Irradiation study of UV Silicon Photomultipliers for the Mu2e Calorimeter

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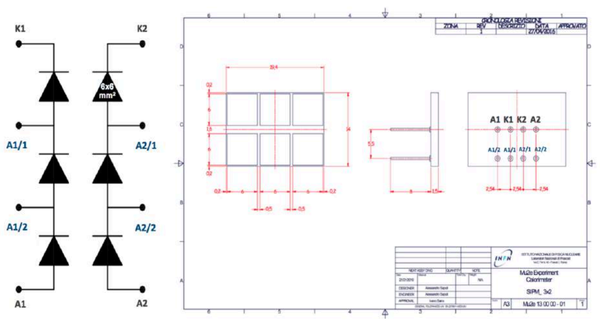
Abstract

The Mu2e calorimeter is composed of 1400 un-doped CsI crystals coupled to large area UV extended Silicon Photomultipliers (SiPMs) arranged in two annular disks. This calorimeter has to provide precise information on energy, timing and position resolutions. It should also be fast enough to handle the high rate background and it must operate and survive in the high radiation environment. Simulation studies estimated that, in the highest irradiated regions, each photo-sensor will absorb a dose of 20 krad and will be exposed to a neutron fluency of 3 × 10^{11} n_{1MeV}/cm^2 in three years of running, with a safety factor of 3 included.
At the end of 2015, we have concluded a campaign at Frascati Neutron Generator (FNG) measuring the response of two different 16 array models from Hamamatsu, which differ for the coating windows.
In 2016, we have carried out two irradiation campaigns to measure the neutrons and photons response at the HZDR of Dresden and at the Calliope gamma irradiation facility at ENEA-Casaccia, respectively.
A negligible increment of the leakage current and gain has been observed with the dose irradiation.
At the end of the neutron irradiation, the gain does not show large changes whilst the leakage current increases of around a factor of 2000. In these conditions, the too high leakage current makes problematic to bias the SiPMs, thus requiring to cool them down in the experiment to a running temperature of ~ 0 °C.

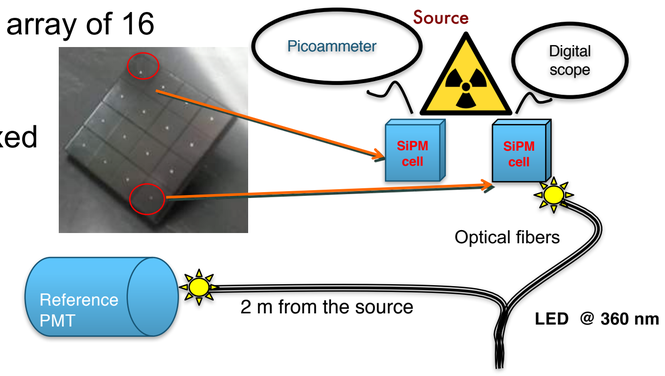
Mu2e Custom SiPM



- The Mu2e SiPM will be made of a 2 x 3 array (6 cells) of 6x6 mm^2 UV extended SiPMs
  - Ensure a high quantum efficiency @ 315 nm (CsI emission peak)
  - A parallel arrangement of two groups of three cells biased in series
  - 2 SiPMs per crystal to ensure redundancy
  - Fast signal for pileup and timing resolution

Experimental setup

- For the Hamamatsu, the SIPM is an array of 16 3 x 3 mm^2 cells. Out of these cells :
  - 1 cell is used for leakage current
  - 1 cell is used for response to a fixed UV LED pulse
  - PMT used as reference for the light input

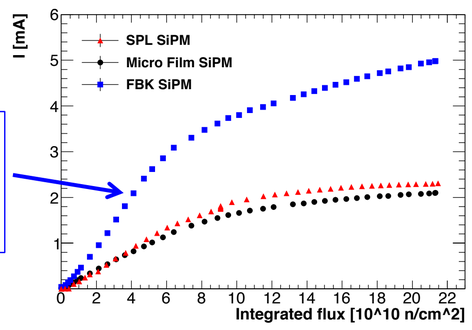


SiPMs tested	Dimensions (mm^2)	Vop (V)
SPL SiPM	12 x 12	53.9
Micro Film SiPM	12 x 12	53.95
FBK SiPM	6 x 6 (monolithic)	32.5

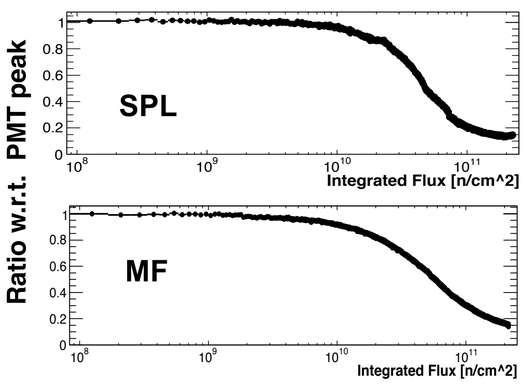
For the monolithic FBK we have measured only the leakage current

