[2503.14622] Measurement of SiPM Dark Currents and Annealing Recovery for Fluences Expected in ePIC Calorimeters at the Electron-Ion Collider

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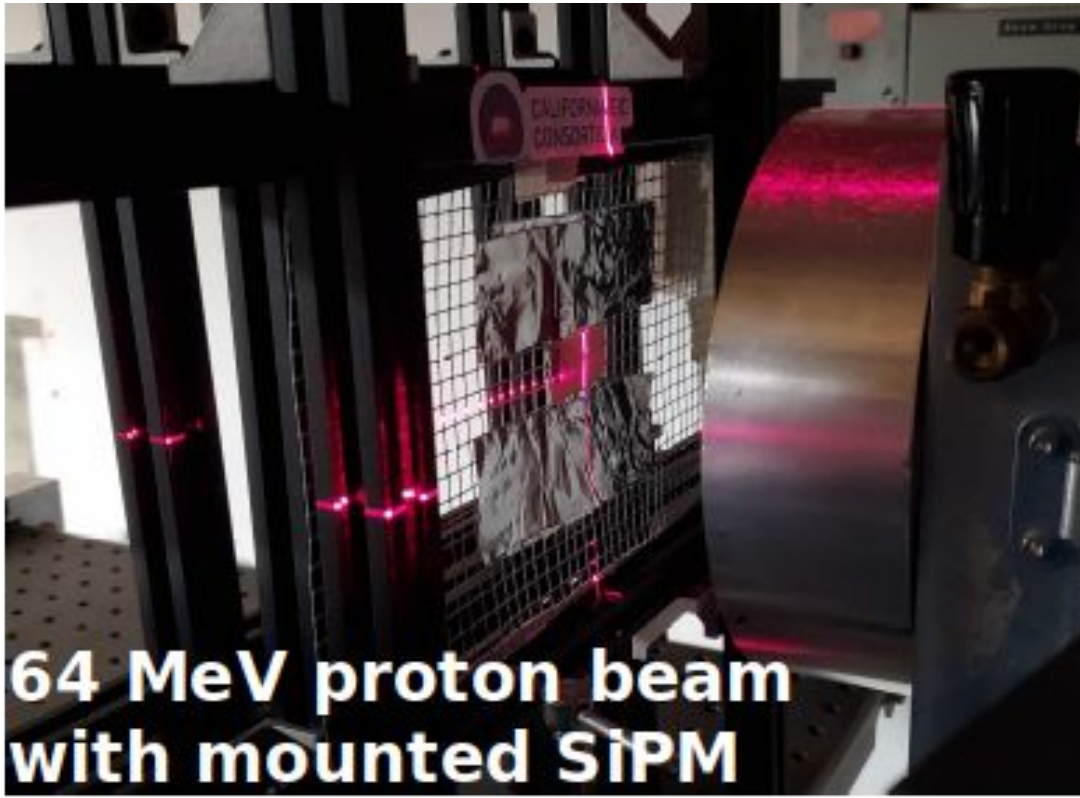


Motivation of SiPM radiation study

Collect reference data for every SiPM model used in the ePIC calorimeters, covering the full range of fluences and operating voltages of interest.

Fluence range of interest

[Radiation Doses - Electron-Proton/Ion Collider Experiment]

