

Searching for $0\nu\beta\beta$ in ^{100}Mo with the CUPID Experiment

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on behalf of the CUPID Collaboration

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What is CUPID?

Forthcoming upgrade to CUORE

CUORE Uppgrade with Particle IDentification

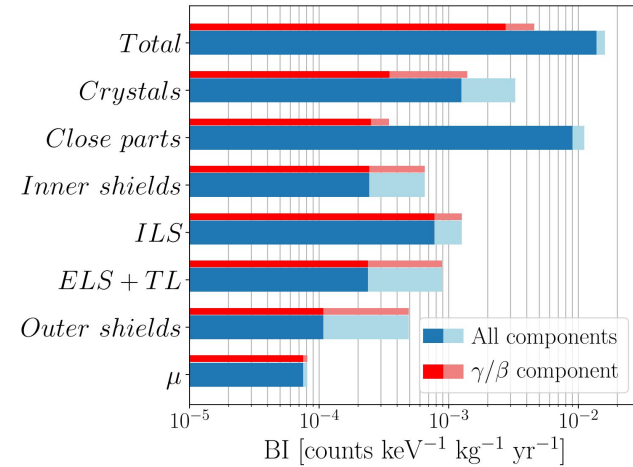
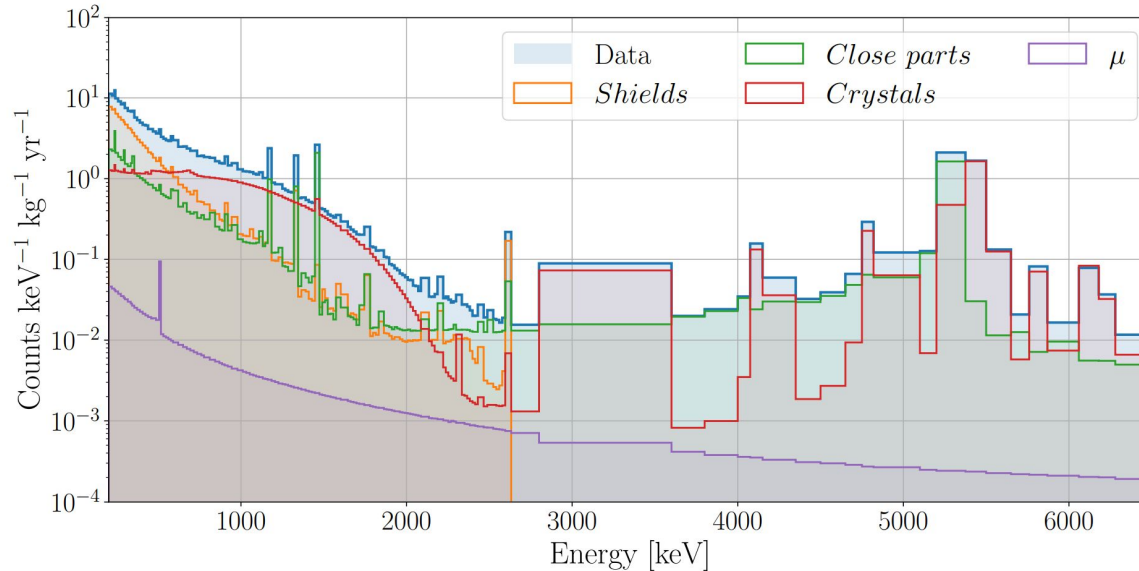
Particle identification comes from correlating energy deposition in heat and light detectors.

Will be located at the current CUORE cryogenic facility in LNGS, Italy

Will use ^{100}Mo as the isotope of interest



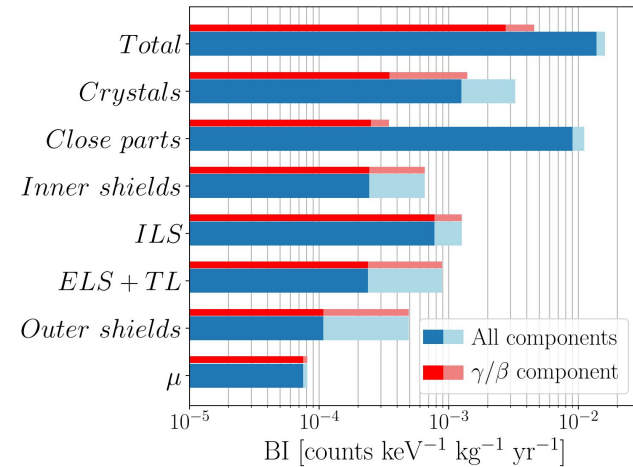
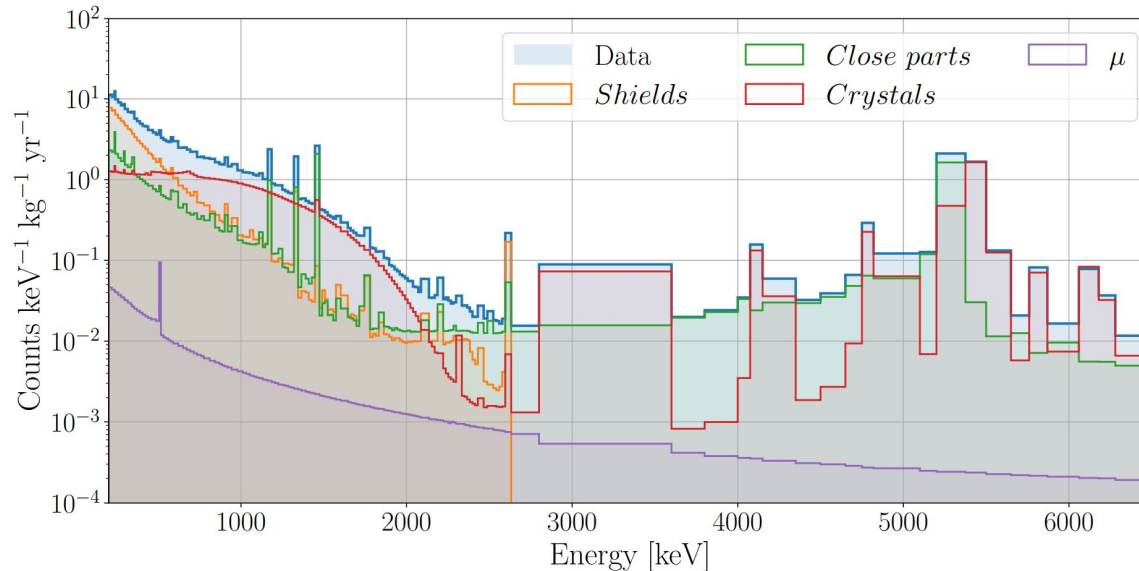
CUORE Background Model



