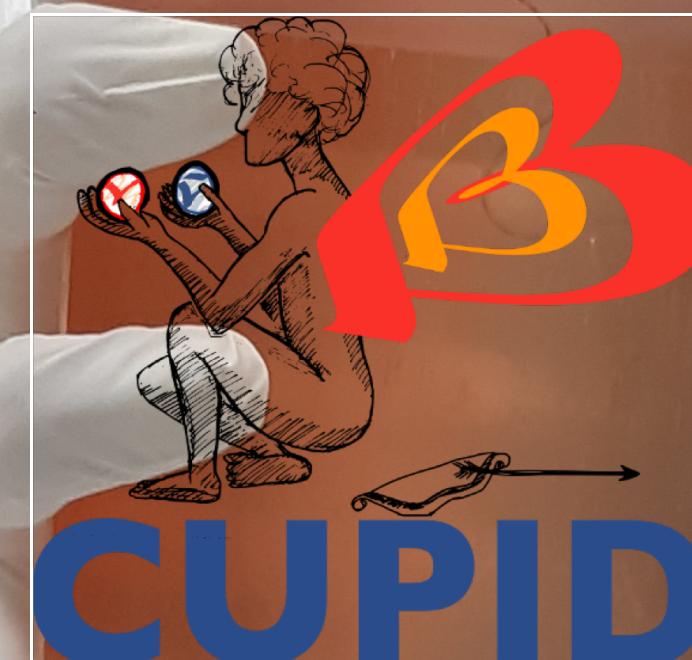


TOWARDS THE CUPID EXPERIMENT FOR NEUTRINO-LESS DOUBLE BETA DECAY

*G. Fantini (CUPID Collaboration)
Sapienza Università di Roma and INFN Sezione di Roma 1*



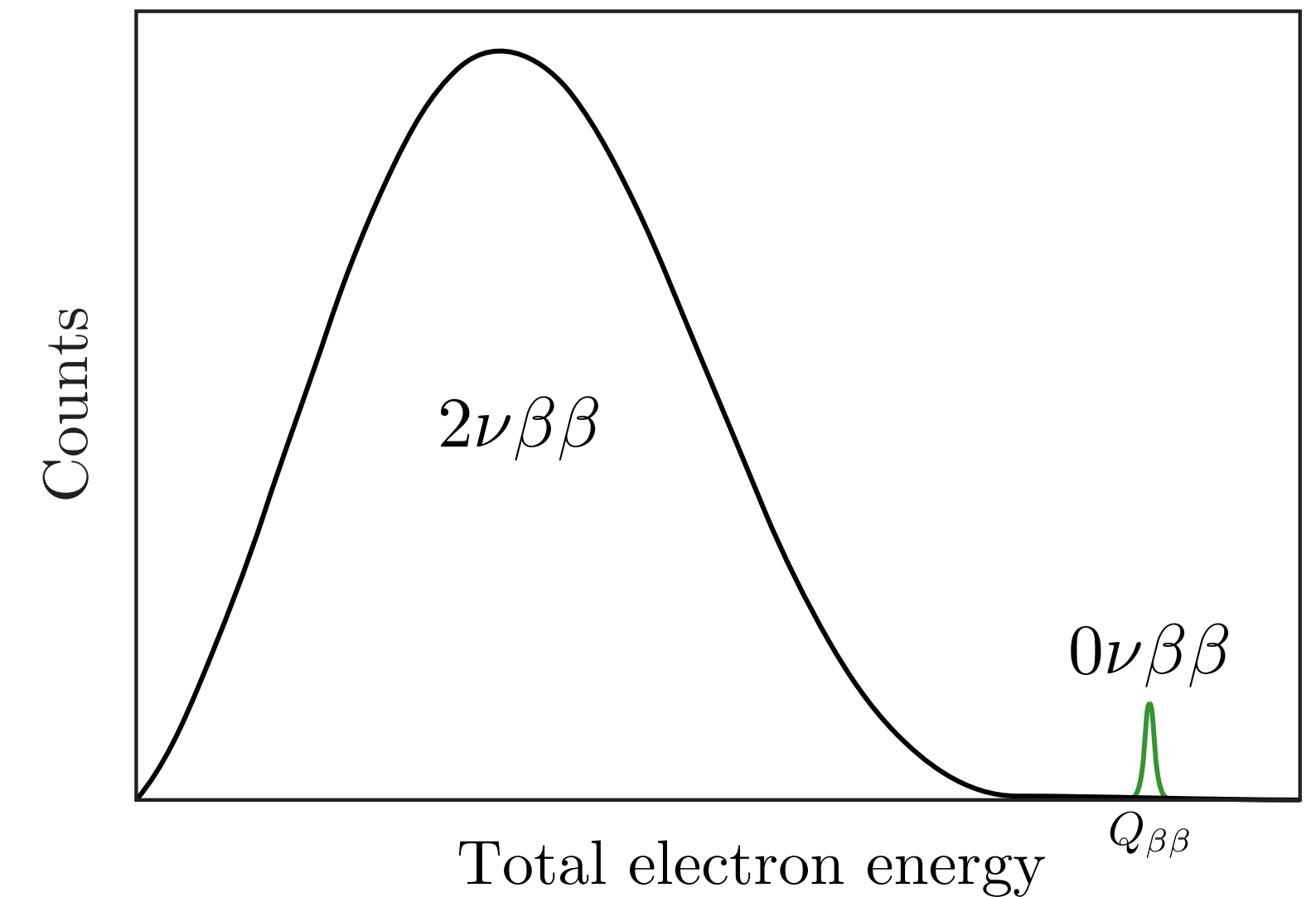
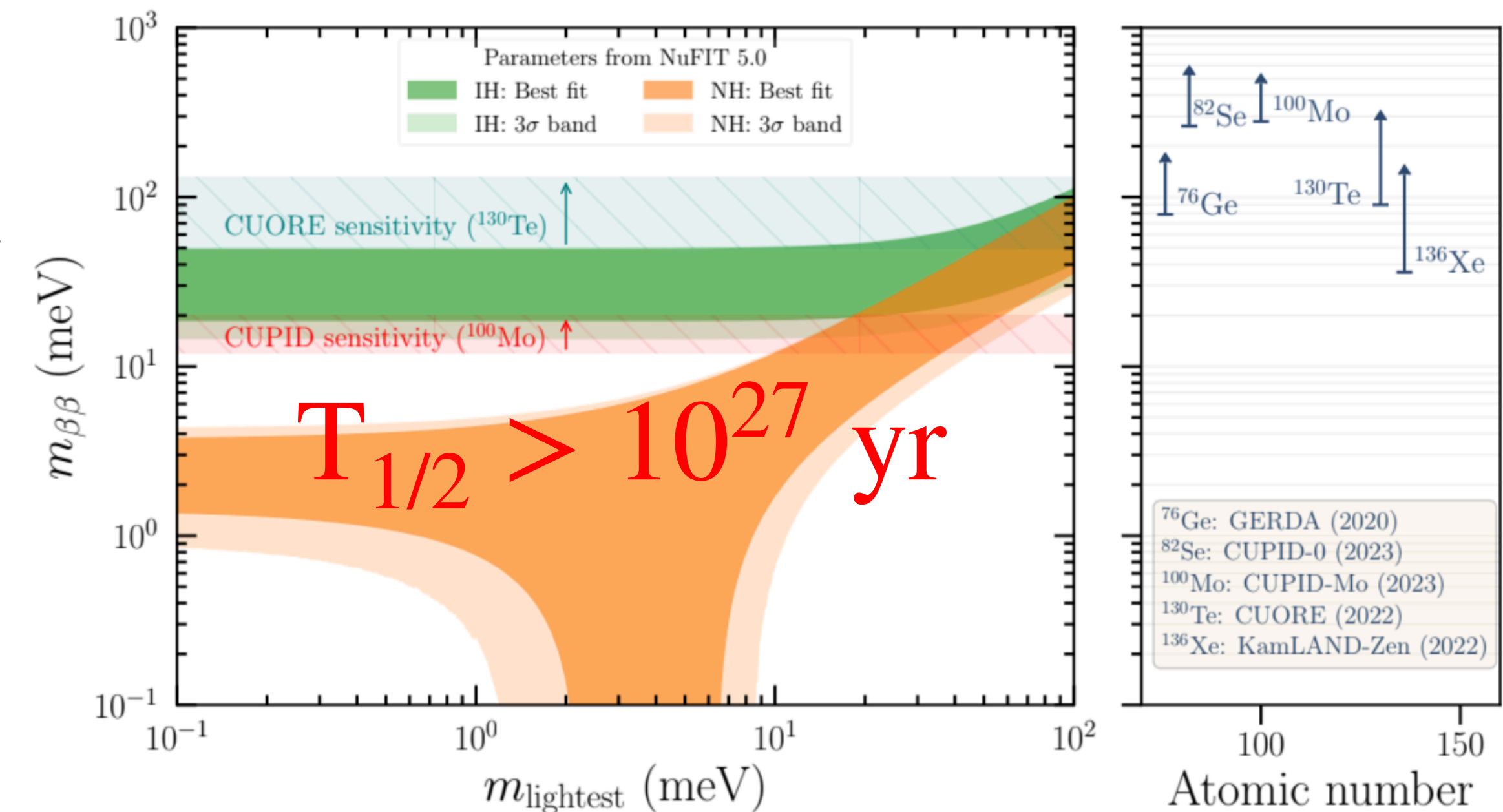
SAPIENZA
UNIVERSITÀ DI ROMA



