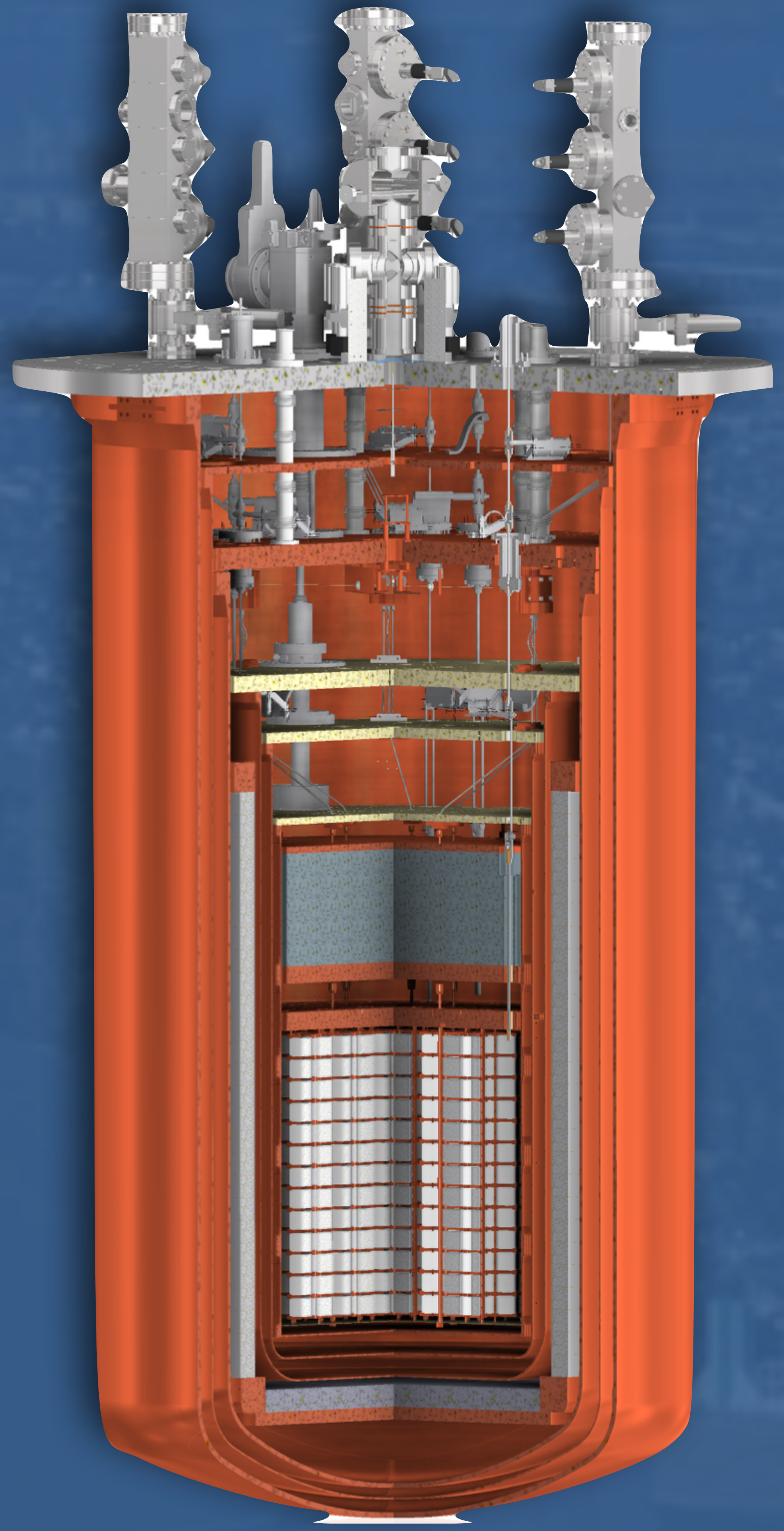
BERKELEY LAB

LAWRENCE BERKELEY NATIONAL LABORATORY

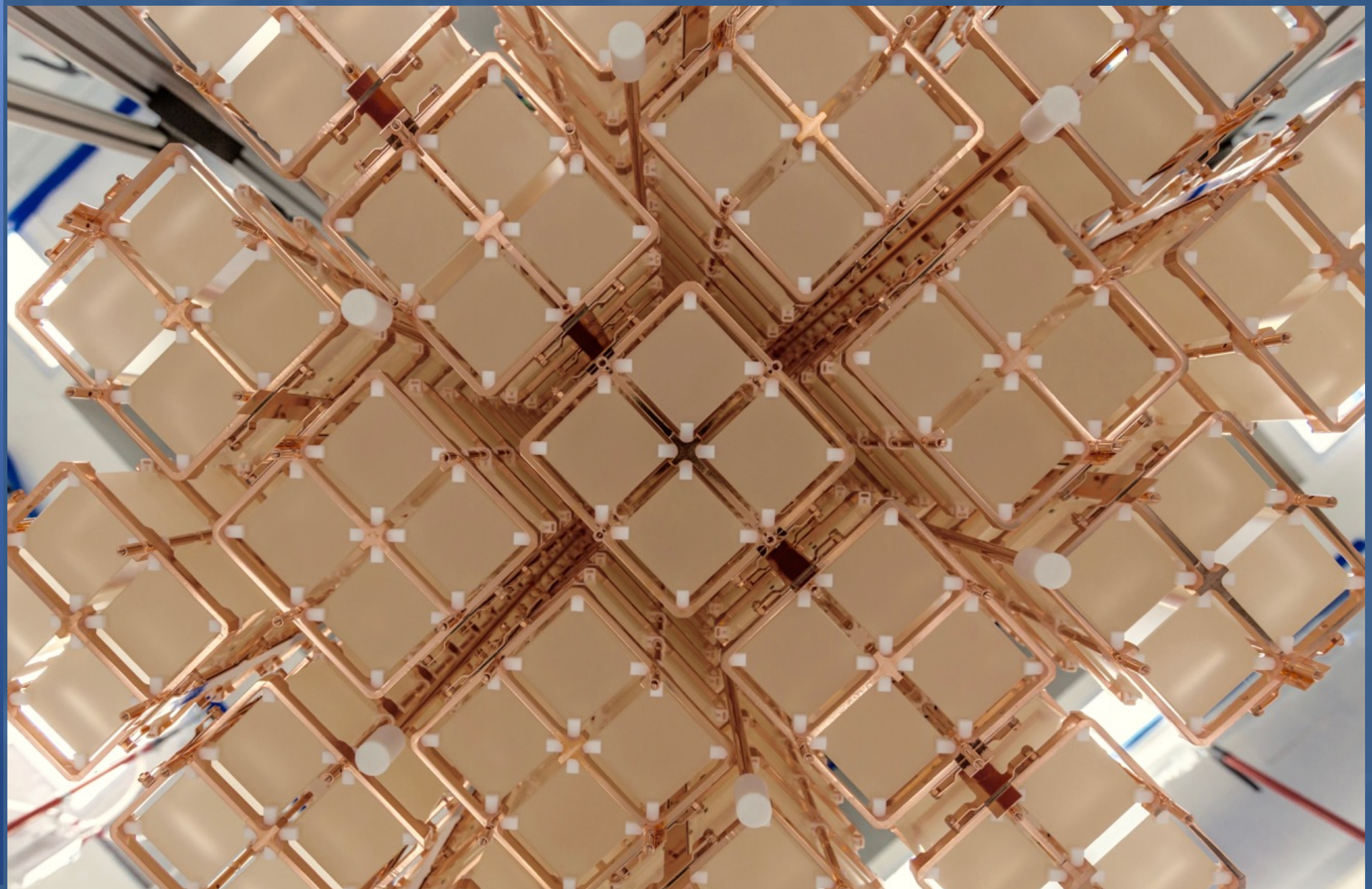
U.S. DEPARTMENT OF ENERGY

Results from the CUORE experiment

FPCP 2019, B. Schmidt 2019-05-09



CUORE



Neutrinoless double beta decay

Implications/Motivation

- $\Delta L = 2$, i.e. lepton number violation
- Majorana mass contribution

Challenge

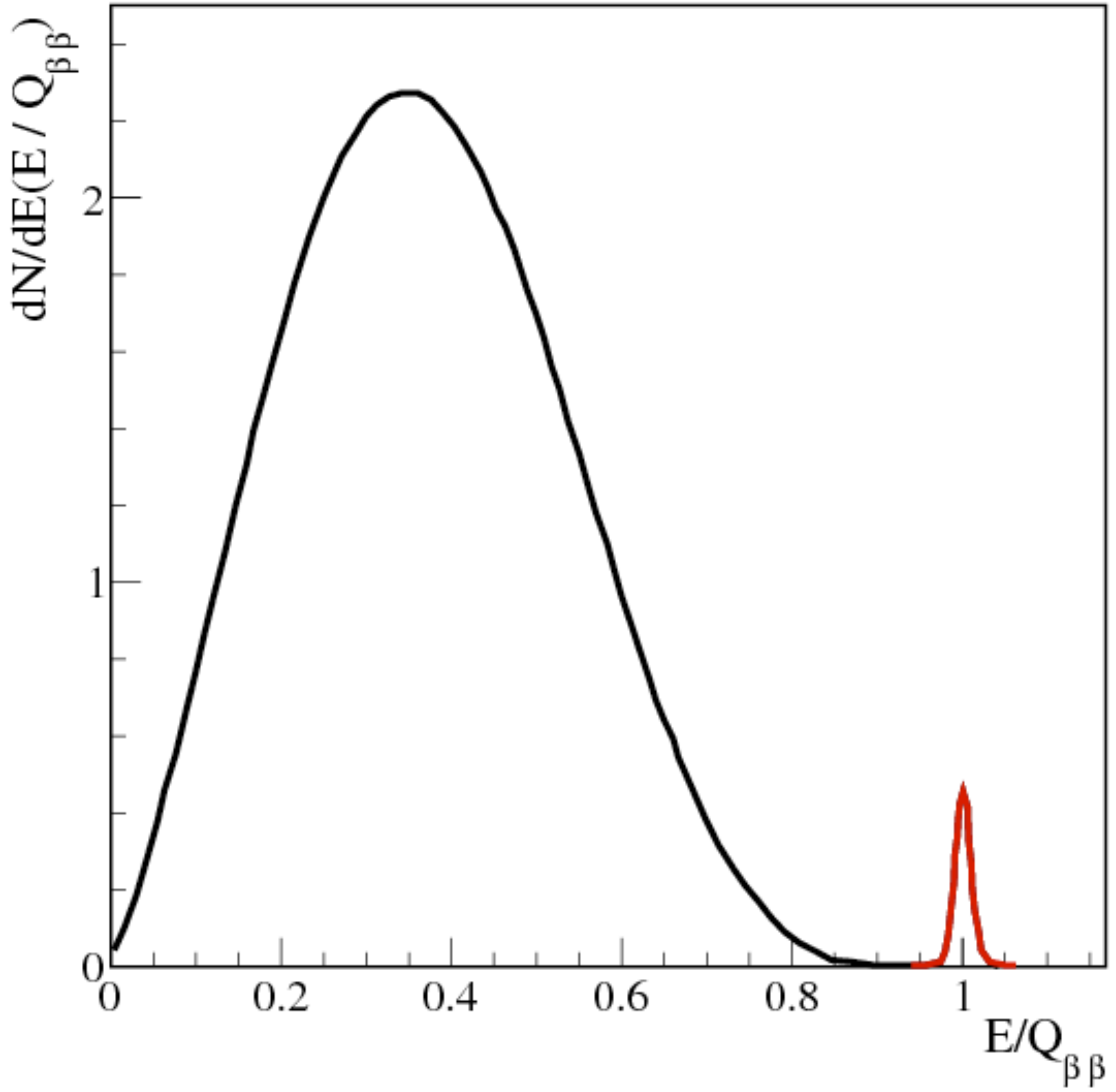
- Current competitive sensitivity - $T_{1/2} > 10^{25\sim26}$ years
- Next generation - $T_{1/2} > 10^{27\sim28}$ years

Candidate isotopes

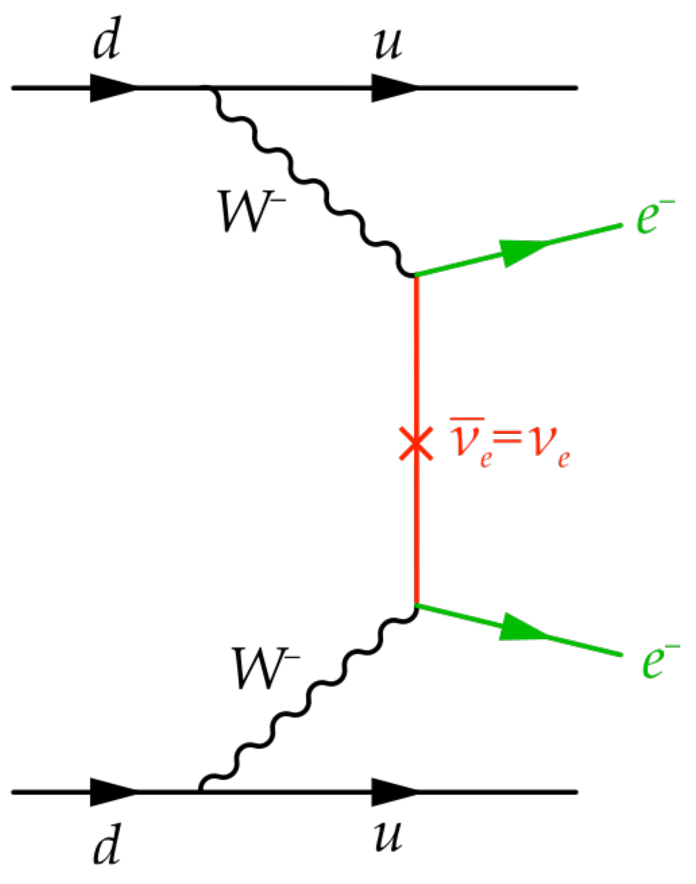
- $2\nu\beta\beta$-isotopes with high Q-value: Even-even nuclei, where the single beta decay is forbidden or suppressed

