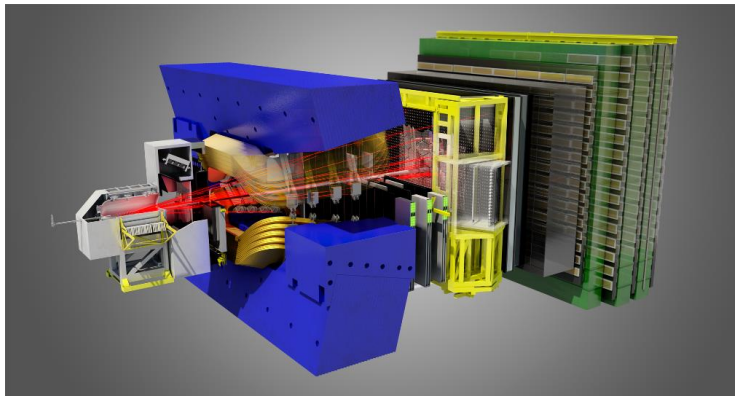
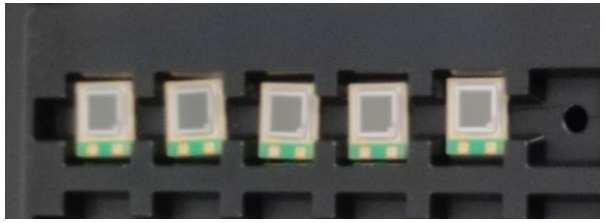
Characterization of SiPMs for LHCb Upgrade II

Constantinos Vrahas

on behalf of the RAL group



Types of SiPMs characterized

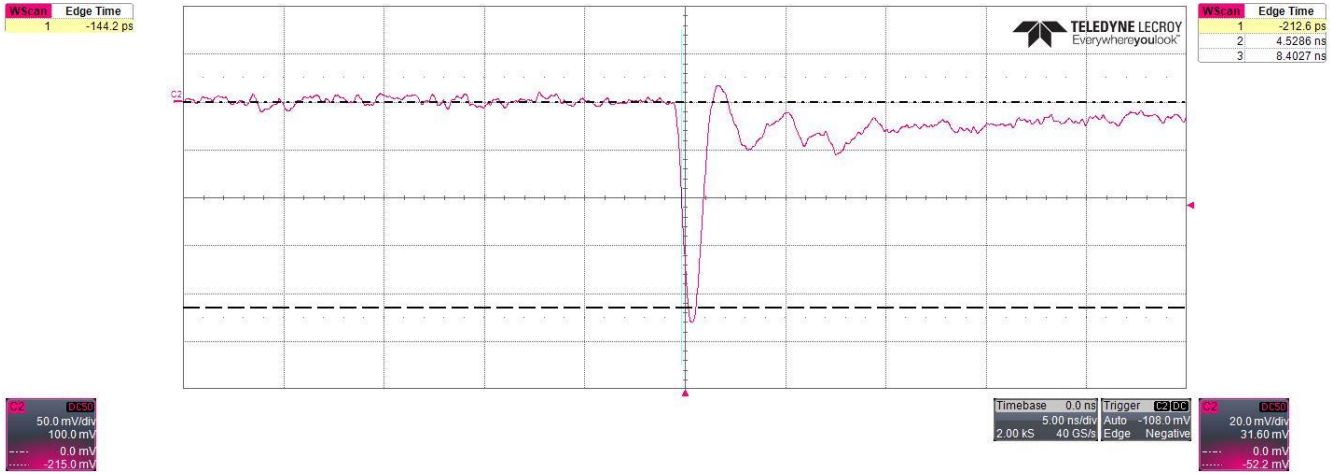


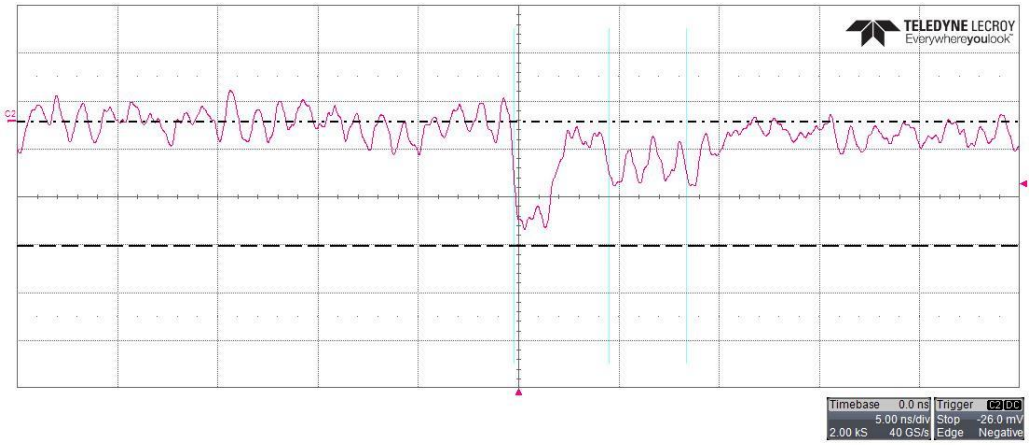
Hamamatsu 13360-1350PS:

- Photosensitive area **– 1.3x1.3mm**
- V_{BD} **@25C – 53V**
- Nominal operating voltage **– 3OV**
- DCR **@25C, 3OV – 90KHz**
- Pixel pitch **– 50µm**
- Nominal gain **– $1.7x10^6$**

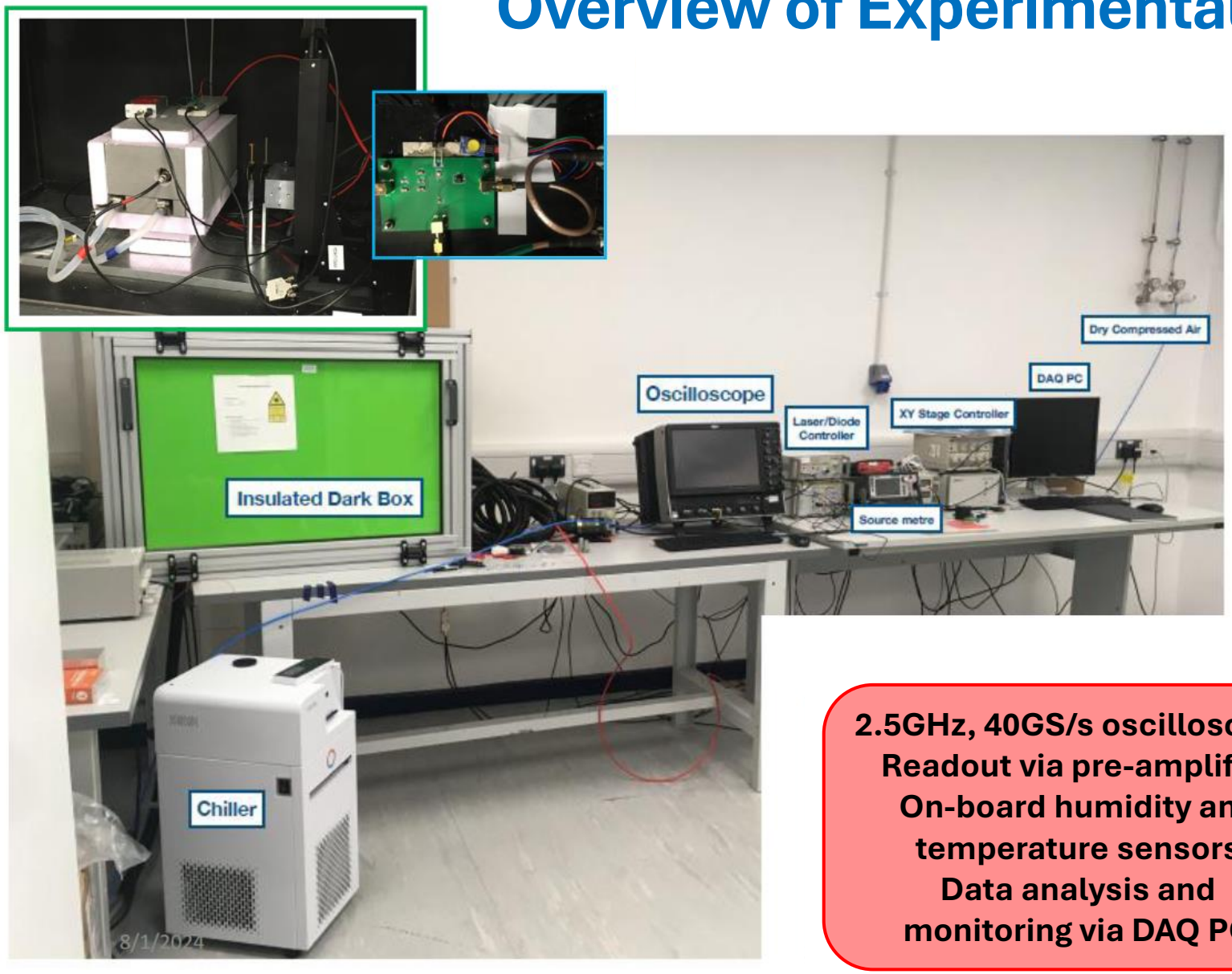
Hamamatsu 14160-1315PS:

