Superconducting Bolometers for the Ricochet Experiment

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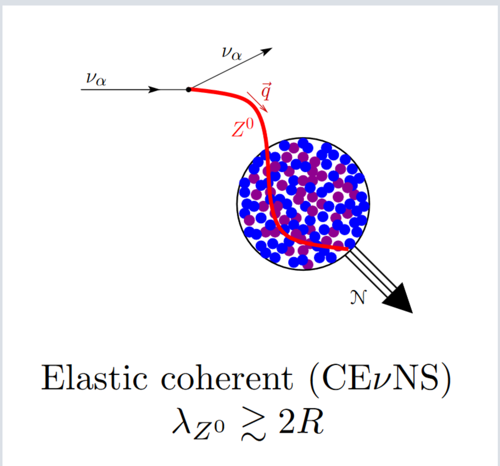
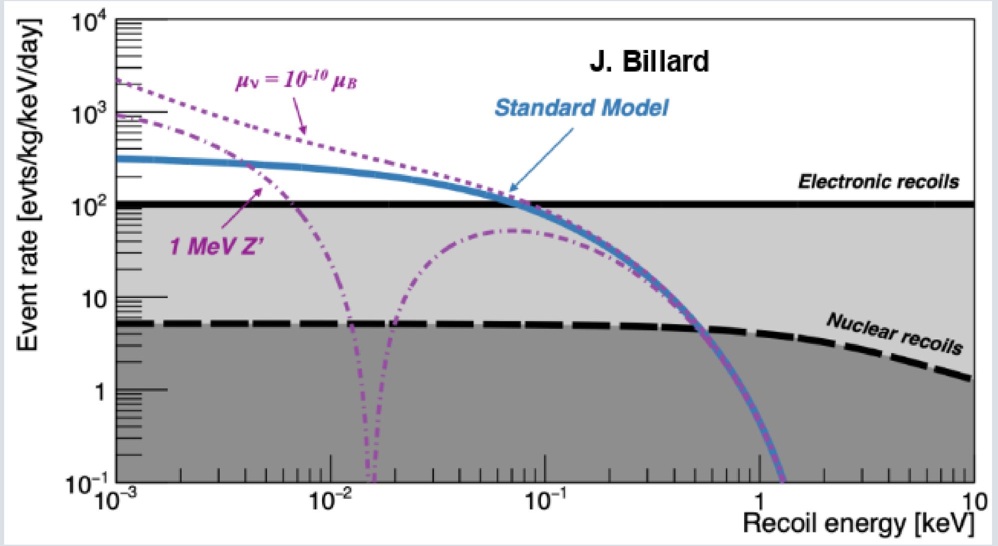
Coherent Neutrino Scattering



CEνNS Diagram from [1].



CEνNS Sensitivity courtesy of J. Billard.

CEνNS (Coherent Elastic Neutrino-Nucleus Scattering) is a process where a neutrino scatters off a nucleus coherently [2].

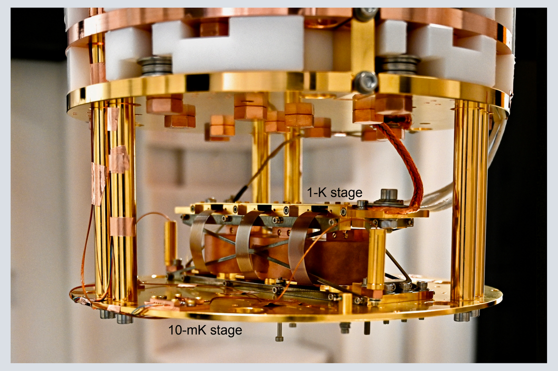
$$\frac{d\sigma}{dE_r} = \frac{G_F^2 M}{4\pi} Q_W^2 \left(1 - \frac{M E_r}{2E_\nu^2}\right) F_W^2(q^2), \quad Q_W^2 = \left[Z(1-4\sin^2\theta_W) - N\right]^2 \simeq N^2$$

weak charge — kinematics — form factor

For momentum transfer less than $|\vec{q}| \sim \mathcal{O}(10)$ MeV/c, the interaction becomes coherent:

- The cross section is enhanced by N^2 (number of neutrons), but the recoil energy is small.
- CEνNS is a sensitive probe of nuclear structure and potential new physics at low energies.
- Reactor experiments like Ricochet benefit from high neutrino flux for CEνNS searches.

