Characterization of SiPMs for LHCb Upgrade II

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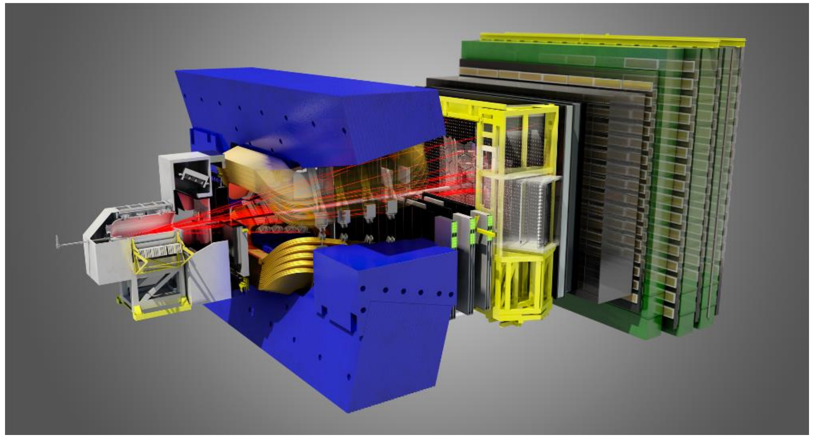
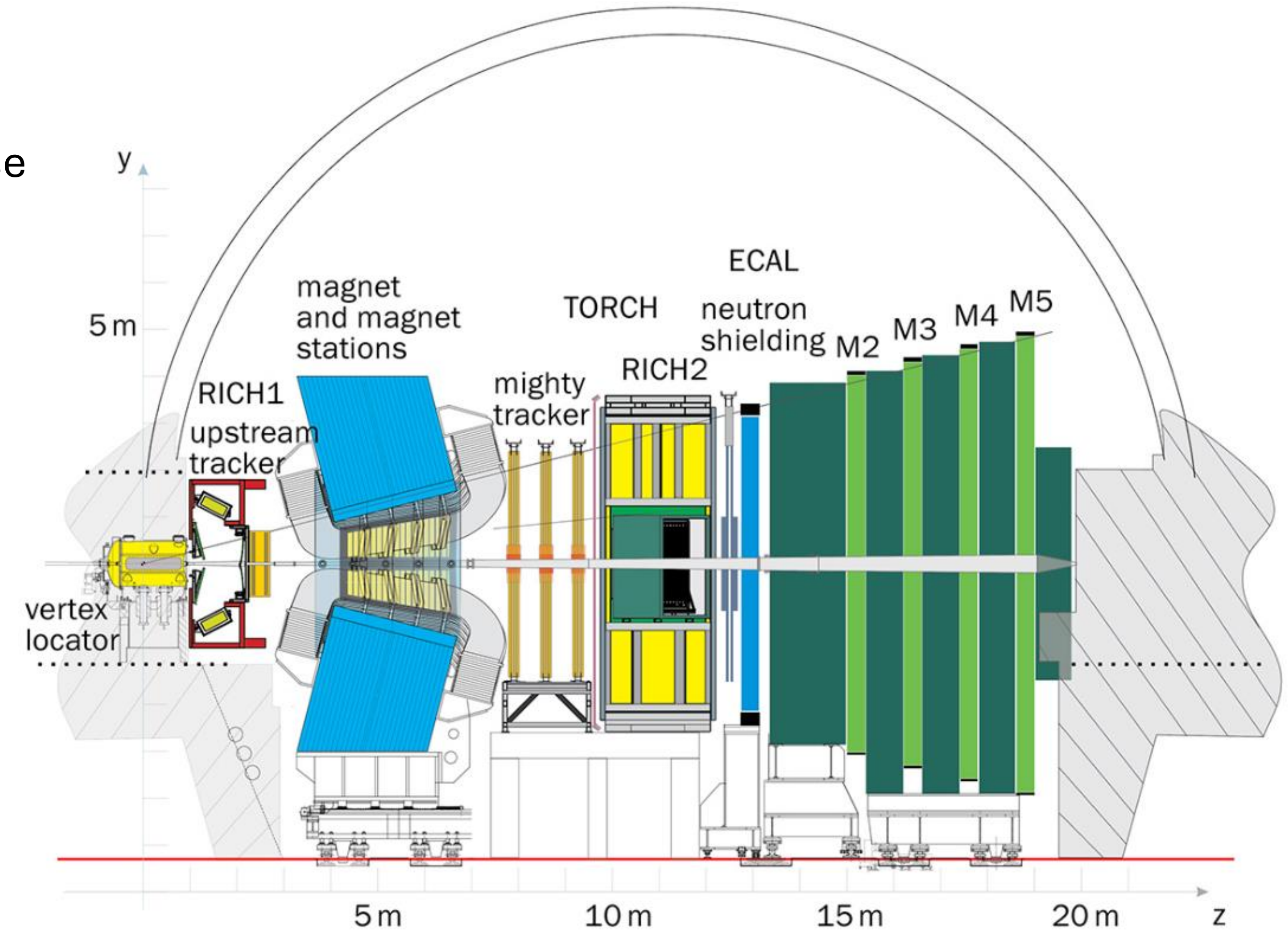
on behalf RAL and UoE



Brief overview of LHCb Upgrade II

- For Upgrade II, the luminosity at LHCb will increase by a factor of 10, having the following effects:
    1. **Increase in detector occupancy**
    2. **Need better timing and angular resolution**
    3. **Higher radiation resistance required**
- New photodetectors are needed for the RICH
- Silicon Photomultipliers (SiPMs) are a promising candidate



Why use SiPMs?

