Fabrication, characterization and testing of silicon photomultipliers for the Muon Portal Project

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1. SiPM application: the Muon Portal Project

Apparatus designed to inspect the travelling cargo containers using the muon tomography technique.

$$\theta_0 = \frac{13.6\text{MeV}}{\beta c p} \cdot z\sqrt{\left(\frac{x}{X_0}\right)} \cdot \left[1 + 0.038 \ln\left(\frac{x}{X_0}\right)\right]$$

$\beta c \rightarrow$ Velocity
$p \rightarrow$ Momentum
$z \rightarrow$ Charge Number
$x \rightarrow$ Width of Medium
$X_0 \rightarrow$ Radiation Length

This technique is based on the determination of the scattering angle of cosmic muons induced by heavy materials.

Specifications of the Muon Portal Detector

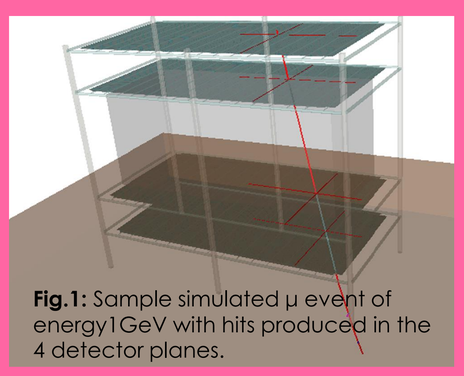


Fig.1: Sample simulated μ event of energy1GeV with hits produced in the 4 detector planes.

- ✓ 8 physical detection planes (4 XY logical planes)
- ✓ Each plane segmented into 6 modules (1m x 3m)
- ✓ Modules consist of 100 strips of extruded scintillator with double WLS fibre readout
- ✓ High PDE, high fill-factor SiPM as readout sensors

Activities and timeline

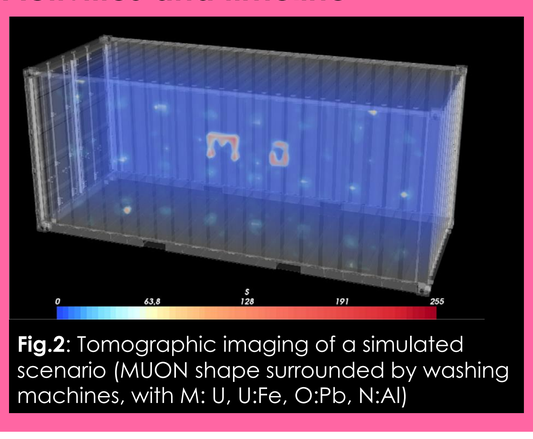


Fig.2: Tomographic imaging of a simulated scenario (MUON shape surrounded by washing machines, with M: U, U:Fe, O:Pb, N:Al)

- ✓ Construction of 48 modules
- ✓ Characterization and tests of the SiPMs
- ✓ Test of the FE and Readout electronics
- ✓GEANT4 replica of the full detector
- ✓ Development of imaging algorithms
- ✓**End of construction expected by mid 2015**

2. SiPM technology

Silicon PhotoMultipliers custom-made by STMicroelectronics n-on-p technology.

- ✓ Compactness
- ✓ Cost-effective
- ✓ Low voltages required
- ✓ High PDE to light from WLS fibres
- ✓ High Fill Factor
- ✓ Several prototypes built, customized for this application

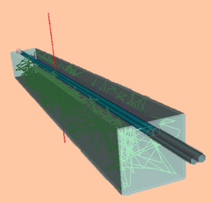


Fig.3: Design of an extruded scintillator strip with 2 WLS fibres, to be coupled to the SiPMs

Final design

4 independent round shaped SiPMs (ϕ~1.5 mm)
- ✓ 2 MUON60 = SiPMs with 60 μm cell pitch
- ✓ 2 MUON75 = SiPMs with 75 μm cell pitch

