CUPID

CUORE Upgrade with Particle Identification

CUORE - Lake Louise Winter Institute 2022

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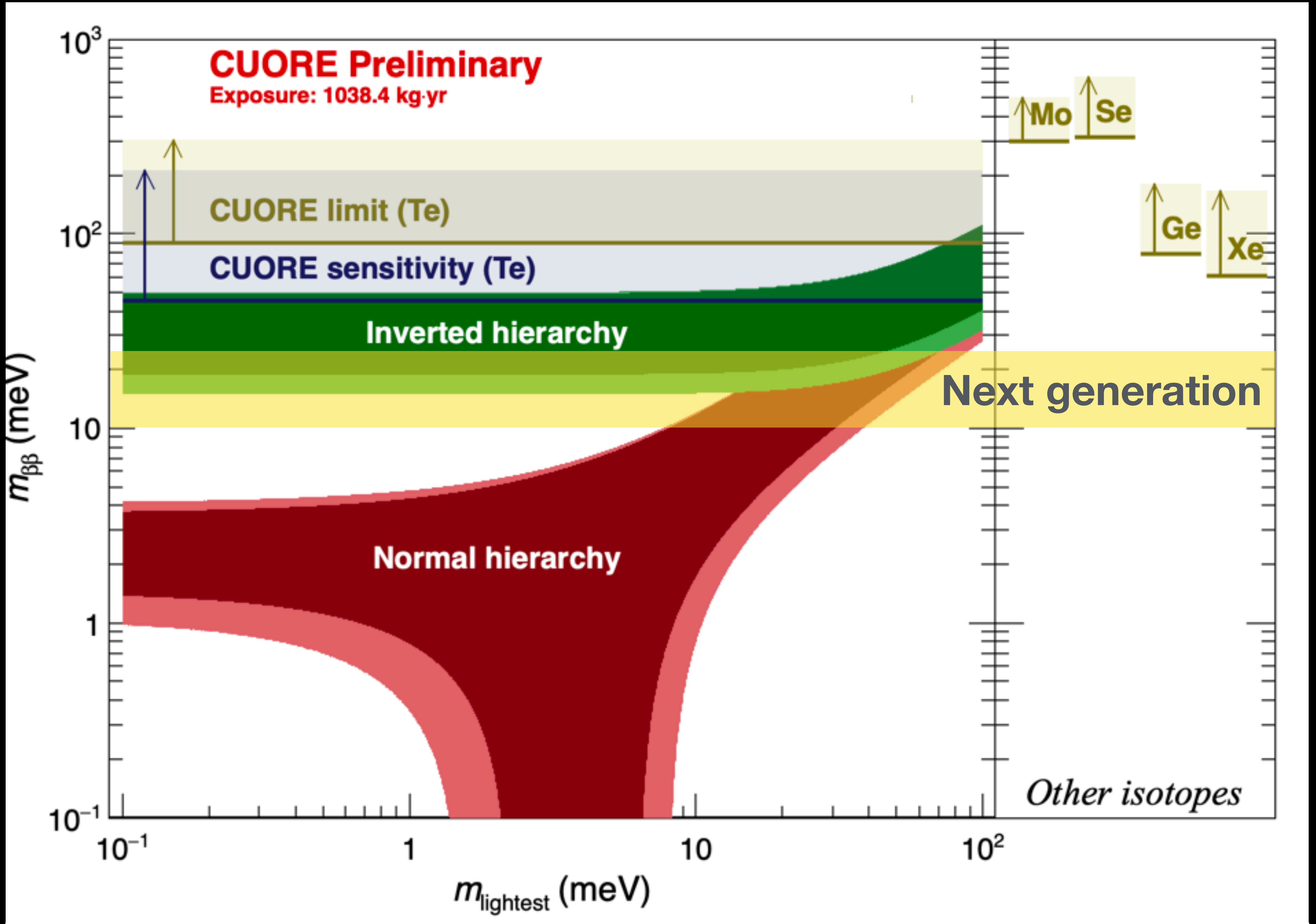
February 24 2022

NEXT GENERATION $0\nu\beta\beta$ EXPERIMENT



Oscillation parameters from NUFIT 2020 are used. All limits are at 90% C.L. and 3σ uncertainty is shown on the inverted and normal hierarchy bands. The CUORE combined limit is now ⟨$m_{\beta\beta}$⟩ < 90 - 305 meV. The sensitivity line corresponds to the one quoted in the CUORE 2017 EPJC sensitivity paper. The limits on Ge, Mo, Se and Xe come from Gerda (2020), CUPID-Mo (2021), CUPID-0 (2019) and KamLAND-Zen (2016) respectively.

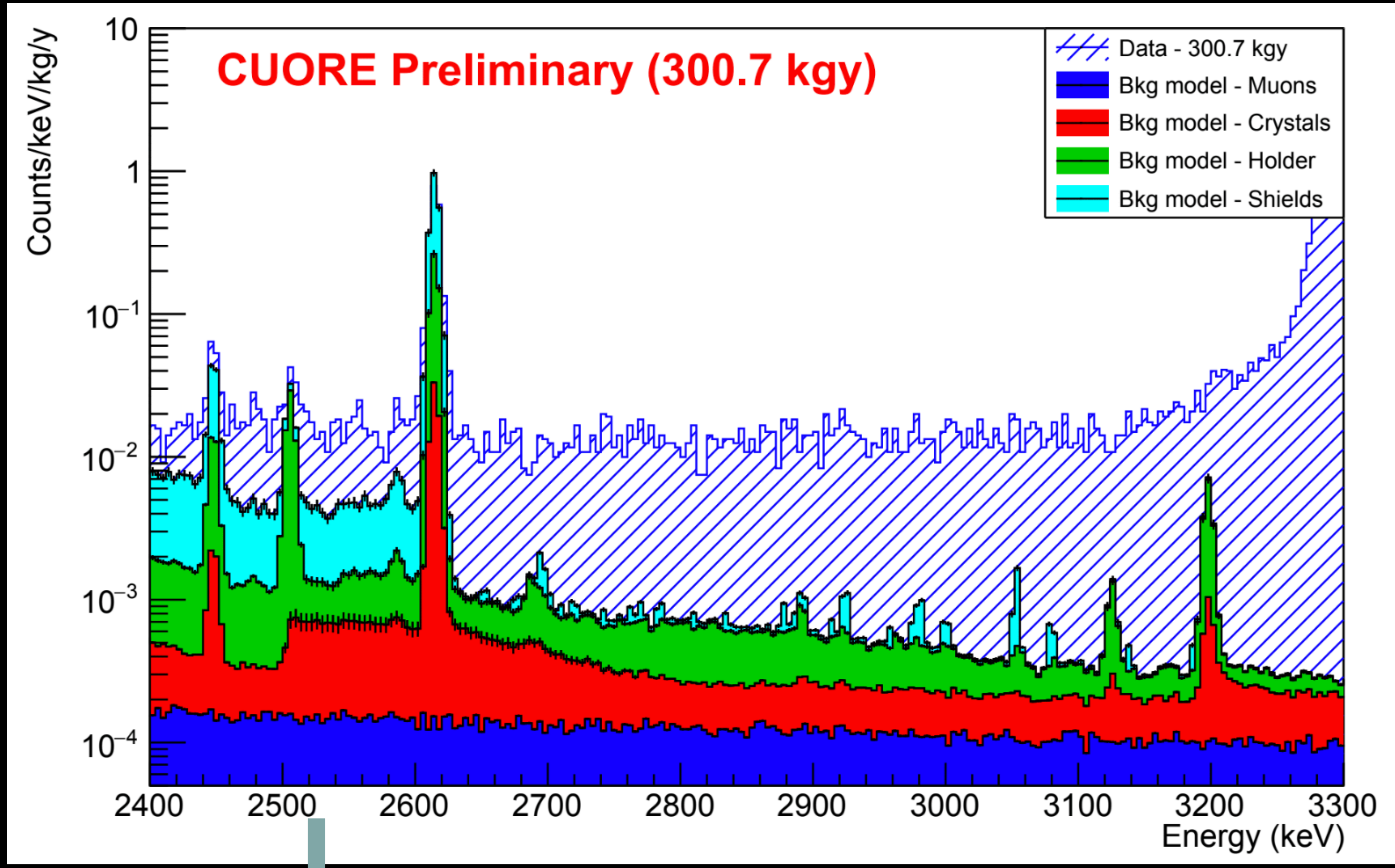
Sensitivity to new physics in terms of effective Majorana Mass

$$\frac{1}{T^{0\nu}_{1/2}} = G_{0\nu} \, |M_{0\nu}|^2 \frac{m_{\beta\beta}}{m_e^2}$$

The goal for next generation $0\nu\beta\beta$ experiments to fully probe the "Inverted Hierarchy" mass range

… but how do we build the next generation experiment?

LESSON LEARNED FROM CUORE



$Q_{\beta\beta}(^{130}Te)$

Experimental sensitivity

$$T^{0\nu}_{1/2}(n_\sigma) = \frac{ln2}{n_\sigma}\frac{N_A i \varepsilon}{A} f(\Delta E)\sqrt{\frac{Mt}{B\Delta E}}$$

- about 90% of CUORE measured background is due to αparticles (U/Th contaminations close to TeO_2 crystals)
  → α/β discrimination is required
- about 10% of β/γ background from environmental radioactivity
  →use of isotope with $Q_{\beta\beta}$ > 2.6 MeV
- <1% muons background (dominant for E>2.6MeV)
  → active muon veto

SCINTILLATING BOLOMETERS

Use of scintillating crystals

Bolometer measures heat channel with extremely good energy resolution

Ge-based light detector measures scintillation light

Particle Identification

2 channel measure measurement: heat + light for each event

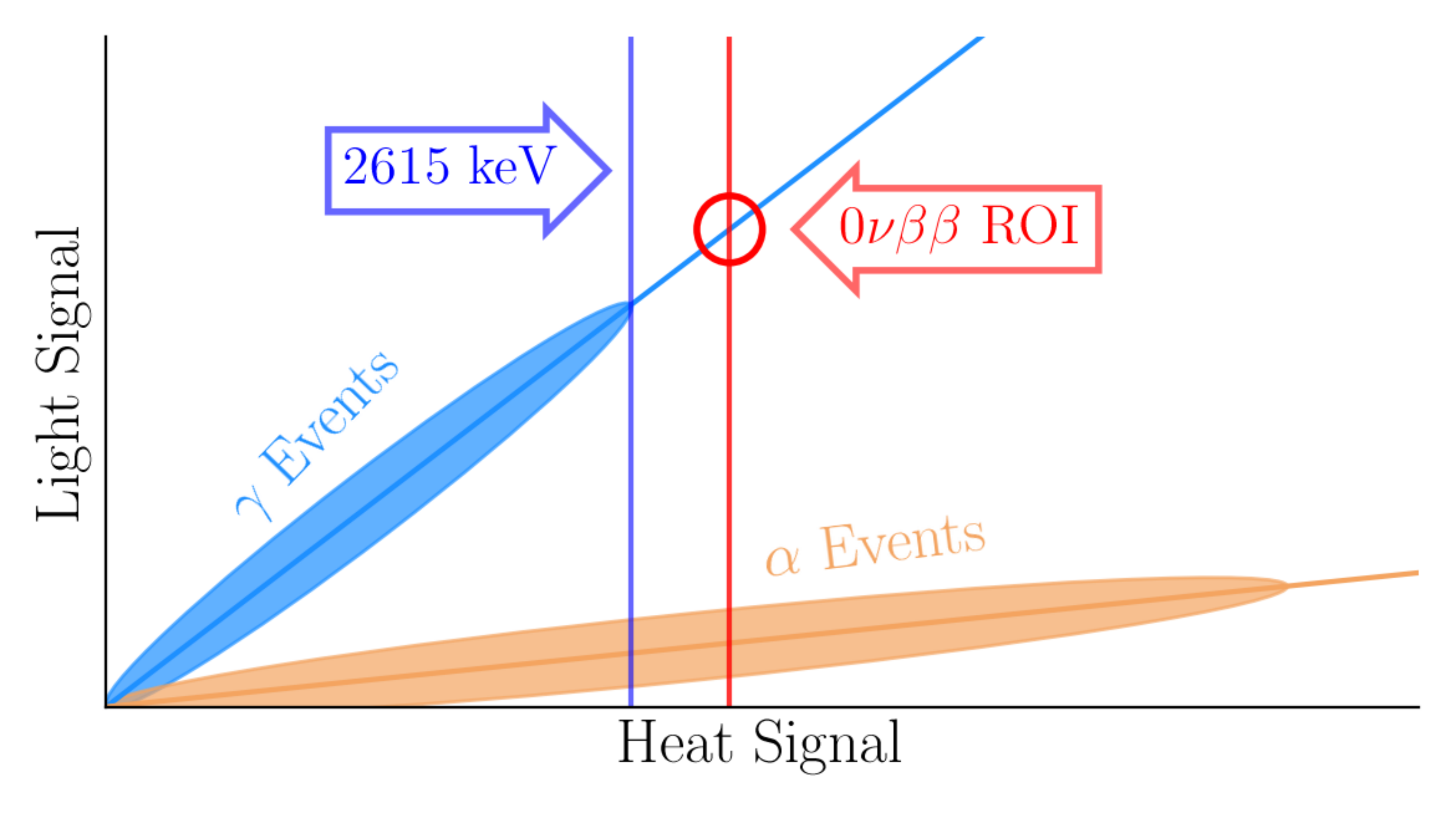
Strong separation between β/γ (signal-like) events and α (background-like) events