CUORE Collaboration. Data-driven background model for the CUORE experiment. *Physical Review D*, 110(5), 052003. (2025)
<https://doi.org/10.1103/PhysRevD.110.052003>

In the region of interest @2527 keV, CUORE's background index is $\sim 10^{-2}$ counts/keV/kg/yr (ckky).

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This background is dominated by degraded alpha events. CUPID seeks to remove this background.

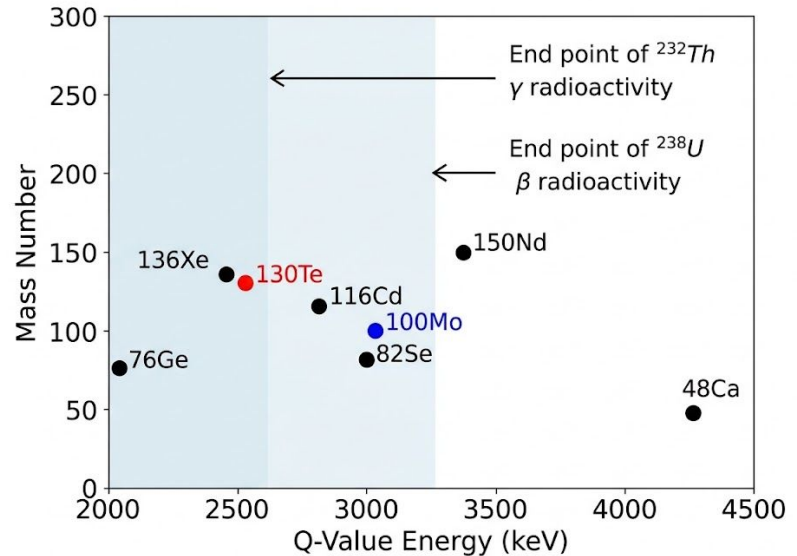


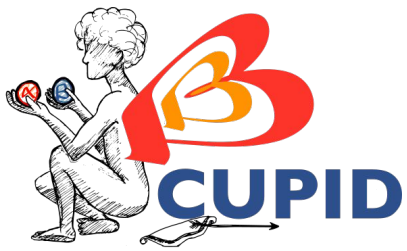
Changing Isotopes

CUPID will use enriched $\text{Li}_2^{100}\text{MoO}_4$ (LMO) crystals instrumented with NTD-Ge thermometers

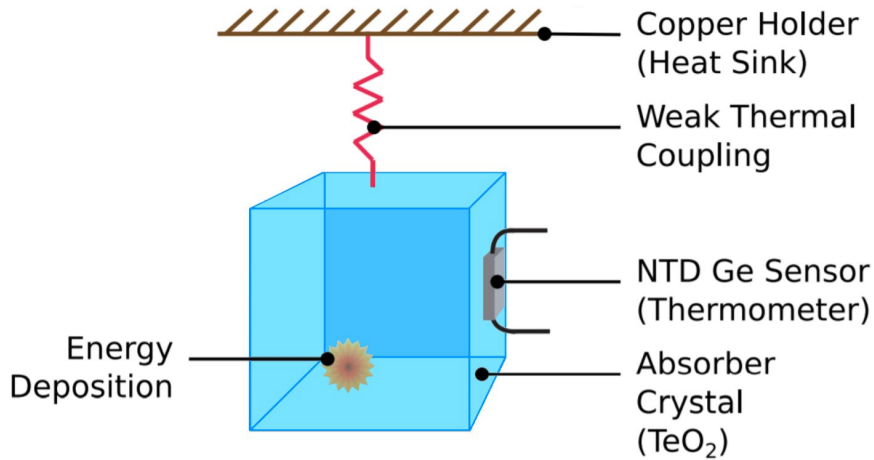
^{100}Mo has a Q-value of 3034 keV

- 3034 lies above the 2615 keV peak from ^{208}Tl in the Thorium chain
- Decay rate scales as Q^5 (Sargent's Rule)
- *Still lies in the degraded alpha region*
 - *In CUORE, alpha background is higher at 3034 keV than at 2527 keV.*

