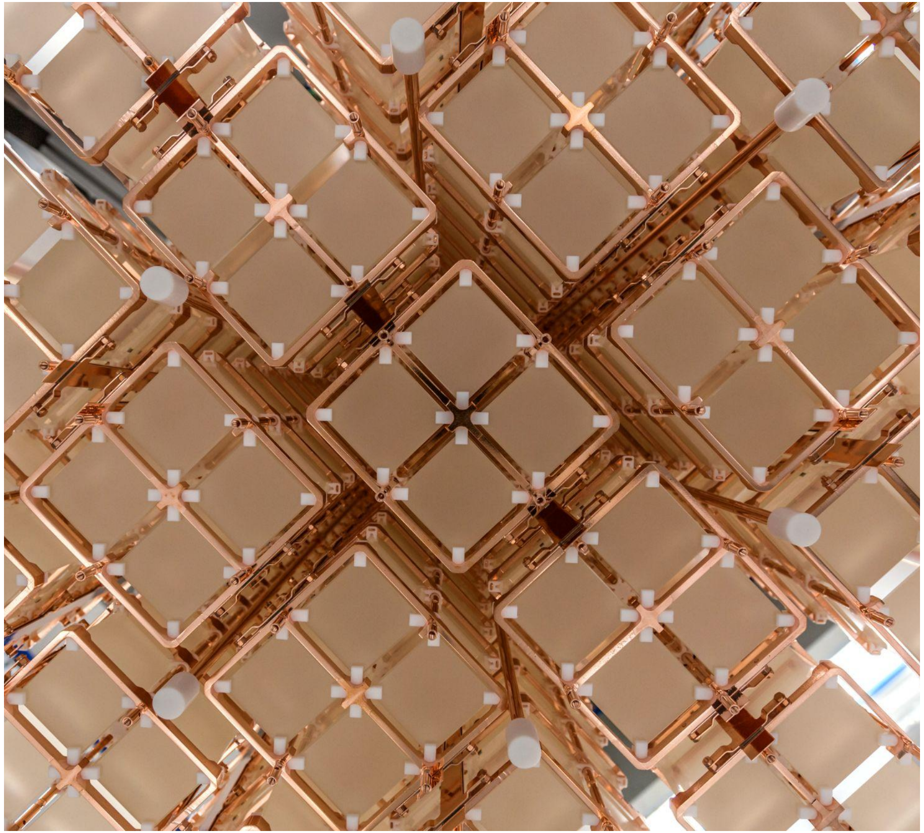


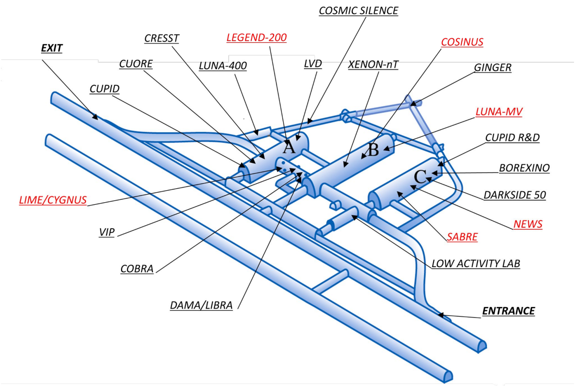
Latest results from the CUORE experiment

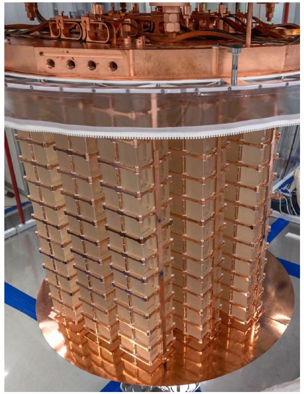
Giovanni Benato
for the CUORE Collaboration

CUORE

GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

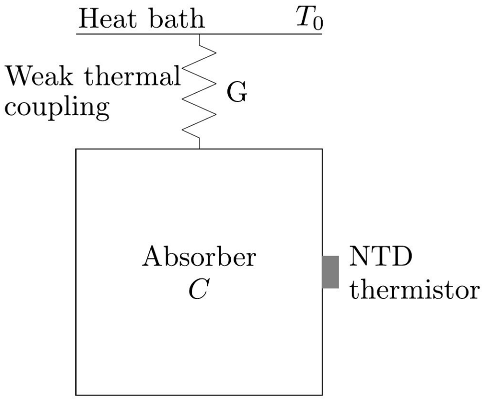
The CUORE experiment

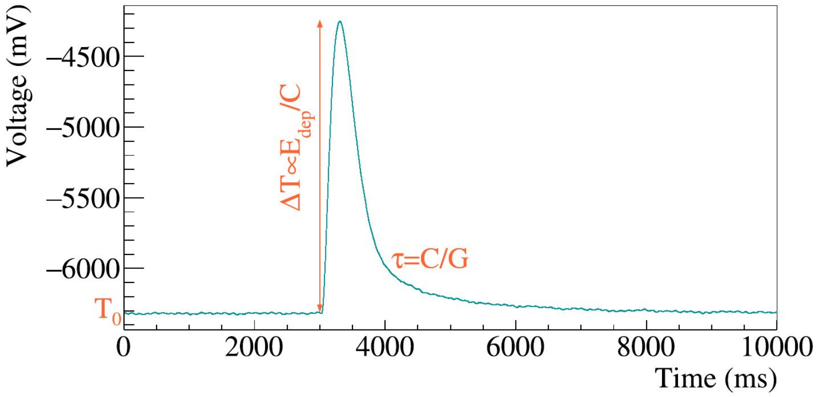




- **C**ryogenic **U**nderground **O**bservatory for **R**are **E**vents
- Located in Hall A of LNGS-INFN
- 988 $^{nat}TeO_2$ crystals at ~10 mK
- 742 kg of TeO_2 → 206 kg of ^{130}Te
- $Q_{\beta\beta}$ = 2527 keV → above most natural γ background