- Photosensitive area **– 1.3x1.3mm**
- V_{BD} **@25C – 38V**
- Nominal operating voltage **– 4OV**
- DCR **@25C, 4OV – 120KHz**
- Pixel pitch **– 15µm**
- Nominal gain **– $3.6x10^5$**
- Hamamatsu claims higher radiation hardness





Overview of Experimental Setup



- Nested box in light-tight enclosure provides cooling, insulation and precise humidity and temperature monitoring

Peltier cooling
Dry air supply
Picosecond photodiode and laser for illumination
Biased using sourcemeter

IN

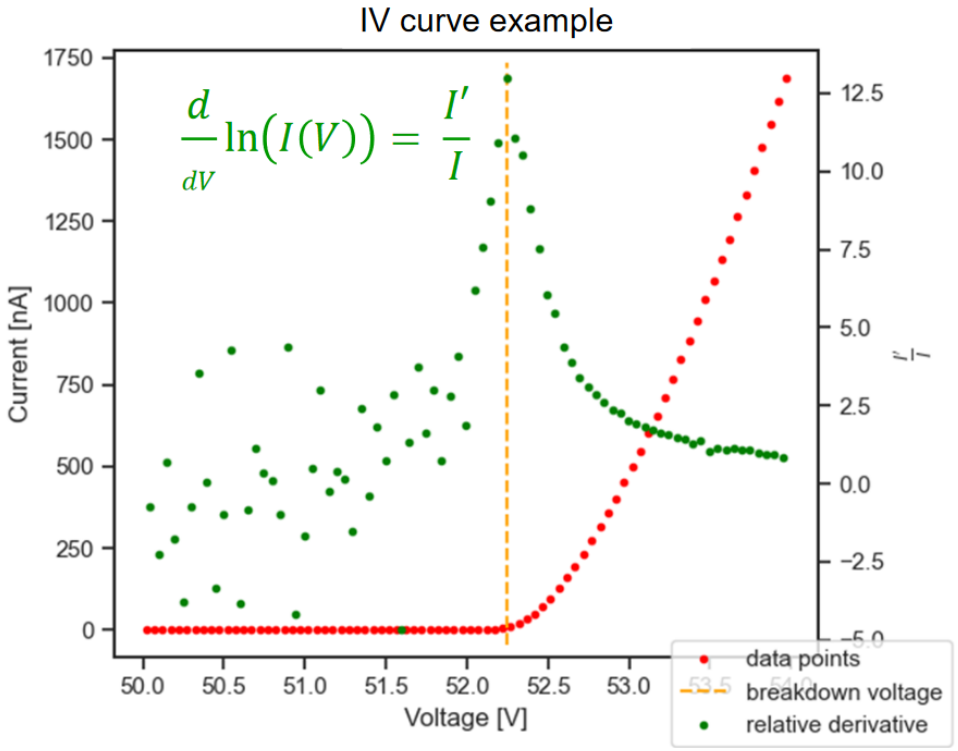
OUT

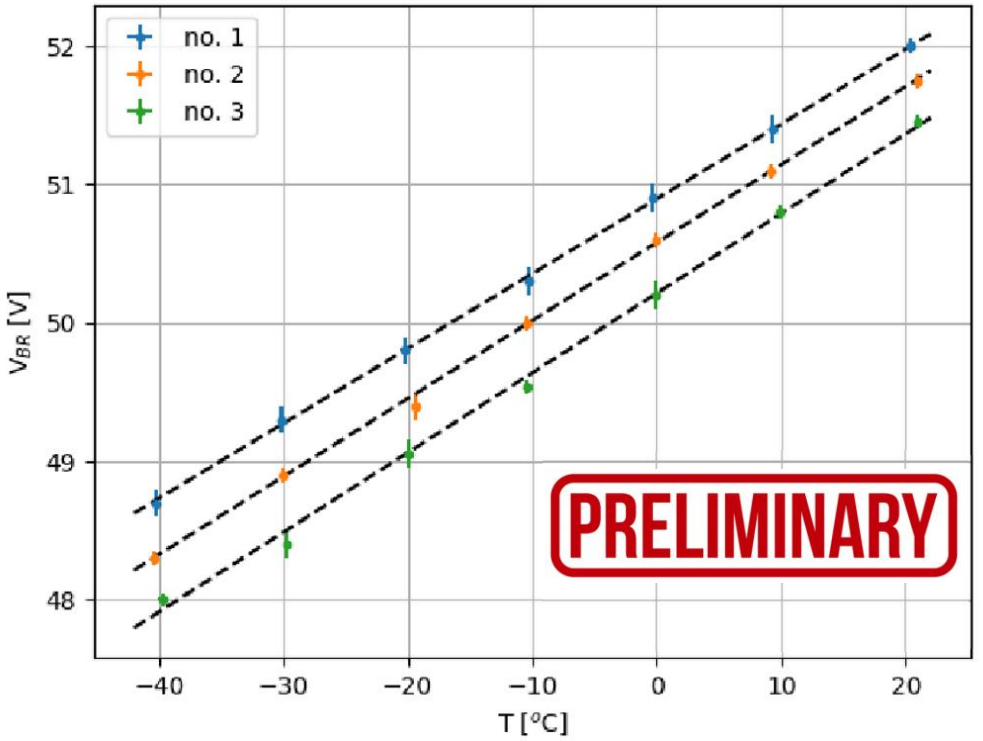
LTE
Coolbox
SiPM

2.5GHz, 40GS/s oscilloscope
Readout via pre-amplifier
On-board humidity and temperature sensors
Data analysis and monitoring via DAQ PC

