Neutrinoless double-beta decay search results from CUORE

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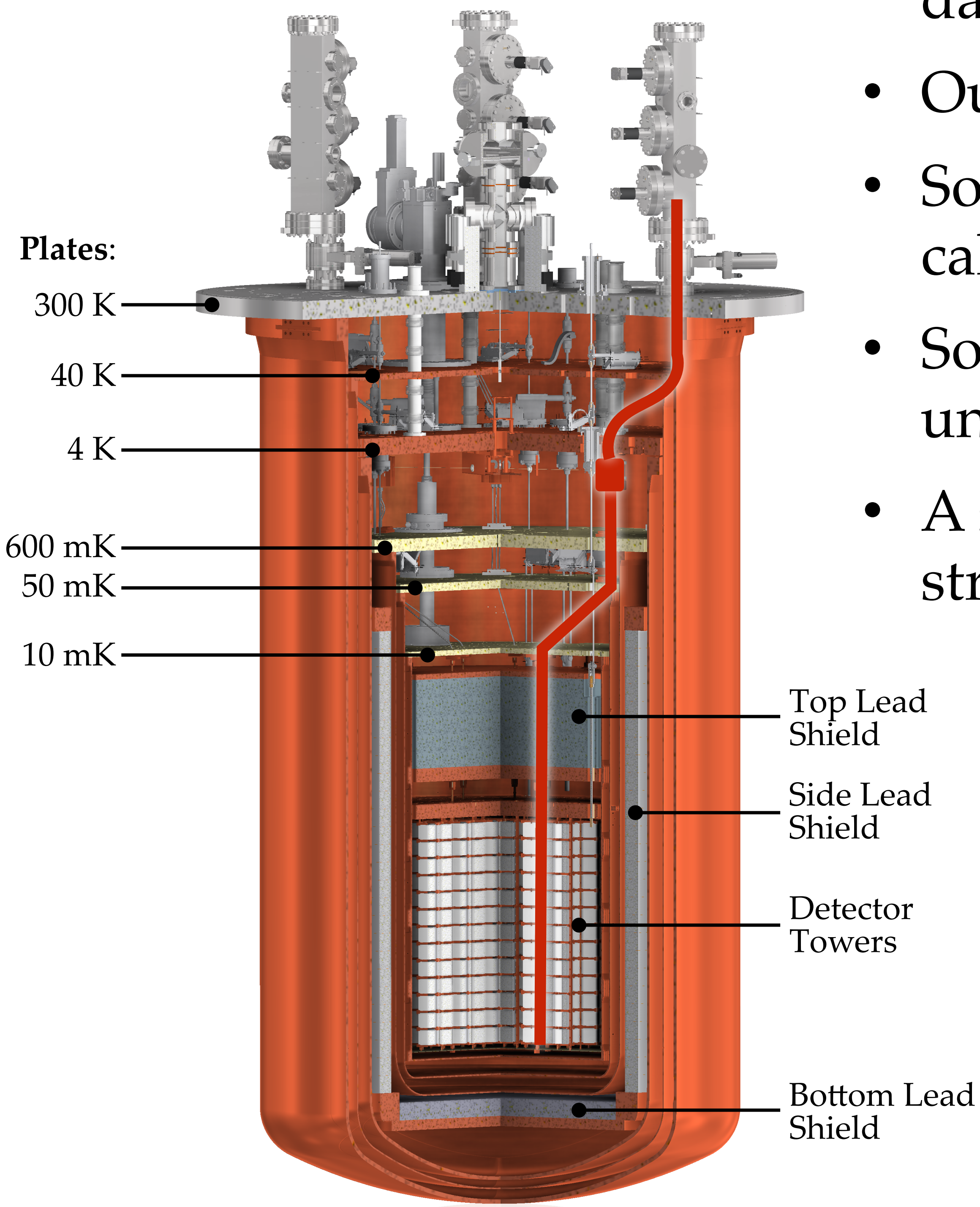
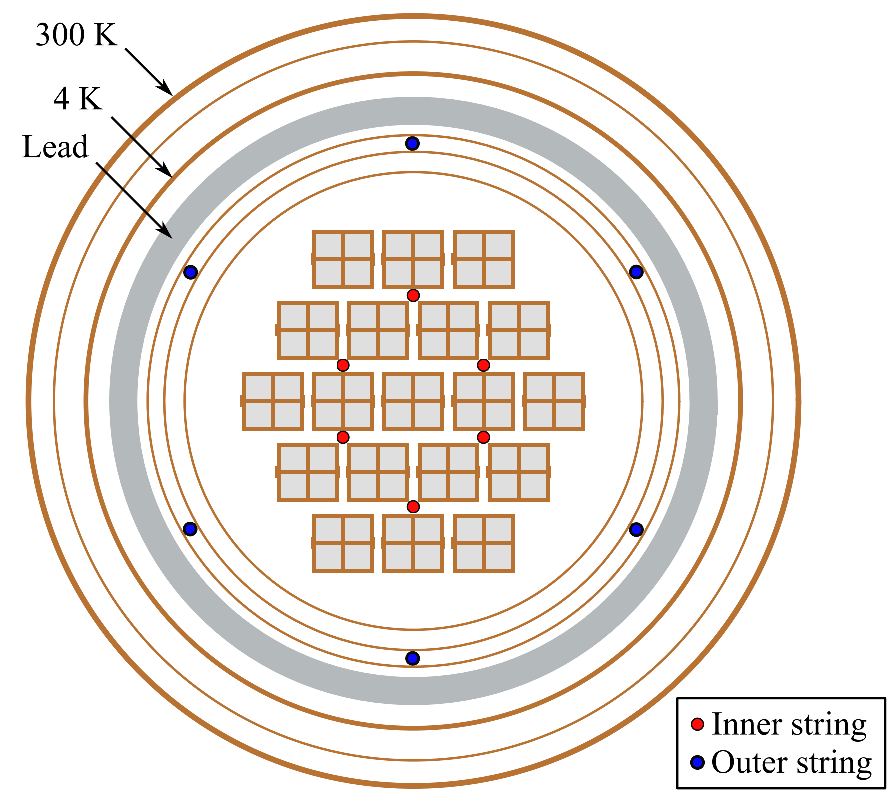
Calibration source deployment

