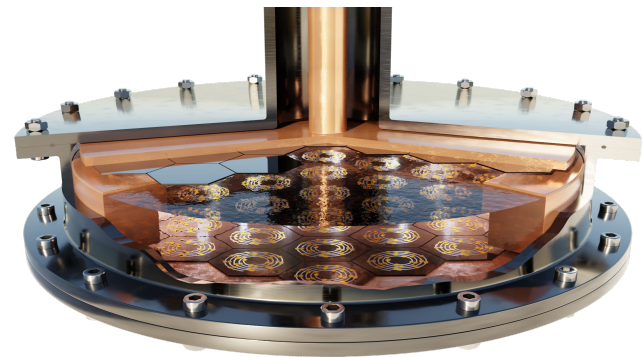
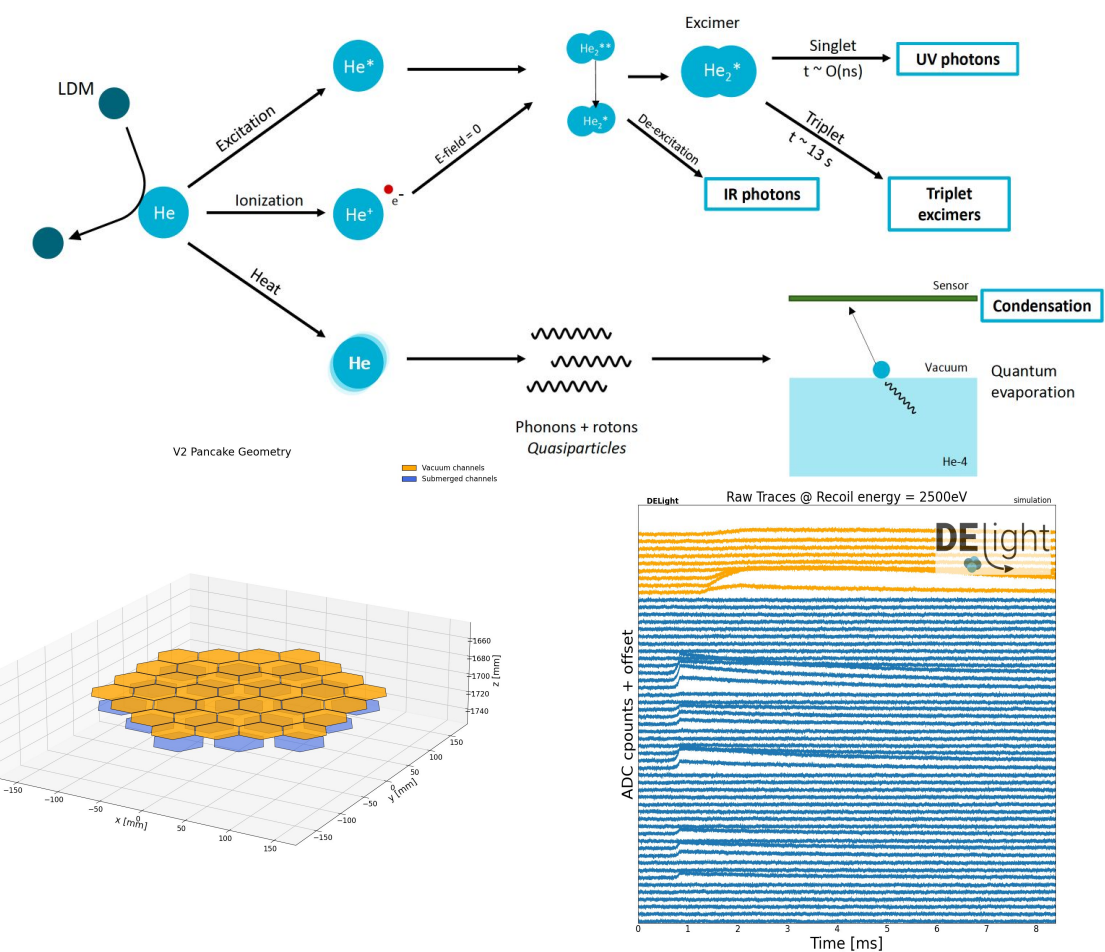


