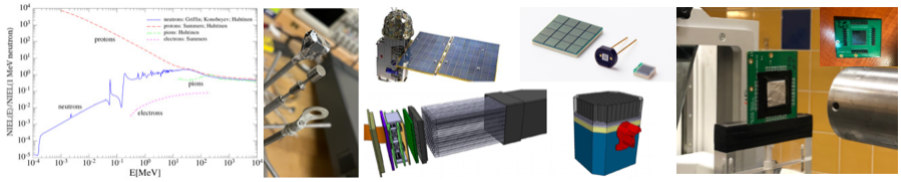
SiPM Radiation: Quantifying Light for Nuclear, Space and Medical Instruments under Harsh Radiation Conditions



Report of Contributions

https://indico.cern.ch/e/1093102

Contribution ID: **1** Type: **not specified**

The Bern medical cyclotron as a facility for radiation hardness studies

Monday, 25 April 2022 13:00 (25 minutes)

Radiation tolerance tests on particle detector components such as SiPMs and their associated electronics are crucial to the success of high-energy physics experiments and scientific missions in space. To this end, an 18 MeV proton beamline is operational at the medical cyclotron of the Bern University Hospital (Inselspital). While the cyclotron's primary purpose is the production of medical radioisotopes, which is typically done overnight, the accelerator is usually available during the day for radiation hardness tests and other multi-disciplinary research activities. The beamline transports the protons from the cyclotron bunker to an adjacent experimental bunker. A 1.8-m thick wall separates the two bunkers, effectively shielding the experimental area from the high radiation environment in the cyclotron bunker. The beam parameters can be adjusted to a high degree to accommodate the user requirements. In particular, the beam spot size can be tuned from a few mm2 to a few cm2, thanks to two independent quadrupole doublets along the beamline, and the ion source current, the Radio-Frequency (RF) and the current in the main coil of the cyclotron can be varied to achieve a proton flux ranging from 5·109 p·cm-2·s-1 to 4·1011 p·cm-2·s-1 on the Device Under Test (DUT). This corresponds to a dose rate to the DUT between 20 Gy/s and 1.5 kGy/s. This talk will introduce the facility, focusing on its potential interest for space applications, and will present some ongoing developments on beam instrumentation. Finally, a new project will be presented in which it is intended to produce a controlled neutron beam for radiation hardness tests, from nuclear reactions induced by the primary proton beam on targets of different materials.

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Session Classification: Irradiation & Testing Facilities

Track Classification: Irradiation or Testing Facilities

Contribution ID: **2** Type: **not specified**

Radiation damage study of SensL J-series SiPMs using 101.4 MeV protons

Tuesday, 26 April 2022 09:00 (25 minutes)

Radiation damage of J-series SiPMs has been studied in the context of using these photodetectors in future space-borne scintillation detectors. Several SiPM samples were exposed to 101.4 MeV protons, with fluences ranging from 1.0e8 p/cm^2 (1 MeV neutron equivalent fluence of 1.3e8 neq/cm^2, absorbed dose of 9.8 rad) to 9.3e9 p/cm^2 (1.2e10 neq/cm^2, 908 rad). An increase in the dark current and noise up to several orders of magnitude was observed for the irradiated SiPMs, which may pose problems for long-running space missions in terms of power consumption, thermal control and detection of low-energy events. As a result of 3-month room-temperature annealing following the irradiation, the dark current decreased by a factor of 3. Measurements performed with a CeBr3 scintillator crystal showed that after the SiPM exposure to 1.2e10 neq/cm^2 followed by the room-temperature annealing, the dark noise of a single 6x6 mm^2 SiPM at room temperature increased from 0.1 keV to 2 keV. Because of the large SiPM noise, the gamma-ray detection threshold increased to approximately 20 keV for a CeBr3 detector using a 4-SiPM array and 40 keV for a detector using a 16-SiPM array. Only a small effect of the proton irradiation on the average detector signal was observed, suggesting no or little change to the SiPM gain and photon detection efficiency.

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Presenter: ULIYANOV, Alexey

Session Classification: SiPM s

Track Classification: Space Applications

Contribution ID: **4** Type: **not specified**

Radiation damage assessment of commercial SiPMs

Tuesday, 26 April 2022 10:15 (25 minutes)

Silicon Photomultipliers (SiPMs) are quickly replacing traditional photomultiplier tubes (PMTs) as the readout of choice for gamma-ray scintillation detectors in space. While they offer substantial size, weight and power saving, they have been shown to be susceptible to radiation damage. SiPM models from various manufacturers were irradiated with 64 MeV protons to simulate the radiation effects seen during previous space missions. The work here expands upon a previous effort with SensL SiPMs and focuses on characterizing the increase in leakage current observed with increasing radiation damage. This work was performed to better quantify this effect as a function of dose and find commercially available options that would prove more robust in the harsh radiation environment of space. In general, results show larger cell sizes are more susceptible to radiation damage with the largest showing the greatest increase in current as a function of dose for similarly designed SiPMs. Within the models tested here, two were found to be roughly an order of magnitude less susceptible to radiation damage compared to the majority of commercially available SiPMs.

Primary author: MITCHELL, Lee

Presenter: MITCHELL, Lee

Session Classification: SiPM s

Track Classification: Space Applications

Contribution ID: **6** Type: **not specified**

The GALI-ISS Mission - a Gamma-ray Burst Localizing Instrument

Thursday, 28 April 2022 13:00 (25 minutes)

The Gamma-ray Burst Localizing Instrument (GALI) is a new concept for localizing γ-ray bursts (GRBs), by utilizing the mutual occultation between numerous small scintillators. In a sense, the method is similar to the coded mask aperture, only that the mask itself is composed of detecting scintillators, so that most of the photons are being detected. The large number of scintillators compensates for the low count rates in each individual scintillator.

