International Conference on the Advancement of Silicon Photomultipliers

Report of Contributions

https://indico.gsi.de/e/6990

Contribution ID: **1** Type: **Talk**

Cryogenic Readout Electronics for a MPPC Based Array Operating at Liquid Xenon Temperature

Friday, 15 June 2018 09:35 (20 minutes)

We present the performances and characterization of an array made of Hamamatsu S13370-3050CN (VUV4 generation) Multi-Pixel Photon Counters for the detection of VUV scintillation light in liquid xenon based applications. The array is readout as a single channel and it is capable of single photon detection making the device a promising option for future generation of neutrino and dark matter detectors based on liquid xenon targets.

The electronics board encloses a low power consumption preamplifier stage, operating at liquid xenon temperature. In the present configuration, a single operational amplifier serves 16 individual MPPCs (corresponding to 1.44 cm^2 of active surface) forming a macro cell. The electronics is capable to readout up to 4 macrocells.

The operational amplifier selected for the realization of the prototype is the current feedback Analog Devices AD8011. The layout does not prevent the use of different models in case of higher performance requirements or for operations at lower temperatures.

A biasing correction circuit, based on Digital To Analog Converters suitable for cryogenic applications, is used for the gain equalization of photosensors with different breakdown voltages.

Detector characteristics, noise analysis and performance will be discussed along with the preliminary radioactivity screening assessment of the preamplifier unit.

Primary author: Dr DI GIOVANNI, Adriano (New York University Abu Dhabi)

Co-authors: Dr CANDELA, Attanasio (Gran Sasso National Laboratory - INFN); Prof. ARNEODO, Francesco (New York University Abu Dhabi); Dr BRUNO, Gianmarco (New York University Abu Dhabi); Dr FRANCHI, Giovanni (AGE scientific SRL); Dr MESSINA, Marcello (New York university Abu Dhabi); Prof. BENABDERRAHMANE, Mohamed Lotfi (New York University Abu Dhabi); Dr FAWWAZ, Osama (New York university Abu Dhabi)

Presenter: Dr DI GIOVANNI, Adriano (New York University Abu Dhabi)

Session Classification: Cryogenic Properties

Track Classification: Cryogenic Properties

Contribution ID: **2** Type: **Talk**

Modular and Custom SiPM for the Mu2e Electromagnetic Calorimeter

Tuesday, 12 June 2018 15:50 (20 minutes)

The Mu2e electromagnetic calorimeter has to provide precise information on energy, time and position for ~100 MeV electrons. It is composed of 1348 un-doped CsI crystals, each coupled to two large area Silicon Photomultipliers (SiPMs). A modular and custom SiPM layout, consisting of a 3 × 2 array of 6 × 6 mm^2 UV-extended monolithic SiPMs, has been developed to fulfill the calorimeter requirements and a pre-production of 150 prototypes has been provided by three international firms (Hamamatsu, SensL and Advansid). A detailed quality assurance process has been carried out on the photosensor pre-production and on the first production batchs: the breakdown voltage, the gain, the quenching time, the dark current and the Photon Detection Efficiency (PDE) have been determined for each monolithic cell of each SiPMs array.
A sample from each vendor has been then exposed to neutrons generated by the Elbe Positron Source facility (Dresden), up to a total fluency of $\sim 8.5 \times 10^{11}$ $n_{1\ MeV}/cm^2$. The test results are also shown. The dependence of the dark current on the device temperature and on the applied bias voltage has been evaluated as well.
This paper also presents an electrically induced annealing technique that provides a partial recovery of the SiPMs damaged by neutrons.

Primary author: Dr SARRA, Ivano (INFN)

Presenter: Dr SARRA, Ivano (INFN)

Session Classification: Large Scale Characterization and Reliability

Track Classification: Large Scale Characterization and Reliability

Contribution ID: **3** Type: **Talk**

Suppressing Optical Crosstalk in SiPMs

Wednesday, 13 June 2018 16:40 (20 minutes)

Compared to conventional photomultiplier tubes (PMTs), silicon photomultipliers (SiPMs) based on multi-cell geiger-mode avalanche photodiodes (GAPDs) have advantages with regards to photon detection efficiency, compactness, robustness and tolerance of both magnetic fields and intense light sources. In addition, SiPMs can be cost effective for applications that require many channels with small unit area. Because of these advantages, SiPMs are starting to replace PMs in many applications.
When used in the cameras of Imaging Atmospheric Cherenkov telescopes, the optical crosstalk of SiPMs needs to be reduced in order to suppress accidental triggers due to the high rate of night sky background caused by scattered starlight and moonlight, and the fluorescence of excited molecules in the atmosphere.
In this contribution, the propagation properties of optical photons in SiPMs are investigated through systematic measurements of the optical crosstalk with varying SiPM pixel and GAPD cell sizes and with and without coatings on the SiPMs. It was observed that a significant portion of the optical crosstalk is mediated by the coating. The propagation of optical photons in the bulk silicon of the SiPM is also discussed.

Primary author: TAJIMA, Hiroyasu (Nagoya University)

Co-authors: OKUMURA, Akira (Nagoya University); ZENIN, Anatolii (Nagoya University); HIDAKA, Naoya (Nagoya University); YAMANE, Nobuhito (Nagoya University); NAKAMURA, Yuki (Nagoya University)

Presenter: TAJIMA, Hiroyasu (Nagoya University)

Session Classification: Nuisance Parameters

Track Classification: Nuisance Parameters

Contribution ID: **4** Type: **Talk**

Assessment of Photodetection Performance of Analog and Digital SiPMs Exposed to Cold Neutrons

Thursday, 14 June 2018 10:10 (20 minutes)

Small Angle Neutron Scattering (SANS) technique uses cold or thermal neutrons for investigation of soft and condensed matter. Significant developments in microelectronics enabled the use of scintillation-based pixelated neutron detectors that exploit Silicon Photomultipliers (SiPM) for detecting visible light generated within a scintillator, in our case a 1 mm thick Ce-doped 6Li-glass [1]. We investigated the dark signal [1], the breakdown voltage, and the photon detection efficiency (PDE) performances [2] of three SiPM technologies: two analog ones and one based on digital counting of avalanche events. The temperature dependence of the dark signal performance, and the breakdown voltages of SiPMs were additionally investigated. The following photodetector arrays have been characterized: SensL Series-C 12×12 array C-30035-144P, Hamamatsu 8 × 8 MPPC array S12642-0808PB-50, and digital Philips DPC3200-44-22 module. We irradiated the photodetector arrays with cold neutrons (lambda = 5 Å) at the KWS-1 instrument [3] of the Heinz Maier Leibnitz Zentrum (MLZ) in Garching, Germany, up to a dose of 6E12 n/cm². During the irradiation campaigns, the SiPM detectors were at all times fully operational, and the measurements were performed partially in-situ.
In this work, we discuss the measurement methods, and instrumentation developed for these tasks. Special emphasis is put on a custom measurement system implemented in a joint effort by the company aSpect Systems GmbH and the Central Institute for Electronic Systems (ZEA-2) of the Forschungszentrum Jülich for temperature and position sensitive measurement of wavelength dependent PDE in the range between 300 nm and 1100 nm. Finally, the results of the characterization of the SiPM arrays carried out before, during, and after cold neutron irradiation are presented.

References
[1] D. Durini et al., "Evaluation of the dark signal performance of different SiPM-technologies under irradiation with cold neutrons" Nucl. Instr. and Meth. A 835, 99–109, 2016, https://doi.org/10.1016/j.nima.2016.08.016
[2] S. Kumar, D. Durini, C. Degenhardt and S. van Waasen "Photodetection Characterization of SiPM Technologies for their Application in Scintillator based Neutron Detectors", Journal of Instrumentation, Vol. 13, Jan. 2018, https://doi.org/10.1088/1748-0221/13/01/C01042
[3] Heinz Maier-Leibnitz Zentrum et al., „KWS-1: Small-angle scattering diffractometer "Journal of large-scale research facilities, 1, A28, 2015, http://dx.doi.org/10.17815/jlsrf-1-26

Primary author: Prof. DURINI ROMERO, Daniel (FZ Jülich / INAOE)

Co-authors: Dr DEGENHARDT, Carsten (Forschungszentrum Jülich); Mr ARUTINOV, David (Forschungszentrum Jülich); Mr KUMAR, Shashank (Forschungszentrum Jülich); Prof. VAN WAASEN, Stefan (Forschungszentrum Jülich)

Presenter: Prof. DURINI ROMERO, Daniel (FZ Jülich / INAOE)

Session Classification: Radiation Hardness

Track Classification: Radiation Hardness

Contribution ID: **5** Type: **Talk**

Characterization of VUV-Sensitive SiPMs for LXe Scintillation Light Detection in nEXO

Tuesday, 12 June 2018 09:50 (20 minutes)

The nEXO experiment will operate an ultra-low background TPC filled with 5\,tons of isotopically enriched liquid Xenon~(LXe) to search for the neutrinoless double beta ($0\nu\beta\beta$) decay of Xe-136. The detector will use $4\,\mathrm{m}^2$~of SiPM tiles operated at~$-104\,^{\circ}\mathrm{C}$ to collect the scintillation light from any events in the xenon. There are strong requirements on the SiPM performance, light collection efficiency and background levels to achieve an excellent energy resolution. Detecting the $0\nu\beta\beta$-decay would have wide-spread implications for particle physics.

The SiPMs have to be sensitive to the vacuum-ultraviolet (VUV) scintillation light of LXe at $178\,\mathrm{nm}$ which is not given for off-the shelf SiPMs. The development and characterization of such VUV-sensitive SiPMs for nEXO has already produced promising results: (1) measured limits for the radio-isotope content of SiPMs (manufactured by Foundation Bruno Kessler, FBK) are consistent with requirements, (2) the photo-detection efficiency exceeds $15\,\%$ for FBK and Hamamatsu Photonics SiPMs at $178\,\mathrm{nm}$, (3) dark noise and correlated avalanche rates are better than the upper limits adopted by nEXO of $50\,\mathrm{Hz/mm}^2$ and $20\,\%$, respectively. The nEXO collaboration is continuing to work with SiPM manufacturers to further improve performances.

nEXO also examines the VUV-reflectance of SiPM. Detector samples are immersed in a LXe cell and irradiated with photons at a wavelength of $178\,\mathrm{nm}$ at the LXe laboratory at M{\"u}nster University. The reflectance for given incident angles can be derived as the ratio of the reflection rate off of the SiPM surface and the reference rate without sample – both measured with a secondary detector for a wide reflectance angle range. Other investigations focus on possibly different behaviours of SiPMs in high electrostatic fields as present in the final TPC by nuisance measurements at various electric field strengths.

In this talk, we give an overview of the current VUV-sensitive SiPM characterisation efforts within the nEXO collaboration focussing on PDE and surface reflectance studies.

Primary author: Mr WAGENPFEIL, Michael (Erlangen University)

Co-author: Mr FIEGUTH, Alexander (University of Münster)

Presenter: Mr WAGENPFEIL, Michael (Erlangen University)

Session Classification: Photon Detection Efficiency

Track Classification: Photon Detection Efficiency

Contribution ID: **6** Type: **Poster**

Physical Model of the Performance of Avalanche Photodiodes with Single Photoelectron Detection

A new physical model of avalanche process with single photon detection capabilities is presented in various Geiger mode photodiodes. The model describes development of avalanche process in time, taking into account the space charge resistance as well as the change of electric field in the avalanche region caused by internal discharge and external recharge currents. Results of simulations are compared with experimental data received with Geiger mode photodiodes from different suppliers. It was found that at fixed over-voltage the signal gain is reduced significantly depending on the space charge resistance. The relative value of the reduction in signal gain depends on the pixel capacitance. The possibilities of improving the parameters of avalanche photodiodes are discussed widely in this work.

Primary author: Mr AHMADOV, Farid (ANAS)

Co-authors: Mr SADIGOV, Azer (National Nuclear Research Center); Dr ABDULLAYEV, Fatali (Institute of Radiation Problems- Administrative Department of ANAS, Baku, Azerbaijan); Dr AHMADOV, Gadir (NNRC-JINR); Dr SADYGOV, Ziraddin (JINR-NNRC)

Presenter: Mr AHMADOV, Farid (ANAS)

Track Classification: Electrical Properties

Contribution ID: **7** Type: **Talk**

Characterization of Position Measurement Error, Position Resolution and Photon Number Discrimination for Position-Sensitive SiPM

Friday, 15 June 2018 12:00 (20 minutes)

Silicon photomultipliers (SiPM) is considered to be a good replacement for photomultiplier tube (PMT) and avalanche photodiodes (APD) in high energy physics, which benefits from its high internal gain, good compactness, excellent timing performance, robustness and insensitivity to magnetic fields. However, pixelated SiPM array generally used in high-resolving scintillation imaging applications, shows its drawbacks of large number of readout channels and limited position resolution by SiPM pixel size. Position-Sensitive Silicon Photomultiplier (PS-SiPM) has been emerged as a special kind of SiPM during the past years; it possesses excellent spatial resolution with greatly reduced readout channels, which enables its promising application, for example, in high resolution PET. Since the PS-SiPM is a relatively new type of SiPM, the standardization of PS-SiPM characterization has not been established, which results in hard comparison of devices from different producers. In this conference, we will propose characterizing methods for the major characteristics of PS-SiPM, including the photon-number resolution, position measurement error and position resolution by taking a 2-D tetra-lateral PS-SiPM developed by NDL (Novel Device Laboratory, Beijing) as an example.

