sPHENIX Director's Review

Calorimeters and Calorimeter Electronics: Silicon Photomultipliers

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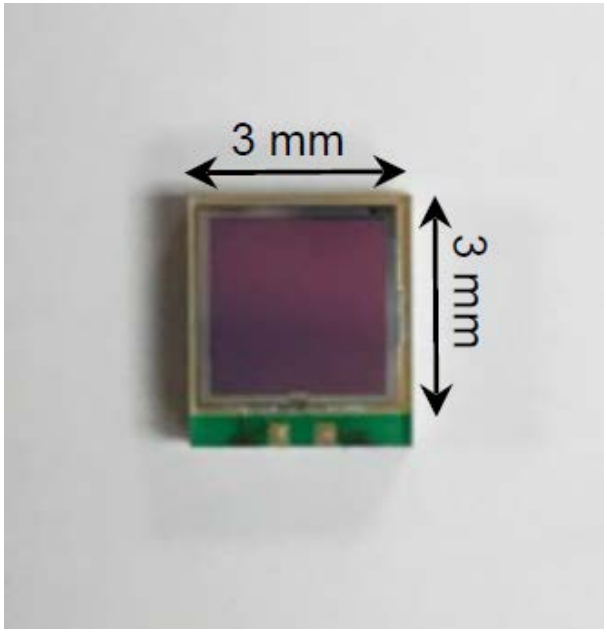
BNL

The Subsystem

- Silicon photomultipliers (SiPMs) – choice of optical sensors for both the EMCal and HCal
- Capable of detecting single photons
- Advantages compared to photomultiplier tubes
  - Insensitive to magnetic fields – critical for calorimetry inside solenoid
  - Significantly lower operating voltages (< 100 V rather than > 1000 V)
- Disadvantages
  - Temperature sensitive: temperature must be monitored
  - Susceptible to neutron damage: increased leakage current

The Subsystem Technical Overview

- Hamamatsu S12572-015P SiPM
  - Catalog item
  - 15 x 15 μm^2 pixel size
  - 40,000 μ-cells
  - Dynamic range: 10^4
  - Gain: $2x10^5$



Scope

- WBS 1.5.1 Optical Sensors:
  - EMCal: 98304 SiPMS
  - HCal: 13824 SiPMs

- SiPM procurement, testing, and sorting
  - Test gain as a function of operating voltage for all ~120k SiPMs required for the EMCal and HCal
  - Sort SiPMs into sets with operating voltage matched for shipment to assembly warehouse
    - For final detector, operating voltage will be controlled for individual calorimeter towers, i.e. groups of 4 SiPMs

Subsystem Collaborators

- University of Michigan
  - Christine Aidala – L3 Manager, Associate Professor
  - Postdoc – currently Michael Skoby
  - Graduate student – currently Nicole Lewis
  - Undergraduates
- Augustana University
  - Nathan Grau – Associate Professor
  - Undergraduates
- Debrecen University – building the testing devices and possible testing site
  - Balazs Ujvary – Associate Professor
  - Jozsef Imrek – FPGA expert
  - Graduate students - Tamas Majoros, Zhandong Sun
  - Undergraduates - electrical engineering as well as physics students

Schedule Drivers

- Delivery by Hamamatsu of 10,000 SiPMs every 4 weeks starting September 2019
- Delivery by Debrecen of first testing device 2018
- Availability starting September 2019 of 3 working SiPM testing devices capable of testing at least 64 SiPMs each in a period of 4 hours or less
- Means of recovering schedule slippage
  - Continue testing during weekends
  - Test 4 rather than 3 batches per day at each site by working at night
  - Use spare testing device
- If one site is no longer able to perform testing, 2 testing devices can be operated at a single site

