and time resolutions around few ns. This approach can lead to high rate and high resolution imaging detectors for fast neutrons and is open to make immediate use of the foreseeable advances in read out resolutions in the next decade. Possible applications include fast neutron imaging, accurate monitoring of fast neutron beamlines and neutron measurements in magnetic or inertial fusion experiments.

Summary:

Is high resolution fast neutron imaging a realistic proposition for a dedicated detector development effort in the next decade? Here we propose a novel detection scheme where micropattern gaseous detectors are used for particle tracking to push fast neutron detection into the micrometer scale.
By recording the full track of the charged particle the neutron interaction point can be inferred with an accuracy that is typically a small fraction of the charged particle range. Micro-Pattern Gaseous Detectors (i.e. GEMs, Micromegas and their derivatives) coupled to suitable converter cathodes have proven in the recent years to be able to efficiently detect neutrons at high rates (> MHz/cm2). The technique used for fast neutron detection is the measurement of the recoil proton coming from an elastic scattering on a hydrogenated material composing the cathode (e.g. polyethylene).
A detailed measurement of the proton track using a Time Projection Chamber (TPC) based on MPGDs coupled to a high definition read-out chip like the Timepix2 allows for space resolutions better that 100 μm and time resolutions around few ns. This approach is open to make immediate use of the foreseeable advances in read out resolutions in the next decade.

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The ideal proton radiography/CT image reconstruction for adaptive proton radiotherapy

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The large potential of the novel proton radiography/CT imaging technique can be used to determine proton stopping powers (PSPs) directly with a high precision down to 1%. To achieve that both the fast and compact detection system and the reconstruction algorithm need to be in synergy. This is crucial to determine an optimum proton treatment plan. The optimized software that reconstructs a proton passing through various tissues in the patient is absolutely necessary. It is one of the crucial parts for the accurate determination of the proton energy losses in the patient.
The reconstruction algorithm needs to consider properly the multiple Coulomb scattering (MCS) of a proton passing through different tissues, which is the main cause of the image blurring. The innovative part of the project is that the algorithm needs to contain an optimized mathematical model for proton path reconstruction in the patient, which needs to process a minimum of 10ˆ6 protons per cmˆ2.
Ultimately, the proton radiography/CT imaging of the patient should be performed immediately before the proton treatment delivery. After that, an immediate/online treatment plan adaptation should be done. The computation time of the proton radiography image reconstruction and the treatment plan adaptation should not exceed half a minute. Therefore, the optimum algorithm should deliver an accurate proton radiography image of the patient in this time, which can be clinically acceptable.

Summary:

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Fast and compact proton radiography imaging system for proton radiotherapy

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The novel proton radiography imaging technique has a big potential for the direct determination of proton stopping powers (PSPs) in various tissues in the patient. The uncertainty of PSPs needs to be minimized from 3-5% or higher, currently used in clinics, to less than 1%, crucial to make an optimum proton radiotherapy treatment plan.

To achieve that PSPs accuracy, both crucial elements in the proton radiography detection system, a position sensitive detectors and an energy detector, need to be equally fast to collect a minimum amount of protons of 10ˆ6 per cmˆ2 for a good radiography image. This amount of protons needs to be processed in a very short time down to half a minute to be applicable in clinics. Additionally, the position sensitive detectors should be able to detect the track of a proton passing through with an excellent angular resolution of a few mrad. It means that such detectors should be built with a minimum amount of material, smaller than 0.5 mm Water Equivalent Thickness (WET), to minimize the multiple Coulomb scattering of the proton before entering the patient. This is possible by using gaseous detectors, which should be (1) compact to minimize the required space on a proton gantry and (2) modular for easy size adaptation according to the needs in a clinic. The detector measuring the proton residual energy should have a high energy resolution of better than 1% for proton energies of 100 MeV and above.

The currently available Timepix3 chip and its follow-up, Timepix4, seem to be a very promising solution for fast proton radiography imaging. However, their integration with a gaseous detector needs definitely more attention to increase the rate of data collection. The energy detector for proton radiography imaging is not yet optimally matched to a position sensitive detector limiting the count rate of the system or the energy resolution.

Fast Timepix3(4)-based gaseous detectors well matched with the energy detector create an innovative compact system that would allow an accurate determination of PSPs in the patient, and thus improve the clinical outcome of proton radiotherapy.

Summary:

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Integrated, autonomous solutions for thermal management in high energy physics and space applications

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Thermal management represents a major challenge in both high energy physics (HEP) and space missions. Whether it is to dissipate the heat generated by readout chips and other electronic components or to extend the service life of silicon sensors susceptible to radiation damage, cooling has become one of the main design concerns in both fields. Furthermore, the harsh environmental conditions encountered in both outer space and HEP experiments impose severe constraints, as the cooling solutions must operate under vacuum and absorb significant radiation doses.
Continuous advances in micro-engineering have opened the door to the development of smaller and more efficient cooling devices capable of handling increasing power densities with a minimum mass penalty. In this respect, previous work carried out at CERN has focused on the use of micro-channels etched in single crystal silicon (ScSi) wafers to circulate a cooling fluid. However, whilst this technology represents an appealing solution for thermal management in detector modules, it poses a number of challenges, particularly for high fluid pressures and long structures. Among these, the brittle nature of ScSi, the lack of suitable interconnections and the difficulties for the integration, packaging and qualification of such devices hinder their application in areas where reliability is paramount.
While some of these issues have been partially resolved, further advances are required to widen the areas of application and simplify the implementation of this technology. In this respect, the Detector Technologies group at CERN is starting a collaborative effort to develop a novel solution in which the sensor and the cooling circuit would be integrated in a single device. This collaboration would build on and benefit from an existing partnership with the École Polytechnique Fédérale de Lausanne (EPFL) and the Swiss Space Center (SSC), the objective of which is the production of silicon micro heat pipes.
From a heat-management standpoint the new device would be completely autonomous, operating in stand-alone mode without any external connection. To that end both a condenser and an evaporator would be included in the micro-fluidic circuit, which would act as a miniaturised loop heat pipe. Once demonstrated, this technology could be employed in a wide range of fields other than HEP experiments and space missions, including medical applications, transport industry, high-power computing and consumer electronics.

Summary:

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CMOS Monolithic Active Pixel Sensors for beta autoradiography

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Beta autoradiography forms a standard procedure for studying metabolic processes in biological systems. Beta ray emitting tracers, namely like H-3, C-14, P-32 and S-35 are attached with chemical methods to biological molecules. Hereafter, the molecules undergo, in vivo or in vitro, metabolic processes. The nature of those processes may be analyzed by i) identifying product molecules by spotting the radio tracers and/or ii) observing the position of beta emissions related to the radio tracers from tissue probes (e.g. slices of rat brain).

While the bio-chemical side of autoradiographie is well established, the radiation detection relies on elder technologies like photographic films, phosphor-plates and scintillator plates, which are typically exposed for several 10 hours to the radiation of the sample. Due to the limited sensitivity and contrast of those systems, the results of those slow measurements show frequently saturated regions while weaker sources are not identified. Moreover, the spatial resolution of the measurements is limited as the beta rays are emitted into 4P and may impinge the sensor with a shallow angle and rather distant from the true emission point.

CMOS Monolithic Active Pixel Sensors (MAPS) as being employed for present and future experiments in particle and heavy ion physics (e.g. STAR, NA61, CBM, ALICE) may overcome this limitations. The devices are suited to detect beta rays with excellent detection efficiency, very high rate capability and outstanding spatial resolution. Moreover, back-thinned MAPS were shown to be sensitive even to the ˜10 keV beta rays of H-3, which are absorbed by the entrance window of almost any other detector system. Finally, MAPS are mostly transparent to natural gamma radiation, which helps to reduce the background of the measurement.

In a first pilot study, we tested the capability of MAPS to recognize RNA fragments, which were marked with P-32 and separated by electrophoresis in a next step. The sample used was produced for regular research and our experiment was carried out once it became obsolete. This and the short half-life of P32 turned into a substantial reduction of the activity of the sample. The MIMOSA-26AHR sensor employed for the test was exposed to the radiation of sources of < few Bq (detection limit of an independent measurement with a Contamat) for several hours. Despite no hardware and few software optimization was carried out, radiation peaks caused by the RNA-fragments were indicated in front of a very low background.

Based on this positive result and our experience with the integration of MAPS into sizable detector systems, we propose to explore the feasibility of employing those sensors in detection systems for beta-autoradiography and to provide on the long term those detection systems to the community. It is anticipated that this improved system will provide multiple advantages with respect to the established detector systems. Among others, we expect:

- A simplified quantitative analysis of the signal as a direct hit counting is carried out.
- An strongly improved contrast (in theory » 1:1e6), which will allow for identifying weak radiation sources without tolerating saturation effects in other parts of the picture.
- An advanced signal over background ration of the measurements, which is provided by the excellent sensitivity of MAPS (>99,9% of MIPS, to be confirmed for soft beta rays) and the outstandingly low background observed in our pioneering study.
  It is expected that this sensitivity will allow to accelerate regular measurements.
  More importantly, one might consider to reduce the amount of radio tracers needed for a standard test. If successful, this will turn into significant improvements with respect to work security in the related radio chemistry laboratories and into a reduction of the nuclear waste related to the test.
- An improvement of the spatial resolution of the pictures. This is possible as one obtains access to the individual beta hits. Based on a cluster shape analyses, it is conceptually possible

to
identify and reject beta rays impinging the sensors with a high angle. This reduces the smearing of the picture caused by beta rays, which are emitted mostly parallel to the sensor surface.

- The option to generate digital high resolution pictures with radio traces with small beta energy (e.g. H-3).