We built a laboratory prototype with 90 SiO2-coated CsI(Tl) scintillators of (9mm)ˆ3 wrapped in Vikuiti film and coupled to Si photomultipliers (SiPMs). To test the direction reconstruction capabilities of GALI, we exposed it to a 10 mCi 241Am source placed ˜3.5 m away to simulate a distant source, so that the flux of the 59.6 keV line is ˜50 ph cm-2 s-1 .Subsequently, we scan the entire hemisphere by rotating the detector system varying θ between 0 and 90° and ϕ between 0 and 360° with 5° intervals. For each angle we acquire two kinds of measurements: a 60 s long exposure (corresponding to up to ˜ 3000 counts on each scintillator), and a series of 100 bursts 0.5 s long. The obtained measurements are analyzed offline.

To quantify the advantages of the instrument, we compared the performance of the GALI prototype with a large 4-scintillator detector system connected to traditional PM Tubes. We found that GALI reconstructs burst directions with an accuracy between 1.3° and 2.8°, compared to between 3° and 21° for the 4-scintillator detector. It can be concluded that GALI performs strictly better in all measured directions.

We are currently building, integrating, and testing a larger version of GALI for the International Space Station (ISS), composed of 362 scintillators We will describe the experiments for lowering the photon-energy threshold and optimizing the electronics (ASIC, FPGA, and CPU) parameters. Namely, we examine the influence of the ASIC bias voltage, threshold voltage and its different calibration modes on spectra of laboratory γ-ray sources We will also present the status of the new GALI-ISS mission and the state of the hardware.

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Presenter: SALH, Julia

Session Classification: Future Applications

Track Classification: Space Applications

Contribution ID: **7** Type: **not specified**

Launch of SiPM Radiation Wiki

Wednesday, 27 April 2022 13:00 (25 minutes)

Due to the plethora of SiPM types, instrument configurations and their respective orbital operations it is sometimes very difficult to easily characterize the origin of "SiPM radiation damage features". Even more so, it can be difficult to translate the results from another group/collaboration into something useful for yourself.

Here I will introduce a wiki, currently hosted by the University of Geneva, to provide an overview of SiPM radiation performances.

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Presenter: HULSMAN, Johannes (Universite de Geneve (CH))

Session Classification: Discussion Session

Contribution ID: **9** Type: **not specified**

Annealing Characterization of Hamamatsu S13360-60xx SiPMs for Space Applications

Tuesday, 26 April 2022 11:50 (25 minutes)

The last decade has increasingly seen the use of silicon photomultipliers instead of photodetectors like photomultiplier tubes. This is due to various advantages of the former on the latter like the compactness, lower operating voltage, insensitivity to magnetic fields and mechanical robustness. All these features make silicon photomultipliers ideal for use on space based experiments where the detectors require to be compact, lightweight and capable of surviving launch conditions. A downside with the use of this novel type of detector in space conditions is its susceptibility to radiation damage. In order to understand the lifetime of silicon photomultipliers in space both the damage sustained due to radiation as well as the subsequent recovery, or annealing, from this damage have to be studied. Here we present these studies for three different types of silicon photomultipliers. Both their behaviour after sustaining radiation equivalent to 3 years in low earth orbit (LEO) in a typical mission is presented as well as the recovery of these detectors while stored in different conditions. The storage conditions varied in temperature as well as in operating voltage. The study found that the annealing depends significantly on the temperature of the detectors with those stored at high temperatures recovering significantly faster and to a higher level. Additionally, no significant difference on the sensor recovery is observed for different bias levels. The effect of annealing on I-V characteristics, single photo-electron resolution, dark count rate, and crosstalk probability is discussed. Finally, an overview of the POLAR-2 mission is given along with the implications of the presented study on its operation.

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Session Classification: SiPM s

Track Classification: Space Applications

Contribution ID: **10** Type: **not specified**

SiPMs proton irradiation for POLAR-2

Tuesday, 26 April 2022 11:00 (25 minutes)

POLAR-2 is a polarimeter built to investigate the polarization of gamma-ray bursts in a cosmic space. The instrument will be launch in 2024 on board of the China Space Station and is therefore subject to background radiation from cosmic rays and solar flares. Contrary to its predecessor POLAR, where the scintillators were read-out using a multi-anode PMT, the plastic scintillators will be read-out by four 16 channel Silicon PhotoMultiplier (SiPM).

During my presentation I will show the results of the proton irradiation of SiPM arrays by mono-energetic 58 MeV protons. In our work, two types of silicon photodetectors from Hamamatsu: S13361 and S14161 are tested. The changes in the SiPM current-voltage characteristics, dark count rate and dark count spectrum before and after irradiation in temperatures in the range of 25 C deg. to −20 C deg. for different doses (up to 7 Gy) will be presented. The results of proton activation analysis will be shown at the end.

