

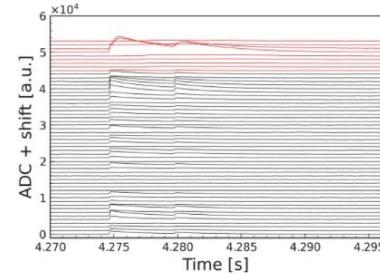
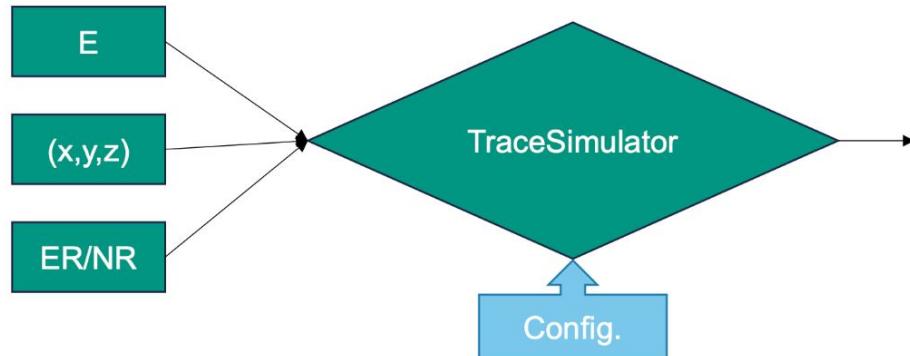
Reconstruction WG

Status Report

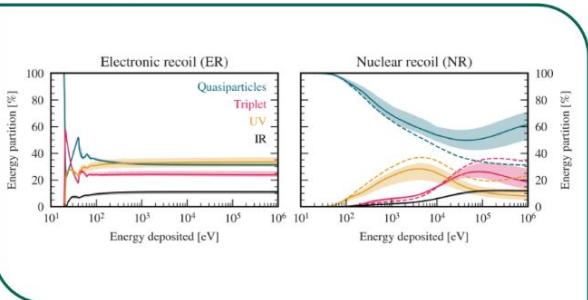
DELight Collaboration Meeting, June 17, 2025

With contributions from Dowling, Eleanor, Francesco, Hristiyan

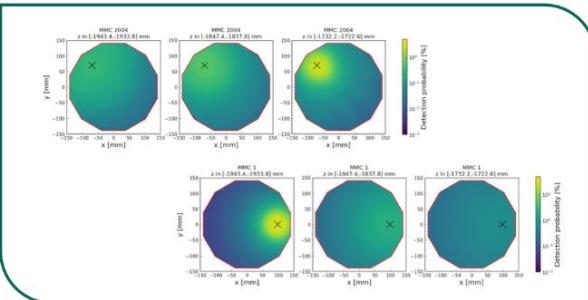
TraceSimulator: the newcomer



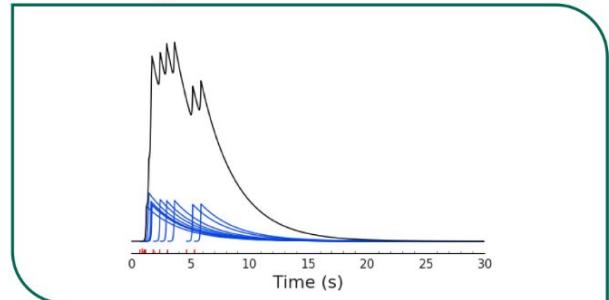
Energy partition



Detector effects

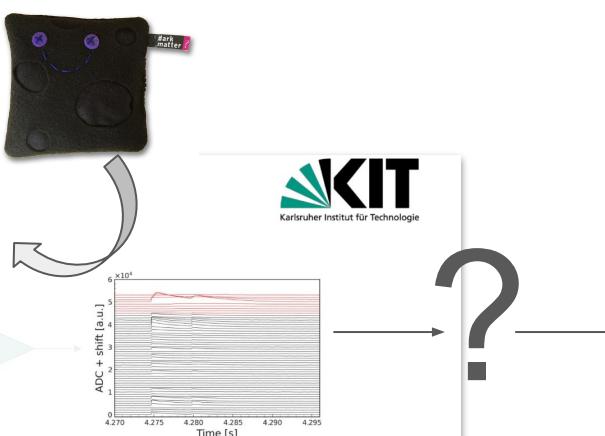
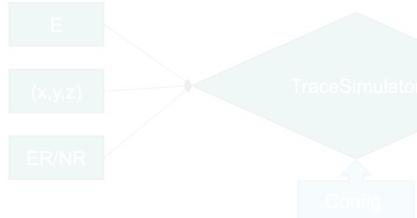


Summing individual contributions



What do we want?

TraceSimulator: the newcomer



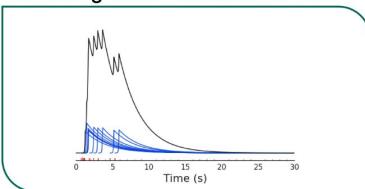
Energy partition



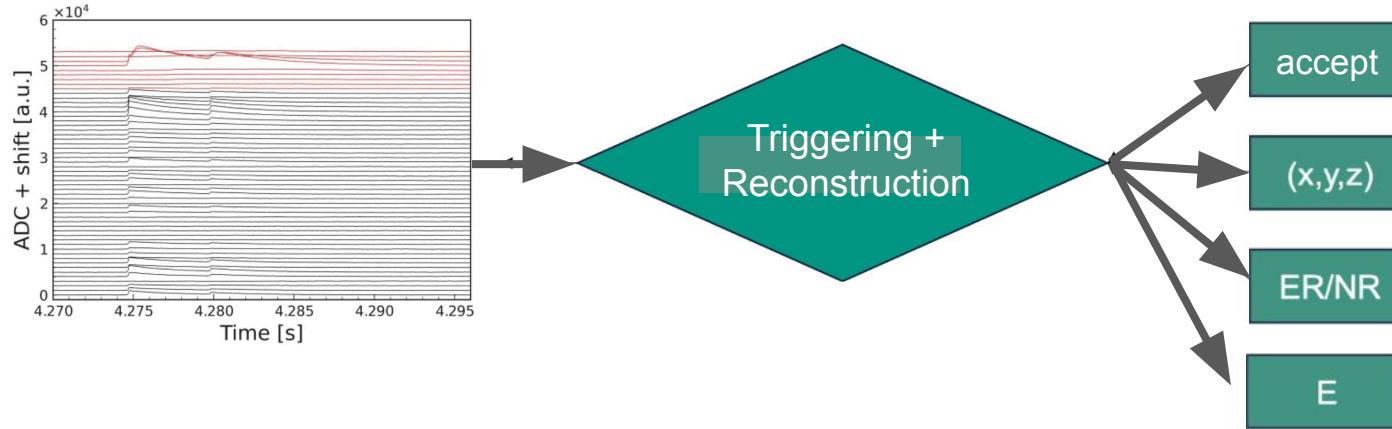
Detector effects



Summing individual contributions



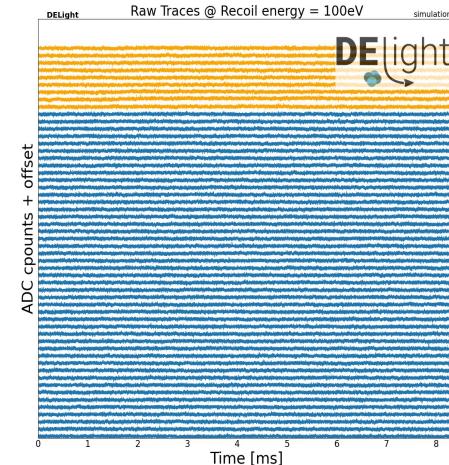
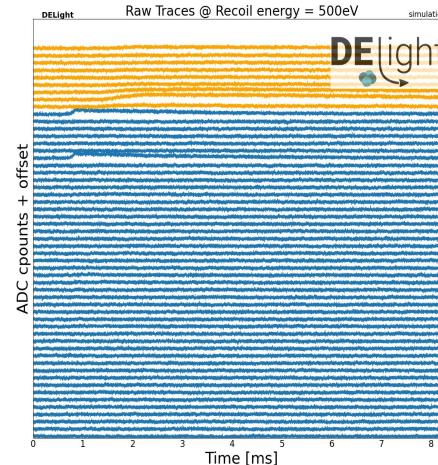
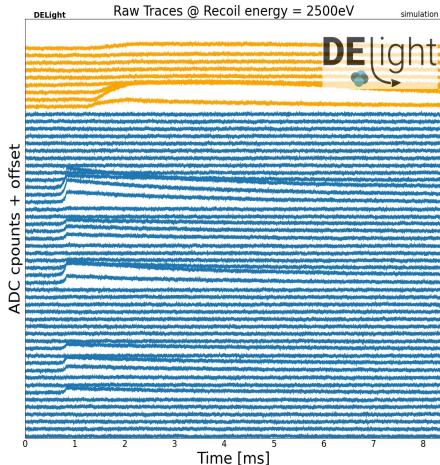
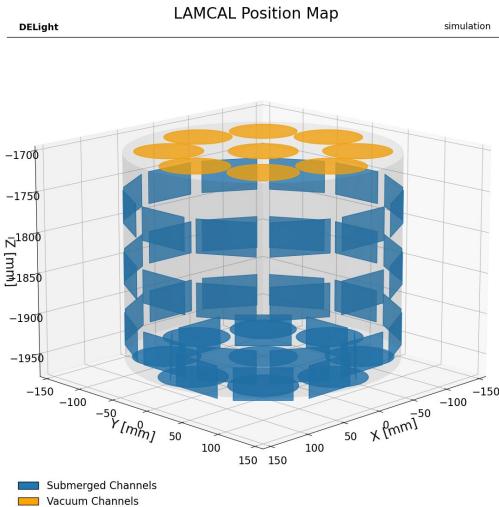
Event reconstruction and classification



