CUORE AND CUPID

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on the behalf of the CUORE and CUPID collaborations

GSSI Scientific Fair, March 2021

INFN

OUTLINE

- **Physics goal of CUORE and CUPID**
- **Cryogenic detectors**
- **The CUORE experiment**
- **The CUPID experiment**
- **Proposed thesis**

PHYSICS GOAL OF CUORE AND CUPID

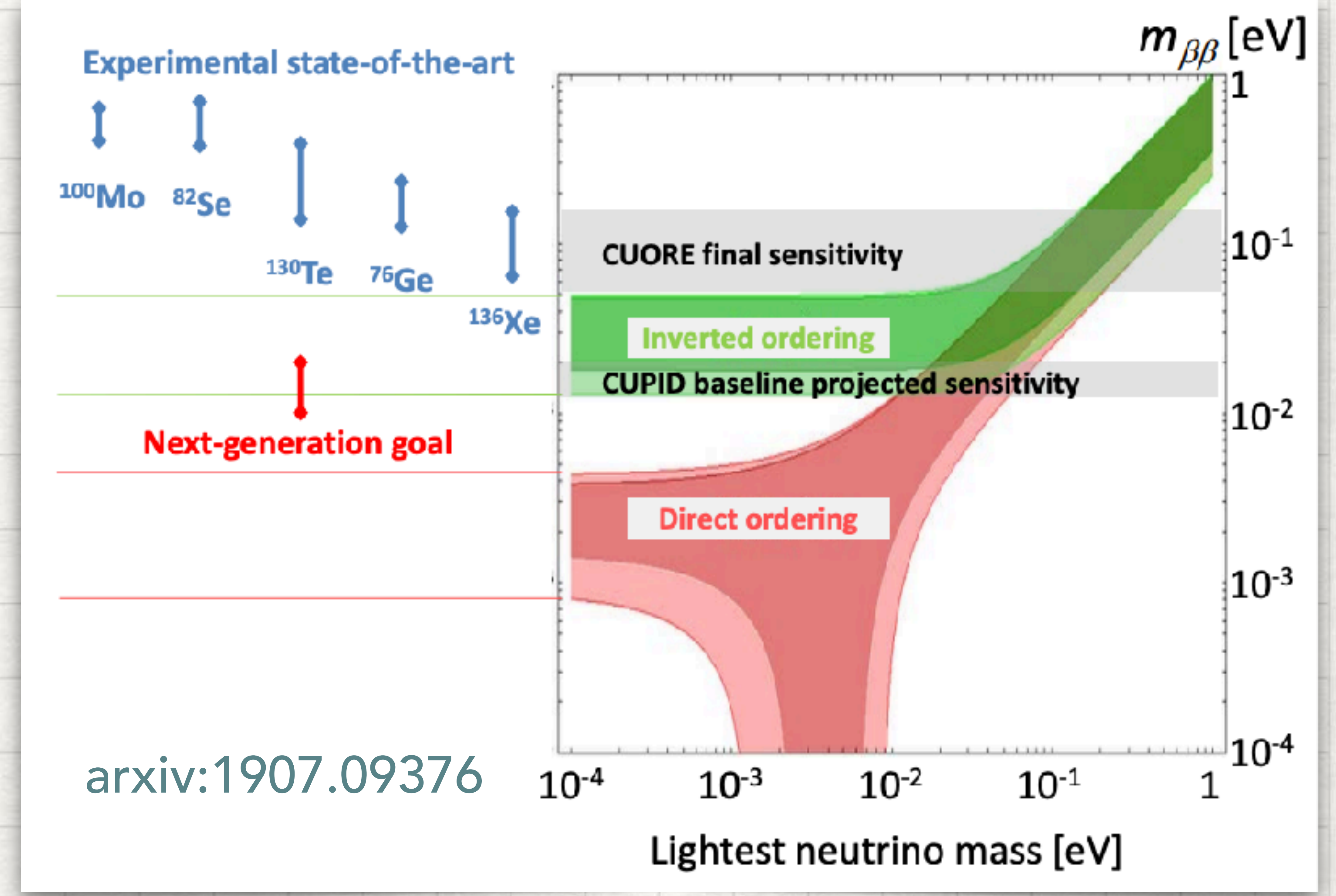
CUORE and CUPID are designed to search for **Neutrinoless Double Beta Decay** in **^{130}Te** and in **^{100}Mo**, respectively.

0νββ decay is a lepton-number violating process that can occur only if neutrinos are Majorana fermions.

The discovery of 0νββ decay would demonstrate that lepton number is not a symmetry of nature and that neutrinos are Majorana particles.

Implications in 0νββ decay:

- constrain the absolute neutrino mass hierarchy and scale
- mass difference between neutrinos and other elementary particles
- expanding the SM with Majorana masses explain neutrinos mass generation
- strong indication of baryogenesis via leptogenesis for the matter-antimatter asymmetry in the Universe



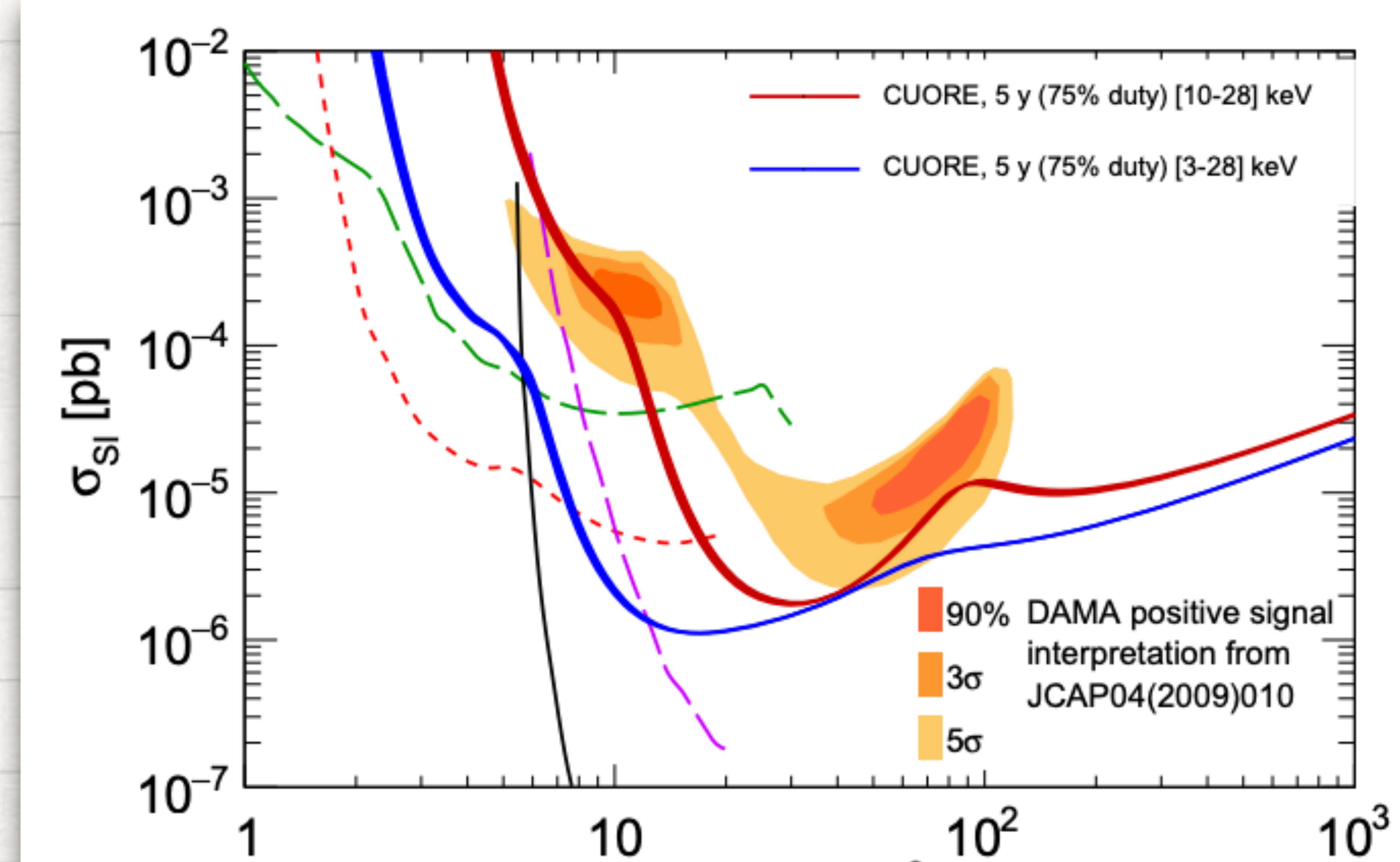
Plot modified from the original work of Dell'Oro, Marcocci, Viel, Vissani published in *Adv.High Energy Phys.* 2016 (2016) 2162659 e-Print: 1601.07512 [hep-ph]

PHYSICS GOAL OF CUORE AND CUPID

A wide area of several nuclear and particle physics processes investigations is accessible thanks to unique features and performance achievable with cryogenic calorimeters: excellent energy resolution, low background, large mass and low threshold

CUORE and CUPID as multipurpose experiments:

- Double beta decay on excited states
- Other rare events searches such as Dark Matter, Axion, solar/supernovae neutrinos, Tri-nucleon decay…
- Discovering new physics from the $2\nu\beta\beta$ spectral shape such as Majoron-emitting decays and Lorentz invariance and CPT violations
- Study the violation of fundamental principles such as Electric charge conservation and Pauli Principle violation

