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Toward CUPID-1T

Virtual Poster #69
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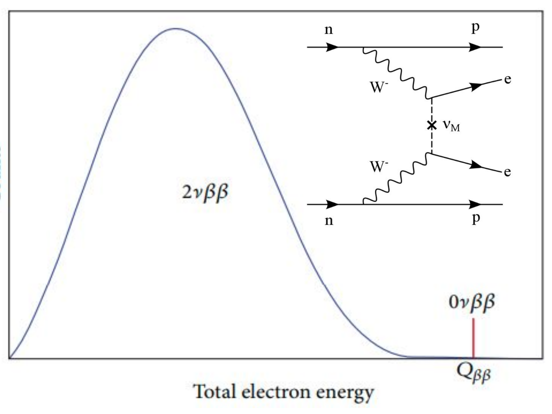
Erin V. Hansen & Danielle Speller for the CUPID Collaboration

Neutrinoless Double Beta Decay with CUPID



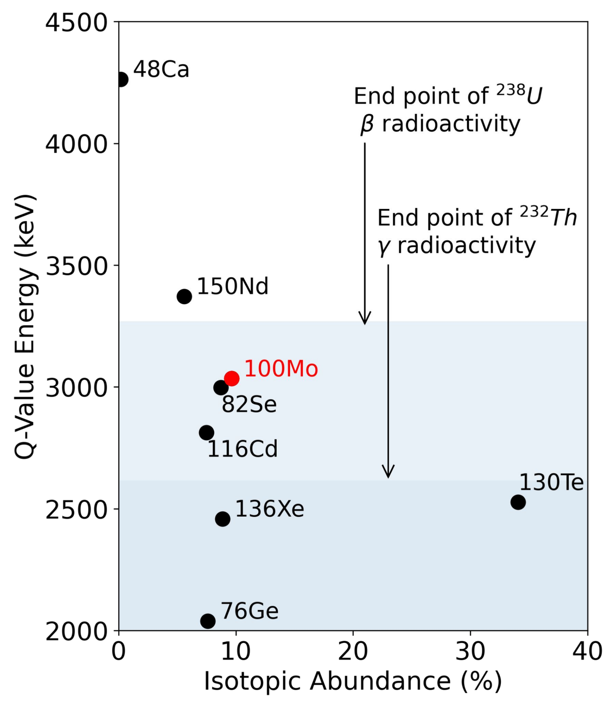
Neutrinoless double beta decay (0νββ) is a second-order rare decay which is theorized to occur if and only if neutrinos are Majorana Fermions (i.e. if neutrinos are their own antiparticle).

In CUPID, we will use the decay

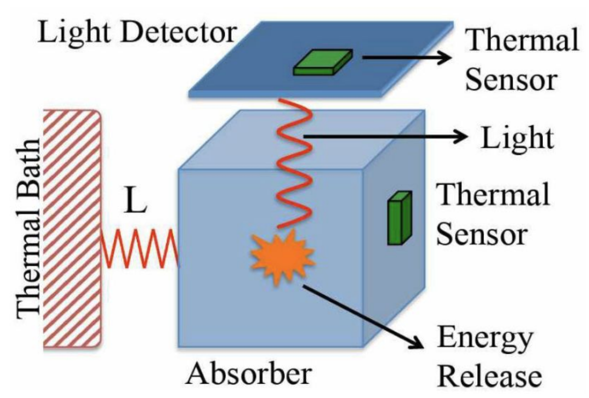
$^{100}Mo \rightarrow {}^{100}Ru + 2e^-$

to search for 0νββ in molybdenum-100. ^{100}Mo is an excellent candidate for this search, as it offers

- a high Q-value (3034 keV) above the bulk of γ environmental background,
- favorable nuclear & kinematic factors which yield an expected decay rate 10x faster than other leading isotopes, and
- ease of embedding into scintillating crystals.

