Characterization of VUV sensitive silicon photomultipliers (SiPMs)

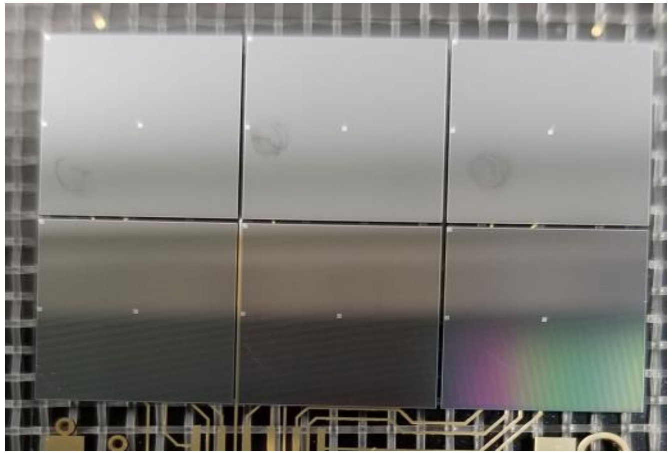
BINDIYA CHANA

SUPERVISOR: DR. SIMON VIEL

CAP CONGRESS, 8TH JUNE 2022

Motivation

- Silicon photomultipliers (SiPMs) are emerging technology in photon detection in particle physics.
- Large future experiments like **nEXO, ARGO** etc. will use SiPM based light detection system



SiPM tile

Challenges

- Quality control and testing of these large number of SiPMs will be a challenge.
- A quick and reliable SiPM testing technique is required at all stages (from single SiPM to fully installed system).

Goals of this project

- Current-voltage (IV) characterization of SiPM
- Develop the IV fit model to understand the IV curves
- Use fit model to extract the empirical parameters of SiPMs
- Compare and verify the results from IV analysis with pulse analysis
- Extend the study to different SiPM devices at a range of temperatures in different light conditions

VERA* setup at TRIUMF

SiPM devices

- FBK** VUV HD3
- Hamamatsu VUV4

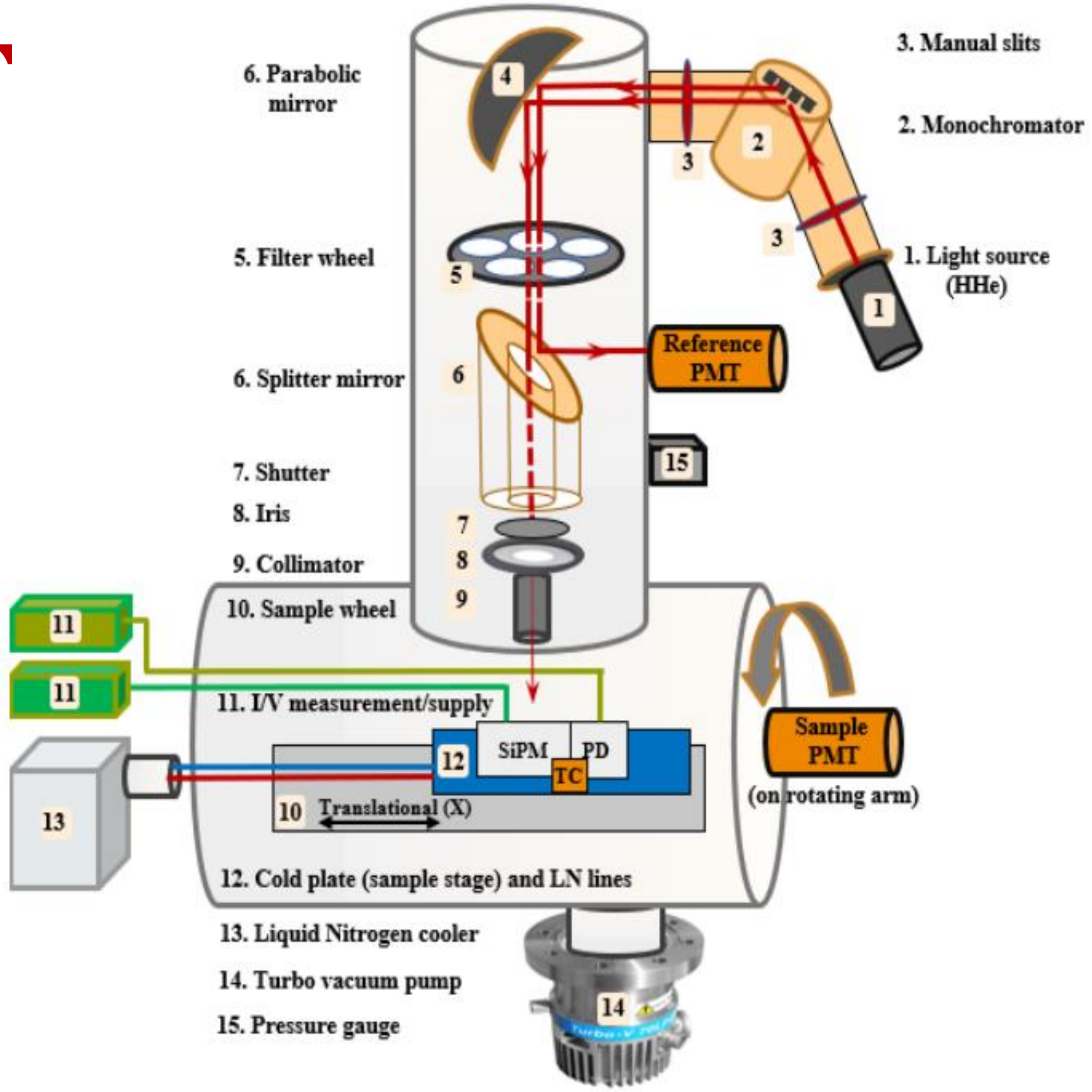
Temperature range

- -110° C to +20° C

Light conditions

- Dark
- Light source – 175nm & 385nm

Thanks to Dr. Fabrice Retiere and Dr. Mahsa Mahtab (TRIUMF) for their support in this project



