^{100}Mo ββ decay search in the CUPID-Mo experiment with enriched scintillating bolometers

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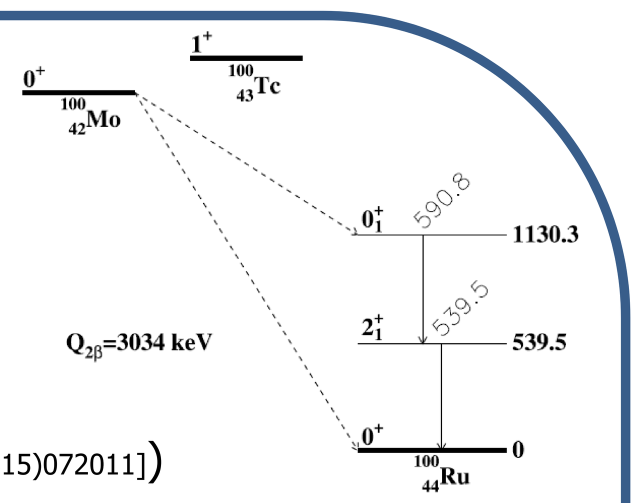
http://cupid-mo.mit.edu
7 countries, 15 institutions, ~110 scientists

I: ^{100}Mo as a ββ source

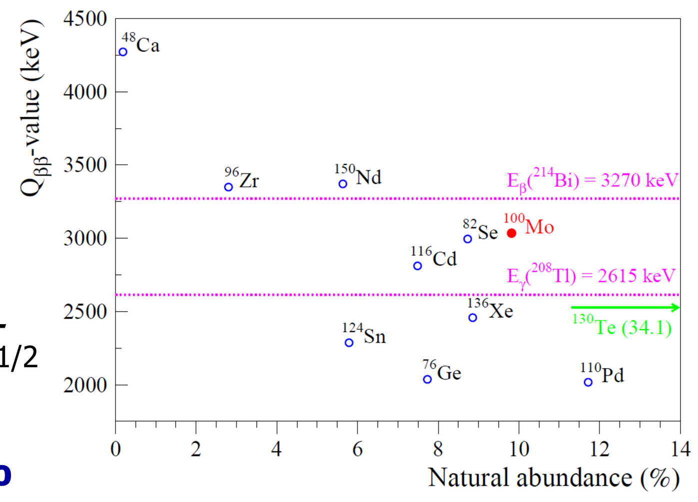
Double-beta decay of ^{100}Mo

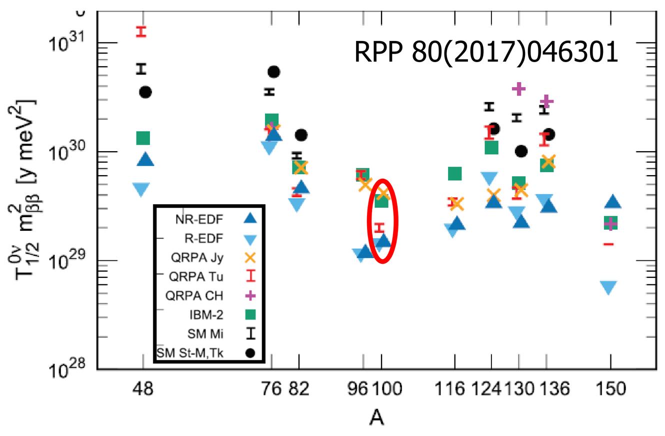
- **Standard Model two-neutrino decay**
  gs→gs: $T_{1/2}$ = (7.1±0.4) × 10^{18} yr (5.6% uncertainty)
  gs→0$_1$: $T_{1/2}$ = 6.7$^{+0.5}_{-0.4}$ × 10^{20} yr (6.6% uncertainty)
  (both half-lives are average values [NPA 935(2015)52])
- **Beyond Standard Model neutrinoless process**
  gs→gs: $T_{1/2}$ ≥ 1.1 × 10^{24} yr @90% CL (NEMO-3 [PRD 92(2015)072011])