- Triggering technically part of reconstruction
→ Online and offline reconstruction
- We do have a reconstruction setup based on OF and a framework Strax/Helix

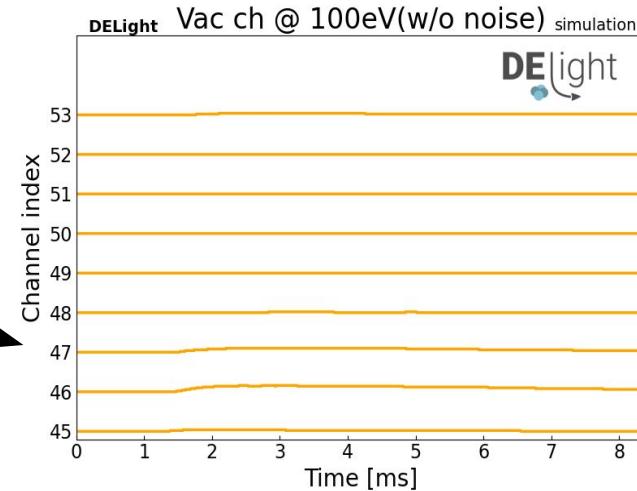
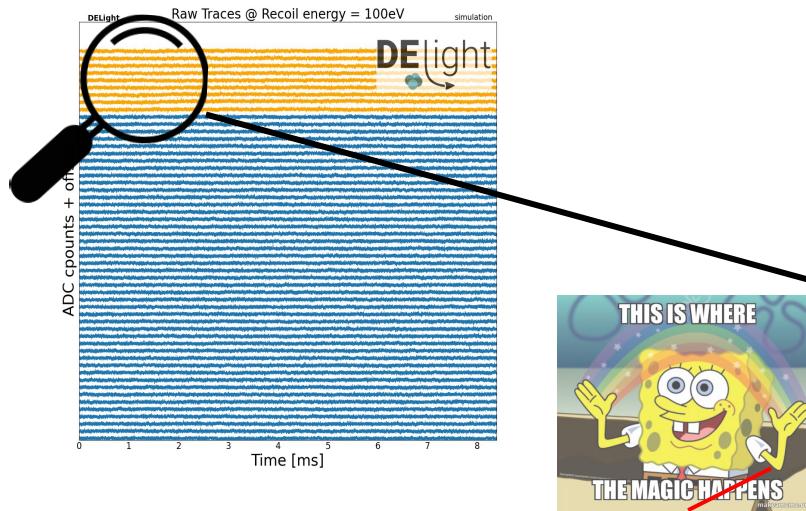
Triggering at threshold

- Characteristic waveforms due to signals in different channels at high recoil energies
- Becomes challenging at 100 eV where most of energy is in top-mounted channels



Triggering at threshold

Barely visible *without noise!*



needs to happen

- How can we trigger and identify these events within noise?
- Exploring advanced techniques for signal processing

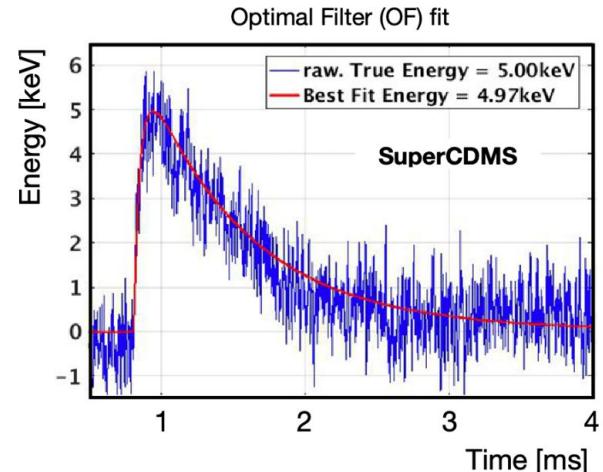
Optimum Filtering

amplitude Time shift (template roll)

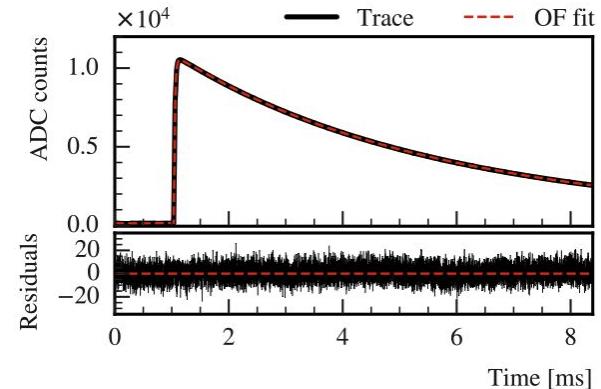
signal template

$$\chi^2 = \int_{-\infty}^{\infty} \frac{|v(f) - Ae^{-i\omega t_0} s(f)|^2}{J(f)} df$$

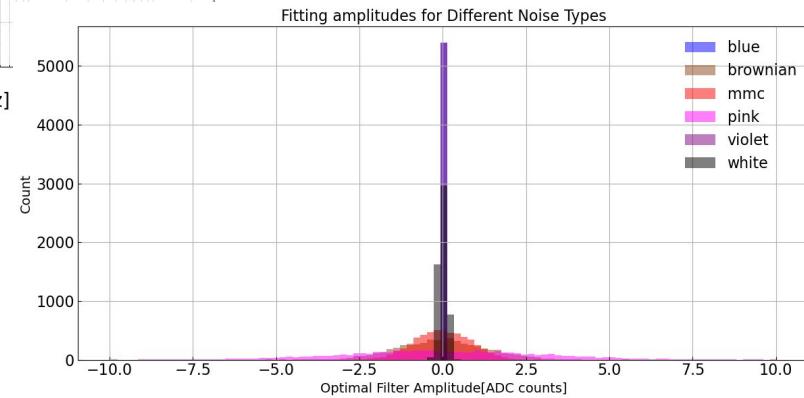
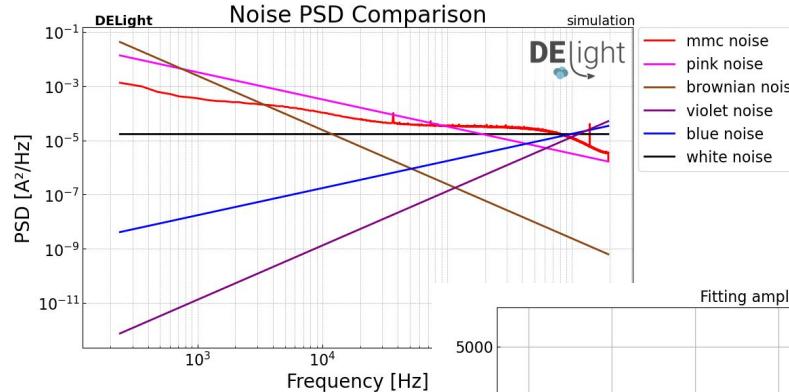
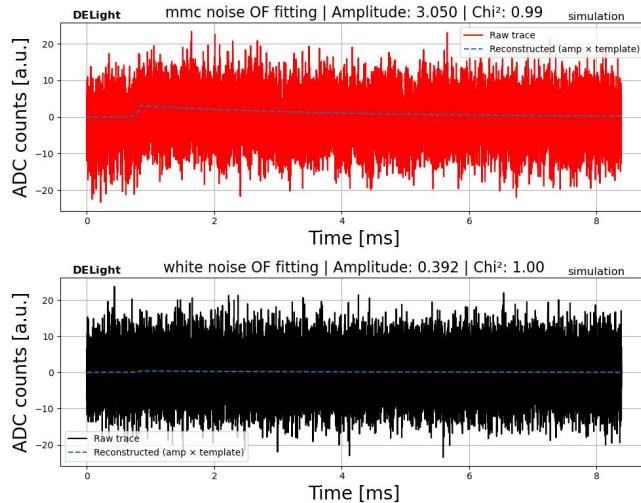
Noise PSD



- Noise-weighted filter maximizing signal-to-noise ratio in frequency domain
- Guaranteed to be optimal in case of known noise and signal template
- Enhances frequency components where signal dominates over noise
- Returns: amplitude estimate (Ampl) and goodness-of-fit metric (χ^2)

