# Rapid characterization of SiPMs for noble liquid experiments

BINDIYA CHANA
SUPERVISOR: DR. SIMON VIEL
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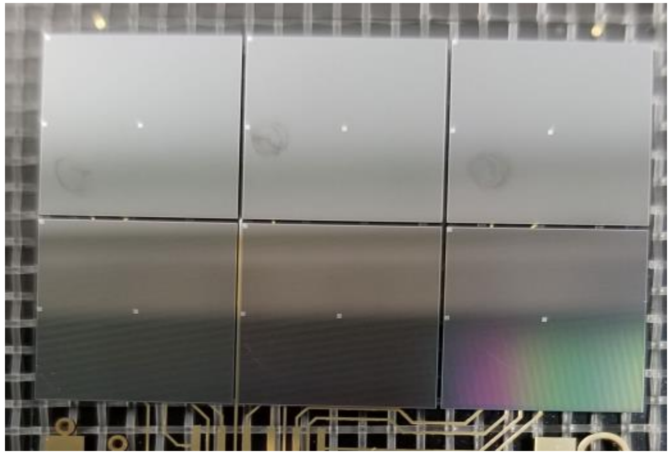
# Motivation

- 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

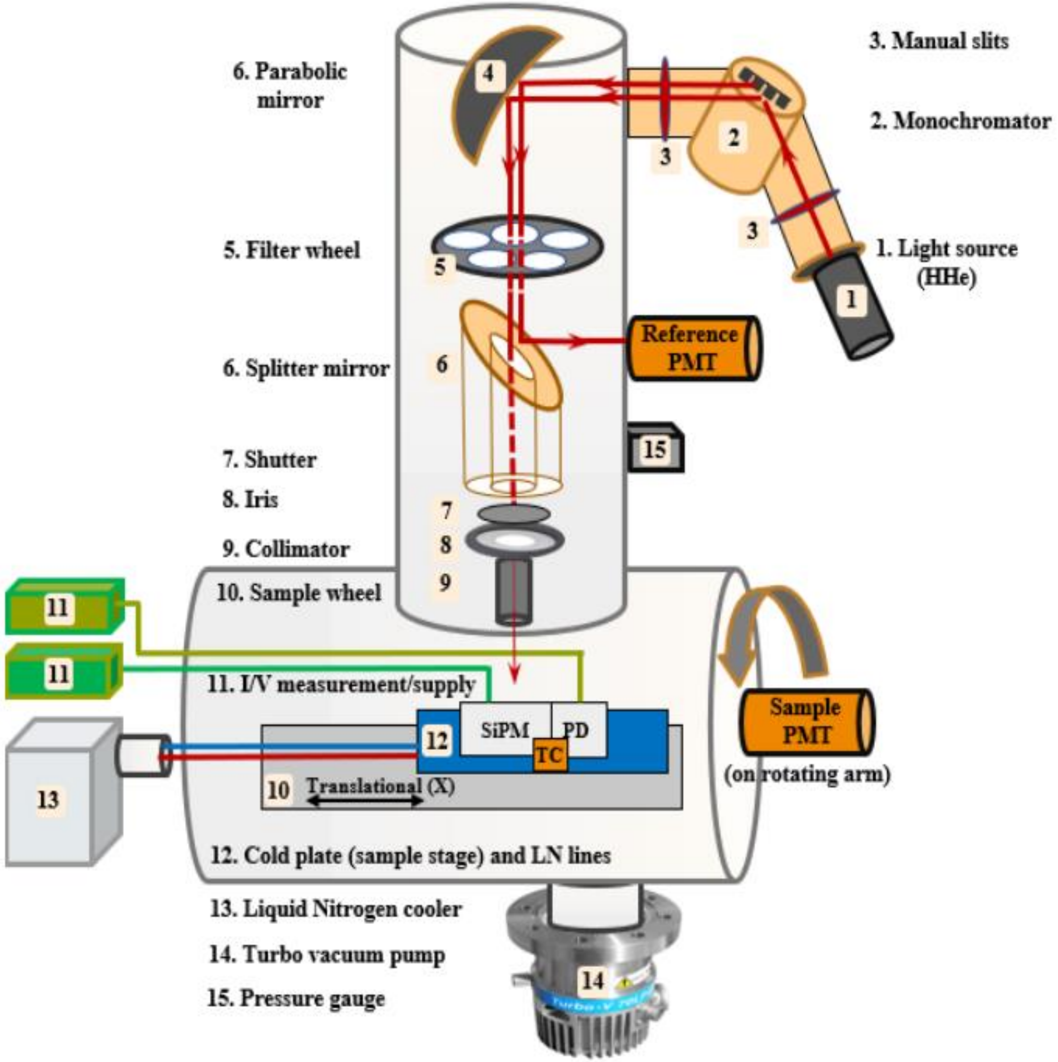
## Temperature range

- -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

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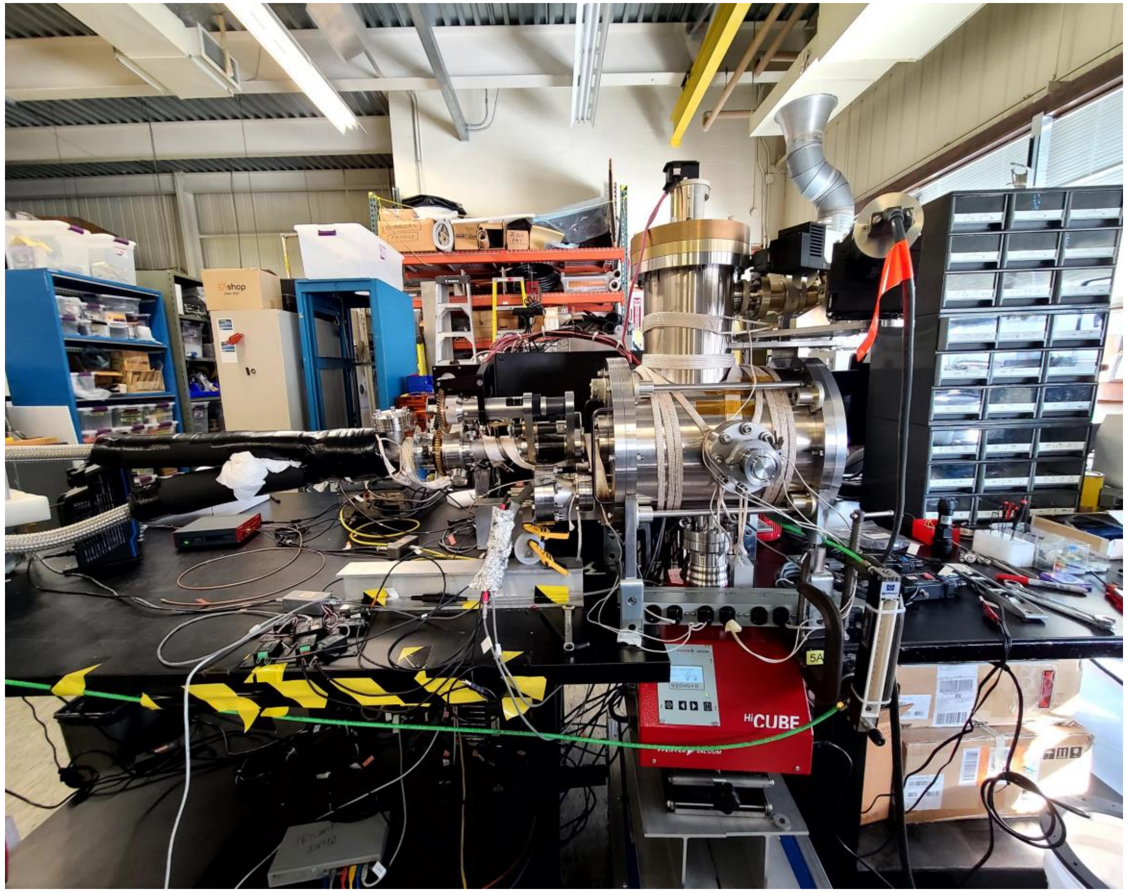


