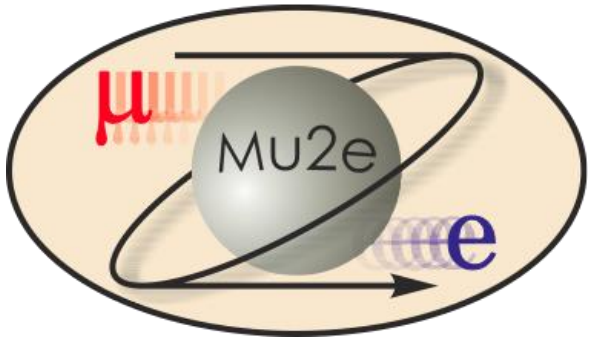


QA of the Mu2e calorimeter SiPMs

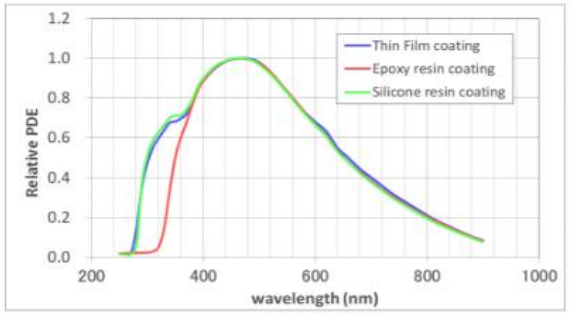
MUSE General Meeting

October 23, 2018

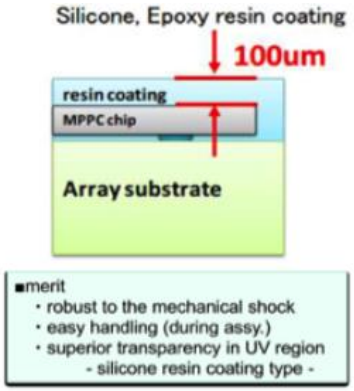
Luca Morescalchi

Mu2e Custom SiPM

The Mu2e SiPM is composed of a 2x3 matrix (6 cells) of 6x6 mm 2 UV-extended monolithic SiPMs



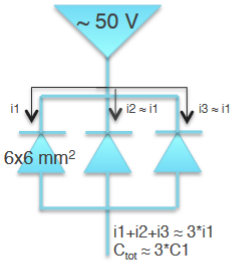
Thin Film coating and Silicon resin coating has PDE advantage in UV region.

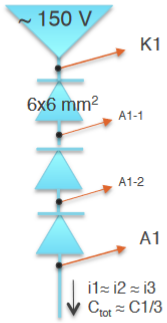


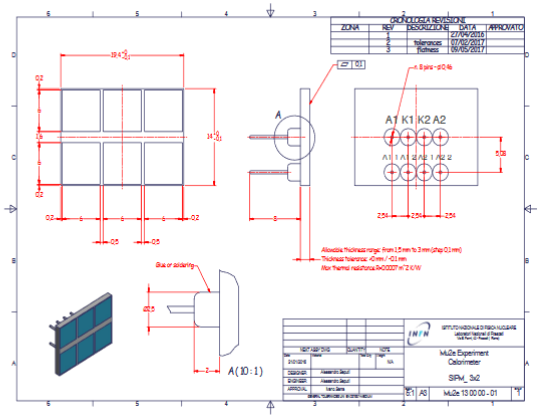
13360-6050CS MPPC

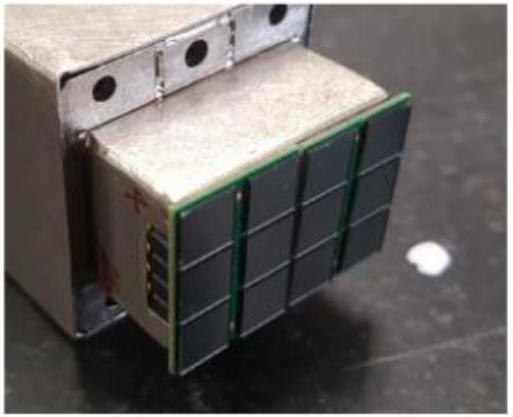
Pixel pitch [μm]	50
Effective photosensitive area [mm]	6.0×6.0
Number of pixel	14400
Window material	Silicon resin
Gain (at 25° C)	2.4×10^6
PDE @ 310 nm	28%

We have chosen a modular SiPM layout to enlarge the active area and maximize the number of collected photoelectrons



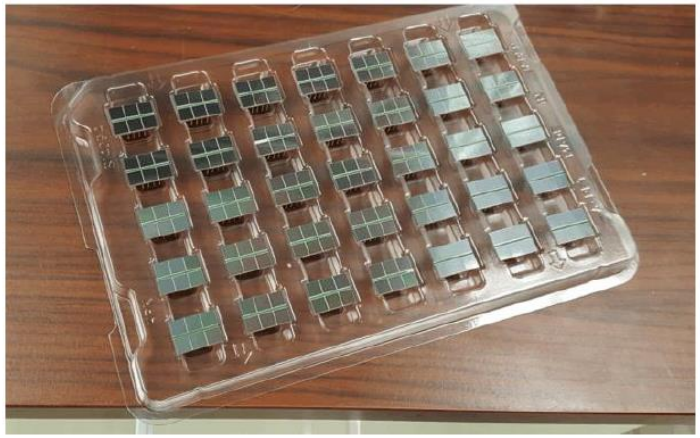






QA Procedure

- The SiPMs QA is all located @ FNAL in a dedicated clean room.
- 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)



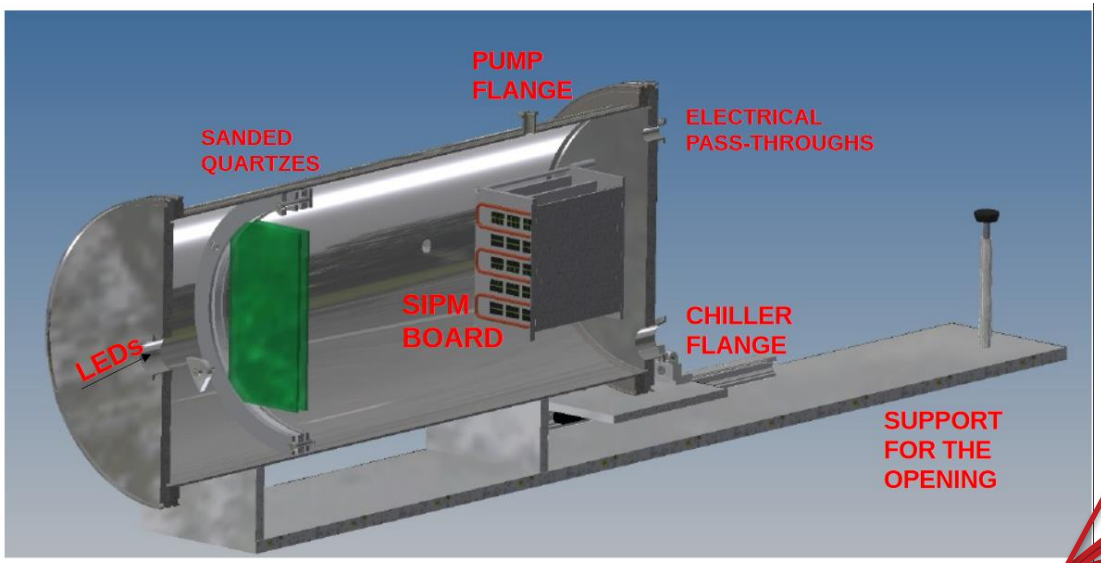
- **Third Step**: Characterization
  - R1) a relative spread in Vop (operational voltage) between the sensor cells < 0.5%.
  - R2) a relative spread in the dark current at Vop between the sensor cells < 15%.
  - R3+R4) a gain x PDE(310 nm) at Vop > 2*10^5 for each cell.