Cryogenic calorimeters (bolometers)

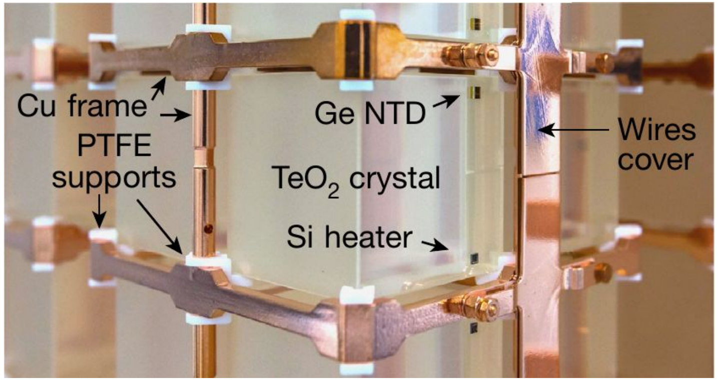


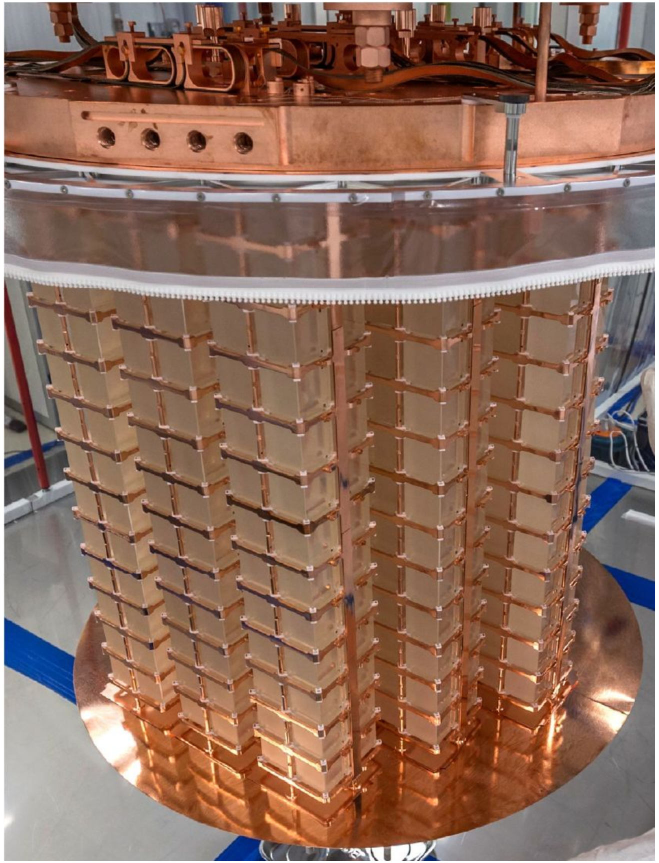


- 0νββ isotope embedded in crystal absorber
- Energy deposition → phonons → heat
  - Voltage signal on NTD-Ge thermistor
  - Weak thermal link to heat bath → Most heat flows through NTD
- Signal amplitude: ~μK → Must operate at ~10 mK temperature

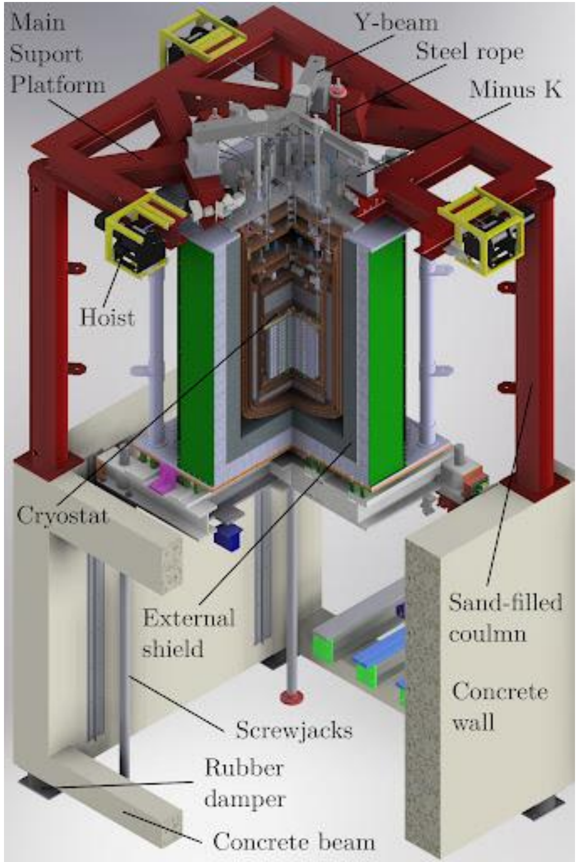
The detector

- 19 towers with 52 detectors each
- Copper tower structure with PTFE supports as weak link
- Si heater to inject controlled heat pulses for stabilization of signal amplitude vs temperature
- PEN+Cu wire trays for NTD biasing, signal readout and heater pulse injection