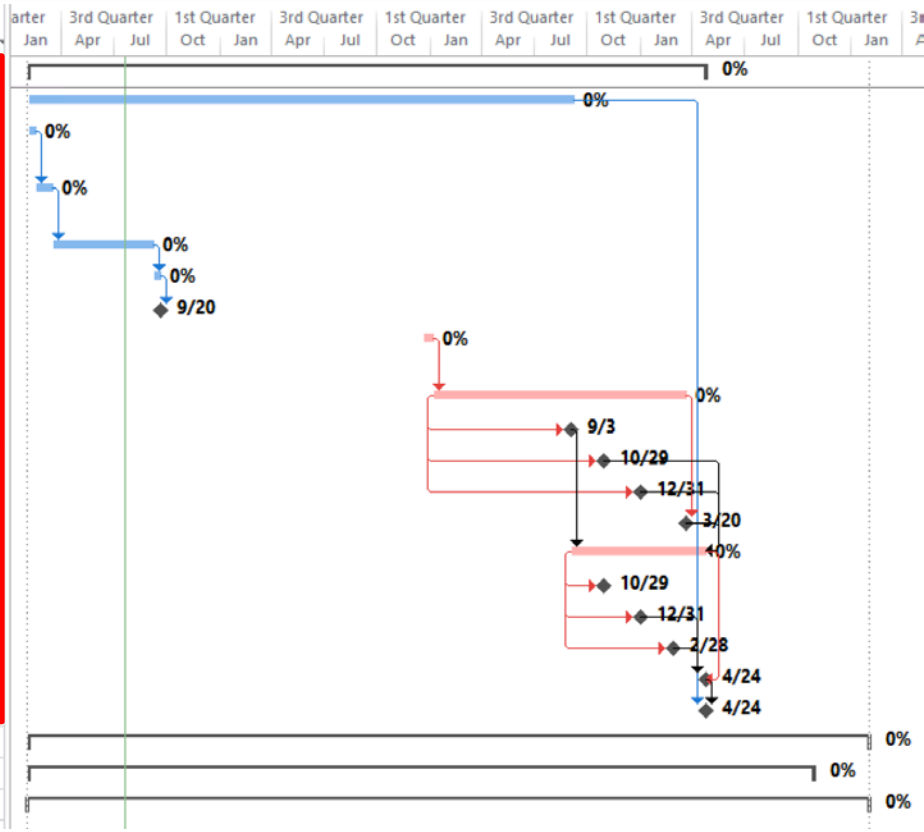
Cost Drivers

- SiPM procurement: Final cost negotiated with Hamamatsu for SiPMs and any testing performed by Hamamatsu

- Hours of labor needed for SiPM testing
  - Current estimates assume each device completes testing of 64 SiPMs in 4 hours, with 3 devices + 1 spare distributed at 3 sites
  - Current estimates assume 8 hours of labor per day needed to test 3 batches each of 64 SiPMs at each site, i.e. continuous supervision of testing device for two batches per day and no supervision for third batch

Basis of Estimate and Resource-Loaded Schedule

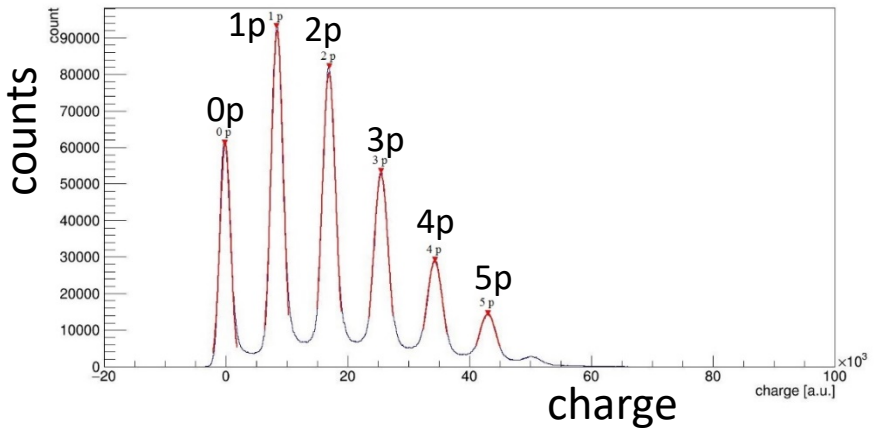
WBS	Task Name	Fixed_Cost_sPHEN
1.5.1	**Optical Sensors**	**$1,095,500.00**
1.5.1.1	L3 Oversite: Optical Sensors	$0.00
1.5.1.2	Write Design Change Specifications for Optical Sensors: Preproduction Prototype	$0.00
1.5.1.3	Obtain Quotes for Optical Sensors: Preproduction Prototype	$0.00
1.5.1.4	Order Sensors: Preproduction Prototype	$25,500.00
1.5.1.5	Q/A Delivered Sensors: Preproduction Prototype	$11,000.00
1.5.1.6	EMCal/HCal Sensors Tested and Delivered: Preproduction	$0.00
1.5.1.7	Write design change specifications for EMCal/HCal sensors: Production	$0.00
1.5.1.8	Order Sensors: Production	$1,048,000.00
1.5.1.9	25% Sensors Received: Production	$0.00
1.5.1.10	50% Sensors Received: Production	$0.00
1.5.1.11	75% Sensors Received: Production	$0.00
1.5.1.12	Sensors: Production Complete	$0.00
1.5.1.13	Q/A EMCal/HCal Sensors: Production	$11,000.00
1.5.1.14	25% Sensors Q/A Tested & Delivered: Production	$0.00
1.5.1.15	50% Sensors Q/A Tested & Delivered: Production	$0.00
1.5.1.16	75% Sensors Q/A Tested & Delivered: Production	$0.00
1.5.1.17	EMCal/HCal Sensors Tested and Delivered: Production	$0.00
1.5.1.18	Optical Sensor Procurement Complete	$0.00
1.5.2	**Calorimeter Front End Electronics**	**$1,684,900.00**
1.5.3	**Calorimeter Digitizer System**	**$1,700,600.00**
1.5.4	**Project Management**	**$0.00**

