# Multiplicity-2 Analysis in CUORE and CUPID Experiment

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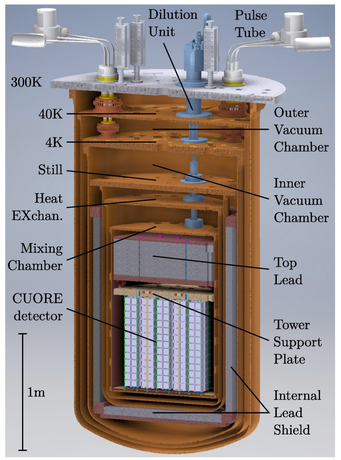
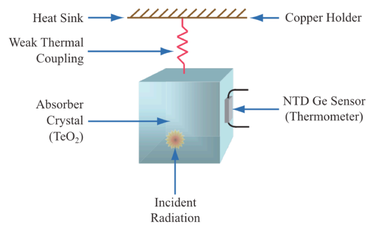
## Introduction: CUORE and CUPID Experiment

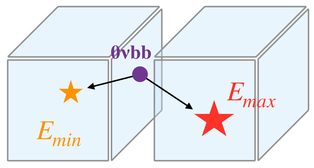
- The Cryogenic Underground Observatory for Rare Events (**CUORE**) is an experiment searching for 0νββ in a ton-scale detector with 19 towers of 988 $TeO_2$ crystals (206 kg $^{130}Te$) at ~ 10 mK, located at the Gran Sasso National Laboratory in Italy.
- From simulation, **~88%** of the signal events deposit energy in one single crystal **(M1)**. **~5-6%** register as dual-site **(M2)** events.




Rendering of the CUORE cryostat
Reference: Cryogenics 102 (2019) 9-21

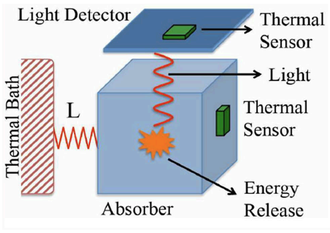



Schematic of a CUORE calorimeter

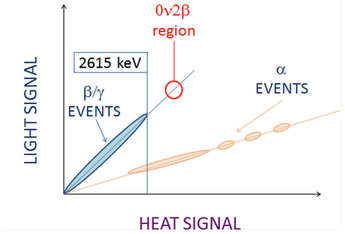



Schematic of a CUORE Multiplicity-2 (M2) event

- CUORE Upgrade with Particle IDentification (**CUPID**) is a next-generation experiment searching for 0νββ and other rare events with $Li_2{}^{100}MoO_4$ scintillating calorimeters using CUORE cryostat.
- With light detector (LD), CUPID can reject most alpha background.
  - M1 background index (BI): $10^{-4}$ cts•keV$^{-1}$•kg$^{-1}$•yr$^{-1}$ (ckky)
  - Discovery sensitivity in $^{100}Mo$ 0νββ half-life: $10^{27}$ yr.




a CUPID scintillating calorimeter

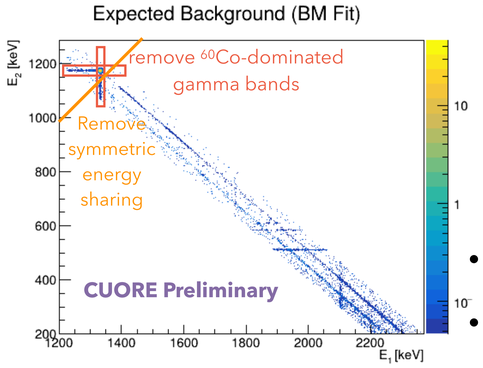


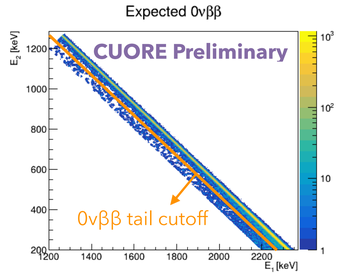

Particle Identification with Light Yield

## CUORE M2 Search with 1 ton-yr Data

- Current analysis uses CUORE 1 ton-yr background model data release: 15 datasets, 1038.4 kg•yr $TeO_2$ exposure.

### Template Fit

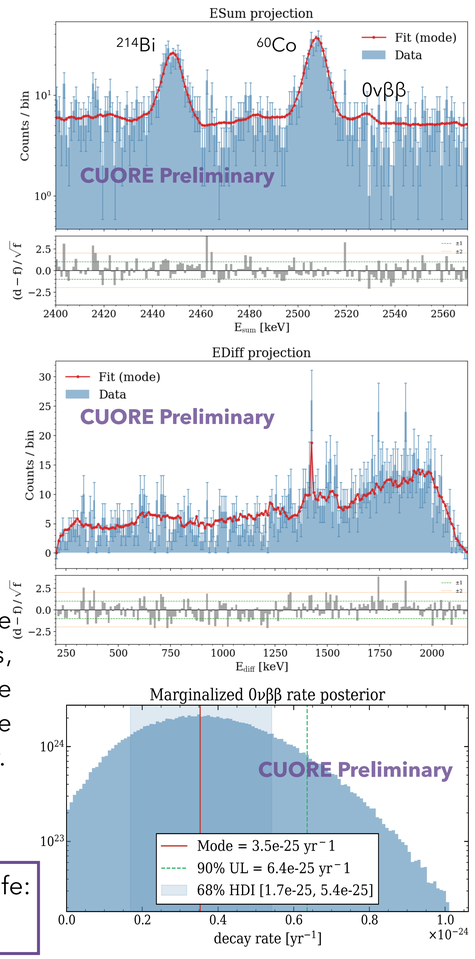



- Reference fit allows $^{60}$Co template shift of +1 keV/MeV.
- Final signal efficiency after M2+analysis cuts: **3.55%**

