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Book of Abstracts

This is the book of Abstracts for the International Workshop on New Photon-detectors 2012

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Performance studies of Silicon Photomultipliers with quench resistors integrated to silicon bulk

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A Silicon Photomultiplier (SiPM) is a novel type of photon-counting device. Due to ongoing developments in SiPM technology, it becomes promising candidate to replace conventional photomultiplier tube in a multitude of applications. The Geiger-mode operation of SiPMs requires a high ohmic quench resistor which is realized in conventional devices by surface growth of a polysilicon layer. This, together with the contacts for the individual resistors, results in an obstacle for incident light and limits the photon detection efficiency of the device. At Max-Planck semiconductor laboratory a novel detector concept was developed in which the quench resistor is integrated into the silicon bulk resulting in a free entrance window for light. Simulations show the feasibility of the device and the first prototypes were produced. Geometrical variations of cell size and gap region were implemented in order to study the influence on detector parameters (recovery time, optical cross talk, etc). The concept of the device and its advantages and disadvantages will be presented. The results of the characterization of prototype production will be discussed. Possible future developments of the concept will be presented.

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DEVELOPMENT OF SCINTILLATION DETECTORS BASED ON MICRO-PIXELS AVALANCHE PHOTODIODES (MAPD)

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This article describes performance of a new generation of the Micro-Pixel Avalanche Photodiode (MAPD). MAPD has the especially advances: gain can reach values of 105, photon detection efficiency is 30-35 % in a wide wavelength range and pixels density is 15000 pixels/mm2. Results of gamma-ray detecting measurements performed using LFS scintillating crystal by MAPD are also presented. Energy resolution was 11.5% and 6.5% for Cs-137 and Co-60.

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Noise Factor of Micro-channel Plate no/with Ion Barrier Film

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According to definition of noise factor of microchannel plate and test basic principle, we established test installation , and measured numerical values of MCPs which made of different material and channel pore include no / with ion barrier film in input of MCP. At the same time, we tested and analyzed relation between noise factor and MCP voltage, combined relation between signal-to-noise ratio of GEN Ⅲ image intensifier and MCP voltage, open out relation between signal-to-noise ratio of GEN Ⅲ image intensifier and noise factor of MCP with ion barrier film.

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Lifetime measurements of recent Microchannel-Plate PMTs

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The PANDA experiment at FAIR will study ppbar-collisions at an energy range of 1 GeV to 15 GeV. The particle identification will be done with two DIRC (detection of internally reflected Cherenkov light) detector systems. Attractive photo sensors for these DIRCs are micro-channel plate (MCP) photomultipliers (PMT), which provide an excellent time resolution of <50 ps and can stand high magnetic fields up to 2 Tesla. Further requirements are a high photon rate stability of >300 kHz/cm² and lifetime for the expected integrated anode charge of >5 C/cm² within 10 years. The demands for the DIRC in the forward hemisphere are even more challenging. We were investigating various MCP-PMT models of different manufacturers with respect to their magnetic field resistance, time resolution, uniformity, dark count rate, rate stability and especially aging. Some of these are illuminated under PANDA conditions to study their lifetime. The results of these measurements, especially the investigations of recent MCP-PMTs with significantly improved lifetime, will be presented.

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Status of ASIC readout for the prototype Si-W electromagnetic calorimeter

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In this work the status of developed readout chain of prototype Electromagnetic Calorimeter for future Linear Collider experiment is presented.
The prototype of Electromagnetic Calorimeter developed base on silicon
as a detector and tungsten as a absorber. For the fine granularity of the
calorimeter, pixel size of 0.5x0.5 cm2 silicon diode is optimized. There is a 36 channel, dual gain, low noise and low power consumption ASIC chip
readout has been developed to readout of silicon detector .

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A new design of large area MCP-PMT for the next generation neutrino experiment

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A new design of large area MCP-PMT for the next generation neutrino experiments is proposed. The main motivation of the design is to improve the quantum efficiency (photo detection efficiency) of the PMT. Two sets of small MCP units, the transmission photocathode coated on the front hemisphere and the reflection photocathode coated on the rear hemisphere are assembled in the same glass envelope to form nearly 4πviewing angle to enhance the efficiency of the photoelectron detection. The photoelectrons from the 4πphotocathode are collected and amplified by two sets of MCP units .Our goal is eventually to produce 20 in. diameter PMT following such an approach. We will report preliminary results of our photo-electronic simulation and the results of a 5 in. diameter prototype PMT. Future plans and prospects are discussed at the end.

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Simulation of Silicon Photomultipliers

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In this talk a generic framework for the simulation of the response of Silicon Photomultipliers (SiPMs) is presented. The framework allows a custom definition of the SiPM parameters and geometry and provides a detailed model of the SiPM response. The simulation generates the signal charge and pulse shape for arbitrary incident light pulse distributions and the specified SiPM properties which can be determined from basic characterisation measurements. The simulation has been validated in the full dynamic range for a Hamamatsu MPPC with 100 pixels and was used to study the effect of optical cross-talk and after-pulsing on the response curve and the photon-counting resolution.

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Timing properties measurements of STMicroelectronics Silicon Photomultipliers for time-of-flight PET scanners

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Positron Emission Tomography (PET) is a medical imaging technique able to observe functional processes in vivo. It is based on the simultaneous back-to-back emission of the two 511 keV photons following positron annihilation by a chemical tracer doped with appropriate radioisotopes. The possibility to use high timing resolution detectors allows to localize the emission source with higher precision along the line defined by the two gammas. This technique, usually known as time-of-flight (TOF) PET requires photo-sensors with an optimal time resolution. Silicon photomultipliers (SiPM) are potentially promising devices for such applications, due to their small size and insensitivity to magnetic fields. Several progresses have been made in recent years to improve also their timing properties, which is the main point of concern.
This contribution describes the setup and preliminary results obtained during a study of the energy resolution and timing properties of recent SiPM devices produced by STMicroelectronics. A study of the dependence of energy and timing resolution in PET-like applications on different SiPM's layout parameters (total area, number of microcells, geometrical fill factor) is under way. The SiPM structures investigated in this work are fabricated on silicon epitaxial p-type wafers and formed from planar N+-P microcells. The quenching resistor, made from low-doped polysilicon, is integrated inside the cell. Thin optical trenches filled with oxide and metal surround the microcell active area in order to reduce electro-optical coupling effects (crosstalk) between contiguous pixels. A suitable double-layer antireflective coating is deposited on the surface of the device to enhance its spectral response in the blue and near ultraviolet wavelength ranges.
In order to measure the time resolution of individual SiPM's with the two 511 keV photons detected in two LYSO crystals, a dedicated setup was designed and built in our lab, to allow for an easy handling of the different devices under test. All the setup is enclosed in a dark box to shield from ambient light.
Preliminary measurements were carried out by means of standard NIM and CAMAC electronics. Signals from the detectors are sent, either directly or through low-gain fast amplifiers, to Constant Fraction Discriminators (CFD) to provide start and stop signals to a CAMAC TDC. Amplitude information was collected as well, employing two CAMAC QDCs, for off-line data processing. Binary files collected during the measurements are further processed and analyzed by the ROOT data analysis package to carry out multidimensional data analysis. To characterize the SiPM response in a wide energy range, measure their energy resolution and study non-linearity effects, different gamma sources (22Na, 137Cs, 54Mn, 65Zn) were employed.
To characterize the timing response of such devices, coincidence measurements are better carried out by means of a high performance digital oscilloscope. In our case a Tektronix DPO7254 2.5 GHz, 20 Gs/s per channel was used, allowing to sample the signals of the two SIPMs with 50 ps steps. Various algorithms for a digital processing of the signals are being tested, in order to optimize the time resolution. The value of the unfolded time resolution was extracted by a set of measurements performed at different bias voltages by a proper selection of the photoelectric peaks in the amplitude spectra. Further developments are in progress and will be reported during the Conference.

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Overview of SiPM applications

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Multicell Geiger-mode avalanche photodiodes or silicon photomultipliers (SiPMs) have proven to be a sound alternative to other types of photodetectors in different fields, and their advantages can significantly overcome the performance previously achieved or enable new possibilities. Their development continues with the improvement of general properties, and/or the enhancement of determined characteristics to fulfil specific requirements for different applications. As the number of SiPM manufacturers rises, their properties improve, and more possibilities for readout appear in the market, an always increasing number of physics experiments tend to replace other type of photodetectors by SiPMs, or to employ them in innovative applications.
SiPMs have been successfully applied, or are being tested, in numerous applications in high energy physics (in calorimeters for CALICE, in T2K or in Cherenkov detectors), in astroparticle physics (such as MAGIC or EUSO), and in medical imaging, for example in the combination of PET and MR imaging modalities, or for time of flight PET. An overview of these and other applications will be given.