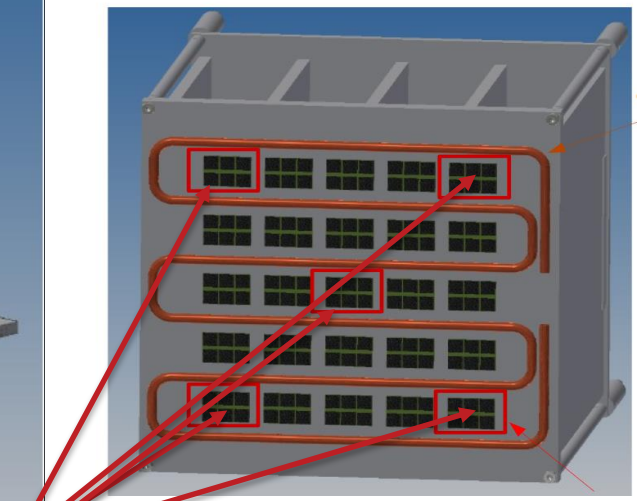
Sensors that don't meet the requirements are discarded.

- 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?

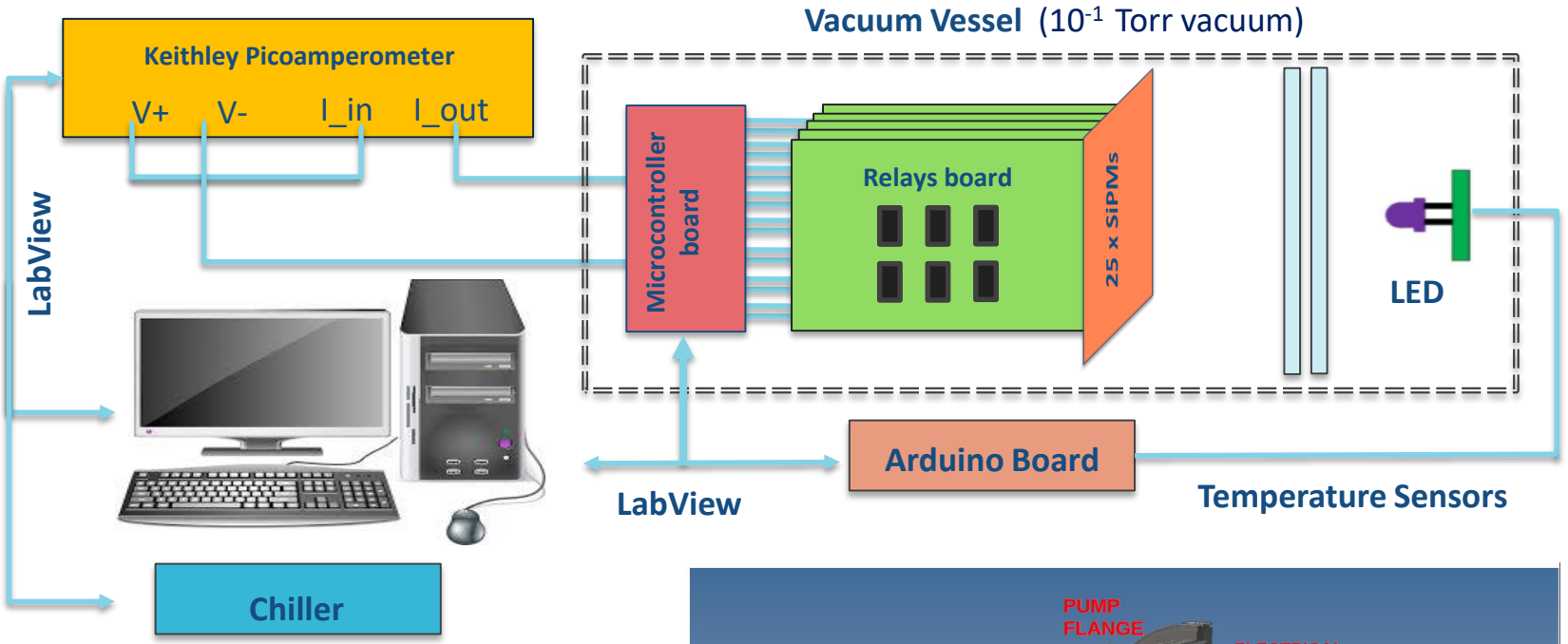
- QA requires 4k*6 = 24k full characterizations -> an automatized system is needed to speed up the measurement process.
- Test station able to measure (1.2 mins/cell) at three temperatures (-10°, 0° and 20° C) :
  1. **V_b** – by fitting the I-V curve;
  2. **I_{dark} @ Vop** – directly by the I-V curve;
  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