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Session Classification: SiPM s

Track Classification: Space Applications

Contribution ID: **11** Type: **not specified**

Quantitative measurement and analysis of in-orbit radiation damage of SiPMs in GRID-02 CubeSat detector

Wednesday, 27 April 2022 10:40 (25 minutes)

Silicon photomultiplier (SiPM) has recently been used in several space-borne missions for scintillator readout, thanks to its solid state, compact size, low operating voltage and insensitivity to magnetic fields. However, a known issue of operating SiPM in space environment is the radiation damage and thus the performance degradation. In-orbit quantitative study of these effects is still very limited. In this work we present in-orbit SiPM characterization results obtained by the second detector of Gamma-Ray Integrated Detectors (GRID-02), which was launched on Nov. 6, 2020. A linear fitting is used to describe the increase of dark current with radiation damage, with the compensation for the temperature coefficient of dark current based on the FE-SRH model. A daily noise level measurement of the SiPM was done with charge injection, and its result (sigma) was fitted in good accordance with the dark current. The increasing rate of ˜100 μA/year per SiPM chip (model SensL MicroFJ-60035-TSV) at 28.5 V and 5℃ is observed, and consequently the overall noise level (sigma) of GRID-02 detector increases ˜7.5 keV/year. This effect is estimated to be ˜50 μA/year per SiPM chip at -20℃, which indicates good effect of using a cooling system. Recently, two subsequent detectors of GRID have been launched in 2022 and the new characterization data are under analysis.

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Presenter: Prof. ZENG, Ming (Tsinghua University)

Session Classification: SiPM Monitoring

Track Classification: Space Applications

Contribution ID: **12** Type: **not specified**

Characterization of performance parameters of irradiated SiPMs

Tuesday, 26 April 2022 13:15 (25 minutes)

SiPMs performance parameters such as dark count rate, the average number of detected photons, cross-talk and after-pulsing, gain and gain fluctuations, are usually extracted from

the pulse-height spectra obtained in the dark or response to low-intensity light illumination.

This method works for non-irradiated SiPMs. The most critical effect of radiation on SiPMs is the increase of the dark count rate, which makes it impossible to resolve signals generated by a single photon from the noise. Once the single photo-electron (SPE) resolution is lost the SiPM gain cannot be directly determined as the separation of the peaks in an SPE distribution. Additionally, the breakdown voltage of the SiPM cannot be determined using the widely applied method of linear dependence of the gain versus bias voltage. In these conditions, current-voltage characteristics are used to access the deterioration of performance parameters.

A dedicated single-cell SiPM structure with a 15 um pitch is designed and measured to investigate the radiation damage effects on the performance parameters of SiPMs exposed to a reactor neutron to a fluence up to 5e13 cm-2. The first results of direct gain and breakdown voltage measurements for highly irradiated SiPMs are presented.

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Session Classification: SiPMs

Track Classification: Nuclear & Particle Physics Applications

Contribution ID: **13** Type: **not specified**

Study of Radiation Damage on FBK SiPMs

Tuesday, 26 April 2022 09:50 (25 minutes)

Study of Radiation Damage on FBK SiPMs

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I. INTRODUCTION

Silicon Photomultipliers (SiPMs) are single-photon sensitive detectors that continue to attract increasing interest in several industrial and scientific applications that require fast detection speed, high sensitivity, compactness, insensitivity to magnetic fields and low noise. In some of these applications, such as high energy physics and spaceborne detectors, SiPMs can be exposed to a significant amount of radiation flux or dose that can cause damage to the detector and deterioration of their properties. For this reason, radiation tolerance is one of the main topics of research for SiPMs that has the goal of increasing their lifetime in these harsh environments and mitigating performance degradation after irradiation.

II. RADIATION SOURCES AND DEVICES

To study the effect of radiation damage on SiPMs we performed several irradiation campaigns on different technologies of FBK detectors. Sensors were irradiated using both protons and X-rays, to study the effects of Ionizing Energy Loss (IEL) and Non-Ionizing Energy Loss (NIEL) on their electrical properties, noise characteristics and photon detection efficiency. Irradiation with protons were carried out at the INFN-LNS in Catania and at the proton therapy facility in Trento for fluences up to $5x10^{14}$ and $5x10^{11}$ p/cm^2 respectively. Irradiation with X-rays was performed at TIFPA in Trento with doses up to 100 kGy. Detectors under study were chosen from several FBK technologies: near ultraviolet (NUV) and vacuum ultraviolet (VUV) sensitive detectors based on a p-on-n junction, visible light (RGB) and near-infrared (NIR) sensitive detectors based on an n-on-p junction [1]. In these irradiation campaigns, detectors with variations of process and layout parameters were tested to evaluate possible differences in their performance variation after radiation. Irradiation both with protons and X-rays were performed in steps of increasing fluence (or dose).

III. RESULTS

Protons induce mainly damages in the bulk of the detector through point or cluster dislocations, enhancing the primary dark count rate (DCR) [2-3]. The detectors performance worsening is generally visible at fluences above ~$5{\cdot}10^7$ p/cm^2 depending on the starting DCR level (non-irradiated), which for FBK SiPMs is generally higher for RGB and NIR technologies than for NUV technologies. At higher fluences, where the proton damage dominates the rate of dark generation, we have not observed a significant difference in DCR between the different technologies. Between approximately 10^8 p/cm^2 and 10^{12} p/cm^2 the DCR seems to increase monotonically with the proton dose, whereas at higher fluences we see a saturation of the DCR, probably due to high cell-occupancy. We performed functional tests (waveform analysis) on the irradiated samples, which confirmed primary DCR increment, and excluded significant variation in breakdown voltage, gain, crosstalk probability and photon detection efficiency (PDE) as a function of irradiation fluence, at least up to ~10^{10} p/cm^2. For higher proton fluences, when the DCR of the detector becomes very high, it