Characterization of Breakdown Voltage

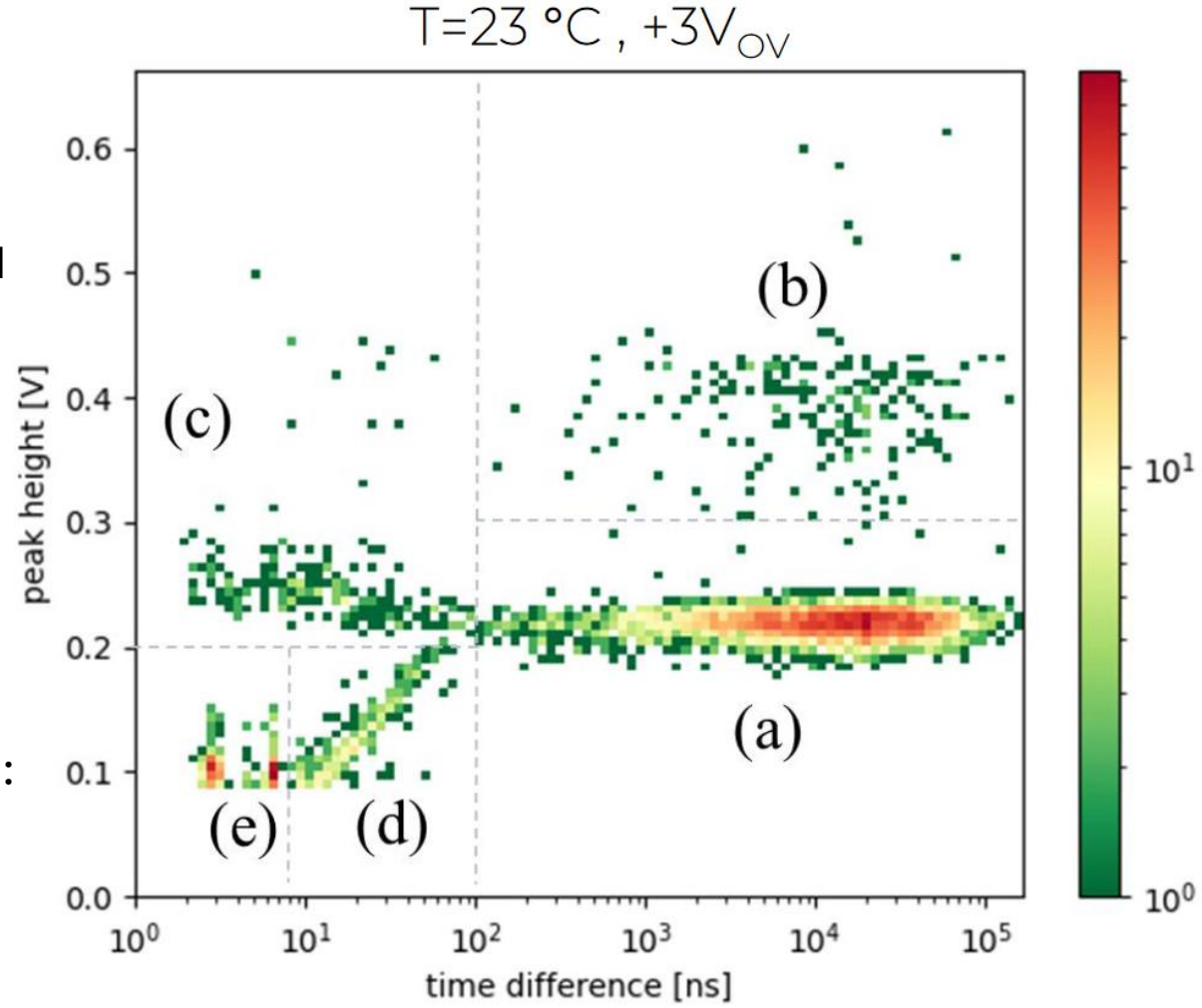
- When biased above this voltage, photon amplification begins
- Characterized using IV curves generated from the sourcemeter
- $\mathbf{V_{BD}}$ at **25C** was found to vary by **±0.5V** between the **3 50μm** samples and showed linear dependence wrt temperature **@54-58mV/C**





Characterization of the Dark Count Rate

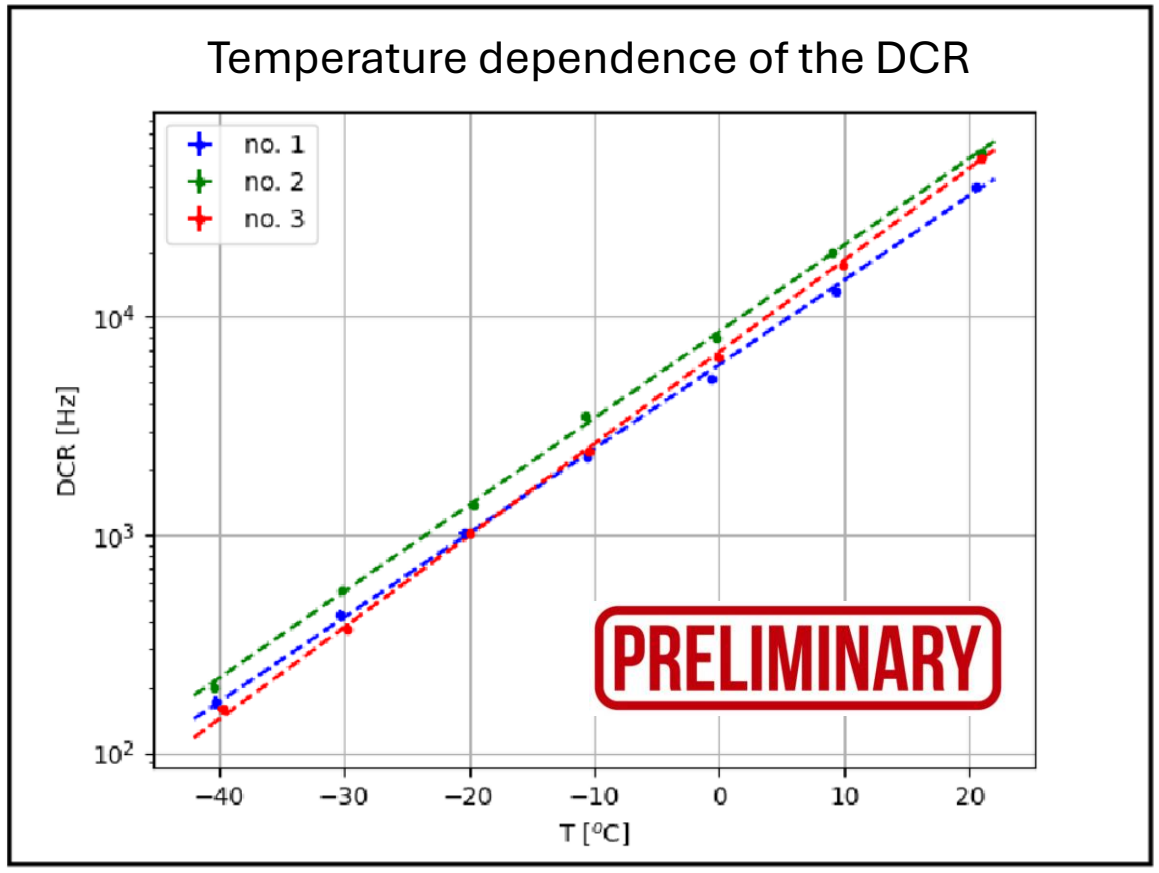
- Random noise generated by thermal fluctuations
- Peak voltage and peak-to-peak time difference used to compute DCR
- 5 populations of dark counts were identified:
  - a) **Dark counts**
  - b) **Direct optical crosstalk**
  - c) **Delayed optical crosstalk**
  - d) **Afterpulses**
  - e) **Electronic noise**
- Fractions observed at **23C** and **3OV** for **50μm** SiPMs:
  1. True dark-counts (**a**) ~ **87%**
  2. Cross-talk (**b**)+(**c**) ~ **7.4%**
  3. Afterpulses (**d**) ~ **5.6%**

