

2026/04/17

# PICO-40L Wall Event Acoustics

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Parker Pigeon (He/Him)



# PICO-40L

# What is it?

- Bubble chamber targeting nuclear recoil interactions with WIMPs
- Superheated freon in the target volume
- Bubble detection via cameras, dytran, piezos, etc.

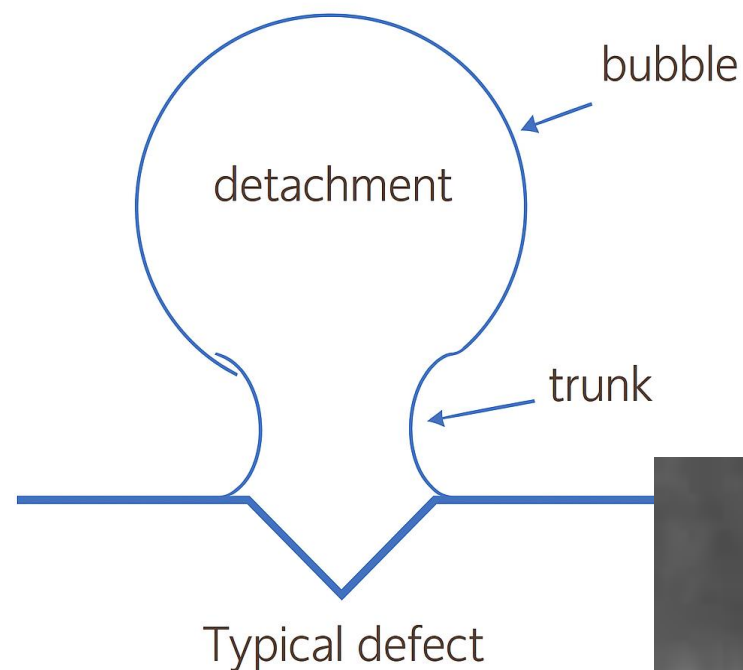


# Wall Events

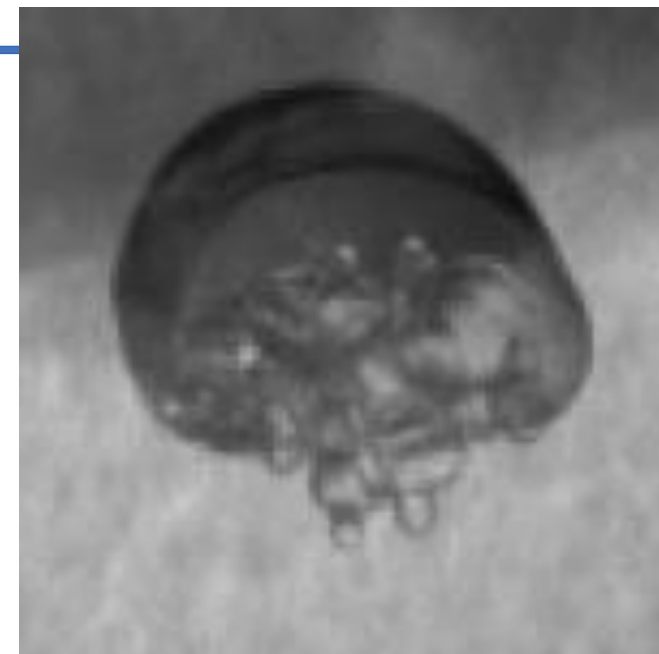
- Background events
- Alphas interacting close to the outer jar
- Two types:
  - Pool
  - Film

# Pool Boiling

- Defect acts as nucleation site for bubble
- Detaches from the trunk at some critical size
- Trunk can pulsate and form a stream of bubbles

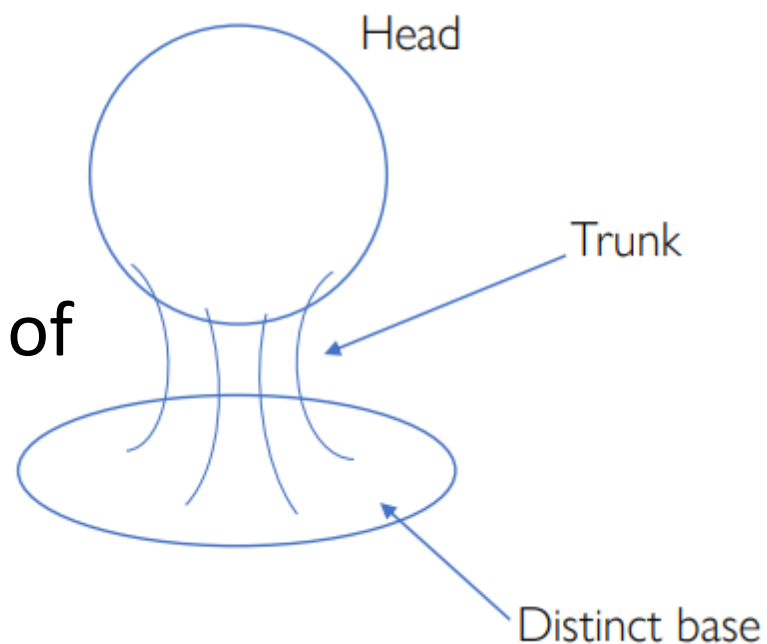


[Wall Boiling, Alexandre Leblanc 2023]

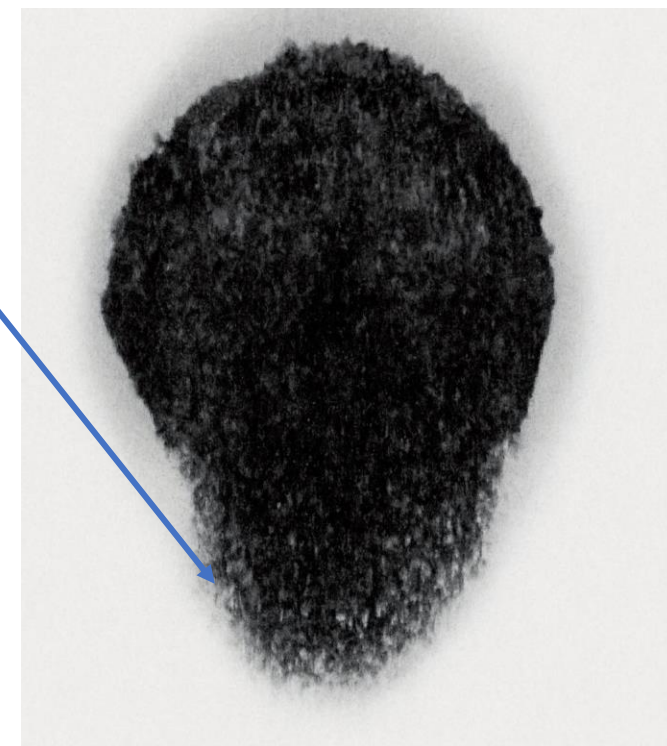


# Film Boiling

- Bubble encounters film of vapour near the wall
- Develops distinct base structure
- Forms an unstable interface as the bubble grows rapidly