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Application of continuous crystals and SiPM arrays to PET and Compton detectors

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Silicon Photomultipliers (SiPMs) offer an alternative to PMTs that allow the implementation of innovative detector types. Continuous scintillator crystals coupled to SiPM arrays provide higher efficiency than pixellated crystals. We are applying this approach in two different medical imaging fields with successful results.
The use of SiPM arrays makes it possible stacking several detector layers in the development of a Compton telescope for dose monitoring in hadron therapy within the European project ENVISION. The prototype under development consists of a stack of three LaBr3 crystals coupled to a SiPM arrays. Tests with two detectors in time coincidence have been carried out, each one consisting of a 16mm x 18mm x 5mm crystal (one LaBr3 and one LYSO) coupled to a SiPM array from Hamamatsu, and employing the SPIROC1 ASIC as readout electronics. Imaging tests are ongoing, and larger detectors are under development.
A small animal PET prototype scanner has been developed, comprising two rotating heads. Each head is composed of a 12mm x 12mm LYSO crystal of 5 or 10 mm thickness coupled to a monolithic, 64 pixel SiPM matrix. The MAROC2 ASIC is employed as front-end electronics. Images of one and two point sources have been reconstructed with a FWHM of 0.7 mm.

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Single Photon THz Timer with Radio Frequency PhotoMultiplier Tube

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Principles of a time tagged time resolved single photon THz counting system, based on the GHz radio frequency photomultiplier tube, RFPMT, is proposed. The time resolution and minimal time bin of the technique is about picosecond. Prompt rate of the technique with dedicated spiral scanning

system can reach THz in a time period of about 100 ns, while average rate is about 1 MHz. The detection and readout systems are based on commercial multichannel plates and regular nanosecond electronics. Timing characteristics of the RFPMT was obtained by means of Monte Carlo simulations. For electron optics simulations, SIMION 8 software has been used. The operation of the dedicated GHz radio frequency deflector is investigated by means of thermionic electron source.

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GEANT4 Simulation of the Time-Resolution of a Fast Scintillation Detector Read-out by a G-APD

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We have recently published [1] a time resolution study with a plastic scintillator read out by a~Geiger-mode Avalanche Photodiode. Time resolution of sigma = 18/(E^0.5) ps*MeV^0.5 was measured. The work presented here aims to simulate that experiment using the Geant4 toolkit, and to identify the parameters which have the largest effect on the total time resolution. We also compare different timing definitions - e.g. leading edge discrimination and constant fraction discrimination.

[1] A. Stoykov, R. Scheuermann, K. Sedlak; Nucl. Inst. and Meth. in Phys. Res. A – in press; http://dx.doi.org/10.1016/j.nima.2011.11.011

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Characterization of a recently developed SiPM for PET

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SiPMs are nowadays available from varying manufacturers. The investigated device was the latest KETEK PM3350. Its peak sensitivity is for blue light, it has an active area of 3 x 3 mm² with 50 µm cell size and operates in a large bias region from 24 - 32 V. The active area is covered with an epoxy layer and the package is kept at the smallest possible size of 3.9 x 4.4 x 2.0 mm³
We determined the performance of the SiPM. From the single-photon spectra measured with a pulsed blue LED, we extracted the breakdown voltage (22.8 V) and photodetection efficiency (up to 40%). Without illumination, the darkcount rate (1.5 MHz @ 26 V), I-V characteristics, single cell resistivity (0.6 MOhm), crosstalk (13% @ 26 V) and afterpulsing have been determined. The SiPM shows a very small temperature coefficient which is one of the main advantages of the device.
Since our later application for the SiPMs is a prototype of a small animal Positron-Emimission Tomograph for simultaneous PET/MRI (Magnetic Resonance Imaging), we also aquired energy spectra with LYSO and different radioactive sources. The SiPM shows promising performance.
We will present our results as well as measurement methods.

Posters A / **16**

Position, timing and particle ID measurement with scintillating fibers readout by SiPMs

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High position and timing resolutions can be simultaneously achieved today using scintillation material coupled with SiPM.
An active target for the MEG experiment based on very thin scintillating fibers readout by SiPMs operating in a high magnetic field (1.3 T) is considered. The tool should provide a very precise measurement of the muon decay vertex and its timing, with a consequently improvement on the positron momentum and angular variable resolutions into the MEG experiment.
The high sensitivity and high quantum efficiency of SiPM allows us to collect few photoelec- trons and to detect the positron and to measure its timing.
Thanks to the fast time response the device can be operated in a high rate environment and applications on beam monitoring are also considered. The detector can be used to measure muon beam rate at the highest intensity on the world and to obtain 1- and 2-dimensional beam profile.
A particle ID can be performed to distinguish between positrons and muons and the information about different particles can be measured in parallel.
Measurements are done using a fast signal digitize (DRS4 Evaluation board) and a custom waveform analysis can be easy implemented.

Electronics / **17**

Latest generation of ASICs for photodetectors readout

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The OMEGA group has designed a new generation of ASICs, the “ROC” family, in AMS (AustriamMicroSystem) SiGe 0.35 µm technology to read out signals from various families of photo-detectors. The chip named MAROC (standing for Multi Anode ReadOut Chip) is dedicated to the readout Multi Anode Photomultipliers (MAPMT), PARISROC(standing for Photomultiplier ARray In SiGe ReadOut Chip) to read out Photomultipliers (PMTs) and SPIROC (standing for SiPM Integrated ReadOut Chip) to the readout of SiPM (Silicon PhotoMultiplier) detectors.
The three of them have similar requirements in terms of low noise, low power and radiation hardness and thus similar design: a low noise input stage for amplification, a slow channel for charge measurement, a trigger channel for photo counting, a conversion stage for internal time and charge digitization and a complex digital part to manage the acquisition, the conversion and the readout.
These multi channel ASICs are therefore real System on Chip (SoC) as they provide charge, time and photon-counting information which are digitized internally. Their complexity and versatility enable innovative frontier detectors and also cover spin off of these detectors in adjacent fields such as medical or material imaging as well as smart detectors.
In this summary, the three ASIC architectures and the test results will be described to give a general panorama of the “ROC” chips performances designed for photo-detectors applications.

SiPM / **18**

Silicon Photomultiplieres with enhanced Blue-Light Sensitivity

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Geiger-mode multi-pixel photon detectors are evaluated and discussed since a few years to replace the traditional photomultiplier tubes in several applications due to their potential high photon detection efficiency, miniaturized device size, insensitivity to high magnetic field and their prospectively low production costs.
To leverage this device for industrial applications the manufactures have to further enhance photon detection efficiency by a factor of 1.5 compared to PMTs as well as to overcome the crucial problems of high dark count rate and high optical crosstalk.
In order to solve these problems, KETEK has recently introduced a new manufacturing technology based on 200 mm wafers which significantly reduces dark rate and optical cross talk by a factor of two and with potential for further refinement. In addition, KETEK was able to improve the photon detection efficiency to 60% in the blue range for its 50µm cell pitch devices (see figure). This is due to an optimization of the geometrical fill factor and the light entrance window. This progress in device performance of the KETEK SiPMs is discussed in detail.

Posters A / 19

Development of economical and large area microchannel plates (MCPs) for photon detectors

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Abstract

The development of large area microchannel plate (MCP) - based photodetectors with high performance has advantages for many potential applications including low-level signal detection, photodetection, astronomy, electron microscopy, time-of-flight mass spectrometry, molecular and atomic collision studies, fluorescence imaging applications in biotechnology, field emission displays, medical imaging, and cluster physics. MCPs are also used to make visible light image intensifiers for night vision goggles and binoculars. The performance of MCP-based photodetectors depends not only on the microchannel plates themselves, but also on their configuration (e.g. single, double; chevron-type or triple; z-stack), as well as on the photocathode, the anode structure, and the signal readout. The Large Area Picosecond Photodetector (LAPPD) Project is a US Department of Energy (DOE)

funded collaborative project [1] that addresses each of these critical components of the photodetector with the goal of developing low cost, large area (20cm x 20cm) MCP-based photodetectors.
The requirement of low cost poses a severe challenge to fabricating the large area MCP component of the large area photodetector and rules out conventional methods. Our approach to this problem combines two recent technical advances. The first is the capability to produce large micro-capillary array blocks developed by Incom Inc. (Charlton, MA). The Incom process uses hollow, multifiber borosilicate (non-leaded) capillaries, eliminating the need to remove the core material by chemical etching. The capillary arrays are fabricated as large blocks that are sliced to form large area wafers, without regard to the conventional limits of L/d (capillary length / pore diameter), and subsequently polished. The second technological advance is the development of coating technology based on atomic layer deposition (ALD) for functionalizing the capillary array plates to impart the desired electrical resistance and secondary emissive properties. Atomic layer deposition is a powerful and precise thin film deposition technique, which utilizes self-limiting chemical reactions between precursor vapors and a solid surface to deposit material in a layer-by-layer fashion. Gaseous diffusion of the precursors, coupled with the self-saturating surface reactions generates extremely uniform and conformal coatings on the high aspect ratio capillary glass arrays. ALD provides atomic level control over the thickness and composition of the films, and allows the properties of the resistive and secondary electron emission (SEE) layers to be tuned independently.
Figure 1 shows the photograph of the 33mm MCP processed at various steps. We have developed several robust and reliable ALD processes for the resistive coatings and SEE layers to provide precise control over the resistance in the target range for MCPs (106-109⊠) and SEE coefficient (up to 8) [2, 3]. The MCPs are tested in stacks of one or two plates and exhibit gains as high as ~107 for a pair of MCPs. This approach allows the functionalization of microporous, insulating substrates to produce MCPs with high gain and low noise. These capabilities allow separation of the substrate material properties from the amplification properties. We studied the various MCP parameters such as gain, background counts, and resistance as a function of the ALD process parameters. Figure 2 shows the performance of the ALD functionalized 33mm MCPs. These MCPs shows the high gain (Figure 2a), long life test (Figure 2b), high spatial resolution, high timing resolution, and very low background rate. Following our initial development on the 33mm substrates, we scaled up the ALD process to functionalize the large area 20cmx20cm MCPs (Figure 3) and similar performance was achieved [3,4]. Here we will discuss the complete process flow to produce fully functionalized working large area MCPs and illustrate their performance.