VERA setup at TRIUMF used to take measurements for SiPMs

*VERA – Vacuum Emission, Reflectance and Absorbance

** FBK - Fondazione Bruno Kessler

VERA* setup at TRIUMF

SiPM devices

- FBK** VUV HD3
- Hamamatsu VUV4

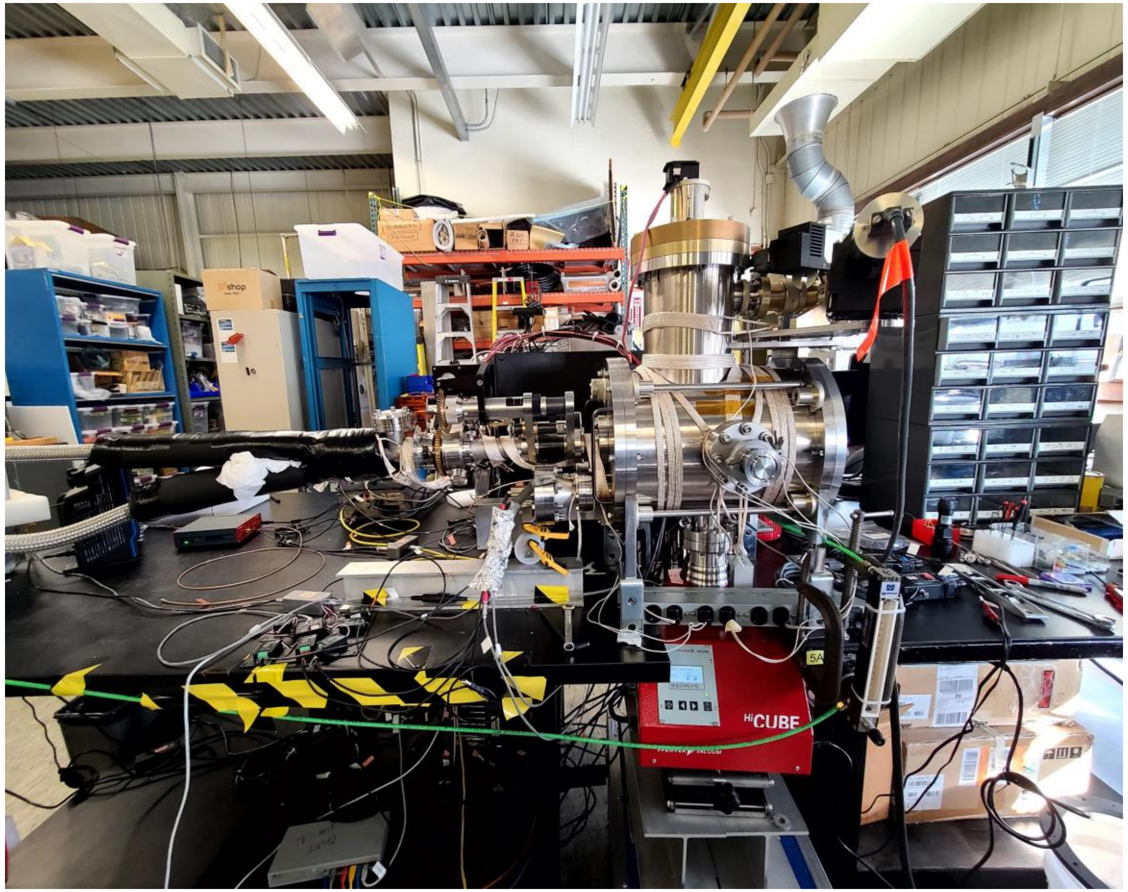
Temperature range

- -110° C to +20° C

Light conditions

- Dark
- Light source – 175nm & 385nm

Thanks to Dr. Fabrice Retiere and Dr. Mahsa Mahtab (TRIUMF) for their support in this project