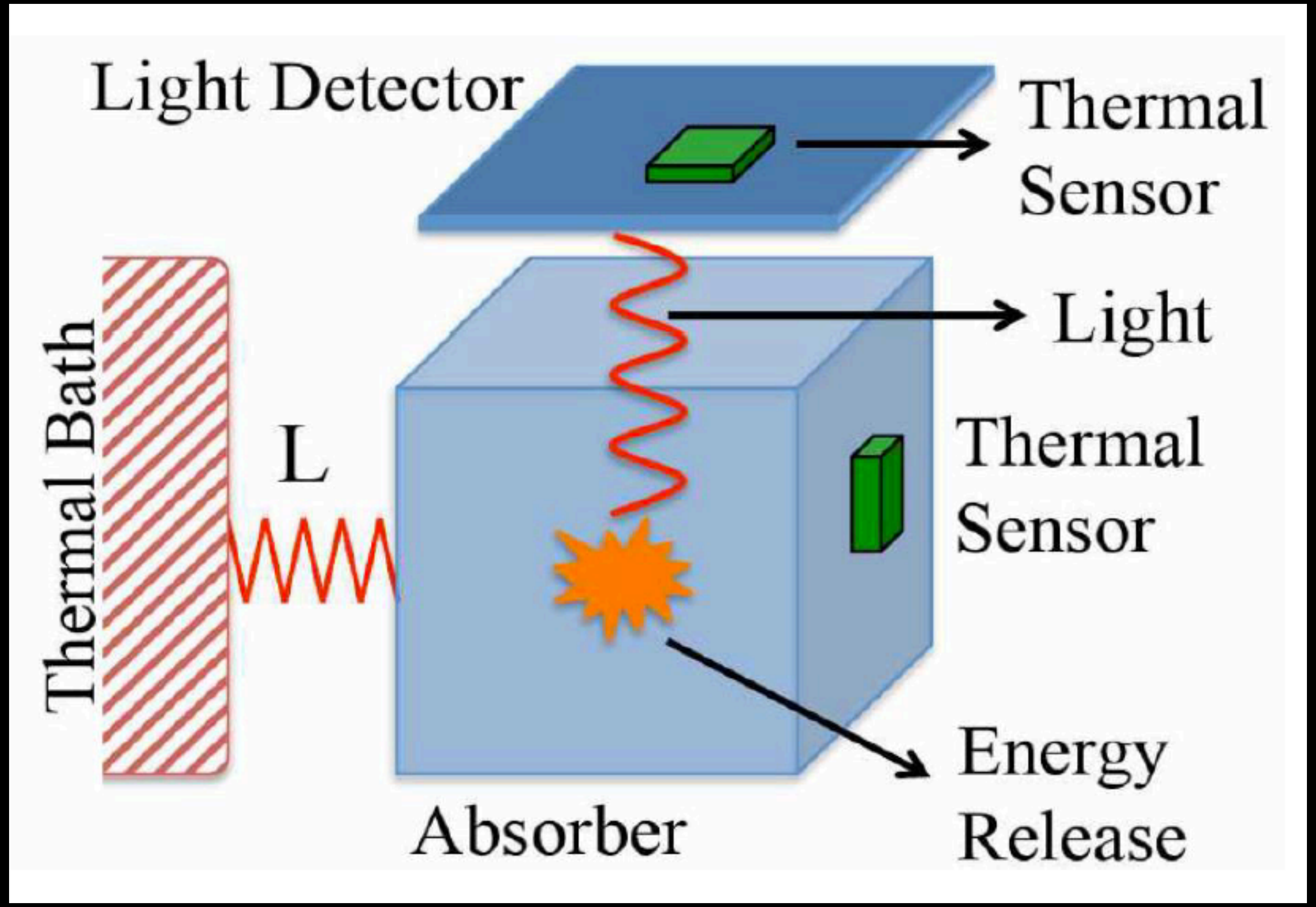
Able to identify and reject >99.9% of α-backgrounds

Technology demonstrated in multiple prototype experiments:

CUPID-0: $Zn^{82}Se$

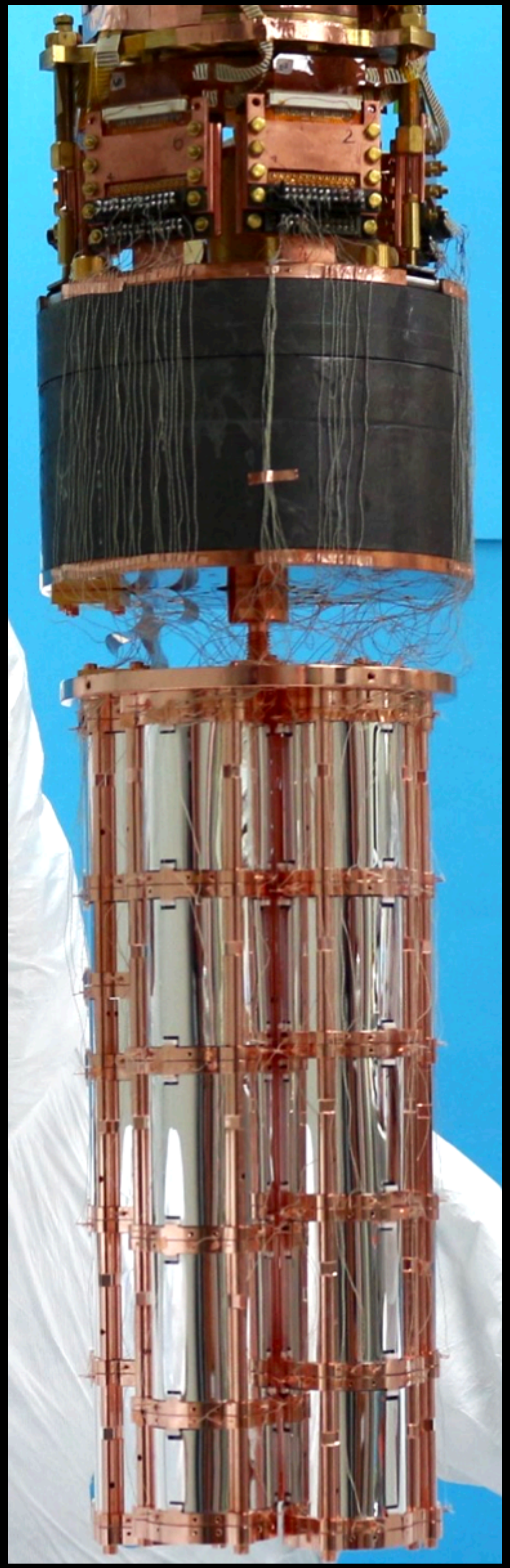
CUPID-Mo: $Li_2{}^{100}MoO_4$





CUPID DEMONSTRATORS

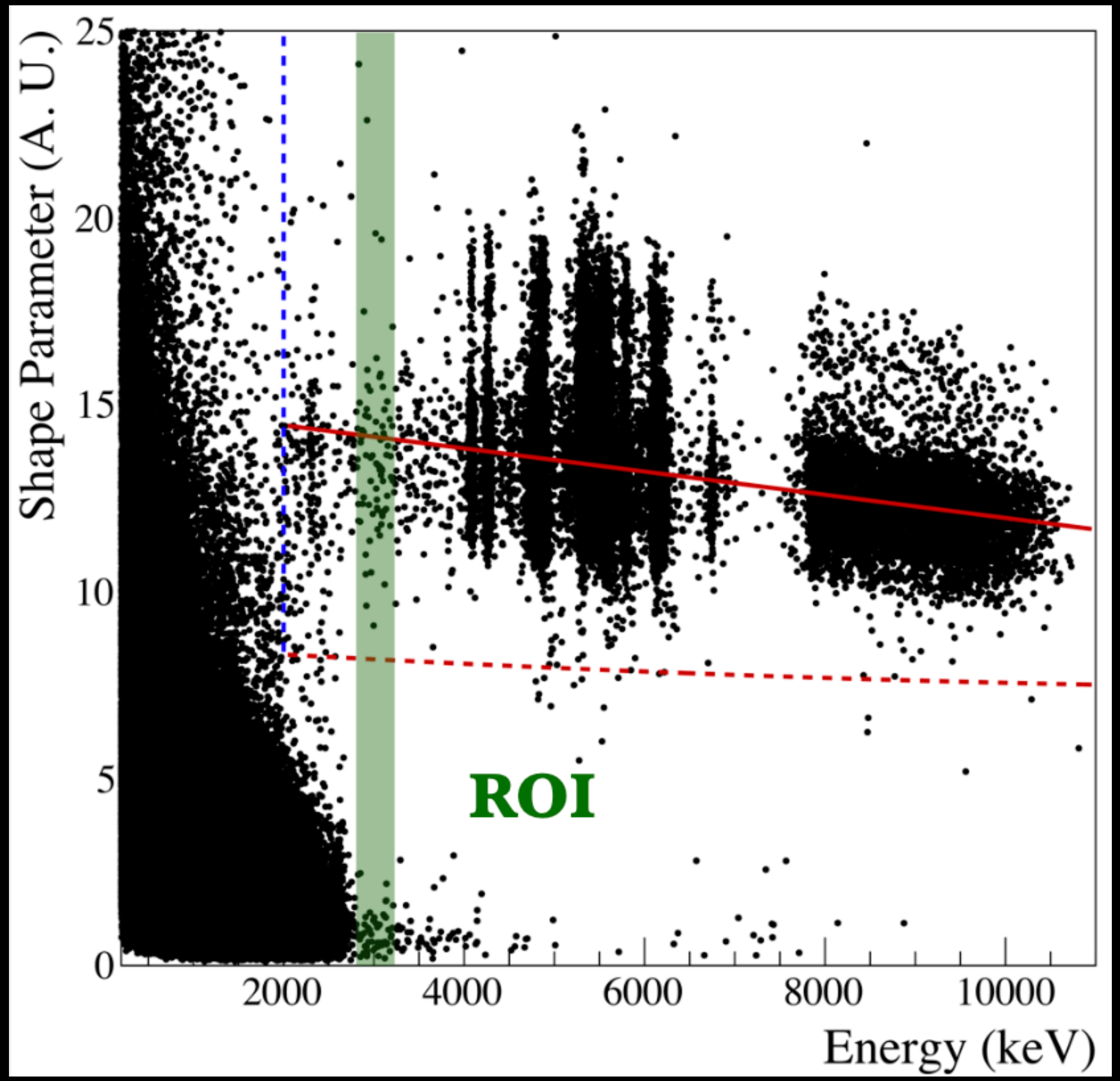
CUPID-0



CUPID-0 is the first pilot experiment of CUPID, hosted in the CUORE-0 Cryostat (LNGS, Italy)