is generally difficult or not possible to implement the typical analysis techniques used for SiPMs, based on pulse-counting, thus the main quantities were extrapolated from measurements of the reverse currents. Using a cryogenic version of SiPMs cooled to liquid nitrogen, however, it was possible to recover single photon counting capability and perform waveform analysis even for the samples irradiated at the highest fluences. Low temperature operation of these detectors allows to extend their lifetime under harsh radiation environments and opens new possibilities for their applications in big physics experiments.
We measured reverse current-voltage characteristics of SiPMs irradiated at different fluences and temperatures and we calculated the activation energy from the Arrhenius plot. It is observed a decrease in activation energy already at fluences of 10^8 p/cm^2 that results in a less effective reduction of DCR with cooling.
Soft/medium X-rays effect on SiPMs is mostly the creation of free charges inside the dielectrics. This produces a deterioration of the SiPMs characteristics that were observed, through reverse current-voltage measurements, starting at doses around 5 kGy. In particular, due to the modified charge in the dielectrics, the leakage current increases while the multiplied current does not change. However, at higher doses (around 20 kGy) the multiplied current also starts to increase. This increment could be explained by a local enhancement of the electric field or by a modification of the charge collection properties inside the SPAD [4]. Different technologies showed different responses to X-ray damage. In particular the NUV-HD-lowCT technology being the most sensitive one, probably due to the presence of optically insulating material inside trenches.
Finally, we studied the effect of room temperature annealing during time windows of a few days. It was observed that, although the NIR technology seems to recover faster compared to the NUV one, the relative change in current after annealing is comparable for the two technologies.

IV. CONCLUSIONS

Irradiation tests on FBK SiPMs, both with ionizing and non-ionizing radiation, showed a deterioration of the detector performance that was partially recovered through room temperature annealing. Further tests and analysis are needed to evaluate the differences between technologies and plan the next steps for the study and the improvement of radiation hardness in future productions of detectors.

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[2] Y. Musienko, “Radiation damage studies of silicon photomultipliers for the CMS HCAL phase I upgrade,” NIM-A (2015): 319-322.
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Presenter: MERZI, Stefano

Session Classification: SiPM s

Track Classification: Nuclear & Particle Physics Applications

Contribution ID: **14** Type: **not specified**

SiPM-based Technologies for Solar and Heliospheric Science

Thursday, 28 April 2022 15:00 (25 minutes)

Neutrons and γ-rays are produced throughout the heliosphere and offer a unique window to understanding the fundamental processes of energetic particles. At the Sun, because neutrons and γ rays are produced by the interaction of accelerated ions in solar eruptive events, they can further our understanding of space-weather agents, processes and effects. Neutron measurements from 20-150 MeV complement high- and low-energy solar γ-ray measurements and fill the decade-wide energy gap (30-300 MeV) in the accelerated proton spectrum at the Sun, i.e., a critical missing piece in understanding the production mechanisms of solar energetic particles. For lunar or planetary studies, broadband neutron spectroscopy (covering thermal, epithermal, and fast neutrons) and γ-ray spectroscopy can serve as an effective probe of regolith composition and in situ resource utilization, including the localization of water-ice. Furthermore, fast neutrons are a particularly hazardous form of radiation for astronauts and space assets within orbiting habitats and on lunar/planetary surfaces. We discuss the critical role of SiPM-based technology in enabling the next-generation neutron/γ-ray instruments.

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Presenter: DE NOLFO, Georgia

Session Classification: Future Applications

Track Classification: Space Applications

Contribution ID: **15** Type: **not specified**

SiPM Irradiation and Characterization with proton and x-ray beams: the TIFPA-INFN facilities in Trento (Italy)

Monday, 25 April 2022 13:25 (25 minutes)

Total Ionizing Dose and Displacement Damage Effects on SiPM are standard required characterizations for applications of SiPM in every Nuclear, Space and Medical Instruments. The TIFPA-INFN Center in Trento (Italy) is equipped with two facilities, the Proton Experimental Area and the x-ray Irradiation Laboratory, where these characterizations can be performed with a proton beam and a x-rays beam. The Proton Experimental Area is part of the Trento Proton Therapy Center, a medical facility where protons are used for the treatment of oncological patients. Proton energy can be tuned in the [70-230] MeV range, the typical proton energy range used for medical applications. The x-ray Irradiation Laboratory is a biological/biophysics laboratory equipped with a x-ray irradiation cabinet containing a 3kW x-ray tube with tungsten anode and [30-195] kV tunable voltage. In this talk will be described in details all the irradiation configurations of the Proton Experimental Area and how the the x-ray irradiation cabinet can be used for SiPM irradiation. The preparation and execution of a proton and x-ray irradiation campaign performed on SiPMs designed and produced by FBK in 2021 will be described also, showing the software packages used for the planification and the configurations adopted in these two facilities for this campaign.

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Session Classification: Irradiation & Testing Facilities

Track Classification: Irradiation or Testing Facilities

Contribution ID: **16** Type: **not specified**

Self-heating Effect in Silicon-Photomultipliers

Wednesday, 27 April 2022 09:50 (25 minutes)

The main effect of radiation damage in a Silicon-Photolumtiplier (SiPM) is a dramatic increase in the dark current. The power dissipated, if not properly cooled, heats the SiPM, whose performance parameters depend on temperature. Heating studies were performed with a KETEK SiPM, glued on an alumina substrate, which is either directly connected to a temperature-controlled chuck of a probe station, or through layers of material with well-known thermal resistance. The SiPM is illuminated by a LED operated in DC-mode. The SiPM current is measured and used to determine the steady-state temperature as a function of power dissipated in the multiplication region of the SiPM and thermal resistance, as well as the time dependencies for heating and cooling. This information can be used to correct the parameters determined for radiation-damaged SiPM for the effects of self-heating. The method can also be employed for packaged SiPMs with unknown thermal contact to a heat sink. The results presented in this presentation are preliminary.