Advantages of ^{100}Mo as a ββ isotope

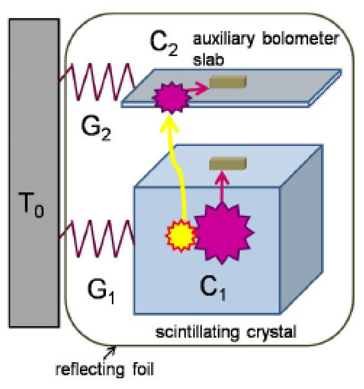
✓ **One of the highest $Q_{\beta\beta}$-values**
✓ **Favorable theoretical predictions**
Expected one of the fastest 0νββ decay rate
Hint on a minimal impact of the g_A quenching on $T_{1/2}$
✓ **Reasonably high natural abundance, availability of industrial enrichment to >95%**
✓ **Variety of ^{100}Mo-containing scintillators perspective as scintillating bolometers**
Source=Detector technique: ~100% efficiency
High energy resolution: ~0.2% FWHM
Particle identification: >99.9% rejection of α's
(e.g., a dominant Bkg in CUORE [EPJC 77(2017)543])
Warning: a slow response requires pileup control

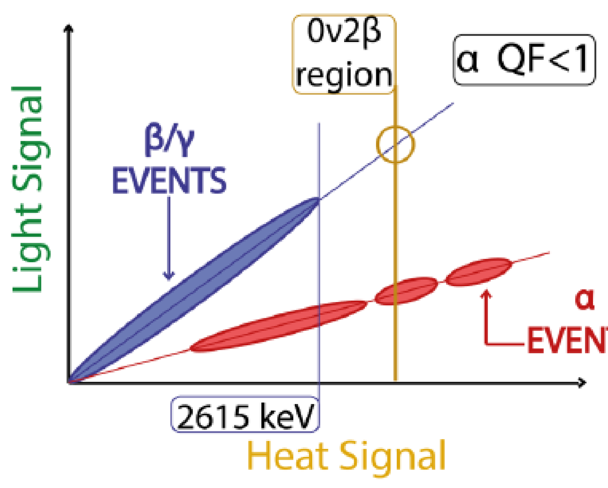




Study of the g_A quenching in QRPA: PRC 96(2018)055501

ββ	g_A (minimal)	$T_{1/2}$ reduction
^{76}Ge	0.59	2.7
^{82}Se	0.56	3.0
^{96}Zr	0.52	4.9
^{100}Mo	0.70	2.0
^{116}Cd	0.62	3.1
^{130}Te	0.35	4.9
^{136}Xe	0.36	5.7





^{100}Mo-enriched bolometers with an active background suppression are in a wish-list of CUPID 1t-scale 0νββ project aiming at utilization of existent CUORE infrastructure

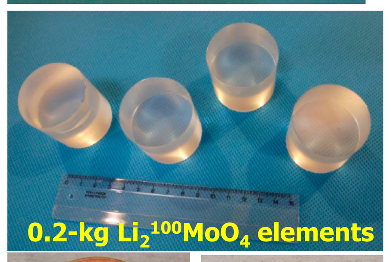
II: Developments toward CUPID-Mo

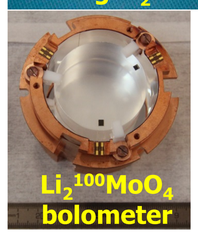
R&D of Li$_2$^{100}MoO$_4$ scintillating bolometers by LUMINEU

