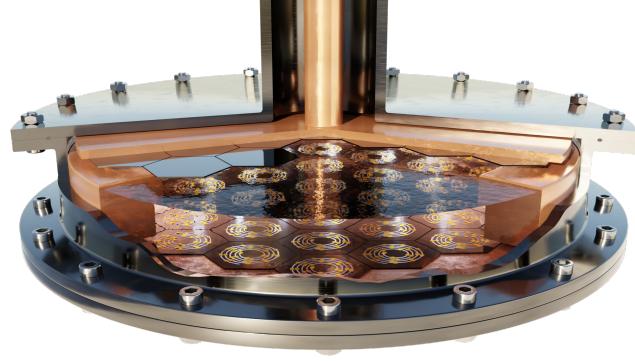
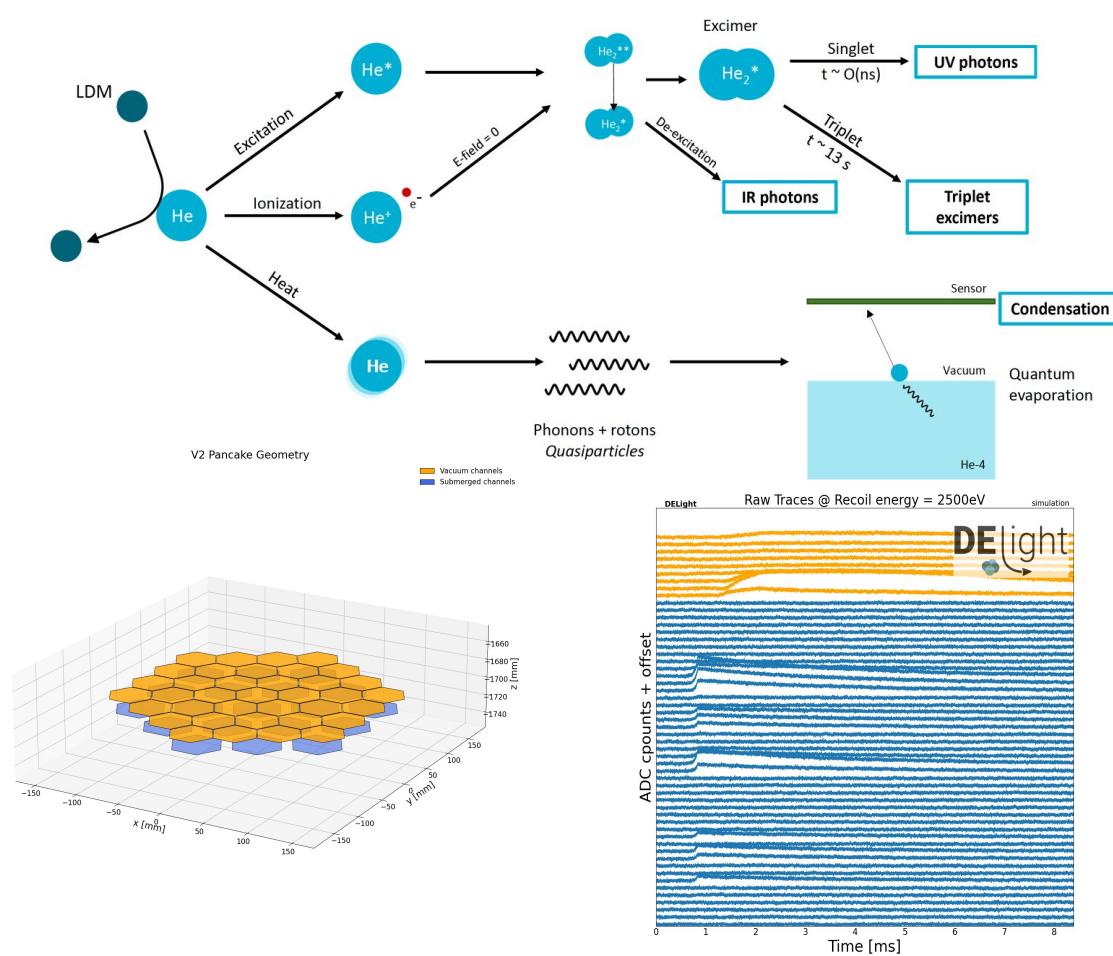


