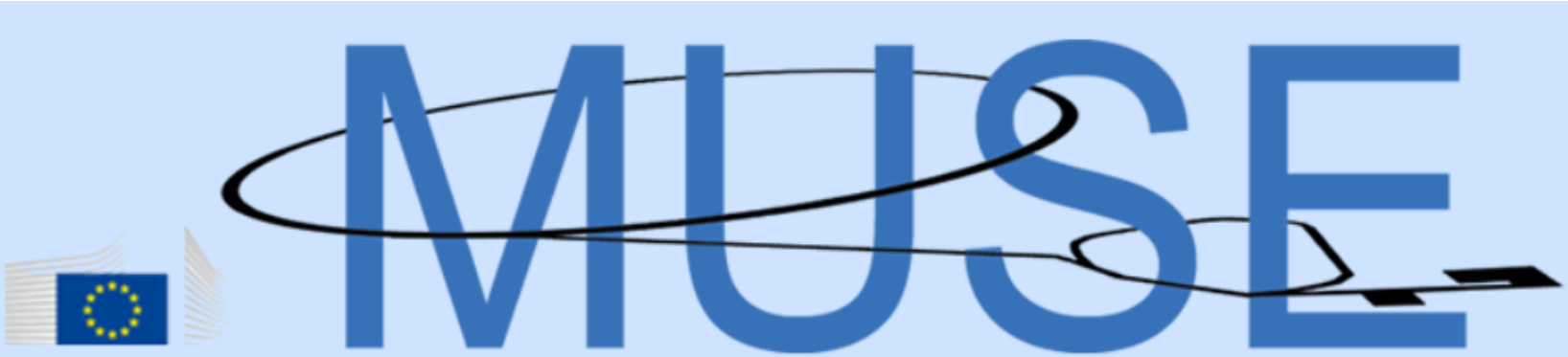


Summary on QA of the Mu2e calorimeter SiPMs

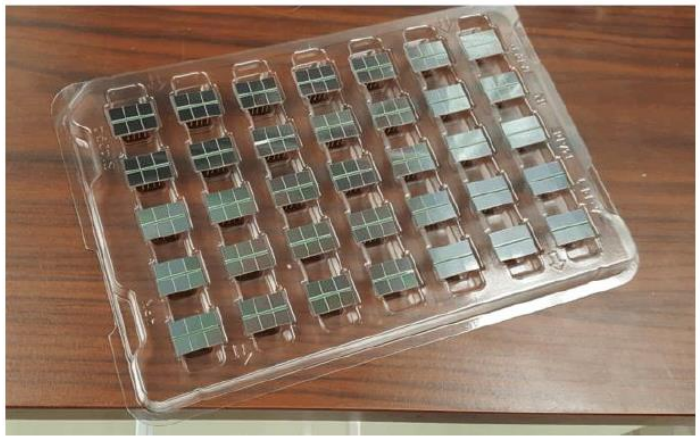
MUSE General Meeting

October 24, 2019

Luca Morescalchi

QA Procedure

- The tests successfully ended in June 2019.
- One batch is ~ 280 pieces. Delivery of one batch/month started from March 2018
- **First Step**: Visive inspection



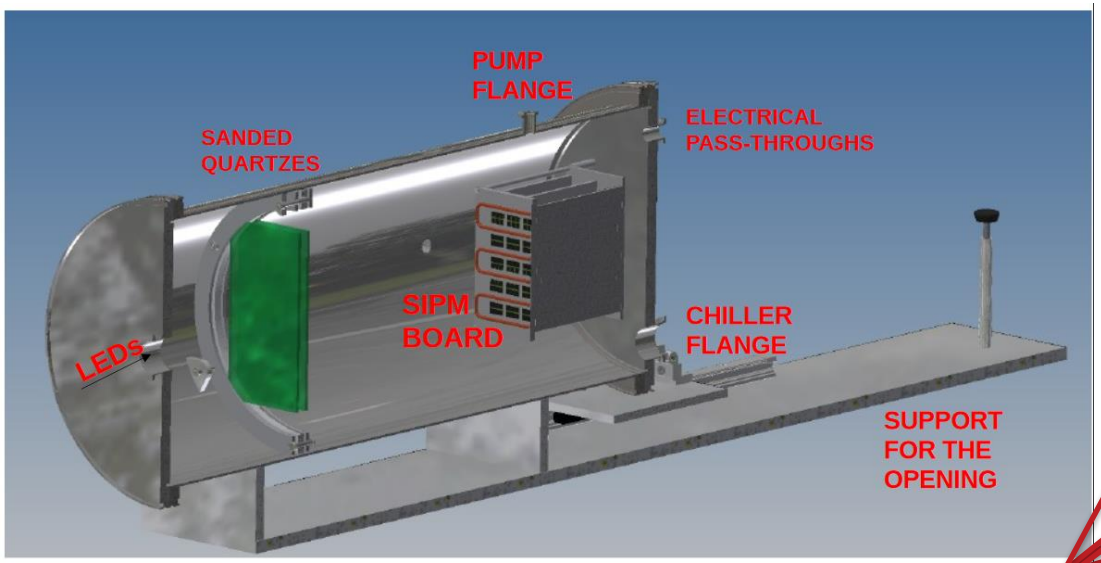
- **Second Step**: Mechanical and dimensional check (100 µm tolerance)
- **Third Step**: Characterization
  - R1) a relative spread in Vop (operational voltage) between the sensor cells < 0.5%.
  - R2) a relative spread in the dark current at Vop between the sensor cells < 15%.
  - R3+R4) a gain x PDE(310 nm) at Vop > 2*10^5 for each cell.

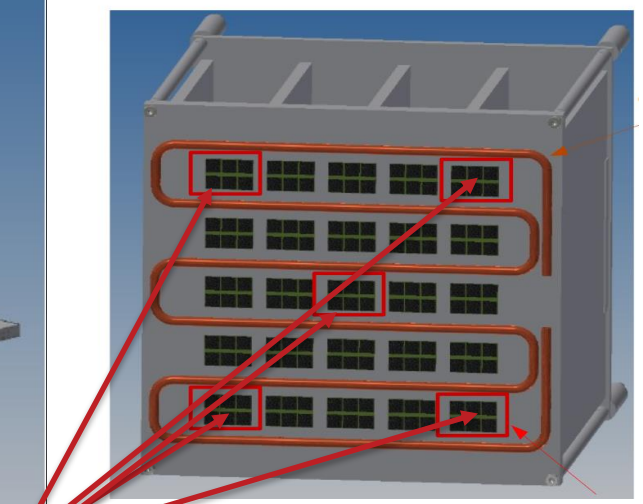
Sensors that didn't meet the requirements have been discarded.

- A random subset of 15 devices/batch is used to evaluate MTTF, while other 5 sensors/batch are used for neutron irradiation

What are we measuring?

