Quality Assurance on a custom SiPMs array for the Mu2e calorimeter

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The Mu2e Experiment

Mu2e will search for coherent μ⁻ Al → e⁻ Al at a sensitivity level of few parts by 10^{-17}, an improvement by 10^4 over the existing limit.

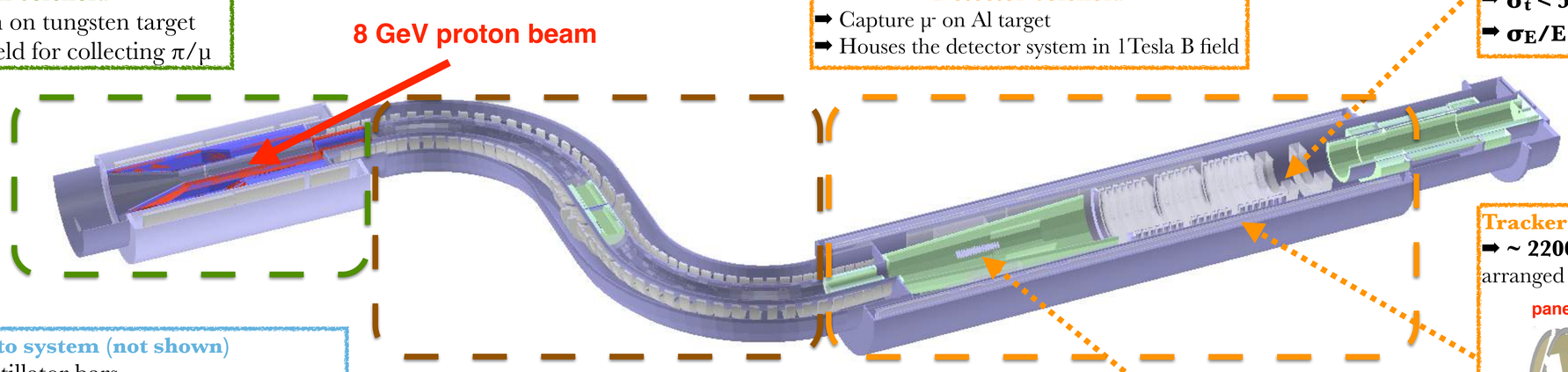
Search for muon conversion explores new physics sector and probes physics scales up to ~ 10^4 TeV, beyond the reach of present or planned high energy colliders.

The experimental expected sensitivity is $R_{\mu e} = \frac{\Gamma(\mu^- + (A,Z) \to e^- + (A,Z))}{\Gamma(\mu^- + (A,Z) \to \text{capture})} \leq 6 \times 10^{-17}$ @ 90% CL

Production Solenoid
- 8 GeV proton beam on tungsten target
- Graded magnetic field for collecting π/μ

Detector Solenoid
- Capture μ⁻ on Al target
- Houses the detector system in 1Tesla B field

Calorimeter
- 2 disks of **~ 678 pure CsI crystals**
- **σ_t < 500 ps @ 100 MeV**
- **σ_E/E < 10% @ 100 MeV**

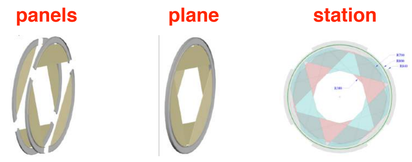


Cosmic Ray Veto system (not shown)
- 4 layers of extruded scintillator bars
- Surrounds the half Transport and the Detector Solenoid
- Designed to provide inefficiency of ~ 10^{-4}

Transport Solenoid
- Select low momentum μ⁻
- Antiproton absorbers

Stopping target
- 17 Al foils; μ lifetime in the Al mesoatom is 864 ns

Tracker
- **~ 22000 straw tubes** filled with Ar/CO_2 arranged in planes on 18 stations



- **$\Delta p/p$ ~ 2‰ @ 100 MeV/c**

SiPM characterization

Mu2e custom SiPM array

The Mu2e calorimeter will use two 2x3 matrix of 6x6 mm² 50 μm pixel **UV extended SiPMs** as readout system. Follow the main specs:
- the analog signal is made by the parallel of two series of 3 SiPMs
- SiPMs employ Si resin coating to improve sensitivity in the UV region