Radioactive background and vibration suppression

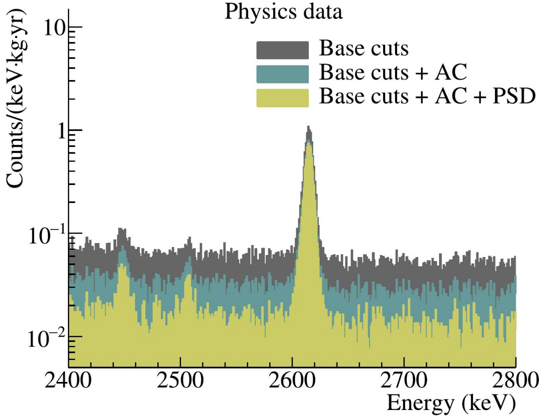


Background suppression

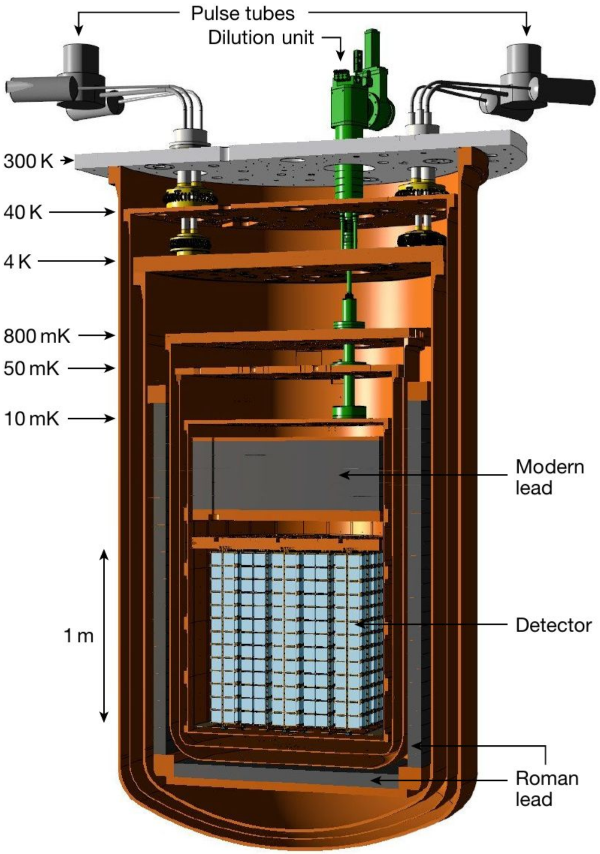
- Underground operation yields muon flux of ~1 μ/m^2/h
- 20 cm polyethylene to suppress neutrons
- 25 cm external lead + internal lead to suppress γ's
- Anti-coincidence cut to actively suppress γ's

Vibration suppression

- Detectors mechanically decoupled from cryostat
- Cryogenic-induced noise actively canceled
- Diagnostic devices installed for offline denoising

