



Current Status and Latest Results from the CUORE Experiment

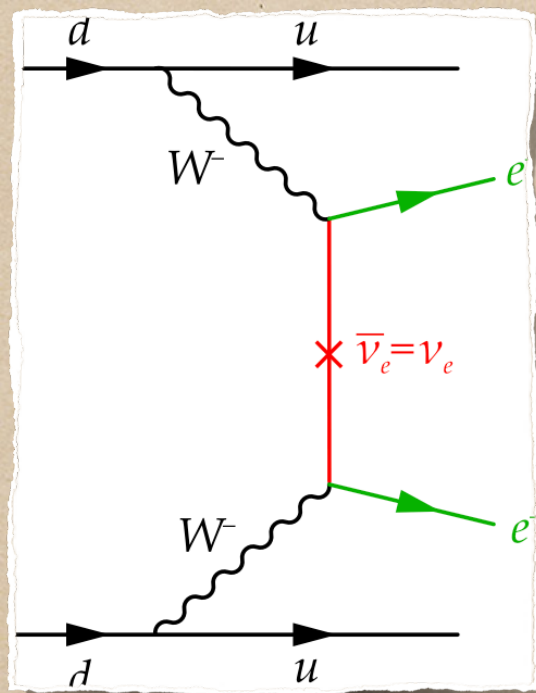
Vladyslav Berest
on behalf of the CUORE collaboration

Low Radioactivity Techniques Workshop 2026
September 21-24, 2026

Neutrinoless double-beta decay

A hypothetical rare nuclear process where a nucleus emits two electrons but no neutrinos

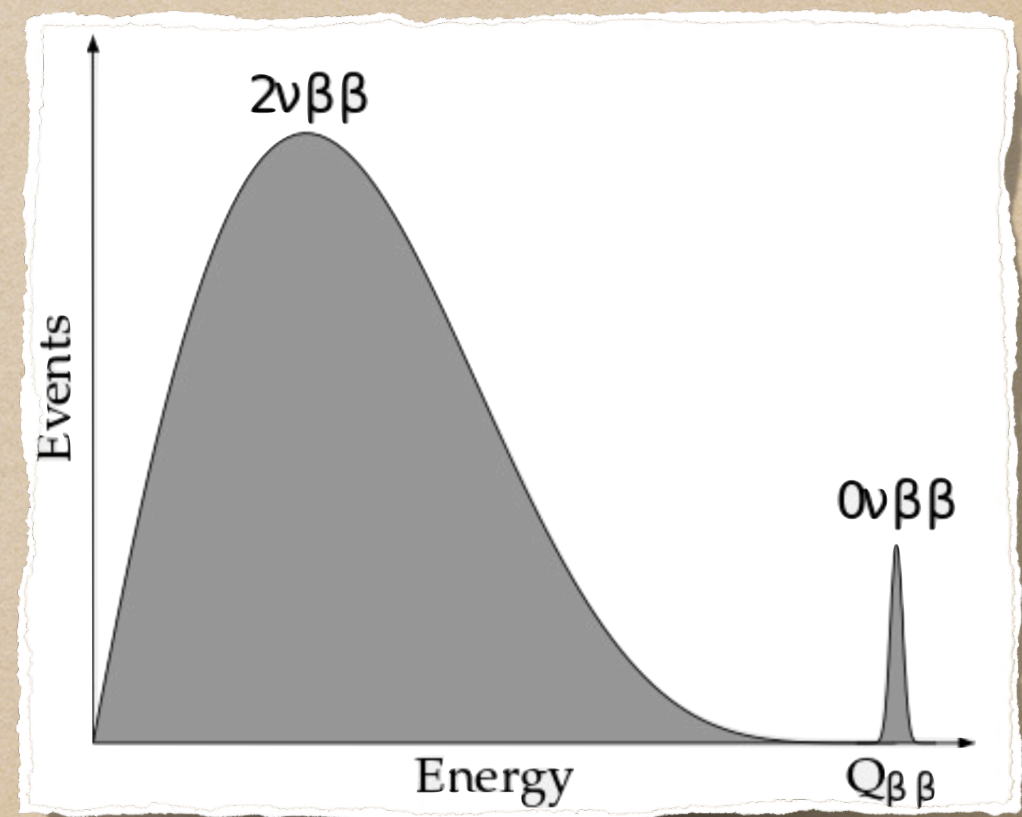
$$(Z, A) \longrightarrow (Z + 2, A) + 2e^{-}$$



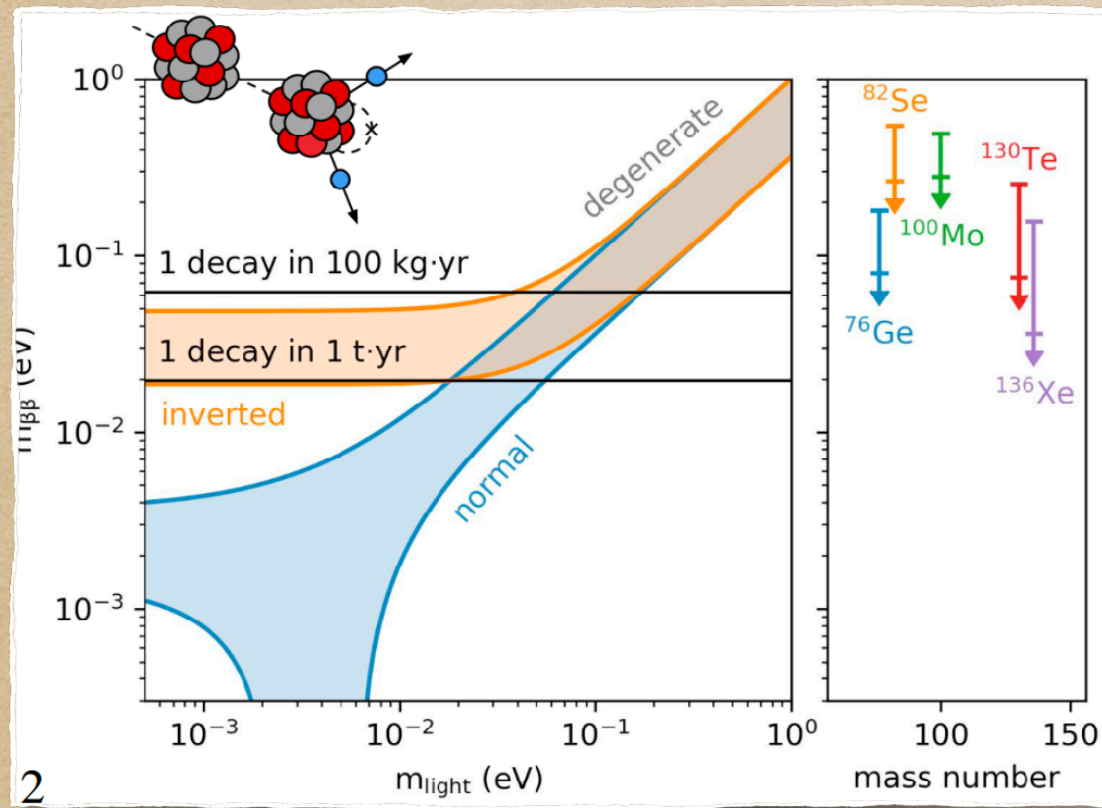
Experimental signature: mono-energetic peak at the isotope Q-value at the end of $2\nu\beta\beta$ continuous spectrum

In case of observation:

- Lepton number not conserved (BSM), $\Delta L \neq 0$
- Neutrinos are Majorana particles
- Information about neutrino mass ordering



Neutrinoless double-beta decay



Experimental sensitivity: (background limited)

$$\left(T_{1/2}^{0\nu 2\beta}\right)^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{M \cdot t}{b \cdot \Delta E}}$$

The modern $0\nu\beta\beta$ experiment requires:

- Large exposure $M \times t$ (big mass, long life-time)
- High a (isotopic abundance)
- Small b (very low background in the ROI)
- Small ΔE (good energy resolution)
- High detection efficiency ϵ

Decay rate:

$$\frac{1}{T_{1/2}^{0\nu}} = G^{0\nu} \cdot |M^{0\nu}|^2 \cdot \frac{|\langle m_{\beta\beta} \rangle|^2}{m_e^2}$$

