Search for neutrinoless double beta decay of ^{100}Mo with the CUPID-Mo detector

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OUTLINE

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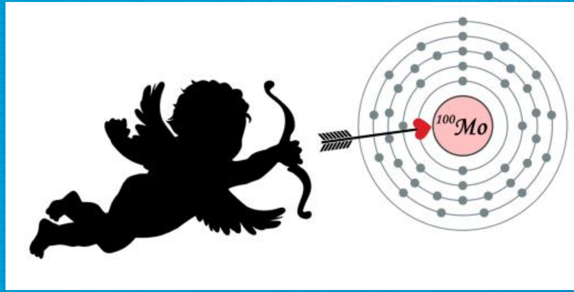
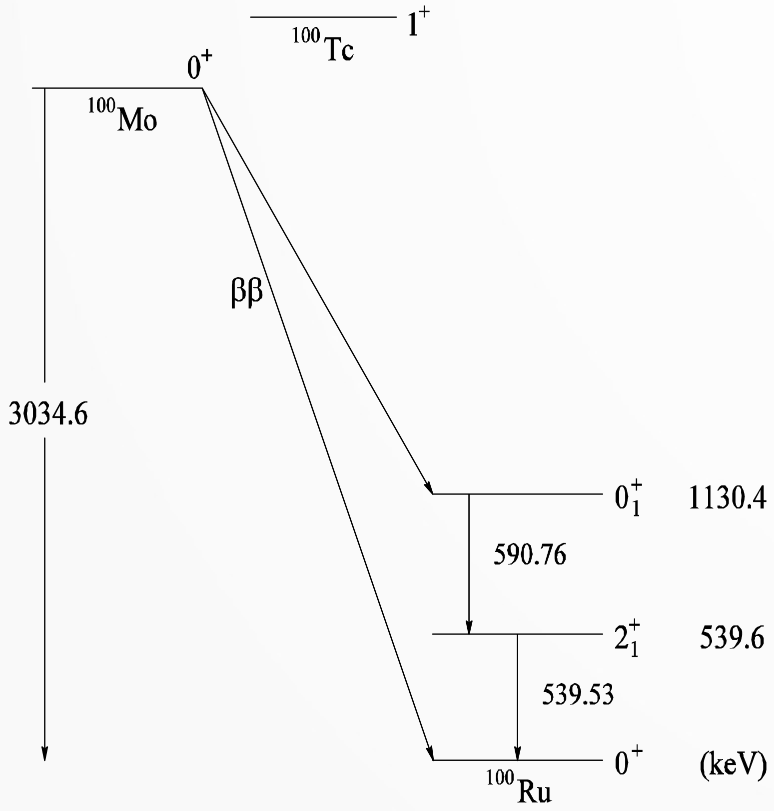
- Experimental data
- Results
- Conclusion

I. INTRODUCTION



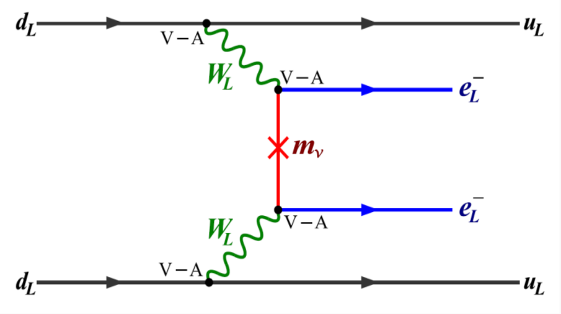


^{100}Mo is one of the best candidates to search for neutrinoless double beta decay

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

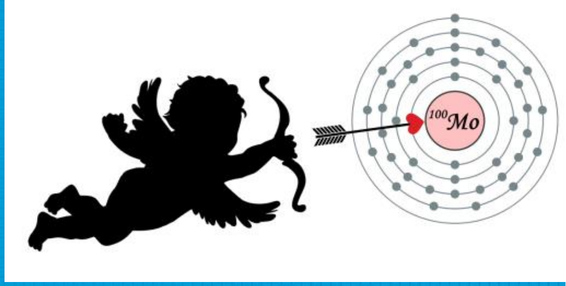
$^{100}Mo \Rightarrow$ $^{100}Ru + 2e^{-} + \chi^{0}$ $(+\chi^{0})$

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



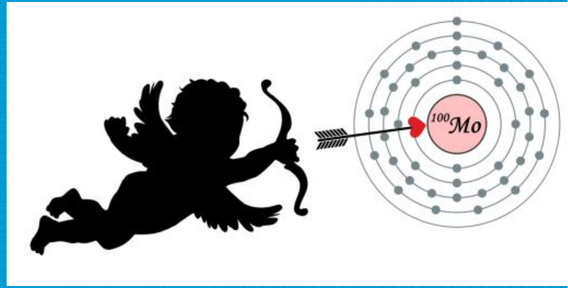
$Q_{\beta\beta}$= 3.034 MeV
Natural abundance is 9.7%
Enrichment by centrifugation

What one can extract from 2β-decay experiments? →



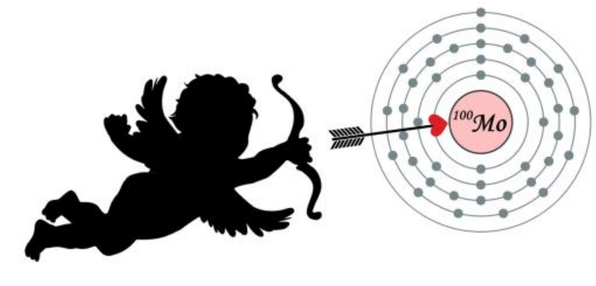
- **Lepton number non-conservation (ΔL=2)**
- **Nature of neutrino mass (Dirac or Majorana?)**
- **Absolute mass scale**
- **Type of mass ordering (normal or inverted)**
- **CP violation in the lepton sector**