In a nutshell

DElight


dwong
Nov 11th, 2025
pages, est. mins

How Dark Matter shows up in Helium-4

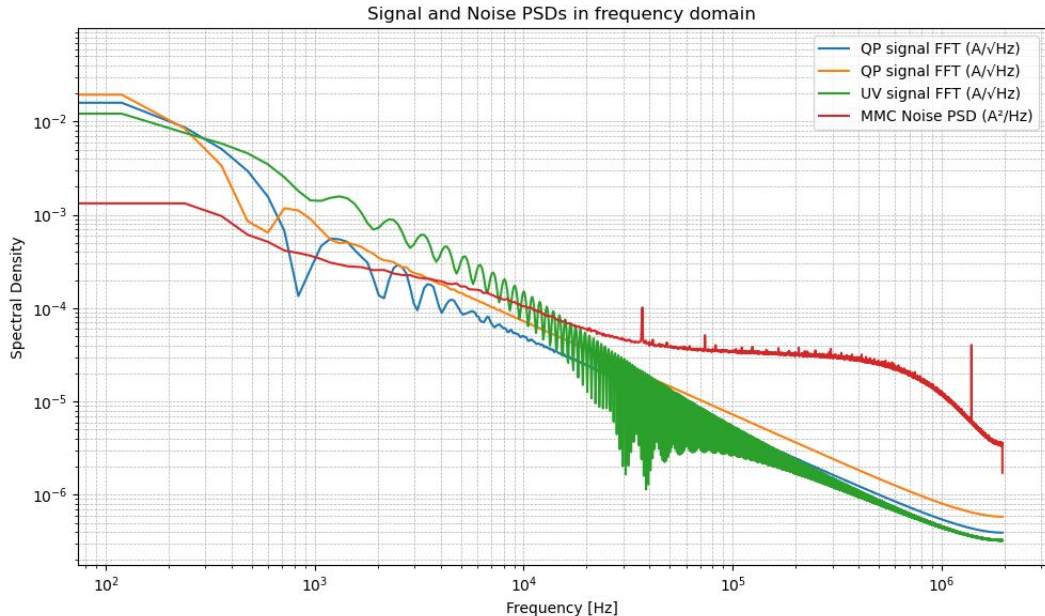


Direct detection of dark matter primarily relies on interactions between **dark matter** particles and the **atomic nuclei or electrons** of the target medium.