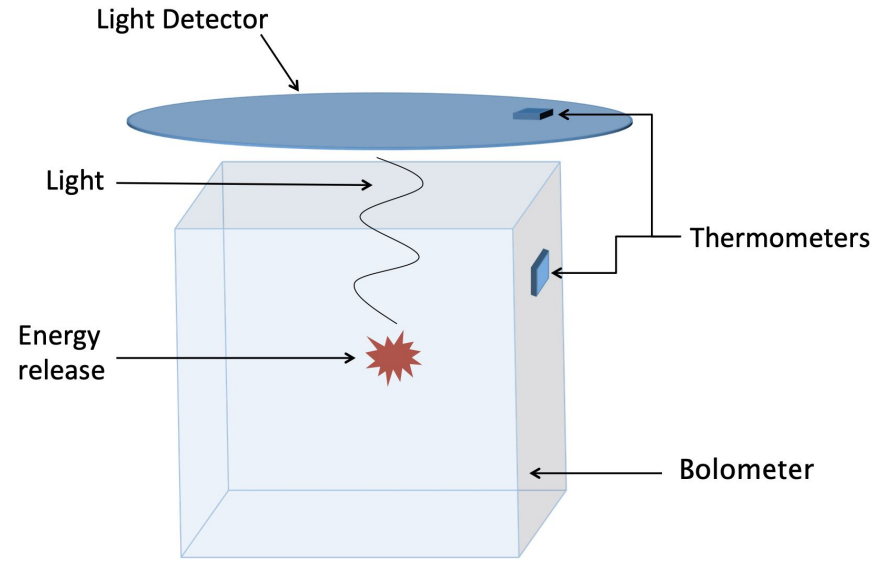




CUORE vs. CUPID



Single Crystal Calorimeter



Scintillating Crystal Calorimeter
+ Ge Wafer Light Detector + SiO ARC

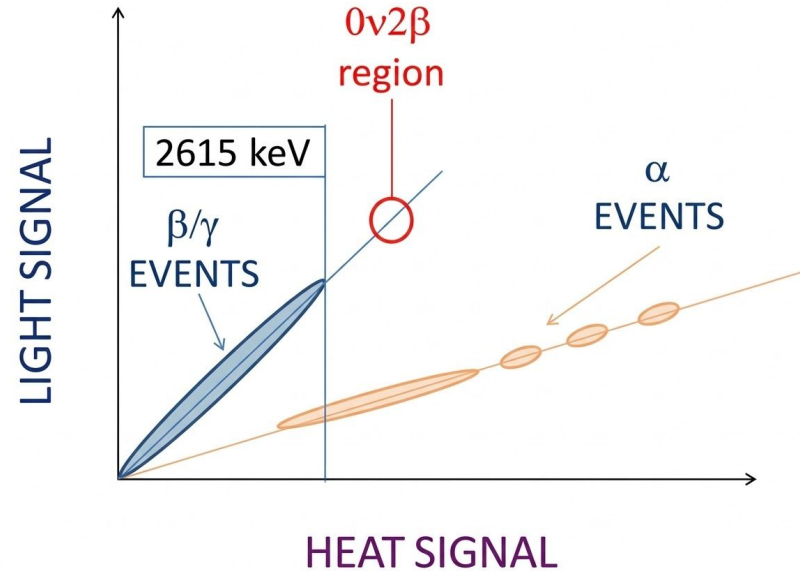


Removing Alpha Events

For a given deposited energy, an α event produces significantly less light than a β/γ event of the same energy.

This separation improves at higher energies, enabling near-complete rejection of α events at $Q_{\beta\beta}$.