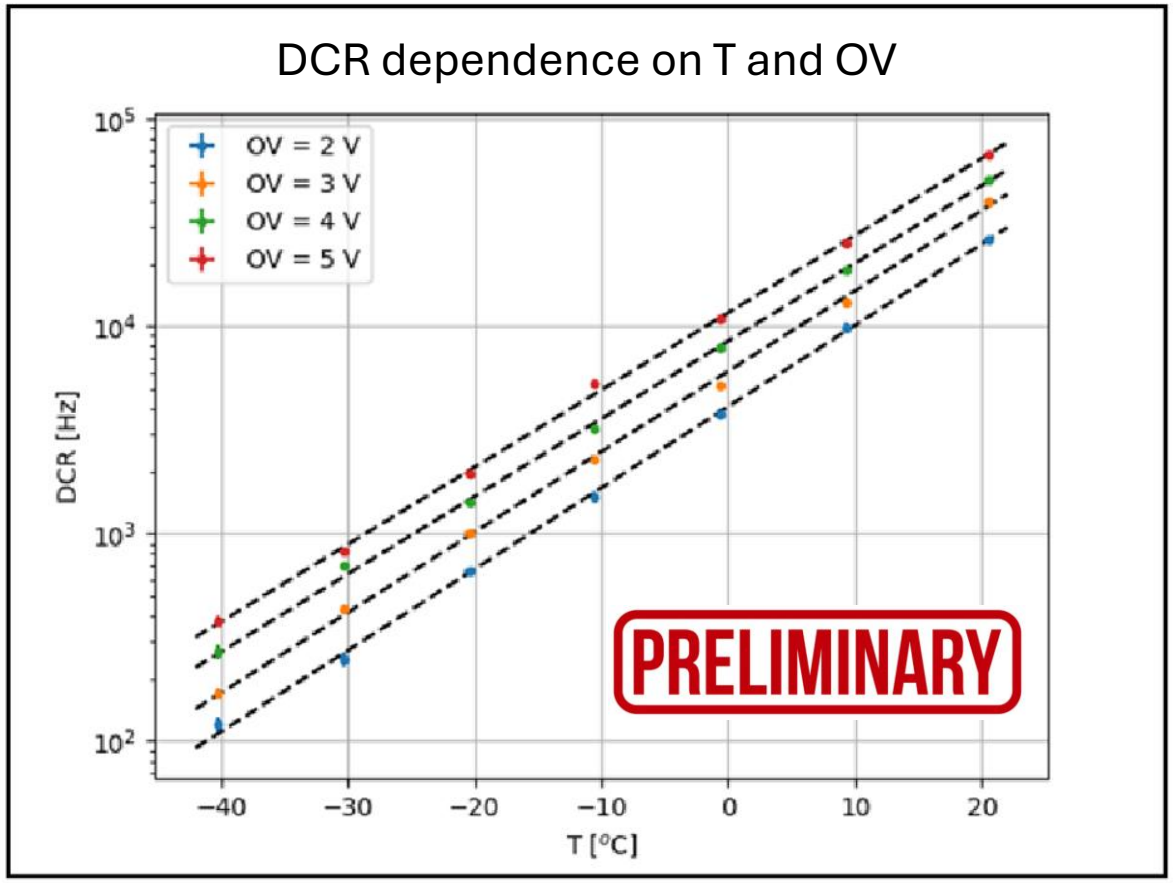


DCR temperature dependence of 50μm SiPMs

1.3x1.3mm SiPMs with **50μm** pitch have been studied before and known results were reproduced:

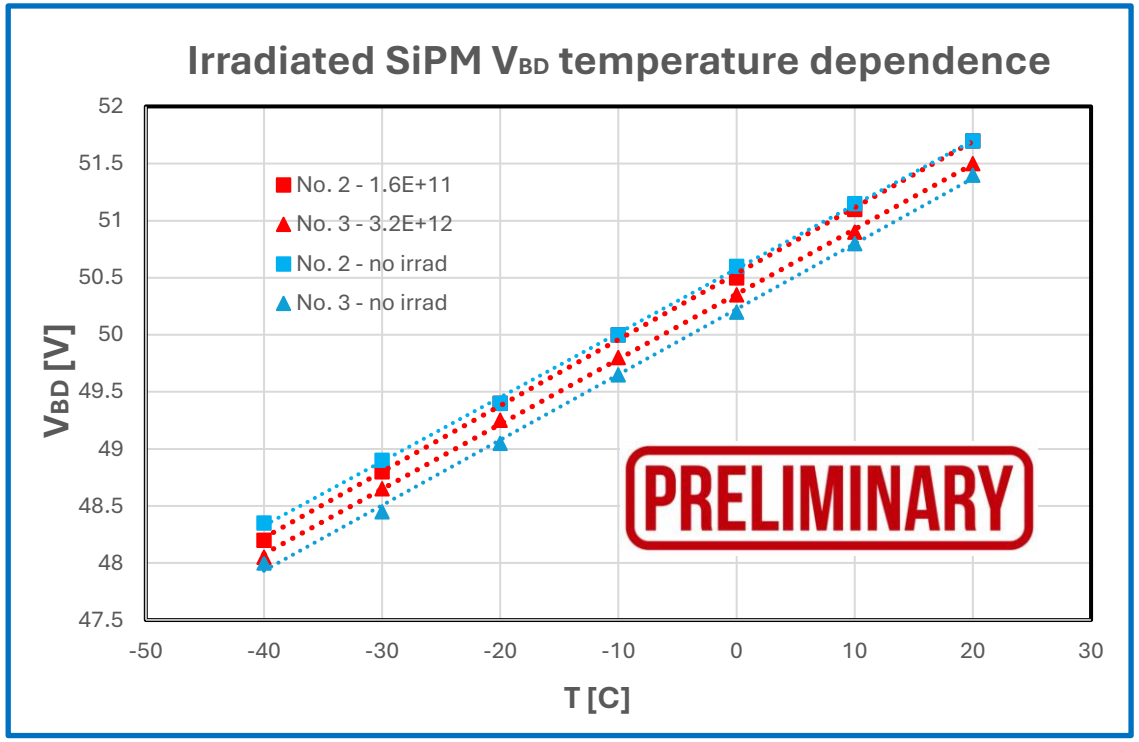
1. Factor of **10** reduction in DCR observed for every **24-26C** decrease in temperature
2. Overvoltage had no significant impact on the temperature dependence of the DCR