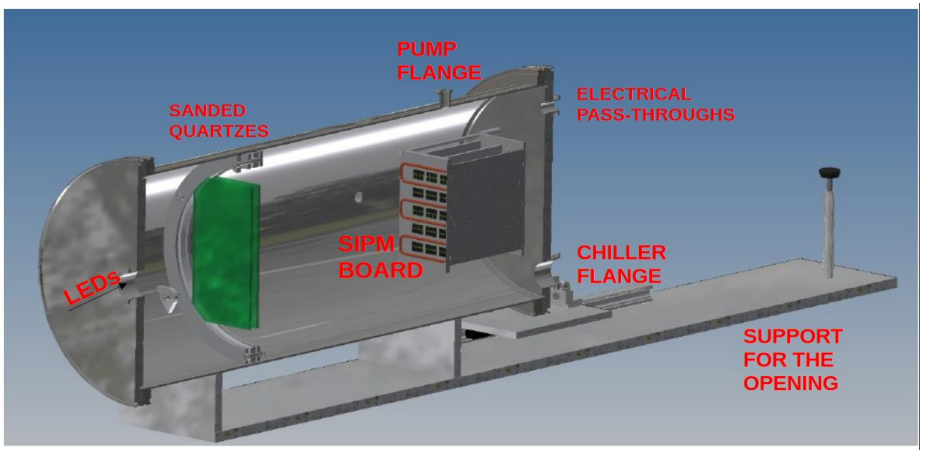
Experimental Setup for QA



-10 °, 0 ° and 20 ° C

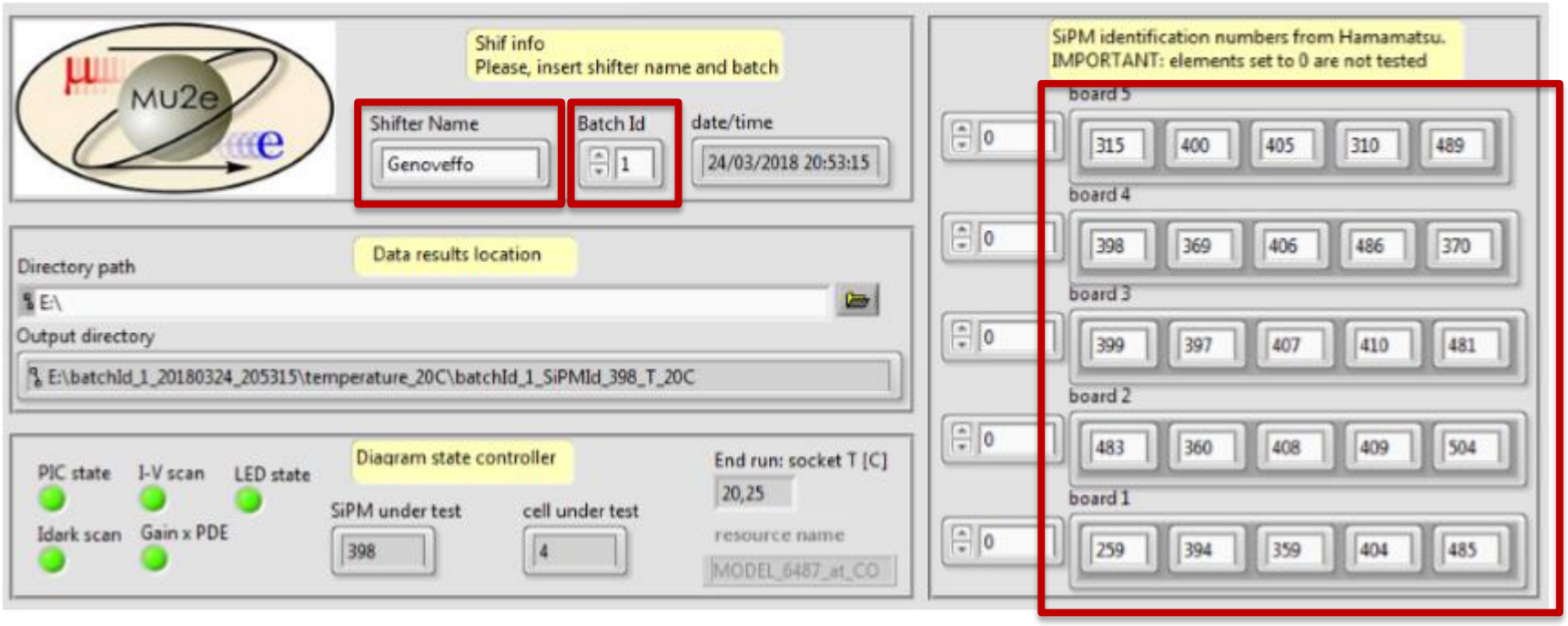
For each cell we measure:

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



Station Labview Interface

- The station is fully automatized and is controlled by a Labview software. In order to start a new run, the user has to modify only:

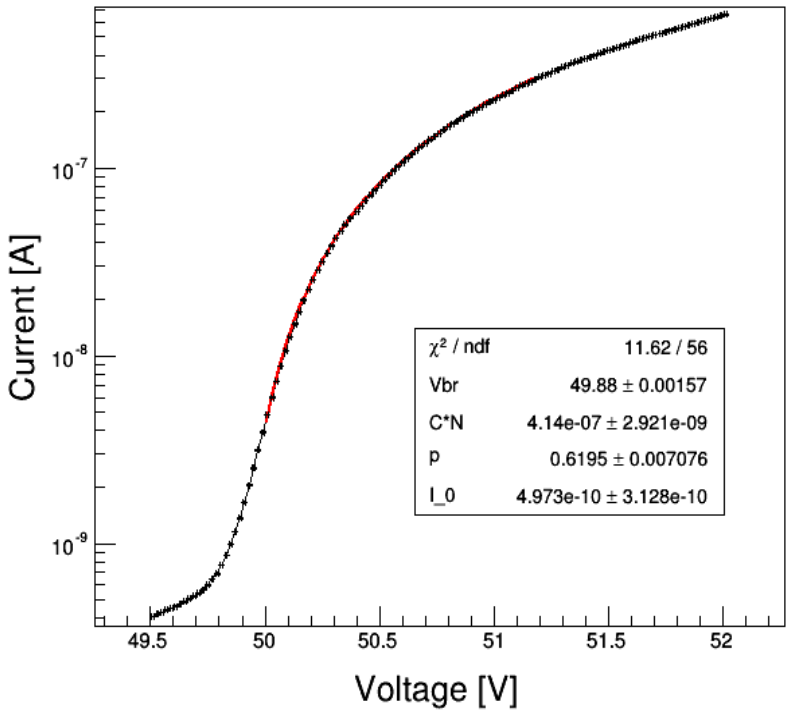


- No particular knowledges needed to run the system..

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 :