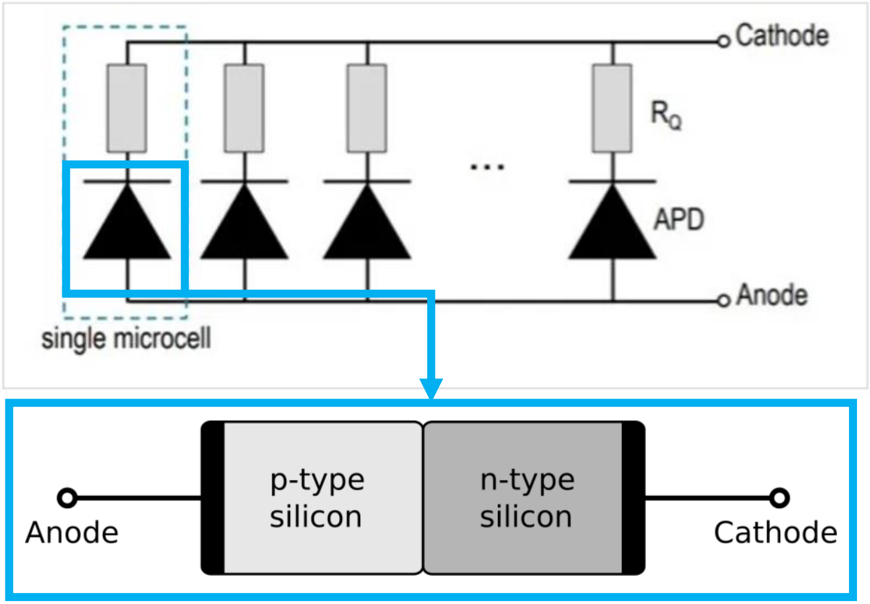
- Arrays of Single-Photon Avalanche photo-Diodes (SPADs) consisting of p-n junctions
- Operated in reverse-bias for photoelectric amplification

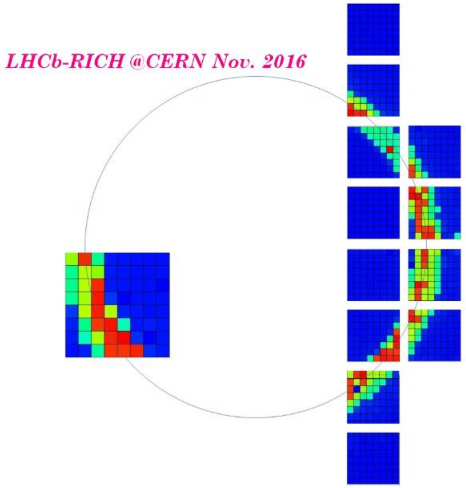
Advantages of SiPMs:

- Higher PDE and readout rate than MaPMTs → high spatial and timing resolution
- Unaffected by external magnetic fields
- Flexible cell size

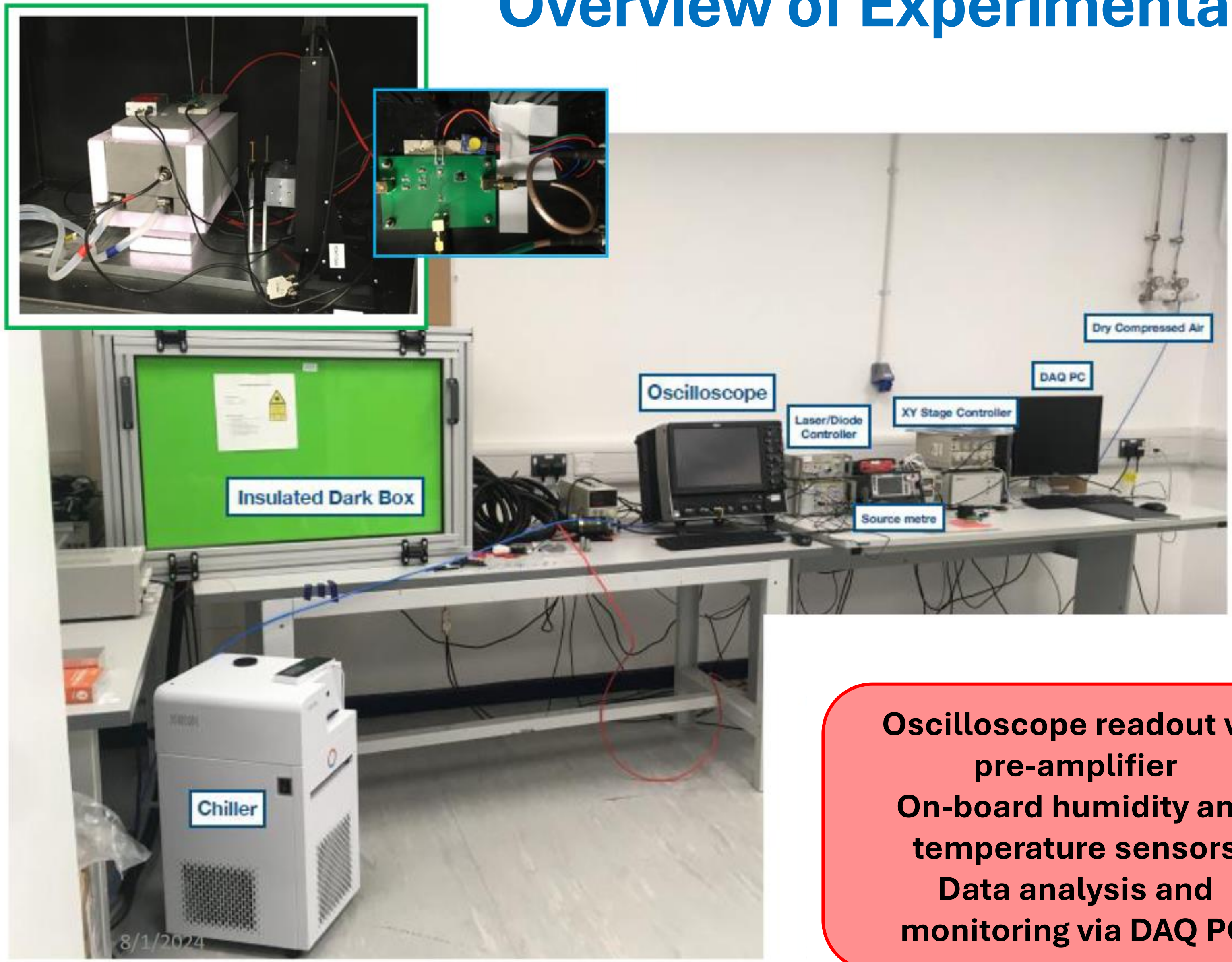
Disadvantages of SiPMs:

- Must be operated at single-photon mode to resolve Cherenkov rings → multiple sources of background
- Susceptible to radiation damage

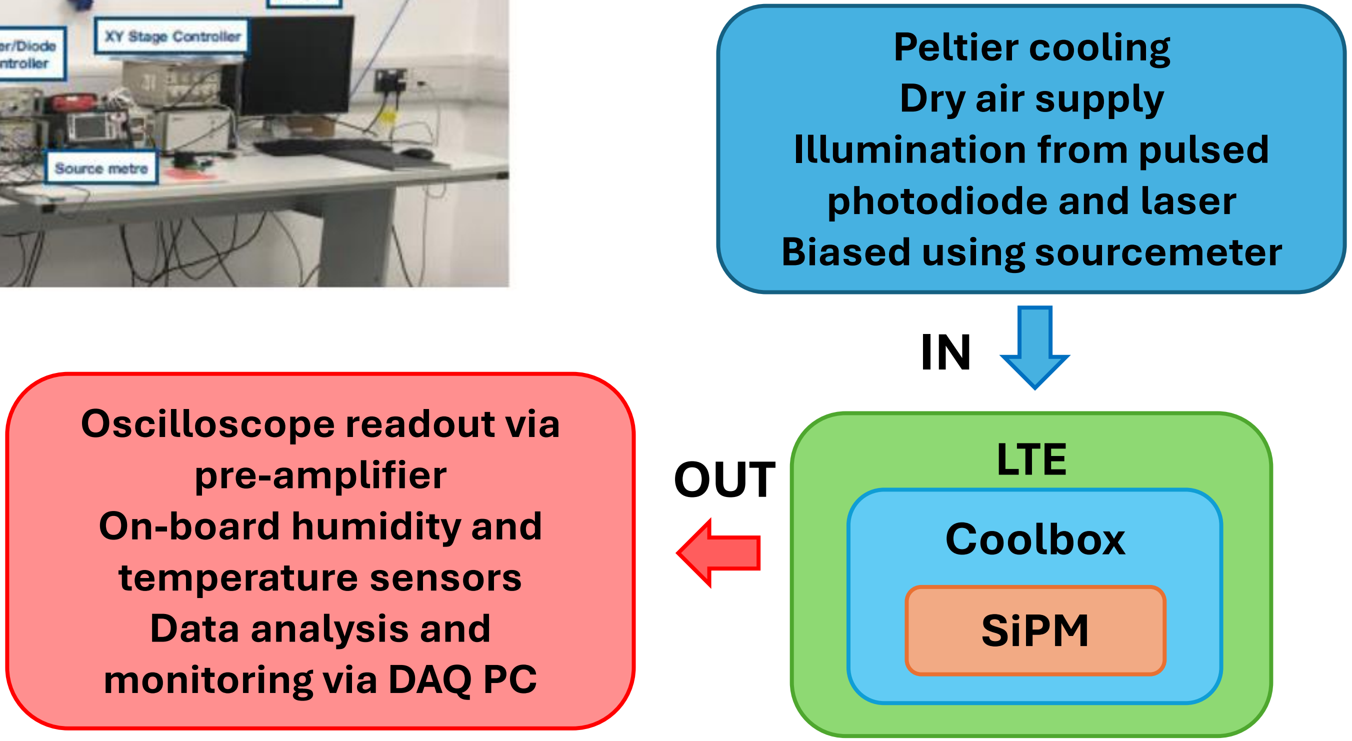




Overview of Experimental Setup

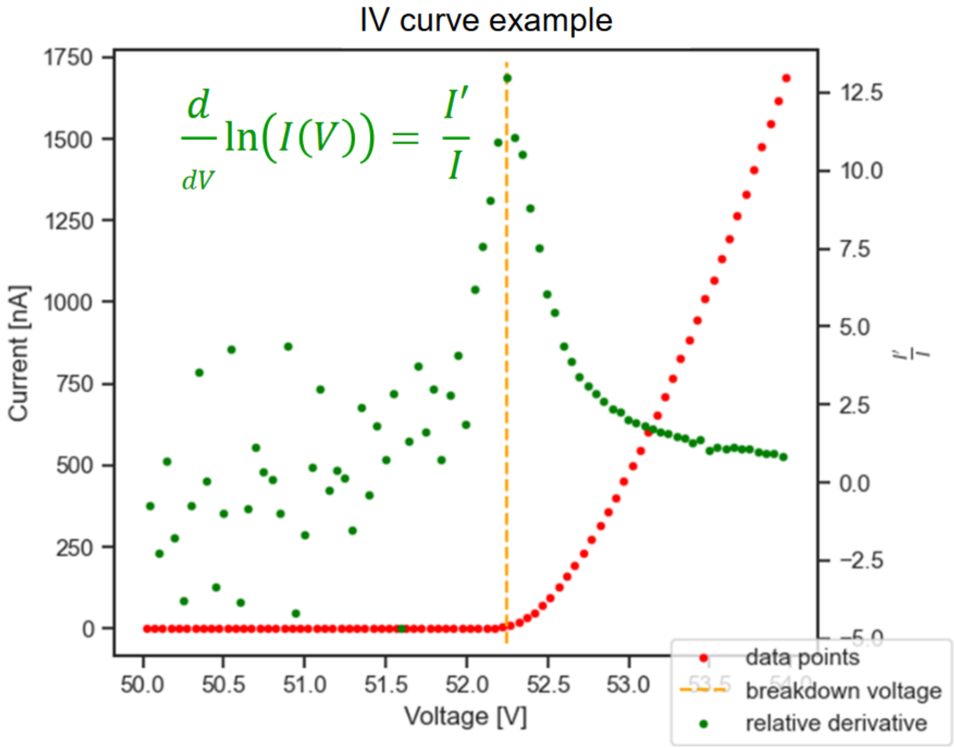


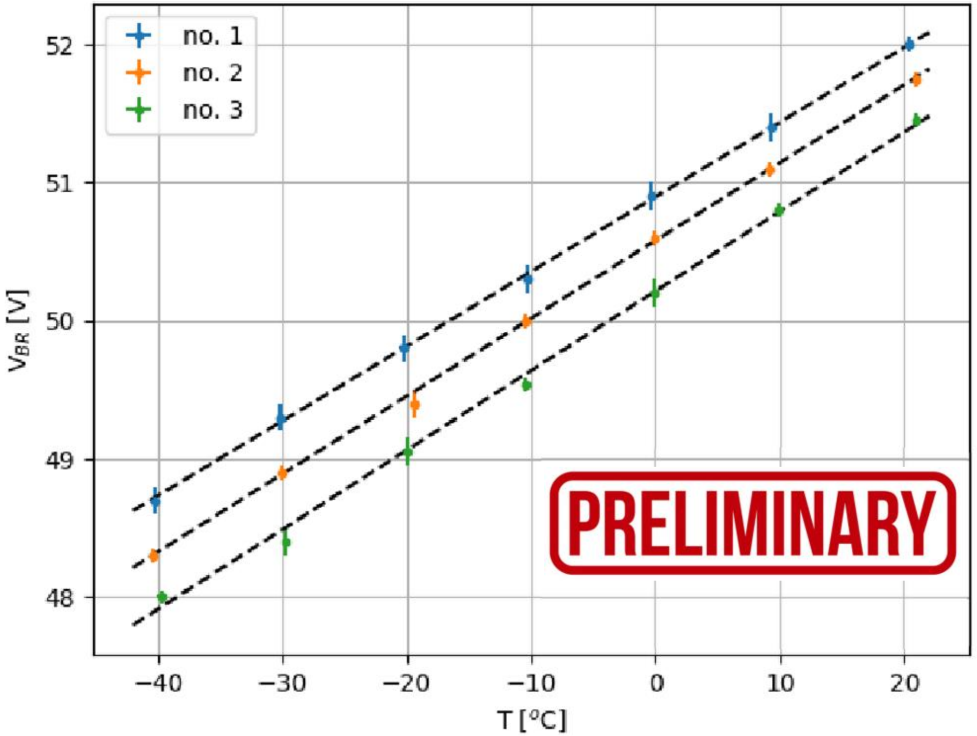
- Nested box in light-tight enclosure provides cooling, insulation and precise humidity and temperature monitoring