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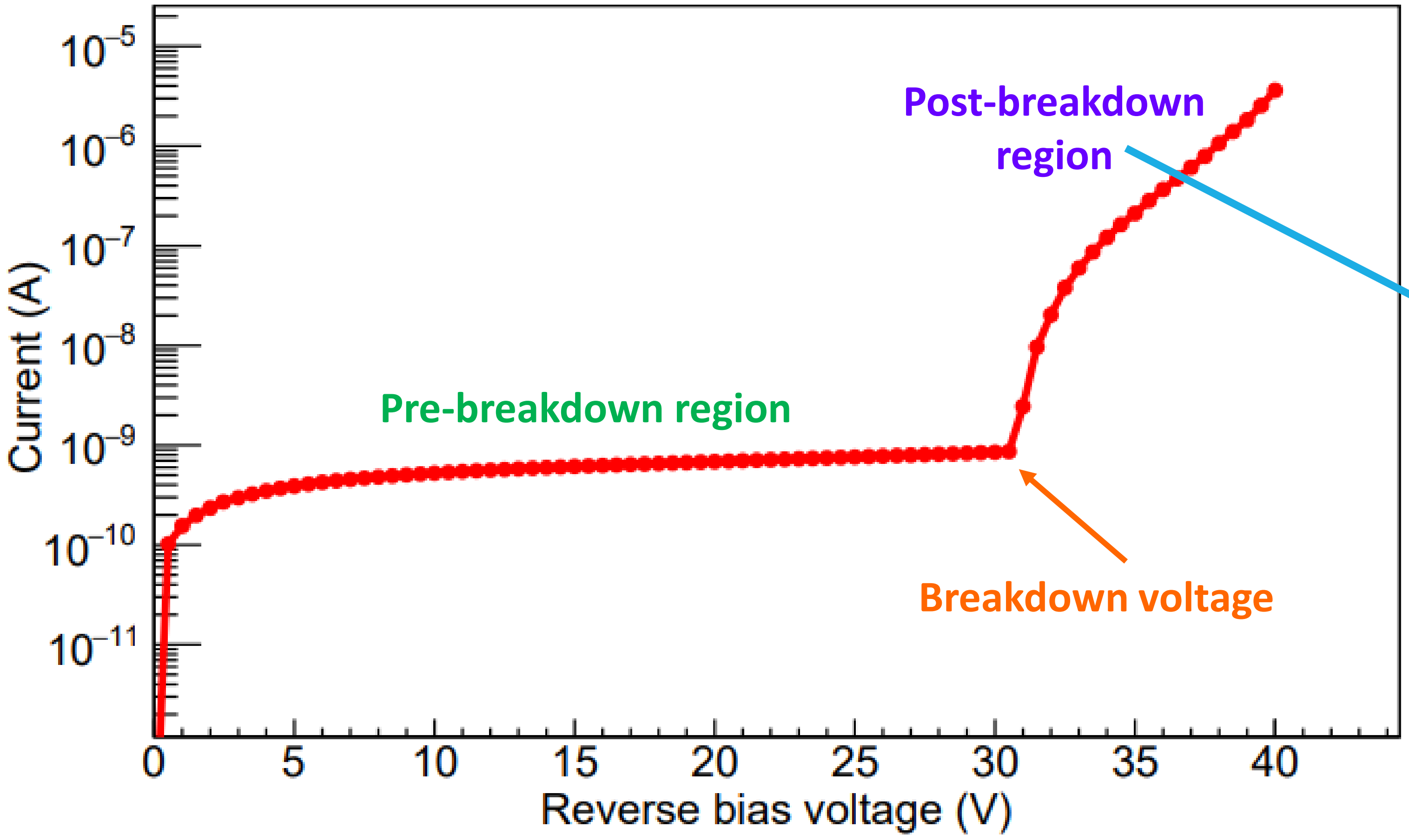
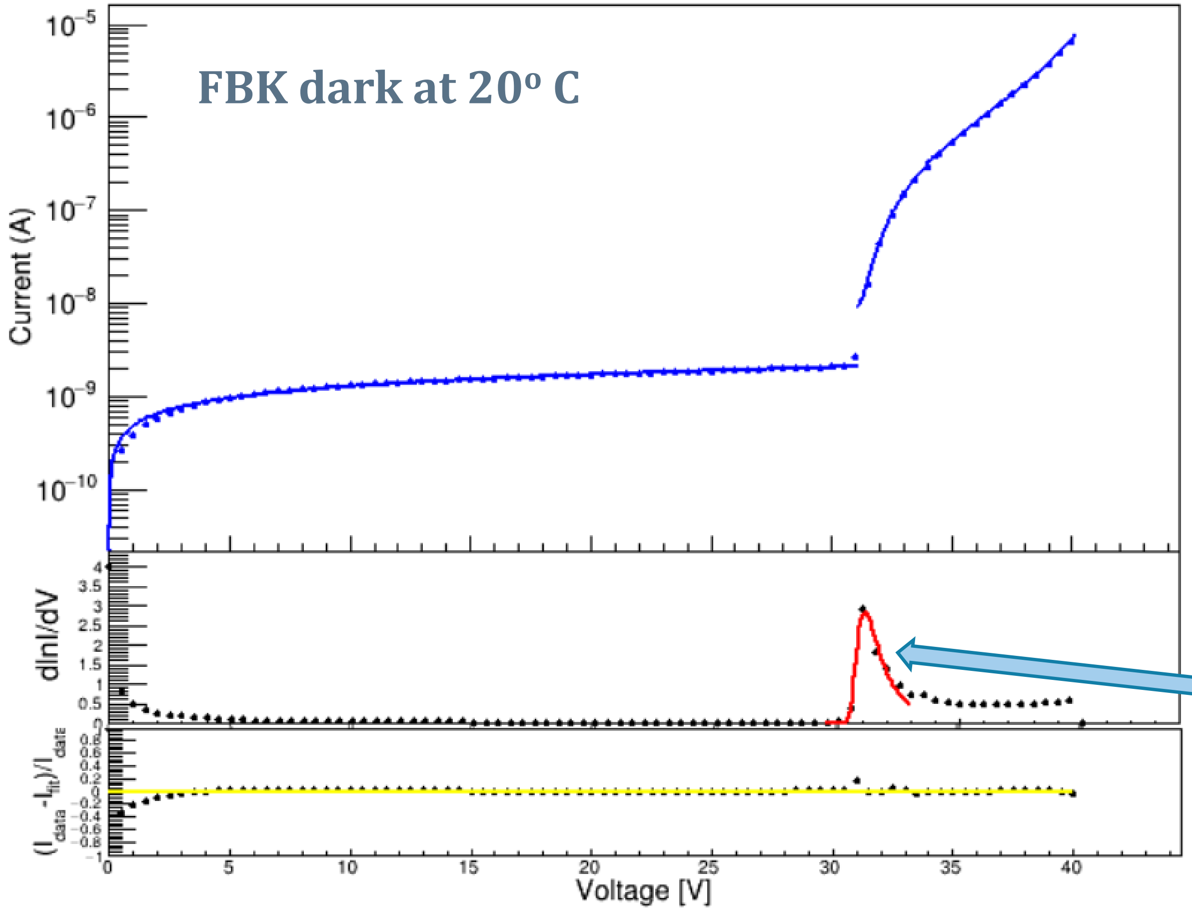
# SiPM IV curve