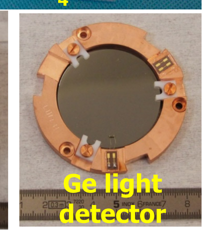
http://lumineu.in2p3.fr

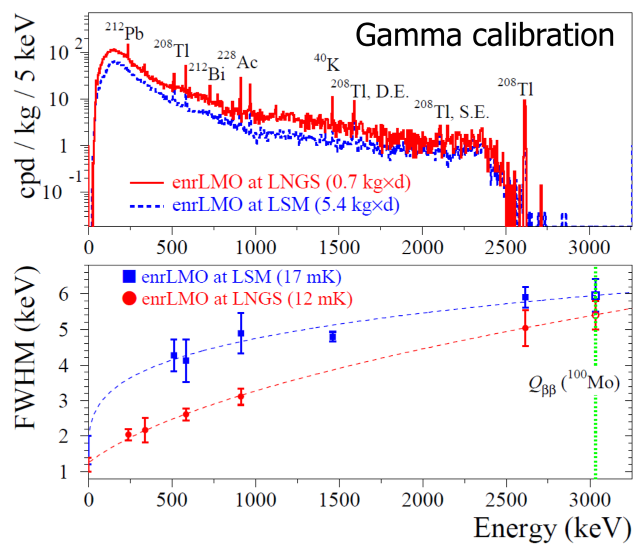
✓ **Molybdenum purification**
Sublimation & recrystallization from aqueous solutions
✓ **Optimization of crystal growth by LTG Cz method**
High optical quality & crystal yield (~80–85% of a charge)
Low total irrecoverable losses of ^{100}Mo (~3%)
✓ **Dedicated R&D to control a ^{40}K content**
Selection of ultra-pure Li_2CO_3 & double crystallization
✓ **Multiple tests of natural & ^{100}Mo-enriched bolometers**
Aboveground @CSNSM, underground @LSM & @LNGS
Array of four enriched detectors in EDELWEISS set-up @LSM

