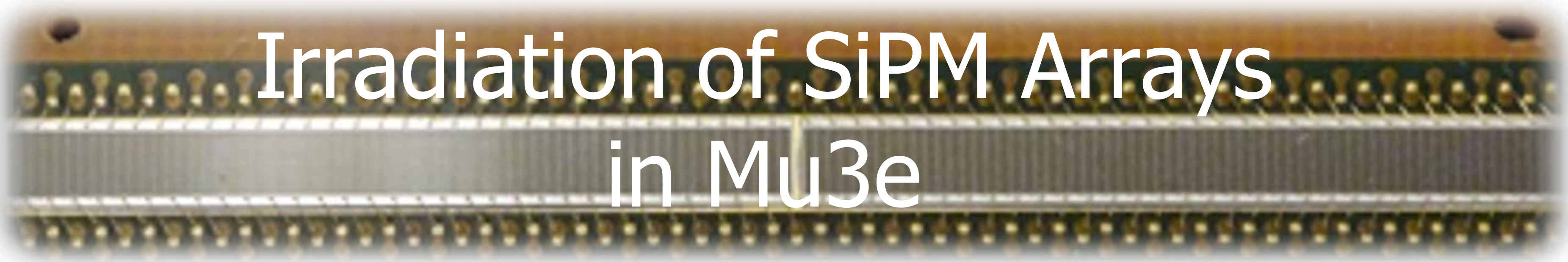
Irradiation of SiPM Arrays in Mu3e



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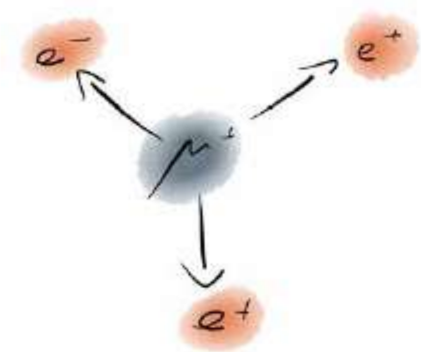
The Mu3e Experiment

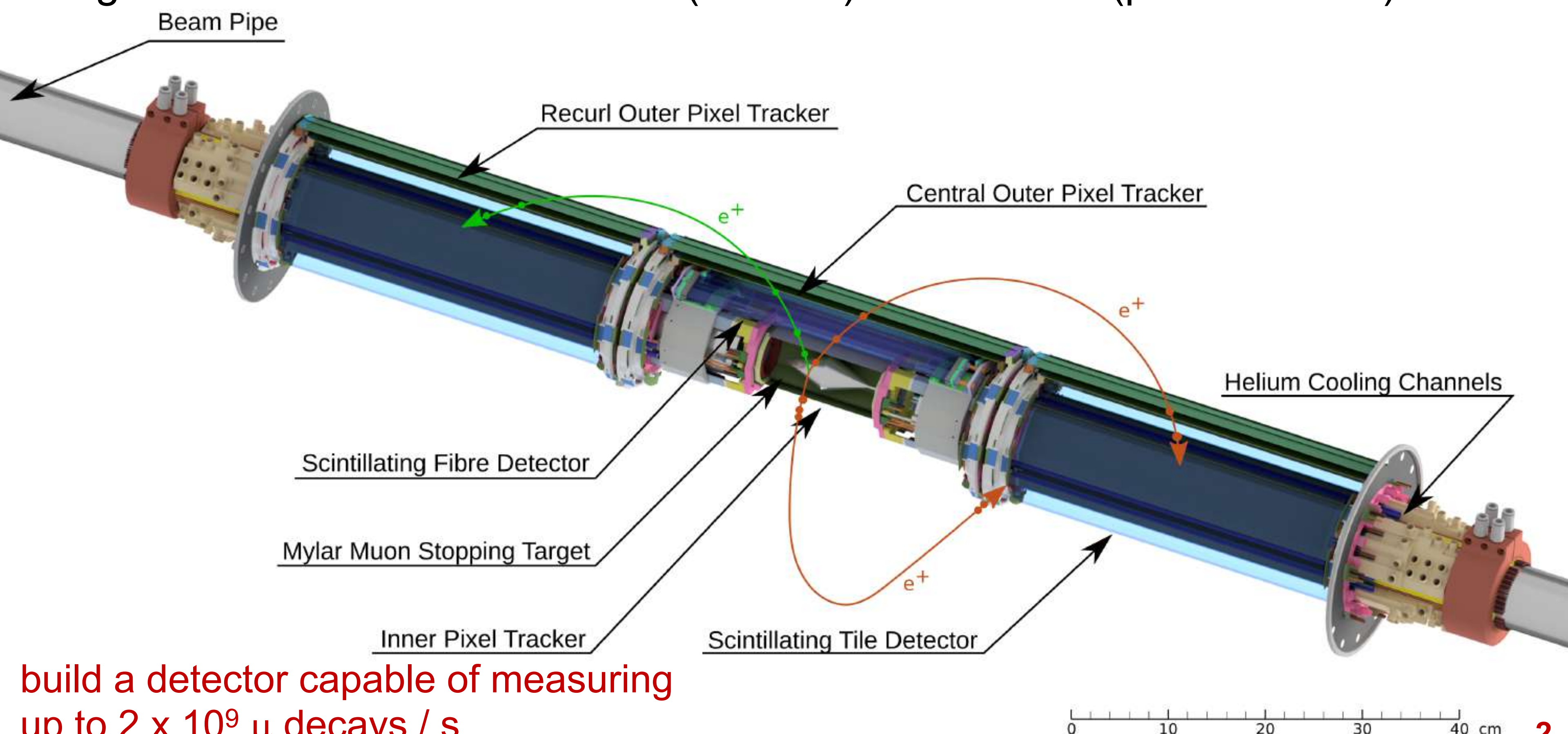


Mu3e: search for the rare μ decay $\mu^+ \rightarrow e^+ e^- e^+$

with sensitivity BR ~ 10^{-15} to 10^{-16} (PeV scale)

$\tau_{(\mu \rightarrow eee)} > 1000$ years ($\tau_\mu = 2.2\ \mu s$)

using the world's most intense DC (surface) muon beam (p ~ 28 MeV/c) at PSI



build a detector capable of measuring up to 2 x 10^9 μ decays / s

The SciFi Detector

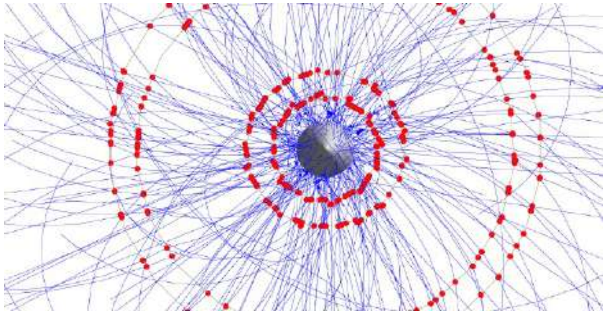
12 SciFi ribbons of 250 μm ø fibers
3 staggered layers

To suppress accidental backgrounds requires "excellent" timing :