Characterization of Breakdown Voltage

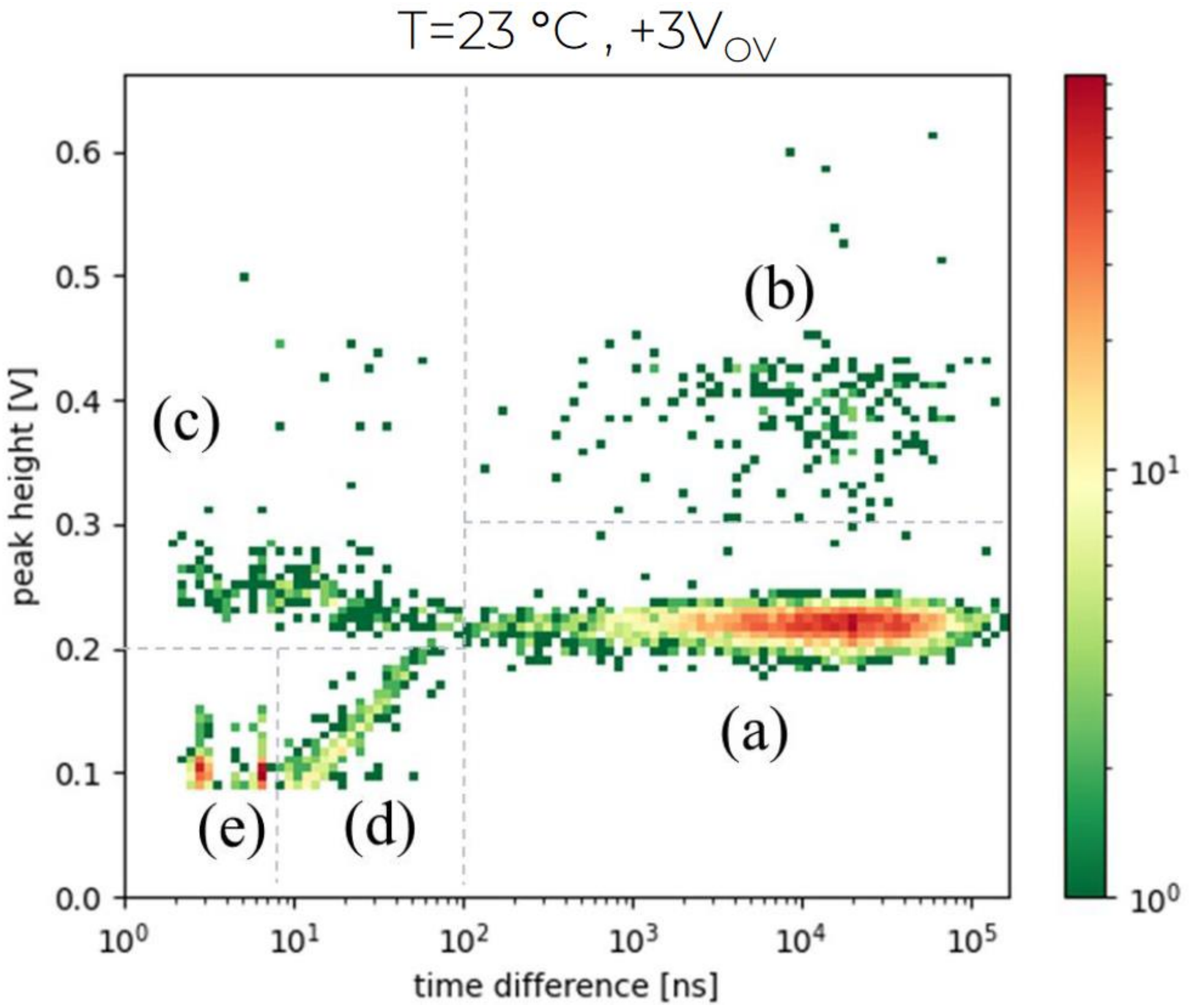
- When biased above this voltage, photon amplification begins
- Characterized using IV curves generated from the sourcemeter
- Computed using the relative derivative of the current
- V_{BD} at $25^{o}C$ was found to vary by ±0.4V between the 3 samples → linear dependence wrt temperature as expected for 1.3x1.3mm SiPMs