NEUTRINO-LESS DOUBLE BETA DECAY

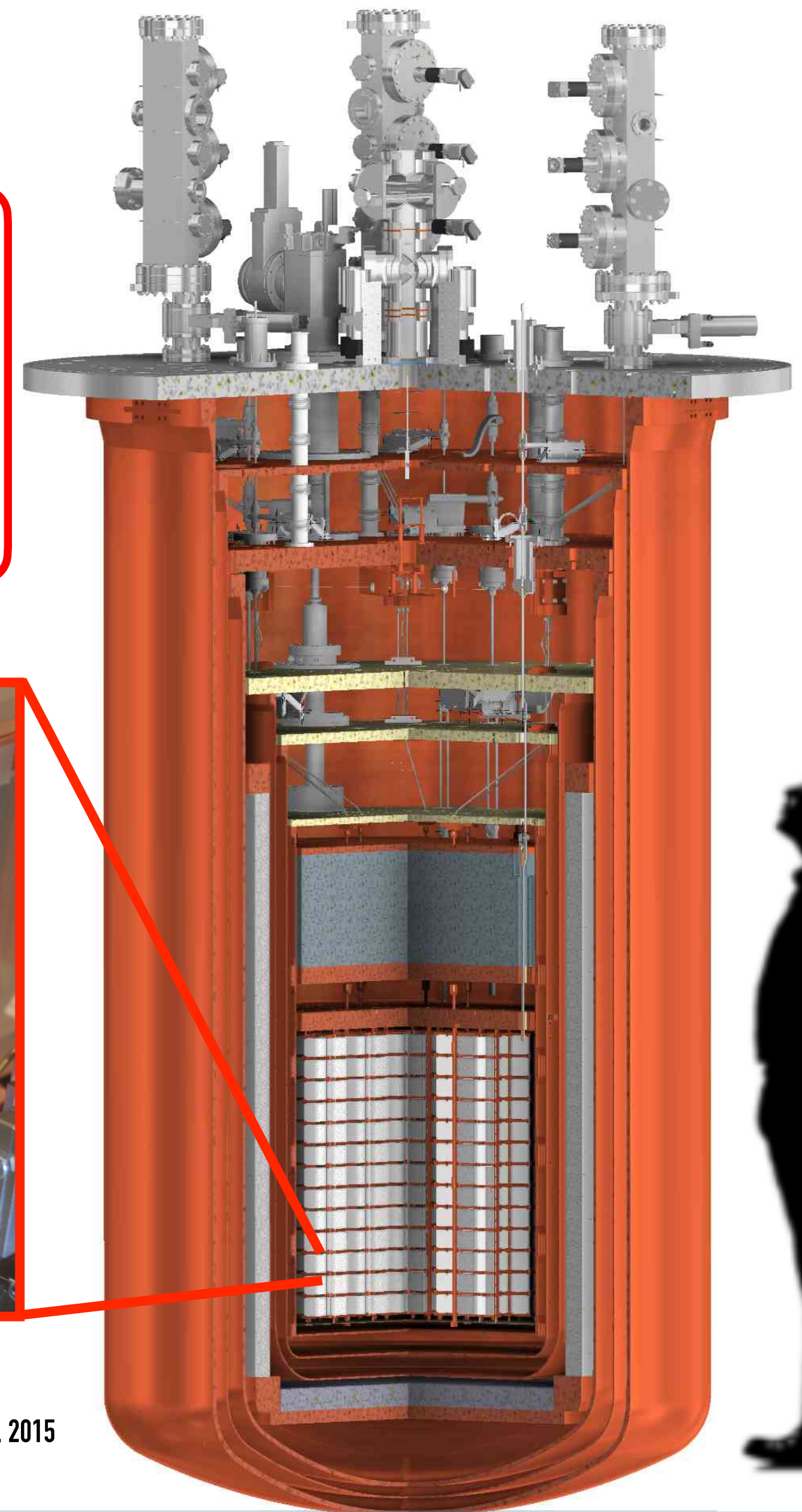
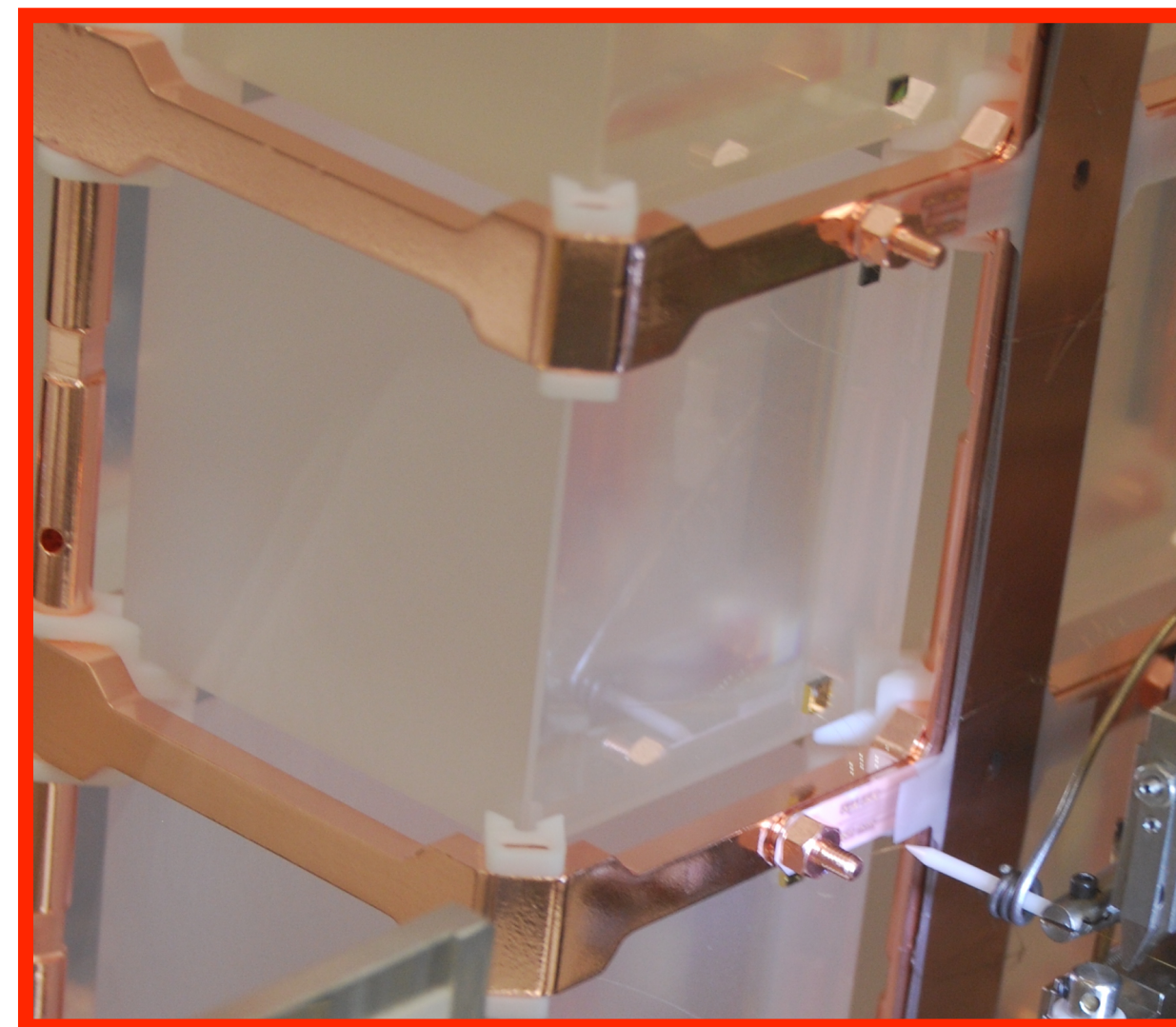
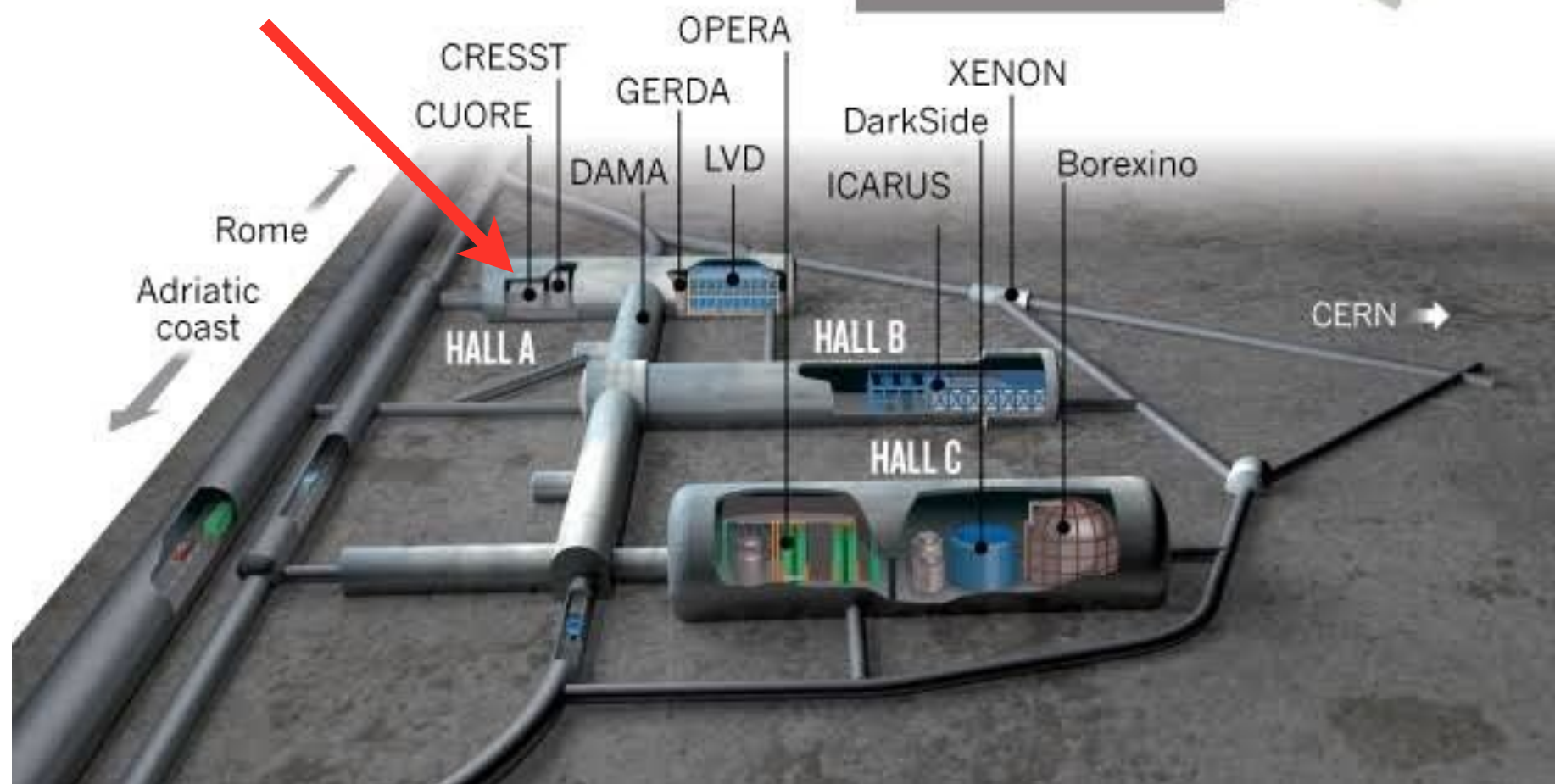
- Beyond Standard Model process accommodating for Majorana neutrinos
- Lepton Number Violation ($\Delta L = 2$)
- Constraints on neutrino mass hierarchy and scale
- Hints on origin of matter/anti-matter asymmetry
- Experimental signature: peak at $2\nu\beta\beta$ endpoint

$$\Gamma_{0\nu} = G_{0\nu} |M_{0\nu}|^2 \frac{\langle m_{\beta\beta} \rangle^2}{m_e^2}$$



THE CUORE EXPERIMENT / HOST LAB

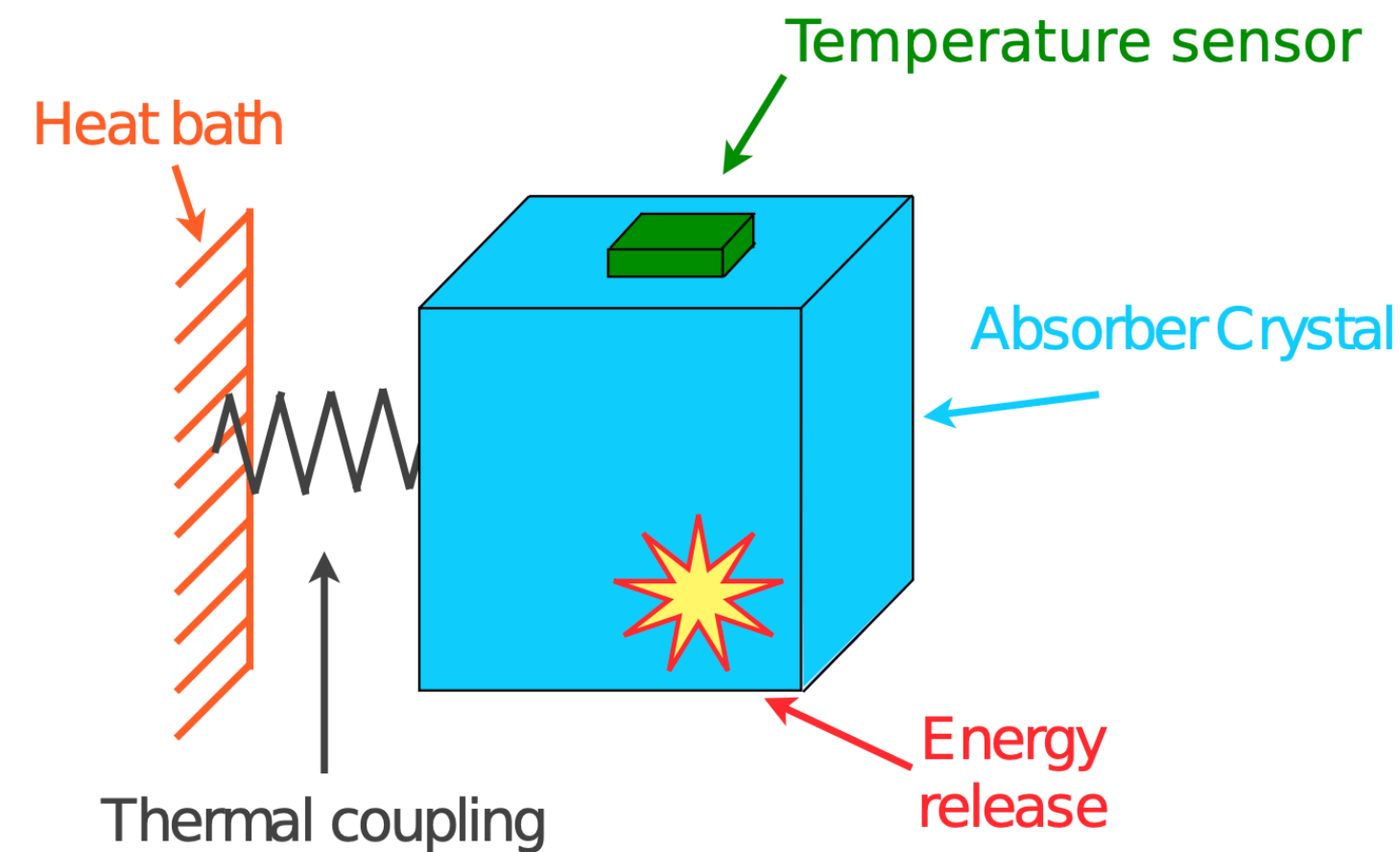
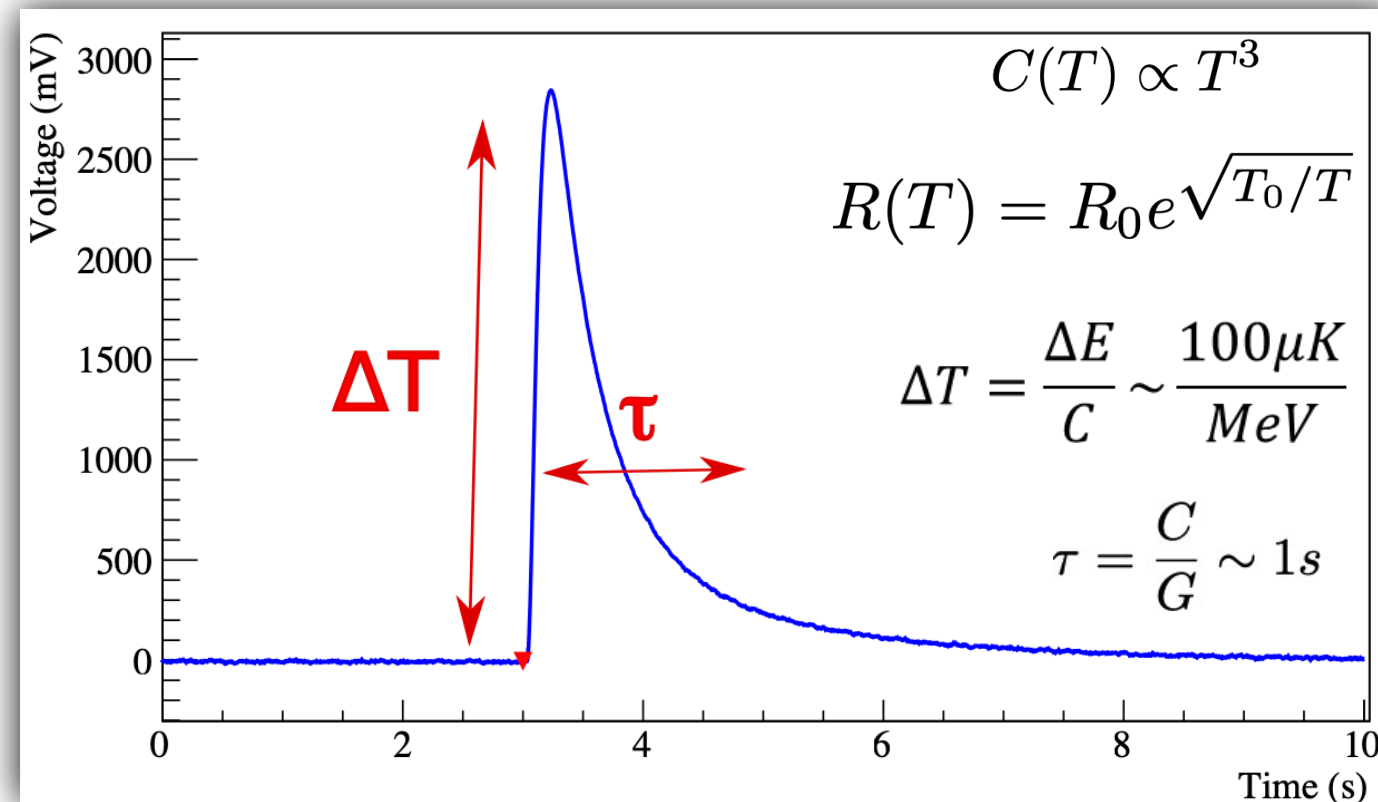
- 988 natTeO_2 crystals at ~ 10 mK
- 742 kg TeO_2 , 206 kg ^{130}Te (34% natural isotopic abundance)
- $Q_{\beta\beta} = 2527.5$ keV above (most) natural γ backgrounds
- Collected > 2 tonne yr exposure to date in ~ 5 yrs of operation