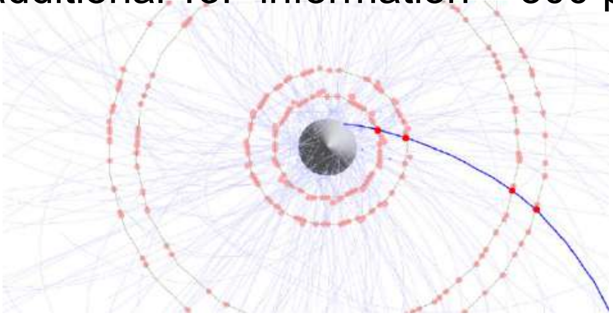
- Timing < 300 ps
- Detection efficiency > 95%

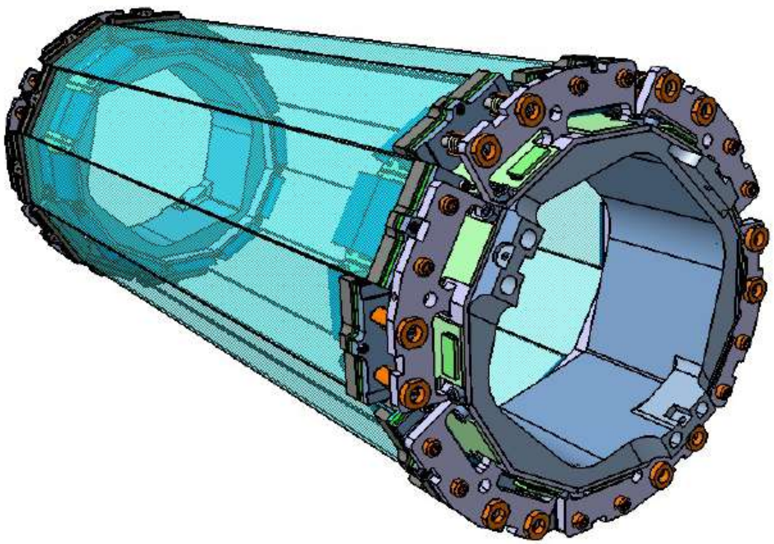
Read out with multichannel SiPM arrays

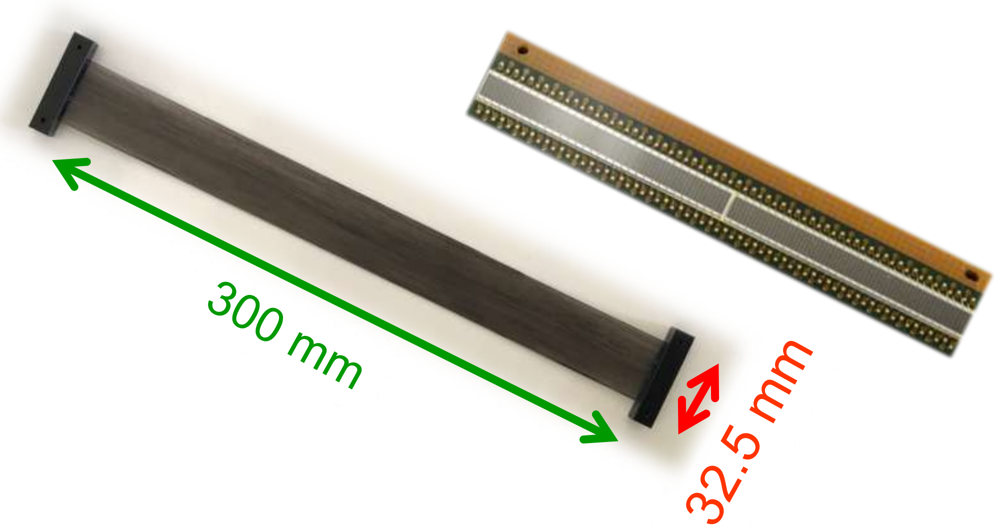
50 ns readout frame



additional ToF information < 300 ps



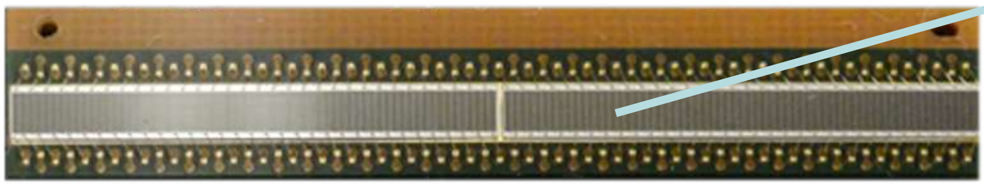




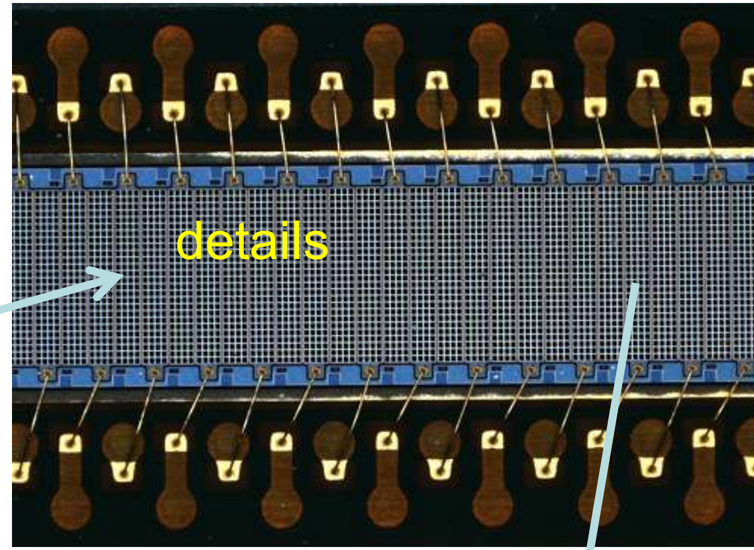
The SiPM Arrays

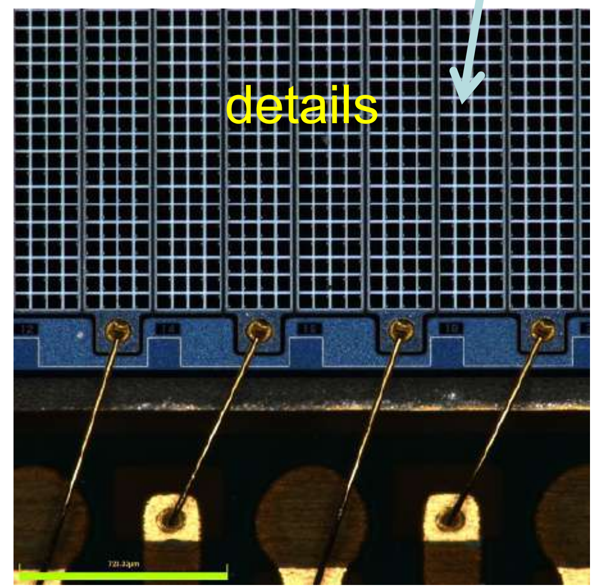
128 channel SiPM array from Hamamatsu (LHCb type) S13552HRQ