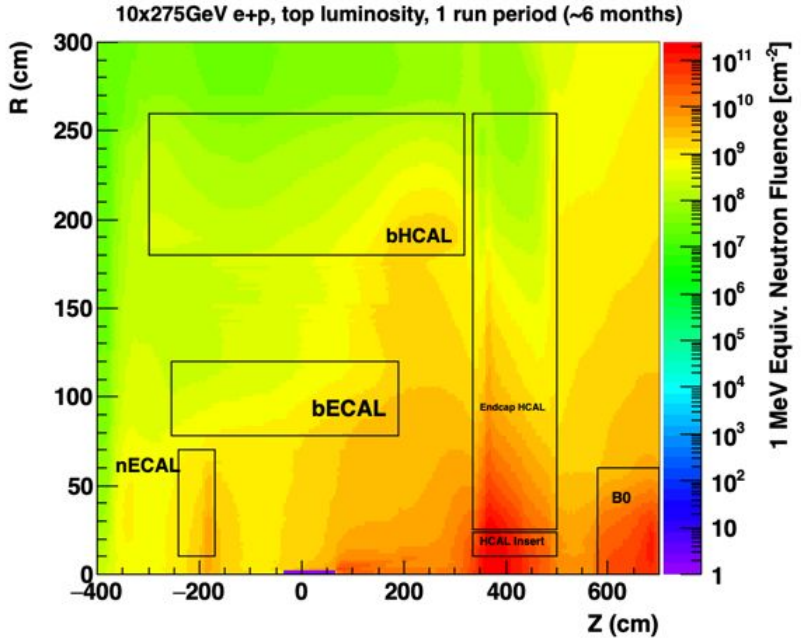


Figure 7: 1 MeV equivalent neutron fluence for minimum-bias PYTHIA e+p events at 10x275 GeV @ top machine luminosity for 6 months of running at 100% machine and detector efficiency. ROOT files can be found here. ROOT files for 1mm (finer) bins in SVT region can be found here

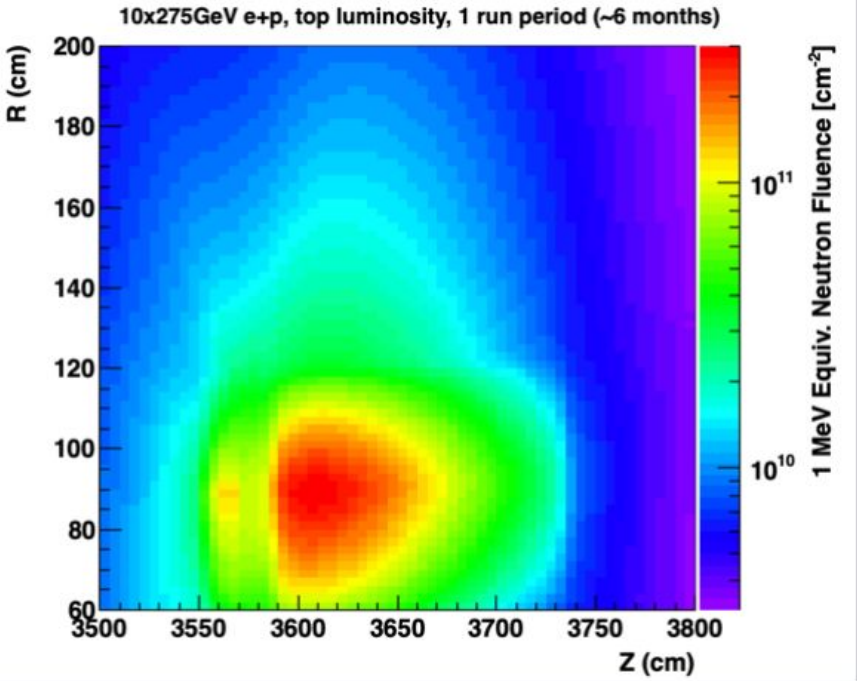


Figure 12: 1 MeV equivalent neutron fluence for minimum-bias PYTHIA e+p events at 10x275 GeV @ top machine luminosity for 6 months of running at 100% machine and detector efficiency. ROOT files can be found here.