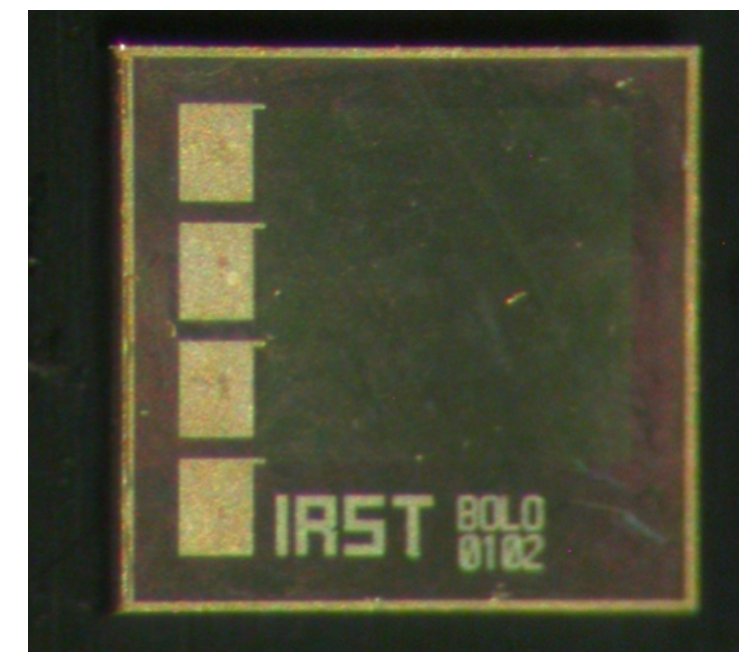
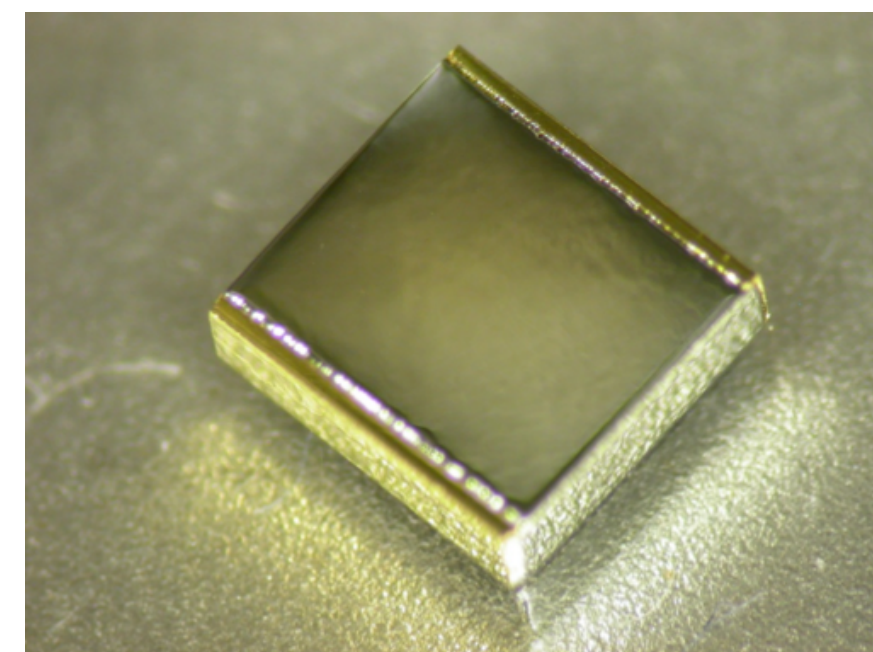
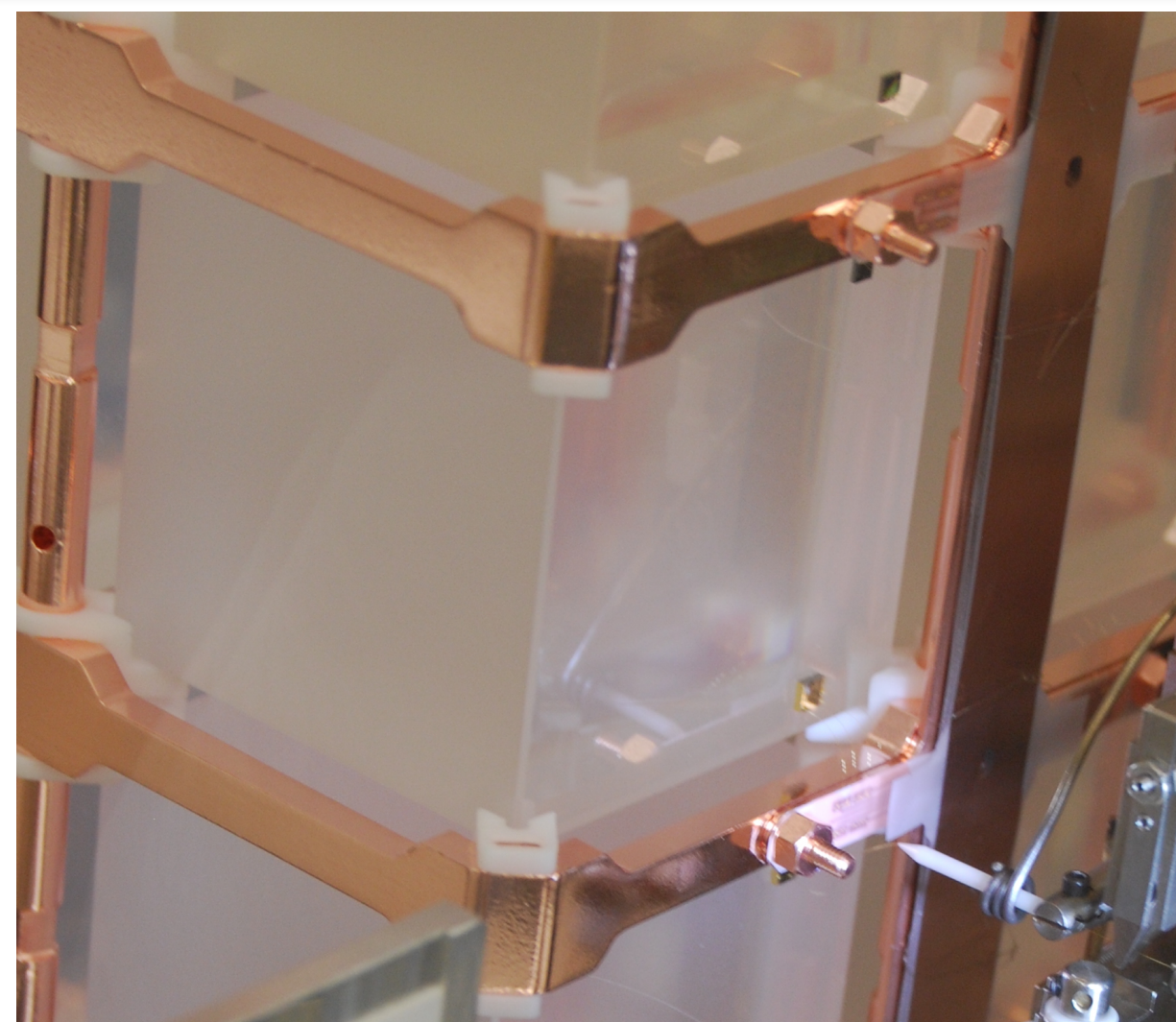

L. Marini
F-2-2 Friday
h10.30

Artusa, D.R. (CUORE Collaboration), Adv. High Energy Phys., 879871, 2015
<https://doi.org/10.1155/2015/879871>

EXPERIMENTAL TECHNIQUE – CRYOGENIC CALORIMETERS



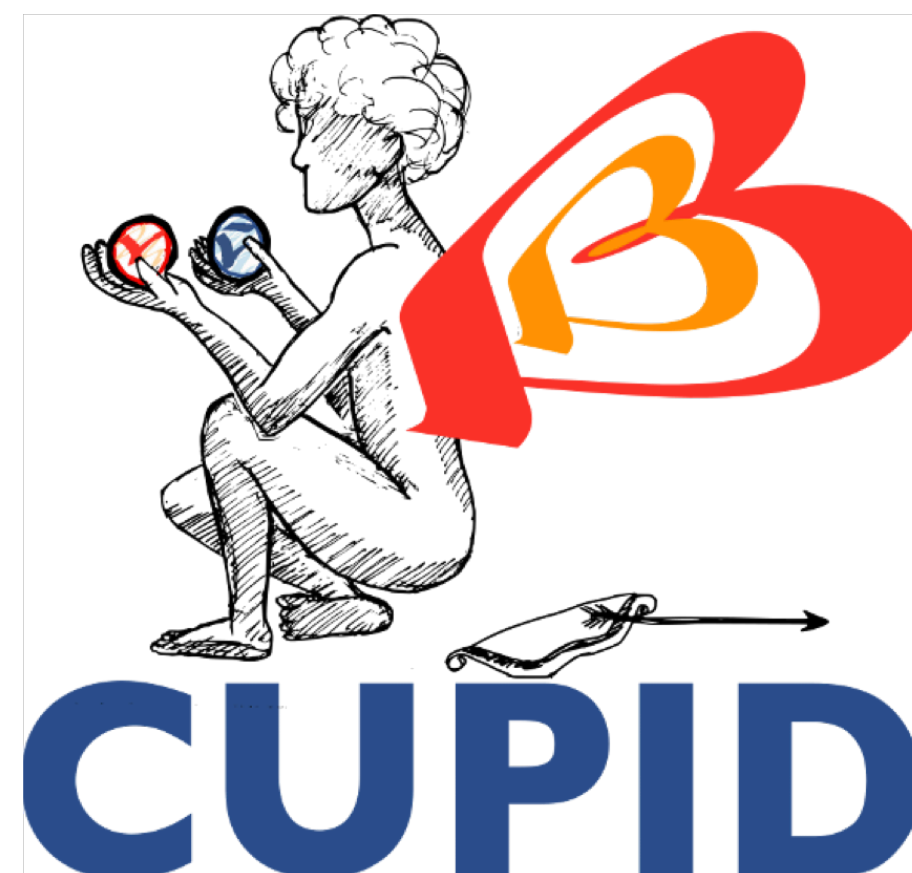
$$\Delta T \sim \frac{\Delta E}{C} \quad \tau \sim \frac{C}{G}$$



- macro-calorimeters
O(100 g)
- instrumented w/ NTD thermistors @ 10 mK
- source = detector
- particle interactions deposit heat into crystals
- voltage pulses induced in NTDs
- Si heaters inject fixed energy in order to correct for thermal gain drifts as a function of temperature

