# Bulk VUV4 Characterization for the SBC-LAr10 scintillating bubble chamber

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**Abstract**

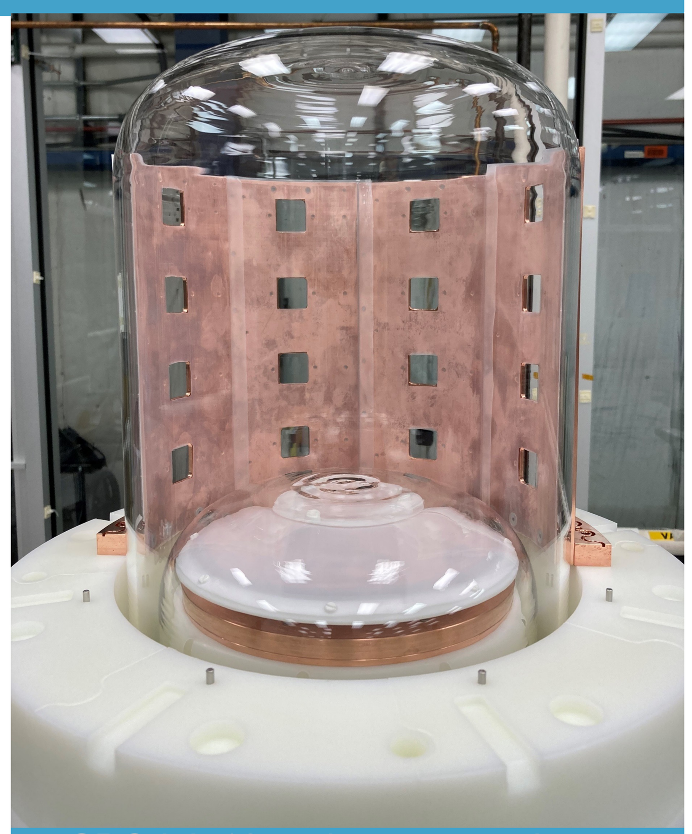
In the continuing search for dark matter, new and more complex technologies have been developed with increasing accuracy and background requirements. The Scintillating Bubble Chamber (SBC) detector combines two proven technologies: bubble chambers and liquid argon scintillator experiments. In order to reach the ultimate projected goal, an energy threshold of 100eV is required and therefore the scintillation system needs to be well understood. This system consists of a liquid argon (LAr) scintillator doped with on the order of 100ppm of Xe, with the light collection accomplished using 32 Hamamatsu VUV4 silicon photomultipliers (SiPMs). One of the requirements of the scintillation detection system is the ability to veto single photoelectron (SPE) events. To distinguish scintillation PE from dark noise ($\mu$) and correlated avalanches (CAs) requires a well understood model of the SPE gain ($A_{SPE}$), $\mu$, and the probability of a correlated avalanche ($N_{CA}$), as a function of temperature and over-voltage (OV). This poster will discuss the efforts of the SiPM characterization chamber consisting of a temperature-variable RF shield inside a vacuum chamber with $\pm$10mK temperature stability from 233K to 293K. A preliminary overview on the analysis to extract the $A_{SPE}$, breakdown voltage ($V_{BD}$), $\mu$ and $N_{CA}$ in a 5μs window will also be discussed.

## The Scintillating Bubble Chamber [1]

Bubble chambers use properties of a supercritical target material to reduce electron recoil (ER) backgrounds. The ER background suppression is an effect of charged particles generally having a smaller stopping power. If enough energy is deposited in a small enough track length, a bubble is created and it expands. Two cameras collect videos during the event and, using the number of bubbles and position in the jars (see right), it is possible to infer the identity of the inducing particle.

Piezo-electric sensors are located around the jars to pick up the expanding bubble sound. This has been shown to help discriminate against alpha-induced events.

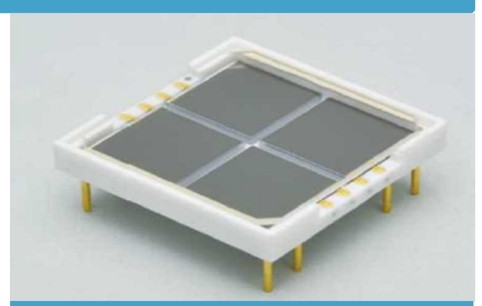
Finally, supercritical scintillators such as liquid argon provide event-by-event energy information that conventional bubble chambers lack. The scintillation channel has also shown to suppress bubble creation.