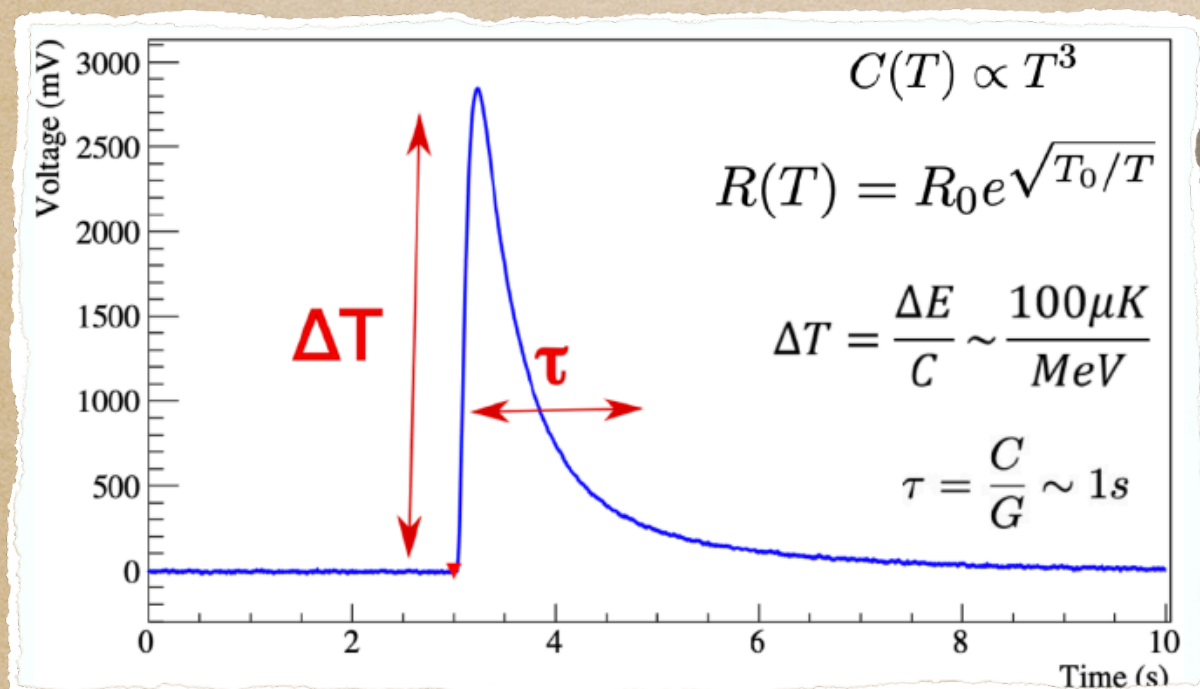
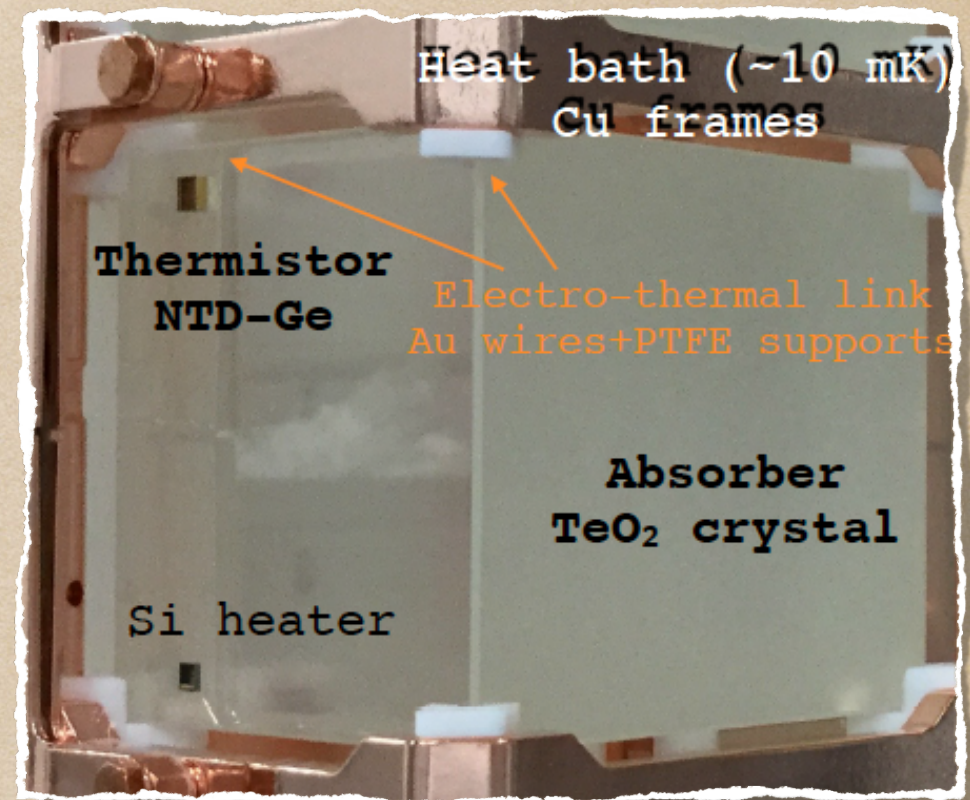
$G^{0\nu}$ - phase space factor

$M^{0\nu}$ - nuclear matrix element

$m_{\beta\beta}$ - effective Majorana mass

Cryogenic calorimeters

- Excellent energy resolution: $<0.3\%$
FWHM in the ROI [Science 390,1029-1032\(2025\)](#)
- High detection efficiency: source = detector approach
- Easily scalable via use of detectors arrays
- Flexible in the choice of materials



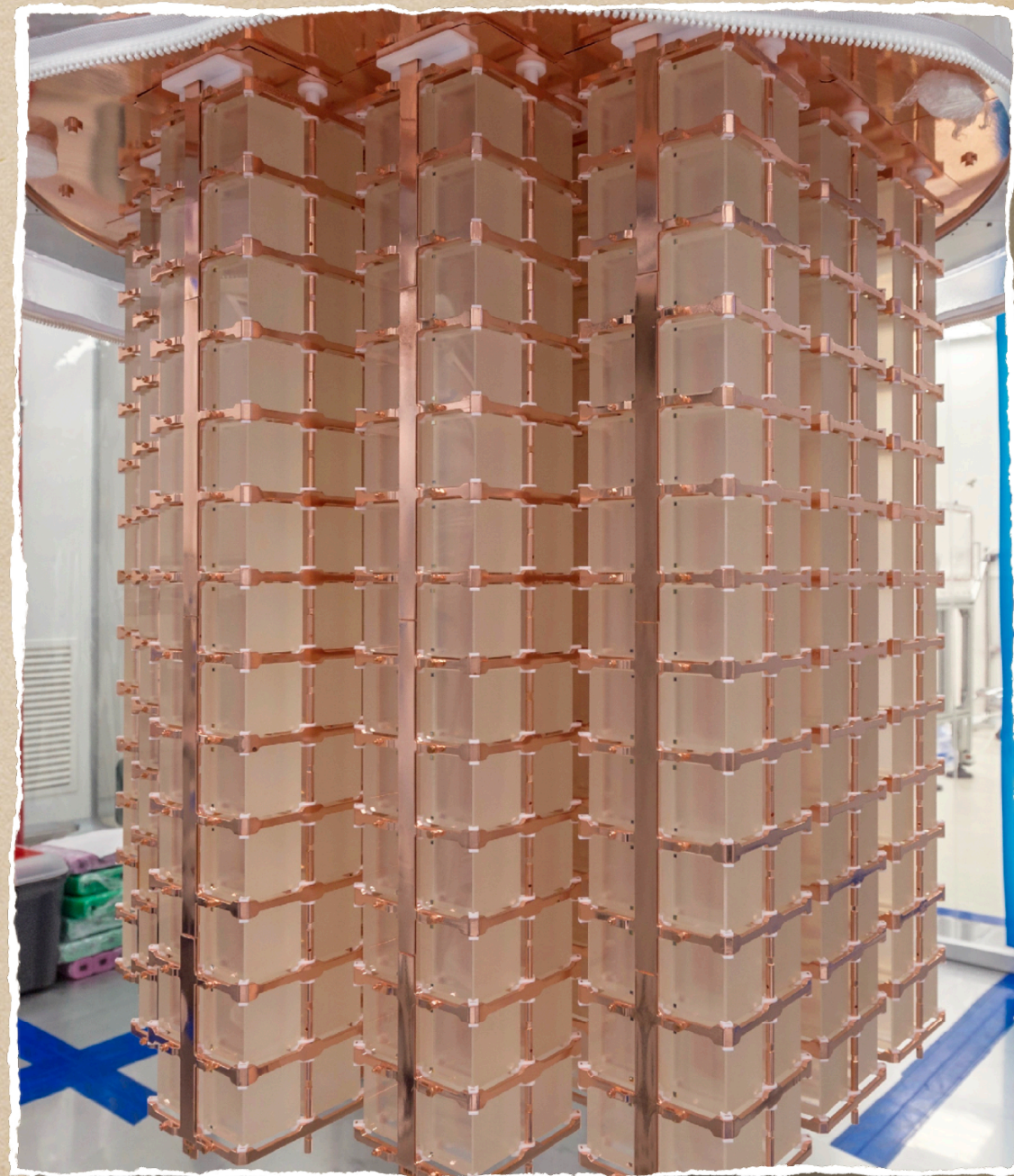
- Operational temperature about 10mK
- Slow time response



The CUORE Experiment

CUORE (Cryogenic Underground Observatory for Rare Events)

- ^{130}Te as $0\nu\beta\beta$ candidate ($Q_{\beta\beta} \approx 2527.5 \text{ keV}$)
- Array of 988 TeO_2 $5\times 5\times 5 \text{ cm}^3$ detectors (750 g each) arranged in 19 towers with 13 floors of 4 detectors each
- Total mass: 742 kg of TeO_2 (206 kg of ^{130}Te)
- Target energy resolution:
 $\sim 5 \text{ keV at } Q_{\beta\beta}$
- Background goal:
 $\sim 10^{-2} \text{ counts / (keV} \cdot \text{kg} \cdot \text{yr) at } Q_{\beta\beta}$



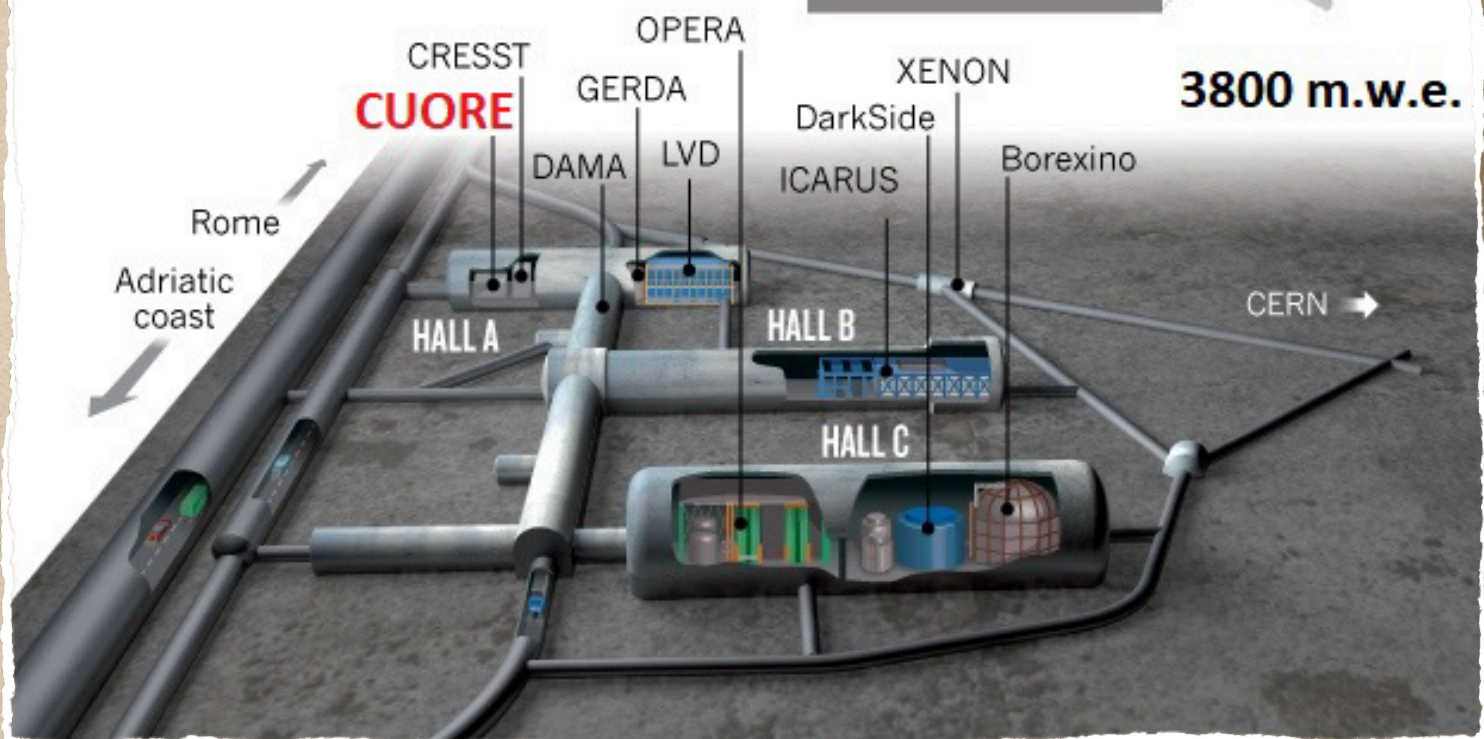
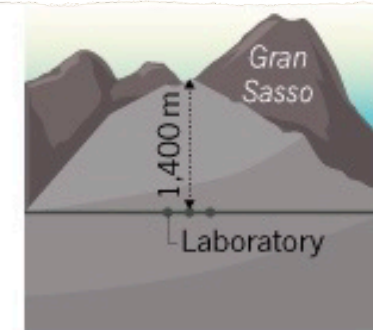
CUORE LNGS location