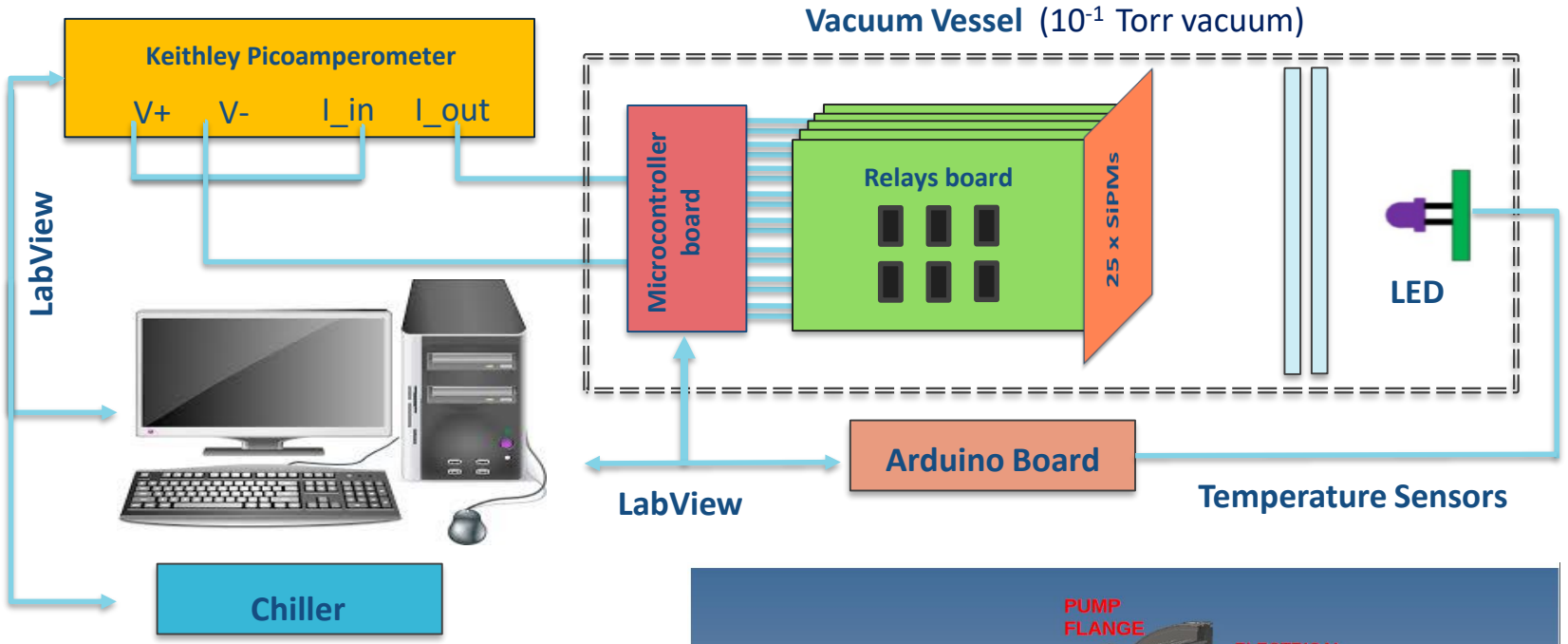
- QA required 4k*6 = 24k full characterizations -> automatized system
- Test station able to measure (1.2 mins/cell) at three temperatures (-10°, 0° and 20°/ 25° C) :
  1. **V_b** – by fitting the I-V curve;
  2. **I_{dark} @ Vop** – directly by the I-V curve;
  3. **Gain x PDE @ Vop** – by the ratio of the currents pulled by the cell and a reference sensor, while illuminating both with a stable and uniform light;





Reference Sensors

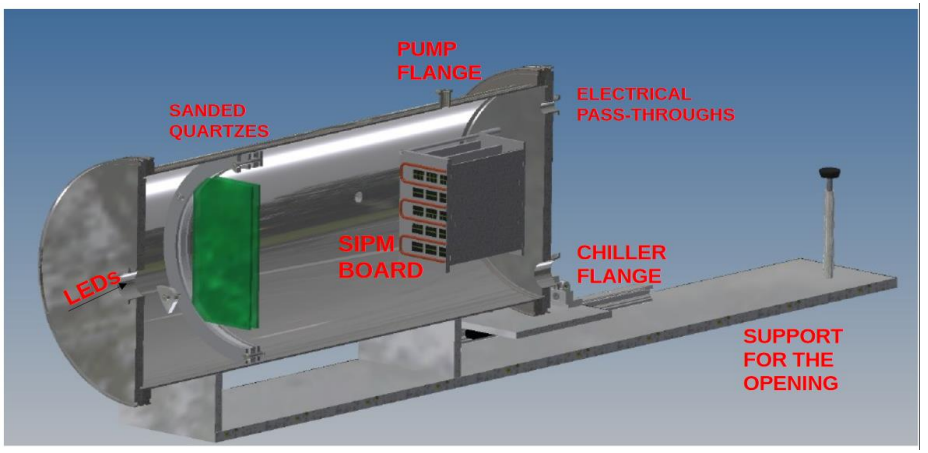
Experimental Setup for QA



-10 °, 0 ° and 20 °/ 25 ° C

For each cell we measure:

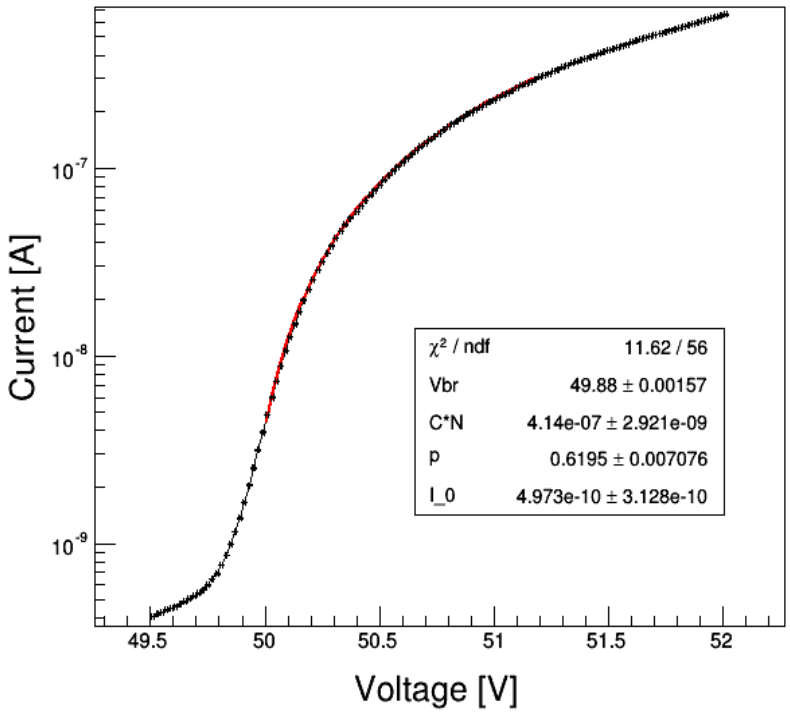
1. **Breakdown Voltage**
2. **Dark Current @ Vop**
3. **Gain x PDE @ Vop**



Measurement of Breakdown Voltage

- To extract the breakdown voltage, a 150 points voltage scan in a 2.5 V range is performed and the obtained curve is fitted with :

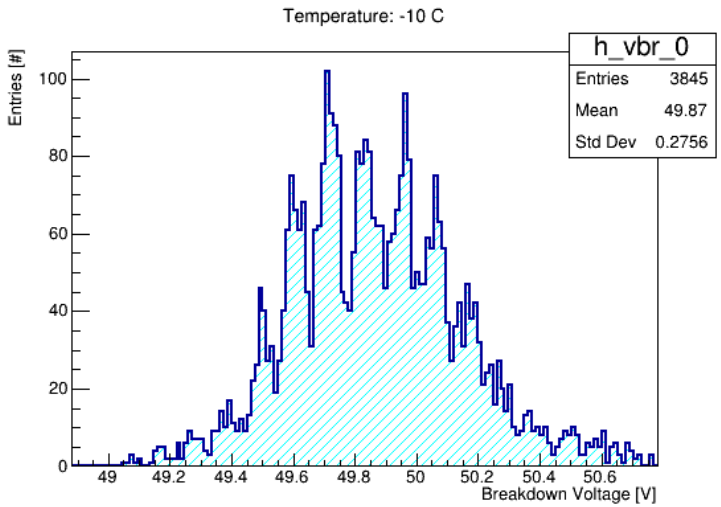
$$I(V) = \begin{cases} I_0 + C \times (1 - e^{-p \cdot (V - V_{\mathrm{br}})} \times (V - V_{\mathrm{br}}) & V > V_{\mathrm{br}} \\ I_0 & V < V_{\mathrm{br}} \end{cases}$$