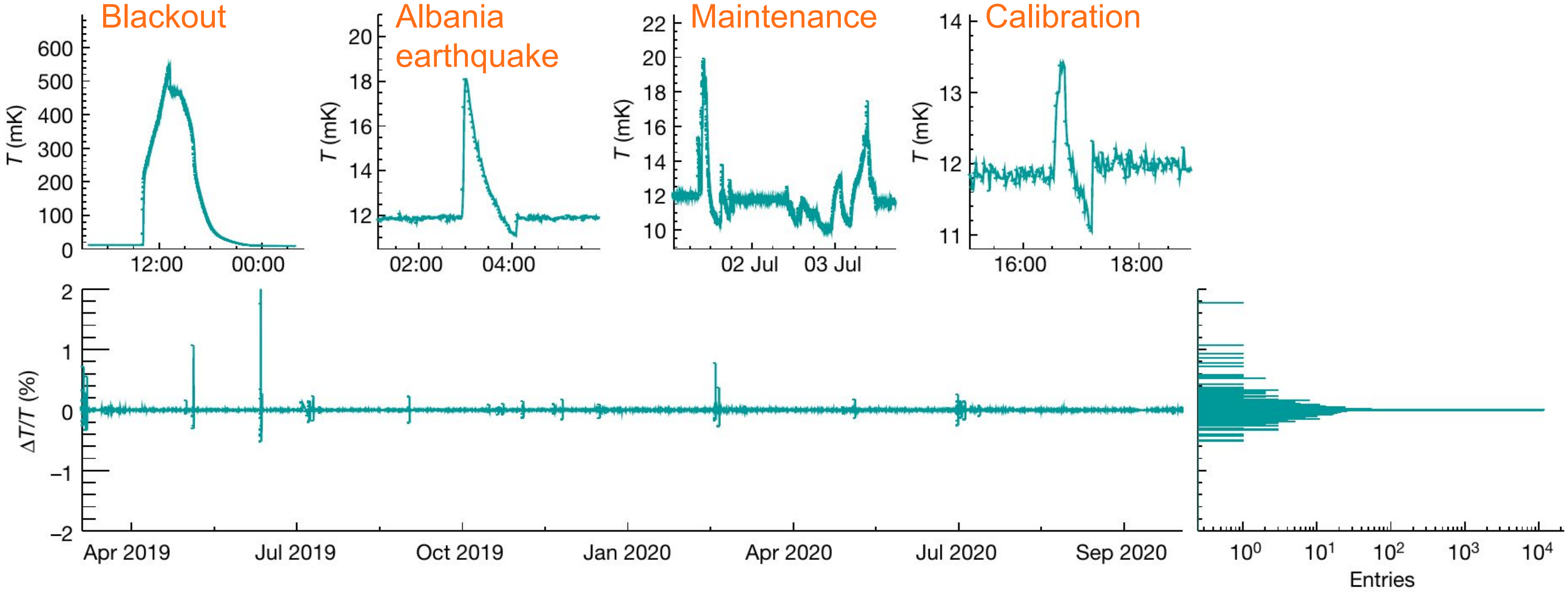


The cryostat



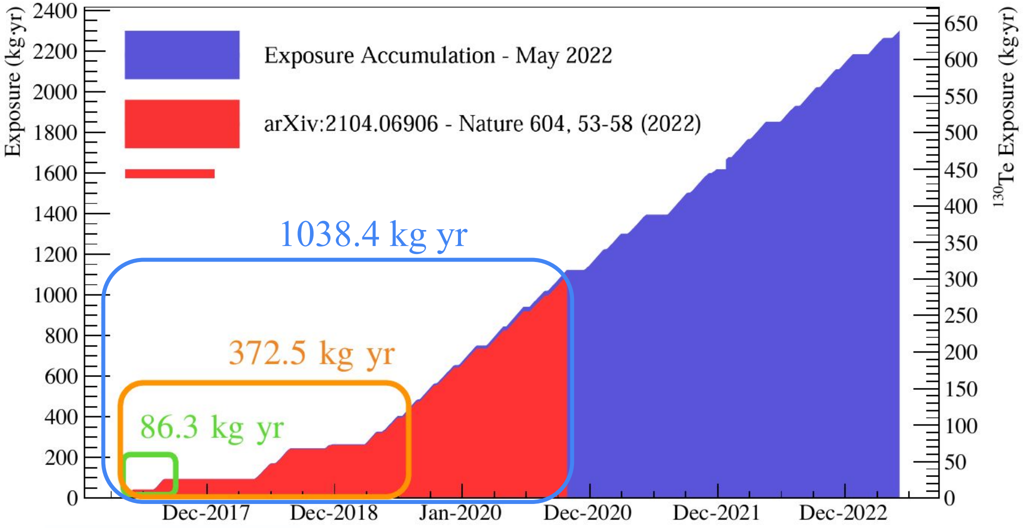
- Custom-made dry dilution refrigerator
  - Demonstrated 7 mK, normally operated at 11-15 mK
  - 1.5 t of material at base temperature for ~5 years!
- 5 pulse-tube refrigerators, no helium bath
  → High duty cycle
  → Relative phases tuned for noise cross-canceling
- 6 nested copper vessels at decreasing temperatures
- Low-temperature lead shielding
  - Modern lead on top of detectors to suppress γ’s from cryogenic components
  - Roman lead lateral shielding to suppress external γ’s

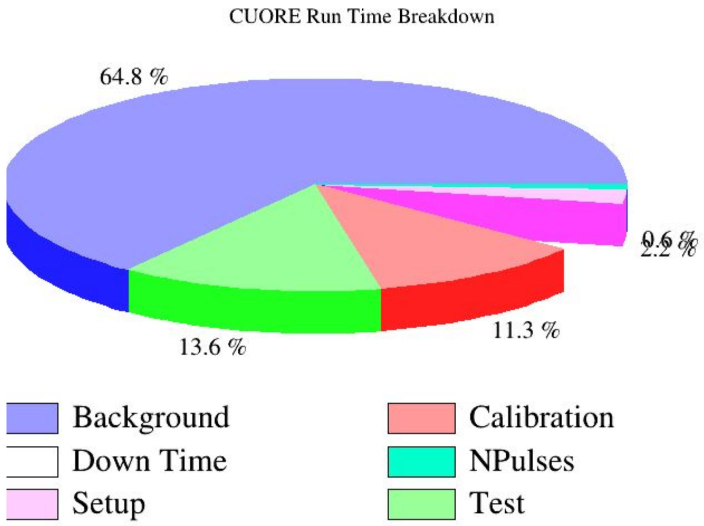
The cryostat performance



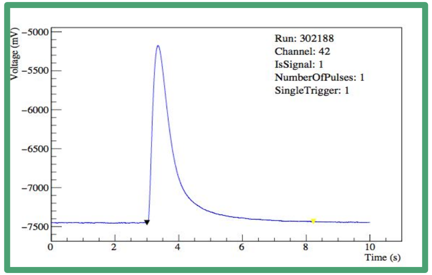
Data collection

- Data taking started in 2017, with first 2 years for cryostat and detector optimization
- Stable data collection since 2019, with >90% uptime
  → Steadily collecting data at 50-60 kg·yr/month ever since
- 2 ton·yr of raw exposure accumulated as of this spring
  → Reprocessing of data ongoing in view of next data release