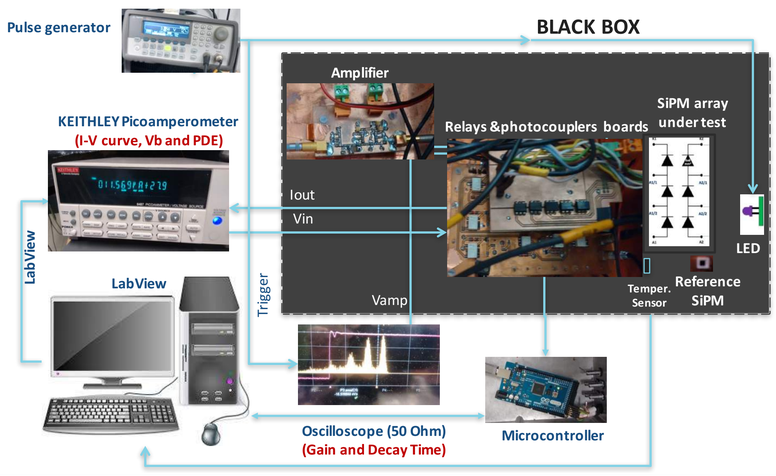
Hamamatsu | SENSL | Advansid

Requirements

The Mu2e SiPM array have to provide the following performance:
- ✓ **gain** above 10^6 @ $\mathbf{V_{op}} = \mathbf{V_{br}}$ + 3 V for each monolithic SiPM cell
- ✓ **photon detection efficiency (PDE)** above 20% at 315 nm
- ✓ **mean time to failure (MTTF)** of at least O(10^6)
- ✓ **radiation hardness** to neutrons up to ~ 10^{12} $n_{1MeV\text{-}eq}/cm^2$
- ✓ **radiation hardness** to ionizing dose up to ~ 20 krad
- ✓ **spread in V_{op}** better than 0.5% within the device
- ✓ **spread in I_{dark}** better than 15% within the device
- ✓ **thermal resistance** below 7x10^{-4} m^2 K/W

Experimental setup

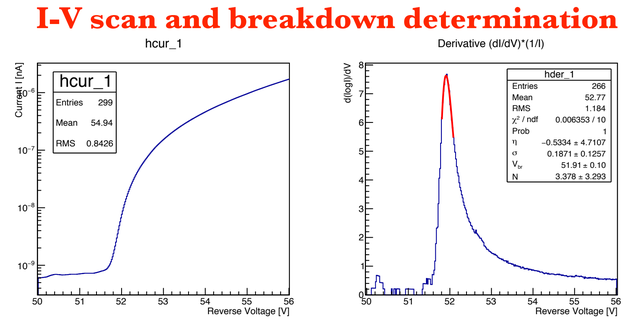
To measure the Gain, Vop, and Idark of the SiPMs we used a semi-automatized system that consists of:
- ✓ Pulse generator + LED @ 315 nm
- ✓ **Source meter** KEITHLEY 6487
- ✓ **Micro-controller** to drive a relay board and a voltage amplifier
- ✓ **1 SiPM** used as **reference** for the PDE measurement
- ✓ Scope based **DAQ system**
- ✓ **Cooling system** to keep temperature stable at 20°deg



SiPM uniformity

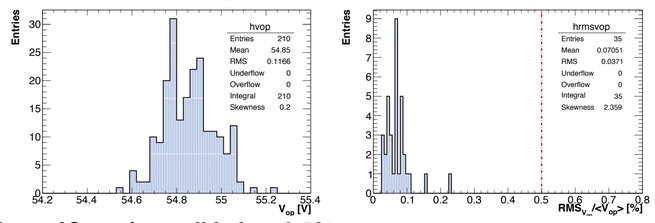
I-V characterization of the single cells provided precise measurement of the breakdown voltage **V_{br}** and of the **I_{dark}** @ $V_{op} = V_{br} + 3$ V

I-V scan and breakdown determination



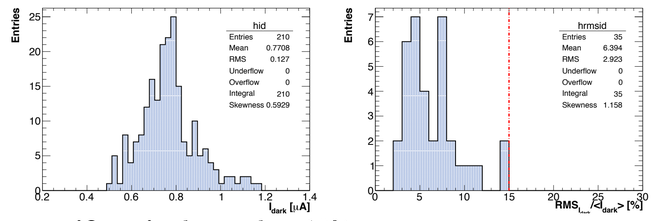
- **V_{br}** was determined using the peak of the **dlog(I)/dV vs V curve**
- Same I-V scan provided the measurement of **I_{dark}** @ **V_{op}**

Operational voltage



✓ **V_{op} uniformity** well below 0.5%

Dark current

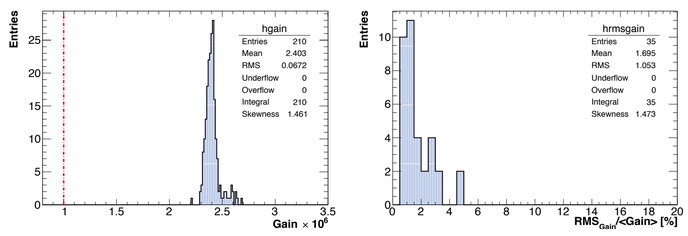


✓ **I_{dark} uniformity** better than 15%

Gain and Photo-Detection Efficiency

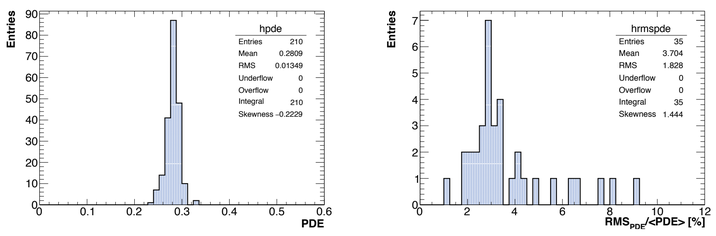
Gain

Photosensor irradiated with an high intensity ^{60}Co source up to 20 krad (200 Gy) @ CALLIOPE - Gamma Irradiation Facility (Casaccia, ENEA)