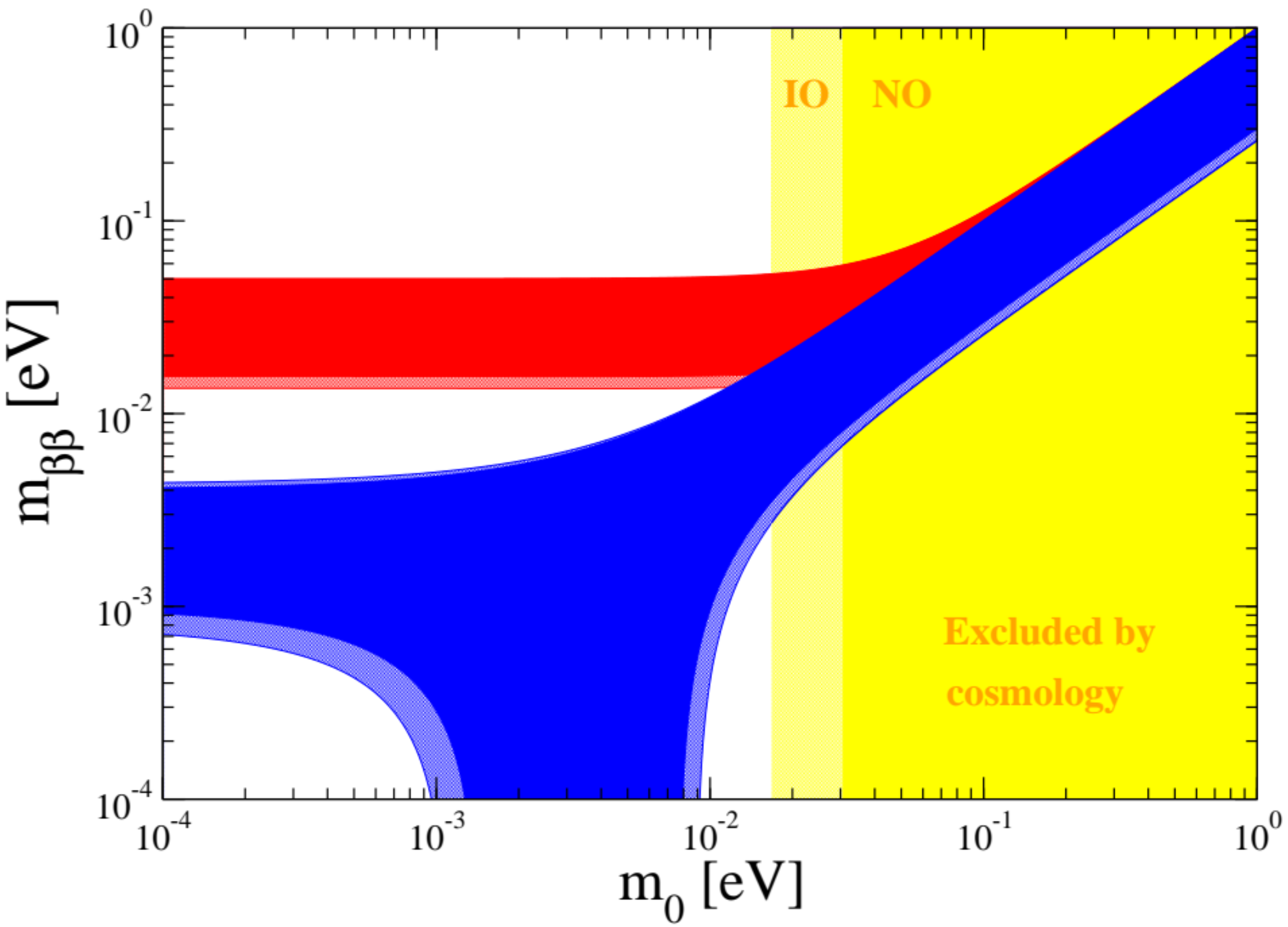
Best present limits on $<m_\nu>$



Nucleus	$T_{1/2}$, yr; 90% CL	$<m_\nu>$, eV QRPA, ISM, IBM-2, PHFB, ...	Experiment
^{136}Xe	> 5.6x10^{25} (> 1.07x10^{26})	**< 0.08-0.23** (< 0.06-0.16)	KamLAND-Zen
^{76}Ge	> 1.8x10^{26}	< 0.08-0.18	GERDA
^{130}Te	>1.7x10^{25} (> 3.2x10^{25})	< 0.10-0.49 (< 0.08-0.36)	CUORE
^{100}Mo	> 1.1x10^{24}	< 0.33-0.62	NEMO-3
^{82}Se	> 3.5x10^{24}	< 0.33-0.75	CUPID-0

DBD and neutrino mass ordering





Inverted ordering (IO):

$<m_\nu>$ = 14-50 meV
(Can be tested by next generation of **2β**-decay experiment)

Normal ordering(NO):
$<m_\nu>$ = 0-30 meV
Limiting case → **$<m_\nu>$** = **1-4 meV**

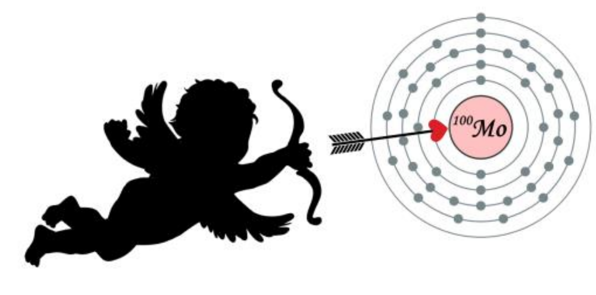
β: $<m_\nu>$ < 1.1 eV

2β: $<m_\nu>$ < 0.18 eV

Σm_ν < 0.12 eV (PLANCK’2018)

Global analysis prefer NO (3-3.5σ);
NO – Σmν > 0.06 eV, IO - Σmν > 0.1 eV

NEXT GENERATION EXPERIMENTS



- **LEGEND, nEXO, CUPID, AMoRE,…**
- **CUPID (CUORE Upgrade with Particle IDentification):**

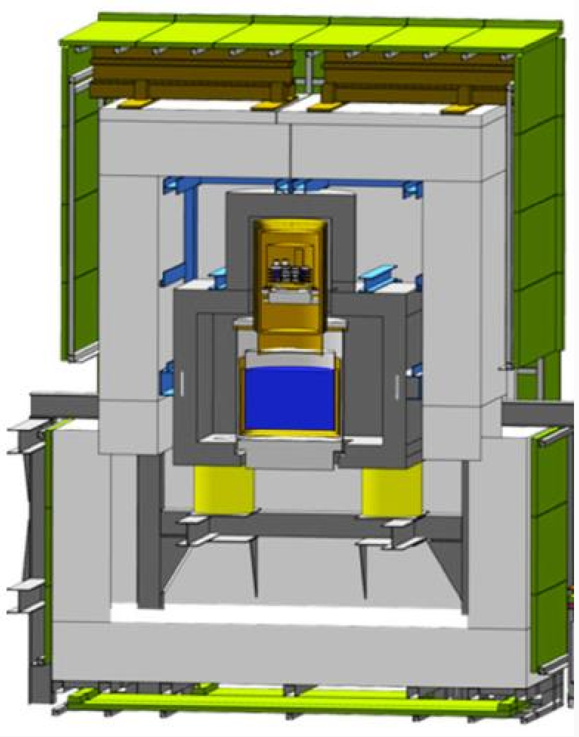
  - Main idea is to use existing CUORE infrastructure and scintillating bolometers Li_2MoO_4 (~ 1500 crystals, ~ 250 kg of ^{100}Mo)