SBC-LAr10 under construction at Fermilab

## VUV4 Hamamatsu Quads

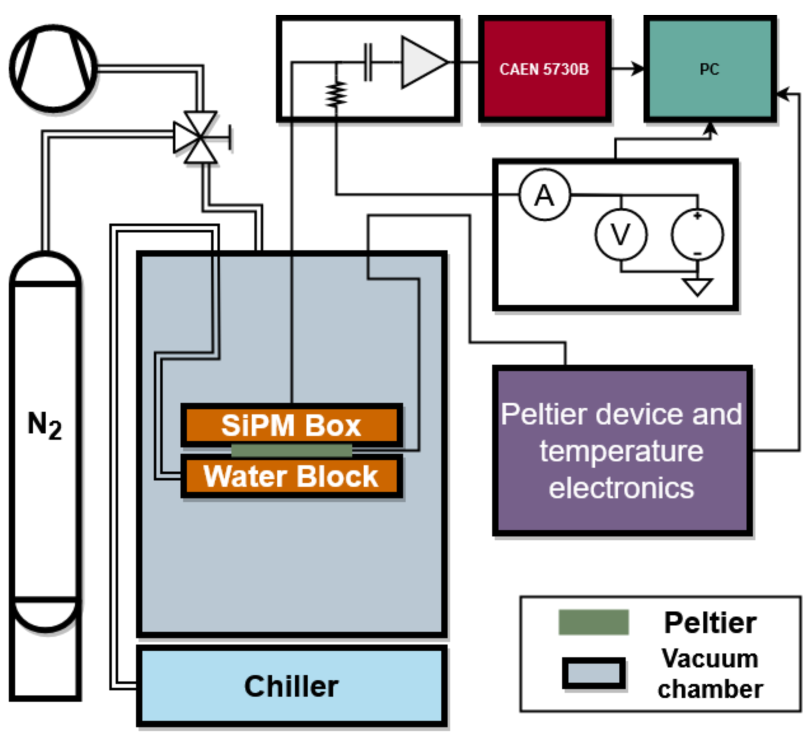
- 4 cells (SiPMs) in 1 quad
- Effective photosensitive area: 34.8mm^2 per cell
- Breakdown voltage expected region $53 \pm 5$V
- Expected 30% quantum efficiency at 170nm which is the xenon scintillation wavelength.
- For more information see [2]



Picture by Hamamatsu

## SBC-Queen's SiPM Characterization Chamber

- Peltier-based temperature control system.
- A final $\pm$0.2K temperature uncertainty dominated by systematics.
- Test up to two SiPMs simultaneously using a HDPE block to block external optical cross-talk.
- Vacuum flushed with nitrogen to avoid oxide build up that can potentially reduce photon detection efficiency.
- 200,000 waveforms were collected for each cell in a VUV4 quad, at 233.15K and 253.15K, and over-voltages from 2V to 8V in steps of 1V.