Test @ Frascati Neutron Generator Facility (FNG, ENEA)

- SiPM irradiated with 14 MeV neutrons up to 2.2 x 10^{11} n/cm^2 (fluence equivalent to 2.2 times the experiment lifetime)
- Total flux delivered in less than 4 hours



For FBK, the current has been corrected by a factor of 4, due to the different active area w.r.t. Hamamatsu



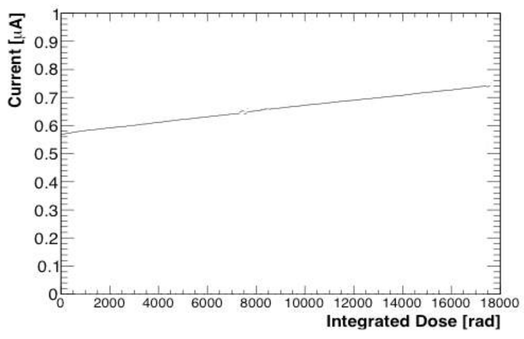
The signal peak decreased from:
- ~ 250 mV to 30 mV for SPL
- ~ 400 mV to 50 mV for MF

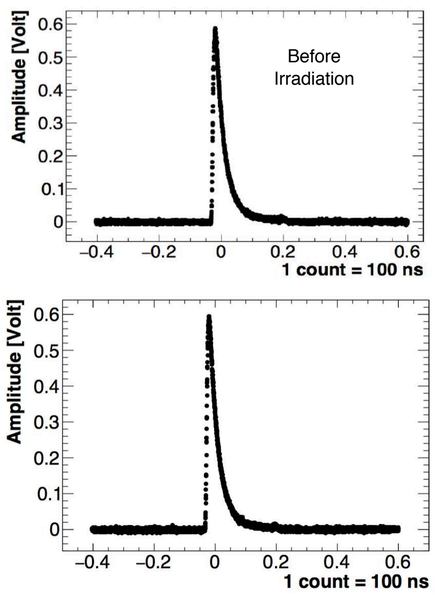
The current increased from
- 16 µA up to 2 mA (MF)
- 100 µA up to 2.2 mA (SPL)
- 86/4 µA up to 19/4 ~5 mA (FBK)

Drop on leakage current and gain dominated by temperature increase during irradiation

Test @ CALLIOPE - Gamma Irradiation Facility (Casaccia, ENEA)

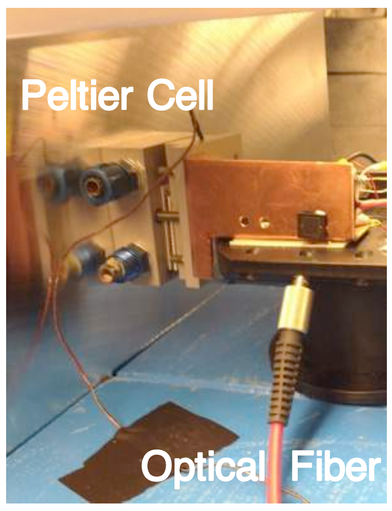
- SPL 3 X 3 mm^2 SiPM tested
- Photo-sensor irradiated with an high intensity ^{60}Co source up to 20 krad (200 Gy)





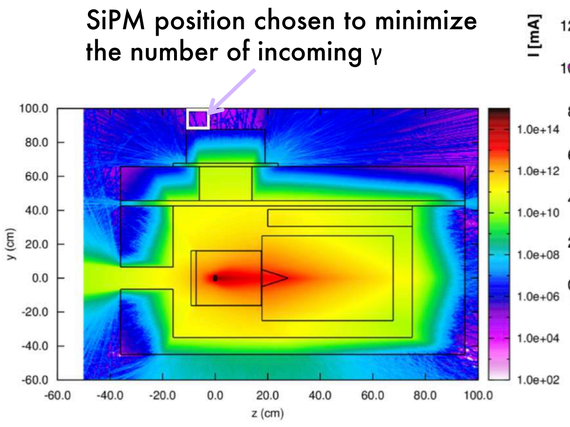
Negligible effect on the response and on the leakage current due to the dose

Test @ EPOS - Neutron Irradiation Facility (Dresden, HZDR)