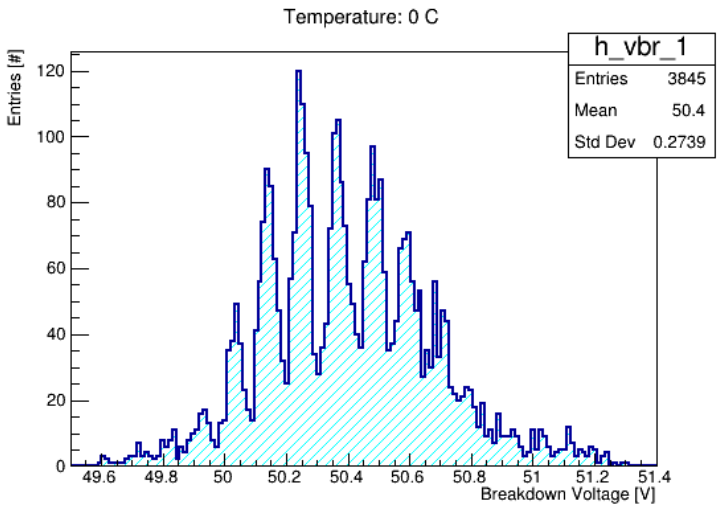


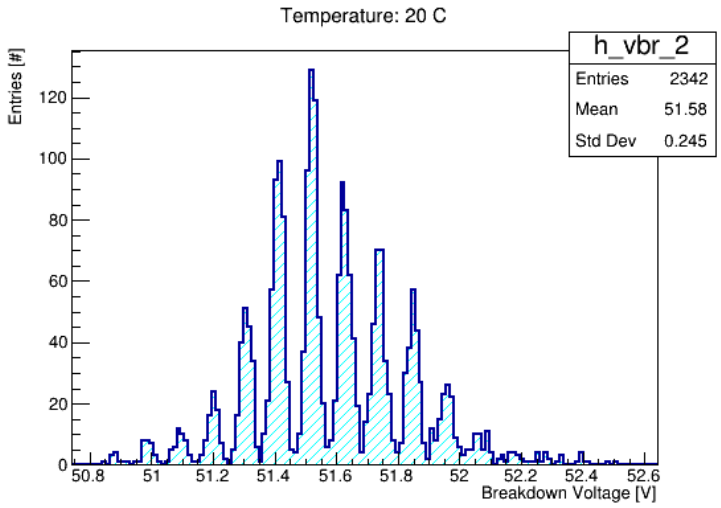
- Where:
  - V is the bias voltage
  - Vbr is the breakdown voltage
  - I_0 is the current before the breakdown
  - P is the Geiger probability
  - C is proportional to the number of the free carriers (thermal + optical)
- It is valid under 2 assumptions:
  - Afterpulse and crosstalk are negligible
  - We are far from the '*second breakdown*' zone

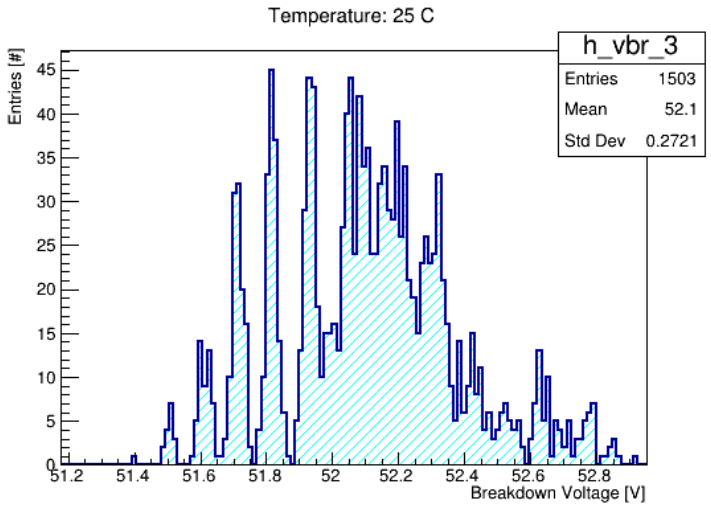
A. Nagai, N. Dinu, A. Para , "Breakdown voltage and triggering probability of SiPM from IV curves"