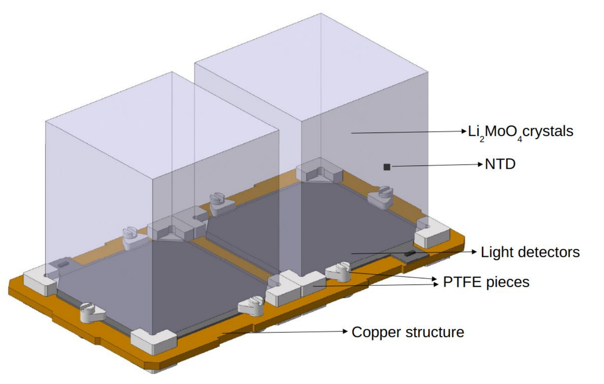


CUPID: CUORE Upgrade with Particle IDentification



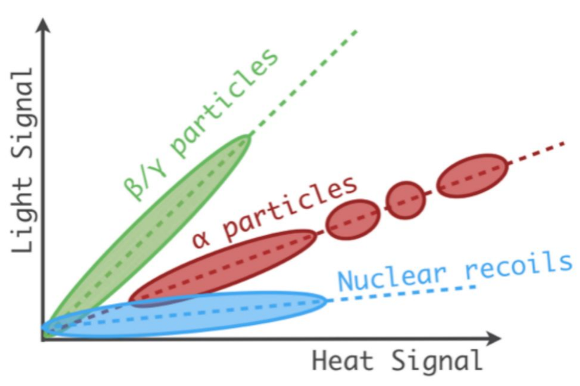
CUPID will use the same cryogenic infrastructure as CUORE at the Laboratori Nazionali del Gran Sasso in Italy.

1596 Li_2MoO_4 cryogenic calorimeters will be instrumented with NTD thermistors for heat signal read out. Each crystal will be 45 x 45 x 45 mm^3, corresponding to a mass of ~280 g each and enriched to >95% ^{100}Mo for a total of 240 kg ^{100}Mo.



Each LMO crystal will also face two Ge light detectors, instrumented with NTDs (a total of 1710 light collectors).

The addition of a photon signal allows for rejection of α backgrounds — CUPID-0 [1] and CUPID-Mo [2] have demonstrated this technique with a success rate of >99%.



Target energy resolution (ΔE) of 5 keV FWHM at Q-value (3034 keV). Target background index of b = 10^{-4} ct/keV/kg/yr.

[1] Phys. Rev. Lett. 123, 032501 (2019)
[2] Phys. Rev. Lett. 126, 181802 (2021)

Discovery sensitivity (3σ, 10 yr)

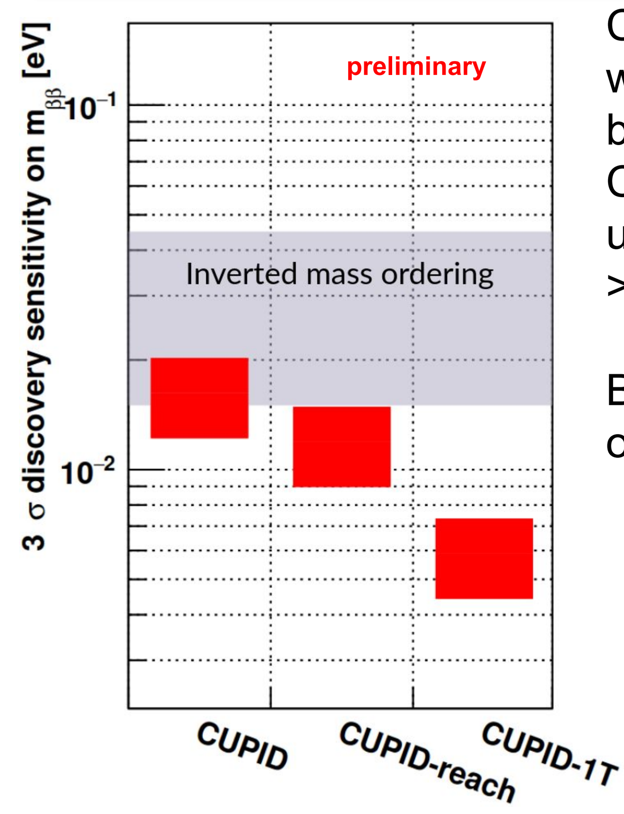
1×10^{27} year

$m_{\beta\beta}$ < 12-20 meV

Acknowledgements

The CUPID Collaboration thanks the directors and staff of the Laboratori Nazionali del Gran Sasso and the technical staff of our laboratories. This work was supported by the Istituto Nazionale di Fisica Nucleare, the Italian Ministry of University and Research (Italy), the European Research Council and European Commission, the US Department of Energy (DOE) Office of Science, the DOE Office of Science, Office of Nuclear Physics, the National Science Foundation (USA), the Russian Science Foundation (Russia), and the National Research Foundation (Ukraine). This research used resources of the National Energy Research Scientific Computing Center (NERSC).