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Temperature Dependence of Response and Its Correction for a Calorimeter Using PPD to Read out Photons from Scintillator Strips

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The CALICE collaboration is developing a granular electromagnetic calorimeter using (5-10) x 45 x 3 mm^3 plastic scintillator strips for a future linear collider experiment. A prototype module has been constructed and tested at Fermilab in 2008 and 2009. It has 2160 scintillator strips and each of them is read out by using a Pixelated Photon Detector (PPD). The experiment in 2009 was held in the temperature condition from 19 to 27 degrees of Celsius. The response to the muon beams as the minimum ionization particles was investigated in this large temperature fluctuation to make a comprehensive temperature correction method. Additionally, the sensitivity to a few photons from LED light also investigated to separately discuss the temperature dependence of PPD response.

The temperature correction established by using the results of these study improves the linear behavior of response to the electron beams from 2 GeV to 32 GeV. The deviation of the measured response from a linear behavior is reduced from greater than 10% to less than 1.5%. The energy resolution is also improved.

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Development of a Four-Layer Depth of Interaction Detector Based on a 6 x 6 SiPM Array for MR-PET

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We are developing a PET scanner which has both depth-of-interaction (DOI) and time-of-flight (TOF) information and can be placed close to a MRI scanner. Here we evaluated the positioning and energy performances of a four-layer DOI detector which consists of a single-layer of a 16 x 16 Lu2(1-x)Gd2xSiO5 (LGSO) crystal array, a light guide, and a 6 x 6 SiPM (MPPC: S10985-050C, Hamamatsu Photonics) array. The size of each crystal element was 2.9 mm x 2.9 mm x 20.0 mm. The four layers DOI encoding is allowed by changing the reflector arrangement of each layer. As results, the four-layer DOI encoding method worked successfully and good energy resolution of 12.9% has been obtained. Further details of experimental results including the timing performance will be presented at the workshop.

SiPM applications / **23**

SiPM Photodetectors for Highest Time Resolution in PET

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Silicon photomultipliers (SiPM) have a wide range of applications in high energy and medical detector physics. Their excellent timing properties and compactness make them particularly interesting for time of flight positron emission tomography (TOF-PET). This study aims at determining the optimum detector conditions for highest time resolution in a TOF-PET system. The measurements are based on the time over threshold method in a coincidence setup using the ultra-fast amplifier-discriminator NINO and a fast oscilloscope. We compare commercial SiPMs of different SPAD types (Hamamatsu MPPC S10931-025P, S10931-050P and S10931-100P) and production batches. Similar to crystal dimensions typically used in current PET facilities, we chose LYSO:Ce crystals of 2x2x10mm3 size and obtained, with SiPMs of 50x50µm2 SPAD size, a coincidence time resolution (CTR) of 175±6ps FWHM. To further explore the timing capabilities of the SiPM, we also coupled shorter, i.e. 2x2x5mm3, Ca-co-doped LSO:Ce crystals to the 50µm type and obtained 142±9ps FWHM CTR. This performance makes SiPMs ideal candidates for photodetectors in high resolution TOF-PET systems. The results will be discussed in terms of SiPM dark noise, photon detection efficiency (PDE) and photon yield.

SiPM / **24**

Timing resolution of MPPCs

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We present the results of measurements of the timing resolution of MPPCs for several pixel sizes. By using LED light, we have measured time jitter of pulses which exceed the threshold voltage. The number of photons illuminated on the MPPCs are from 10 to 10000 , while the timing resolution stays more or less constant. There are several types of MPPPC which have different number of pixels in 1mm x 1mm sensitive area. Here we show our results for 100, 400, 1600, 2500 pixels. Timing resolution as a function of average number of fired pixels shows a clear scaling for several MPPCs, which indicate timing measurement is dominated by the threshold behavior of the analog signals and little relation the the size of the MPPC pixels.

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Miniaturized multi-channels SiPM read-out electronics for medical imaging application

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This work presents a miniaturized photo-detection system based on a new semiconductor photon-detector namely SiPM and a special read-out electronics build around a dedicated ASIC.
The used SiPM arrays have important advantages compared to classical photomultipliers tubes (compactness, good sensitivity, low bias voltage) and the ASIC's read-out electronics developed at LAL offers multi-channels processing in a very small area.
The whole system is aimed to be inserted in an intra-operative probe for image guided surgery of tumors. This on-going work is developed in collaboration between LAL, IMNC and Lariboisière Hospital and is named SIPMED project (SIlicon Photomultiplier for MEDical applications).

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Hybrid Photo-Detectors for the Hyper-Kamiokande Project

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Hyper-Kamiokande is a huge Cherenkov neutrino detector with water of 1 million metric tons planned for the near future in Japan. Several Photo-Detector (PD) candidates are being newly developed. At first, an 8-inch Hybrid-PD with an avalanche diode will be tested in a 200-ton water Cherenkov detector loaded with Gadolinium. We report the plan and status, as well as the basic performance measured before installing the Hybrid-PD into the 200-ton tank.

SiPM / 27

Novel approach for calibration breakdown voltage of large area SiPM.

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SiPMs have a very good single photoelectron pulse (SPE) response which can be used for absolute calibration of them and defining breakdown voltage. Unfortunately with increasing size of SiPM it becomes more difficult to measure the SPE pulse due to pile up from the increased dark counts. Also this SPE calibration method requires high gain low noise amplifier, which makes it impossible to use with readout electronics designed for detection relatively big signals from scintillators.
In this work we propose a novel method for SiPM calibration using high intensity light pulse. The duration of pulse must be much smaller than recovery time of SiPM and the intensity of light pulse must be chosen big enough to trigger all u-cells simultaneously(~10-30 primary e-h/ucell/pulse). In this case, the signal is proportional to gain and number of cells in the device and practically linear even at small over voltage. Since the amplitude of the pulse is big, it does not need a preamplifier for measurements, even when SiPM operates as a regular avalanche photodiode below the breakdown voltage. We will present this calibration method for different SiPMs. Also this method allows investigation of SiPM operating in the linear and avalanche (non-Geiger regime) modes and can be very useful for study of the break down avalanche process and transition in to the Geiger mode.

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Development of PPD Sensitive to Deep UV Scintillation Photons of Liquid Xenon

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We are developing Pixelated Photon Detector (PPD) sensitive to deep UV scintillation photons of liquid xenon. Liquid xenon scintillation photons are successfully detected by the first prototypes of the PPD. The performance of the PPD measured in liquid xenon will be presented.

Posters A / 29

Optical to electrical detection delay in avalanche photodiode based detector and its interpretation

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We are presenting a set of measurement to determination of the optical to electrical delay of the photon counting detector. The absolute value of the time interval between the time of arrival of the signal photon onto the detector input aperture and the time when the electrical output signal is exceeding the predefined level have to be determined. Also results showing a temporal relation between the optical input and the electrical output of a photodiode are presented to describe an effect used device bandwidth. The presented results are a byproduct a of more complex experiment which aims to identify the absolute delay contributors in picosecond time-resolved single photon detection technique.

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Development of Intraoperative Beta Probes based on Silicon Photomultipliers

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Intraoperative localization of malignant tissues labeled with positron radiotracers opens up new prospects to improve the efficiency of cancer surgery. Because Silicon Photomultipliers (SiPM) introduced a breakthrough for the development of miniaturized imaging devices, we are currently designing two intraoperative beta probes based on this technology: a light imaging device with a small field of view (~5cm2) to perform tumor localization and post-operative control of the surgical cavity, and a miniaturized counting probe to guide in real time the excision of the tumor lesion. The first step of our project was focused on the characterization and optimization of SiPM devices as photodetectors for intraoperative beta detection. We studied the influence of temperature and bias voltage on the thermal and correlated noises and photon detection efficiency of different SiPM devices. The impact of these two parameters on the overall beta sensitivity was quantified as a function of the intensity of the scintillation light following a simple physical model. According to the results of this comprehensive study, the optimization of the detection head design of the two intraoperative probes was studied using Monte Carlo simulations. Detailed description of the simulation study as well as the performance characterization of the first prototypes will be presented at the conference.

