Pre-Production and Quality Assurance of the Mu2e Silicon Multipliers

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On the behalf of the Mu2e calorimeter collaboration
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mu2e.fnal.gov

1. The Mu2e Experiment: a Search for $\mu + N \rightarrow e + N$

The **Mu2e Experiment** will search for coherent, neutrinoless conversion of muons into electrons in the field of a nucleus**. Such a charged lepton flavor-violating reaction allows to probe energy scales up to thousands TeV**, far above the highest energy reachable at the most powerful colliders. If no conversion events are observed in three years of running, Mu2e will set a limit on the ratio between the conversion rate and the capture rate: **$R_{\mu e,}$<6 x 10^{-17} (@ 90% C.L.).**

Production Solenoid (PS)

An **8 GeV proton beam** hits a tungsten target
A graded magnetic field reflects muons to the TS

Cosmic Ray Veto (CRV)

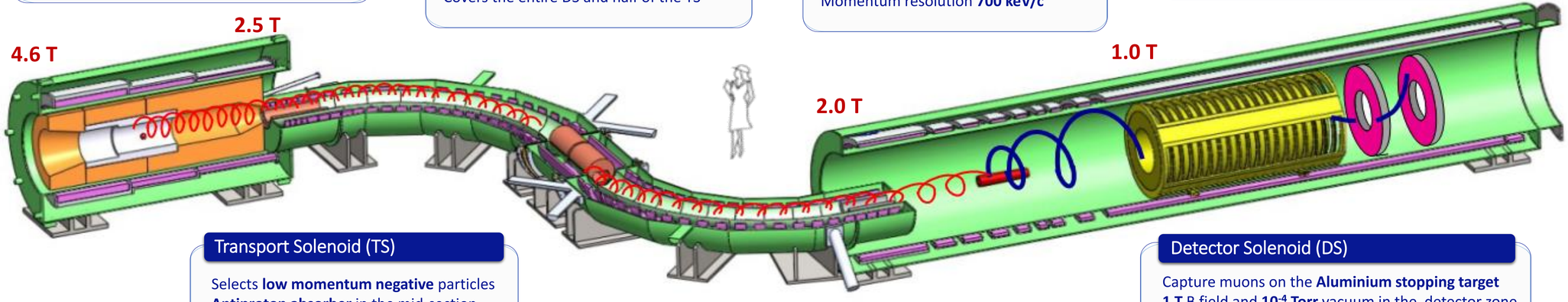
4 layers of plastic scintillator bars
Covers the entire DS and half of the TS

Straw Tracker (TRK)

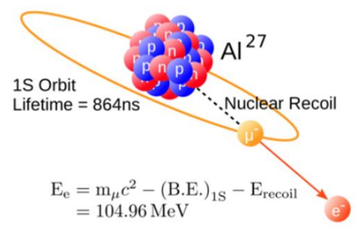
20000 low mass straw drift tubes
Momentum resolution **700 keV/c**

Electromagnetic Calorimeter (ECAL)

1348 undoped CsI crystals
Energy, Time and Position measurements



Schematic view of the Mu2e beamline



Transport Solenoid (TS)

Selects **low momentum negative** particles
Antiproton absorber in the mid-section

Detector Solenoid (DS)

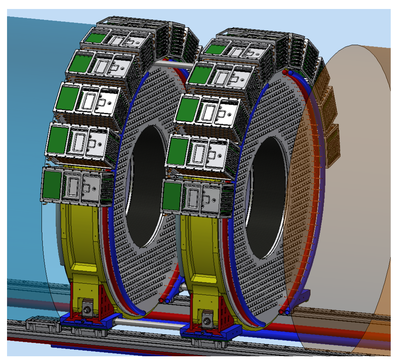
Capture muons on the **Aluminium stopping target**
1 T B field and **10^{-4} Torr** vacuum in the detector zone

Experimental Technique

Stop muons in Aluminium
Muons quickly get to 1S orbit
Lifetime of muonic atom is 864 ns
Look for the 105 MeV conversion electron

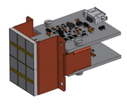
2. The Electromagnetic Calorimeter

The Electromagnetic Calorimeter is an high granularity crystal calorimeter consisting of about 1348 **undoped CsI crystals**, 3.4x3.4x20 cm^3 each. The crystals are arranged in **two disks**, separated by 75 cm, with inner and outer radii of 37.4 cm and 66 cm respectively.



Calorimeter disks

Each crystal is coupled to two 14x20 mm^2 **large area UV-extended SiPM**, for a total of **2694 electronics channels**. Photosensors are packed using a parallel arrangement of two groups of three cells biased in series.