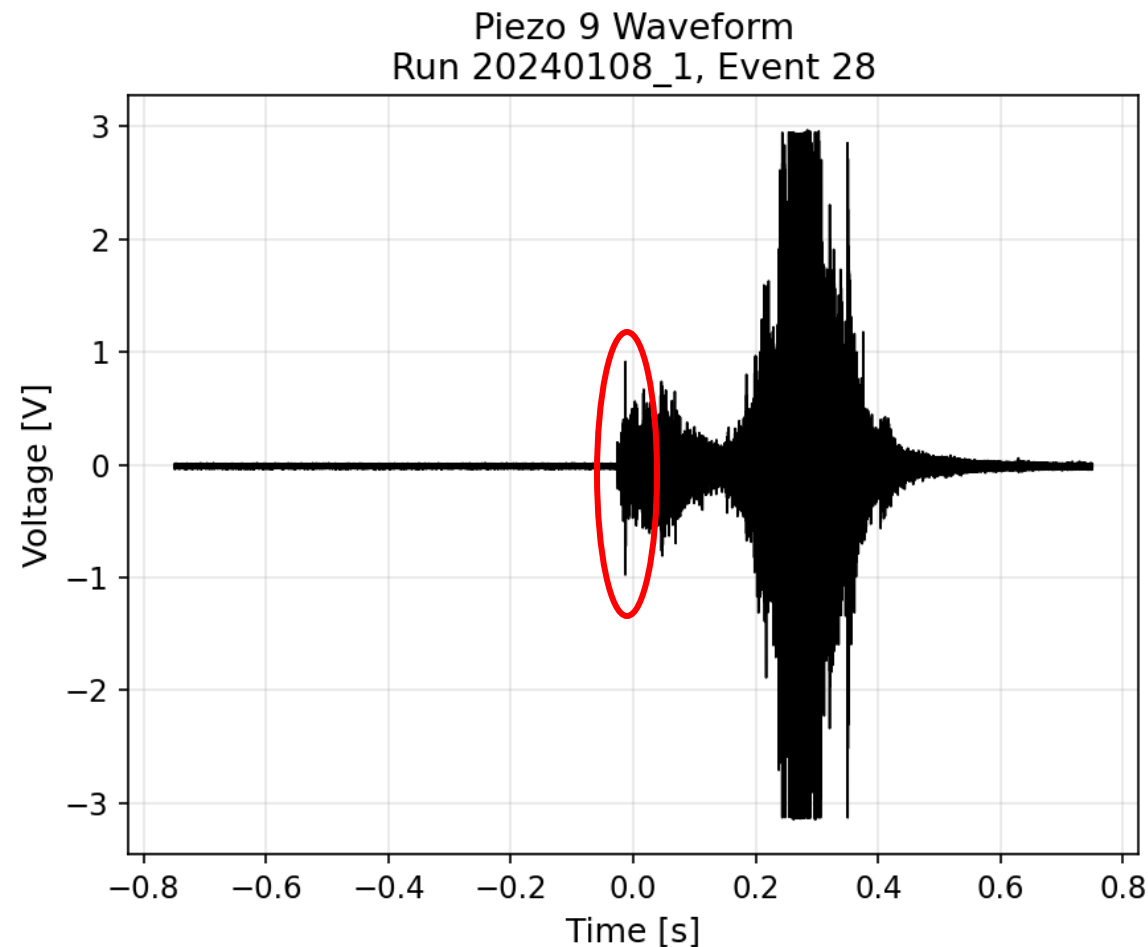
[Wall Boiling, Alexandre Leblanc 2023]



# Wall Event Acoustics

# Acoustic Signal

- Tracked by several piezos in various locations around the detector
- Recorded as a measure of time and voltage
- Only a small part of the signal is from the bubble

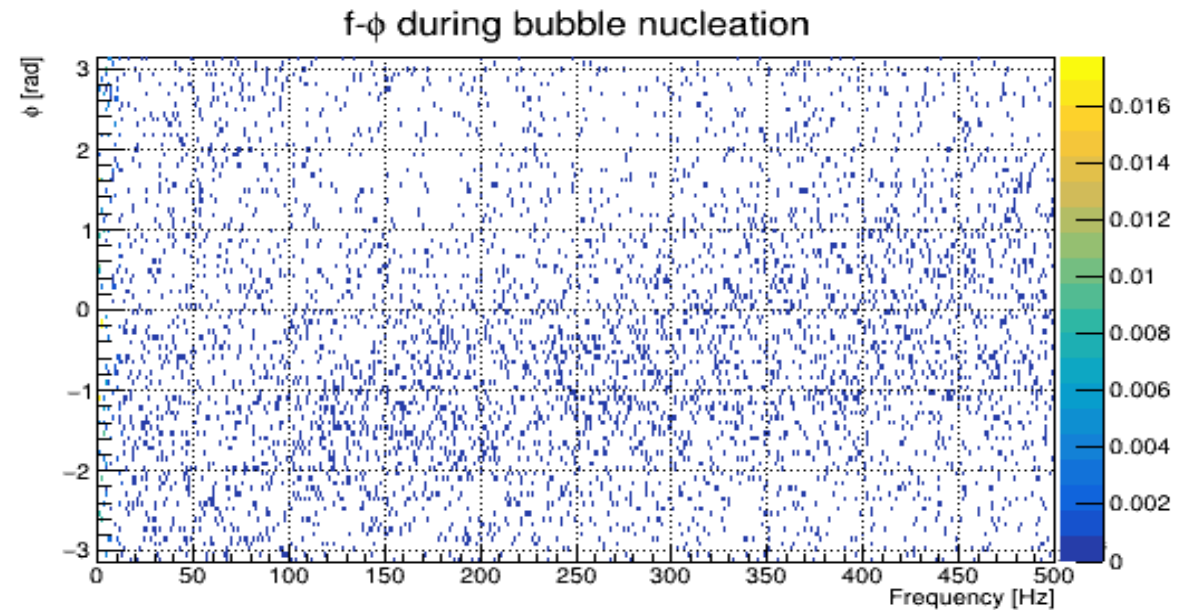
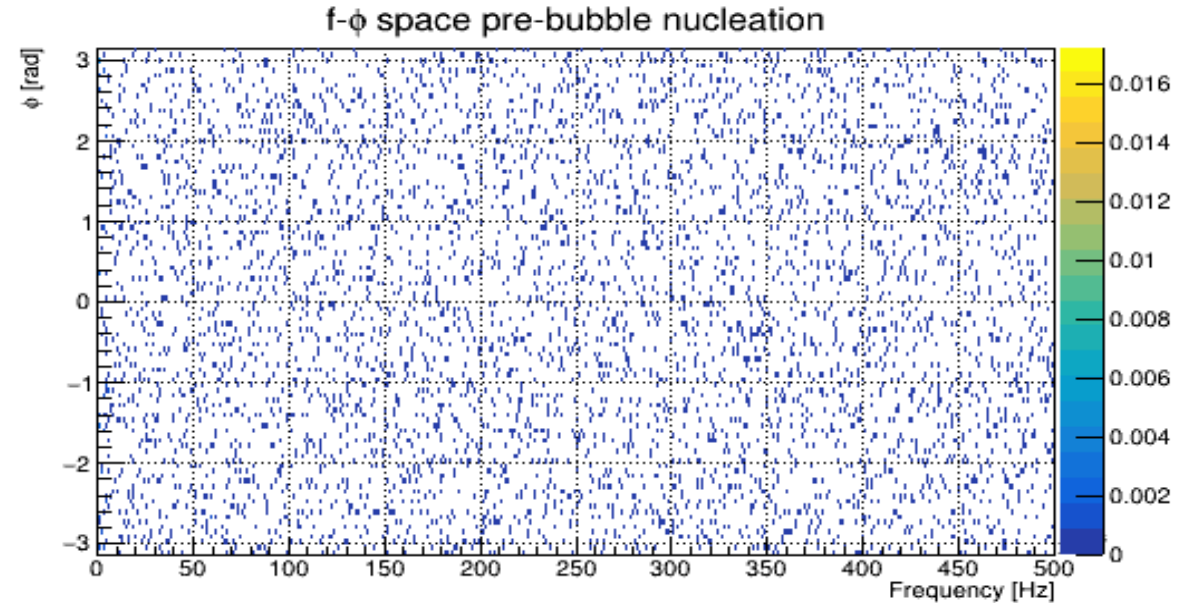


# Fourier Transform

Apply the FFT (NumPy implementation)

$$A = \sum_{m=0}^{n-1} a_m \exp\left(-2\pi i \frac{mk}{n}\right)$$

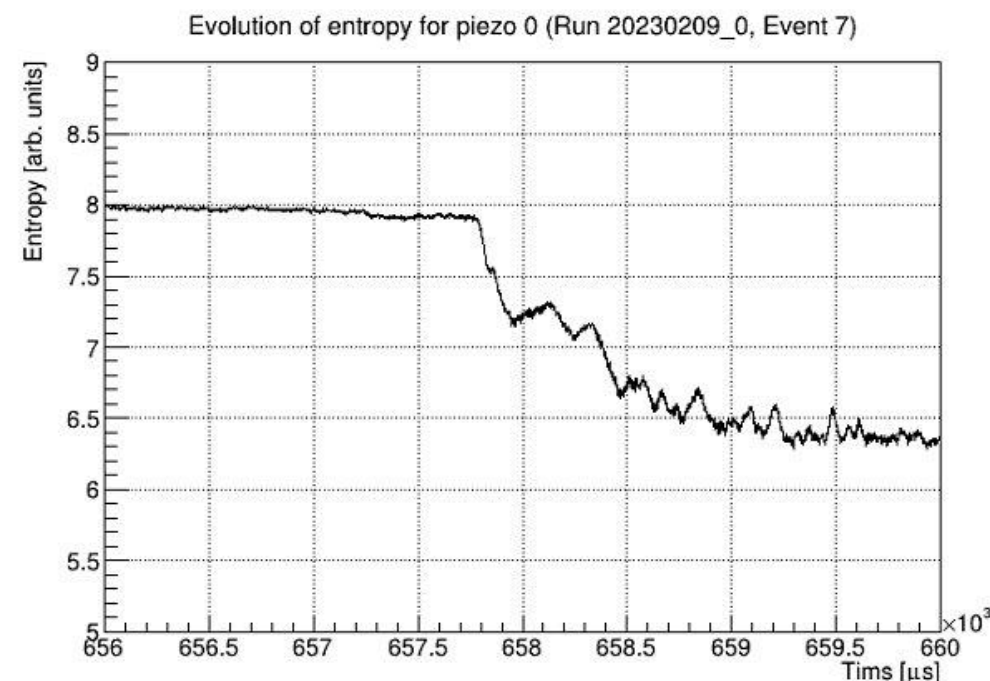
- *Frequency-phase* space appears disperse at baseline
- Bands form during bubble nucleation