- 24 95%-enriched $Zn^{82}Se$ crystals + 2 natural
- 31 Ge light detectors
- Total Mass: 10.5 kg (ZnSe) - 5.17 kg (^{82}Se)
- $Q_{\beta\beta}$ = (2997.9 ± 0.3) keV
-

α/β separation power: >99.9 %



EPJC (2018) 78:428 (Detector Paper)

Phys.Rev.Lett. 123 (2019) no.3, 032501 (Results phase I)

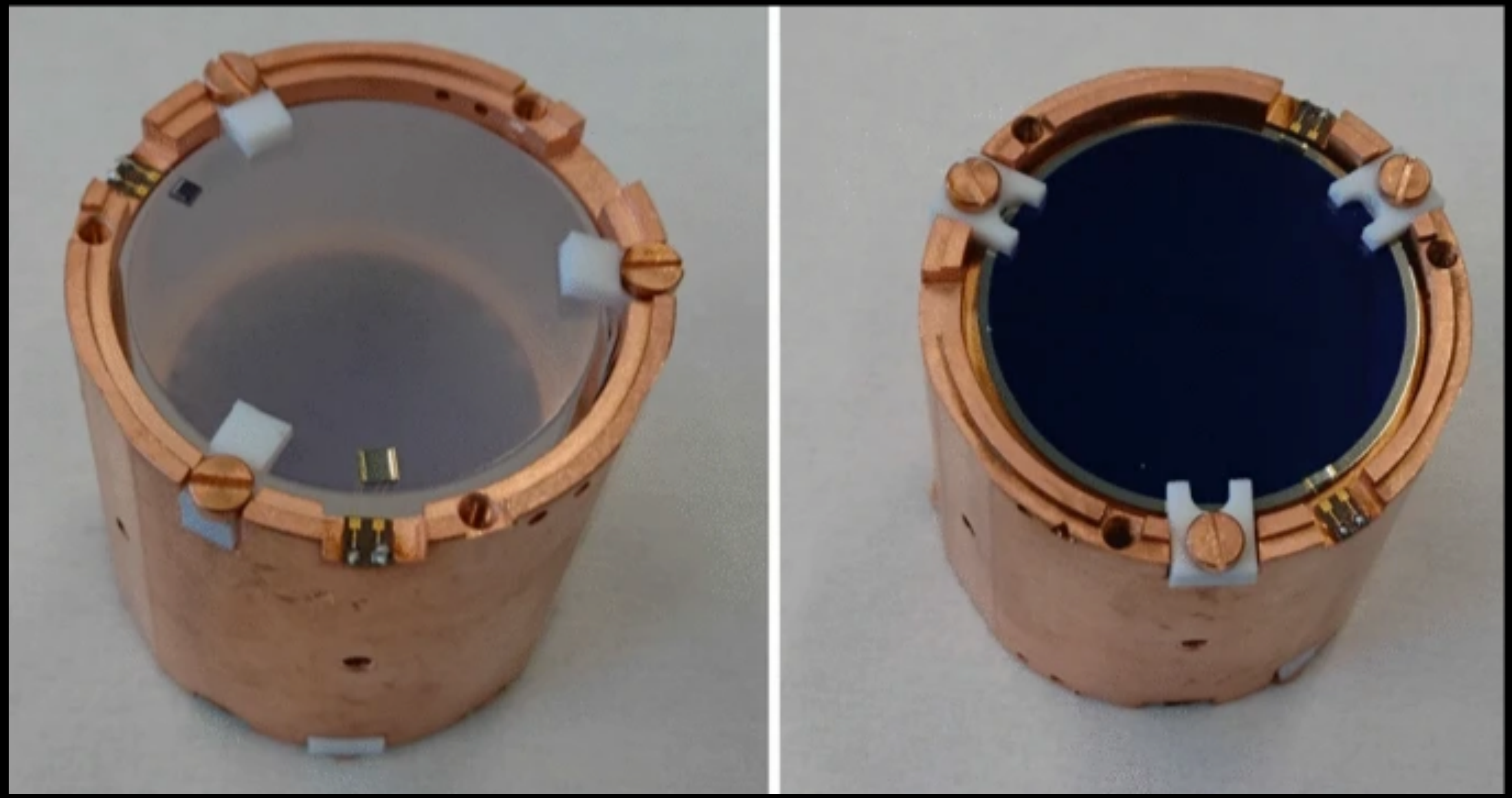
Eur.Phys.J. C 79 (2019) 7:583 (Background Model)

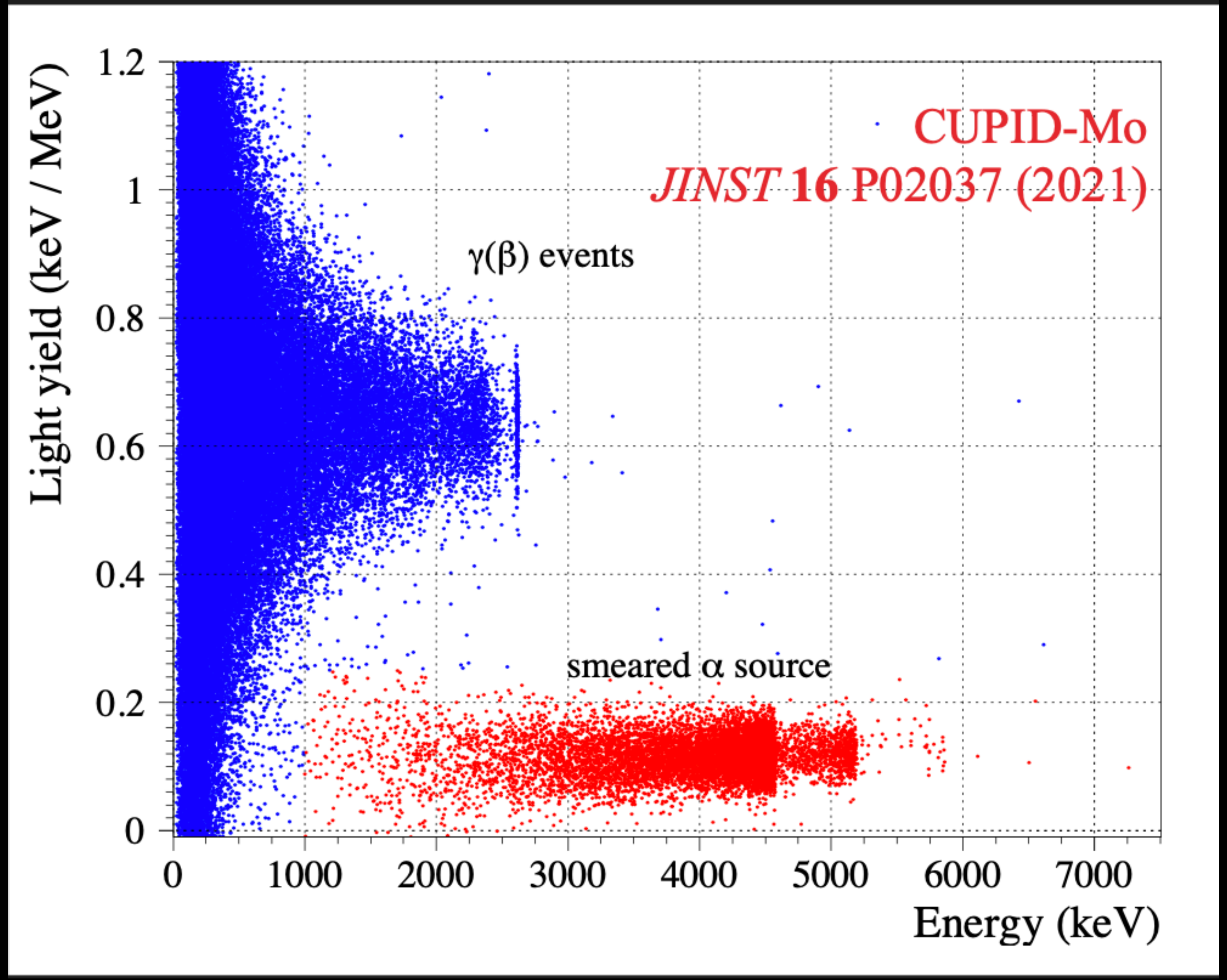
CUPID DEMONSTRATORS

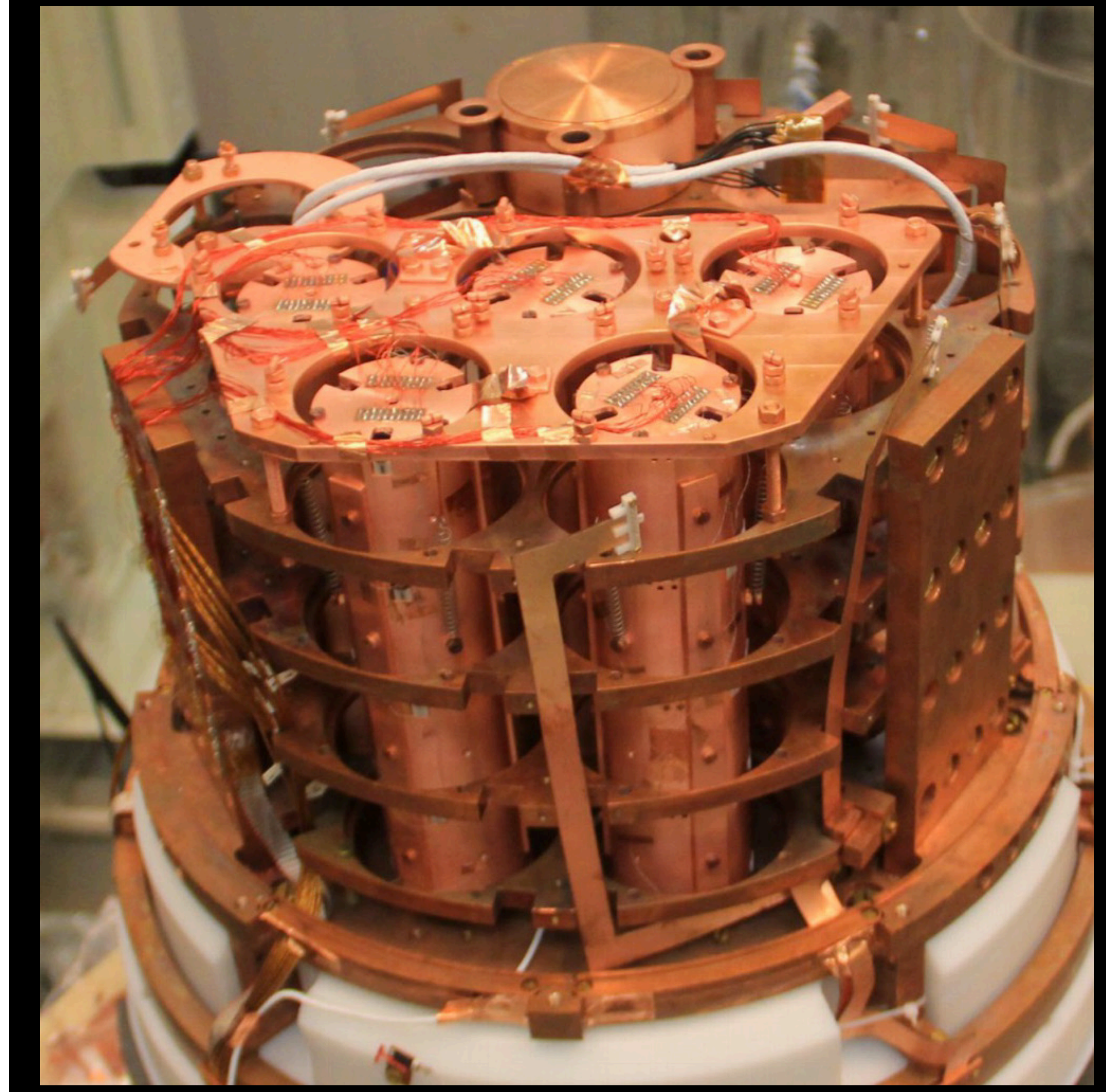
CUPID-Mo

CUPID-Mo Operated at Laboratoire Souterrain de Modane (LSM) in the EDELWEISS cryostat