PDE

Photosensor irradiated with an high intensity ^{60}Co source up to 20 krad (200 Gy) @ CALLIOPE - Gamma Irradiation Facility (Casaccia, ENEA)

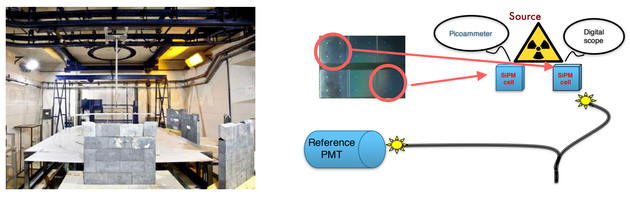


Radiation hardness tests & Mean Time to Failure

Damage from ionizing dose

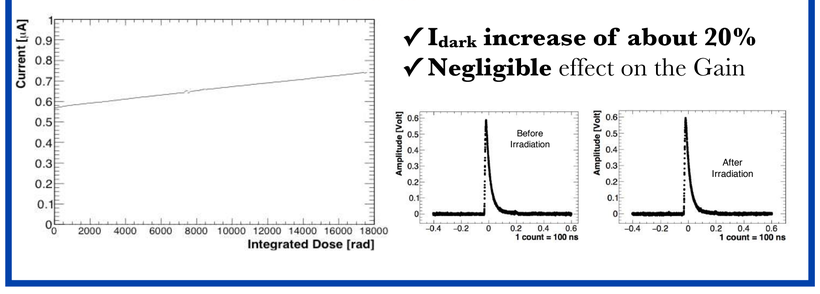
Photosensor irradiated with an high intensity ^{60}Co source up to 20 krad (200 Gy) @ CALLIOPE - Gamma Irradiation Facility (Casaccia, ENEA)

experimental setup



- 1cell used to measure Idark and the other to monitor the Gain
- One PMT was used as reference for the Gain measurement

results

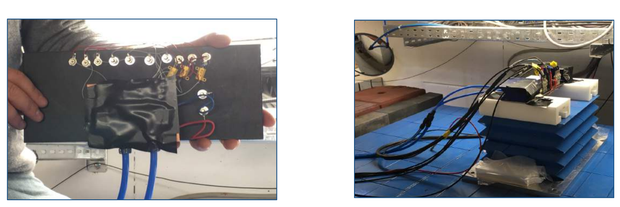


- ✓ **I_{dark} increase of about 20%**
- ✓ **Negligible** effect on the Gain

Damage from non-ionizing dose

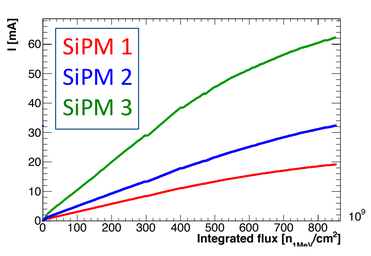
Tests performed @ Elbe Positron Source (HZDR, Germany), which produces neutrons firing e- on a W target, up to ~ 9 x 10^{11} $n_{1MeVeq}/cm2$

experimental setup

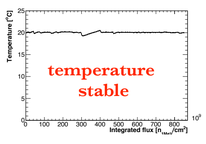


- **3 SiPMs** tested together
- Temperature **stabilized and monitored** @ 20 deg

results



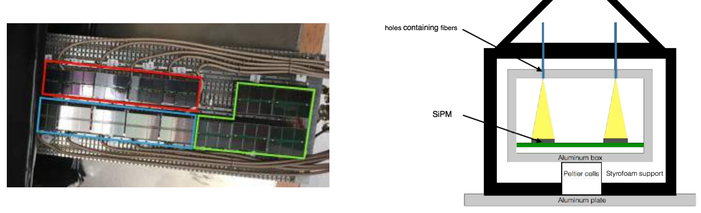
- ✓ **I_{dark} increased** due to the neutron induced damage
- ✓ **Negligible** effect on the Gain



Mean Time To Failure

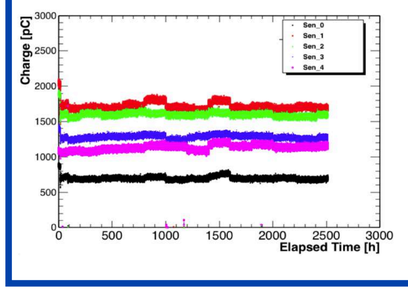
The MTTF evaluated by testing for a long period a small number of sensors at 50 °C using 2 Peltier cells

experimental setup



- Stress temperature **50° C for 3.5 months**
- Charge response to a LED light acquired every 2 minutes

results



- ✓ MTTF > 0.6 x 10^6 hours