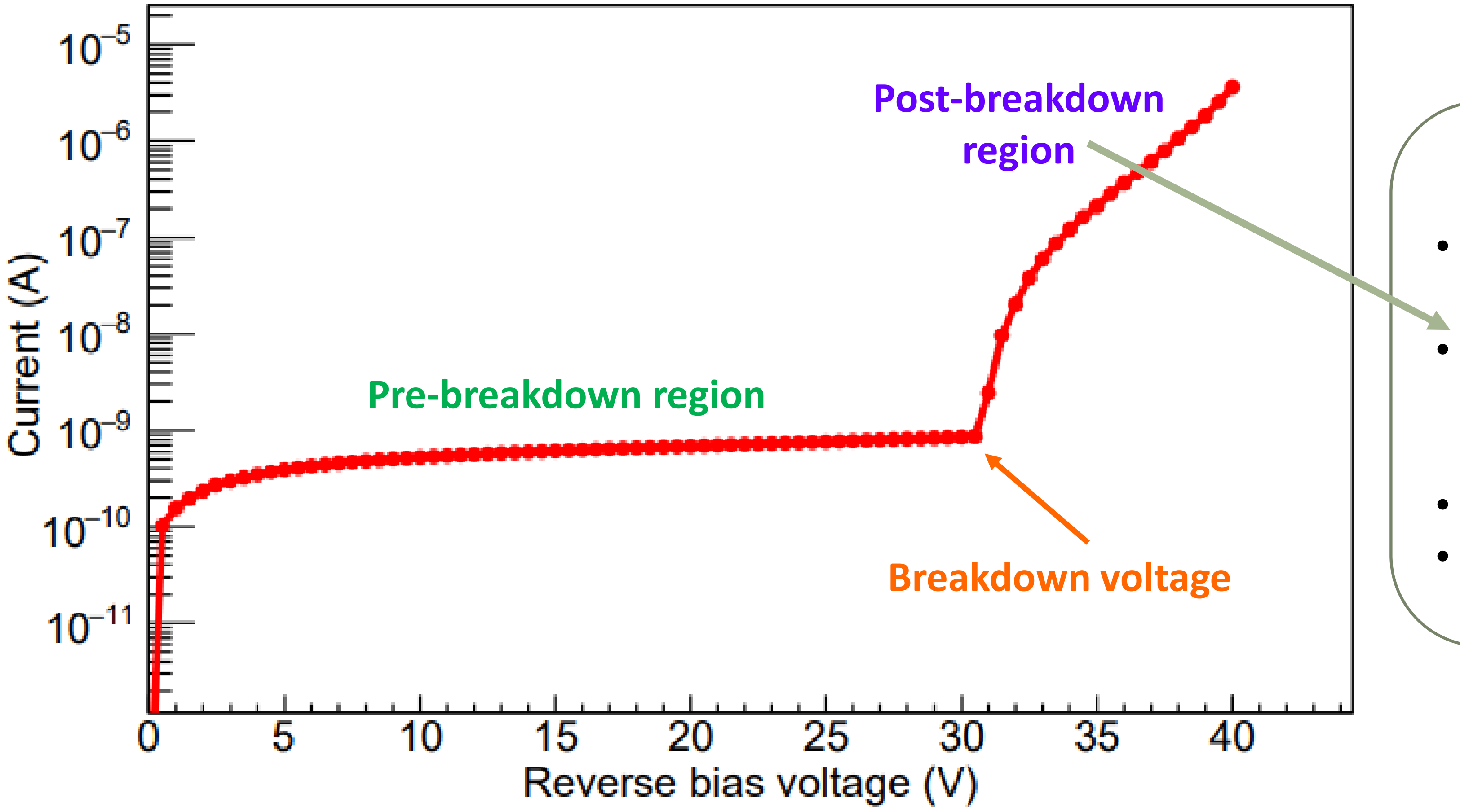


VERA setup at TRIUMF used to take measurements for SiPMs

---

*VERA – Vacuum Emission, Reflectance and absorbance
** FBK - Fondazione Bruno Kessler

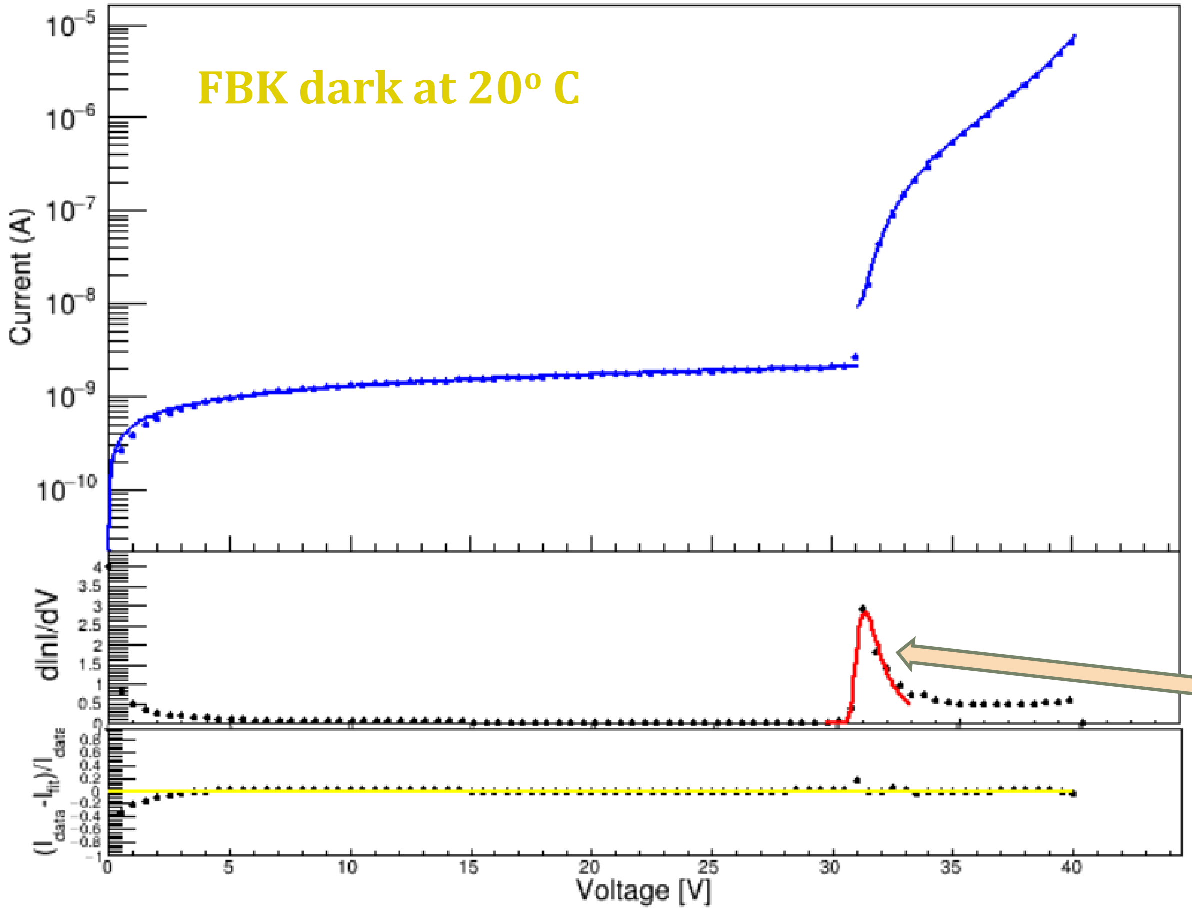
SiPM IV curve

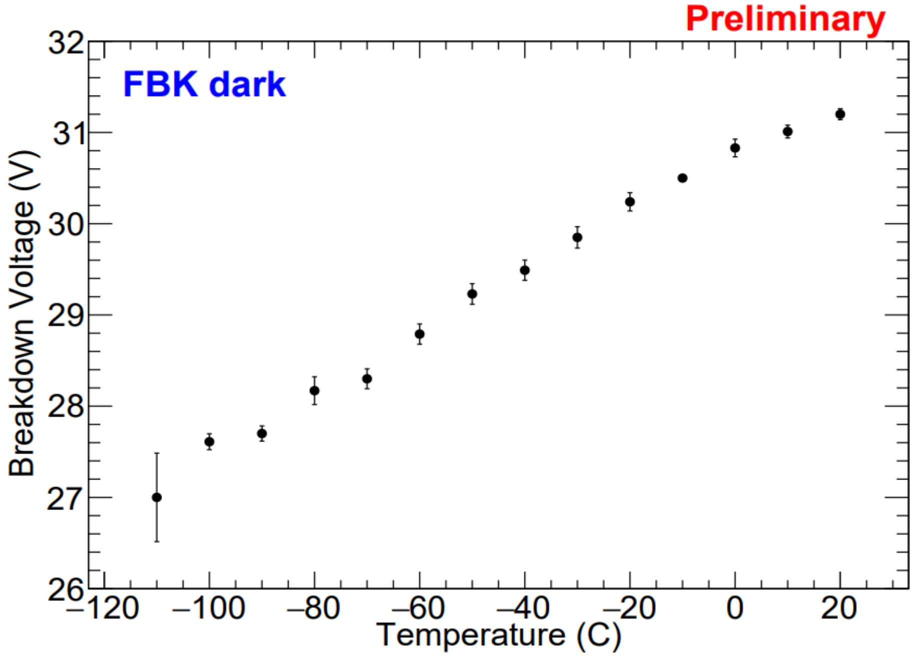


Post-breakdown region

- SiPMs are usually operated in post breakdown region
- Geiger mode – a single charge carrier is able to trigger an avalanche
- High gain
- Correlated avalanche noise