- 20x ~210 g cylindrical $Li_2{}^{100}MoO_4$ (LMO) crystals
- ^{100}Mo enriched to ~97%
- Ge wafer with SiO anti-reflective coating for light
- ~20 mK operation March 2019 — July 2020
- $Q_{\beta\beta}$ = 3034 keV

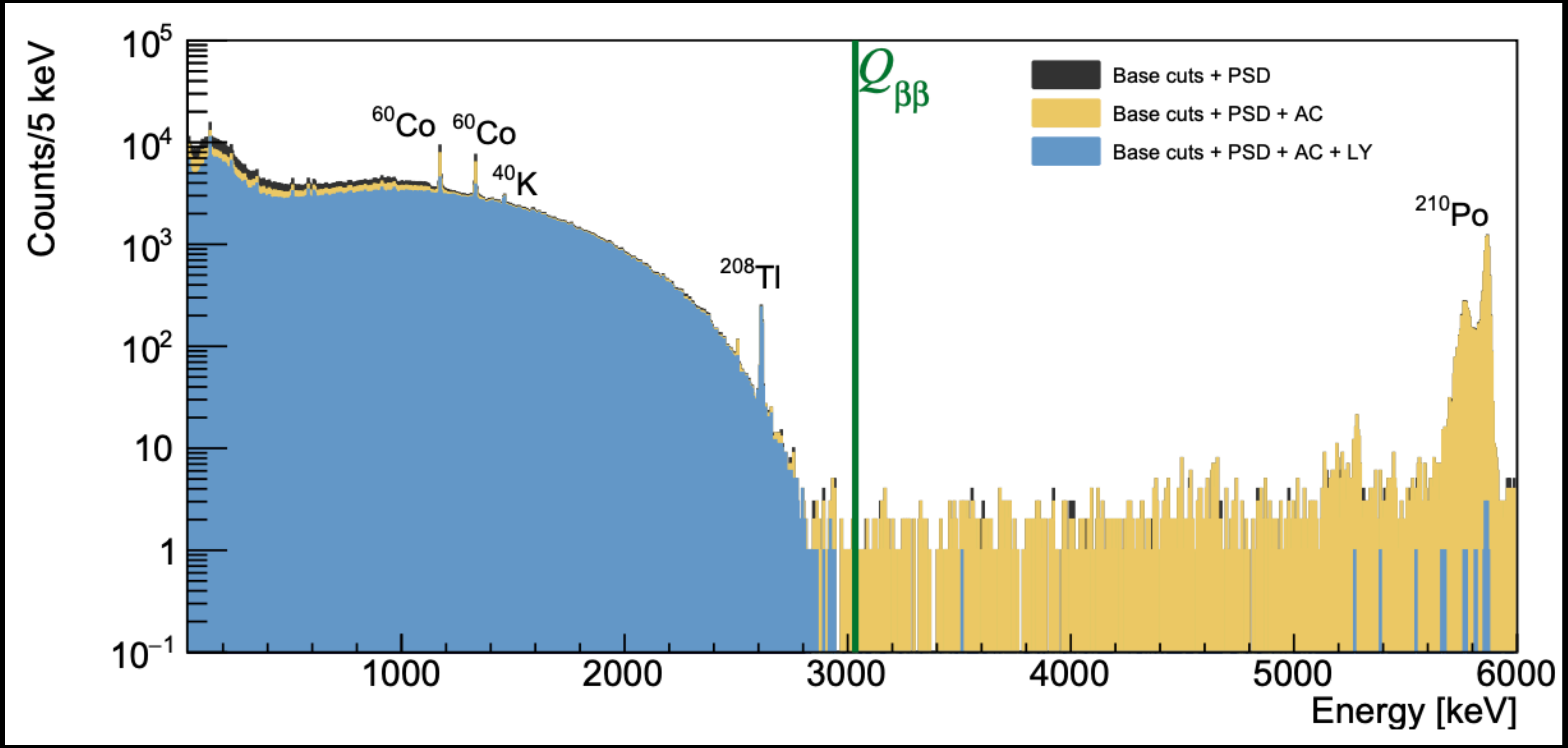






CUPID DEMONSTRATORS

Latest results from CUPID-Mo arXiv:2202.08716 since 17 Feb 2022



Higher exposure and improved analysis compared to the previous results

Phys. Rev. Lett. 126(18), 181802 (2021)

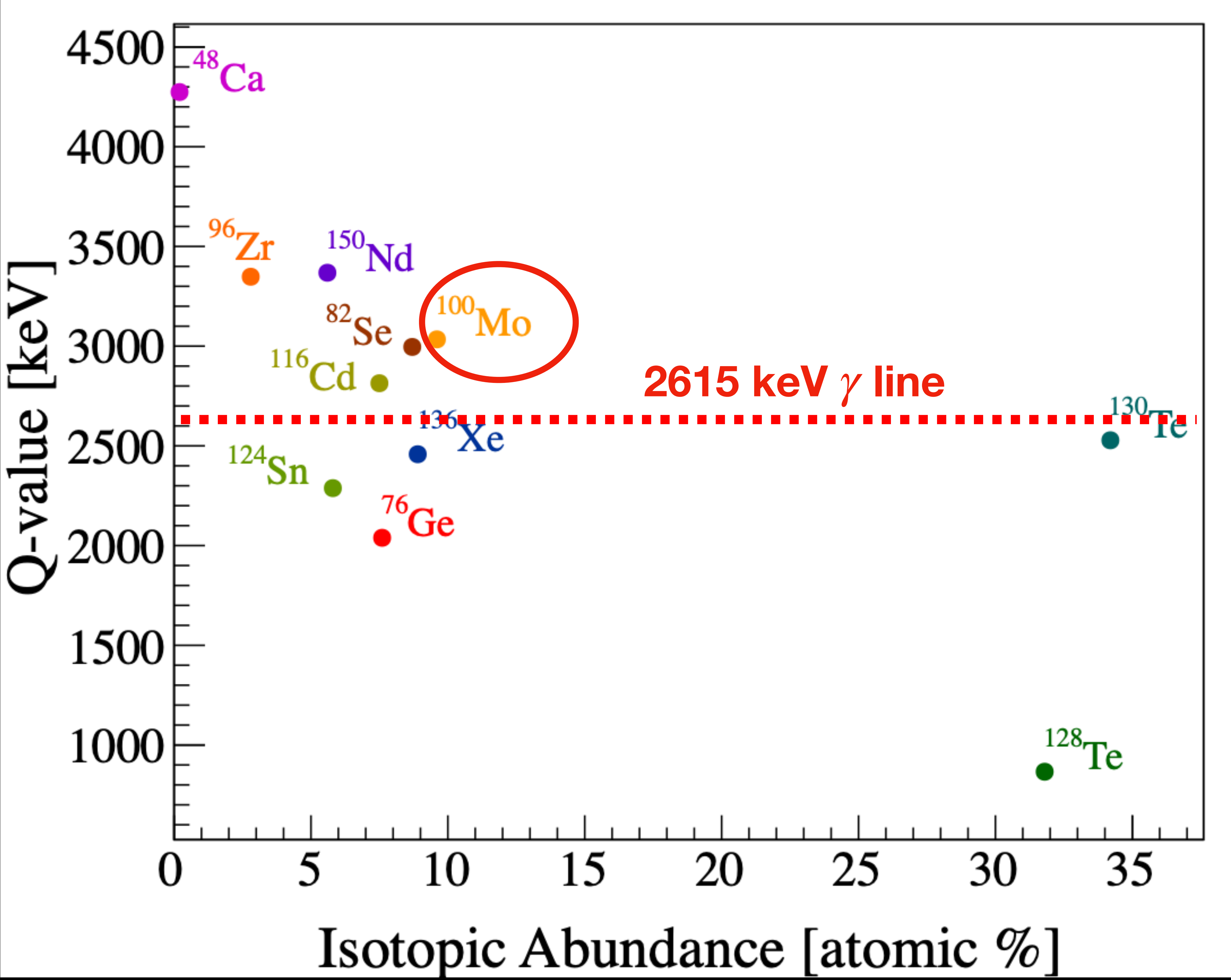
$0\nu\beta\beta$ decay half-life limit $T_{1/2} > 1.8 \times 10^{24}$ yr at 90% C.I.

exposure 2.71 kg×yr (1.47 kg×yr in ^{100}Mo)

limit on the effective Majorana mass of $m_{\beta\beta} < (0.28–0.49)$ eV

CHANGING ISOTOPE

Absorber Material: TeO_2 (34% ^{130}Te) → Li_2MoO_4 (enriched >95% ^{100}Mo)

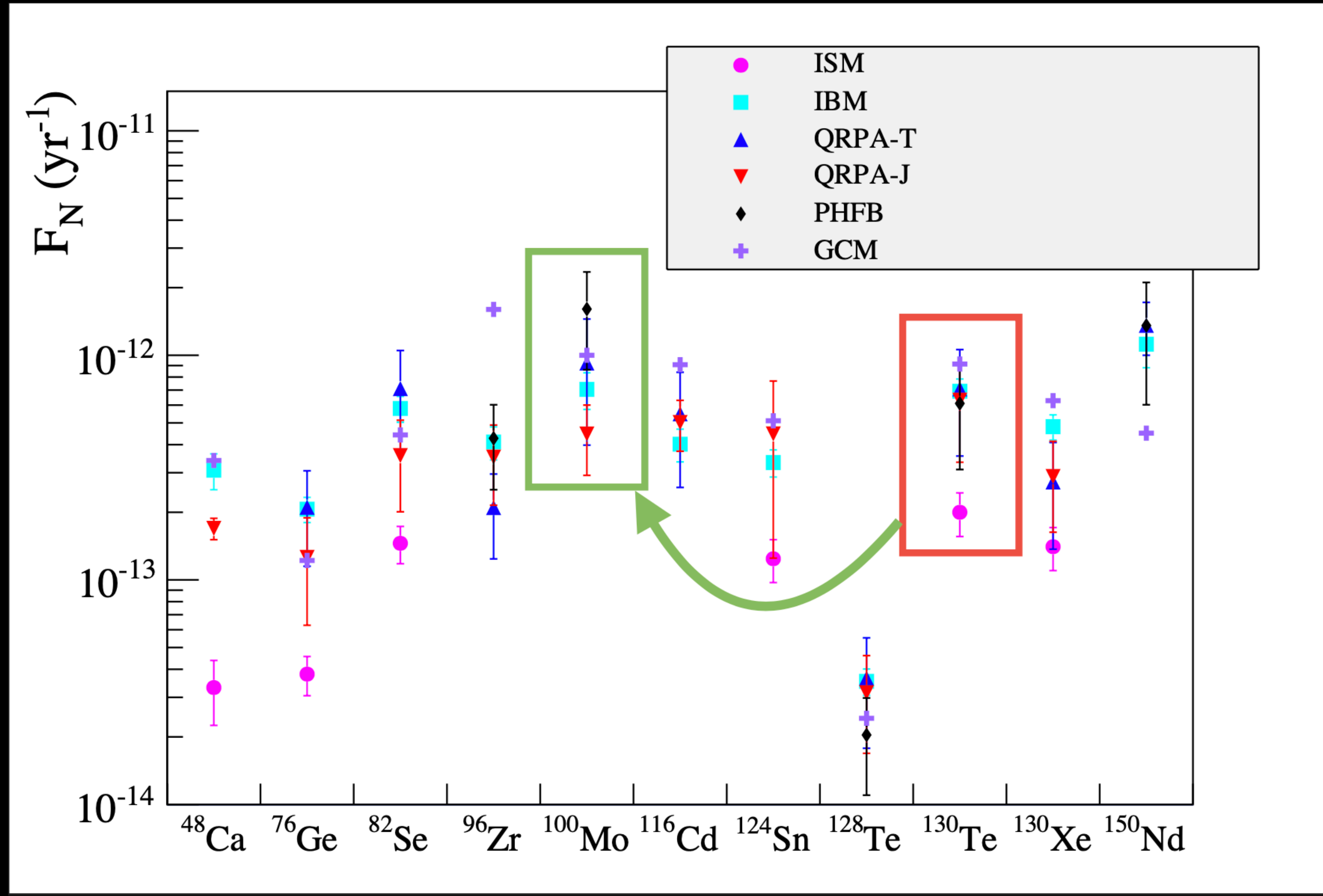


Very short 2νββ half-life: $[7.12^{+0.18}_{-0.14}(stat) \pm 0.10(syst)] \times 10^{18} yr$