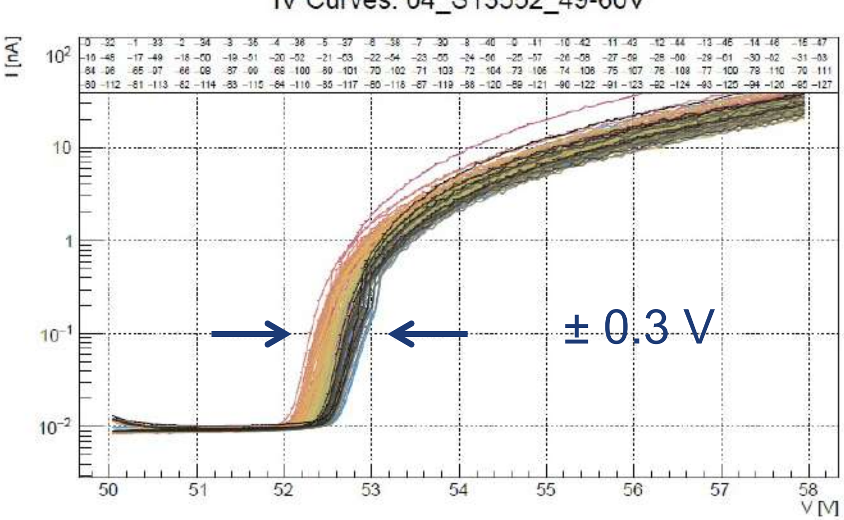
- 250 μm pitch
- pixel size 57.5 μm x 62.5 μm
- 4 x 26 pixels per column
- 230 μm x 1625 μm column area
- V_{break} ~ 52.5 V ($\pm$ 0.3 V same array)
- high quenching resistor



32.5 mm (two 64 ch. dyes)



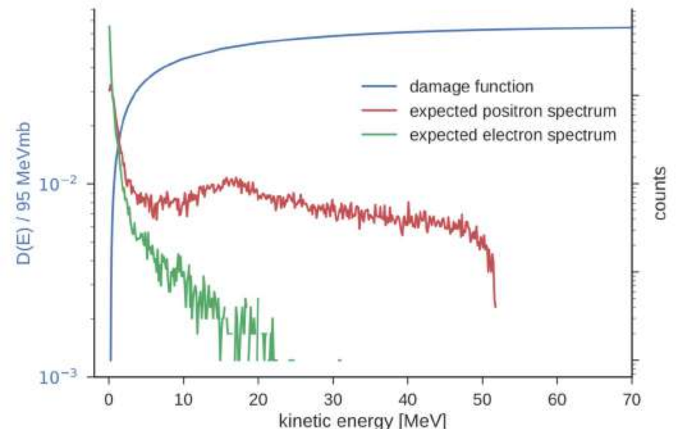


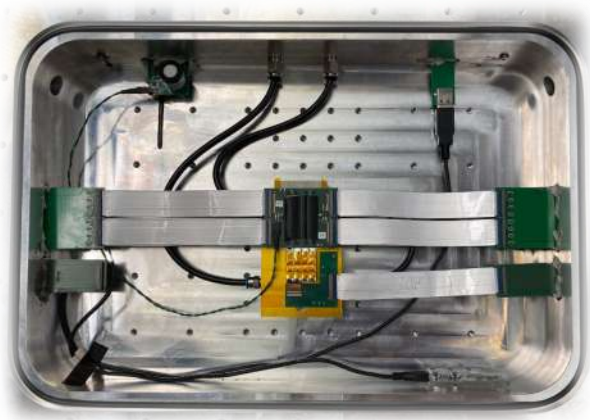


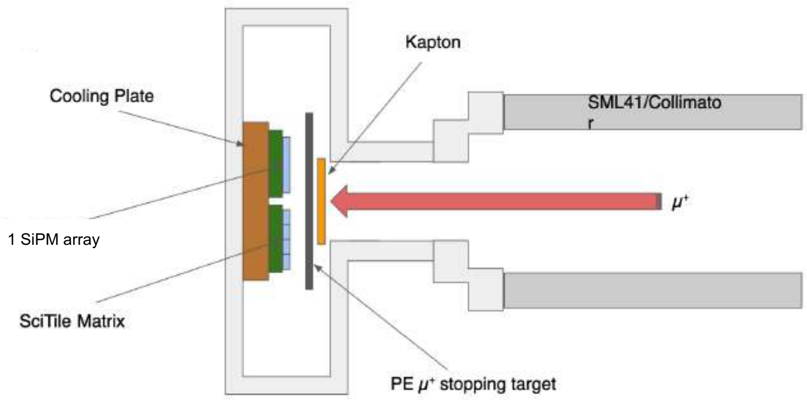
Irradiated SiPM Arrays

The radiation damage in Mu3e comes mainly from irradiation with low energy positrons up to 53 MeV

Therefore, we irradiated several SiPM arrays at different doses in PiE5 using positrons from muon decays at rest (i.e. Michel electrons)



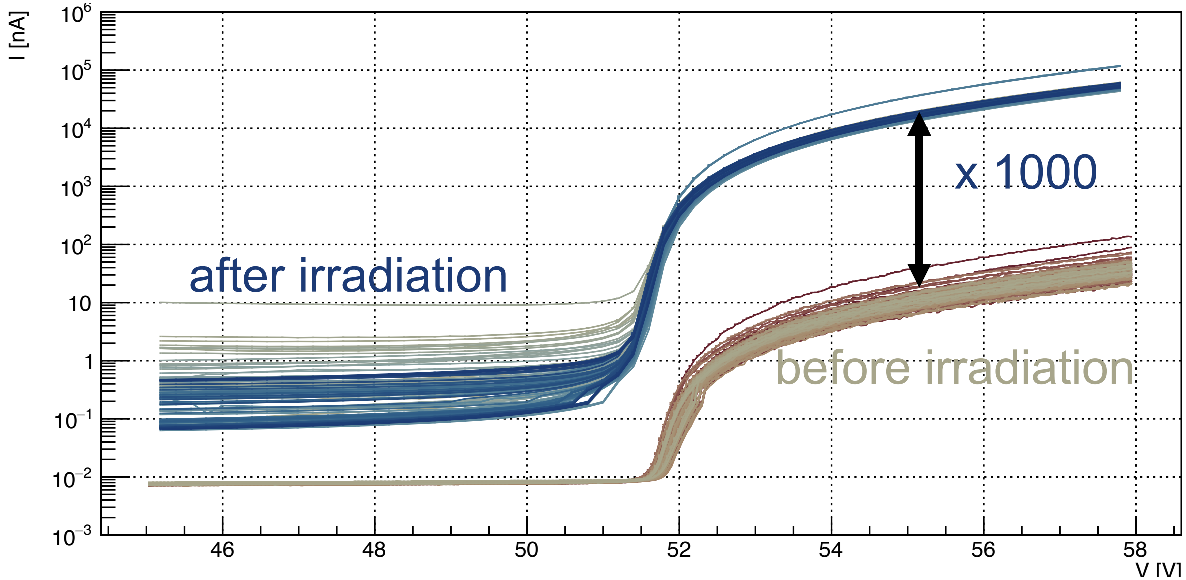




In phase I (i.e. 2.5 x 10^{15} muons stops) the SiPM arrays will absorb a dose of O(10^{11}) neutrons equivalent / cm^2 .
In this study: 5 irradiated SiPMs at different doses.
The maximum dose corresponds to ~ 10^{12} part./cm^2 .
(conversion between positrons and $neutron_{eq}$ is not straightforward)