Primary author: Ms PENG, Yu (Beijing Normal University)

Co-authors: Prof. HAN, Dejun (NDL, Beijing Normal University); Dr LIANG, Kun (NDL, Beijing Normal University); Dr YANG, Ru (NDL, Beijing Normal University); Mr ZHAO, Tianqi (NDL, Beijing Normal University)

Presenter: Ms PENG, Yu (Beijing Normal University)

Session Classification: Miscellaneous and Others

Track Classification: Exotica and Emerging Methods

Contribution ID: **8** Type: **Poster**

New Micropixel Avalanche Photon Detector with Fast Response

The design and operation principle of a new avalanche photon detector are presented. The innovative avalanche photon detector consists of a matrix of photosensitive micropixels with individual quenching resistors, as in the known SiPM with surface pixels, and a matrix of microtransistors with individual ballast resistors. The new device has two independent signal outputs; standard output from the pixels connected in parallel and fast output from microtransistors, connected in parallel. Signals from each pixel operating in Geiger mode have an additional amplification in the individual phototransistor operating in digital mode. The design of the new device make it possible to solve the main problems of the known SiPMs, namely, significantly reduce the probability of cross-talk and after-pulses, as well as significantly increase the area of the device and improve its performance. The basic idea underlying the new photon detector is the reduction the avalanche amplification in photosensitive pixels and uses an individual amplifying element for each pixel to obtain a sufficiently high gain.

Primary author: Mr SADIGOV, Azer (National Nuclear Research Center)

Co-authors: Mr AHMADOV, Farid (National Academy of Science); Mr AHMADOV, Gadir (National Academy of Science); Prof. SADYGOV, Ziraddin (National Nuclear Research Center)

Presenters: Mr SADIGOV, Azer (National Nuclear Research Center); Mr AHMADOV, Farid (National Academy of Science)

Track Classification: Timing Properties

Contribution ID: **9** Type: **Talk**

Dynamic Range Characterization of SiPM with a Double Light Superposition Method

Thursday, 14 June 2018 16:50 (20 minutes)

We present a new method, Double Light Superposition (DLS) to characterize the dynamic range (DR) of silicon photomultipliers (SiPMs). This self-calibrated technique does not need the calibration procedures for the intensity of the light source from single photon to the level of SiPM saturation, makes the measurement easy and robust, thus can be a candidate of standard for DR measurement of SiPM. It is also benefit to be compatible to characterize the recovery time of SiPM, thus deducing the maximum photon-counting rate for the device operation. The setup of the DLS method includes two identical LEDs, coupled to an optical integrator with fly-eye lens; two short-pulse drivers, with the same frequency and phase, to drive the two LEDs and adjust their light intensity independently. The SiPM functions as both a device under test and a photon meter that is illuminated by the uniform pulsed light in a light tight box. The pulsed signal outputted from the SiPM is inputted to an oscilloscope, to which a synchronous signal correlated to the dual pulsed signals is fed as a trigger to reject the dark counts. The procedure steps of DLS method are as follow: (1) Adjust the intensity of each pulsed light from the dual LED to achieve an output of ~ 1 MFPN (mean fired pixel number) from the SiPM respectively. It is set as N_{init} and is equal to the MPEN (mean photoelectron number) under few photons level, and an initial point (photoelectron number, fired pixel number) $= (N_{init}, N_{init})$ is thus obtained. Then, the two pulse light are superposed (i.e., doubled) and re-measure the MFPN from the SiPM, the second point of ($2N_{init}$, MFPN) is obtained. (2) Increase the light intensity of each light pulse to achieve the same MFPN as the previous superposed one, respectively, and then superpose the two light beams and re-measure the outputted MFPN. (3) Follow this alternative, double increasing and self-calibrated measurement procedure, the dependence of the fired pixel number on photoelectron number can be obtained. We will report DLS method in detail in this conference, and present the results and discussion on the dynamic range of NDL latest C series EQR-SiPM with high density of micro cell $(10^4/mm^2)$.

Primary author: Mr LIU, Jian (Beijing Normal University)

Co-authors: Prof. HAN, Dejun (NDL, Beijing Normal University); Dr LIANG, Kun (NDL, Beijing Normal University); Mr DAI, Lei (NDL, Beijing Normal University); Dr YANG, Ru (NDL, Beijing Normal University); Mr CHENG, Wenxuan (NDL, Beijing Normal University); Ms PENG, Yu (NDL, Beijing Normal University)

Presenter: Mr LIU, Jian (Beijing Normal University)

Session Classification: Nonlinearity and Saturation

Track Classification: Nonlinearity and Saturation

Contribution ID: **10** Type: **Talk**

SensL: Application Specific Testing and Qualification of SiPM

Monday, 11 June 2018 16:15 (30 minutes)

SensL SiPM sensors have been in mass production for many years. To ensure quality and reliability, characterisation and qualification procedures are in place that can process high volumes in a short amount of time.

Increasingly SiPMs are being used in new applications, in particular as the reciever element in LiDAR systems. LiDAR is a ranging technique that typically uses NIR light which conventional SiPMs have only minimal senstivity to. We have developed a new fully-CMOS silicon process to improve the NIR sensitivity of SiPM for these applications. These R-Series sensors can achieve >10% PDE at 905 nm. Although SensL's standard characterisation and qualification procedures can be applied to these new sensors, different applications bring some specific additional requirements. In particular, automotive applications have strict qualification requirements that are specified in the AEC-Q102 standard that specifically covers optoelectronic components. We will discuss how this automotive qualifications standard is applied to SensL SiPM sensors.

Primary author: Dr HERBERT, Deborah (SensL Technologies)

Co-author: Mr CIARLONE, Antonio (SensL)

Presenter: Dr HERBERT, Deborah (SensL Technologies)

Session Classification: SiPM Producers

Track Classification: Miscellaneous and others

Contribution ID: **11** Type: **Poster**

Mass Testing of SiPM for the Electromagnetic Calorimeter of the COMPASS II Experiment

The electromagnetic calorimeter ECAL0 is additional calorimeter for the upgraded COMPASS II experiment. A Hamamatsu MPPC S12572-10P was chosen as readout photosensor in order to meet the detector's requirements as: high dynamic range, low recovery time, etc. During 2015 about 2 000 photosensors were thoroughly tested. In this talk mass testing methods and criteria which we used for SiPM selection are presented.

Primary author: Mr RYBNIKOV, Arseniy (JINR)

Presenter: Mr RYBNIKOV, Arseniy (JINR)

Track Classification: Large Scale Characterization and Reliability

Contribution ID: **12** Type: **Talk**

Large Scale Characterization and Quality Assurance Tests for CALICE AHCAL ”Engineering Prototype”

Tuesday, 12 June 2018 14:10 (20 minutes)

The CALICE collaboration have studies different concepts for the hadronic calorimeters for a future linear collider detector. The Analog Hadronic Calorimeter (AHCAL) concept is a sampling calorimeter of tungsten or steel absorber plates using plastic scintillator tiles read out by silicon photomultipliers (SiPMs) as active material.
SiPMs evolved to match scintillator light wavelength, allows to optimize tile design for scalable production. Optimization of tile geometry allows to use industry standard package and PCB placement procedures
After having demonstrated the capabilities of the technology in the “physics prototypes”, the AHCAL “engineering prototype”, consisting of 24K channels, was built this year with the focus on proving scalability to a full AHCAL detector with more than 8 million channels.
This talk will focus on the Large scale characterization tests and quality assurance tests of the surface mounted SiPMs used in the production of the AHCAL “engineering prototype”.

Primary author: Dr MUNWES, Yonathan (Heidelberg University)

Presenter: Dr MUNWES, Yonathan (Heidelberg University)

Session Classification: Large Scale Characterization and Reliability

Track Classification: Large Scale Characterization and Reliability

Contribution ID: **13** Type: **Talk**

SiPMs as Photo-Sensors in a Liquid Xenon Time Projection Chamber (TPC)

Friday, 15 June 2018 09:55 (20 minutes)

Liquid Xenon Time Projection Chambers (LXeTPC) are used in rare event searches for Dark Matter, neutrinoless double beta decay or in applications as Compton telescope or camera where the noble medium offers a combination of scintillation light and ionization that can be used to build large, uniform 3D position sensitive detectors. We test the feasibility of replacing the common used photomultiplier tubes (PMTs) by SiPMs in such a detector. As most commercially available SiPMs are not sensitive to the scintillation light of xenon in the VUV regime at 178nm, a special construction of the SiPMs, or a special treatment of commercial devices is neccesary. We operate a test stand to observe the operational stability and to measure the sensitivity, crosstalk and afterpulse properties of three VUV-sensitive SiPM samples in liquid xenon at -100℃.
A 1" PMT is operated simultaneously for reference while scintillation light is provided by a ^{241}Am source immersed in liquid xenon.

Primary author: Mr HILS, Christopher (Mainz University)

Co-authors: Dr BROGNA, Andrea (PRISMA Detektor Labor, Johannes Gutenberg-Universität Mainz); Mr WENZ, Daniel (Johannes Gutenberg-Universität Mainz); Dr ALFONSI, Matteo (Johannes Gutenberg-Universität Mainz); Prof. OBERLACK, Uwe (Johannes Gutenberg-Universität Mainz)

Presenter: Mr HILS, Christopher (Mainz University)

Session Classification: Cryogenic Properties

Track Classification: Cryogenic Properties

Contribution ID: **14** Type: **Talk**

Review on SiPM Readout Circuitry

Thursday, 14 June 2018 11:45 (30 minutes)

Review of SiPM model, front end circuits for SiPM readout, digitization techniques, System-On-chip solution and new trends.

Primary author: Dr GASCON, David (University of Barcelona)

Presenter: Dr GASCON, David (University of Barcelona)

Session Classification: Electrical Properties

Track Classification: Electrical Properties

Contribution ID: **15** Type: **Talk**

Study of Evolution of MPPC Properties Induced by Neutrons

Thursday, 14 June 2018 09:50 (20 minutes)

During my talk I would like to show and discuss results of evolution of MPPC properties during irradiation by neutrons. Two models of Multi-Pixel Photon Counters: S13360-3050CS and S13360-6050CS from Hamamatsu with different size (3x3 mm^{-2} and 6x6 mm^{-2}, respectively) and the same subpixel pitch size (50 μm) were irradiated by neutrons from two sources: PuBe source with continuous energy spectrum up to 11~MeV and mono-energetic 4.8~MeV neutrons produced in (d,d) reaction. For both cases the neutron fluence/(MPPC size) in a range of 10^9 mm^{-2} was achieved. The observed changes of current-voltage characteristics and breakdown voltage evolution for neutron fluence increase will be shown . The energy resolution degradation of 662 keV gamma line from ^{137}Cs, obtained for non-irradiated GAGG scintillator, as a function of neutron fluence will be presented. Finally, calculated contribution of noise component in measured energy resolution will be also shown.

Primary author: Dr MIANOWSKI, Slawomir (National Centre for Nuclear Research)

Co-authors: Mr BASZAK, Jaroslaw (Hamamatsu Photonics Deutschland GmbH); Prof. MOSZYNSKI, Marek (National Centre for Nuclear Research); Dr SIBCZYNSKI, Pawel (National Centre for Nuclear Research); Dr SZCZESNIAK, Tomasz (National Centre for Nuclear Research); Dr GLEDENOV, Yuri (Joint Institute for Nuclear Research, Frank Laboratory of Neutron Physics); Dr KOPATCH, Yuri (Joint Institute for Nuclear Research, Frank Laboratory of Neutron Physics); Mrs MIANOWSKA, Zuzanna (National Centre for Nuclear Research)

Presenter: Dr MIANOWSKI, Slawomir (National Centre for Nuclear Research)

Session Classification: Radiation Hardness

Track Classification: Radiation Hardness

Contribution ID: **16** Type: **Poster**

Camera Prototype Performances and Calibration for the Cherenkov Telescope Array

The Cherenkov Telescope Array (CTA) will comprise a sub-array of up to 70 small sized telescopes (SSTs) in the southern array. Different implementations are proposed for the SSTs but all of them feature Silicon Photo-Multpliers (SiPM), which can guarantee excellent performance and allow observation also under moonlight increasing the observational time and then physics reach. The SST-1M project, a 4 m-diameter Davies Cotton telescope with 9 degrees FoV and a 1296 pixels SiPM camera (hexagonal SiPM S10943-2832(X)), is designed to meet the requirements of the next generation of ground based gamma-ray observatory CTA in the energy range above 3 TeV.