[Reference: Phys. Rev. D 110, 052003 (2024)]

- Fit the observed M2 events using MC-derived templates for 0νββ, $^{60}$Co, $^{238}$U, $^{232}$Th, and all other background sources.
- Background template normalizations use weak CUORE background model (BM) priors.
- Reference fit gives 0νββ count = $11.7^{+8.7}_{-6.8}$ events.
- Toy-MC injection study corrects fit bias: 0νββ count = $15.3^{+8.6}_{-6.7}$ events.




### Systematics and Preliminary Result

Uncertainties from lineshape parameters, BM statistics, $^{60}$Co shift selection etc. are propagated by smearing the extracted 0νββ rate posterior.

**Fitted 0νββ rate:**

$$\Gamma^{0\nu} = 3.5^{+1.9}_{-1.8} \times 10^{-25}\ \text{yr}^{-1}$$

90% C.I. on $^{130}Te$ 0νββ half-life:
$T^{0\nu}_{1/2} > 1.1 \times 10^{24}$ **yr**.

## CUPID M2 Sensitivity Analysis

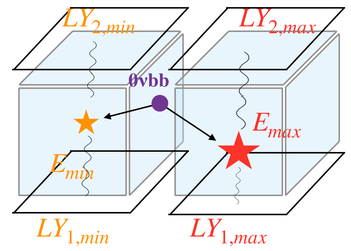
**CUPID Signal Simulation**

| Event Type | No Cuts | In ROI* |
|---|---|---|
| M1LD0 | 82.2% | 72.7% |
| **M2LD0** | **9.6%** | **6.0%** |
| **M1LD1** | **2.1%** | **1.3%** |
| **M2LD1** | **2.3%** | **1.6%** |
| M3LD0 | 2.4% | 1.3% |
| Other | 1.4% | 0.6% |
| Total | 100.0% | 83.5% |

*ROI: Q=3034 ± 4 keV

CUPID Preliminary

- Events can deposit energy in LD through ionization.
- Denote event types: MXLDY [X: number of crystal hits, Y: number of LD hits]




Schematics of M2LD0

### M2LD0

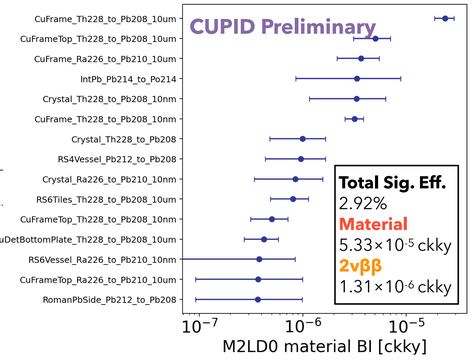
- Main backgrounds in M2LD0 are:
  - **Radioactive background** from surrounding materials.
  - **Coincident 2νββ background** in adjacent crystals.
- Based on simulation, selections designed:
  - Delayed Coincidence: reject beta/gamma from decay chains.
  - Topological Selection: require neighboring crystals.
  - Alpha Rejection: using light yield to reject alphas.
  - Energy-asymmetry Selection: reject 2νββ by selecting asymmetric M2 energy sharing.

**Median Sensitivity in Half-Life**

| Event Type | Discovery Sensitivity ($3\sigma$) [$10^{26}$ yr] | Exclusion Limit (90%) |
|---|---|---|
| M1LD0* | 10.01 | 18.29 |
| M2LD0 | 0.51 | 0.73 |
| **M1LD0 +M2LD** | **10.16** | **18.58** |

CUPID Preliminary

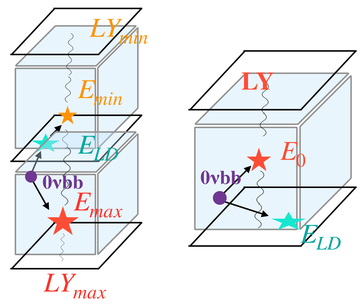
* From CUPID baseline design




M2LD0 material background components

### M1LD1, M2LD1

- Material BIs in M1LD1/M2LD1: **O($10^{-6}$ ckky)** (<1 ROI event/10 yr).
- BI can be further suppressed by energy selection .
- If LDs are well-calibrated at MeV level, M1LD1 and M2LD1 can be potential pseudo **background free** channels for 0νββ search.




Schematics of M2LD1, M1LD1

Other CUORE CUPID Posters

## Acknowledgement

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