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

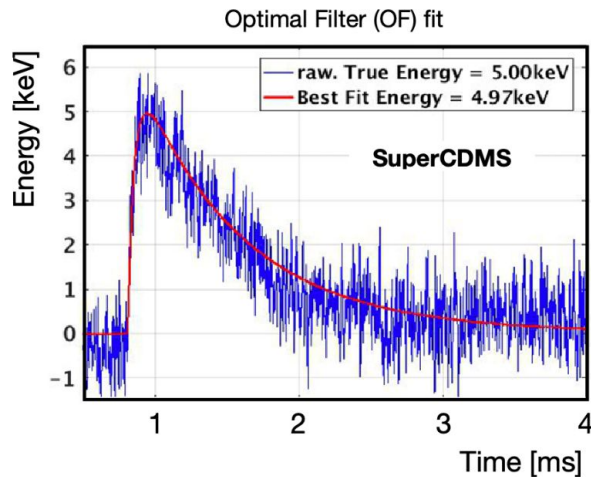


amplitude Time shift (template roll) template

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

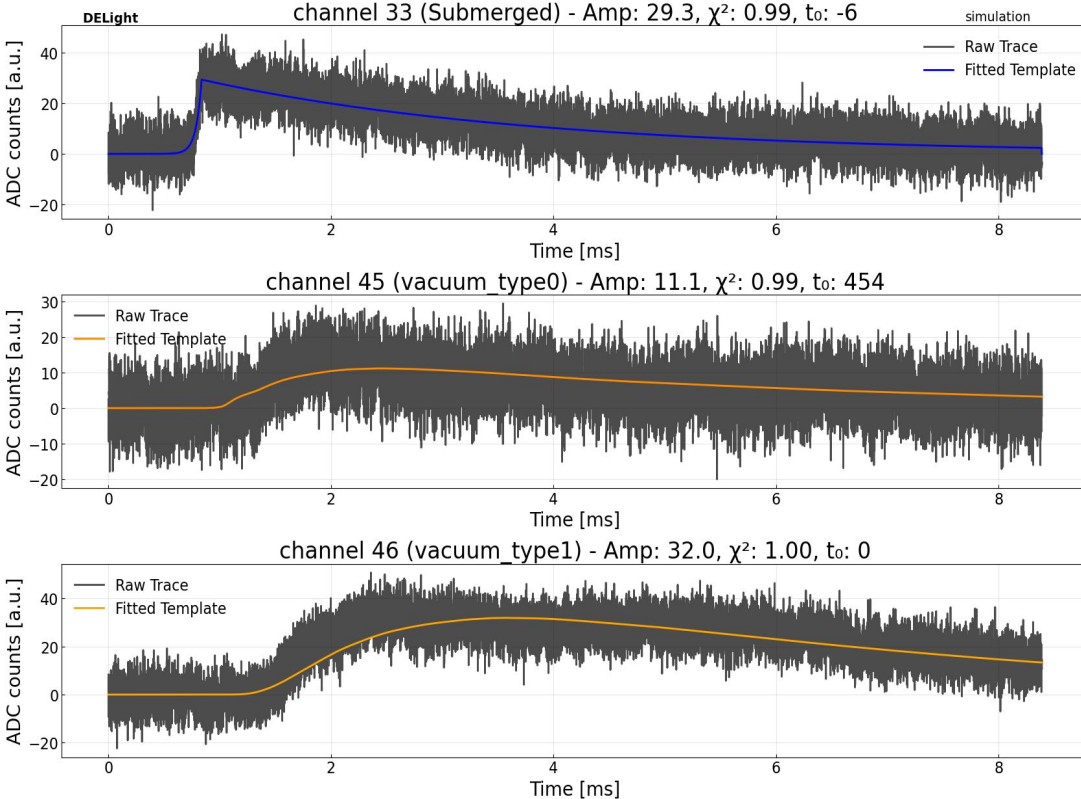
Noise PSD

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

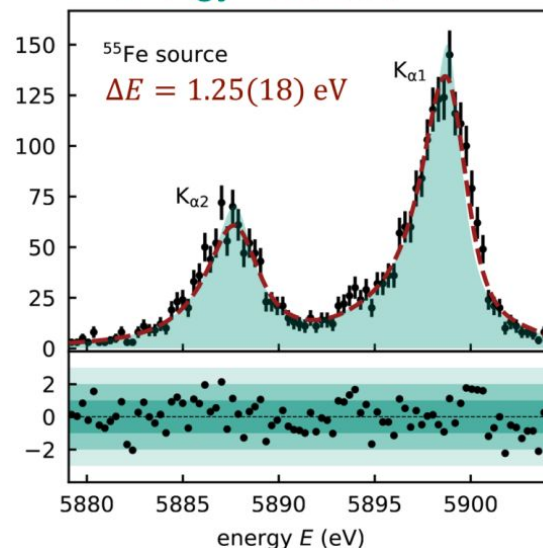


Amplitude estimator: Energy reconstruction