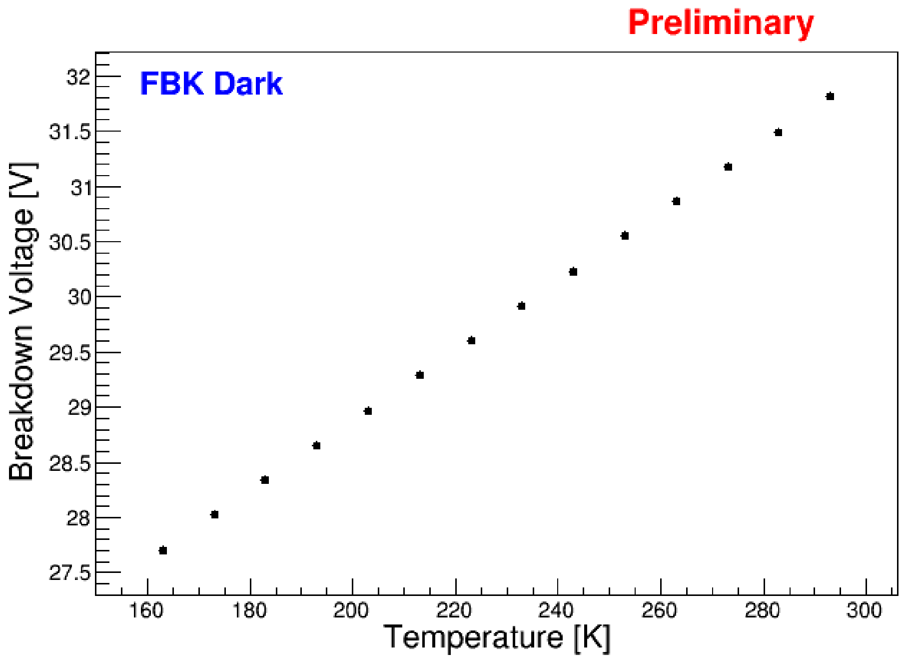



**Post-breakdown region**

- 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



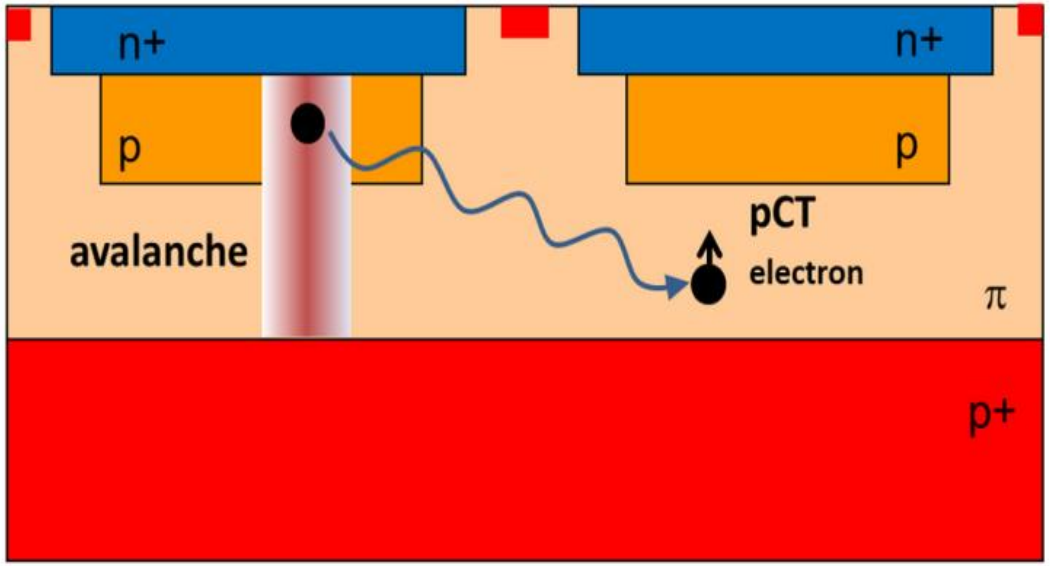




Breakdown voltage increases linearly with temperature.

- 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.