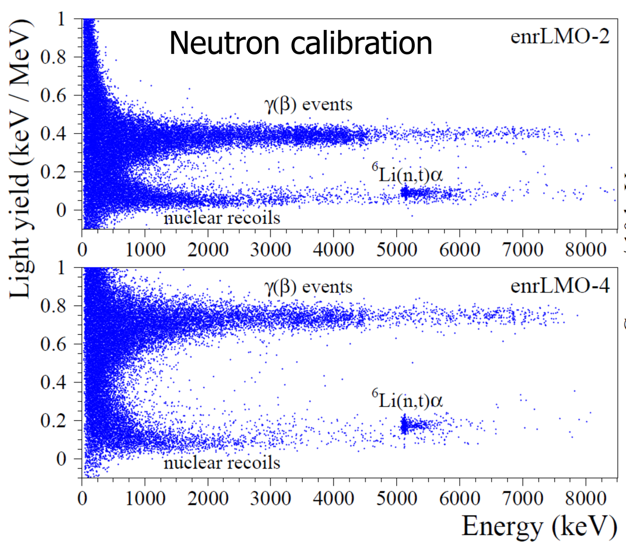

0.6-kg Li$_2$^{100}MoO$_4$ boule

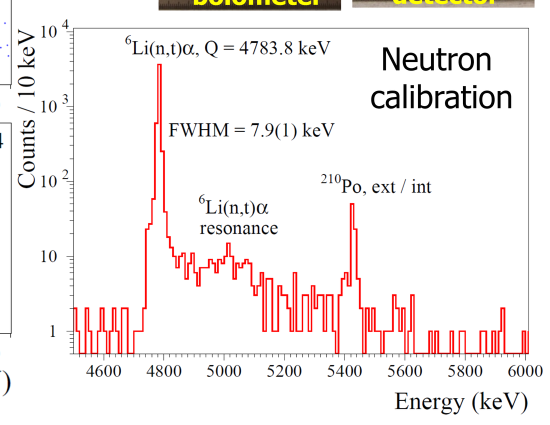

0.2-kg Li$_2$^{100}MoO$_4$ elements


Li$_2$^{100}MoO$_4$ bolometer


Ge light detector

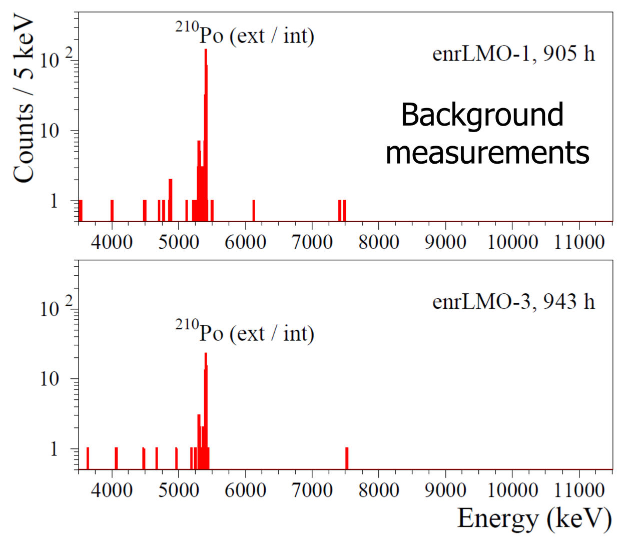






Performance & radiopurity	Li$_2$^{100}MoO$_4$ bolometers @LSM			
	186 g	204 g	213 g	207 g
FWHM [keV] @2.6 MeV	5.8(6)	5.7(6)	5.5(5)	5.7(6)
Separation α's from γ(β)'s	9σ *	9σ *	14σ	14σ
Activity [μBq/kg] of ^{228}Th	≤ 4	≤ 6	≤ 3	≤ 5
^{226}Ra	≤ 6	≤ 11	≤ 3	≤ 9
^{210}Po	450(30)	200(20)	76(10)	20(6)

* – no reflecting film



More details can be found in the following Refs. (and references therein): Eur. Phys. J. C 77 (2017) 785 & AIP Conf. Proc. 1894 (2017) 020017

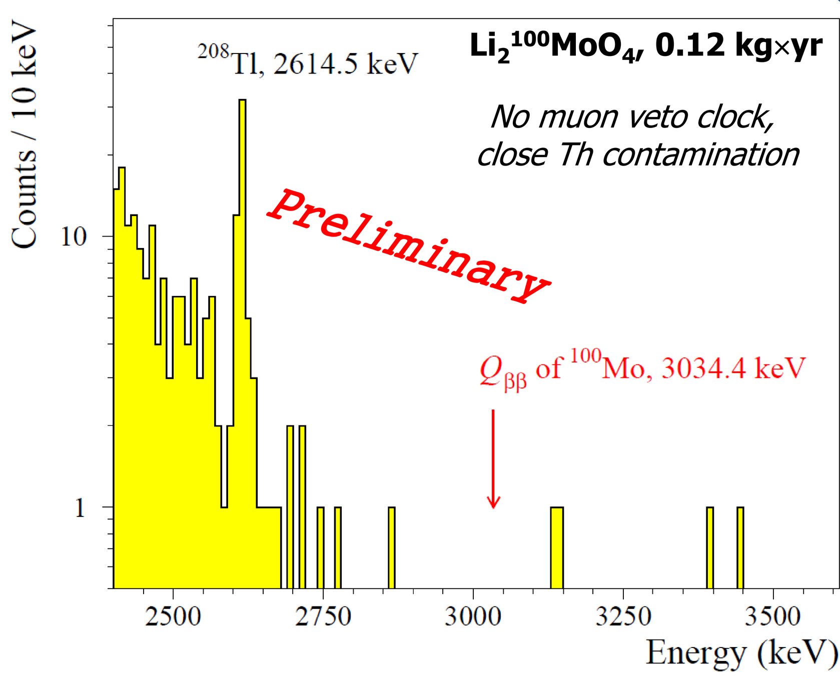
Developed technology of Li$_2$^{100}MoO$_4$ scintillating bolometers
➢ **Protocol of enriched crystals batch production**
➢ **Protocol of a detector array with high performance & radiopurity**