*In a nutshell*

**DE**light

dwong  
Nov 11th, 2025  
pages, est. mins

# How Dark Matter shows up in Helium-4

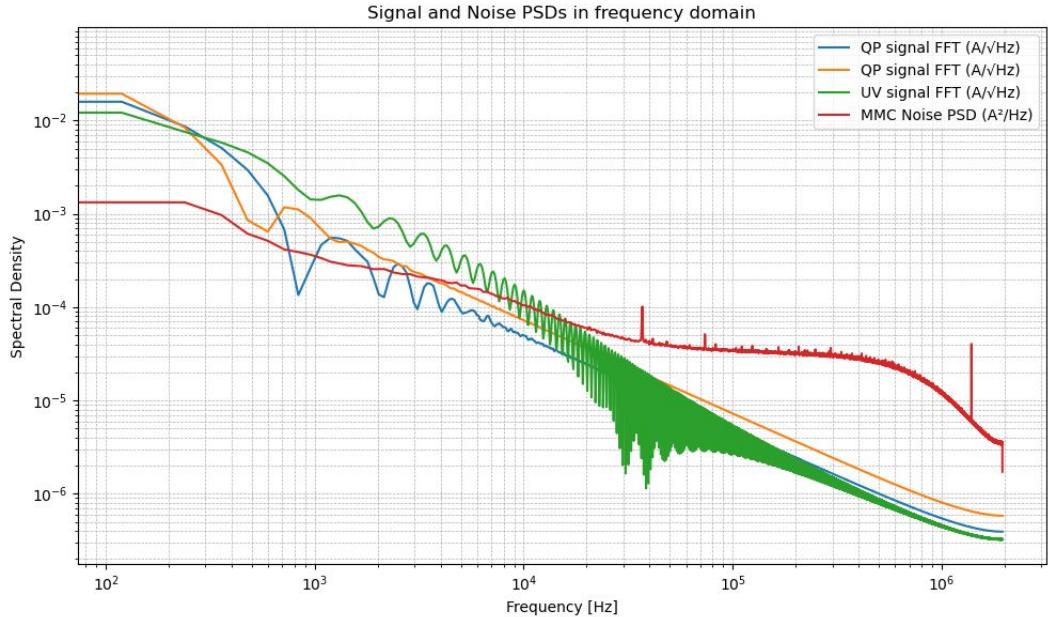


Direct detection of dark matter primarily relies on interactions between **dark matter** particles and the **atomic nuclei or electrons** of the target medium.

In a helium-4 detector, the energy transferred converted into two types of signals:

- **Phonons**, where recoil energy is converted into heat
- **Photons**, where recoil energy is converted into scintillation light

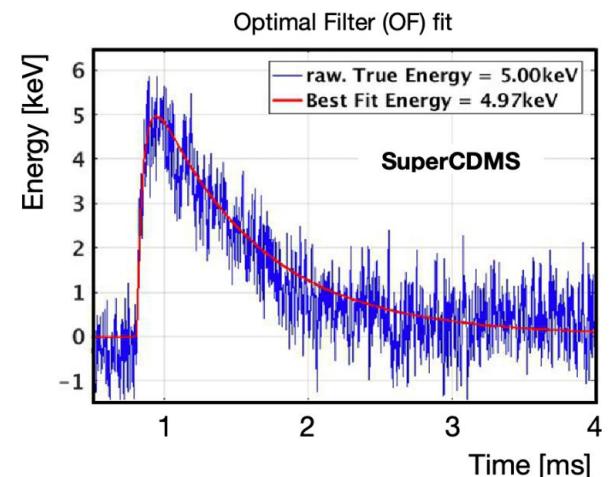
# Optimum Filters: discriminator in frequency domain