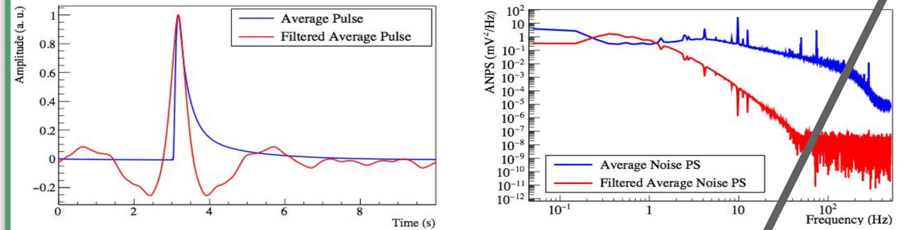




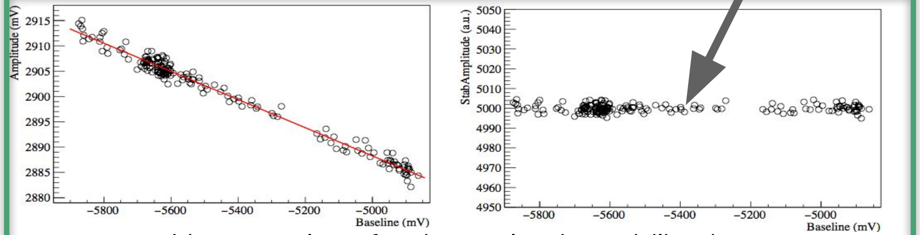
Data processing



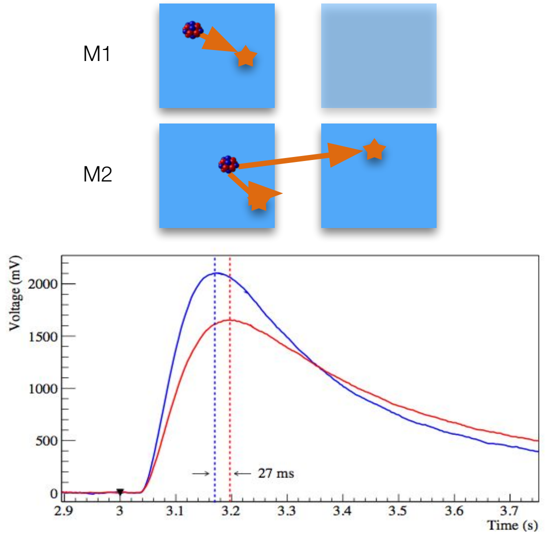
Optimum Filter → Gain Correction → Energy Calibration → Coincidences



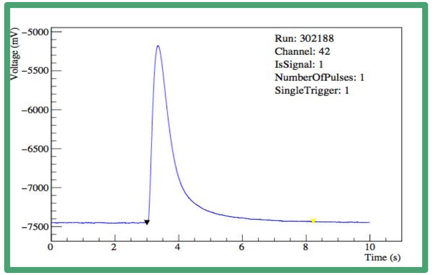
Matched filter that maximizes the signal-to-noise ratio



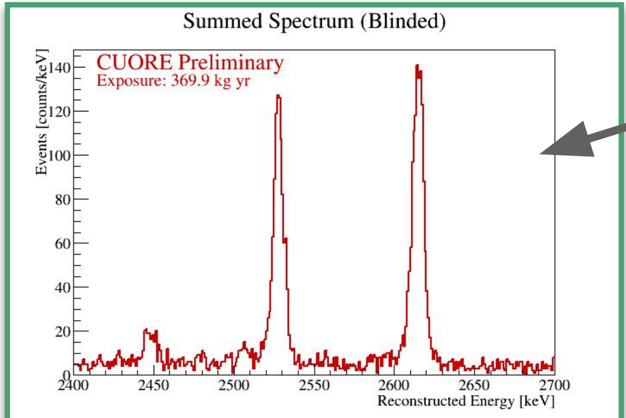
Heater pulses for thermal gain stabilization



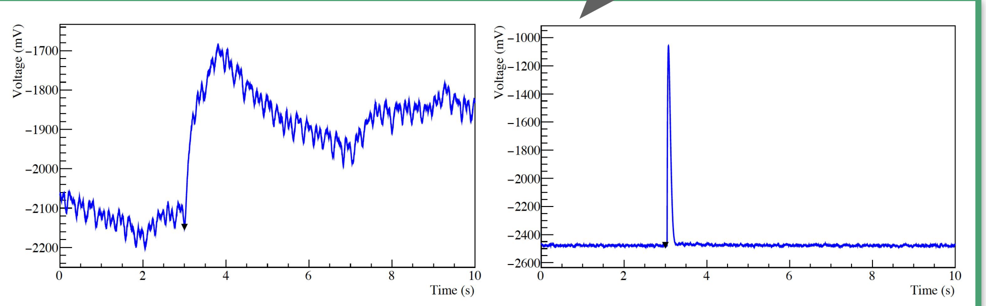
Data processing



Optimum Filter → Gain Correction → Energy Calibration → Coincidences → PSA → ROI blinding → Data quality selection → Unblinding