The large scale production of the telescopes imposes a fully automated calibration strategy of SiPM cameras. A dedicated hardware, the Camera Test Setup (CTS), has been designed and built for such purpose. For each camera pixel, CTS is equipped with two LEDs, one operated in pulsed mode to emulate signal and one in continuous mode to emulate night sky background.

In this work, a special emphasis will be given to the commissioning results but also to the latest performance validation tests such as charge resolution, trigger efficiency together with Monte-Carlo comparison. These results will allow to validate the camera prototype in laboratory for the second observation campaign with the telescope prototype foreseen this Summer in Krakow.

Primary author: ALISPACH, Cyril (Université de Genève)

Co-authors: Dr BARBANO, Anastasia (Université de Genève); Dr NAGAI, Andrii (University of Geneva, DPNC); Dr DELLA VOLPE, Domenico (Université de Genève); Dr AL SAMARAI, Imen (Université de Genève); Dr HELLER, Matthieu (Université de Genève); Prof. MONTARULI, Teresa (Université de Genève); NJOH EKOUME, Théodore Rodrigue (Université de Genève); ISAAC, Troyano-Pujadas (Université de Genève); Dr RENIER, Yves (Université de Genève)

Presenter: ALISPACH, Cyril (Université de Genève)

Track Classification: Large Scale Characterization and Reliability

Contribution ID: **18** Type: **Talk**

Investigation of a 10-Channel SiPM Module in a Neutron Beam at NPI of ASCR

A readout module developed and produced in LHEP JINR (Dubna, Russia) containing 10 channels of scintillators, SiPM photo-sensors, amplifiers and high voltage control circuit was investigated for two years at NPI of ASCR (Rez, Czech Republic) at a neutron source with a spectrum of 6-35 MeV.
The module was investigated for study the possibilities of SiPM applications in position-sensitive neutron detectors and for the study of radiation hardness of such photo-sensors in harsh environment of experiments at future accelerators.
Three experiments were carried out during 2015-2017. A period of a few months was allowed after every irradiation to reach maximum of self-annealing effect. After irradiation to the total fluence of about 10E13 n/cm2 all SiPMs became inoperable due to drastically increased noise and decreased light sensitivity, however amplifiers and bias voltage circuitries still operate reliably.
After final experiment all SiPMs were removed from the module and investigated in laboratory of NPI. Main attention was devoted to study of distribution of electric field within SiPM internal structure and changing of ratio of mean density of defects to mean time of life of minority carriers. Electric field distributions for 10 SiPMs were obtained and compared to the results before irradiation. Analysis of changing of electric field distribution within SiPM volume and character of behavior of ratio of mean density of defects to effective time of life of minority carriers show that the main reason of increased noise is a result of changing of electric field distribution near surface, that decrease the efficiency of collection of charge of minority carriers that were generated by short wave light.

Primary author: Dr KUSHPIL, Vassily (NPI of ASCR)

Co-authors: Dr KHRENOV, A (JINR); Dr KUGLER, Andrej (Nuclear Physics Institute CAS); Dr ISUPOV, S (JINR); Dr PIYADIN, S (JINR); Dr REZNIKOV, Sergey (JINR); Dr KUSHPIL, Svetlana (NPI of ASCR); Prof. LADYGIN, Vladimir (Veksler and Baldin Laboratory of High Energy Physics(JINR-VBLHEP))

Presenter: Dr KUSHPIL, Vassily (NPI of ASCR)

Track Classification: Radiation Hardness

Contribution ID: **19** Type: **Poster**

Electric Fields in the SiPM Active Volume by Volt-Farad Characteristics Analysis

The aim of this study is to understand a changing of SiPM structure after irradiation. We compared profile of electric field in SiPM (KETEK) active region for ten not-irradiated and irradiated detectors. Standard method of measurement of C-V characteristics was applied using two configurations (serial and parallel circuit) to exclude an influence of the serial resistance. Dependencies of capacitance on frequency was studied in range from 10 to 1000 KHz. For non irradiated detectors we detected in CV characteristics local instability basically connected with accumulation of charge on boundary optical isolator-silicon. Also hysteresis of C-V characteristics was detected. For irradiated detectors also local instability was visible, but hysteresis of C-V characteristics was not detected. The results demonstrate that applied method can be used for relative analysis how SiPM active region properties changed after irradiation.

Primary author: Dr KUSHPIL, Vassily (NPI of ASCR)

Co-authors: Dr KUGLER, Andrej (Nuclear Physics Institute CAS); Dr KUSHPIL, Svetlana (NPI of ASCR)

Presenter: Dr KUSHPIL, Vassily (NPI of ASCR)

Track Classification: Electrical Properties

Contribution ID: **20** Type: **Talk**

Studies of SiPM Behavior under Continuous Light Illumination

Tuesday, 12 June 2018 11:35 (20 minutes)

This work reports on the behavior of the Silicon Photomultiplier (SiPM) detector under continuous light illumination. Large area ~ 1 cm^2 hexagonal SiPM S10943-2832(X) produced by Hamamatsu HPK for the single mirror small size telescope SST-1M (one of the projects proposed for the implementation of the small size telescopes of the Cherenkov Telescope Array CTA) has been used for studies. The bias circuit of the SiPM contains a resistor meant to prevent the sensor from drawing high current and cut high frequency electronic noise. However, this resistor together with SiPM quenching resistor introduce a voltage drop during light detection at the SiPM input, impacting the stability of its operation. Electrical (i.e. breakdown voltage, gain, pulse amplitude), noise (dark count rate and optical crosstalk) and optical (i.e. photon detection efficiency) parameters were studied under five different light illumination levels from 3 MHz up to 1 GHz of photons per SiPM micro-cell at room temperature (T = 25 ^{0}C). The experimental results were compared with toy Monte Carlo simulation. From our studies, a model have been developed in order derive the parameters needed to account for it at the data analysis level. Also, a solution is proposed to compensate for the voltage drop and will be presented.

Primary author: Dr NAGAI, Andrii (University of Geneva)

Co-authors: Dr BARBANO, Anastasia (Universite de Geneve); Dr HAUNGS, Andreas (KIT—Karlsruhe Institute of Technology); ALISPACH, Cyril (Universite de Geneve); Dr STROM, Derek (MIT—Max-Planck-Institute for Physics); Dr DELLA VOLPE, Domenico (Universite de Geneve); Dr AL SAMARAI, Imen (Universite de Geneve); TROYANO-PUJADAS, Isaac (Universite de Geneve); Dr HENJES-KUNST, Katharina (DESY—Deutsches Elektronen-Synchrotron); Dr HELLER, Matthieu (Universite de Geneve); Dr MIRZOYAN, Razmik (MIT—Max-Planck-Institute for Physics); Dr MONTARULI, Teresa (Universite de Geneve); Dr BERGHOEFER, Thomas (DESY—Deutsches Elektronen-Synchrotron); EKOUME, Théodore (Universite de Geneve); Dr RENIER, Yves (Universite de Geneve)

Presenter: Dr NAGAI, Andrii (University of Geneva)

Session Classification: Miscellaneous and Others

Track Classification: Electrical Properties

Contribution ID: **21** Type: **Talk**

Method and Experimental Setup to Measure SiPM Saturation

Thursday, 14 June 2018 17:10 (20 minutes)

We present the experimental method and a corresponding setup to measure the response of SiPM as a function of incoming light intensity. In particular, the saturation behavior is investigated. The method introduces a calibrated quantity to measure the incoming number of photons independently of the photon detection efficiency and the optical crosstalk of the SiPM. In this way, different sensors operated at different bias voltages can be compared. The experimental setup is based on a picosecond laser diode with programmable intensity. Fiber optics is used to split the beam in order to measure the laser intensity with a reference diode in parallel to the SiPM. A XYZ-positioning system in combination with an engineered diffuser is used to ensure a uniform exposure of the SiPM surface. The SiPM signal is read out with a charge-to-digital converter synchronized to the laser pulses. The measured response curves for several SiPM are presented and compared to different response models.

Primary author: Mr KRAUSE, Sascha (Mainz University)

Co-authors: Dr BROGNA, Andrea S. (Detector Laboratory, PRISMA Cluster of Excellence, Johannes Gutenberg University Mainz, Staudingerweg 9, 55128 Mainz, Germany); Mr BERNHARD, Peter (Detector Laboratory, PRISMA Cluster of Excellence, Johannes Gutenberg University Mainz, Staudingerweg 9, 55128 Mainz, Germany); Dr WEITZEL, Quirin (Detector Laboratory, PRISMA Cluster of Excellence, Johannes Gutenberg University Mainz, Staudingerweg 9, 55128 Mainz, Germany); Mr DEGELE, Reinhold (Institute of Physics, Johannes Gutenberg University Mainz, Staudingerweg 7, 55128 Mainz, Germany); Prof. TAPPROGGE, Stefan (Institute of Physics, Johannes Gutenberg University Mainz, Staudingerweg 7, 55128 Mainz, Germany); Dr SCHÄFER, Ulrich (Institute of Physics, Johannes Gutenberg University Mainz, Staudingerweg 7, 55128 Mainz, Germany)

Presenter: Mr KRAUSE, Sascha (Mainz University)

Session Classification: Nonlinearity and Saturation

Track Classification: Nonlinearity and Saturation

Contribution ID: **22** Type: **Talk**

Analytical Approach to Fundamental Properties of SiPMs at Cryogenic Temperatures

Friday, 15 June 2018 10:15 (20 minutes)

Silicon photomultipliers are important in liquid argon detectors of short-baseline neutrino oscillation experiments. Furthermore, in spin-polarized proton and deuteron targets of photoproduction experiments, SiPMs are used for recoil identification down to absolute zero temperature.
For these and future applications a characterization over the full cryogenic temperature range is obligatory.

Based on physical principals, an analytical description of the temperature dependence of breakdown voltage and single-cell capacity was developed. It enables constant gain control from room down to liquid helium temperature.

To calculate the number of ionizations in the depletion layer and thereby the avalanche triggering probability, Wolff's theory for high electrical fields was adopted. This approach lead to predictions of the photon detection efficiency and the crosstalk probability.

Finally, the single-cell signal-to-noise ratio was investigated to find the optimum operational temperature. All these calculations were supported by analyzes of pulse height spectra and forward as well as reverse characteristic curve measurements.

Primary author: Mr BIROTH, Maik (Mainz University)

Co-authors: Dr THOMAS, Andreas (Institut für Kernphysik, Mainz); Prof. ACHENBACH, Patrick (Johannes Gutenberg-Universität Mainz(UMz)); Dr LAUTH, Werner (Institut für Kernphysik, Mainz)

Presenter: Mr BIROTH, Maik (Mainz University)

Session Classification: Cryogenic Properties

Track Classification: Cryogenic Properties

Contribution ID: **23** Type: **Talk**

Direct Measurement of Optical Crosstalk in SiPMs Using Light Emission Microscopy

Wednesday, 13 June 2018 16:00 (20 minutes)

Silicon Photomultipliers (SiPMs) are attractive light detectors for high energy and astroparticle physics experiments. They are compact in size, have fast (few ns) response time, operate at lower voltage compared to classical photomultiplier tubes, are insensitive to magnetic fields, and the newer samples offer photon detection efficiencies of > 40%. The optical cross-talk effect, whereby light emitted during the initial avalanche breakdown process may be absorbed by neighboring cells causing additional breakdowns, can degrade the performance of SiPMs. We describe ongoing work at the Max Planck Institute for Physics in Munich where we constructed a light emission microscopy setup to directly measure the emission due to optical cross-talk in SiPMs.

This method provides the most precise measurement of cross-talk as well as allows one to inspect and directly visualize the existence of hot cells, which could over-proportionally contribute to the noise of a SiPM chip. We will report on the comparison of the cross-talk measurements by using the method of light emission microscopy and the traditional "blind" measurement based on amplitude measurements. Also, by using the light emission microscopy, we are exploring the possible influence of the topology of a SiPM on the cross-talk; this could help developing methods for further reducing the cross-talk. We present an overview of our setup and measurements performed.