# Acoustic Entropy

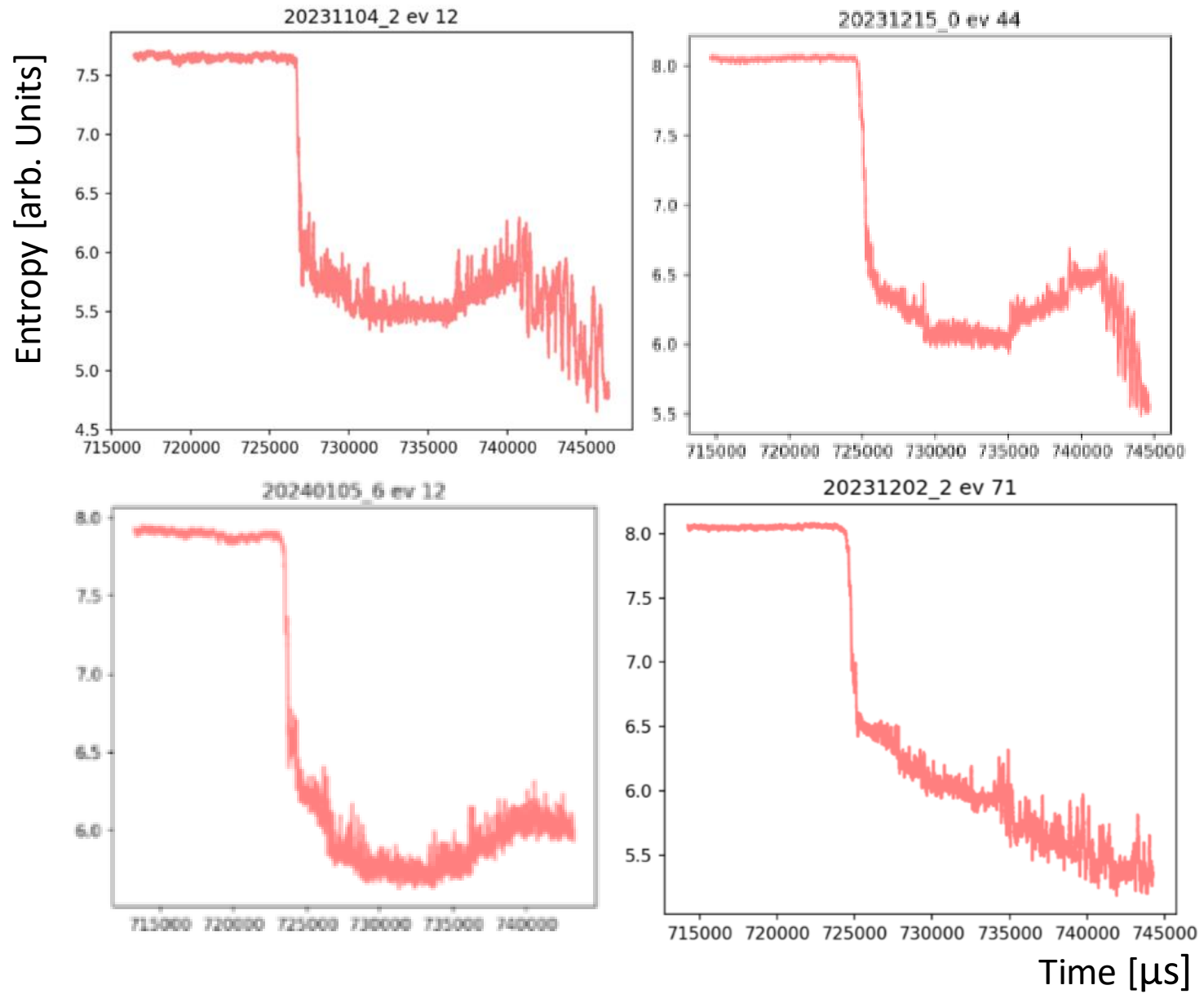
- Shannon Entropy quantifies the degree to which the frequency space is non-uniform
- Does the entropy evolve similarly for different event types?

$$S = - \sum_{i=0}^n \sum_{j=0}^m p(x_i, y_j) \log(p(x_i, y_j))$$

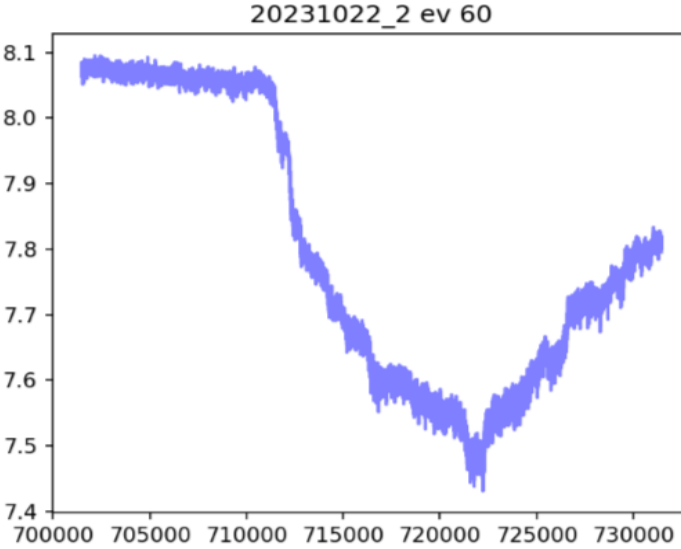
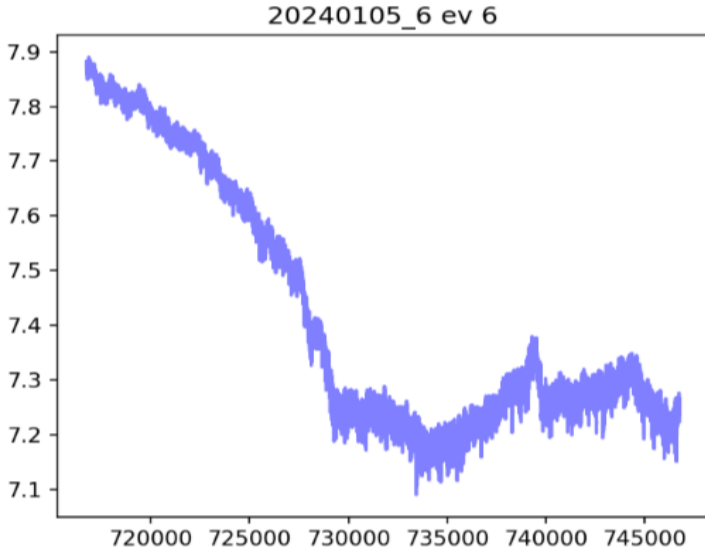
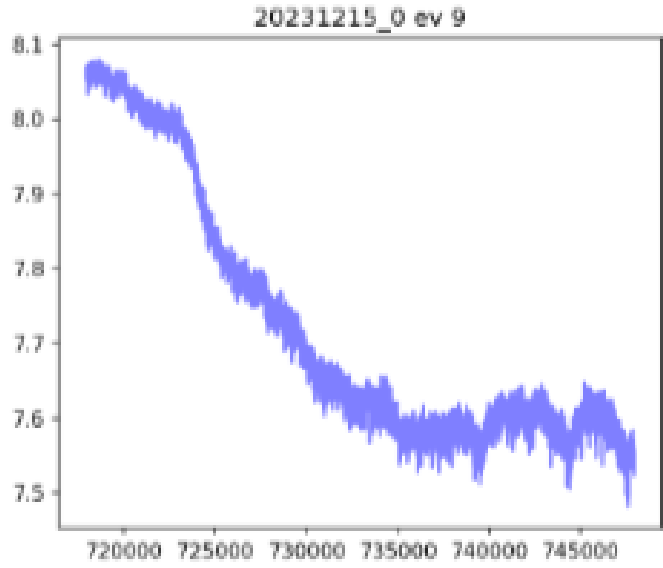
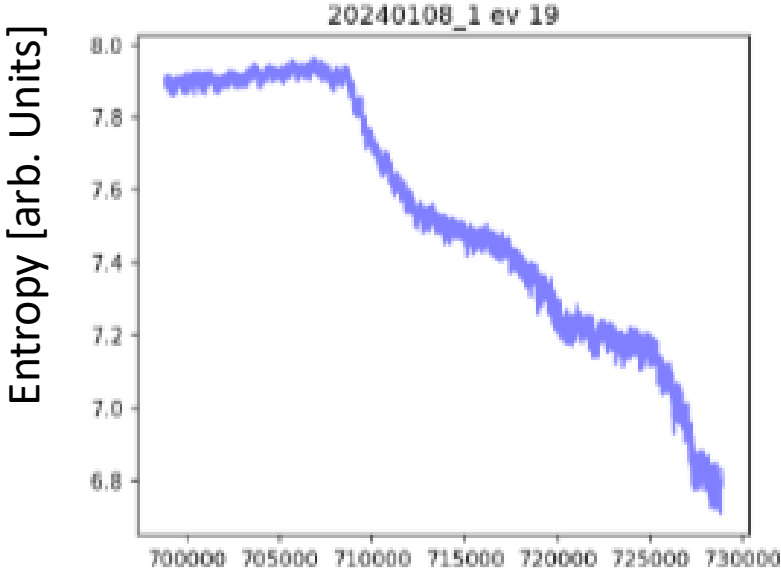