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:
  1. Dark counts
  2. Direct optical crosstalk
  3. Delayed optical crosstalk
  4. Afterpulses
  5. Electronic noise
- Fractions observed at $23^{o}\mathrm{C}$ and $3\mathrm{V}_{\mathrm{OV}}$:
  1. True dark-counts (a) ~ **87%**
  2. Cross-talk (b)+(c) ~ **7.4%**
  3. Afterpulses (d) ~ **5.6%**

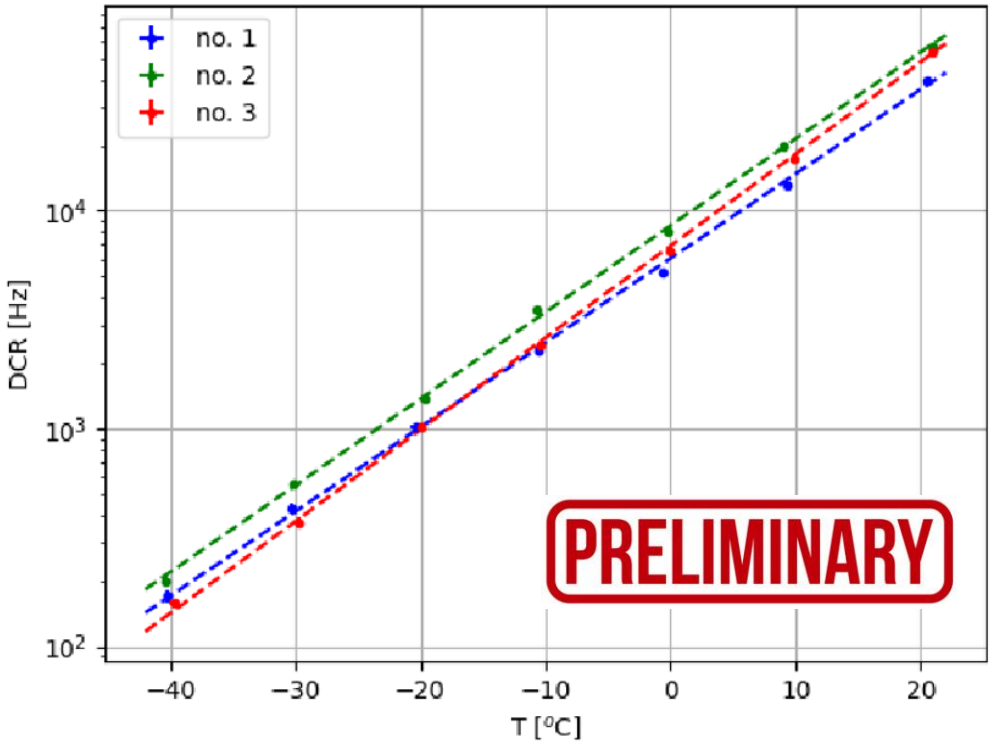


Temperature dependence of the DCR of 1.3x1.3mm SiPMs

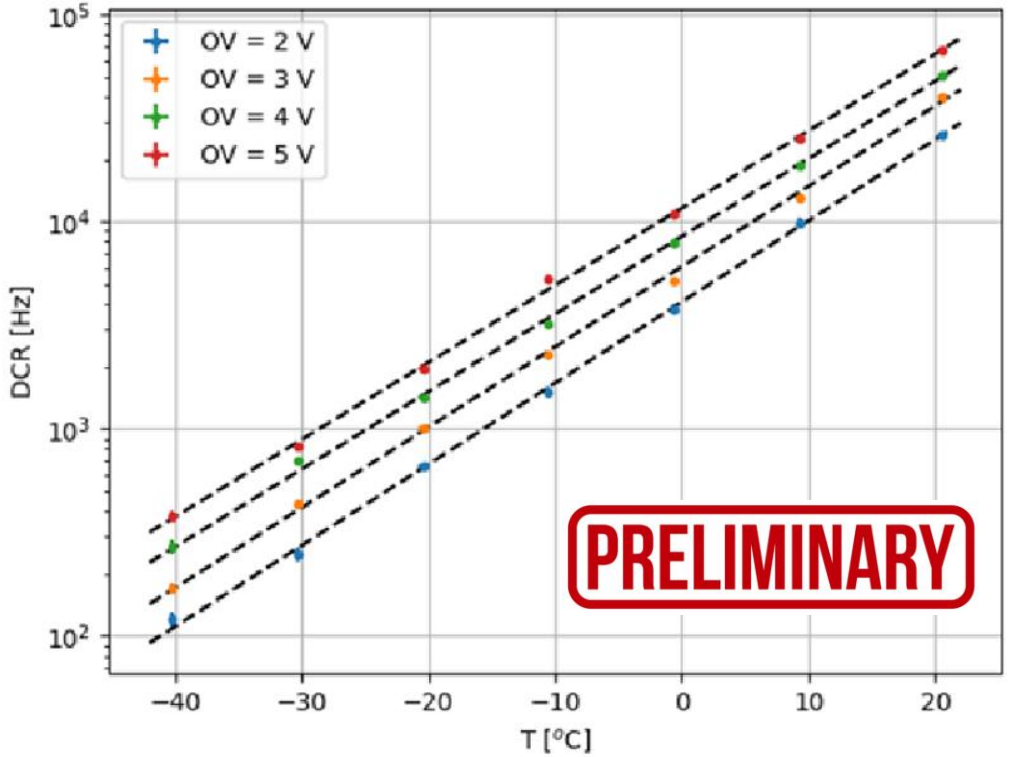
1.3x1.3mm SiPMs with **50µm** pitch have been studied before and known results were reproduced:

1. Factor of **10** reduction in DCR observed for every **24 to** $26^{o}C$ decrease in temperature
2. Overvoltage had no significant impact on the temperature dependence of the DCR

Temperature dependence of the DCR

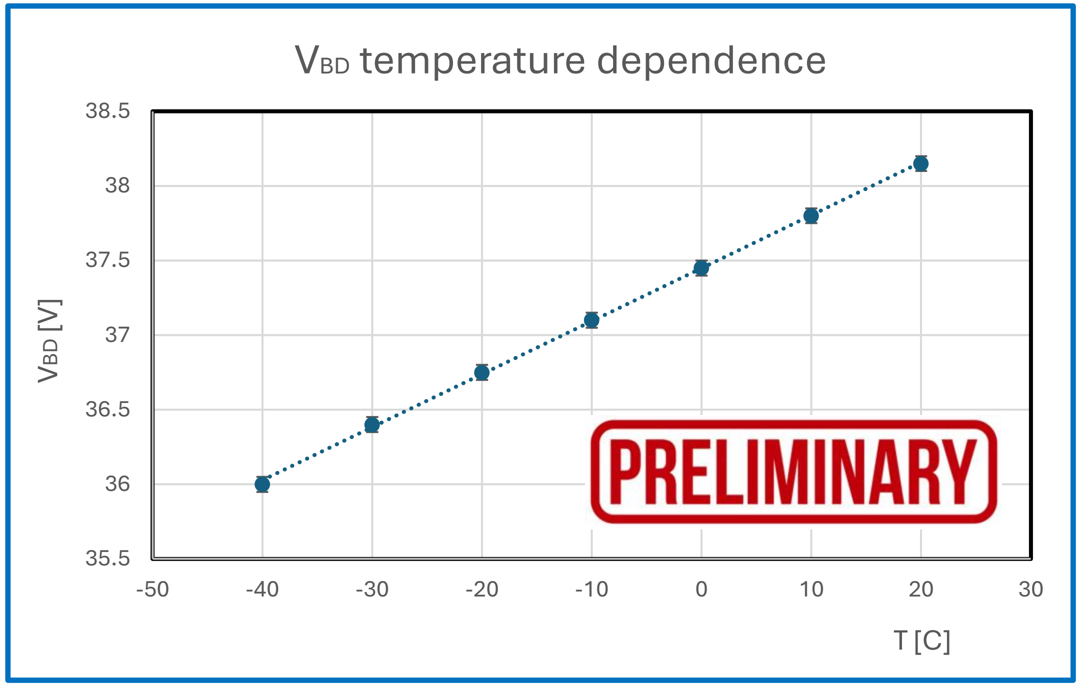


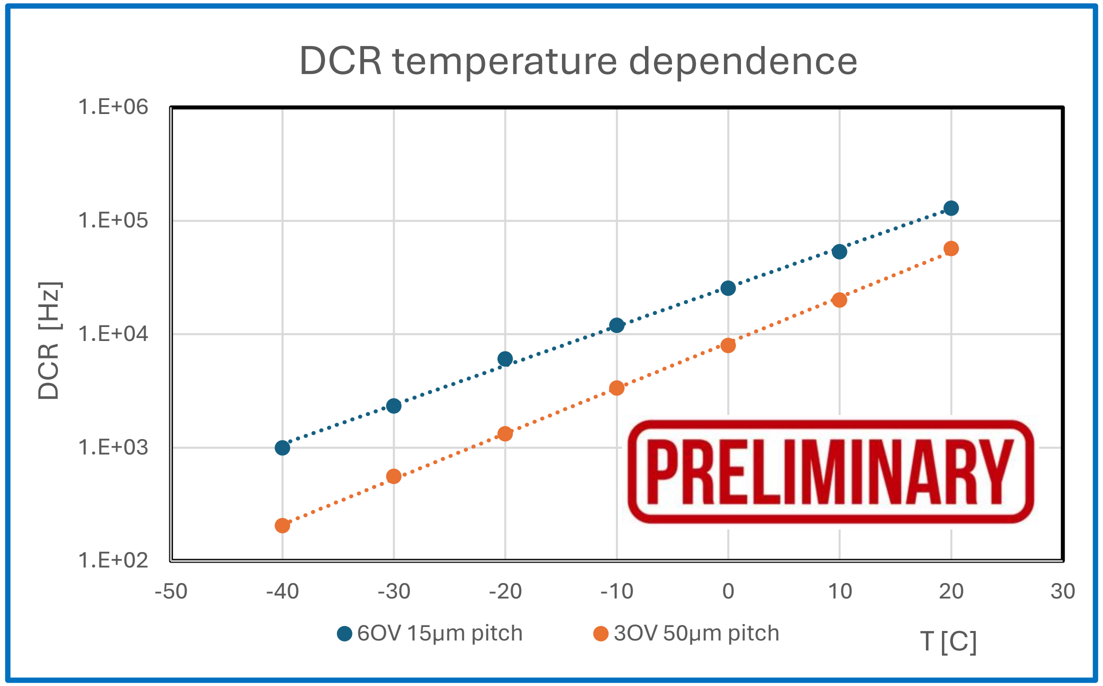
DCR dependence on T and OV



Testing 1.3x1.3mm SiPMs with 15μm pitch

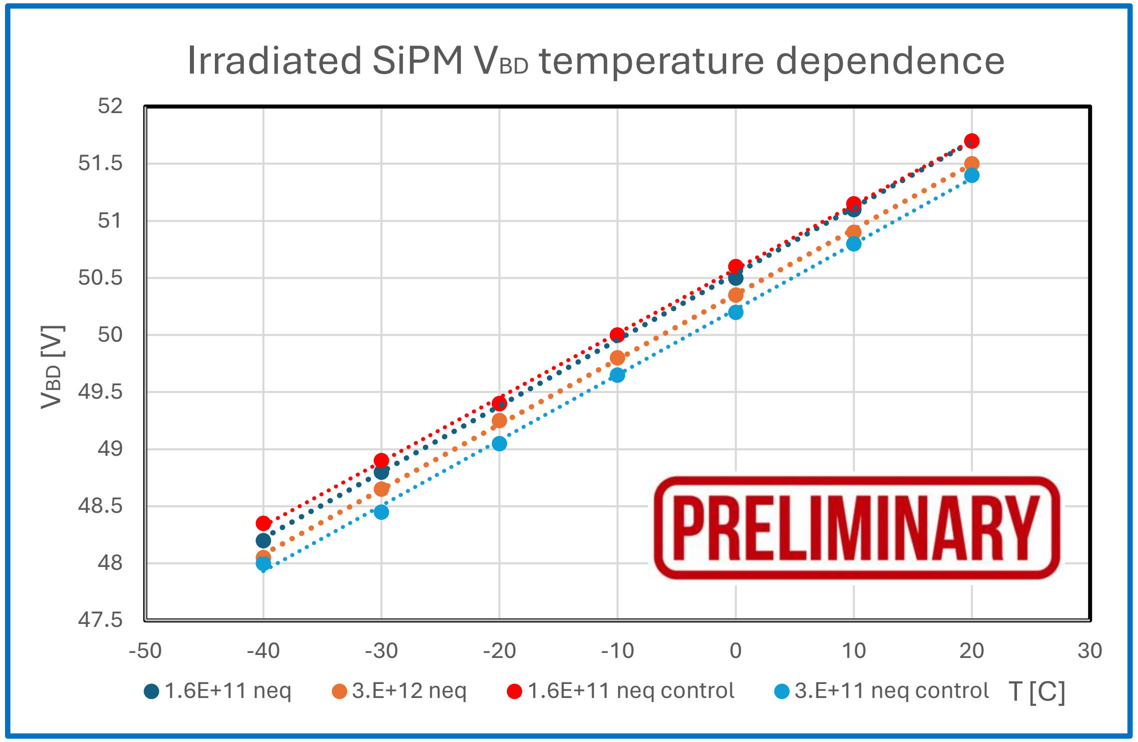
- SiPMs with lower pitch have smaller microcells → affects operation of the cell → gain decreases → higher overvoltages must be used
- Motivation: Potentially improved PDE and radiation hardness → high importance for the RICH
- V_{BD} different than 50μm SiPM but temperature dependence is linear and within expectation