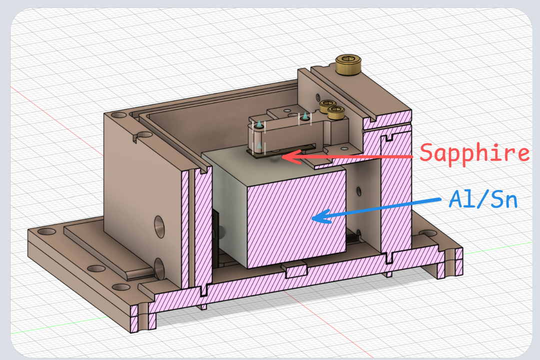
Ricochet Overview



Installed MiniCryoCube.

- Ricochet is actively taking data at the ILL reactor in Grenoble, France with Ge detectors (CryoCube).
- A complementary array of superconductor bolometers (Q-Array) is in development.
- Bulk superconductor has a smaller excitation energy ($2\Delta_{Sn}$=1.13 meV) compared to Ge (~ 2.6 eV).

- Ricochet operates near a 58 MW reactor in Grenoble.
- Expected CEνNS rate: 11 events/day/kg at 50 eV threshold.
- Reactor on/off cycles and shielding help us estimate and reduce backgrounds.

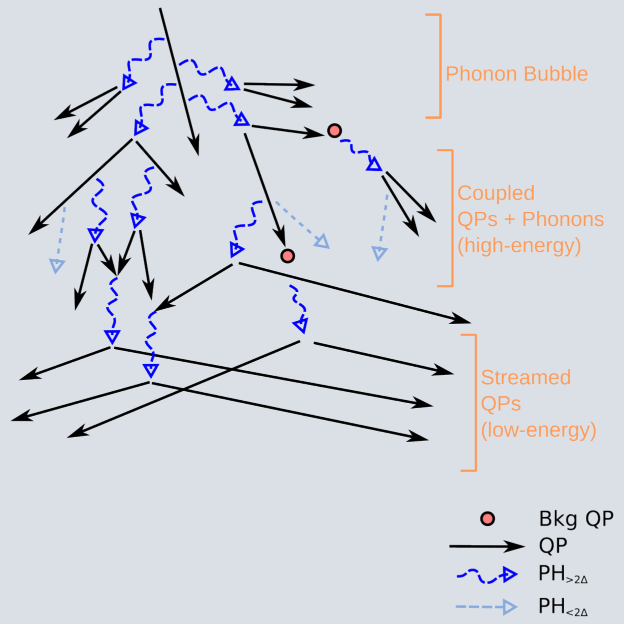


Q-Array Box Design.

Energy Downconversion Process in a Metal Superconductor

When a particle interacts, it initiates a cascade of quasiparticles and phonons:

- High-energy electrons create quasiparticles and Debye phonons.
- Phonons above 2Δ break Cooper pairs, multiplying excitations.
- Recombination emits more pair-breaking phonons.
- Phonons below 2Δ propagate ballistically.
- The cascade carries energy to the sensor as signal.