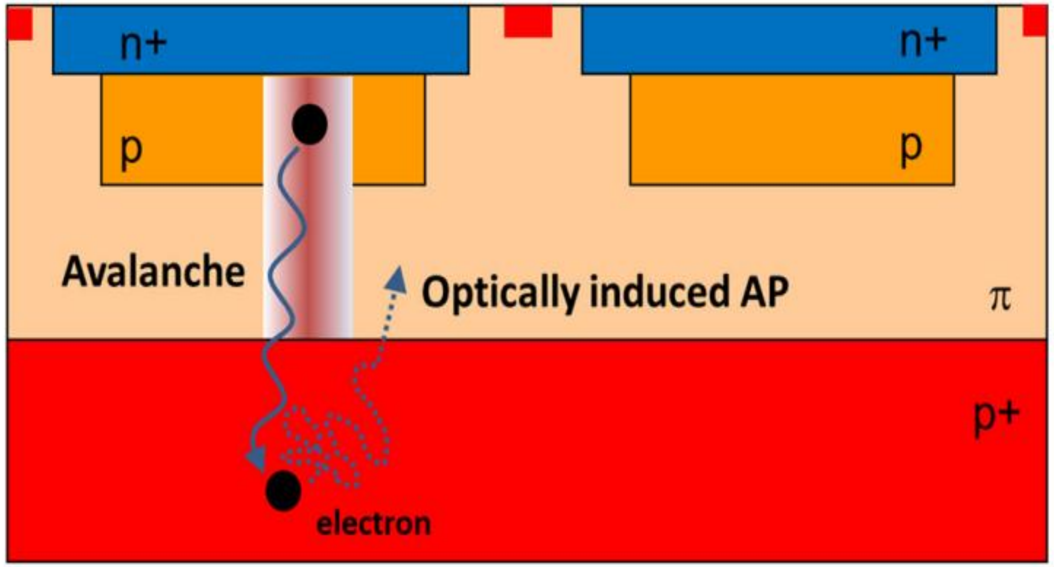
# Correlated noise parameters

## 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 :

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

$C_{srh}$ = 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))

} Empirical parameters

# Reverse bias fit model (contd.)

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

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

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

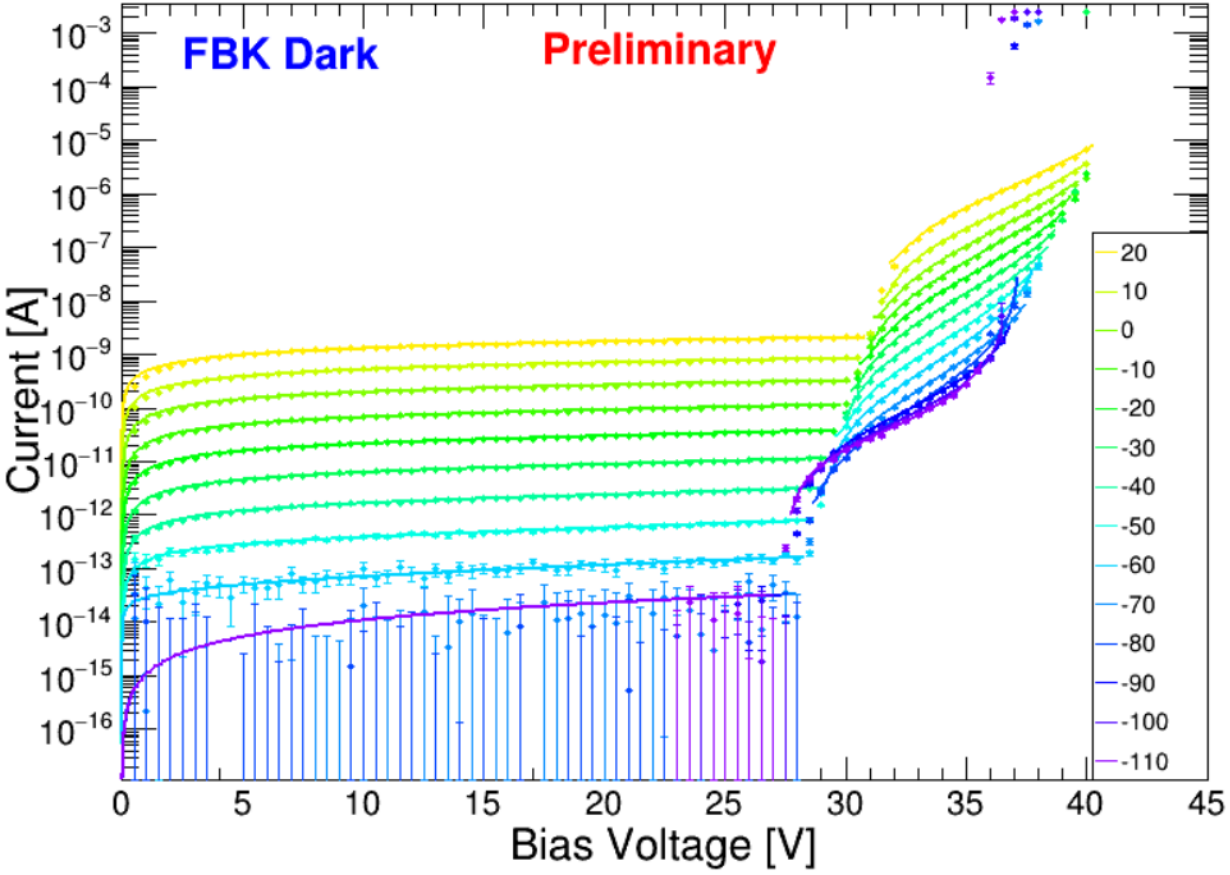
$V_{br}$ = **Breakdown voltage** ; $C$ = Capacitance; $I_o$ = leakage current