signal      amplitude      Time shift (template roll)  
template

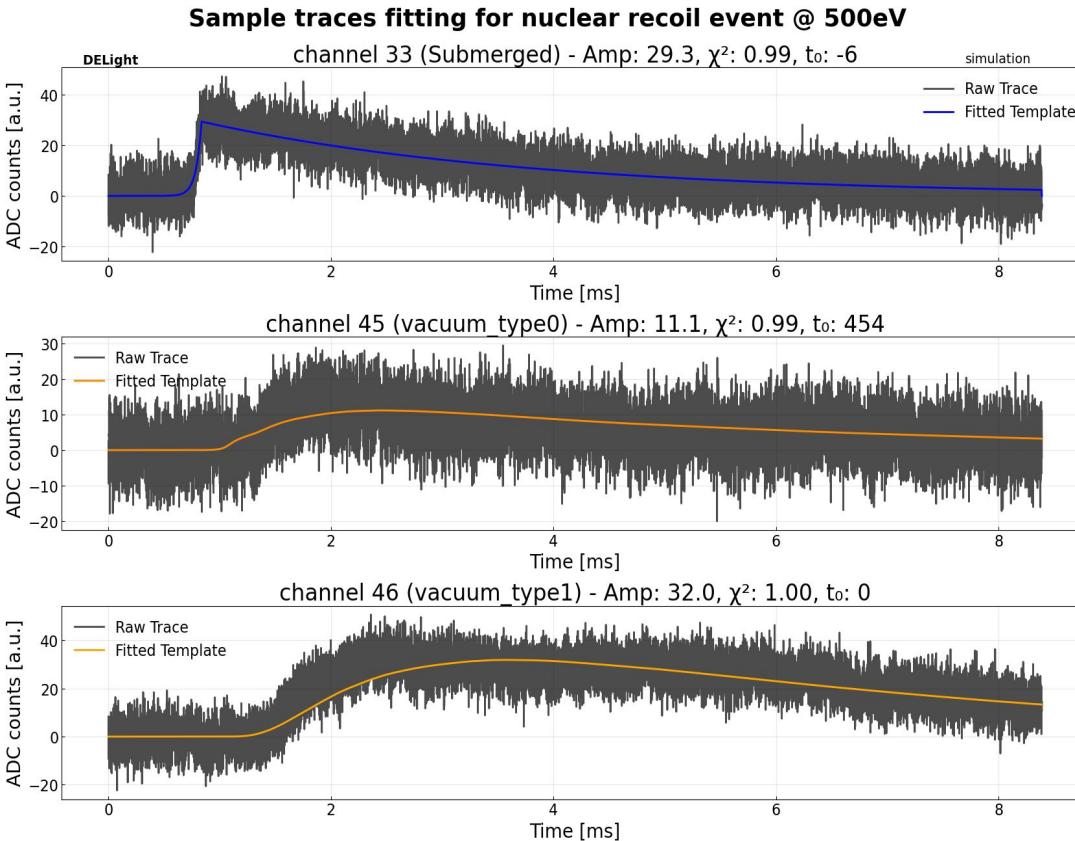
$$\chi^2 = \int_{-\infty}^{\infty} \frac{|v(f) - Ae^{-i\omega t_0} s(f)|^2}{J(f)} df$$

Noise PSD

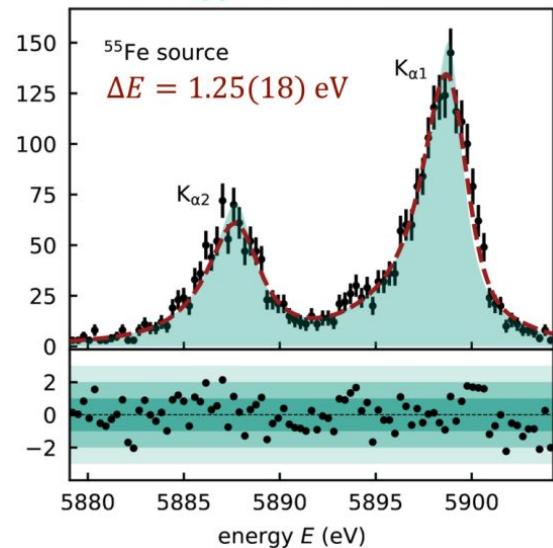


- A noise-weighted filter maximizing signal-to-noise ratio in frequency domain
- Guaranteed to be optimal in case of known noise and signal template