  - Sensitivity ~ $1.5 \cdot 10^{27}$ yr, $\langle m_\nu \rangle$ ~ 10-17 meV

- **CUPID-Mo – is a demonstrator for CUPID**

INSTALLATION

CUPID-Mo at Modane



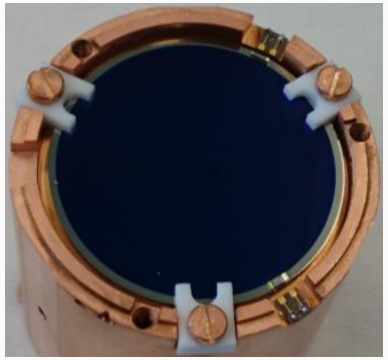
4800 m w.e. depth

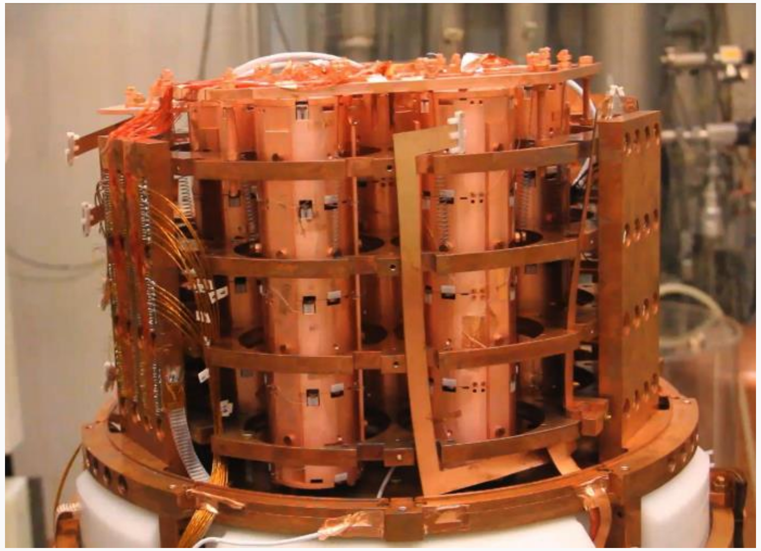
shared EDELWEISS cryogenic Infrastructure operated at @ 20 - 22 mK

20 $Li_2{}^{100}MoO_4$ detectors of ~210 g, 96.6% enriched **(2.26 kg ^{100}Mo)**