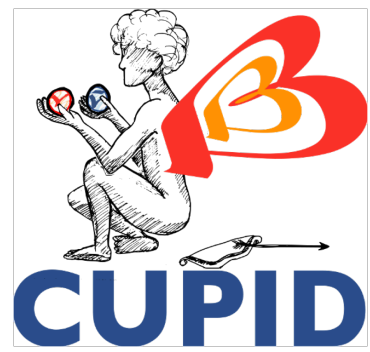

 Alduino, C. et al. (CUORE Collaboration), J. Inst. 11(07), P07009, 2016
<https://doi.org/10.1088/1748-0221/11/07/p07009>


 Vignati, M., J. Appl. Phys. 108, 084903, 2010
<https://doi.org/10.1063/1.3498808>

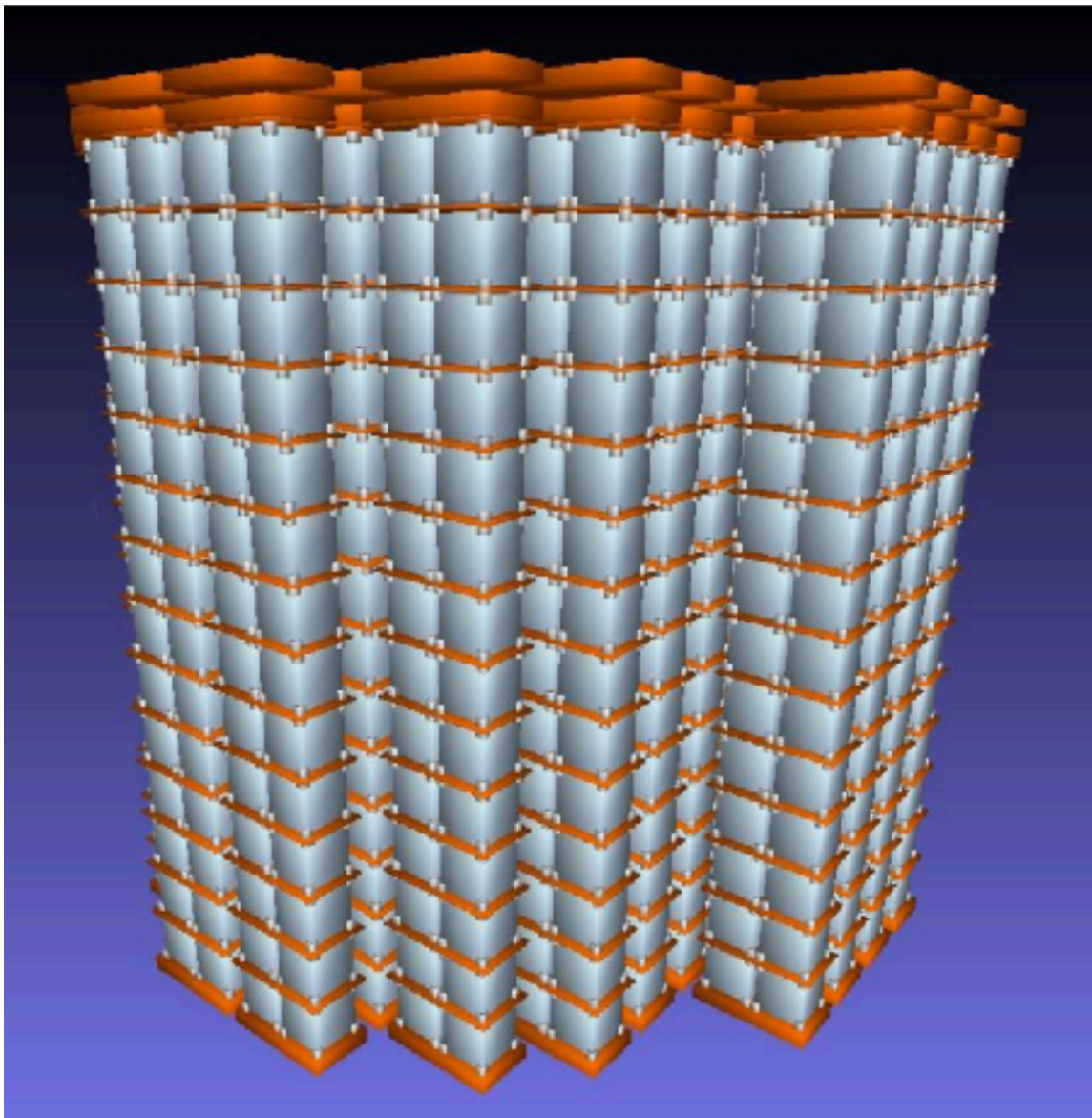
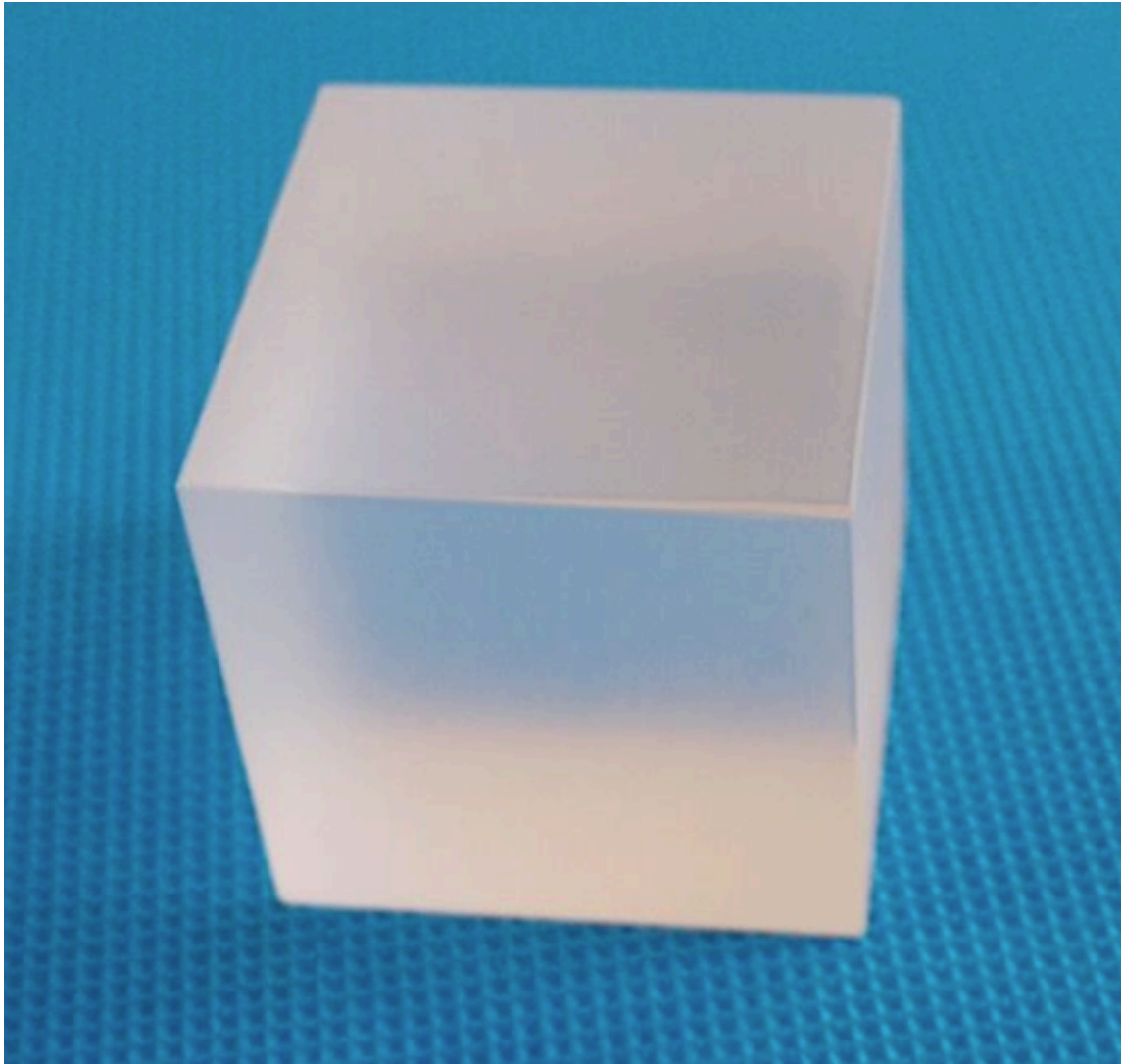
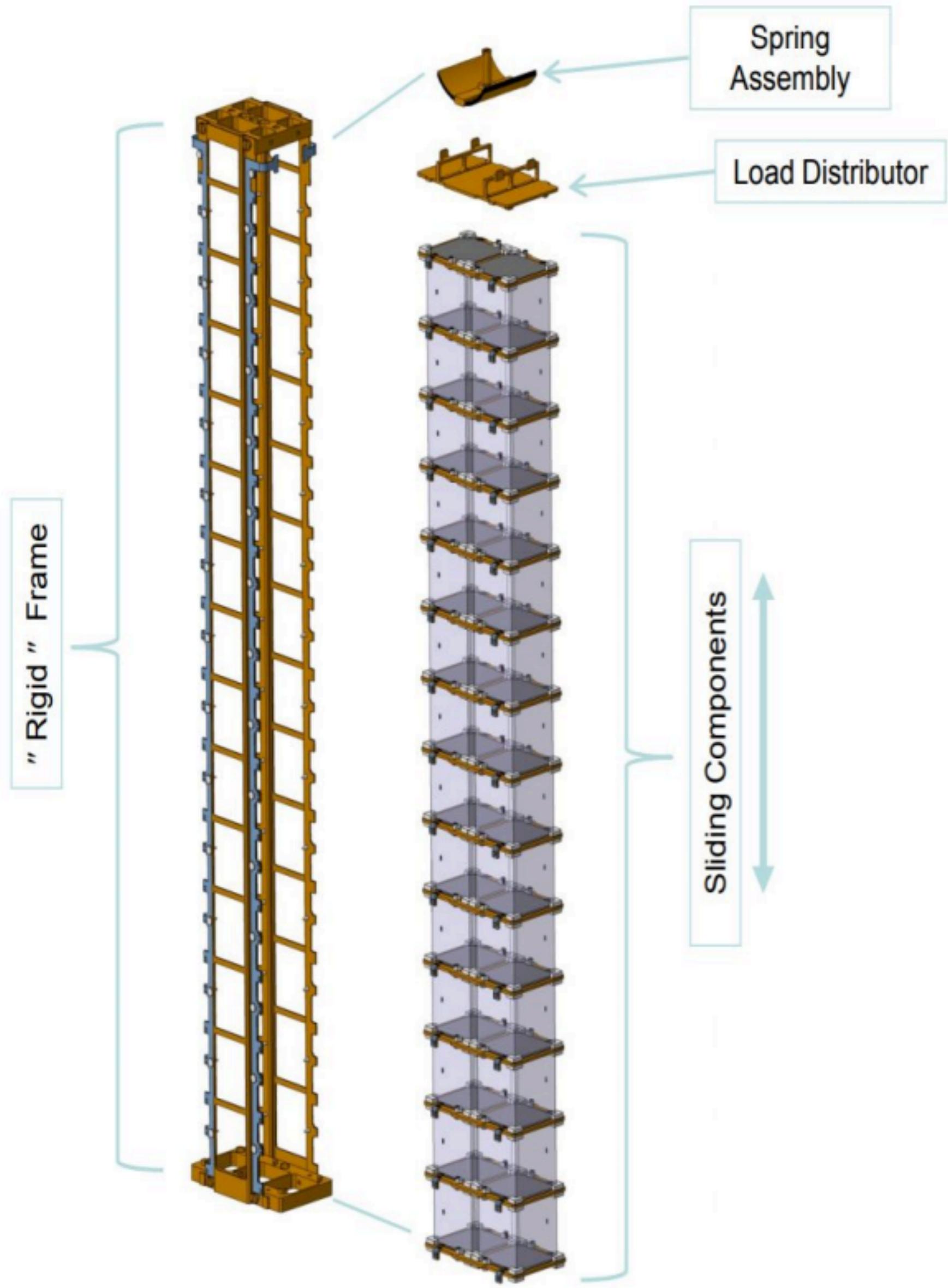