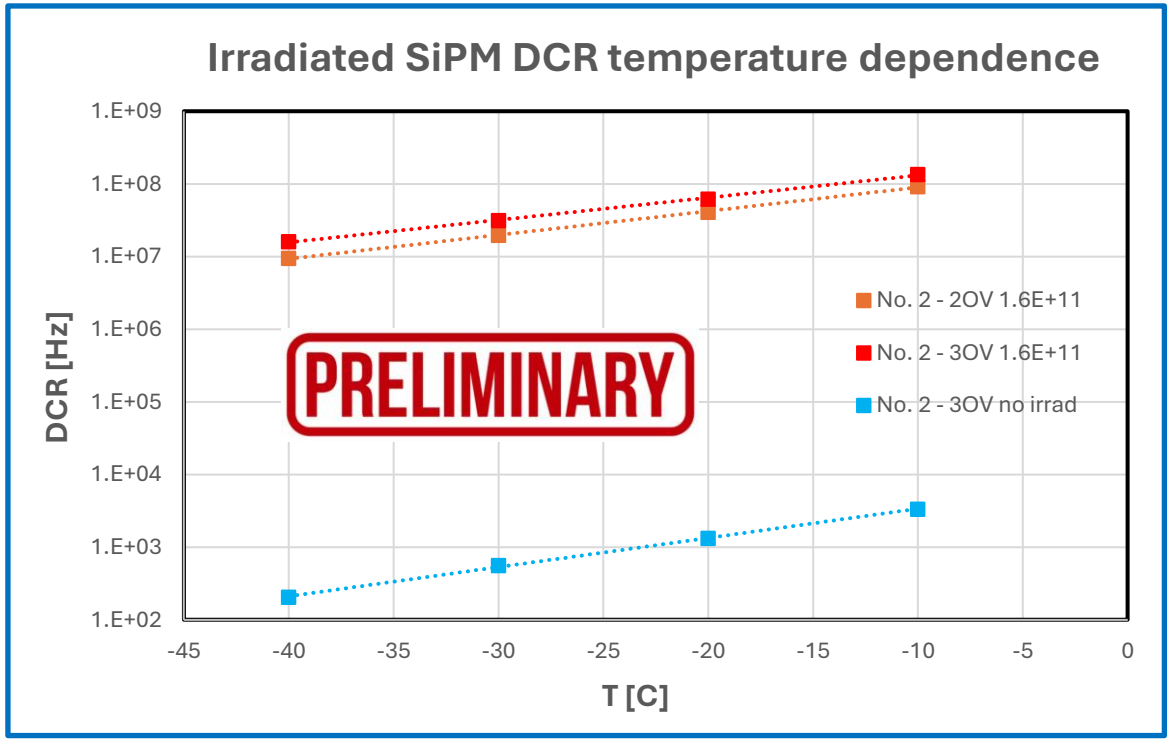




DCR and V_{BD} of irradiated 50μm SiPMs

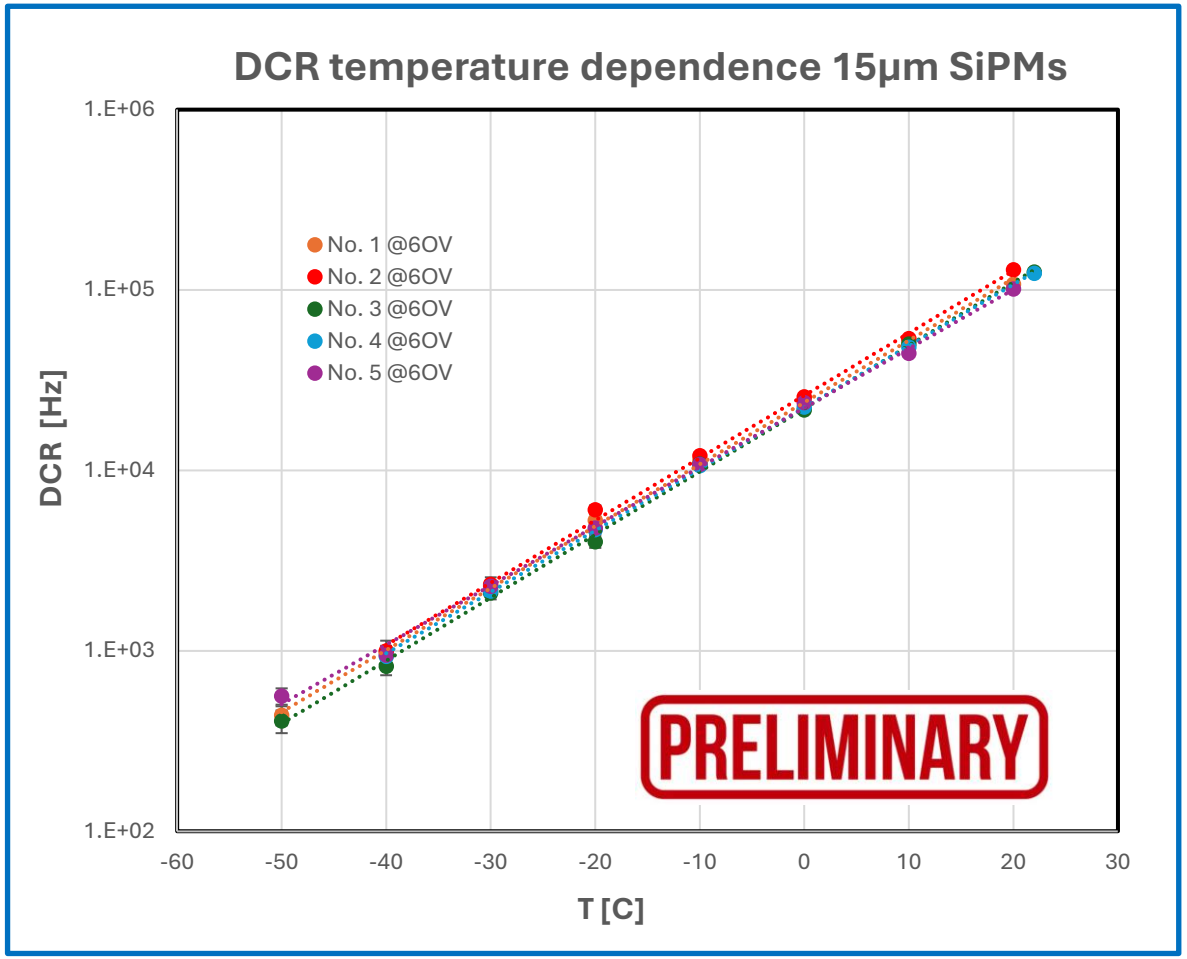
- Two **1.3x1.3mm 50μm** pitch SiPMs irradiated to fluences of **1.6x10^{11}** and **3x10^{12}** n_{eq}/cm^2
- Similar V_{BD} observed for both SiPMs and change with temperature remains linear
- DCR measured for low dose SiPM at **2** and **3OV** where an increase of approximately **4.5 orders of magnitude in DCR** was observed after irradiation
- Change in temperature dependance observed after irradiation, **24-26C → 30-32C** reduction in temperature required to decrease DCR by factor of **10**