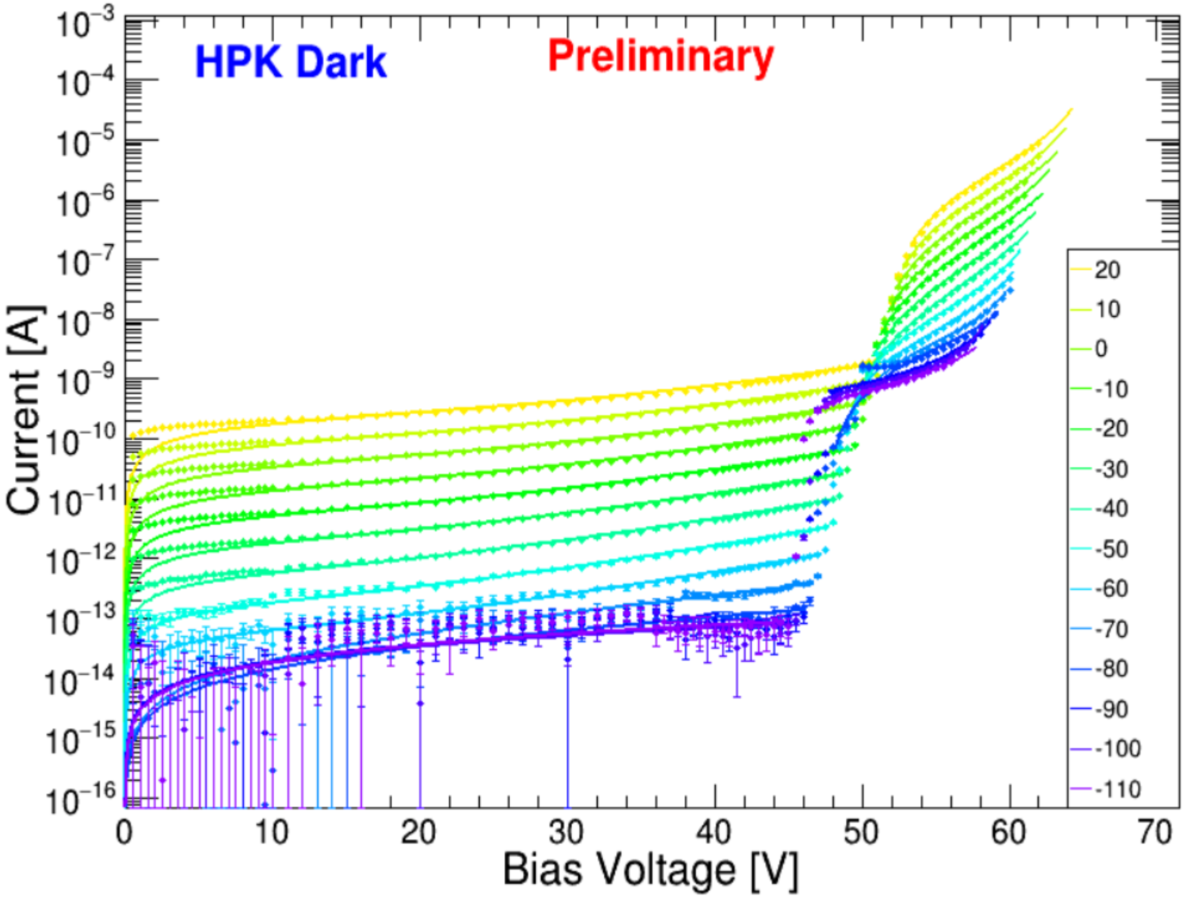
$P_{CN}$ = **probability of correlated noise;**

$a$ = empirical parameter accounts for non-linear dependence of voltage on dark noise rate

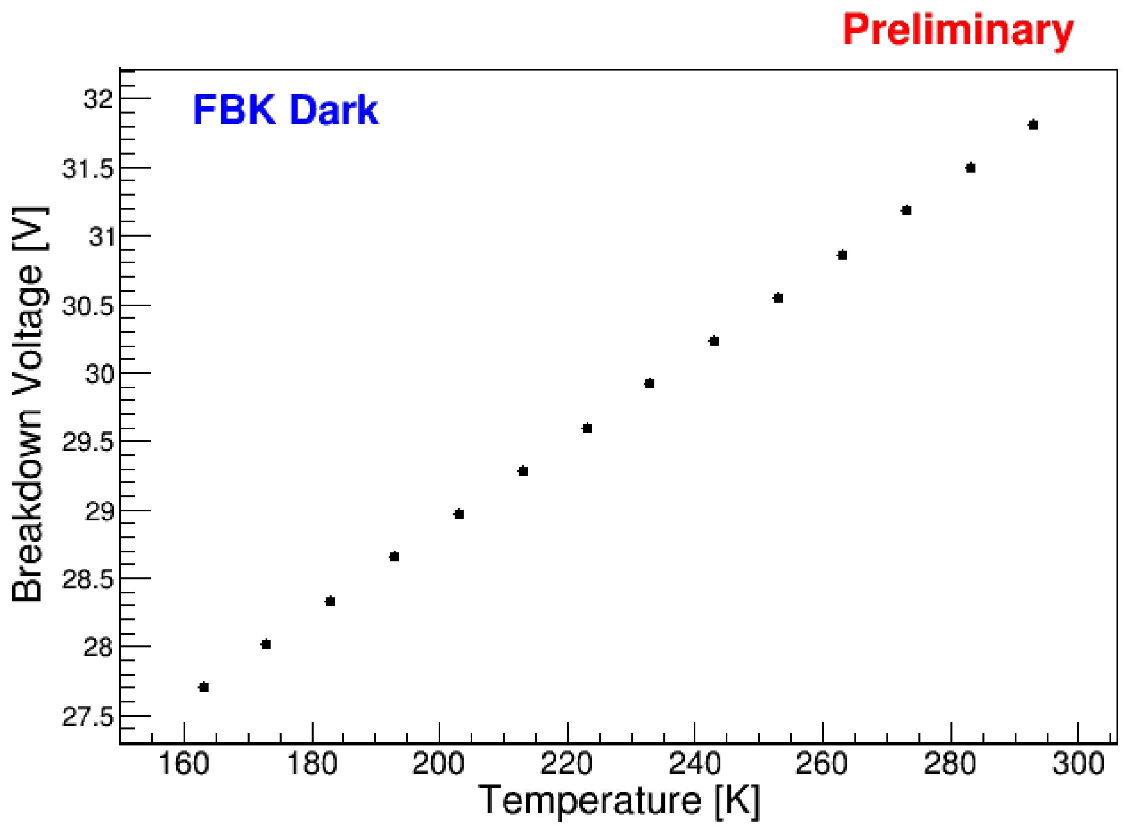
$\left(1 - exp\left(-\frac{V_{rel}}{\alpha}\right)\right)$ = **triggering probability**