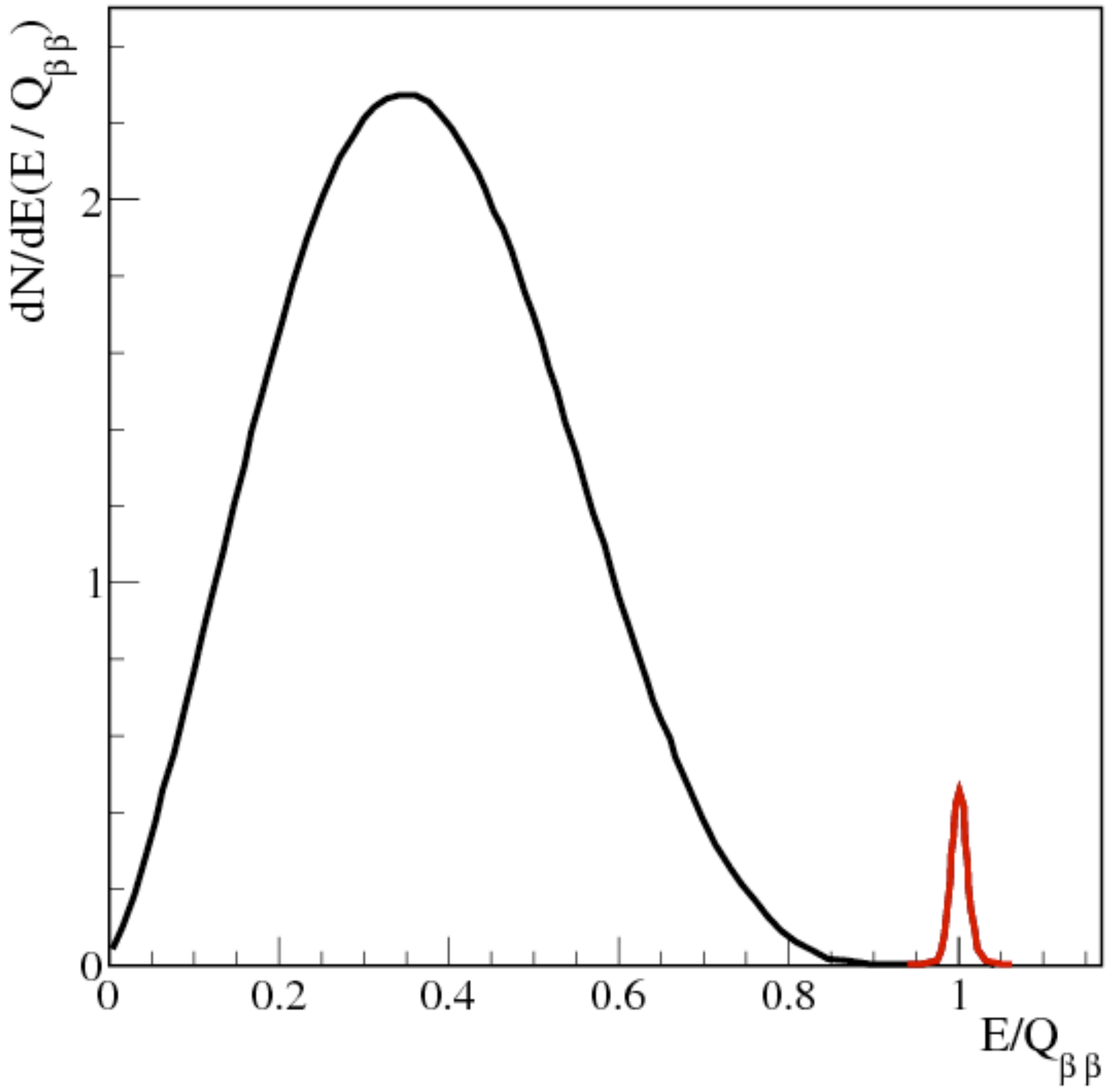
Observable

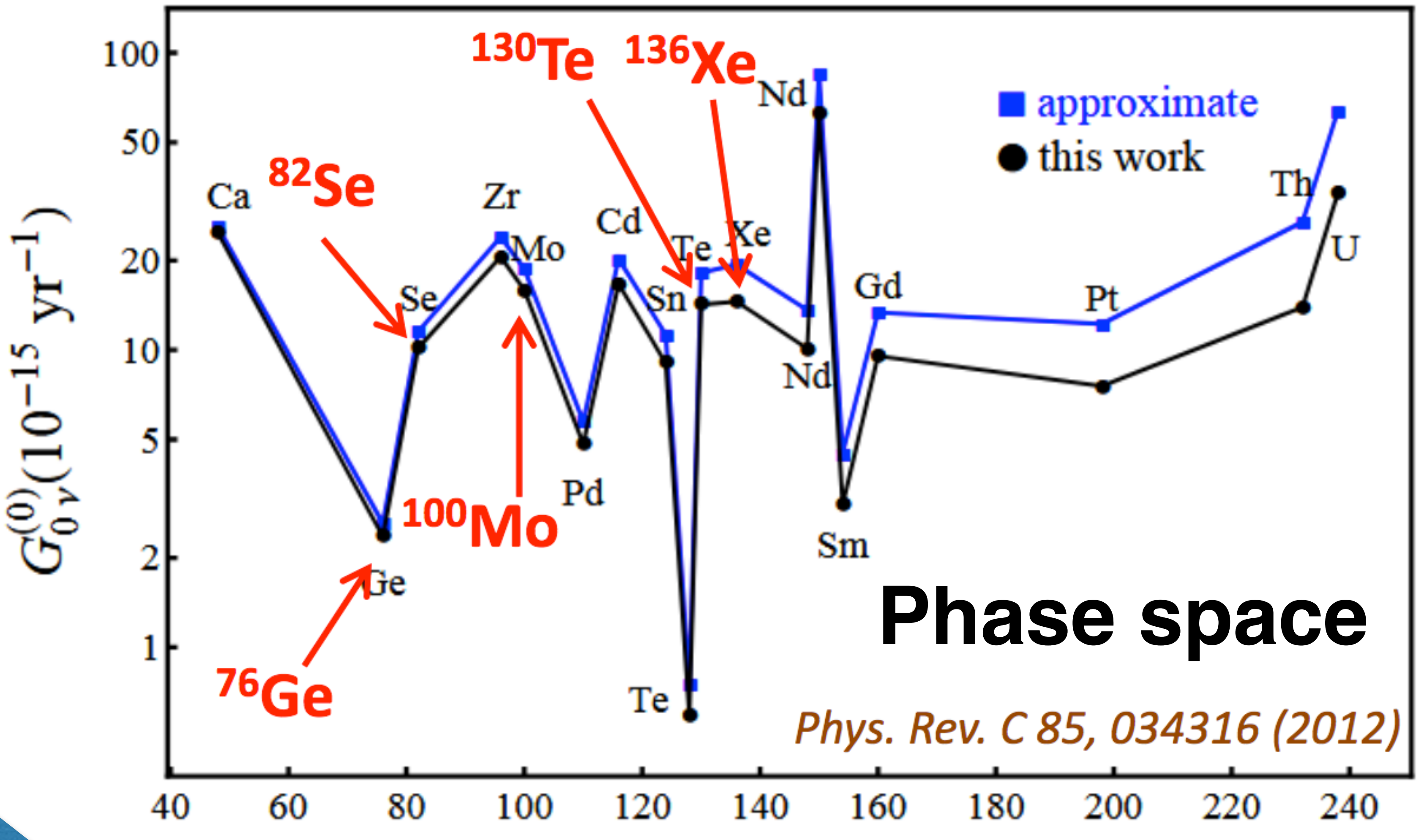
- Line at the Q-value

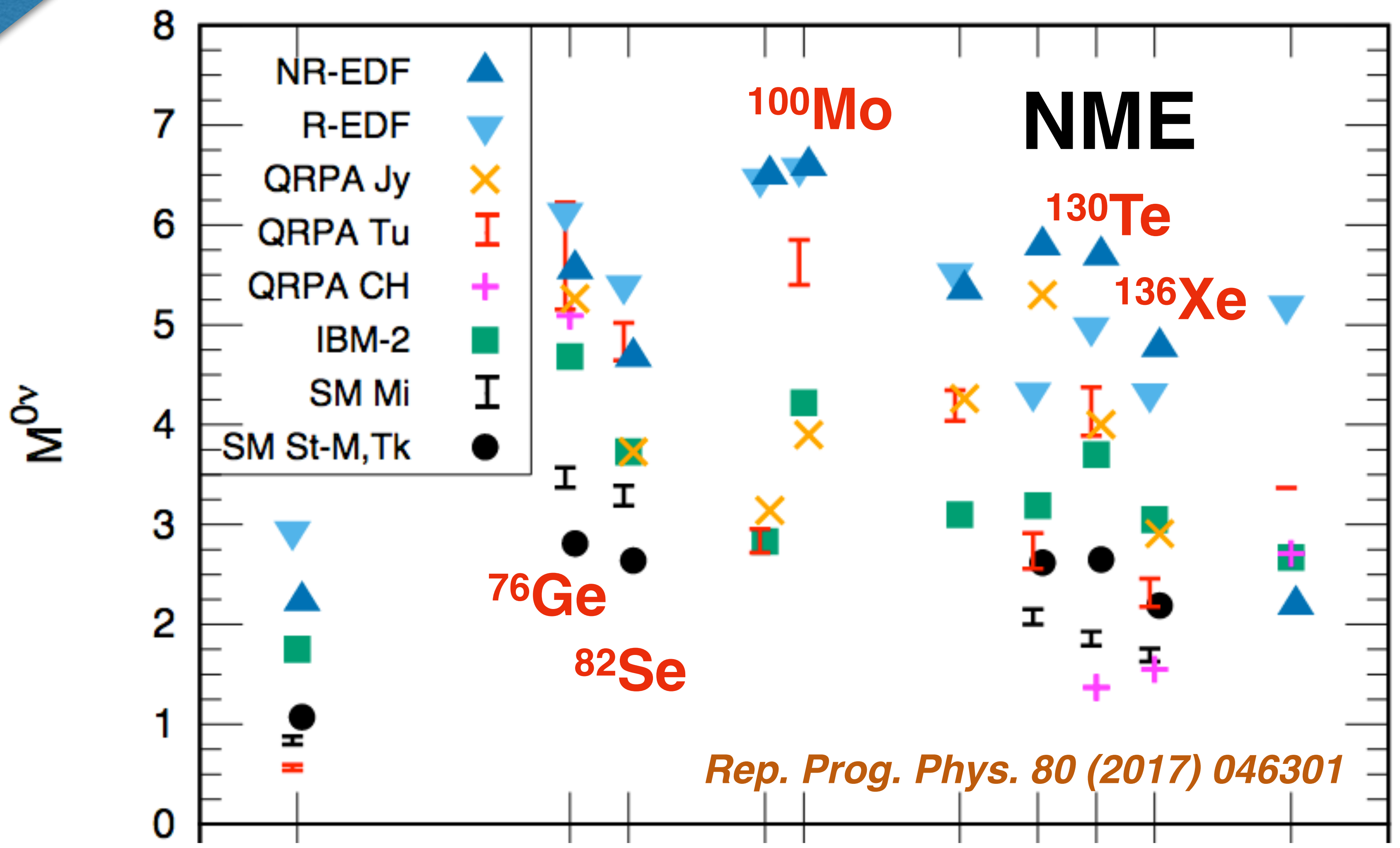


Neutrinoless double beta decay
light Majorana neutrino exchange







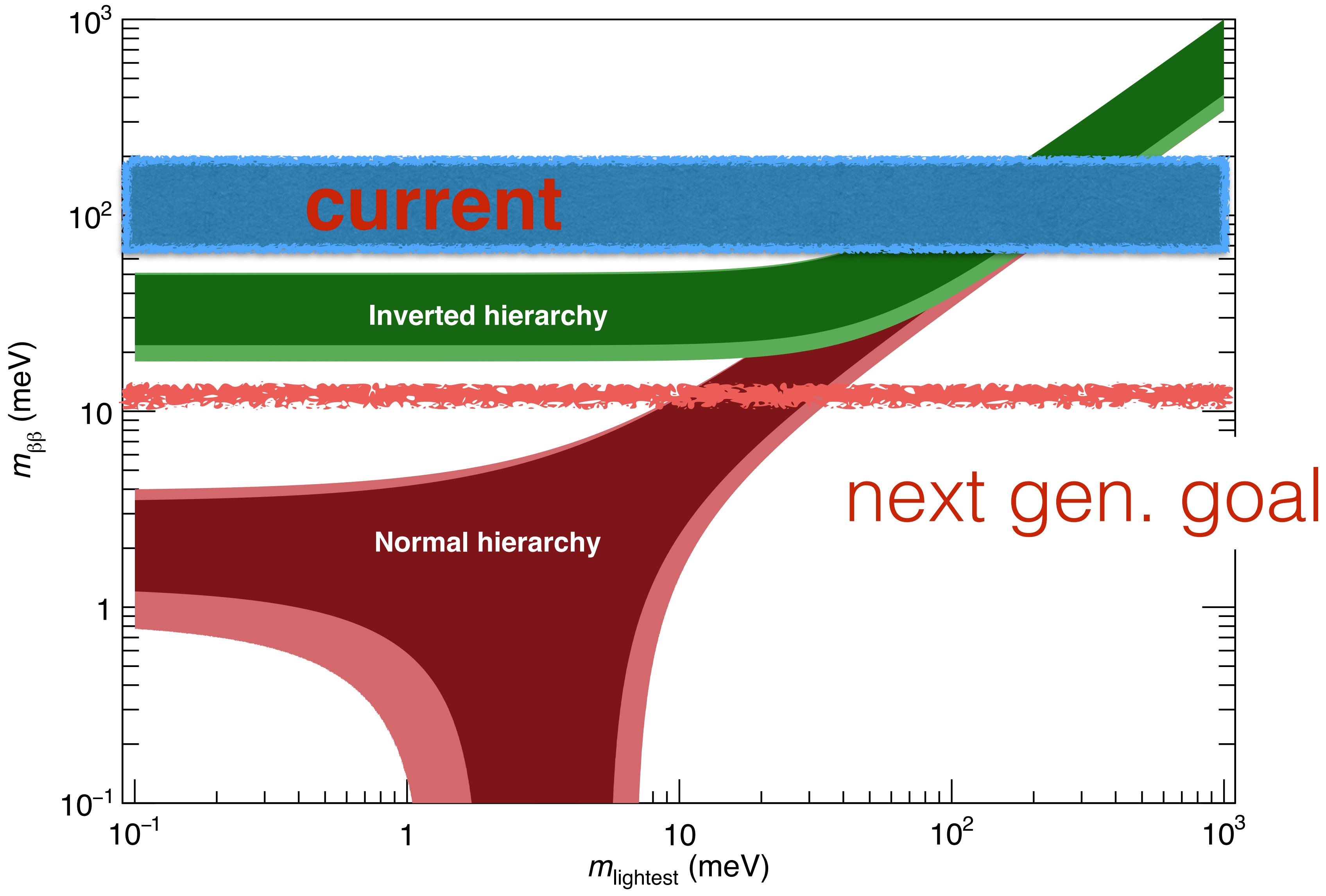


Effective Majorana mass
$\langle m_{\beta\beta}\rangle^2 = \left|\Sigma_{i=1,2,3} U^2_{e,i} m_i\right|$

Nuclear matrix element

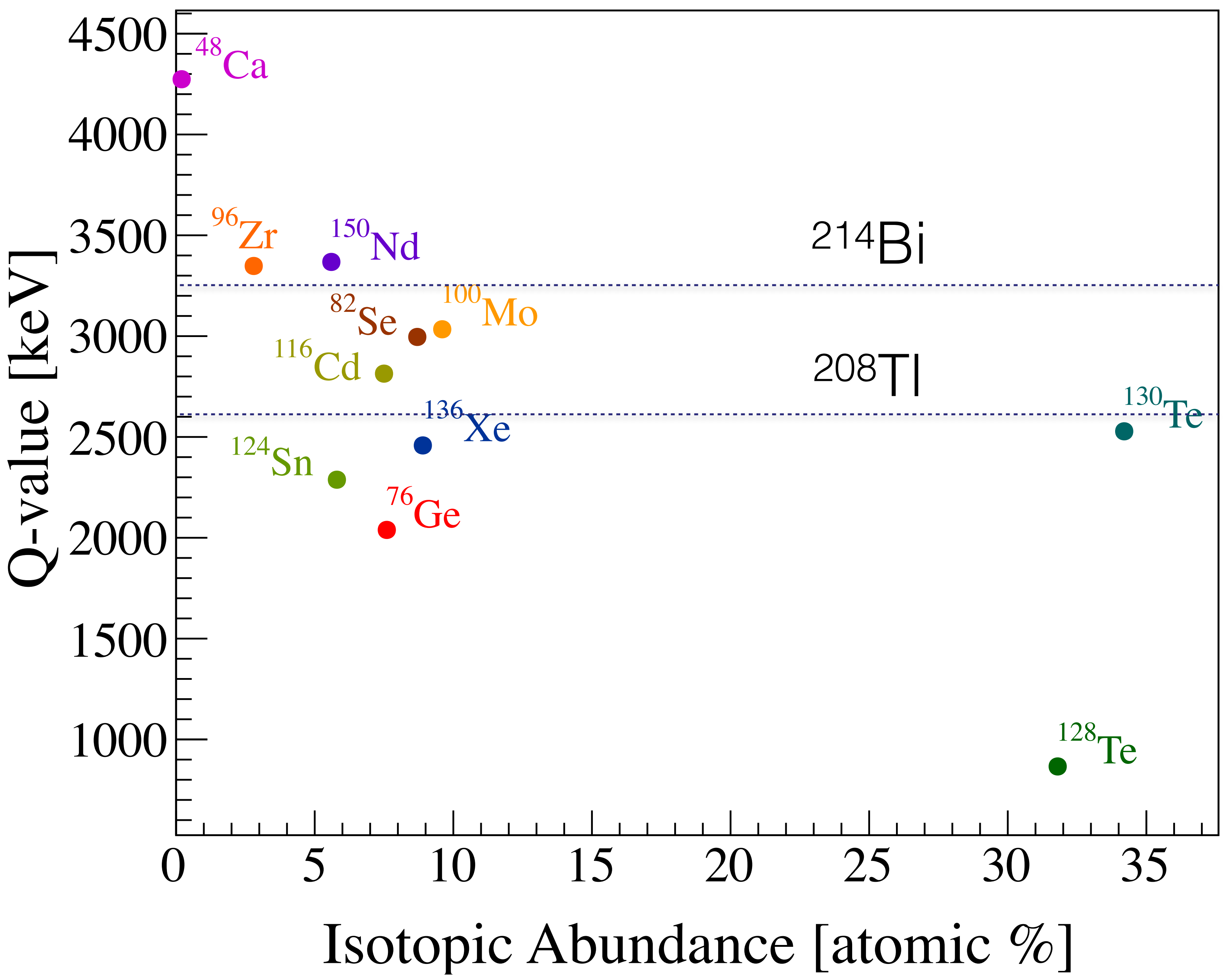
Phase space

$$(T^{0\nu\beta\beta}_{1/2})^{-1} = G^{0\nu} \left|M^{0\nu}\right|^2 \frac{\langle m_{\beta\beta}\rangle^2}{m_e^2}$$