Distribution of the Breakdown Voltage

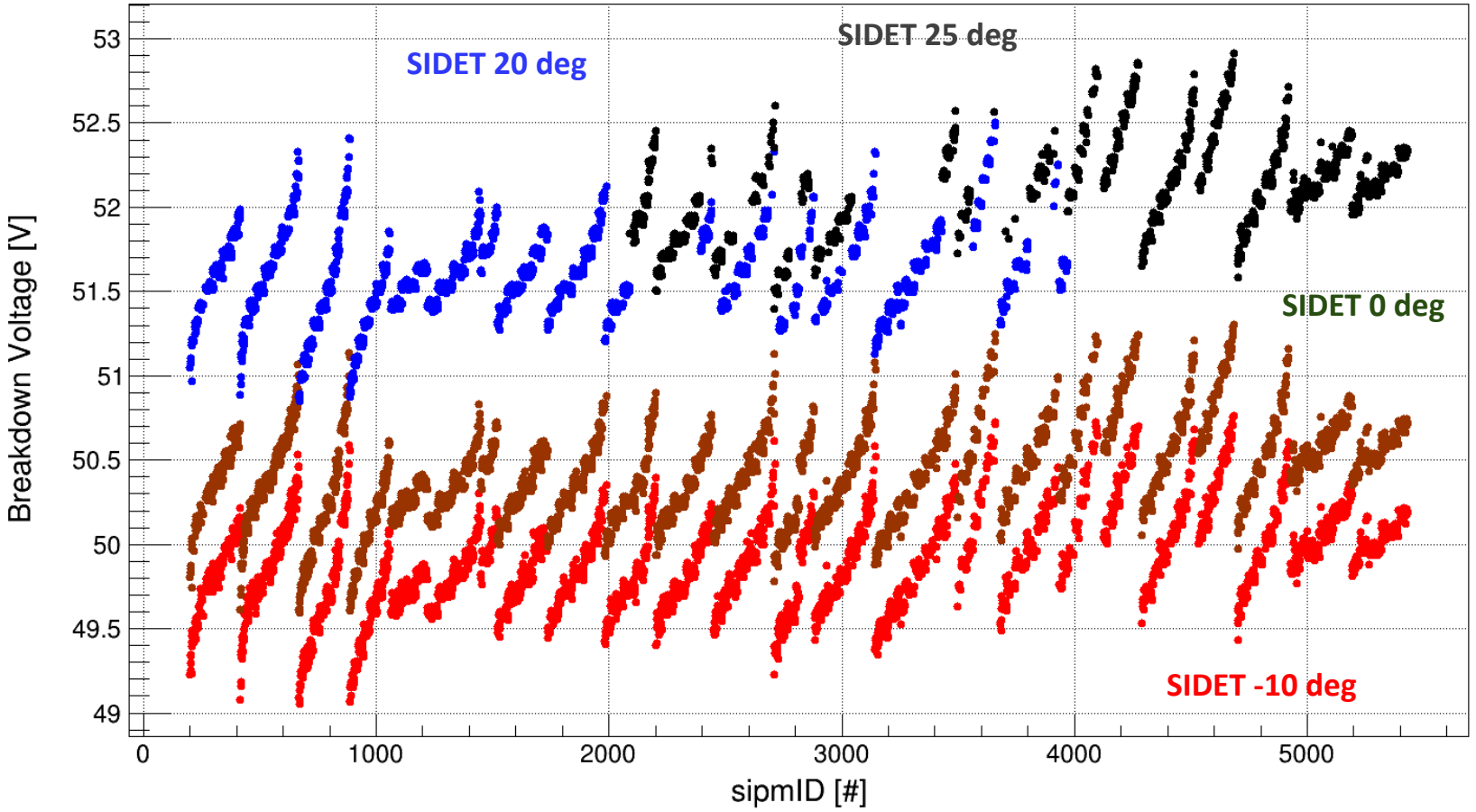




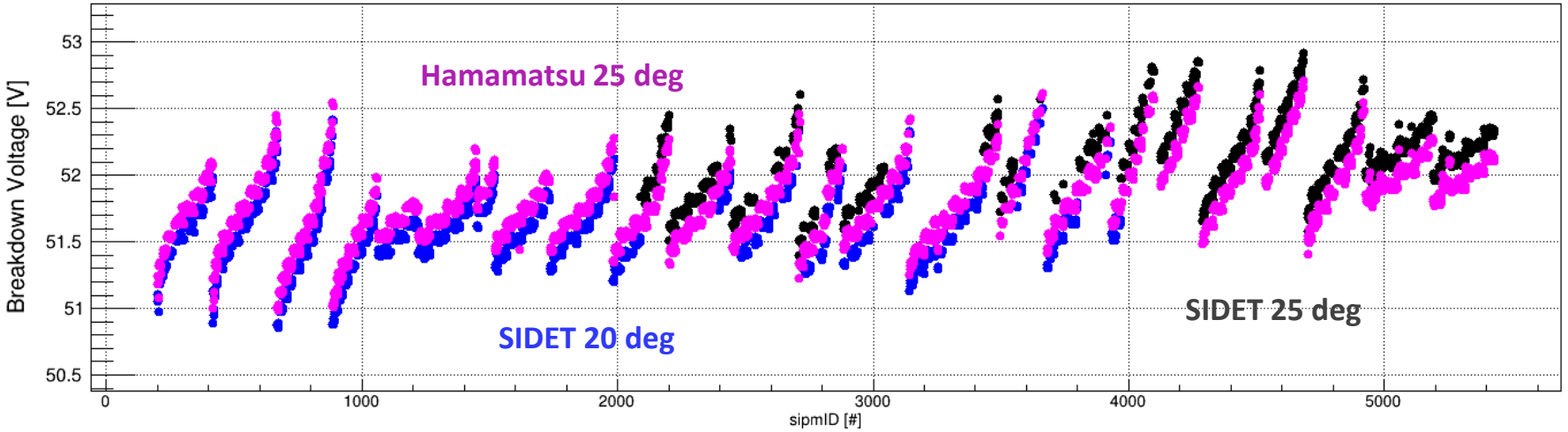


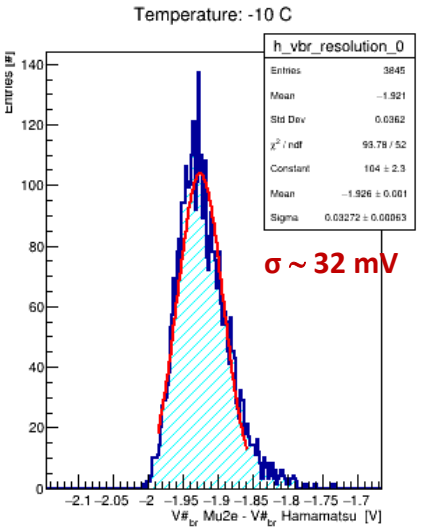


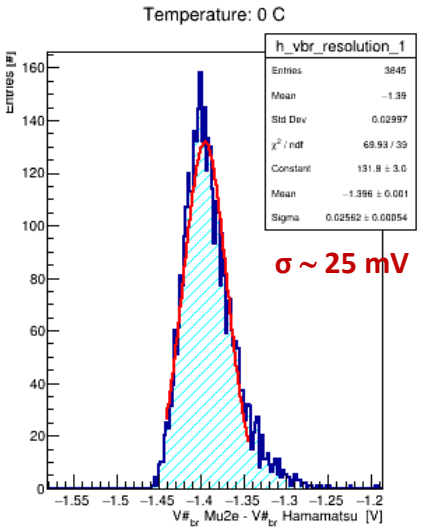
Breakdown Voltage Vs sipmID

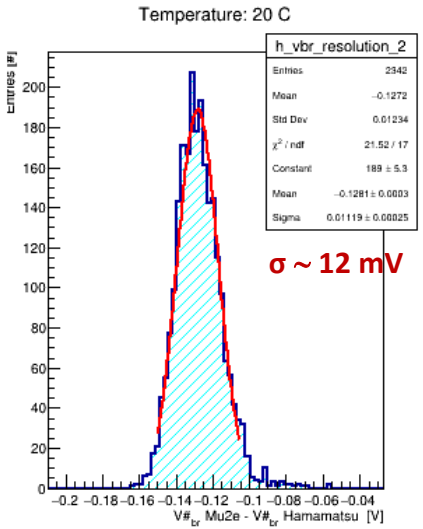


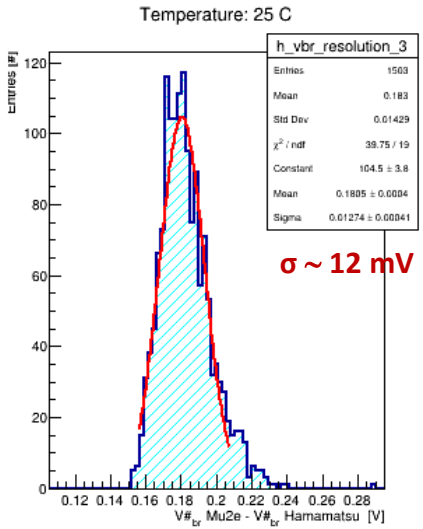
Comparison with Hamamatsu



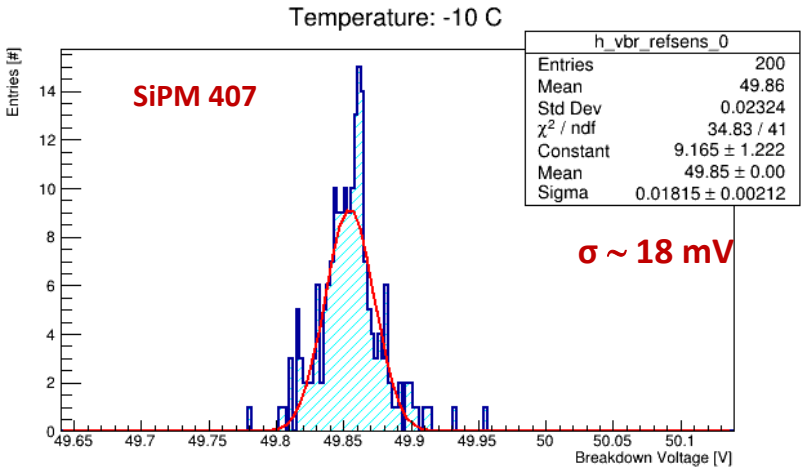


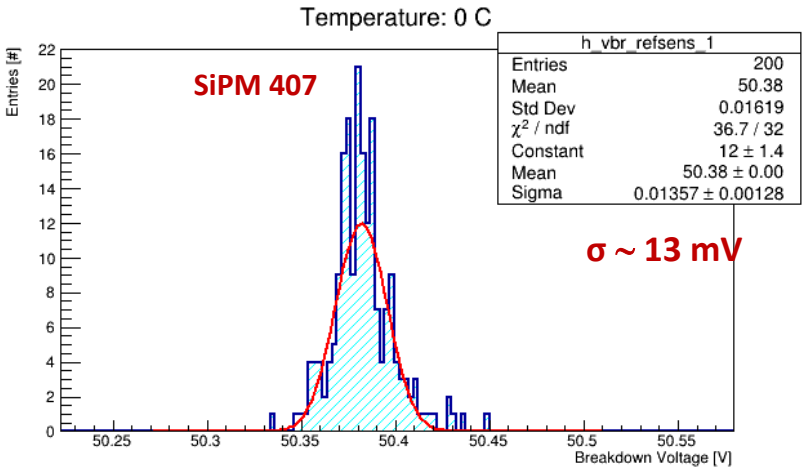