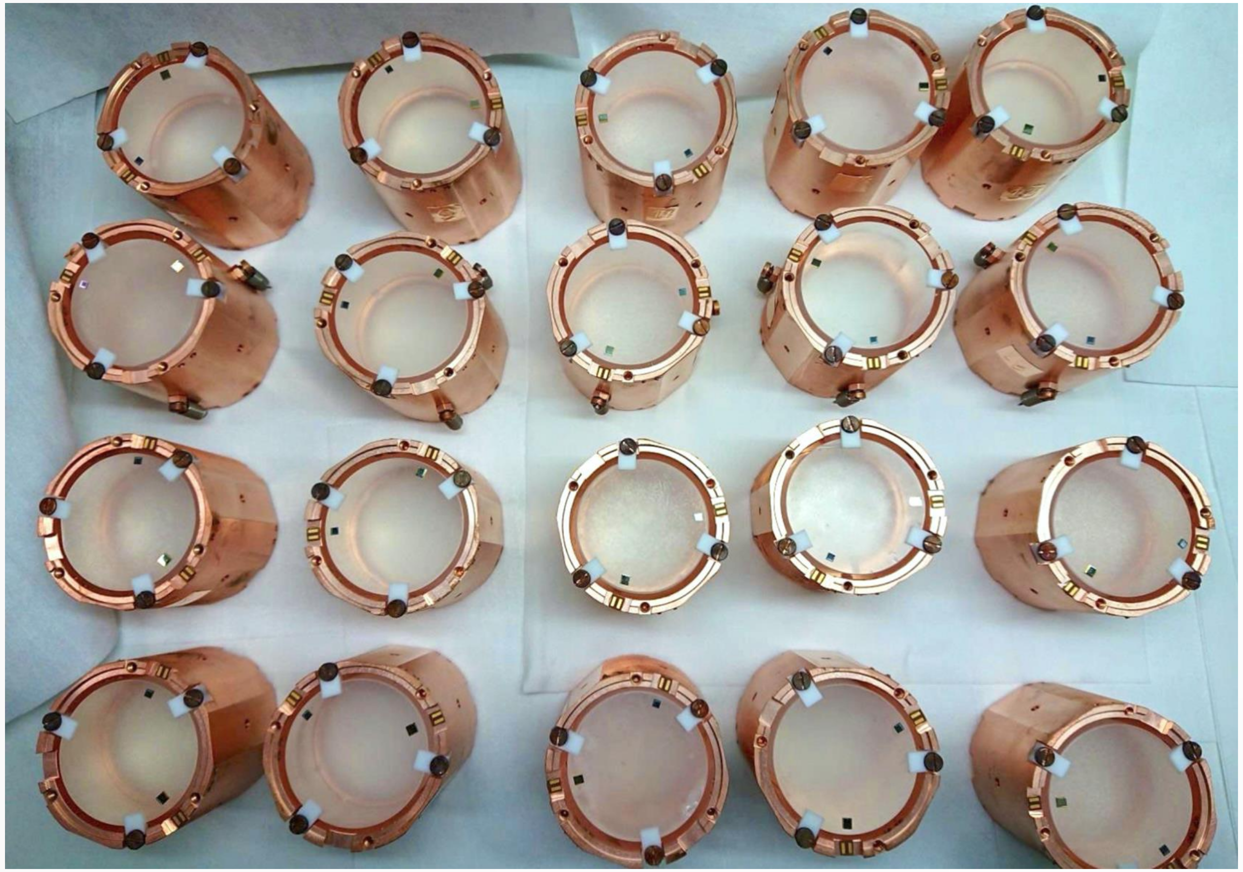
Ge-NTD based sensor readout

physics data taking
March 2019 - June 2020





CUPID-Mo design



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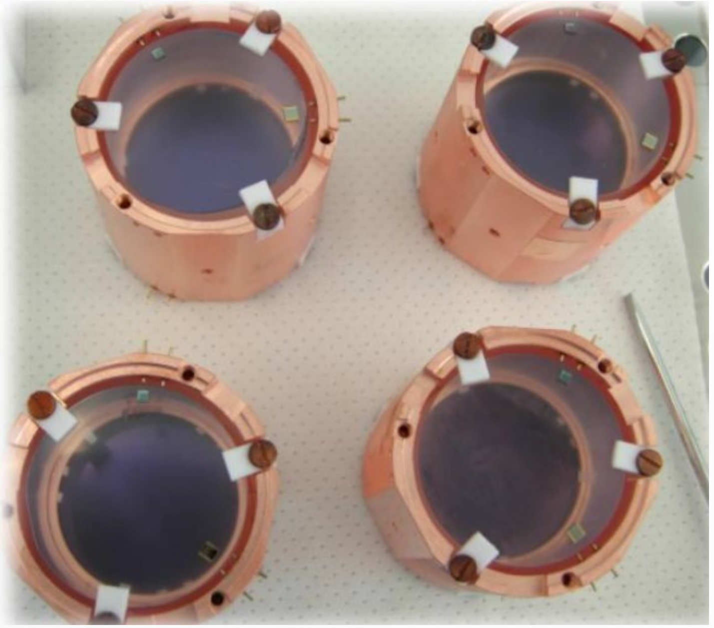
Crystal growth and ^{100}Mo Enrichment

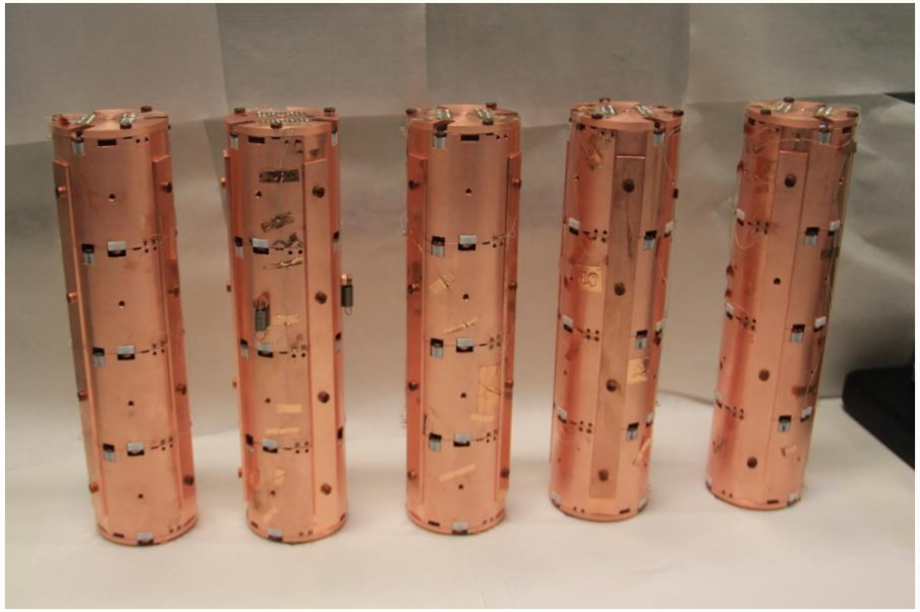
NIIC, Novosibirsk, Russia

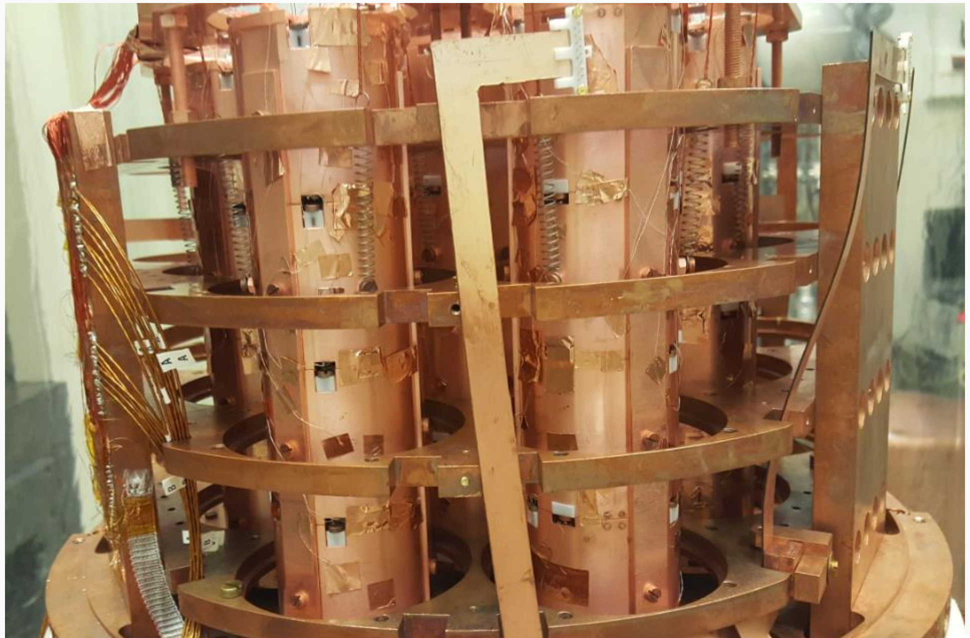
- purification of enriched Mo (from the NEMO-3 experiment) to MoO_3
- low radioactivity Li_2CO_3
- double crystallization (low thermal gradient Czochralski technique)
- surface polish with radio-pure SiO_2 oil based slurry
- storage in dry N_2 atmosphere (Li_2MoO_4 is slightly hygroscopic)