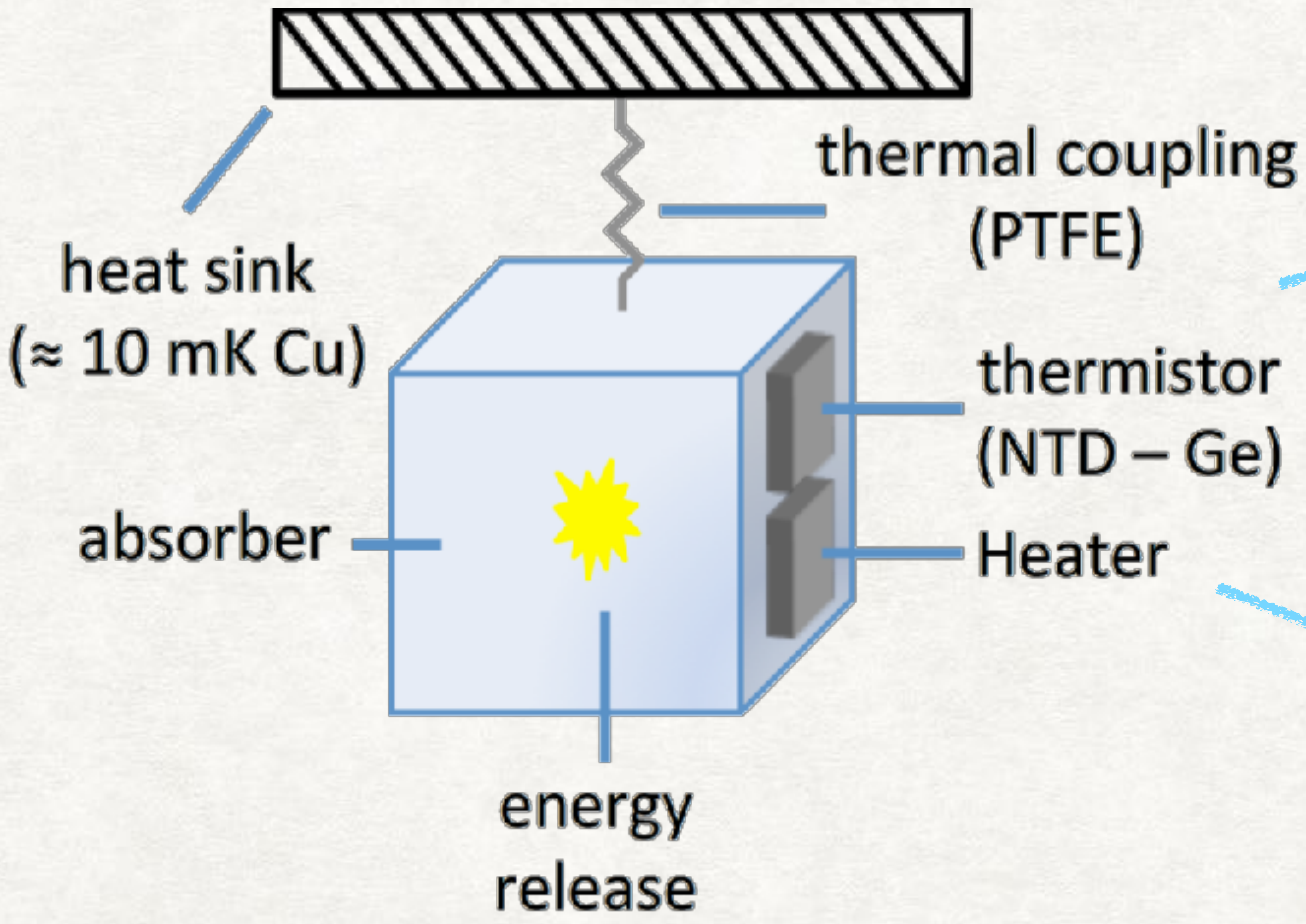


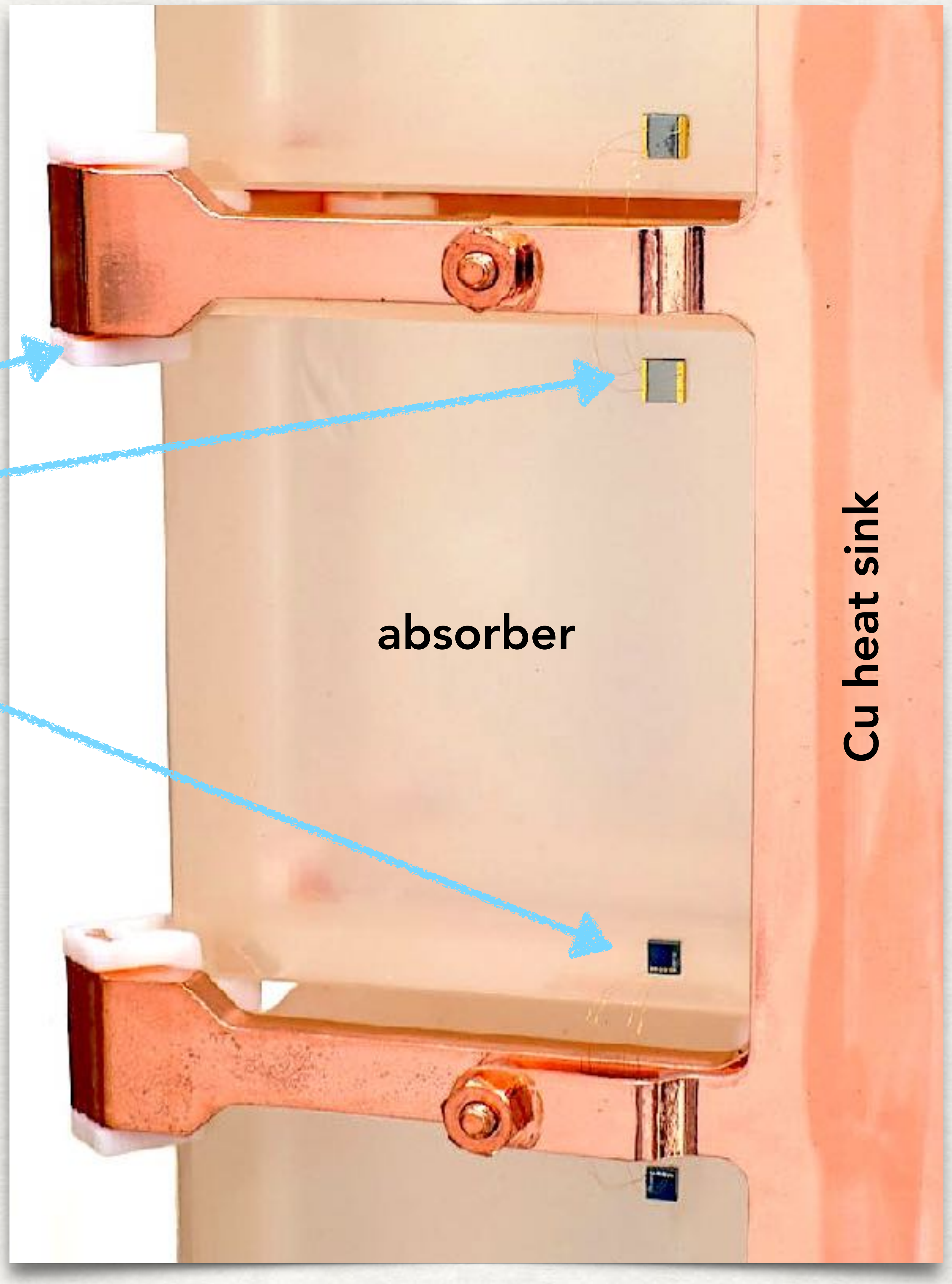
arxiv: 1708.07809

CRYOGENIC DETECTORS

HOW TO MEASURE PARTICLE INTERACTION WITH OUR CRYOGENIC CALORIMETERS

A particle interaction in the absorber causes an energy release resulting in an increase in temperature, measured by the NTD thermistor