Summary:

Beta autoradiography is an established tool for analyzing biochemical processes in life science. It consists in marking bio-molekules, which are expected to undergo a metabolic process, with radioactive markers and to identify the location or nature of the reaction products by identifying them based on the related beta emission.

It is proposed to improve this methode by replacing the traditional radiation sensors (e.g. photographic films, phosphor plates) by CMOS Monolithic Active Pixel Sensors, which were developed for vertex detectors of experiments in particle and heavy ion physics. Besides improving the sensitivity of the method, this may reduce the amount of required radio tracers. If so, one will presumabyl create less nuclear waste and improve the work security in the related radio-chemical laboratories.

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Real time 4D imaging of energy flow towards intelligent designer materials.

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Intelligent designer materials with exactly tailored properties and function are centerpiece to future technological developments with impact across many areas of society including medicine and biochemistry, energy and information processing, just to name a few. Unfortunately, such materials are rarely found serendipitously but rather need to be manufactured and tailored using the principles revealed by science. The basic requirement to understand and control functionality is therefore our ability for probing and understanding the dynamics of interactions between photons, electrons and chemical bonds starting from the fastest "triggering" events, on the attosecond time scale, and at the shortest relevant length-scales, on the Ångstrom length scale. The need for such new photonics tools has been recognized globally 1 since society's ability to design molecular assemblies and materials directly relies on the development of new quantitative experimental tools that can track time-evolving structural changes and electronic excitations in a comprehensive manner. The much needed experimental tools consist of specialized light sources in combination with new detection methodologies. While light sources are now available [2] which combine the required temporal resolution with element specificity, currently available detection technology is not adequate to exploit the full potential of these new methodologies which hampers progress severely. We propose a remedy with a radically advanced detection technology which permits attosecond temporal probing with single photon element selectivity in real time. The envisioned detection technology is phase-sensitive 4D detection (2D space, time and energy) and will have breakthrough consequences for many areas of science and industry. State of the art are time of flight cameras, such as from heliotis.ch, which feature on chip demodulation and pixel fill factors of 80% to decrease the data transfer rate from 90 billion samples/s to manageable 5000 frames/s with full amplitude and phase information. Based on this already existing technology, the decisive next step will be the combination of lock-in detection with energy dispersive readout and single photon detection sensitivity in the water window soft X-ray region. Single photon detection capability in this photon energy range would require engineering of well depths and new concepts beyond silicon drift detectors which achieve energy resolutions of 1 eV compared to the currently available 134 eV. The soft X-ray water window is defined between the C and O absorption edges of materials (294 eV to 534 eV) and is so important since it contains the fundamental absorption edges of organic matter (C, N, O) [3]. A camera with 4D single photon sensitivity would enable attosecond temporal resolution imaging of energy flow and molecular transformation with molecular fingerprinting accuracy within electronic sensors and magnetic storage materials, biological tissue or biochemical assemblies. I.e. we could "see" and therefore "follow" the flow of energy from one atom to the next in real time and for the first time. Such capability would profoundly impact fundamental science and, at the same time, radically advance and transform many areas of industry and technology.

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Summary:

We propose a radically advanced methodology which will permit seeing and following the energy flow inside biochemical assemblies, quantum materials and sensors in real time and with element selectivity. This advance will draw from 4D single photon imaging in the soft X-ray regime in combination with on chip phase sensitive detection. Such capability will profoundly impact fundamental science and, at the same time, radically advance and transform many areas of industry and technology.

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ORANGE: a high sensitivity particle tracker based on optically read out GEM

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GEM-based detectors had a noticeable development in last years and have successfully been employed in different fields from High Energy Physics to imaging applications. Light production associated to the electron multiplication allows to perform an optical readout of these devices. The big progress achieved in CMOS-based photosensors makes possible to develop a high sensitivity, high granularity and low noise readout.
In this paper we present the results obtained by reading out the light produced by a triple-GEM structure by means of a 4 mega-pixel CMOS sensor having a noise level less than two photons per pixel.
The choice of a CF_4 rich gas mixture (He/CF_4 60/40) and a detailed optimisation of the electric fields allowed to reach a light-yield high enough to obtain very visible signals from minimum ionizing particles.
In a test performed with 450 MeV electron beam, 800 photons per millimeter were collected and a space resolution of about 75 μ m was obtained.

Summary:

Micro-Pattern Gas Detectors, CMOS-Sensors, High-Granularity Tracker

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Towards a picosecond fully-photonic detector module for direct 3D PET and future HL colliders

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One of the major challenges our society faces today is providing personalized high-quality healthcare to all citizens in a sustainable way. Several improvements in current Positron Emission Tomography (PET) scanners are needed to transform in-vivo molecular imaging into a standard tool for personalized medicine: reduce the radiation dose, scan time and costs per patient. A way to achieve it is pushing time-of-flight Coincidence Time Resolution (CTR) to ˜10 ps, enabling direct 3D imaging 1.

Current PET technology is based on scintillating crystals. However, there is an intrinsic limit in the time resolution that can be achieved by scintillation in crystals. Together with photodetector technology limitations, makes that CTR achievable with current technology is at the level of 100 ps (300 ps for commercial scanners). For sub-100 ps time resolution, mechanisms involving the production of prompt photons need to be considered. Cherenkov emission and cross-luminescent materials can offer a solution [10]. However, the light yield is very low and happens in the UV part of the spectrum, where sensors detection efficiency is not very high. There are some transient phenomena in the relaxation process that can be possibly exploited for the generation of prompt photons [10]. Another interesting option are photonic crystals which an enhance the light output of dense scintillators with a high refractive index (between 1.8 and 2.2 for the majority of scintillators) by a large factor (2 in air and by at least 50% in grease). As a consequence, PhCs can offer attractive perspectives in the search for higher timing resolution in scintillator-based detectors [3]. Moreover, recent works open the possibility to use Cherenkov radiation for photonic crystals in medical imaging and particle physics [4].

In conclusion, achieving a CRT of 10 ps FWHM in PET technology would allow accessing the huge untapped potential of direct 3D PET and it requires the use of prompt light emission due to intrinsic limitations in the time response of the scintillating mechanism. As prompt light emission is weak (few photons) and in some cases happens in the UV region, to fully exploit it, new advances are required in photodetector and front end technology aiming for an overall Single Photon Time Resolution (SPTR) in the order of few tens of ps and enhanced UV sensitivity. The SPTR of Single-Photon Avalanche Diodes (SPADs) can be as low as 20 ps or less, as it was early recognized [5]. However, time resolution of SPAD imagers is much higher than 100 ps due to limited performance of a per-pixel Time to Digital Converter (TDC). In the same way, the SPTR of Silicon Phtotomultipliers (SiPMs) or Digital Photon Counters (DPCs) is severely degraded by cell non-uniformities and by interconnection parasitic.

As first step, we propose to develop a "digital" SPAD based sensor which shall be optimized for a detector based on prompt light emission, which provides the time of arrival of the n first impinging photons. We propose a hybrid sensor combining a sensor in a dedicated high quality process with a CMOS front end and readout electronics. The integration of the SPAD sensor IC and the readout IC requires 3D integration techniques. Developments in on-chip optical link integration (system on a chip and multi-chip-modules) may allow an optical interface to the readout and synchronization, which shall be extremely useful in terms of integration, noise and performance.

At this point, we would have a photon detector with optical output, so why don't go step further? *Why don't dream about a* ***fully photonic detector, including signal processing****?* Photons can be used as information carriers, making it possible to reach ultrahigh-speed and ultrawide-band information processing based on optical computing, which is a long-term pursuit of researchers. Researchers dream of achieving a photonic computer with untiring efforts. A crucial point is to realize the photon center processing unit (CPU) which is mainly composed of all-optical logic devices. Several schemes have been proposed in the past years, such as using photonic crystals [6], silicon photonics or surface plasmon polaritons.

Since photonic crystals could eventually be used both for detection [3] and processing [6] and since optical links are often the best choice in high energy physics and medical imaging, a fully photonic detector (optical I/O) will open enormous opportunities do develop high speed and extremely compact detectors. Obviously, many technological challenges will be faced, but optical processing elements such as comparators are being developed [7]. This is an endeavour for the next 10 years, many new amazing possibilities will open for high-energy physics colliders, such as HL-LHC or CLIC, with a bunch-crossing rate of 2 GHz, as well as for direct 3D PET in medical imaging.

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doi:10.1038/srep03869

Summary:

photonic crystals, optical processing, molecular imaging, direct 3D PET,Cherenkov detector, HL-LHC, CLIC, SPAD, SiPM, 3D integration, ASIC

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Developing a physics inspired neural recording platform

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Background
Conventional recording and analysis of electrical brain activity is done with a neuro-biological rather than physical perspective. The way signals are treated, closely reflect the prevalent neuro-biological theories, which see the functional organization of the brain as an electro-chemical digital circuit.

Typically, the recorded data are high-pass filtered and thresholded to produce binary sequences carrying information much like a digital computer. This signal processing, once justified by technical limitation in computational resources or users' culture, poses potential limitations to the investigation and discovery of neuronal communication strategies.

The challenge
In order to move beyond current practice, one must rethink data collection. Conventionally, electrodes used to record brain activity are sampled at low frequencies that reflect the time-scale of "binary" neural signals, however neural "spikes" cannot be reduced to delta-function when recorded with any technique but patch clamping, and may contain higher frequency components than suggested by the minimum interval between any two spikes, or prime neighbors' "echoes" to be deconvolved.
Therefore, it could be interesting to sample neural signals at a higher rate to explore whether any potentially relevant information has been ignored so far. Furthermore, EEG pulses are the resultant of several overlapped signals. It could help that the spatial relation between sources and sensors is in principle knowable and fixed once measured, thus opening to the possibility of implementing a deconvolution, in order to identify the individual signal sources, through the charge centroids images generated on the sensors. Higher space-time resolution sampling could offer room for new ways of thinking about neuronal communication. However, one of the essential challenges is to avoid spurious cross talk in the recording process itself; specifically, conventional electrodes are subject to unwanted inter-electrode cross-talk when electrodes are close together. Also, one would like to explore the limits of the field of action of a given sensing technology, to optimize its design according to the feasible positioning.