I-V Curves

I-V curve



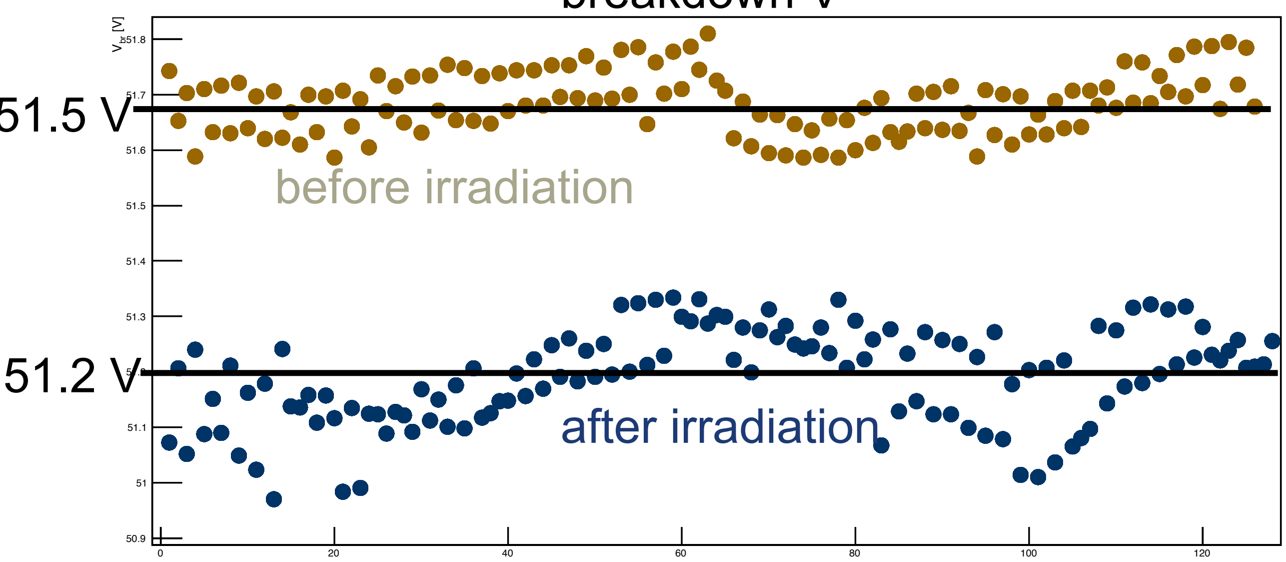
at room temperature ~25° C

after irradiation,
before annealing

Maximum dose SiPM

Note: area = 26 mm², i.e. ¼ cm²

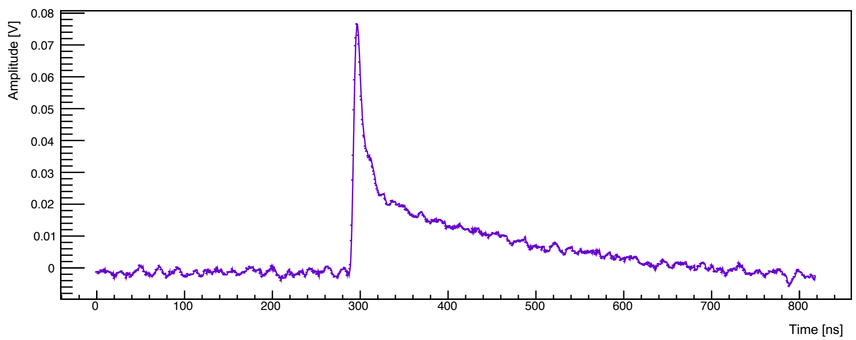
breakdown V



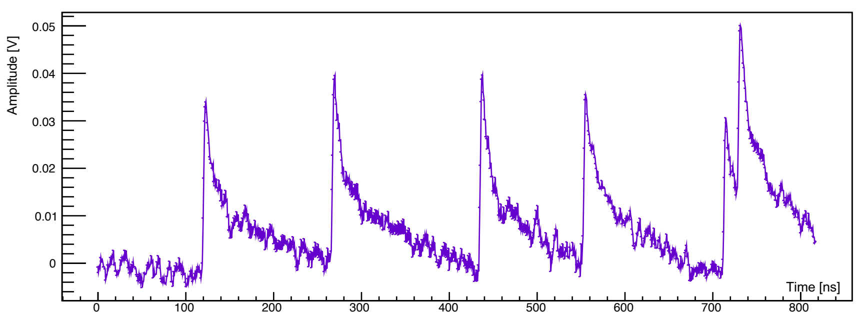
Waveforms

Waveforms after amplification with gain 40 dB,
using a random trigger and with a bias voltage V_{bd} + 3V
Maximum dose SiPM