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

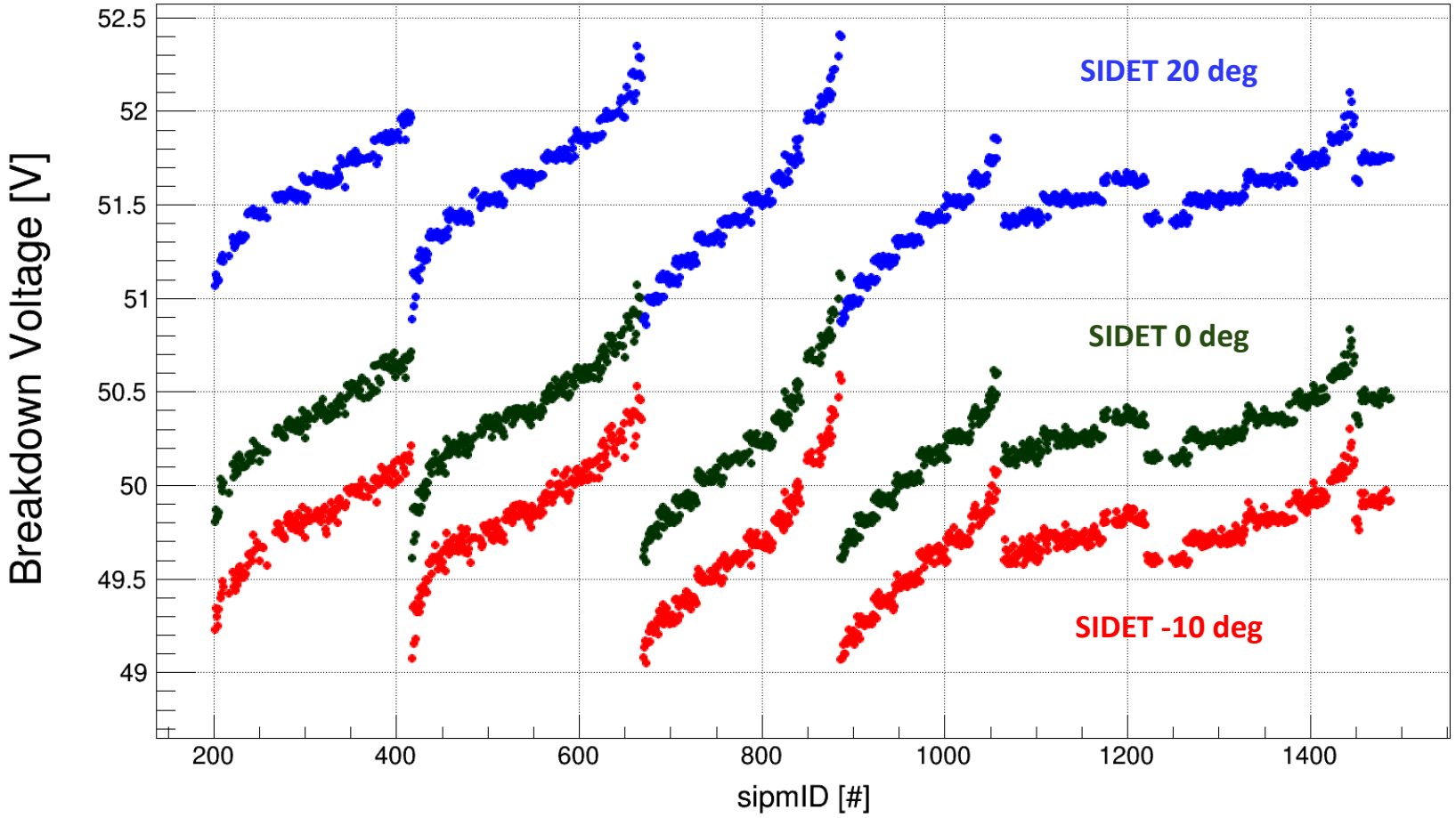


- Where:
  - V is the bias voltage
  - Vbr is the breakdown voltage
  - I_0 is the current before the breakdown
  - P is the Geiger probability
  - C is proportional to the number of the free carriers (thermal + optical)
- It is valid under 2 assumptions:
  - Afterpulse and crosstalk are negligible
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

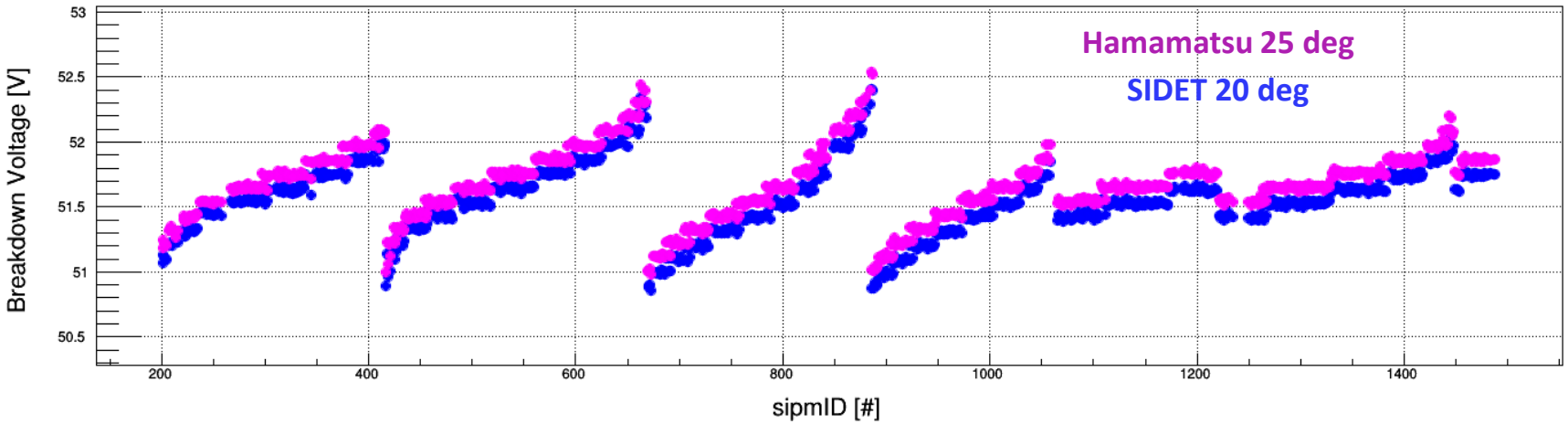
A. Nagai, N. Dinu, A. Para , "Breakdown voltage and triggering probability of SiPM from IV curves"

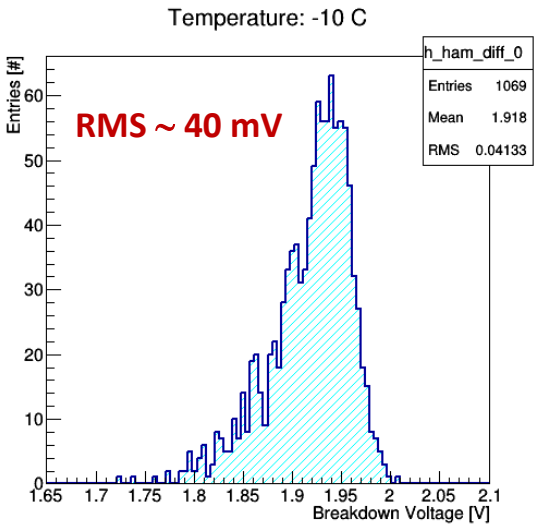
Breakdown Voltage Vs sipmID

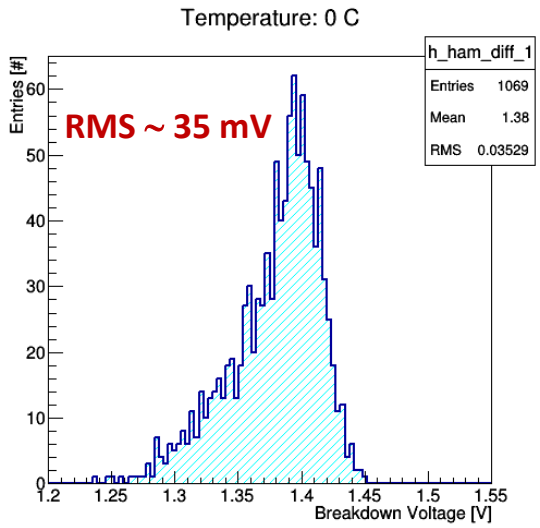
- There is a clear dependance of the Breakdown Voltage on the sipmID, probably due to different silicon wafers..