III: ^{100}Mo ββ search by CUPID-Mo precursor

Search for 0νββ decay

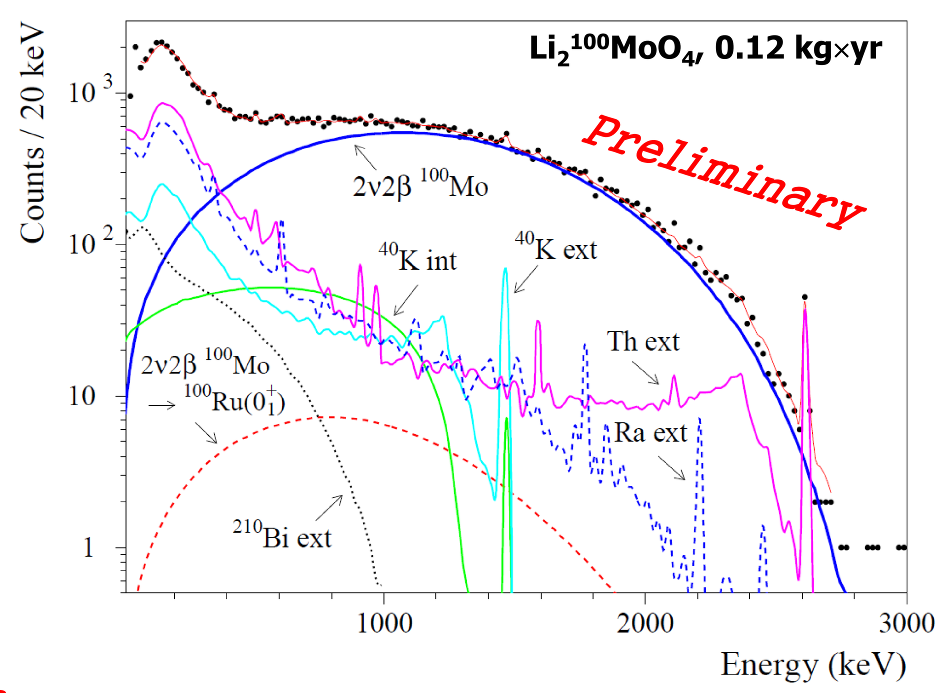
- **Exposure** = 42 kg×d @LSM
- **Enrichment** = 97% of ^{100}Mo
- **ROI** = 10-keV-wide @ $Q_{\beta\beta}$
- Detection **efficiency** = 69%
- **BI** = 0.06(3) counts/(yr kg keV) in 2.8-3.6 MeV energy interval
- **0νββ Signal** = 0 events
  ⇒ lim$S$ = 2.5 counts @90% CL

$T_{1/2}$ (0νββ ^{100}Mo) ≥ 0.7 × 10^{23} yr
⟨$m_{\beta\beta}$⟩ ≤ 1.4–2.4 eV



Investigation of 2νββ decay

- Selection **efficiency** = 95%
- **Best fit** in 1060–2680 keV
  SSD vs HSD: χ^2/ndf = 0.89 vs 0.94
  Signal / Background = 10
- **2νββ Signal** = 36256 ± 289 decays
  ⇒ **Statistical error** = 0.8%
- **Systematic error** ~ few %
  Major contribution comes from:
  background model
  selection efficiency
  2νββ spectral shape



Preliminary

$T_{1/2}$ (2νββ ^{100}Mo) = [6.90±0.06(stat)] × 10^{18} yr

Our preliminary estimate of the systematics indicates that the measured ^{100}Mo 2νββ half-life could be the most precise ever achieved

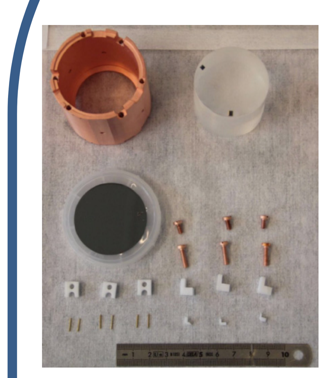
ββ	2νββ $T_{1/2}$ relative uncertainty (%)	Experiment
^{116}Cd	± 5.3	AURORA
^{76}Ge	± 4.9	GERDA-I
^{136}Xe	± 3.3	KamLAND-Zen
	± 2.8	EXO-200