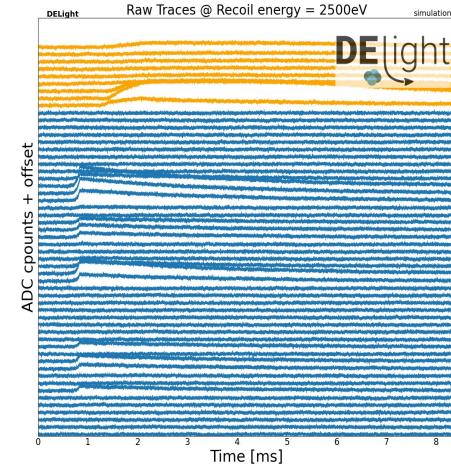
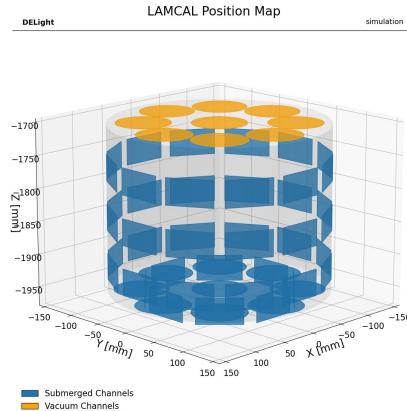
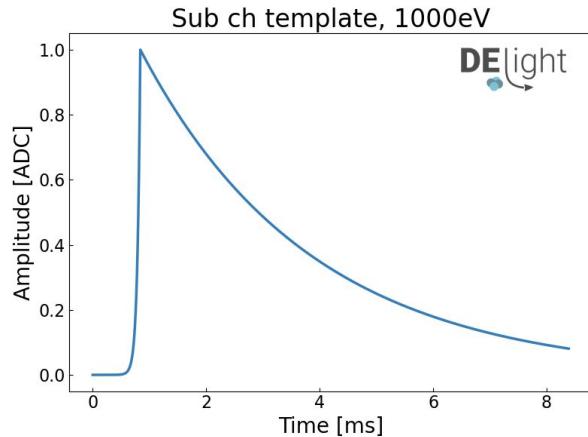


OFs applied to noise (aka “what if there is no DM?!”)



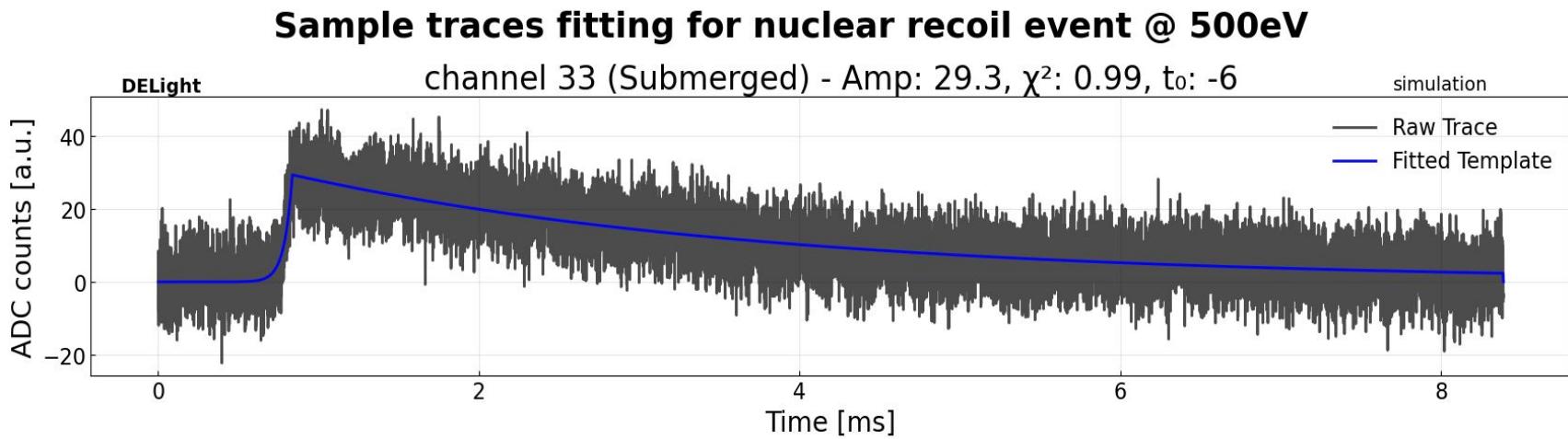
- Using PSD extracted from MMC
- For now: Use uncorrelated noise across different channels

Signal template for submerged channels

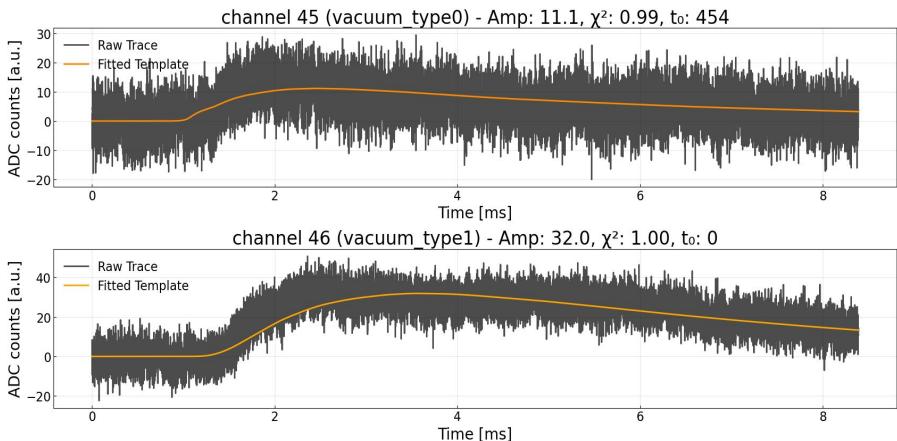
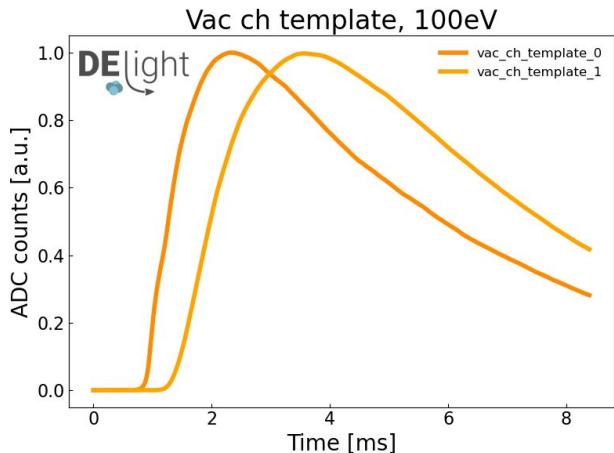
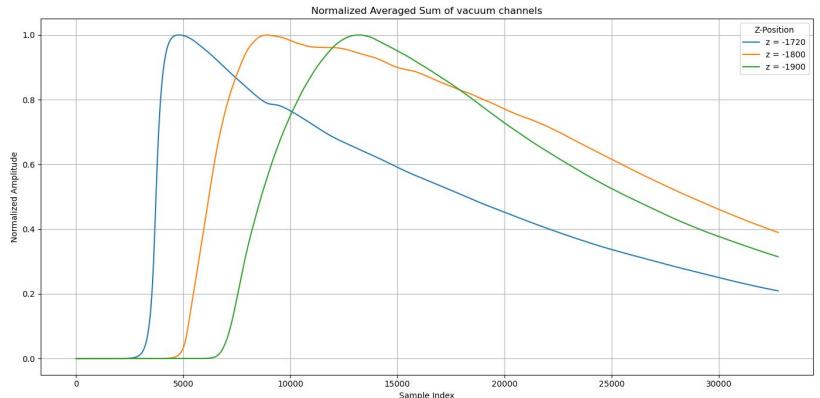


- Submerged channels detect UV photon signals
- Obtain high-fidelity templates by averaging 1000 normalized, noise-free 1 keV electronic recoil events without ADC quantization

Example fit in submerged channel



Signal template in vacuum channels



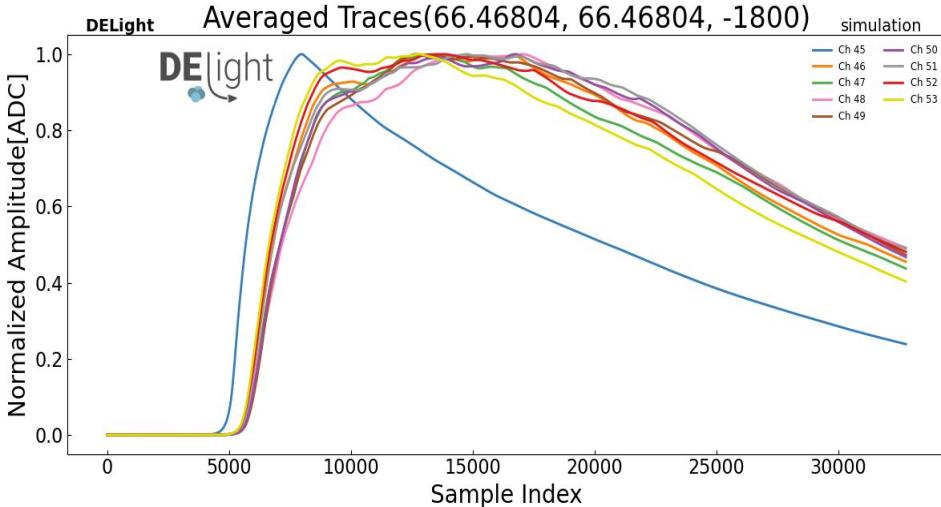
- Less clear due to finite phonon propagation time and variance at low energies
- Method not ironed out yet
- Several templates?
- Template sum?
- ...