Methods
The expected S/N should be similar to the typical one for high resolution particle detectors, but the signal density is much higher on the much slower typical pulse time scale of 1 ms. All in all the problem can be faced by taking from high resolution particle detector experience, exasperating the pileup countermeasures and strategies.
The present project proposes to design and prototype an analogue programmable recording platform based on high-density micro-pattern readout system, with optimized resistivity of the contacts to avoid contact noise, and resistivity of the read-out system/cabling to avoid EM disturbances. This platform will allow programming and testing custom sampling modalities to investigate how to optimally treat and encode signals, to support electrophysiology research.

Summary:

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Heterogeneous computing for real-time systems

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The main idea of this proposal is to exploit, in the same hardware, the computing power offered by computing units of different nature, as GPU, FPGA, Associative memoriesm DSP arrays and ASIC. In standard computing the algorithms are designed for a single type of processor trying to adapt the logic of the processing to the architecture of the hardware, in heterogeneous computing the processing is split according the different kinds of specialized computing units. In such a scheme particular care is devoted to data transportation and resource sharing in order to take full advantage of the computing power offered by processing units designed with different architecture. Moreover, the software structure able to fully enable the hardware abstraction of this kind of system, will be completely design exploiting the progress obtained in recent years in the field of high performance

computing.
Last but not least, particular care will be devoted to data transportation, both for bandwidth and latency issues, by exploting new comunication busses and protocols that are arriving on the market (as, for instance, NVLINK by NVIDIA).
The direct application of this idea will be in the design of next generation high performance low level triggers in High Energy Physics experiments. In this application the need to move more and more the intelligence of online data selection to the front end electronics, asks to imagine computing systems that are able to extract the interesting features of the physicsl events with a predictable low-latency. This kind of system can find application in different fields where hard real-time responses are essential. The most natural place are robotics, automatic control, high computing simulation, computer vision, imaging reconstruction for medical application.

Summary:

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Lighting up a photonic network inside a living body

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So imagine this: An infrared LED pours light into a plastic fiber whose soft tip I press onto my skin, in a precise spot. As I increase the power, light couples into one of my veins. The long wavelength prevents excessive scattering and absorption, so light is actually guided into my body, slowly scattering into the surrounding living tissue. Some of the scattered infrared light leaves the body. It is not visible directly to the human eye, but I can easily capture the image using any silicon-based video camera. The image is slightly blurred, but, then again, not that much at all. As I look closely, I have a glimpse of a childhood moment, playing in the dark with my torchlight, seeing the outline of the bones in my hand as light pressed through the flesh and reached my eyes. But that was visible light passing through the hand. This is far different. Here it is IR light and it is not simply hitting the skin, it is coupled into it. Now, different tissues in the flesh reflect and scatter the IR light into many regular patterns. On a closer look, I can see inside the flesh. Literally. Actually, there are specific spots that are reflecting the IR light very, very effectively. These are constellations of metallic gold droplets placed according to specific patterns on my bones. These give the precise references to the image, allowing a quantitative imaging and even three-dimensional rendering of the bones in proximity of the illuminated flesh.
Looking inside what appear to us as opaque or reflecting objects is an all-time dream. When the system is opaque mainly because of scattering of density fluctuations, adaptive optics can be harnessed to reconstruct an emitter. Unfortunately, exactly like looking at stars through the turbulent and fluctuating atmosphere with an adaptive telescope, the technique requires you to know already what shape you are looking for. If it is an illuminated point in the sky, that is fine. If you are aiming to see extended shapes inside flesh, well, that is a wholly different story. In turn, imagine this technique being used to tailor the intensity and phase profile of the light exiting from the plastic multimode fiber. Then one can tune the launch pattern to achieve optimal coupling into the vein, or even design where and how light is allowed to escape into the flesh. So, instead of using adaptive optics to reconstruct an emitting spot from a blurred blob, adaptive optics is used to deliver light, where no precognition of what is going to be observed is needed.
A different approach is to embed inside the opaque tissue specific tags and markers, fluorescent emitters, that bind to specific tissues and molecules to allow the localization and, in some case, the super-resolved imaging of features from the outside. Once again, what could be done using the body itself to funnel light to specific portions under study?
In a more general context, can the body or portions of it be used to route light, to modulate it, to detect it, to generate it? Can light be used to transfer information? for example, placing the tip of a finger onto a source and the tip of another finger onto a detector, can light pass through the body, in the process detecting and sensing?
Pioneering the field will require the development of innovative tissue compatible fiber tips, the study of waveguiding in the flesh, the study of imaging using tags, and the mapping in terms of an optical network of portions of the human body. On a side, there is one portion of the body that naturally

guides and funnels light. This occurs in glial cells in the vertebrate eye, where basic tissue typical of the brain differentiates into perfectly functional waveguides. In fact, in the eye, it is these natural glial cells with their transparent elongated form that funnel light through the opaque mass of tissue that protects the photosensitive tissues.

Summary:

Seeing in real-time inside living tissue, using living tissue as an optical network, infrared imaging, plastic optical fibers, adaptive optics, fluorescence imaging, gold droplets.

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The Impossible and the Unusable? Neutron Detectors: from 2D to 4D Sensors

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This dream aspires to take neutron detectors from 2D position sensitive devices to 4D sensors with energy and timing information. These extra dimensions of information are presently seen as impossible and unusable respectively. Novel instrumentation is nearly always the forerunner of new diagnostic methods. This vision is about enabling new transformational instrumentation that subsequently leads to novel interrogation techniques.

The first additional dimension is the holy grail for neutron detectors: energy measurement. This is presently unachievable and seen as impossible, as the information on the neutron energy is lost in the nuclear conversion of the neutron to detectable products. Advanced statistical methods may give the possibility to measure this.

Secondly, present-day timing resolution on neutron detectors is limited, rarely better than 10us, as few applications today require even this moderate timing resolution. However, the nature of the interaction in a thin layer detector allow imagination of a timing resolution of a factor 100 or more. Complex correlations may allow the expoitation of this for as yet unimagined investigations, if this capability were developed.

The potential for achieving these future capabilities is grounded in the intensive R&D efforts that have come since the Helium-3 crisis, and in particular the Boron-10 thin film detectors, where the neutron interacts in very thin layers of neutron sensitive material. Successful R&D thus far has led to a plethora of replacement technologies, which can already equal the performance of Helium-3 detectors.

By using a multi-disciplinary approach with developments linked across mathematical and statistical methods, material science and thin film technologies, and detector technologies, achieving this dream would give revolutionary instrumentation that would be transformational for neutron interrogation techniques.

Summary:

The vision and building blocks towards energy sensitive neutron detectors with ultimate timing resolution are outlined, which would revolutionise the capabilities of neutron detectors.

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The project 2-SPaCE: 2-dimensional materials for Single Photon CountErs

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The far-infrared region (wavelengths in the range 10 μm – 1 mm) is one of the richest areas of spectroscopic research, encompassing the rotational spectra of molecules and vibrational spectra of solids, liquids and gases. Both basic research studies and applications in this spectral region are hampered by the absence of sensitive detectors. Moreover, for certain applications an ultimately high sensitivity reaching a photon-counting level is indispensable. For instance, the single photon detection in the sub-THz spectral range may allow direct detection of dark matter in a region of the parameters space difficult to reach with different techniques, but particularly interesting from a theoretical point of view (axions, ALPs, dark photons, etc.).

However, in THz range photon energies are far smaller (hν < 124 meV for λ > 10 μm) and the single-photon detection is no longer trivial, in marked contrast to the visible and near-infrared regions (wavelengths shorter than about 1.5 μm), in which single-photon counting is possible.

Despite recent efforts to improve the available detector technologies, attainable sensitivities are currently far below the level of single-photon detection, In the last decade, a variety of novel detection schemes have been proposed [1-3]. Among them, semiconductor quantum device have used as single-photon detectors. The experimentally achieved noise equivalent power (NEP), less than 1 × 10^{-19} W/Hz$^{-1/2}$, is by several orders of magnitude lower than typical state-of-the-art detectros operating in the THz range. Such ultra-high sensitivity reaching singe-photon detection level, as well as ultra-broad dynamic range are consequence of the unconventional detection mechanism in a nanometric phototransistors.

The unique physical properties of graphene, like high carrier mobility, robustness and stability, make this material of potential use for several forefront applications in detector R&D [4,5]. Beyond graphene, there are many other 2D materials that due to confinement of electrons and to the lack of strong interlayer interactions usually exhibit optical and electronic properties different from their analogous 3D systems [6]. The size-dependent properties can be exemplified by molybdenum disulphide (MoS_2) that is semiconducting with an indirect bandgap as bulk material, and becomes a direct gap semiconductor in the 2D form. The functional flexibility offered by 2D atomic crystals is considered to be a key property for next device generation.