Electronics / 31

NECTAR: New Electronics for the Cherenkov Telescope Array

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The international CTA consortium is currently in the preparatory phase for the development of the next-generation Cherenkov Telescope Array (CTA), based on the return of experience from the three major current-generation arrays H.E.S.S., MAGIC and VERITAS. To achieve an unprecedented sensitivity and energy range for TeV gamma rays, a new kind of flexible and powerful yet inexpensive front-end hardware will be required for the order of 100000 channels of photodetectors in up to 100 telescopes. One possible solution is the NECTAr (New Electronics for the Cherenkov Telescope Array) system, based on the integration of as much as possible of the front-end electronics (amplifiers, fast analogue samplers, memory and ADCs) into a single ASIC for very fast readout performance and a significant reduction of the cost and the power consumption per channel, while offering a high degree of flexibility both for the triggering and the readout of the telescope. The current status of its development will be presented, along with newest results from measurements and simulation studies.

Vacuum photo-detectors / **32**

Study of 144 Channel Multi-Anode Hybrid Avalanche Photo-Detector for the Belle II RICH Counter

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New hybrid avalanche photo-detector has been developed as a photon sensor for the Belle II RICH counter.
Single-photon response was investigated in the presence of a magnetic field and excellent performance was demonstrated. In addition, the radiation damage was studied in detail.
By building a prototype consisting of 6 photo-detectors, a test beam experiment was carried out. We successfully obtained a clear Cherenkov image and potentail pi/kaon separation power is expected to be more than 4 sigma at 4 GeV/c.

SiPM / **33**

Delayed avalanches in Multi-Pixel Photon Counters

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Hamamatsu Photonics Multi-Pixel Photon Counters (MPPCs) achieve high photodetection efficiency with relativelity low dark noise. The MPPC gain is comparable to Photomultipliers but but the pixel avalanches tend to trigger others either in neighboring pixels (crosstalk) or in the same pixel at a latter time (after-pulsing). Cross-talk and after-pulsing avalanches are one of the main limitation of MPPCs preventing operation at large operating voltage. Crosstalk avalanches are thought to be due to optical photons created in the avalanche and absorbed in a neighboring pixels. On the other hand, after-pulsing avalanches are thought to be due to charge carriers produced in the avalanches that become trapped on impurities and released at latter time. We investigate the possibility that after-pulsing avalanches are also due to visible photons created in the avalanches but absorbed in the silicon bulk rather than in neighboring pixel high field region. Then, the charge carriers created in the silicon bulk diffuse back to the high field region, yielding delayed avalanches. The MPPCs were illuminated with laser light at wavelength ranging from 404 to 820 nm and the timing distribution of the avalanches was measured. Delayed avalanches were observed at 637 and 820 nm showing that some holes do diffuse to the high field region. Simulations show that optical photons are responsible for at least half of the after-pulsing avalanches. The data also shows that the MPPC single photon timing resolution cannot be described by a simple Gaussian distribution.

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The developement of the calorimeter with a large MPPC-array

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Co-authors: Koji Miwa [1]; Ryotaro Honda [1]; Yuki Matsumoto [1]

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We are deveroping a calorimeter to detect the scattering proton
and measure its energy.

The calorimeter consists of BGO or LFS crystal and MPPC-array.
We will report the performance of this calorimeter.

Vacuum photo-detectors / 35

Recent progress in vacuum photon detectors from Hamamatsu

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Hamamatsu Photonics has developed 12-inch large size PMT for Neutrino physics experiments and 3-inch metal bulb PMT for Dark Matter experiments. These PMTs and other new products will be shown in this presentation.

SiPM applications / 36

Test beam experiment with FARICH prototype

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The FARICH ('Focusing' Aerogel RICH) system is suggested for particle identification at Super Charm-Tau Factory project currently being developed at Budker Institute of Nuclear Physics (Novosibirsk, Russia). The only candidate for the photon detectors of the FARICH are SiPMs. The FARICH prototype was tested with 1 GeV electrons on the test beam line at VEPP-4M collider. Multilayer focusing aerogels as well as a single layer aerogel were tested. The radius resolution of Cherenkov ring has been obtained and agrees well with the predicted value.
The photon detector of the prototype consisted of 32 SiPMs with active area 2.1x2.1 mm produced by the CPTA company (Moscow, Russia). The custom made discriminator boards and the CAEN V1190B multihit TDC were used for the signal readout. The timing resolution for single photons varies from 350 to 900 ps for different channels in the presence of a very high dark rate (up to 10 MHz per channel). The dependence of timing resolution from dark rate was investigated.
The new photon detector for the FARICH prototype with better coordinate resolution is under development. This detector will consist of 64 SiPMs with active area 1.28 mm^2. The main purpose of this detector will be detailed measurement of 'focusing' aerogel radiators parameters.

Posters A / 37

Toward a Time Resolved Single Photon Image Sensor based on SPAD array

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Time resolved imaging up to the single photon sensitivity is one of the most ambitious and important goals of photonics. Currently there are no commercial devices able to provide both the information on position (imaging) and arrival time of photons emitted by weak and ultra-weak source. Only very expensive sensors (ICCD) are able to reach the single photon threshold with the possibility to get information in small time window (few ns) but unfortunately such devices are not able to provide any information on arrival time of photons.
There are applications where time correlation analysis is fundamental and actually this analysis is performed only by using the information of few points in the image. Many scientific areas like astronomy, biophysics, biomedicine, nuclear and plasma physics etc. can benefit from a time resolved imaging device; it can provide physical information otherwise inaccessible.
Recently, thanks to technological developments on Single Photon Avalanche Diodes (SPAD) [1 and internal ref.], the implementation of a time resolved imaging device, based on SPADs, has been proposed [2].
The key point is the read-out strategy; it should be easy, in order to read a great number of elements, and able to address the information of each individual sensor, in order to get its time response. The simplest strategy is to address each diode, with a consequent requirement of a great number of channels, n2 for a square matrix of n x n diodes. We proposed an alternative solution, a [1], initially based on the signals collection from both anode and cathode of the same diode. Signal extracted from anode is used to determine the row position while the cathode signal for the column position. The rows x columns strategy require a number of reading channels of 2n instead of n2. recent results will be discussed. We will present also the R&D work in collaboration with FBK (Fondazione Bruno Kessler) – Trento on the new bi-dimensional arrays, where we improved the pixel red-out by using two quenching resistor and the large-scale integration. General performance of the first prototypes will be presented.

SiPM applications / 38

Development of a scintillation counter with MPPC readout for the internal tagging system

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Co-authors: Fumiya Yamamoto [1]; Kazushige Maeda [1]; Takashi Nishizawa [1]; Yuma Kasai [1]

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We have been developing an array of electron counters for the photon tagging spectrometer at the Research Center for Electron Photon Science, Tohoku University (ELPH). Since it is installed in the limited space of the bending magnet of the accelerator, compact size and insensitivity to the magnetic field are required.
We chose the multi-pixel photon counter (MPPC) HAMAMATSU S10362-33-100C as photon sensors for the scintillation counters. The counter is a plastic scintillator in a shape of a small rectangular prism with 3 mm-square cross section, coupled to the MPPC. We fabricated a prototype of the electron detector and performed a beam test at the NewSUBARU BL1. In this presentation, we report the result of the test of the prototype detector and the current status of the development of the photon tagging system.

Posters B / **40**

Detection of single photons with hybrid ThickGEM-based counters

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Architectures based on multiple layers of THick-Gas Electron Multipliers (THGEM) represent a possible answer to the quest for novel gaseous counters with single photon detection capability able to overcome all the limitations of the present generation of gaseous photon detectors.
A systematic R&D programme has been performed to achieve a deep understanding of the THGEM characteristics and to optimise their parameters in view of the photon detection application. Recently a new hybrid approach has been considered: an architecture where the last multiplication stage is obtained by using a Micromegas stage.
The R&D studies are summarised and some preliminary results obtained with the hybrid architecture prototypes are reported.

SiPM / **41**

SensL New Fast Timing SPM - High-Speed Silicon Photomultiplier Signal Output for High-Performance Timing Applications

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In this paper we report on a new silicon photomultiplier (SPM) architecture with additional signal output for a timing measurement. This additional output has very fast single photo electron response (about 2 ns FMTM). This new device can be easily integrated into legacy systems by providing the ability to operate as a normal SPM with Anode readout or in new designs with an additional fast output. As result the rise time of timing signal for LYSO scintillator coupled to this new fast SPM is about 2ns, compared with typical 20-40ns for SPM's anode signal. This enables unprecedented coincidence-timing performance improvements for SPM devices, from 570 ps (Coincidence Resolved Time FWHM) to better than 380ps (CRT FWHM) coincidence timing resolution for SM series devices.

Posters B / **42**

SiPM PDE measurement with continuous and pulsed light

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The absolute measurement of the Photo Detection Efficiency (PDE) of a SiPM over the whole visible range using continuous light is not a straightforward task as it requires the accurate determination of the detector gain. The SiPM gain given by the producer does not take into account all the secondary effects (cross-talks, after-pulses events), which leads to an overestimation of the PDE.
To measure the absolute SiPM PDE, we have carried out at LAL two kinds of measurements following what we call "the "Counting method" and the "Photocurrent method".
In the "counting method", the very low number of photons in the short light pulses is Poisson distributed which allows us to count the photoelectrons produced. With this method, we do not need to consider the SiPM gain and the PDE is measured with an accuracy of 5 %.
With the "Photocurrent method", the SiPM is illuminated by continuous light and the number of converted photons is determinate measuring the generated photocurrent and the gain.
We detail these two methods and compare their results.