CUORE **U**PGRADE WITH **P**PARTICLE IDENTIFICATION

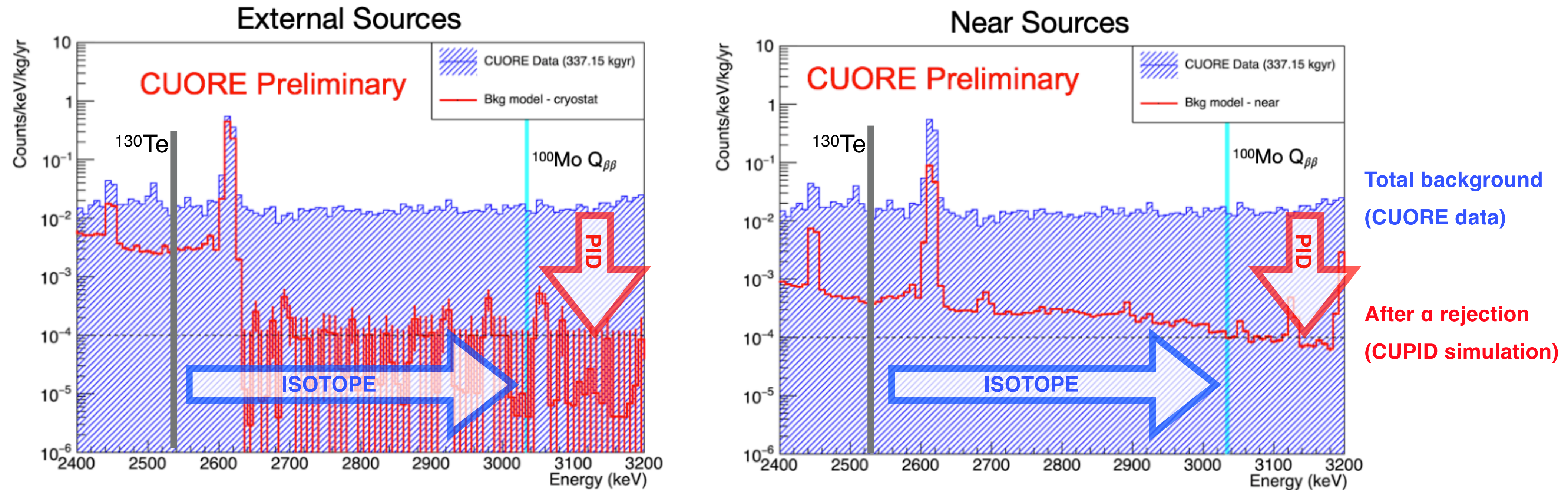
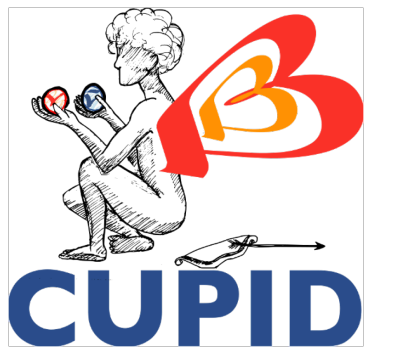
THE CUPID DETECTOR



Parameter	Value
Crystal	$\text{Li}_2^{100}\text{MoO}_4$
Size	45x45x45 mm ³
Heat Channels	1596
Light Channels	1710
Detector mass	450 kg
Enrichment	95%
¹⁰⁰ Mo mass	240 kg

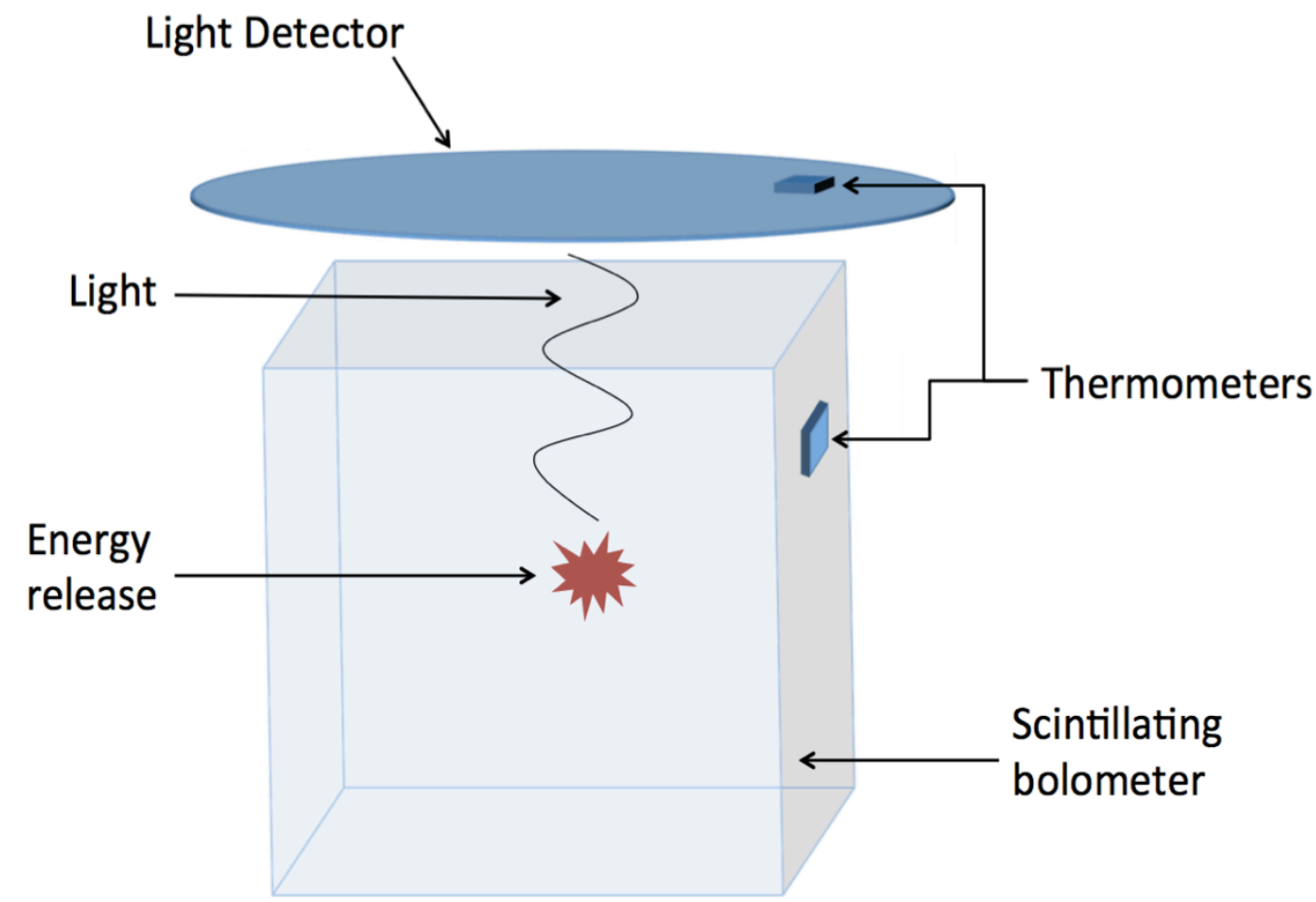
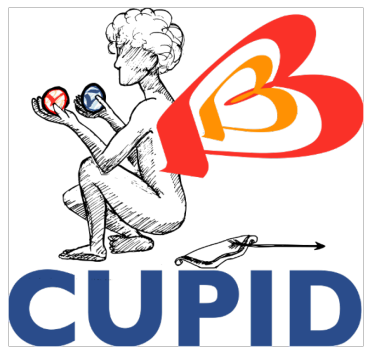


PARTICLE IDENTIFICATION WITH SCINTILLATION LIGHT



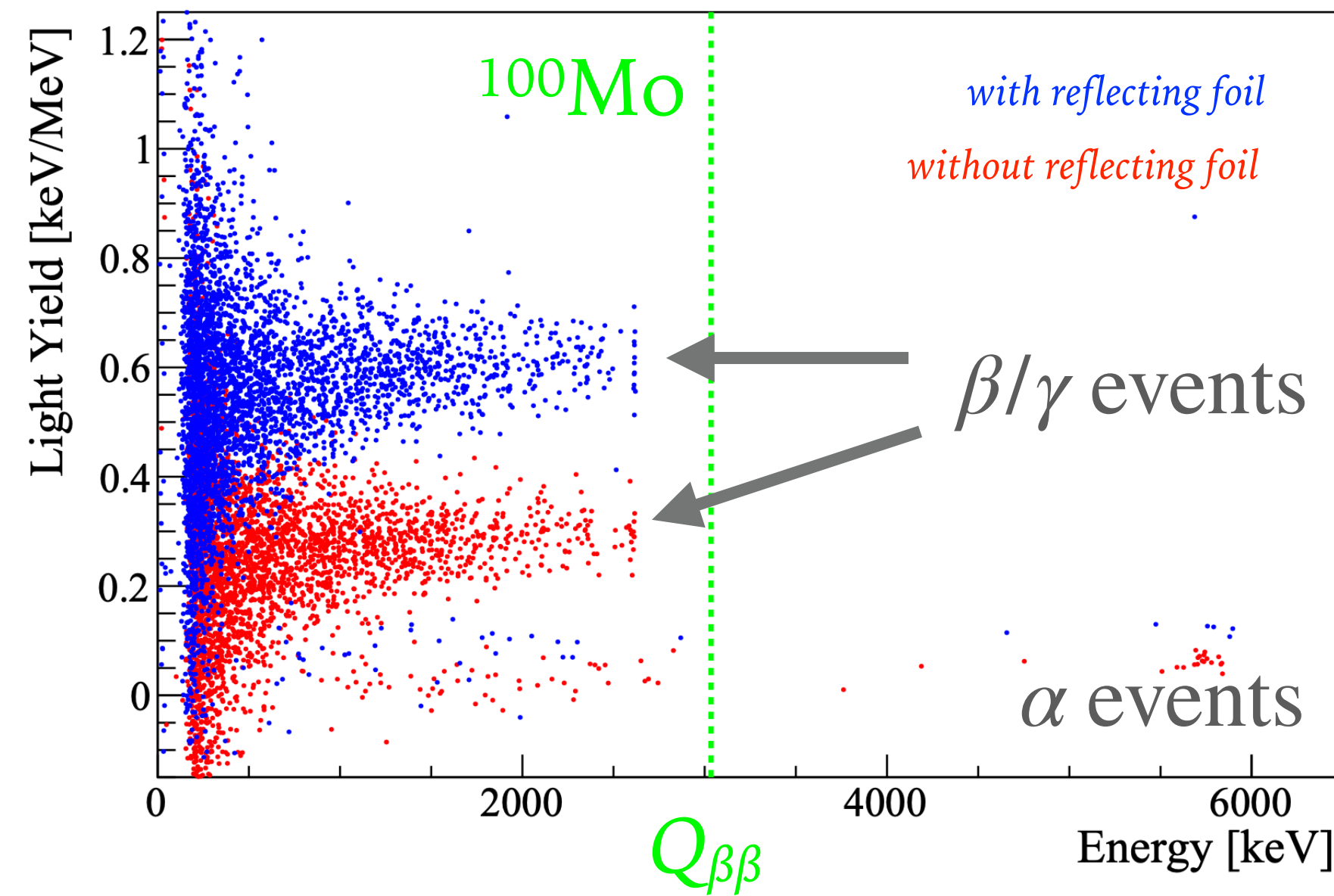
- Far sources (left): cryostat, shields, lab
- Near sources (right): crystals, copper holders
- Particle identification will provide a factor 100 background abatement

PARTICLE IDENTIFICATION WITH SCINTILLATION LIGHT

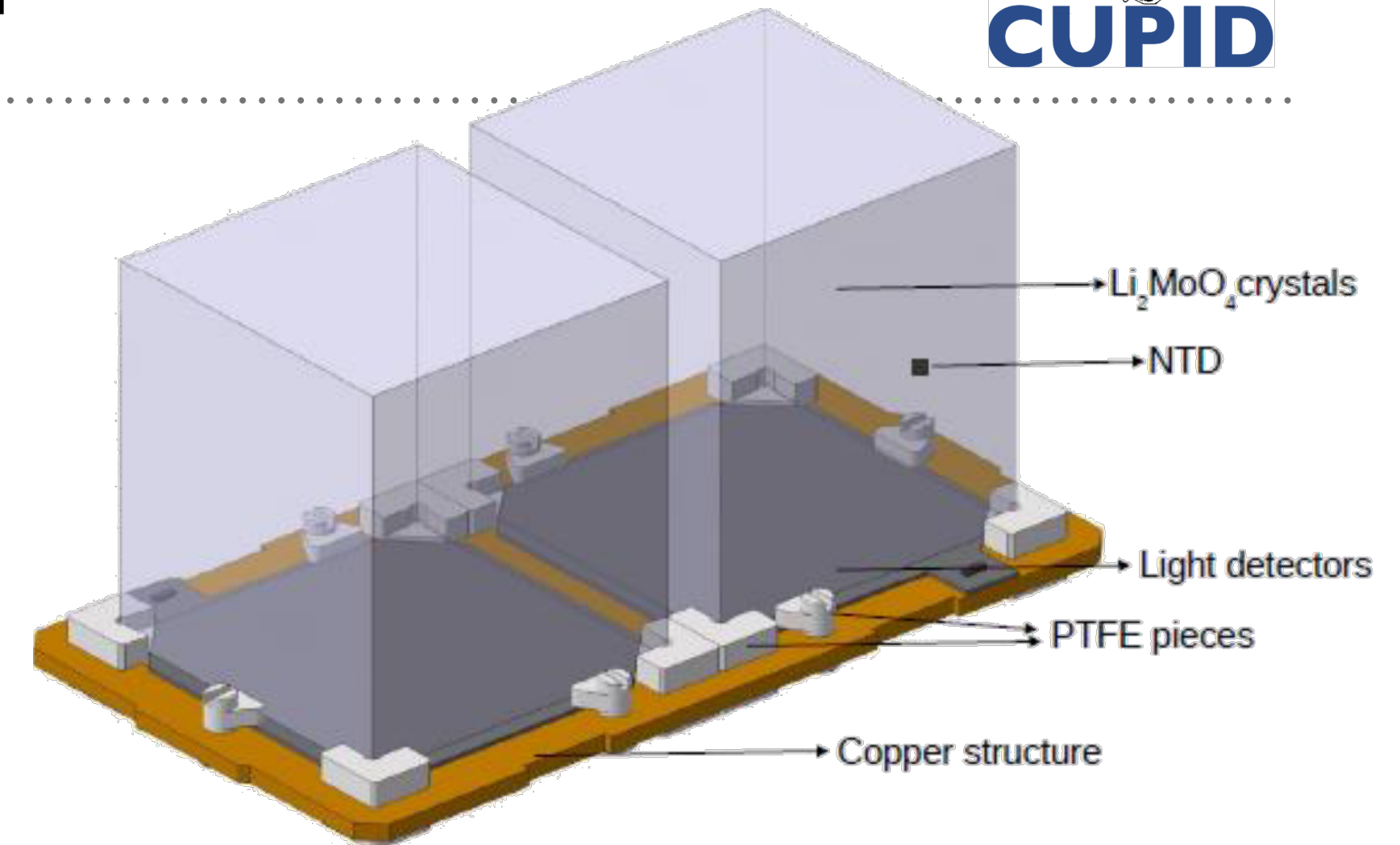


Rahman, S. et al., Phys. Lett. B 662(2), 111 (2008)
<https://doi.org/10.1016/j.physletb.2008.02.047>