The proposed project (2SPaCE, 2-dimensional materials for Single Photon CountErs) is aimed at the development of a technological platform for advanced detectors based on 2D materials, graphene and MoS_2, to be employed as single photon counters in the sub-THz and THz regions.
The main goal of the project will be the investigation of novel detector schemes where 2D materials may play a potentially revolutionary role, by designing and fabricating proof-of-concepts devices. Different device architectures will be explored to achieve efficient detection in the spectral range of interest, by combining the different key concepts which are generally considered for future device generation based on this class of materials:

-Many of the appealing properties of 2D materials arise from the combination of strong light-matter interaction, and electronic transport dominated by hot-carriers effects and collective interactions, like the plasmonic effects that can be activated in the FETs canne [7]. Nowadays, plasmonics in 2DES is one the key concepts for the realization of novel optical devices working in different spectral ranges - from THz to visibile. In particular, the spectroscopic studies on the hydrodynamic response of a 2D electronic plasma confined in the transistor micrometric channel have demonstrated that 2D-based FETs can be used to realize a frequency-tunable THz detectors based on plasmonic micro-cavities[8].

-The remarkable electrodynamics and thermal properties of grahene, at present very well understood at room-T [9], are much less explored at low-T [10]. However, several reports indicated the possibility to reach very high sensitivity as both a bolometer and as a calorimeter [11].

For all the proposed 2D-based devices, one crucial point will be the integration of the 2D materials into the device technology needed for the addressed detector type. With the aim of fabricating detectors using the 2D layered materials, we will propose and develop novel solutions for the micro-fabrication of future electronic devices, contributing to the advancement of 2D materials science and device technology, whose foreseen applications will be not only in field of dark matter studies. The focus will be the study of the properties that could make 2D layered materials usable in detectors, but the results are expected to be relevant for the knowledge on 2D materials in general.

To date, CVD revealed to be a suitable method to growth controlled quality graphene[12] on large area, a least at R&D level. However, for future device applications, reliable solutions for the integration of the graphene-platform at wafer-scale level are still to find, as they are within the objectives of the "Graphene Flagship" started in 2013. Beyond graphene, the controlled synthesis and fabrication solutions for other 2D-based devices is still lacking or just emerging, hence a fundamental understanding of the processes involved and intensive work at R&D level are still required.

Among the goals of the 2-SPaCE project is the implementation of new equipments and the strengthening of pre-existing facilities for the growth and the analysis of graphene and MoS2. Graphene will be grown at the Laboratori Nazionali di Frascati (LNF) of the INFN (the host institution), by using the expertise developed and facilities set-up within a research program funded by the host institution in the 2014-2015 period and involving the proponents.

As the 2-SPaCE project is concerned with the fabrication and study of novel devices, the final results will be constituted by the demonstration of the proposed detectors concepts. The final deliverables could be possibly both in the form of experimental proof-of-principle prototypes or in the form of ready-to-use demonstrators, together with material synthesis methods, fabrication process solutions and experimental results. The project aim is demonstrating physical principles and indicating the pathways towards optimization of the proposed concepts.

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Summary:

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Trends towards Ideal Thermal Neutron Detectors: How good can it get?

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The Helium-3 crisis, which started in 2009, has by now become the Helium-3 reality, has spawned an intensive R&D effort for replacement technologies for neutron detectors. Neutron Scattering, which made up ca. 40% of Helium-3 demand prior to the crisis was particularly hard hit. These development efforts, along with several new facilities present under construction, including the European Spallation Source in Lund Sweden, have also revitalised the search for better performant neutron detectors that enhance the ability of the next generation of neutron instruments, by allowing the instrument to assert higher performance requirements on the detector technology. This quest for replacement technologies has been a pan-disciplinary effort, and has already almost achieved equivalence with the performance of Helium-3 detectors.

Neutron detector performance is primarily characterised by the neutron convertor, which interacts with the neutron via a nuclear reaction to produce daughter products which are detectable. To identify the trends over the next decade, and in the spirit of this search for better performing technologies, viable converters and their realistic limits of performance are determined.

With a survey of present day state of the art, an outlook is given on the potential "headroom" in improved technology performance that could be achieved with a development programme in the coming decade, given present technology trends. Spatial resolutions of such sensors could improve from mm to microns, neutron rate performance by more than a factor of 1000, timing resolution by more than a factor of 100, larger areas are possible, and background levels could be reduced by at least 1 or 2 orders of magnitude. A broad canvas of technological improvements in micro-mechanics, electronics, mechatronics, integration and data utilisation will be required to achieve this.

Such improvements will significantly impact present neutron interrogation techniques, and also open the doors to this miniturisation of instrumentation utilising neutrons, which is a wider technological trend in society. The quantum leap in performance which could be afforded by such a development programme also allows wider application of neutrons to industrial and societical challenges of the coming decades.

Summary:

The wish for better thermal neutron detectors is examined, to identify possible trends in performance that a development programme might yield over the coming decade. For most performance metrics,

orders of magnitude improvement are theoretically possible. Such powerful instrumentation would greatly enhance the diagnostic potential of neutron interrogation, with great societal impact both for present fields of application as well as opening up future ones.

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Fast neutron spectroscopy with very high energy and time resolution for diagnosing fusion DT burning plasmas

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Neutron spectroscopy is a key diagnostics of high power fusion plasmas 1. In particular, it can determine the plasma ion temperature, the so called thermal to non-thermal fusion power ration and the fuel ion ratio (nD/nT) of the concentration of deuterium and tritium isotopes in a DT burning plasma. The latter is a crucial parameter to be measured in order to control the produced fusion power. The determination of the fuel ion ratio requires to measure with very high energy resolution and sensitivity minor components in the expected 14 MeV neutron energy spectrum In particular, one must be able to distinguish from the main 14 MeV neutron thermal emission a fraction of about 1% of suprathermal neutrons, the latter emitted by reactions between neutral beams and thermal ions and emitting neutrons up to about 18 MeV [2].
In recent times, diamond-based detectors (CVD- chemical vapour deposition diamonds [3]) have shown an interesting potential as high resolution neutron spectrometers for fusion and other applications [4]. Diamond features 1) insensitivity to magnetic fields; 2) high radiation resistance; 3) low dark current; 4) good energy resolution (˜1% FWHM@14MeV), at present limited by the fast preamplification electronics; 5) very high counting rate capability (>1 MHz). A neutron spectrometer based on a 12-pixel CVD diamond matrix has been built and installed at the JET fusion tokamak in United Kingdom. This technology has already been identified of interest by ESA [5] also for application others than nuclear fusion.
The sensitivity of present diamond neutron spectrometers to weak components in the neutron spectrum is today limited at about 1% in "normal" (i. e. natural isotopic carbon concentration with about 99% of 12C and 1% of 13C) diamond detectors. There are two competitive reactions of neutrons in the MeV energy range, namely 12C(n,alpha)9Be and 13C(n,alpha)10Be, the latter featuring a Q value of about 2 MeV lower than the first reaction. The resulting detector response function is thus such that sets the sensitivity to weak components in the high energy tail of the 14 MeV neutron spectrum to about the 1% level.
Target goals of this proposal is the realization of a prototype diamond based neutron spectrometer which features an energy resolution<0.5% at 14 MeV, counting rate capability of 5 MHz and a signal to background >10ˆ4 in the neutron energy range 12-20 MeV. This will be realized first, by the development of a custom low noise fast spectroscopy preamplifier. Second, it is proposed the development of 13C-free CVD diamond. The CVD technique allows to grow enriched 12C crystal by the use of 13C-free methane as a starting gas. 13C-free methane can be obtained by the use of gas centrifuges, a standard technology already used not only for the isotopic separation of uranium

but also for other atoms like zinc or lithium [6]. Aim of this proposal is to grow high purity single crystal CVD diamonds enriched at least at 99.99% of 12C, build the detector and characterize in the laboratory and at fast neutron sources, including 14 MeV monoenergetic sources. The measured performances will be benchmarked to standard natural carbon composition diamond spectrometers. If the development will be proven to be successful, the first application will be the installation at JET fusion laboratoris in UK for the next DT campaign and tested for determination of the fuel ion ratio. the Other possible applications can be spectroscopic analysis of charged particles, such as protons or alpha particles or radiation therapy dosimetry, the latter being favored by the tissue-equivalent behavior (atomic number of the detector is very close to the mean of human tissue).

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Summary:

Future DT burning plasma experiments such as ITER will require dedicated nuclear diagnostic for monitoring the plasma performance and evolution. Spectroscopy of 14 MeV neutrons is a key diagnostics of high power fusion plasmas since it allows the measurement of the plasma ion temperature, of the so called thermal to non-thermal fusion power ratio and of the fuel ion ratio of the concentration of deuterium and tritium isotope. In this proposal we propose to develop a new compact neutron spectrometer which, for the first time, features i) very high energy resolution (<0.4%@14MeV); ii) enhanced sensitivity to weak components in the neutron spectrum; iii) time resolution on the 10-100 ms scale thanks to a counting rate capability up to 5 MHz. The spectrometer will be based on CVD diamond detectors. A successful demonstration of such compact diamond neutron spectrometer prototype will open up the possibility to perform time resolved measurement of the ion temperature and of the fuel ion ratio, and to achieve spatial resolutions by performing multiple line of view observation in a camera configuration.