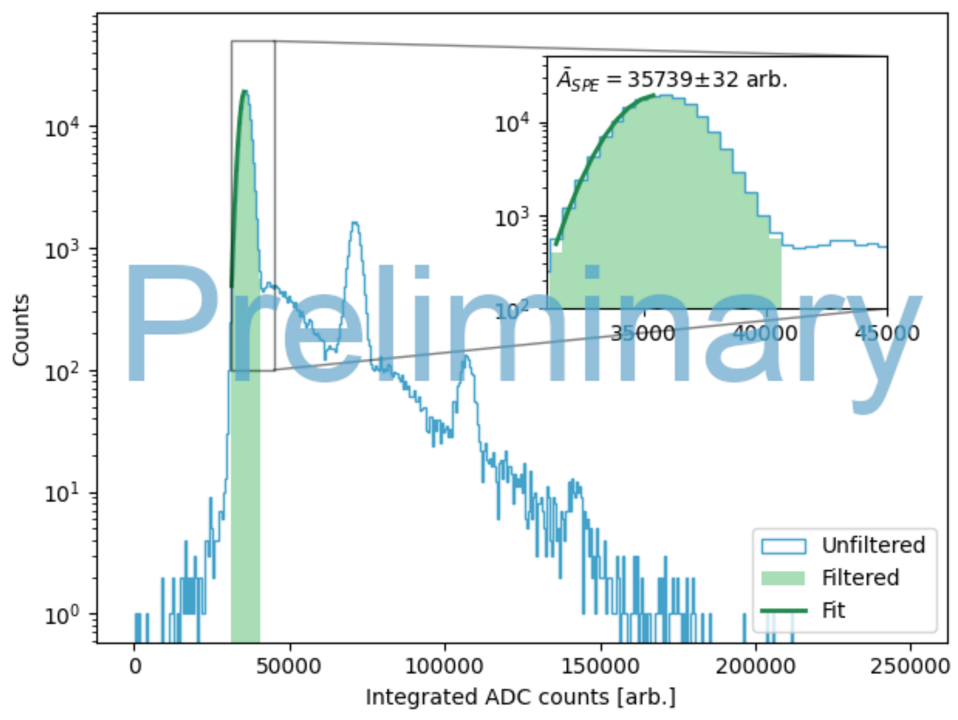

## Analysis

The first step is to extract SPE waveforms required to determine the $A_{SPE}$ and $V_{BD}$ [3]. After the removal of abnormal waveforms, charges are obtained by summing the waveform counts of the first pulse. Then, DBSCAN (a clustering algorithm) is used to extract the SPE waveforms.

Afterwards, the $A_{SPE}$ is estimated from a Gaussian bell fit to the left side of the potential SPE waveforms. Using only the left side helps mitigate the bias effect of CAs. Then, $V_{BD}$ is calculated from a linear fit of gain vs voltage using all the voltage data for one cell at each temperature.

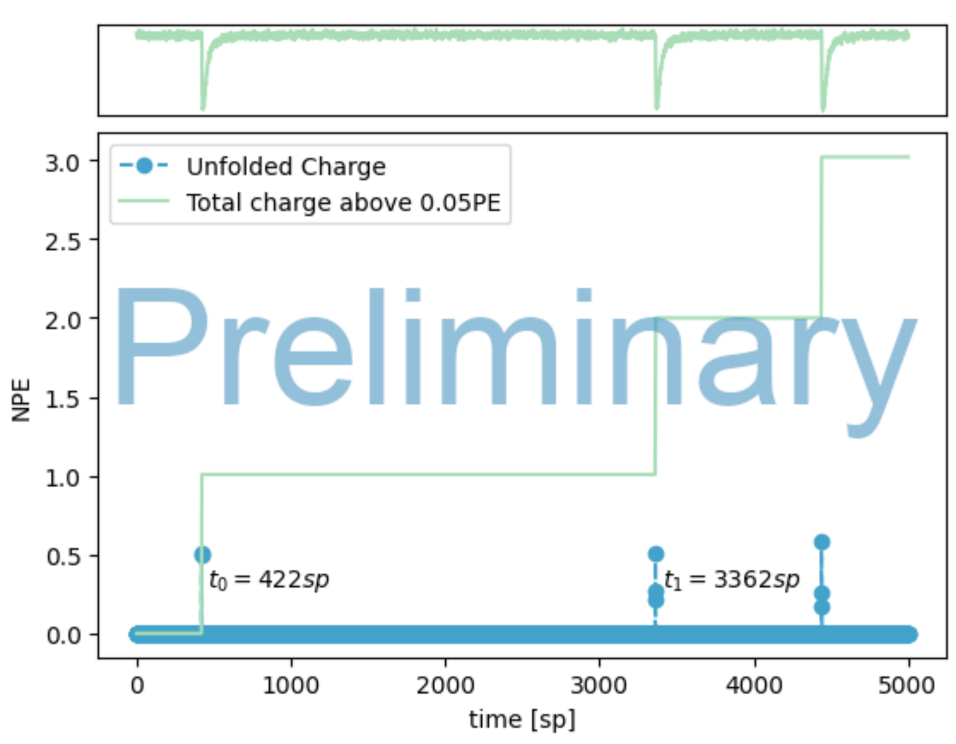
Finally, a sample of SPE waveforms is used to calculate an average SPE waveform necessary for the upcoming step.

The next step is to find all the pulse instances. This process is called waveform unfolding. The method employed for this analysis uses a modification of the charge-fitting algorithm from [4] using the average SPE waveform as the function template instead of a pulse response function.