This work is part of SENSE, a roadmap for the ideal low light level sensor development and funded by the European Commission under Future and Emerging Technologies Open Coordination and Support Action.

Primary authors: Dr STROM, Derek (MPI Physik); Dr BESENRIEDER, Jürgen (Max Planck Institute for Physics); Dr MIRZOYAN, Razmik (Max Planck Institute for Physics)

Presenter: Dr STROM, Derek (MPI Physik)

Session Classification: Nuisance Parameters

Track Classification: Nuisance Parameters

Contribution ID: **24** Type: **Talk**

Neutron Radiation and Recovery Studies on SiPMs

Thursday, 14 June 2018 09:10 (20 minutes)

SiPM lost its performance characteristics when exposed to high dose of neutrons. However, the distinct hallmark of SiPMs, low dark count and excellent photon-number-resolving capability, can be recovered by thermal annealing. Several Hamamatsu and FBK series SiPMs are characterized before and after exposure of up to 1010 neutron/cm2 dosage using a 14 MeV neutron generation source. Collectively, we established that the typical orders of magnitude increase in dark current upon neutron irradiation can be lowered substantially after processing them with a novel thermal annealing procedure, and single-photon detection are to some extent recovered. Moreover, we found no significant difference on neutron damaged behavior when SiPMs are irradiated at room or liquid nitrogen temperatures.

Primary author: TSANG, Thomas (BNL)

Presenter: TSANG, Thomas (BNL)

Session Classification: Radiation Hardness

Track Classification: Radiation Hardness

Contribution ID: **26** Type: **Talk**

SiPM Experience from more than Six Years Operation of FACT

Tuesday, 12 June 2018 11:55 (20 minutes)

The First G-APD Cherenkov Telescope (FACT) is pioneering the usage of SiPM in Imaging Atmospheric
Cherenkov Telescopes. Its camera consists of 1440 SiPM, each coupled to a solid light-guide and an
individual read out. In October 2011, the camera was installed in a refurbished telescope structure with a mirror area of 9.5m^2 at the Canary island La Palma, and successful data taking started within few hours. Since then, FACT is taking data whenever observation conditions permit, with the primary goals of gaining long-term experience with operation of SiPM under harsh conditions
as well as monitoring a set of variable extragalactic high energy gamma-ray sources.

For the science goal, stable performance of the photo detectors is crucial and therefore has been studied in great detail. Special care has been taken with regards to keep the gain of the SiPM constant
despite their temperature varying by more than 25 deg. This is reached through implementation of a feedback system that regularly adjusts the applied voltage to the sensor temperature as well as
to the current drawn due to varying night-sky brightness.

Several independent long term measurements were conducted to analyze and verify SiPM stability. As example, dark count spectra, which also make for an excellent self calibration mechanism, were used to study and model the temperature dependencies. Trigger thresholds are adjusted to the night-sky background by measuring the current drawn by individual groups of pixels.

With these methods, the performance of the FACT camera is kept stable without the need for any external calibration device. While each of the 1440 SiPM has collected a charge of more than ???C so far, there is no indication of any ageing or any other sensor-related problems. The exceptional reliability of the system allows to operate FACT as the only Cherenkov telescope so far in a fully robotic way.

In this talk, the results of the long term performance studies and experience gained from the six years operation of SiPM will be presented.

Primary author: Mr NEISE, Dominik (ETH Zurich)

Presenter: Mr NEISE, Dominik (ETH Zurich)

Session Classification: Miscellaneous and Others

Contribution ID: **27** Type: **Talk**

PDE Measurement for Digital SiPMs: Comparison Between Pulsed and Continuous Light Methods

Tuesday, 12 June 2018 09:30 (20 minutes)

The information extracted from the characterization of Silicon Photomultipliers (SiPM) is a key element to their future technological development. These experimental data allow SiPM manufacturers to refine their devices and make them more efficient. As there are several methods of characterization across the scientific community, it is essential to define measurement standards to obtain reliable and comparable results. One important characteristic that defines SiPMs is the Photon Detection Efficiency (PDE). In the literature, the characterization of PDE is done in three different ways : the photocurrent method [Bonanno 2009], the pulsed-light counting method [Otte 2006] and the continuous-light counting method [Piemonte 2012]. Despite minor differences, each approach is able to determine the absolute PDE with a good degree of reliability and repeatability [Zappalà 2016]. However, for special type of SiPMs some of the aforementioned methods could be more appropriate. For example, digital SiPMs are built most of the time following an application-specific architecture where data is formatted in situ and transfered digitally. We elaborate on the distinctions between each method and compare their applicability to the measurement of absolute PDE for digital SiPM.

Primary author: VACHON, Frédéric (University of Sherbrooke)

Co-authors: NOLET, Frédéric (University of Sherbrooke); Prof. DAUTET, Henri (University of Sherbrooke); Prof. PRATTE, Jean-François (University of Sherbrooke); PARENT, Samuel (University of Sherbrooke); Prof. CHARLEBOIS, Serge A. (University of Sherbrooke)

Presenter: VACHON, Frédéric (University of Sherbrooke)

Session Classification: Photon Detection Efficiency

Track Classification: Photon Detection Efficiency

Contribution ID: **28** Type: **Talk**

Statistics and Models of SiPM Nonlinearity and Saturation

Thursday, 14 June 2018 16:10 (20 minutes)

SiPM is an inherently nonlinear detector. Nonlinearity and saturation effects are originated from excess random losses of photon detection events due to a limited number of SiPM cells and non-instant recovery of the cells. From a statistical point of view, SiPM nonlinearity and saturation could be completely characterized by a probability distribution of a SiPM response in a required range of incident light signals. Partial characterization could be provided by a mean and variance of the response distribution, and it is the most important practical case for SiPM calibration and evaluation of the SiPM energy resolution beyond a linear operating range.
Known analytical models of the SiPM probability distribution could not simultaneously combine key factors affecting SiPM nonlinearity and saturation, namely, a limited number of cells, recovery process, crosstalk, and afterpulsing. Therefore, corresponding approximate expressions for the mean and sometimes also for the variance are proposed and used for the calibration. However, such combined expressions could hardly be associated with solid probabilistic grounds.
The report presents an overview of the state-of-art and modern developments in statistics and models of the SiPM nonlinearity and saturation as well as some practical recommendations on their applicability for calibration and energy resolution related applications of the SiPM.

Primary author: Dr VINOGRADOV, Sergey (Lebedev Physical Institute)

Presenter: Dr VINOGRADOV, Sergey (Lebedev Physical Institute)

Session Classification: Nonlinearity and Saturation

Track Classification: Nonlinearity and Saturation

Contribution ID: **29** Type: **Talk**

Statistical Modeling of SiPM Noise

Wednesday, 13 June 2018 14:20 (20 minutes)

SiPM noises are very complicated in general due to a presence of correlated processes, namely, crosstalk and afterpulsing. From a statistical point of view, SiPM noises are stochastic processes contributing to a total SiPM response charge. The charge is a random variable which could be completely characterized by its probability distribution. Partial characterization of the SiPM response by its mean and variance is the most important practical case. However, discrimination and analysis of specific noise contributions in the total response and optimization of SiPM operations appear to be rather uncertain because of their correlations (the means and variances could not be summed up for dependent variables) and their different dependencies on a bias voltage (relative weights are changeable).
Excess noise factor (ENF) approach extends a well-known measure of an avalanche multiplication noisiness to any stochastic processes especially initiated by a non-random unit input quantity (single electron, single-fired cell). Therefore, all specific noise contributions are represented, distinguished, and analyzed by corresponding ENFs, and the total response ENF is approximately equal to a product of the specific ENFs.
The report presents an overview of statistics and models related to the specific ENFs of the gain, dark counts, crosstalk, and afterpulsing as well as some practical recommendations on their applicability for analysis, optimization, and energy resolution related applications of the SiPM.

Primary author: Dr VINOGRADOV, Sergey (Lebedev Physical Institute)

Presenter: Dr VINOGRADOV, Sergey (Lebedev Physical Institute)

Session Classification: Nuisance Parameters

Track Classification: Nuisance Parameters

Contribution ID: **30** Type: **Talk**

Problems in the Appearance of SiPMs: A Brief History and Perspectives

Monday, 11 June 2018 10:40 (30 minutes)

A brief history on the development of the micropixel avalanche photodiodes – MAPDs (or silicon photomultipliers SiPMs) is presented since the 80s years of the last century. It is shown that the main problem in creation of APDs with high gain was appearance the local uncontrolled breakdowns in the p-n junctions. The following topics concerning the stages of developments of the modern SiPMs are discussed:
• Two different approaches in development of APDs: improvement of technology and search for new designs to avoid the local breakdowns.
• Differences in performance of traditional SPAD devices and MAPDs.
• A long way from APD to MAPDs via the avalanche MIS and MRS structures.
• Three advanced designs of MAPDs.
• A new avalanche detector – micropixel avalanche phototransistor.

Primary author: Prof. SADYGOV, Ziraddin (JINR)

Presenter: Prof. SADYGOV, Ziraddin (JINR)

Session Classification: Opening Session

Track Classification: Miscellaneous and others

Contribution ID: **31** Type: **Talk**

Prototyping of Large-Size SiPM Based Detector Modules in IACTs

Tuesday, 12 June 2018 12:15 (20 minutes)

MAGIC is a system of two imaging atmospheric Cherenkov telescopes (IACTs) operated by an international collaboration at the Canary island of La Palma. Like all large-size IACTs (>12 m diameter), MAGIC uses imaging cameras consisting of more than a thousand photomultiplier tubes (PMTs). The modular assembly of the camera and the design of its structure offer the possibility to install a maximum of six additional prototype detector modules next to the PMTs, at the vertexes of the hexagonal structure and to operate them in parallel with the camera. We developed three silicon photomultiplier (SiPM) based detector modules using SiPMs from Hamamatsu, SensL and Excelitas. Their purpose is to investigate the potential use of SiPMs in large-size IACTs.

The capacitance of SiPMs limits the size (speed and gain) of the active area of a single sensor. Therefore we use a matrix of up to nine 6x6 mm² SiPMs to achieve an active area comparable to a 1-inch PMT and actively sum the individual signals to a composite output.
The first SiPM prototype was installed in 2015 in one of the open corners in the MAGIC-1 camera. In 2017 two second-generation modules, with improved photon detection efficiency and fill factor, were installed. All three SiPM modules are integrated into the standard data taking procedure, providing data for a performance comparison during real telescope operations.

SiPM detector modules were calibrated using single-photoelectron spectra and the F-factor (excess-noise) calibration method. Artificial light pulses as well as real Cherenkov light from air showers, are used for our performance comparison. Details of the methods will be presented.

Primary authors: Mr HAHN, Alexander (MPI Physik); DETTLAFF, Antonios (Max-Planck-Institut für Physik, Munich, Germany); Dr MAZIN, Daniel (Max-Planck-Institut für Physik, Munich, Germany and Institute for Cosmic Ray Research, Tokyo, Japan); FINK, David (Max-Planck-Institut für Physik, Munich, Germany); Prof. TESHIMA, Masahiro (Max-Planck-Institut für Physik, Munich, Germany and Institute for Cosmic Ray Research, Tokyo, Japan); Dr MIRZOYAN, Razmik (Max-Planck-Institut für Physik, Munich, Germany)

Presenter: Mr HAHN, Alexander (MPI Physik)

Session Classification: Miscellaneous and Others

Track Classification: Large Scale Characterization and Reliability

Contribution ID: **33** Type: **not specified**

PDE Discussion & Summary

Tuesday, 12 June 2018 10:30 (15 minutes)

Presenter: OTTE, A. Nepomuk (Georgia Tech)

Session Classification: Photon Detection Efficiency

Track Classification: Photon Detection Efficiency

Contribution ID: **34** Type: **Talk**

Experimental SiPM Parameter Characterization from Avalanche Triggering Probabilities

Wednesday, 13 June 2018 16:20 (20 minutes)

Efficient and low noise detection of vacuum ulta-violet (VUV) scintillation photons is critical for the nEXO experiment to achieve its projected sensitivity to zero-neutrino double beta decays. VUV SiPMs are being developed by Fondazione Bruno Kessler and Hamamatsu Photonics to fulfill nEXO's requirements. It is desirable to operate the SiPMs at high over-voltage in order to achieve maximum efficiency and single photon sensitivity while minimizing electronics power dissipation. However, the over-voltage is limited by cross-talk and after-pulse that eventually drive the detector performances. In order to understand the over-voltage dependence in detail, we have built a new model by extracting the electron and hole avalanche triggering probabilities using VUV and Infra-red light sources. Then we show that we can describe the over-voltage dependence of the dark noise, after-pulsing and cross-talk rates using a minimum set of parameters and extract the relative contribution of electrons vs holes for each process. We also show that this model predicts the behavior of the IV (current-voltage) curve. The data that are used in this analysis are for Hamamatsu VUV4 at temperatures ranging from -40 to -110C. In this talk, we will also review a method for extracting after-pulsing rates and discuss a new concept for probing the behavior of charge carrier produced deep in the silicon using two-photon ionization.