$0\nu\beta\beta$ isotopes and sensitivity scaling

The 11 experimentally considered candidate isotopes



Isotope choice considerations:

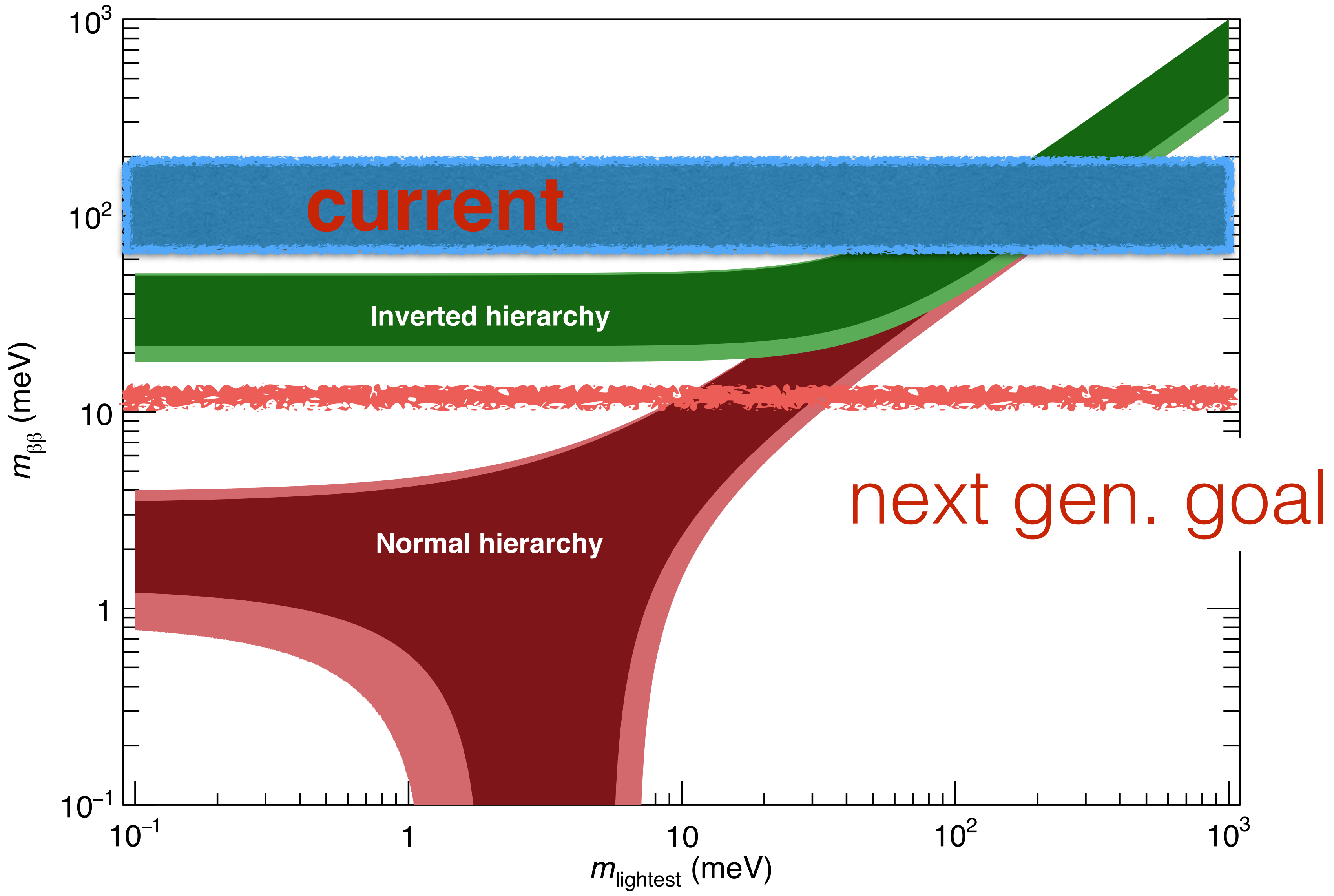
high Q-value -> large phase space, typically low natural radioactivity backgrounds

good energy resolution or bg rejection techniques -> improve signal/background

large isotope mass/ abundance, cost effectiveness for scaling

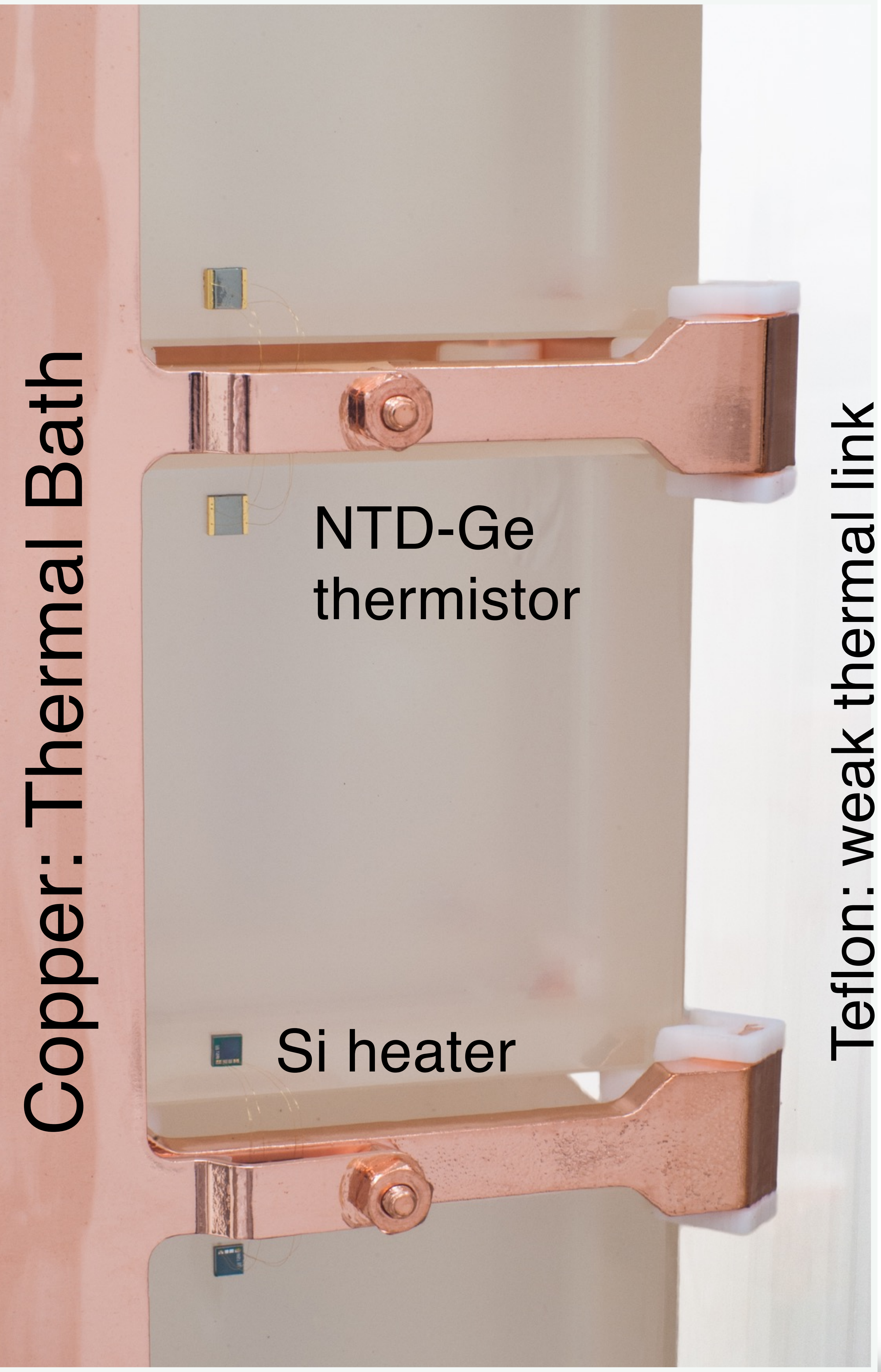
Experimental sensitivity on $T_{1/2}$ with Bg

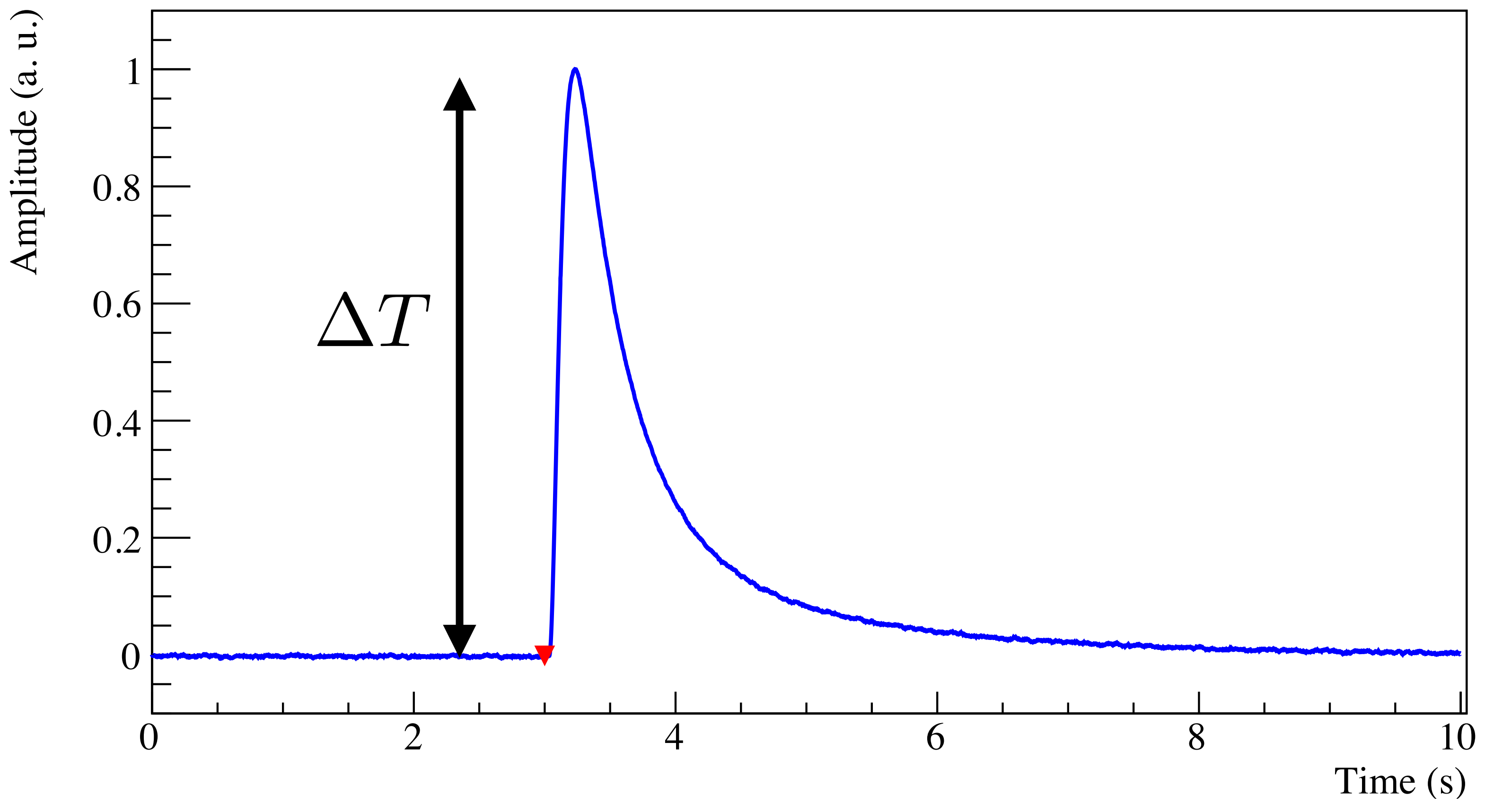
$$S \propto \frac{N_A}{M_{mol}} \eta \epsilon \sqrt{\frac{Mt}{b \cdot \Delta E}}$$