[Remington Hill]

# Film Boiling

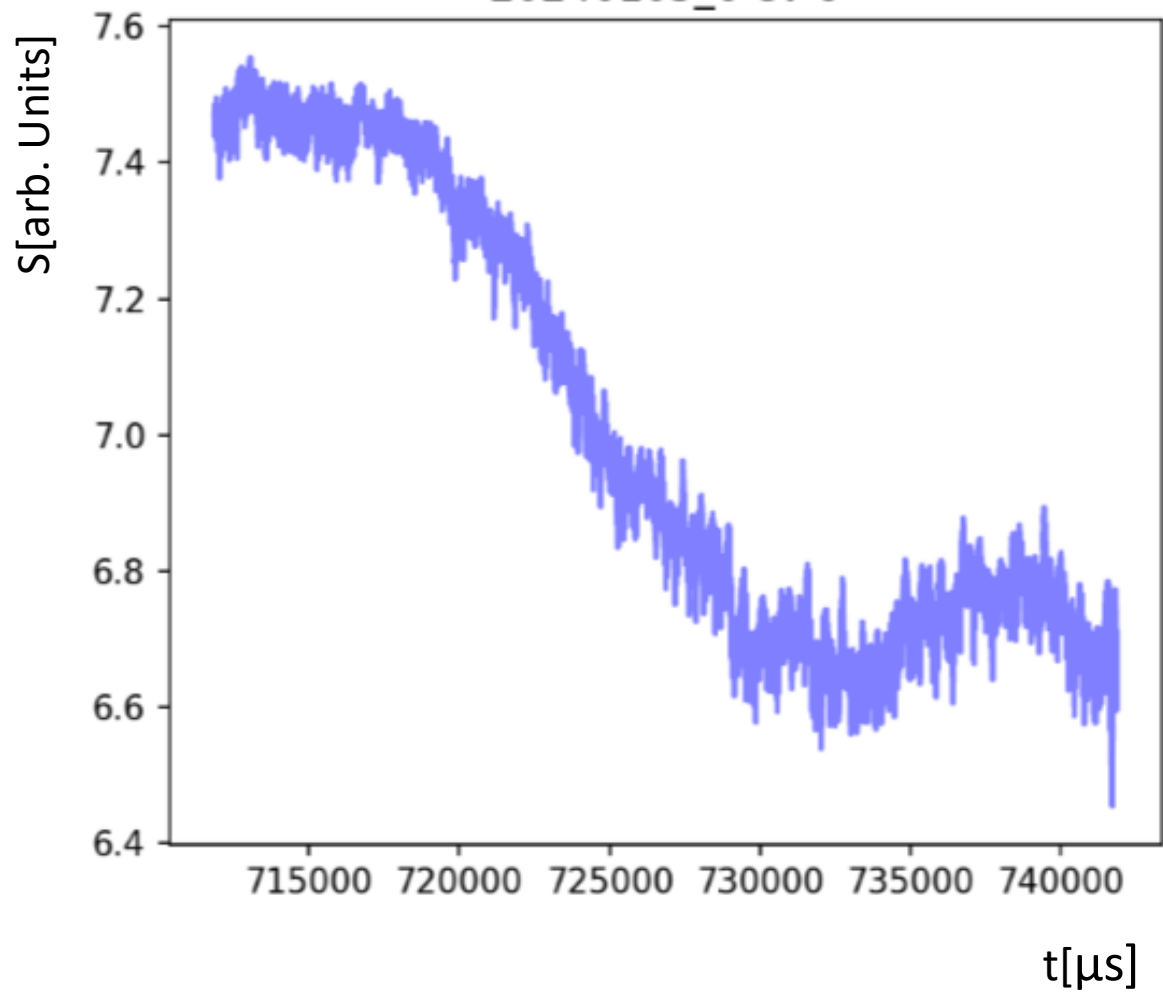


# Pool Boiling

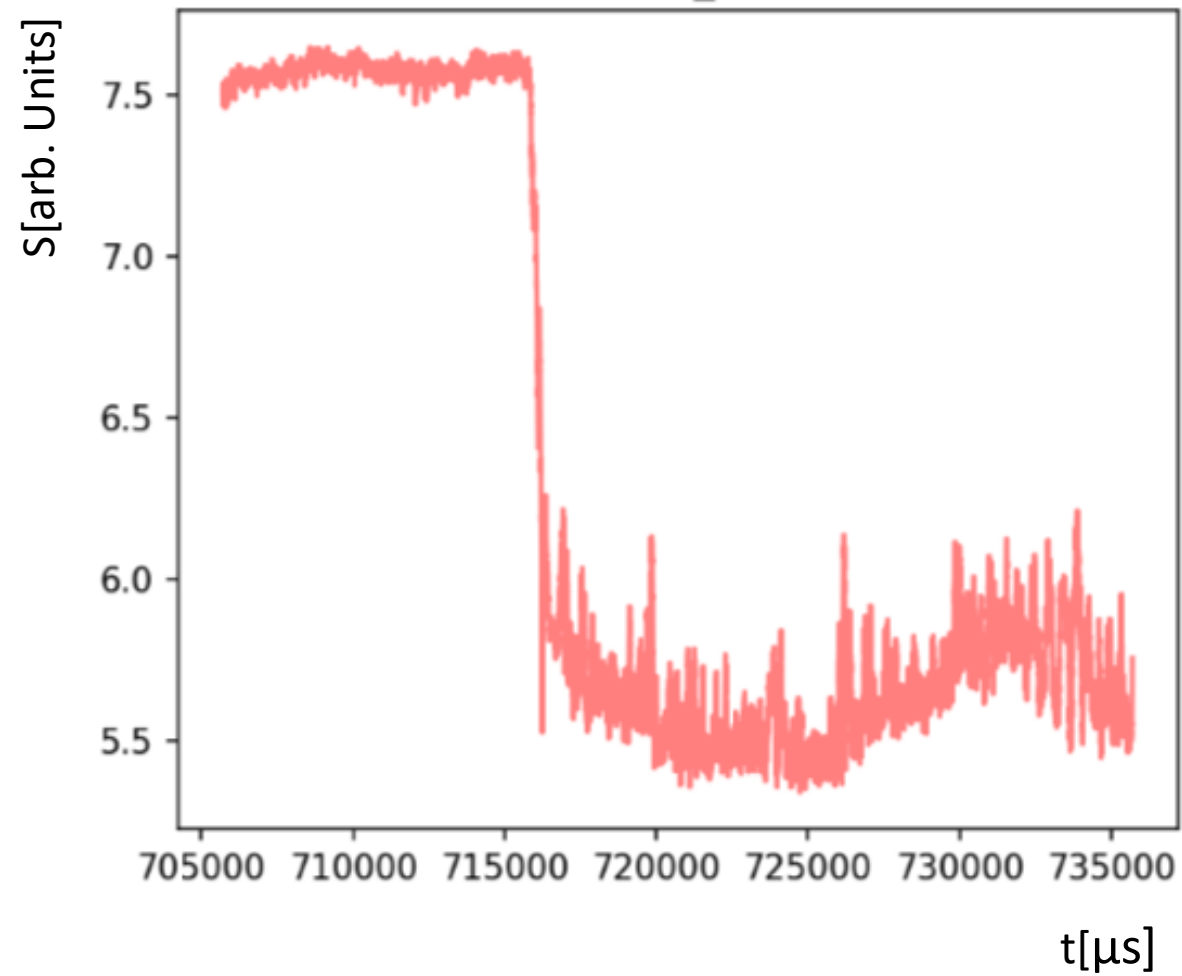


Time [μs]