- CUORE experiment operated underground at Laboratori Nazionali del Gran Sasso, Italy (average depth ~ 3650 m.w.e.)
 - μ flux: $3 \cdot 10^{-8} \mu/s/cm^2$
 - n flux: $4 \cdot 10^{-6} n/s/cm^2 < 10$ MeV
 - γ flux: $\sim 0.73 \gamma/s/cm^2 < 3$ MeV



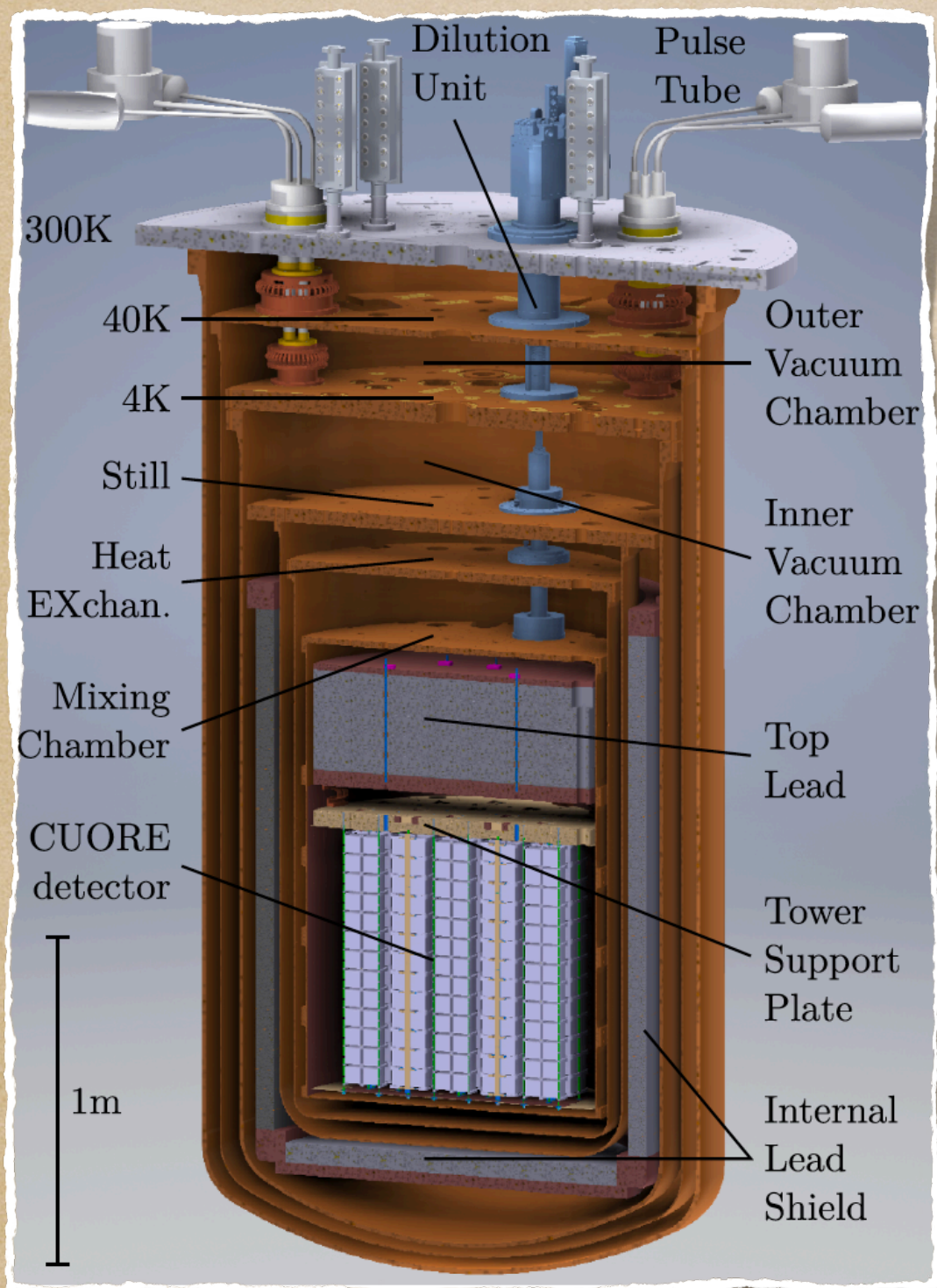
THE A, B AND C OF GRAN SASSO

Experiments at the Gran Sasso National Laboratory are housed in and around three huge halls carved deep inside the mountain, where they are shielded from cosmic rays by 1,400 metres of rock.



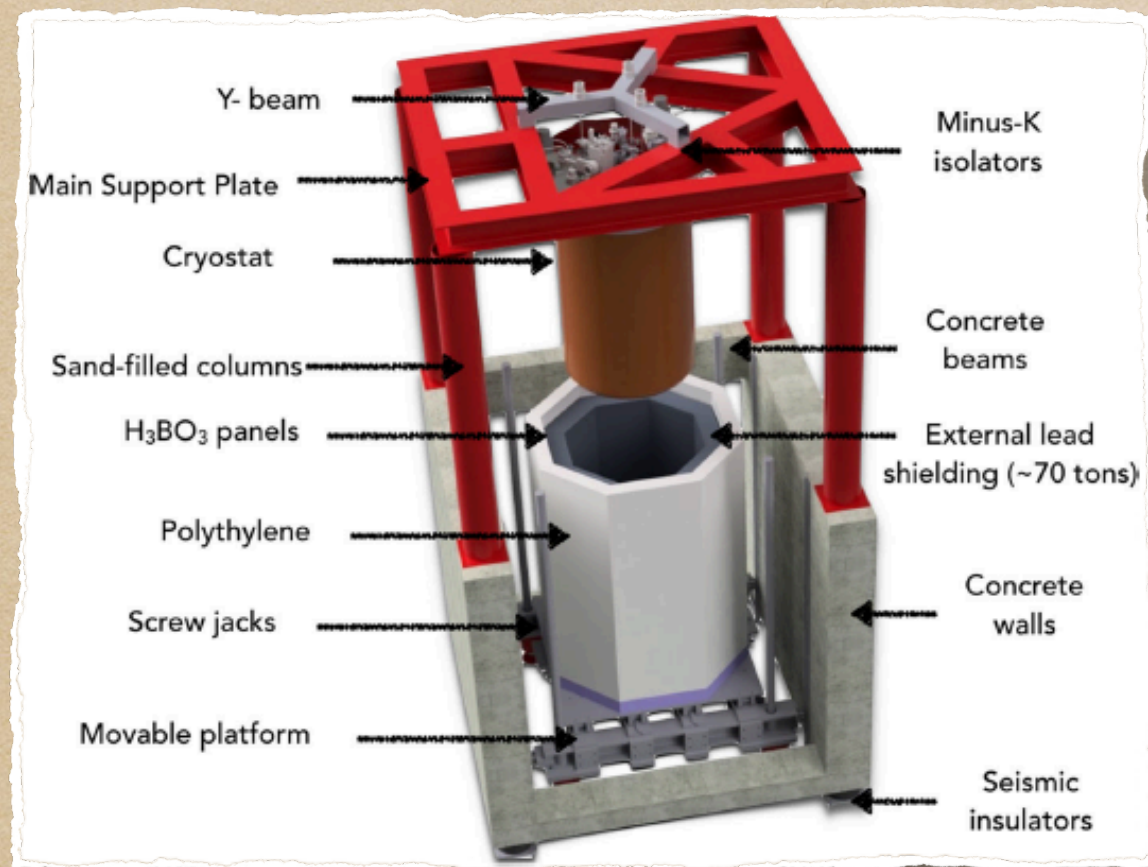
Astroparticle Physics 34 (2010) 18-24

Cryogenic facility



- Custom-made dry dilution refrigerator
- 5 pulse-tube coolers
- Strict cryostat material selection and cleaning to achieve lowest possible background
- Base temperature ~ 6.9 mK
- Large experimental volume ~ 1 m³
- Total cryostat mass: ~ 30 ton (including 7 ton of lead for passive shielding)
- 15 ton cooled below 4 K
- 3 ton cooled below 50 mK
- Almost 10 years of operation at base temperature