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Presenter: VILLALBA PETRO, Carmen Victoria (Hamburg University (DE))

Session Classification: SiPM Monitoring

Track Classification: Nuclear & Particle Physics Applications

Contribution ID: **17** Type: **not specified**

Atmospheric-like neutrons at the ChipIr beamline

Monday, 25 April 2022 14:15 (25 minutes)

ChipIr is a beamline dedicated to the irradiation of microelectronics with atmospheric-like neutrons; it has been built on the second target station of the ISIS spallation source at the Rutherford Appleton Laboratory, UK. The beamline is specifically dedicated to the study of single event effects and its design is therefore optimized to extract a neutron spectrum as similar as possible to the atmospheric one with intensity increased by a factor up to 10^9 depending on configuration.

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Session Classification: Irradiation & Testing Facilities

Track Classification: Irradiation or Testing Facilities

Contribution ID: **18** Type: **not specified**

Time evolution of GECAM GRD in-flight background and performance

Wednesday, 27 April 2022 10:15 (25 minutes)

The Gravitational Wave Electromagnetic Counterpart All-sky Monitor (GECAM) was launched on December 10, 2020 (Beijing Time). It is composed of two microsatellites and each GECAM satellite consists of 25 SiPM-based gamma-ray detectors (GRDs) and 8 SiPM-based charged particle detectors (CPDs). The in-flight background of GRD mainly consists of cosmic X-ray background, SAA proton activated LaBr3 radiation, albedo gamma, cosmic proton and LaBr3 inner radiation. These gamma-ray lines can provide the in-flight gain calibration. However, the in-flight radiation (especially the SAA area radiation) causes some unexpected influences on both the LaBr3 crystal and SiPM array of GRD. The total current of SiPM arrays is increasing all the time because of radiation damage. The decrease of GRD gain was observed in-flight which is caused by the LaBr3 radiation damage and SiPM performance deterioration. The evolution of the GRD in-flight gain, energy resolution and energy range will be reported and plans and suggestions for the future in-flight SiPM application will also be discussed in this presentation.

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Presenter: Dr ZHANG, Dali

Session Classification: SiPM Monitoring

Track Classification: Space Applications

Contribution ID: **19** Type: **not specified**

GECAM: a SiPM-based Gamma-ray All-Sky Monitor

Wednesday, 27 April 2022 09:25 (25 minutes)

Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor (GECAM) is an all-sky monitor composed of two microsatellites launched in Dec. 2020. Each GECAM satellite is equiped with 25 SiPM-based gamma-ray detectors (GRD) and 8 SiPM-based charged particle detectors (CPD). Due to the anomalies in the satellite power supply, only one satellite (GECAM-B) can observe about 10 hours per day. Neverthelss, GECAM-B has detected many gamma-ray transients, including gamma-ray bursts (GRBs), soft gamma-ray repeaters (SGRs), bursts from X-ray Binaries (XRB), Solar Flares and Terrestrial Gamma-ray Flashes (TGFs). In this talk, I'll give an overview of the GECAM mission and the observation results of GECAM-B. The in-flight performance of the SiPM-based detectors will be also presented.

Primary author: Dr XIONG, Shaolin

Presenter: Dr XIONG, Shaolin

Session Classification: SiPM Monitoring

Track Classification: Space Applications

Contribution ID: **20** Type: **not specified**

Proton irradiation facilities and radiotherapy centre at IFJ PAN

Monday, 25 April 2022 13:50 (25 minutes)

The Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Krakow has two proton cyclotrons, the AIC-144 60 MeV cyclotron (designed and built at the IFJ PAN), and the IBA Proteus C-235 cyclotron, which produces a proton beam with an energy of 230 MeV mainly for proton radiotherapy.
The proton radiotherapy center (Cyclotron Centre Bronowice) at IFJ PAN is equipped with Proteus C-235 cyclotron two gantry rooms with PBS nozzle, a beam line dedicated for proton eye radiotherapy. In addition, CCB has an experimental room for nuclear physics experiments.
The AIC-144 60 MeV proton cyclotron facility has two proton irradiation stations: a small field horizontal line installed in the eye therapy hall and a high intensity proton line delivered beam to the AIC-144 experimental hall. These irradiation facilities enable proton irradiation to be performed very accurately over a wide range of doses (proton fluencies) and dose rates. The adjustable range of the proton beam current is 1- 100 nA, its energy range is 10-60 MeV, with proton flux values ranging between 5e5 p/cm - 2 s-1 and 1e9 p/cm -2 s-1. The total absorbed doses delivered to passively forming fields of about 10 cm in diameter may range between 5 mGy and 120 kGy.
This very precisely controlled and reproducible set of beam parameters allows proton beams to be applied in testing and quality control of clinical radiation detectors designed for radiotherapy purposes, in irradiating biological samples, including radiobiological experiments with animals, and in designing and performing tests of radiation hardness of electronics and materials applied in the space industry or around research accelerators.
Adequate beam-time at this stand-alone 60 MeV proton facility is readily available to external users, unlike in other such facilities that are typically share their beams on “parasitic”principles, competing with principal research or patient irradiation.