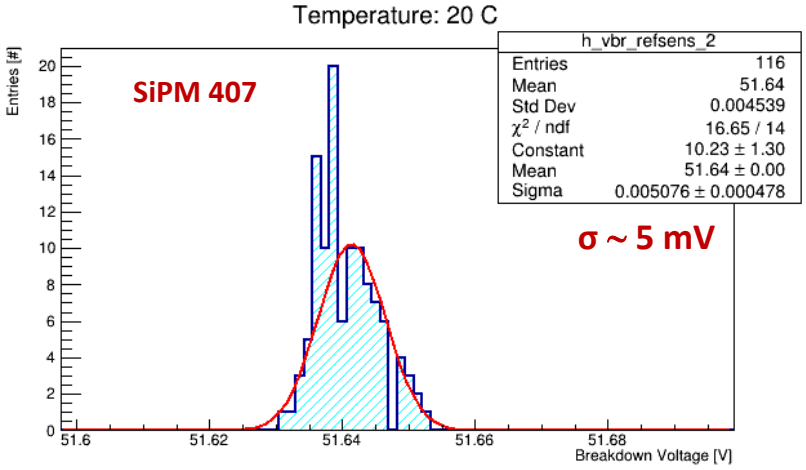


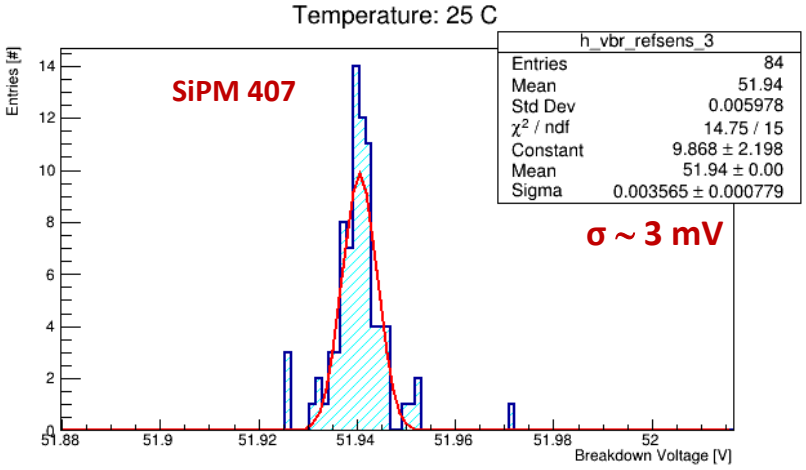


Stability of Breakdown Voltage

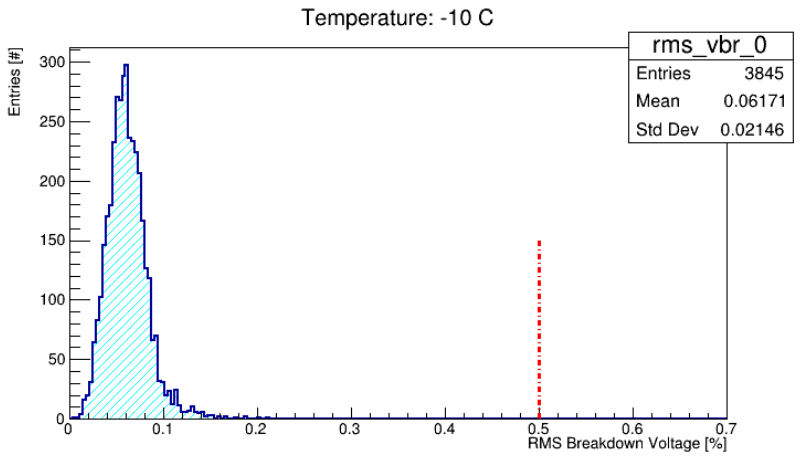


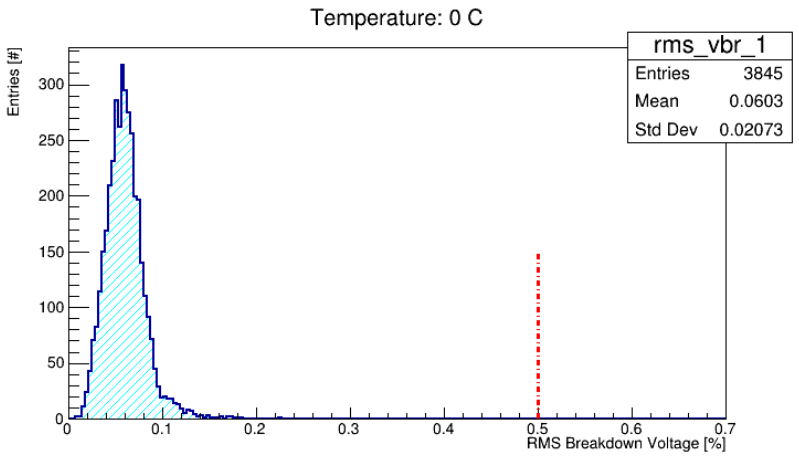


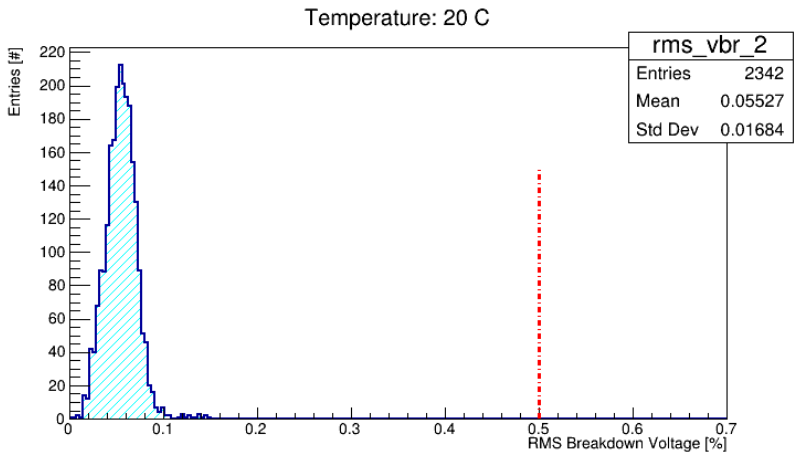


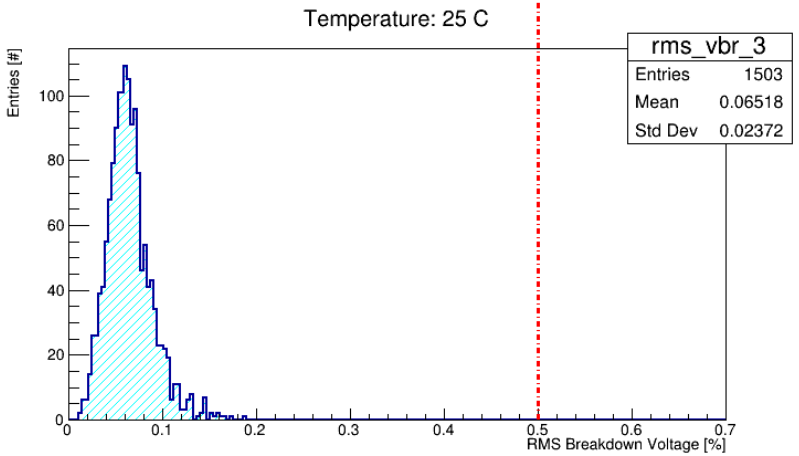


Breakdown Voltage RMS



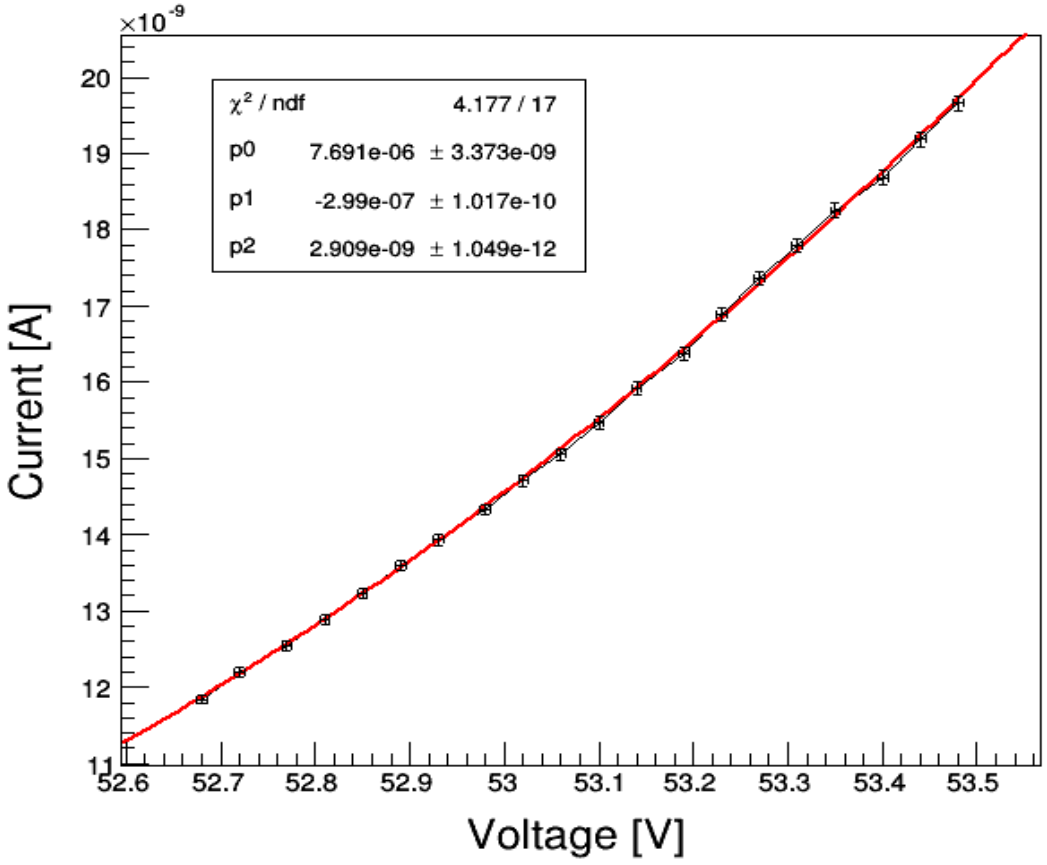






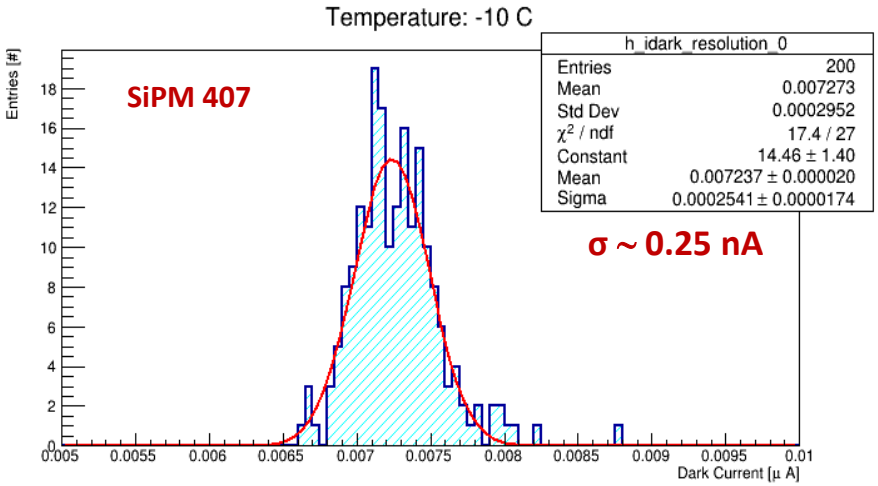
Dark Current Measurement