Test with the Sn Cube

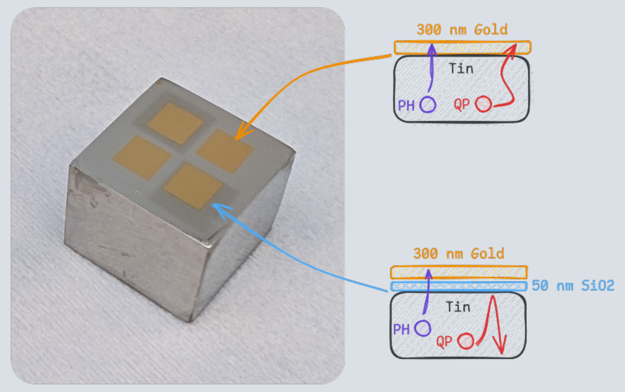
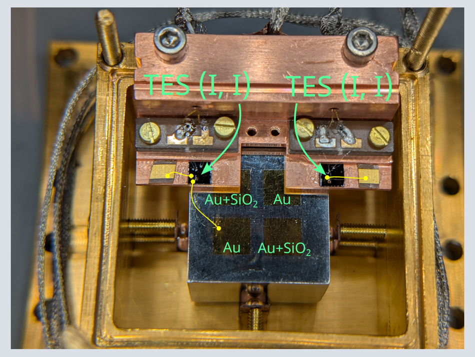


Diagram of the Sn cube and collection pad.



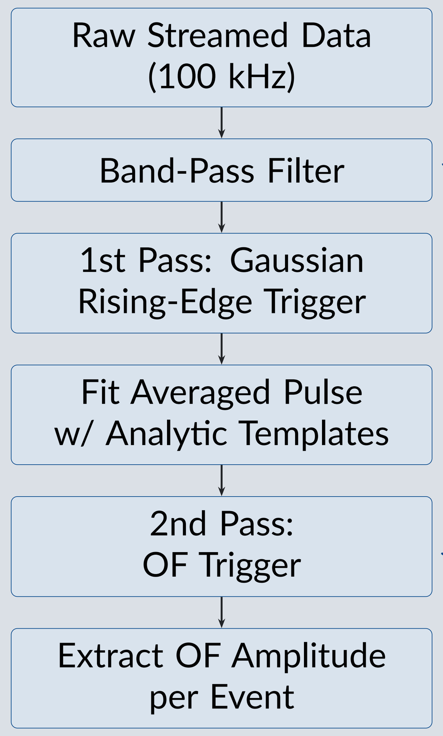
The Q-Array box as assembled.

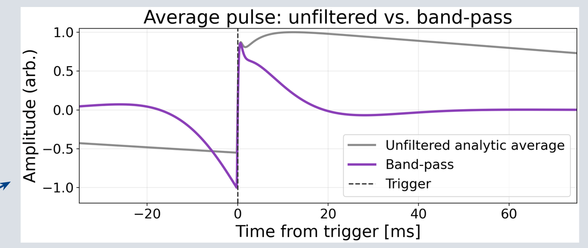
- Sn is chosen due to its faster recombination time compared to Al.
- A SiO_2 insulation layer between the Au collection pad and the crystal is used to test quasiparticle vs. phonon separation.
- Two datasets acquired: one with a SiO_2 insulation layer and one with direct Au contact between the collection pad and crystal.

Focus of This Work

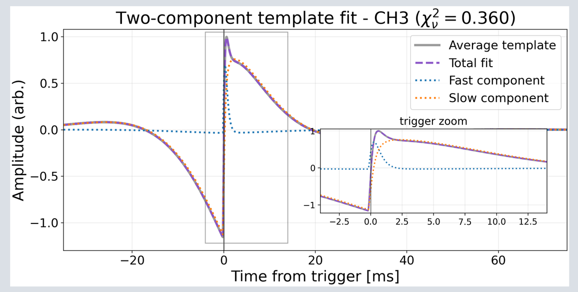
We focus on the direct contact dataset to characterize the detector response and energy resolution. There is no "fast component" in the insulation layer dataset.

Data Processing Pipeline with PyCRP

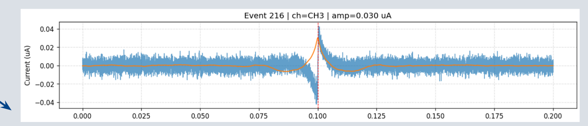




Raw average and band-passed.