Sample traces fitting for nuclear recoil event @ 500eV



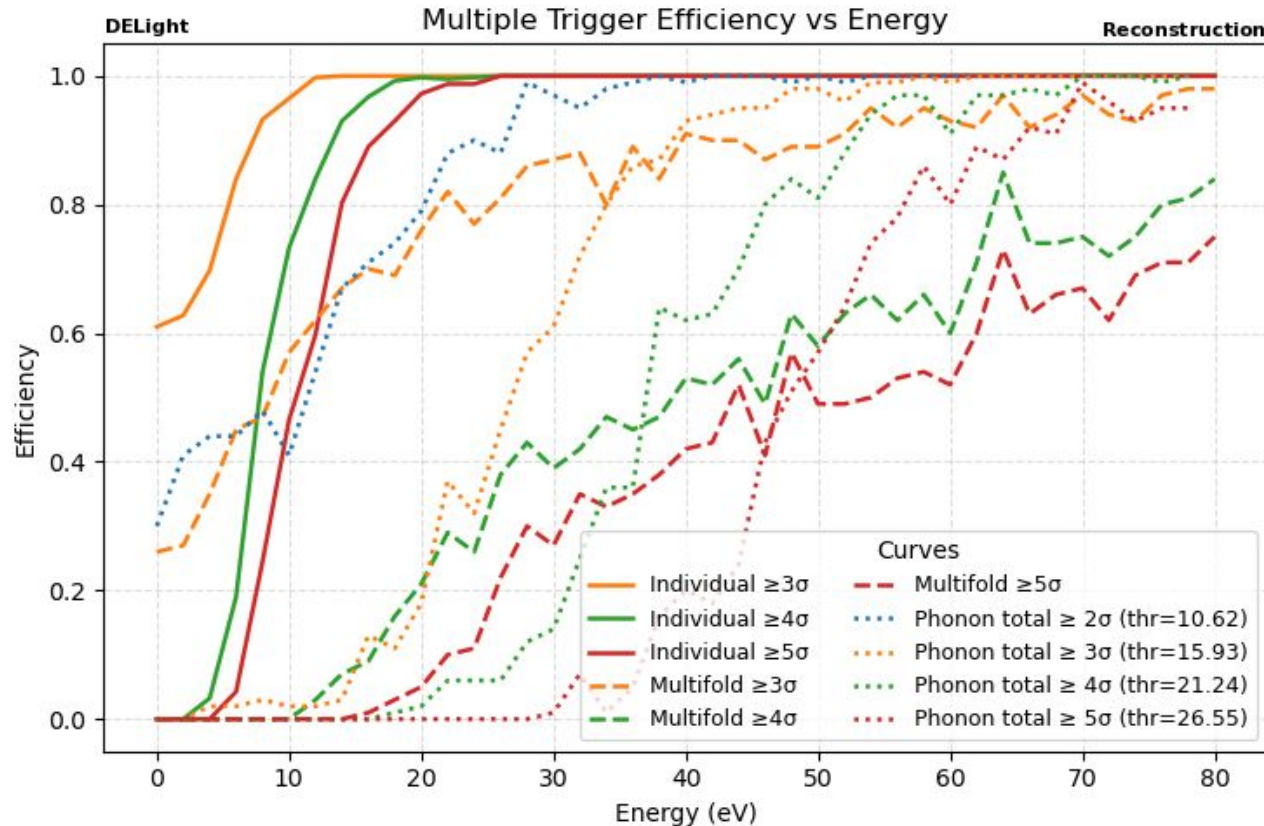
World record
energy resolution



Calibration function of energy is described by a
second-order polynomial:

$$E = p_1 \cdot A_{\text{cOF}}^2 + p_2 \cdot A_{\text{cOF}}$$

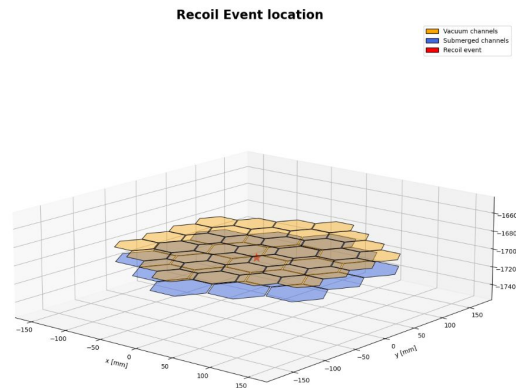
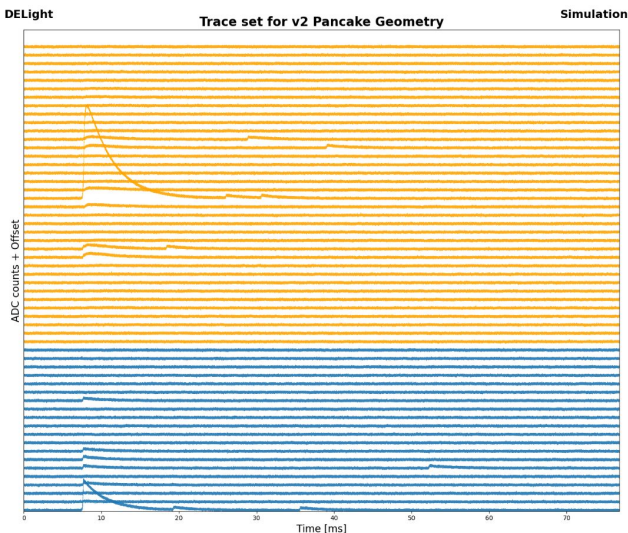
Amplitude estimator: Software trigger



- 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