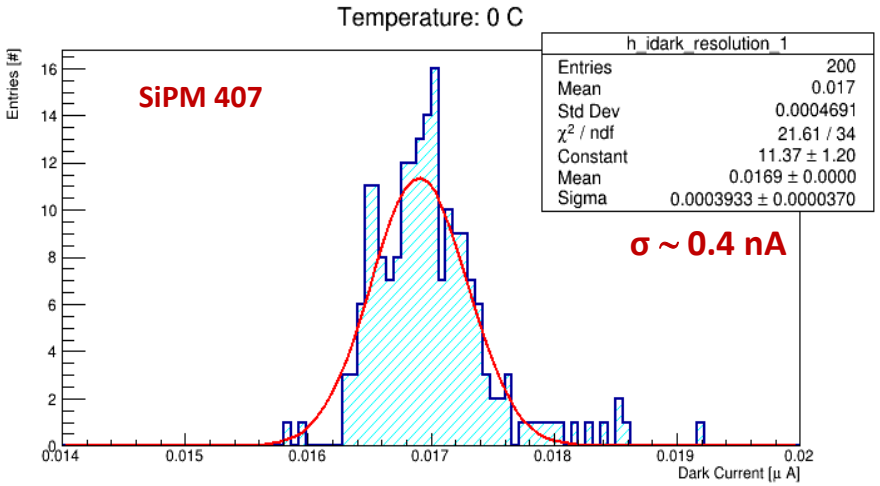
- The dark current measurement has been performed according to three steps:

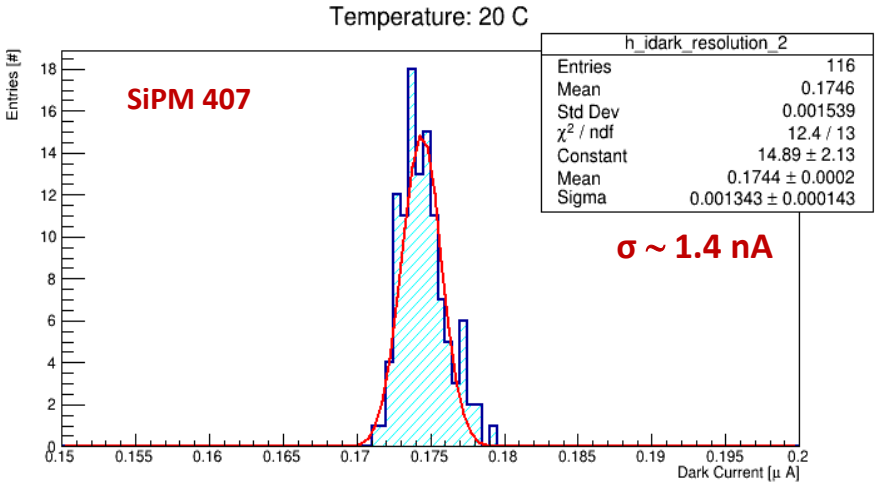


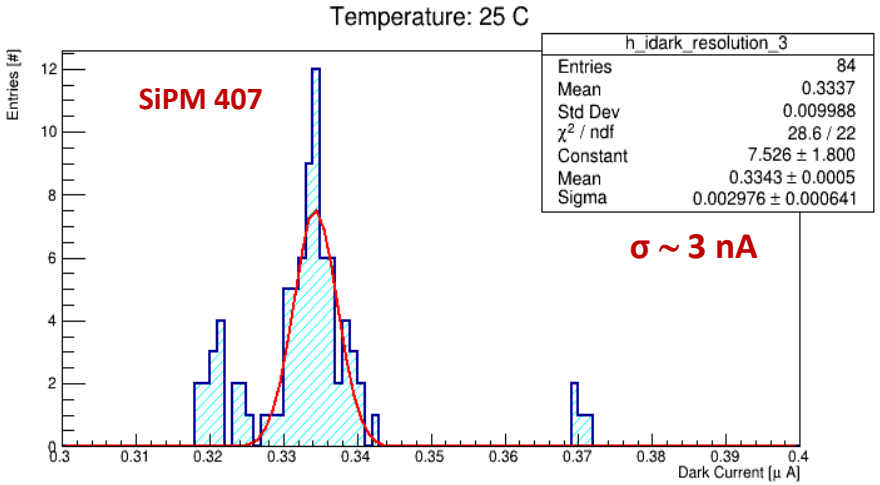
- A scan of 0.8 V around the peak of the dlog(I)/dV + 3 V is performed
- The current is fitted with a pol2
- The dark current is obtained by taking the value of the pol2 at the Vbr extracted from the curve, corrected for temperature, +3