IN BOTH CUORE AND CUPID THE ABSORBER IS ALSO THE SOURCE OF THE DOUBLE BETA DECAY, MAXIMISING THE DETECTION EFFICIENCY

CRYOGENIC DETECTORS

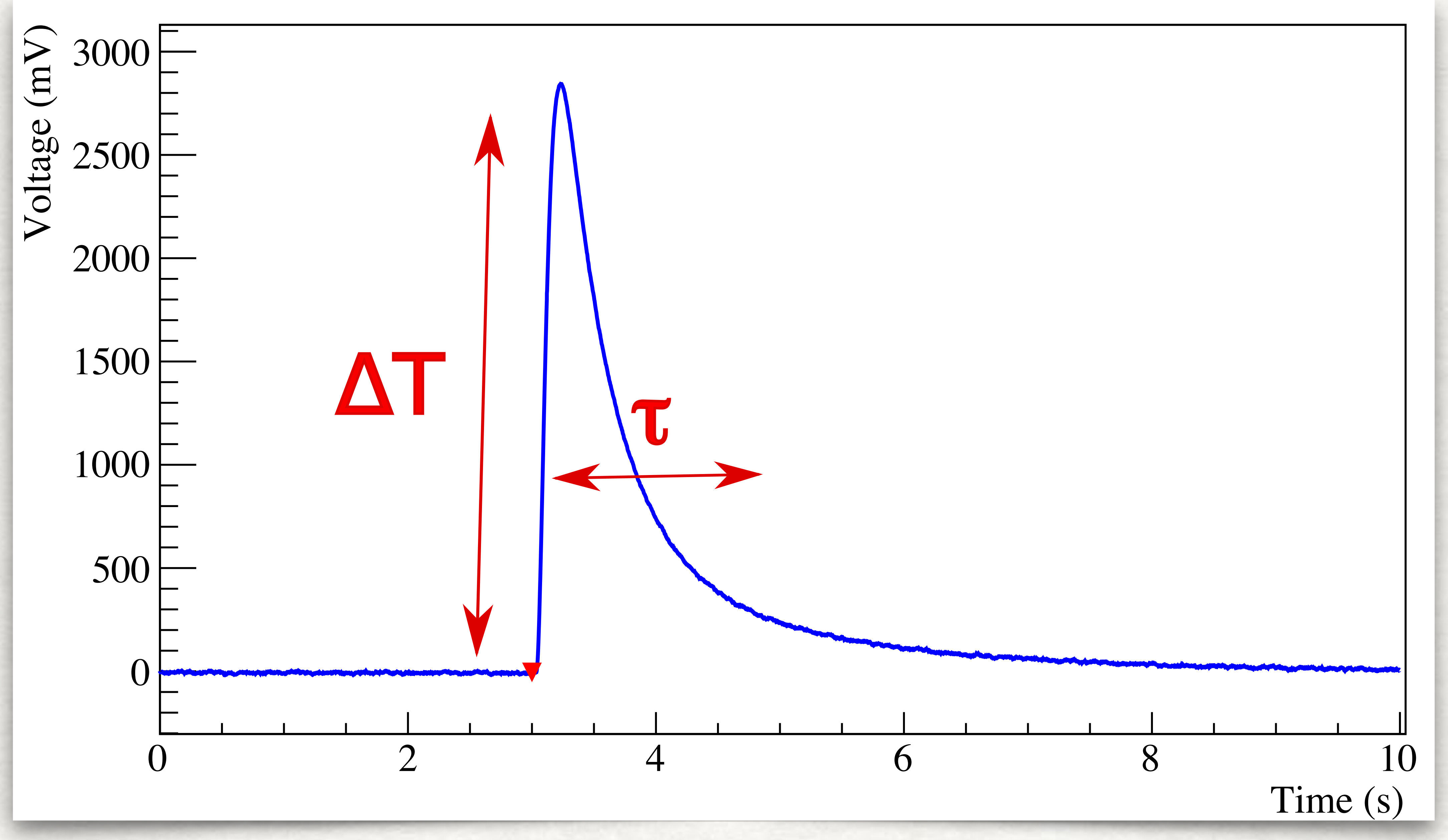
CRYOGENIC CALORIMETERS SIGNAL

$$\Delta T = \frac{\Delta E}{C} \sim \frac{100\mu K}{MeV}$$

$$\tau = \frac{G}{C} \sim 1s$$

$$C(T) \propto T^3$$

$$R(T) = R_0 e^{\sqrt{T_0/T}}$$



C: absorber capacity
ΔT: temperature variation
ΔE: energy deposition
G: thermal conductance
t: signal decay time

- low heat capacity @ base temperature ~10mK
- excellent energy resolution (0.2 % FWHM)
- large number of energy carriers (phonons)
- equal detector response for different particles
- slow signal suitable for rare event searches

CUORE

CRYOGENIC UNDERGROUND OBSERVATORY FOR RARE EVENTS

THE CUORE IN A NUTSHELL

The CUORE detector is hosted in a cryogen-free cryostat:

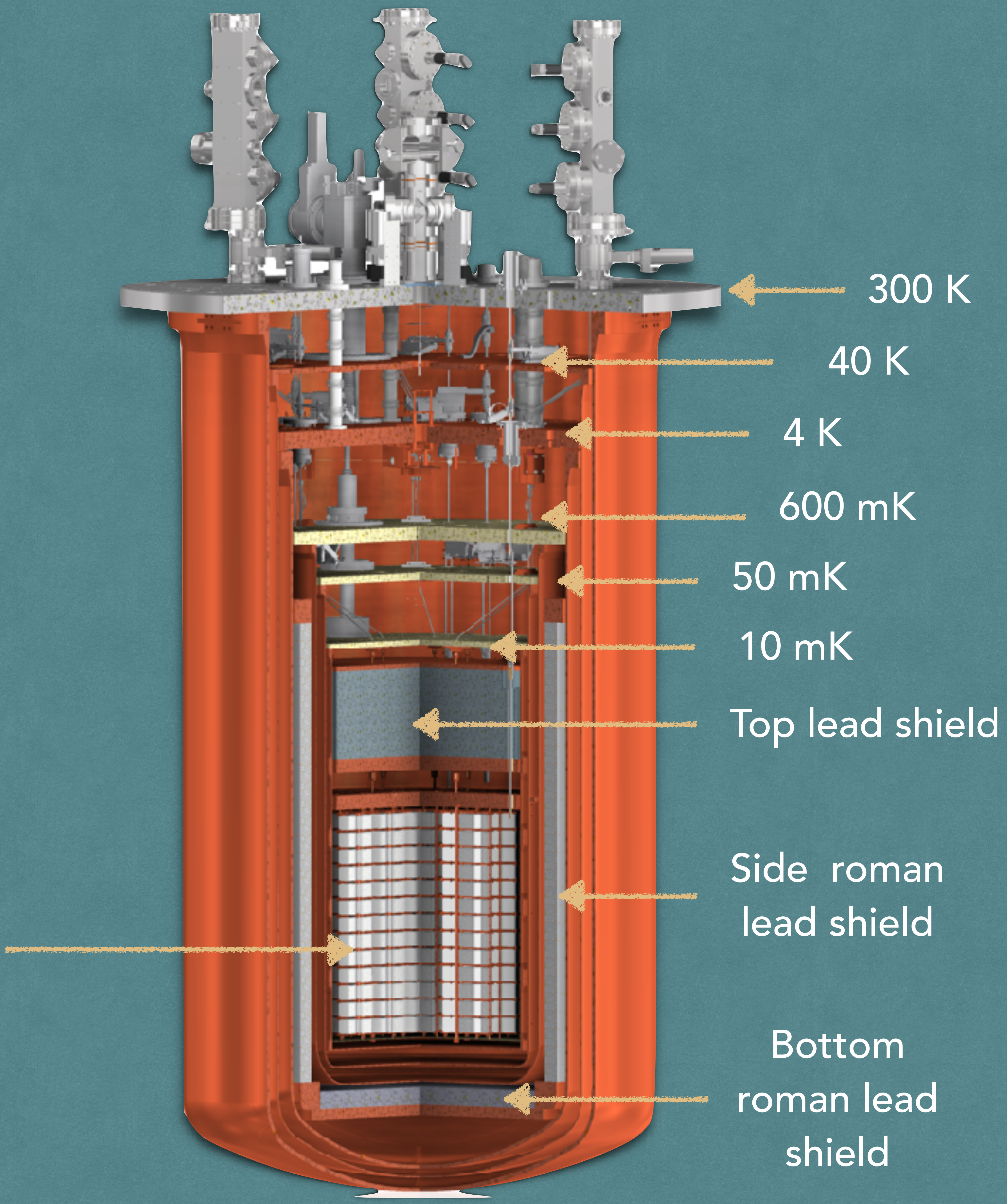
- Mass to be cooled < 4K: ~15 tons (Pb, Cu and TeO_2)
- Operating temperature 10 mK
- Designed to guarantee extremely low radioactivity and low vibrations environment