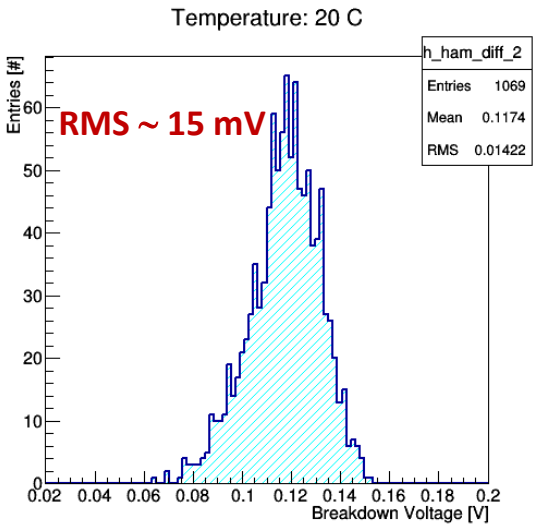


Comparison with Hamamatsu



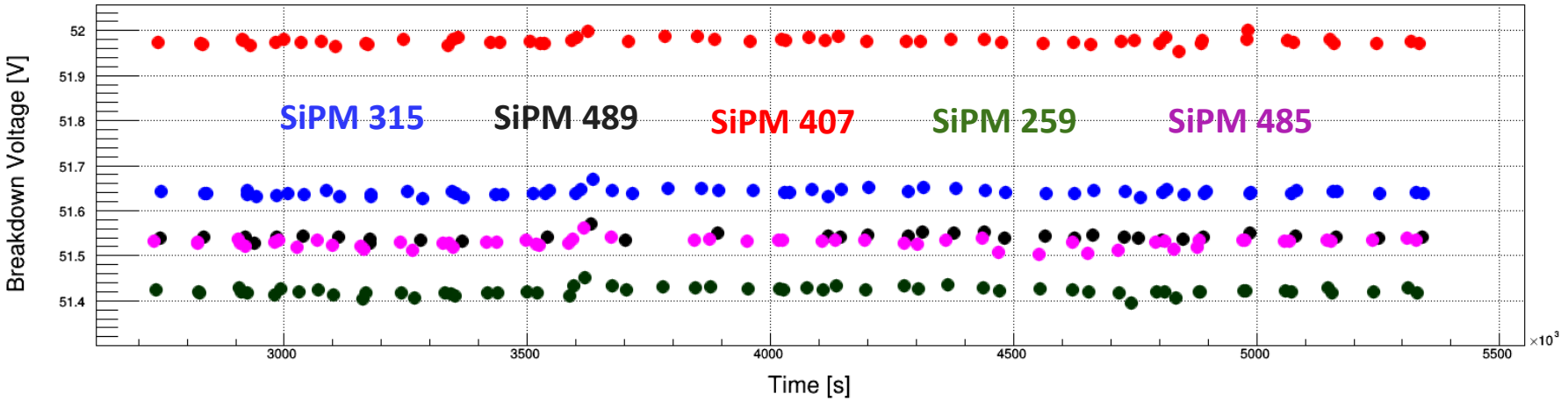


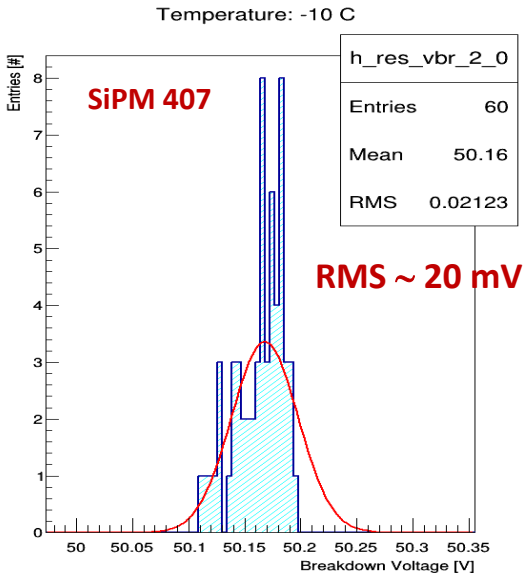


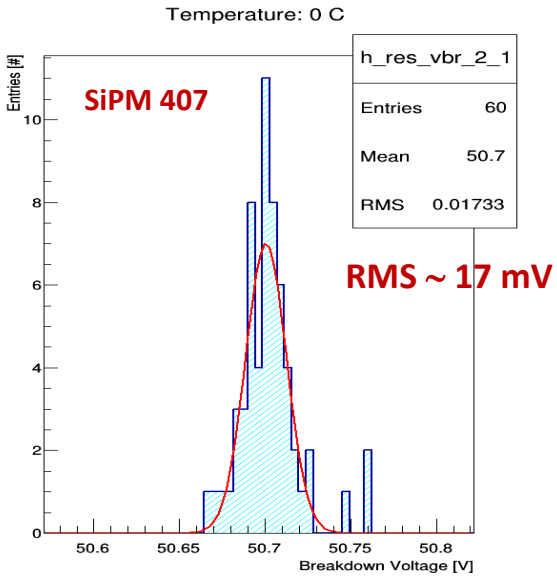


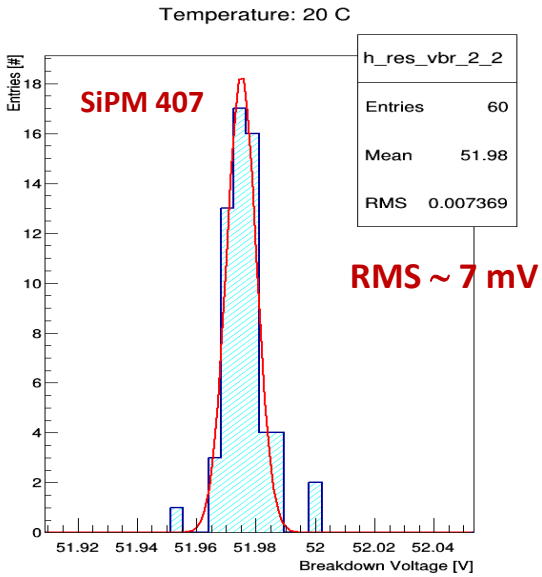
- Good agreement with Hamamtsu at 20 C; 0 C and -10 C are inside a 1 deg T stability