Issues with current trace simulator

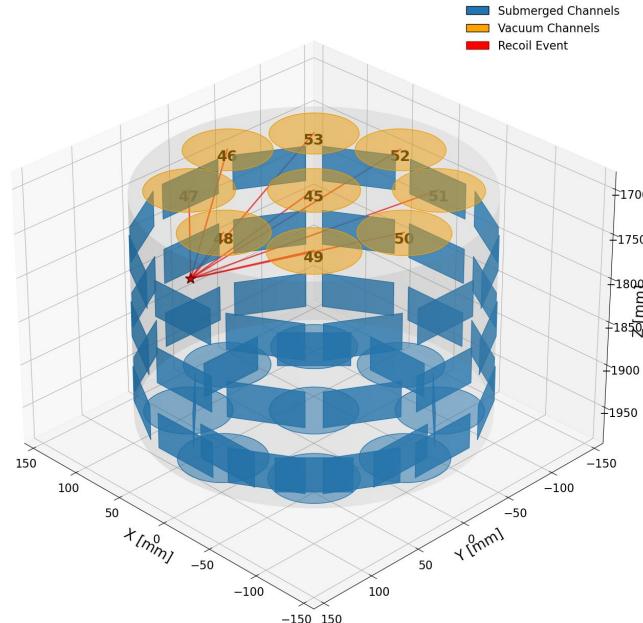
Channel 45 (vacuum, center) always arrives first, no matter the event location

Traced down to bug in efficiency maps

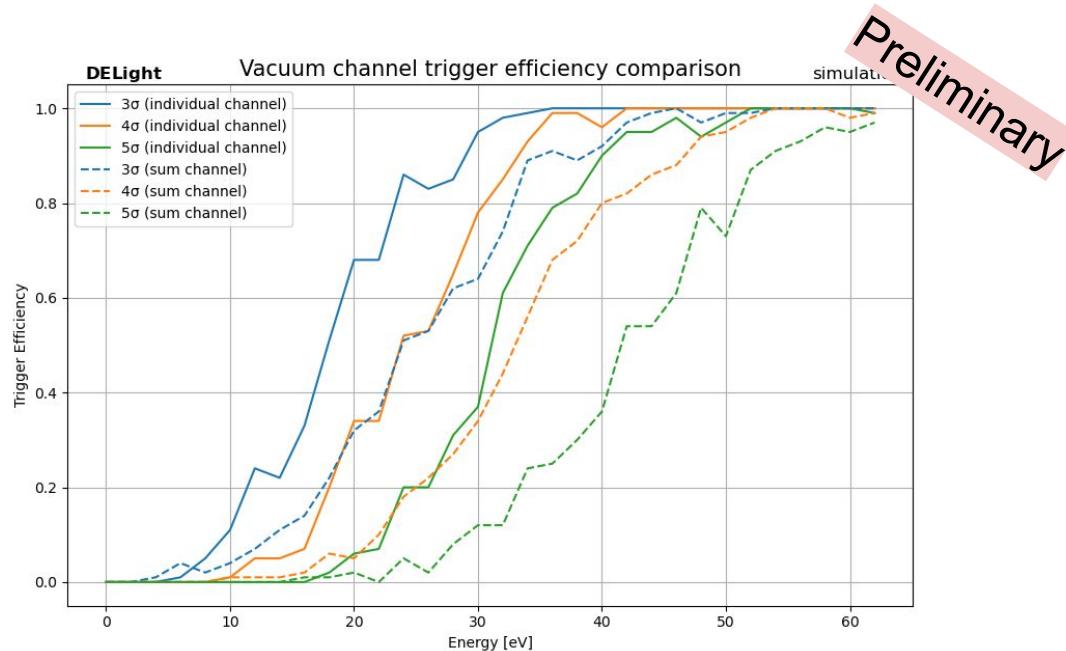
Fixed but not propagated into results yet



LAMCAL Position Map with Recoil Event
Recoil Position: (66.5, 66.5, -1800)



Trigger efficiency for vacuum channels

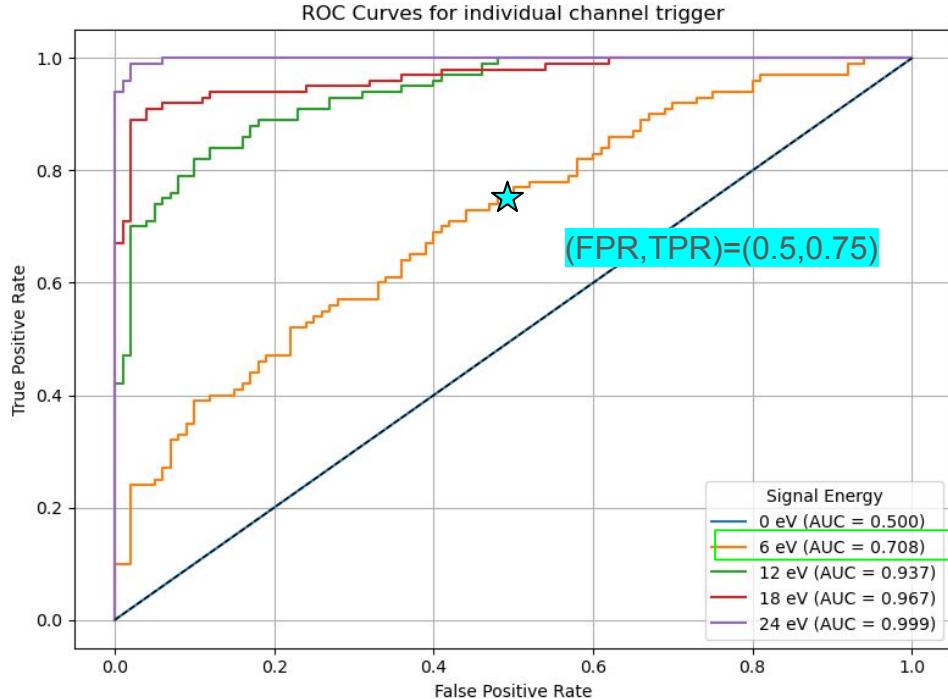
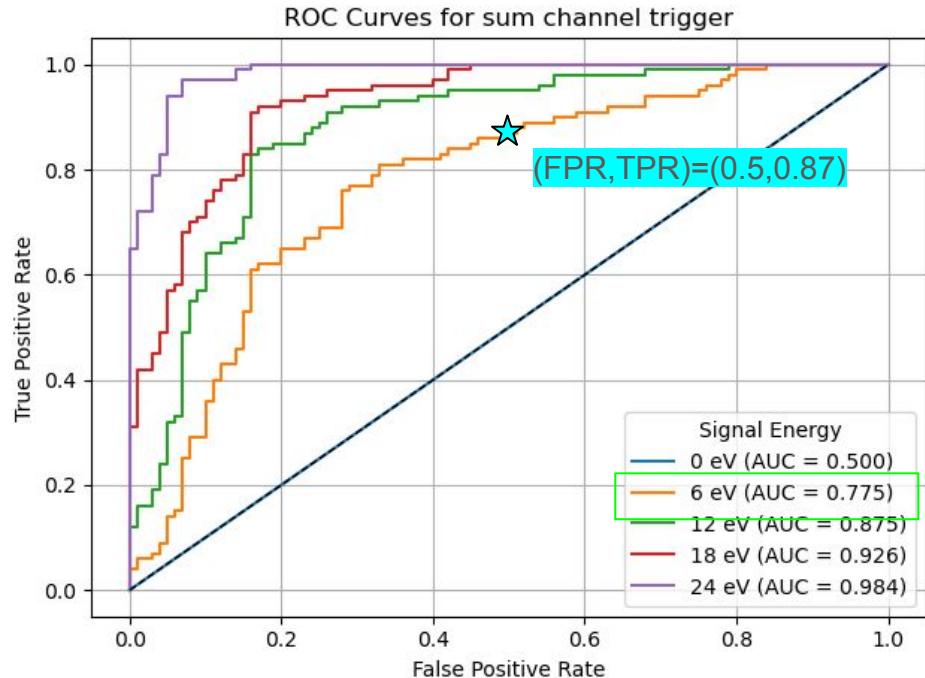


Preliminary

Sum channel: Sum OF ampl > threshold
Individual channel: Any vac ch OF ampl > threshold

ROC for vacuum channel trigger

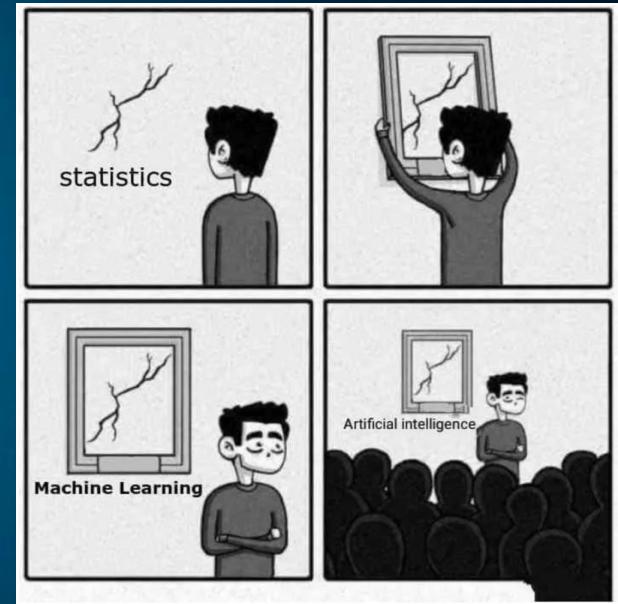
Preliminary



- Sum channel trigger has advantage for extremely low recoil energies

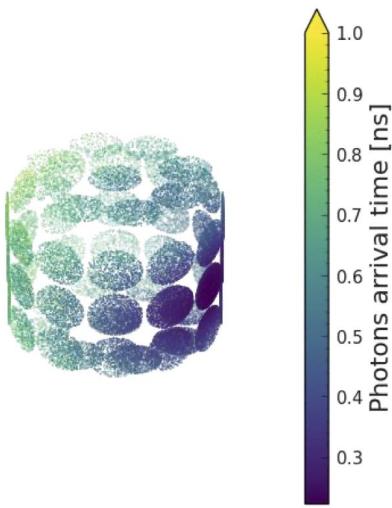


Can artificial intelligence help?