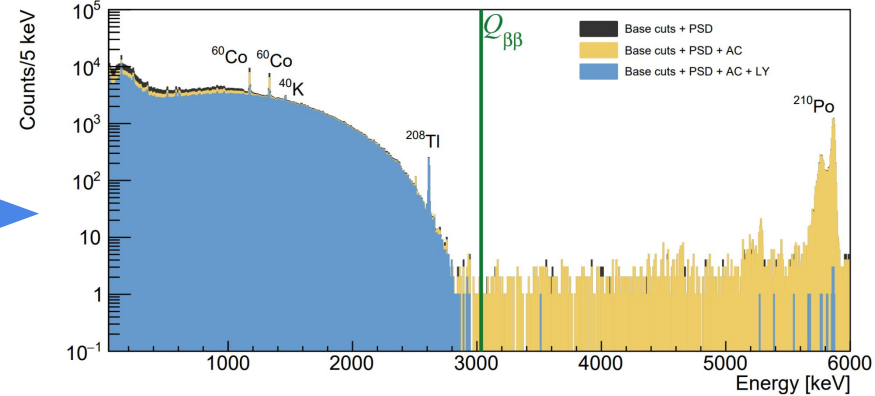
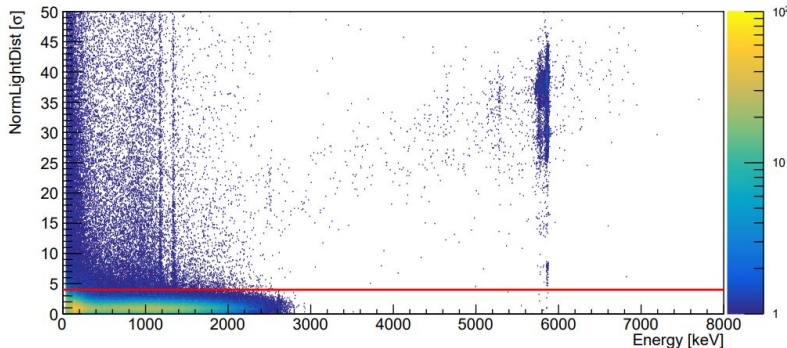
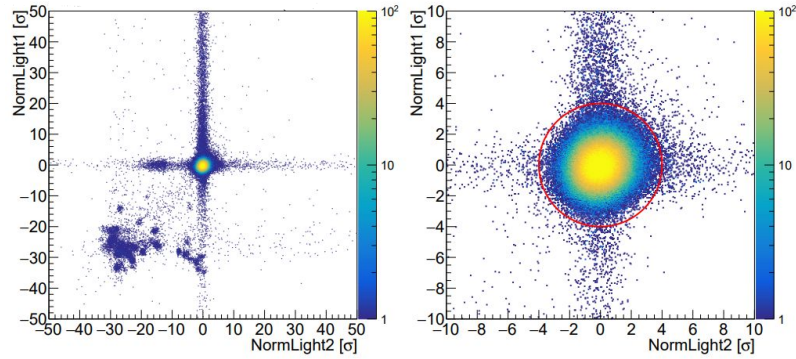
With light detectors above and below each calorimeter crystal, we further enhance discrimination by combining the signals from all three detectors.



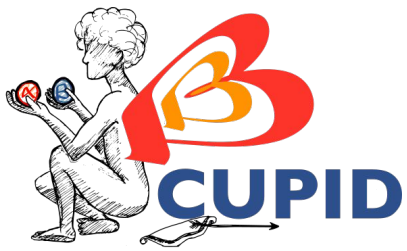
CUPID Collaboration. CUPID, the CUORE upgrade with particle identification. Eur. Phys. J. C 85, 737 (2025).
<https://doi.org/10.1140/epjc/s10052-025-14352-1>



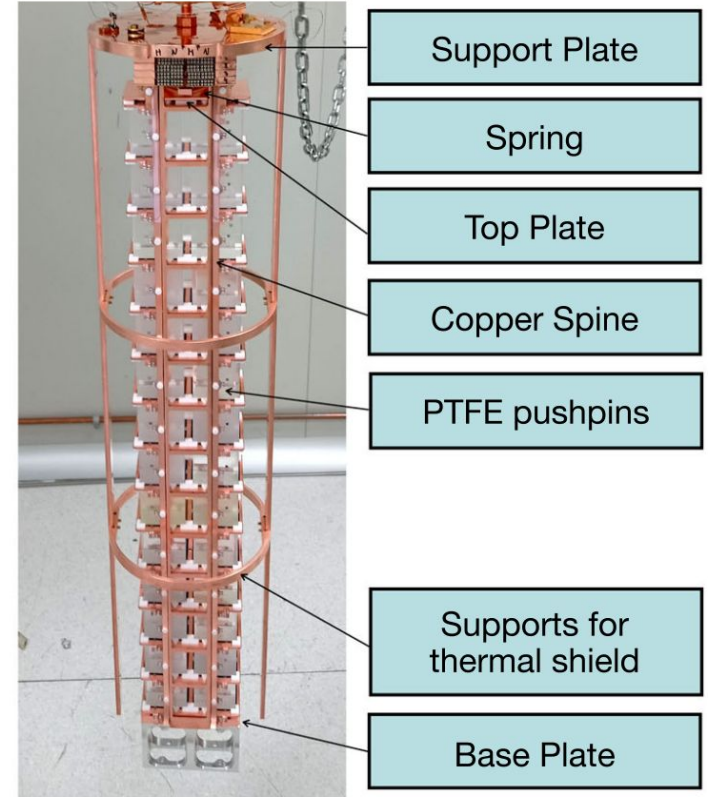
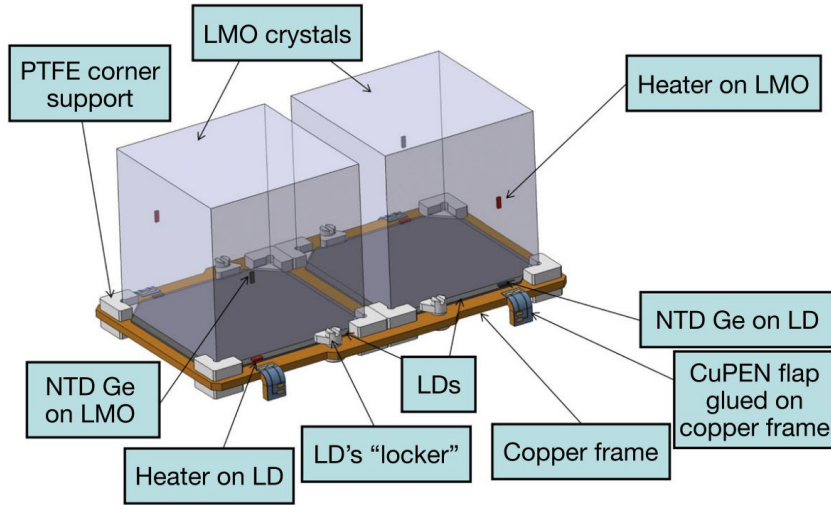
Removing Alpha Events