Posters B / **43**

Another step towards VSiPMT: recent developments.

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In the present work we show the most recent results of the preliminary work that our group is carrying out before the realization of a first Vacuum Silicon PhotoMultiplier Tube (VSiPMT) prototype. It is divided in three phases, the first one consisting in the realization of a full characterization of the SiPM with a laser source, the second one in the simulation of electron backscattering over SiPM surface, while the third one consists in the characterization of our SiPM with an electron source. In this work we will describe the last one, in particular describing our experimental apparatus and our preliminary results.

Electronics / **44**

The development of the multi PPD readout electronics with EASIROC and SiTCP

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We are developing an electronics to readout many PPDs for J-PARC (Japan Proton Acclerator Research Complex) E40 in Japan. In the E40 experiment, differential cross section of hyperon-proton scattering will be measured by using a liquid hydrogen target and high intensity pion beam (up to 10 MHz) in the K1.8 beamline. Two different types of new detectors, consisted of scintillation fibers and PPDs, are under development. One is a beamline fiber detector to measure the pion beam position and time of flight (TOF). The other is a cylindrical fiber tracker surrounding the target to measure the energy and scattering angle of the scattered protons. The total number of PPDs for these detectors will be about 5,000 channels. To handle such a large number of PPDs in our experiment, development of a serial readout electronics for PPDs is indispensable. All essential functions such as gain adjustment of PPD to data transmit to DAQ system should be included in one electronics to save cost. In addition, both of charge and timing measurements are required for our readout system.
We are developing a new readout system for multi PPDs with Omega IN2P3 and KEK. The readout electronics consists of Extended Analogue SiPM Integrated Read Out Chip (EASIROC) developed by Omega in LAL in France and Silicon TCP (SiTCP) developed by KEK. EASIROC is an ASIC which can operate 32 channels of PPDs. EASIROC has the implemented features such as gain adjustment, double gain amplifier, discriminator, multiplexed analogue output and parallel discriminator outputs. By using SiTCP, we can use TCP/Ethernet data transmission without any expensive CPU. Charge and timing are measured by the pipeline ADC and digital Multi-hit TDC (MHTDC) in FPGA, respectively. The first version of the readout board has been developed. We evaluated performance for the charge and timing measurements and the data transmit speed. The mean DAQ rate is over 10 kHz. Implementation of MHTDC which has 2 us time window, 8 depth and 1 ns LSB resolution was succeeded. These performances are sufficient for J-PARC E40. In this conference, I'll introduce about the evaluation board and the test results.

Posters B / 45

Study of photocathode aging in MCP PMT

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Photomultiplier tubes (PMT) based on microchannel plates (MCP) found a number of applications in colliding beam experiments at Budker Institute of Nuclear Physics (Novosibirsk, Russia). We report on the degradation of MCP PMT main characteristics after 8 years of operation in the threshold Cherenkov ASHIPH counters of the KEDR experiment at e+e- collider VEPP-4M.
The photocathode aging in MCP PMT is systematically studied with the view of possible applications of such PMTs in future HEP experiments. The comparison of different types of alkali-antimonide photocathodes has shown that the treatment of photocathode with vapors of cesium and antimony can dramatically reduce the photocathode aging rate. The photocathode lifetime of the best MCP PMT sample has been measured at the photon counting rate of 10 MHz/cm^2 and the initial gain of 10^6. The peak quantum efficiency degraded by 20% after accumulation of 3.3 C/cm^2 anode charge.

SiPM applications / 46

Initial Experience with Digital SiPMs in Detectors for Time-of-Flight PET

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Silicon photomultipliers (SiPMs) have recently been shown to enable better timing resolution than photomultiplier tubes (PMTs) when used as light sensors in scintillation detectors. This makes them interesting for use in time-of-flight (TOF) positron emission tomography (PET). Additional features for this application are their compactness and magnetic field compatibility, enabling MRI-compatible PET detectors. Recently, a fully digital version of the SiPM, the so-called digital silicon photomultiplier (dSiPM), has been introduced. In these devices the quench resistor in each microcell is replaced by active quenching circuitry. Integrated trigger logic is used to determine a time stamp and the total number of photons detected in the light pulse. Here, we present an overview of recent results obtained with single elements as well as 8 x 8 arrays of dSiPMs in combination with Ca-codoped LSO:Ce crystals. A coincidence resolving time (CRT) of 120 ps FWHM was achieved with 3 mm x 3 mm x 5 mm LSO:Ce,Ca crystals, illustrating that dSiPMs allow for excellent timing resolution. Moreover, the use of dSiPM arrays in combination with monolithic LSO:Ce,Ca crystals appears to enable a unique combination of sub-mm spatial resolution, good energy resolution (~11.5% FWHM), and a CRT < 350 ps FWHM. At the conference, the latest results of these ongoing studies will be presented. Furthermore, the application of digital SiPMs will be discussed from the viewpoint of achieving the best possible performance at the full system level in future TOF-PET and PET/MRI scanners.

Posters B / **47**

Study of Geiger-mode APDs performances at cryogenic temperatures

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We compare the performances of different types of Geiger-mode APDs (GAPDs or SiPMs), manufactured by CPTA company, at cryogenic temperature, namely at 87 K. Noise rate, gain characteristics and signal shapes were measured, both at room and cryogenic temperature. Four types of GAPDs were investigated, having an active area of 1x1, 2.1x2.1, 2.5x2.5, and 3x3 mm2. The best performance showed the GAPD with 2.1x2.1 mm2 active area, in terms of the maximum gain, minimum noise rate and effective active area. This study is done in the frame of the project, developed in our laboratory, on the Cryogenic Avalanche Detector (CRAD) with optical readout using combined THGEM/GAPD-matrix multiplier. Preliminary results on the data acquisition system of the 3x3 GAPD-matrix are also presented. This technique is aimed at applications in rare-event experiments, such as those of coherent neutrino-nucleus scattering and dark matter search.

SiPM / **48**

Development of very low threshold detection system for low-background experiments

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A concept of readout of noble gas two-phase emission detectors by means of multipixel avalanche Geiger photodiodes (MGPDs or SiPMs) and a THGEM structure is presented.
It is well known that a two-phase emission technique with noble gases is a very sensitive method of detection of very small ionisation signals (down to few or single ionisation electrons). Electroluminescent "amplification" provides the unique possibility to detect reliably even the single ionisation electron extracted from the liquid to the gas phase. Due to this reason such detectors are currently successfully used in the Dark Matter search experiments and are considered for the use in the neutrino experiments: for coherent scattering of reactor antineutrino off atomic nuclei.
To increase the capabilities of a two-phase detector a system of THGEM + WLS (wavelength shifter) +MGPD is used for its readout. Additional amplification of the charge in the THGEM holes gives the large light signal of electroluminescence detected with an array of SiPMs. This readout system provides the mm accuracy for even very low-energy events, that is important for the reliable separation of the rare physical events from the background ones caused by spontaneous emission of the electrons from the liquid noble gas surface. The results of analysis experimental data and comparison MC simulations are present.

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New developments at LNS-INFN on Time Of Flight PET with Depth Of Interaction feasible, based on SiPM detectors

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In our measurements at LNS-INFN we proved that by coupling two Silicon Photomultipliers on both the sides of a LYSO scintillator finger, with suitable surfaces treatment, allow to achieve optimal performances in terms of time and spatial resolution, thus strongly supporting the feasibility of a high resolution TOF-PET probe. With a detector element of 1.5mm x 1.5mm x 10mm, we have achieved simultaneously a time-of-flight resolution around 150 ps and simultaneously DOI resolution below 1 mm.
In our opinion this proof of principle paves the way to the feasibility of a TOF-PET probe with unprecedented features and performance.

New devices / 50

Linear photon-counting with HgCdTe APDs

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HgCdTe APDs have been shown to exhibit single carrier multiplication (SCM) which gives desirable properties such as low multiplication excess noise (F<1.2) and gain independent response time up to multiplication gains exceeding 1000. Combined with quantum efficiencies (QE) which can approach 100 % in optimized detectors, theses detectors have the highest information conservation ratio QE/F of all amplified detectors, from ultra-violet wavelengths up to the infra-red cut-off of the APDs. Theses properties open new perspectives for photon-counting applications in a linear mode that enables proportional photon-counting, high photon detection efficiency (PDE), low after-pulsing, high count rates and low dark count rates (DCR).

In this communication we present the status of HgCdTe APD technology at CEA/Leti and show first results on photon-counting circuits made of HgCdTe APDs hybridized with specially designed read-out integrated circuits (ROICs). The ROICs are made using compact CMOS electronics to enable integration into large area-small pixel focal plane arrays. The results will be discussed in terms of the impact of the HgCdTe APD gain and response time characteristics on the most common photon-counting figure of merits and which perspectives that can be expected from improved APD and ROIC design.