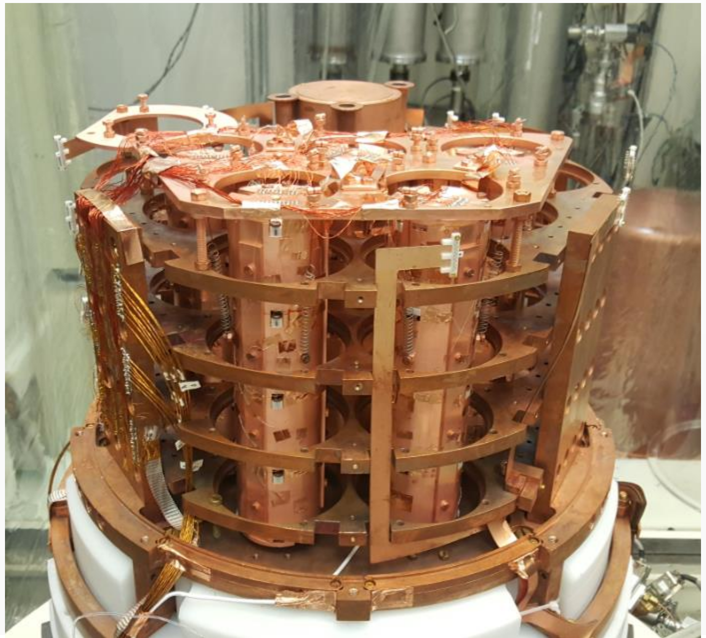
Isotope concentration: 96.6±0.2 %
4.158 kg $Li_2{}^{100}MoO_4$
2.258 kg ^{100}Mo