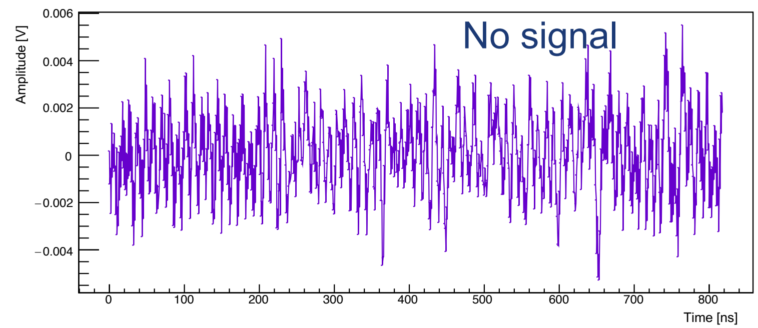
Not irradiated

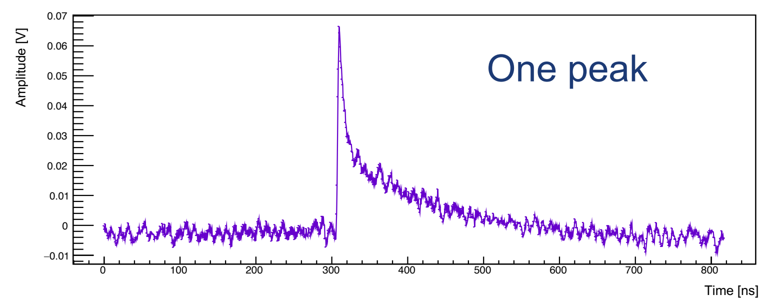


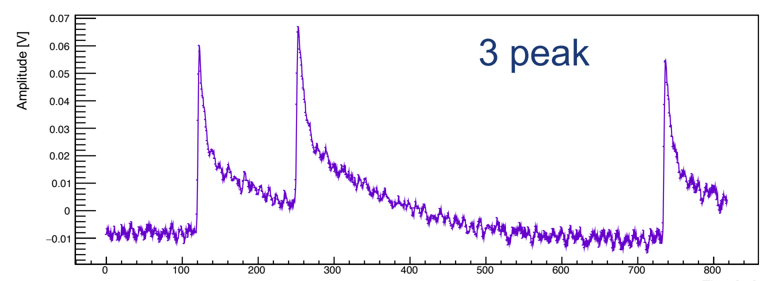
irradiated at 20°C



irradiated at -7°C



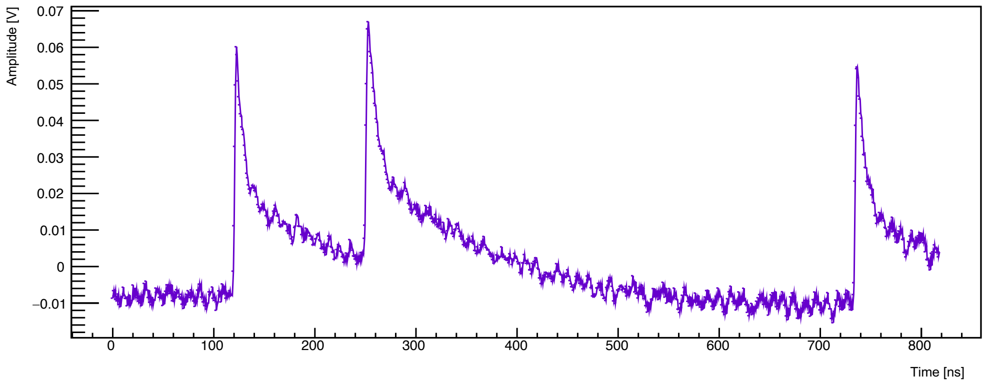




"Dark Count Rates"

To estimate the dark count rate we count the number of "peaks"
in the waveforms recorded with the DRS4 waveform digitizer over a 800 ns "gate" (normalize to 1 s)

Counting peaks by "eye"
bias voltage V_{bd} + 3V



irradiation dose full dose

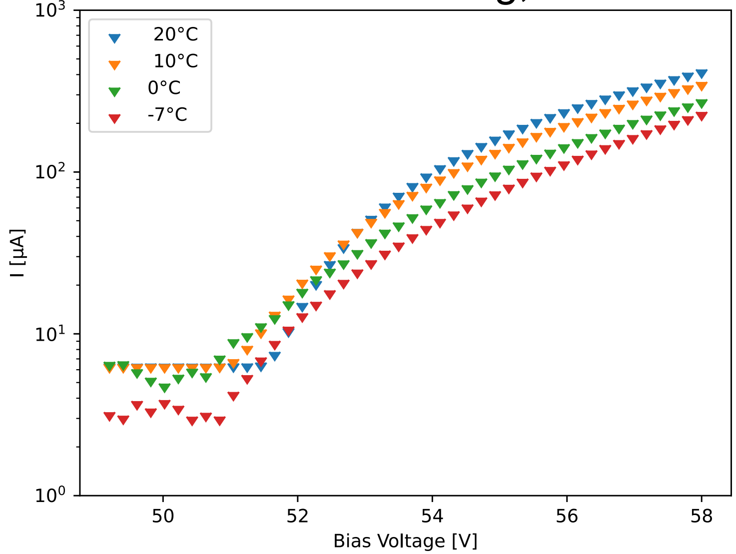
Irradiated at 20°C : ~2.5 MHz/channel
Irradiated at 10°C : ~1.6MHz/channel
Irradiated at 0°C : ~0.7 MHz/channel
Irradiated at -7°C : ~0.4 MHz/channel

Prospect :
At -20°C expect ~ 100 kHz/channel

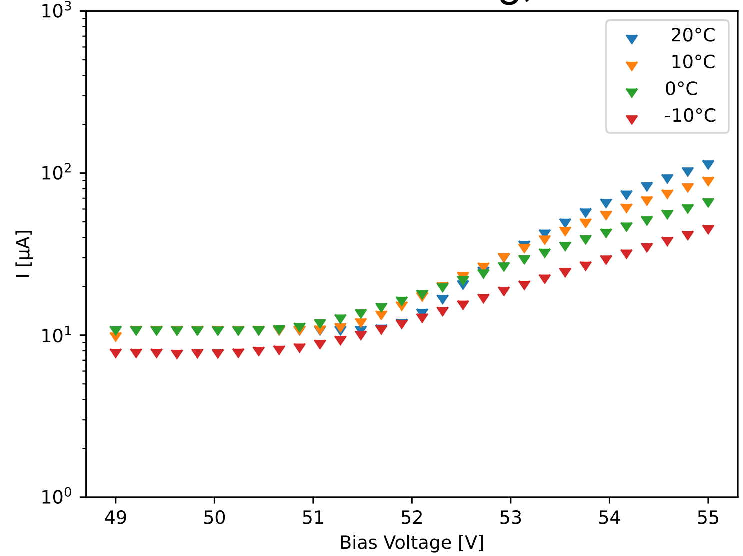
Dark Current vs V_{bias} for Different T