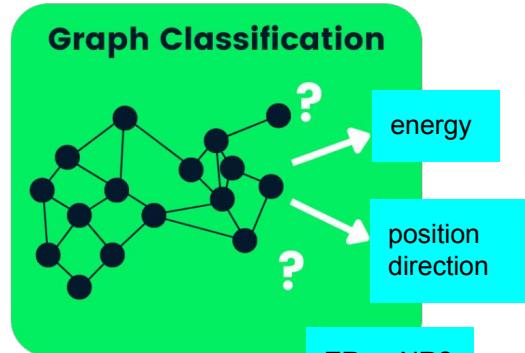
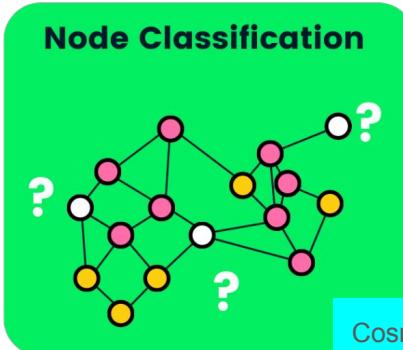
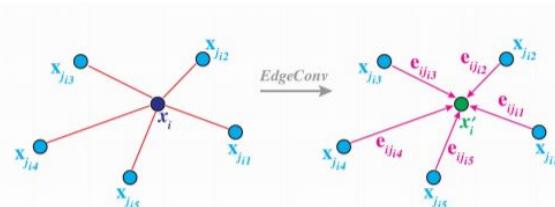
Event reconstruction and classification

Web (“point cloud”) of 50-100 MMCs surrounding cell

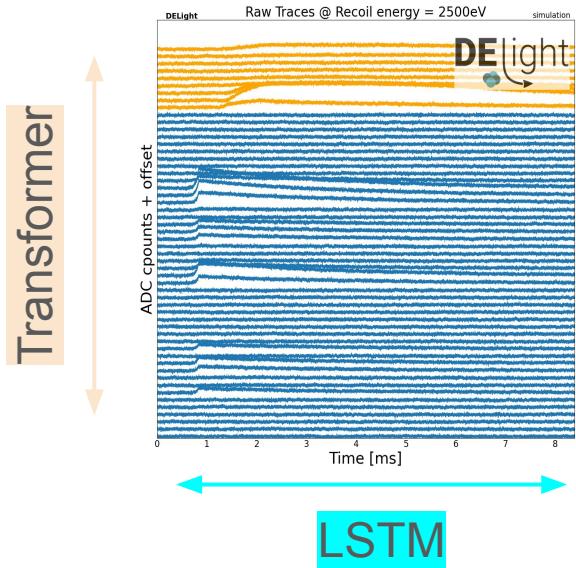
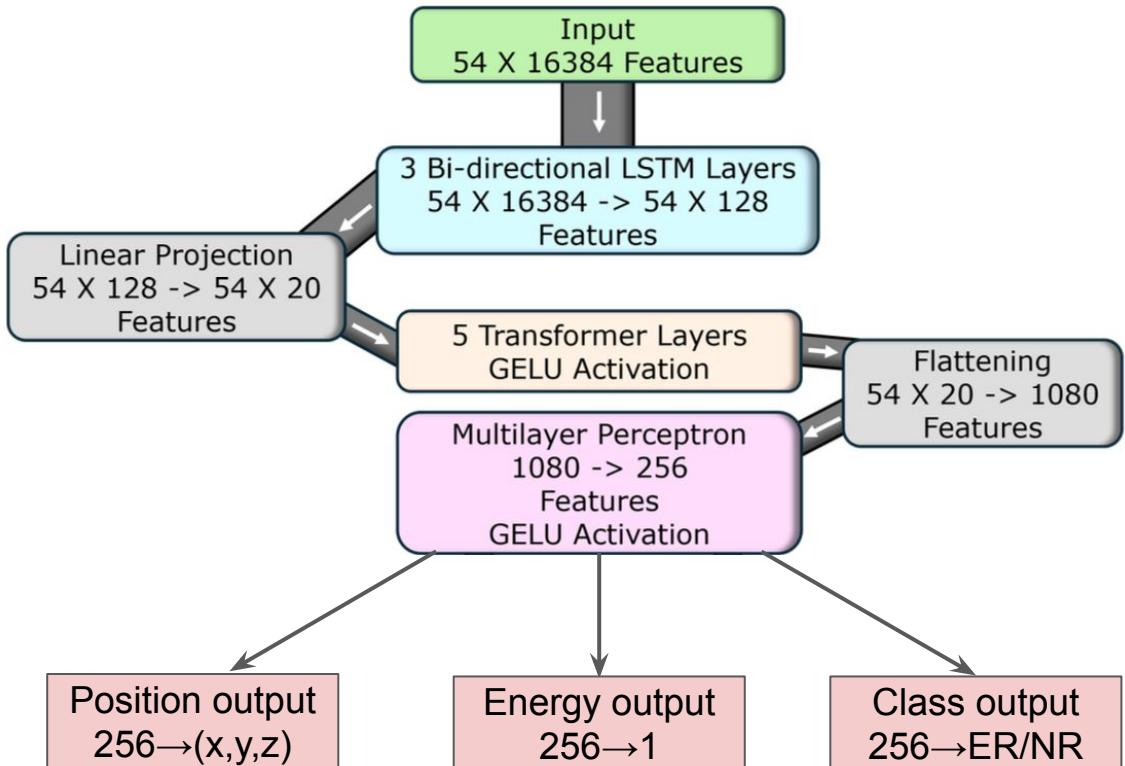


Lesson from Machine Learning in Particle Physics:

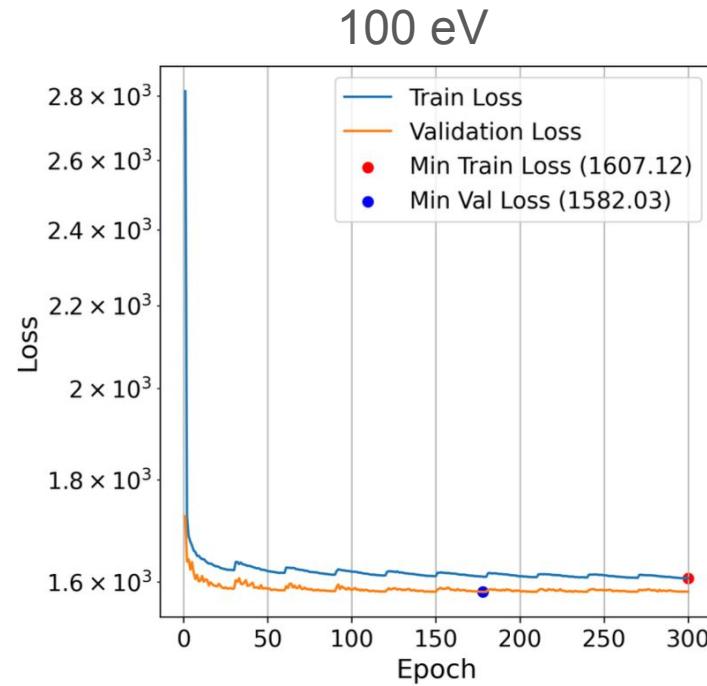
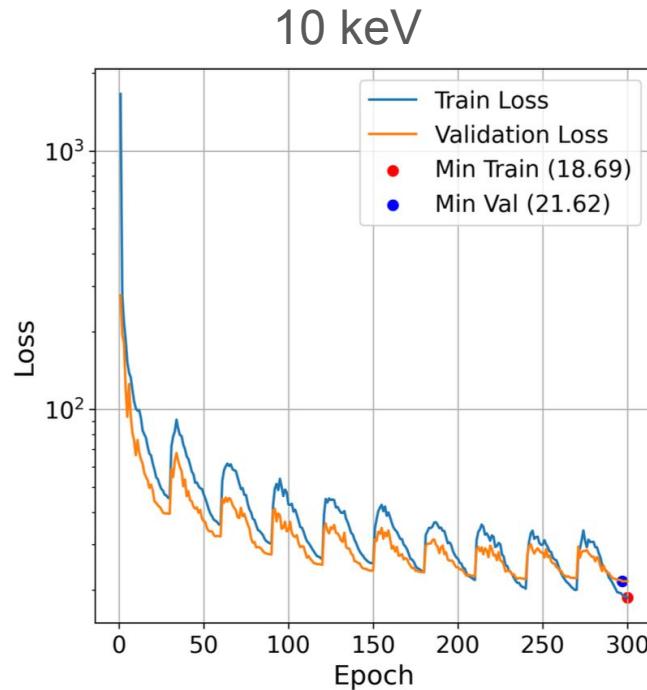
- Best performance if structure of your data matches neural network architecture