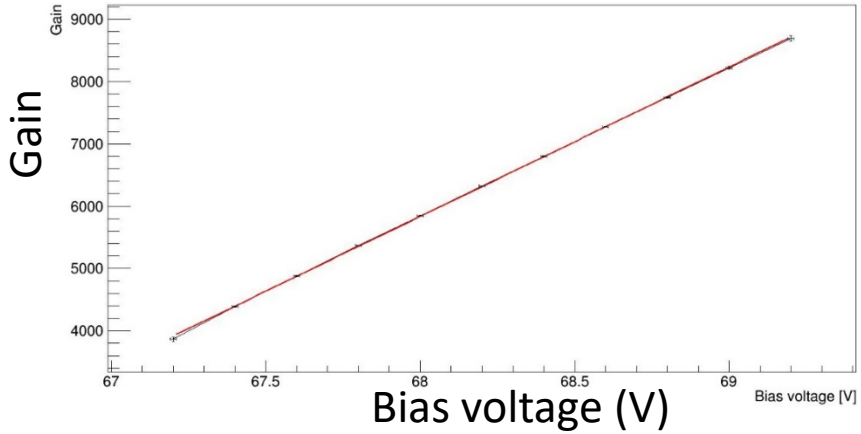


- SiPM cost and schedule based on quotes from Hamamatsu
- SiPM testing device expected specifications and cost based on information provided by Debrecen. Prototype testing device has already been produced.

Status and Highlights

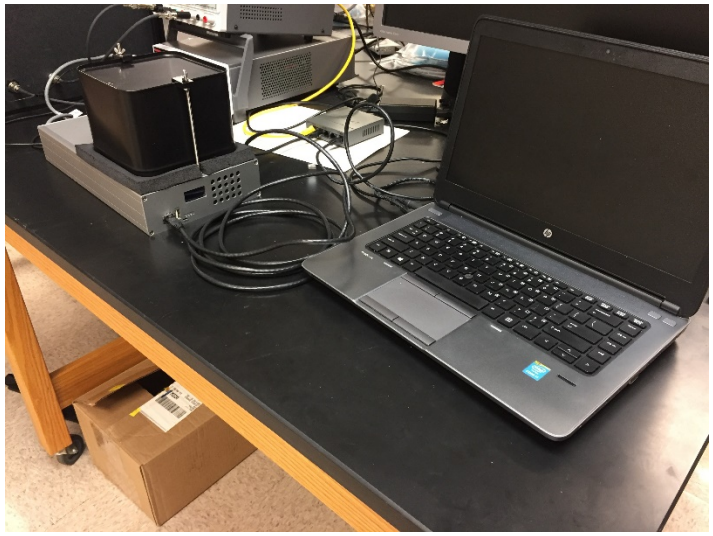
- Debrecen taking lead in developing testing hardware
  - Have produced prototype capable of testing 4 SiPMs at a time
  - Device self-contained including LED and power supplies, requiring only dedicated computer with Ethernet and virtual machine
- Michigan leading the testing efforts
  - Lab space of C. Aidala, 867 sq. ft. (~81 sq. m) available
  - Prototype testing device currently at Michigan, set up to allow remote operation from Debrecen or elsewhere
- Measurements
  - Current as a function of bias voltage, allowing determination of breakdown voltage
  - Integrated charge at 11 operating voltages, showing 1-, 2-, 3-photon peaks, etc. Allows calculation of gain in order to determine operating voltage within 0.02 V