988 TeO_2 crystals (19 towers)

742 kg total mass, 206 kg ^{130}Te mass
$Q_{\beta\beta}(^{130}Te) = 2527.5$ keV

Background goal:
10^{-2} counts/keV/kg/yr at $Q_{\beta\beta}$

Sensitivity goal:
$T^{0\nu}_{1/2} = 9 \cdot 10^{25}$ yr with 5 yr of live time

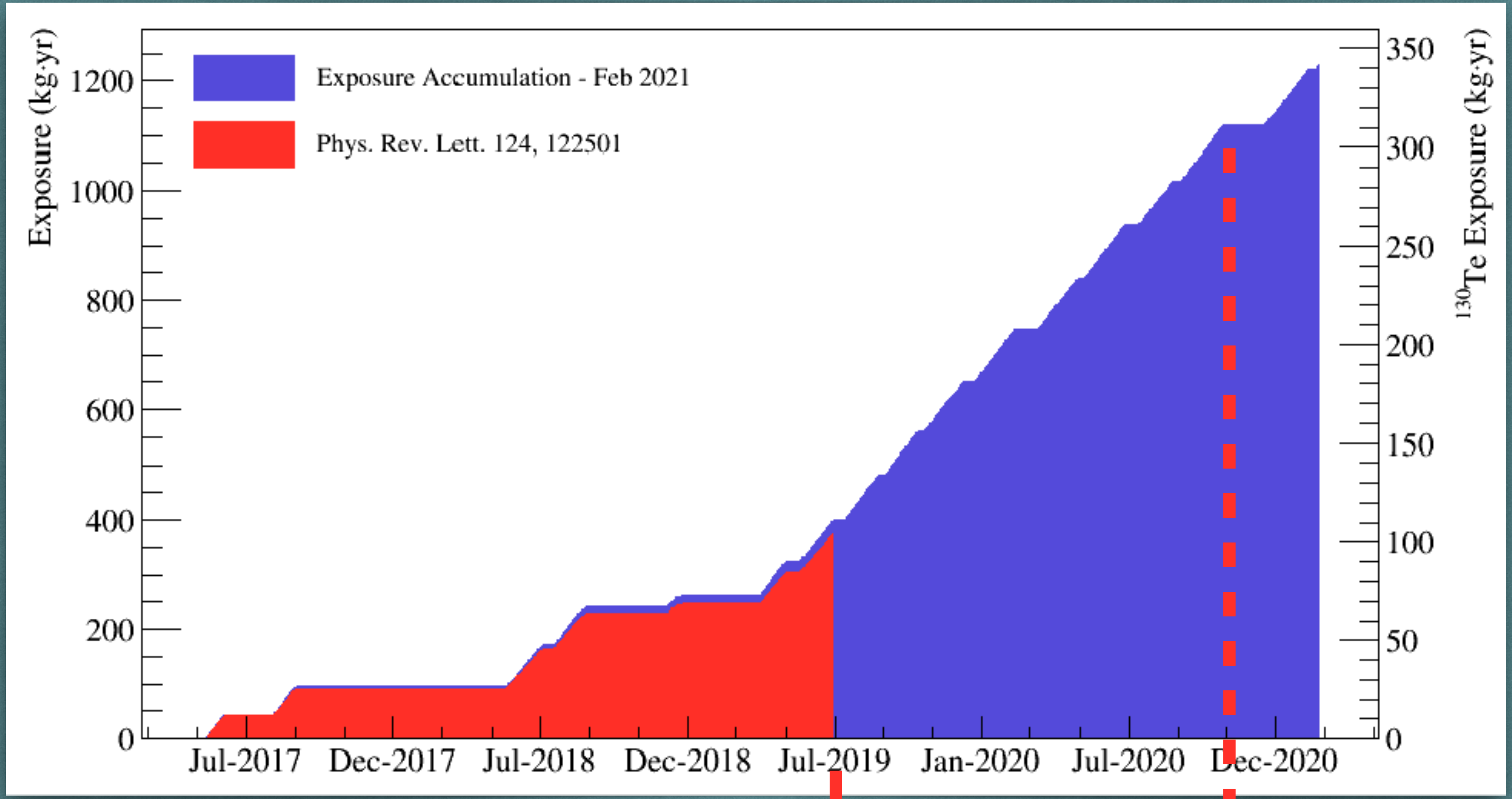


DATA TAKING AND ANALYSIS

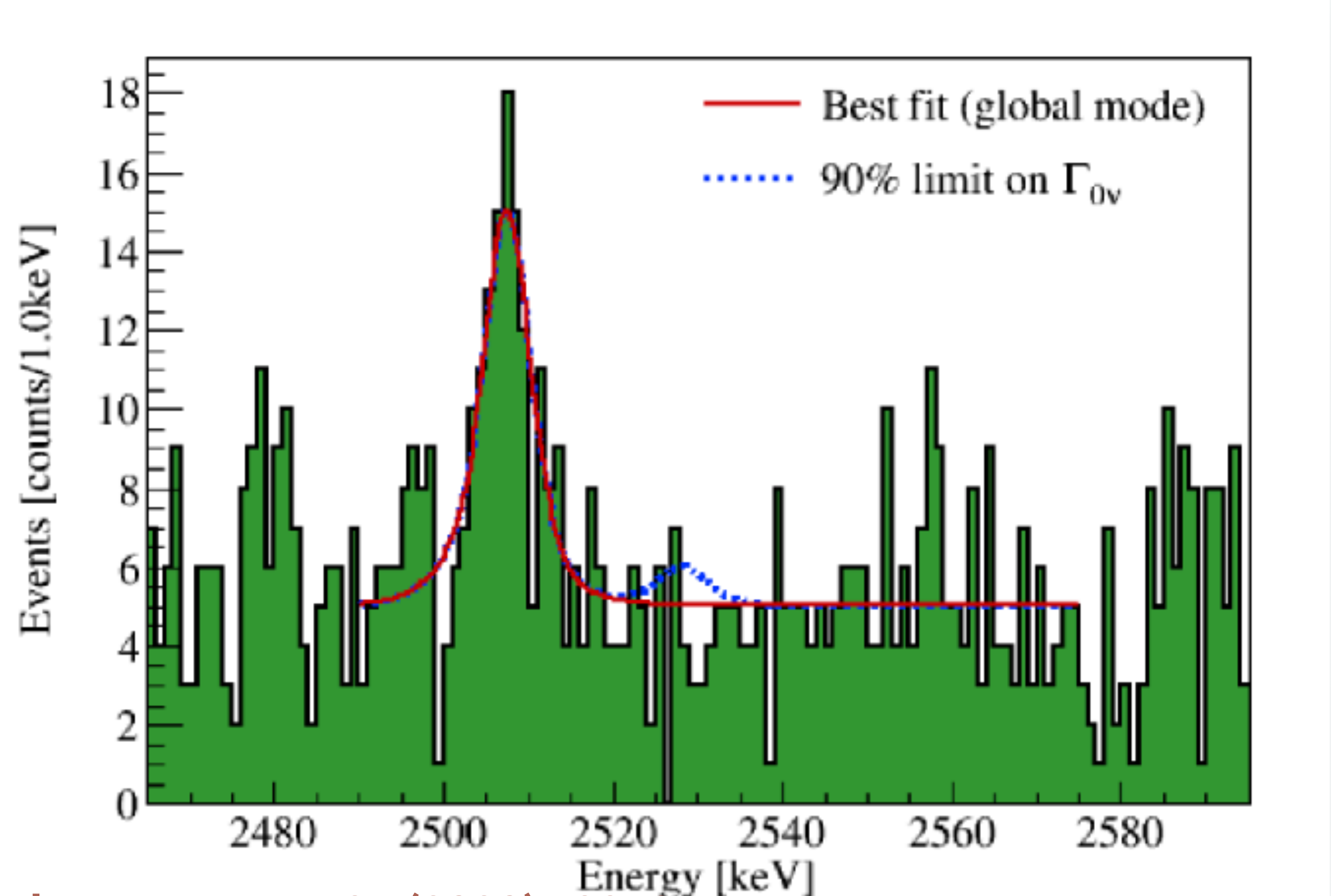
984/988 active channels (99.6%)

Average Rates (per channel):
- *Calibration*: ~50 mHz
- *Physics*: ~6 mHz

The CUORE data taking is splitted in datasets, separated by periods of calibration and detector maintenance.