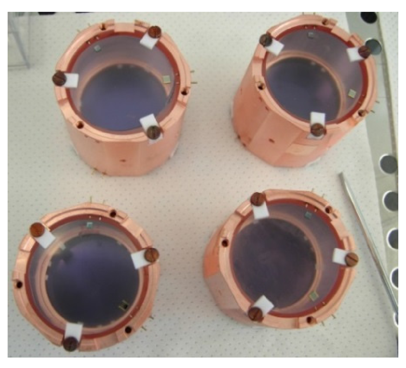
Note: for other ββ isotopes (^{48}Ca, ^{82}Se, ^{96}Zr, ^{128}Te, ^{130}Te, ^{150}Nd, and ^{238}U) $T_{1/2}$ values were measured with (7–30)% uncertainty [NPA 935(2015)52]

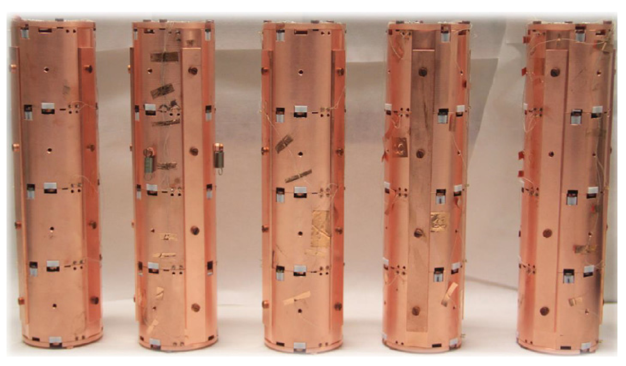
Great potential of Li$_2$^{100}MoO$_4$ scintillating bolometers to perform high-sensitivity ^{100}Mo 0νββ searches and precise 2νββ studies

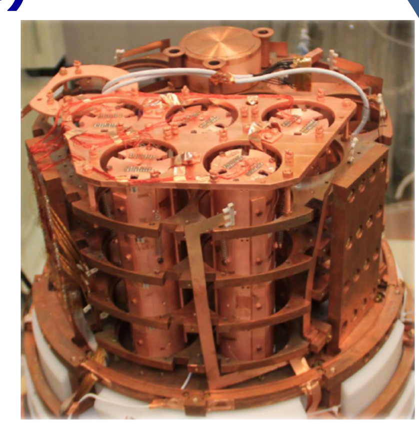
IV: CUPID-Mo experiment

Phase I: Twenty Li$_2$^{100}MoO$_4$ scintillating bolometers in EDELWEISS set-up @LSM (France)