Qββ=3034 keV, above majority of γ-background

^{100}Mo has a very favorable NME

$G_{0\nu}$ (phase space) depends from $Q^5_{\beta\beta}$: the higher the Q-value, the better the sensitivity

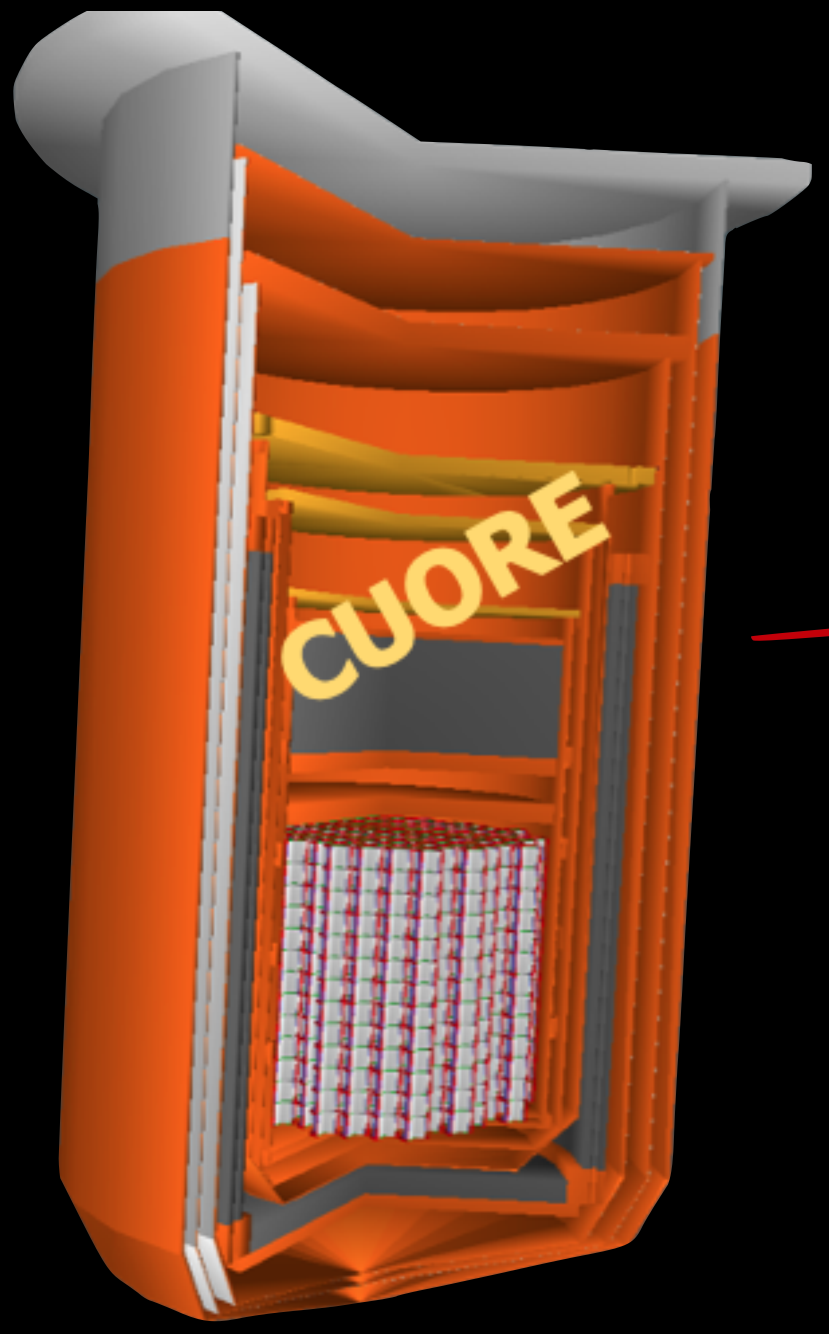


A NEW COLLABORATION

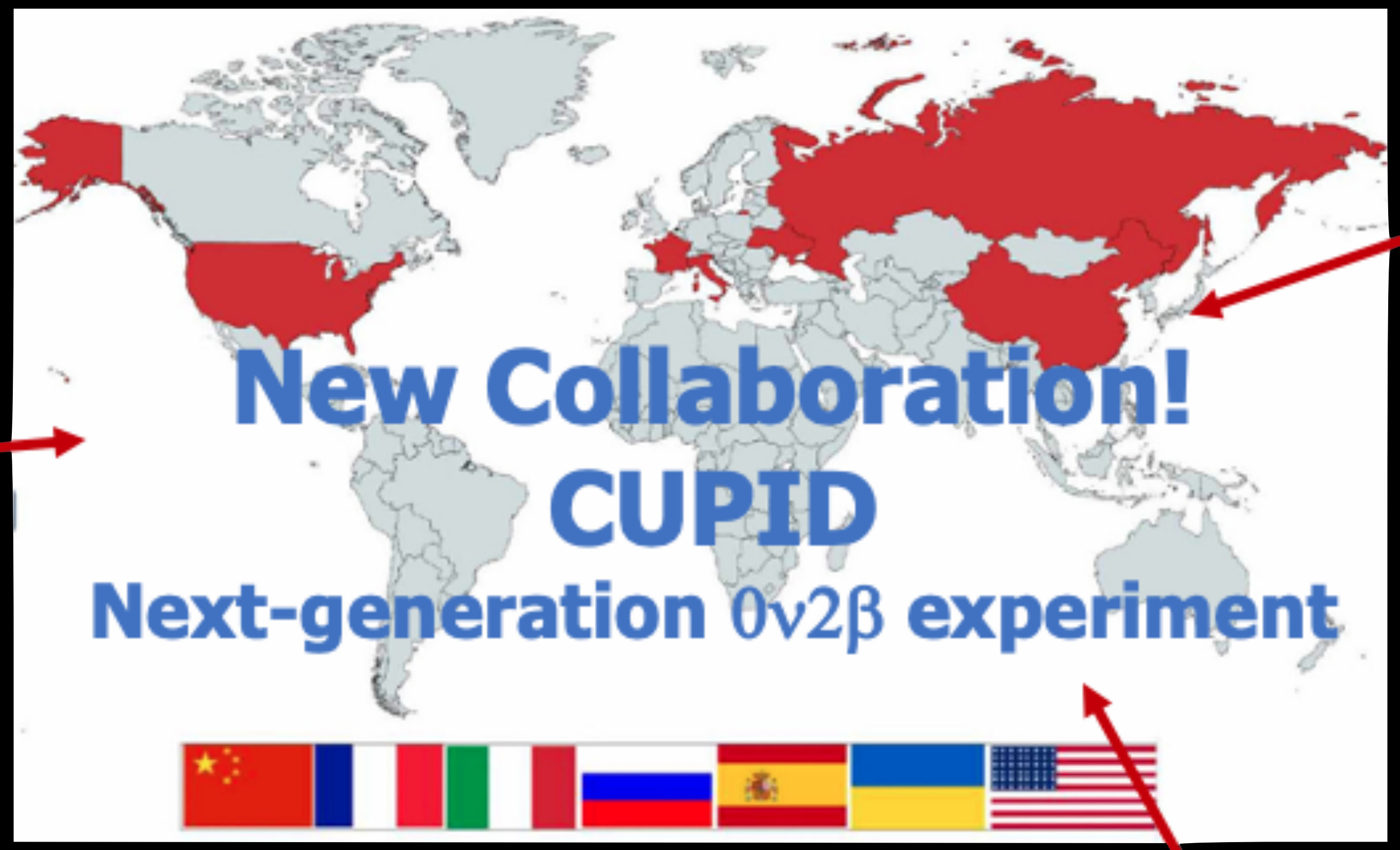
SINCE MAY 2021

CUPID:

CUORE
Upgrade with
Particle
IDentification



Best world limit on ^{130}Te
$T^{1/2}_{0\nu}$> 3.2 10^{25}y @90% CI



7 countries
~180 members

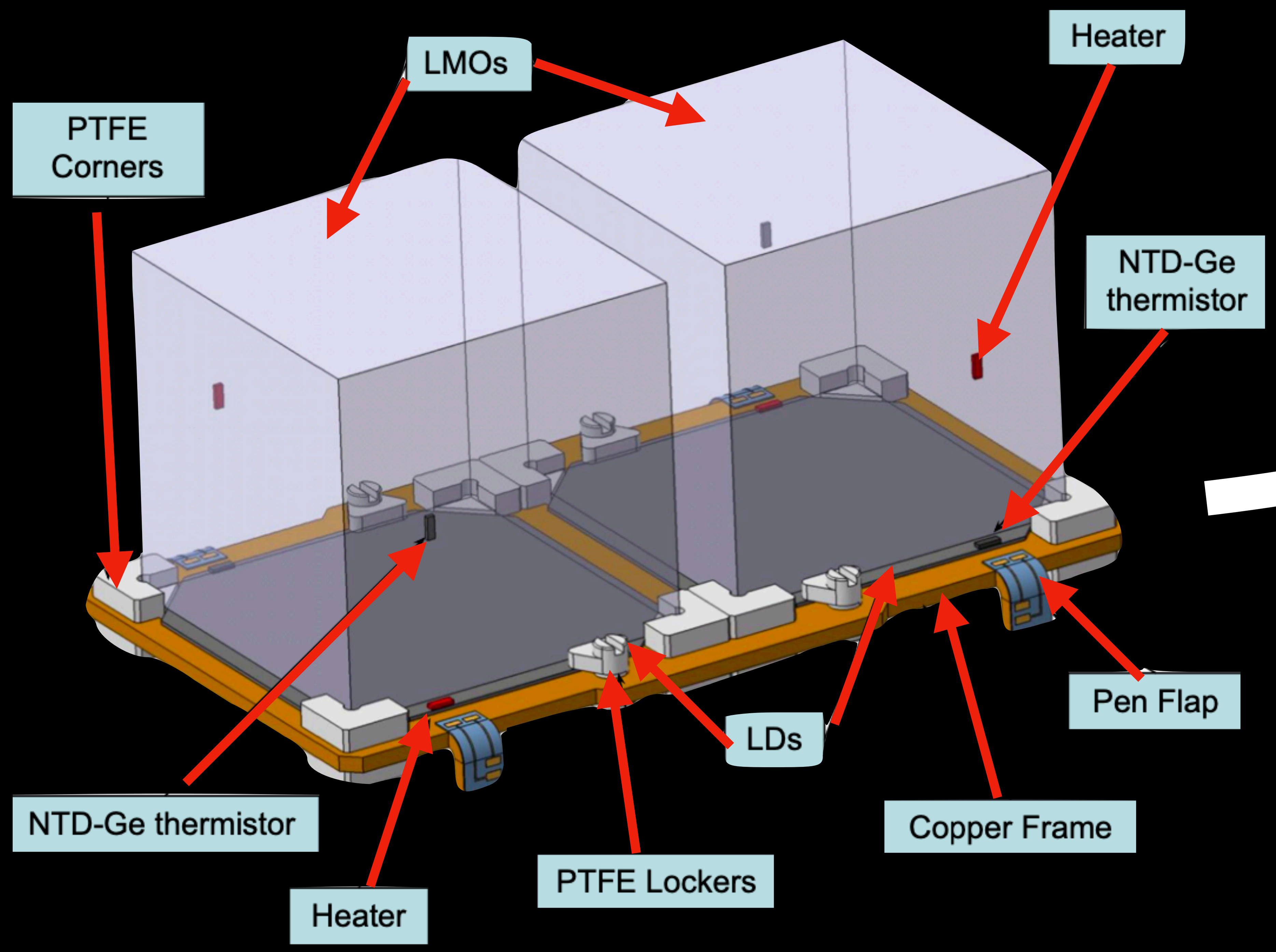
Best world limit on ^{82}Se
$T^{1/2}_{0\nu}$> 3.5 10^{24}y @90% CI