The CUPID-Mo installation at LSM

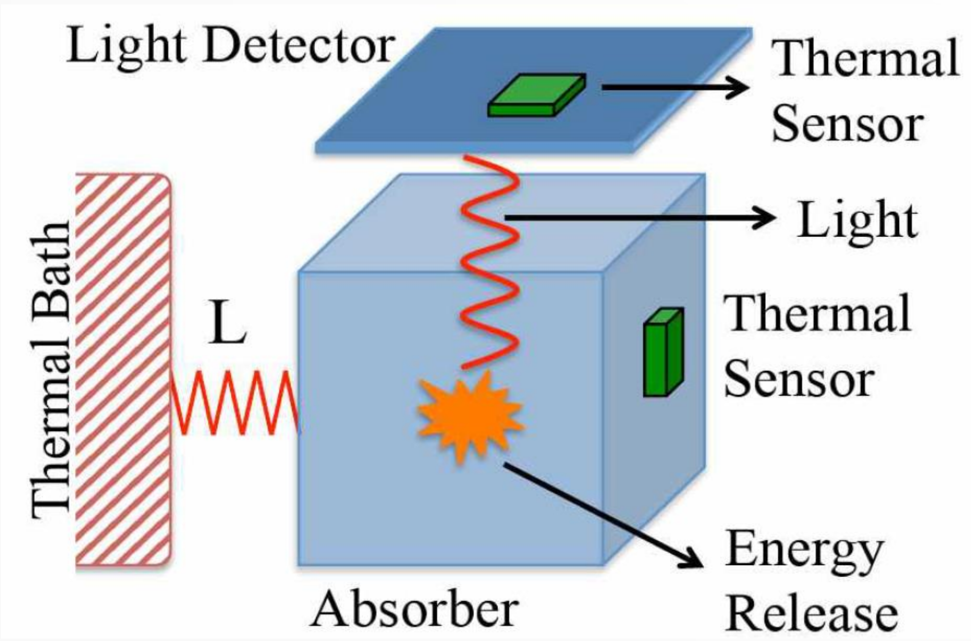


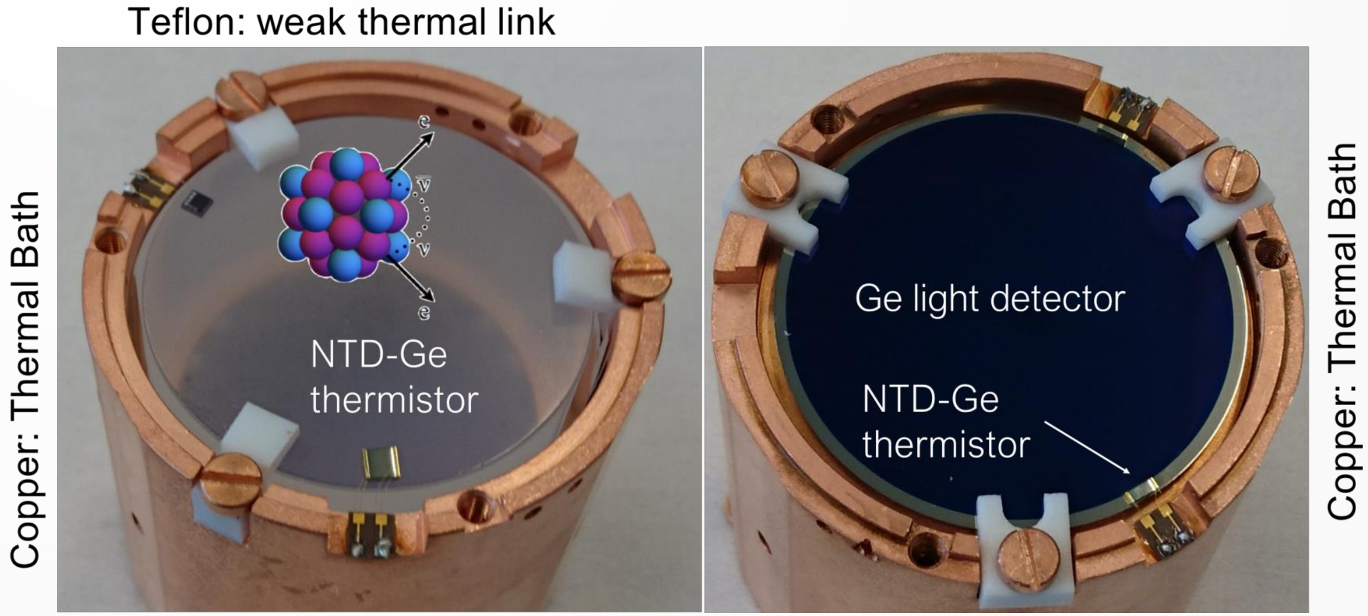






CUPID-Mo single module



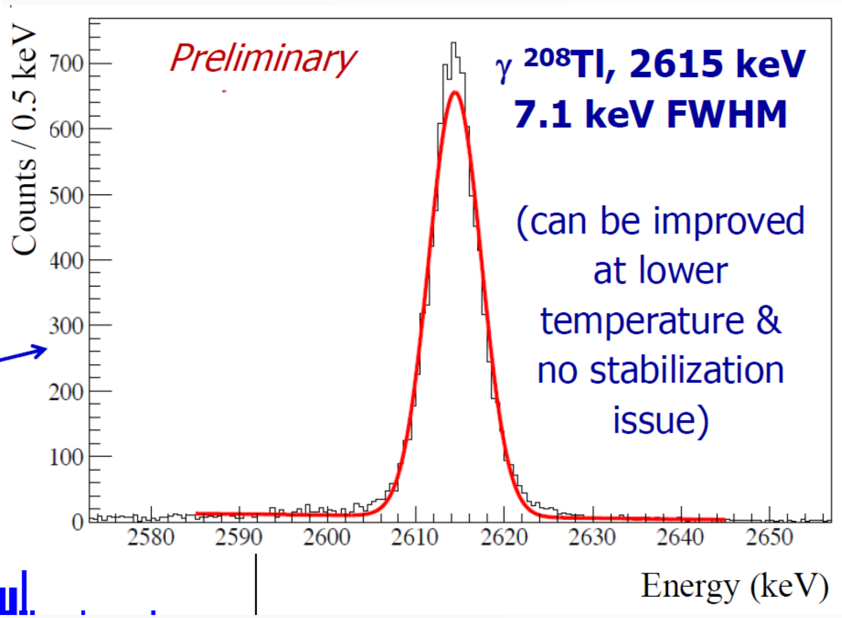


Source ^{100}Mo = Detector Li_2MoO_4

(High detection efficiency)

CUPID-Mo performance

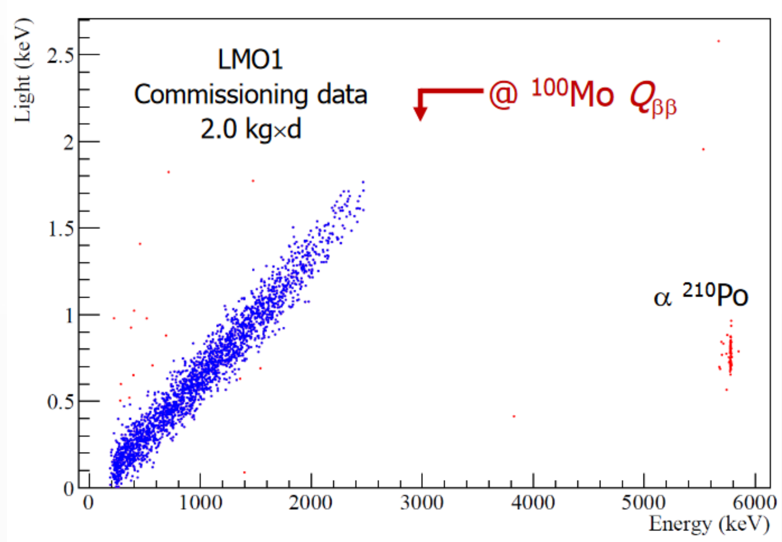
Energy resolution



Average energy resolution is 7.7 keV (FWHM) at $Q_{\beta\beta}$ (3040 keV)

α rejection power:

> 99.9% for all detectors

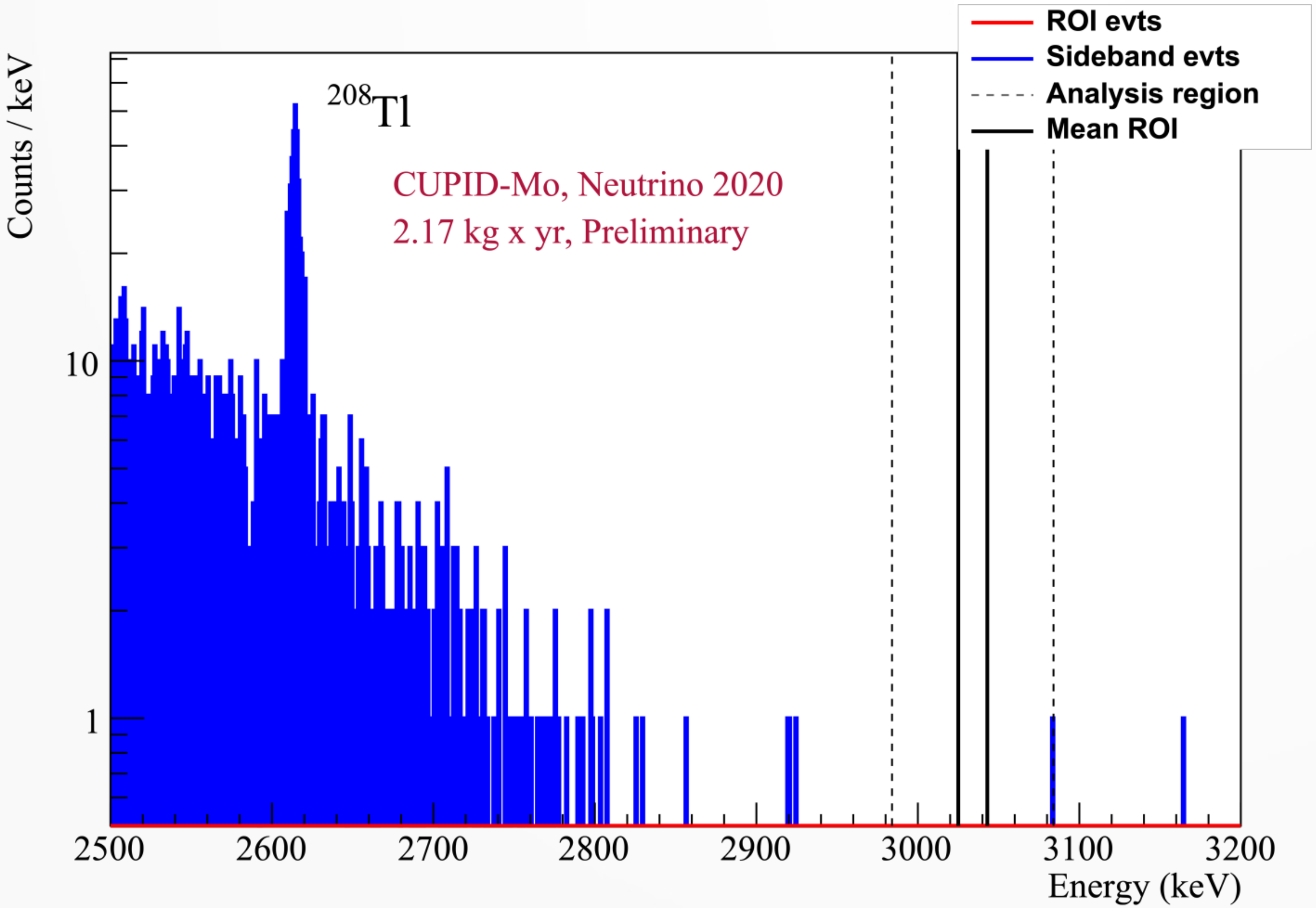


Crystals bulk α activity
(19/20 $Li_2{}^{100}MoO_4$, 2.17 kg×yr)