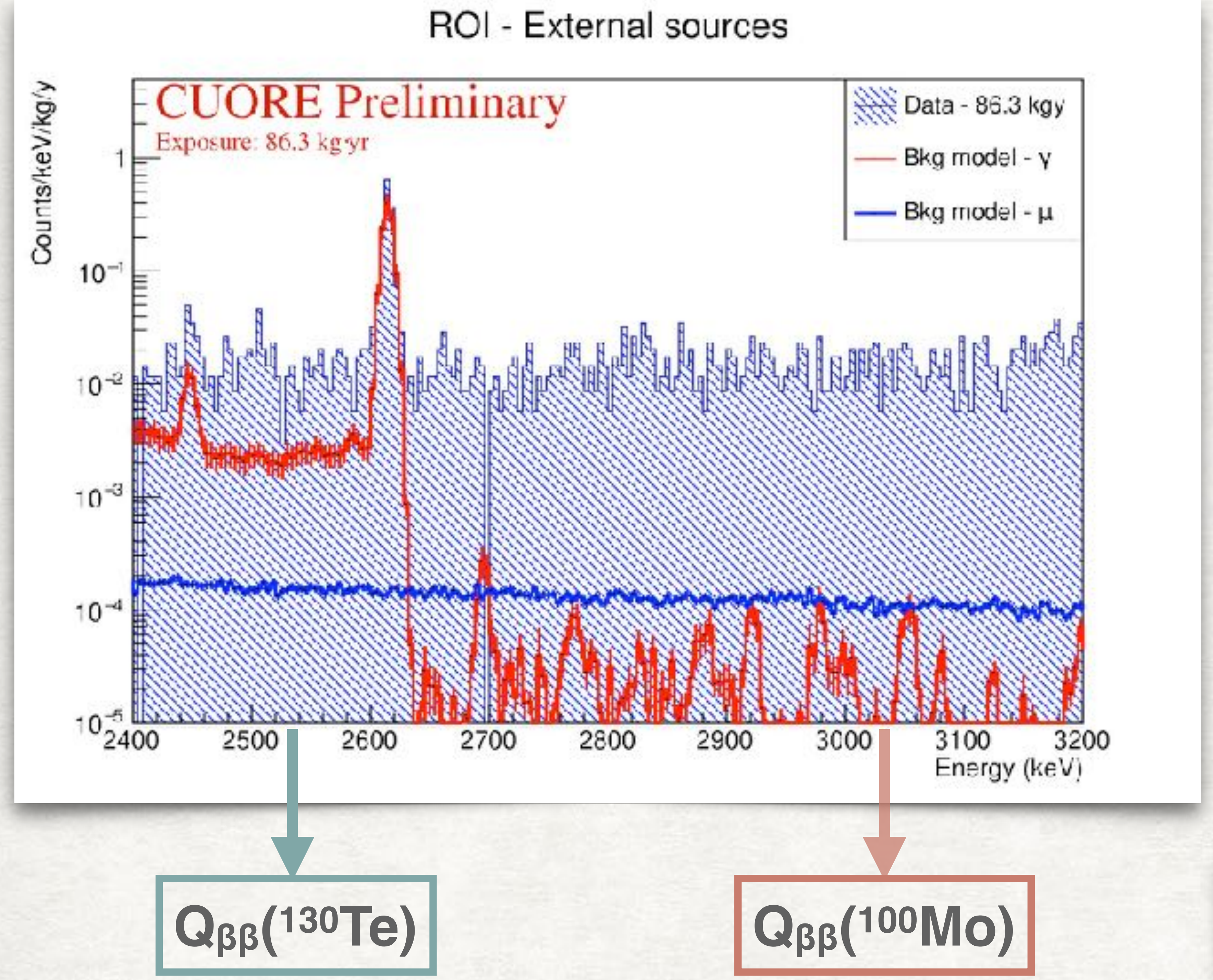
1 ton yr analysis ongoing



Phys. Rev. Lett. 124 (2020) 122501

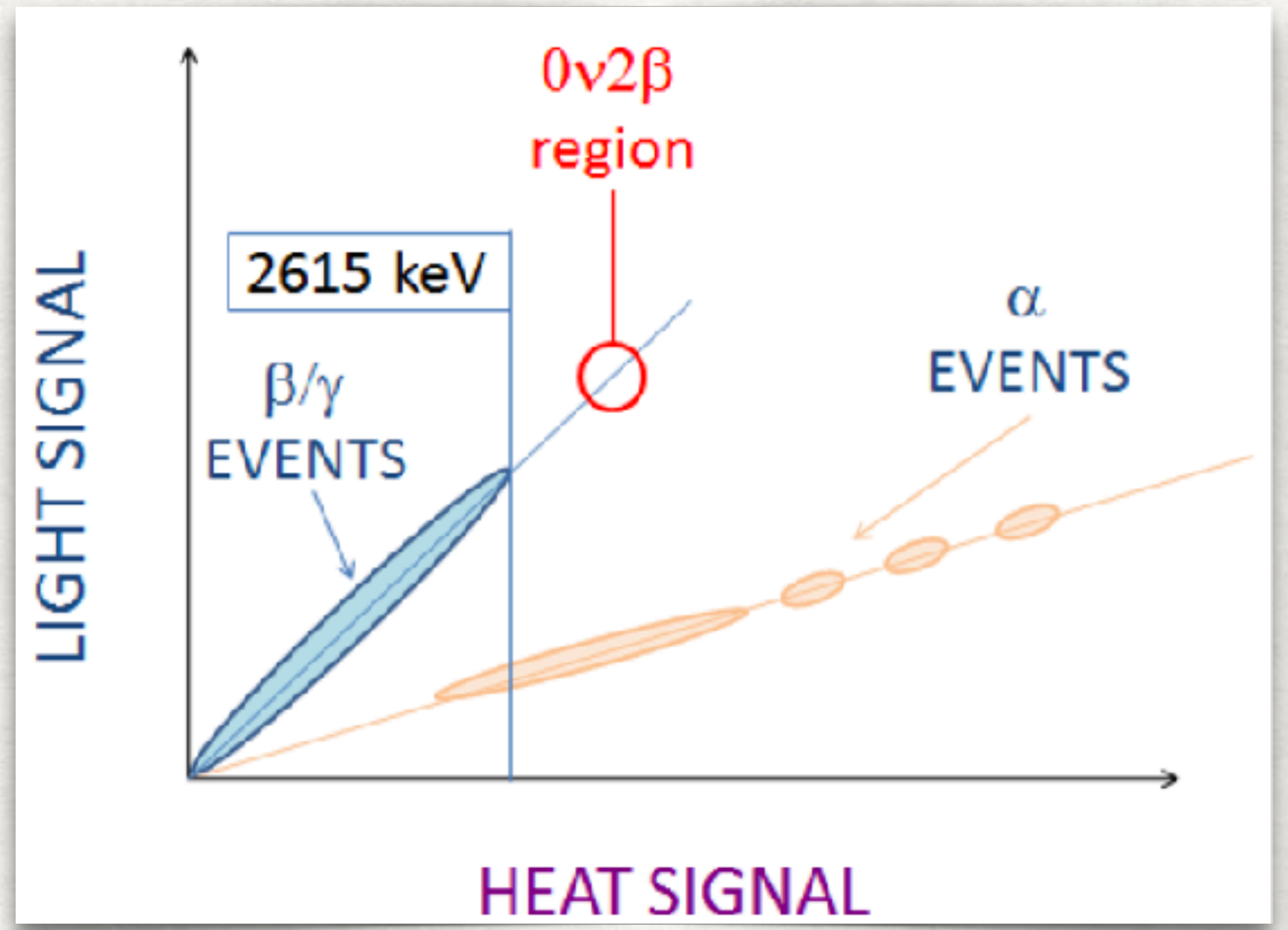
7datasets published (372.5 kg yr)
^{130}Te halflife: $T^{1/2}_{0\nu} > 3.2\ 10^{25}$ yr at 90% C.I.

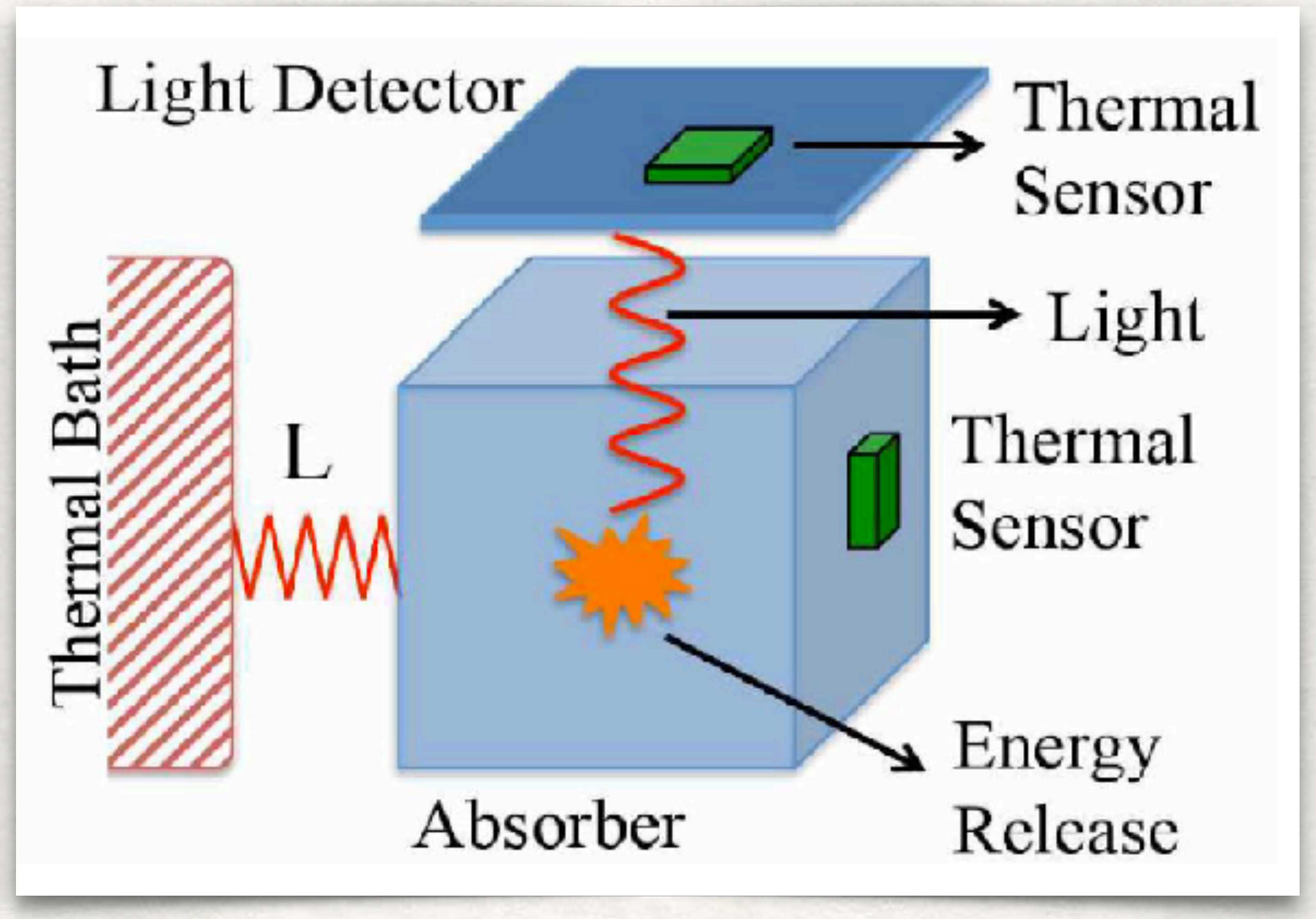
LESSON LEARNED FROM CUORE



- Most measured background is due to α particles (U/Th contaminations close to TeO_2 crystals)
  → α/β discrimination is required using light detectors
- With a $Q_{\beta\beta}$ < 2.6 MeV presence of β/γ background from environmental radioactivity →use of isotope with $Q_{\beta\beta}$ > 2.6 MeV
- Muons are the dominant contribution → active muon veto

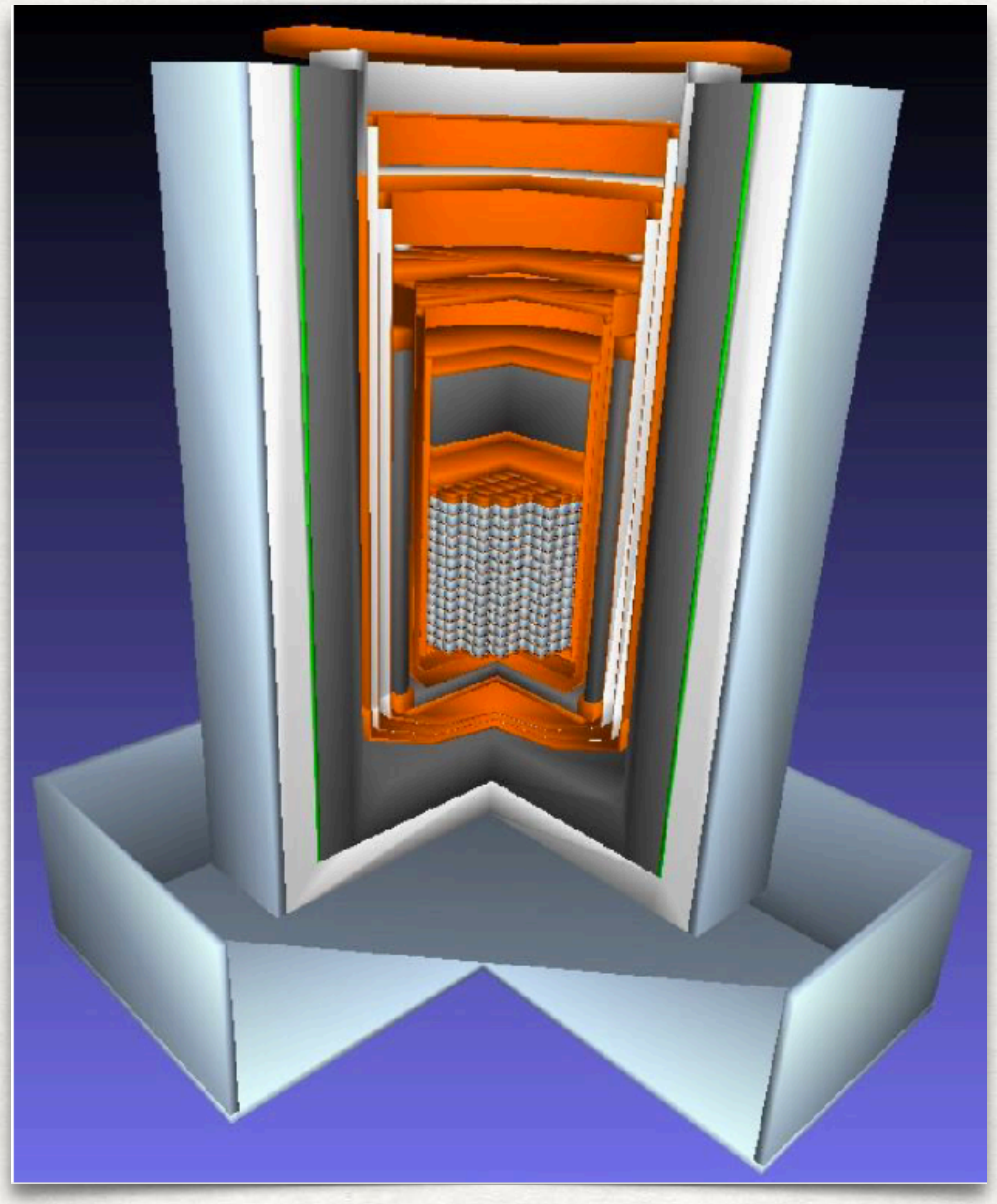
CUPID will use $Li_2{}^{100}MoO_4$ crystals coupled to Ge light detectors for particle discrimination