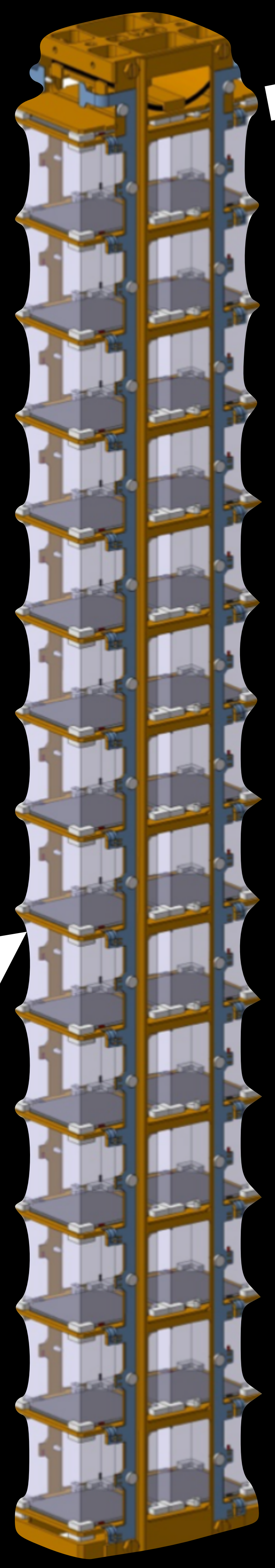
Best world limit on ^{100}Mo
$T^{1/2}_{0\nu}$> 1.5 10^{24}y @90% CI

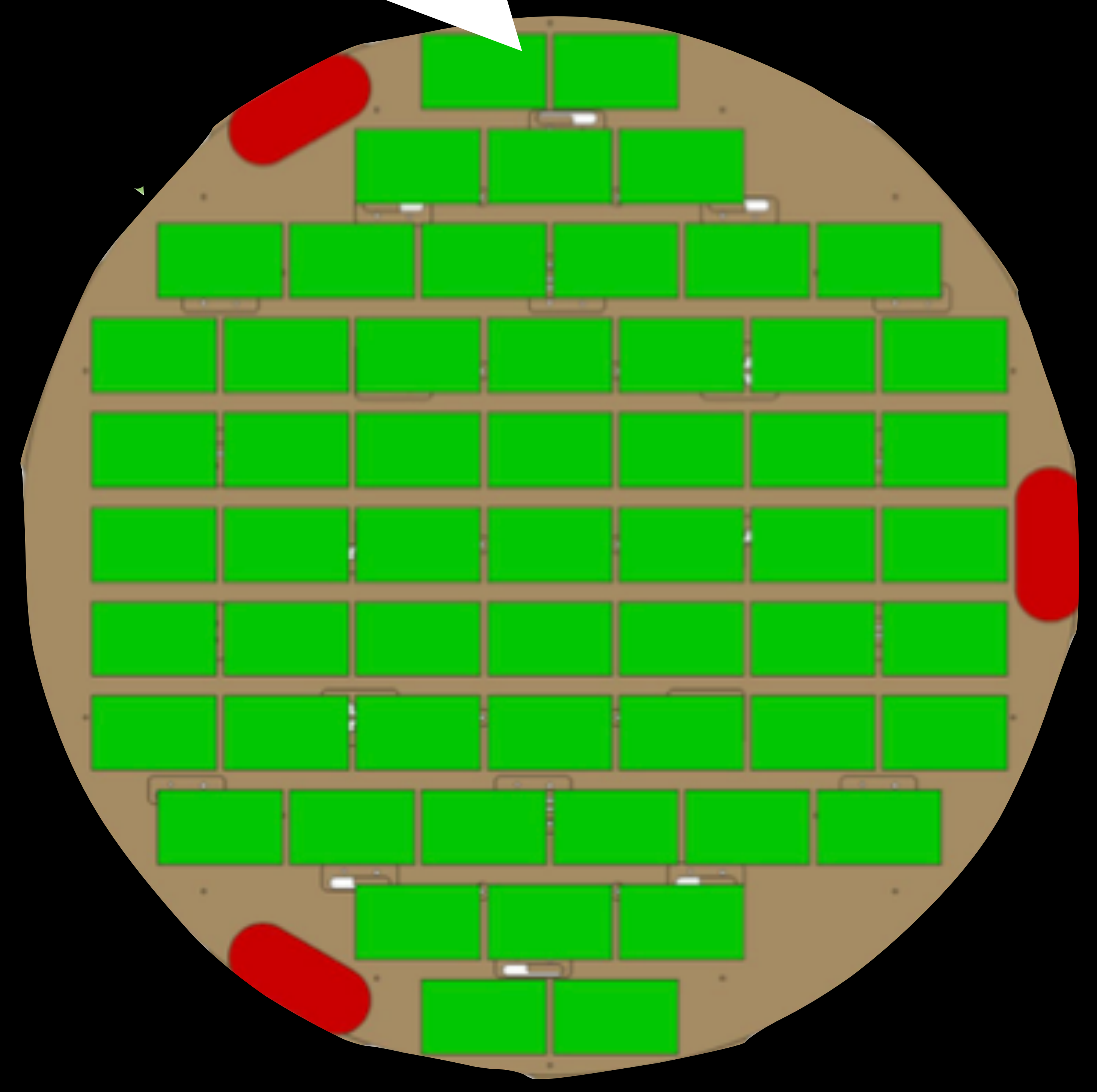
FRESH FORCES!

THE CUPID EXPERIMENT IN A NUTSHELL

- CUPID will use the CUORE cryostat and infrastructure
- Single module: $Li_2{}^{100}MoO_4$ 45x45x45 mm –280 g
- 57 towers of 14 floors with 2 crystals each -1596 crystals
- 240 kg of ^{100}Mo with >95% enrichment







PAST AND FUTURE R&D TOWARDS CUPID

Past tests at LNGS and Canfranc to define the final design for CUPID

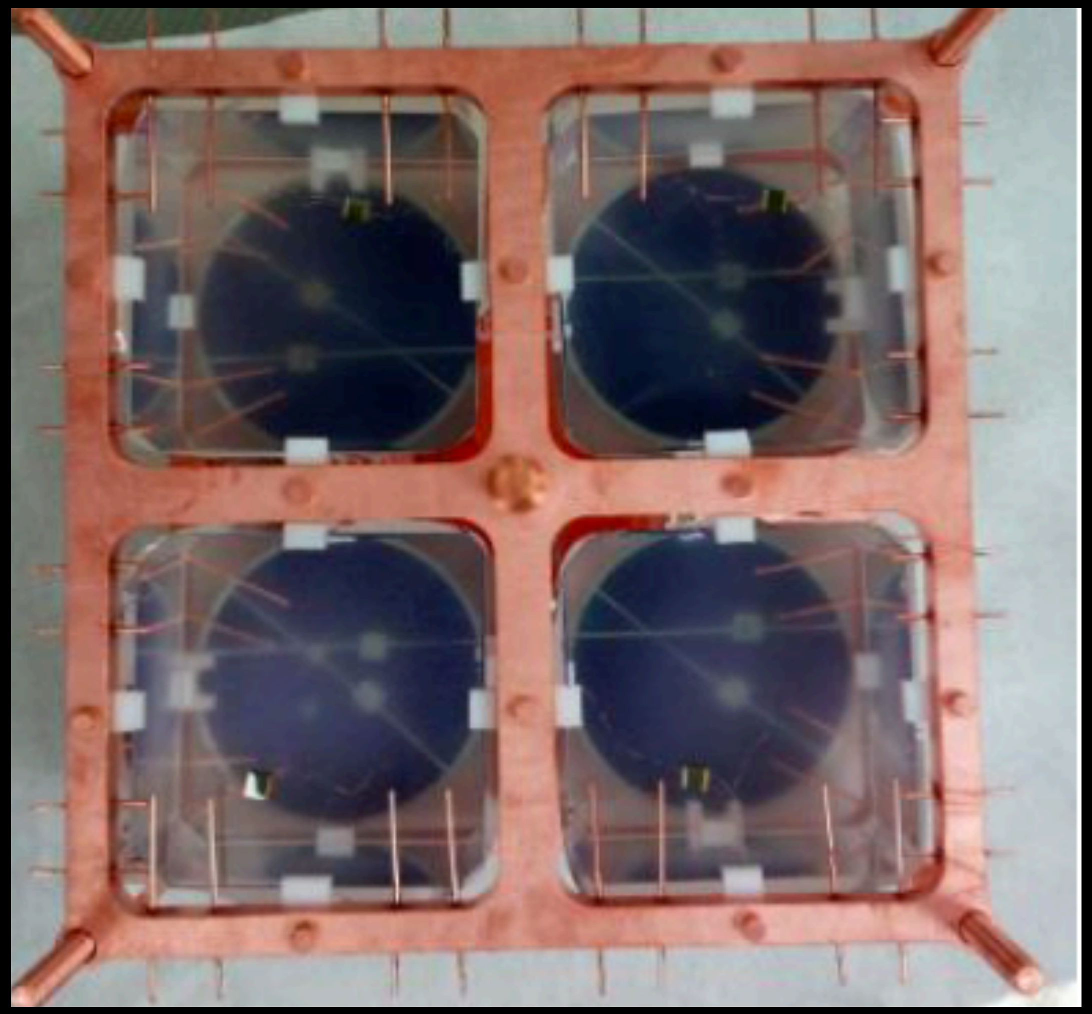
- **Crystal shape (cubic vs cylindrical)**
- **New tower structure**
- **New light detector position**
- **LY comparison with and without reflecting foil**
- **Additional pile-up tests using heater induced pulses**