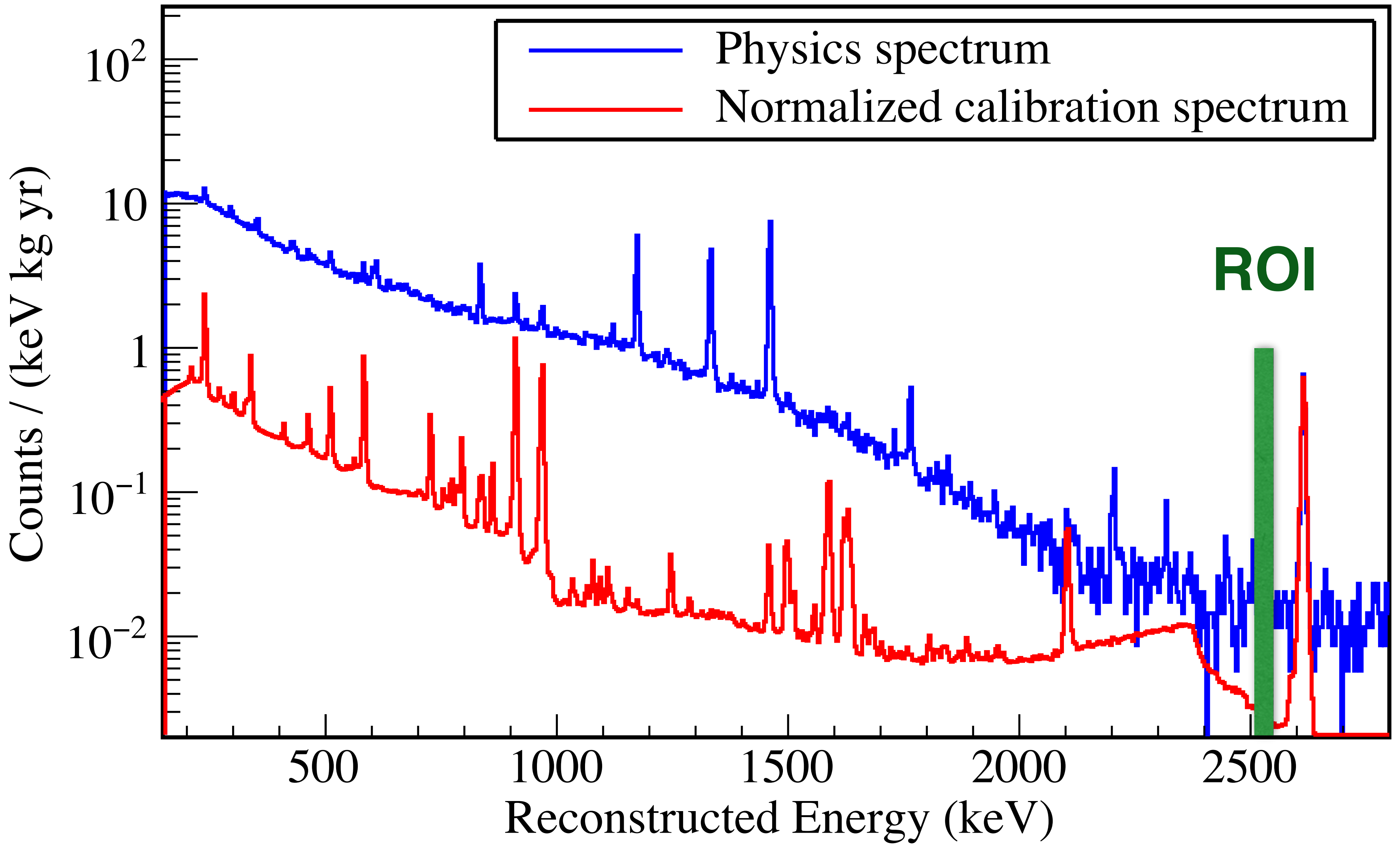


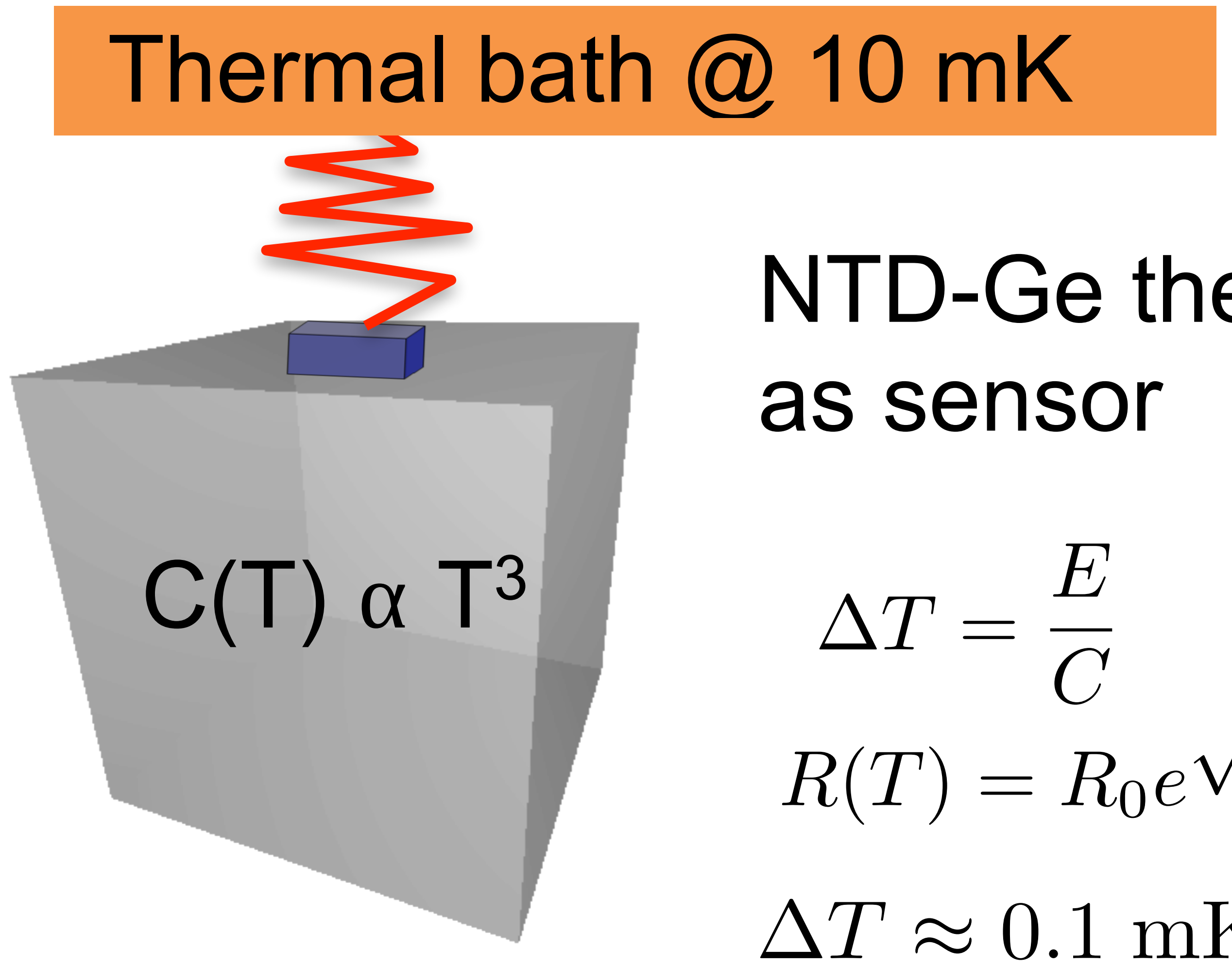
No Background $S \propto \frac{N_A}{M_{mol}} \eta \epsilon Mt$

Cryogenic calorimeters in CUORE









NTD-Ge thermistor as sensor

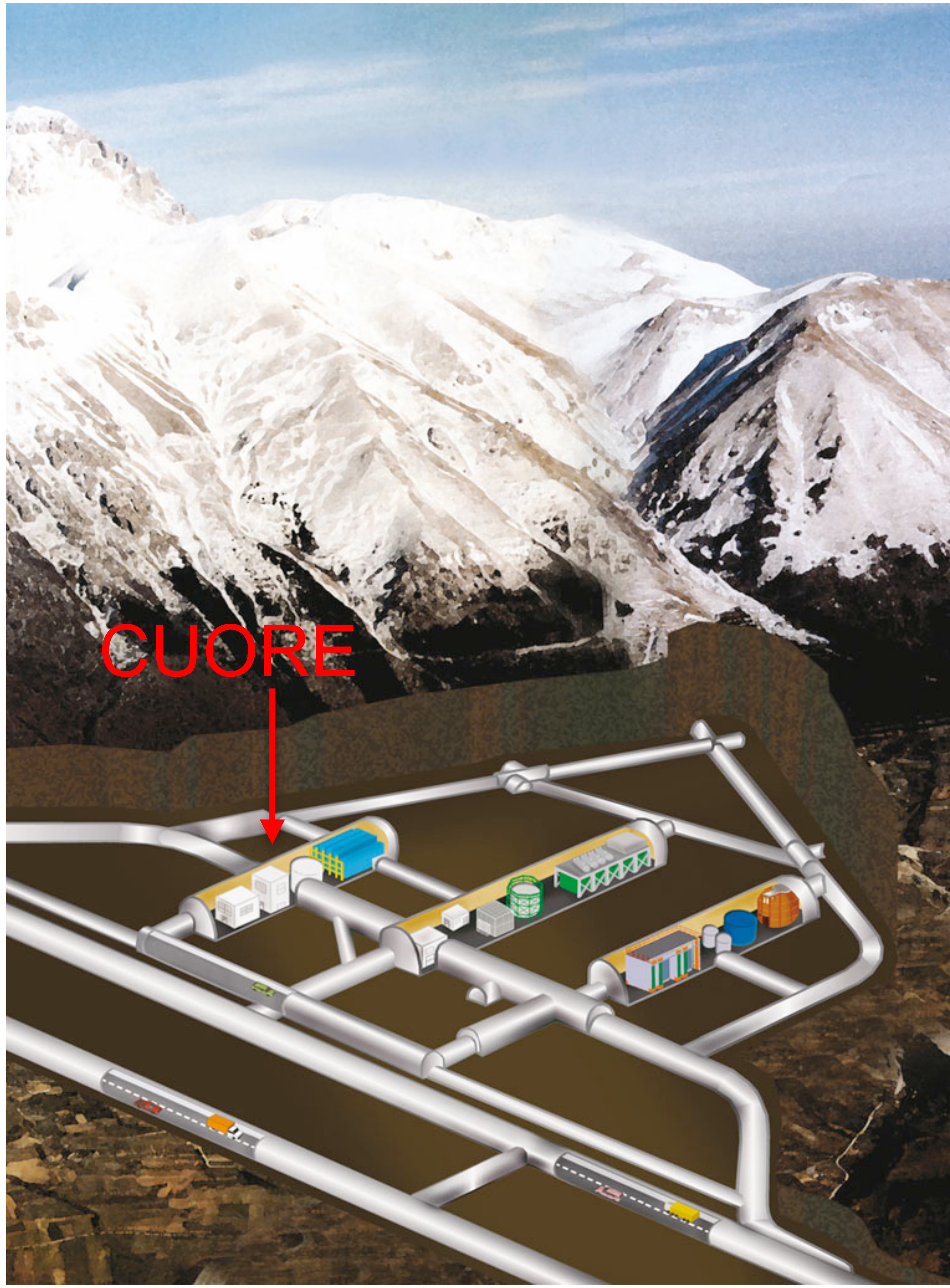
$$\Delta T = \frac{E}{C}$$

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

$$\Delta T \approx 0.1 \text{ mK/MeV}$$

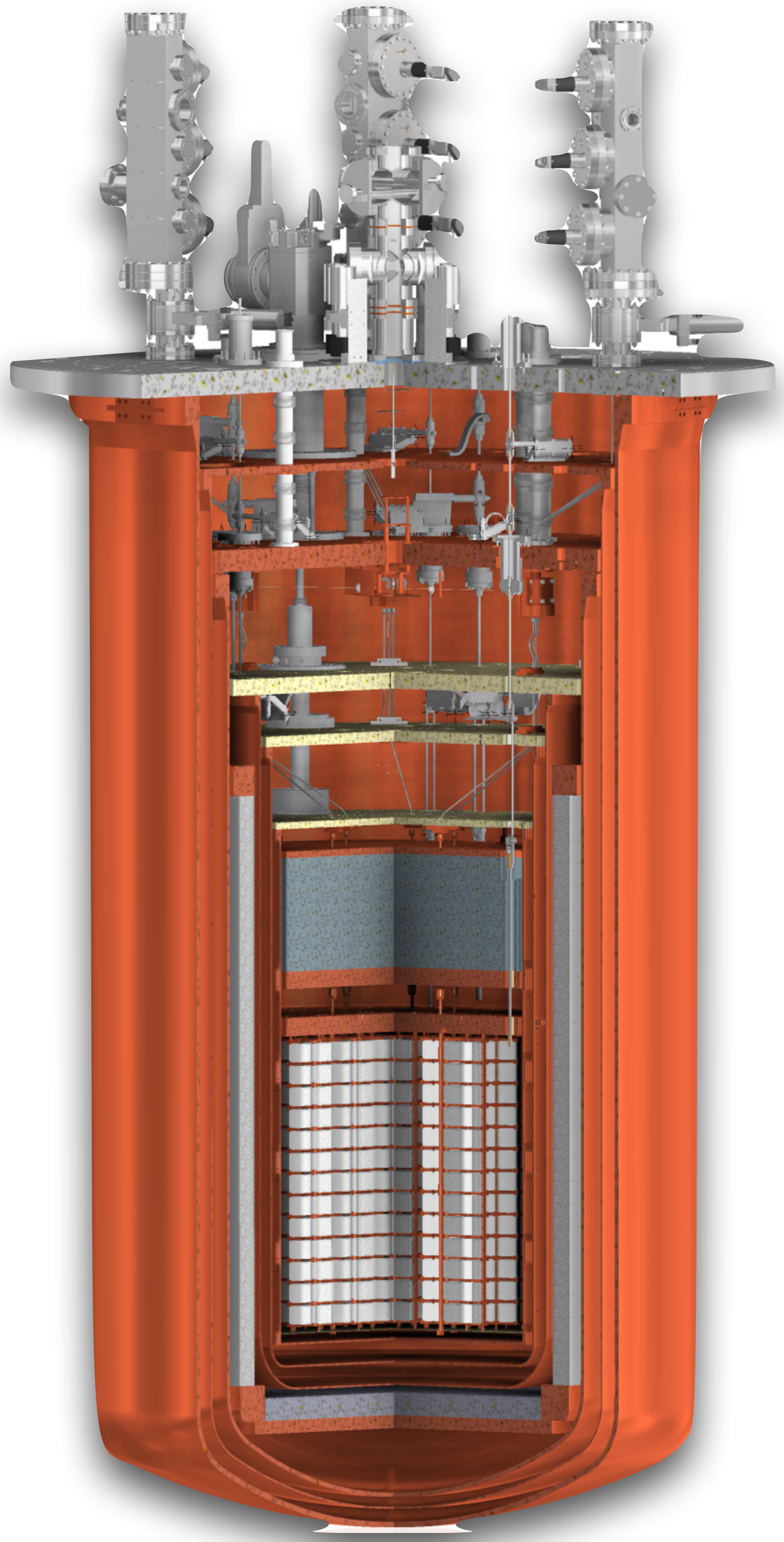
- **Excellent energy resolution**
- **Multiple isotopes can be used in bolometric measurement**
- **Ton scale cryogenic infrastructure at LNGS**

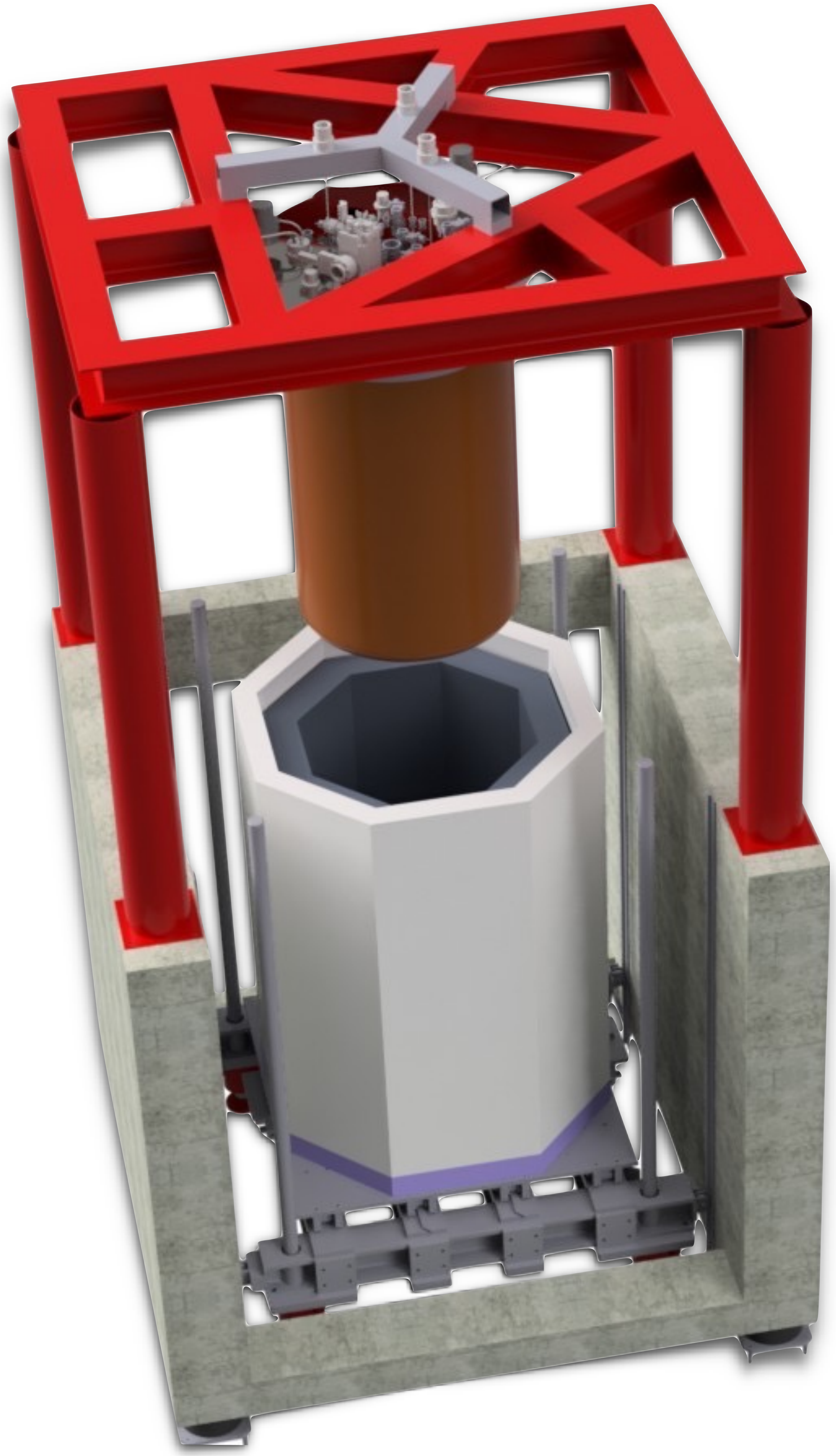
Laboratori Nazionali del Gran Sasso



CUORE infrastructure

- At LNGS ~ 3600 m.w.e.
- Pulse tube cooled (dry) fridge with vibration dampening systems
- No particle ID -> careful material screening, small amount of passive materials close to detectors (reduced amount of copper)
- Careful surface cleaning (plasma etching…), N_2 glove boxes for assembly
- more shielding
  35 cm Pb, 18 cm PET + 2 cm H_3BO_3
  + 6 ton of lead < 4 K