Primary authors: Prof. RETIÈRE, Fabrice (TRIUMF); Mr GALLINA, Giacomo (TRIUMF); Mr KROEGER, Jens (TRIUMF); Dr WARD, Mark (TRIUMF); Dr GIAMPA, Pietro (TRIUMF)

Presenter: Mr GALLINA, Giacomo (TRIUMF)

Session Classification: Nuisance Parameters

Track Classification: Nuisance Parameters

Contribution ID: **35** Type: **Talk**

SiPMs in Astroparticle Physics

Monday, 11 June 2018 11:40 (45 minutes)

Presenter: Dr MIRZOYAN, Razmick (MPI Physik)

Session Classification: Review Talks

Contribution ID: **37** Type: **Talk**

Broadcom

Monday, 11 June 2018 14:45 (30 minutes)

Presenter: Mr PIEMONTE, Claudio (Broadcom)

Session Classification: SiPM Producers

Contribution ID: **38** Type: **Talk**

Timing Properties Introduction

Wednesday, 13 June 2018 09:00 (10 minutes)

Presenter: Dr GUNDACKER, Stefan (CERN)

Session Classification: Timing Properties (FAST Action WG3 Meeting)

Track Classification: Timing Properties

Contribution ID: **41** Type: **Talk**

Techniques for Characterizing Light Source Emission Statistics at Single-Photon Level

Tuesday, 12 June 2018 10:10 (20 minutes)

Characterizing the underlying processes contributing to a light field has wide ranging applications throughout physics. For instance, knowledge of the mode structure is vital for engineering sources of nonclassical light that minimize loss and decoherence of quantum information due to coupling to unwanted modes. Photon-number statistics are used to characterize a variety of optical systems including single-photon sources [1–3], cavity QED [4,5], and lasers [6,7].
The aim of this talk is to review the techniques, in particular the ones investigated in INRIM (Italy), for characterizing the statistical emission of single-photon or low-light sources [8-11] and eventually their mode structure reconstructions [12]. This is very important in the context of photon detection efficiency (PDE) characterization of single-photon sensitive detector like, SPADs and silicon photomultipliers (SiPM). The PDE measurements of SiPM are generally based on light sources that are assumed presenting Poissonian statistics in the photon emission, but this has to be properly tested.
Furthermore, a validation of the measurement techniques is on going thanks to pilot comparisons lead by INRIM between European national metrological institutions on the measurement of the second-order Glauber auto-correlation function in the VIS-NIR and at telecom wavelength for both pulsed and CW sources. These comparisons are carried on under the European metrological project EMPIR 14IND05 “MIQC2” [13], from the skills developed and results obtained in the previous project on metrology at single photon level, namely IMERA+ qu-Candela [14], EMRP IND06 “MIQC” [15], and EMRP EXL05 “SIQUTE” [16].

[1] C. Kurtsiefer, S. Mayer, P. Zarda, and H. Weinfurter, Phys. Rev. Lett. 85, 290 (2000).

[2] D. Press, S. Gotzinger, S. Reitzenstein, C. Hofmann, A. Loffler, M. Kamp, A. Forchel, and Y. Yamamoto, Phys. Rev. Lett. 98, 117402 (2007).

[3] W. Schmunk, M. Gramegna, G. Brida, I. P. Degiovanni, M. Genovese, H. Hofer, S. Kuck, L. Lolli, M. G. A. Paris, S. Peters, M. Rajteri, A. M. Racu, A. Ruschhaupt, E. Taralli, and P. Traina, Metrologia 49, S156 (2012).

[4] M. Aßmann, F. Veit, M. Bayer, M. van der Poel, and J. M. Hvam, Science 325, 297 (2009).

[5] M. Hennrich, A. Kuhn, and G. Rempe, Phys. Rev. Lett. 94, 053604 (2005).

[6] D. Elvira, X. Hachair, V. B. Verma, R. Braive, G. Beaudoin, I. Robert-Philip, I. Sagnes, B. Baek, S. W. Nam, E. A. Dauler, I. Abram, M. J. Stevens, and A. Beveratos, Phys. Rev. A 84, 061802 (2011).

[7] M. Aßmann, F. Veit, M. Bayer, C. Gies, F. Jahnke, S. Reitzenstein, S. Hofling, L. Worschech, and A. Forchel, Phys. Rev. B 81, 165314 (2010).

[8] C.J. Chunnilall, I. P. Degiovanni, S. Kück, I. Müller, A. G. Sinclair, Optical Engineering 53 (8), 081910 (2014)

[9] E. Moreva, P. Traina, J. Forneris, I.P. Degiovanni, et al., Physical Review B 96 (19), 195209 (2017)

[10] I.P. Degiovanni, S. Polyakov, A. Migdall, H.B. Coldenstrodt-Ronge, I. A. Walmsley, F. N. C. Wong, “Single-Photon Generation and Detection” (Chapter 7: “Hybrid Detectors”), Elsevier Inc. 2013.

[11] D.G. Monticone, K. Katamadze, P. Traina, E. Moreva, J. Forneris, I. P. Degiovanni et al. Physical review letters 113 (14), 143602 (2014)

[12] E.A. Goldschmidt, F. Piacentini, I.R. Berchera, S.V. Polyakov, S. Peters, S. Kück, I.P. Degiovanni et al. Phys. Rev. A. 88 (1), 013822 (2013)

[13] http://empir.npl.co.uk/miqc2/

[14] http://www.quantumcandela.org/

[15] http://projects.npl.co.uk/MIQC/

[16] https://www.ptb.de/emrp/siqute-home.html

Primary author: Dr TRAINA, Paolo (INRIM)

Co-author: Dr DE GIOVANNI, Ivo Pietro (INRIM)

Presenter: Dr TRAINA, Paolo (INRIM)

Session Classification: Photon Detection Efficiency

Track Classification: Photon Detection Efficiency

Contribution ID: **43** Type: **not specified**

Nonlinearity and Saturation Introduction

Thursday, 14 June 2018 16:00 (10 minutes)

Presenter: Dr VINOGRADOV, Sergey (Lebedev Physical Institute)

Session Classification: Nonlinearity and Saturation

Track Classification: Nonlinearity and Saturation

Contribution ID: **44** Type: **not specified**

Nonlinearity and Saturation Discussion & Summary

Thursday, 14 June 2018 17:30 (20 minutes)

Presenter: Dr VINOGRADOV, Sergey (Lebedev Physical Institute)

Session Classification: Nonlinearity and Saturation

Contribution ID: **47** Type: **Talk**

Noise Sources in SiPM

Wednesday, 13 June 2018 14:00 (20 minutes)

Presenter: Dr GOLA, Alberto (FBK)

Session Classification: Nuisance Parameters

Contribution ID: **48** Type: **Talk**

SiPM Noise Measurements with Waveform Analysis

Wednesday, 13 June 2018 14:40 (20 minutes)

Presenter: Mr ENGELMANN, Eugen (KETEK)

Session Classification: Nuisance Parameters

Contribution ID: **49** Type: **not specified**

Nuisance Parameters Discussion

Wednesday, 13 June 2018 15:00 (30 minutes)

Presenter: Dr GOLA, Alberto (FBK)

Session Classification: Nuisance Parameters

Contribution ID: **50** Type: **not specified**

Nuisance Parameters Discussion & Summary

Wednesday, 13 June 2018 17:20 (20 minutes)

Presenter: Dr GOLA, Alberto (FBK)

Session Classification: Nuisance Parameters

Contribution ID: **51** Type: **Talk**

Simulation of SiPM Noise

Wednesday, 13 June 2018 17:00 (20 minutes)

Presenter: Dr BREUER, Johannes (Siemens Healthineers)

Session Classification: Nuisance Parameters

Contribution ID: **52** Type: **Talk**

KETEK: Characterization of SiPMs for Large Scale Applications

Monday, 11 June 2018 16:45 (30 minutes)

-

Primary author: Mr ENGELMANN, Eugen (KETEK)

Presenter: Mr ENGELMANN, Eugen (KETEK)

Session Classification: SiPM Producers

Track Classification: Large Scale Characterization and Reliability

Contribution ID: **53** Type: **Talk**

Physics and Experimental Studies of SiPM Nonlinearity and Saturation

Thursday, 14 June 2018 16:30 (20 minutes)

Silicon Photomultiplier (SiPM) is often considered at the basic level as an array of Geiger mode APD cells which are connected in parallel, operate independently, and produce a sum of binary signals equal to number of fired cells. However, many specific effects make SiPM much more complicated device than just a collection of independent GM APDs.
Namely, during Geiger discharge and recovery of the SiPM cell a p-n junction potential drops down and turns back to its initial value resulting in non-binary response of the cell with loss of responsibility due to lower probability of avalanche triggering and lower gain in case of triggering. recovering. Correlated effects (crosstalk and afterpulsing) result in loss of independency of cell operations due to a random number of false events - fired cells.These effects are also sensitive to effective value of the cell potential thus being dependent on a state of the recovery process.
These simple factors are very important in considerations of SiPM nonlinearity and saturation as they lead to a quite complicated dependence of an output SiPM signal on input photons (SiPM response curve), especially for an arbitrary light pulse shape.
Generally, the response curve has three different parts determined by a number of impinging photons (photoelectrons) per cell. One can assume that the linear operating regime is characterized by the low number of photoelectrons per cell Npe « 1, the oversaturation appears at Npe » 1, and the nonlinear or saturated regime is between them.
It is obvious that the cell recovery process plays a key role in a behavior of the response curve for the saturated second and third regime in their dependence on light intensity. To understand it in detail, one should start from single cell studies and then takes into account all these effects in their interactions and complications associated with multi-cell operations of the SiPM.
Physics and experimental studies of the single-cell SiPMs and different types of SiPMs related to the nonlinearity and saturation will be presented.

Primary author: Dr POPOVA, Elena (MEPhI)

Presenter: Dr POPOVA, Elena (MEPhI)

Session Classification: Nonlinearity and Saturation

Track Classification: Nonlinearity and Saturation

Contribution ID: **54** Type: **Talk**

Hamamatsu

Monday, 11 June 2018 15:15 (30 minutes)

Presenter: Mr GHASSEMI, Ardavan (Hamamatsu)

Session Classification: SiPM Producers

Track Classification: Miscellaneous and others

Contribution ID: **55** Type: **Talk**

Characterization of Radiation Damaged SiPMs

Thursday, 14 June 2018 11:10 (20 minutes)

SiPMs with 4384 pixels of 15 μm x 15 μm produced by KETEK have been irradiated with reactor neutrons to fluences between 10^9 and 5 10^14 cm-2. After the irradiation C-V, I-V, and current transients with and without pulsed light have been performed at +20℃ and −30℃. No annealing, in addition to the annealing during the transport and the measurements, has been applied. Outside of the measurements the SiPMs were stored at −25℃
From the C–V measurements at 26 V, which were taken at 25 frequencies between 100 Hz and 2 MHz, the SiPM electrical parameters, the pixel capacitance, Cpix, the quenching resistance Rq and the capacitance Cq parallel to the quenching resistor, have been determined using a simple R–C model. It is found that the value of Cpix neither depends on dose nor on neutron fluence, whereas the value of Rq increases for fluences above 10^12 cm-2. As expected for a poly-Si resistor, Rq also increases with temperature. The frequency dependence of the measured complex resistance at high fluences shows effects of radiation-induced defects. The C–V measurements at a fixed frequency have been used to investigate the doping profile and electric field of the SiPM. Indications for a small decrease of the electric field in the vicinity of the p+n junction are found, which are attributed to donor (P) removal.
The I–V data without illumination are used to determine the breakdown voltage, Vbd. We note that for the SiPMs investigated, we found previously that the breakdown voltage determined from the I–V data is approximately 1 V higher than the voltage obtained by extrapolating the linear Gain–V relation to Gain = 1. We identified the latter with the turn-off voltage, Voff, the voltage at which the Geiger discharge stops. The method of the minimum of the Inverse Logarithmic Derivative, ILD, as well as a fit of the I–V data assuming a quadratic dependence of ILD on V are used to determine Vbd. For the non-irradiated and the SiPMs irradiated to low fluences, the ILD method gives a Vbd value, which is systematically higher by about 100 mV. For the fluence dependence of Vbd it is found that it is constant up to 5 10^12 cm-2 and then increases. The I–V data are also used to estimate the dependence of the Dark Count Rate, DCR, on voltage, fluence and temperature. The DCR increases by up to seven orders of magnitude with neutron irradiation. Using the concept of Pixel Occupancy, eta, the reduction with voltage of the dynamic range of the SiPM as a photo-detector is estimated. At the highest fluences the occupancy at low excess voltage is so high, that the SiPM is expected not be any more a useful photodetector.
By integrating the current-transients without illumination pulse-area spectra for gate widths of 15, 30, 45, 60 and 75 ns are obtained and their moments determined. From the variances the DCR as a function of excess voltage, neutron fluence and temperature is derived. The results are compared to the DCR results discussed above. An analysis of the uncertainty related to the difference of Vbd and Voff for the gain and of the excess noise factor, which could not be determined at high DCR, is presented.
From the current transients of the SiPM illuminated by a blue pulsed LED with a pulse width of ≈3 ns, the performance of the SiPMs as light detectors as a function of neutron fluence and temperature is determined. The number of photons, which was chosen to give about 100 Geiger discharges per pulse, is sufficiently high, so that signal and dark pulses are well separated. The results are compared to the results of the occupancy method discussed above.
The main emphasis of the talk is on the methods developed for characterizing the properties and performance of radiation-damaged SiPMs.