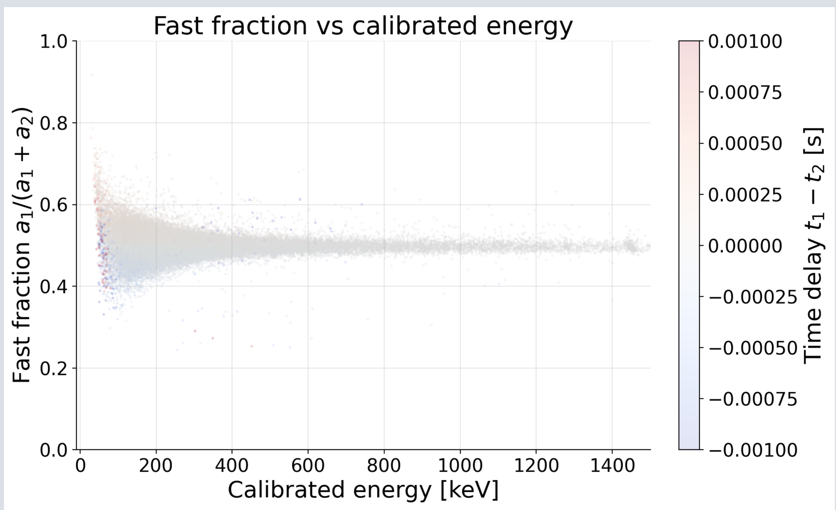


Two-component template fit.



OF trigger example.

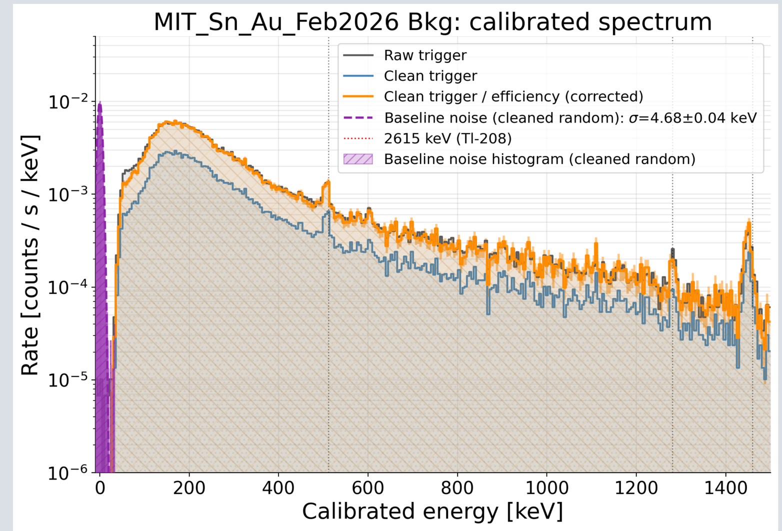
Pulse Shape Parameters



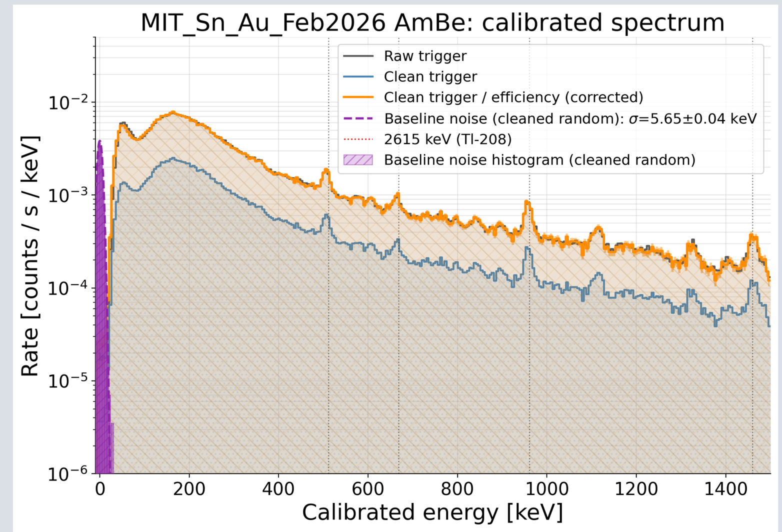
Amplitude ratio for the Bkg run (without any external source) between the two components colored by the time delay.