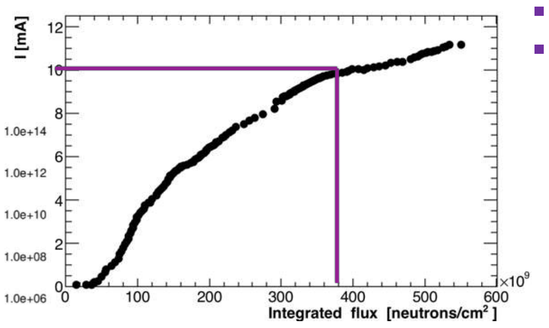


- 6 x 6 SiPM with ceramic package irradiated with ~1 MeV neutrons.
- Temperature kept almost stable using a Peltier cell and monitored with a PT1000
- Total 1 MeV neutron fluence delivered in 5 days > 4x10^{11} n/cm^2

SiPM position chosen to minimize the number of incoming γ

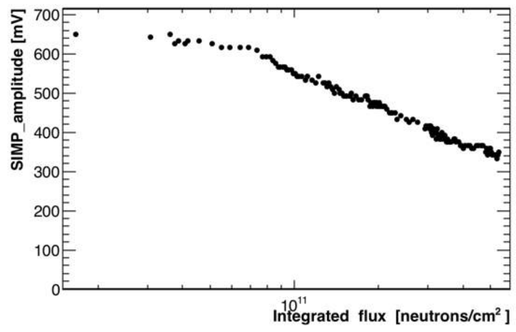


Photon fluence (γ/cm²/s) at 100 µA e- beam

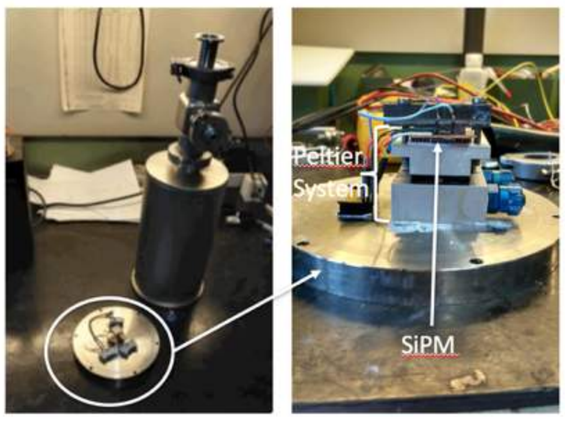


- Current increases from:
  - 60 µA up to ~12 mA

- The response decreases of a factor of ~2:
  - 650 mV up to ~ 341.5 mV
  - Part of this decrease still related to a residual temperature variation (31.5-35) °C during irradiation

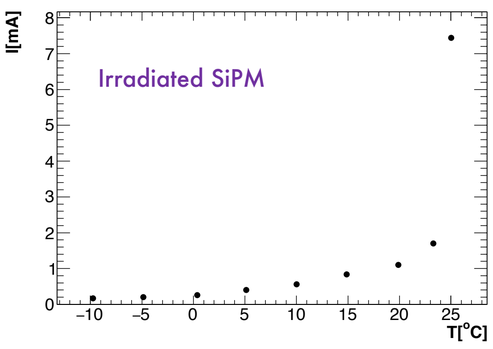


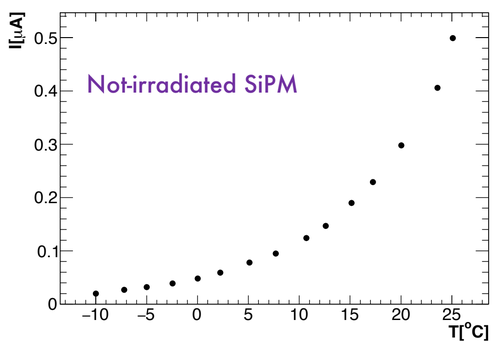
Study of V_{op} and I_{dark} temperature dependance



- Leakage current and operation voltage measurements performed on Dresden SiPM after 1 month of annealing maintaining a fixed gain
- Measurements in vacuum (@10^{-4} mbar) with a system of two Peltier cells and a T1000
- SiPM illuminated with UV led

- Leakage current for a 6x6 mm^2 SiPM ~0.5 mA @ 0 °C
- Total current expected in Mu2e SiPM of ~ 1 mA inside FEE requirement





Conclusion

The determination of the SiPM charge and leakage current variation during the irradiation tests provides an important benchmark for the Mu2e calorimeter where a high radiation environment is foreseen. While the total neutron flux causes a large increase of the leakage current, a dose up to 200 Gy causes a negligible effect. The response is slightly affected by the irradiation. Changes are still acceptable for the running condition in the experiment but requires to cool down the SiPM to a running temperature of ~ 0 °C.

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