Chain	Nuclide	Activity [μBq/kg]
^{232}Th	^{232}Th	0.22(9)
	^{228}Th	0.38(9)
	^{224}Ra	0.34(9)
	^{212}Bi	0.22(7)
^{238}U	^{238}U	0.35(10)
	^{234}U+^{226}Ra	1.22(17)
	^{230}Th	0.48(12)
	^{222}Rn	0.47(10)
	^{218}Po	0.35(9)
	^{210}Po	95(6)
	^{190}Pt	0.19(8)

U/Th: < 1 μBq/kg

CUPID-Mo results



$B = (4 \pm 2)\cdot 10^{-3}$ **counts/kev·kg·yr**

New world leading limit on 0ν2β of ^{100}Mo:

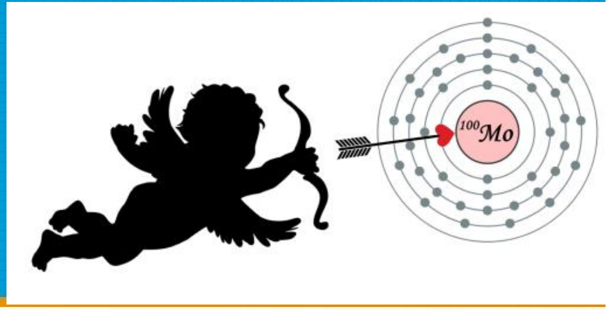
$T_{1/2}(0\nu) > 1.4\text{x}10^{24}$ **yr**

$<m_\nu> <$ **310-540 meV (90% C.L.)**

[$T_{1/2} > 1.1\cdot 10^{24}$ **yr (NEMO-3; 2015)**

$T_{1/2} > 0.95\cdot 10^{23}$ **yr (AMoRE; 2019]**

Future prospects



I. Full statistics is 2.8 kg·yr. So, we hope to improve the limit in ~ 30% (up to ~ $1.8 \cdot 10^{24}$ yr)

II. Next possible step with CUPID-Mo (+ CROSS):

- ~ 50 $Li_2{}^{100}MoO_4$ crystals
- 3 years of measurements

$T_{1/2} > 1.5 \cdot 10^{25}$ yr; $\langle m_\nu \rangle < 100$-$170$ meV

III. CUPID:

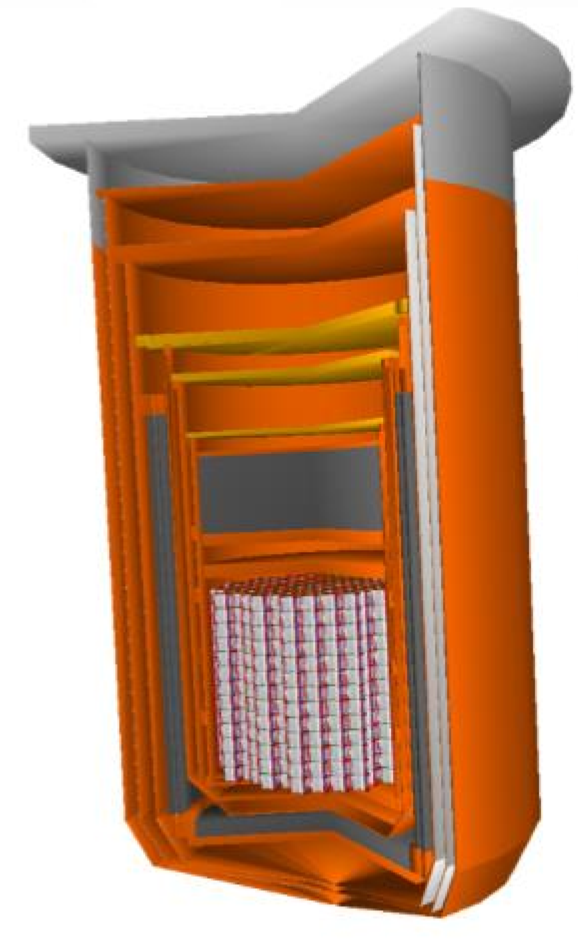
$T_{1/2} > 1.1 \cdot 10^{27}$ yr (3σ); $\langle m_\nu \rangle < 12$-$20$ meV

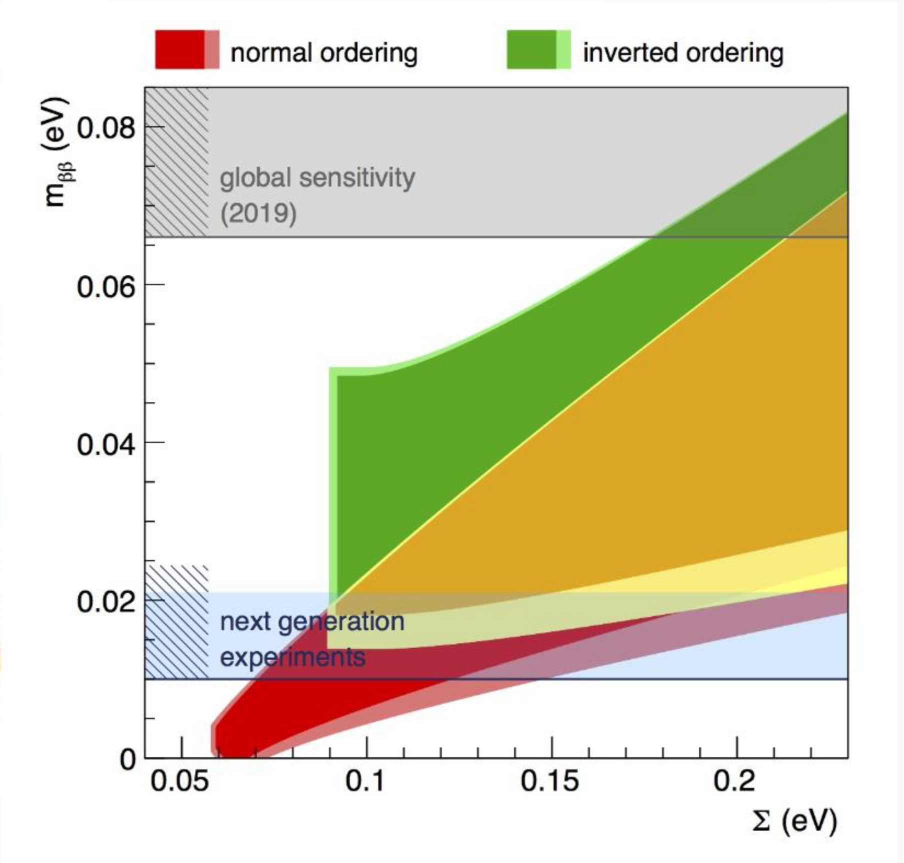
CUPID (arXiv:1907.09376)