20240105\_6 ev 6



20231202\_2 ev 57

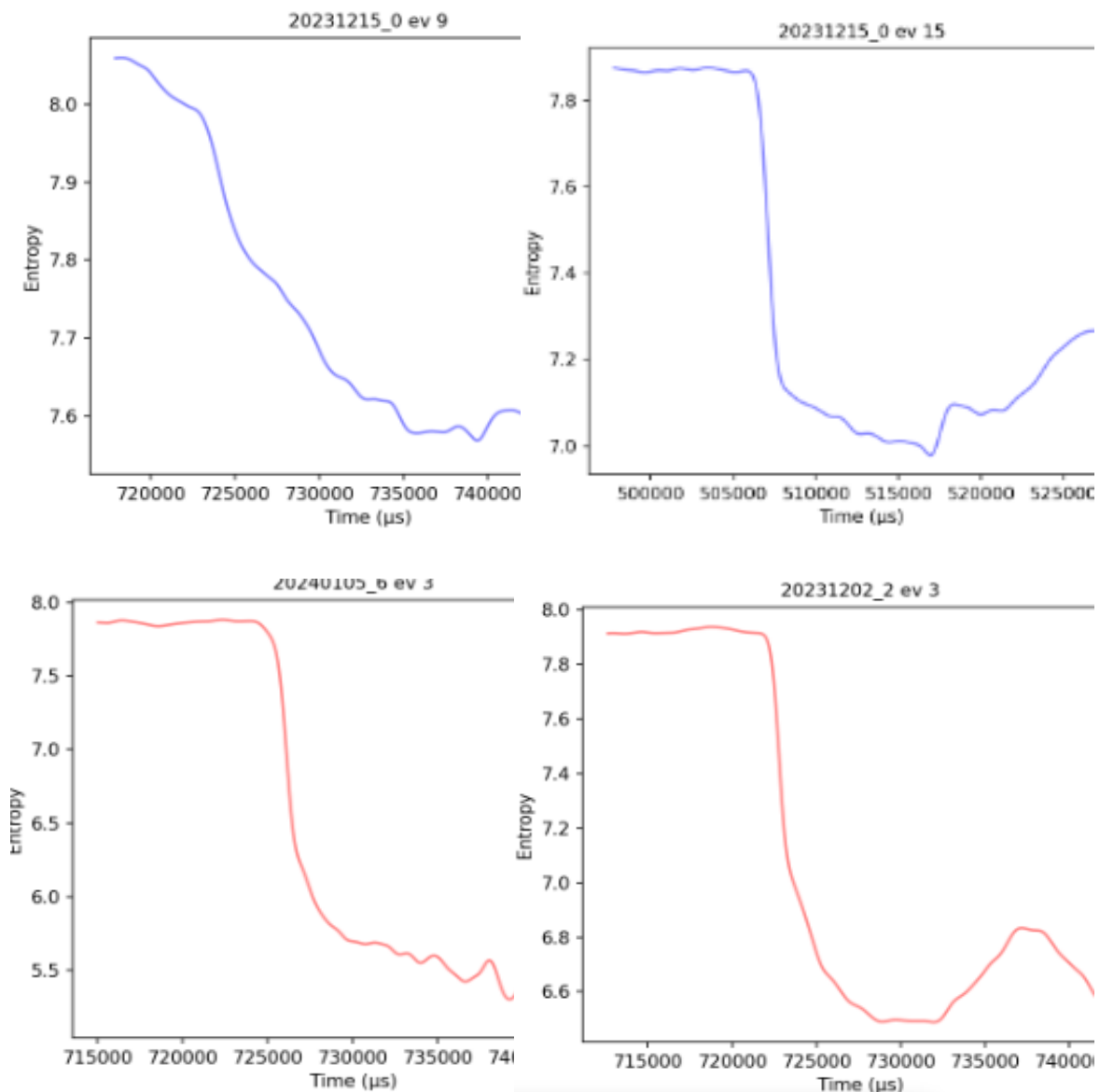


# Are these differences consistent over many events?

- Use rate of change in entropy to compare pool versus film events

# Smoothing

- Taking derivative requires smoothing
  - Gaussian kernel regression
  - Bandwidth (h)

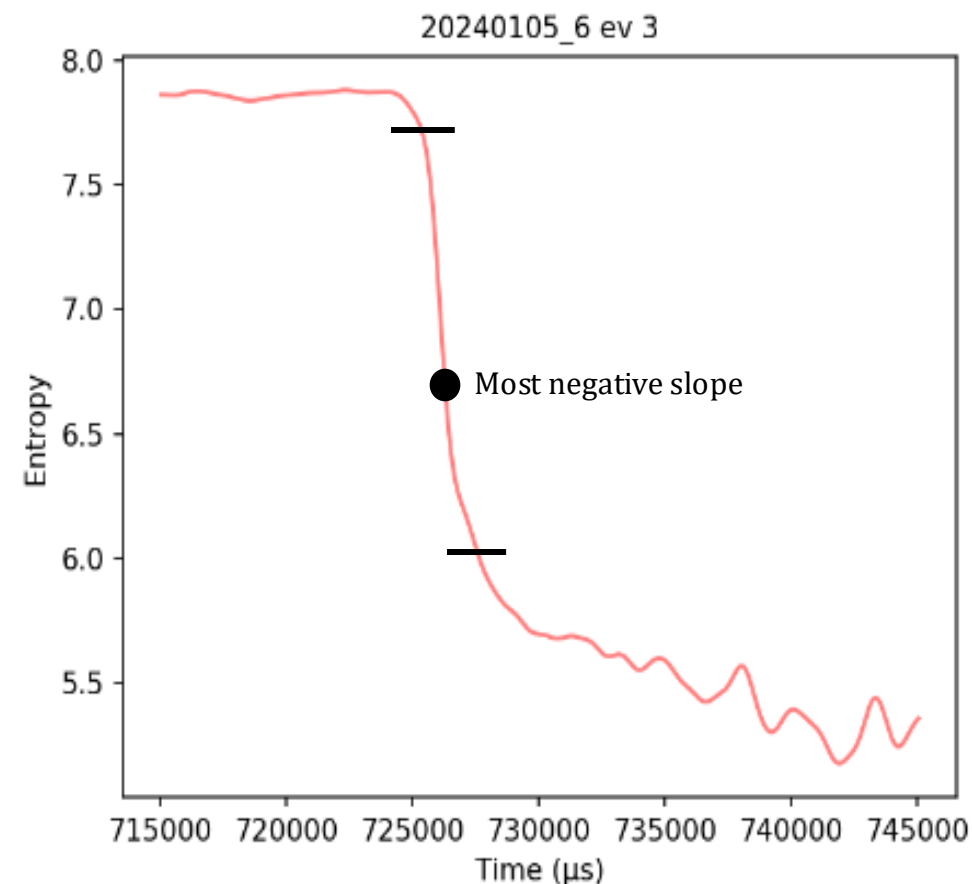


$$K_h(x) \propto \exp\left(-\frac{1}{2}\left(\frac{x}{h}\right)^2\right)$$

$$\hat{s}(t_0) = \frac{\sum_{j=1}^n K_h(t_0 - t_j) s_j}{\sum_{j=1}^n K_h(t_0 - t_j)}$$