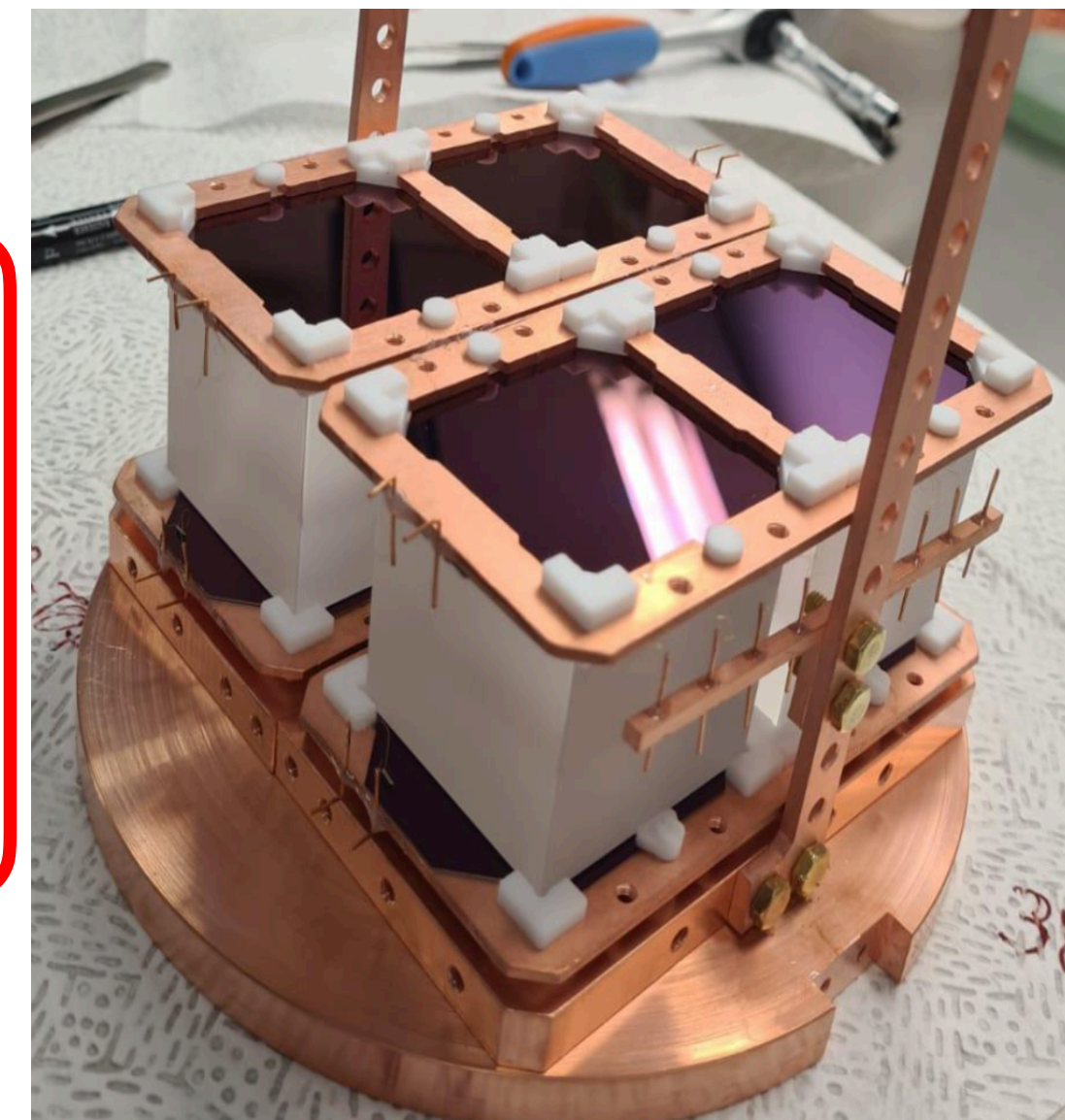
$$Q_{\beta\beta} = 3034.4(2) \text{ keV}$$



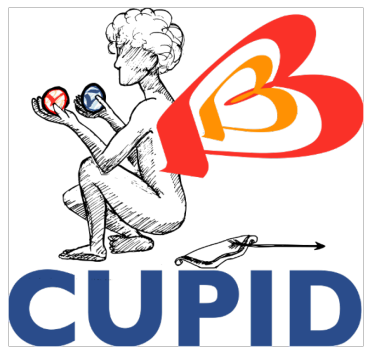
Armatol, A. et al (CUPID Collaboration), Eur. Phys. J. C (2021) 81:104
<https://doi.org/10.1140/epjc/s10052-020-08809-8>



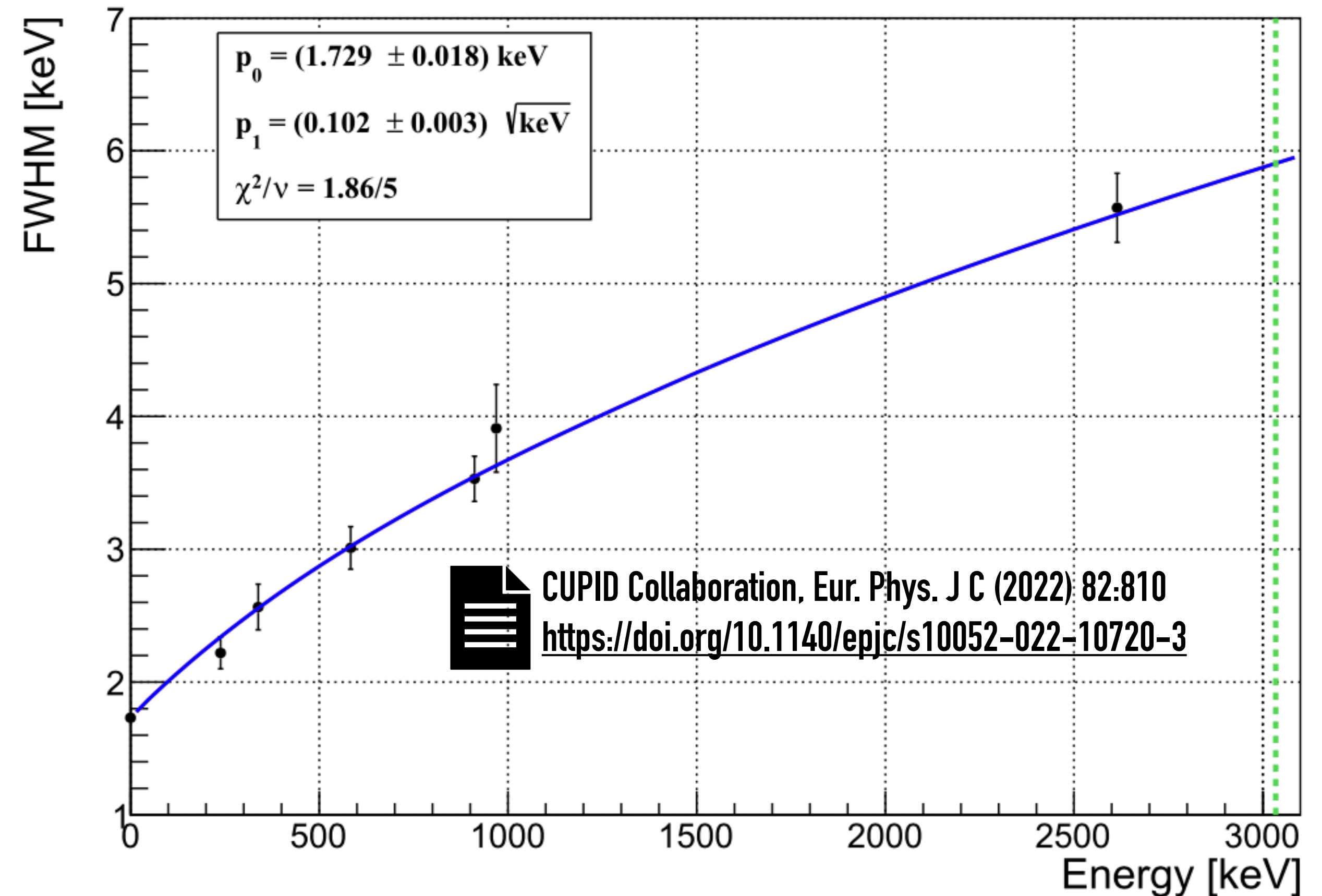
A. D'Addabbo
 T-4-5 h 17.05



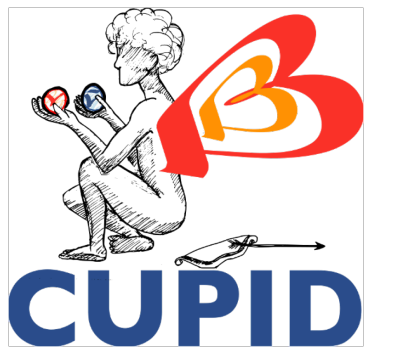
HEAT CHANNEL – DETECTOR PERFORMANCE



- 8 $\text{Li}_2^{100}\text{MoO}_4$ crystal array operated in a pulse tube cryostat
- Light Detector performance validated
 α rejection efficiency > 99.9 %
- FWHM resolution extrapolation
 $\Delta E(Q_{\beta\beta}) = (5.9 \pm 0.2) \text{ keV}$



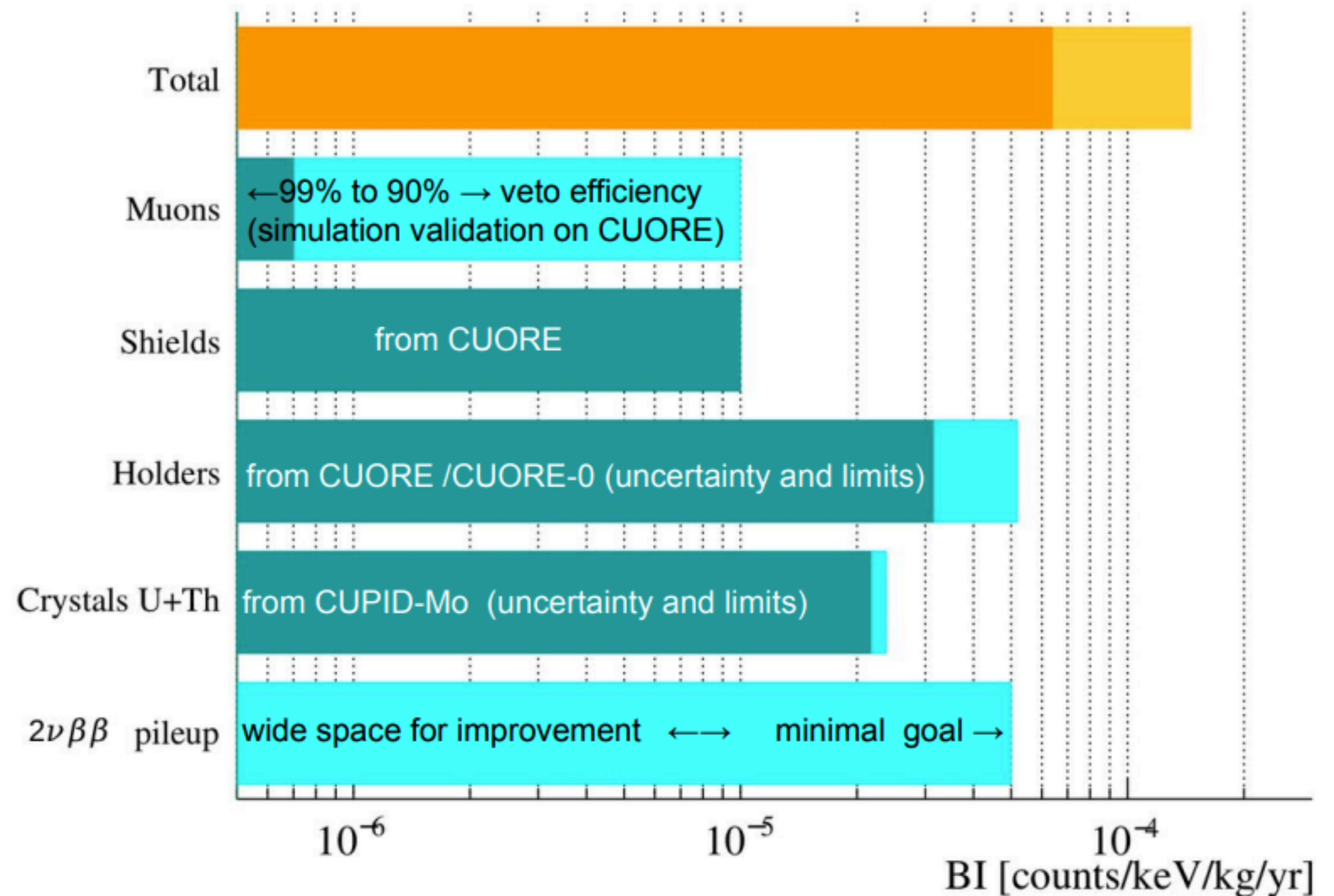
BACKGROUND BUDGET



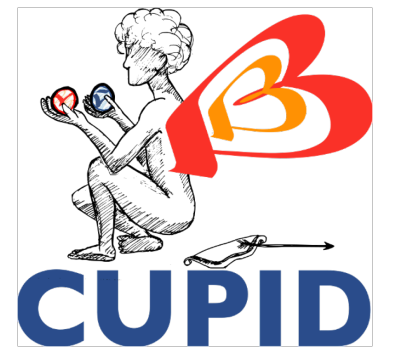
- Data-driven background budget
- Screening available for all materials