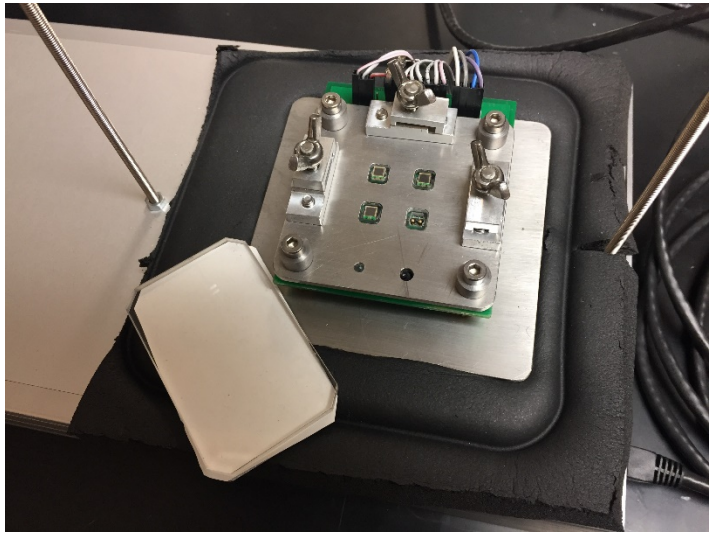


Status and Highlights

- Prototype testing device will be brought to BNL September 1, 2017 for modifications by the Debrecen group that will improve the testing rate, and for subsequent testing of the 1500 SiPMs needed for final prototype calorimeter in preparation for FNAL beam test in 2018
- SiPM testing for final prototype calorimeter will be performed at BNL by personnel from Debrecen and Michigan
- Experience gained during this larger-scale testing will serve to finalize the design of the large (64 channel) SiPM testing devices to be built by Debrecen



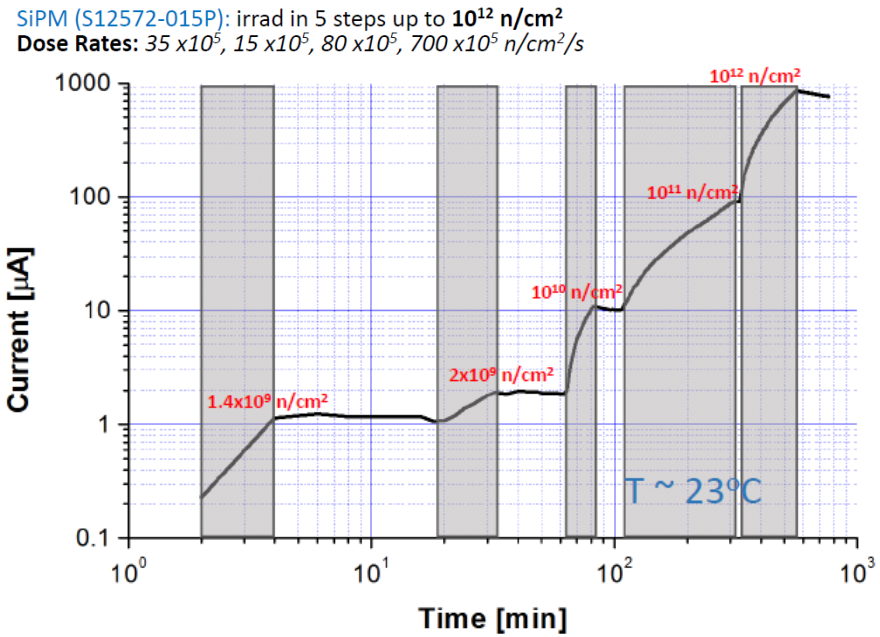
Prototype testing device at Michigan



Issues and Concerns

- Effects of neutron radiation damage to SiPMs over time still need to be considered in detail
- Initial irradiation studies performed at ATOMKI and BNL