Stability of Dark Current

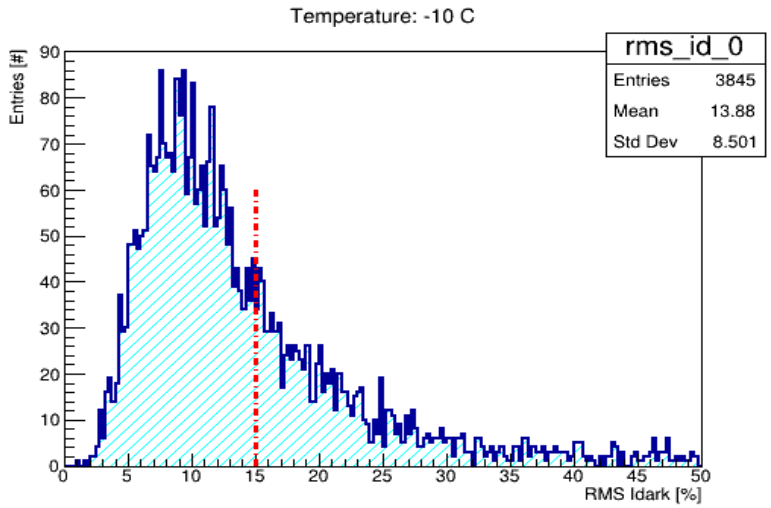


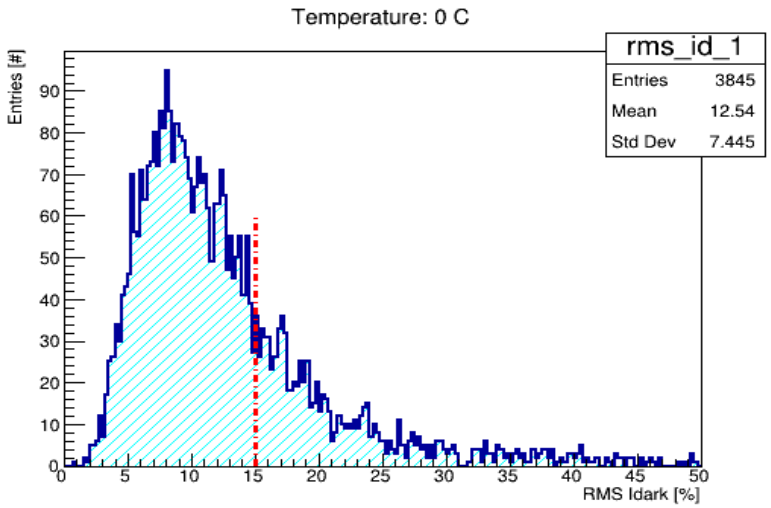


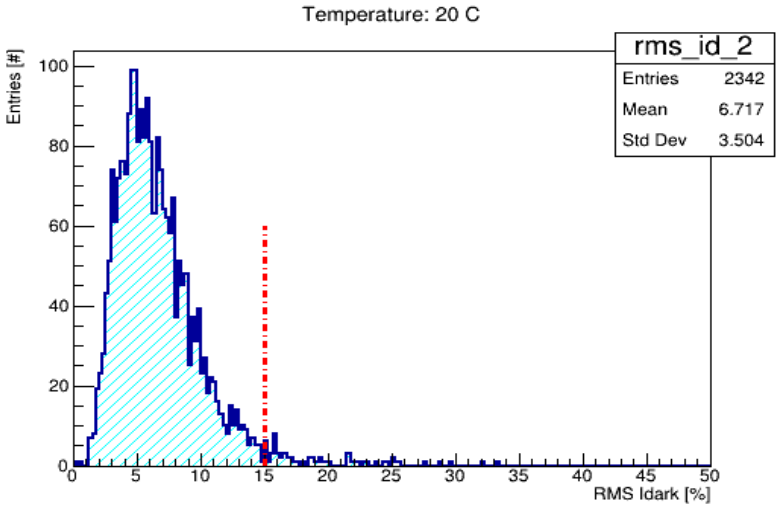


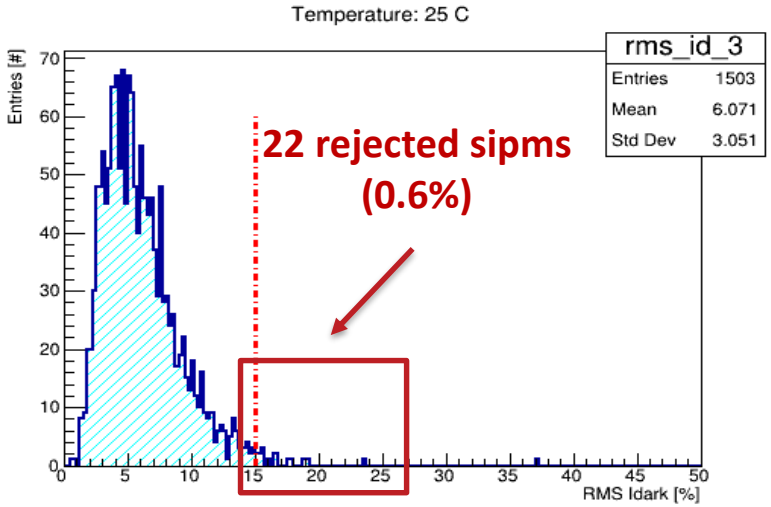


Dark Current RMS



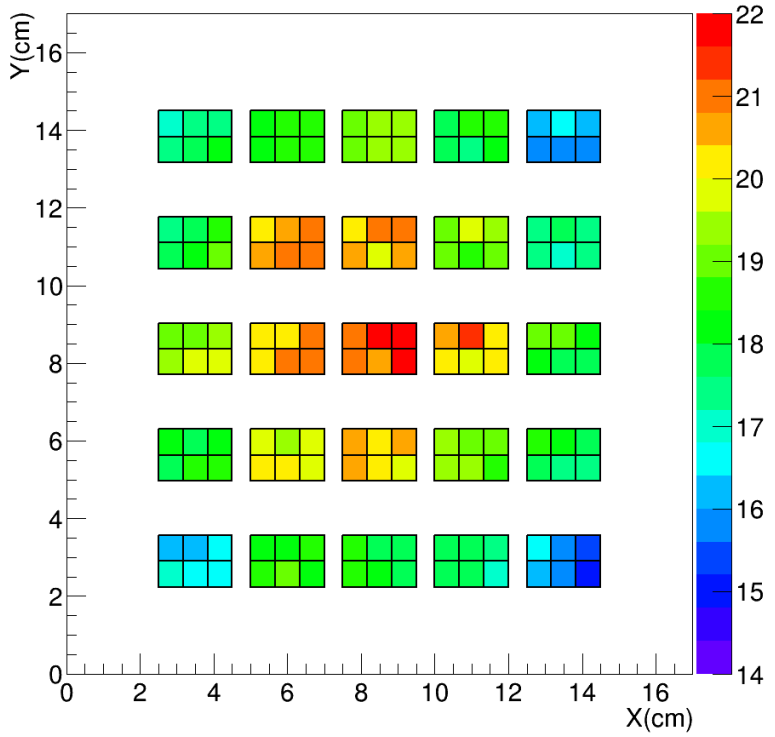


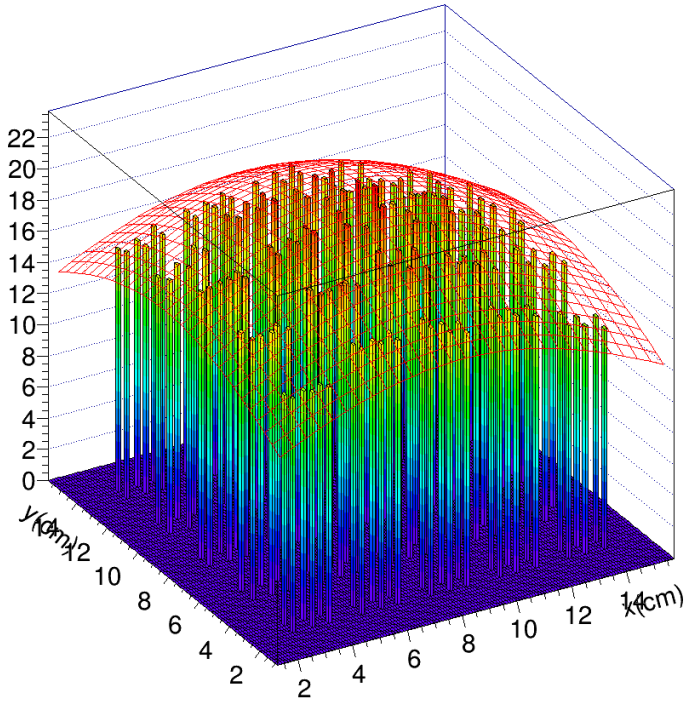




Gain x PDE Measurement - Light Profile

- The light of the LED is not uniform on the sensors plate but has a gaussian profile:

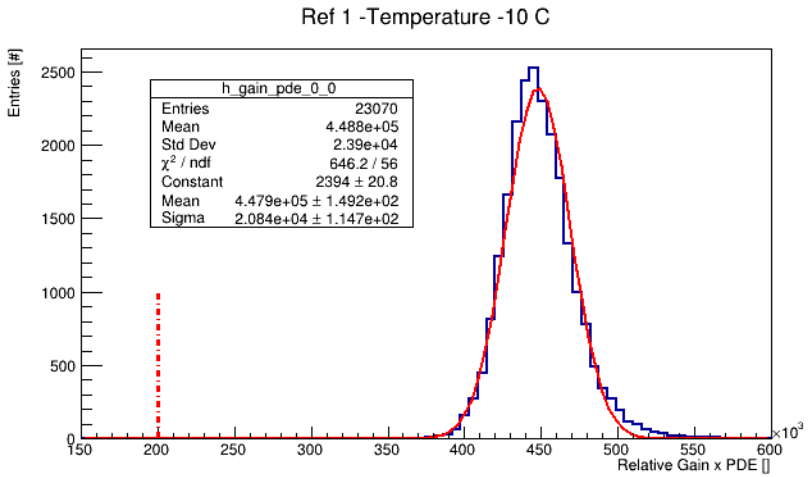


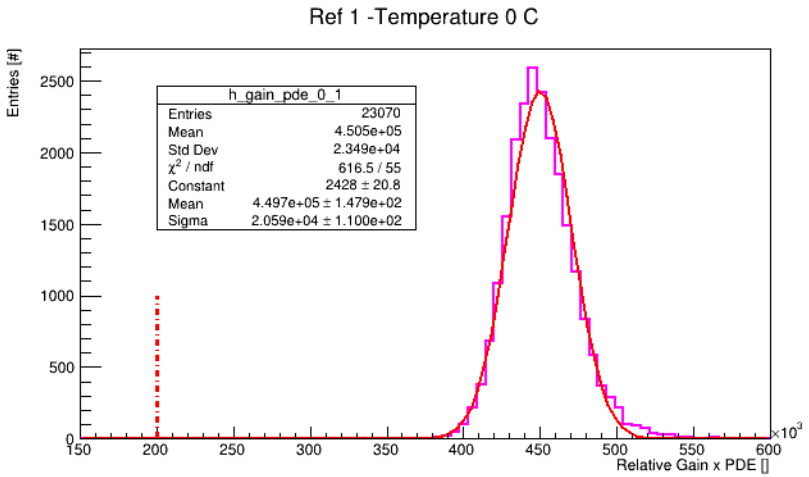


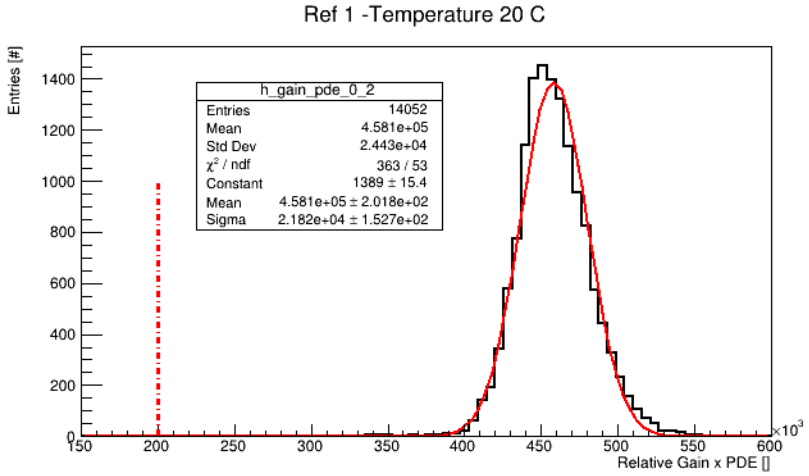