Passive shielding and support system



J. Low Temp. Phys. 193, 867-875 (2018)

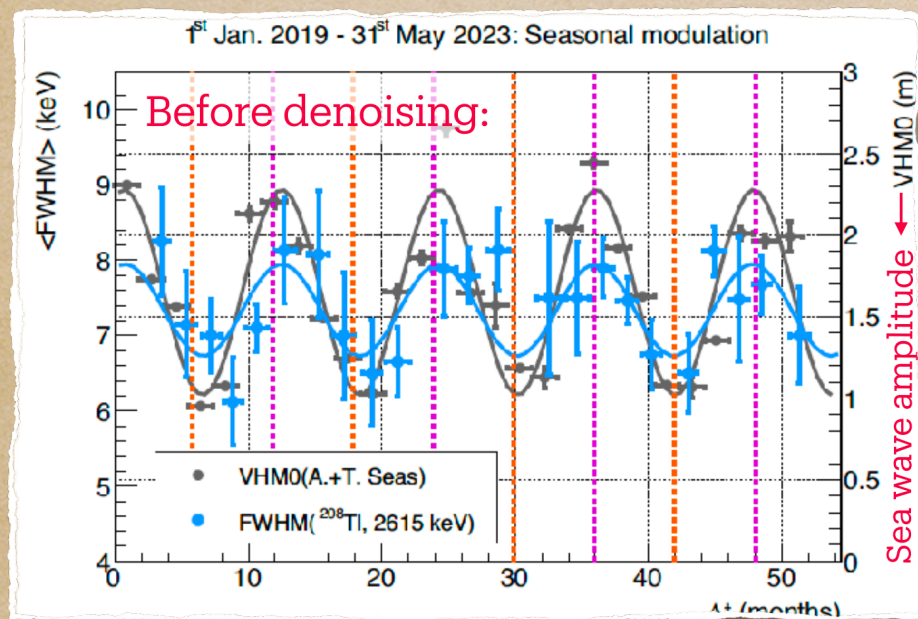


Cryogenics 102 (2019) 9

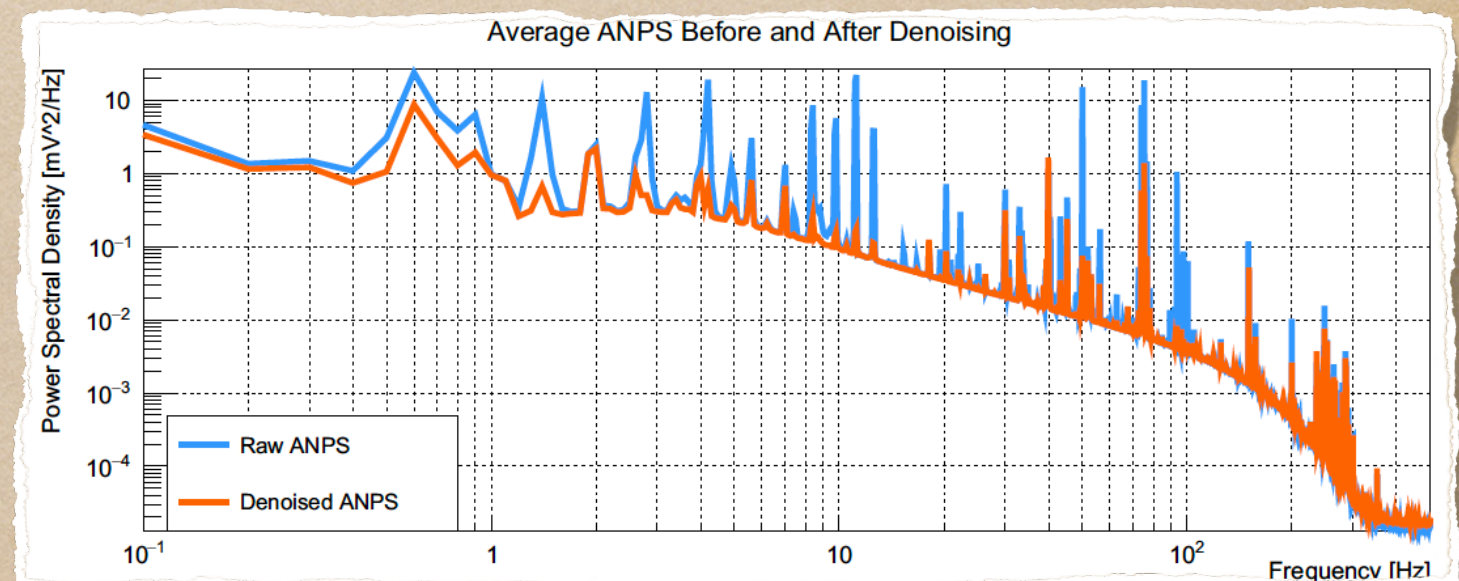
- Ancient Lead: 5 t at 4 K (bottom/sides) for low internal activity.
- Modern Lead: 2 t at 50 mK (top) against overhead radiation.
- Lead Outer Layer: 70 t, 25 cm thick against ambient γ -rays.
- Neutron Shield: Polyethylene & boric acid panels on a movable platform.

Vibrational Noise Control

- Noise sources: cryogenic system, anthropogenic activities, environment (microseismic, earthquakes, and sea swell motion)
- Cryogenic detectors are extremely sensitive to vibrational noise
- Pulse Tube cryocoolers (PT) are the dominant source of noise in the signal bandwidth (0-20 Hz) $\rightarrow$ we developed a system to tune the relative phases of the PTs, minimizing their induced noise
- Software denoising is used to further suppress PT and seismic noise in our detector measurements



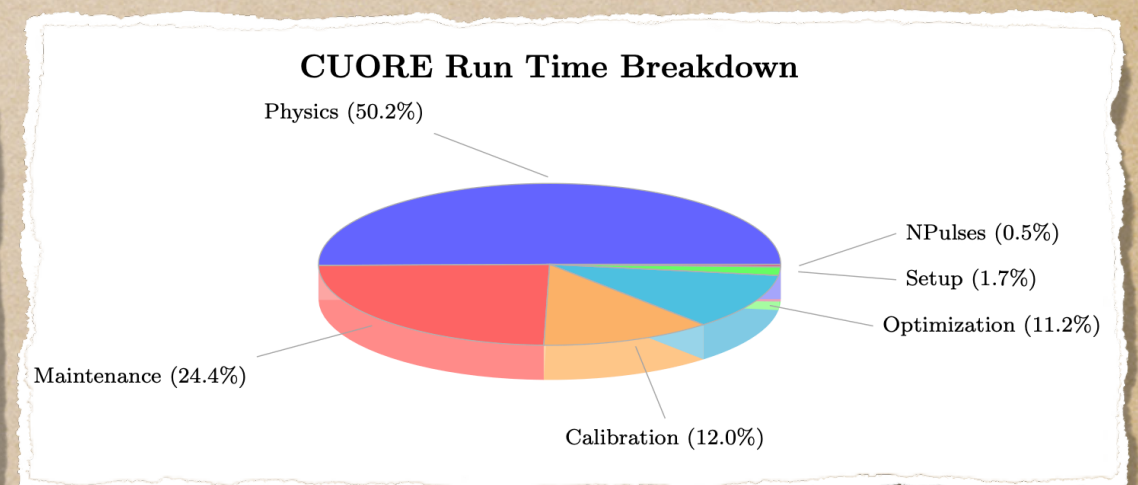
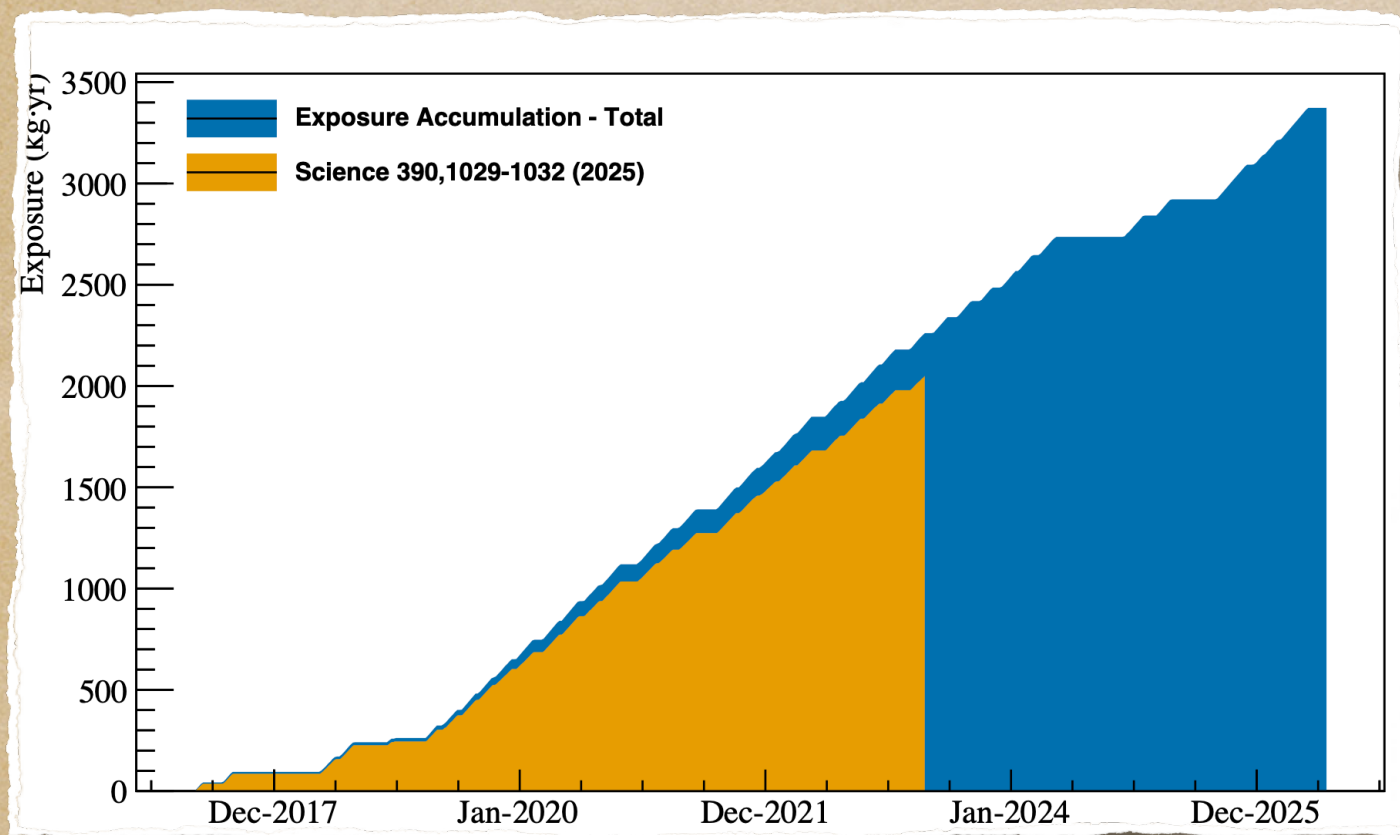
Cryogenics.93(2018)