Breakdown voltage



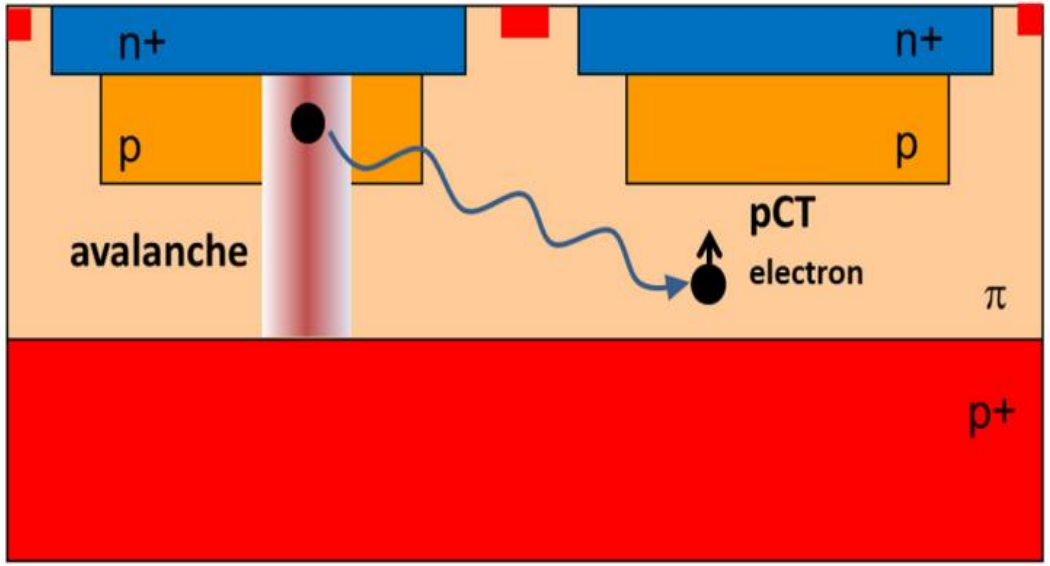


Breakdown voltage increases linearly with temperature.

- Relative logarithmic derivation method to extract the breakdown voltage.
- **Landau fit function on** $\frac{d(\ln(I))}{dV}$ and mean value gives the breakdown voltage.

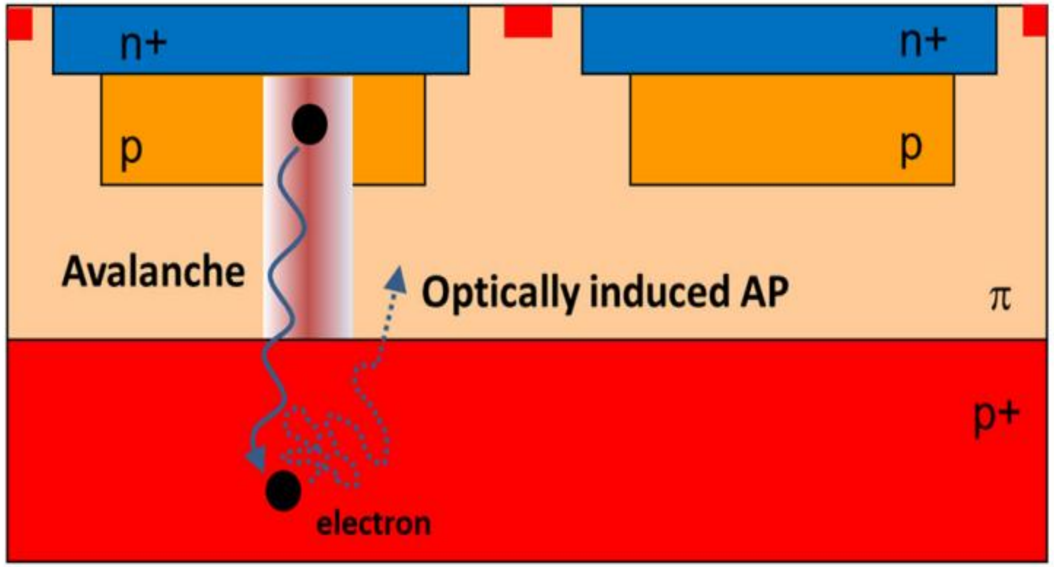
Correlated noise parameters

Cross-talk



- During avalanche, accelerated carriers in the high field region could emit photons
- That photon can initiate a secondary avalanche in a neighbouring microcell.

Afterpulsing



- Carriers get trapped in defects in the silicon.
- Released after a delay which initiate an avalanche in the same microcell.

Figures from Piemonte C and Gola A (2019)

Reverse bias fit model

Pre breakdown fit function :

$$\boxed{I = q * C_{srh} * W_o * \left\{\left(\left(1 - \frac{V}{V_{int}}\right)^p - 1\right) + A\left(exp\left(\frac{V}{B}\right) - 1\right)\right\}}$$

C_{srh} = Shockley-Read-Hall recombination factor

W_o = Zero bias depletion layer width

V_{int}, p = CV parameters

A, B = empirical parameters (Otte et al (2017))

Reverse bias fit model (contd.)