# Amplitude estimator: Energy reconstruction

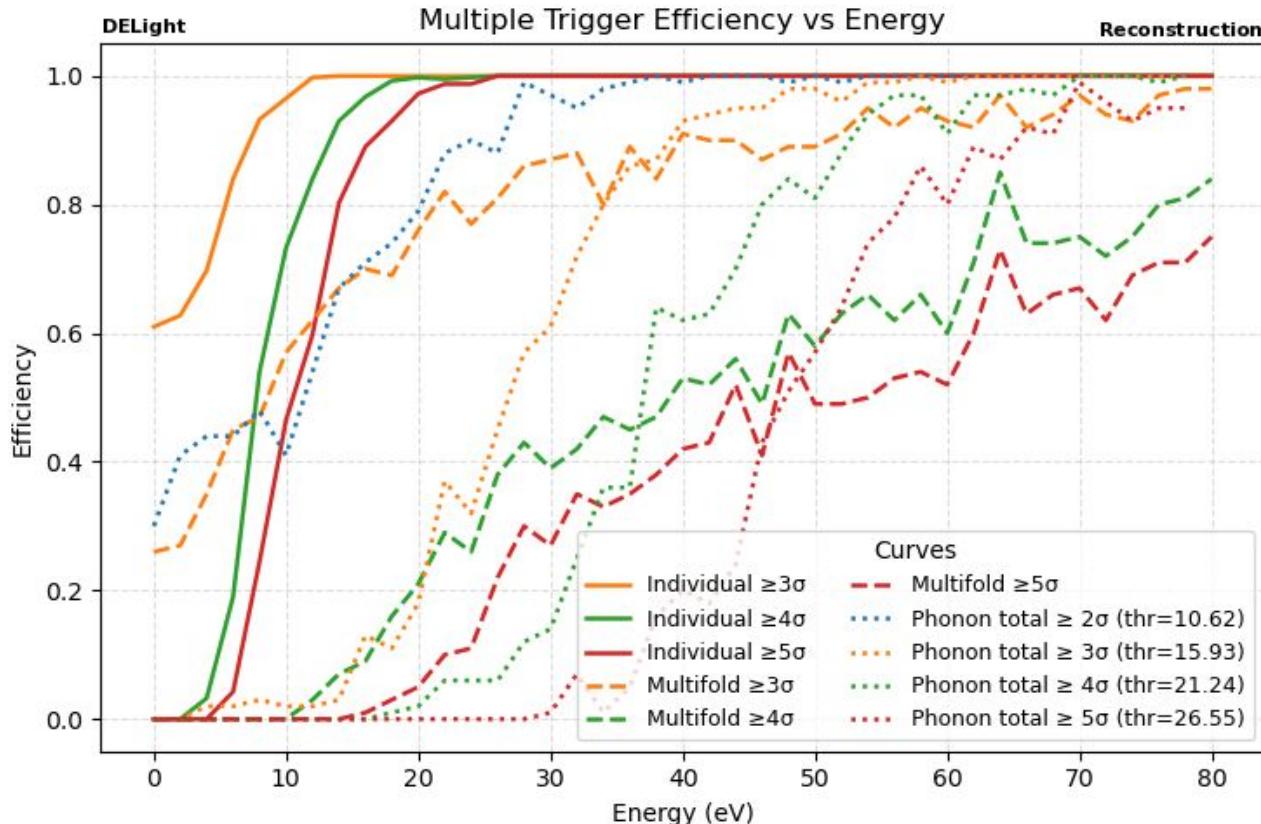


World record  
energy resolution



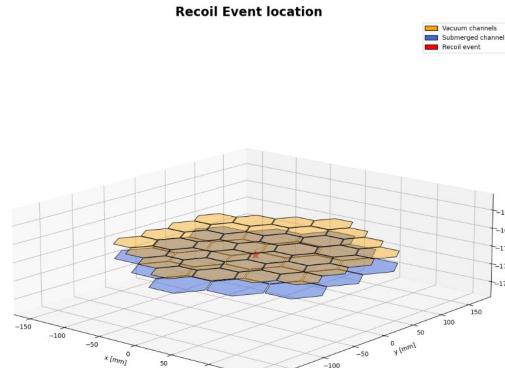
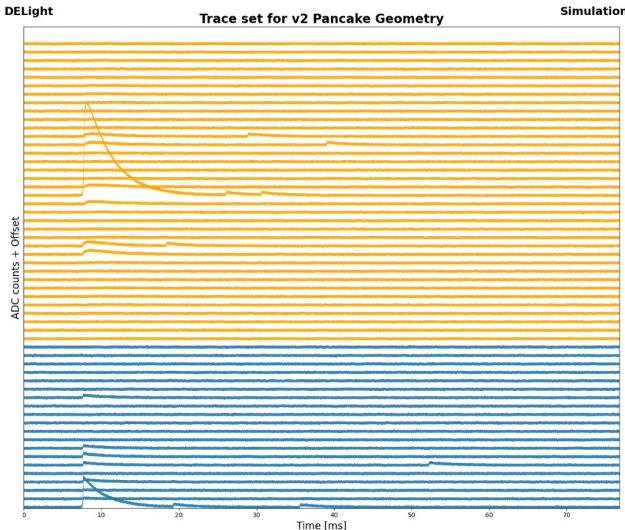
Calibration function of energy is described by a second-order polynomial:  
 $E = p1 \cdot A_c OF^2 + p2 \cdot A_c OF$

# Amplitude estimator: Software trigger



- Optimum filter,
- OF w/ shift
- Rolling OF
- Joint ch OF
- Signal Multifold
- Sum ch OF
- Downsampling
- Downcasting
- Concurrency
- Compression algo

# Attention is all you need: Time-then-channel Transformer for (3+2)D reconstruction



**Waveform analysis:**  
SuperCDMS: LSTM?  
long sequential dependencies and temporal ordering  
**LIGO:** AutoEncoder?  
Anomaly detection, learn the noise form  
**Transformer?**  
channel-level spatial correlation,  
parallelizable inference, self-attention