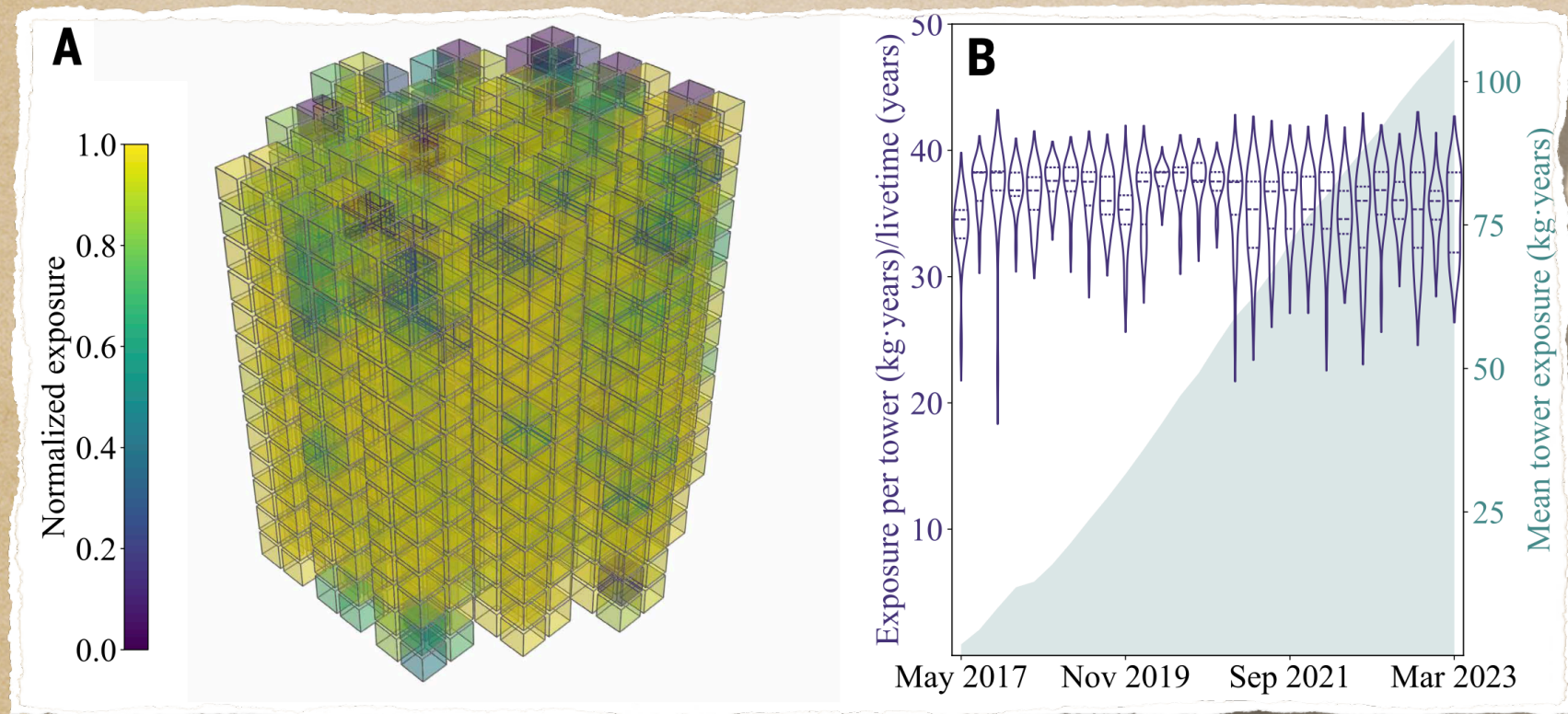
Communication.Physics.9(2026)

CUORE data-taking

- Data-taking started in 2017
- Nearly a decade of stable cryogenic operation at 11-15 mK with >99% active detectors
- 3.37 ton·yr of raw TeO_2 exposure accumulated (before analysis cuts)
- CUORE main physics program completed on June 9, 2026
- A benchmark for future large-scale cryogenic experiments



CUORE Detector Performance

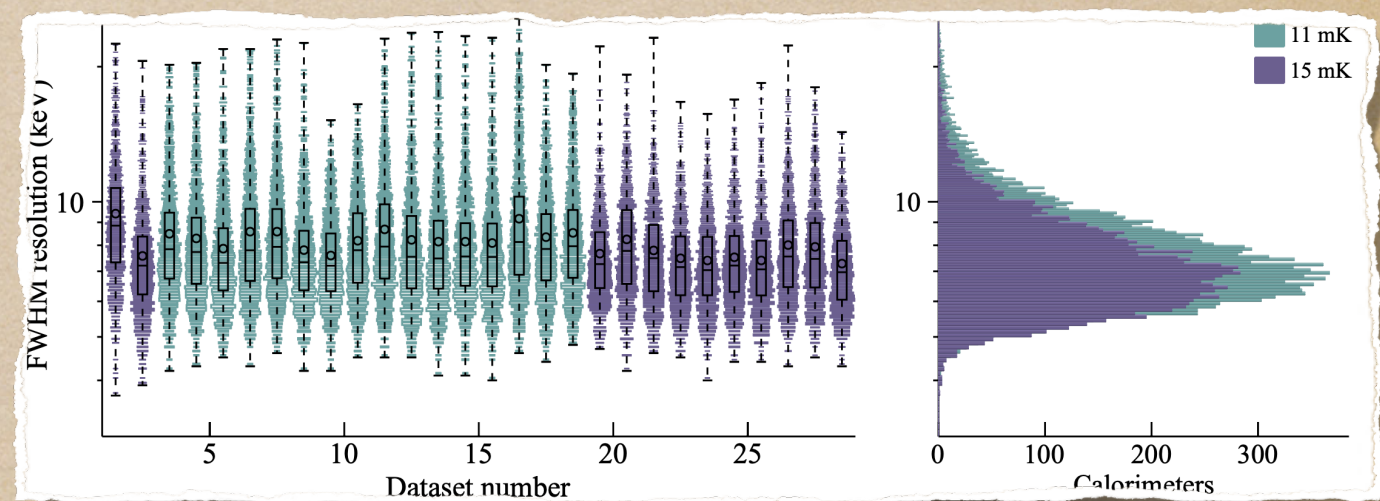


Science 390,1029-1032 (2025)

- Currently analyses exposure ~ 2 ton·yr
- Data analysis of the 3rd ton·yr is ongoing

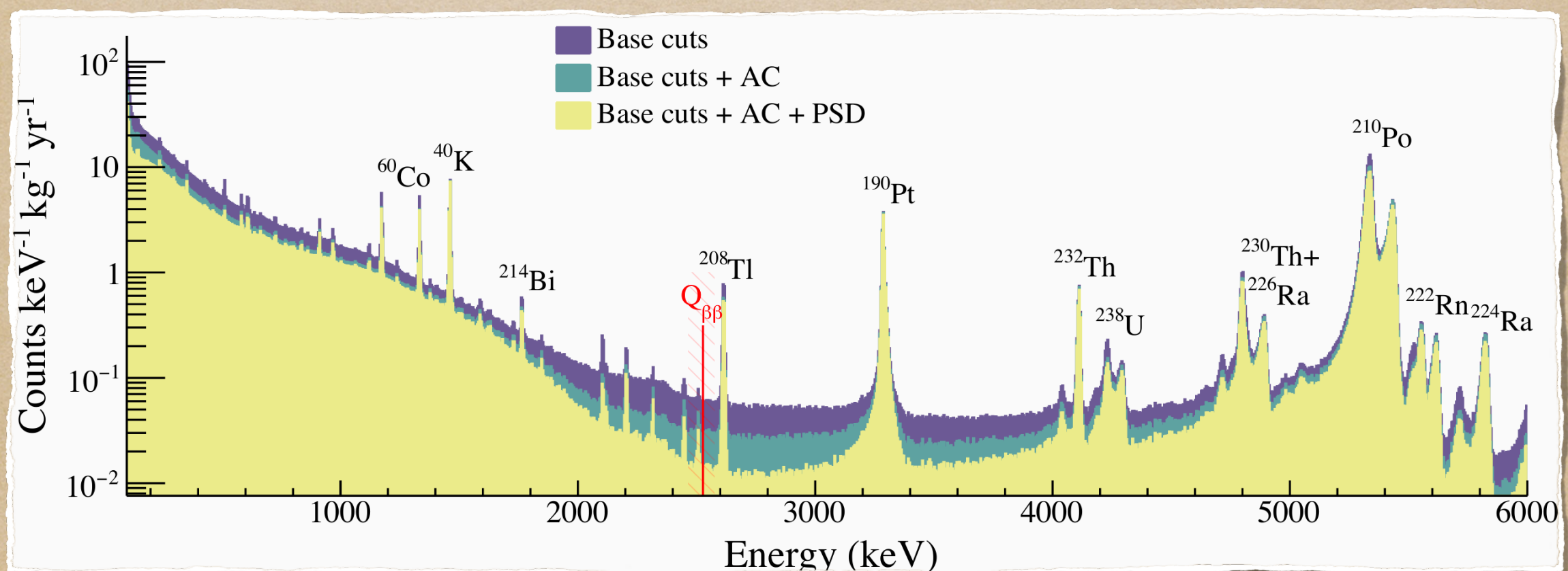
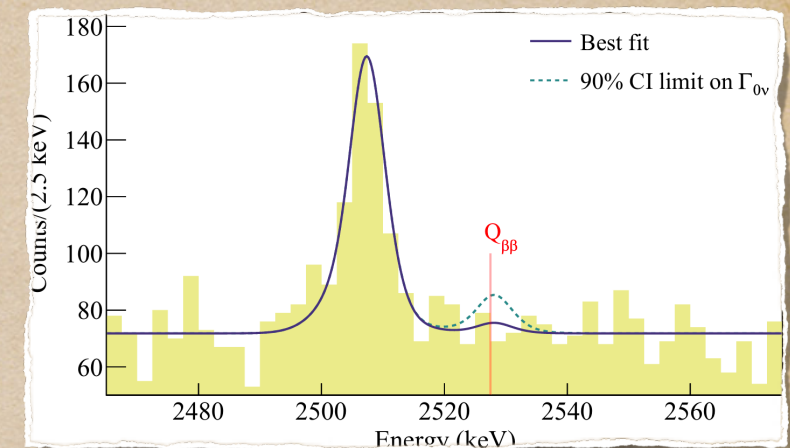
- Excellent cryogenic calorimeters performance stability on a years-long timescale
- Energy resolution

$$\text{FWHM}_{2615} = 7.540 \pm 0.024 \text{ keV}$$



CUORE 2TY spectrum

- Several sequential analysis cuts (analysis threshold = 40 keV): [Science 390,1029-1032 \(2025\)](#)
 - Base cuts: trigger, energy reconstruction, pile-up
 - Anti-coincidence (AC): only single-crystal events
 - Pulse shape discrimination (PSD): only signal-like events
- Total analysis cut efficiency: 93.4(18) %
- 2 tonne-year average background index in the ROI: $b = 1.42^{+0.03}_{-0.02} \times 10^{-2}$ counts/keV/kg/y