- Similar DCR considering above nominal OV but decreases more slowly with temperature at $29^{o}\mathrm{C}$ for an order of magnitude reduction in DCR

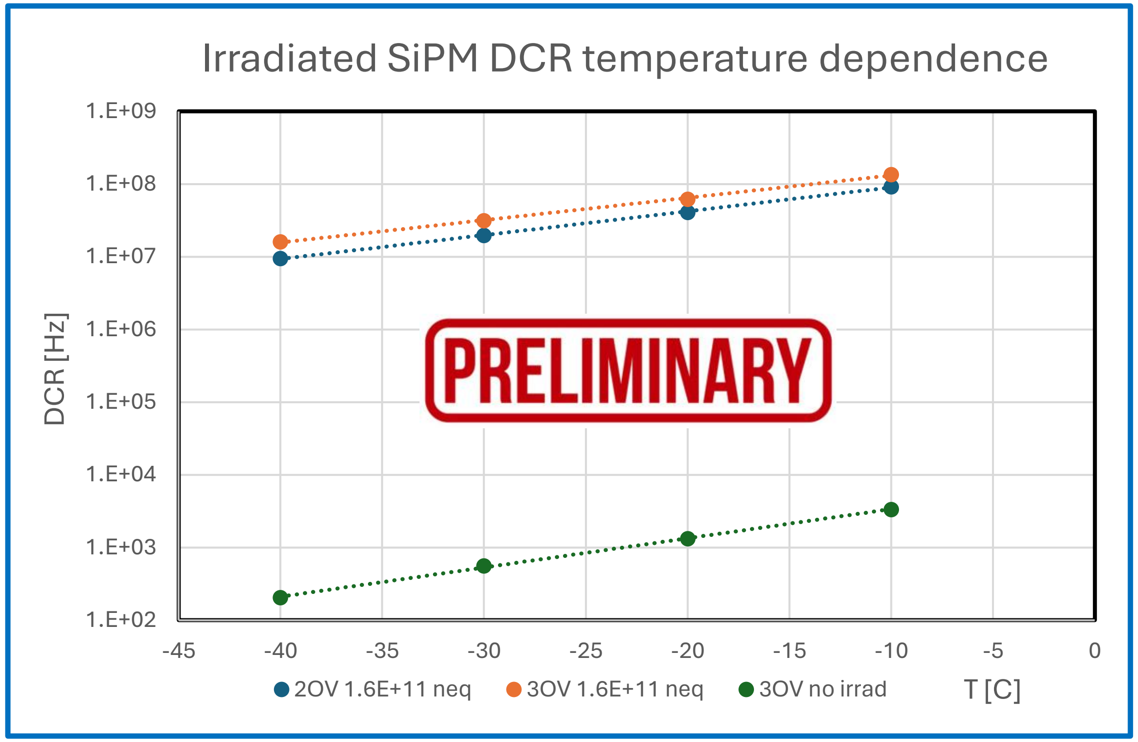




DCR and V_{BD} of irradiated SiPMs

- Two 1.3x1.3mm 50μm pitch SiPMs irradiated to fluences of $\mathbf{1.6 * 10^{11} n_{eq}/cm^2}$ and $\mathbf{3 * 10^{11} n_{eq}/cm^2}$
- Similar V_{BD} observed for both SiPMs and change with temperature remains linear
- DCR measured for low dose SiPM at **2** and $\mathbf{3V_{OV}}$ where an increase of approximately **4.5 orders of magnitude in DCR** was observed after irradiation
- Change in temperature dependance observed after irradiation, $\mathbf{24 - 26^oC \rightarrow 30.5 - 32.5^oC}$ reduction in temperature required to decrease DCR by factor of 10