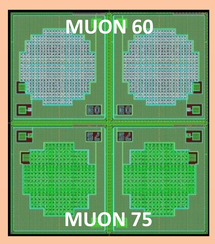


Fig.4: SiPM module layout

Parameter	Muon60	Muon75
Sensitive area size (mm^2)	19728	18000
Number of cells	548	320
Cell fill factor (%)	67.4	73.8
Cell size (μm^2)	60 × 60	75 × 75
Quenching resistor squares number	28	28
Quenching capacitor area (μm^2)	26	26
Cell active area (μm^2)	2427	2427
Cell perimetral area (μm^2)	844	844
Diode bonding pad area (μm^2)	140 × 140	140 × 140
SiPM bonding pad area (μm^2)	140 × 140	140 × 140
Metal grid area (pads included) (μm^2)	124392	97828

3. Optical characterization

Photon Detection Efficiency and DCR measurements

Monochromatic light sent to an integrating sphere hosting a calibrated reference photodiode and the SiPM under test (MUON60- 1mm² device).

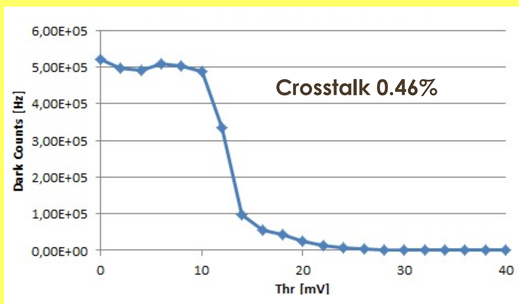


Fig.5: Dark staircase for SMP10H6-60N (OV=4V, T=28 °C)

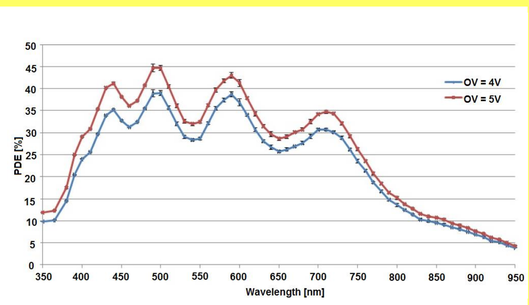


Fig.6: PDE for SMP10H6-60N (gate time 90ns, T=28 °C)

4. Electrical characterization

Charge spectrum and gain measurement

Experimental setup based on the CAEN SiPM evaluation kit.