Beyond CUORE: CUPID

CUPID: **C**UORE **U**pgrade with **P**article **ID**



- 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

- Goal: sensitivity to the full IH region

$$T^{0\nu}_{1/2} \sim 10^{27} - 10^{28}\,\text{years}$$

- Requires:
  - ➡ CUORE-like energy resolution

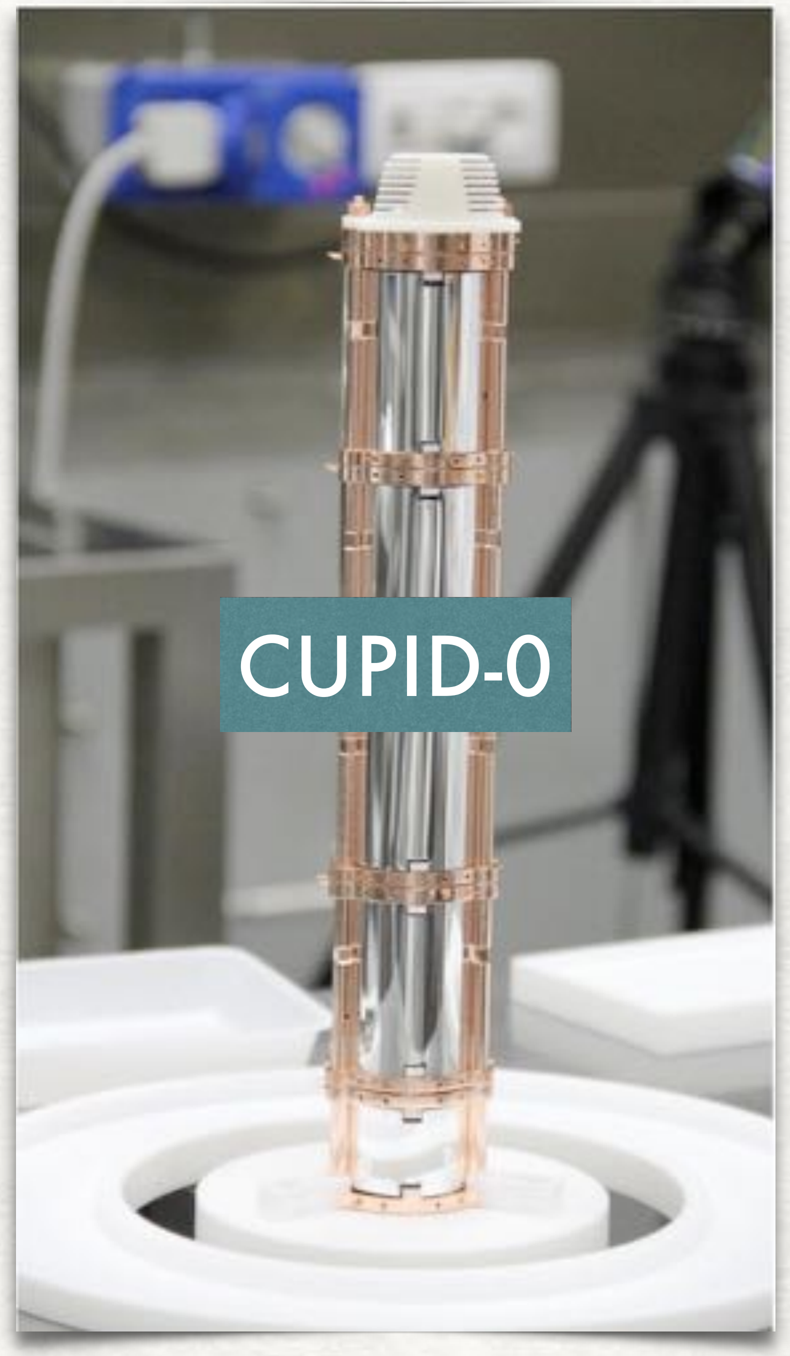
$$\delta E/Q_{\beta\beta} \sim 0.2\%\,(\text{FWHM})$$

  - ➡ Background index

$$b = 10^{-1}\,\text{counts/keV/ton/year}$$

  - ➡ $\geq\times10^2$ reduction relative to CUORE

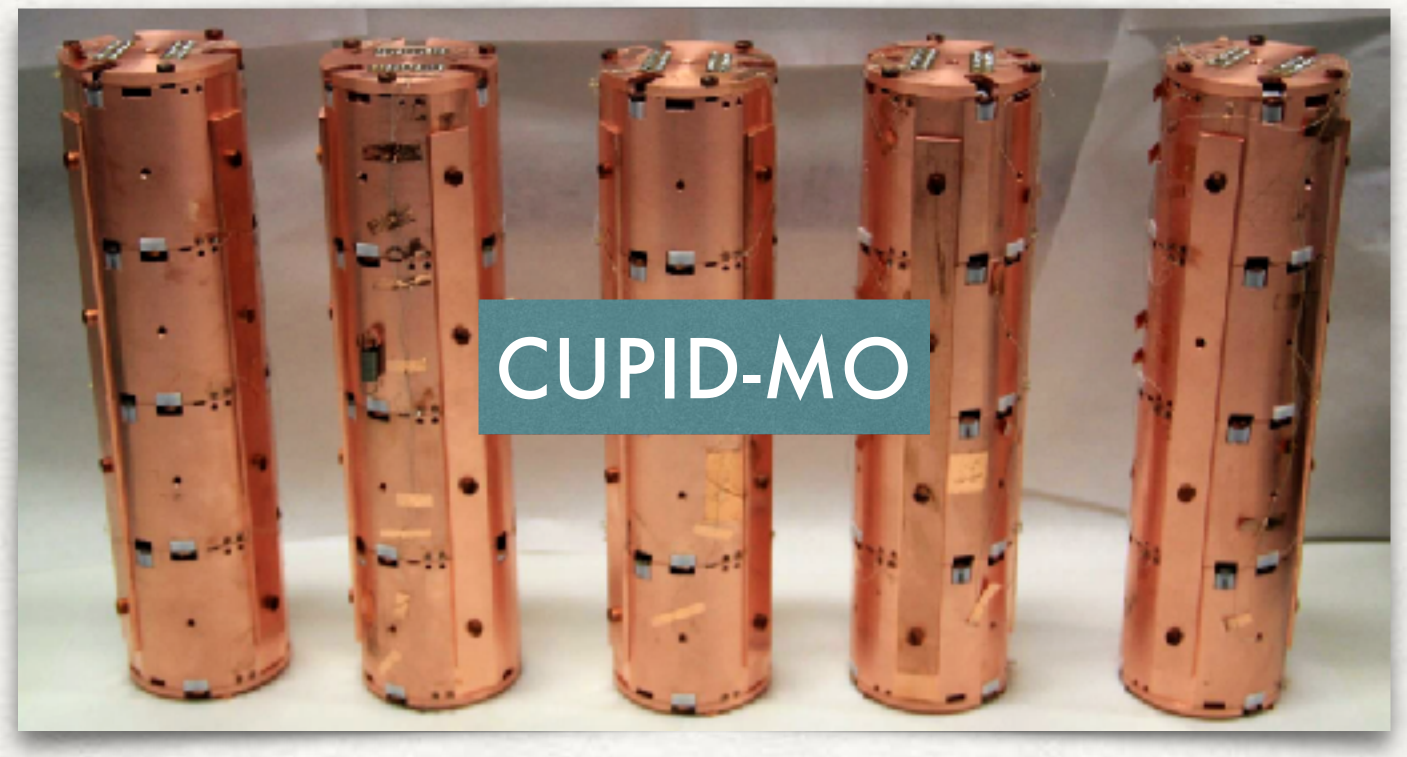
NEW COLLABORATION!