[2503.14622] Measurement of SiPM Dark Currents and Annealing Recovery for Fluences Expected in ePIC Calorimeters at the Electron-Ion Collider

Physics > Instrumentation and Detectors

[Submitted on 18 Mar 2025]

Measurement of SiPM Dark Currents and Annealing Recovery for Fluences Expected in ePIC Calorimeters at the Electron-Ion Collider

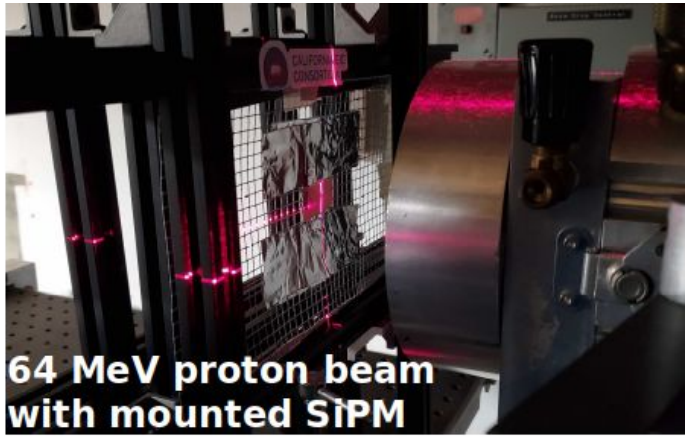
Jiajun Huang, Sean Preins, Ryan Tsiao, Miguel Rodriguez, Barak Schmookler, Miguel Arratia

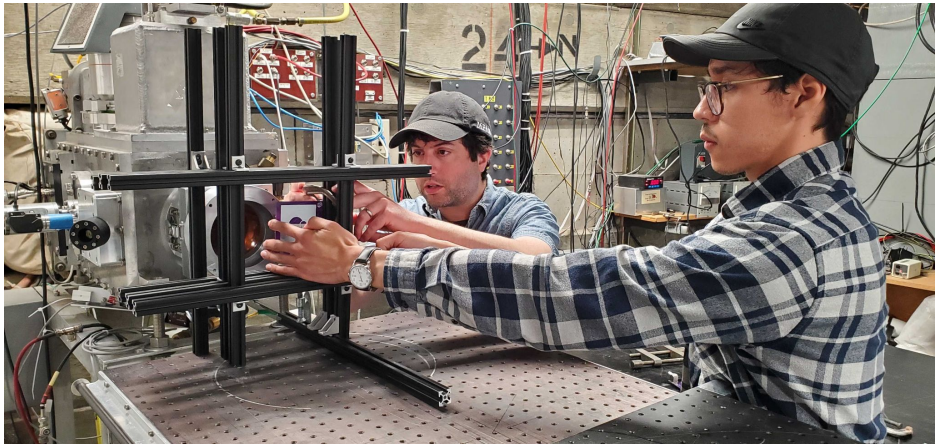
Silicon photomultipliers (SiPMs) will be used to read out all calorimeters in the ePIC experiment at the Electron-Ion Collider (EIC). A thorough characterization of the radiation damage expected for SiPMs under anticipated EIC fluences is essential for accurate simulations, detector design, and effective operational strategies. In this study, we evaluate radiation damage for the specific SiPM models chosen for ePIC across the complete fluence range anticipated at the EIC, 10^8 to 10^{12} 1-MeV n_{eq}/cm^2 per year, depending on the calorimeter location. The SiPMs were irradiated using a 64 MeV proton beam provided by the University of California, Davis 76" Cyclotron. We measured the SiPM dark-current as a function of fluence and bias voltage and investigated the effectiveness of high-temperature annealing to recover radiation damage. These results provide a comprehensive reference for the design, simulation, and operational planning of all ePIC calorimeter systems.