Post breakdown fit function : involves the contribution of dark noise and correlated noise – afterpulsing and cross-talk

$$I_{post} = C * R_{DN} * V_{ov} * \left(1 - exp\left(-\frac{V_{rel}}{\alpha}\right)\right) * \left\{\left(\frac{1}{1 - P_{AP}(V_{ov})}\right)\left(\frac{1}{1 - P_{CT}\left(V_{ov}^{2}\right)}\right)\right\} + I_o$$

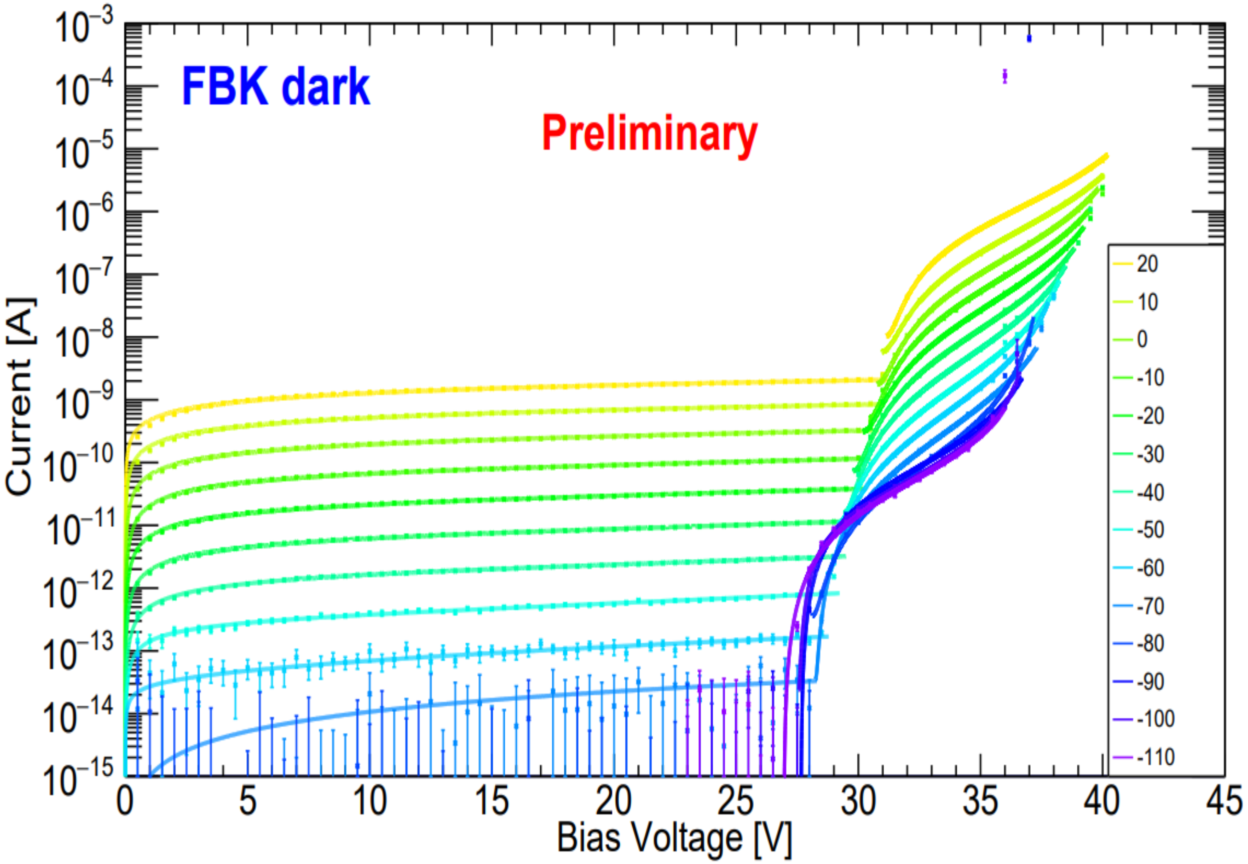
R_{DN} = **Dark noise rate** $V_{ov} = (\mathrm{V} - V_{br})$ = Overvoltage , $V_{rel} = \frac{V_{ov}}{V_{br}}$

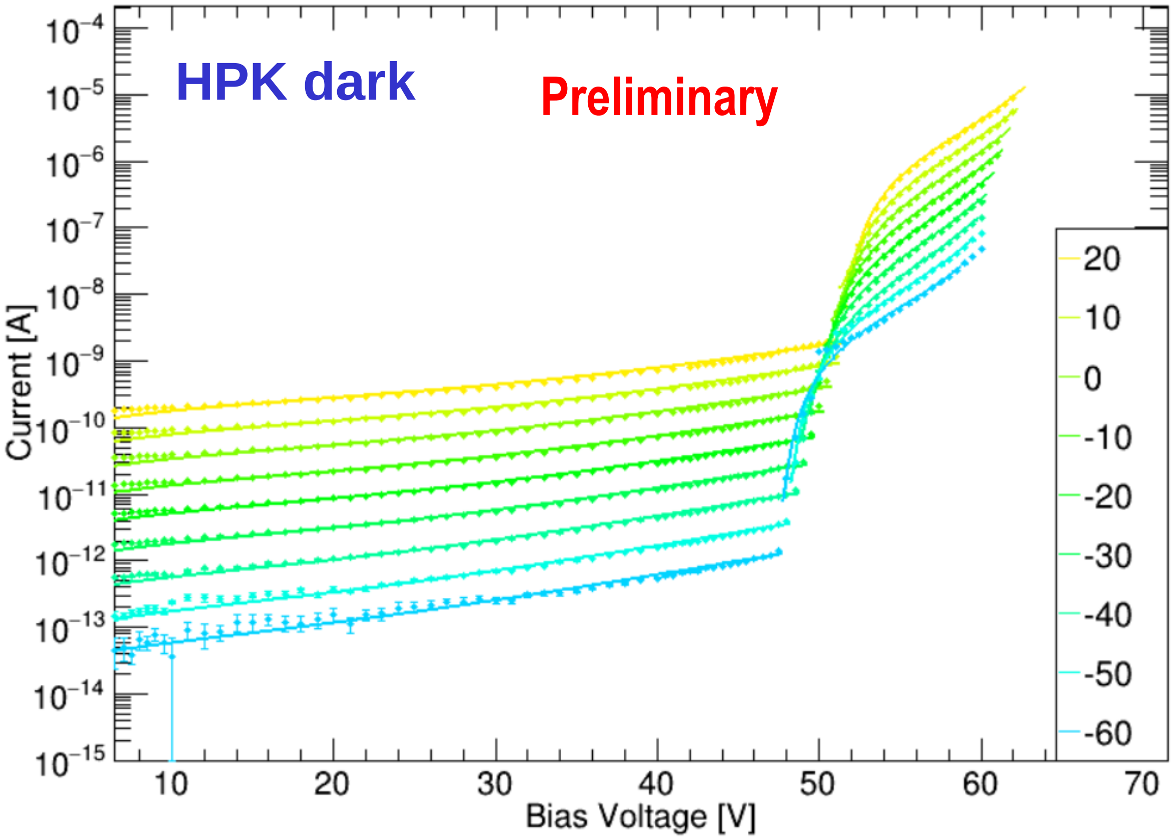
V_{br} = **Breakdown voltage** ; C = Capacitance; I_o = leakage current