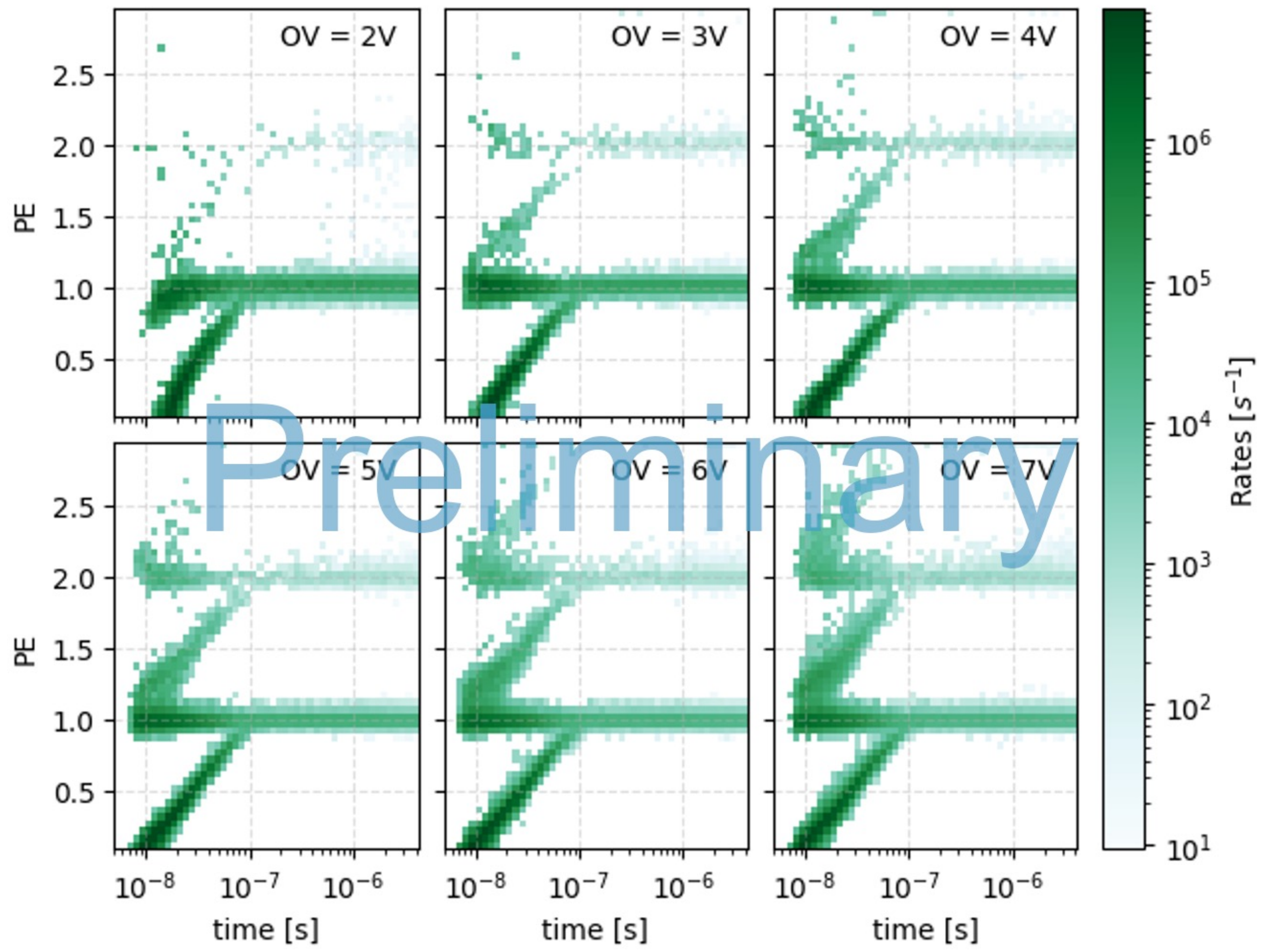



An example "finger plot" is shown above from SiPM 200, cell 1, 253.15K at OV of 4V. The shaded region indicates the potential SPE waveforms from DBSCAN.