Primary author: Prof. SWAKON, Jan (Institute of Nuclear Physics Polish Academy of Sciences)

Presenter: Prof. SWAKON, Jan (Institute of Nuclear Physics Polish Academy of Sciences)

Session Classification: Irradiation & Testing Facilities

Track Classification: Irradiation or Testing Facilities

Contribution ID: **21** Type: **not specified**

The Terzina Cherenkov telescope onboard the NUSES space mission

Thursday, 28 April 2022 13:25 (25 minutes)

Terzina is a satellite base Cherenkov telescope designed to operate at ˜535 km altitude with sun-synchronous orbit. Its primary goal is to probe the new concept of detecting ultra high energy cosmic rays and neutrinos by observing Cherenkov light from an extensive shower produced in the atmosphere. It is part of the NUSES space mission with a wide scientific program. Also, the mission includes the ZIRE apparatus for flux measurements of electrons, protons, light nuclei with energies spanning from a few to hundreds of MeV's and MeV gamma rays.

The telescope is composed of a spherical primary mirror, a small spherical mirror, a corrector lens, and Photon detection plane. The optical system can fit the tube-like envelope with 394 mm diameter and 350˜mm length. It is inclined by 67.5 deg. with respect to nadir, having an optical axis pointing towards the Earth limb. The photon detector plane is conceived to detect the photons from below and above the limb. It has a rectangular shape with a 2×5 aspect ratio. The camera is composed of 10 SiPM arrays (8 x 8) pixel each and 3 x 3 mmˆ2 pixel size. The telescope have 7 deg. Field-of-View this corresponds to 0.18 deg. per pixel. It can observe the vast volume of the atmosphere with 140 x 360 km in cos-section.

To estimate expected signal we develop full Geant4 based simulation of the Terzina telescope. It takes into account mirror and corrector lens reflectivity and transparency, quantum efficiency and geometry of the photon sensitive camera. We use Emission for Extensive Air Showers Cherenkov Simulation (EASCherSim) as event generator.

Primary author: Dr BURMISTROV, Leonid (University of Geneva)

Presenter: Dr BURMISTROV, Leonid (University of Geneva)

Session Classification: Future Applications

Track Classification: Space Applications

Contribution ID: **22** Type: **not specified**

200 MeV proton damages on Hamamatsu MPPCs (Si-PMs) and GRBAlpha CubeSat status

Wednesday, 27 April 2022 09:00 (25 minutes)

We measured 200 MeV proton damages on Hamamatsu MPPCs (Si-PMs), S13360-6050CS and S14160-6050HS, using the Wakasa Wan Energy Resarch Center in Japan. To achieve the lower energy threshold of CsI(Tl) with the damaged MPPCs, we measured the performances at different operation voltages and temperatures. The lower operational voltage is preferred due to the large increase of the dark current. The results are reported in https://doi.org/10.1016/j.nima.2020.164673 and https://doi.org/10.1016/j.nima.2020.164945.

GRBAlpha is 1U CubeSat launched in 2021 Mar. The detector is 75x75x5mm CsI(Tl) readout by 2x4 MPPCs (S13360-3050PE). It successfully detected several Gamma-Ray Bursts (GRBs). We present the status and the trend of the low-energy threshold caused by the MPPC degradation.

Primary authors: TAKAHASHI, Hiromitsu; AND THE GRBALPHA TEAM

Presenter: TAKAHASHI, Hiromitsu

Session Classification: SiPM Monitoring

Track Classification: Space Applications

Contribution ID: **23** Type: **not specified**

Proton irradiation on modified Hamamatsu MPPCs (Si-PMs)

Tuesday, 26 April 2022 09:25 (25 minutes)

We studied 200 MeV proton irradiation effects on Hamamatsu MPPCs (Si-PMs) in the Wakasawan Energy Research Center in Japan. Hamamatsu K.K. made test versions of MPPCs (S14420-3050MOD, S14160-3050MOD) and we studied these performances. As a result, dark current and lower energy threshold of modified MPPCs were comparable to the old one, and thus there were no significant improvements observed in our experiments.

Primary author: IMAZAWA, Ryo (Hiroshima University)

Presenter: IMAZAWA, Ryo (Hiroshima University)

Session Classification: SiPM s

Track Classification: Space Applications

Contribution ID: **24** Type: **not specified**

Annealing characteristic of Hamamatsu MPPCs (Si-PMs) after keeping in room temperature and after baking

Tuesday, 26 April 2022 11:25 (25 minutes)

We studied annealing characteristic of Hamamatsu MPPCs (Si-PMs) in two ways after 200 MeV proton irradiation. First, we report the annealing characteristic after kept in room temperature during seven months. Second is baking at 150 degrees Celsius during 3 hours. In both cases, the increased dark current is reduced by 1/2-1/3.

Primary author: MATAKE, Hiroto (Hiroshima University)

Presenter: MATAKE, Hiroto (Hiroshima University)

Session Classification: SiPM s

Track Classification: Space Applications

Contribution ID: **25** Type: **not specified**

SiPM applications in novel SmallSat missions for gamma-ray astronomy

Thursday, 28 April 2022 14:35 (25 minutes)

MoonBEAM and StarBurst are two novel SmallSat designs for missions in the field of gamma-ray astronomy. Given their size constraints, these types of spacecraft highly favor the use of SiPMs over PMTs in their scintillation-based detector designs. However, the one major problem for SiPM detector designs is operational lifetime given that SiPM power draw increases significantly with radiation damage. This can begin to exceed spacecraft power requirements after just a year in low Earth orbit. I will provide an overview of the MoonBEAM and StarBurst missions as well as the viability studies for SiPM use that were explored during their design phase.