CUORE ^{130}Te $0\nu 2b$ search results

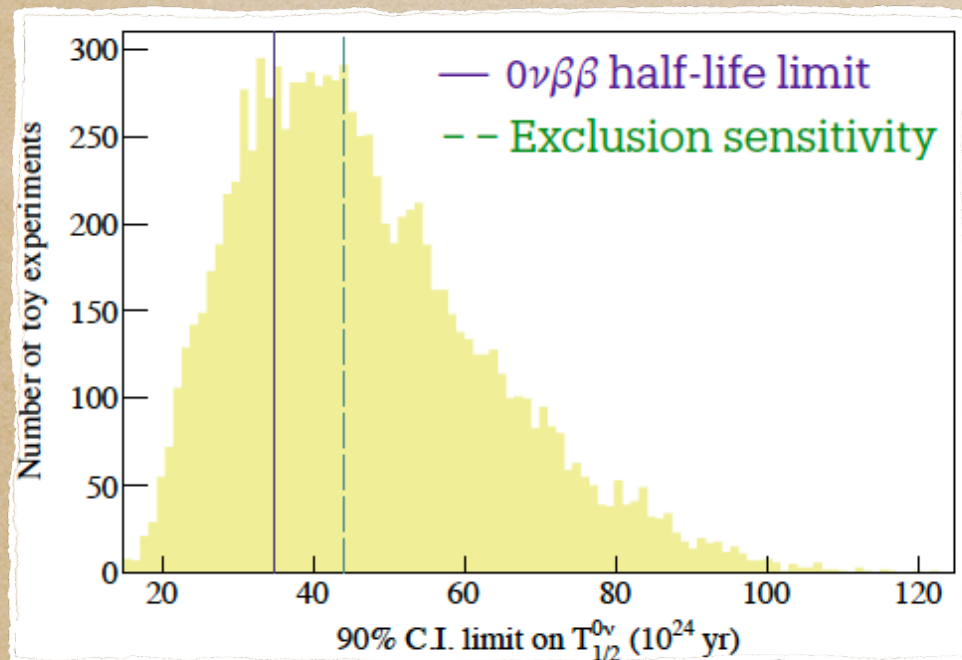
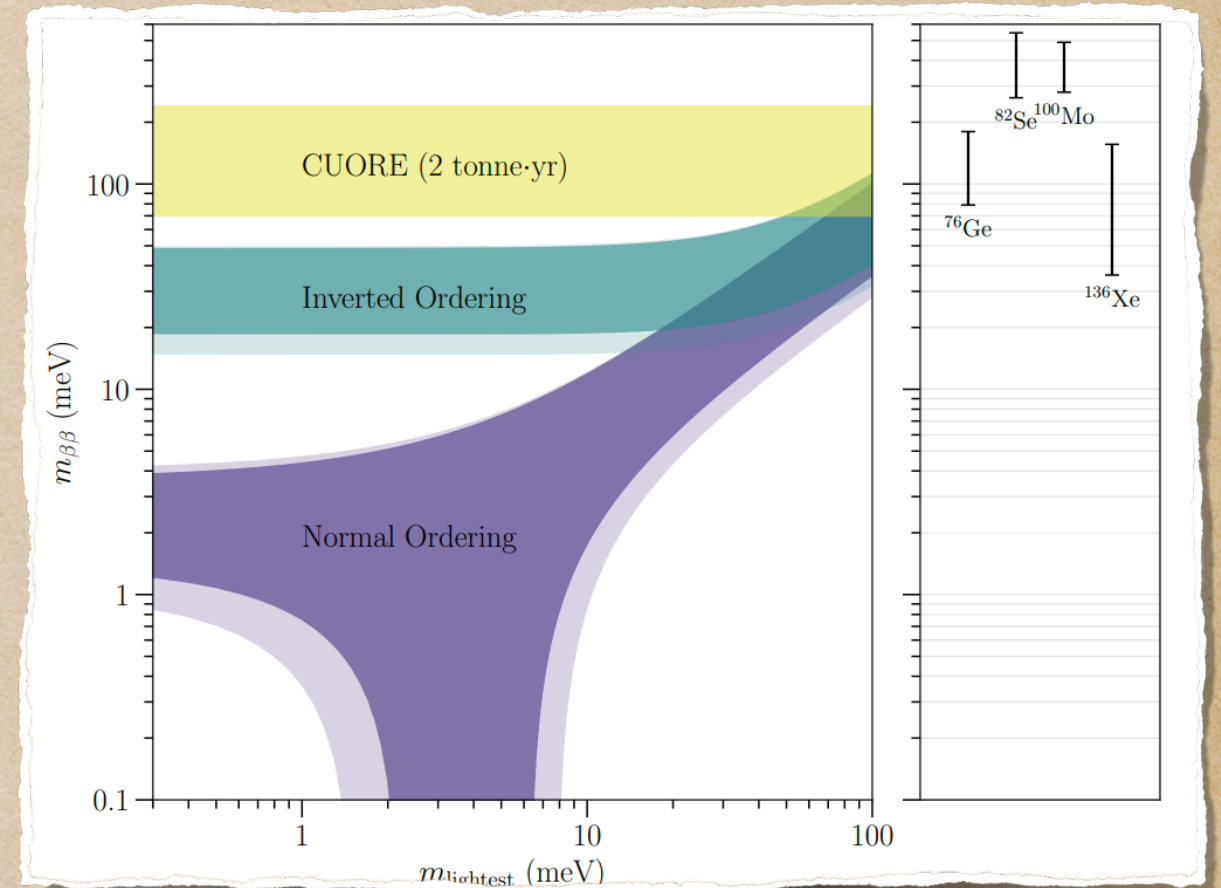
Science 390,1029-1032 (2025)

- Unbinned Bayesian fit with $\Gamma_{0\nu} > 0$
- Decay rate limit:

$$\Gamma_{0\nu} < 2.0 \times 10^{-26}/\text{yr} \text{ (90\% C.I.)}$$
- ^{130}Te $0\nu\beta\beta$ decay half-life:

$$T_{1/2}^{0\nu} > 3.5 \times 10^{25} \text{ yr (90\% C.I.)}$$
- Median exclusion sensitivity from 10^4 toy MC experiments in background-only hypothesis:

$$T_{1/2} = 4.4 \times 10^{25} \text{ yr (90\% C.I.)}$$



Assuming the exchange of a light Majorana ν , the limit on the effective Majorana mass with 2 tonne-year of data of CUORE is:

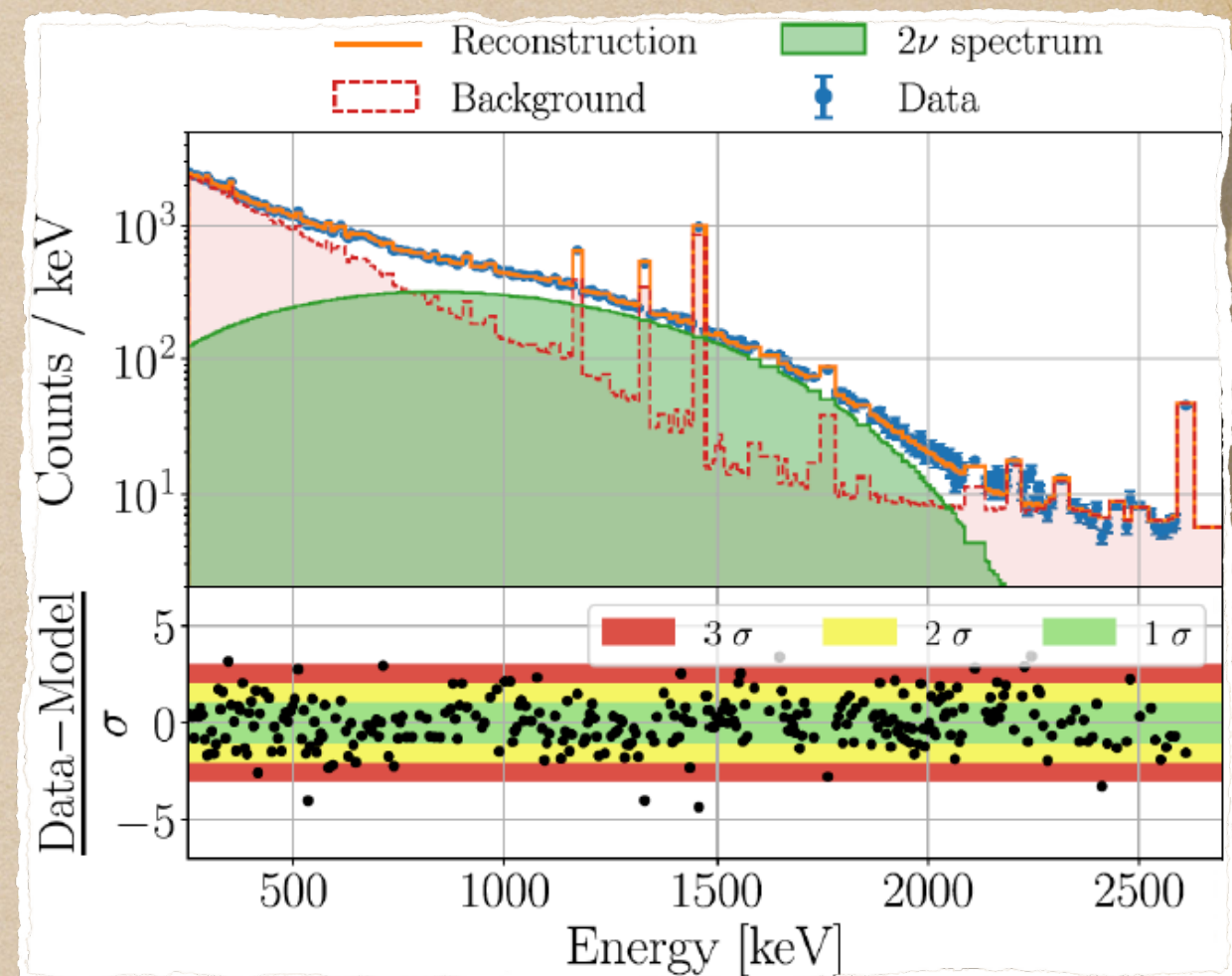
$$m_{\beta\beta} < 70 - 250 \text{ meV (90\% C.I.)}$$

CUORE ^{130}Te $2\nu 2\beta$ results

- A robust background model was developed using 1038.4 kg-year of TeO_2 exposure, validating the design background projections
- This model enabled the most precise measurement of the ^{130}Te $2\nu\beta\beta$ half-life:

$$T_{1/2}^{2\nu} = (9.32_{-0.04}^{+0.05}\text{stat}_{-0.07}^{+0.07}\text{syst}) \times 10^{20} \text{ yr}$$

- The $2\nu\beta\beta$ decay spectral shape was also studied, confirming the preference for the Single State Dominance (SSD) model.