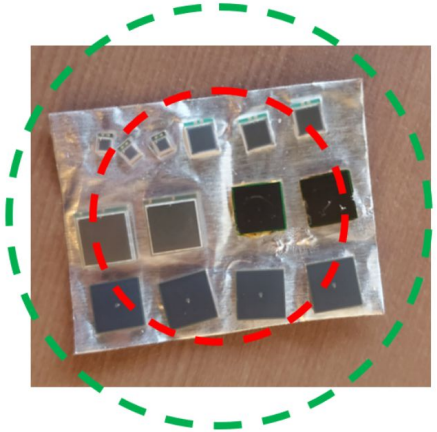
Subjects: **Instrumentation and Detectors (physics.ins-det)**; High Energy Physics - Experiment (hep-ex); Nuclear Experiment (nucl-ex)
Cite as: arXiv:2503.14622 **[physics.ins-det]**
(or arXiv:2503.14622v1 **[physics.ins-det]** for this version)
https://doi.org/10.48550/arXiv.2503.14622

SiPM proton irradiation test at UC Davis Cyclotron

May 2024







1.5
cm

Method: IV via POGO pins to PCB, 3D printed holder

No soldering, to avoid high-temperature annealing.

No destructive test, such that annealing Studies could be performed afterwards

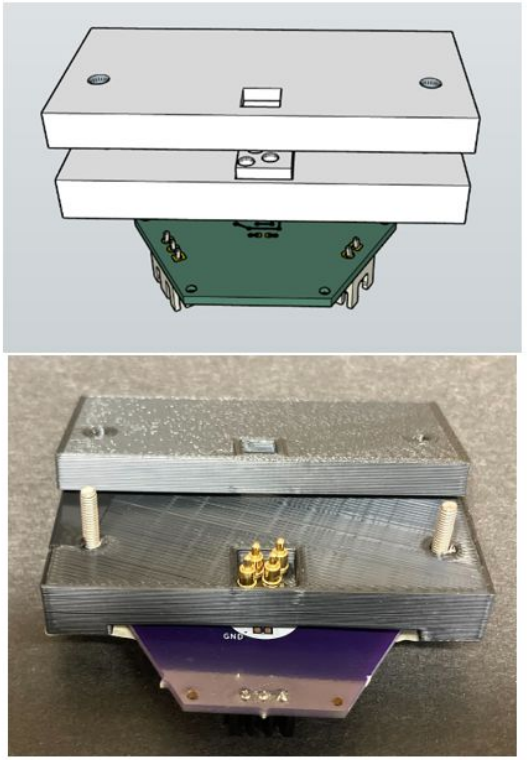


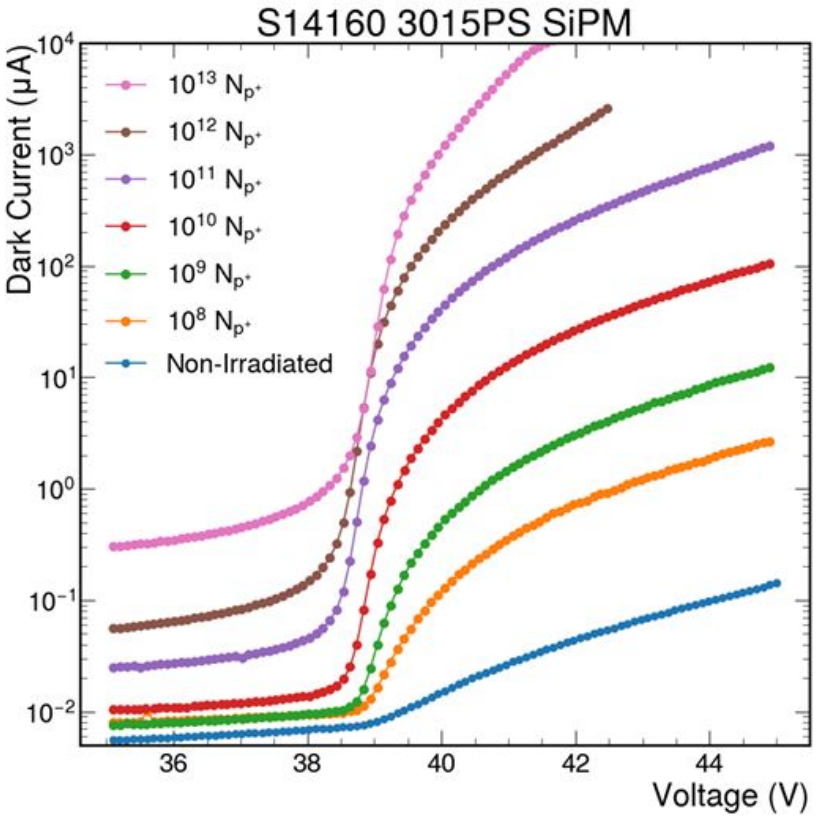
Figure 2: Figure (a) (top) shows a SketchUp 3D model of the holders. Figure (b) (bottom) shows the 3D-printed holders with a hexagon board and pogo pins