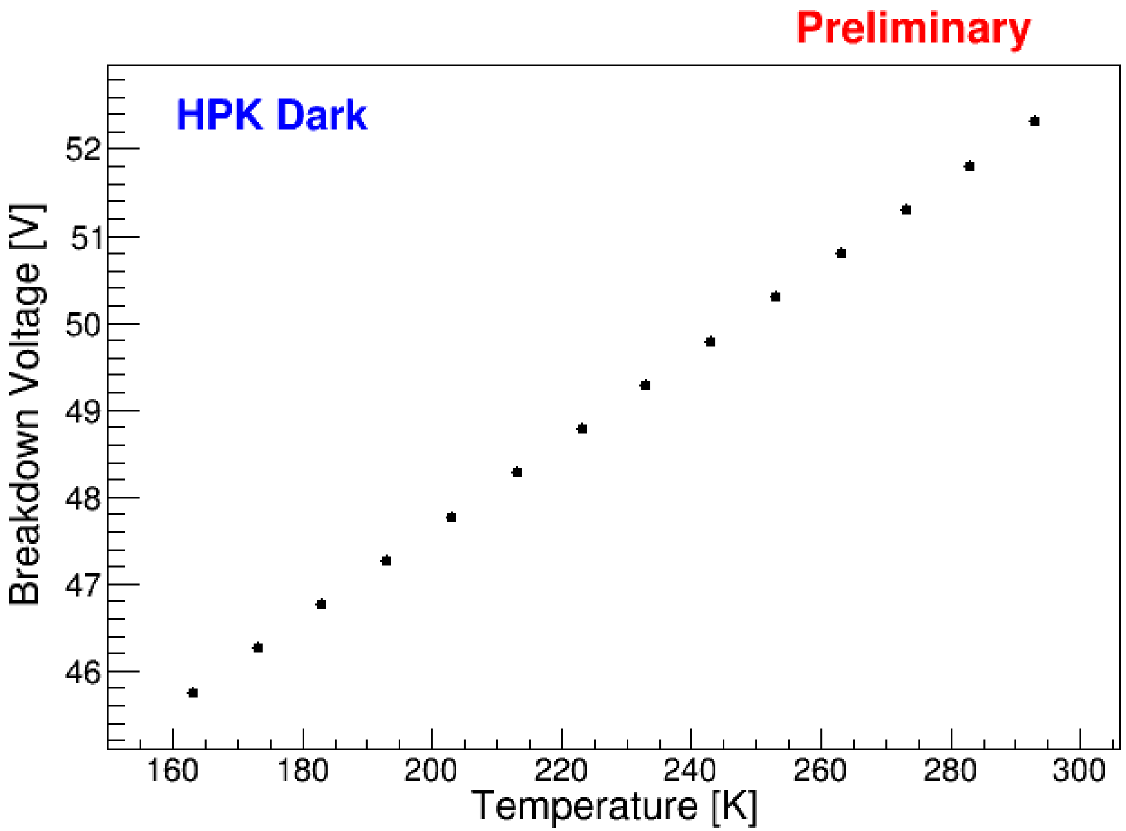
# IV fits for 2 devices



# Breakdown Voltage

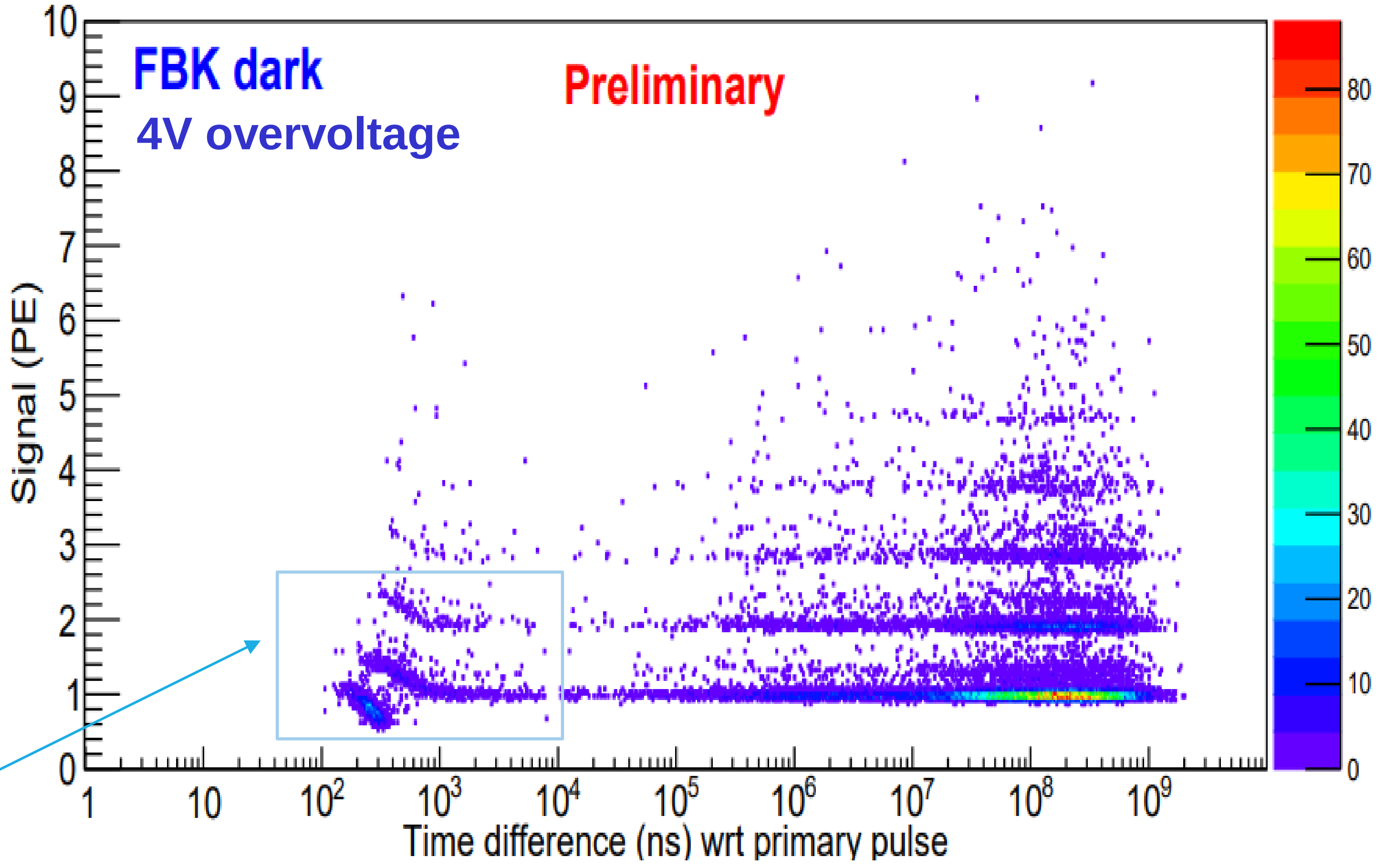


# Pulse analysis

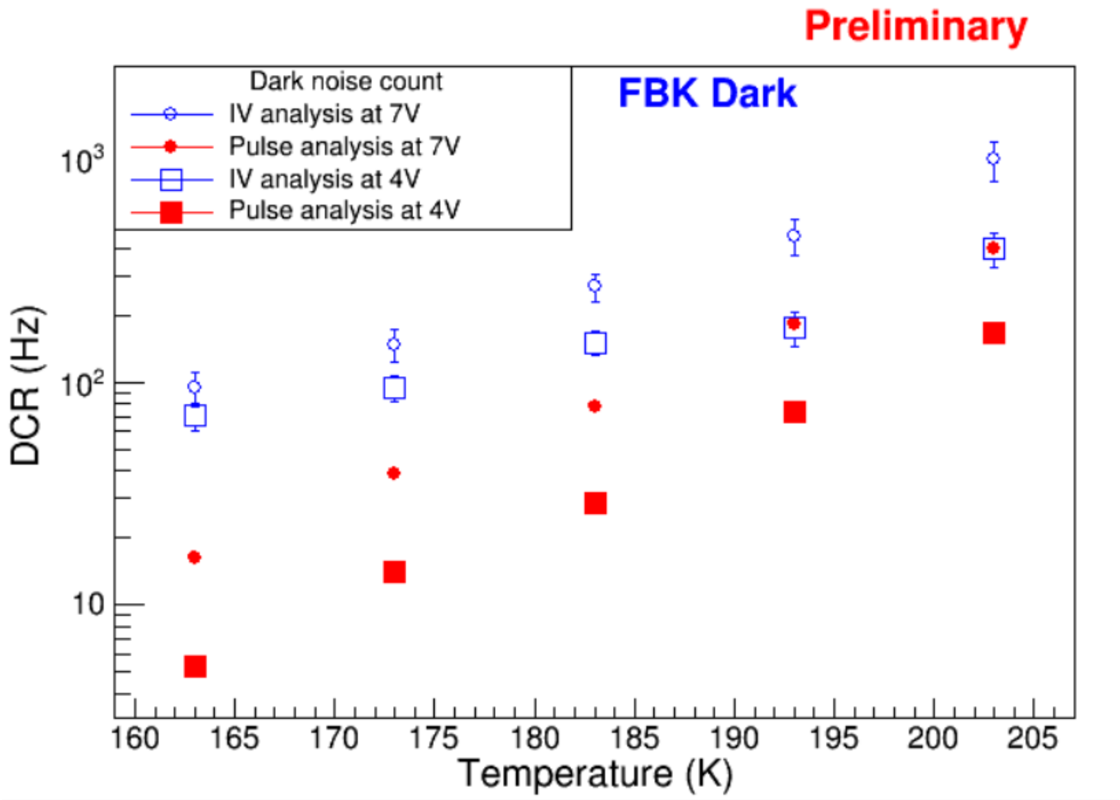