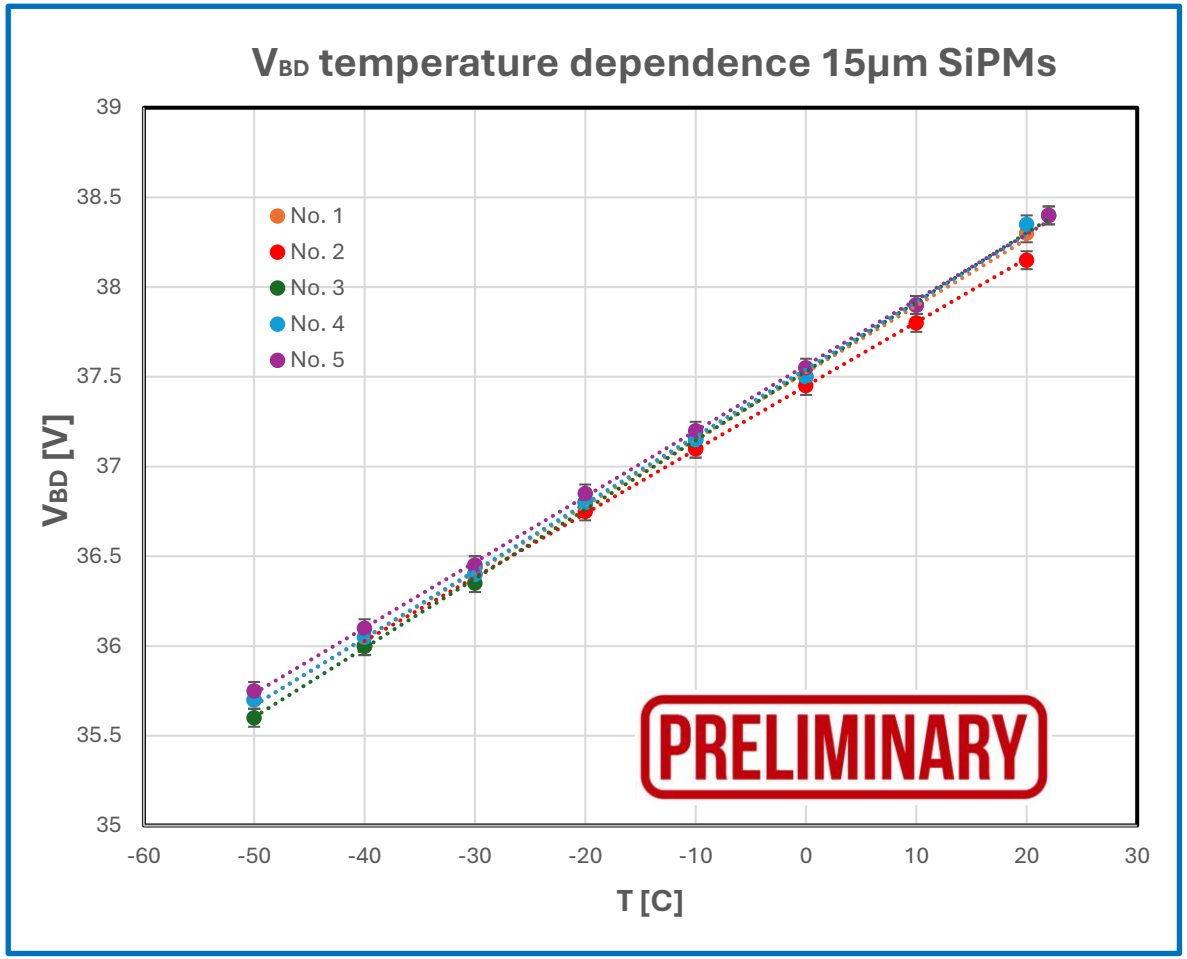




DCR and V_{BD} temperature dependance for 15μm SiPMs

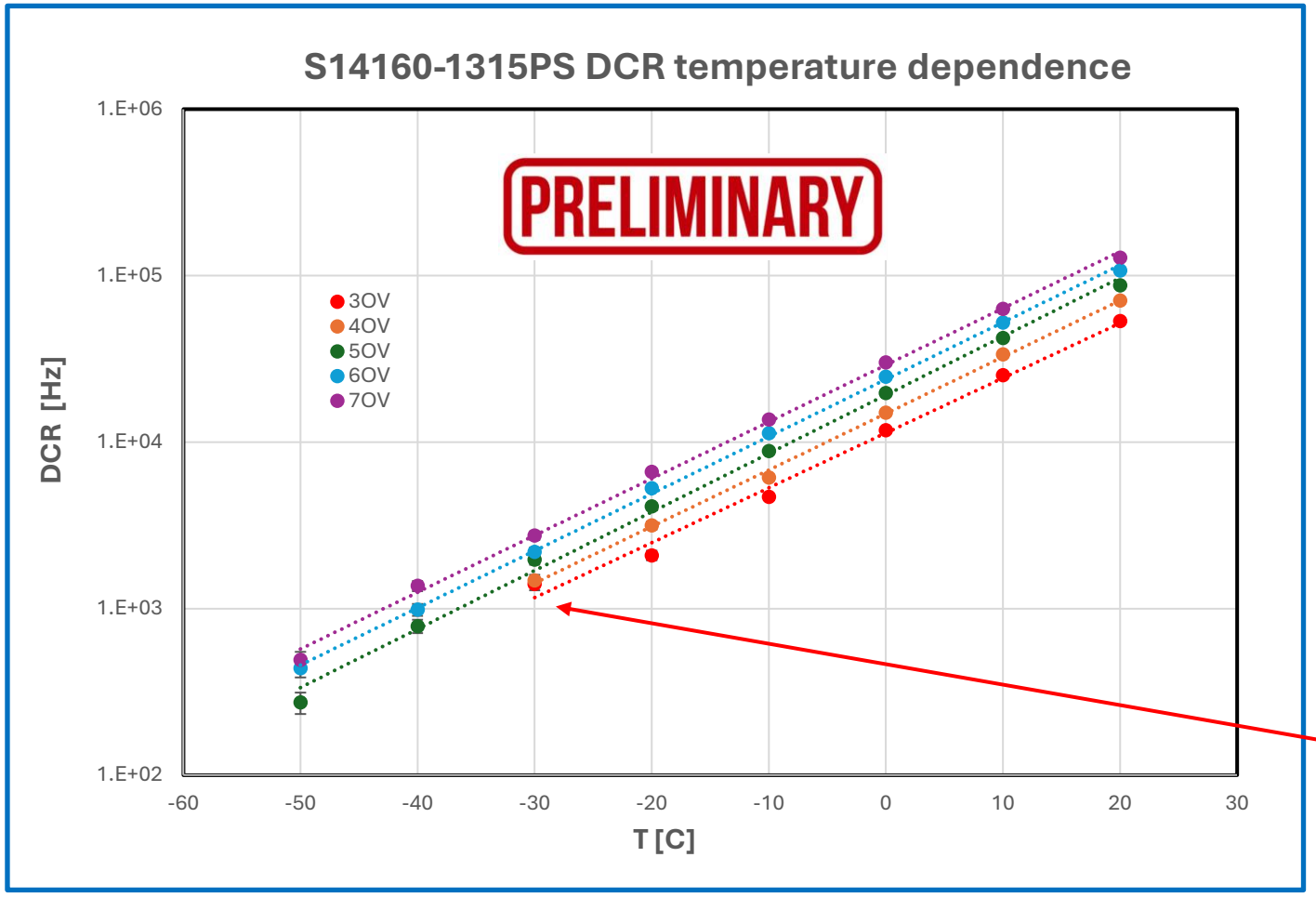
- For **15μm** SiPMs, factor of **10** reduction in DCR observed every **28-30C @6OV** across **5** samples
- V_{BD} temperature dependance very similar for all **15μm** SiPMs **@35-38mV/C**

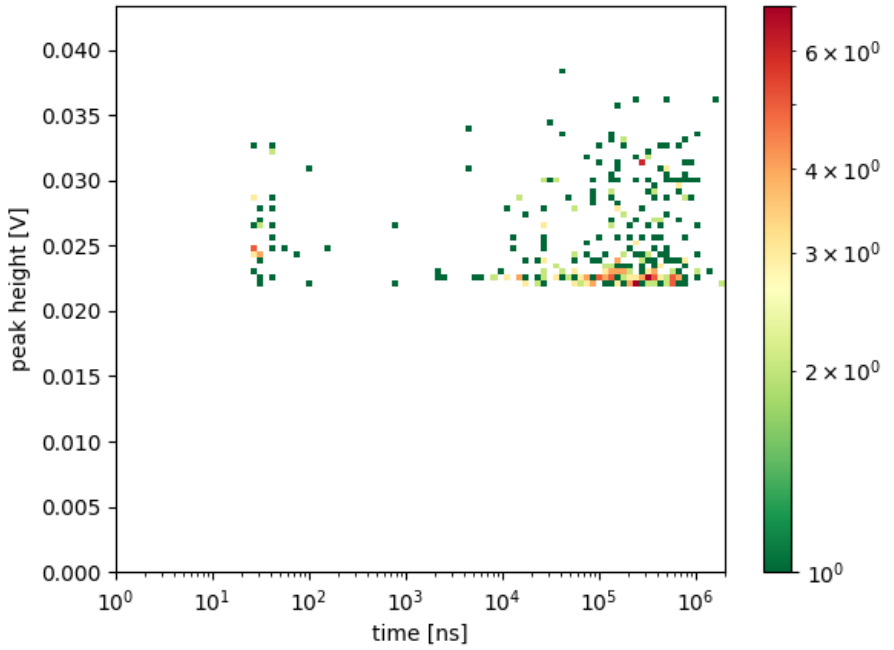




Full characterization of 15μm SiPM DCR

- Factor of **10** reduction in DCR observed every **28-30C** reduction in temperature **@3-7OV** respectively, no significant variation observed in temp dependence wrt OV
- **@3 and 4OV**, significant overlap is observed between electronics noise and Dark Count populations → difficult to measure DCR accurately