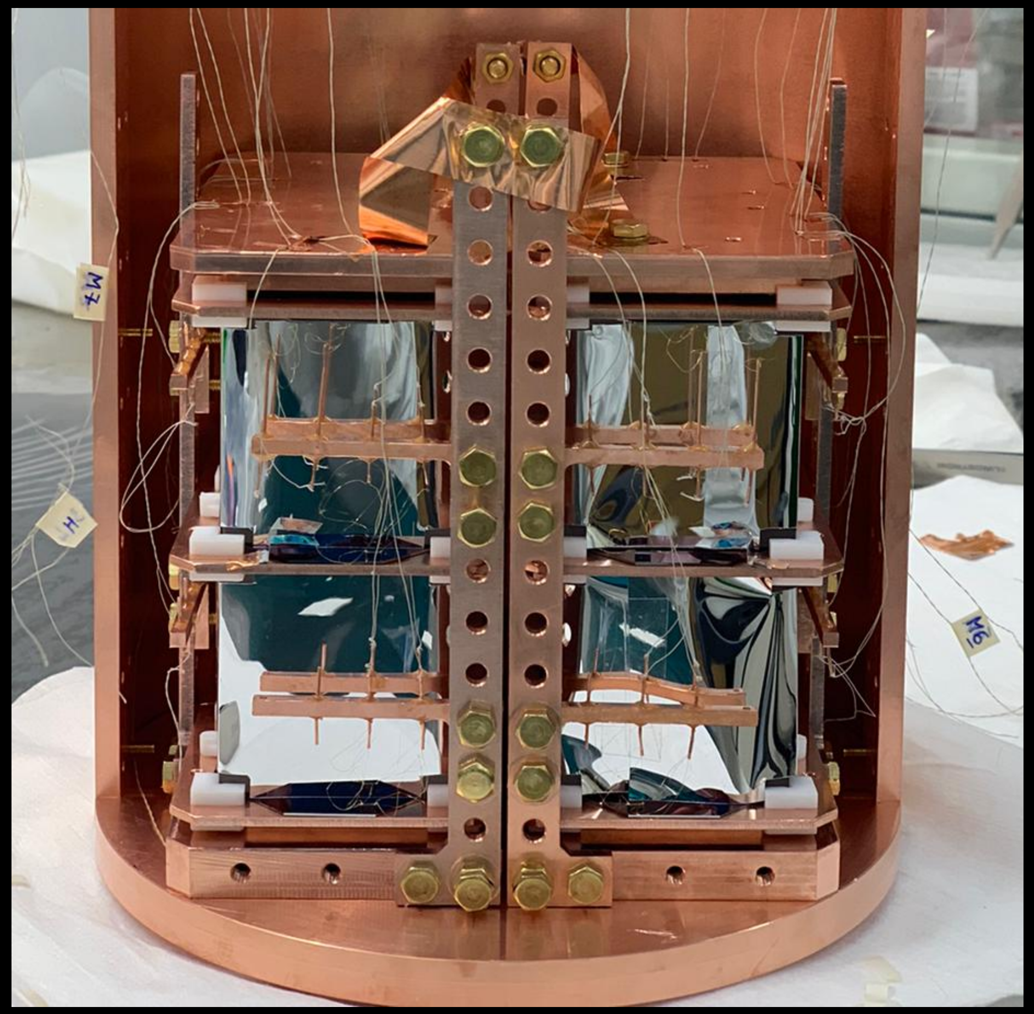
Eur. Phys. J. C (2021) 81: 104

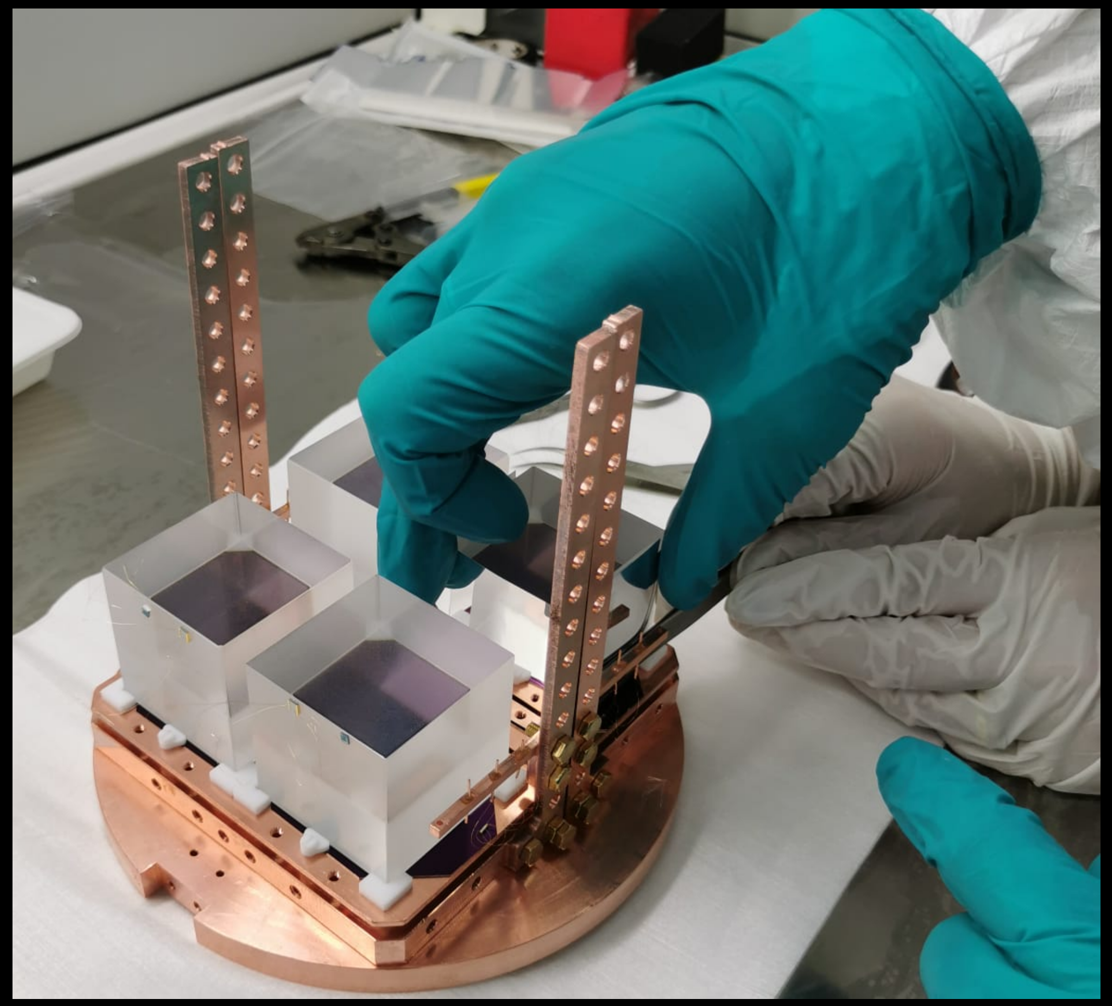
JINST 16 (2021) P02037

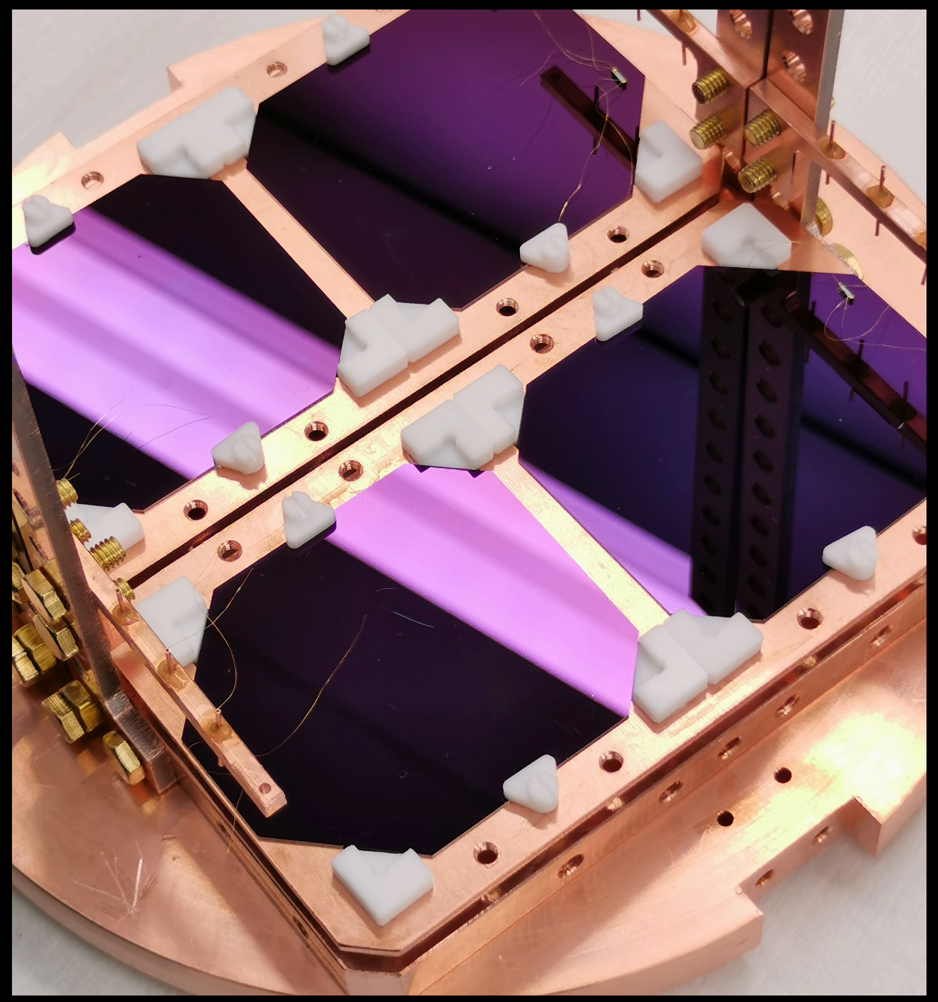
arXiv:2011.11726

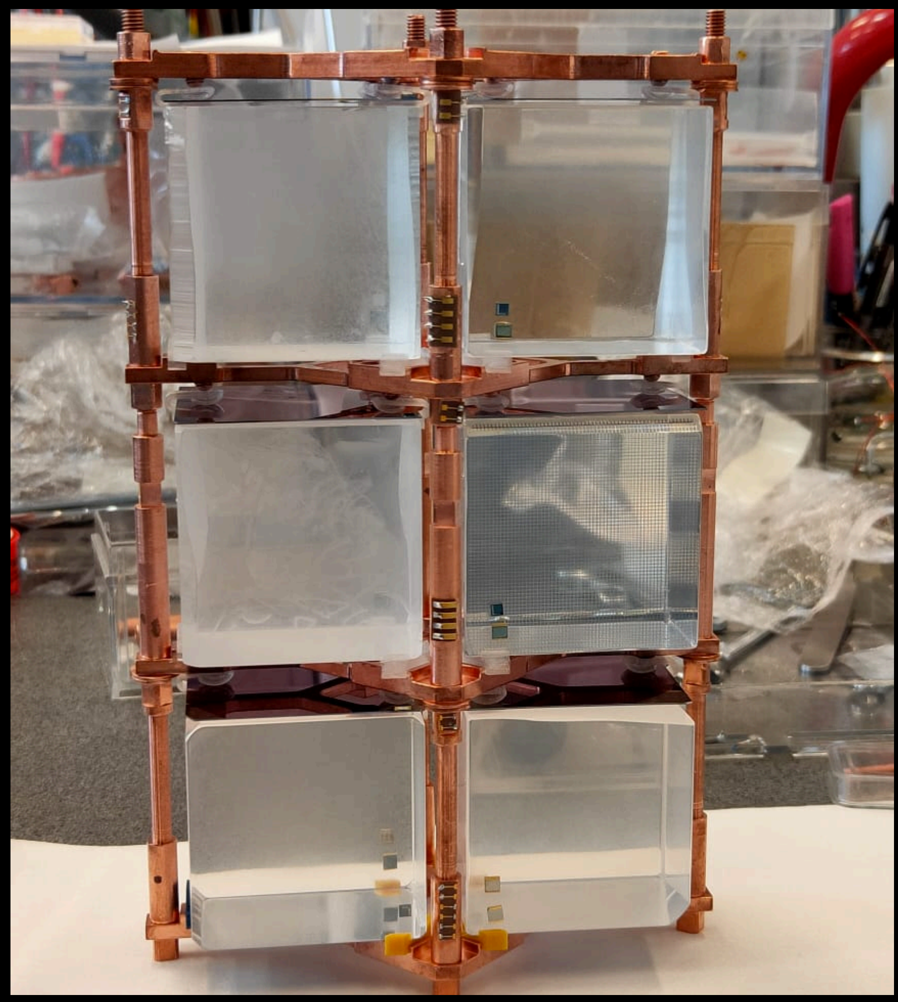
arXiv:2202.06279







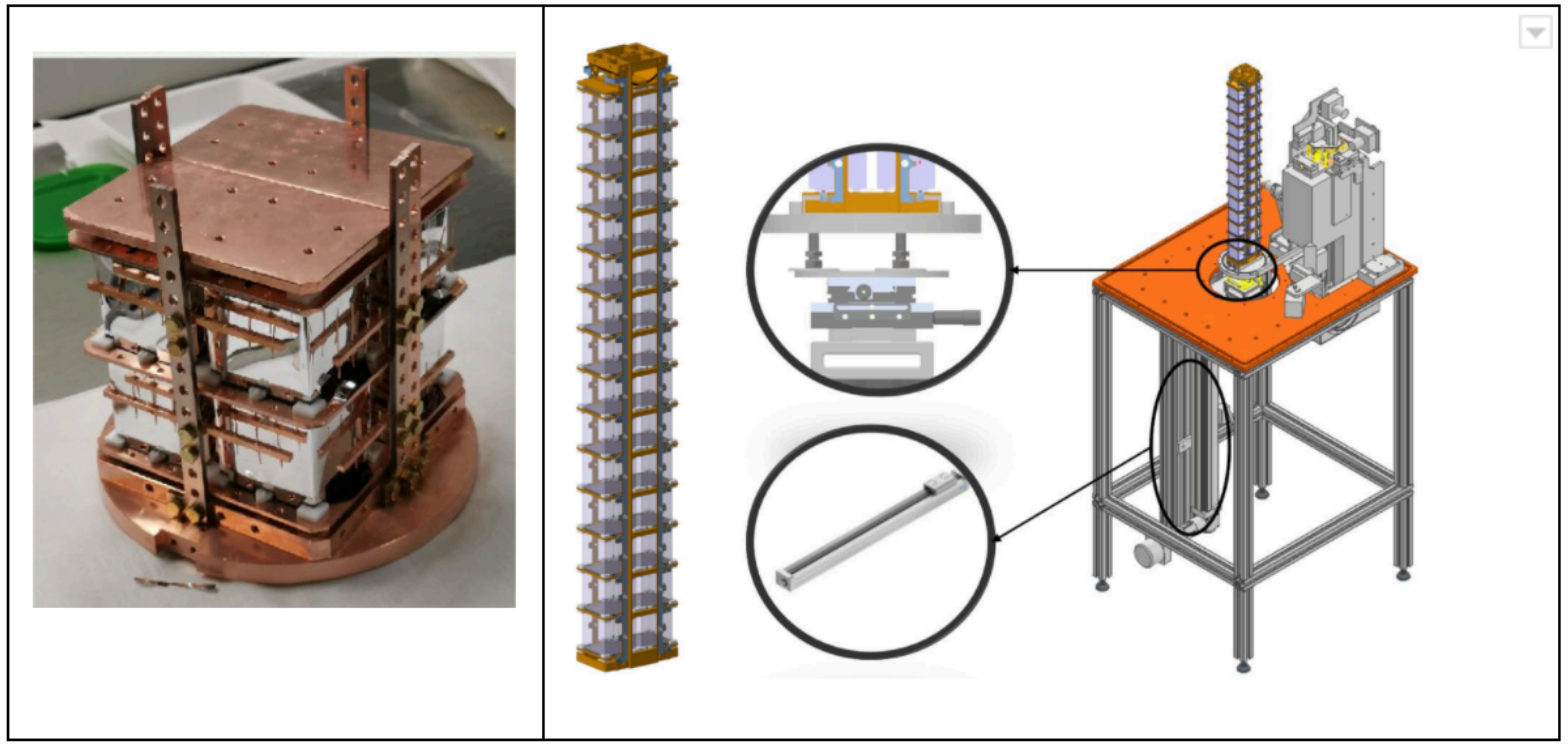




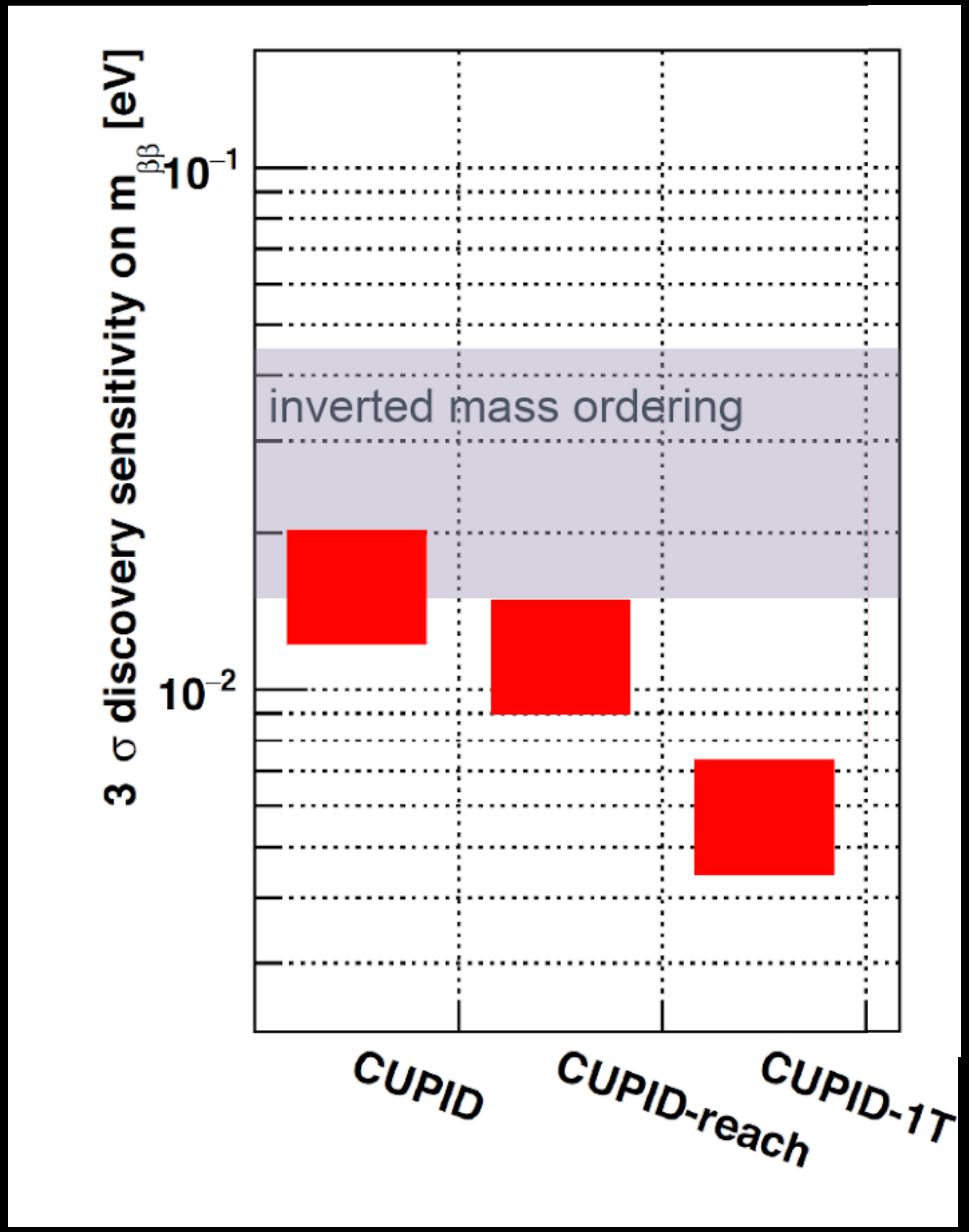
PAST AND FUTURE R&D TOWARDS CUPID

Current and future measurements at LNGS to test the final design for CUPID

- Crystals quality (4 crystals CCVR)
- Baseline tower performance (full size CUPID tower in the CUORE-0 & CUPID-0 cryostat)