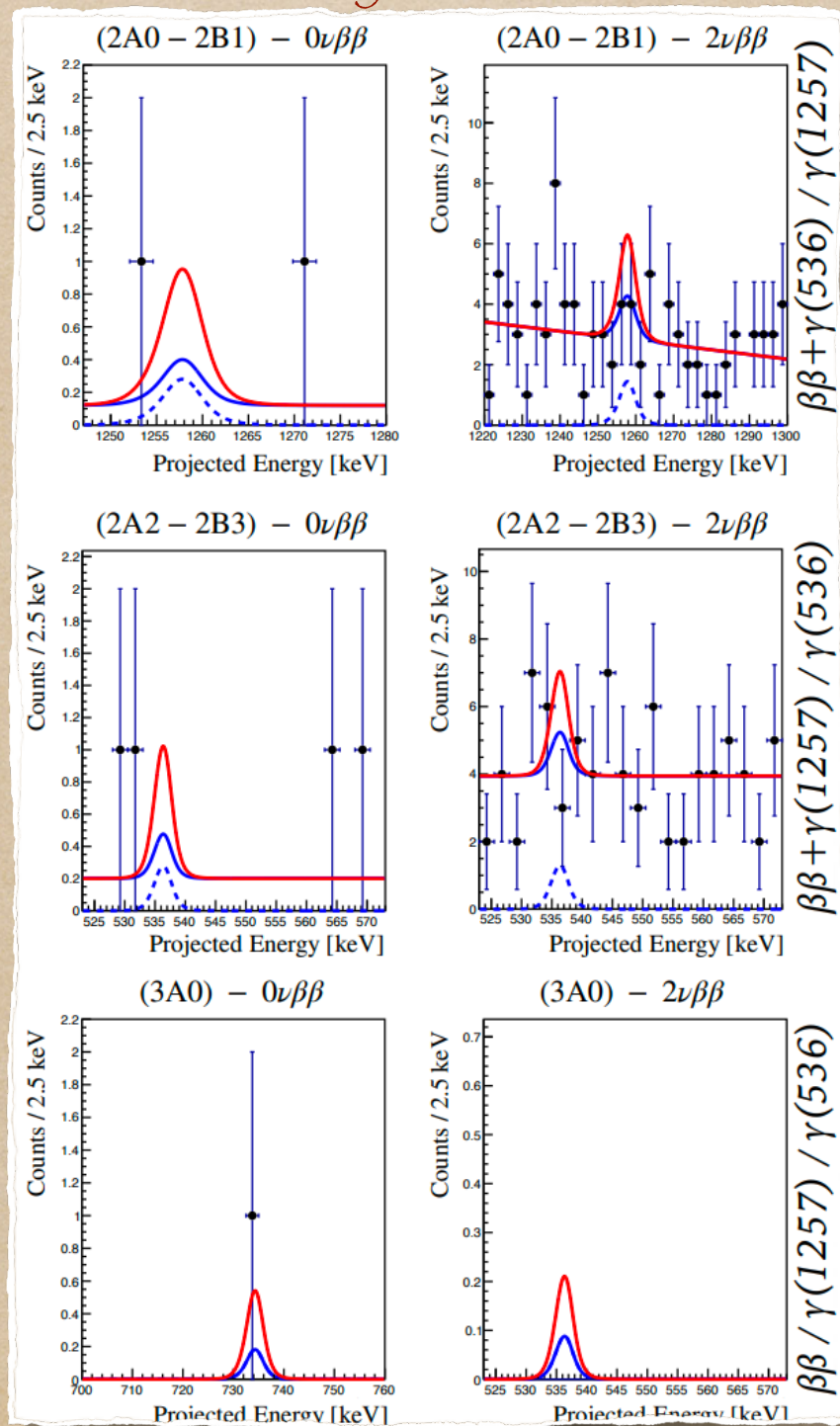
[Phys. Rev. Lett. 135, 082501 \(2025\)](#)

[Phys. Rev. Lett. 110, 052003 \(2024\)](#)

Other rare event searches

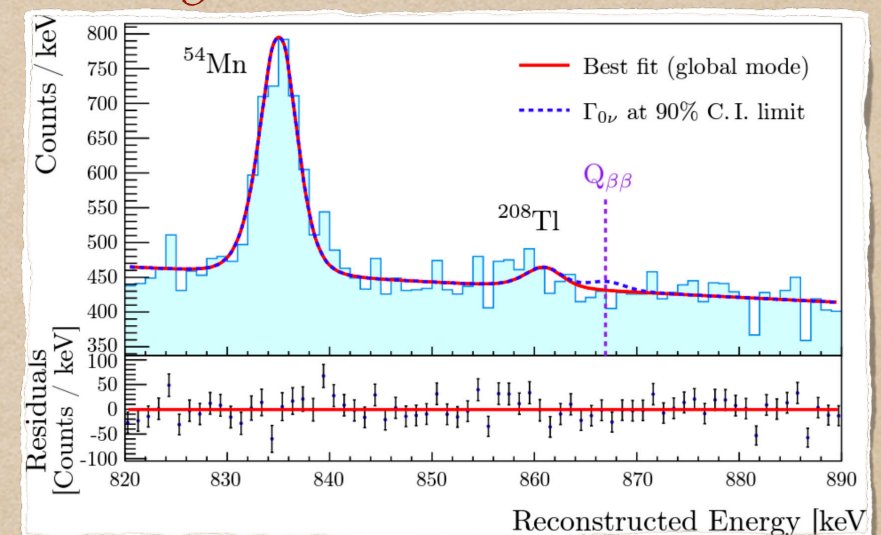
- ^{130}Te decay to 1st excited state

Eur. Phys. J. C 81, 567



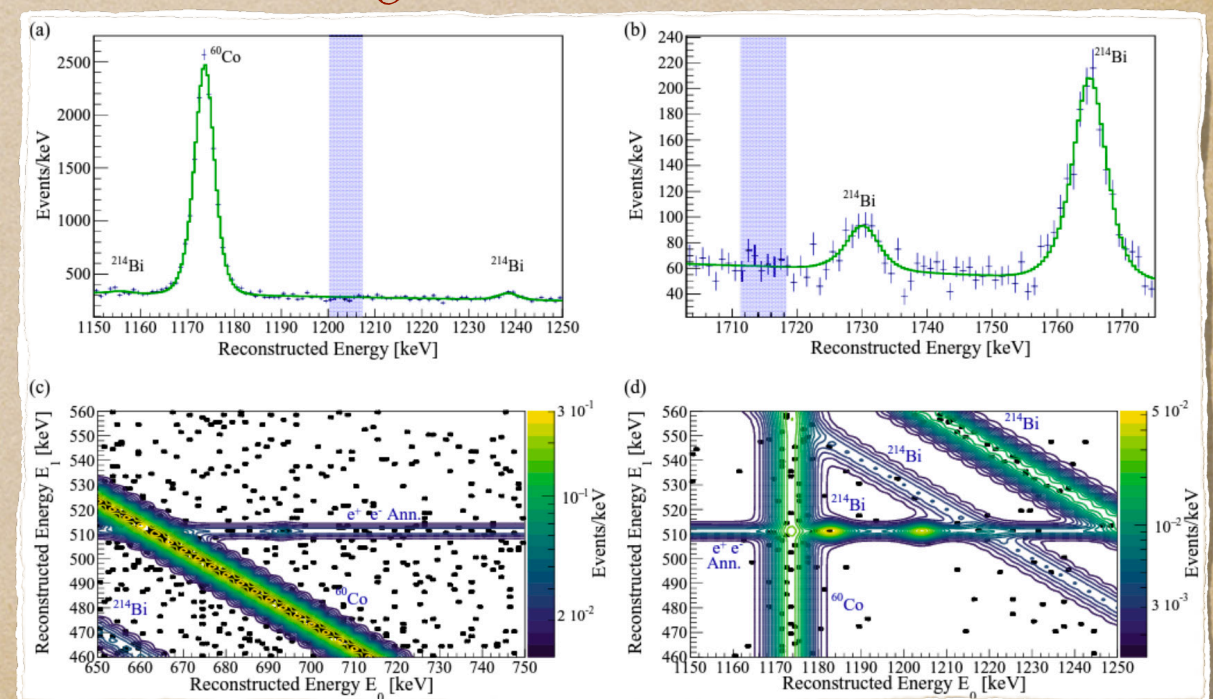
- ^{128}Te $0\nu\beta\beta$ decay to ground state