After annealing months at room temperature

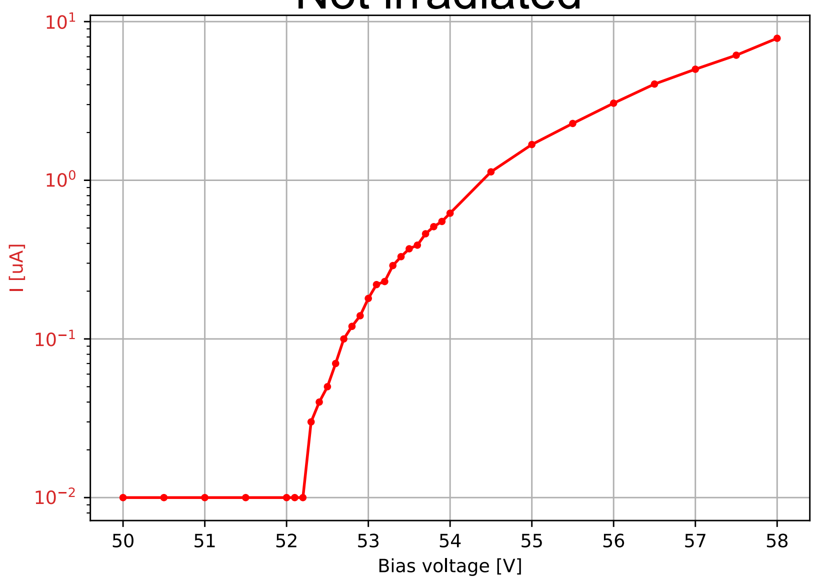
Irradiated after annealing, max dose



Irradiated after annealing, ~½ of max dose

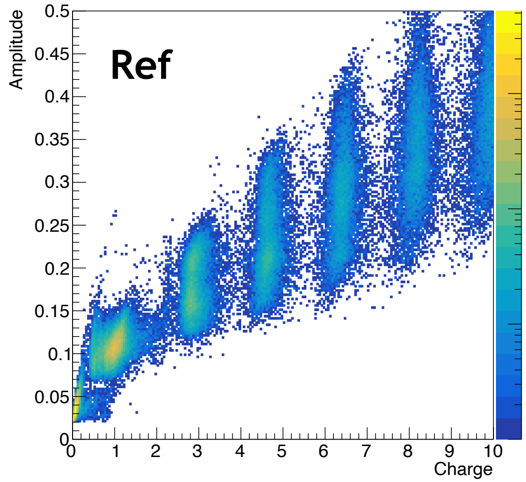


Not irradiated

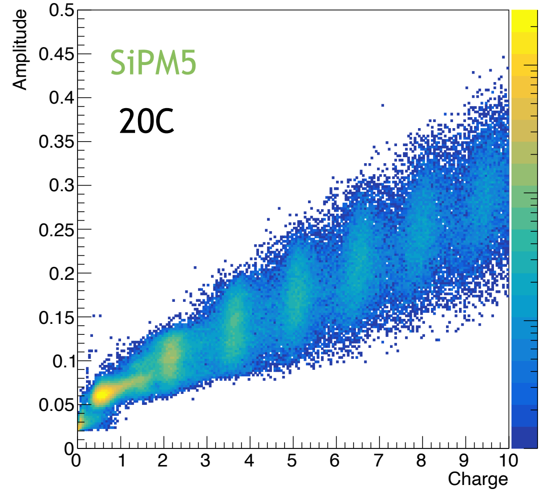


Amplitude vs. Charge

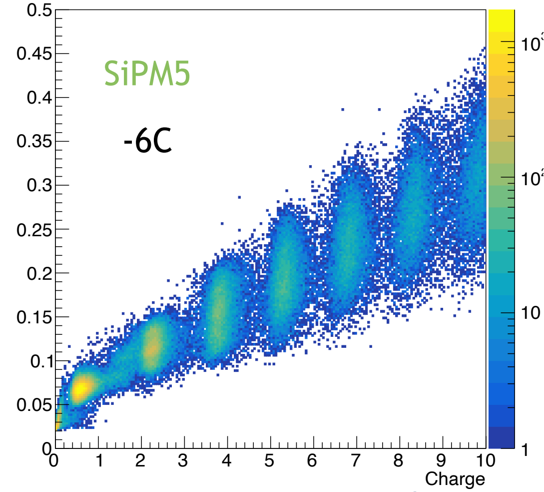
non-irradiated



irradiated at 20^0 C



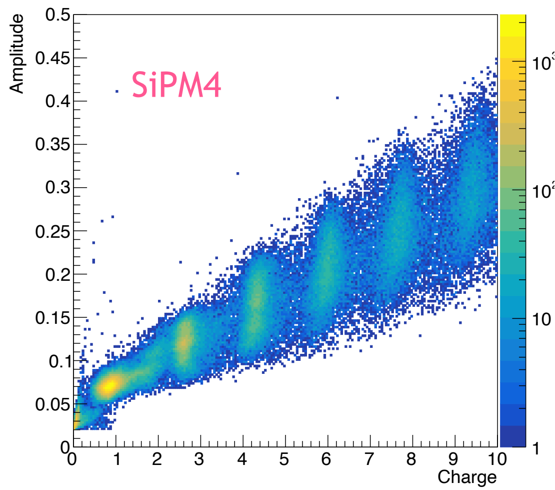
irradiated at -6^0 C



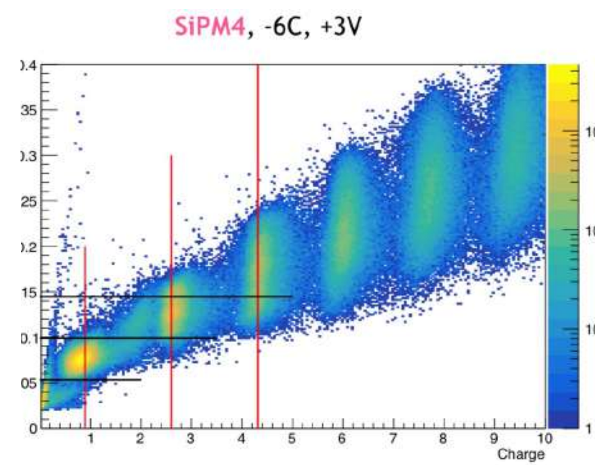
At bias voltage V_{bd} + 3V

SiPM 5: ~½ max dose
SiPM 4 ~¼ max dose
(irradiation max dose
i.e. ~10^{11} n_{eq}/cm^2)