Primary author: Prof. KLANNER, Robert (Hamburg University)

Co-authors: Dr LOMIDZE, David (Hamburg University); Prof. GARUTTI, Erika (Hamburg University); Dr SCHWANDT, Joern (Hamburg University); CERIOLI, Sara (Hamburg University)

Presenter: Prof. KLANNER, Robert (Hamburg University)

Session Classification: Radiation Hardness

Track Classification: Radiation Hardness

Contribution ID: **56** Type: **not specified**

Conference Introduction

Monday, 11 June 2018 10:30 (10 minutes)

Presenter: Prof. OTTE, A. Nepomuk (Georgia Tech)

Session Classification: Opening Session

Contribution ID: **58** Type: **Talk**

FAST: Fast Advanced Scintillator Timing

Monday, 11 June 2018 17:35 (20 minutes)

Scintillator-based detectors have been very successful in high energy physics (HEP) calorimetry, medical imaging, and many other applications. In particular, the potential of such detectors to achieve precise timing information is of increasing importance for those applications. The demand to discriminate between closely spaced bunch trains in future highest luminosity accelerators and to deliver space points in addition to the traditional back-to-back line of response reconstruction algorithms of positron emission tomograph (PET), requires a further step in time resolution, i.e. below 100ps. The implications of such a radical improvement in time resolution come with dramatic benefits in many domains. HEP will profit from a significant increase in detection efficiency and the health sector from an unprecedented improvement in imaging quality and image reconstruction time. Such a 'paradigm' change, however, must go hand-in-hand with a similar break in the interdisciplinary domain of photon detection. Therefore, new expertise must be gained in the fields of scintillators, photodetectors, as well as electronics to develop ultrafast timing scintillator-based detectors.
The Trans Domain COST Action (FAST, Fast Advanced Scintillator Timing) aims to establish a multidisciplinary network that brings together European experts from academia and industry to ultimately achieve scintillator-based detectors with time precision better than 100ps and provides an excellent training opportunity for researchers interested in this domain. The FAST COST (Action TD1401) started on November 20 2014 and will end on November 19 2018. In this presentation we will present the FAST Action on its main achievements.

Presenter: Mr PIEMONTE, Claudio (Broadcom)

Session Classification: EU Projects

Contribution ID: **59** Type: **Talk**

Review on Cryogenic Applications

Wednesday, 13 June 2018 11:00 (45 minutes)

Presenter: RETIERE, Fabrice (TRIUMF)

Session Classification: Review Talks

Track Classification: Cryogenic Properties

Contribution ID: **60** Type: **Poster**

Integrated General Purpose SiPM Based Optical Module with High Dynamic Range

In this talk, we will present an integrated optical module based on SiPMs optimized for applications in plastic scintillator detectors. Hosting two 25 μm SiPMs in parallel, three independent pre-amplifier channels are necessary to exploit the full dynamic range of the SiPMs of about 10^6. Light guides increase the sensitive area which are optimized for the read-out of wavelength shifting fibers. The optical and electrical performance of the module has been characterized in detail in laboratory measurements. Prototypes have been installed and tested in scintillator detectors developed for AugerPrime, the upgrade of the Pierre Auger Observatory. We emphasize the importance of the large dynamic range and show results of dedicated measurements from the lab.

Primary authors: Mr SCHUMACHER, Johannes (RWTH Aachen University); Mr KEMP, Julian (RWTH Aachen University); Prof. BRETZ, Thomas (RWTH Aachen University)

Presenter: Mr SCHUMACHER, Johannes (RWTH Aachen University)

Track Classification: Nonlinearity and Saturation

Contribution ID: **61** Type: **Talk**

Effects of Neutron and Gamma Radiation on SiPMs

Thursday, 14 June 2018 10:50 (20 minutes)

The effects of radiation damage in SiPMs from gamma rays has been measured and compared with the damage produced by neutrons. SiPMs were exposed to 60Co gamma rays at the Solid State Gamma-Ray Irradiation Facility at Brookhaven National Lab and the Institute for Nuclear Research (Atomki) in Debrecen, Hungary. The gamma ray exposures ranged from 1 krad to more than 1 Mrad and the neutron exposures ranged from 109 n/cm2 to 1012 n/cm2. The main effect of gamma ray damage is an increase in the noise and leakage current in the irradiated devices, similar to what is seen from neutron damage, but the level of damage is considerably less at comparable high levels of exposure. In addition, the damage from gamma rays saturates after a few hundred krad, while the damage from neutrons shows no sign of saturation, suggestive of different damage mechanisms in the two cases. The change in optical absorption in the epoxy window of the SiPMs due to radiation was also measured, as well as the effect of thermal heating due to the increased dark current on the breakdown voltage. These various effects due to radiation and a comparison between neutrons as gammas are discussed in this paper, as well as discussion of the possible effects mechanisms for producing this damage in both cases.

Primary authors: Dr UJVARI, Balazs (University of Debrecen); Dr WOODY, Craig (BNL); Dr DAVID, Gabor (Stony Brook University); Mr STOLL, Sean (BNL)

Co-authors: Dr MANNEL, Eric (BNL); Dr KIERSTEAD, James (BNL); HAGGERTY, John (BNL)

Presenter: Mr STOLL, Sean (BNL)

Session Classification: Radiation Hardness

Track Classification: Radiation Hardness

Contribution ID: **62** Type: **Talk**

Metrological Characterisation of Single-Photon Avalanche Diodes

Thursday, 14 June 2018 14:45 (45 minutes)

Single-photon avalanche diodes (SPADs) are currently the most used detectors for the single-photon detection in many quantum technologies, such as quantum communication, quantum key distribution, quantum biology, etc. [1, 2]. The success of such technologies greatly depends on the performance of the single-photon detector used. In the last decade, the performance of such SPAD detectors, e.g. quantum efficiency, dead time, dark counts, gating rate, etc., has been significantly improved due to the great advances in new avalanche quenching technologies and cooling systems [2, 4]. Basically, two types of SPAD detectors are nowadays commercially available: gated and free-running SPAD detectors [5, 6]. In both cases, the metrological characterization of their optical parameters is essentially required to fully guarantee the reliability of the quantum detection system. Therefore, the PTB, and other National Metrological Institutes (NMIs), are putting great efforts in developing novel measurement methods and calibration facilities, which allow the traceable characterization of the optical parameters of these detectors by using reference standards [7, 8]. In this conference, the detailed metrological characterization of Si- and InGaAs- SPAD detectors including the measurement setup, traceability and uncertainty analysis will be presented.

Acknowledgment:
This work has been supported by EMPIR-14IND05 “MIQC2” (the EMPIR initiative is co-funded by the EUH2020 and the EMPIR Participating States).

[1] Robert H. Hadfield, “Single-photon detectors for optical quantum information applications”, Nature Photonics 3, 696–705 (2009)
[2] Damien Stucki, et al., “Photon counting for quantum key distribution with peltier cooled InGaAs/InP APDs”, Journal of Modern Optics, 48, Issue 13, 1967-1981 (2001)
[3] I. Prochazka, et. al., “Recent achievements in single photon detectors and their applications”, Journal of Modern Optic, 5, Issue 9-10 1289-1313 (2004)
[4] Jun Zhang, et al., “Advances in InGaAs/InP single-photon detector systems for quantum communication”, Light: Science & Applications, (2015)
[5] http://www.micro-photon-devices.com
[6] https://www.idquantique.com
[7] M. López, et al, “Detection efficiency calibration of single-photon silicon avalanche photodiodes traceable using double attenuator technique, Journal of Modern Optics 62, S21 – S27, 2015.
[8] G. Porrovecchio, et al., “Comparison at the sub-100 fW optical power level of calibrating a single-photon detector using a high-sensitive, low-noise silicon photodiode and the double attenuator technique”, Metrologia 53, 1115-1122 (2016).

Primary author: Dr LOPEZ, Marco (PTB)

Presenter: Dr LOPEZ, Marco (PTB)

Session Classification: Review Talks

Track Classification: Miscellaneous and others

Contribution ID: **63** Type: **Talk**

Application of SiPMs and MCP-PMTs in the PANDA PID detectors

Wednesday, 13 June 2018 11:45 (20 minutes)

PANDA is a hadron physics experiment at the FAIR facility at GSI which will employ a high intensity antiproton beam of up to 15 GeV/c to do high precision studies of, among others, objectives like charmonium spectroscopy and search for gluonic excitations. These measurements require a robust and compact PID system with excellent timing capabilities placed inside a magnetic field of $>$1 Tesla. For charged tracks above a Cherenkov threshold of $\beta > 0.68$ DIRC-type detectors will be used, while for slower particles time-of-flight (TOF) detectors were chosen.

Due to the harsh boundary conditions in the focal plane vicinity of the PANDA Cherenkov detectors (DIRC) microchannel-plate (MCP) PMTs were identified as the only suitable photon sensors. After solving a long-standing aging problem these devices are currently the best-performing photon sensors for cases when single photon detection with a sub 100 ps time resolution is required inside strong magnetic fields. Due to serious radiation hardness issues readout efforts with digital SiPMs were abandoned for this type of detector.

For slow particles a new TOF detector (PANDA barrel TOF) with $<$100 ps time resolution built of a large array of small 5 mm thick scintillating tiles and read out by analogue SiPMs will surround the interaction point in about 0.5 m distance. In this case every traversing particle will produce thousands of photons in the scintillator and each readout sensor will be faced with multiple (~100) photons. Under these circumstances the radiation hardness of the SiPMs is of lower importance. After a period of R&D work and several improvements of the scintillator/SiPM configuration a time resolution of ~50 ps was obtained almost independently of the hit position of the traversing particle. In this talk the various R&D steps towards the final configuration and their results will be presented and discussed. We started with small (30x30x5 mm^3) tiles read out by single SiPMs at opposite side, tested long and thin (~120x5x5 mm^3) scintillating rods with the same readout, and finally ended up with long and wide (~120x30x5 mm^3) scintillating tiles readout by four serially connected SiPMs at the opposite sides.

Primary author: Dr LEHMANN, Albert (Erlangen University)

Co-author: Mr BÖHM, Merlin (Universität Erlangen(UErl))

Presenter: Dr LEHMANN, Albert (Erlangen University)

Session Classification: Miscellaneous and Others

Track Classification: Miscellaneous and others

Contribution ID: **64** Type: **Talk**

Commissioning of VUV-MPPCs for MEG II Liquid Xenon Detector

Friday, 15 June 2018 11:05 (20 minutes)

A liquid xenon photon detector based on highly granular scintillation readout by 4092 VUV-sensitive MPPCs is in preparation for the MEG II experiment.
The VUV-MPPCs have been commissioned and operated in the liquid xenon detector in 2017. The performance of the VUV-MPPCs measured in the commissioning as well as the results from an in-beam test of the liquid xenon detector will be presented.

Primary author: Dr OOTANI, Wataru (University of Tokyo)

Presenter: Dr OOTANI, Wataru (University of Tokyo)

Session Classification: Cryogenic Properties

Track Classification: Cryogenic Properties

Contribution ID: **65** Type: **Talk**

Time Resolution Measurement with Analog SiPMs: Measurements and Setup Examples

Wednesday, 13 June 2018 09:10 (20 minutes)

Silicon Photomultipliers (SiPM) are multi-cell photodetectors that have been studied and improved over the last few years. They are used in several applications ranging from the detection of single photons to multiple photons. Among others properties, the single-photon time resolution (SPTR) is an important characteristic of the SiPMs which has been studied in depth over the last few years by different groups employing different setups and techniques. The single-photon time resolution has been considered one possible limiting factor for the coincidence time resolution (CTR), where SiPMs are coupled with scintillators in applications like positron emission tomography (PET). It is also becoming increasingly important in low-light applications such as Cherenkov-light detection, and in SiPM-based light-detection and ranging (LIDAR).