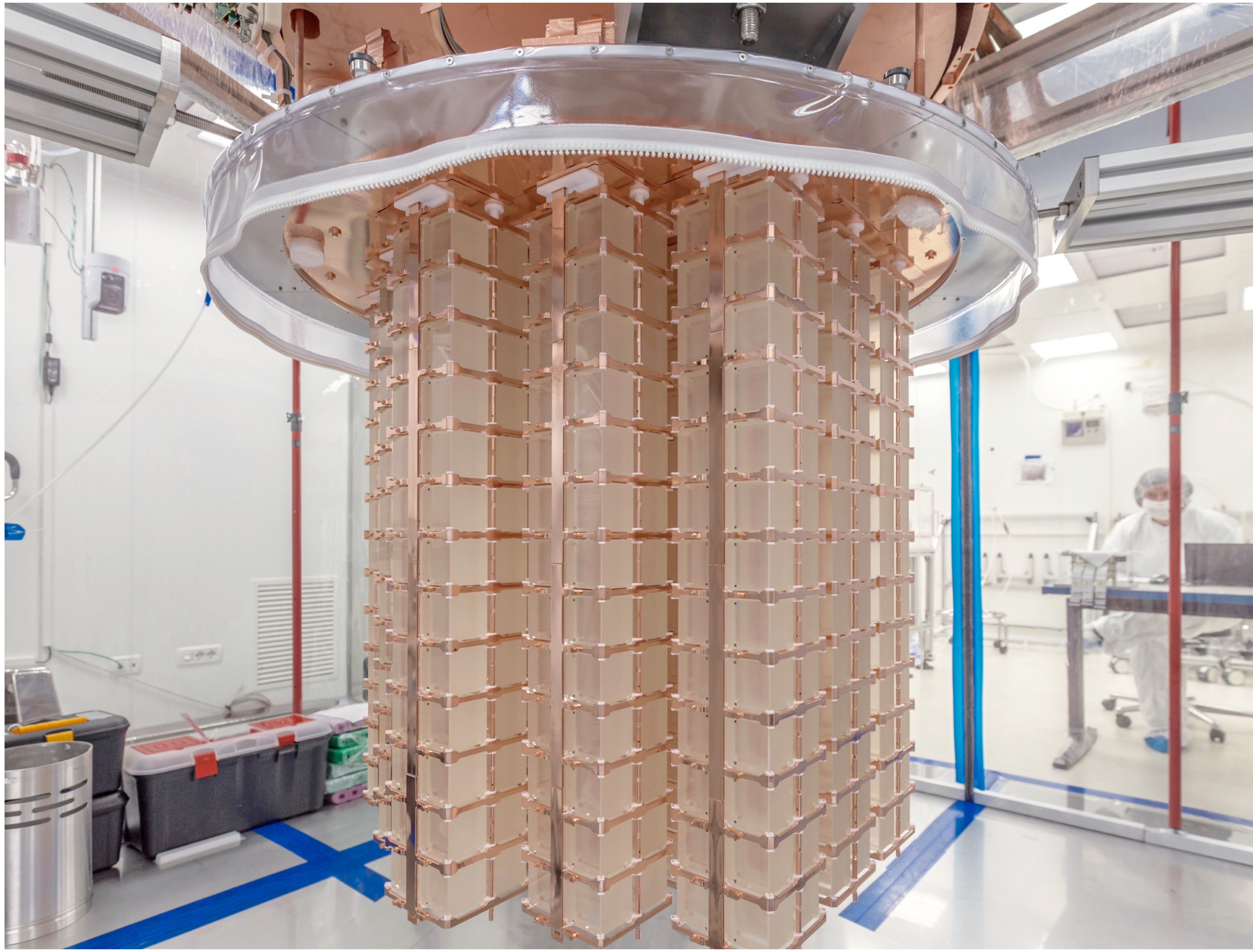


CUORE detector

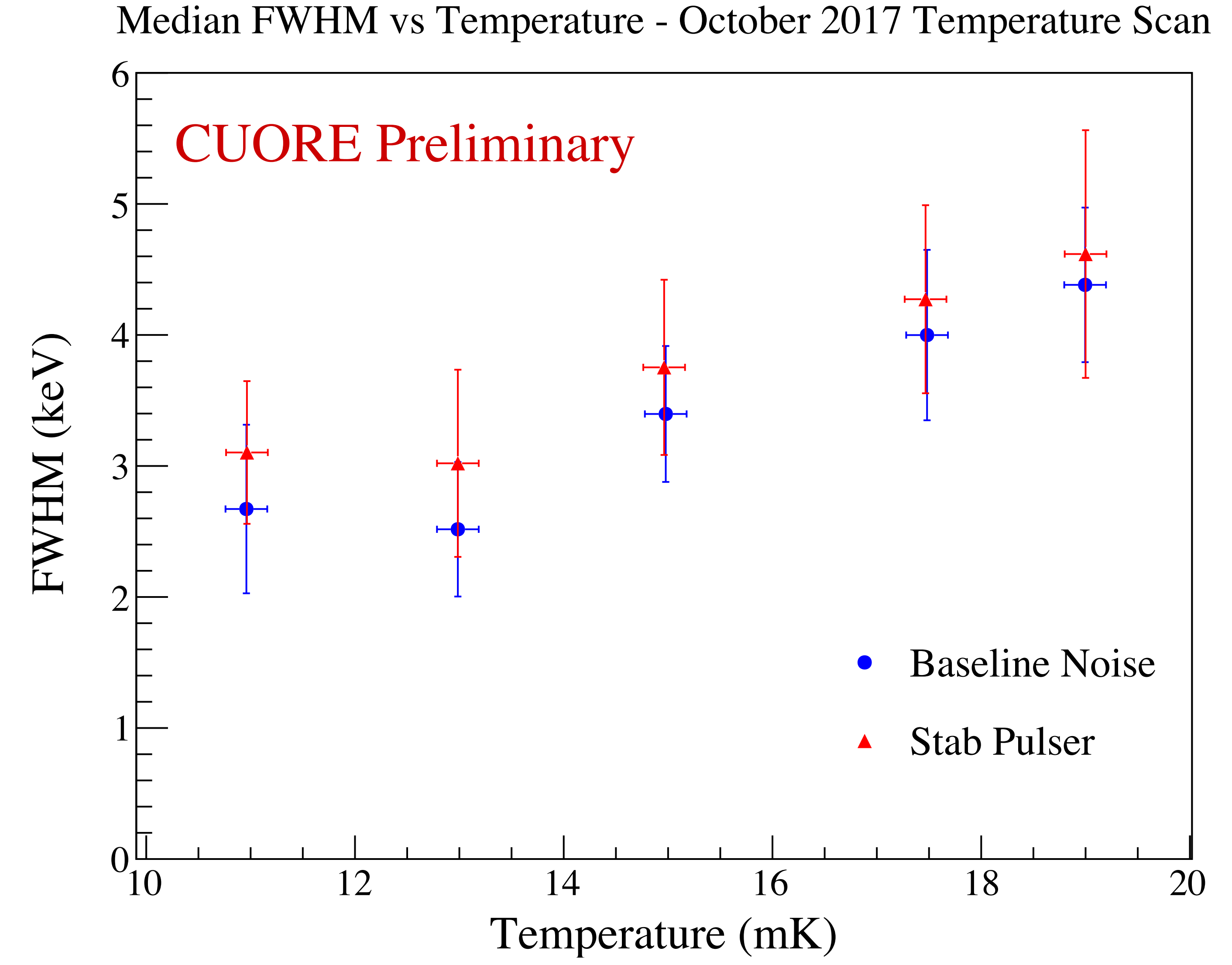
- At LNGS ~ 3600 m.w.e.

- Pulse tube cooled (dry) fridge with vibration dampening systems
- No particle ID -> careful material screening, small amount of passive materials close to detectors (reduced amount of copper)
- Careful surface cleaning (plasma etching…), N_2 glove boxes for assembly
- more shielding
  35 cm Pb, 18 cm PET + 2 cm H_3BO_3
  + 6 ton of lead < 4 K

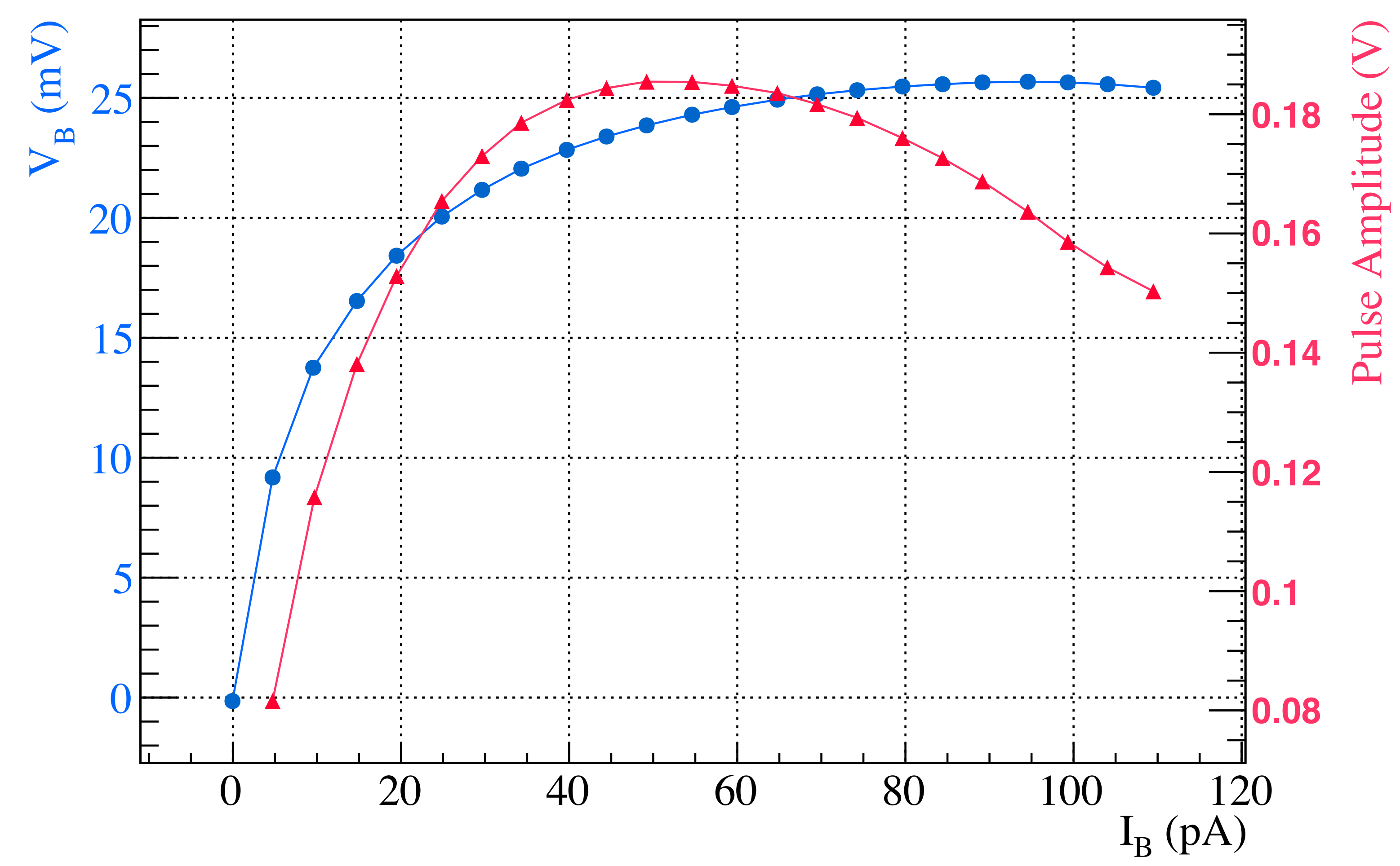
- 742 kg of TeO_2, **206 kg of ^{130}Te**
  19 towers, 4 columns, 13 floors (988 crystals)