Event reconstruction and classification

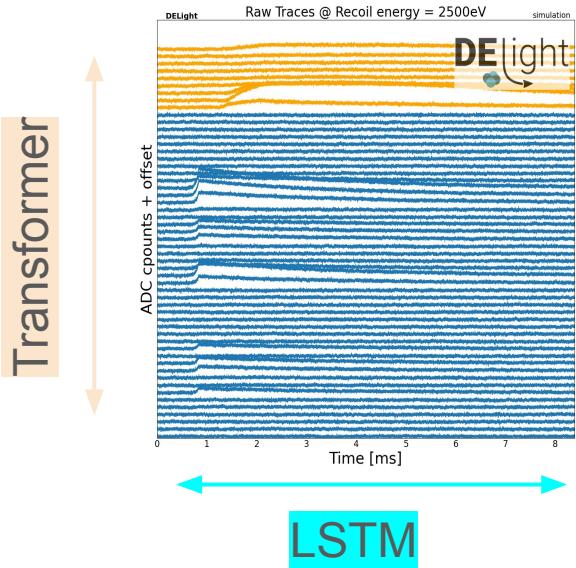
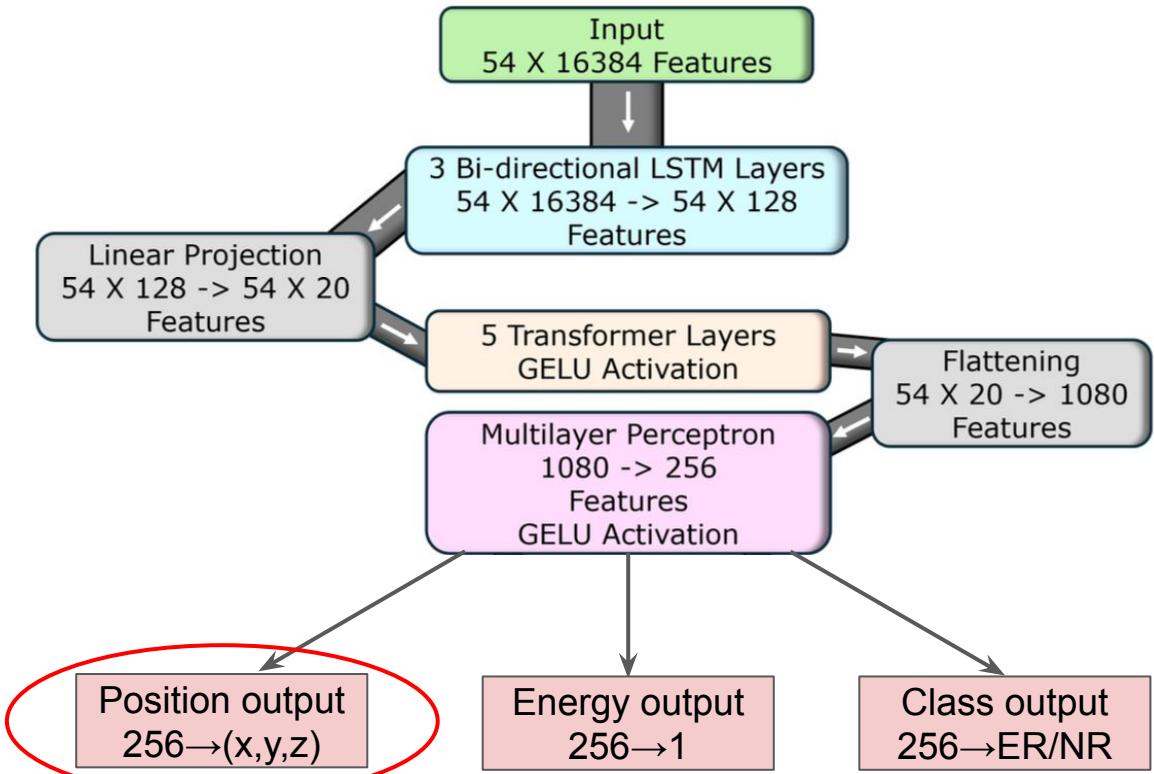


Noiseless data - total loss



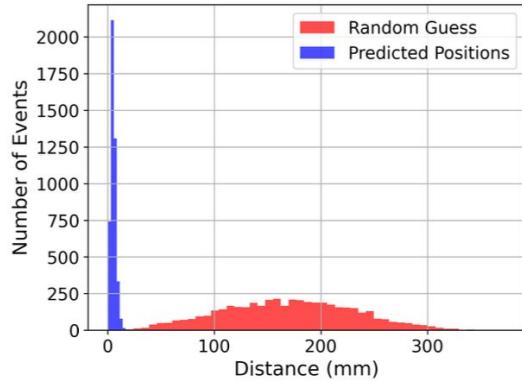
- Loss an order of magnitude larger for 100 eV
- Speaks to the challenge faced at low energies