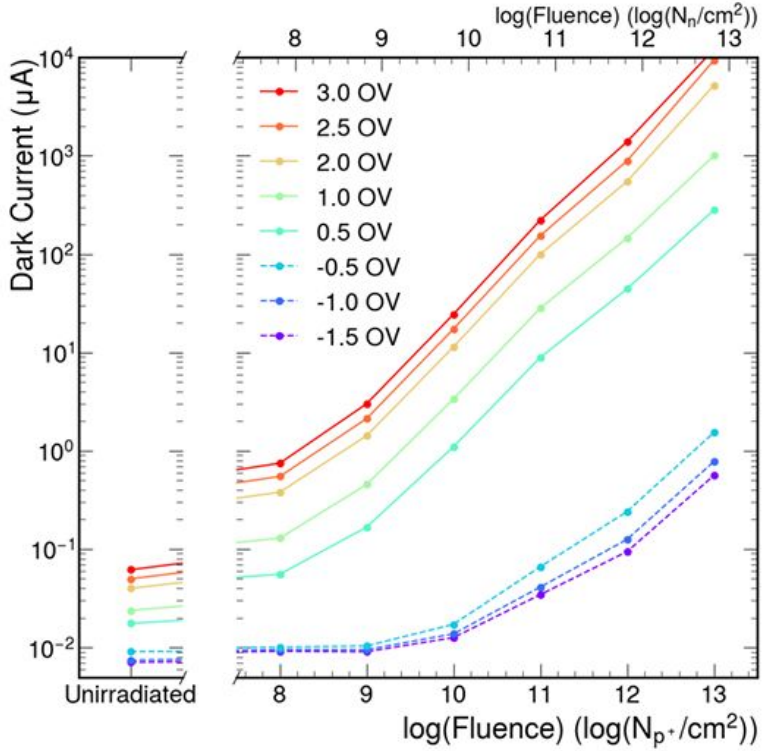
SiPM models tested, fluence tested

Models of SiPMs	10^8 $\mathbf{N}_{p^+}$	10^9 $\mathbf{N}_{p^+}$	10^{10} $\mathbf{N}_{p^+}$	10^{11} $\mathbf{N}_{p^+}$	10^{12} $\mathbf{N}_{p^+}$	10^{13} $\mathbf{N}_{p^+}$	**ePIC Detector Usage**
S14160 1315PS	1	3	3	3	3	2	nHCAL, pHCal
S14160 3015PS	1	2	2	3	3	1	nEMCAL , bHCAL, pHCal(Insert), ZDC
S14160 6015PS	1	1	1	2	2	1	nEMCAL, bEMCAL, pEMCAL
S14160 6050HS	2	4	4	4	4	2	bEMCAL , pEMCAL, pHCAL (Insert), ZDC
S13360 6050VE	2	2	2	2	2	0	bEMCAL

Table 1: Number of SiPMs irradiated at each fluence level. All SiPM models are manufactured by Hamamatsu. The calorimeter nomenclature is as follows: nHCAL, bHCAL, and pHCAL denote the electron-going endcap, barrel, and hadron-going endcap hadronic calorimeters, respectively. Similarly, nEMCAL, bEMCAL, and pEMCAL refer to the electron-going endcap, barrel, and hadron-going endcap electromagnetic calorimeters. ZDC stands for Zero Degree Calorimeter. The term "Insert" refers to the region of the pHCAL covering the pseudorapidity range $3.0 < \eta < 4.0$ with respect to the proton beam.