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Mimicking nature in growing detectors

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It is a plausible approach to tackle some of the near future technical challenges by mimicking living nature, which solved many problems during evolution. The fact that helicopters or airplanes are flying is due to the technical translation of biological solutions. Regarding imaging sensors and visual systems, nature came up with far beyond state of the art solutions, which are worth to be translated into the next generation of detection systems

In wildlife, nature developed the ultimate imaging systems carrying out a number of complex tasks which includes the reception of light on high throughput image sensors (130 Mpixel, 10GB/s on human retina), on the fly data compression (two orders of magnitude from retina to optical nerve) and subsequent data processing. The latter comprises the formation of monocular representations with the subsequent buildup of a binocular perception from a pair of two-dimensional projections. This allows the identification and categorization of visual objects, assessing distances to and between objects and their movement in real-time. Eventually large data volumes are stored incrementally and over long time in relatively small data back ends (some tenths of cm3).
These complex systems are grown and self assembled from a single seed and built up by nanometer-sized building blocks whereas neuronal activity profoundly influences the growth of axonal terminals, contributing to their final size and form. During the final phases of visual system development,

adult patterns of neuronal connectivity are achieved via an activity-driven process of synaptic rearrangement.
With these characteristics in mind and in view of future challenges in imaging technology it is worth the effort to try to mimic nature's approach in growing and self-assembling detectors from nanometer-sized building blocks. Obviously it will take a long way to grow and self assemble an entire imaging system, however, with the technology available nowadays such as graphene, 3-d printing or molecular beam epitaxy (MBE), at least sensors can be grown.
Due to their tunable and direct band gap detectors grown by MBE utilizing III/V semiconductor materials are extremely interesting for the next generation of multi wavelength imaging systems operating in regimes from THz to hard x-rays with sub nano second time resolution. The latter is due to nanometer sized quantum structures, which allows to host two-dimensional electronic gases possessing extreme high charge carrier mobility and enables charge amplification on the sensor level.
With regard to ATTRACT the idea would to grow small size (max 2 ") pixilated sensors (pixel size ˜ 50 µm) using InGaAs and InAAs comprising single or multiple quantum wells for charge amplification. A thorough sensor characterization includes the assessment of efficiency for different wavelengths including THz radiation, and the assessment of spatial and time resolution with ultra FEL soft x-ray pulses utilizing standard readout electronics. To go further 3D bioprinting techniques using will be fathomed to assemble high complexity nerve tissue for the sensor read out. Polymer materials will serve as scaffold for growing nerve tissues. The final functionality will be achieved by integrating graphene as the electrical conductor.

Summary:

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Omni-purpose detectors based on stacks of CMOS active pixel sensors

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Experiments in subatomic physics rely on multi-measurements to identify precisely the final quantum state under study. This results in rather large detection systems involving various technologies dedicated to specific tasks, like tracking and calorimetry to name a few. The evolution of science demands for increasing event rates and thus drives detectors towards higher granularity in space and time. But these specifications are conflicting in a single sensing technology, typically because more channels leads to longer readout time. Reaching the same specifications by combining heterogeneous technologies with small sensing elements also meets some practical obstacles related to integration.
We propose to overcome these limitations with very compact detection systems built by stacking CMOS monolithic active pixel sensors (CMOS-MAPS) in direct contact. The overall volume of the apparatus will be continuously sensitive but for the thin (few micrometres) electronic layers and the necessary interconnections. The best analogy describing such systems is the one of an electronic nuclear emulsion.
The main strength brought by multi-point measurement is to maximize the information extracted for each radiation penetrating the stack. The system registers the propagation through sensitive materials with potentially 3+1+1D granularity: space, time and energy-loss. The particle history is traced through the stack both in a tracker and a calorimeter ways. The complete set of measurements achieved includes: initial impact position, direction and time, energy loss, particle range and potential decays.
Regarding the sensitivity to the various particle types (especially charged versus neutral) and the range of energies, stacking sensor layers present decisive benefits. While first layers stop low range radiations, the more penetrating ones are still measured further away in the stack. Potential inserts of non-active

materials can also be considered, like thin scintillator layers to the light of which CMOS-MAPS are sensitive.
Without being exhaustive, we underline two additional benefits of proximity measurement redundancy. First, multi-measurement enhances radiation tolerance, since missing information from a damaged cell can be replaced with a subsequent adjacent cell without severe loss for the overall information extraction. Second, such a system is more capable to handle large particle flux; because either radiation are measured by different layers or the historical information on each particle helps disentangle each of them.
Types of information and stack depth needed depend naturally on the application. This is the reason CMOS-MAPS are particularly well suited to the task, since they nowadays exist with a variety of detection performances, with respect to sensitive depth, pixel size, readout speed and signal amplitude resolution. Additionally, a number of these features can be adjusted after the chip fabrication, enhancing the plasticity of the apparatus. For instance, the sensitive depth obtained over a highly resistive substrate is controlled through the biasing voltage in a range from 10 to 100 micrometres. In the near future, sensors will offer re-configurable embedded signal treatment algorithm, like neural networks, to fit the same chip to various situations.
The proposed system presents both unprecedented performances and versatility. It is hence expected to impact a wide variety of domains, from which we take a few illustrative examples.
In particle physics, a few layers stack will allow reconstructing directly helices corresponding to particle trajectories within a magnetic field, complemented with finer timing and more radiation tolerance. A tracker based on such stacks would feature improved counting rate, signal-background separation capabilities and an overall low material budget since a low number of such stacks would be needed to complete a full tracker.
A deep stack about a centimetre depth, would detect simultaneously charged ions species, as a perfect Delta-E / E telescope used in nuclear physics, and neutrals as a segmented scintillator block, with the addition of correlated timing information. The system would match perfectly proton radiography requirements.
Considering X-ray detection, a thick sensor stack would be effective over a wide range of energies and increase the counting rate with respect to a single sensing layer. The evolution of counts with depth would also directly provide spectroscopic analysis of the energy distribution.
In the general scientific images domain, the proposed stack would bring advantages like multi-modality (X-rays, visible light, electrons, neutrons) and analysis power (since more information is collected). Non-destructive tests widely spread in industry would benefit from these progresses at various scales, from production good or material controls to aging building checks (in nuclear installations for instance).
While CMOS-MAPS fulfilling the needs exist or almost exist, integrating a large number of these chips over a useful area (at least 100 cm2) and thickness (from few millimetres to centimetres) set the real challenge. Interconnection, mechanical stability, power dissipation and data extraction count among the pivotal issues to solve. A number of processes from the semi-conductor industry already provide potential solutions. Nevertheless, a dedicated large scope effort is required within the next ten years to properly optimise and

Summary:

The trend in subatomic physics experiments is to increase the granularity of measurements, in space and time. Practical difficulties limit the achievable performances, since current experiments mostly rely on the integration of heterogeneous technologies. In contrast, a continuous pixelated sensitive volume could replace a complete complex setup and provide unprecedented performances, if the material can detect various particle types.
CMOS monolithic active pixel sensors (CMOS-MAPS) benefit nowadays from a high sensitivity and a thickness almost entirely sensitive. A stack of CMOS-MAPS in direct contact would act as the volume dreamed for, providing tracking, calorimetric and timing information. The number of layers in the stack, their thickness and the specifications of their pixel sensors would be adapted to optimise the overall performances depending on the type of particles (charged

particles, ions, X-rays, gamma-rays), their energy and flux.
The potential applications of this new type of instruments span a vast range of domains, from scientific to industrial measurements. The plasticity of the stack configuration and versatility offered by CMOS-MAPS will grant cross-fertilisation between these fields.
The realisation of such stacks of CMOS-MAPS will combine and optimise processes from the semi-conductor industry to solve the main issues, among which are interconnections, mechanical stability, power dissipations and data throughput.

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Mimicking nature in growing detectors

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It is a plausible approach to tackle some of the near future technical challenges by mimicking living nature, which solved many problems during evolution. The fact that helicopters or airplanes are flying is due to the technical translation of biological solutions. Regarding imaging sensors and visual systems, nature came up with far beyond state of the art solutions, which are worth to be translated into the next generation of detection systems

In wildlife, nature developed the ultimate imaging systems carrying out a number of complex tasks which includes the reception of light on high throughput image sensors (130 Mpixel, 10GB/s on human retina), on the fly data compression (two orders of magnitude from retina to optical nerve) and subsequent data processing. The latter comprises the formation of monocular representations with the subsequent buildup of a binocular perception from a pair of two-dimensional projections. This allows the identification and categorization of visual objects, assessing distances to and between objects and their movement in real-time. Eventually large data volumes are stored incrementally and over long time in relatively small data back ends (some tenths of cm3).
These complex systems are grown and self assembled from a single seed and built up by nanometer-sized building blocks whereas neuronal activity profoundly influences the growth of axonal terminals, contributing to their final size and form. During the final phases of visual system development, adult patterns of neuronal connectivity are achieved via an activity-driven process of synaptic rearrangement.
With these characteristics in mind and in view of future challenges in imaging technology it is worth the effort to try to mimic nature's approach in growing and self-assembling detectors from nanometer-sized building blocks. Obviously it will take a long way to grow and self assemble an entire imaging system, however, with the technology available nowadays such as graphene, 3-d printing or molecular beam epitaxy (MBE), at least sensors can be grown.
Due to their tunable and direct band gap detectors grown by MBE utilizing III/V semiconductor materials are extremely interesting for the next generation of multi wavelength imaging systems operating in regimes from THz to hard x-rays with sub nano second time resolution. The latter is due to nanometer sized quantum structures, which allows to host two-dimensional electronic gases possessing extreme high charge carrier mobility and enables charge amplification on the sensor level.
With regard to ATTRACT the idea would to grow small size (max 2 ") pixilated sensors (pixel size ˜ 50 µm) using InGaAs and InAAs comprising single or multiple quantum wells for charge amplification. A thorough sensor characterization includes the assessment of efficiency for different wavelengths including THz radiation, and the assessment of spatial and time resolution with ultra FEL soft x-ray pulses utilizing standard readout electronics. To go further 3D bioprinting techniques using will be fathomed to assemble high complexity nerve tissue for the sensor read out. Polymer materials will serve as scaffold for growing nerve tissues. The final functionality will be achieved by integrating graphene as the electrical conductor.