# Slope Calculation

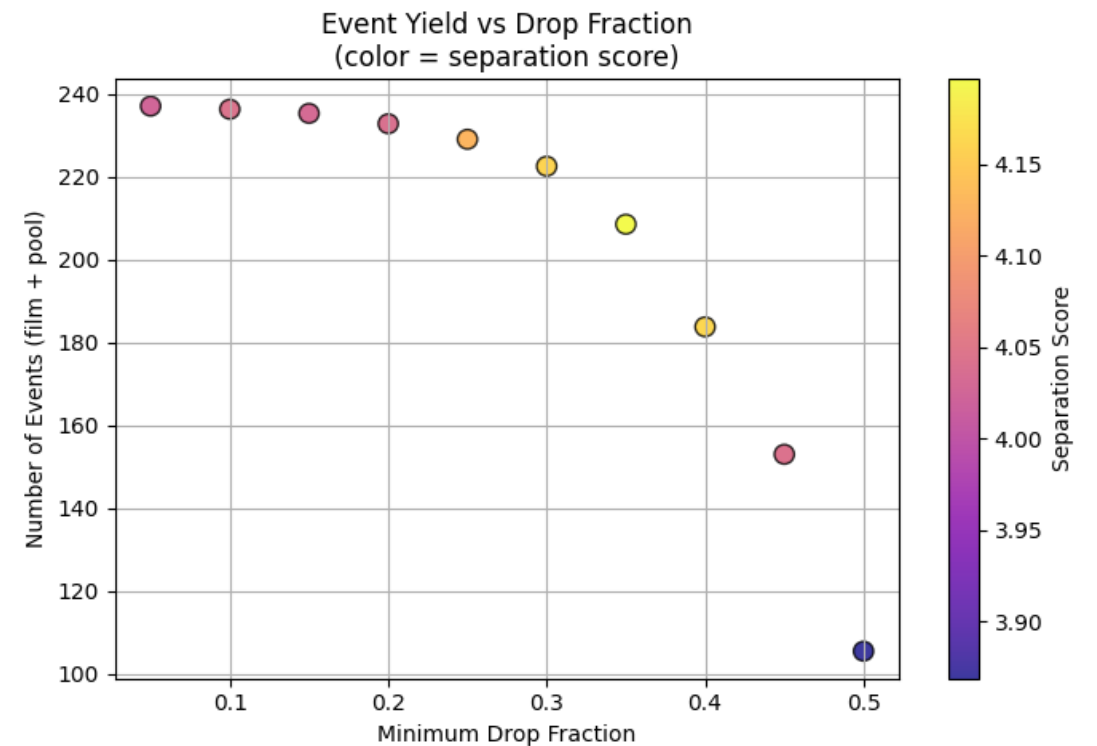
- Compute derivative, detect the minimum
- Build interval outward from minimum such that the derivative does not drop below fractional threshold
- Check to see if interval covers a significant amount of entropy range, and time (not just a tiny spike in the curve)
- Calculate average slope from end points of interval



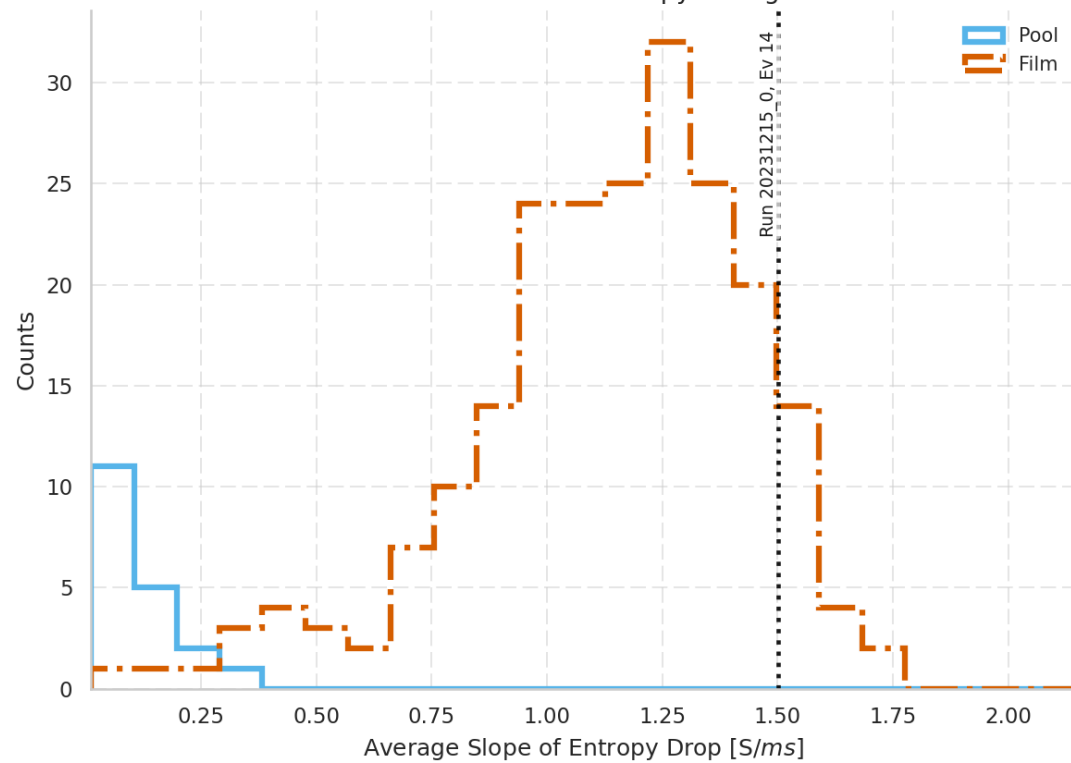
# Optimization



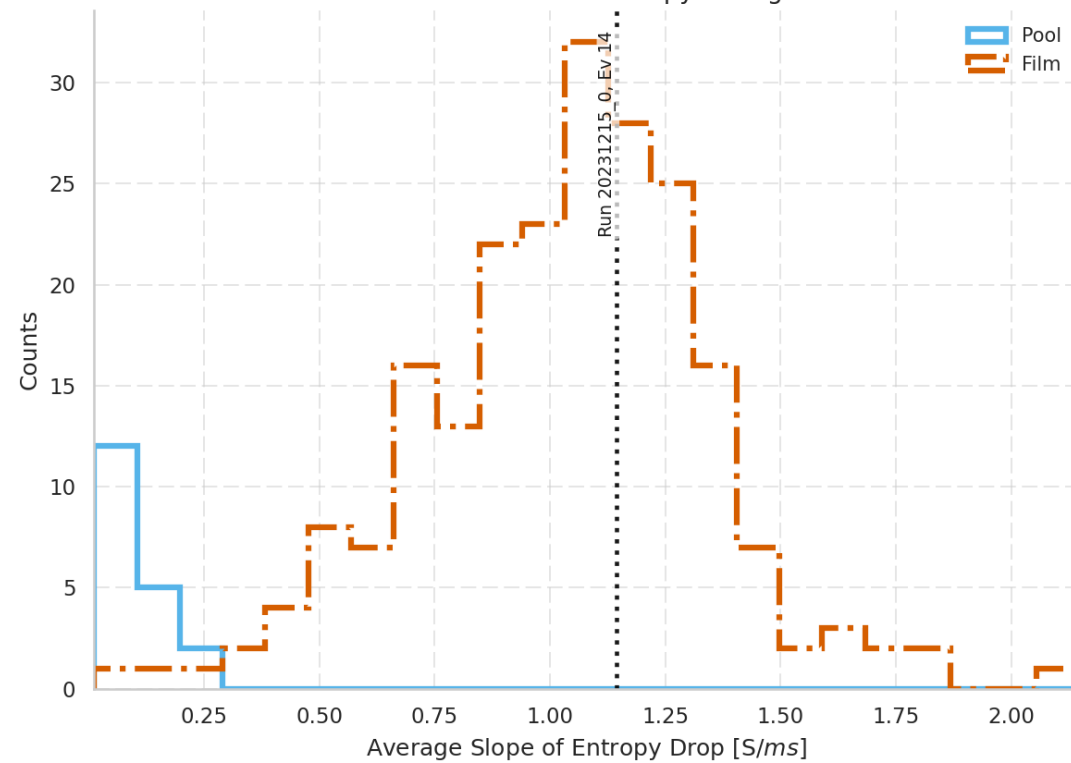
- Test a range of values for each parameter involved in the calculations of the slope
- Assign a score based on the difference in mean relative to the standard deviations
- Maximize score, and number of events accepted