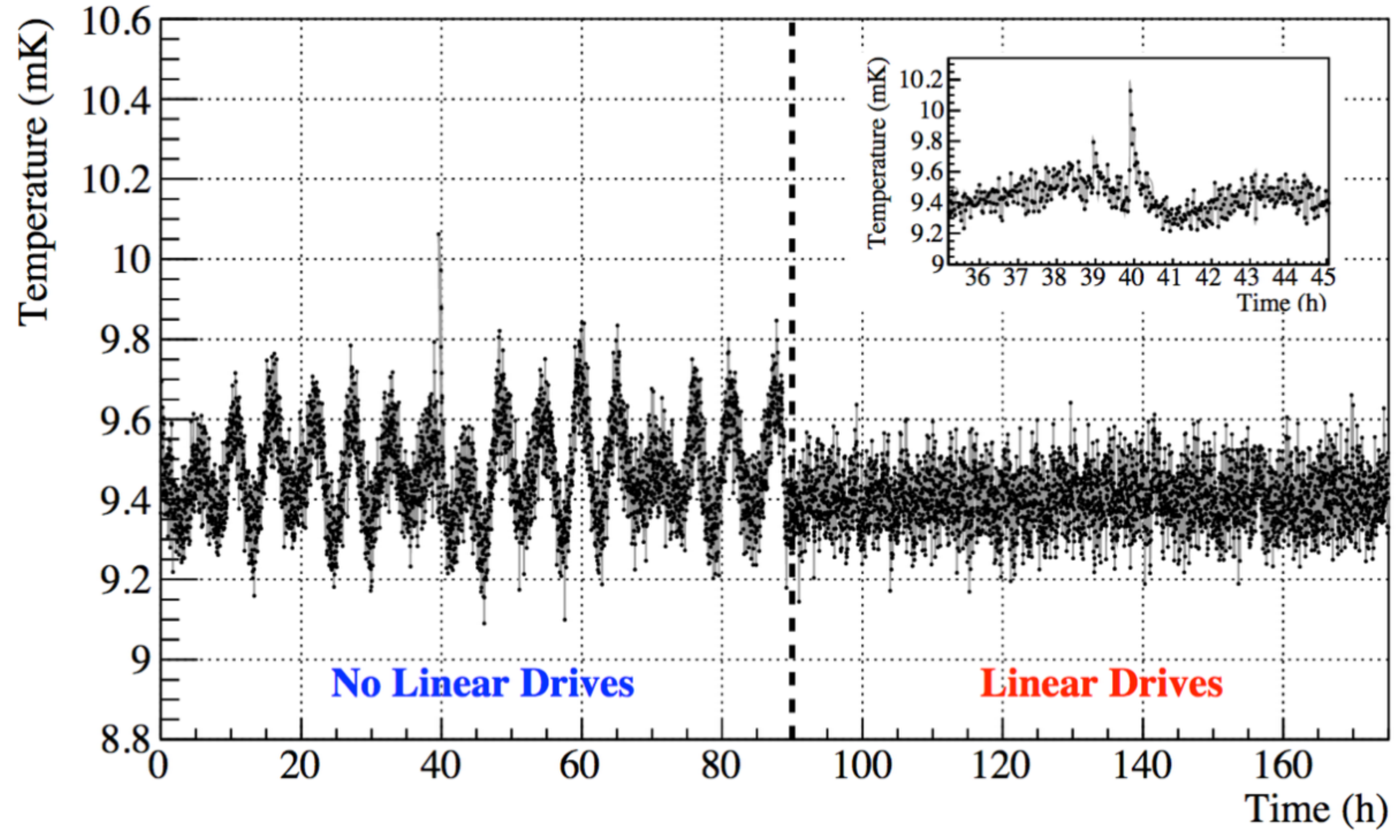


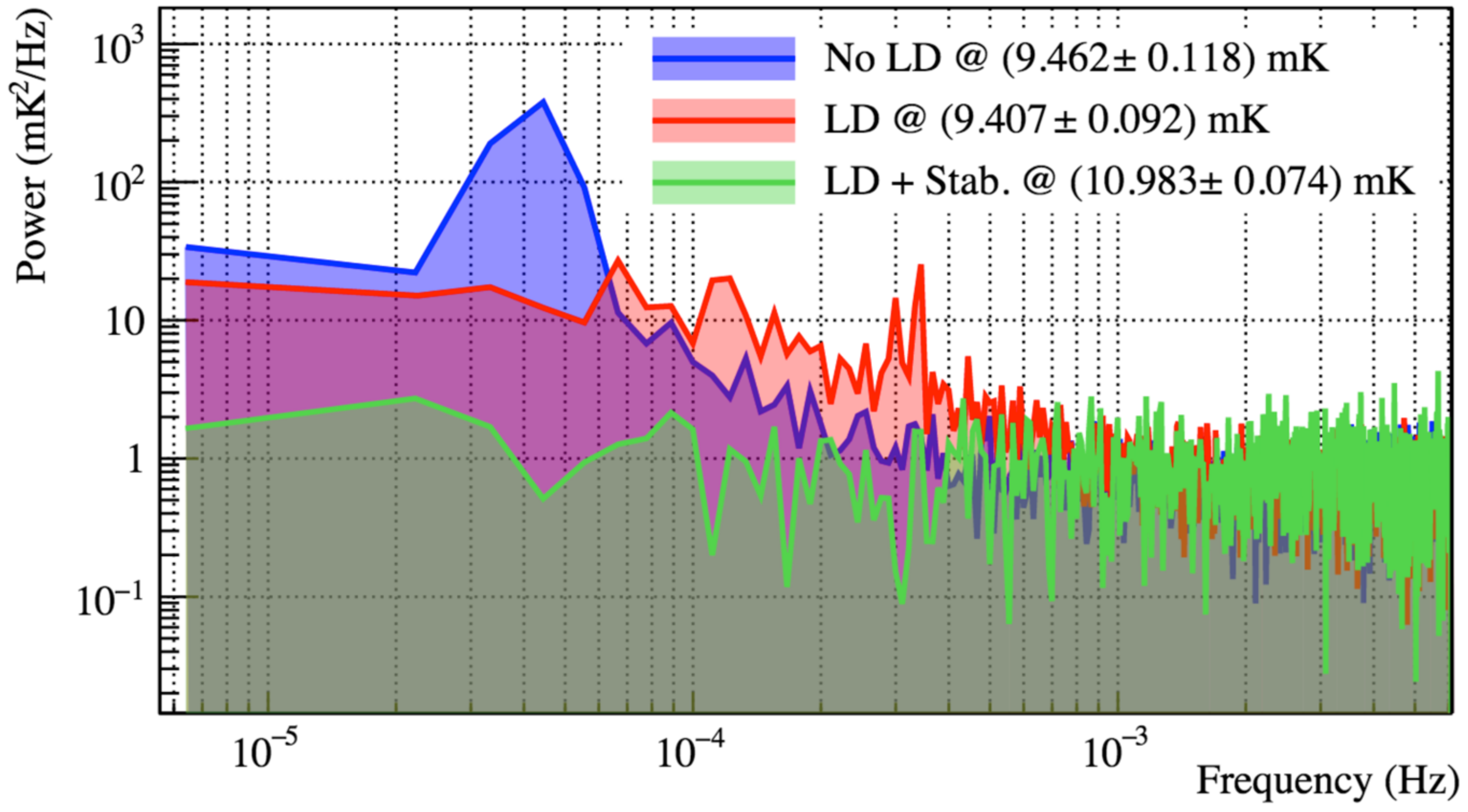
CUORE detector optimization



- Temperature scan to find optimal working temperature
- IV-data for every detector to select optimal bias point
- Vibrational noise reduction with linear drive for the Pulse Tube motors and relative phase locking of the 4 PTs in operation
- Low noise electronics

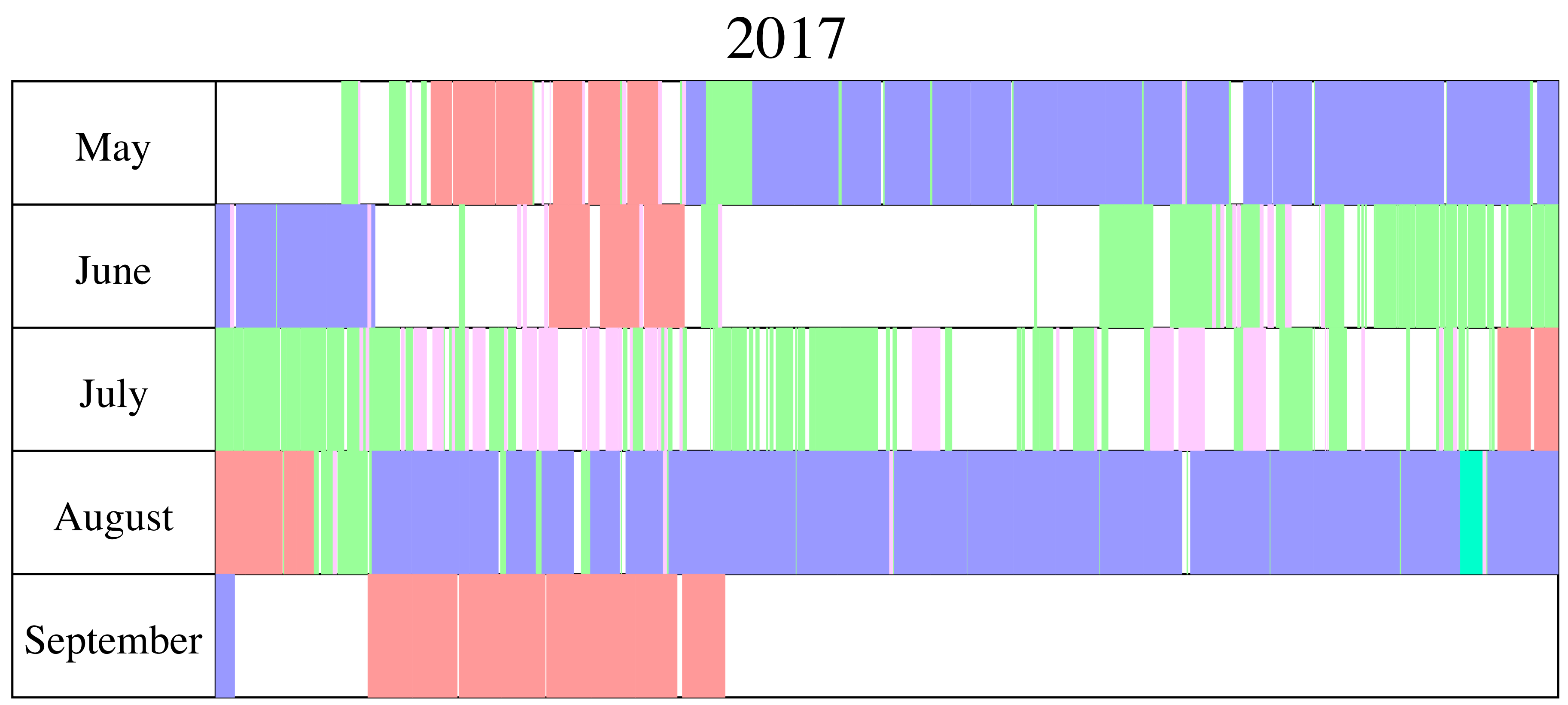






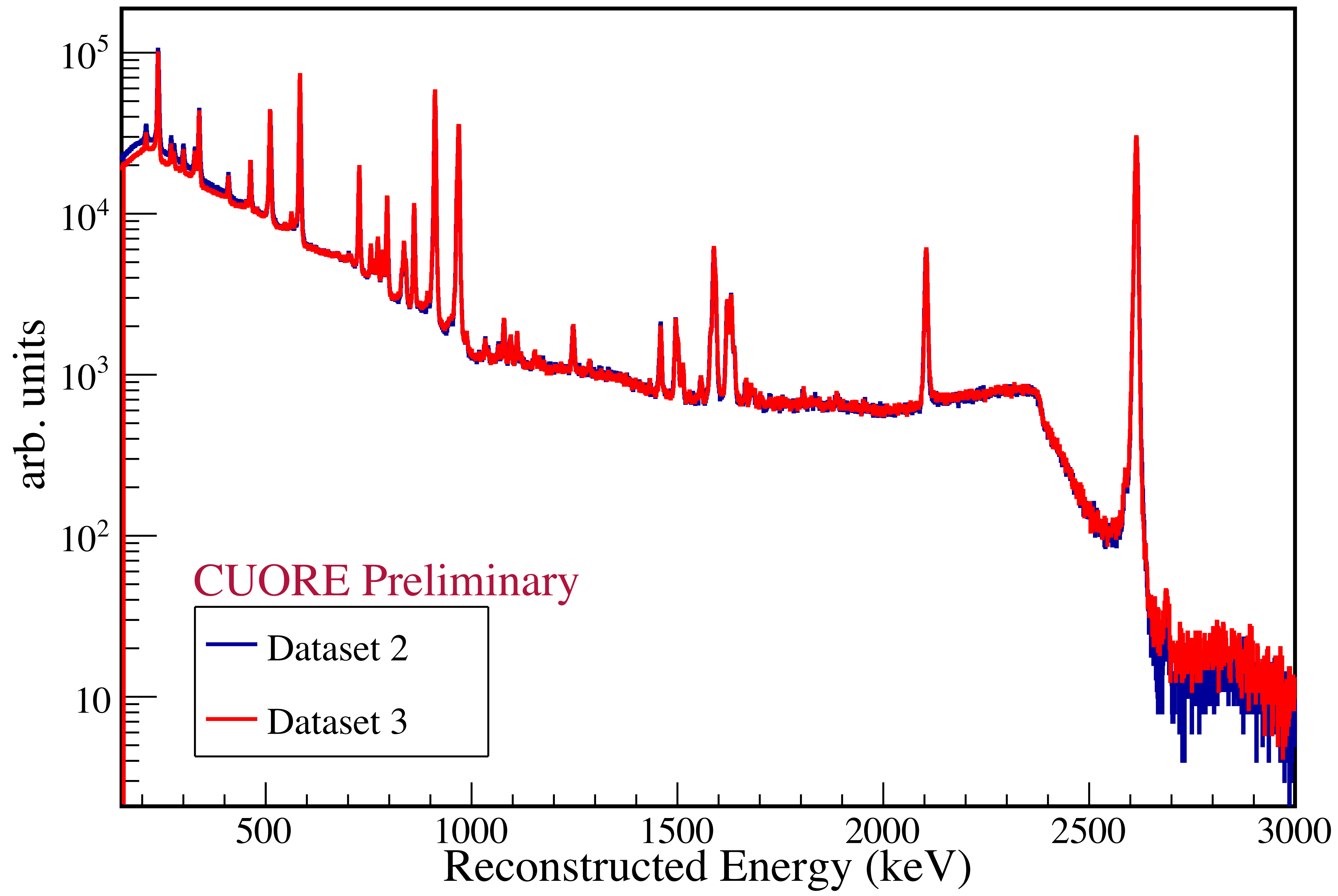
CUORE data taking

First data taking campaign **($0\nu\beta\beta$ – analysis)**
Phys. Rev. Lett. 120, 132501 (2018)
red:calibration, blue:bg, green:optimization, pink:test



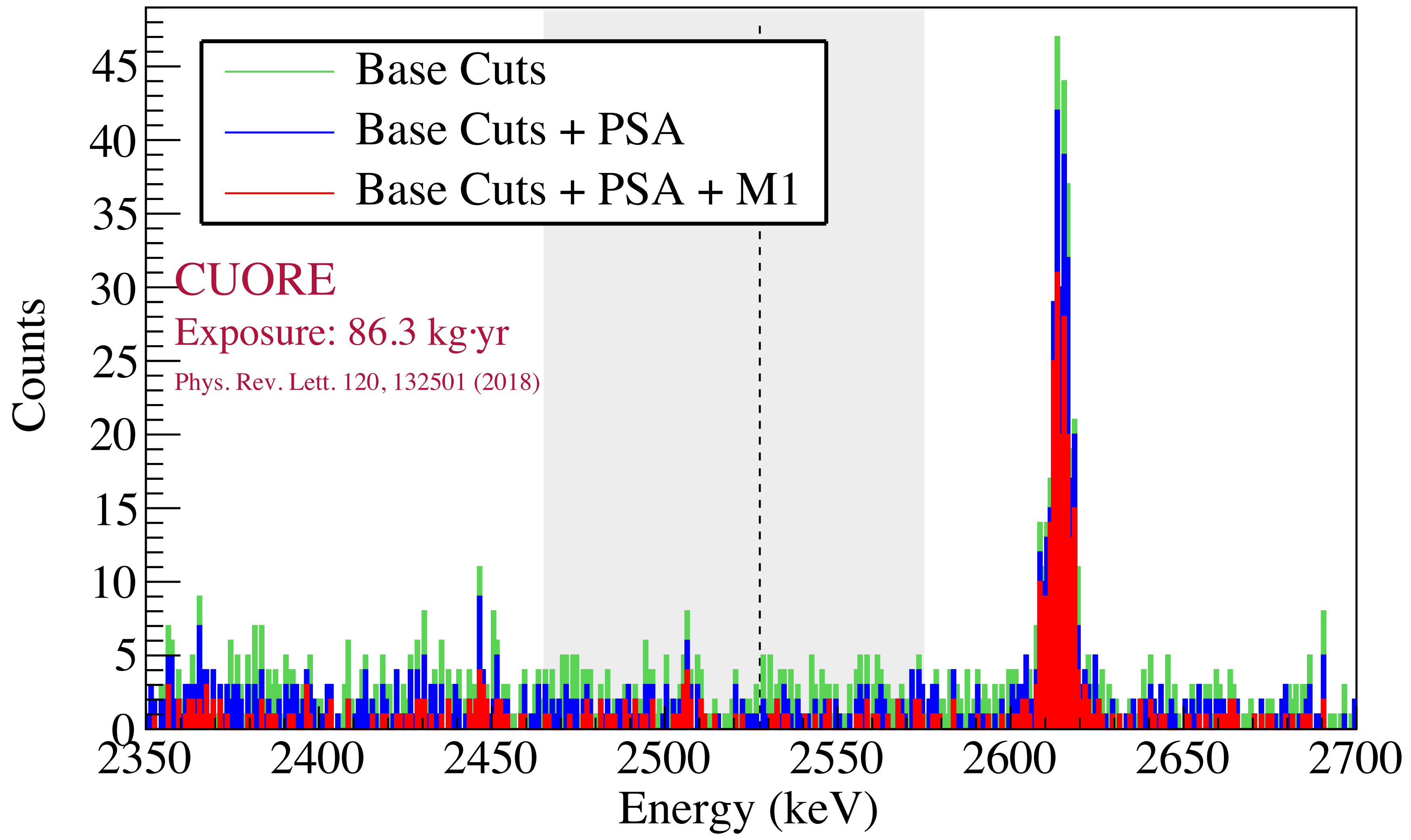
Operational performance:
984/988 channels live
Good performance channel,dataset pairs:
1811 (92% of live channels)
(876 in DS1 + 935 in DS2)