Summary:

Due to their tunable and direct band gap detectors grown by MBE utilizing III/V semiconductor materials are extremely interesting for the next generation of multi wavelength imaging systems operating in regimes from THz to hard x-rays with sub nano second time resolution. The latter is due to nanometer sized quantum structures, which allows to host two-dimensional electronic gases possessing extreme high charge carrier mobility and enables charge amplification on the sensor level. With regard to ATTRACT the idea would to grow small size (max 2 “) pixilated sensors (pixel size ˜ 50 µm) using InGaAs and InAAs comprising single or multiple quantum wells for charge amplification. A thorough sensor characterization includes the assessment of efficiency for different wavelengths including THz radiation, and the assessment of spatial and time resolution with ultra FEL soft x-ray pulses utilizing standard readout electronics. To go further 3D bioprinting techniques using will be fathomed to assemble high complexity nerve tissue for the sensor read out. Polymer materials will serve as scaffold for growing nerve tissues. The final functionality will be achieved by integrating graphene as the electrical conductor.

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Multispectral method for Bone Mineral Densitometry-Emerging Imaging Technologies call

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The objective is a Feasibility study for multispectral method of BMD to improve accuracy over current DXA methods. Results up to date: Feasibility demonstrated, showing improved performance over DXA; Additional IP created in energy calibration for multispectral detectors. Market Opportunities opening in 2 markets.

Summary:

The objective is a Feasibility study for multispectral method of BMD to improve accuracy over current DXA methods. Results up to date: Feasibility demonstrated, showing improved performance over DXA; Additional IP created in energy calibration for multispectral detectors. Market Opportunities opening in 2 markets.

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High granularity scintillating fiber trackers based on Silicon Photomultiplier read-out

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Scintillating fibers coupled to photosensors provide flexible, fast and high granularity detectors which are able to work even in high rate environment. We will report about the performances obtained with a multi-layer detector prototype based on 250 µm multi-clad square scintillating fibers, 20 cm long, coupled
to 1.3×1.3 mm 2 active area silicon photomultiplier (SiPMs). Current measurements show results never reached up to now: high detection efficiency for minimum ionizing particles (m.i.p.) already with single layer (> 90%, mean collected light/fiber 8.5 phe). Also a good spatial resolution can be

achieved by keeping the optical cross-talk between fibers at a negligible level (<1%). Finally, the time resolution of the order of 500 ps has been achieved for m.i.p. in a single layer configuration. The resolution improves with increasing the number of detector layers. All measurements have been supported with a Monte Carlo simulation based on Geant4 and a custom code, describing the response of the SiPMs.

Summary:

Scintillating fibers coupled to photosensors provide flexible, fast and high granularity detectors which are able to work even in high rate environment. We will report about the performances obtained with a multi-layer detector prototype based on 250 μm multi-clad square scintillating fibers, 20 cm long, coupled
to 1.3×1.3 mm 2 active area silicon photomultiplier (SiPMs). Current measurements show results never reached up to now: high detection efficiency for minimum ionizing particles (m.i.p.) already with single layer (> 90%, mean collected light/fiber 8.5 phe). Also a good spatial resolution can be achieved by keeping the optical cross-talk between fibers at a negligible level (<1%). Finally, the time resolution of the order of 500 ps has been achieved for m.i.p. in a single layer configuration. The resolution improves with increasing the number of detector layers. All measurements have been supported with a Monte Carlo simulation based on Geant4 and a custom code, describing the response of the SiPMs.

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Weighting Resistive Matrix technique (WRM) for high speed, critical decision-making in data evaluation

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A device based on critical decision-making must evaluate data in a time scale short enough for the decision to be useful in the application context. Exemplary cases are the autonomous vehicles and robots, or medical robotic prosthetics, with the inherent needs to fast and meaningfully react to the environment. The very same need is also present in frontier science experiments, where sensors produce higher than manageable data flows, and data driven selective fast decision is needed, also known as either trigger or compressive sensing.
The above-mentioned problems are often combinatorial, because data produced by individual sensors assume a meaningful interpretation only in correlation with the other sensors, in a non-predictable way. Their computational complexity represents a limit to the present state of the art systems, when the tolerated latency prevents to use a distributed computing architecture (such as a cloud) or when the application dictates severe limitation in local weight, volume and power consumption. In facts, the classic approach is based on a rigid sequence: $sensor \rightarrow digitization \rightarrow serialization \rightarrow transmission \rightarrow deserialization \rightarrow computing$. This scheme, where any intelligence is centralized far away from the sensor, is generally adopted due to the digital standardization advantages, but is in principle inefficient since it accumulates latency and concentrate the data before any processing, which is the opposite of what would suggest a divide and conquer strategy.
A representative attempt to implement a fast decision process are the Associative Memories, content addressable memories that contain a set of precomputed solutions for a fixed set of inputs. These are very fast solutions to manage a big data flow, but their potential scalability is strongly limited by the fact that the address space grows with a factorial progression with dimension of the input parameter space.
Deep neural networks (DNN) are considered instead the mainstream approach to complex data. They consist in a concatenation of simple neural network trained with data, behaving like tailored filters, as flexible as the number of layers of concatenated networks, each representing a possible degree of freedom for the data matching. DNN are more and more often optimized by running on GPUs and/or FPGAs, to increment their speed, at the expenses, though, of power consumption. The amount of flexibility is appreciable but limited by the fact that a DNN is essentially a black box, every time learning from scratch, thus not eligible for an engineering based on incremental knowledge trough problem modelling.

An attempt in overcoming these limitations, is the Weighting Resistive Matrix technique (WRM), conceived for discriminating vertices in real time in HEP experiments; by relying on an analog computing architecture it implements the equivalent of a probabilistic regression at nanosecond scale, without actually computing but exploiting the physics of a specific network. Thanks to this it extracts directly from data the most likely fit parameter values, using the energy of the input signal in a single clock cycle independently from the input. For this feature the WRM is an extremely fast and low power consumption device. A WRM chip has been already produced for HEP and adapted to artificial vision applications. The extensive studies performed in this application, from the full software simulation to the real demonstrator, have shown that WRM potential has never been fully exploited as it is essentially hindered by the digital design inheritance of the present WRM, and by the limited dimensionality of the matrix, constrained by the standard IC technology. The study finally revealed an impressive and very inspiring similarity between the WRM technique and the neural information processing, from the retina up to the visual cortex.
We propose to develop a new IC architecture, inspired to the WRM principles and overcoming its limits, integrating sensors, front end and data processing in the same device, to work ahead of the digitization so to achieve an extreme computing power intensity per electric power unit. This will be done by studying a fully analog neuro-inspired matrix, relying on a high level of internal connectivity, which can be dynamically configured through a memristors-like network. We intend to investigate how this technology can be employed to enable data driven decision at the front end, across successive levels of data abstraction, enabling the mobile things awareness concept. We envisage as realistically reachable target a new generation of reliable and lightweight self-driving vehicle and autonomous robots safely interacting with the environment.

Summary:

A device is proposed based on critical decision-making in evaluating data in a time scale short enough for the decision to be useful in the application context. Exemplary cases are the autonomous vehicles and robots, or medical robotic prosthetics, with the inherent needs to fast and meaningfully react to the environment.

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2D (Graphene) – Quantum dot Hybrid photodetector technology for CMOS compatible high performance photodetectors from the UV to Short-wave Infrared.

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There is an urgent need for a detector technology platform that concomitantly offers high sensitivity, broad spectral response (from UV to mid-IR), low manufacturing cost and CMOS monolithic integrability. In that respect we will present our recently discovered technology platform for photodetectors enabled by graphene's high mobility and atomically thin profile and the tailored and high absorption of colloidal quantum dots. Following up to our original report in 2012 1, where we demonstrated a new hybrid phototransistor architecture covering both UV-Vis and SWIR (short wave infrared) spectral regimes providing exceptionally high gain on the order of 107 and normalized detectivity in the range of 1013 Jones, we will proceed showing some recent results in which the passive sensitizing layer of QDs is transformed into an electrically active QD photodiode. In doing so we report a 4-orders of magnitude improvement in gain-bandwidth product over our first report achieving at the same time responsivity of 106 A/W, electrical bandwidth on the order of kHz and quantum efficiency of up to 75% (thrice higher than what can be achieved through a passive QD layer) [2].
In the second part of the talk we will present results from hybrid 2D-QD photodetectors in which the 2D transistor channel is implemented with a semiconducting 2D transition metal dichalcogenide

MoS2 layer [3]. In doing so, we can modulate the transistor reaching very low dark currents and responsivities on the order of 105 A/W . We will discuss advanced interface engineering employed to simultaneously cater for high charge transfer efficiency from the QD layer to the MoS2 layer and maintain the modulation of the MoS2 channel [4].
In the last part of our talk we will briefly present some recent prototypes based on this technology in the field of image sensing and wearable and IOT applications.

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Summary:

We will present our recently discovered technology platform for photodetectors enabled by graphene's high mobility and atomically thin profile and the tailored and high absorption of colloidal quantum dots.

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Neuroscience beyond neurons

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The human brain displays amazing computing capacities. Unfortunately, it also often goes wrong with dramatic consequences. Diseases of the central nervous system cost each European € 5500 every year and represent one third of the financial burden of European public health systems 1. For historical and technological reasons, neuroscience has focused mostly on neurons and derives its name as a field from that specific cell type. However, the human cortex consists of numerous cell types, and neurons only represent 20% of that overall population [2]. In recent years, new imaging technologies have allowed us to investigate non-neuronal cell types, collectively called glial cells. Unlike neurons, glial cells are not electrically active but show tremendous activity when monitored via imaging techniques that assess fluctuations of their internal calcium concentration. These studies have revealed that glial cells play a key role in all aspects of brain function, both in health and disease. Because of the relative novelty of this line of inquiry, there is no algorithm to segment and analyze calcium-imaging data in glial cells, and there is no theory to make sense of the data.