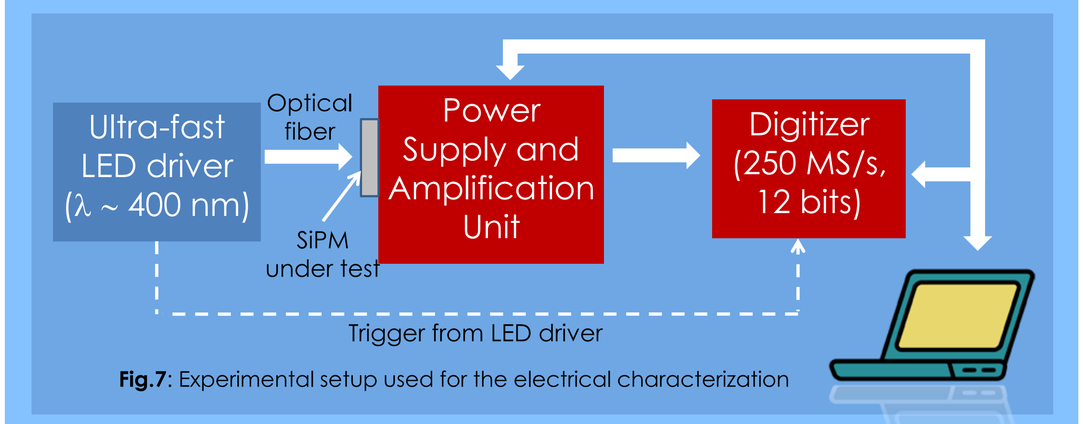


Fig.7: Experimental setup used for the electrical characterization

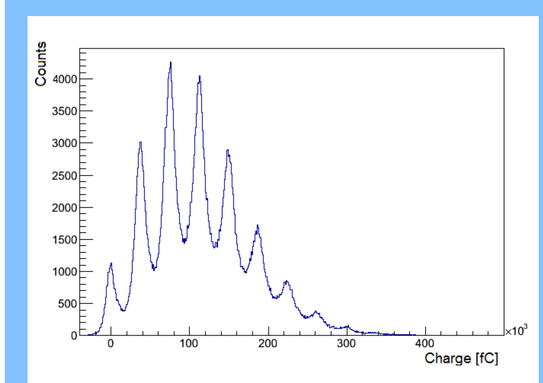


Fig.8: Charge spectrum of MUON60 at OV=1V

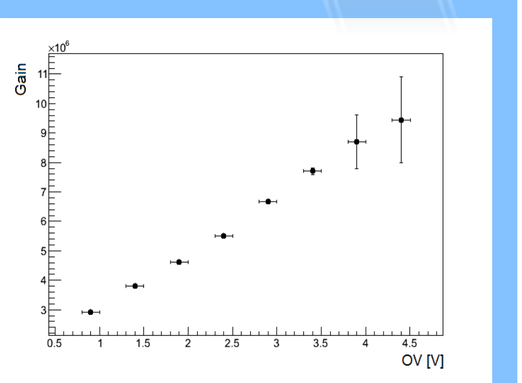


Fig.9: Gain of MUON60 vs overvoltage

5. SiPM classification

SiPMs with similar characteristics (in terms of breakdown voltage BV and current) will be installed in the same region of the detector in order to set, for group of 10 SiPMs, the same bias voltage and threshold level.

Selection criteria

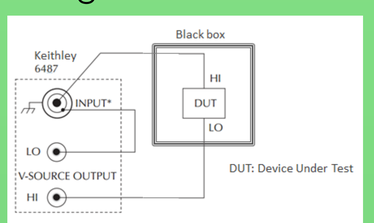


Fig.10: Setup for the I-V measurement

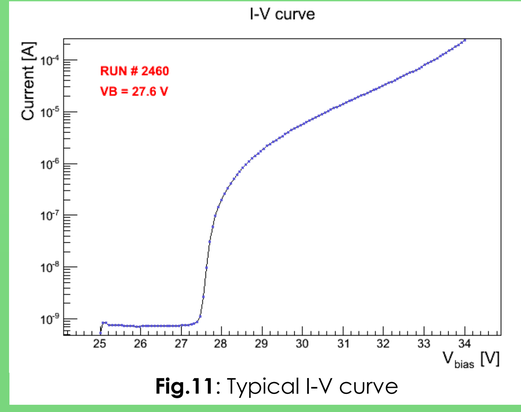
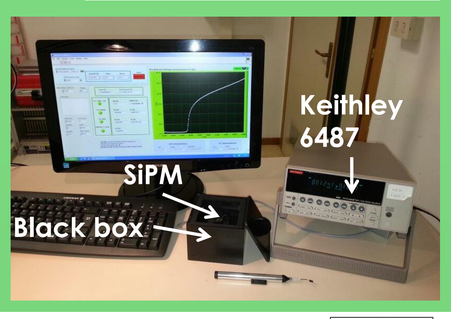


Fig.11: Typical I-V curve



After the construction of the I-V curve, SiPMs not satisfying stringent criteria on the BV will be rejected (i.e. BV<27 or BV>29). Other selection criteria are applied to the current values corresponding to BV+5V and BV-2V.

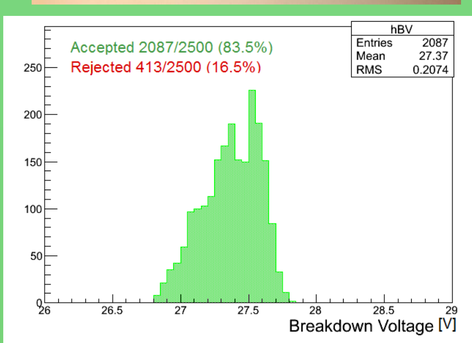


Fig.12: V_{BR} measured over a 2500 sample

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