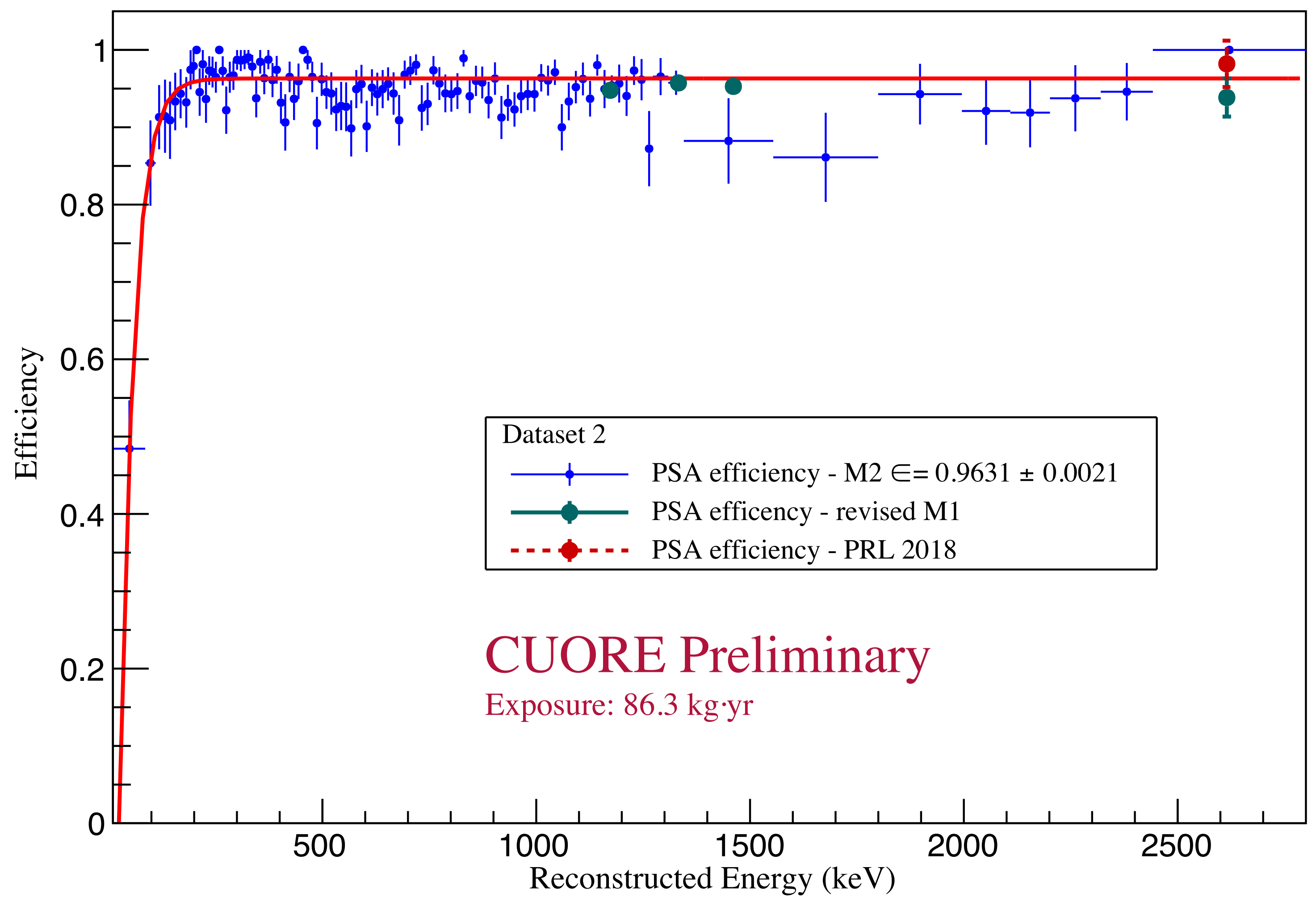
Second data taking campaign since April 2018
($2\nu\beta\beta$ analysis in preparation)

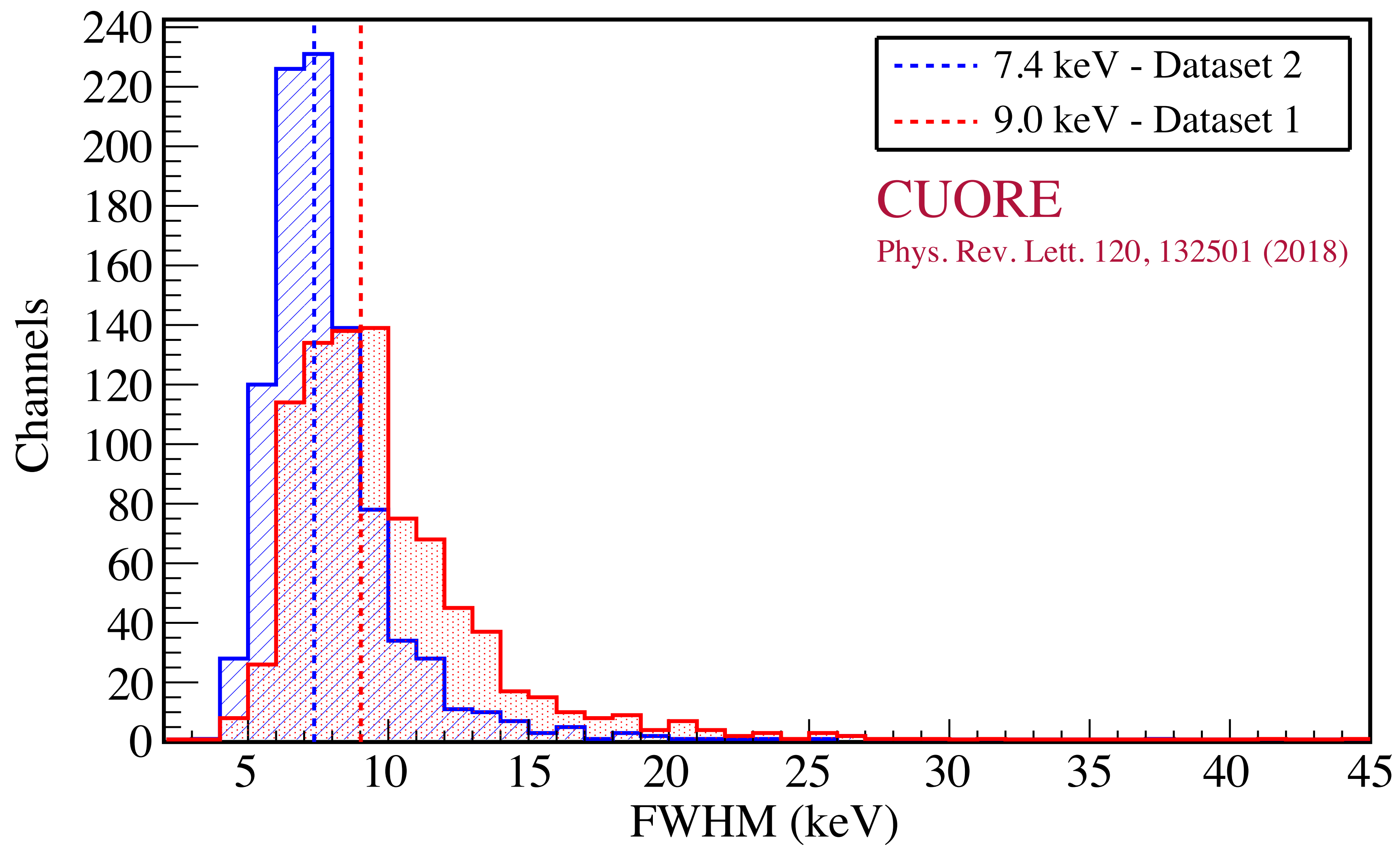


Fully recovered prev. operation performance
At present taking physics data for new data release at TAUP 2019

CUORE analysis & performance







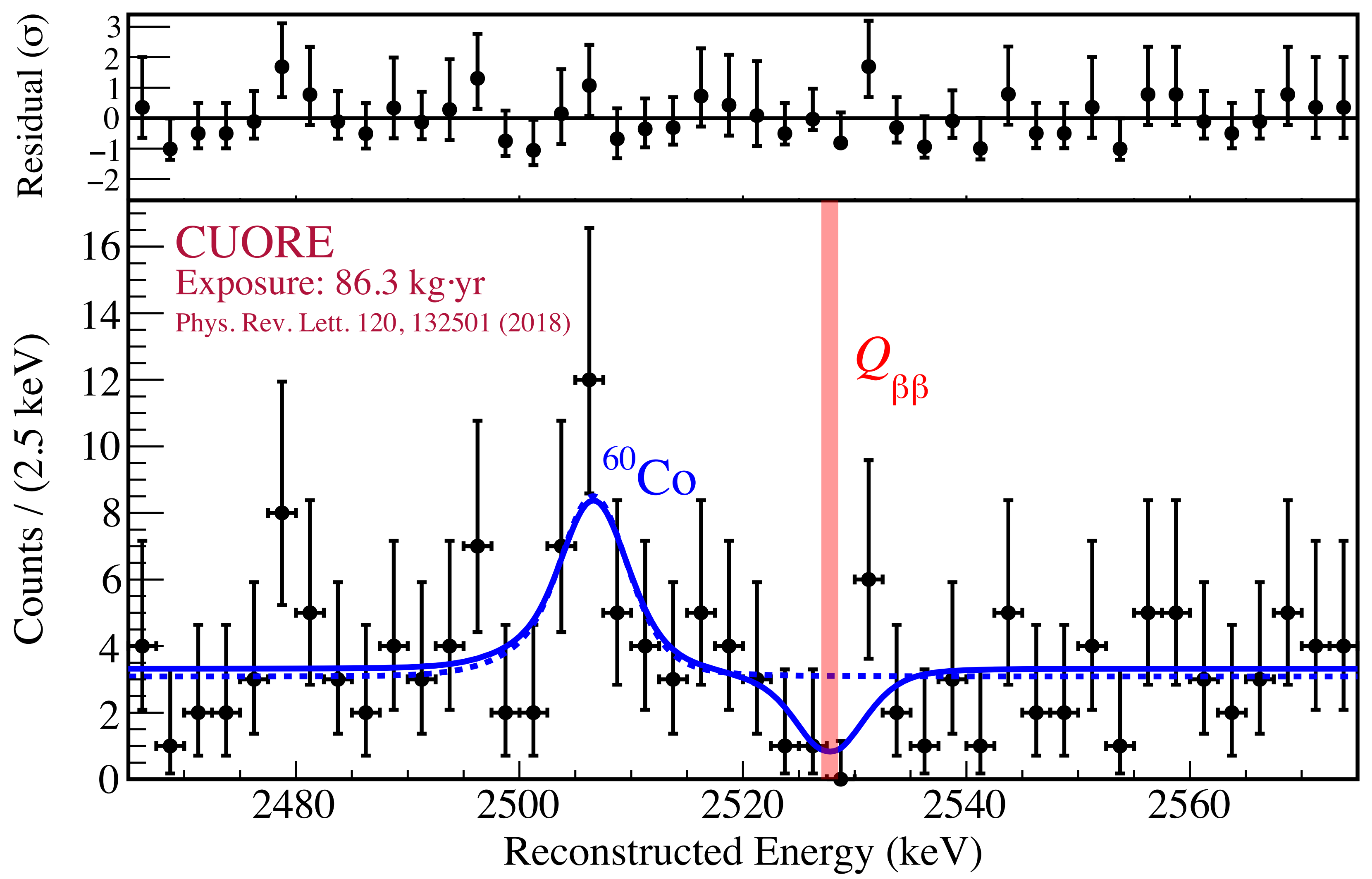
Efficiency after cuts:

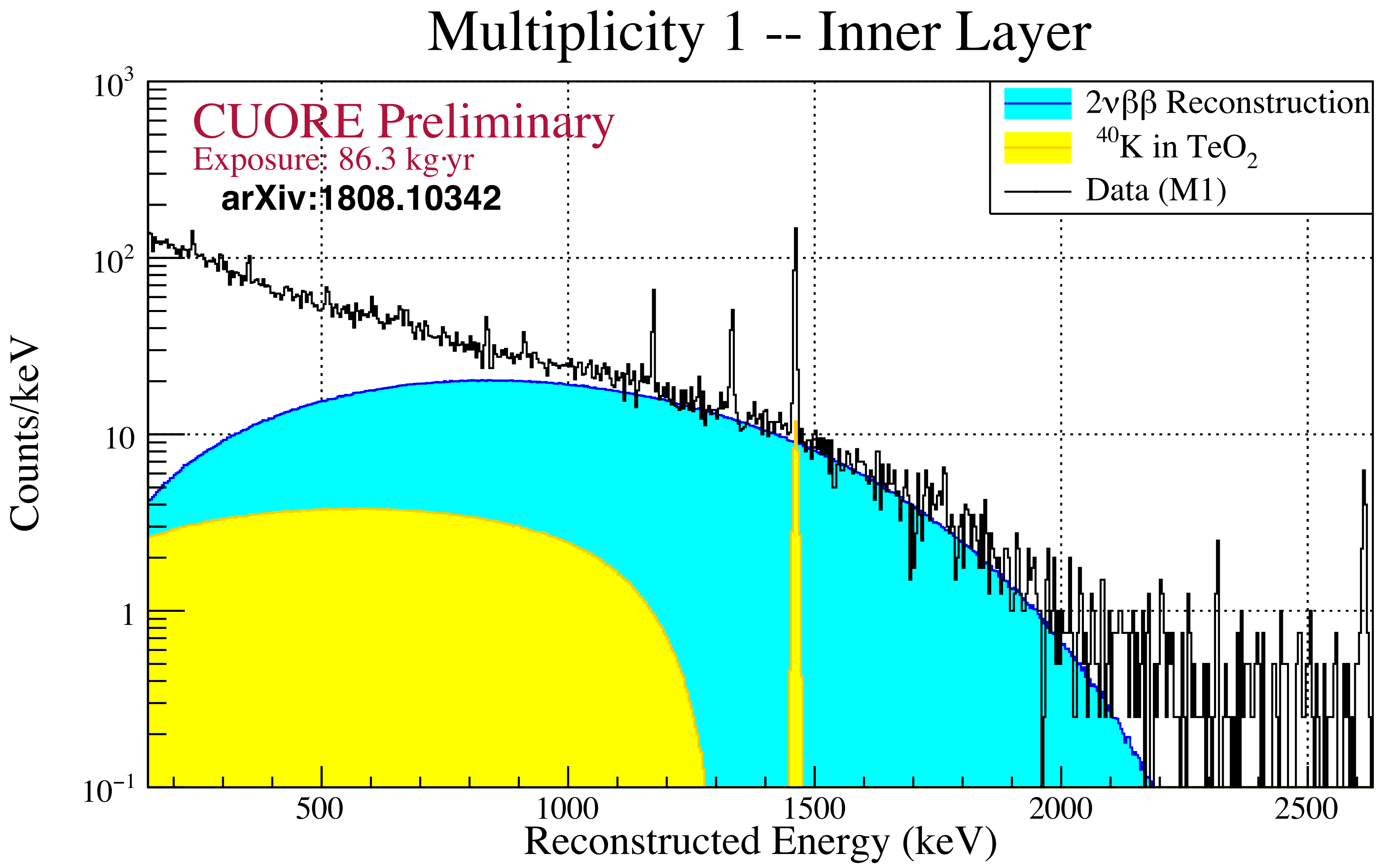
	DATASET 1	DATASET 2
Trigger	(99.766 ± 0.003) %	(99.735 ± 0.004) %
Energy reconstruction	(99.168 ± 0.006) %	(99.218 ± 0.006) %
Base cuts	(95.63 ± 0.01) %	(96.69 ±0.01) %
Anti-coincidence	(99.4 ± 0.5) %	(100.0 ± 0.4) %
Pulse Shape Analysis	(91.1 ± 3.6) %	(98.2 ± 3.0) %
$0\nu\beta\beta$ containment	(88.345 ± 0.085)%	
Total	(75.7 ± 3.0) %	(83.0 ± 2.6) %