Neuroscience is faced today with the challenge of developing new image-processing technologies and a new theoretical framework to go beyond mere neural networks, which we know do not represent the biological reality underlying our computing prowess and diseases [3].
To tackle this challenge, this project will bring together experimental neuroscientists, computer vision experts, engineers and computational biologists to collect, store and share the data in an open fashion, to develop the necessary imaging and pattern recognition techniques, and to develop the missing theoretical framework. Through this transformative effort, we expect that neuroscience will mature into brain science. This project will have an impact on our understanding of brain function, paving the way for better machine intelligence algorithms, and it will have an impact on our understanding of the onset and progression of diseases of the central nervous system, opening new therapeutic avenues.

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Summary:

This project will bring together experimental neuroscientists, computer vision experts, engineers and computational biologists to collect, store and share the data in an open fashion, to develop the necessary imaging and pattern recognition techniques, and to develop the missing theoretical framework.

Renaud Jolivet 1,2, Suhita Nadkarni 3, Clare Howarth 4, Olga Beltramello 2

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Video-Based Drone Detection for Collision Avoidance Purposes

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We are headed for a world in which the skies are occupied not only by birds and planes but also by unmanned drones ranging from relatively large Unmanned Aerial Vehicles (UAVs) to much smaller consumer ones. Some of these will carry transponders that make them easy to detect but not all. In addition to these unequipped drones, one must also account for other flying objects such as paragliders, blimps, and even large birds that all constitute potential collision threats.
To allow aircrafts to safely navigate such a crowded environment without requiring heavy or expensive equipment, we will develop a lightweight videobased system that can detect threats and alert the pilot to it.

We have begun developing video-based algorithms that rely on classifying descriptors extracted from spatio-temporal image cubes. These cubes are formed by stacking motion-stabilized image windows over several consecutive frames, which gives more information than using a single image. What makes this approach both practical and effective is a learning-based motionstabilization algorithm. Unlike those relying on optical flow, it remains effective even when the shape of the object to be detected is blurry or barely visible. This arises from the fact that learning-based motion compensation focuses on the object and is more resistant to complicated backgrounds.

Our current results are encouraging but our algorithms are not yet reliable enough, in large part because rely on Statistical Machine Learning, and more specifically on Deep Nets that require very large training databases to reach their full potential. Since such databases do not yet exist, the main goal of this project will be to build them and then exploit them to the full to achieve the required detection reliability

Summary:

We have begun developing video-based algorithms that rely on classifying descriptors extracted from spatio-temporal image cubes for Collision Avoidance Purposes. These cubes are formed by stacking motion-stabilized image windows over several consecutive frames, which gives more information than using a single image.

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Computer Vision Aid for the Visually Impaired

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The goal of this project is to develop a daily life assistance system for the visually impaired in uncontrolled
environments. Currently, Computer Vision techniques have been playing on a limited role in assisting the visually impaired, mainly due to the challenging requirements for making the system practical.

Among the many, the system needs to run on mobile devices, while performing complex pattern recognition tasks in uncontrolled environments. Moreover, the design of the Human Computer Interfaces (HCI) is particularly complex, since it should be adapted to the way visually impaired people perceive the world.
Today, the outcome of the research in Augmented Reality carried on within the EDUSAFE Project, as well as recent advances in large scale vision based recognition systems, allow us to enable new research directions and applications.

Our system will provide a mobile application (Android), helping the user analyze the surrounding environment. The user will provide vocal inputs asking questions about the surroundings; the system will process the queries and provide the requested information by analyzing pictures and videos taken from a wearable embedded camera. This setup will keep the user's hands free, a critical requirement for usability, and will also ensure a longer battery life by avoiding excessive use of the phone camera. Some example queries that our system will be able to assess are: "Is there a free seat on this bus ? Bring me there!"; " Bring me to the closest crosswalk."; " How many people are there in the line in front of me? " and so on.

For this, we will need to improve state of the art in several domains, such as:

VISION:
a novel 3D Tracking framework is required, able to deal with hundreds of object categories by coupling Pattern Recognition with Navigation and Mapping methods. While the 3D Tracking successfully developed for the EDUSAFE European Project would provide a sound theoretical basis, an entirely new framework is required for scalability.

EMBEDDED COMPUTING :
we need to bridge the gap between the massive computational resources
required by modern Pattern Recognition techniques and the limited capability of mobile platforms.
Moreover, we will develop a miniaturized, wearable camera module able to seamlessly stream images to
mobile platforms in real time, using low power consumption wireless techniques such as the Low Power
Bluetooth standard.

INTERFACES/USABILITY:
a voice recognition system will be put in place for interpreting the
user's voice commands and high level queries, working in noisy, uncontrolled environments. As for the
output, the most suitable way of conveying information for users with different degrees of inability will be
sought. Furthermore, though mainly addressed for the visually impaired, our system will be straightforwardly adaptable to assist individuals with other kinds of disabilities, such as autistic patients, for navigation and analysis of unknown environments.

Summary:

The goal of this project is to develop a daily life assistance system for the visually impaired in uncontrolled
environments.

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A miniaturized gamma camera allowing real time radiation visualization

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Our goal is to develop break-through technologies and ingrate them in a wearable system that will effectively assist operators during planned and emergency maintenance in radioactive environments (nuclear installations, nuclear power plants, research laboratories, emergency responses, CBRNe accidents,…). Those operations require a stringent monitoring program in order to: 1) Secure the protection of the environment and the workers, and 2) allow the optimization of the operational scenarios that are most relevant to the technical.

The aim is to technically advance and combine several technologies and integrate them as integral part of a personnel safety system to improve safety, maintain availability, reduce errors and decrease the time needed for scheduled or sudden interventions. The research challenges lie in the development of real-time (time-lags less than human interaction speed) data-transmission, high resolution 3D gamma imaging, instantaneous analysis of data coming from different inputs (vision, sound, touch, buttons), interaction with multiple on-site users, complex interfaces, portability and wearability, wear/tear. The breakthrough innovation will be a next generation gamma imager with improved characteristics in terms of portability, sensitivity and angular resolution. The camera is able to produce automatically panoramic and 3D gamma images superimposed on panoramic visible images using only one single pixellated detector. The gamma camera is based on a portable high resolution-resolution gamma-ray detector based on state-of-the-art Cadmium Zinc Telluride (CZT) sensors.

The advances for the gamma camera sensor will address: 1) Higher detection efficiency, which results in lower integration times and sensitivity to very low activity sources, 2) Radiation source localization with high spatial resolution and imaging over a wide field of view, 3) Ability to reconstruct 3D images, based on the intrinsic stereo detection capability, 4) Spectroscopy capability with good energy resolution, 5) Implementation of a calibration procedure between gamma sensor and depth sensor. The main goal from an application standpoint is to estimate the distance of a radioactive source (if present) automatically and with no knowledge of the environment a priori, 6) Registration between gamma sensor and optical sensor. This allows to have a gamma image automatically superimposed on the optical image, without any parallax adjustment needed. Even for complex surfaces that are not orthogonal to the camera head, the superimposition will automatically performed with an average of one pixel accuracy. 7) Design and implementation of an algorithm for gamma 3d reconstruction, 8) develop point cloud gamma information with 3d point cloud data model regarding

radioactive surfaces/objects, 9) develop a volumetric integration dynamically merged with the textured 3D mesh and the information of the radioactive source.
The gamma images and 3D dose rates will be displayed on Head Mounted Display utilizing the latest AR and VR technologies. These developed technologies, integrated in a wearable and low power system, will enable the operator to virtually visualize the dose rates in 3D and in real time with a very high accuracy. We propose to develop radically new CZT pixelated gamma camera and techniques on the field of computer vision to analyze in real time Gamma 3D models and depth sensors.

Summary:

Our goal is to develop break-through technologies and ingrate them in a wearable system that will effectively assist operators during planned and emergency maintenance in radioactive environments (nuclear installations, nuclear power plants, research laboratories, emergency responses, CBRNe accidents,…).

CERN (Geneva)

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Vision Talk 2 ”The physical measurement limits of semiconductor radiation detectors: Where do we stand and what can be improved”

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Vision Talk 3 - Imaging for the 20's and beyond

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Image sensors and detectors are one of the key technologies enabling future applications like smart homes or autonomous driving, all part of the Internet of Things. Whether through Moore's scaling or 'more than Moore', semiconductor technology remains an essential driver for the advancement of imagers and detectors. This talk will review the status and trends of some areas of semiconductor technologies, looking at the expected evolution of key technology parameters, e.g. pixel size, data rate, detection efficiency, …, going towards the horizon of 2025 and beyond. Some wishes and dreams of what we might be able to do with future technologies will be presented.

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Speaker Slot Lottery

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Presentation 19 ”Fast Timing Micro-Pattern Gaseous Detector”

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Presentation 20 ”Real-time 4D Imaging”

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Presentation 21 ”A new High-Rate and High-Resolution X-ray Spectroscopy Detector”

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Presentation 22 ”Simultaneous x-ray transmission and fluorescence CT”

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Presentation 30 ”Fast neutron micro-imaging by 2025?”