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Study of detection effciency distribution and areal homogeneity of SiPMs

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Silicon photomultipliers (SiPM) are a very attractive option for light detection in highly granular scintillator-based sampling calorimeters in future high energy physics experiments at Linear Colliders (ILC, CLIC). The CALICE collaboration has already successfully operated a 1 m3 physics prototype with about 8 000 small scintillator tiles, each read out by a SiPM, demonstrating the power of this new technology. We have developed a setup for the measurement of relative photon detection efficiency (PDE), crosstalk probability and other important characteristics of SiPMs to study the performance of different devices. The precise positioning system of the setup together with excellent focusing of the light source provides scanning capabilities that allow a study of the spatial distributions of PDE, crosstalk etc. over large sensor areas with sub-pixel resolution. A brief description of the setup, final results of a study of two types of Hamamatsu MPPCs and first scans of SiMPl devices, developed at MPI Semiconductor Lab, will be presented.

SiPM applications / **52**

COMPET a high-resolution, high-sensitivity pre-clinical PET scanner

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COMPET is aiming for high-resolution with a high sensitivity by the use of a novel detector geometry. In classical PET detectors where detector elements are mounted radially the number of photo detectors to be read out scales with the square of the detector resolution. The lack of depth of interaction information contributes to a position dependent parallax error. The COMPET detector overcomes these issues with a geometry that consists of four modules forming a square barrel, each with five layers. Each layer consists of 30 LYSO crystals (80×3×2 mm^3) axially mounted interleaved with 24 wavelength shifting fibers (80×3×1mm^3). The resulting detector has an effective voxel size of 0.6×3×2 mm^3. The precise measurement of the gamma ray point of interaction in three dimensions gives a small parallax error which is uniform across the field of view thus allowing us to place the detector elements close to the imaged object, effectively increasing the sensitivity. There are in total 600 LYSO crystals with 480 wavelength shifting fibers which are read out separately with SiPMs. The DAQ chain consists of an analog pre-amplifier which charge integrates and discharges linearly with a constant current source. This signal is input to a comparator, and a Time-Over-Threshold (ToT) signal as output. The ToT signal is input to an FPGA where energy and event start time is extracted from a deserializer running at 1 Gbps. One read-out card handles one layer (54 channels), and a total of twenty read-out cards are needed to read out all twenty layers. Synchronization is done with a logic clock distributed by a central coincidence processing unit (FPGA), and coincidence processing is done asynchronously with the use of a 1 Gbps UDP/IP network.

SiPM applications / **53**

First experience with the FACT camera

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The application of Geiger-mode multi pixel photon devices in the field of ground-based Cherenkov astronomy is currently being evaluated in the FACT (First G-APD Cherenkov Telescope) project. The FACT collaboration built a camera with 1440 pixels for the use in Imaging Atmospheric Cherenkov Telescopes, each pixel consisting of a Hamamatsu MPPC with a solid light collecting cone glued to it. The full trigger and readout electronics is integrated in the camera. The photosensor signals are digitized using the Domino Ring Sampling (DRS4) chip.

In October 2011, the camera was installed in a refurbished HEGRA telescope on the Roque de los Muchachos (La Palma, Spain). Only hours after the completion of the installation, the first air showers were observed. The camera is now being operated for several months both for commissioning and observations, allowing us to evaluate the technology and gain important experience in the operation of such a camera for future projects.

In this talk, the challenges and solutions in the assembly of the optical components as well as our experience with the operation of the camera are presented.

SiPM / 54

Study of PPDs with multi-wavelength laser microscope system

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Measurement of PPD (Pixelated Photon Detector) characteristics with various wavelengths is important for understanding and improvement of the sensor performances. We have developed a new pulsed laser microscope system whose wavelength is continuously tunable from 410 nm to 2200 nm by using OPO laser system. Laser spot can be focused to ~2 um, small enough to measure pixel-by-pixel performance of PPD. In this workshop, new multi-wavelength measurements of various types of PPDs using the laser microscope system will be reported.

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The stability of vacuum phototriodes to varying light pulse loads and long term changes in response

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Vacuum Phototriodes (VPTs) are radiation resistant photodetectors, designed to operate in a strong quasi-axial magnetic field. This paper reports the long and short term changes in response of production vacuum phototriodes to pulsed light for devices installed in the CMS experiment at the CERN LHC. Both long and short term dynamic effects occur because of pulse rate changes during LHC operation and the effect of increasing integrated charge taken from the photocathode. We have investigated these effects over time periods exceeding two years of simulated operation and discuss the implications for the long term performance of the VPTs in CMS.

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Optimisation of SiPM intrinsic and coincidence time resolution using digital techniques

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A variety of modern physics applications, ranging from medical to high energy physics, require very fast light sensors, characterised by a response in the range of tens of picoseconds. Silicon Photomultipliers (SiPMs, or Multi pixel photon counters (MPPCs)) are a relatively new solid-state pixellated detector type that satisfies this requirement, with the advantage of being compact, cheap, operating at low bias and insensitive to magnetic fields. Moreover, the device's high photodetection efficiency and high signal to noise ratio (SNR) make it a suitable candidate as scintillating crystal readout detector, in place of traditional Photomultiplier Tubes (PMT).
In this work the timing properties of two different Hamamatsu MPPCs are studied. In particular, the instrinsic time resolution, i.e. the time required for the pulse formation under a light stimulus and the coincidence between a pair of sensors were measured, using a femto second pulse laser (Ti:Sapphire). Digital filters were used to improve the SNR and the time jitter of the digitised signals and three different algorithms for the time stamp pick-up were developed and evaluated. Very good intrinsic time resolution, of the order of 35 ps and coincidence time resolution of the order of 45 ps were found. These values are strongly dependent on the choice of the values of the filter parameters, precisely the cut-off frequency. The main limitation to the time resolution is then represented by the high frequency noise affecting the signals, which deteriorates the SNR, and not by the bandwidth of the readout electronics.

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Development & performance of the Capacitive Division Imaging Readout (CDIR) detector, and future applications

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We present results from a photon-counting microchannel plate (MCP) imaging detector using the Capacitive Division Image Readout (C-DIR), designed to provide moderate position resolution (of the order of 100x100 pixels^2), with timing resolution of 25 ps and a maximum event rate of 10 MHz, limited by microchannel plate count rate saturation. The NINO and HPTDC ASIC combination, developed at CERN, simultaneously provide picosecond event timing and time over threshold determination of charge amplitude as required for position sensitivity using a centroiding technique. Measurements of the detector's performance will be presented, with a discussion of our experience with utilising ASICs designed for high energy physics for alternative applications.

These electronics, in principle, can be extended to provide sub-pixel resolution for multi-anode MCP detectors, SiPM arrays and other similar multi-channel devices. This approach can combine the parallel event readout capabilities of multi-channel detectors, with the higher resolution provided by centroiding imaging algorithms. This addresses the traditional limitation of using centroiding techniques in high event rate applications, where the serial nature of these devices coupled with slow shaping amplifiers limits the maximum event rate.

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Studies for the evaluation of the performance of the Time over Threshold technique for the digitization of the signal of a Very Large Volume Neutrino Telescope

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KM3NeT (km3 Neutrino Telescope) is planned to be a deep-sea multidisciplinary observatory in the Mediterranean Sea that will provide innovative science opportunities spanning Astroparticle Physics and Earth and Sea Science. KM3NeT will consist of several hundreds of vertical structures, which carry photo-sensors and devices for calibration and environmental measurements. The photo-sensor unit is a digital optical module (DOM) consisting of a 17-inch diameter pressure resistant glass sphere housing 31 3-inch photomultiplier (PMT) tubes. The front-end electronics is based on the use of the time over threshold (ToT) as the main signal processing technique.
The track reconstruction techniques applied to the KM3NeT data uses the arrival times of the first photon on each PMT and the deposited charge. We report on the performance of the ToT technique in reconstructing the PMT signal characteristics, in particular the first photon arrival time and the charge deposited on the PMT. For this study, we have used simulated data generated with the HOURS (HOU Reconstruction & Simulation) software package.