**The graph on the right shows an example of the unfolding of a waveform with 3 pulses showing the potential of extracting all the pulses with their charges and times. With a collection of these times and charges it is possible to estimate $N_{CA}$, and $\mu$.**




## Analysis (cont.)



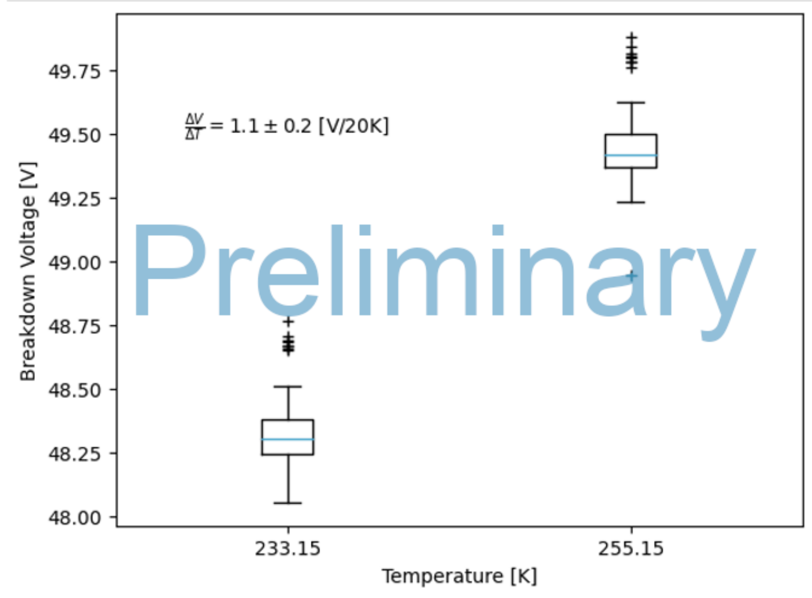

Using the time difference between the first and second pulses, and the charge of the second pulse, the histograms shown above are built. After "unshadowing" the histogram, $\mu$ and $N_{CA}$ can be calculated for each OV and temperature.

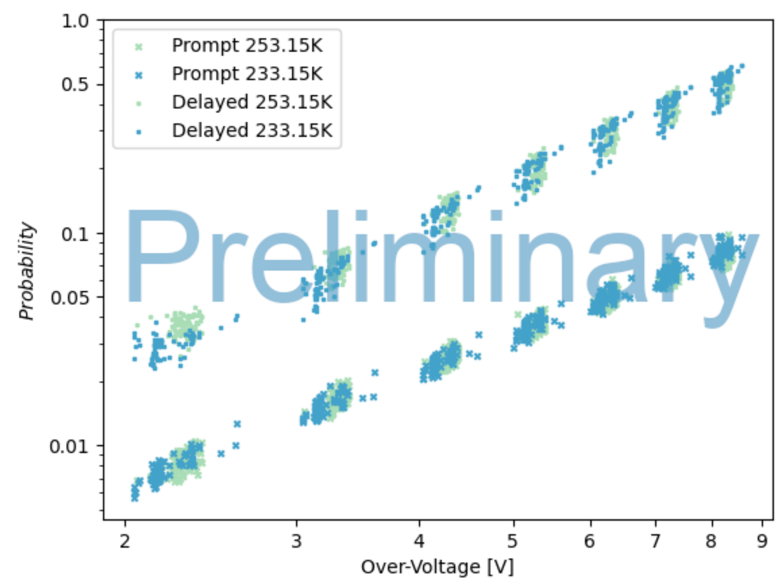
The shadowed histograms show that as the over voltage increases, the number of PEs increases as well. Any pulses with an apparent charge less than 1PE are after-pulsing CAs, anything above 1PE are combinations of different types of CAs. Also, any pulse that appears after 100ns are usually dark noise pulses.