- The time delay (fast component start minus slow component start) between the two components is consistent with 0, which can be used as a signal quality cut.
- In the current dataset analyses, we have not yet observed differences between electron and nuclear recoil events.

Energy-calibrated Spectra



Background spectrum after cut-efficiency correction.



AmBe spectrum after cut-efficiency correction.

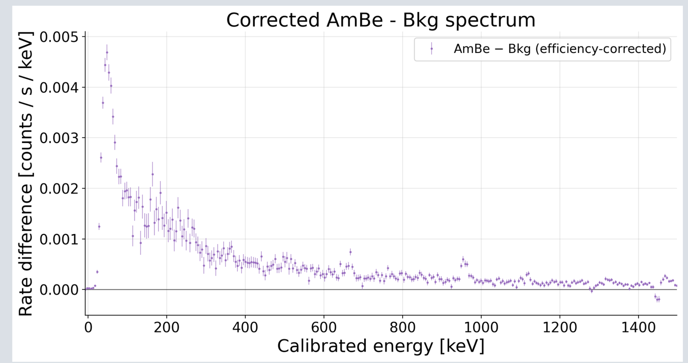
- Clean-trigger spectra are calibrated and corrected for cut efficiency.
- AmBe run shows an elevated continuum and source-induced structures above background.
- Calibration lines remain visible across the full energy range.

Detector Performance:

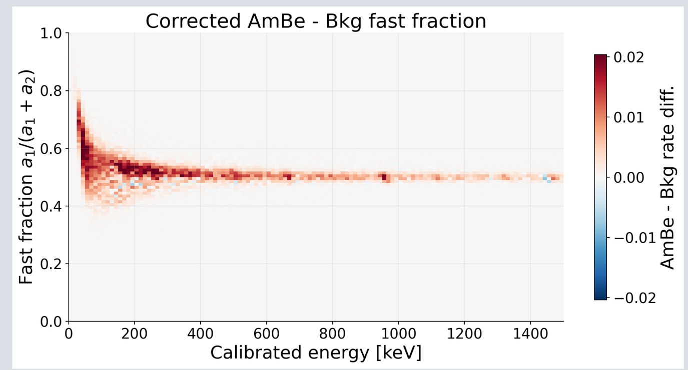
- Background baseline: (4.65 ± 0.02) keV
- AmBe baseline: (5.77 ± 0.03) keV

Outlook: The resolution is limited by the signal-to-noise ratio. Reducing the crystal size and therefore its heat capacity could improve the resolution in the future.

Background Subtracted Histograms



Subtraction histogram between AmBe and Bkg.



Fast fraction vs. energy.

- AmBe−background subtraction uses calibrated, cut-efficiency corrected rates.
- The source excess is largest below 300 keV and falls with energy, rough consistent with the expected maximum neutron recoil energy.
- The 2D subtraction localizes this excess in a fast-fraction band near $0.5 \sim 0.8$.
- Residual narrow structures line up with the same calibration features seen in the spectra.

Summary and Outlook

- Direct-contact Sn data are now energy calibrated and cut-efficiency corrected.
- Baseline resolutions are (4.65 ± 0.02) keV for background and (5.77 ± 0.03) keV for AmBe.
- AmBe−background subtraction shows a low-energy source excess consistent qualitatively with the expected neutron recoil energy.
- Next steps: refine pulse-shape interpretation, compare to the insulation-layer dataset, and use simulations to model energy transport.

References

[1] M. Cadeddu et al. "A view of Coherent Elastic Neutrino-Nucleus Scattering." In: *Europhysics Letters* 143.3 (Aug. 1, 2023), p. 34001. ISSN: 0295-5075, 1286-4854. arXiv: 2307.08842[hep-ex,physics:hep-ph,physics:nucl-ex,physics:nucl-th].

[2] Daniel Z. Freedman. "Coherent effects of a weak neutral current." In: *Physical Review D* 9.5 (Mar. 1, 1974), pp. 1389–1392.

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