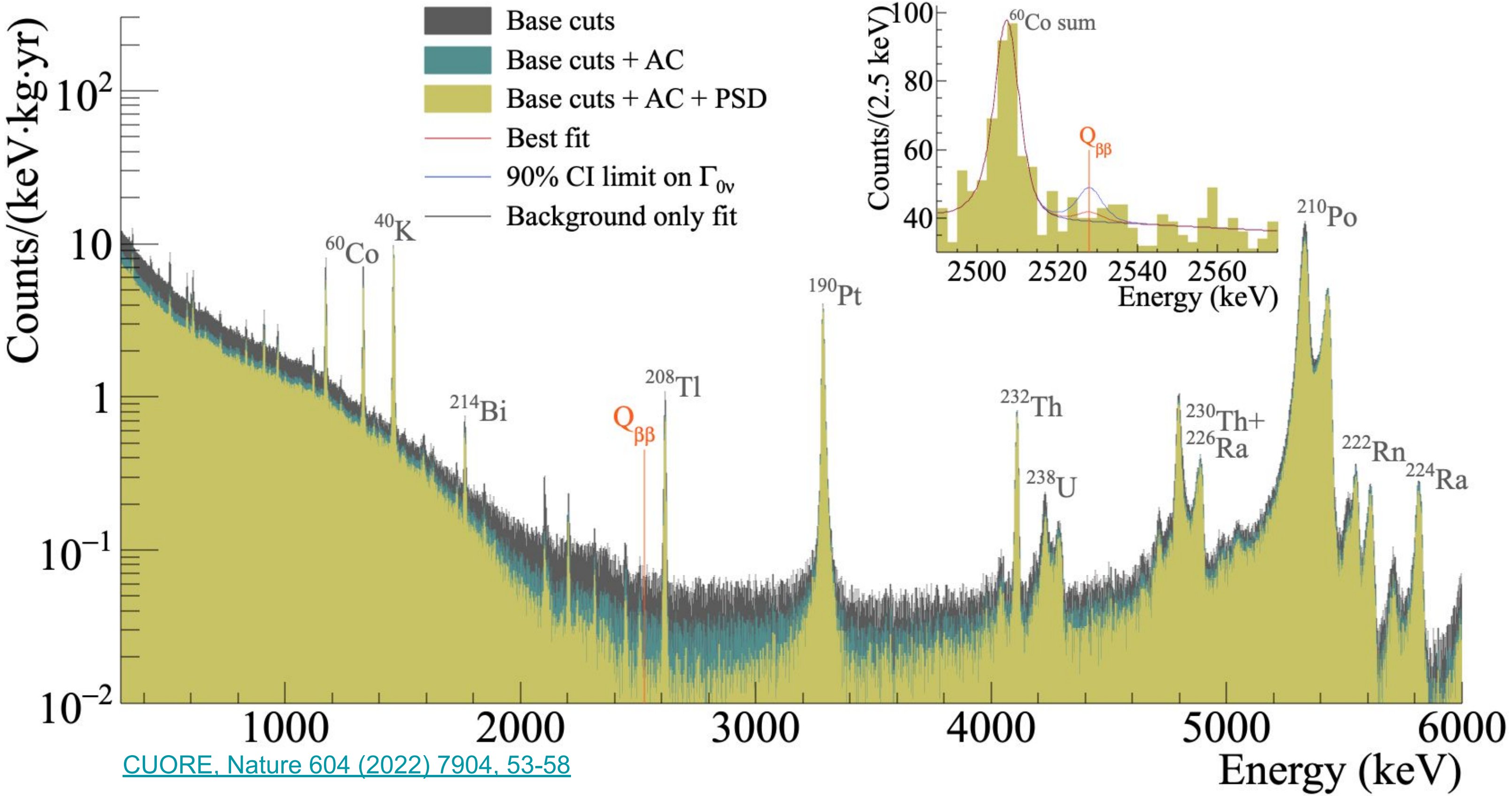


Quality cuts optimization on blinded data



Reject non-physical pulses

Physics data - 1 ton·yr exposure

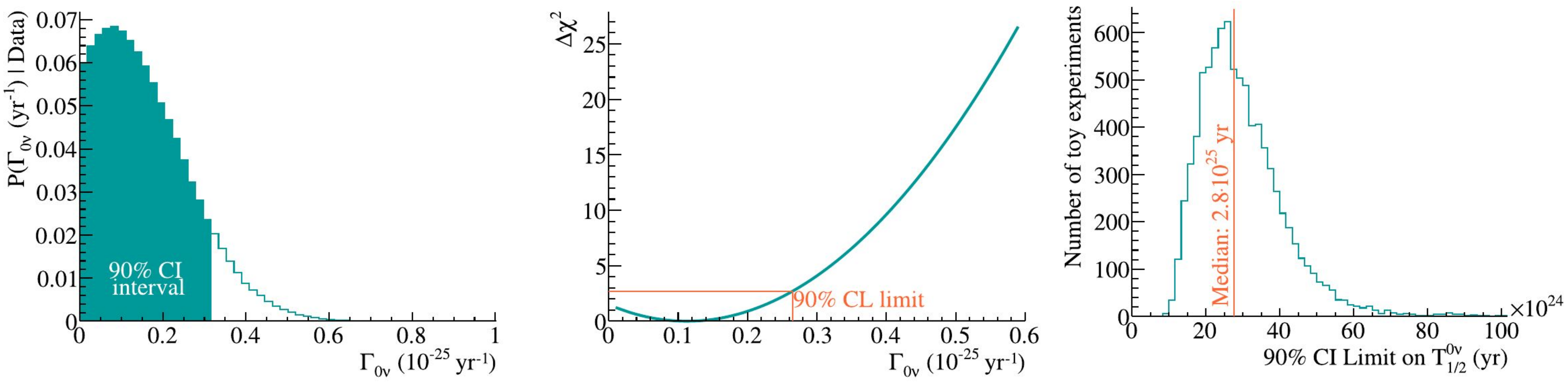


CUORE, Nature 604 (2022) 7904, 53-58

Detector performance figures

Number of datasets	15
Number of analyzed channels	934 (on average)
TeO_2 exposure	1038.4 kg·yr
^{130}Te exposure	288 kg·yr
FWHM at 2615 keV in calibration	(7.78±0.03) keV
FWHM at $Q_{\beta\beta}$ in physics data	(7.8±0.5) keV
Event reconstruction efficiency	(96.418±0.002) %
Anticoincidence efficiency	(99.3±0.1) %
PSD efficiency	(96.4±0.2) %
Total analysis efficiency	(92.4±0.2) %
Containment efficiency	(88.35±0.09)%

$0\nu\beta\beta$ decay search



- BI: $1.49(4) \cdot 10^{-2}$ counts/keV/kg/yr
- Bayesian limit: $\mathbf{T_{1/2}^{0\nu} > 2.2 \cdot 10^{25}}$ **yr @90% c.i. →** $\mathbf{m_{\beta\beta}}$ **< 90-305 meV**
- Bayesian 90% c.i. sensitivity: $T_{1/2}^{0\nu} = 2.8 \cdot 10^{25}$ yr
- Frequentist limit (Rolke): $T_{1/2}^{0\nu} > 2.6 \cdot 10^{25}$ yr @90% C.L.
- Frequentist 90% C.L. sensitivity: $T_{1/2}^{0\nu} = 2.9 \cdot 10^{25}$ yr