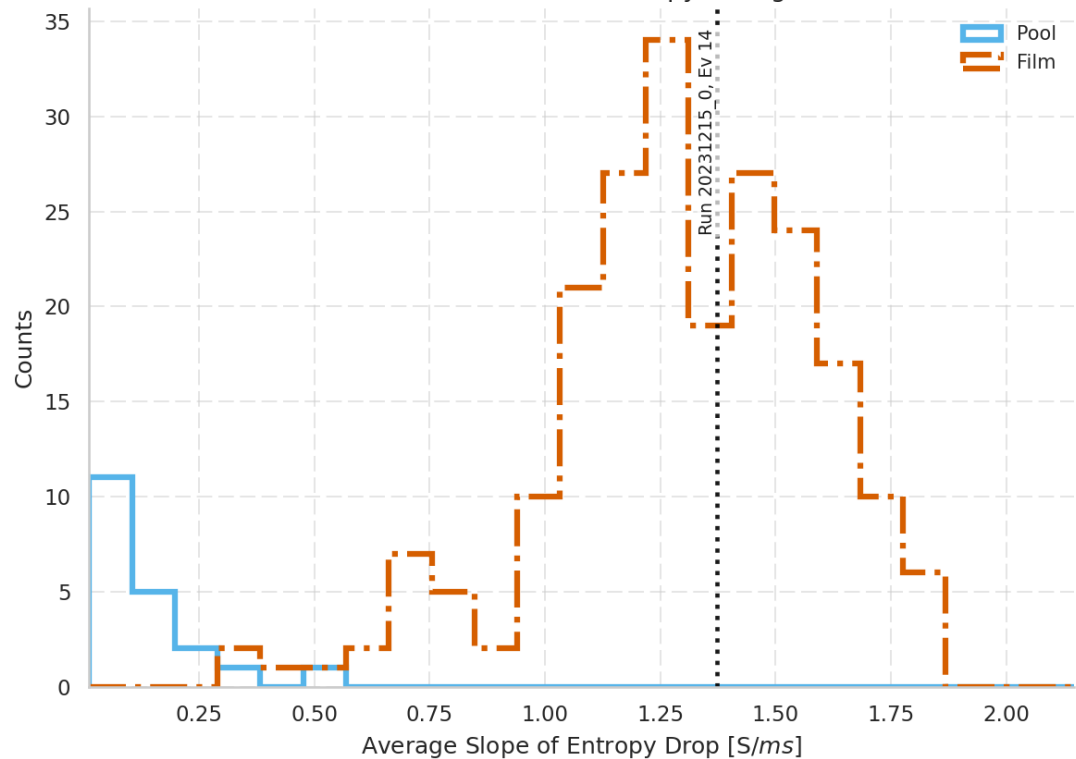
Piezo 0 - Distribution of Entropy Change Rates



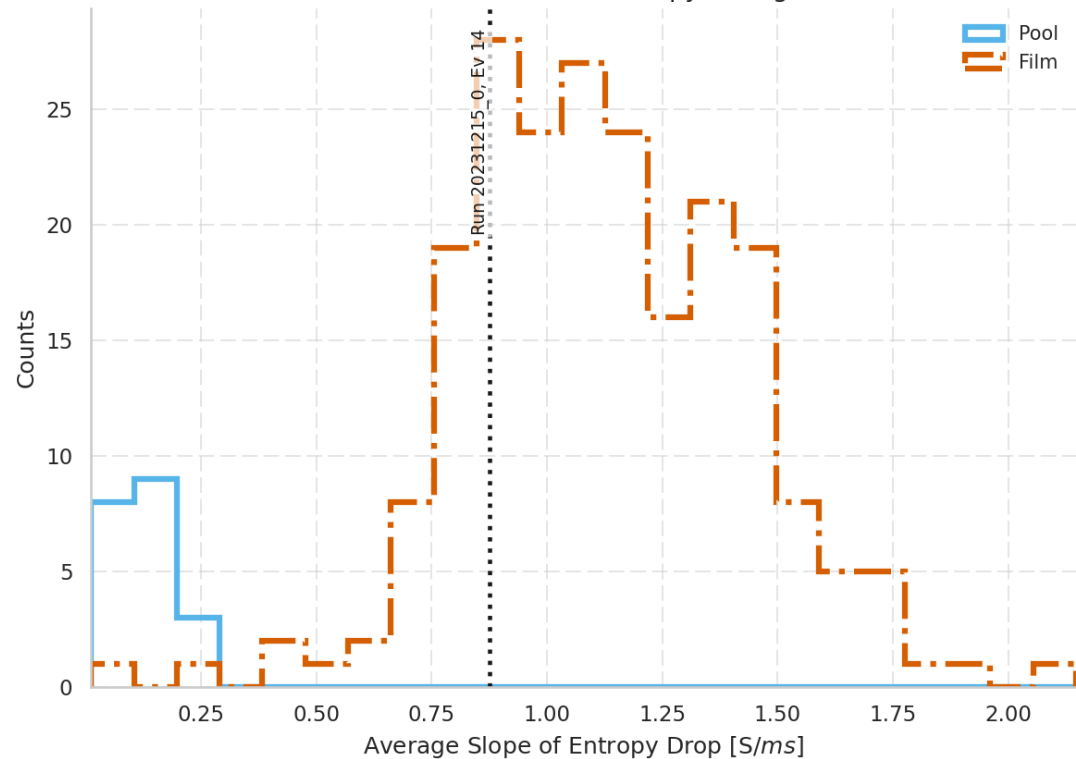
Piezo 9 - Distribution of Entropy Change Rates