Sample of results





Consistency checks

Current scales with area, as expected.

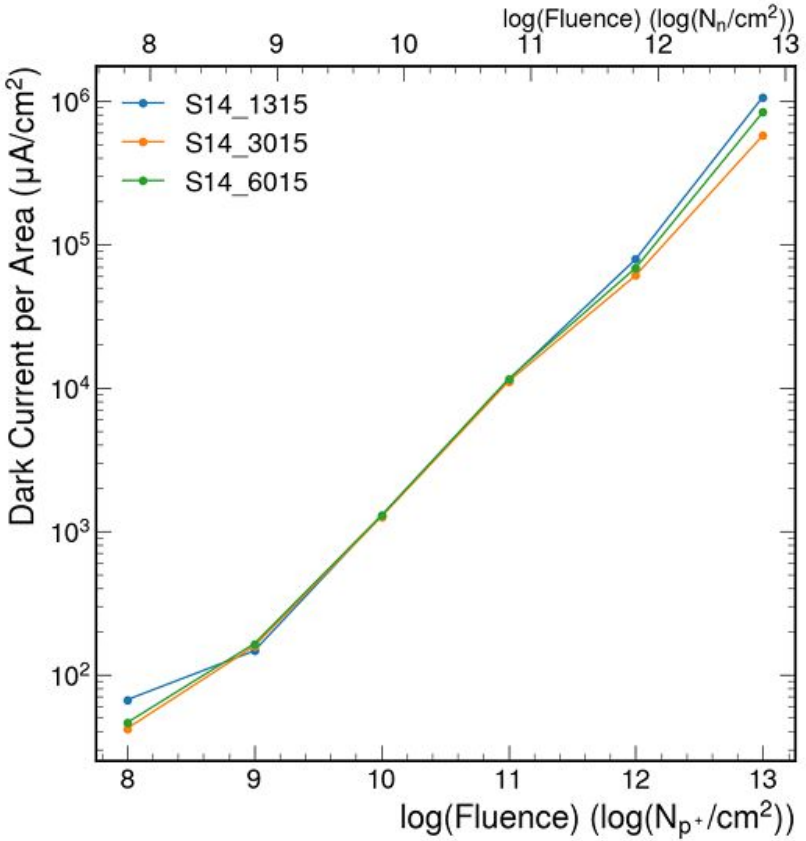


Figure 4: Dark current per unit area vs fluence for different types of SiPMs operating at +2V overvoltage. The data in the plot are scaled based on the acquisition date of each data point to account for room-temperature annealing effects.