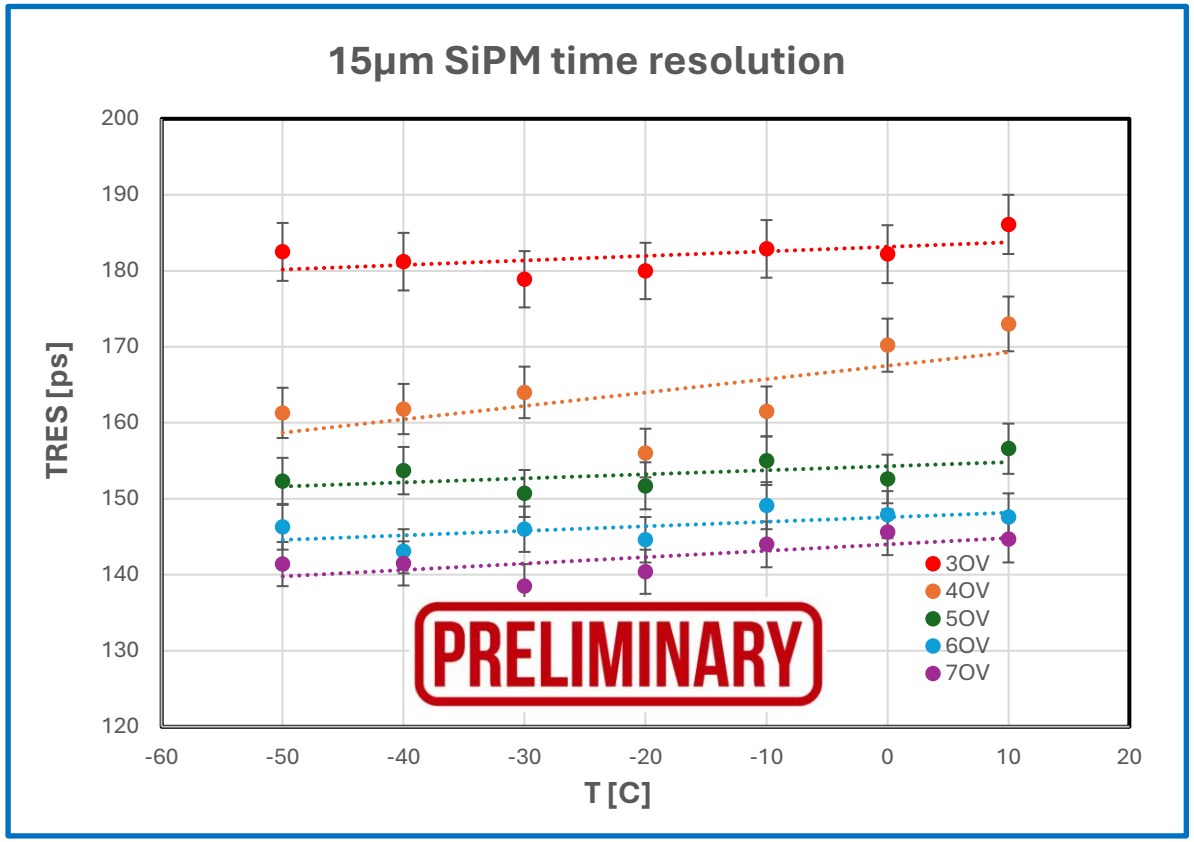


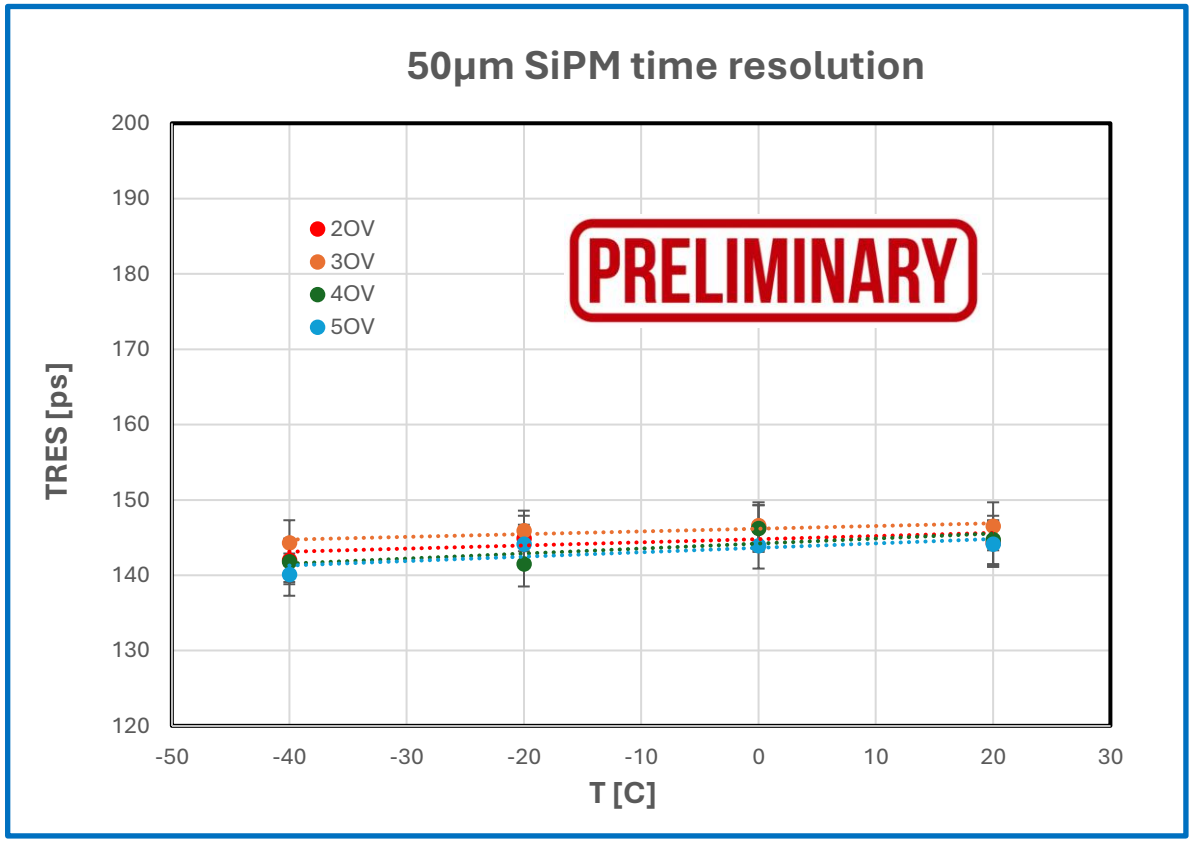


3OV @-30C, cut at **22mV**: noise baseline dominates, effect can be seen on plot

Characterization of time resolution for 15 and 50μm SiPMs

- Time resolution measurements do not account for photodiode jitter → **true resolution should be better**
- Measurements limited by scope resolution **(25ps)**
- Time resolution dependence wrt temperature seems marginal, slight decrease wrt temperature attributed to fewer dark counts
- Dependance wrt OV is significant for **15μm** SiPM but not for **50μm** SiPM → noise baseline affects measurement at low OV? → **gain too low for 15μm SiPM?**