P_{AP} = **probability of afterpulsing ;** P_{CT} = **probability of crosstalk**

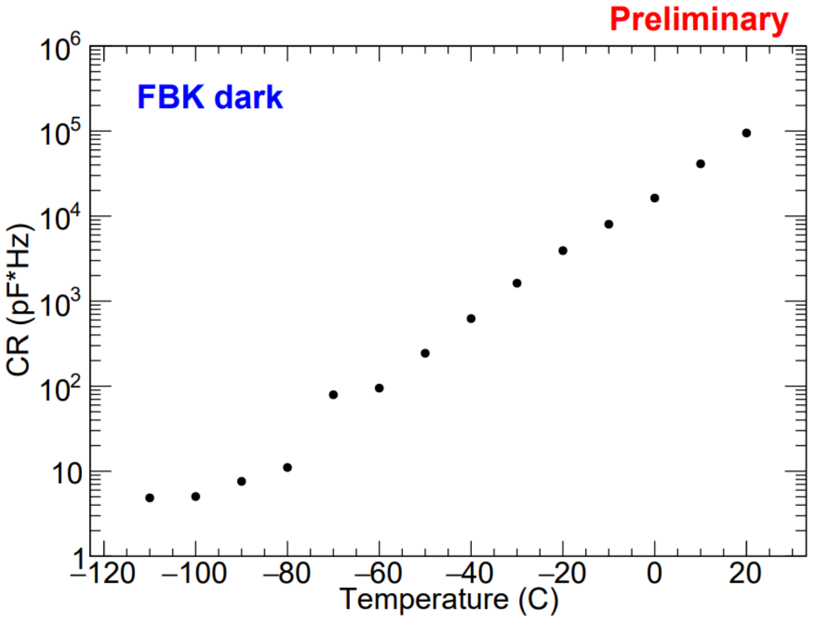
$\left(1 - exp\left(-\frac{V_{rel}}{\alpha}\right)\right)$ = **triggering probability**

IV fits for 2 devices

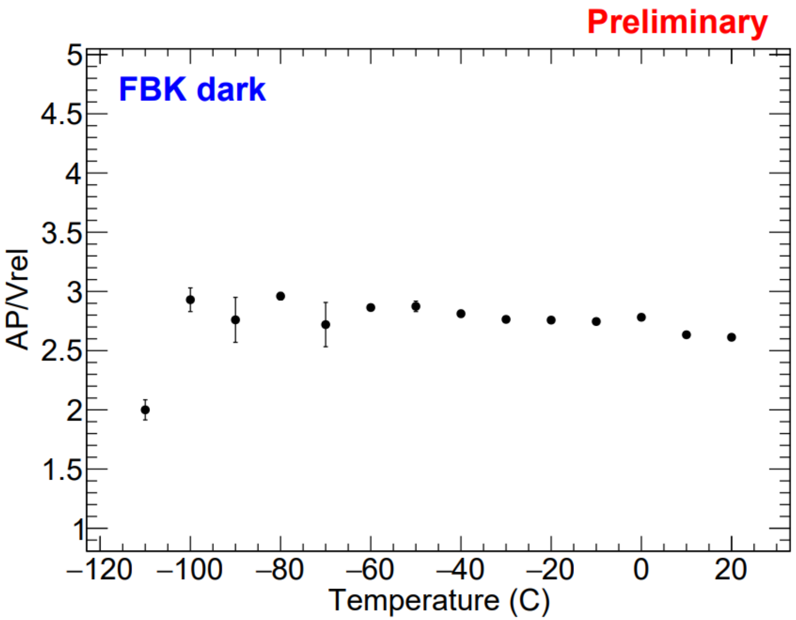




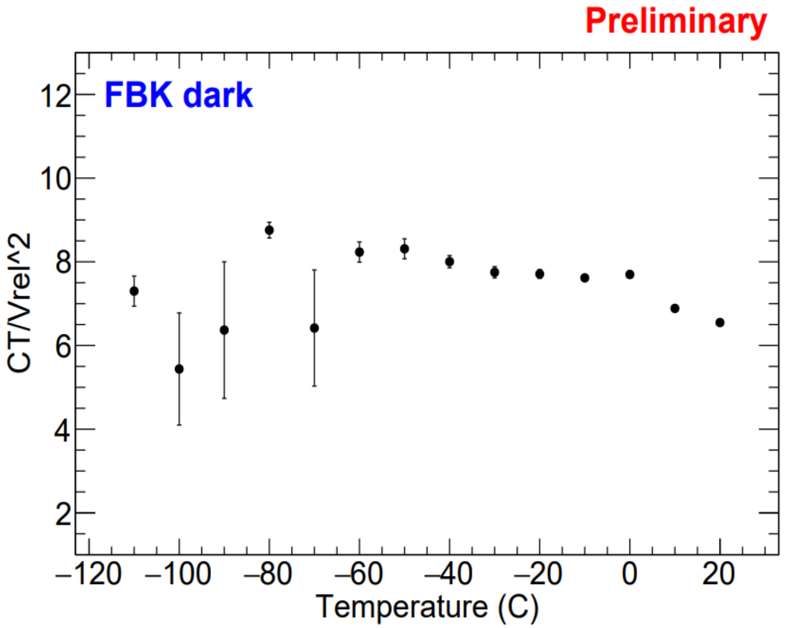
IV parameters



Considering C to be constant over different temperatures, R increases exponentially with temperature



Parameter AP(V) tends to stay constant with temperature, similar results are indicated in literature