Overall exposure weighted efficiency for $0\nu\beta\beta$ 80%

FWHM at 2615 keV in calibration data, exposure-weighted: 8.0 keV

CUORE results

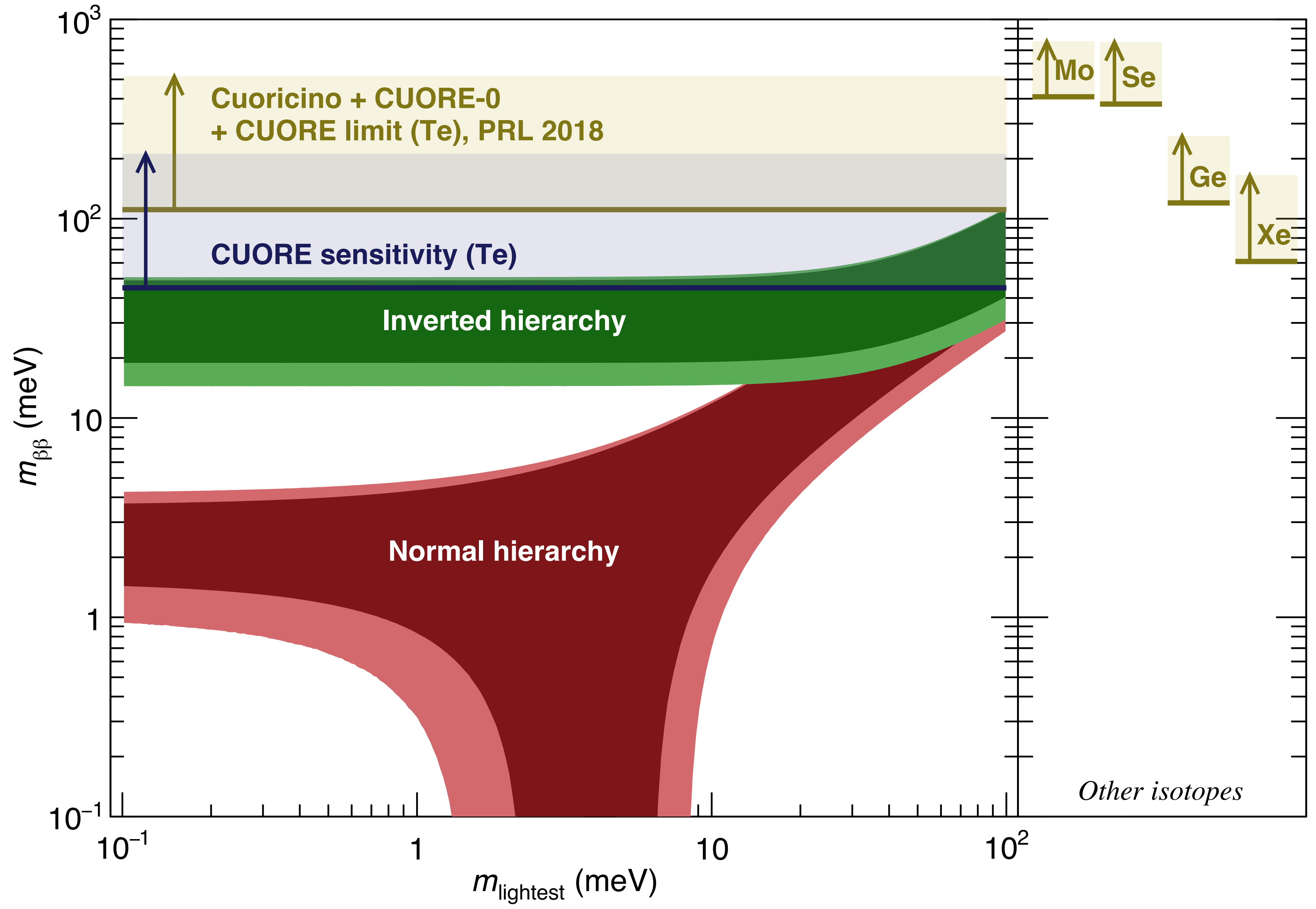




0νββ search of ^{130}Te

7.7 keV FWHM at Q_{bb}
BI (1.4 ± 0.2) x 10^{-2} c/(keV kg yr)
Bayesian analysis:

$$T^{0\nu}_{1/2} > 1.5 \times 10^{25}\text{yr} \ \ (90\%\text{C.L.})$$



Preliminary

2νββ Datasets 1&2 only

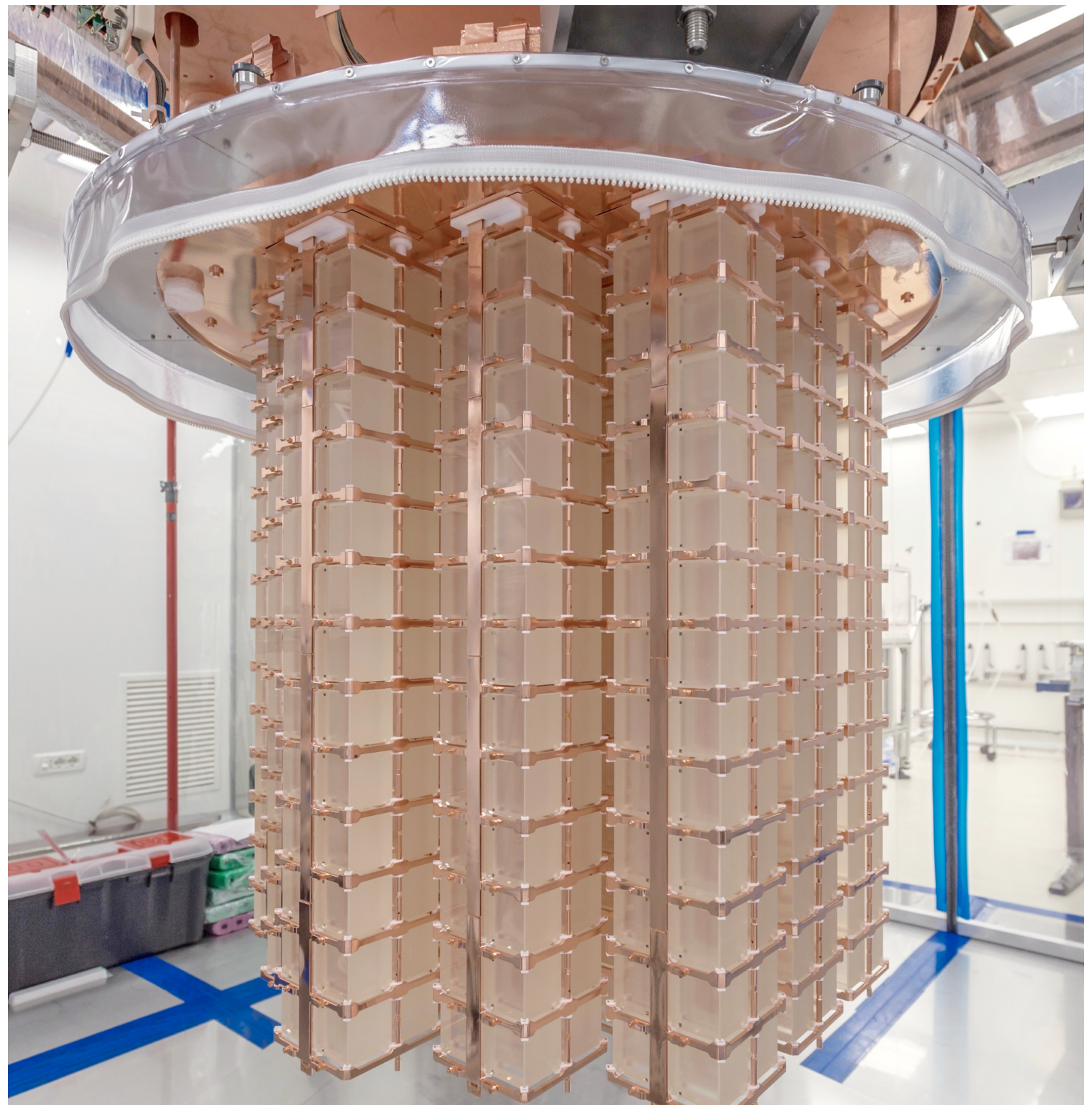
~60 sources (MC - spectra)
MCMC fit (Gibbs sampling)

$$T^{2\nu}_{1/2} = (7.9 \pm 0.1(\text{stat}) \pm 0.2(\text{syst.})) \times 10^{20}\text{yr}$$

CUPID - CUORE Upgrade with Particle ID

Mission: Discover $0\nu\beta\beta$ if $m_{\beta\beta} > 10$ meV
(half-life in $^{100}Mo > 10^{27}$ years - Baseline design)

Require Particle ID & lower γ BG



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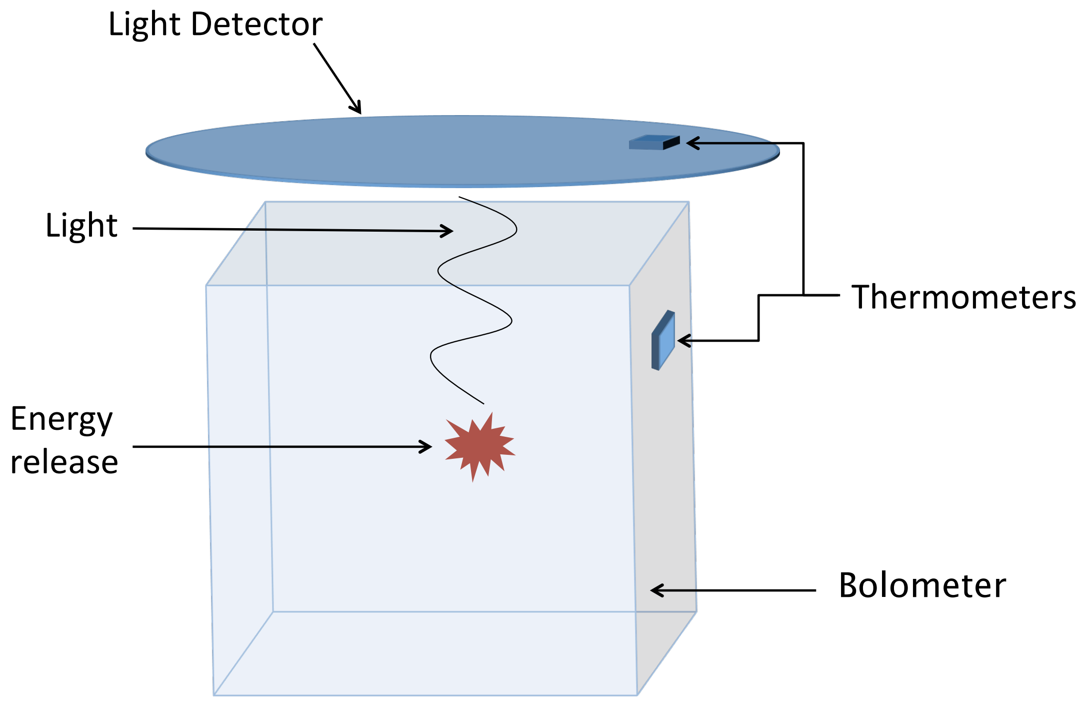
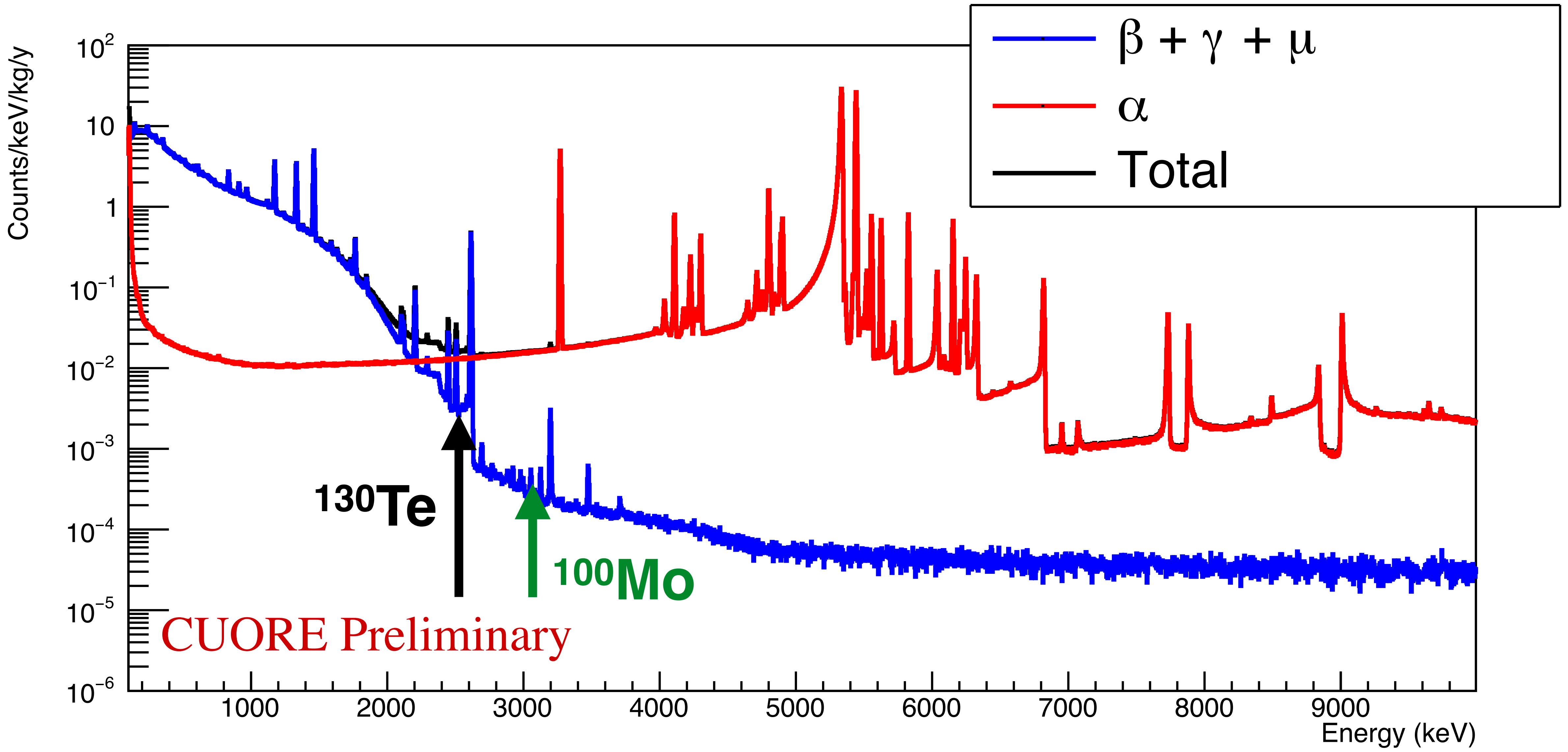


- Large-scale enriched $Li_2{}^{100}MoO_4$ crystal production feasible
- Internal radio-purity targets met
- Demonstrated active background rejection
- Energy resolution ~5 keV demonstrated
- Total background of ~0.1 counts/(ton*kev*year) achievable



CUORE

Thank you & stay tuned for

TAUP 2019 TOYAMA