Augier, C., *et al.* Final results on the decay half-life limit of Mo from the CUPID-Mo experiment. *Eur. Phys. J. C* 82, 1033 (2022).
<https://doi.org/10.1140/epjc/s10052-022-10942-5>



The CUPID Detector



CUPID Collaboration. A gravity-based mounting approach for large-scale cryogenic calorimeter arrays. *Eur. Phys. J. C* 85, 935 (2025).

<https://doi.org/10.1140/epjc/s10052-025-14613-z>



Background Expectations

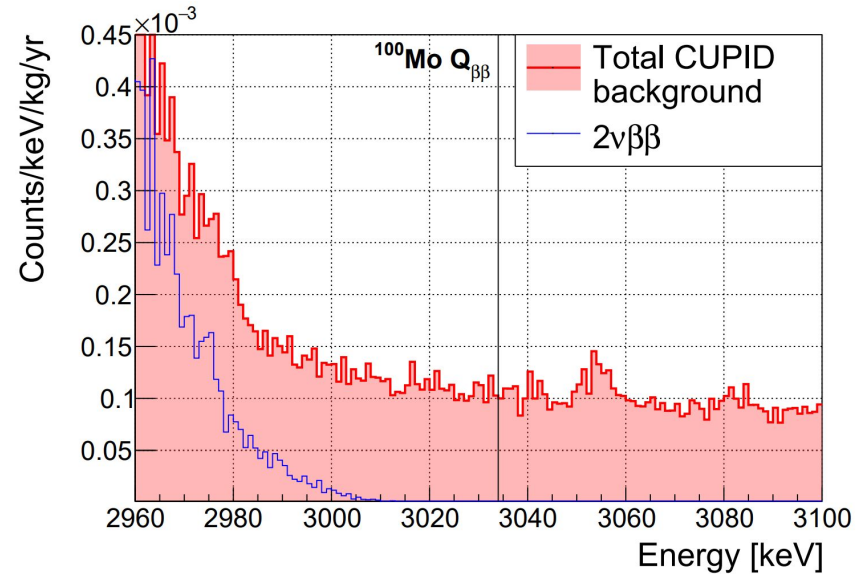
CUPID will be hosted in the CUORE cryogenic facility.

We can use the knowledge from CUORE to inform the CUPID background model.

Expected CUPID background at $Q_{\beta\beta}: 10^{-4}$ ckky

Light detectors also provide pileup rejection which helps reduce the beta/gamma background at $Q_{\beta\beta}$

- Faster response to events and better SNR



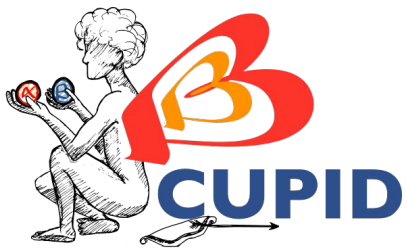
Alfonso, K., et al. Sensitivity of the CUPID experiment to $0\nu\beta\beta$ decay of ^{100}Mo . arXiv preprint arXiv:2504.14369 (2025).
<https://arxiv.org/abs/2504.14369>



Experimental Parameters

	CUORE Performance	CUPID Projected Value*
Crystal Mass	742 kg	450 kg
Isotopic Mass	206 kg	240 kg
Energy Resolution (FWHM)	~ 7.5 keV	5 keV
Livetime	8 years (ongoing)	10 years
Containment efficiency	88%	79%
Selection Efficiency	93%	90%
Background Index	10^{-2} ckky	10^{-4} ckky

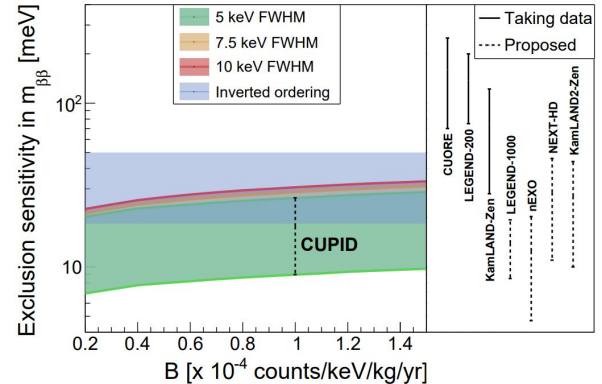
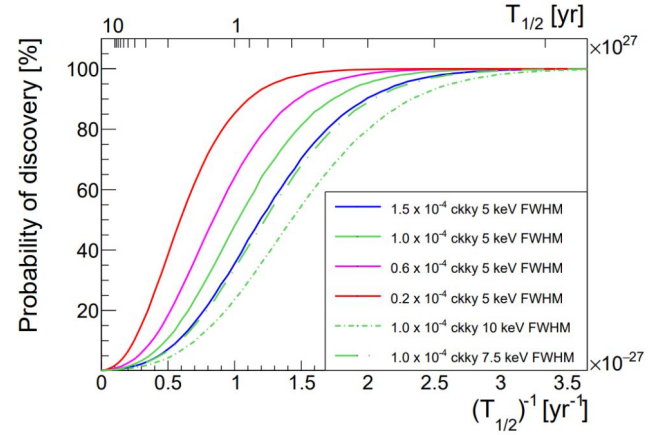
*Values from: Alfonso, K., et al. Sensitivity of the CUPID experiment to $0\nu\beta\beta$ decay of ^{100}Mo . arXiv preprint arXiv:2504.14369 (2025). <https://arxiv.org/abs/2504.14369>