CONCLUSIONS



Bolometers are a very flexible technology for 0νββ decay search

CUPID builds on CUORE, the largest bolometric array ever built

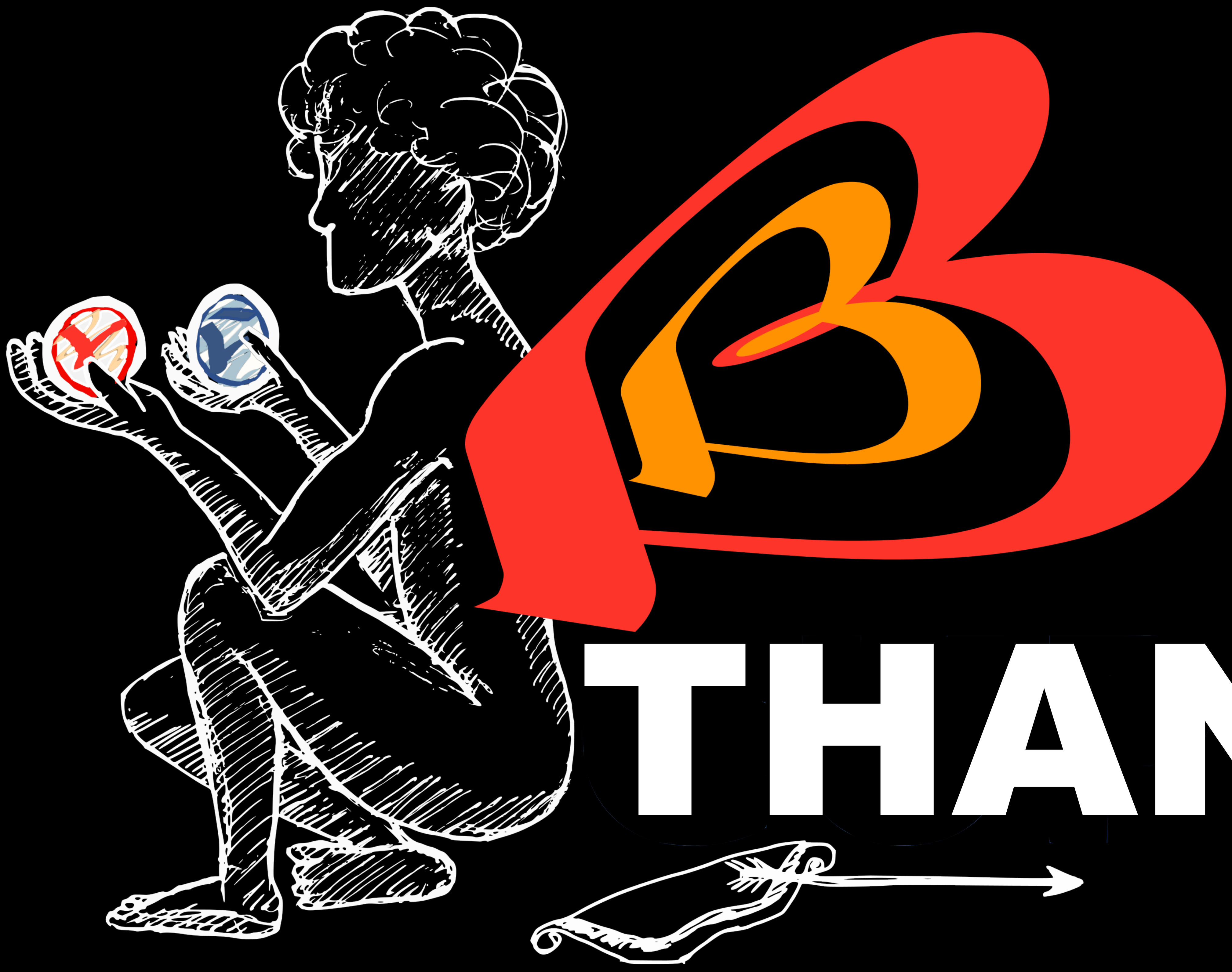
Particle identification with scintillating Li_2MoO_4 bolometers has been demonstrate

Isotopic enrichment and crystals growth has been demonstrated

Data driven based on CUORE, CUPID-0, and CUPID-Mo experiments

Using only 240 kg of ^{100}Mo

Next-next generation CUPID-1T capable of probing into Normal Hierarchy, or multiple isotope precision measurements in Inverted Hierarchy



THANKS