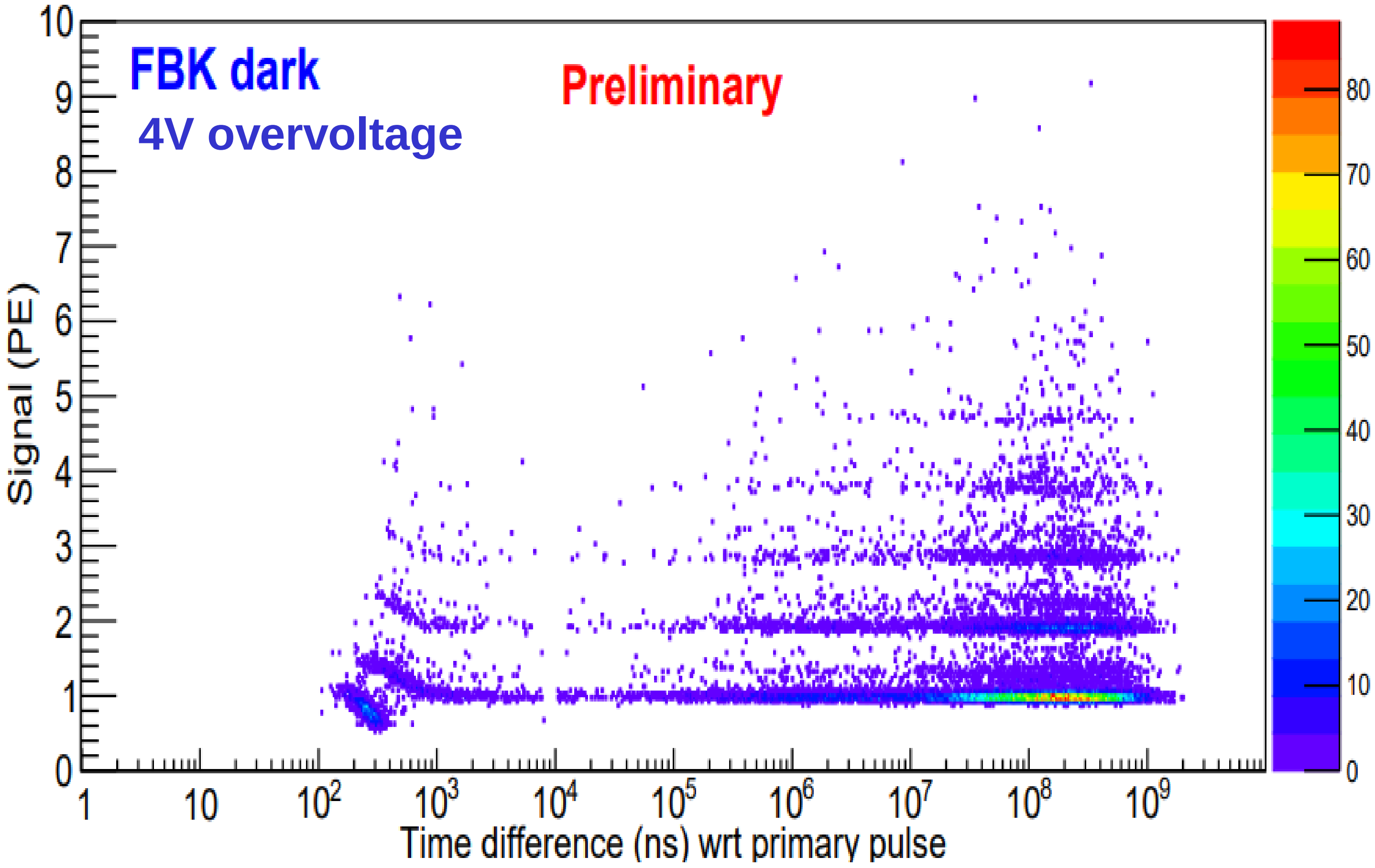
Parameter CT(V^2) tends to stay constant with temperature

* Only statistical error bars are shown

Pulse analysis

- SiPM pulse data was taken at two overvoltages (4 & 7V) at 0.5PE threshold.

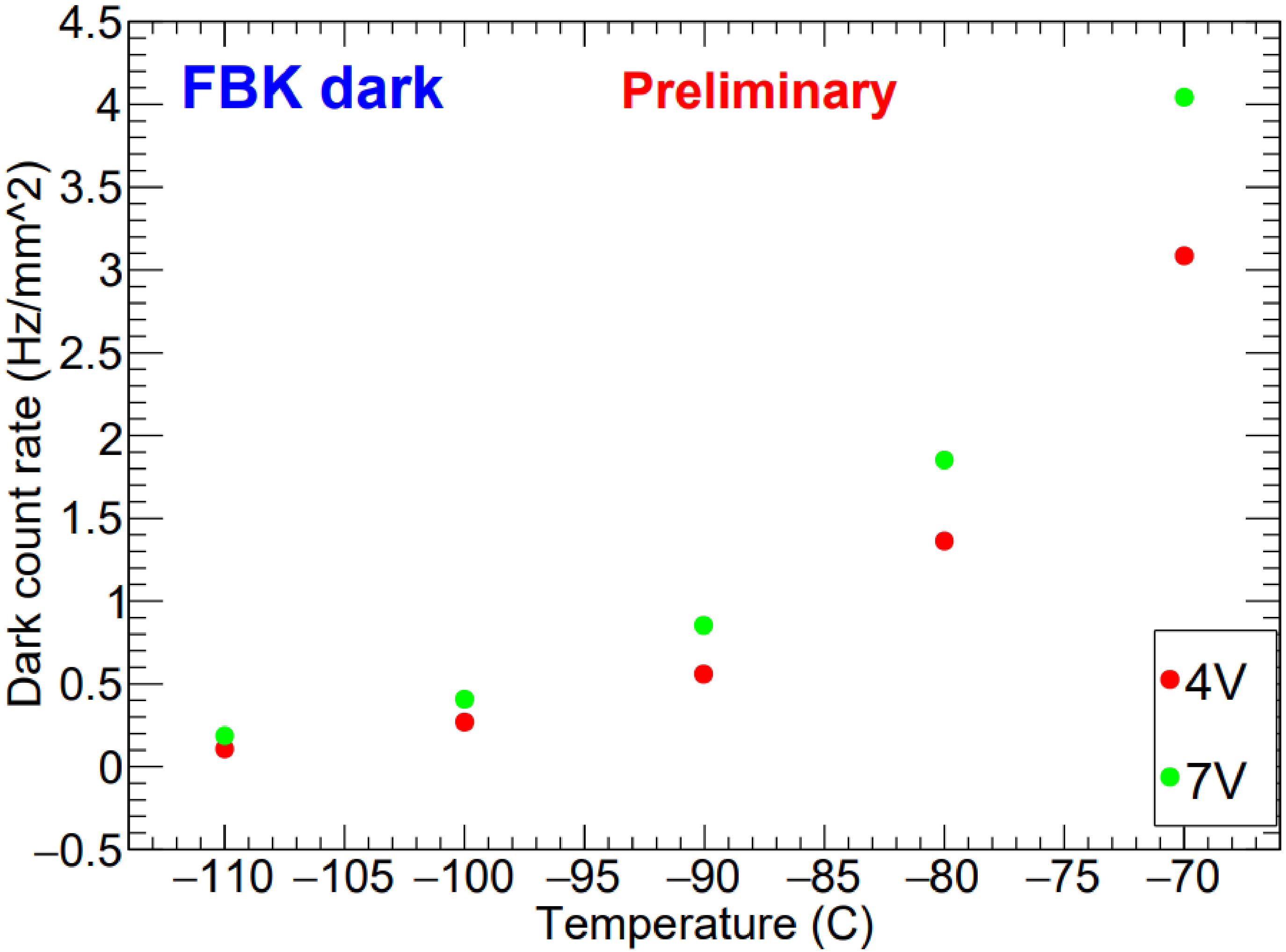
- Primary pulse selection :
  - It should be single PE (0.5 - 1.5PE)
  - It should happen atleast 500μs later than previous pulse.