irradiated at 20^0 C



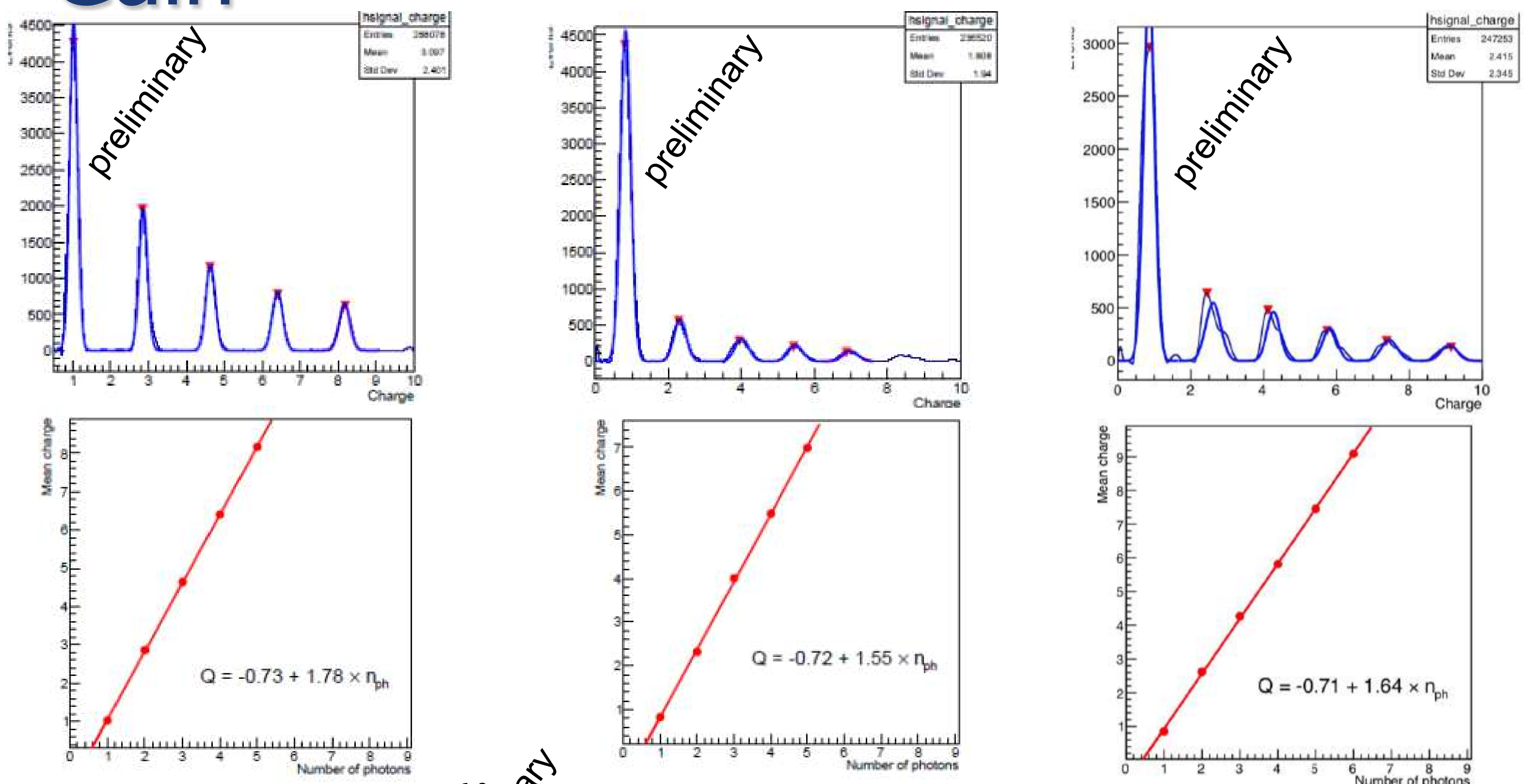
irradiated at -6^0 C



As the temperature drops, we recover single-photon resolution, allowing for a correct threshold determination (no clustering in these plots)

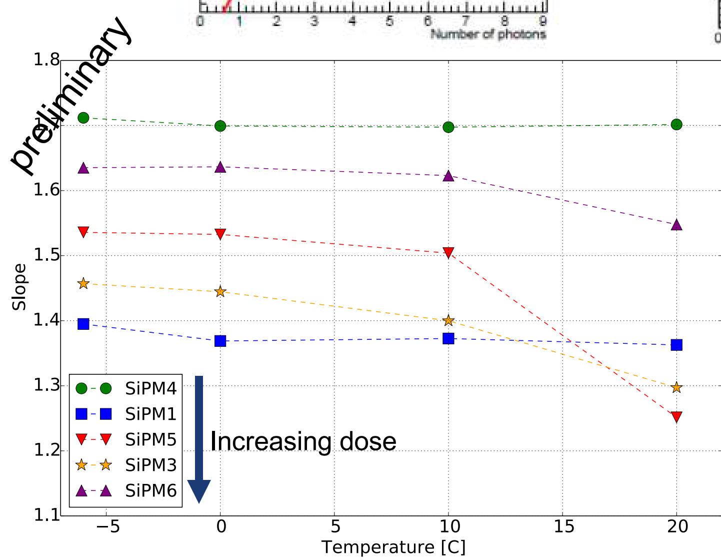
Gain

linearify (baseline subtracted) charge



At bias voltage V_{bd} + 3V

SiPM6 max dose
(irradiation full dose
(i.e. ~10^{11} n_{eq}/cm^2)
SiPM 5: ½ max dose
SiPM 4 ¼ max dose



Slope = relative gain

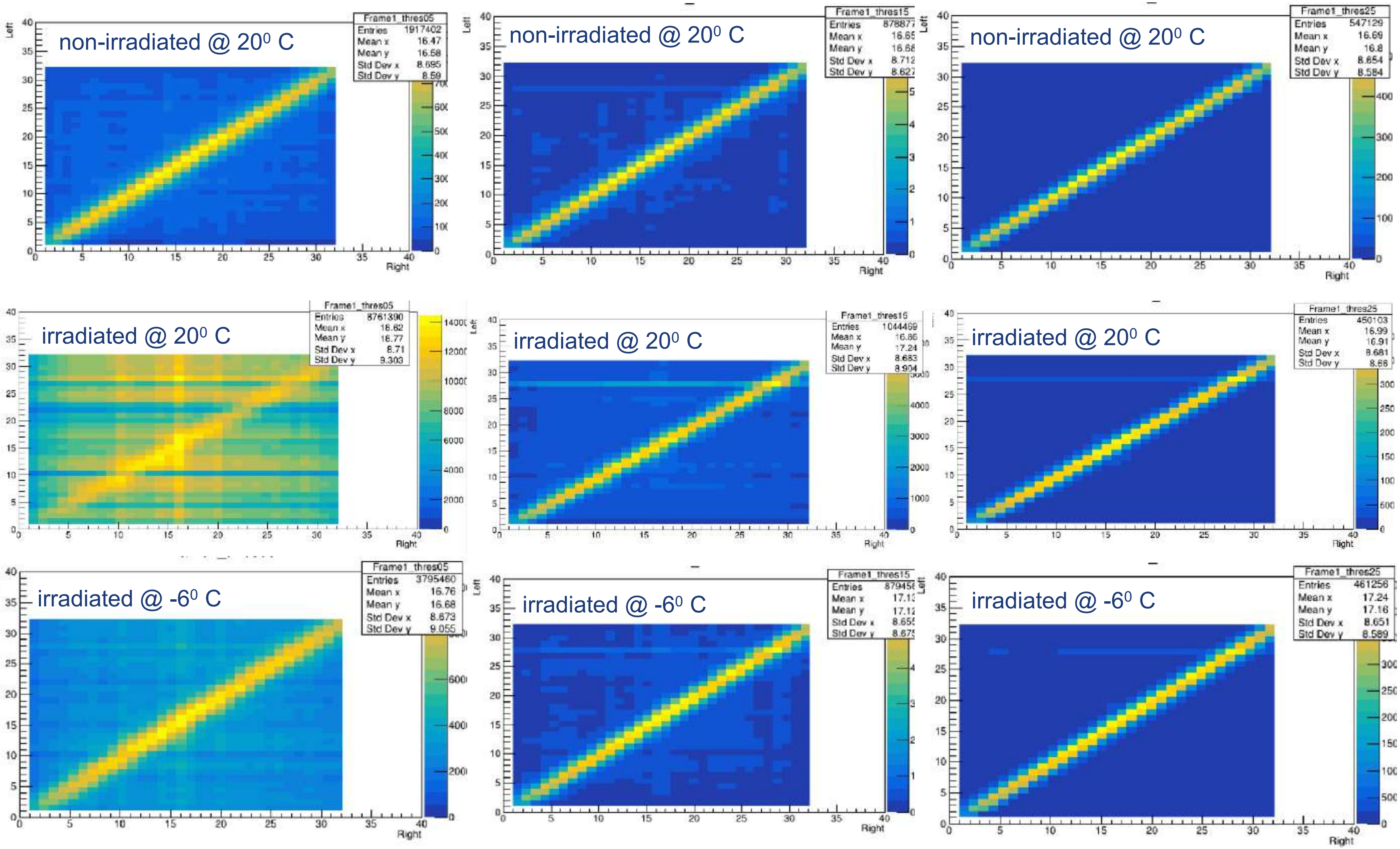
Left-Right Correlations

Only one side irradiated SiPM

threshold 0.5 ph.el. | threshold 1.5 ph.el. | threshold 2.5 ph.el.