In this contribution we will discuss different measurements setups and readout methodologies used by various groups to characterize the SPTR of analog SiPMs with a critical view of the possible sources of error and with an overview of the practical aspects. In addition we will discuss the measurement related aspects such as the type of laser, attenuation of light and the identification of single photon events. The two commonly used techniques to measure timing are waveform acquisition and ASIC readout. In waveform acquisition, the SiPM output is amplified and acquired directly using an oscilloscope for the signal to be then analyzed to extract the timing histogram and SPTR. In ASIC readout the output is either a time stamp or a discriminated signal that can further be digitized by an external TDC. Irrespective of the readout technique, only the single photon events are selected for measuring the signal time delay against a reference. The SPTR is affected by the choice of the excess bias and by the discriminating threshold: they both have always to be specified. By examining the SPTR measurement techniques for analog SiPM, we intend to have comparable parameters for the measurements performed by groups across several fields and institutions.

Primary author: Dr ACERBI, Fabio (FBK)

Co-authors: Dr GOLA, Alberto (FBK); Dr POPOVA, Elena (MEPhI); VENIALGO, Esteban (TU Delft); Dr PRATTE, Jean-Francois (univ. sherbrooke); Dr NEMALLAPUDI, Mythra Varun (Academia Sinica, Taiwan); Dr DOLINSKY, Sergei (GE); Dr VINOGRADOV, Sergey (University of Liverpool); Dr BRUNNER, Stefan (TU Delft); Dr GUNDACKER, Stefan (CERN); Dr GANKA, Thomas (KETEK)

Presenter: Dr ACERBI, Fabio (FBK)

Session Classification: Timing Properties (FAST Action WG3 Meeting)

Track Classification: Timing Properties

Contribution ID: **66** Type: **Talk**

SiPM Applications in Particle Physics Experiments

Thursday, 14 June 2018 14:00 (45 minutes)

Nowadays many new scintillator-based and Cherenkov-radiation-based detectors in particle physics use or plan to use Silicon Photomultipliers (SiPMs) for reading out the produced light pulses. The talk will present some of the considered detector concepts, the status of the corresponding development and the SiPM features most relevant for the different applications.

Presenter: Prof. SCHULTZ-COULON, Hans-Christian (Heidelberg University)

Session Classification: Review Talks

Track Classification: Miscellaneous and others

Contribution ID: **67** Type: **Talk**

Scintillation Tile Hodoscope for the PANDA Barrel Time-Of-Flight Detector

Tuesday, 12 June 2018 16:10 (20 minutes)

The PANDA barrel time-of-flight detector will be conducted as scintillator tile, covering phi=1m x 2m long surface. The area is segmented in 2000 tiles, each of which has a dimension of 9x3cm2 and 5mm thickness. Photons are detected at two ends of each tiles, at each end 4 SiPMs are combined serially to increase the effective sensitive are of SiPM. Tiles are mounted on a large PCB backplane with MMCX coaxial connectors. The PCB backplane integrates signal transmission lines with the microstriplines technique. In 16 multilayer PCB board 5-6 signal lines are stacked vertically within the width of about 1mm. The signal processing and digitisation circuit is concentrated on one end of the backplane, realising a nearly cable-less design. The current prototype shows reasonably homogeneous performances over the surface. The average time resolution is about 50ps in standard deviation.
In this paper, we present the ground design of the detector based on the Technical Design Report, accepted recently by FAIR, and recent topics toward mass production.

Primary author: Dr SUZUKI, Ken (ÖAW)

Co-authors: LEHMANN, Albert (Universität Erlangen(UErl)); SCHWARZ, Carsten (GSI, Darmstadt); STEINSCHADEN, Dominik (Stefan Meyer Institute); ORTH, Herbert (GSI, Darmstadt); Mr BÖHM, Merlin (Universität Erlangen(UErl)); Mr KRATOCHWIL, Nicolaus (Stefan Meyer Institut, Vienna); Mr ZIMMERMANN, Sebastian (Justus-Liebig-Universität Gießen(JuLGi-2PI)); NALTI, William (Stefan Meyer Institut(SMI))

Presenter: Dr SUZUKI, Ken (ÖAW)

Session Classification: Large Scale Characterization and Reliability

Track Classification: Large Scale Characterization and Reliability

Contribution ID: **69** Type: **Talk**

Large Scale Characterization of Si-APDs @ FAIR/GSI

Tuesday, 12 June 2018 14:50 (30 minutes)

During the last decades, large area APDs (Avalanche Photo Diodes) reached more and more popularity as readout devices e.g. for calorimeters in various high energy- and nuclear physics experiments. In many cases the APD characteristics need to be individually known to allow for a careful match of the operating parameters to the particular experimental needs and conditions like temperature, expected irradiation dose, desired gain etc.. As a consequence, the experiment dependent requirements on the sensor performance have to be reflected in the large scale characterization process. Potentially occurring variations in designated sensor parameters within large scale production should be identified and classified during this process. For this purpose a modularly usable large scale characterization facility for APDs and eventually also Si photo sensors in general has been established at FAIR/GSI. Motivated from the experience of the large volume characterization work, several R&D topics are being pursued as e.g. a varying behavior under different irradiation conditions.

Primary author: Dr WILMS, Andrea (GSI)

Co-author: SCHMIDT, Christian Joachim (GSI, Darmstadt)

Presenter: Dr WILMS, Andrea (GSI)

Session Classification: Large Scale Characterization and Reliability

Track Classification: Large Scale Characterization and Reliability

Contribution ID: **70** Type: **Talk**

Overview on Experimental Setups to Study SiPM Parameters Down to Cryogenic Temperature

Friday, 15 June 2018 11:25 (20 minutes)

Many important SiPM parameters, like breakdown voltage, signal shape, gain, dark count rate, afterpulses probability present significant temperature variations. Therefore, a study of these parameters in a wide temperature range, down to cryogenic temperatures allows to have a closer look to the physical phenomena staying behind this temperature dependence and eventually find equivalent operating conditions independent of temperature. Moreover, since some different physical phenomena's which lead to same SiPM parameter, but may show different variation with temperature. Therefore, studies of those physical phenomena's as a function of temperature may be only the way to separate them and find the dominated one.
This work reports the overview on experimental set-ups developed for studies of SiPM parameters as a function of temperature. Moreover, it should lead to guide line for future scientists who would like to build their set-ups for temperature studies. Work includes practical suggestions in design, calibration and usage of such kind of set-ups, which was collected by authors during building their own facilities.

Primary author: Dr NAGAI, Andrii (University of Geneva)

Co-author: PARA, Adam (Fermilab)

Presenter: Dr NAGAI, Andrii (University of Geneva)

Session Classification: Cryogenic Properties

Track Classification: Cryogenic Properties

Contribution ID: **71** Type: **Poster**

Implementation and Experimental Validation of a SiPM Model in GATE

The aim of this work is to implement a model of Silicon PhotoMultiplier (SiPM) that can be used to simulate scintillator-based spectrometers implementing SiPMs with the GATE simulation platform.

GATE is a Monte Carlo simulation tool built on top of GEANT4 developed in order to ease the simulation of medical imaging systems like PET scanners. The use of SiPMs, instead of PMTs in PET scanners has increased and our aim is to provide the community with an easy way to accurately simulate gamma ray detectors based on scintillator crystals coupled with SiPMs.

In this work, we present the implemented model and its validation against measured data, specially for timing applications that are crucial in the context of time-of-flight PET. We show how it is possible to reproduce delay distributions of optical photons issued from a monolithic scintillator crystal coupled with a SiPMs array.

Primary authors: Mr MEHADJI, Brahim (Aix-Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France); Mr DUPONT, Mathieu (CPPM CNRS/AMU)

Co-author: Prof. MOREL, Christian (CPPM (CNRS/AMU))

Presenter: Mr DUPONT, Mathieu (CPPM CNRS/AMU)

Track Classification: Miscellaneous and others

Contribution ID: **72** Type: **not specified**

Cryogenic Properties Introduction

Friday, 15 June 2018 09:00 (15 minutes)

Presenter: PARA, Adam (Fermilab)

Session Classification: Cryogenic Properties

Track Classification: Cryogenic Properties

Contribution ID: **73** Type: **not specified**

Cryogenic Properties Discussion & Summary

Friday, 15 June 2018 11:45 (15 minutes)

Presenter: PARA, Adam (Fermilab)

Session Classification: Cryogenic Properties

Track Classification: Cryogenic Properties

Contribution ID: **74** Type: **not specified**

Radiation Hardness Introduction

Thursday, 14 June 2018 09:00 (10 minutes)

Presenter: TSANG, Thomas (BNL)

Session Classification: Radiation Hardness

Track Classification: Radiation Hardness

Contribution ID: **75** Type: **not specified**

Radiation Hardness Discussion & Summary

Thursday, 14 June 2018 11:30 (15 minutes)

Presenter: TSANG, Thomas (BNL)

Session Classification: Radiation Hardness

Track Classification: Radiation Hardness

Contribution ID: **76** Type: **Talk**

Physics of SiPMs

Monday, 11 June 2018 11:10 (30 minutes)

Primary author: Dr POPOVA, Elena (MEPhI)

Presenter: Dr POPOVA, Elena (MEPhI)

Session Classification: Opening Session

Contribution ID: **77** Type: **not specified**

Large Scale Characterization Introduction

Tuesday, 12 June 2018 14:00 (10 minutes)

Presenter: Dr ANFIMOV, Nikolay (JINR)

Session Classification: Large Scale Characterization and Reliability

Contribution ID: **78** Type: **not specified**

Large Scale Characterization Discussion & Summary

Tuesday, 12 June 2018 16:30 (20 minutes)

Presenter: Dr ANFIMOV, Nikolay (JINR)

Session Classification: Large Scale Characterization and Reliability

Contribution ID: **79** Type: **not specified**

PDE Introduction

Tuesday, 12 June 2018 09:20 (10 minutes)

Presenter: OTTE, A. Nepomuk (Georgia Tech)

Session Classification: Photon Detection Efficiency

Contribution ID: **80** Type: **Talk**

Applicability of Digital SiPMs in RICH Detectors

Wednesday, 13 June 2018 12:05 (20 minutes)

Silicon photomultiplier (SiPM) seems to be a promising photon sensor to be used in future large-scale Ring Imaging Cherenkov (RICH) detectors of the modern experiments due to their potentially low costs, compactness and immunity to magnetic field. The only drawbacks are relatively high dark counts and radiation hardness issues.

Digital SiPMs integrating most of the front-end electronics on chip may offer even more to conventional SiPMs: more compactness, superior timing resolution at the level of tens of ps, SPAD-size position resolution and individual control on SPADs.

In June 2012 an aerogel RICH detector prototype based on dSiPMs from Philips named Digital Photon Counter (DPC) was tested with a mixed hadron beam at CERN. The prototype consisted of a 20x20 cm DPC array with 2304 pixels of 4x4 mm size each. Dead time of the DPC was 720 ns. In order to reduce the dark count rate and raise the photon detection efficiency the detector was cooled to -40℃ in addition to disabling individual SPADs. Cherenkov rings with 12 photoelectrons in average for relativistic particles were observed, single photon timing resolution was estimated at 50 ps, inter-pixel crosstalks were 4%. Signs of radiation damage was observed during this test. Later we studied radiation damage for Philips DPC cooled down to -20℃ with a proton beam at FZJ reaching a proton fluence of 4*10^11 p/cm^2. Dark count rate of damaged DPC as function of proton fluence and temperature is studied. Annealing effect during 7 hours at +45℃ was also studied. Absolute PDE measured for a few DPC pixels and corrected for dead time is about 20% for 470 nm wavelength.

Measured characteristics of the current DPC design prevents from using it in RICH application mainly due to large dead time and susceptibility to radiation.

Desired dSiPM parameters for RICH applications are proposed for discussion.