- A good approximation of this profile has been obtained by fitting the current of the sensors biased at the operative voltage.. residuals have an RMS ~ 4%

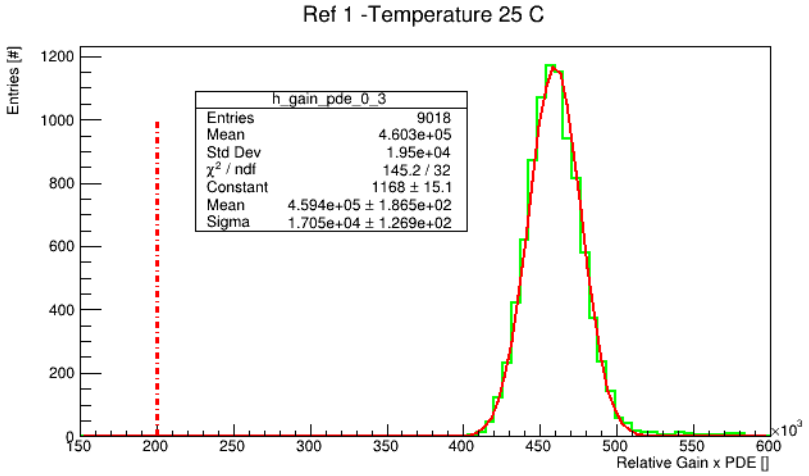
Gain x PDE

Refsens n.1, ID = 301 **G x PDE ref = 4.e10^5** **σ / μ ~ 5 %**









Conclusions

- The QA process for the Mu2e calorimeter Silicon PhotoMultipliers ended in June
- 14 batches have been tested for a total of 3875 photosensors
- 48 rejected sensors (about 1% of the total):
  - 26 for construction problem (dimensions, IV test failed..)
  - 22 for too large dark current RMS
- Photosensors ready for the assembly with FEE