Annealing time constant

Most relevant for Insert and ZDC

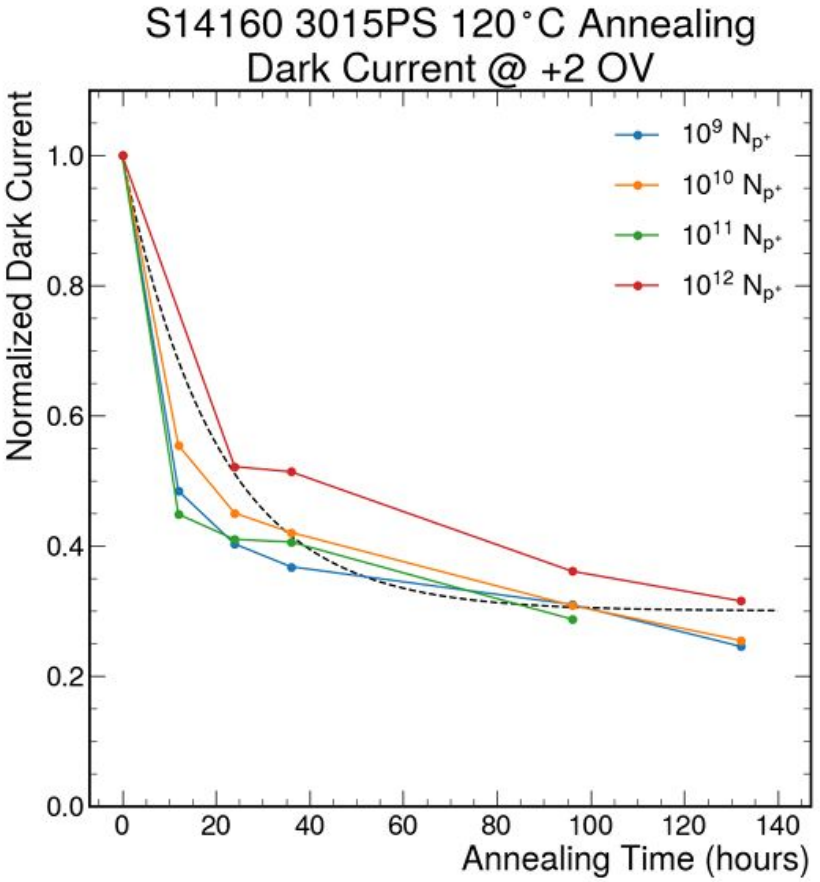


Figure 5: Dark current trends for various irradiation fluences measured at di
ferent annealing times at a constant temperature of 120 °C and at +2V ove
voltages.

4. Summary and Outlook

We have presented a comprehensive dataset of dark current in radiation-damaged SiPMs irradiated at fluence levels expected at the EIC. Our dataset comprises measurements spanning all relevant bias voltage ranges, fluence levels, and SiPM models used in every calorimeter subsystem of the ePIC detector. We also measured the recovery of radiation damage after high-temperature annealing—a process likely required for subsystems operating under the harshest conditions, such as the calorimeter Insert and the Zero-Degree Calorimeter.

Our dataset will underpin future studies on expected noise levels and realistic thresholds, which vary by system because different subsystems employ distinct digitization schemes ranging from ASICs to custom solutions with discrete components.

Our dataset informs realistic simulations and defines operational strategies, including determining the appropriate overvoltage for each subsystem, establishing mitigation strategies (such as planning high-temperature annealing), and setting safety factors. It will also enable realistic simulations of physics performance under the expected noise levels.

Published December 18, 2024 | Version v1

Dataset Open

EIC SiPM Test Dataset: SiPM Irradiation and Annealing Data

Huang, JiaJun

Data file used in 'Measurement of SiPM Dark Currents and Annealing Recovery for Fluences Expected in ePIC Calorimeters at the Future Electron-Ion Collider'. Data files consist of LabVIEW readout of 'Voltage, Current, Voltage, ...' pattern with Units of "Volt and Amp". Each folder separates SiPMs types and test performed on the SiPM.

Files

Data.zip

Data.zip

- Data
  - S13_6050
    - New_Irradiated
      - 6050A08_UTC_20241004__00_12.txt 2.6 kB
      - 6050A09_UTC_20241004__00_22.txt 1.3 kB
      - 6050A10_UTC_20241004__00_25.txt 1.3 kB
      - 6050A11_UTC_20241004__00_29.txt 1.3 kB

Versions

Version v1 Dec 18, 2024

10.5281/zenodo.14520936

Cite all versions? You can cite all versions by using the DOI 10.5281/zenodo.14520935. This DOI represents all versions, and will always resolve to the latest one. Read more.

External resources

Indexed in

OpenAIRE

Details

Special thanks to Sasha (EIC project) for paying the beam time, and the UCR team for doing great work:

Barak, Jiajun, Sean, Ryan, Miguel R.