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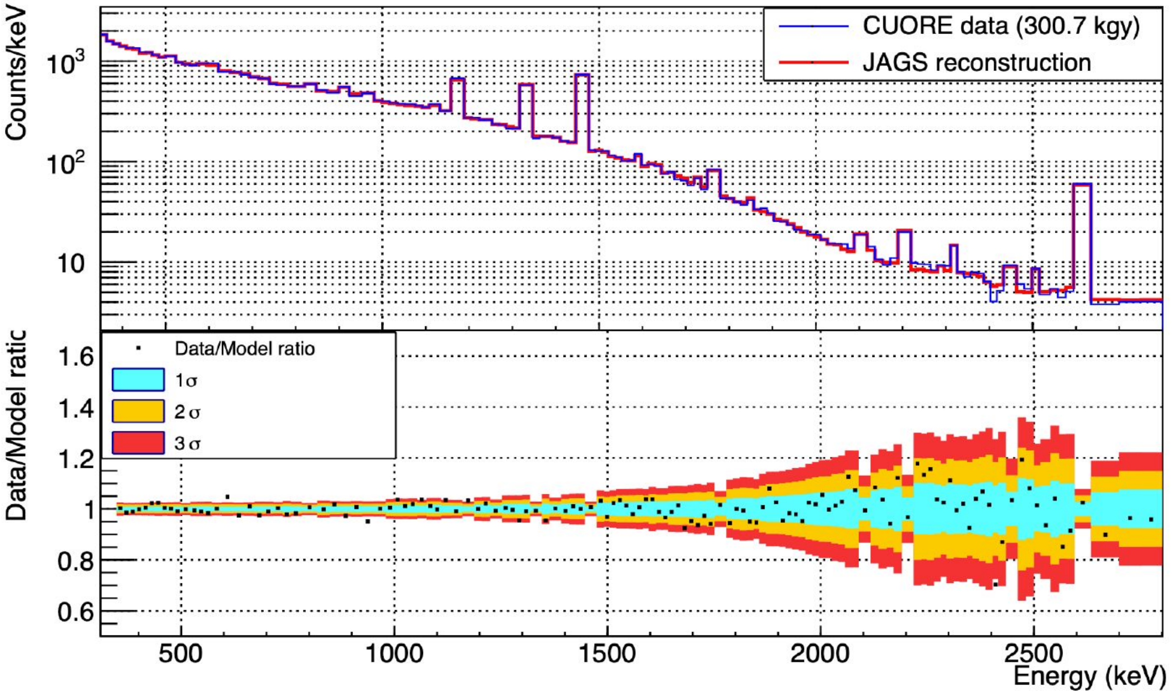
Background model

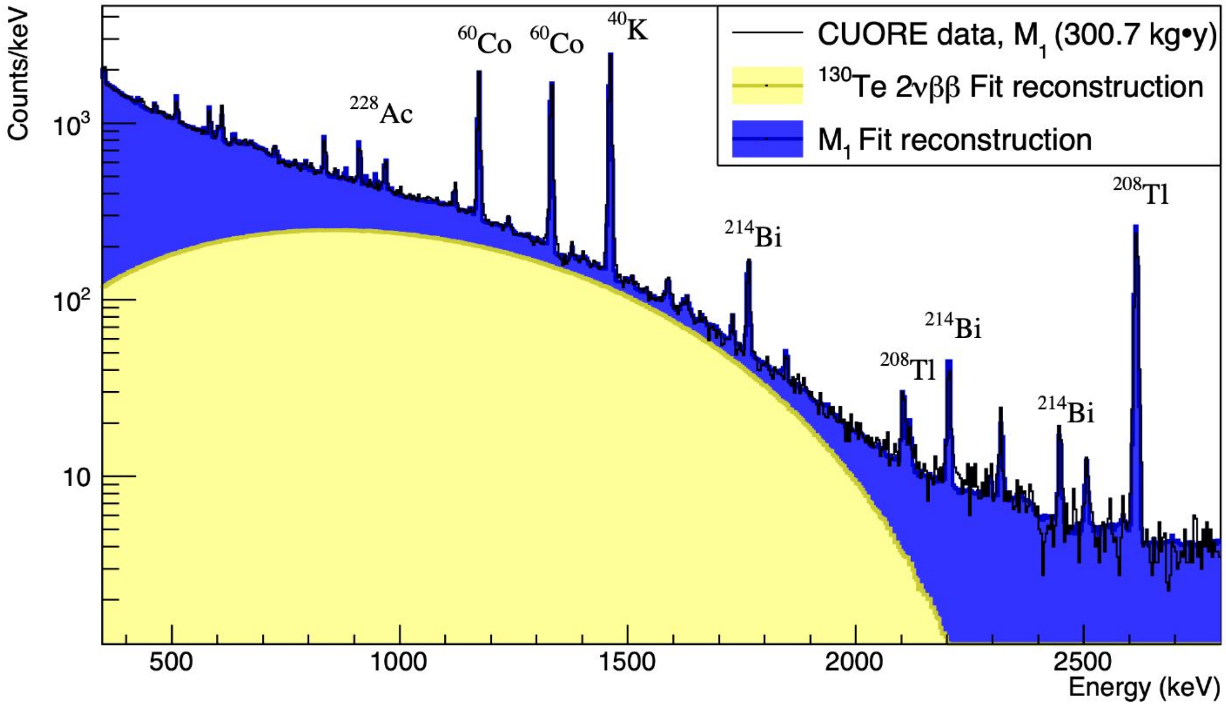
- Full detector geometry and particle interaction implemented in Geant4
- Geant4 output post-processed to include detector response
- 62 simulated sources (bulk, surface, muons)
- Coincidence events used to constrain source location
- JAGS-based MCMC binned Bayesian fit
- Uniform priors for all components, except muons