Research and Development towards CUPID-1T



CUPID-Reach relies on the same CUPID infrastructure with updated analysis tools for a 5x reduction in background.
CUPID-1T would host 4x the mass of CUPID using updated technology, including multiplexed readout for >10k channels.

Background can be realistically 20x reduced to the level of 5 x 10^{-6} ckky by

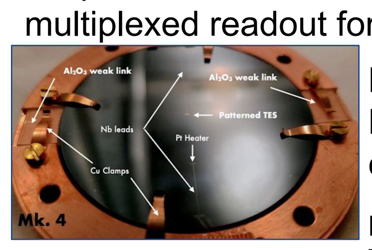
- materials screening & radiopurity,
- improved timing resolution of TES-based detectors,
- passive reduction and active veto for elimination of surface backgrounds,
- further purification of LMO crystals,
- cleaner cryogenic shields for reduction of γ backgrounds, and
- reconstruction of 0νββ event topology.

preliminary

Parameter	CUPID-Baseline	CUPID-Reach	CUPID-1T
Crystal	$Li_2{}^{100}MoO_4$	$Li_2{}^{100}MoO_4$	$Li_2{}^{100}MoO_4$
Detector mass (kg)	450	450	1871
^{100}Mo mass (kg)	240	240	1000
Energy resolution FWHM (keV)	5	5	5
Background index (counts/(keV·kg·yr))	10^{-4}	2 x 10^{-5}	5 x 10^{-6}
Containment efficiency	78%	78%	78%
Selection efficiency	90%	90%	90%
Livetime (years)	10	10	10
Half-life exclusion sensitivity (90% C.L.)	1.4 x 10^{27} y	2.2 x 10^{27} yr	9.1 x 10^{27} yr
Half-life discovery sensitivity (3σ)	1 x 10^{27} y	2 x 10^{27} y	8 x 10^{27} yr
$m_{\beta\beta}$ exclusion sensitivity (90% C.L.)	10–17 meV	8.4–14 meV	4.1–6.8 meV
$m_{\beta\beta}$ discovery sensitivity (3σ)	12–20 meV	9–15 meV	4.4–7.3 meV

Superconducting Sensors

Requirements include fast timing resolution and multiplexed readout for >10k channels.

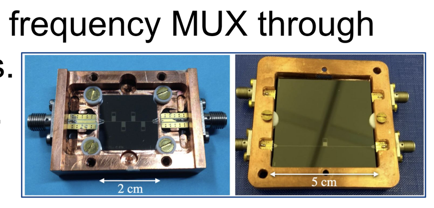


Hennings-Yeomans et.al. Journal of Applied Physics 128, 154501 (2020)

Low-impedance TES
Production is easy to scale, & compatible with multiplexing.

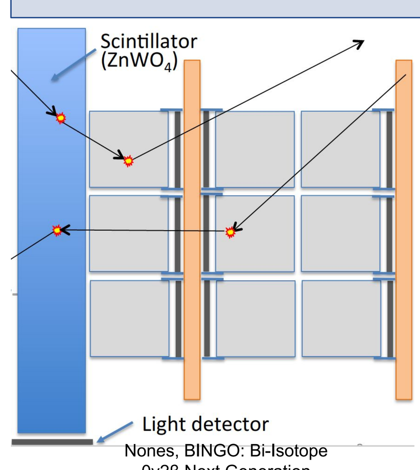
Energy resolution = 100 eV
Timing resolution = 10 μsec

MKIDs: Natively pairs with frequency MUX through tuning of individual devices.
Ongoing work of CALDER.
Noise RMS = 90 eV (vibration dominated)
Risetime = 120 μsec



Cardani et.al. Eur. Phys. J. C 81, 636 (2021)