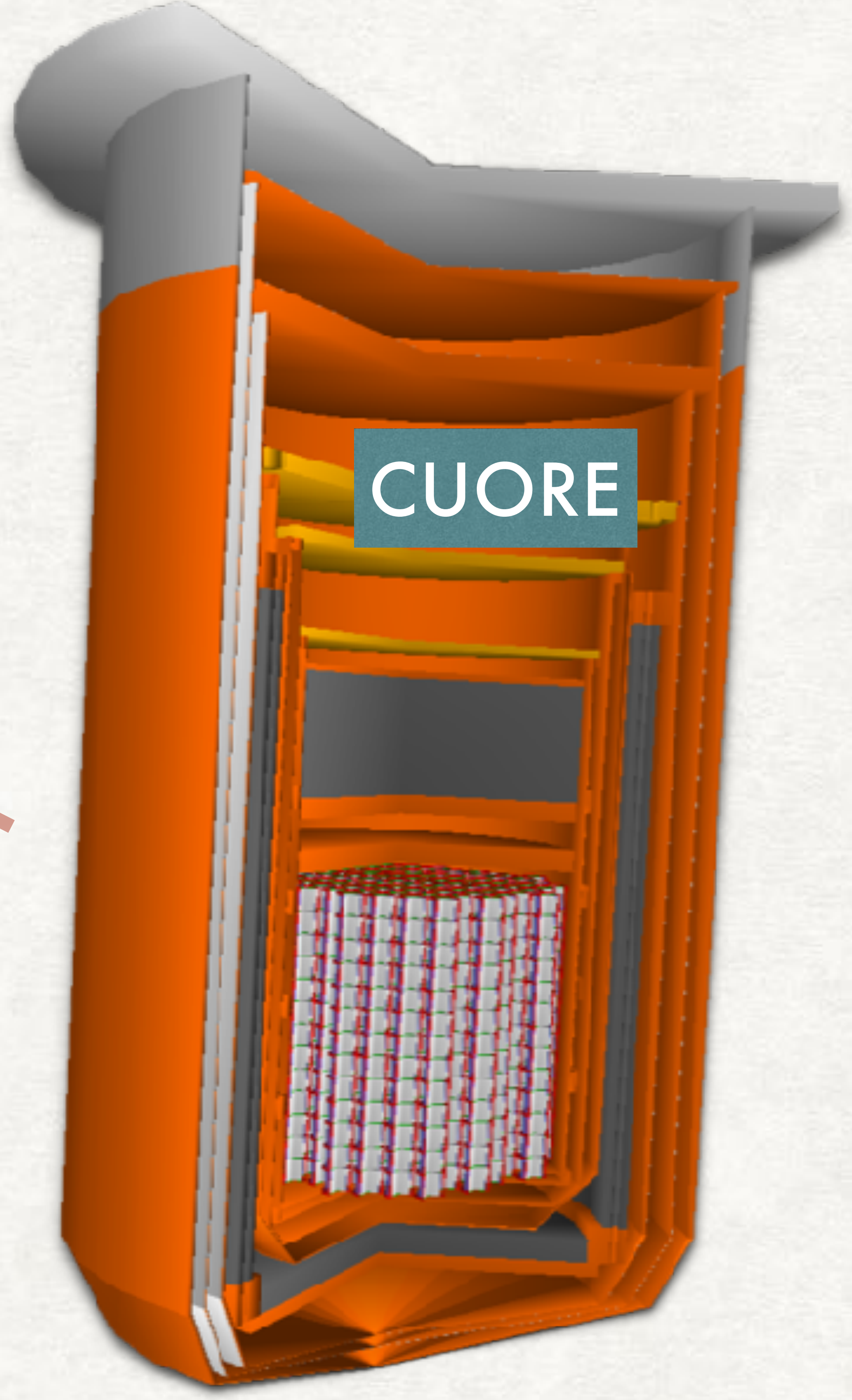
Best world limit on ^{82}Se
$T^{1/2}_{0\nu}$> 3.5 10^{24}y @90% CI

7 countries **180 members**

NEW FORCES



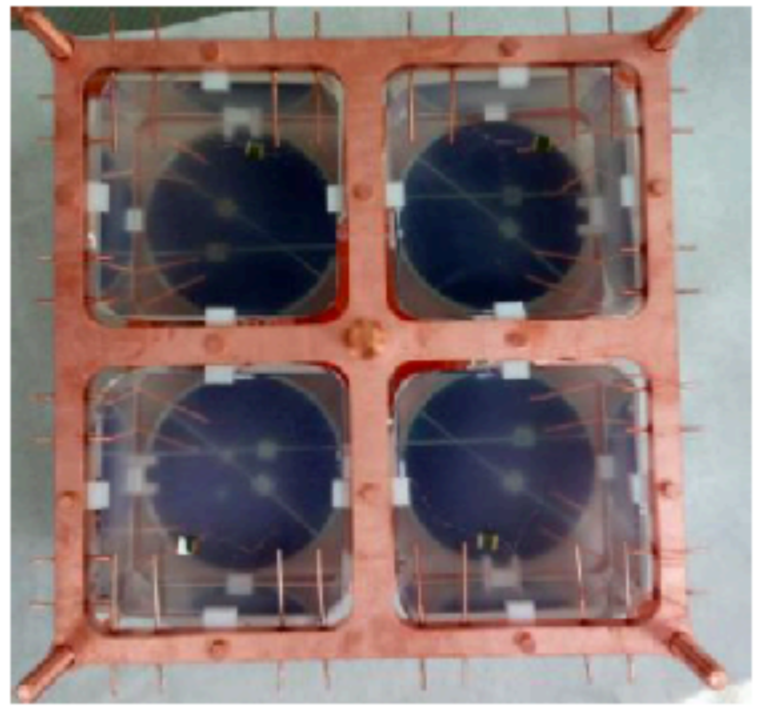
Best world limit on ^{100}Mo
$T^{1/2}_{0\nu}$> 1.5 10^{24}y @90% CI



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

PAST AND FUTURE R&D @LNGS TOWARDS CUPID

LNGS test – Hall C facility

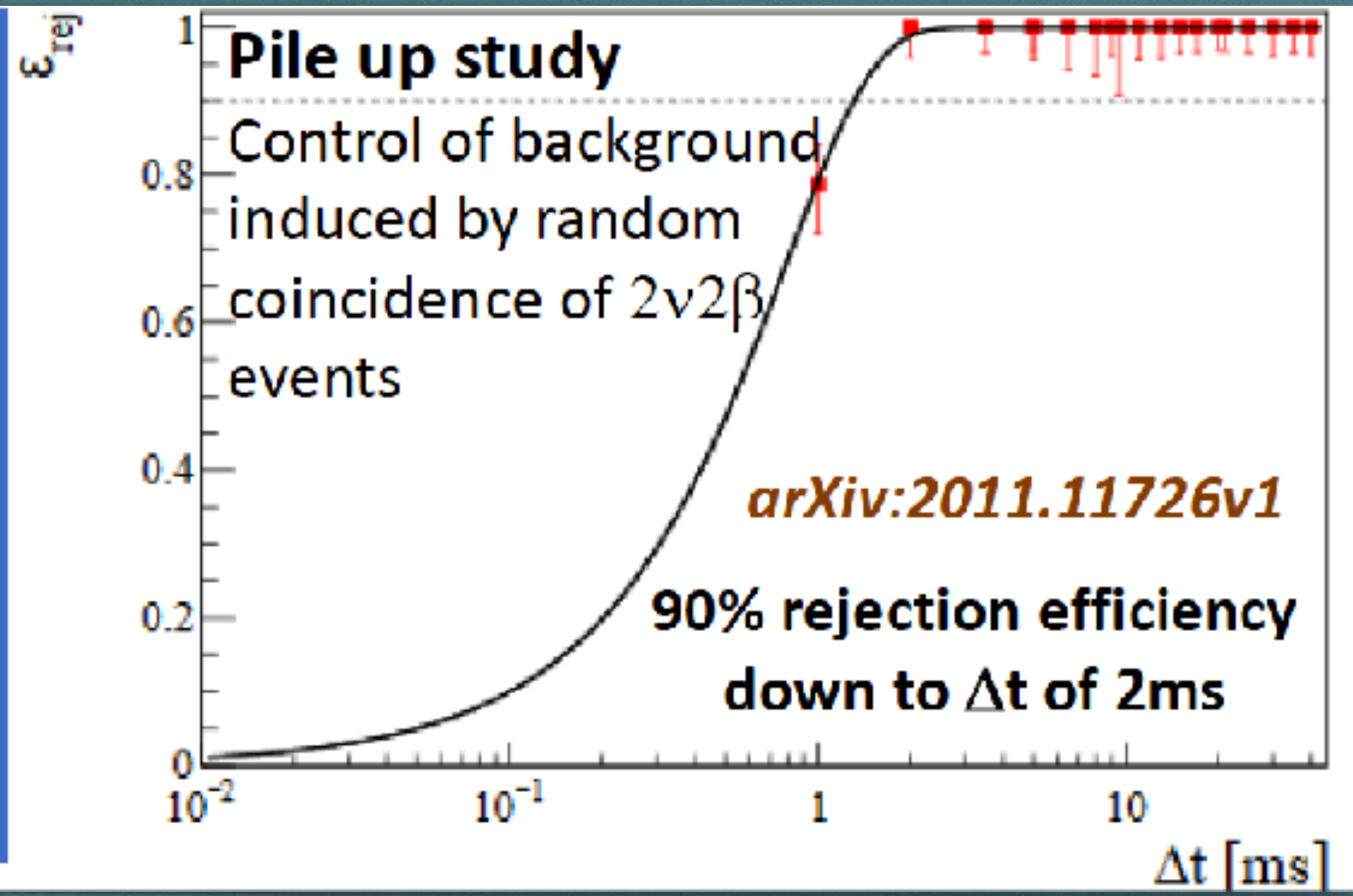


8 crystal array (4 without reflective foil)
12 round light detectors ∅ 44 mm (as CUPID-Mo)

- with reflective foil ⟶ **α/β separation at 8-10σ**
- without reflective foil ⟶ **α/β separation > 4σ**