Projected Sensitivities

Assuming 10^{-4} ckkY bkg. index and 5 keV energy resolution:

- Discovery sensitivity (3σ Frequentist):
 - $T_{1/2} = 1.0 \times 10^{27}$ years
 - $m_{\beta\beta}$ range: 12 – 36 meV
- Exclusion Sensitivity (90% Bayesian):
 - $T_{1/2} > 1.6 \times 10^{27}$ years
 - $m_{\beta\beta} < 9.6 - 28$ meV



Alfonso, K., et al. Sensitivity of the CUPID experiment to $0\nu\beta\beta$ decay of ^{100}Mo . arXiv preprint arXiv:2504.14369 (2025). <https://arxiv.org/abs/2504.14369>

Conclusions

CUPID is the forthcoming upgrade to CUORE, replacing TeO_2 crystals with enriched $\text{Li}_2^{100}\text{MoO}_4$ crystals instrumented with light and heat detectors.

The experiment will use the existing CUORE infrastructure and profit from the accumulated body of knowledge from CUORE.

With a predicted background index of 10^{-4} ckky, CUPID seeks to achieve a discovery sensitivity to $0\nu\beta\beta$ half-life of 10^{27} years.

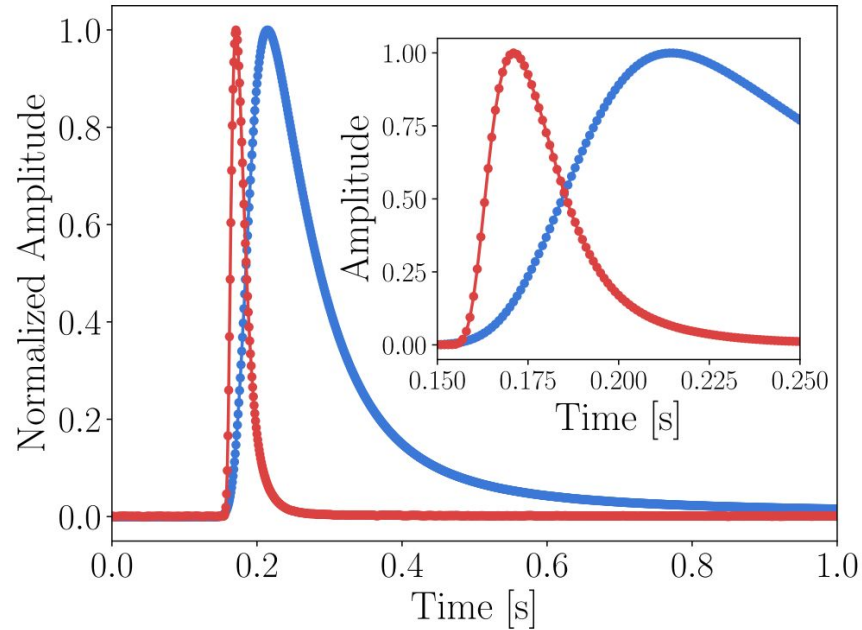
CUPID will also aim to exclude much of the allowed $0\nu\beta\beta$ parameter space in the inverted mass ordering.



Thank you!