Primary authors: Mr BARNYAKOV, Alexander (BINP); KUYANOV, Ivan A. (Budker Institute for Nuclear Physics(BINP)); BARNYAKOV, Mikhail (Budker Institute of Nuclear Physics); Mr KONONOV, Sergey (BINP)

Co-authors: Prof. ONUCHIN, Alexei (Budker Institute of Nuclear Physics); Dr KRAVCHENKO, Evgeniy (Novosibirsk State University); Mr PRISEKIN, Vyacheslav (Budker Institute of Nuclear Physics)

Presenter: Mr KONONOV, Sergey (BINP)

Session Classification: Miscellaneous and Others

Track Classification: Miscellaneous and others

Contribution ID: **81** Type: **not specified**

Summarizing Discussions

Friday, 15 June 2018 12:20 (20 minutes)

Session Classification: Concluding Session

Contribution ID: **82** Type: **not specified**

Publication Strategy for a White Paper

Friday, 15 June 2018 12:40 (20 minutes)

Session Classification: Concluding Session

Contribution ID: **83** Type: **not specified**

Electrical Properties Discussion & Summary

Thursday, 14 June 2018 12:15 (15 minutes)

Presenter: Dr GASCON, David (University of Barcelona)

Session Classification: Electrical Properties

Contribution ID: **84** Type: **Talk**

Instrumentation for the Scintillator Upgrade of IceTop

Tuesday, 12 June 2018 11:15 (20 minutes)

IceCube is a cubic-kilometer neutrino detector installed in the ice at the geographic South Pole. It comprises a deep-ice detector (installed between 1450 and 2450 m under the ice surface) and a surface array called IceTop, featuring 162 tanks with frozen water. More than five thousand photomultipliers detect the Cherenkov light emitted by charged particles; these detections are used to reconstruct energy and direction of those particles and their progenitors which have cosmic origins.
Over the past twelve years, snow accumulation on top of the IceTop tanks has reached depths that affect the sensitivity to low energy cosmic-ray showers. The IceCube Collaboration plans to install a few hundred homogeneously spaced scintillator detectors as a new calibration instrument for the IceTop tanks. Each detector features extruded plastic scintillator bars and wavelength shifting fibers, which collect the scintillation light produced by minimum ionizing particles and guide it to a silicon photomultiplier. Custom readout electronics allows for the precise measurement of light pulses from a single photo-electron to tens of thousands and features nanosecond time resolution, with the ability to resolve time development of complex light pulses of order one hundred nanoseconds in duration.
Prototypes of such detectors have been installed over the last austral summer. The project will also serve as a platform to develop instrumentation, electronics and an infrastructure system that could be scaled to a future large array, spanning up to 20 thousand sensors distributed over 75 km^2.

Primary author: TOSI, Delia (WIPAC / University of Wisconsin Madison)

Presenter: TOSI, Delia (WIPAC / University of Wisconsin Madison)

Session Classification: Miscellaneous and Others

Track Classification: Miscellaneous and others

Contribution ID: **86** Type: **Talk**

Large Scale Characterization of SiPMs in the MEG II Experiment

Tuesday, 12 June 2018 14:30 (20 minutes)

The upgrade of the MEG experiment, called MEG II, highly relies on the application of SiPMs. Two main detectors use a large amount of SiPMs for highly granular readouts of scintillation light. The Timing Counter uses 6144 NUV-type SiPMs from AdvanSiD. We tested all the sensors before the assembly with respect to I-V characteristics and sensitivity to the scintillation light. During the experiment, the performance and the radiation damage level have been monitored using a dedicated laser system as well as the sensor currents. The LXe detector uses 4092 VUV-type SiPMs from Hamamatsu Photonics. One device is composed of independent 4 sensor chips, totaling 16,368 chips, and all of them were tested individually at room temperature before the assembly for the full characterization. During the experiment, the SiPM characteristics, such as gain and PDE, have been monitored and calibrated by means of alpha sources and LEDs in the detector. In this talk, we will present the methods and results.

Primary author: Dr UCHIYAMA, Yusuke (PSI)

Presenter: Dr UCHIYAMA, Yusuke (PSI)

Session Classification: Large Scale Characterization and Reliability

Track Classification: Large Scale Characterization and Reliability

Contribution ID: **87** Type: **Talk**

Timing Properties Discussion & Summary

Wednesday, 13 June 2018 10:10 (20 minutes)

The rapidly growing use of silicon photomultipliers (SiPMs) makes it necessary to standardize the various parameters related to this device with the final goal of rendering measurements comparable within different research groups and the industry. This summary talk will focus on the intrinsic timing parameters of SiPMs, i.e. the single photon time resolution (SPTR).

We will present our reasoned definition of the SPTR for the analog and digital SiPM with an explanation and justification of the corresponding terms via detailed physical models. The link to applications, e.g. time of flight positron emission tomography, will additionally rationalize our approach. After discussing the main definitions we will show how a typical measurement setup can be conceived and consider in detail all components and parameters of the setup for a reliable and comparable SPTR measurement. A further focus will be given on the intrinsic difference of analog and digital SiPM with the goal of establishing a common platform for comparing both types of photodetectors in terms of their timing performance.

Primary author: Dr GUNDACKER, Stefan (CERN)

Co-authors: Dr GOLA, Alberto (FBK); Dr POPOVA, Elena (MEPhI); Mr VENIALGO, Esteban (TU Delft); Dr ACERBI, Fabio (FBK); Dr NEMALLAPUDI, Mythra Varun (.); Dr JEAN-FRANCOIS, Pratte (Sherbrooke); Dr DOLINSKY, Sergei (GE); Dr VINOGRADOV, Sergey (MEPhI); Dr BRUNNER, Stefan (Broadcom); Dr GANKA, Thomas (Ketek)

Presenter: Dr GUNDACKER, Stefan (CERN)

Session Classification: Timing Properties (FAST Action WG3 Meeting)

Track Classification: Timing Properties

Contribution ID: **88** Type: **Talk**

Multi-Photon Time Resolution and Applications

Wednesday, 13 June 2018 09:50 (20 minutes)

There are many applications demanding for a photon-number-resolving detection of light pulses, some of them also require an extreme timing resolution at the multi-photon level (TOF PET, LIDAR, 4D calorimetry). Silicon photomultipliers (SiPMs) operate in both detection modalities with outstanding performance and appear to be a well-recognized detector of choice in such applications.
Therefore, it is necessary to understand all factors and limitations affecting the time resolution of SiPM-based detectors. Indeed, the time resolution of SiPMs is extensively studied in experiments and Monte-Carlo simulations mostly with respect to scintillation detection. These approaches clarify some basic features, however, there is still a lack of analytical models and results describing multi-photon time resolution (MPTR), especially for an arbitrary pulse shape.
This study is focused on how the single photon time resolution (SPTR) influences the MPTR, because it is still a less clarified point with respect tofactors as, for example, photon detection efficiency (PDE) of a photodetector.
Our goal is to represent and analyze the MPTR analytically as a function of the most important SiPM parameters (SPTR, PDE, single electron response pulse shape) and the light pulse (number of photons, rise and decay times or FWHM).
This analytical model of the MPTR and its correspondence with some experimental results (exponential and Gaussian shapes of the light) will be presented and discussed.

Primary author: Dr POPOVA, Elena (MEPhI)

Co-authors: Mr STIFUTKIN, Alexey (mephi); Mr PHILIPPOV, Dmitriy (mephi); Mr BUZHAN, Pavel (MEPHI); Dr VINOGRADOV, Sergey (Lebedev Physical Institute)

Presenter: Dr POPOVA, Elena (MEPhI)

Session Classification: Timing Properties (FAST Action WG3 Meeting)

Track Classification: Timing Properties

Contribution ID: **89** Type: **Talk**

SENSE - Ultimate Low Light Level Sensor Development

Monday, 11 June 2018 17:15 (20 minutes)

SENSE is a project funded by the EC Horizon 2020 as FET Open Coordination and Support Action (CSA).
Within the project a European R&D roadmap towards the ultimate LLL sensor was developed and with the experts group the progress in developments with respect to the roadmap will be monitored.
In addition, a collaboration between several labs experienced in measuring photosensors was developed to characterize LLL sensors and standardize measurements and analysis procedures. Further cooperation especially with industrial partners is in preparation.
Dissemination of results and the communication between all involved partners and interested parties is a main aspect of the project. Therefor the SENSE website provides all kind of information related to photosensors, starting from a calendar with interesting events over information about the project itself to portraits of experiments working with photosensors and the different test facilities. The SENSE forum allows for communication between all involved actors. In the future a database containing the results of SiPM characterization is planned.
Several outreach activities and special trainings for students are also part of the project and will be extended in the future.
The consortium has four partners: DESY (Coordinator), Germany; UNIGE, Switzerland; MPP, Germany and KIT, Germany. Several international experts on all parts of LLL developments are involved in the expert or working group of the project.

Primary authors: HENJES-KUNST, Katharina (DESY); Dr LINK, Katrin (KIT)

Co-authors: Dr HAUNGS, Andreas (Karlsruhe Institute of Technology); Dr NAGAI, Andrii (University of Geneva, DPNC); Mr STROM, Derek (Max Planck Institute for Physics); DELLA VOLPE, Domenico (University of Geneva); Dr MIRZOYAN, Razmik (Max Planck Institute for Physics); Prof. MONTARULI, Teresa (University of Geneva); Dr BERGHÖFER, Thomas (DESY); HUBER, Thomas (Karlsruhe Institute of Technology)

Presenter: HENJES-KUNST, Katharina (DESY)

Session Classification: EU Projects

Track Classification: Miscellaneous and others

Contribution ID: **90** Type: **Poster**

Multichannel SiPM Arrays for the LHCb Scintillating Fibre Tracker

LHCb will undergo a major upgrade during LHC LS2 in 2019/2020 to cope with increased instantaneous luminosities and a trigger-less 40 MHz read-out. The current inner and outer tracking detectors will be replaced by a single homogeneous detector based on scintillating fibres.

The Scintillating Fibre (SciFi) tracker covers an area of 340 m^2 by using more than 10,000 km of scintillating fibre with 250 μm diameter, read-out by customised Hamamatsu Silicon Photomultipliers (SiPMs) with 524k channels in total. The 128-channel linear SiPM arrays are optimised for high photon detection efficiency (PDE), low correlated noise, short recovery time and dense packaging. During the operation the SiPMs will be exposed to a neutron fluence of 6×10^{11} neq/cm^2. In order to maintain single photon detection capability, the detectors are cooled to -40°C reducing the dark count rate (DCR) by order of a factor 100 compared to room temperature operation.

In this presentation we give a short overview of the detector design and status of production and focus on the extensive studies of the SiPM parameters in the context of the SciFi tracker, including PDE, correlated noise probabilities, breakdown voltage, DCR and photon counting capability. The SiPM performance after irradiation will be also discussed.

Primary author: GRUBER, Lukas (CERN)

Presenter: GRUBER, Lukas (CERN)

Track Classification: Large Scale Characterization and Reliability

Contribution ID: **91** Type: **Talk**

Review of Readout Technics for Cryogenic Experiments

Friday, 15 June 2018 09:15 (20 minutes)

Presenter: Dr OOTANI, Wataru (Tokyo University)

Session Classification: Cryogenic Properties

Contribution ID: **92** Type: **Talk**

SiPMs for PET - An Important but not Exclusive Factor

Monday, 11 June 2018 14:00 (45 minutes)

Presenter: Prof. ZIEMONS, Karl (Aachen University of Applied Sciences)

Session Classification: Review Talks

Track Classification: Miscellaneous and others

Contribution ID: **93** Type: **Talk**

Case Study of Digital SiPMs

Wednesday, 13 June 2018 09:30 (20 minutes)

Single-photon timing resolution (SPTR) is a key parameter for SiPM that influences the system-level timing performance, e.g. in applications such as positron emission tomography (PET), correlated photon detection or ranging (LiDAR). Appropriate standardization of SPTR in digital silicon photomultipliers (D-SiPMs) encounters a challenge as it is dependent of the electronic readout architecture, which is inherently different for individual D-SiPMs. Additionally, comparing analog SiPMs (A-SiPMs) to D-SiPMs in a meaningful way is limited by their different intrinsic device natures.

In this presentation, we start from the basic definition of SPTR and apply it to the characterization of several D-SiPMs cases, such as multichannel digital silicon photomultipliers (MD-SiPMs), 3D digital SiPM (3DdSiPM) and the digital photon counter (DPC). We compare the D-SiPMs' architectures and their impact on the timing performance including a description of on-chip testing circuits that has been used for characterization. Architecture independent and dependent parameters are identified and discussed in order to build a standardization flow. We specify the measurement conditions and system settings in order to obtain a fair comparison between architecture-independent parameters, and a recommendation for a standardized measurement procedure. In addition, we will outline the main differences in SPTR measurements between D-SiPMs and A-SiPMs and present a subset of conditions and standardized parameters that could enable a comparison between them.

Primary author: Mr VENIALGO, Esteban (Delft University of Technology)

Co-authors: CHARBON, Edoardo; PRATTE, Jean-Francois; BRUNNER, Stefan

Presenter: Mr VENIALGO, Esteban (Delft University of Technology)

Session Classification: Timing Properties (FAST Action WG3 Meeting)

Track Classification: Timing Properties