Path towards 10^{-4} cts/(keV kg yr)

- Crystal purity quality control in place (required purity already demonstrated)
- CUORE protocols for material cleaning
- Cryogenic infrastructure / host lab / shields well understood
- Pile-up well modeled, minimal goal possible with current technology, work in progress for further reduction

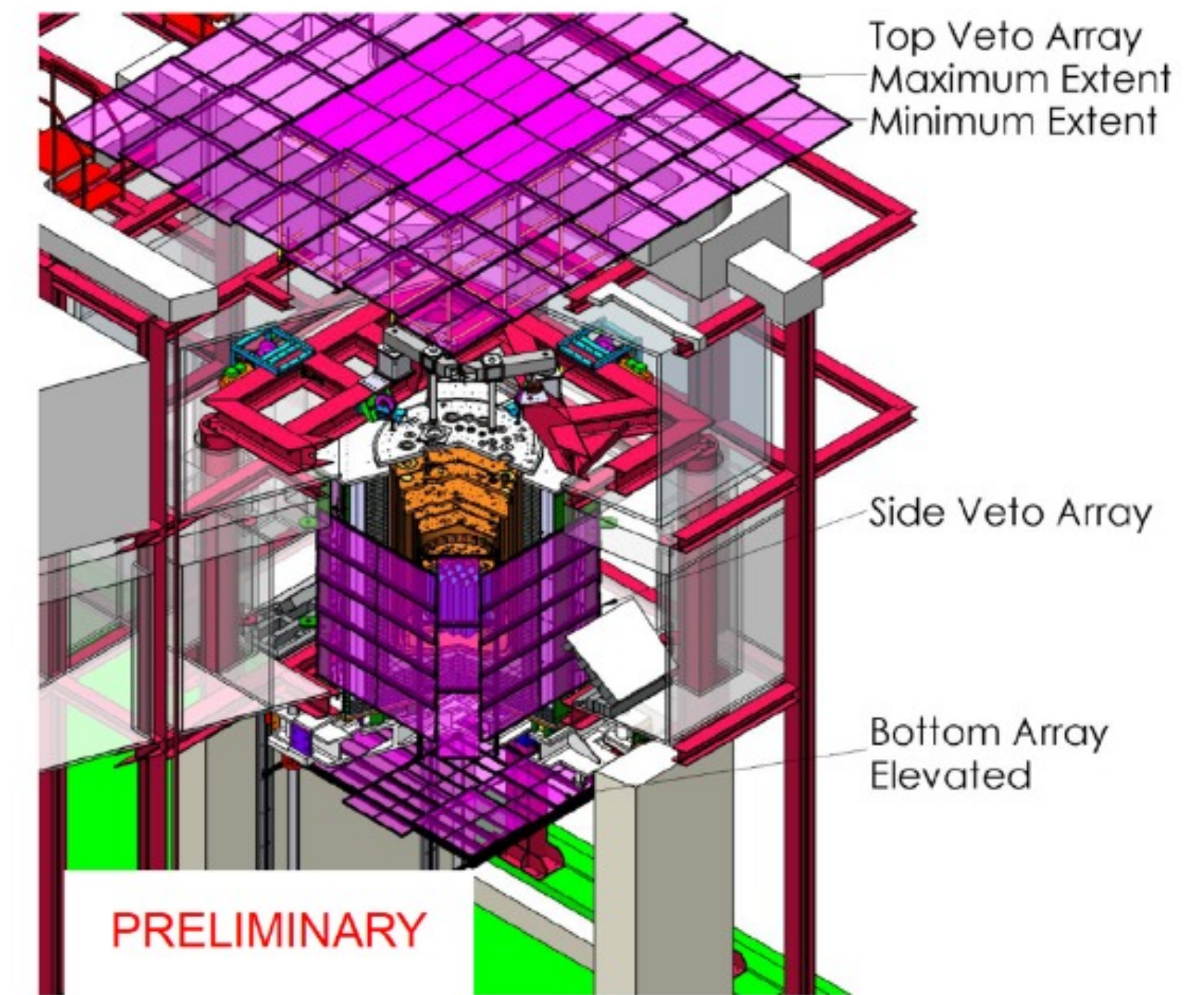
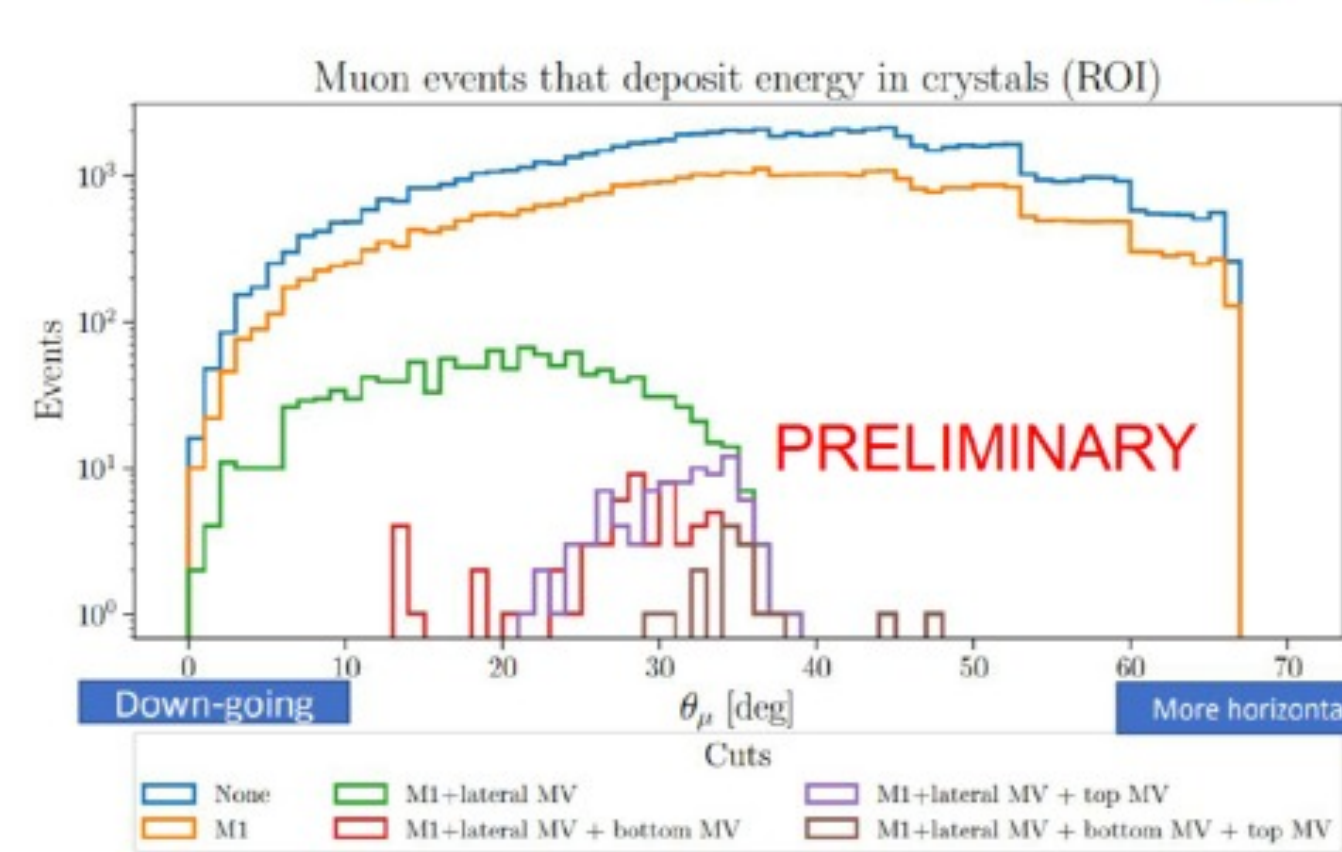
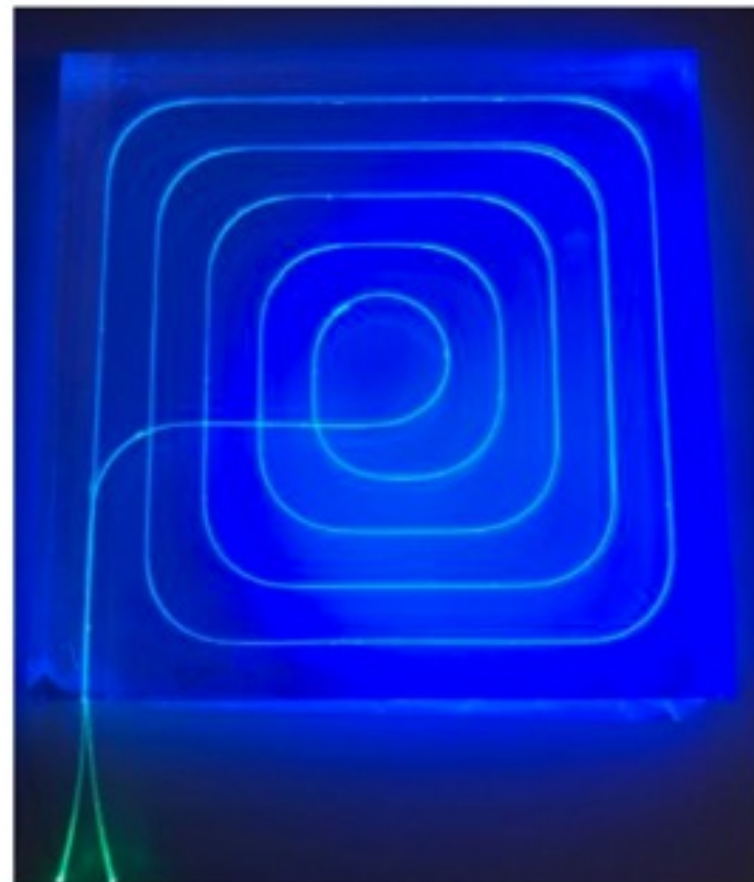


MUON VETO AND NEUTRON SHIELD

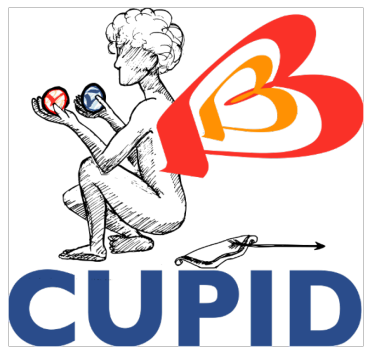


- **Muons** and **neutrons** induced background is negligible in CUORE but expected to be relevant in CUPID → increase in shielding and tagging required
- Both contributions are measured in CUORE:
 - high multiplicity events from muon tracks and showers to constraint contribution in M1
 - high energy gamma cascades from neutron capture

Muon veto scintillating tiles to intercept >90% muons → 99% reduction of M1 background when combined with detector granularity