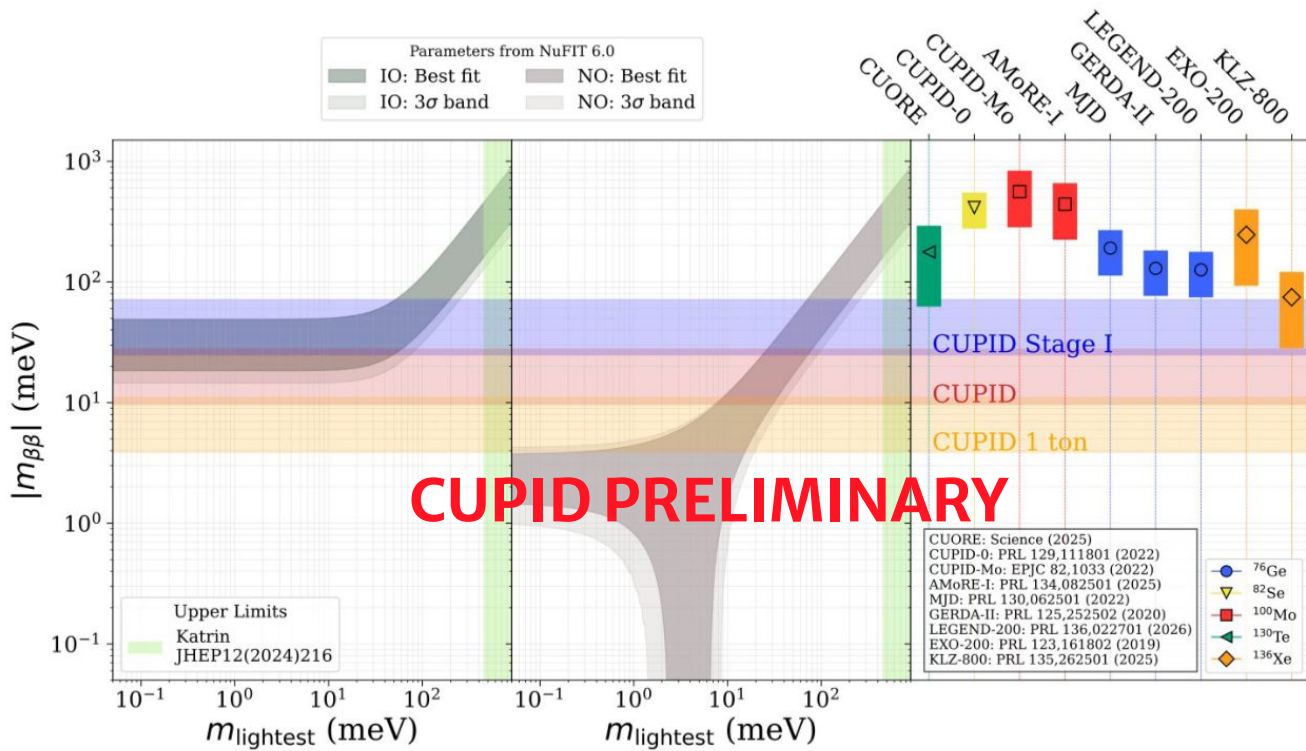
Backup

LD Pulse vs TD Pulse



CUPID Collaboration. A gravity-based mounting approach for large-scale cryogenic calorimeter arrays. *Eur. Phys. J. C* 85, 935 (2025).
<https://doi.org/10.1140/epjc/s10052-025-14613-z>

A Phased Approach





The CUPID Baseline Design

$(45 \text{ mm})^3 \text{Li}_2^{100}\text{MoO}_4$ crystals, 280g each

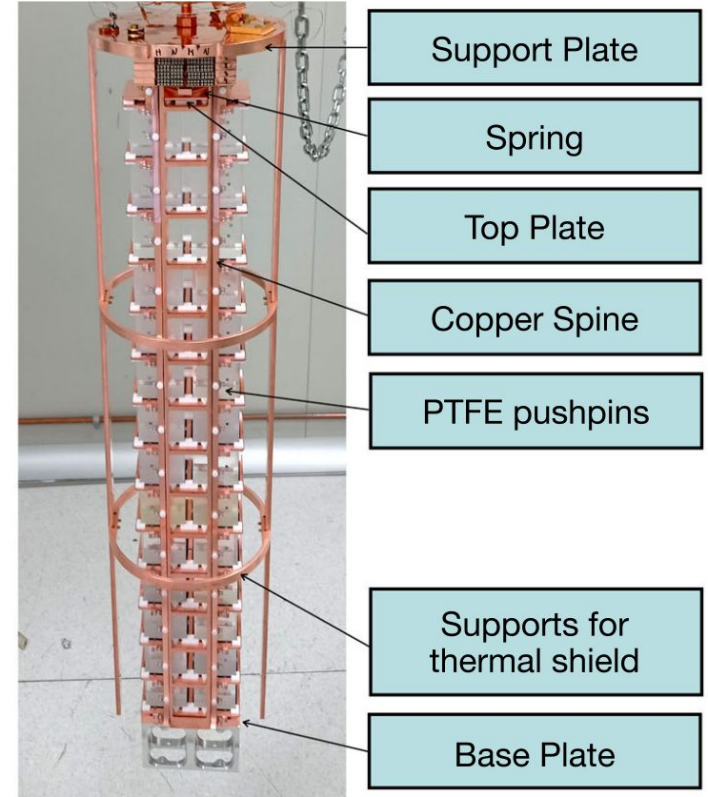
Ge light detectors on top and bottom of each crystal

57 towers of:

- (2x14) LMO crystals = 1596 total crystals
- (2x15) Light detectors = 1710 light detectors

CUPID Collaboration. CUPID, the CUORE upgrade with particle identification. *Eur. Phys. J. C* 85, 737 (2025).

<https://doi.org/10.1140/epjc/s10052-025-14352-1>



Ongoing Demonstrators

Recent demonstrator results published in *EPJC*.