Stability of Breakdown Voltage



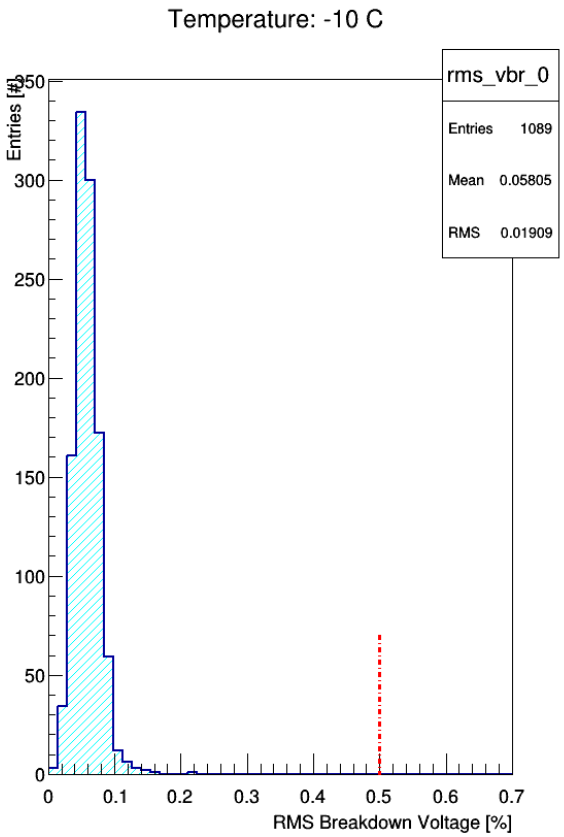


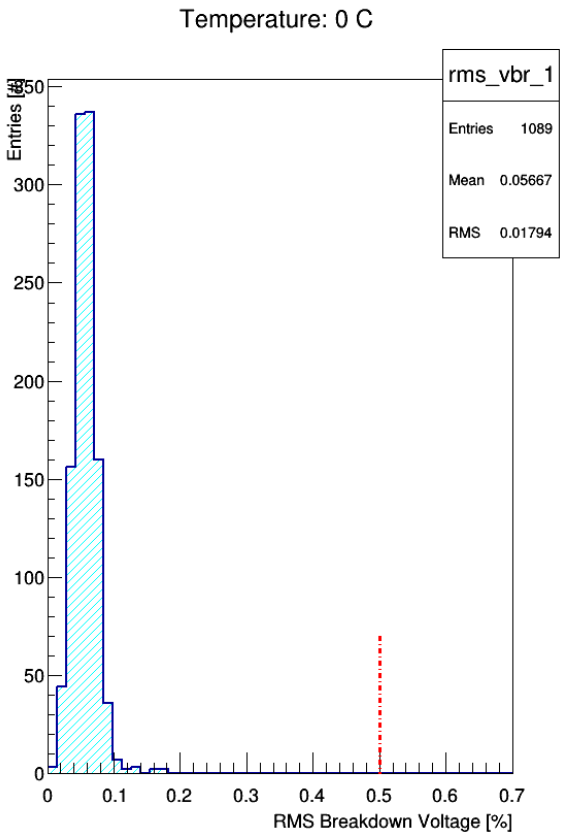


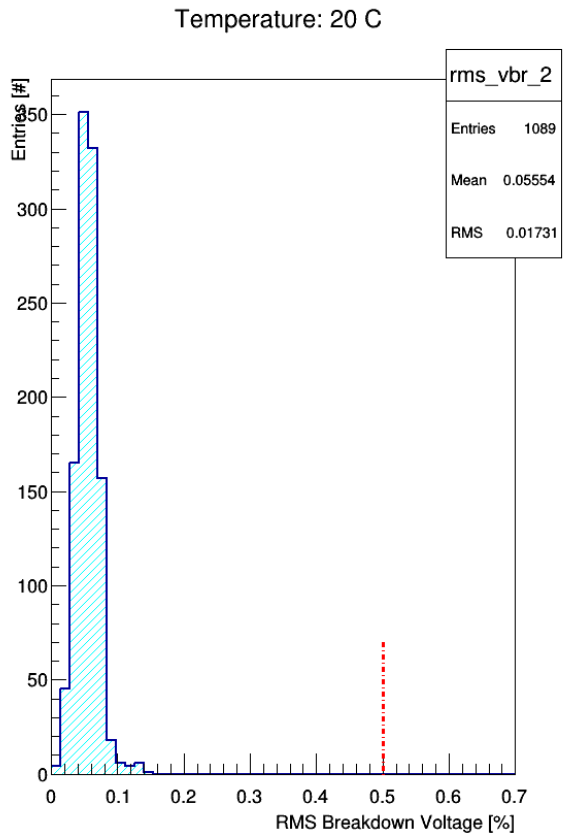


Breakdown Voltage RMS

- Looking at the QA criteria:

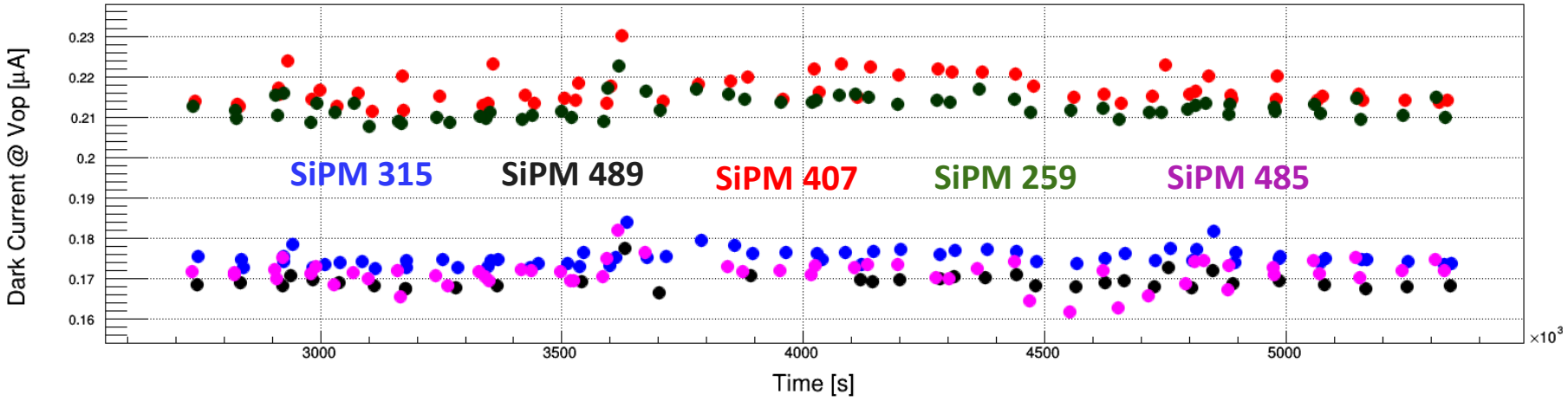


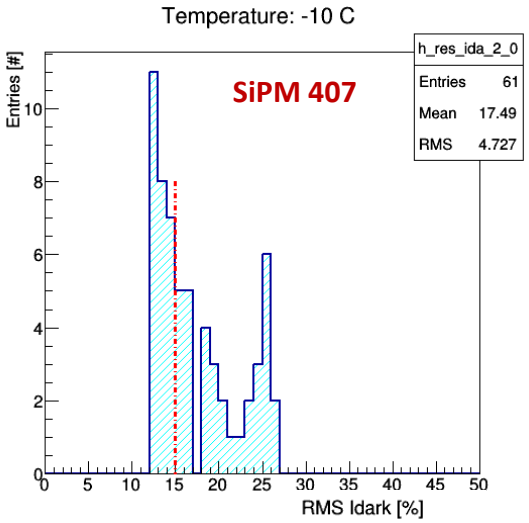


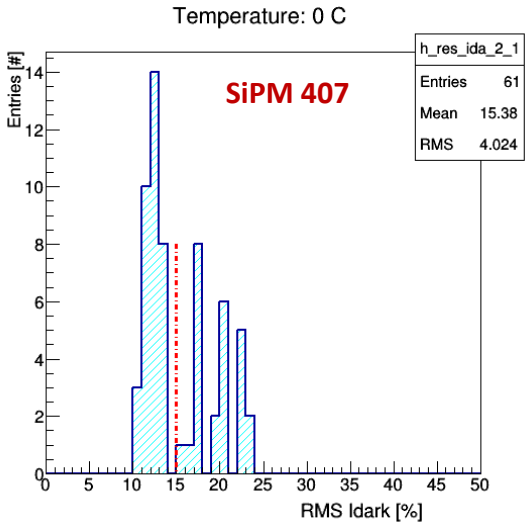


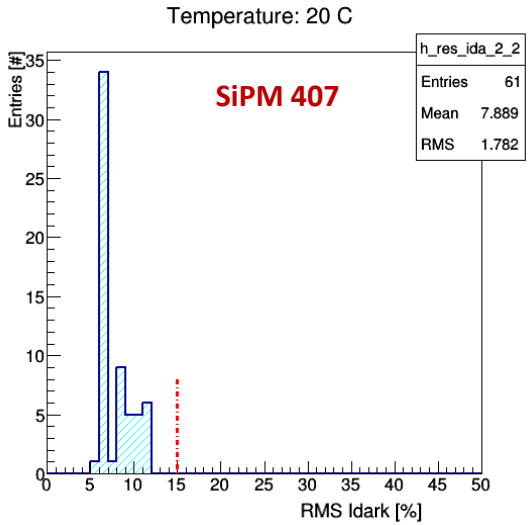
- All the tested sensors still well below the 0.5% limit!

Stability of Dark Current





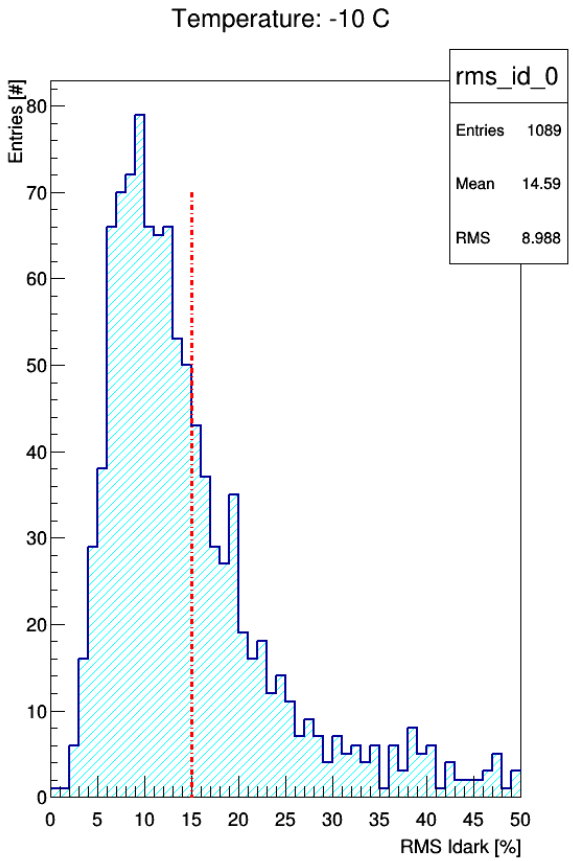


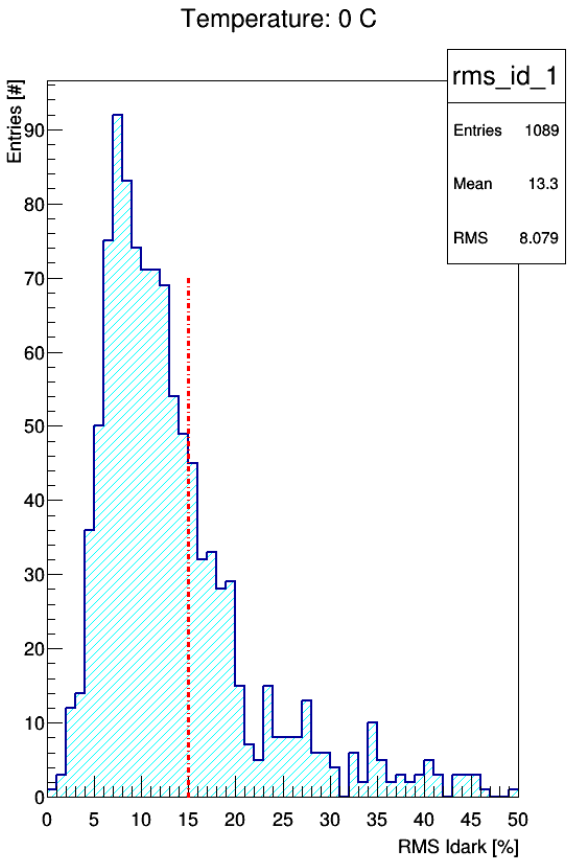


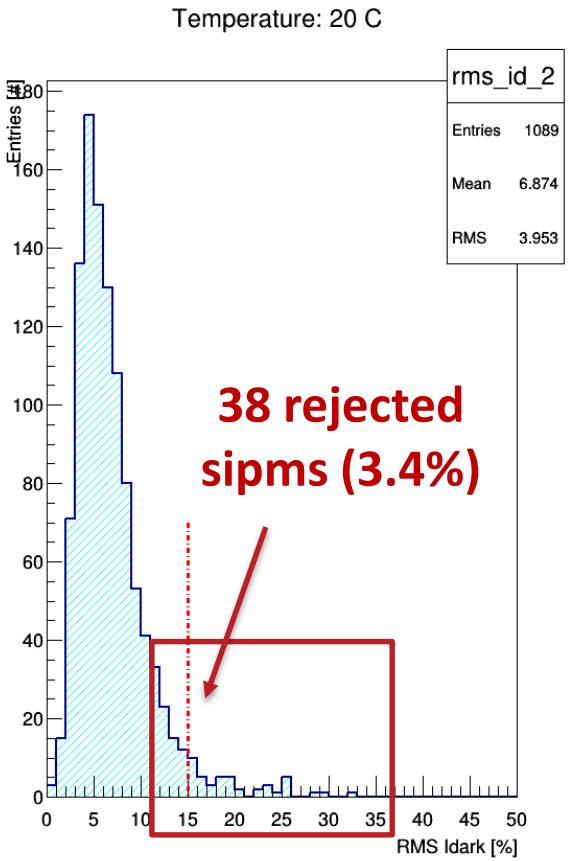
- The idark RMS measurements at 20 C is ok, while at -10 C and 0 C we do not have enough resolution