- SiPM pulse data was taken at two overvoltages (4 & 7V) at 0.5PE threshold.

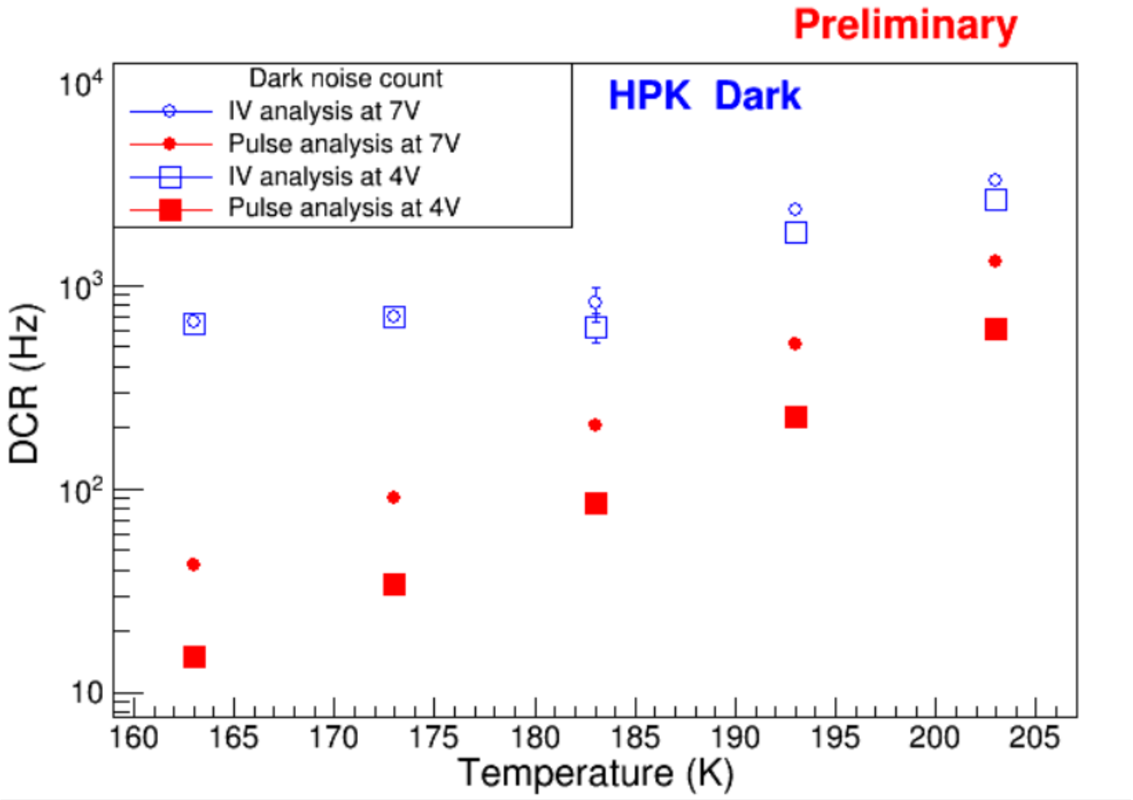
- Primary pulse selection :
  It should be single PE (0.5 - 1.5PE)
  It should happen at least 500μs later than previous pulse.