CUPID in a nutshell

- ~1500 $Li_2{}^{100}MoO_4$ scintillating crystals (~250 kg of ^{100}Mo)
- FWHM: 5 keV at $Q_{\beta\beta}$
- α rejection via light vs heat cut: > 99.9%
- Background index: 10^{-4} counts/(keV · kg · yr)
- $T_{1/2}(0\nu) > 1.1 \cdot 10^{27}$ yr (3σ)
- $<m_\nu> < 12\text{-}20$ meV (IH)

CUORE cryostat, mature design, data-driven background model





Can be built now!

- TDR and construction readiness for end 2021
- Schedule and budget will be driven by ^{100}Mo enrichment → ~ 4 years

CONCLUSION

I. CUPID-Mo detector has been successfully tested and has shown excellent performance.

II. The world leading limit on 0νββ decay of ^{100}Mo was obtained:

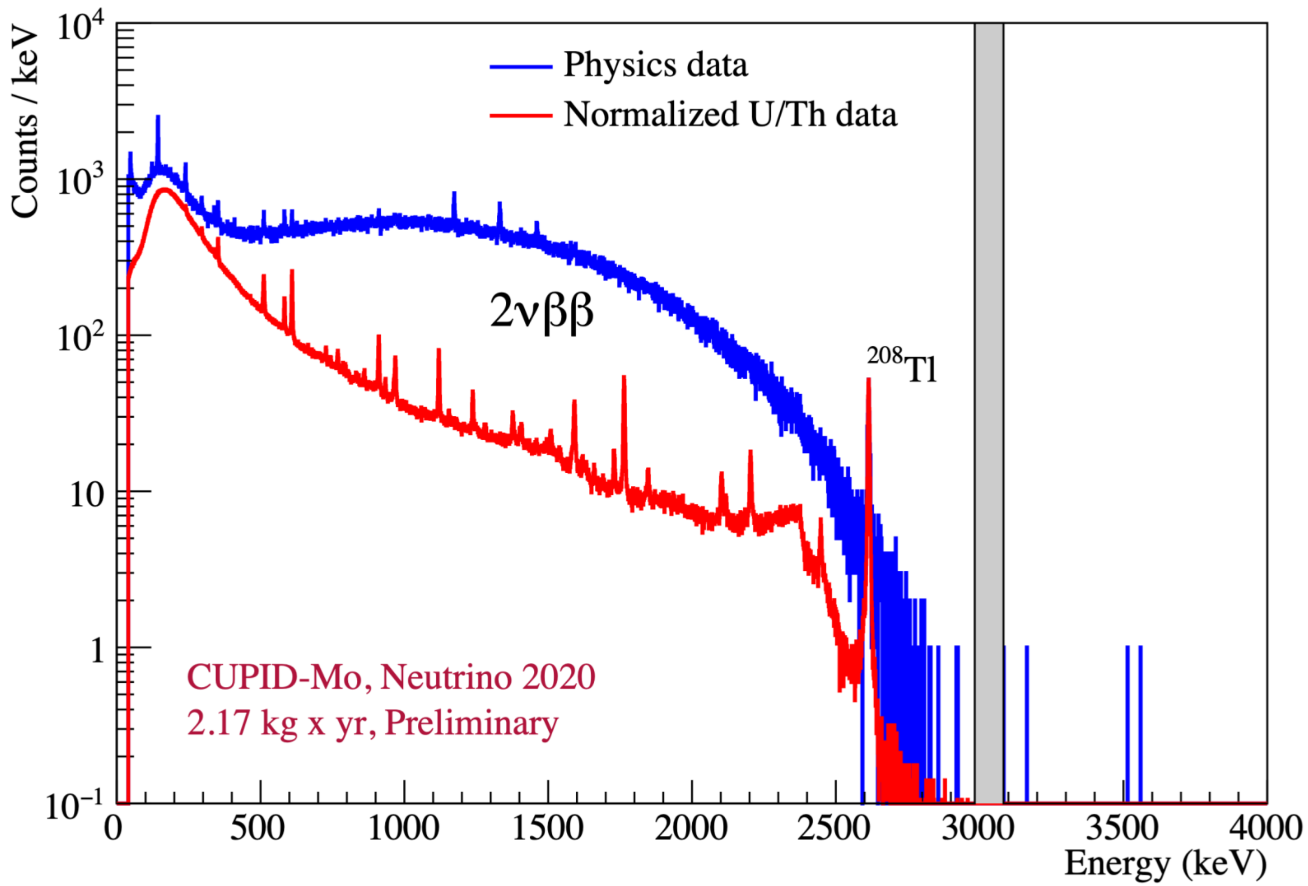
$$T_{1/2} > 1.4 \times 10^{24}\ \text{yr}; \quad \langle m_\nu \rangle < 310\text{-}540\ \text{meV}$$

III. Good prospects of CUPID have been demonstrated.

CUPID-Mo Collaboration

Back up slides

Calibration spectrum



- 19/20 detectors with good performance
- Analysis efficiency 90.5 %
- 200 days of physics data,
  ~7 keV FWHM @ 2615 keV (calibration)

NME from:

1.F. Šimkovic, V. Rodin, A. Faessler, P. Vogel, Phys. Rev. C 87, 045501 (2013).

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7. P.K. Rath et al., Phys.Rev.C88, 064322 (2013).

8. F. Šimkovic, A. Smetana, and P. Vogel, Phys. Rev. C 98, 064325 (2018).

9. P.K. Rath, Ramesh Chandra, K. Chaturvedi and P. K. Raina, Front. Phys. 64, 1 (2019).