Dark noise rate

$$Dark\ count\ rate = \frac{N_{>0.5PE}}{Run\ time\ (s)}$$

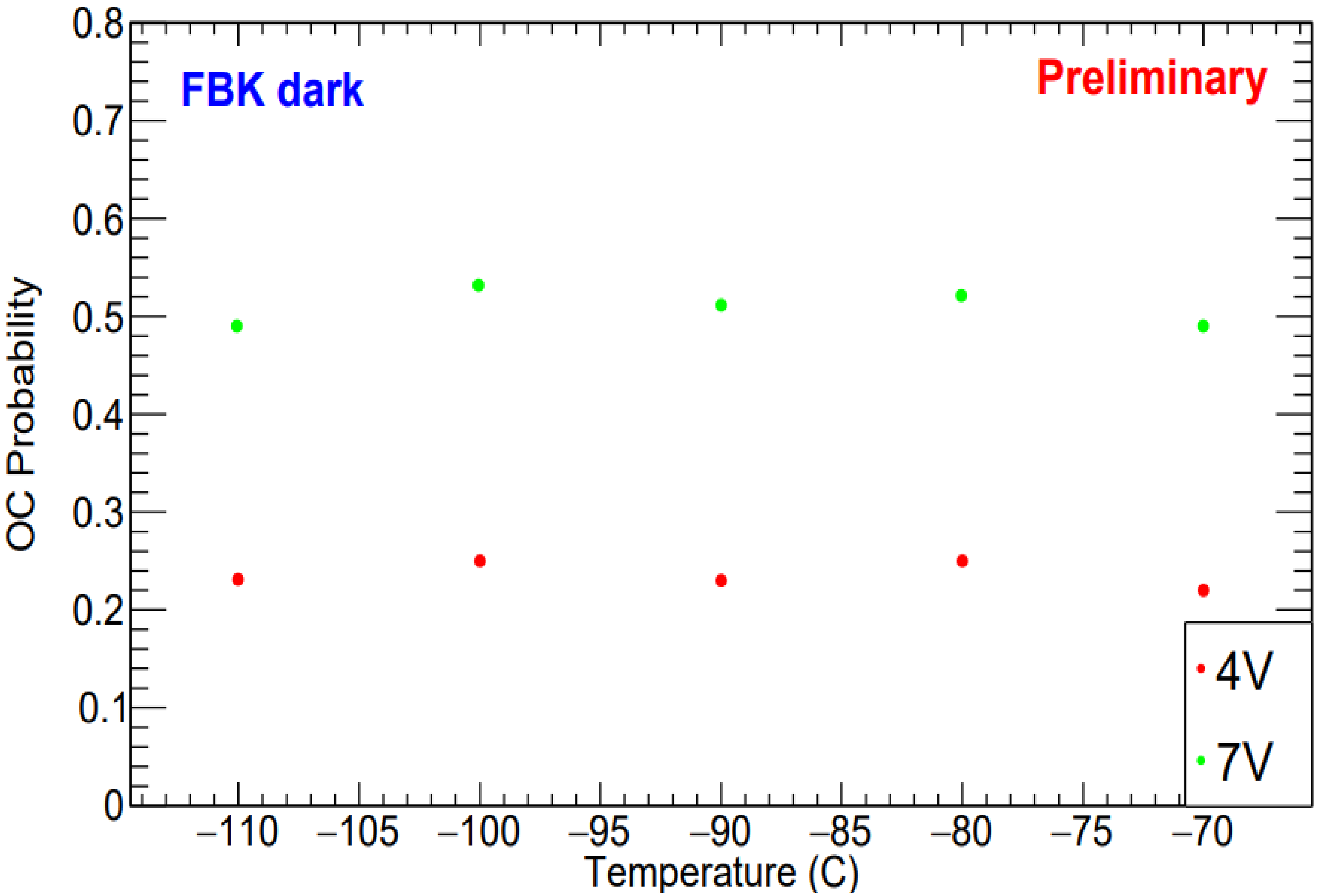
- Dark count rate (DCR) showed exponential rise with temperature
- It also increases with increase in overvoltage



Optical crosstalk

$$OC\ probability = \frac{N_{>1.5PE}}{N_{>0.5PE}}$$

- OC probability increases with overvoltage
- Crosstalk seems to be independent of temperature, similar results are indicated by IV analysis as well.



Summary and future plans

- IV characterization and fit model looks promising over a range of temperatures for both FBK and Hamamatsu SiPM devices
- Improve the IV model for dark data
- Extend the fit functions with some additional terms for light data
- Improve pulse analysis for HPK device data
- Light data has already been taken and analysis for both IV and pulse data are ongoing
- At TRIUMF, Cryo probe facility will use IV characterization to test thousands of SiPMs for nEXO.