Event reconstruction and classification

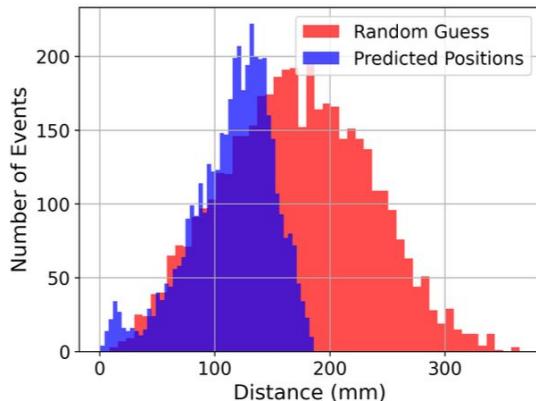


Position reconstruction accuracy

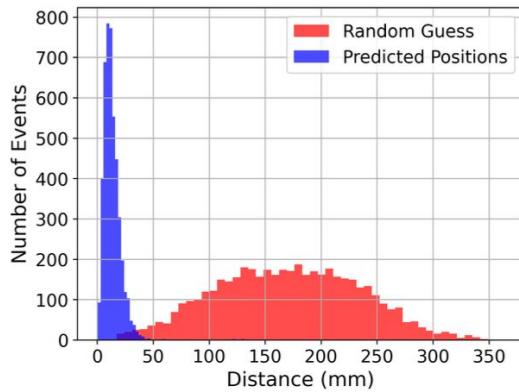
500 eV, NR, noiseless



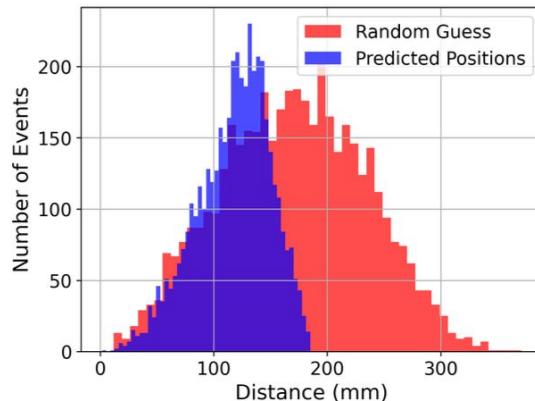
50 eV, NR, noiseless



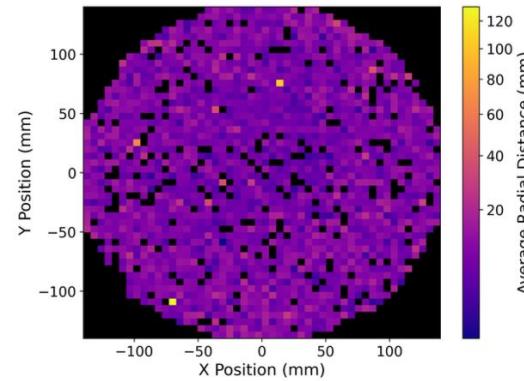
noised



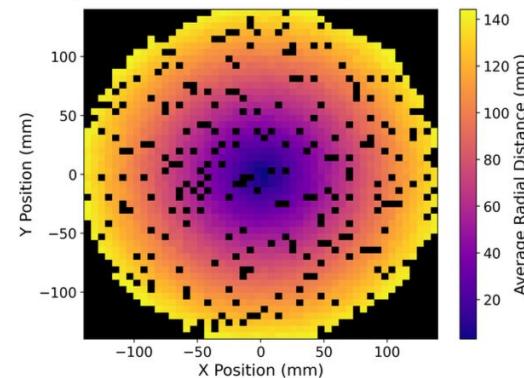
noised



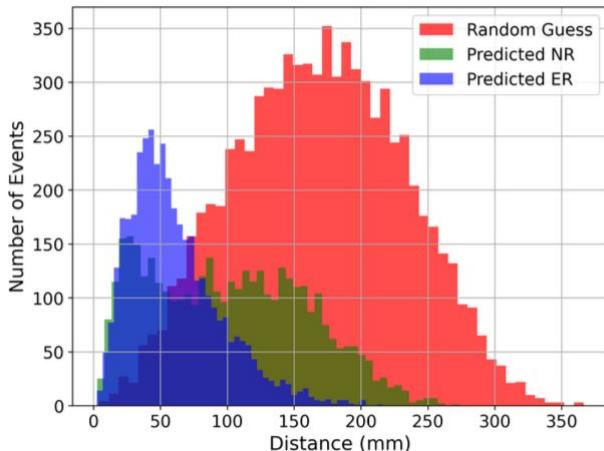
noised, xv



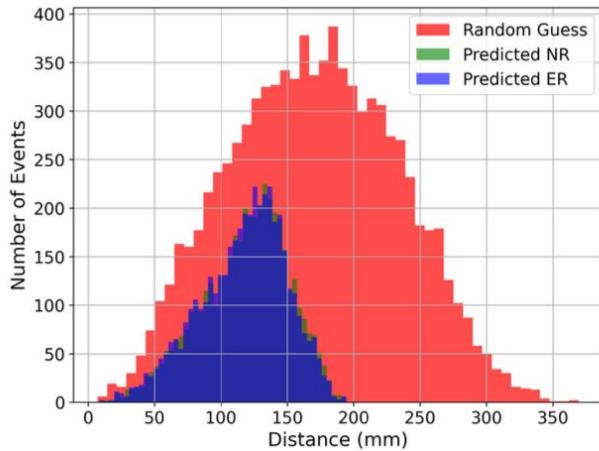
noised, xy



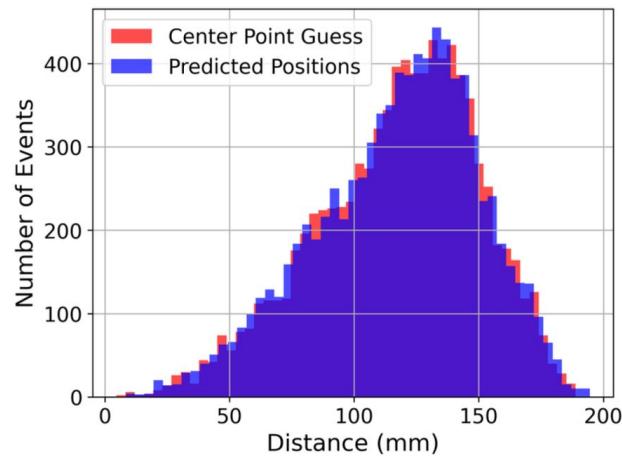
Position reconstruction accuracy



100 eV, noised



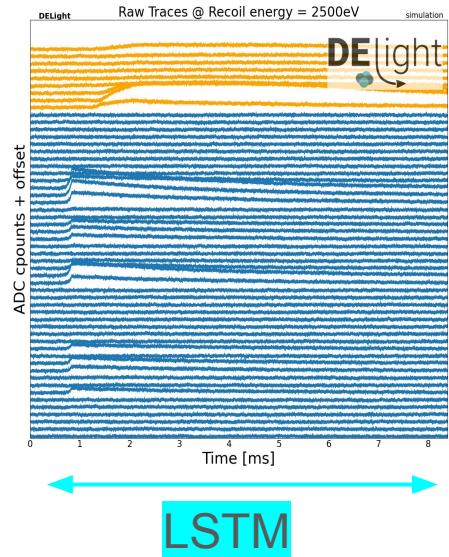
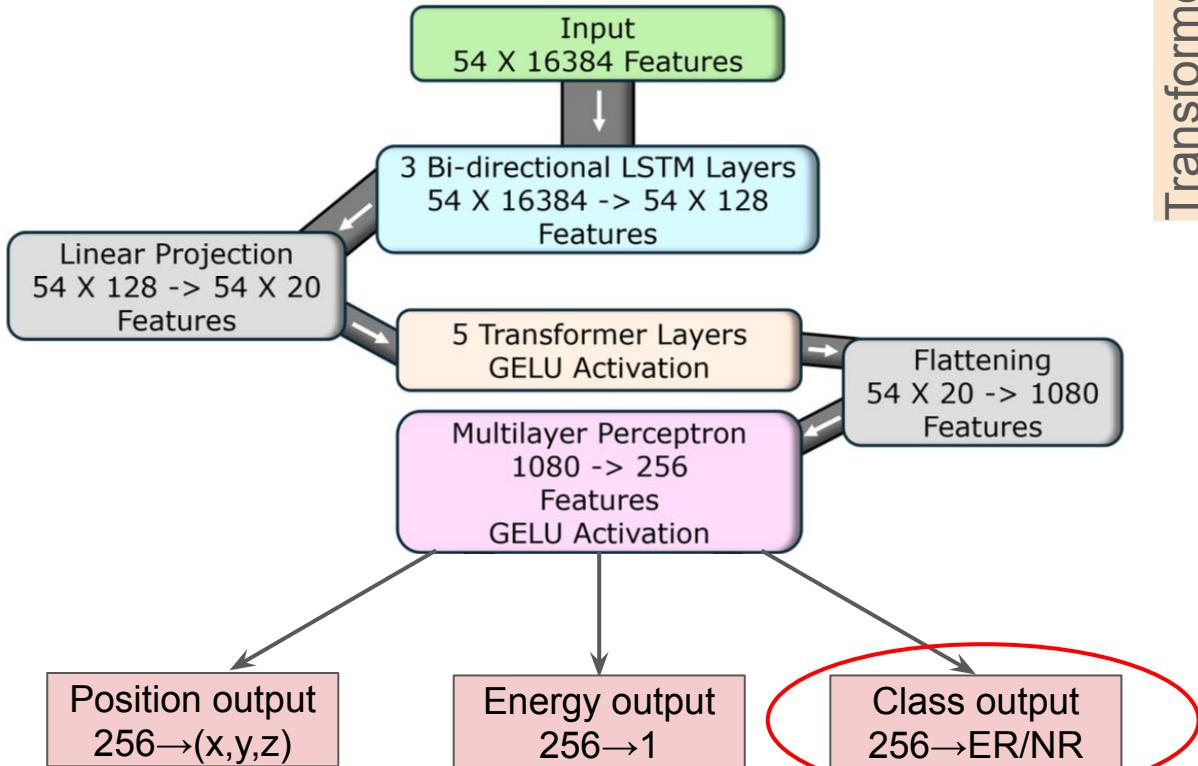
50 eV, noised



50 eV, noised

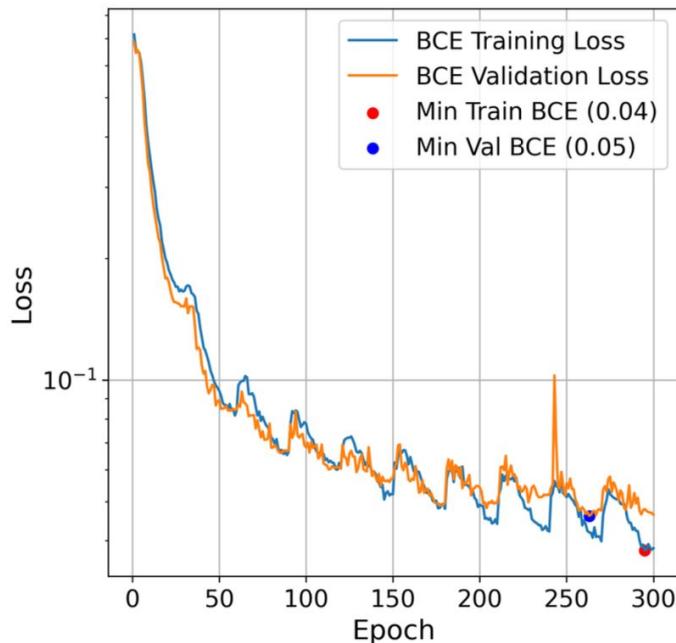
- Better for ER due to enhanced presence of UV!
- Losing all handles on position somewhere between 100 and 50 eV