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Study on large area photomultipliers with super bialkali photocathode

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Photomultipliers with large photocathode area have been widely used in proton decay, astrophysics and neutrino detectors in recent years, since large detection volumes can be reached with a reduced number of detectors. The sensitivity of a photomultiplier is described in terms of its quantum efficiency (QE), i.e. the number of photoelectrons emitted from the photocathode divided by the number of incident photons. QE is currently limited to typical values of around 25% at the spectral peak (400nm). Hamamatsu has developed a new super bialkali (SBA) photocathode which improves quantum efficiency up to 35%. Considering the detection efficiency of a detector as the number of detected events divided the number of events emitted by source, an increase of the quantum efficiency improves the detection efficiency as well as an increase in detection surface. With that in mind, a large study on performance of super bialkali large area photomultiplier type R7081 (10" photocathode) and type R5912 (8" photocathode) was done, and the results were compared to those of standard bialkali photocathode with the same mechanical design.
Firstly, measurements of the increase of the detection efficiency were performed carefully. In order to define whether the quantum efficiency improvement process could have secondary effects, time and charge characteristics, fraction of spurious pulses and dark count rate were investigated and compared with the measurements on a batch of 72 standard bialkali PMTs. Measurements of the parameters have been performed illuminating the whole photocathode surface using a 400 nm pulsed laser attenuated in single photoelectron condition. The results confirmed an increase in the quantum efficiency up to values of 35%, as declared by manufacturer. The main secondary effects of the super bialkali photocathode were an increase for the dark count rate and a considerable increase of the fraction of the after pulses. About the dark count rate, the tested SBA PMTs had a mean value of about 2 times greater than that measured on the batch of standard PMTs. The noise rate decay time after a short light exposure was measured for a standard and a SBA photomultiplier: the super bialkali PMT exhibited a decay time of over ten hours, greater of the time of about six hours measured on the standard PMT. The local measurements performed scanning the photocathode surface with a narrow laser beam confirm that the uniformity of the super bialkali photocathode is not worse than that of the standard PMTs.
Another important issue was the study on the influence of the Earth's magnetic field. It is well

known that the performance of a photomultiplier tube is subject to significant variation due to magnetic fields. This is particularly true for large area PMTs, because of the long trajectories of electrons from the photocathode to the anode. While the effects of Earth's magnetic field on the performances of a large area photomultiplier are principally due to deflections in the trajectories of the photoelectrons drifting from photocathode to first dynode, trajectories of secondary electrons in the dynode chains can also be affected, depending on the orientation of the PMT relative to Earth's magnetic field. The influence of the Earth's magnetic field on the main parameters was studied on two Hamamatsu PMTs, 8-inch R5912 types, one of these with super bialkali photocathode, and compared with measurements on a 10-inch R7081 type with a standard bialkali photocathode. The various characteristics of the PMTs were measured while varying the PMT orientations with respect to the Earth's magnetic field. The effect of a mu-metal cage as magnetic shield was also studied. In general, for the 8" PMTs the impact of the magnetic field was found to be smaller than that on the 10" PMT. The super bialkali 8" PMT has shown the same behaviour of the standard one with respect to the Earth magnetic field. The increased quantum efficiency in the 8" super bialkali PMT almost compensated its smaller detection surface compared to the 10" PMT. It was also confirmed that the super bialkali photocathode produced significantly greater type-1 and type-2 after-pulsing than the standard bialkali photocathode.
At last, an accurate study and measurement about the ageing effects on two large area photomultipliers has been performed for over three years. The PMTs were 10", 10 stages Hamamatsu R7081, one with standard bialkali and the other one with super bialkali photocathode. Gain, dark count rate, charge and timing properties have been measured, as well as the fraction of the spurious pulses. During the ageing cycles, the anode current of the two photomultipliers has been monitored and recorded in order to measure the total output anode charge and determine the ageing grade. The ageing conditions have been set by the use of a 400nm LED regulated to about 3 photoelectrons at about 400 kHz. The ageing process was stopped when the total charge arrived up to about 2000 C for both the PMTs. Considering the main results, only the gain showed a variation while all the other parameters remain quite stable. A first phase of up-drift shows an increase of the gain of about 10% and is followed by a final phase of down drift, which shows a faster diminution of the gain of about 30%. The mechanism of the gain drift has been modelled and compared with the results.

SiPM / 60

Characterization of Hamamatsu MPPC for use in liquid xenon scintillation detectors.

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Liquid xenon is an excellent scintillator with large atomic number, relatively high density, high light yield and short decay time which makes it suitable for a number of applications in particle physics, astrophysics and nuclear medicine. In particular, large liquid xenon detectors are being used in several dark matter experiments. While in most cases the optical readout is done with photomultiplier tubes (PMTs), the possibility of replacing the PMTs by solid state devices such as silicon Multi Pixel Photo Counter (MPPC) are currently under investigation.

There are three main difficulties in using MPPC in a xenon scintillation detector. first, xenon scintillation spectrum lies in the short wavelength region centered at 175 nm. Therefore, for efficient detection of liquid xenon scintillation the photodetectors have to be sensitive to the VUV light. Second, they have to be compatible with high purity liquid xenon environment. Third, they must perform under rather severe conditions, namely, low temperature (about -100°C) and external pressure variations. On the other hand, cooling down the device in many cases helps to considerably reduce the noise, in which case the cryogenic conditions turn in fact into an advantage.

In this work we present the performance results for several types of MPPCs (Hamamatsu) operating at temperatures down to -100°C. Under these conditions, the devices demonstrated drastically reduced noise count rate (<1 Hz for >1 photoelectron) and elevated gain (>10^6). On the downside,

the quantum efficiency for the xenon scintillation light is quite low (~3%) compared to a typical PMT (20-30%). Also the afterpulsing fraction seems to increase at low temperature (up to ~20% probability per photoelectron). The operation of MPPCs immersed in liquid xenon will be reported.

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Characterization of the Hamamatsu R11265 Multi-Anode Photomultipliers tube with single photon signals

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The RICH upgrade in LHCb requires a new front-end electronics for the detector readouts at the LHC frequency of 40 MHz. In particular the photon detector currently used in the RICH features an embedded front-end elctronics inside the tube. This calls for a replacement of readout electronics that involves the alteration of the whole HPD. On the other hand, the Milano-Bicocca group chose to study a different kind of light detector for the RICH upgrade, that is multianode photomultipliers. In the last three years the group has worked with two different multianode photomultiplier tubes manufactured by Hamamatsu, the H9500 and the R7600. All these detectors were tested in the single photon condition, a fundamental requirement for the RICH of LHCb. Dark anode current, single photon signals spectra, gain and uniformity were measured. Also the
cross-talk level, the behavior of the phototubes in a magnetic field, time resolution and aging effect were studied. In this paper the last measurements performed on the new R11265 Multi-Anode Photomultiplier are presented. A complete characterization will be available by the end of may.

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Multi-pixel Geiger mode imager for medical application

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The domain of Geiger-APD has reached an advanced development in the last years. The idea of this work is to use the spatial resolution and rapidity of the Geiger-APD in the field of very low light intensities; it would be possible to explore new areas. The equipment that we intend to achieve will be a series of Geiger-APD arrays (imagers) based on the principle detector unit.

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Evaluation of high UV sensitive SiPMs from MEPhI/MPI for use in liquid argon

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The TUNKA EAS Cherenkov experiment operates in the Tunka Valley in Siberia. The main physics goals of the experiment are measurements of energy spectrum and mass composition of primary cosmic rays in the energy region of 10^15-10^18 eV and detection of high energy gamma-rays from supernova remnants with energy threshold of 20-50TeV. New 8" hemispherical PMTs from Hamamatsu and ET have been thoroughly studied. They are developed especially for such kind of applications and can withstand high anode current due to night sky background. In case of high energy gamma-ray detection PMTs sensitivities to Cherenkov light are increased by depositing WLS foils on PMTS.

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Evaluation of high UV sensitive SiPMs from MEPhI/MPI for use in liquid argon

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The results of evaluation studies of high UV sensitive SiPMs produced by MEPhI/MPI operating in liquid argon. The SiPMs have PDE>50% in the wavelegth region of 350-400 nm. SiPMs were coupled with different types of WLS foils to reach high sensitivity to LAr scintillation light. The main parameters of SiPMs (PDE, noise, cross-talks, afterpulses, stability) in LAr have been thoroughly studied.

Posters B / 65

Detailed Monte-Carlo simulation of SiPM-based scintillation detectors for PET

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A detailed model for a Monte-Carlo simulation of the response of Silicon Photomultipliers (SiPMs) is presented. Comparisons with experimental data show a good agreement. The model allows investigating which SiPM-specific features affect energy and time resolution. Furthermore, the simulation is an important tool for the optimization of a detector layout and the design of read-out schemes.

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Recovery Time and Double Hit Resolution Measurements of SiPMs Using a Double Pulsed Laser

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The Silicon Photomultiplier (SiPM) is an extremely versatile photo detector which can be used in various fields ranging from astrophysics, particle and nuclear physics to medical imaging. One of the important parameters of a photo sensor is the performance in high rate environments. In order to characterize the rate capability and the double hit resolution of SiPMs, we performed an experimental study to determine the cell recovery time for various sensors of different manufacturers.

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Bolometric light detectors for Neutrinoless Double Beta Decay search

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Bolometric light detectors provide an efficient method to collect light signals at small thresholds in cryogenic experiments and are being exploited in next-generation experiences for the search of Neutrinoless Double Beta Decay. Sample light detecting bolometers made up of a ultra-pure Ge slab read by a phonon sensor thermistor were assembled and tested at very low temperatures, below 30 mK; their performances are investigated in terms of their reproducibility, signal amplitude, signal to noise ratio and energy resolution.

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Neganov-Luke effect assisted Light Sensors

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Rare event physics like Direct Dark Matter and Neutrino-less Double Beta Decay detection strongly benefit of event-by-event discrimination capabilities. Composite Heat and Light bolometric detectors have shown excellent performance of environmental gamma's, beta's and alpha's tagging and rejection and therefore are widely used in such physics.
The rejection capabilities mainly rely on the light detector performance. We present here tantalizing results obtained with ultra-pure germanium light sensors, assisted by Neganov-Luke effect, and showing a gain of the signal-to-noise ration of the order of four and a light detection threshold of about 20 eV.