Active γ Veto

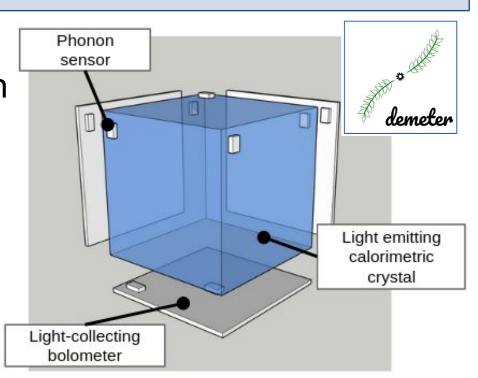


Nones, BINGO: Bi-Isotope 0v2β Next Generation Observatory, TAUP 2021

BINGO (Bi-Isotope 0v2β Next Generation Observatory) is a demonstrator experiment which developed an internal cryogenic active shield based on $ZnWO_4$ or BGO scintillators. Encouraging results for both LMO and TeO_2 source crystals.

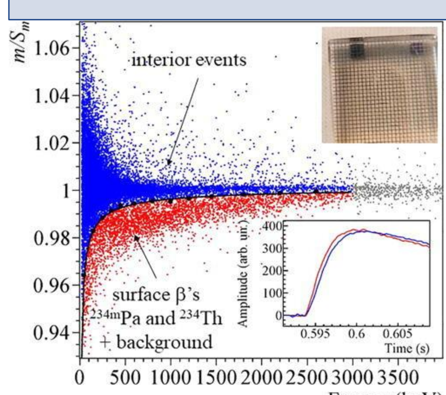
Topological Reconstruction

DEMETER focuses on both phonon and photon reconstruction at the crystal scale to provide physics info & background ID to large scale detectors like CUPID-1T.



Potentially transformative technology: Modular TeO_2 calorimeters with topological reconstruction and PID (Cherenkov and phonon imaging) could mitigate need for enriched detectors.

Reduction in Surface Events



Appl. Phys. Lett. 118, 184105 (2021);

The CROSS project seeks to discriminate surface from bulk events through the use of grid coatings on the LMO crystals. (Left) Al-Pd grid coating, with U source. Surface β rejection efficiency 93(10)%

BINGO (see above) also seeks to reduce surface backgrounds passively, by exposing crystals to only active elements.

CUPID-1T: Beyond 0νββ

A detector with a full ton of target isotope such as CUPID-1T provides an excellent opportunity to search for physics beyond the Standard Model, especially due to the low background rate, the short decay half-life of ^{100}Mo 2νββ, and the large source mass. ***https://arxiv.org/pdf/2203.08386.pdf***

Symmetry Violations & Majorons

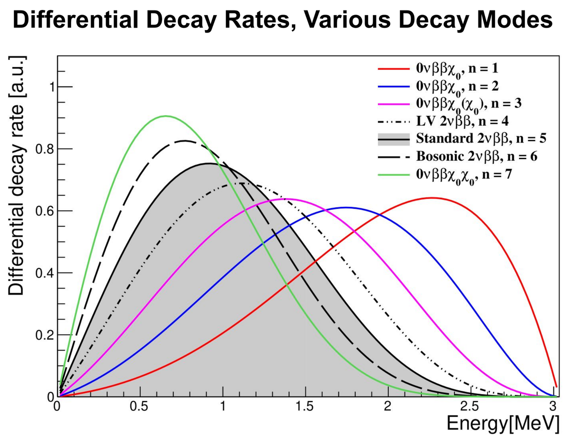
Searches for Lorentz-Violating effects and for Majorons are complementary.