Phys. Rev. Lett. 129, 222501



- ^{120}Te $0\nu\beta^+/\text{EC}$ decay to ground state

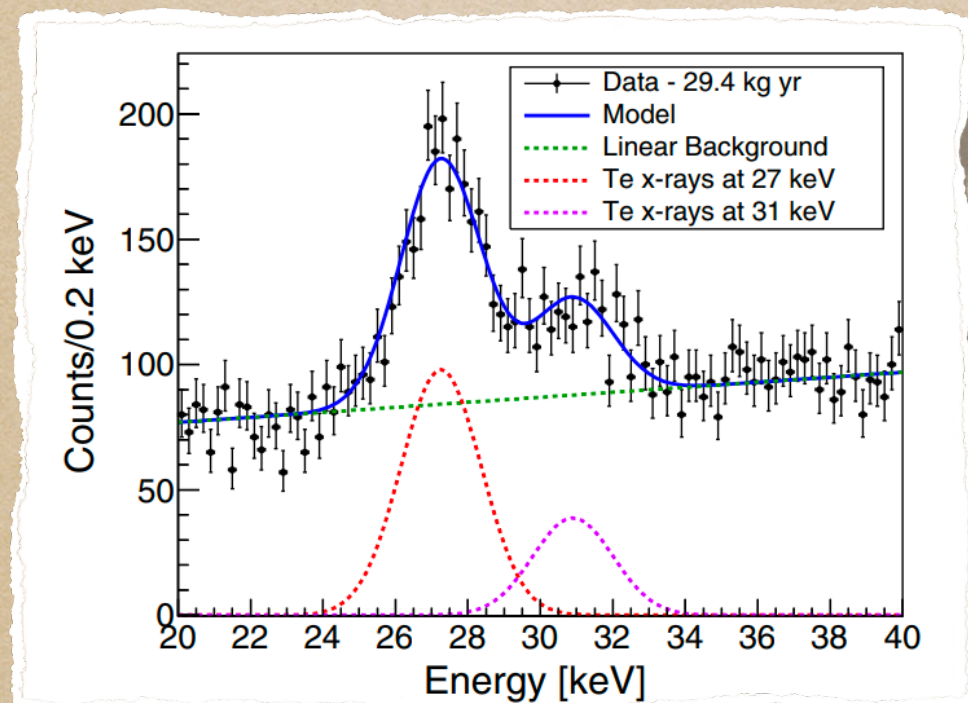
Phys. Rev. C 105, 065504



Other CUORE results

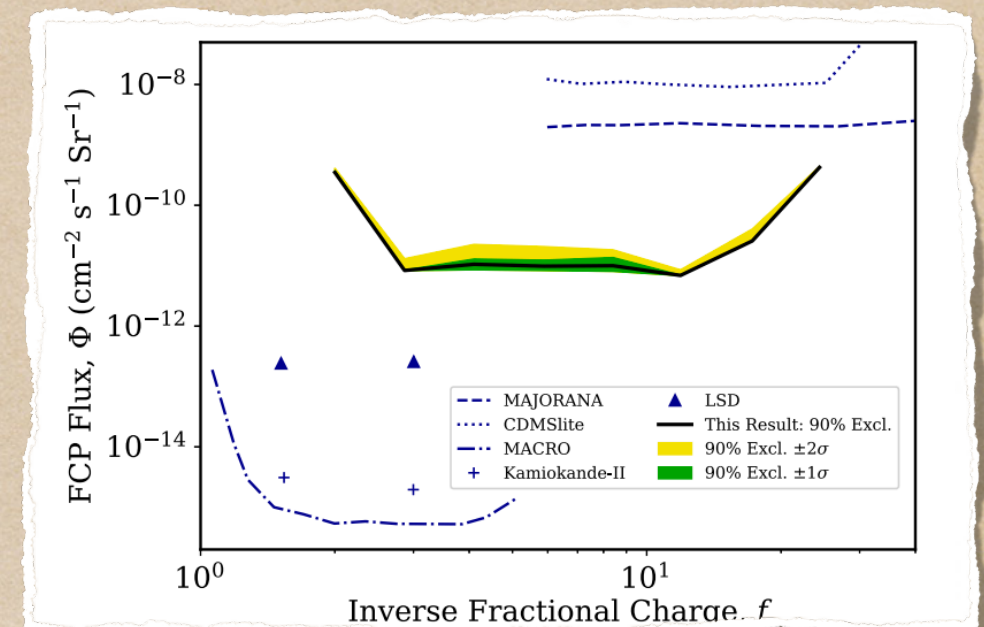
- Low energy analyses to optimize sensitivity for solar axions, WIMP searches

PhysRevLett.133.241801



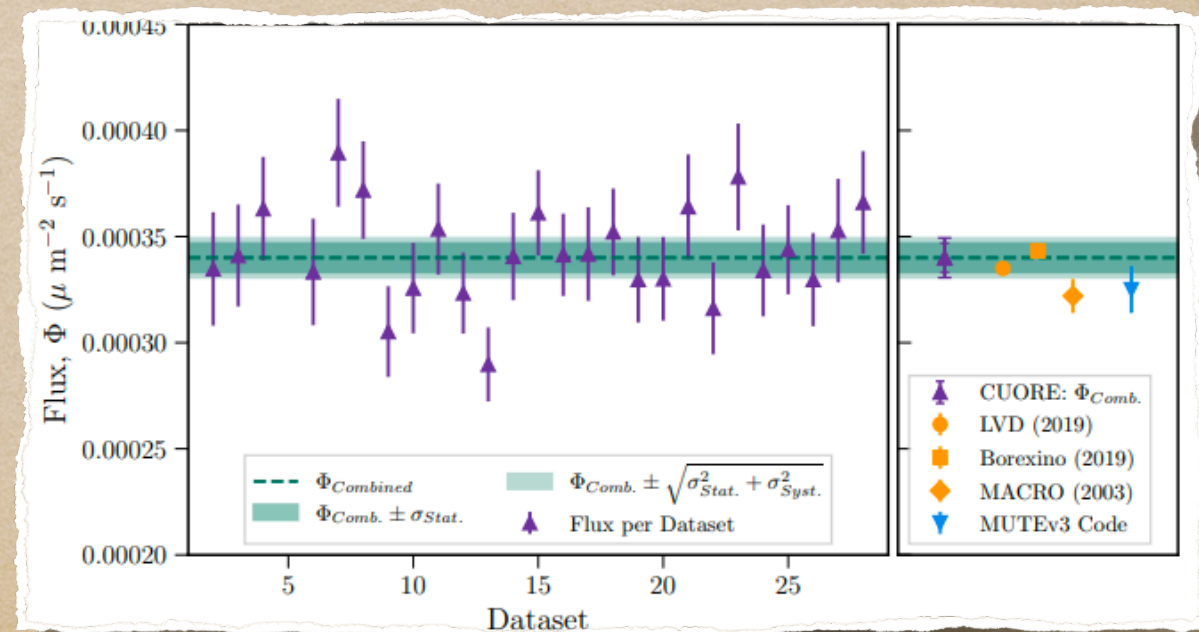
- Multi-spectral search for fractionally charged particles

Phys. Rev. D 113, 012012

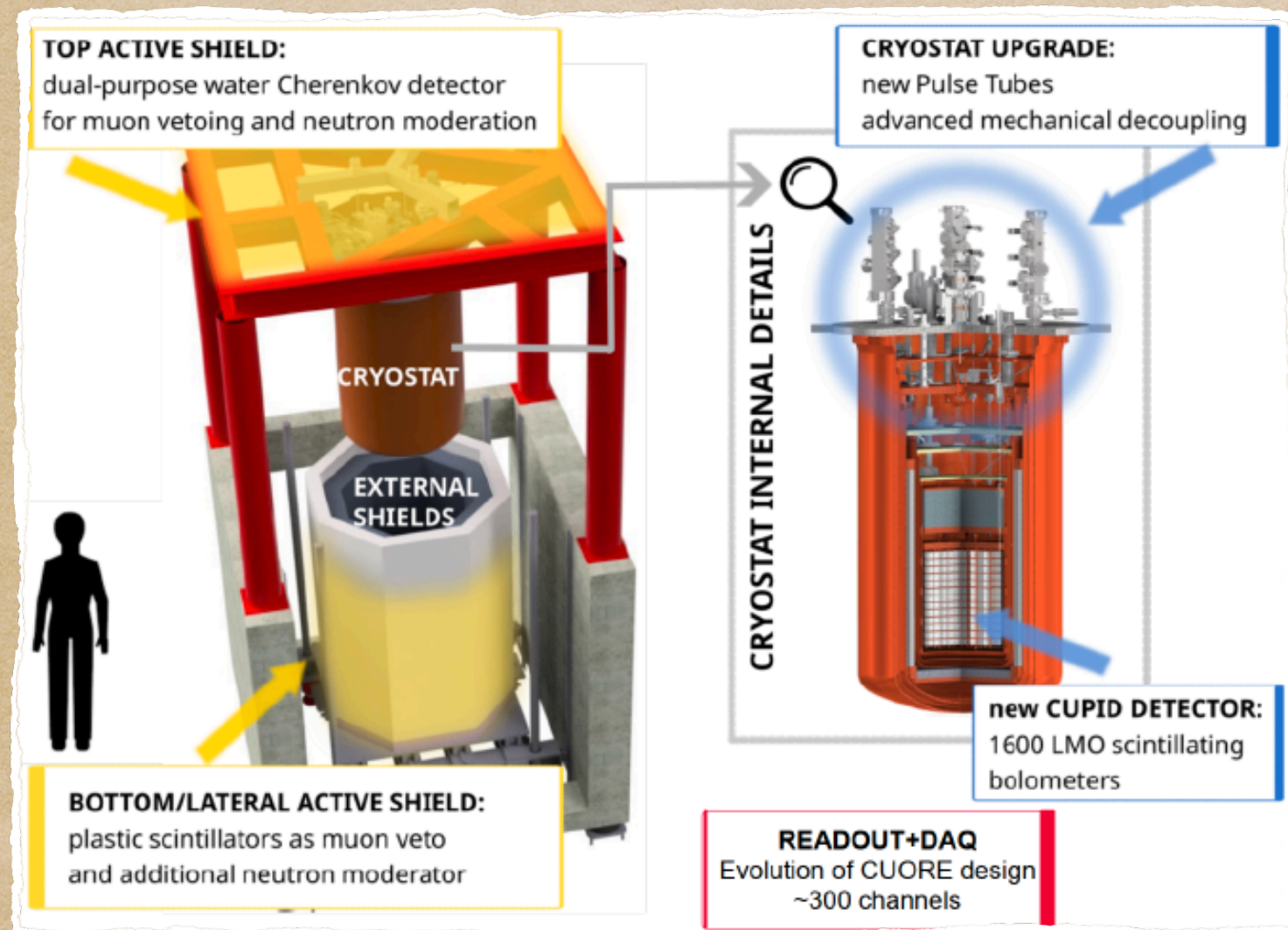


- Muon Event Reconstruction

Eur. Phys. J. C 86, 749 (2026)



Current status (preparing for CUPID)



- CUORE is currently undergoing technical runs and will be warmed up in late fall.
- The CUORE detector array will remain in place; will be cooled down again to validate the performance improvements after the cryostat upgrade and the installation of bottom and lateral muon veto.
- Subsequently, the top active shield, the upgraded readout, and the CUPID detector array will be installed.

Summary

- CUORE is the largest and longest operating double beta decay experiment.
- CUORE is the first experiment to demonstrate the stable operation of a tonne-scale millikelvin cryogenic calorimeter over nearly a decade.
- After analyzing 2 ton·yr of TeO_2 exposure CUORE set the most stringent limit on ^{130}Te $0\nu\beta\beta$:
 - $T_{1/2}^{0\nu} > 3.5 \times 10^{25} \text{ yr}$ (90% C.I.)
 - $m_{\beta\beta} < 70 - 250 \text{ meV}$ (90% C.I.)
 - $b \approx 1.42^{+0.03}_{-0.02} \times 10^{-2} \text{ counts}/(\text{keV}\cdot\text{kg}\cdot\text{yr})$
- CUORE has successfully completed its physics program: the data analysis is still ongoing with new results expected soon.
- After the infrastructure upgrade, CUORE is expected to improve the measurement efficiency at low energies, enabling precise data-quality control across the full energy range.

Thank you!



Acknowledgement

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