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The silicon photo-multiplier physics and technology: a review

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The physics of the device, the main technological issues and the related solutions adopted by the various manufacturers together with the most recent advances and open issues will be discussed.

The device working principles will be covered in detail, by focusing on the phenomena related to avalanches development and to carrier generation and transport in silicon, which are relevant to explain the device intrinsic characteristics like gain, dark noise, after-pulsing, cross-talk, photodetection efficiency and timing properties.

The most relevant characterization measurements related to various types of SiPM devices will be summarized, by focusing on the understanding of the device properties under the influence of various environmental factors (eg. low temperature performances, radiation hardness, light intensity regime etc...)

Relationships (in terms of the underlying physics) among the above mentioned intrinsic characteristics will be shown and the resultant tradeoffs (eg timing vs detection efficiency) in actual devices will be discussed. The impact on front-end electronics and on selected application performances will be briefly covered. Finally, possible improvements and future trends will be illustrated and eventually suggested.

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Design and Characterization of a Micro-Strip RF Anode for Large-Area MCP-based Photodetectors

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We describe an inexpensive micro-strip RF anode designed to measure the time and position in large-area MCP-based photo-detectors. The

anode has been optimized to match the bandwidth of the intrinsically fast MCPs (risetime < 1ns). The timing, two-dimensional position, and energy of the MCP pulses are extracted by fast waveform digitization at both ends of the anode micro-strips. The anode geometry consists of 30 equidistant, silver microstrips silk-screened on a 20cm-by-20cm, 2.75 mm-thick, Borofloat glass plate. A solid ground plane is referenced on the opposite side of the glass. The anode is measured to have an analog bandwidth of 2 GHz (175 ps risetime), cross-talk coupling between strips of -10dB, and impedance control of the 50-ohm lines of better than 10% over the entire bandwidth. The anode geometry and construction allows for multiple anodes to be connected in series, efficiently increasing the photosensitive area for the same number of electronics channels.

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A Fast Waveform-Digitizing ASIC-based Electronics and DAQ for a Position \& Time Sensing Large-Area Photo-Detector System

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A data acquisition (DAQ) system using 10-15 Gigasamples/second (Gsa/s) waveform sampling ASICs for the readout of large active-area micro-channel plate photomultiplier tubes (MCP-PMTs) is presented.
Currently being developed by the Large-Area Picosecond Photo-Detector (LAPPD) collaboration, a single MCP photo-detector tile' has an active area of 400 sq. cm and a dual-end, 50-ohm transmission line anode
comprised of 30 parallel microstrips. The position, timing, and energy of the incident pulse are extracted from the full waveforms that are recorded at both anode terminals. With this anode geometry, a larger photo-sensitive area may be formed by connecting several detector tiles in series, allowing for the use of the same readout electronics and acquisition system for many potential applications.
A custom fast, low-noise, and low-power waveform digitizing ASIC,PSEC-4', was designed in 0.13 μm CMOS for the front-end readout of these detectors. With
6-channels, the PSEC-4 has a buffer depth of 256 samples on each channel, a chip-parallel Wilkinson ADC, and a serial data readout that includes the capability for region-of-interest windowing to reduce dead-time. Sampling rates of up to 15 Gsa/s are possible on each channel with an analog bandwidth of 1.5 GHz. A flexible DAQ system matched
to the large-area detector anode, in which PSEC-4 calibrations and signal feature extraction are implemented in two layers of FPGAs, has been designed and code development is underway. Further details of
the readout system, including the PSEC-4 ASIC capabilities and DAQ performance, will be reported.

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Using ultra fast analog memories for fast photo-detector readout.

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The recent progresses in the field of photo-detection have pushed the performances of the detectors toward the picosecond scale. Currently existing electronics dedicated to precise charge and time measurement is mainly based on the use of high-end oscilloscopes. Numerous test benches are also based on both Charge-to-Amplitude Converters and Constant Fraction Discriminators (CFD) associated with Time to Digital Converters (TDC). The time resolution obtained with some commercial modules is very good (Time to Analog Converters ~ 5 ps rms after amplitude correction), but said modules house very few channels. Some TDC boards offer a higher number of channels, based on a coarse measurement performed by a digital counter associated with a fine measurement (interpolation) using Delay Line Loops, but their overall resolution is only of the order of 30 ps rms.
Recently, alternative methods based on digital treatment of the analogue sampled then digitized detector signal have been developed. Such methods permit an easy calculation of the charge and amplitude, and achieve a timing resolution far better than the sampling frequency. Digitization systems have followed the progress of commercial ADCs, but the latter have prohibitory drawbacks like their huge output data rate and power consumption. Conversely, high speed analog memories now offer sampling rates far above 1GHz at low cost and with low power consumption.
The new 16-channel WaveCatcher board has been designed to provide high performances over a short time window. It houses sixteen 12-bit 500-MHz-bandwidth digitizers sampling between 400 MS/s and 3.2 GS/s. It is based on the patented SAMLONG ASIC, a high-performance low-power analog circular memory designed in a cheap pure CMOS 0.35µm technology. The board offers a lot of functionalities like smart trigger configurations and embedded charge integration. It houses 480 Mbits/s USB and 1.5Gbits/s optical link interfaces.
The board will soon been tested in different test benches dedicated to the characterization of fast MCP-PMTs or SiPMs, but a reproducible time precision better than 10 ps rms has already been demonstrated.
The WaveCatcher board thus seems to be a powerful tool for photo-detector characterization and high-scale readout.

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Overview of SiPM readout electronics

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Solid-state photomultipliers (SiPM/MPPC) are increasingly popular and replacing vacuum-based devices in many applications. Although their signal properties (gain, capacitance…) are similar and can thus be readout with the same electronics, several dedicated ASICs have been developed worldwide to take benefit of the high level integration that can be reached with these devices. Furthermore, charge and timing measurements can reach unprecedented accuracy and enable new applications in various domains of physics or medical imaging.
The talk will review the basic front-end architectures that can be used to take full benefit from the device (voltage/current/charge sensitive preamplifiers, current conveyors…) to optimize their performance. It will also compare the various readout architectures that are being used for readout (discrete, ASICs, waveform digitizers, "digital SiPM" …).
Finally, it will review the status and performance of the various ASICs developed worldwide (SPIROC, BASIC, NINO, PETA, KLAUS, SPIDER, EASIROC, RAPSODI…)

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Studies of timing properties of SiPms at Fermilab

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A short report of our Fermilab activity with SiPms timing.

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The AX-PET experiment: A demonstrator for an axial Positron Emission Tomography

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The AX-PET (AXial Positron Emission Tomography) experiment proposes a novel geometrical approach for a PET scanner, in which long LYSO scintillator crystals are placed axially in the tomograph. Arrays of WLS strips, placed behind each layer of crystals, provide the measurement of the axial coordinate. Both the crystals and the WLS strips are individually read out by G-APDs (Geiger-mode Avalanche Photo Diodes). Such a matrix of LYSO crystals and WLS strips allows for a 3D localization of the photons interactions (both photoelectric absorption and Compton scattering), with good spatial resolution and without compromising on the sensitivity of the detector.
Two AX-PET modules have been built at CERN and fully characterized with point-like Na-22 sources, demonstrating competitive performance in terms of spatial and energy resolutions. Operated in coincidence, the two modules represent the demonstrator for a PET prototype, which has been successfully used for the reconstruction of images of several phantoms filled with F-18 in aqueous solution. The AX-PET detector concept, its performance, the reconstructed images of different phantoms will be described briefly. The emphasis will be put on the actual limitations of the current demonstrator set-up and how part of these limitations could be overcome by the use of the novel digital Silicon Photomultiplier (dSiPM) technology from Philips. With their highly integrated read-out electronics and excellent intrinsic time resolution, dSiPMs may allow for compact detector modules with Time of Flight capability (TOF-PET). We will present a number of performance measurements in view of their application in the AX-PET concept.

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Welcome talks

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Conference diner at Musée d'Orsay

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Summary talk

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Conclusion talk

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Light Emission from Light Detectors

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Visible light emission from both photomultipliers (PMT) and semiconductor p-n junctions in reverse bias has been known for over half a century. As photomultipliers and silicon photomultipliers (SiPM) are sensitive, their own light emission has a feedback, which needs to be understood. Furthermore it can be used to develop new evaluation tools.
With light emission microscopy we can show that the avalanche size in SiPM is finite. With a new method, it is also possible to measure the cross-talk morphology via the light emission. When developing small size cells, these results have to be taken into account, e.g. the timing resolution has a lower limit.
PMTs show fast spurious signals, correlated to an incident photon. As sensitive light detectors, their own light emission can cause fast afterpulses. We show how the electrons interact with the dynode material, time resolved on the nanosecond scale. Wavelength dependent light emission proves that not only the dynodes, but also their support structure emits light.
The performed experiments help to understand the fundamental effects of light emission in light detectors, applied to afterpulses and backscattering in PMTs and cross-talk in SiPMs in particular.