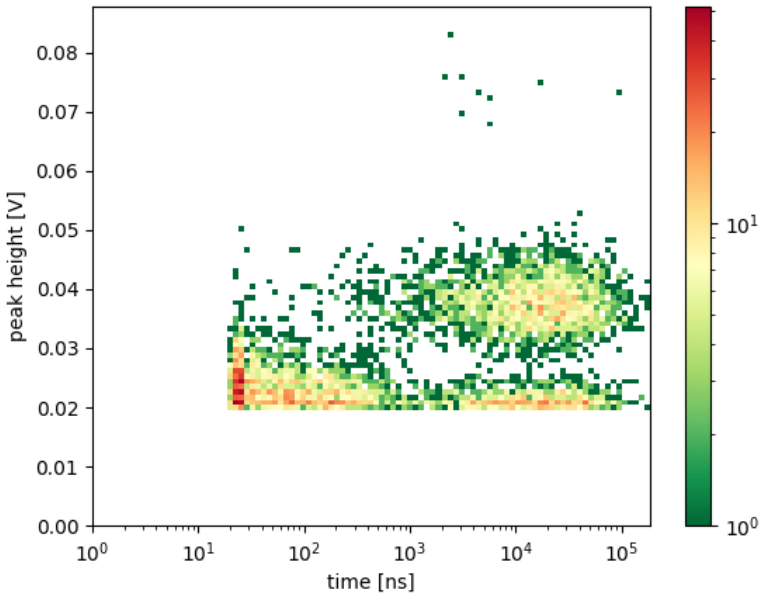


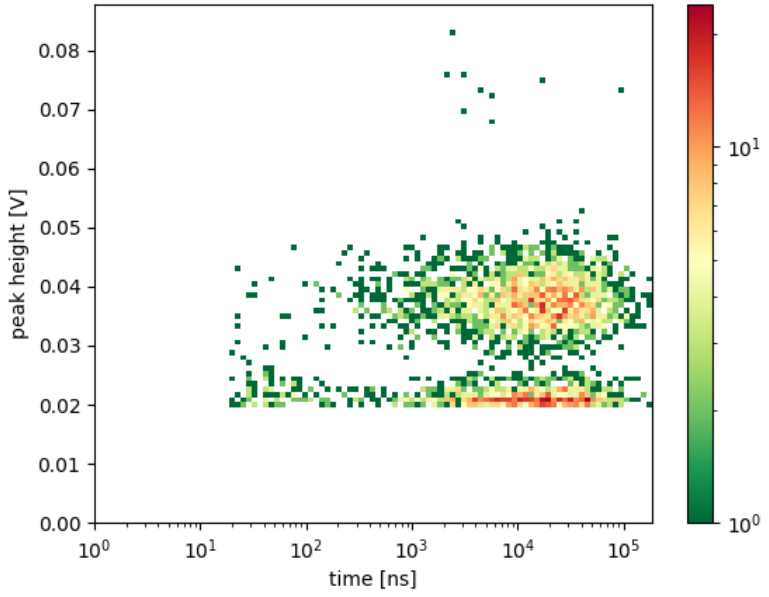


Future plans

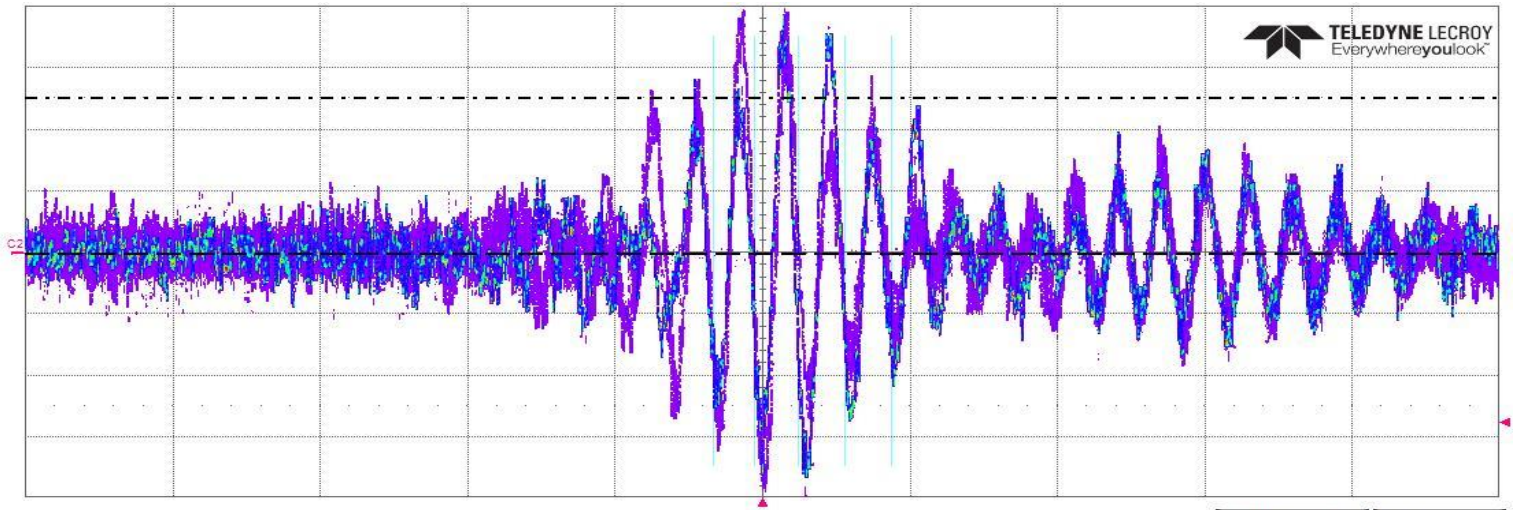
- Analysis of irradiated samples for both **15** and **50μm** pitch SiPMs – expected to receive **12 units this month – 4 units of 50μm** pitch and **8 units of 15μm** pitch irradiated to fluences of **~10^{11}**, **10^{12}**, **10^{13}** and **10^{14}** $\mathrm{n_{eq}/cm^2}$ in the same reactor for accurate comparison of both types
- **Diode jitter** and **PDE** yet to be characterized
- **Commissioning of a cryogenic cooling system** – design completed, manufacturing has begun, expected to begin operation in the lab by the end of the month → **necessary to take DCR measurement with SiPMs irradiated to high fluence**
- Annealing studies to be performed with existing climatic chamber after cryogenic studies conclude
- Discussing with other LHCb groups the testing of **8x8 arrays of 50μm** pitch SiPMs for exposure to 2025 testbeams

Appendix: DCR noise/humidity elimination



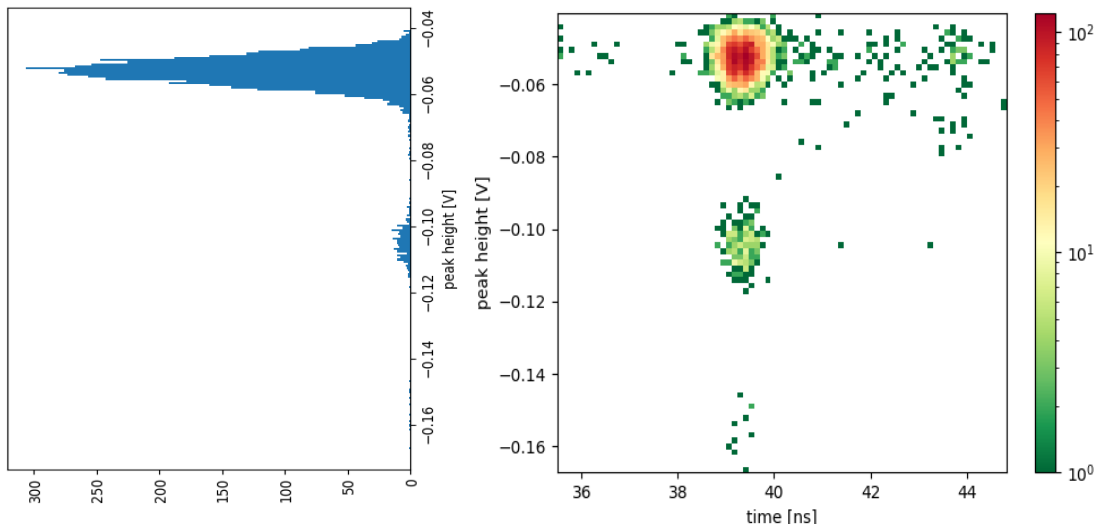


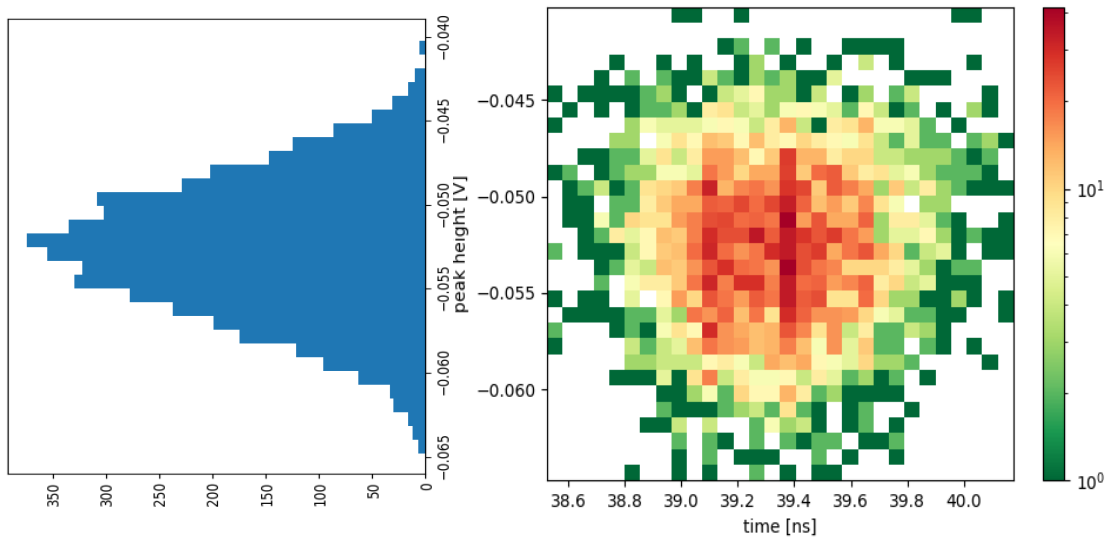
WScan	Edge Time
1	-16.3675 ns
2	-2.3790 ns
3	12.3814 ns
4	28.1484 ns
5	43.8431 ns



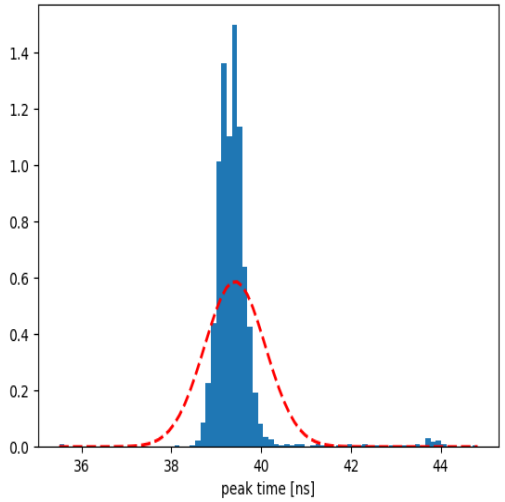
- Occasional noise observed when acquiring data under cooling, which greatly increases in occurrence at temperatures **< -30C**
- DCR scatter before files with huge number of hits were removed (> 5x normal) shown on left and result after removal of files shown on right

Appendix : Time resolution analysis methodology

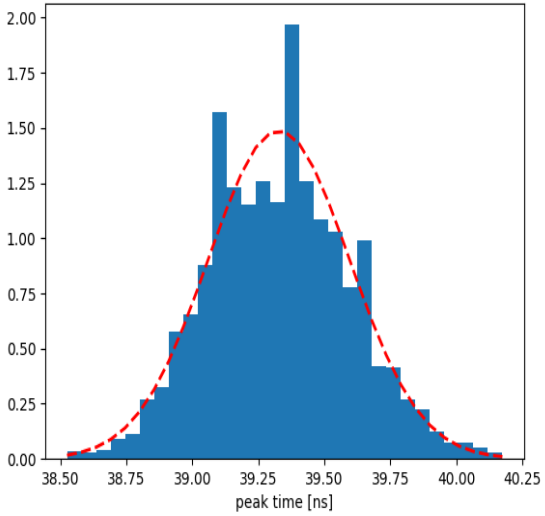




1) Cut signal peak height to select only single-photon peaks



2) Cut on diode pulse to single photon time difference to remove contributions from crosstalk, dark counts and after-pulses



Appendix: Example waveforms at 4 and 6OV for 15um SiPM