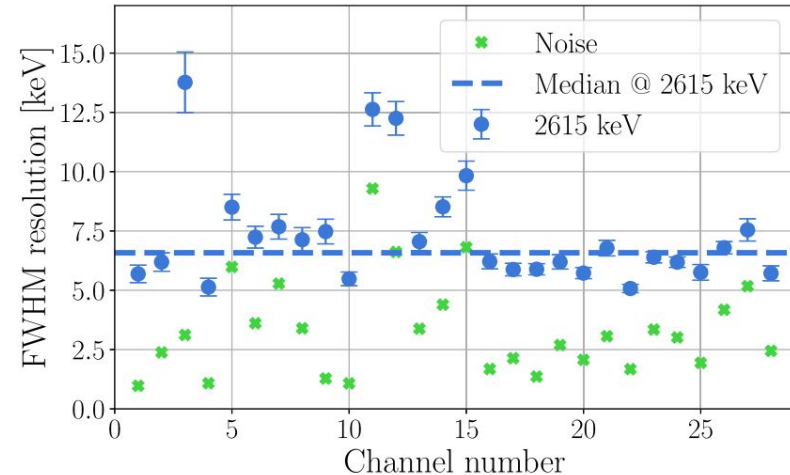
Single CUPID tower with 28 crystals and 30 light detectors

- 21 unenriched crystals
- 7 crystals enriched to $\sim 98\%$ ^{100}Mo

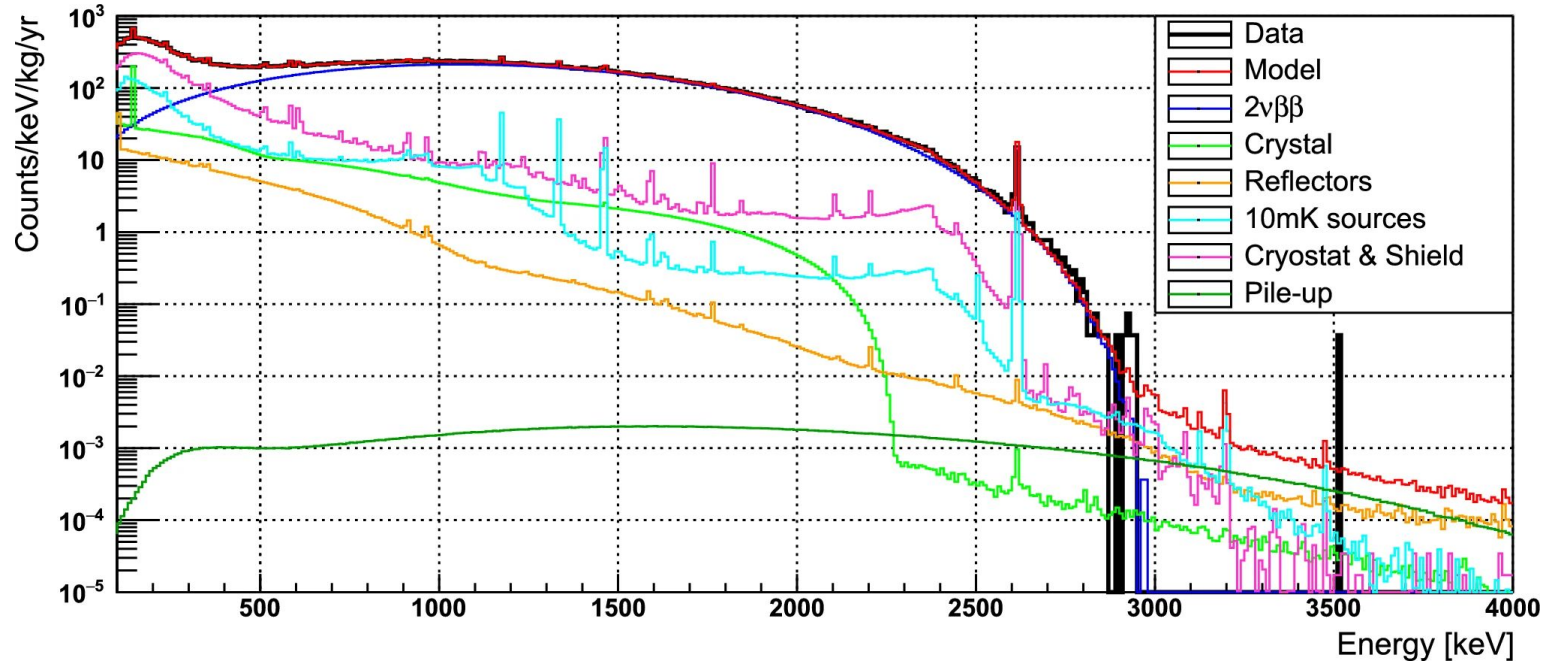
Results:

- Stable temperature conditions: 10 ± 0.5 mK
- Avg resolution @ 2615 keV: 6.6 ± 2.2 keV (FWHM)
- Light yield (LD signal / heat signal): 0.36 keV/MeV

CUPID Collaboration. A gravity-based mounting approach for large-scale cryogenic calorimeter arrays. *Eur. Phys. J. C* 85, 935 (2025).
<https://doi.org/10.1140/epjc/s10052-025-14613-z>



CUPID-Mo Bkg Model



Augier, C. et al. (CUPID-Mo Collaboration) (2023). The background model of the CUPID-Mo $0\nu\beta\beta$ experiment. *The European Physical Journal C*, 83(7), 1–24.

<https://doi.org/10.1140/epjc/s10052-023-11594-5>

CUPID Projected Sensitivity