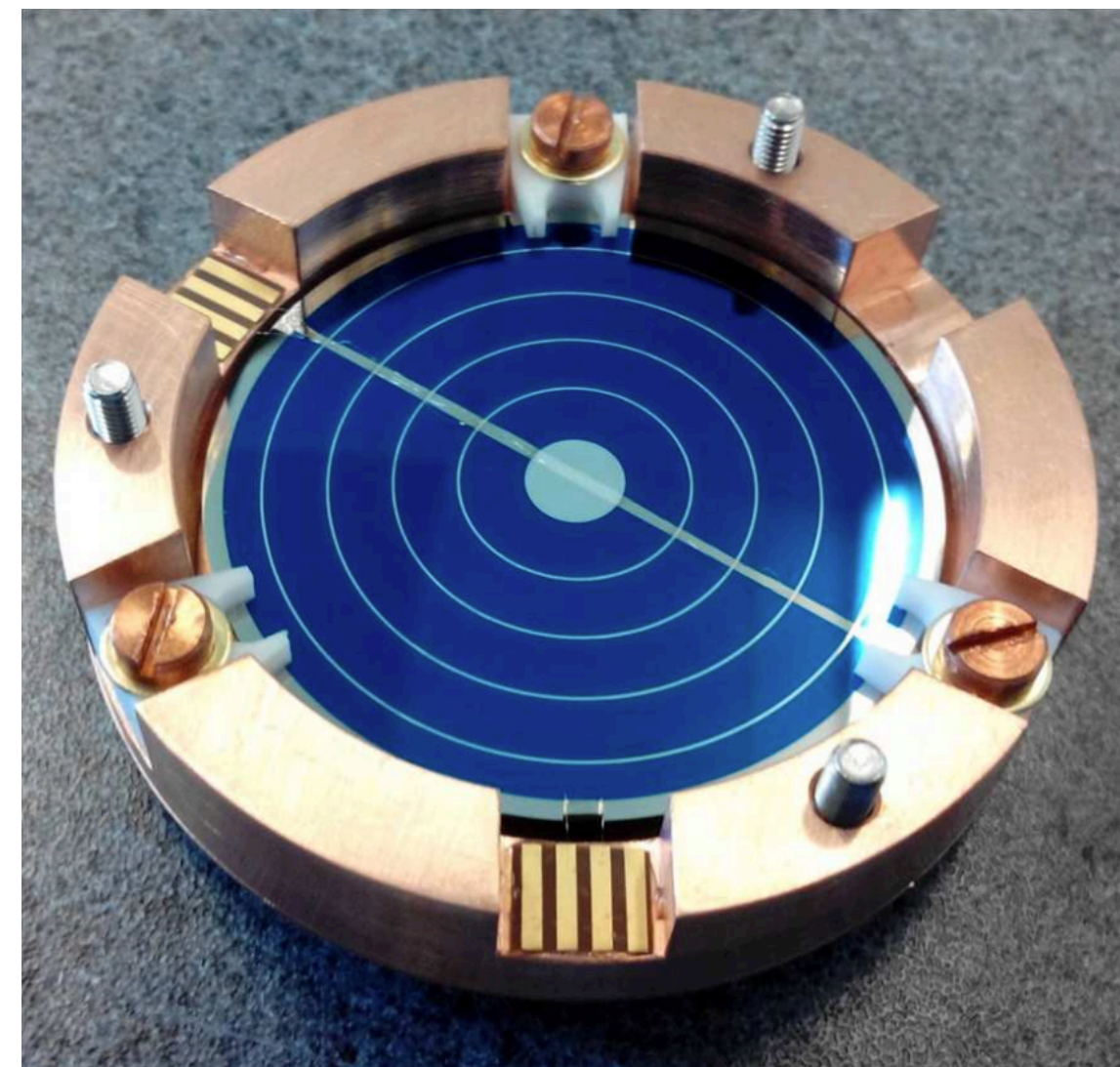


PILE-UP REJECTION WITH NTL DETECTORS



Parameter	Value
Light yield	0.3 keV/MeV
Background Index	10^{-4} cts/(keV kg yr)
Light resolution	< 100 eV RMS
Pile-up resolution	SNR/RiseTime > 160 kHz
Alpha rejection	$> 99.9\%$

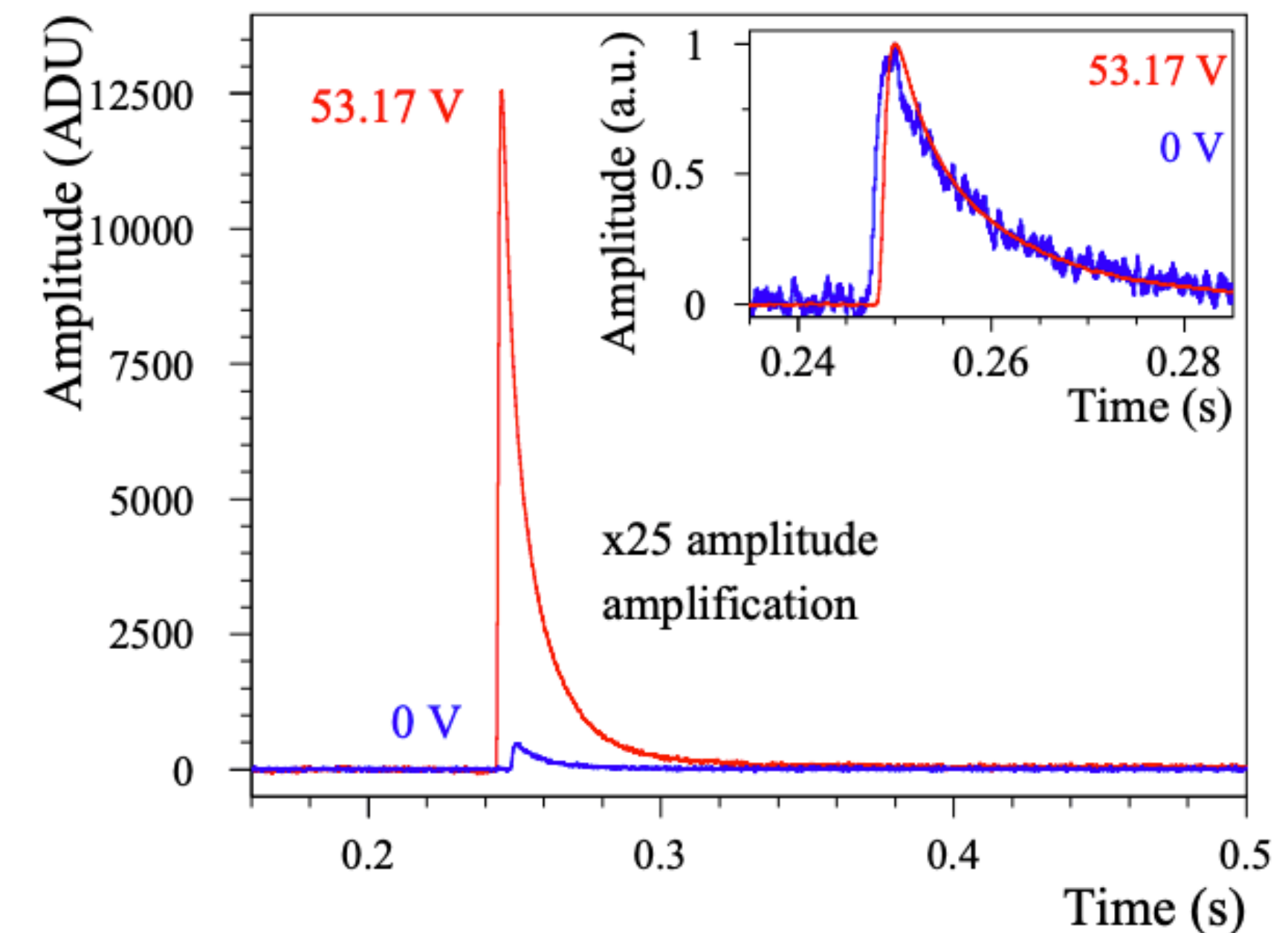
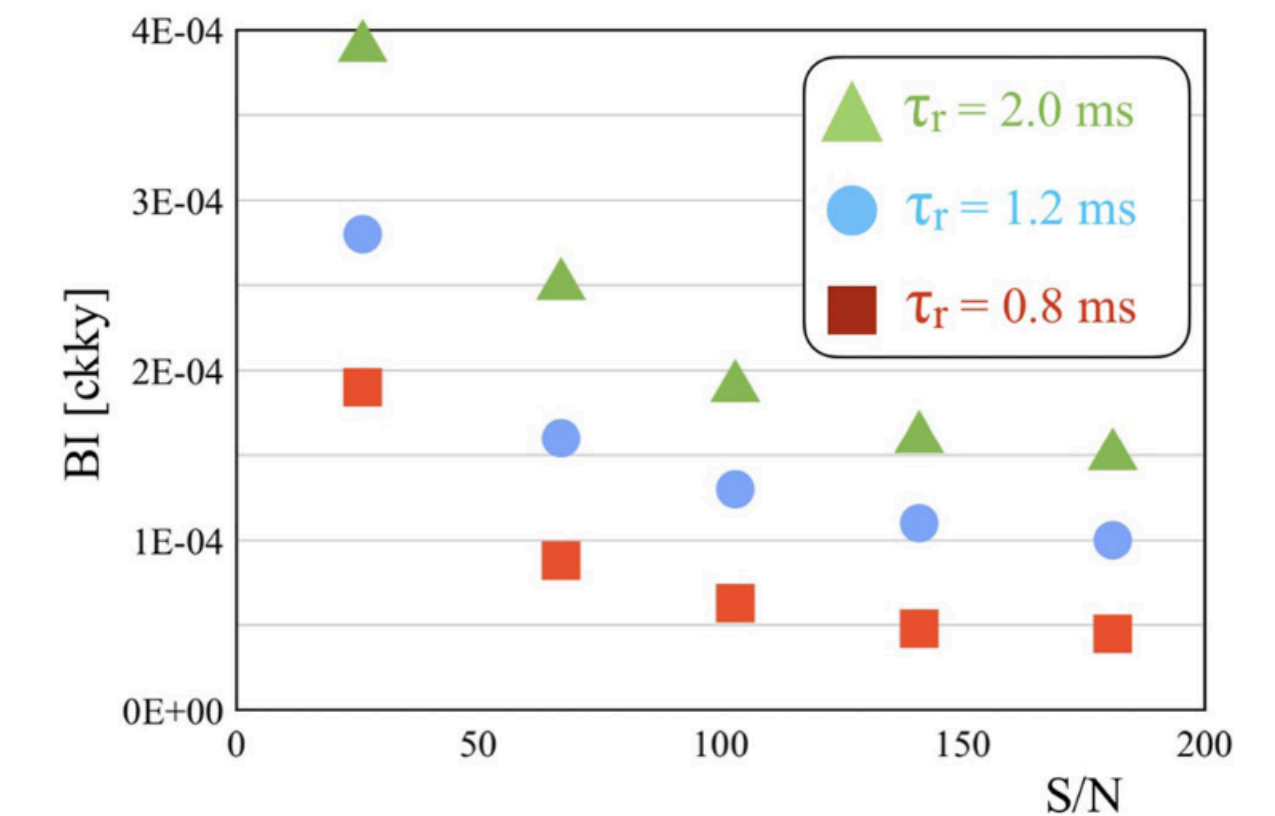
- Al electrodes on a Ge substrate
- NTD readout
- 50-100 V bias
- same noise
- signal amplification ~ 25



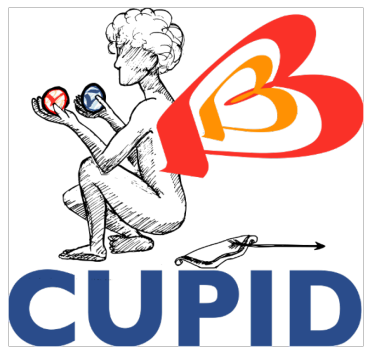
Chernyak, D. M. et al., Eur. Phys. J. C 77 (2017)
<https://doi.org/10.1140/epjc/s10052-016-4565-z>

Novati, V. et al, Nucl. Inst. Meth. A (2019) 940:320-327
<https://doi.org/10.1016/j.nima.2019.06.044>

Ahmine, A. et al, Eur. Phys. J. C (2023) 83:373
<https://doi.org/10.1140/epjc/s10052-023-11519-6>



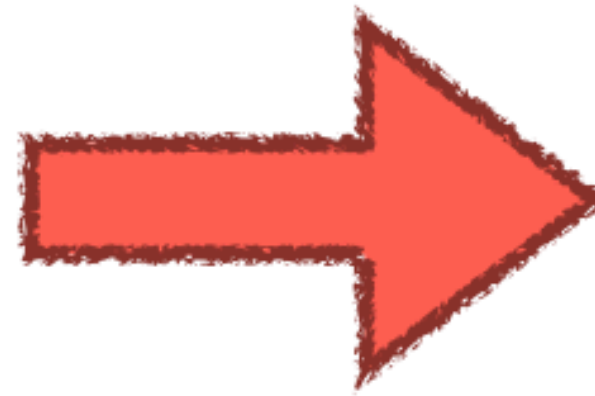
THE CUPID COLLABORATION



CUORE
Experience in a operating ton-scale
cryogenic bolometers for years

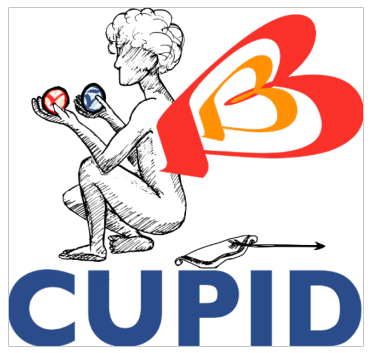
+

CUPID-0 and CUPID-Mo
Experience in operating detectors with
particle identification technology



> 150 scientists, ~30 institutions from all over the world
(Italy ~60 collaborators, US ~40 collaborators, France ~25 collaborators.
Other countries: Ukraine, Russia, Spain, China)

SUMMARY



- CUPID is a timely and cost-effective $0\nu\beta\beta$ inverted hierarchy explorer
- Builds on proven CUORE expertise and cryogenic infrastructure at LNGS
- Performance of small-scale modules is robust and compliant with specifications (demonstrators, CUPID-Mo, CUPID-0)
- Multiple R&D programs ongoing towards a future tonne-scale experiment