Primary author: Dr WOOD, Joshua (NASA/MSFC)

Co-author: HUI, Michelle

Presenter: Dr WOOD, Joshua (NASA/MSFC)

Session Classification: Future Applications

Track Classification: Space Applications

Contribution ID: **26** Type: **not specified**

Irradiation Studies for the Mu3e Tile detector

Tuesday, 26 April 2022 13:40 (25 minutes)

The Mu3e experiment at PSI is designed to search for the CLFV decay $^{+}\rightarrow e^{+}e^{+}e^{-}$ with a sensitivity of 10^{-16}. To reduce the combinatorial background from muon decays while efficiently identifying 3-electron final states, a scintillating-tile detector with a required timing resolution < 100 ps and efficiency close to 100% is under development.

The Irradiation damage of SiPMs to be used in the tile detector (MPPC S13360) were investigated by exposing the sensors to the decay electrons from stopped muons at the PiE5 beamline at PSI. For the SiPMs irradiated with a dose up to 1.57×10^{11} 1 MeV neq/cm², corresponding to 70% of the maximum dose of the Mu3e Phase I run, the dark current increased by a factor 10^{3}.
We will report on the irradiation campaign performed, measurements of dark current and impact on annealing at different temperatures, as well as measurements of the time resolution of SiPM+Tile matrices after irradiation, studied in test beam measurements at DESY.

Primary author: ZHONG, Tiancheng

Co-author: BRIGGL, Konrad

Presenter: ZHONG, Tiancheng

Session Classification: SiPMs

Track Classification: Nuclear & Particle Physics Applications

Contribution ID: **29** Type: **not specified**

SiPMs in radiation environments

Monday, 25 April 2022 11:35 (25 minutes)

A general overview of SiPMs in radiation environments.

Primary author: GARUTTI, Erika (Hamburg University (DE))

Presenter: GARUTTI, Erika (Hamburg University (DE))

Session Classification: SiPM

Contribution ID: **30** Type: **not specified**

Silicon Photomultipliers: Enabling Future Astroparticle Physics Missions

In this talk I discuss three proposed space-based missions covering a variety of astroparticle physics science topics: the AMEGO-X MIDEX-class all-sky medium-energy gamma-ray telescope, the TIGERISS Pioneers-class cosmic-ray telescope for measuring nuclear abundances over a very wide range of charges, and the developing GECCO concept combining a Compton telescope with a deployable coded mask for high angular resolution imaging for medium-energy gamma rays. These missions designs all incorporate silicon photomultipliers as an enabling technology. I will discuss briefly the motivation for each of these instruments, their overall detector designs, and the specific roles that silicon photomultipliers uniquely play in their implementation.

Primary author: Dr CANNADY, Nicholas (Goddard Space Flight Center)

Presenter: Dr CANNADY, Nicholas (Goddard Space Flight Center)

Session Classification: Future Applications

Track Classification: Space Applications

Contribution ID: **31** Type: **not specified**

An Overview of SiPMs

Monday, 25 April 2022 11:10 (25 minutes)

An Overview of SiPMs

Primary author: Dr SUAREZ, Federico (National Scientific and Technical Research Council (CONICET))

Presenter: Dr SUAREZ, Federico (National Scientific and Technical Research Council (CONICET))

Session Classification: SiPM

Contribution ID: **32** Type: **not specified**

The SiPM for LHCb SciFi Tracker

Tuesday, 26 April 2022 14:55 (25 minutes)

The LHCb SciFi (Scintillating fibre) Tracker with an active area of 320˜m^2 features over 500'000 SiPM channels in a high radiation environment. Unlike other SiPM applications exposed to radiation, the SciFi SiPM is required to provide single photon amplitude resolution throughout the detector lifetime. With a light yield of 18˜pe decreasing to 12˜pe over the lifetime of the detector, low noise cut thresholds are crucial to maintain high hit detection efficiency. The major factors to achieve this are fast shaping, short integration time (20 ns), small active channel area (0.3 mm^2), low correlated noise and cold operation at $-40°$˜C. The photo-detector was characterised after the exposure to a neutron fluence of 6×10^{11} $1\mathrm{MeV}\,\mathrm{n_{eq}}/\mathrm{cm}^2$ at various temperatures and overvoltages. In this talk I will concentrate on the chosen optimisation process, discuss the production quality assurance procedure and show some statistics on the production parameter spread. The 128 channel detector array was produced and delivered in 2018 by Hamamatsu. They were mounted on Kapton flex PCBs and installed in the detector modules during 2019-2020 and the final detector installation was finalised in April 2022, just in time for the Run 3 start of the LHC accelerator.\\

Primary authors: TRIPPL, Carina (EPFL - Ecole Polytechnique Federale Lausanne (CH)); HAEFELI, Guido (EPFL - Ecole Polytechnique Federale Lausanne (CH)); ZAFFARONI, Ettore (EPFL - Ecole Polytechnique Federale Lausanne (CH))

Presenter: HAEFELI, Guido (EPFL - Ecole Polytechnique Federale Lausanne (CH))

Session Classification: SiPMs

Track Classification: Nuclear & Particle Physics Applications

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

SiPM neutron hardening with Cf-252 for space environments

Tuesday, 26 April 2022 14:30 (25 minutes)

A single SiPM Hamamatsu S13360-6050PE was irradiated with an isotopic Cf-252 source at the NIST Californium Neutron Irradiation Facility (CNIF) to evaluate damage for the POLAR-2 polarimeter, as a first approach to evaluate the damage produced by atmospheric neutrons in space. The source has a diameter of 7.7 mm and its activity at the time of the irradiation was 1.688 x 10^7 neutrons per second. The SiPM was located at 2.3 cm away from the source center in several irradiation periods without gamma shielding. The estimated neutron fluence delivered to the SiPM during the first irradiation after 1 hour of exposition was estimated to be 9.04 x 10^8 per cm^2. A increase of the dark-current of the SiPM measured immediately after 1 hour of irradiation was observed to be more than 280 times in comparison with previous measurements at same temperature and polarization conditions. Additional measurements and characterization of the irradiated SiPM and a non-irradiated SiPM are also discussed in this work with the intention of providing clues about the usability of the damaged SiPM to generate the scientific results expected by the project.