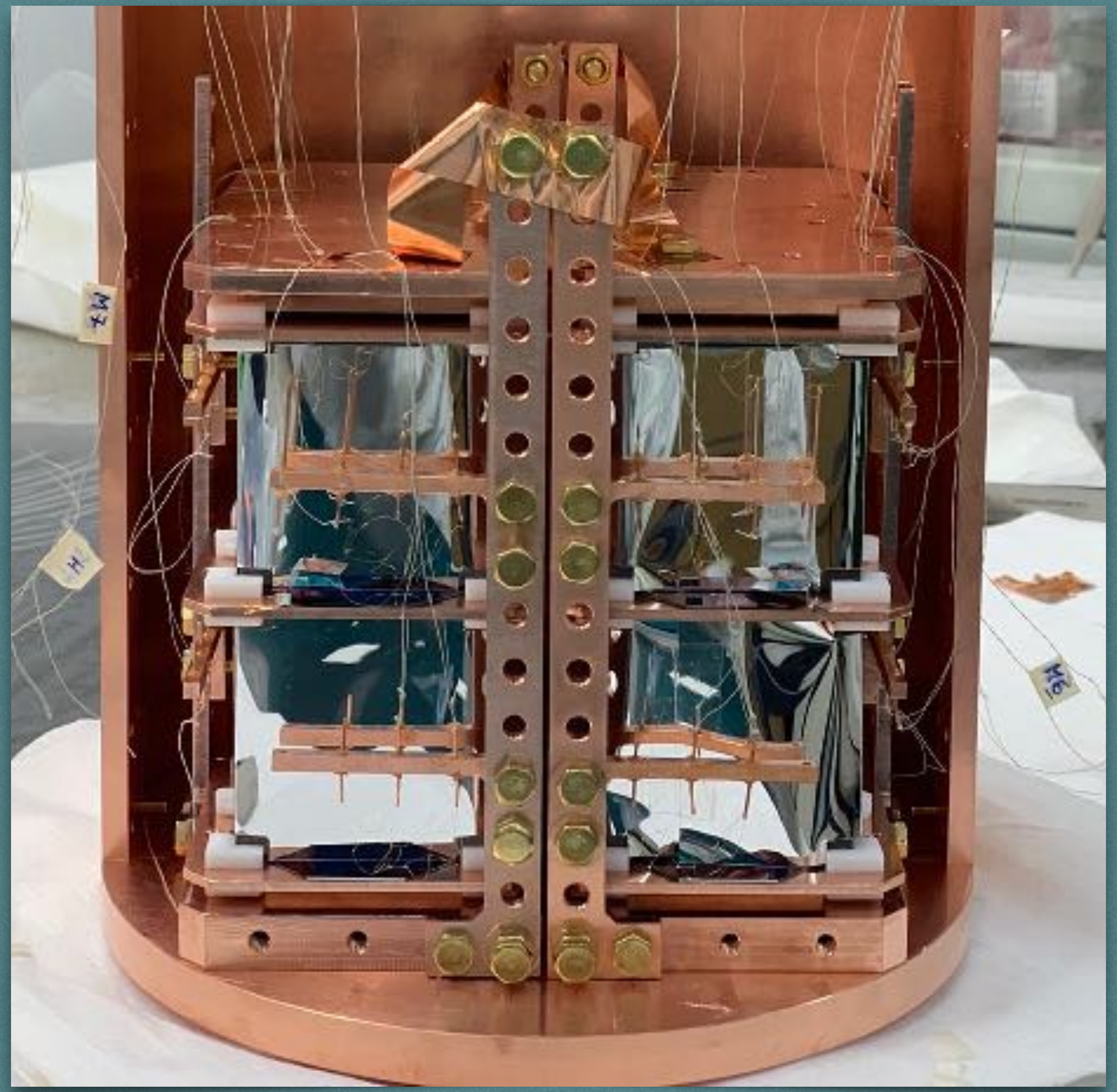
Extrapolated energy resolution at $Q_{\beta\beta}$
6.7 ± 0.6 keV FWHM

EPJC 81 (2021) 104



Ongoing tests at LNGS to define the final design for CUPID

- New tower structure
- New light detector position and LY comparison
- Additional pile-up tests using heater induced pulses



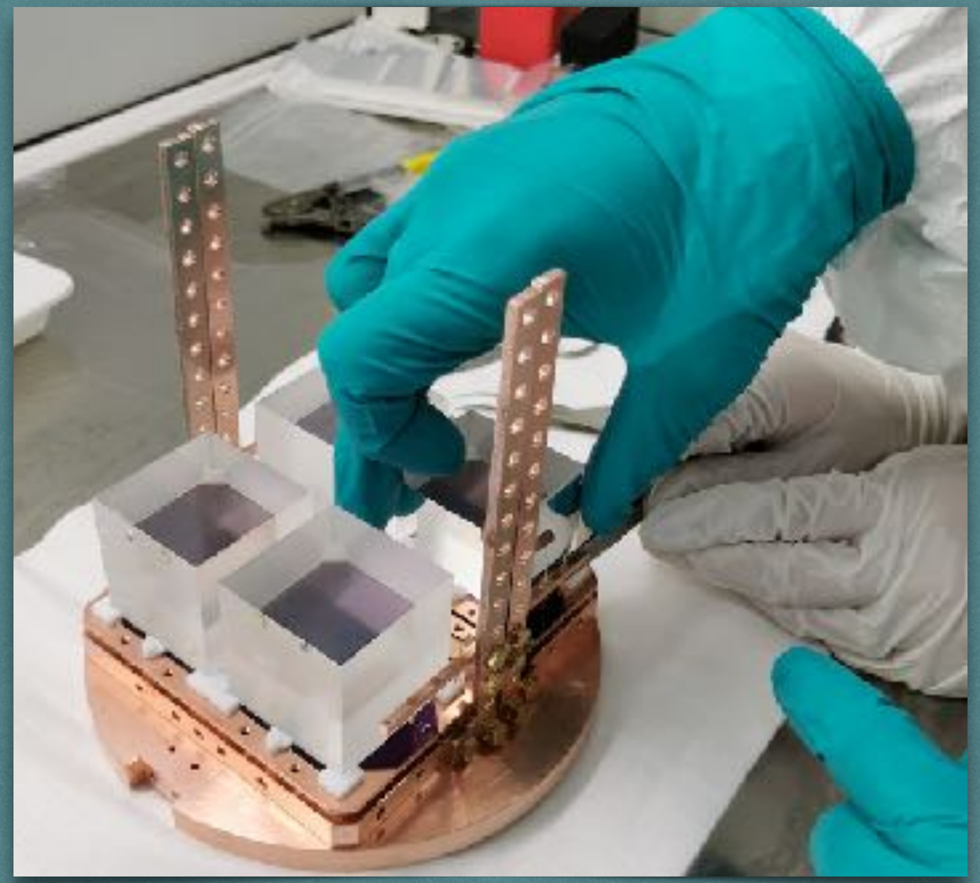
PROPOSED THESIS TOPICS

Exploiting 1 ton yr of exposure:

- CUORE background model
- $2\nu\beta\beta$ of ^{130}Te
- Low energy spectrum and dark matter analysis
  - Dark matter annual modulation
  - Axions
  - Supernovae/solar neutrino
- $0\nu\beta\beta$ of ^{130}Te with Majoron emission
- Lorentz and CPT violation in beta decay
- $0\nu\beta^+\beta^+$, $0\nu\beta^+EC$, $0\nu ECEC$ of ^{120}Te
- $0\nu\beta\beta$ and sterile neutrino
- $0\nu\beta\beta$ and $2\nu\beta\beta$ of ^{130}Te on excited states of ^{130}Xe
- Thermal model and detector response

Many hardware tasks

- LNGS R&D tests towards CUPID demonstrator
  - Single detector tests
  - Light detector
  - Pile-up versus response speed
  - Tower design tests



- Commissioning low background and low noise large cryogenic LNGS facility
- Acoustic and vibrational noise decorrelation/reduction in CUORE/CUPID detectors
- Upgrade of CUORE cryostat
- Upgrade CUORE front end electronics (preamp)

CONTACT US

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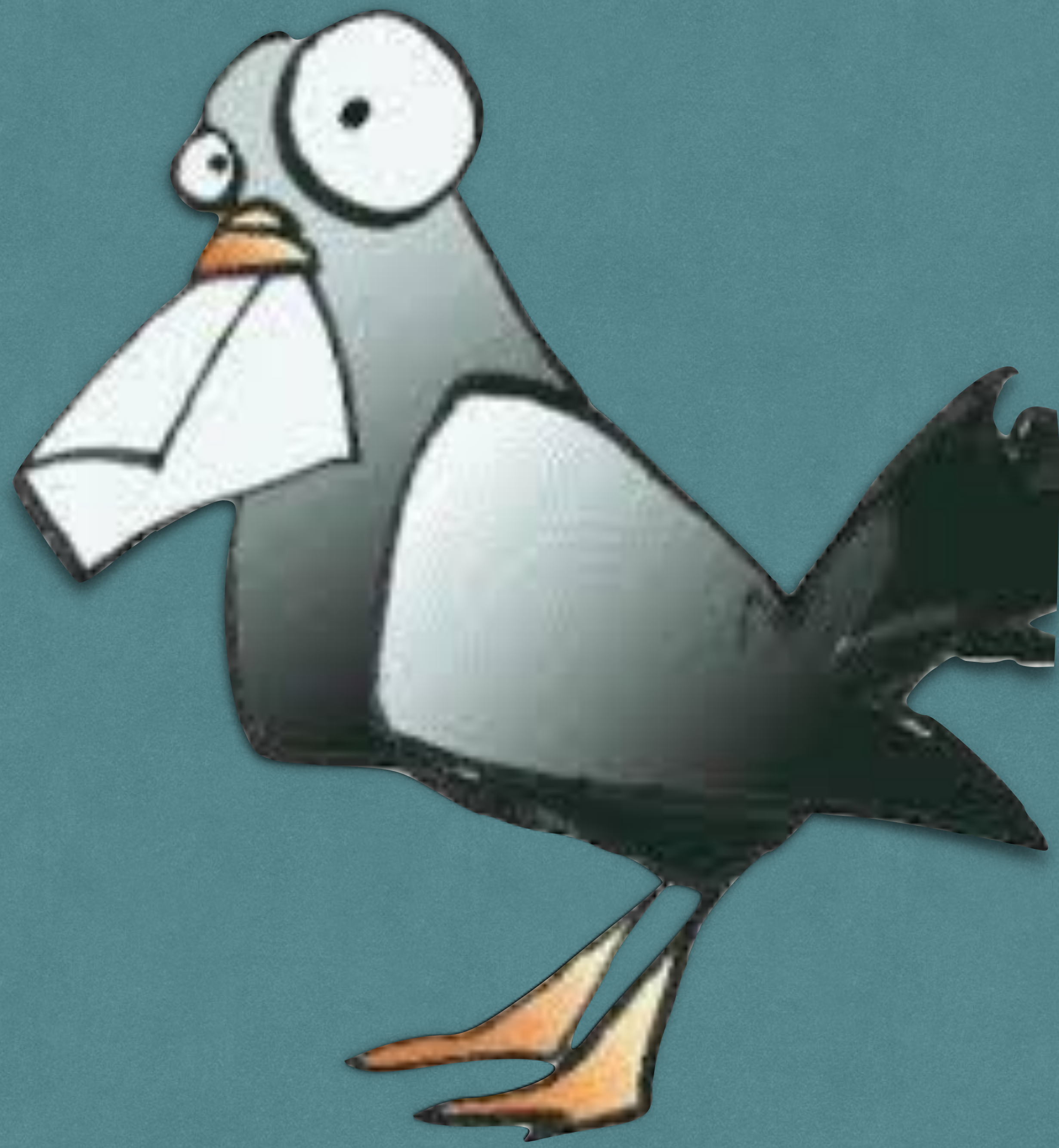

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