Event reconstruction and classification

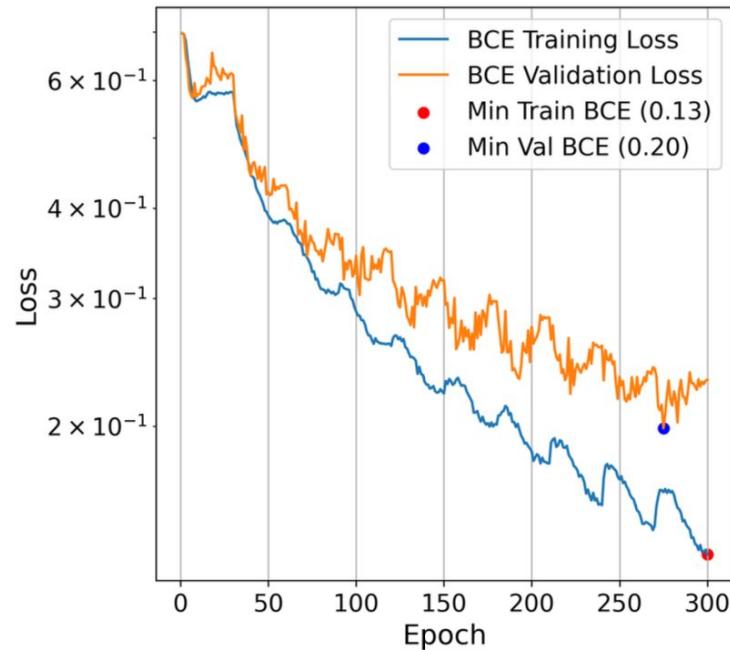


Noised data - NR vs ER classification loss

500 eV

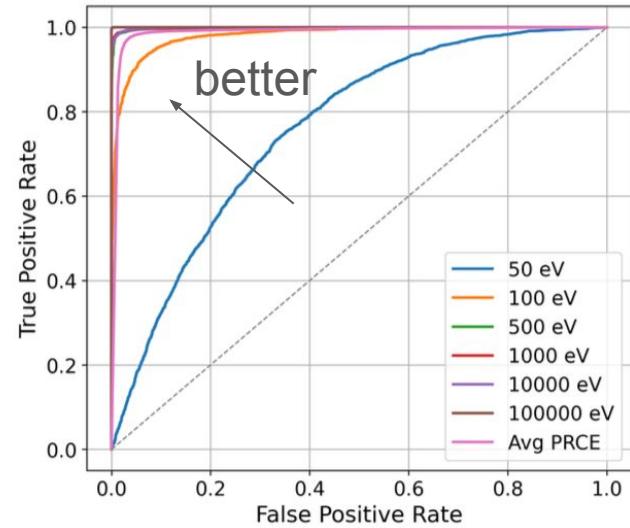
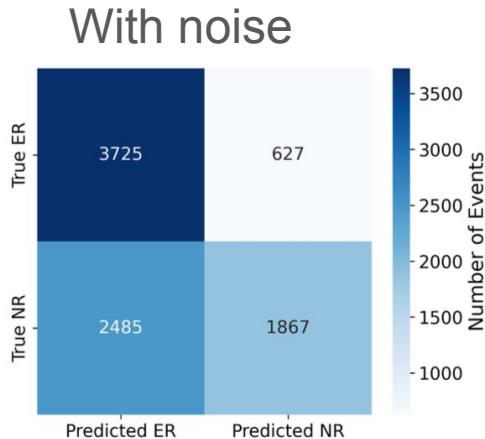
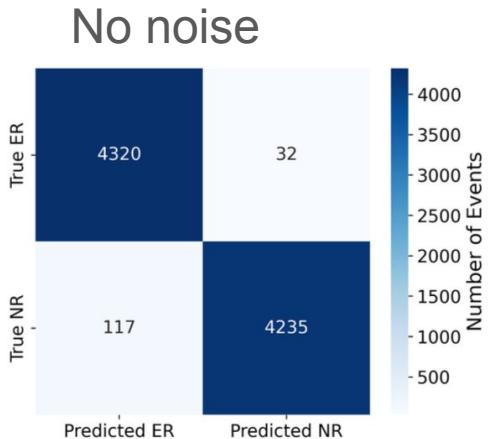


100 eV



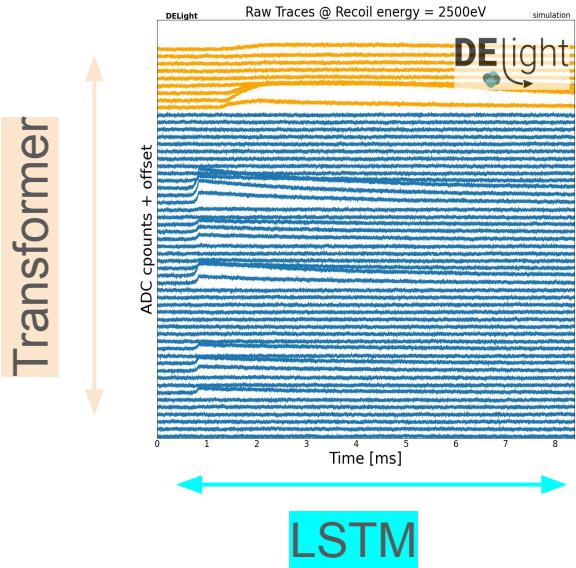
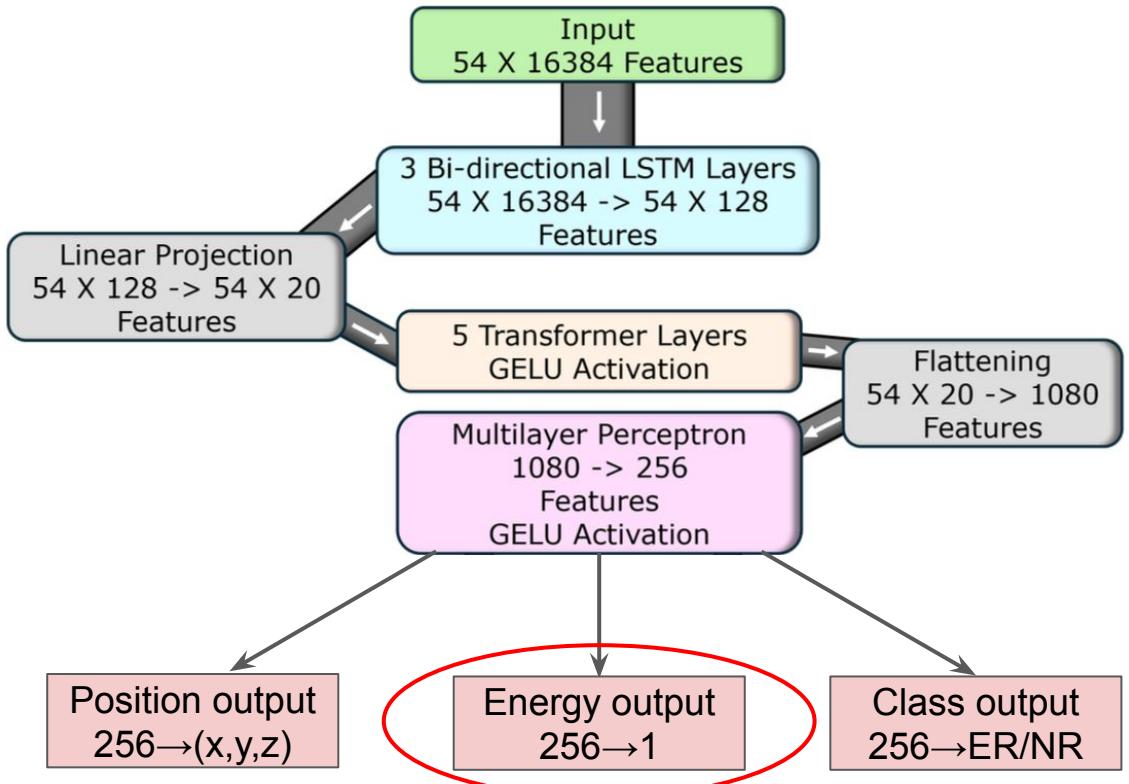
- NR vs ER is a doable challenge at 500 eV
- 100 eV not trained to convergence yet + some sign of overfitting

NR vs ER classification accuracy

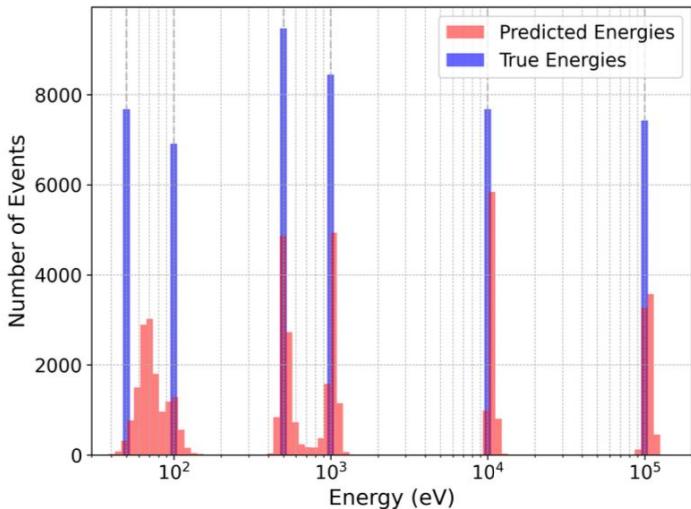


- Dramatic drop in ER vs NR for 50 eV when adding noise
- Otherwise, excellent ER vs NR discrimination

Event reconstruction and classification



Energy regression performance



Energy (eV)	Noised	
	Bias (%)	Resolution (%)
50	33.03	15.06
100	-15.38	21.40
500	4.01	11.55
1000	1.58	10.01
10000	6.37	4.50
100000	5.12	5.28
Average	10.91	11.39

- Training on a mixture of energies 50 eV-100 keV
- Struggles at lowest energies
- To be compared to optimum filtering

Conclusion

- Progress on OF-based and ML-based reconstruction
- Converging towards estimate for trigger efficiencies (highest prio)
- Improving understanding of simulation along the way
- Everything to be updated with new geometry