Primary author: SUAREZ, Federico (National Scientific and Technical Research Council (CONICET))

Presenter: SUAREZ, Federico (National Scientific and Technical Research Council (CONICET))

Session Classification: SiPMs

Track Classification: Space Applications

Contribution ID: **34** Type: **not specified**

SiPM characterization and fully automated test facilities for astroparticle detection space projects

Monday, 25 April 2022 14:40 (25 minutes)

Most of the astrophysics experiments use astro particle detectors comprising scintillators coupled large number of photomultipliers (either PMTs or SiPMs) to generate the electrical pulses corresponding to the detected particle. The performance of the detectors is strongly dependent to the parameters of each photodetector and therefore they have to be thoroughly and individually characterized to better design the detector, improve the understanding of the systematics and increase the quality during the production phase of the projects. Furthermore, each individual channel has to be tested as a single photomultiplier in the case of multi-channel photomultipliers and also evaluation of possible influence in-between channels has to be performed, highly increasing the stress and demmand of a perfected and fast test bench. A dedicated and accurate testing facility is highly recommended for the R&D phase of the projects while a fully automated testing facility is normally used for mass production as part of the quality assurance plan to match the project specs and for better understanding of the spread in the parameters of large numbers of photomultipliers. Preliminary results of characterization of a Hamamatsu S13360-6050PE MPPC are shown in this work together with an overview of a fully automated test system for mass production. This automated test facility at CNEA was used for the R&D and mass production of the enhancement and upgrade projects of the Pierre Auger Observatory.

Primary author: Dr LUCERO, Luis Agustin (Laboratorio Argentino de Haces de Neutrones)

Presenter: Dr LUCERO, Luis Agustin (Laboratorio Argentino de Haces de Neutrones)

Session Classification: Irradiation & Testing Facilities

Track Classification: Irradiation or Testing Facilities

Contribution ID: **35** Type: **not specified**

Irradiation of multi-channel SiPM arrays in Mu3e

Tuesday, 26 April 2022 14:05 (25 minutes)

Mu3e is a novel experiment under preparation at PSI searching for lepton flavor violation in the neutrinoless $\mu \to eee$ decay. To suppress accidental backgrounds a scintillating fiber timing detector read out with multi-channel SiPM arrays at both ends has been developed. The SiPM arrays will be exposed to a very high flux of low energy positrons (E ~ 10 to 50 MeV) from μ decays, which cause much more damage than MIPs. The expected dose during Phase I of the experiment is estimated around 10^{11} neutron equivalent / cm^2. In this talk we will present our experience with the irradiated multi-channel SiPM arrays exposed at different doses and operated at different temperatures.

Primary author: DEMETS, Yannick (University of Geneva)

Presenter: DEMETS, Yannick (University of Geneva)

Session Classification: SiPMs

Track Classification: Nuclear & Particle Physics Applications

Contribution ID: **36** Type: **not specified**

SiPM-based CubeSat for Measuring the Cosmic X-ray Background

Thursday, 28 April 2022 13:50 (25 minutes)

The Cosmic X-ray Background (CXB) dominate the X-ray fluxes over the sky, as it is believed to be a superposition of numerous discrete sources, which are primarily Active Galactic Nuclei (AGNs). The CXB intensity therefore offers an unique probe to study the AGN population. Limited by background modeling and (cross) calibration issues, the uncertainty of the CXB measurements remain currently at an order of 20 per cent on its normalization. A dedicated CXB detector is therefore needed to measure the CXB accurately. Benefiting from SiPM technologies which relax the design constraints, space-borne detectors are increasingly formed into CubeSat missions. We present here the concept, simulated performances and science goals of the EQUATOR mission, which is mainly consist of an array of collimated spectrometers with a rotating shutter on top of the aperture. With two years operation in space, such a mission is expected to measure the CXB with ˜1 per cent uncertainty in 10-100 keV energy range, and thus gain us knowledge of the accretion power in the Universe.

Primary author: LI, Hancheng (University of Geneva)

Presenter: LI, Hancheng (University of Geneva)

Session Classification: Future Applications

Track Classification: Space Applications

Contribution ID: **37** Type: **not specified**

Overview on ”Irradiation & Testing Facilities”

Friday, 29 April 2022 09:00 (10 minutes)

Presenter: DE ANGELIS, Nicolas (Universite de Geneve (CH))

Session Classification: Review Talks

Contribution ID: **38** Type: **not specified**

Overview on ”SiPM & Protons”

Friday, 29 April 2022 09:10 (20 minutes)

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

Session Classification: Review Talks

Contribution ID: **39** Type: **not specified**

Overview on ”SiPM & neutrons/electrons”

Friday, 29 April 2022 09:30 (20 minutes)

Presenter: SUAREZ, Federico

Session Classification: Review Talks

Contribution ID: **40** Type: **not specified**

Overview on ”SiPM Monitoring”

Friday, 29 April 2022 09:50 (20 minutes)

Presenter: HULSMAN, Johannes (Universite de Geneve (CH))

Session Classification: Review Talks

Contribution ID: **41** Type: **not specified**

Overview on ”Future Applications”

Friday, 29 April 2022 10:10 (20 minutes)

Presenter: KOLE, Merlin (Universite de Geneve (CH))

Session Classification: Review Talks