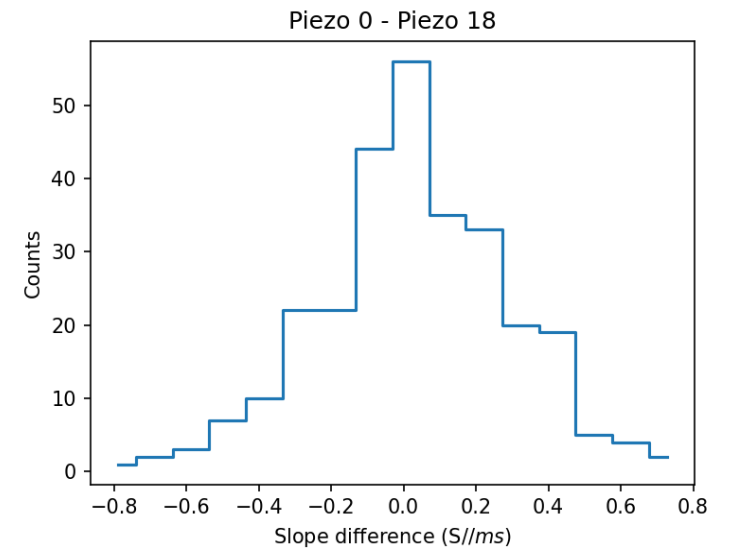
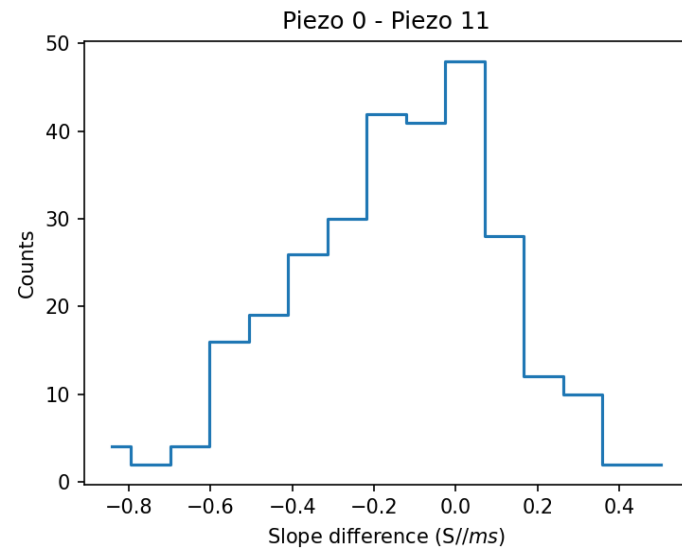
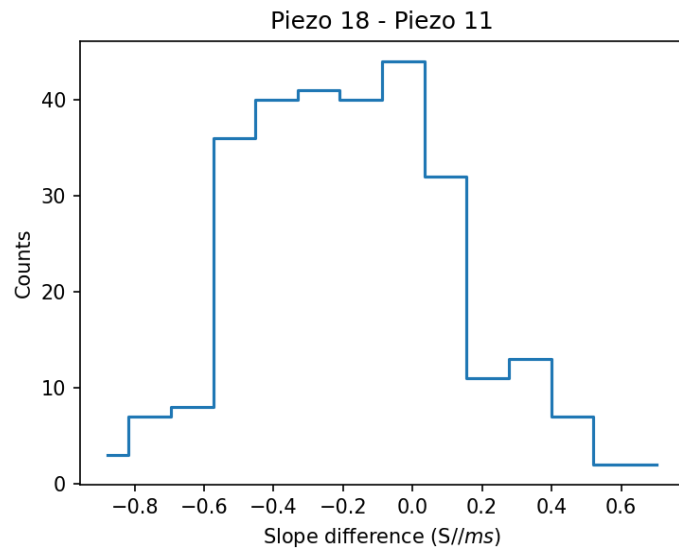
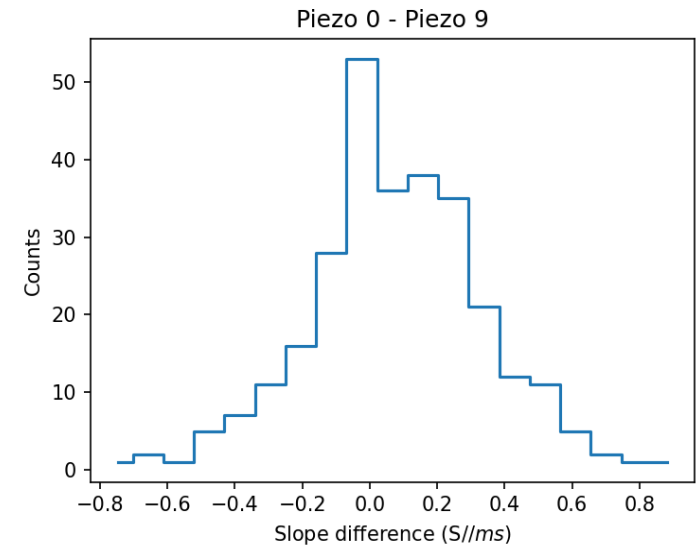
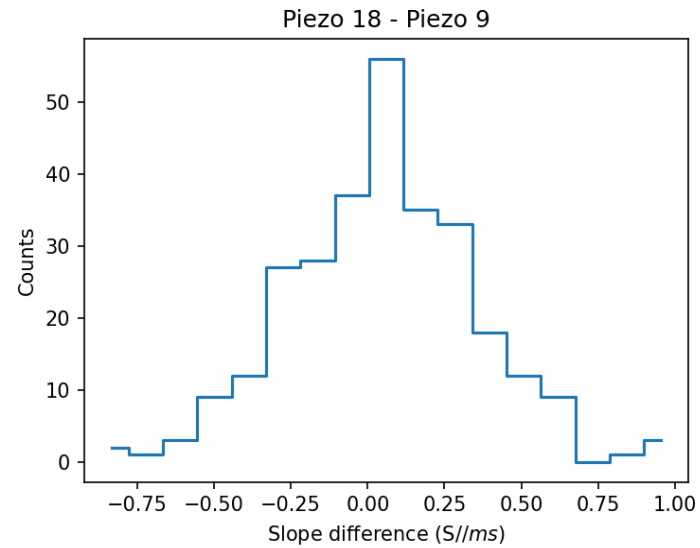
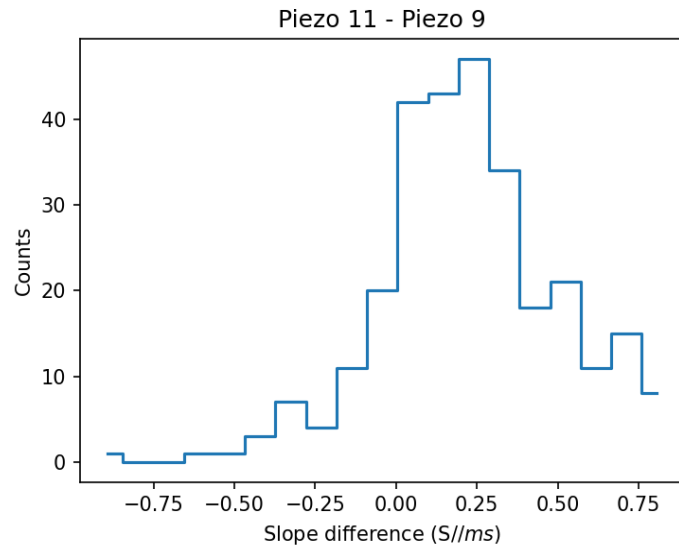
Piezo 11 - Distribution of Entropy Change Rates



Piezo 18 - Distribution of Entropy Change Rates



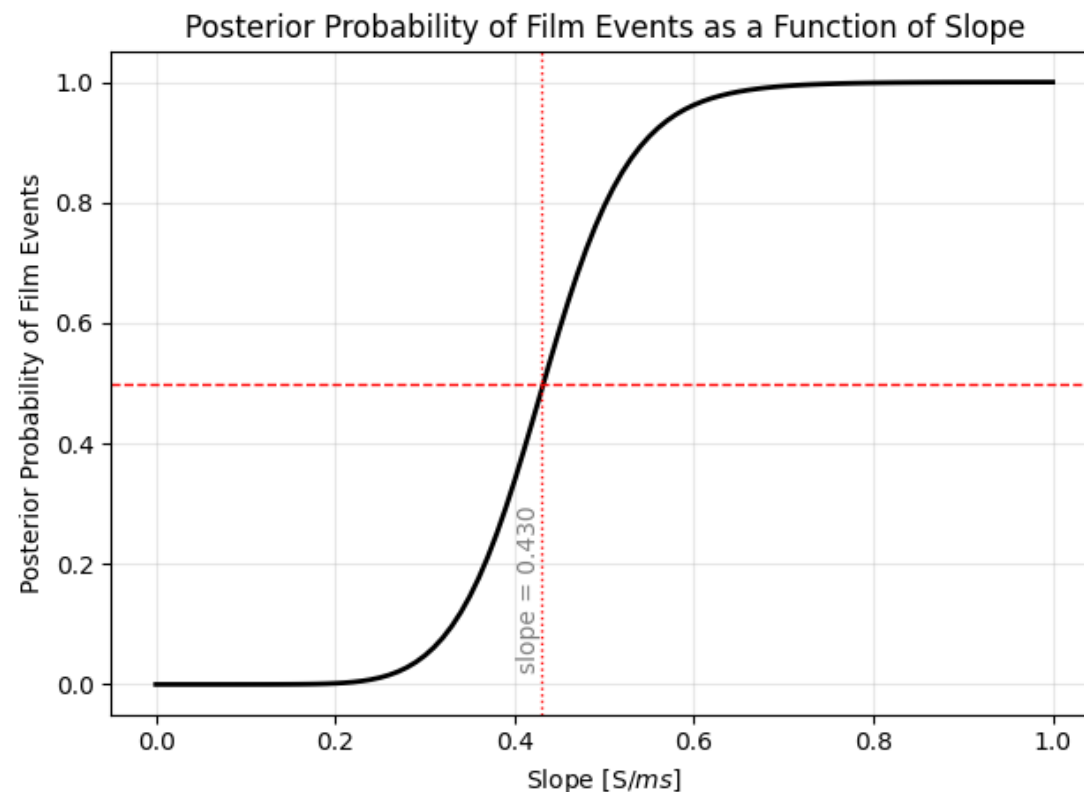
# Slope Differences Between Piezos



# Likelihood Function

- Evaluates entropic slope values to find the probability of the event being Pool or Film
- Value for each piezo, can multiply together to form overall probability

$$\mathcal{L}(x) = \frac{\pi_{\text{film}} f_{\text{film}}(x)}{\pi_{\text{film}} f_{\text{film}}(x) + \pi_{\text{pool}} f_{\text{pool}}(x)}$$



# Results

- PICO will be able to distinguish between the types of wall events easily and effectively
- Can build large datasets for further analysis without tediously hand scanning each individual event



Thank you to the PICO team, and everyone who supported me throughout the term!

- Remington Hill
- Dr. Ian Lawson
- Dr. Stephen Sekula
- Shane Meister
- Paul Grylls
- Christian Gaudreau
- Ashley Mathewson

Thank you! Questions?