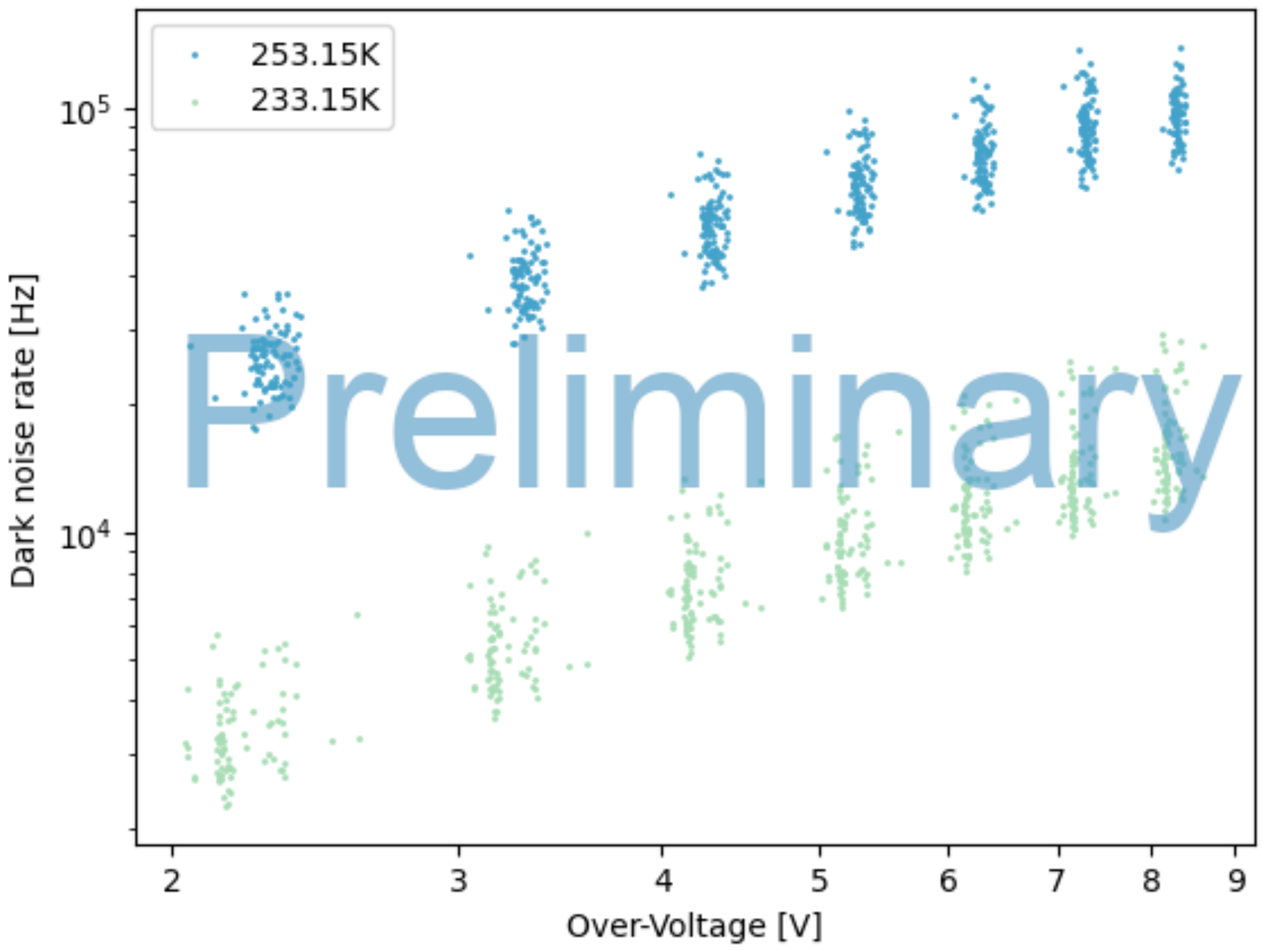
## Results (Preliminary)

The $V_{BD}$ are shown in the plot on the top left for both test temperatures across all VUV4 cells. Outliers are VUV4 quads obtained at a later date from Hamamatsu.

Preliminary results are shown for $\mu$ and the probability of delayed and prompt types of CAs are also shown below.




### Conclusions

Characterizing $V_{BD}$, $\mu$, and $N_{CA}$ have their own challenges and complications. For the case of breakdown voltages, the analysis suggests that the spread is dominated by systematics such as artefacts in the linear fit. For $\mu$ and $N_{CA}$, the analysis is too incomplete to suggest if the spread is coming from the analysis or the manufacturer. In the future, a more extensive study of the analysis will be conducted using monte carlo data. However, the lack of outliers (with the exception of one cell in one SiPM) shows that quality control batch-to-batch of Hamamatsu VUV4 is reliable and predictable for $V_{BD}$ and $A_{SPE}$.

**A complete analysis and results will be presented in an arXiV preprint later this year.**

Citations
[1] Snowmass 2021 Scintillating Bubble Chambers: Liquid-noble Bubble Chambers for Dark Matter and CEvNS Detection, arXiv:2207.12400 [physics.ins-det]
[2] https://hamamatsu.su/files/uploads/pdf/3_mppc/s13370_vuv4-mppc_b_(1).pdf
[3] G. Gallina et al, Characterization of the Hamamatsu VUV4 MPPCs for nEXO, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. **940** (2019) 371–379
[4] J.H. Peterson and on behalf of the IceCube Collaboration, JINST, 16 (2021)