Single module
0.2-kg Li$_2$^{100}MoO$_4$
∅44×0.17-mm Ge

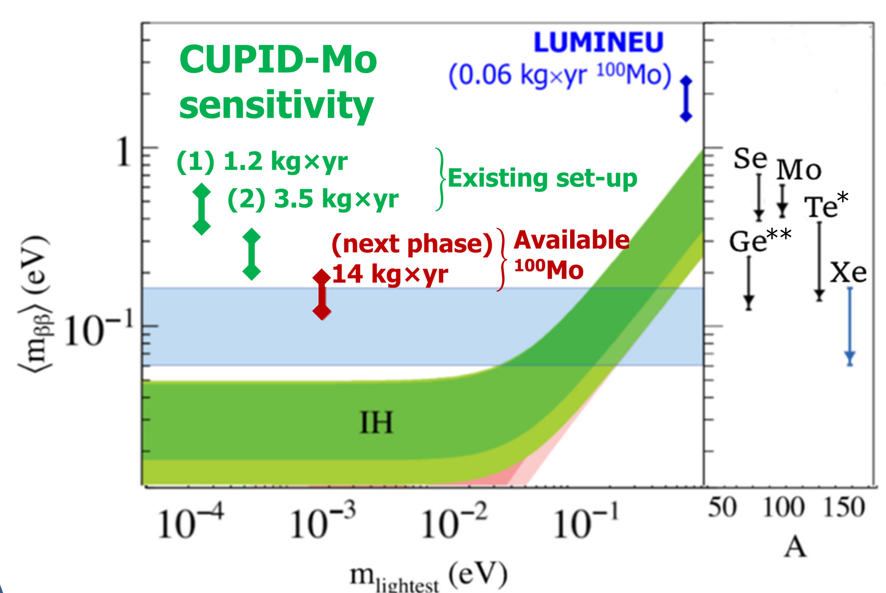

Four modules per tower


Five suspended towers
4.18 kg crystals ⇒ 2.34 kg of ^{100}Mo


CUPID-Mo in EDELWEISS set-up

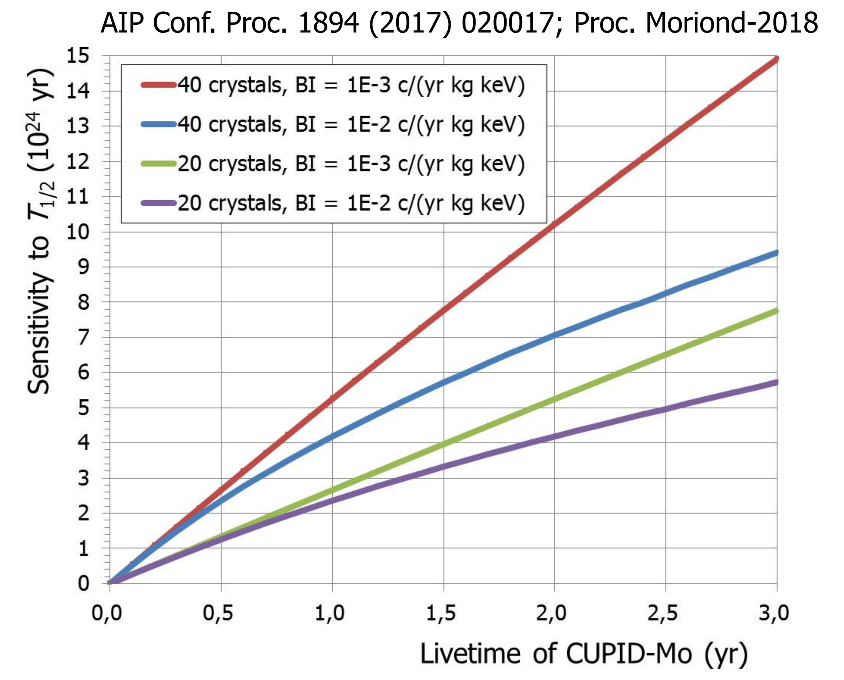
CUPID-Mo goals:

➢ **At least 6-months-long run @LSM & expected extension @LNGS**
➢ **Li$_2$^{100}MoO$_4$ bolometric technology confirmation on a larger scale**
➢ **Zero background conditions in ROI BI ~ 10^{-3} counts/(yr kg keV)**
➢ **Improved ^{100}Mo 2νββ investigation and 0νββ half-life limit**



Configuration [crystal×yr]	Sensitivity @90% CL	
	$T_{1/2}$ [yr]	⟨$m_{\beta\beta}$⟩ [eV]
(1) Phase I 20×0.5	1.3 × 10^{24}	0.33–0.56
(2) Phase I 20×1.5	4.0 × 10^{24}	0.19–0.32
(next phase) 40×3.0	1.5 × 10^{25}	0.10–0.17

AIP Conf. Proc. 1894 (2017) 020017; Proc. Moriond-2018



ββ	Experiment	Exposure [kg×yr]	Ref.
^{82}Se	CUPID-0	2	arXiv:1802.07791
^{100}Mo	NEMO-3	34	PRD 92(2015)072011
^{76}Ge	GERDA-II	23	arXiv:1710.07776
^{130}Te	CUORE	24	PRL 120(2018)132501
^{136}Xe	KamLAND-Zen	504	PRL 117(2016)082503

Prospects of CUPID-Mo to be among the most sensitive 0νββ experiments and to validate the technology for the next-generation studies