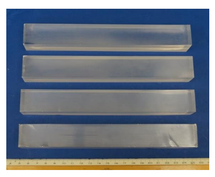
SiPM and FEE

Calorimeter Requirements:

- Particle identification μ/e
- Seed for track pattern recognition
- Tracking independent trigger

⇨ **$\Delta E/E$ < 10% and Δt < 500 ps**

⇨ **Position resolution of O(1 cm)**



CsI crystals

Electronics crates are located **inside the cryostat** to limit the number of pass through connectors.

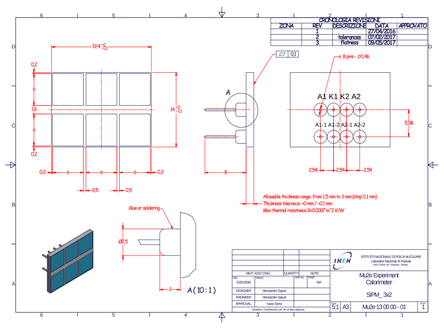
3. The Mu2e Custom SiPM

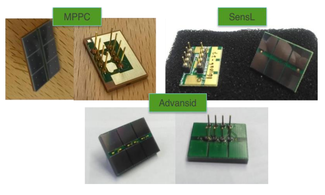
SiPM Requirements:

- A Gain greater than 10^6
- A PDE above 20% at 310 nm
- A fast rise and recovery time
- A large reliability

And to stand a very heavy radiation environment:

- **Total Ionizing Dose (TID) of 7 kRad/yr**
- **Neutron flux of 1x10^{11} 1 MeV (Si)/yr**





The Mu2e custom SiPM are made of a 2x3 array of 6x6 mm^2 UV-extended SiPM. The two series readout reduces the overall capacity and allows to reach a faster signals.

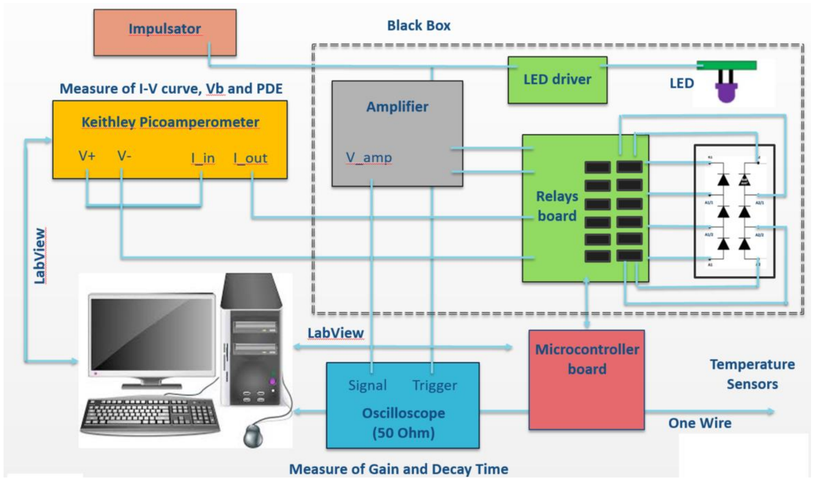
A pre-production of 150 Mu2e SiPMs has been procured by three international firms (Hamamatsu, Sensl and Advansid).

4. Quality Assurance Process

Automatized Test Station:

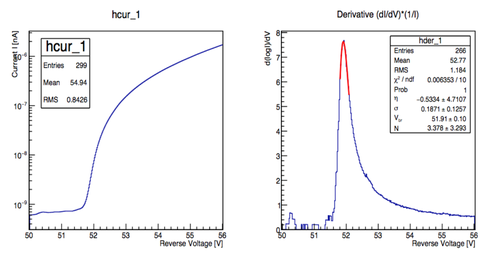
Each SiPM single cell is tested using a semi-automatized station controlled by Labview.

- Black box to prevent external light on the Sensor Under Test (SUT) encapsulated in a copper box in order to provide a thermal coupling between the package and the copper.
- Copper support refrigerated with a chiller → temperature stable at 20°C
- Custom relay board to select the cell biased by a KEITHLEY 6487
- I-V curve and Breakdown Voltage measurements
- SiPM cells illuminated with a 315 nm LED light
- Cascade of Mar-8 ampliers, with a total gain of Gamp = 250,→Gain and PDE measurements

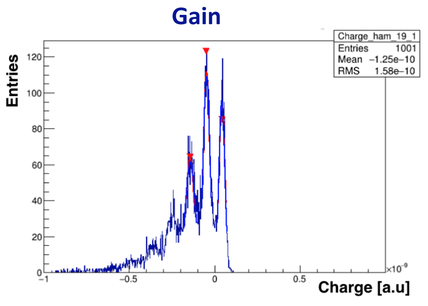


Scheme of the test station.