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Presentation 29 ”Tracking Particles with Optical Readout GEMs”

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Presentation 28 ”Auto-sampling image sensors”

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Presentation 27 ”Heterogeneous computing for future triggering””

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Presentation 25 ”PIXFEL”

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Presentation 26 ”A pixelised detector for thermal neutrons”

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Presentation 23 ”Beam monitor based on MPGD detectors for hadron-therapy”

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Presentation 24 ”3D Associative Memory Chip”

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Fast Timing Micro-Pattern Gaseous Detector for PET-TOF and Future Colliders applications

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Today, the newly developed micro-structure technology opens the possibility to realize a new generation of gaseous detectors. Research focused in particular on the radiation induced processes leading to discharge breakdown, and led to the development of a family of more resistant devices with similar performance named Micro-Pattern Gas Detectors (MPGDs). The main features of the MPGDs are: flexible geometry; high rate capability (> 50MHz/cmˆ2); excellent spatial resolution (down to

50um); good time resolution (down to 3ns); reduced radiation length. Recently a detector layout has been proposed that would combine both the high spatial resolution (100um) and high rate capability (100MHz/cm^2) of the current state-of-the-art MPGDs with a high time resolution of 100ps. This contribution introduces a new type of MPGD, namely the Fast Timing MPGD (FTM) detector.

The Fast Timing MPGD can potentially reach sub-millimeter spatial resolution and 100 ps time resolution. Such a detector, able to measure photons with excellent time and spatial resolution, will allow the development of an affordable TOF-PET scanner with improved image contrast. This fast timing MPGD will enable at the same time muon tracking, under high radiation, allowing identification of the originating collision vertex at High Energy Physics (HEP) experiments for future colliders. These techniques will be highly recommended to trigger and reconstruct multi-muon signatures as predicted by many extensions of the Standard Model, while distinguishing this signature from background due to muons originating from neighbouring collisions.

The Fast Timing MPGD consists of a stack of several coupled layers where drift and multiplication stages alternate in the structure, yielding a significant improvement in timing properties due to competing ionization processes in the different drift regions. Three FTM prototypes have been developed so far. The first one consisting of two amplification stages made of 50um thick kapton foil, covered on both sides with resistive material. The second one, also with two amplification stages, has a resistive Micromegas-like structure, with multiplication developing in a region delimited by a resistive mesh. The third one consisting of four multiplication stages made of 200um thick PCB covered with resistive material. The structure of these prototypes will be described in detail and the results of the characterization study performed with an X-Ray generator with two different gas mixtures will be presented. First results on rate capability and time resolution based on data collected with cosmic rays and muon/pion test beams will also be presented.

Summary:

The design and development of a new detector, combining high time resolution with high spatial resolution, while exploiting the advantages of a reasonable energy resolution will be a boost for the design of affordable TOF-PET systems. The use of a gas detector to instrument on the one hand large areas in a cost-effective way, and with very good spatial resolution, and on the other hand obtaining a very fast signal will be a leap forward in the development of TOF-PET devices, which are also under study to use as dose monitoring in hadron therapy. The increase in image contrast obtained with these detectors will allow for shorter scanning times (lowering the risk for the patient) and better diagnosis of the disease. On the other hand this project will also develop a gas detector with high spatial and time resolution, being cost-effective to instrument large detectors foreseen for future colliders. The development of fast timing is critical to allow for unambiguous assignment of muon tracks to the right collision vertex, amongst hundred of pile-up collisions. This will allow for LHC-like particle reconstruction and identification at much higher background levels. The studies made in this project will pave the way for the development of a new generation of fast front-end electronics for these gaseous detectors.

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Light for wireless data/energy transmission

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In the last few years, the most common approach for wireless data transmission has been that based on the radiofrequency (RF) waves. For example, one of the most mature technology allowing the connection of electronic systems (e.g. laptops or smartphones) to a wireless LAN (WLAN) network is the WiFi one, which can operate in three center frequencies (2.4, 5 and 60 GHz). In the wireless data transmission there is a continuous trend to move the operating frequency towards higher frequencies in the electromagnetic spectrum. This trend is due to the need of maximizing the bit rate in the point-to-point and point-to-multipoint data transfer. In this scenario, a very innovative technology is under development, the light-fidelity (LiFi) one 1. Since it enables the bi-directional multiuser communication, LiFi is conceptually equivalent to the WiFi but it uses visible light instead RF waves. The key devices of the transceiver utilized in the LiFi technology are the single photon avalanche diodes enabling the O/E transduction and the GaN micro-LEDs for the E/O transduction. Due to the widespread deployment of LED lighting, the existing lighting infrastructures cab be easily used for the generation of the modulated light carrying data. The main advantages of LiFi with respect to WiFi are the avoidance of the radio frequency spectrum crunch (10,000 times more capacity), the enhanced energy-efficiency due to the combination of data communication and illumination, and complete elimination of health concerns due to the use of RF waves. The maximum bit rate in the LiFi network is around 10 Gbps. This value can be further enhanced up to 100 Gbps if laser diodes operating at visible wavelength instead of GaN micro-LEDs are utilized for the data transmission [2].

Light can be used for the wireless transmission of both data and energy. Wireless power transmission is a general concept referring to the transmission of electrical power without using the conventional conducting wires. Several experiments on the use of microwaves to transmit energy have been carried out since the beginning of the 20th century [3], but in the last few decades the advances in the laser technology has motivated an increasing research effort on the wireless energy transmission by laser beams. The basic concept of the photonic wireless energy transmission is quite simple. Electricity is converted into a laser beam that is pointed towards a photovoltaic cell re-converting the laser power into electrical energy. The key advantages of using laser beams instead of microwaves for wireless energy transmission are the possibility of transmitting energy over large distances, the absence of interference with the radio communication systems, and the potential compact size of both transmitter and receiver. Safety of the system is the main critical aspect of this technology. A block diagram of a system for wireless energy transmission by laser beams is shown in Fig. 1. The conversion of the electrical energy provided by the generator is obtained by a high-power laser diode. The laser beam is directed toward a photovoltaic array where the transduction of the optical power into electrical power takes place.

Fig. 1. Block diagram of a system for wireless energy transmission by laser beams [4].

Since the typical operating wavelength of the most efficient laser diodes is in the retinal hazard region (400−1400 nm), the systems for wireless power transmission by laser beams usually have to use appropriate techniques to mitigate the eye hazards and to protect animals from the optical beams carrying energy. One possible approach to make safe the laser power beaming is the inclusion within the wireless system of a sub-system detecting any object approaching the laser beam and switching off the laser transmitter when the beam is potentially dangerous. The use of laser sources operating outside the retinal hazard region could be a better solution to improve the safety level of the laser power beaming. Unfortunately, the lasers operating in the mid infrared, i.e. outside the retinal hazard region, typically exhibit low efficiency and are more expensive with respect to the laser diodes operating in the near infrared.

In the last few years, several experiments on the laser power beaming have been carried out. In particular, the wireless power delivery to an electric quadrotor helicopter in flight has been demonstrated [4]. In addition, the wireless power transmission over a distance of about 80 m from a Nd:YAG laser at 532 nm to a rover vehicle has also been experimented [5].

Wireless data and power transmission may become of particular importance for future HEP detectors in order to steer and control complex detector systems with reduced number of cables. Minimizing the amount of material in the region of the tracking detectors will reduce multiple scattering and nuclear interactions that degrade the tracking performance. We will also investigate the use of wireless techniques in detector readout in order to reach high data transfer rates, required by the highly granular detectors in HEP.

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Summary:

Wireless data and power transmission may become of particular importance for future HEP detectors in order to steer and control complex detector systems with reduced number of cables. Minimizing the amount of material in the region of the tracking detectors will reduce multiple scattering and nuclear interactions that degrade the tracking performance. We will also investigate the use of wireless techniques in detector readout in order to reach high data transfer rates, required by the highly granular detectors in HEP.

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4D fast tracking for experiments at HL-LHC

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Several efforts have been recently devoted to develop high-resolution timing detectors for tracking at the High Luminosity LHC experiments while track triggers, implemented with dedicated hardware, have been used at hadron colliders to select heavy-flavour decays. In this R&D project we propose to combine the two methods to develop an innovative detector, based on accurate time and position particle hit measurements, for 4D tracking and fast track trigger. The precise measurement of the hits' time is the key feature to operate an effective pattern recognition that guarantees a high tracking efficiency while enhancing the ghost track rejection, and to perform selective track triggering. We ultimately aim to exploit this detector in flavour physics experiments, in conditions of a high event pile-up, where sensors and front-end electronics are required to provide a hit time resolution of the order of 20 ps and a hit position resolution better than 40 µm, and are able to continuously operate in a harsh radiation environment (up to a total flux of 1017 1-MeV neutrons equivalent per cm2).

State of the art tracking pixel detectors with precise time-tagging show a time resolution of about 200 ps 1, and we aim to reduce this by one order of magnitude. Crucial aspects to achieve this ultimate time resolution are the optimization of pixel sensor geometries (in both 3D and planar technologies) to achieve the most uniform electric field, and the design of fast and low noise dedicated front-end ASIC. This front-end will incorporate a fast current amplifier followed by a discriminator and a time-to-digital converter, and will be developed in 65 nm CMOS technology with fault tolerant architecture which matches the radiation hardness requirements.
Feasibility studies of a 4D fast track finding system, using hits' space and time information, has been recently presented [2] as a possible solution for the low level track trigger of the HL-LHC experiments. The system is based on a massively parallel algorithm implemented in commercial FPGAs using a pipelined architecture and allows a precise real-time determination of the track parameters (including time) while maintaining a low fraction of reconstructed fake tracks.
The proposed detector will allow to perform flavour physics at LHC while operating at instantaneous luminosities more than one order of magnitude larger than the

current ones, while guaranteeing large tracking efficiencies and a negligible ghost tracks rate.

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Summary:

The proposed detector will allow to perform flavour physics at LHC while operating at instantaneous luminosities more than one order of magnitude larger than the current ones, while guaranteeing large tracking efficiencies and a negligible ghost tracks rate.