Predicted limit of LV term is

$$\mathring{a}^{(3)}_{of} < 5.5 \times 10^{-8}\ \mathrm{GeV}$$

Predicted limits on half-lives and J-v coupling g_{ee} below. (All limits 90% CI for 1 yr of CUPID-1T datataking)

Differential Decay Rates, Various Decay Modes

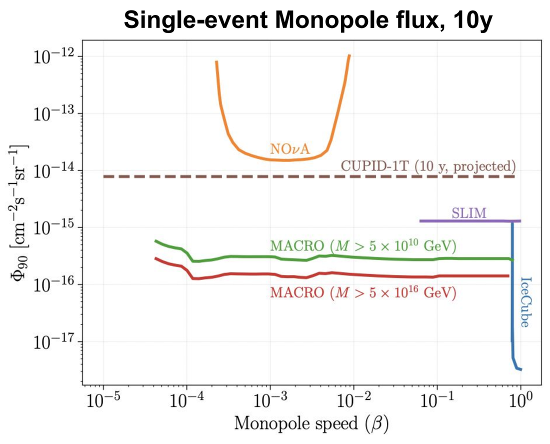


n	mode	predicted lower limit on $T_{1/2}$ [yr]	g_{ee} exclusion sensitivity
1	χ^0	1.3×10^{24}	(4.7 - 6.6) $\times 10^{-6}$
2	χ^0	2.0×10^{23}	-
3	χ^0	6.7×10^{22}	(0.8 - 1.4)
3	$\chi^0\chi^0$	2.7×10^{22}	(4.0 - 5.9) $\times 10^{-3}$
7	$\chi^0\chi^0$	1.2×10^{22}	(3.8 - 7.1) $\times 10^{-1}$

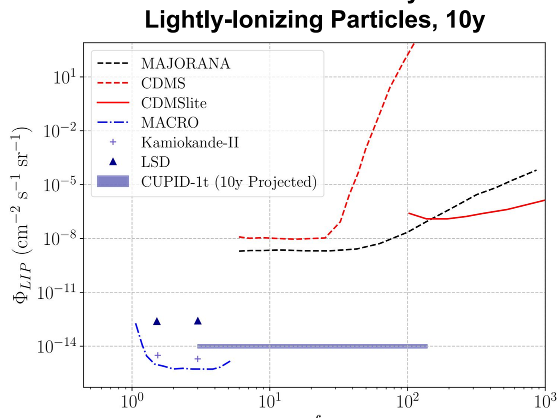
Dark Matter and Track-like Events

- CUPID-1T projects sensitivity to several key BSM dark matter candidates, including Majorons, axions, weakly interacting massive particles (WIMPs), and lightly-ionizing particles.
- Detections would have immediate astrophysical and cosmological relevance

Single-event Monopole flux, 10y



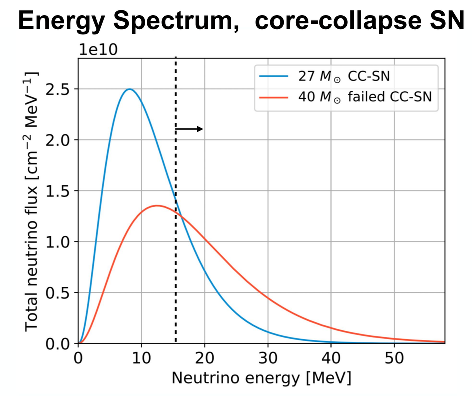
CUPID-1T Sensitivity to Lightly-Ionizing Particles, 10y



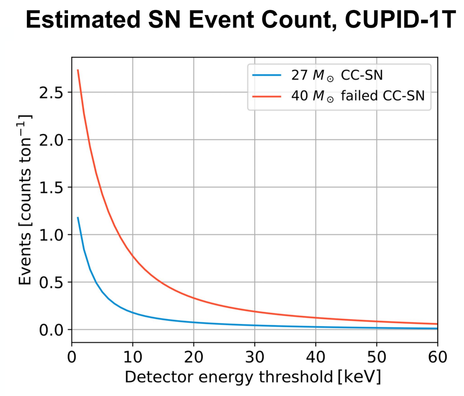
Solar and Stellar Studies

- Neutrinos and antineutrinos produced in supernovae may yield insight into the process of stellar core-collapse
- Sensitivity to higher-energy core collapse neutrinos may be possible through detection of CEvNS

Energy Spectrum, core-collapse SN



Estimated SN Event Count, CUPID-1T



- Axions comprise a class of hypothetical BSM particles that may be produced by several mechanisms, and can be produced in the sun.
- Axions were initially proposed to address the strong-CP problem in particle physics
- Detection of axions in tonne-scale calorimetric detector may be approached via several mechanisms, including the axio-electric effect
- Axions may also be contributors to astrophysical dark matter as relics produced in the early universe