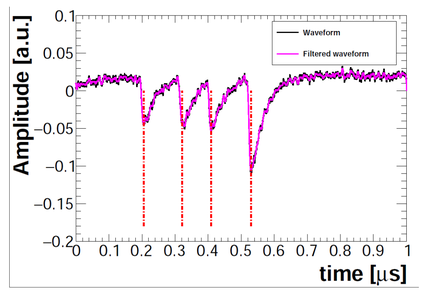
I-V Dark Curve and Breakdown Voltage

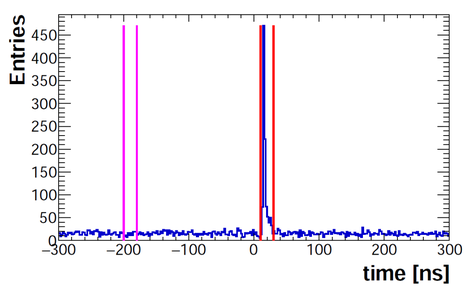


Gain



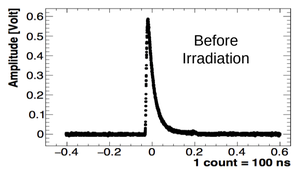
Photon Detection Efficiency

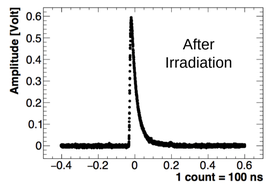


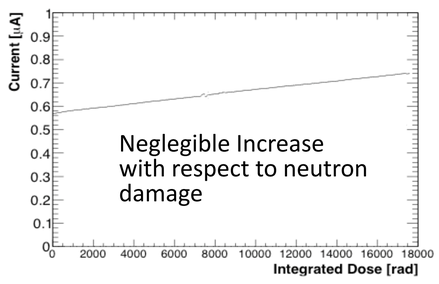


5. Radiation Hardness

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

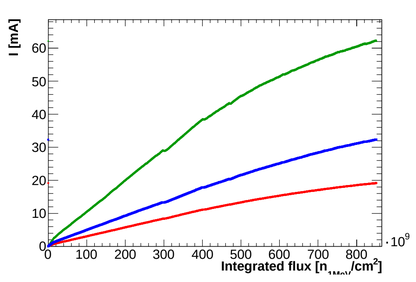






3 SiPMs irradiated @ EPOS (HZDR, Dresden)

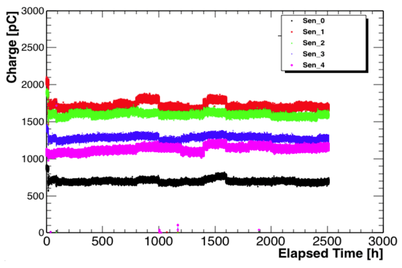
- Integrated flux 8.5 x 10^{11} n_{1MeV}/cm^2
- Cooling system: chiller + Peltier cell
- Temperature stable at 20 ˚C monitored by a PT100
- Single cell + temperature acquired with a Agilent 34972A LXI Data Acquisition / Data Logger Switch Unit every 10 s



Current @ start and end of the irradiation

SiPM 1: 3 uA -19.5 mA
SiPM 2: 22 uA – 32.4 mA
SiPM 3: 29 uA – 62 mA

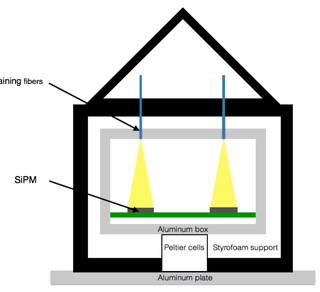
6. Mean Time To Failure



$MTTF > 0.5 \times N_{hours} \times AF \times N_{SiPM}$

2556 100.1 5 per vendor

- Stress temperature 50 ˚C
- Charge response to a LED light acquired every 2 minutes
- No ”deads” →MTTF> 0.6 x **10^6 hours**



7. Conclusions

A pre-production of 150 Mu2e SiPMs has been procured by three international firms (Hamamatsu, Sensl and Advansid). A detailed quality assurance, QA, has been carried out on each SiPM for the determination of its own operation voltage, gain, quenching time, dark current and PDE. The measurement of the MTTF for a small random sample of the pro-production group has been also completed as well as the determination of the dark current increase as a function of the neutron fluency.

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