non-irradiated @ 20⁰ C

irradiated @ -6⁰ C and 20⁰ C

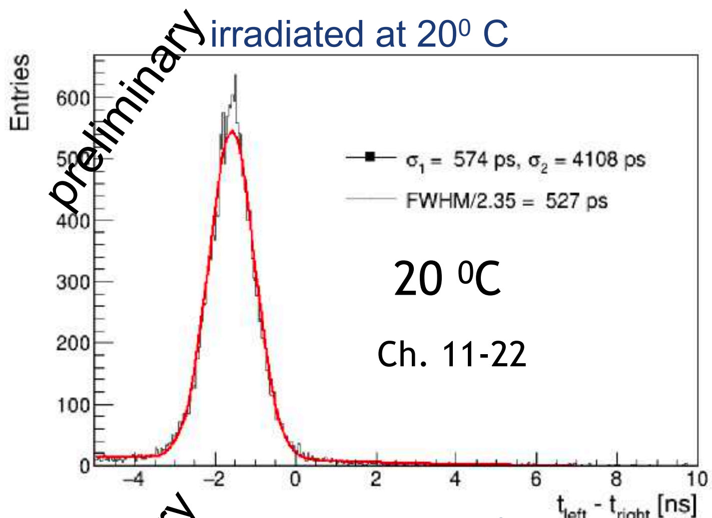


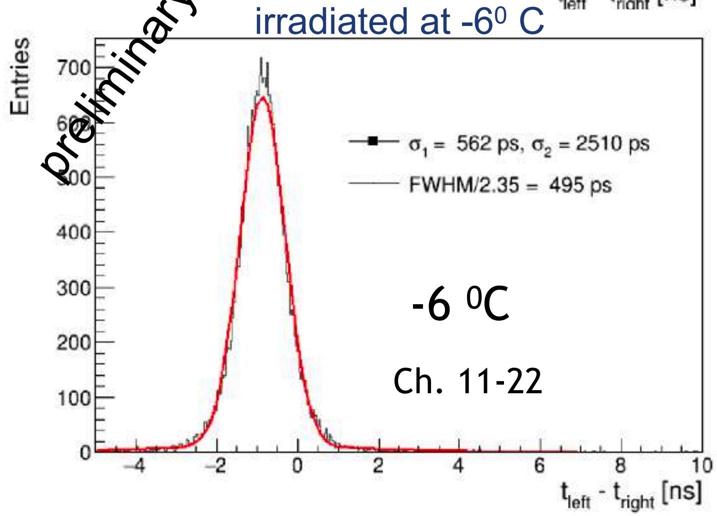
from the correlation plot one can “guess” the cluster size.

With SiPM6 max dose

Timing performance

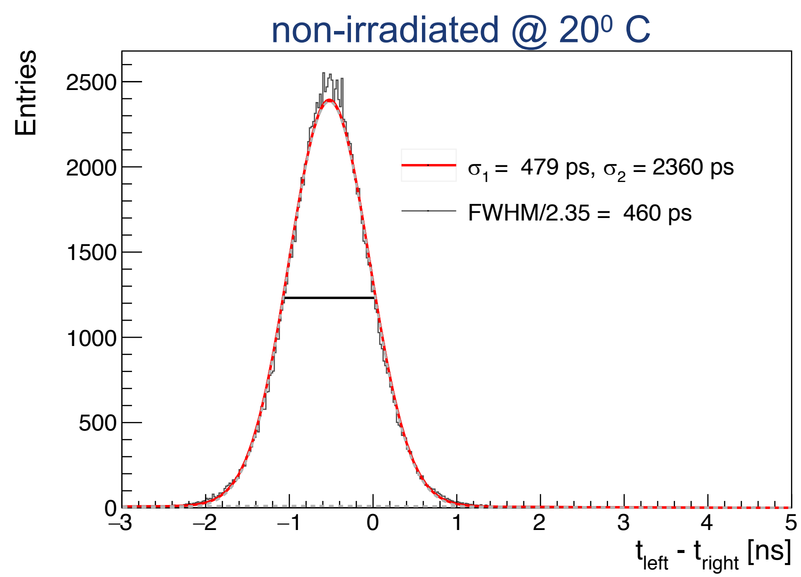
Only one side irradiated SiPM





Affects the time resolution compared to the time resolution of the non irradiated SiPM (only one side)

Improves with cooling



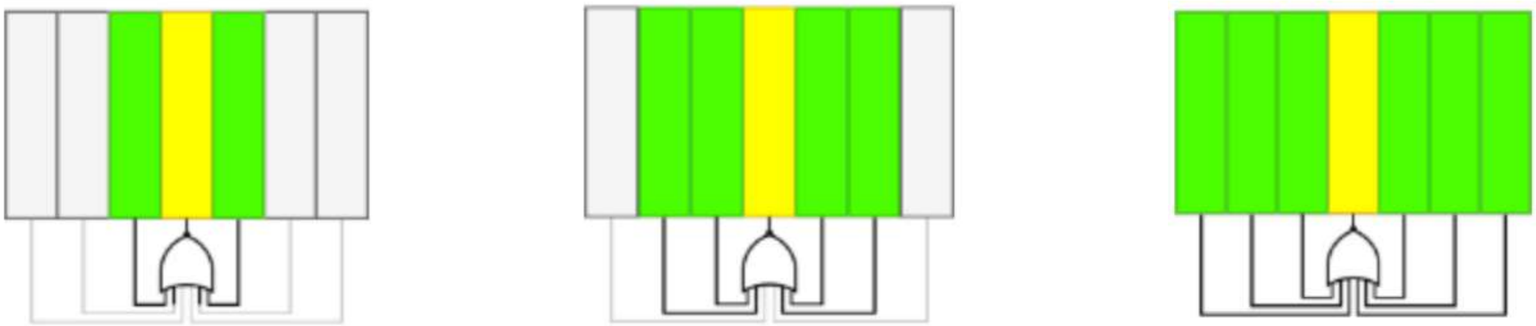
With SiPM5 ~½ max dose

Noise Reduction

- Clustering
  goal of the clustering algorithm is to group signals caused by an ionizing particle together while eliminating any unwanted contribution from accidentally fired SiPM channels

- Time matched clusters
  allows for more constraining and therefore better identification when a particle crosses one SciFi ribbon

- MuTRiG2 clustering algorithm embedded in ASIC (Coincidence logic)
  Hits are only stored if a coincidence with a neighboring channel is seen. Neighbors can be selected from a matrix of 3 nearest neighbors, for each channel independently.



Conclusions

- Work in progress. Studies on irradiated SiPM's are ongoing.
- At beamtest studies has been done and analysis is ongoing.
- Lab studies are in progress

- If necessary, replace SIPM arrays (already foreseen)
- Higher threshold : if thresholds at 1.5 ph.e. , depending on how we implement the algorithm, no efficiency loss.
- Cooling

- Ignorant question :
  Is it possible to conceive a SiPM resistant to electron radiation ?

Thank you.