Pulse fitting analysis needs improvement for afterpulses and the work is in progress

# Dark noise rate

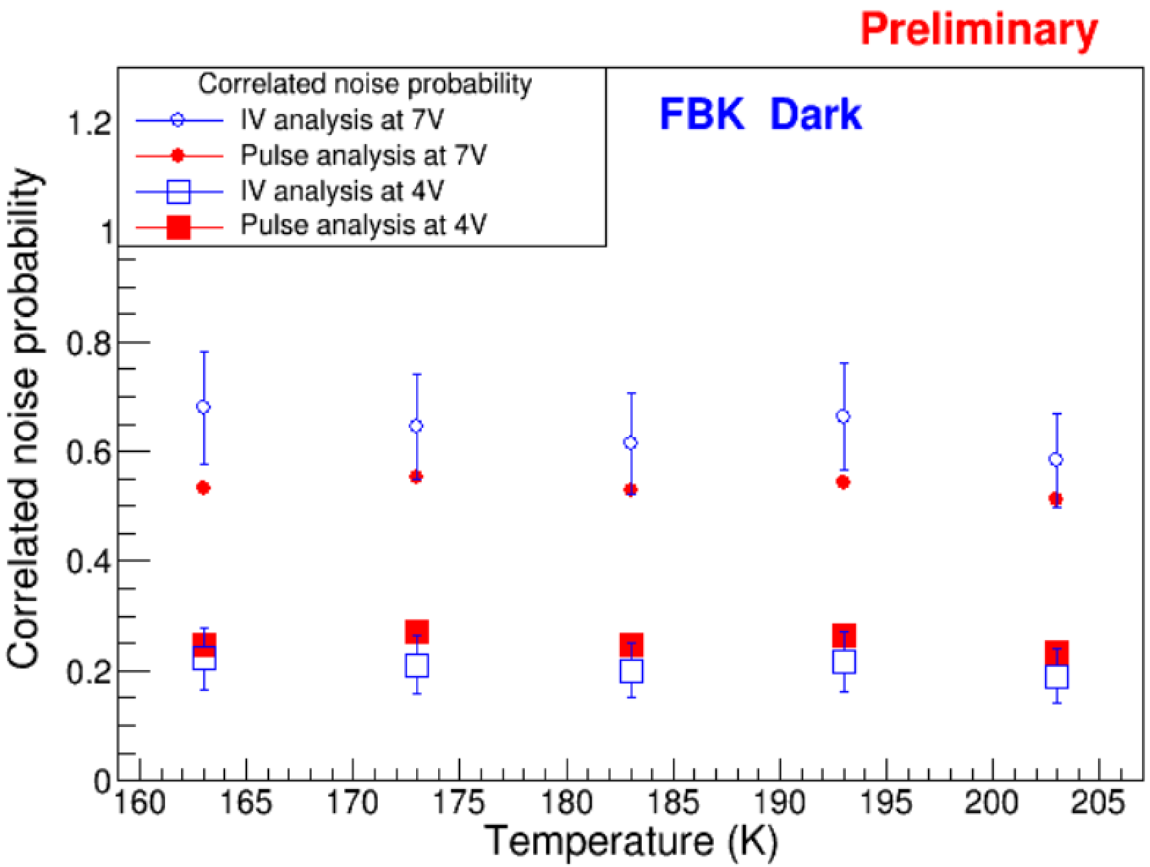


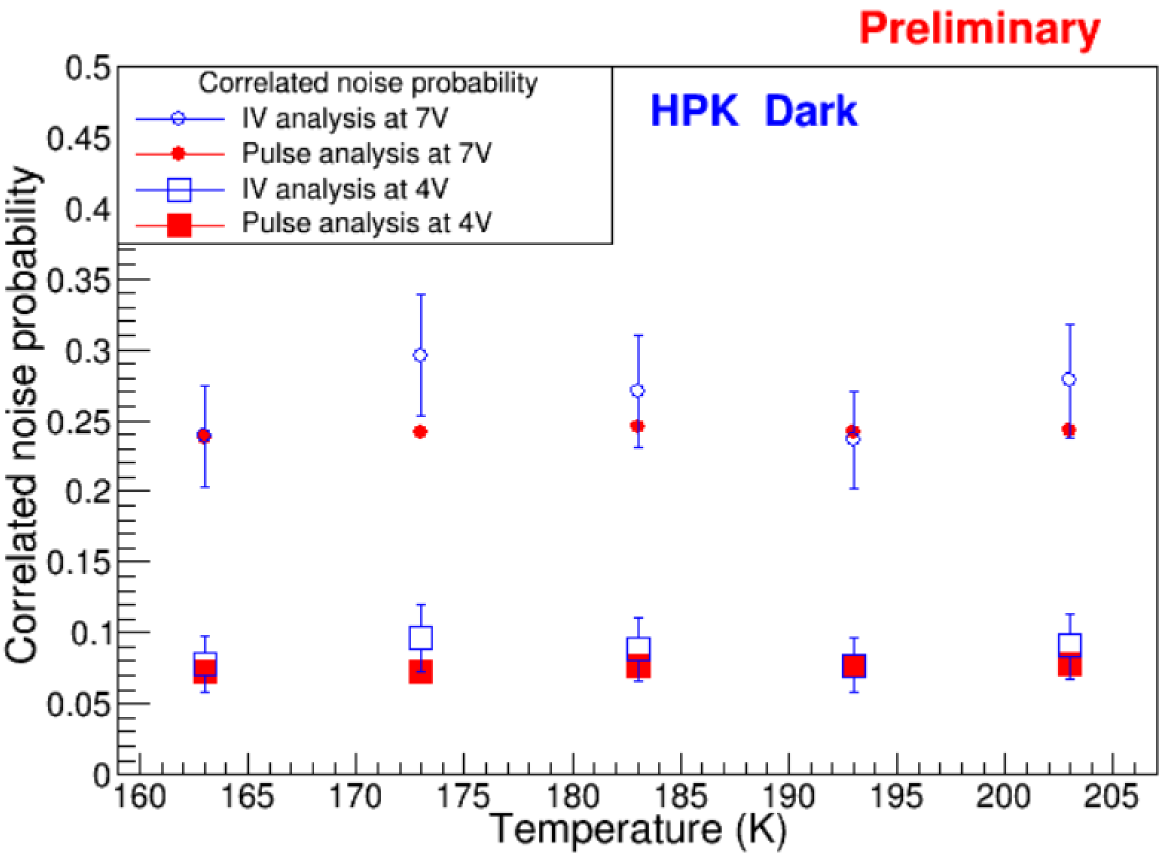




$$\textbf{Dark count rate} = \frac{N_{>0.5PE}}{\textbf{Run time}\ (s)}$$

- Dark count rate (DCR) showed exponential rise with temperature
- It also increases with increase in overvoltage
- IV method overpredicted DCR compared to pulse analysis

# Correlated noise probability




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

- OC probability increases with overvoltage
- Correlated noise 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
  - 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.