ATOMKI



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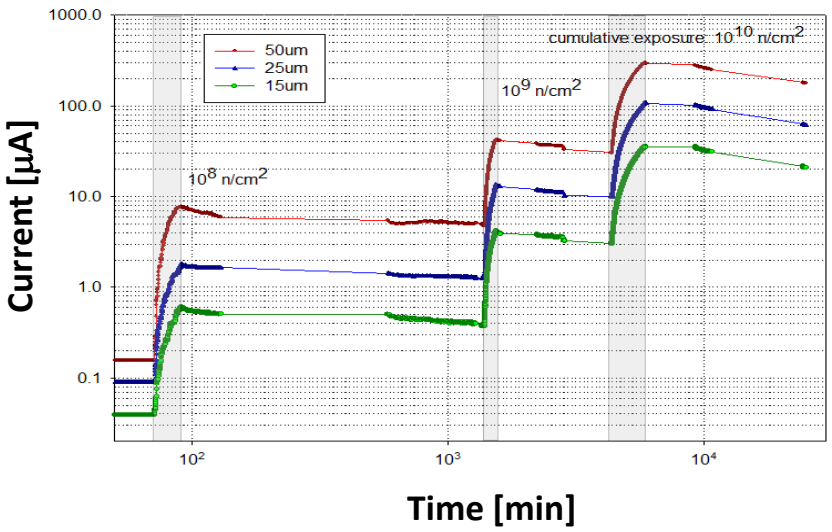


Back Up

Testing Plan

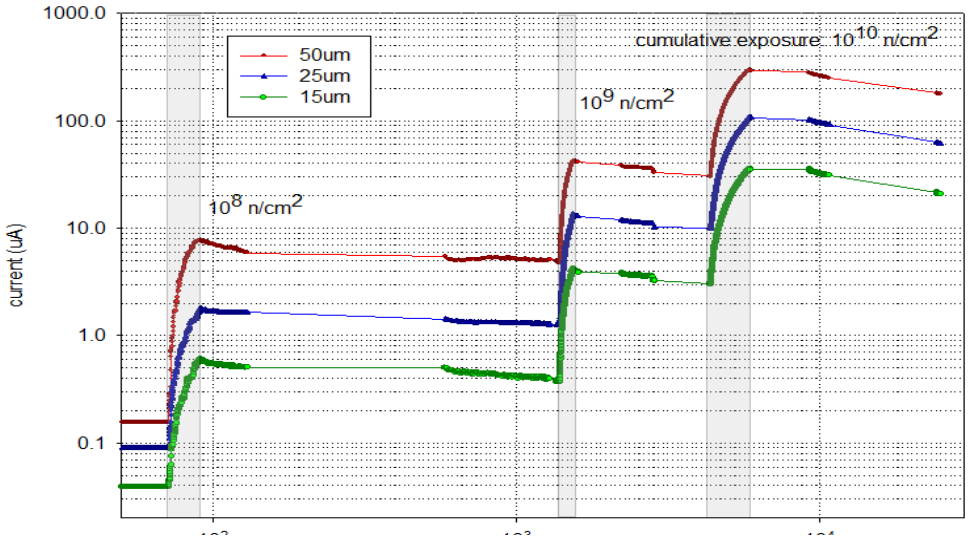
- SiPMs to be tested in parallel at Michigan, Augustana, and 1 other institution, requiring 3 testing devices + 1 spare, about $8,000 each (TBC).
- Starting in September 2018, Hamamatsu will ship about 10k SiPMs every 4 weeks, requiring about 500 devices to be tested each day (5 days a week). The SiPMs will be shipped on 13x13 trays, therefore, each institution will receive about 60 trays every 4 weeks.
- The SiPMs will have an accompanying traveler sheet that lists the SiPMs by tray position and serial number. Hamamatsu will also provide the operating voltage and gain for 3% (TBD) of the devices. Before testing begins on an individual tray, the traveler sheet will be scanned and its information uploaded into an Excel database. This database will be part of the testing device software and is being developed by Debrecen and Michigan collaborators.
- Next, each SiPM will be placed in the 8x8 testing array and the SiPM array position will be recorded in the database. The handling of the SiPMs will only require common tweezers. Once the SiPMs are in place, the testing device will measure the gain at a series of supply voltage settings, determine the operating voltage (breakdown voltage + 4V) for each SiPM, measure the corresponding temperature, and automatically record this information into the database (TBD). The testing device will require about 4 hours (TBD) to complete measurements for all 64 SiPMs.
- The SiPMs will then be sorted by operating voltage before placing the next set of 64 SiPMs into the testing device. Because the SiPMs need to be matched within 0.02 V (TBC) and Hamamatsu has indicated that all SiPM operating voltages will be within +/- 1 V, the devices will be sorted into 100 0.02-V bins. The voltage bin and tray position of each SiPM will be recorded in the database. This sorting procedure will take about 20 minutes for each set of 64 SiPMs. Loading the next set of 64 SiPMs into the testing device will take less than a few minutes.
- Testing and sorting of sets of 64 SiPMs will done up to 3 times per day for each institution (3 sets x 64 SiPMs x 3 testing devices = 576 SiPMs/day).
- Schedule for shipping SiPMs from institutions to the assembly warehouse TBD.