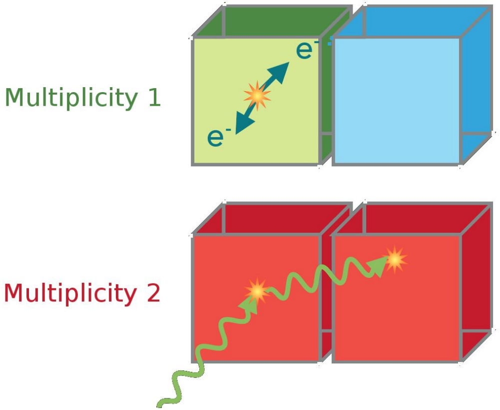


CUORE, PRL 126 (2021) 17, 171801

2νββ decay search

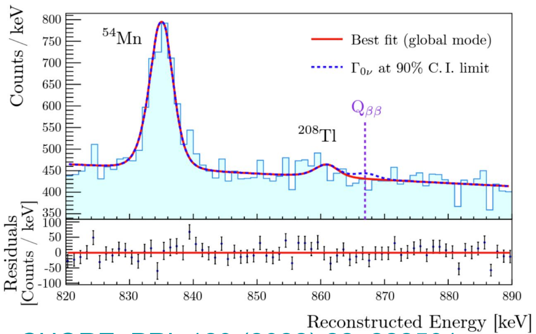
- $T_{1/2}^{2\nu} = 7.71^{+0.08}_{-0.06}(\text{stat})\ ^{+0.12}_{-0.15}\ (\text{syst}) \cdot 10^{20}$ yr
- Upgraded background model using 1 ton·yr exposure being finalized



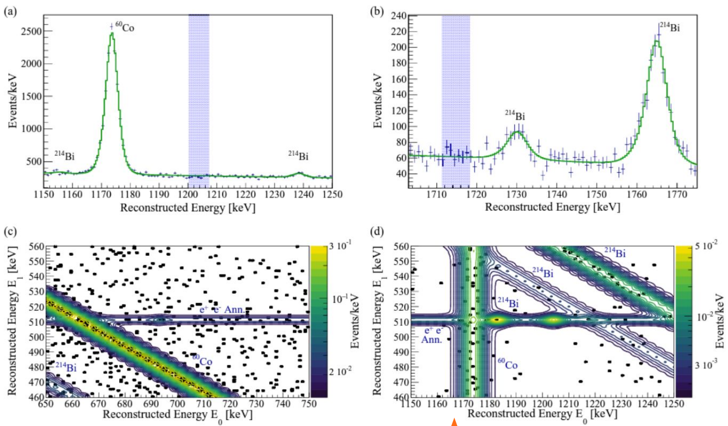


CUORE, PRL 126 (2021) 17, 171801

Other rare event searches



CUORE, PRL 129 (2022) 22, 222501



CUORE, PRC 105 (2022) 065504

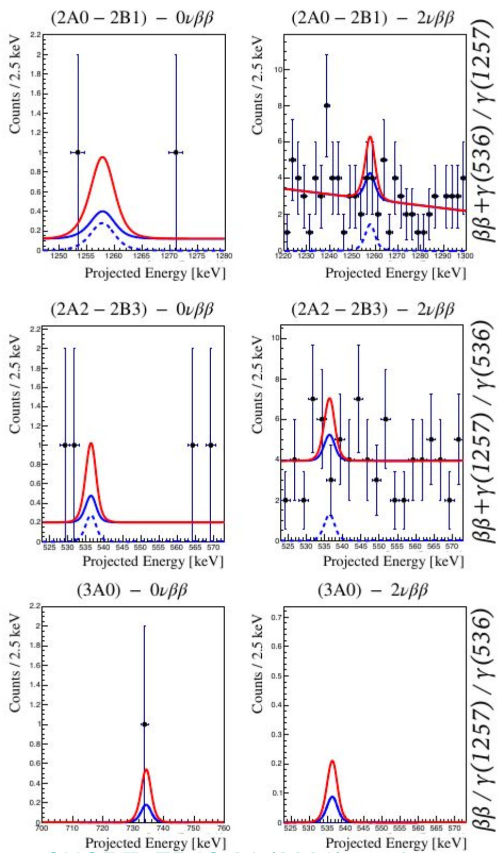
^{128}Te 0vββ decay: $T_{1/2}(^{128}Te) > 3.6 \cdot 10^{24}$ yr @ 90 % c.i.

^{120}Te 0vβ$^+$/EC decay: $T_{1/2}(^{120}Te) > 2.9 \cdot 10^{22}$ yr @ 90% c.i.

^{130}Te 0vββ and 2vββ decay to first 0$^+$ excited state:

$T_{1/2}^{0v} > 5.9 \cdot 10^{24}$ yr @ 90% c.i.

$T_{1/2}^{2v} > 1.3 \cdot 10^{24}$ yr @ 90% c.i.



CUORE, EPJC 81 (2021) 7, 567

What's next?

- CUORE goal: reaching 3 ton·yr exposure
- CUORE will run until the start of CUPID commissioning
- Big effort being put on updated and new analyses, e.g.:
  - Updated background model and $2\nu\beta\beta$ decay analysis
  - Delayed coincidence analysis for precise characterization of crystal contamination
  - Multi-signature $0\nu\beta\beta$ and $2\nu\beta\beta$ decay analysis
  - β^+EC / ECEC searches on ^{120}Te
  - Low energy analyses (dark matter, axions, supernova neutrinos, …)
- Significant work on the mitigation of noise sources to improve energy threshold and resolution
  - Noise study on diagnostic devices (accelerometers, microphones, seismometers)
  - Noise decorrelation

Thank you for the attention!