Dark Current RMS

- Looking at technical specification: Idark RMS of the 6 cells in the SiPM array @ VOP < 15% @ 20^{0}:



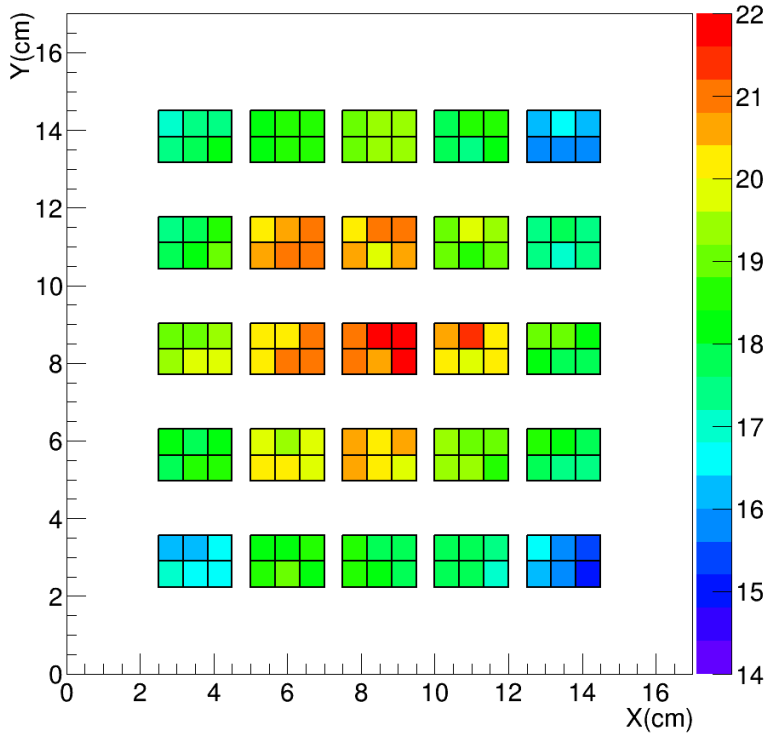


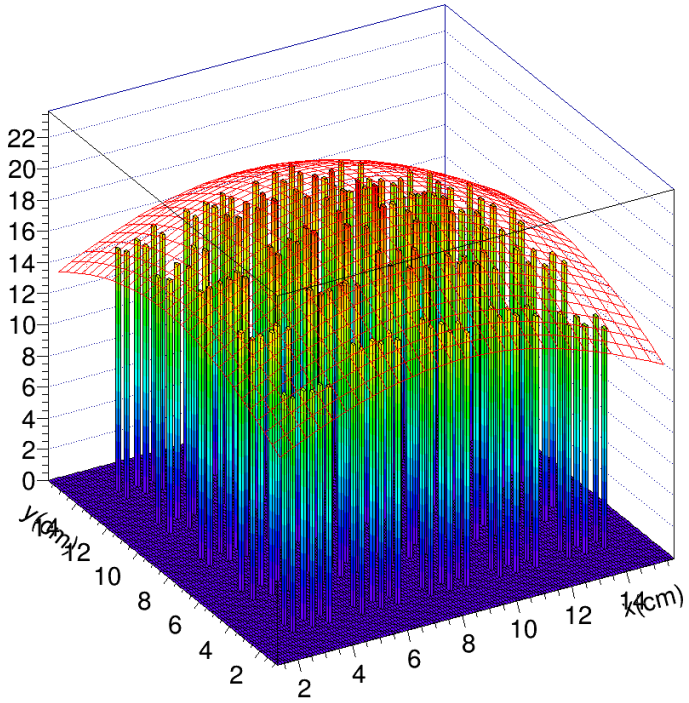


- It seems a tail effect

Gain x PDE Measurement - Light Profile

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



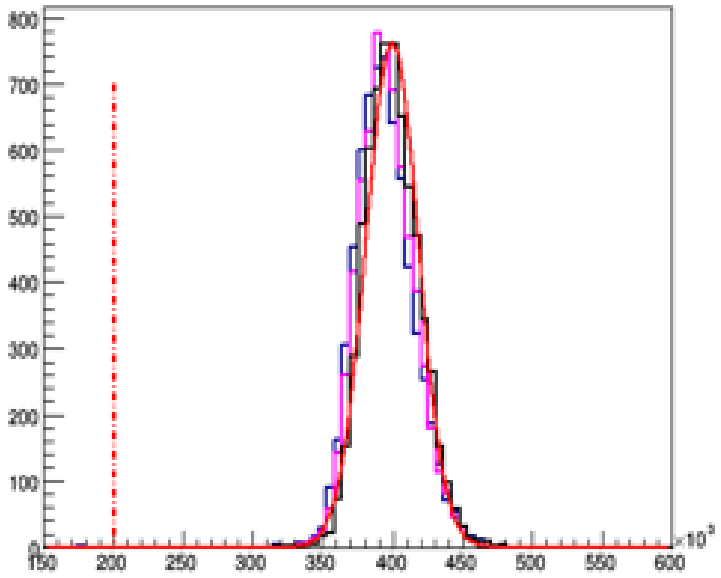


- A good approximation of this profile has been obtained by fitting the current of the sensors biased at the operative voltage.. residuals have an RMS ~ 3%

Gain x PDE Measurement

- The relative Gain x PDE is so be obtained by normalizing the incident light on the sensor wiith the one on a reference sensor:

$$\text{Gain} \times \text{PDE} = \frac{I}{I_{ref}} \times \frac{LightProfile(x_{ref}, y_{ref})}{LightProfile(x, y)} \times (\text{Gain} \times \text{PDE})_{ref}$$



Magenta: -10°
Black: 0°
Blue: 20°

σ / μ ~ 4 %

G x PDE ref = 4.e10^5

Conclusions

- The QA process for the Mu2e calorimeter Silicon PhotoMultipliers is running smoothly since the beginning of March
- The analysis procedure is stable
- We tested 7 batches, more than half of the total
- 3 % of tested SiPMs rejected (high idark RMS)
- The qualification of all the photosensors will end in middle 2019