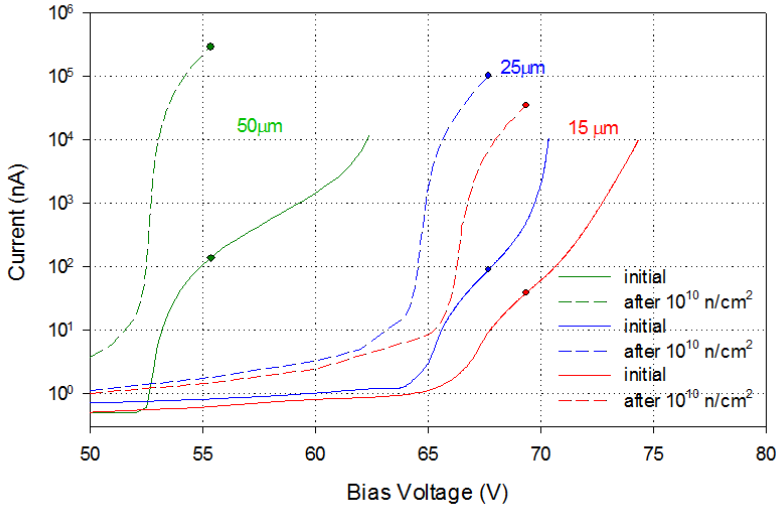
Test Capability at Debrecen

- In addition to physics, also a strong program in electrical engineering
  - About 300 BSc/MSc/PhD students combined
- SiPM experts not just in the department, but also in the neighboring institutes
  - ATOMKI, Department of Nuclear Medicine, also a long-time collaboration with National Instruments, which has their European center at Debrecen
- Dedicated lab for SiPM development (and testing) from September 2017
- 2 PhD students and 1-2 experts can manage the test, 5-10 students can be involved easily

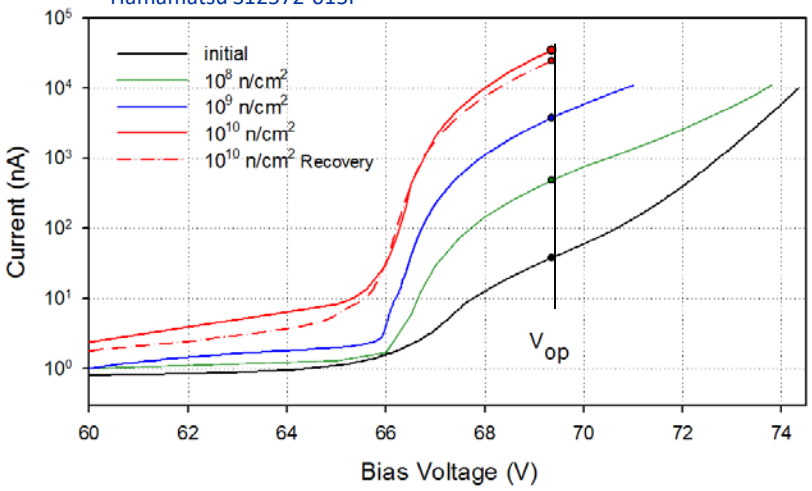
Neutron Irradiation

SiPMs irradiated with 14 MeV neutrons up to 10^{10} n/cm^2 (BNL)





Hamamatsu S12572-015P



Pixel Size	I_{int} at V_{op} (nA)	I_{final} at V_{op} (µA)	Factor Increase
15 µm	38	36	937
25 µm	96	104	1085
50 µm	137	290	2116

- Steady increase in current with dose
- Small initial recovery followed by slow long term recovery at RT
- Small increase in current below V_{op}
- Large increase at V_{op}
- Smaller pixel sizes show less damage