Summary and Prospects

What has been achieved so far:

- First batch of SiPMs characterized down to $-40^{\mathrm{o}}\mathrm{C}$
- Irradiation of SiPMs to low and high dose, characterization is underway
- More 15μm pitch SiPMs procured, and characterization is almost finished
- Improvements to our cooling setup allow measurements at $-60^{\mathrm{o}}\mathrm{C}$
- Design for a cryogenic cooling system has begun → characterization of SiPMs at liquid nitrogen temperatures

Our plans for the near future:

- Continued improvement of our setup to reach even lower temperatures
- Characterization of PDE and time-resolution for control and irradiated SiPMs
- Procuring and irradiating more types of SiPMs
- Annealing studies to potentially restore irradiated SiPMs
- Plans to bring more types of SiPMs to testbeams

Backup - Effects of irradiation on SiPMs

Understood effects of irradiation on SiPMs:

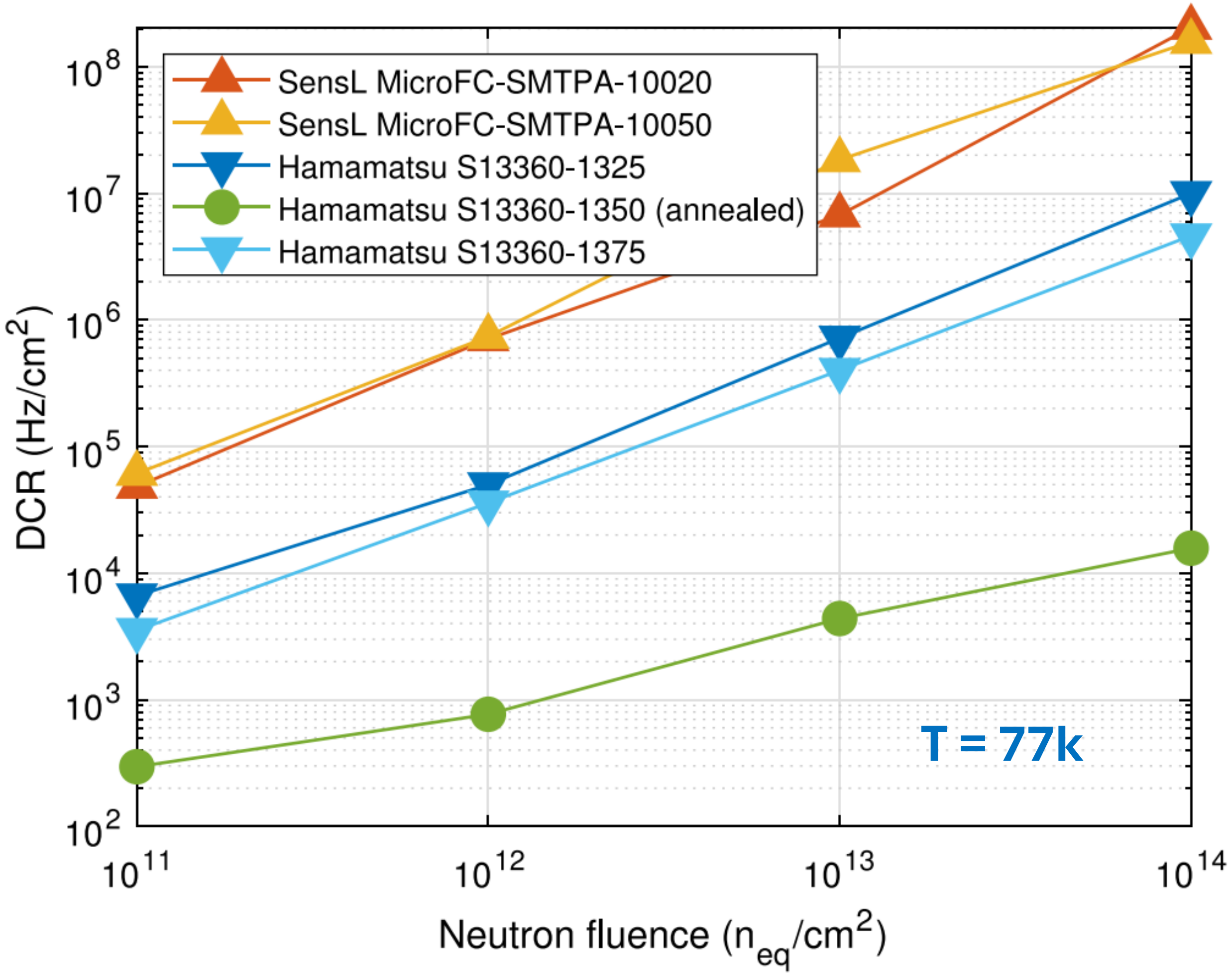
1. Increase in DCR due to defects reducing the energy required to cause avalanches
2. Greatly increased noise below V_{BD}
3. Increased afterpulses due to higher retention of charge from defects

Less understood effects of irradiation:

1. Shift in V_{BD} at higher fluences
2. Effects on PDE and time-resolution

Methods of mitigating DCR and noise:

1. Cooling lowers DCR to acceptable levels
2. Annealing to regularize defects caused by irradiation



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Calvi, M. *et al.* (2020) 'Photon detectors and front-end electronics for rich detectors in high particle density environments', *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 952, p. 161788. doi:10.1016/j.nima.2019.01.015.