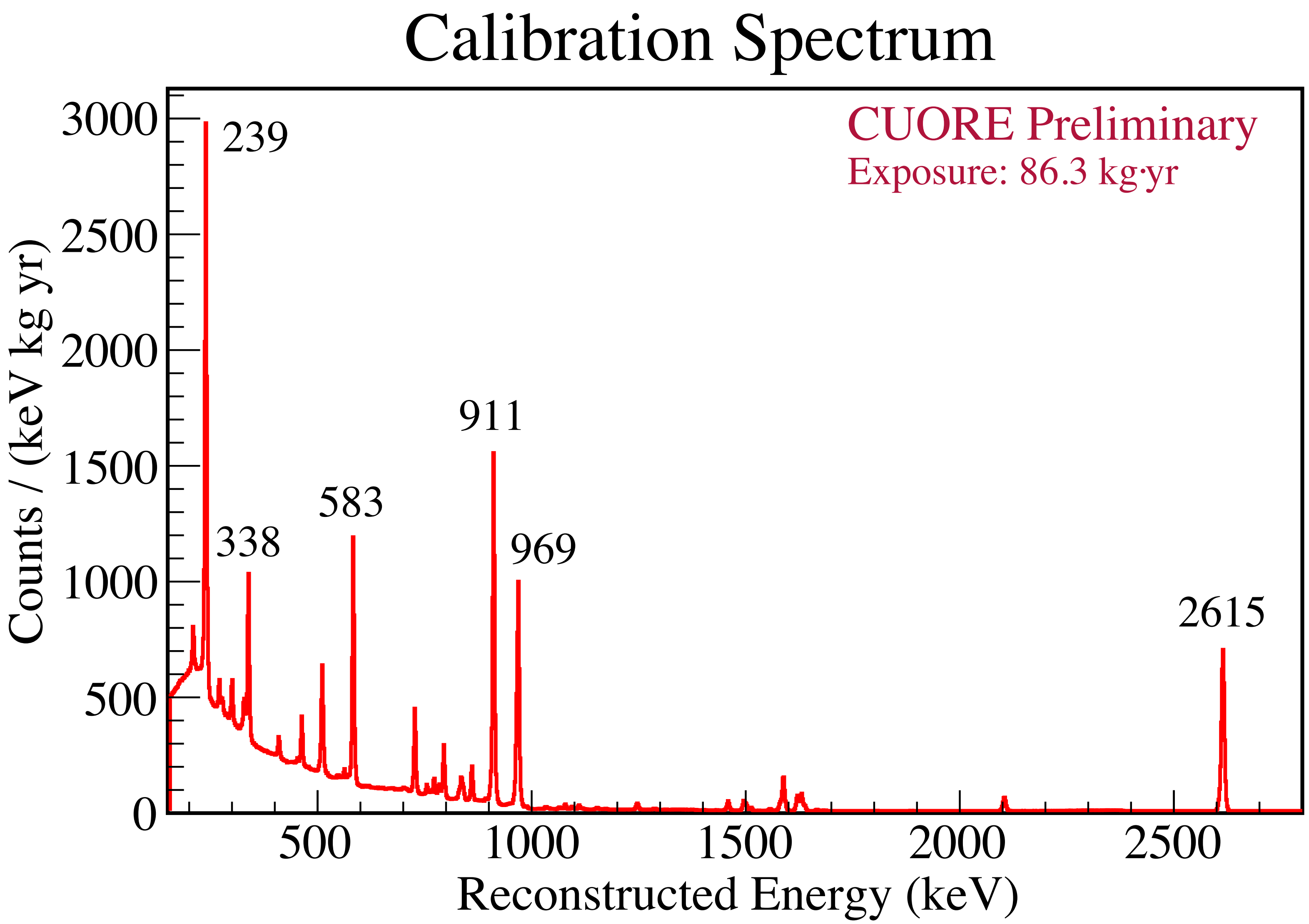


- Sources are outside cryostat during physics data-taking
- Outer bolometers shield inner bolometers
- Sources must be lowered into cryostat for calibration and cooled to 10 mK
- Sources are put on strings and are lowered under their own weight
- A series of tubes in the cryostat guide the strings



Calibrations

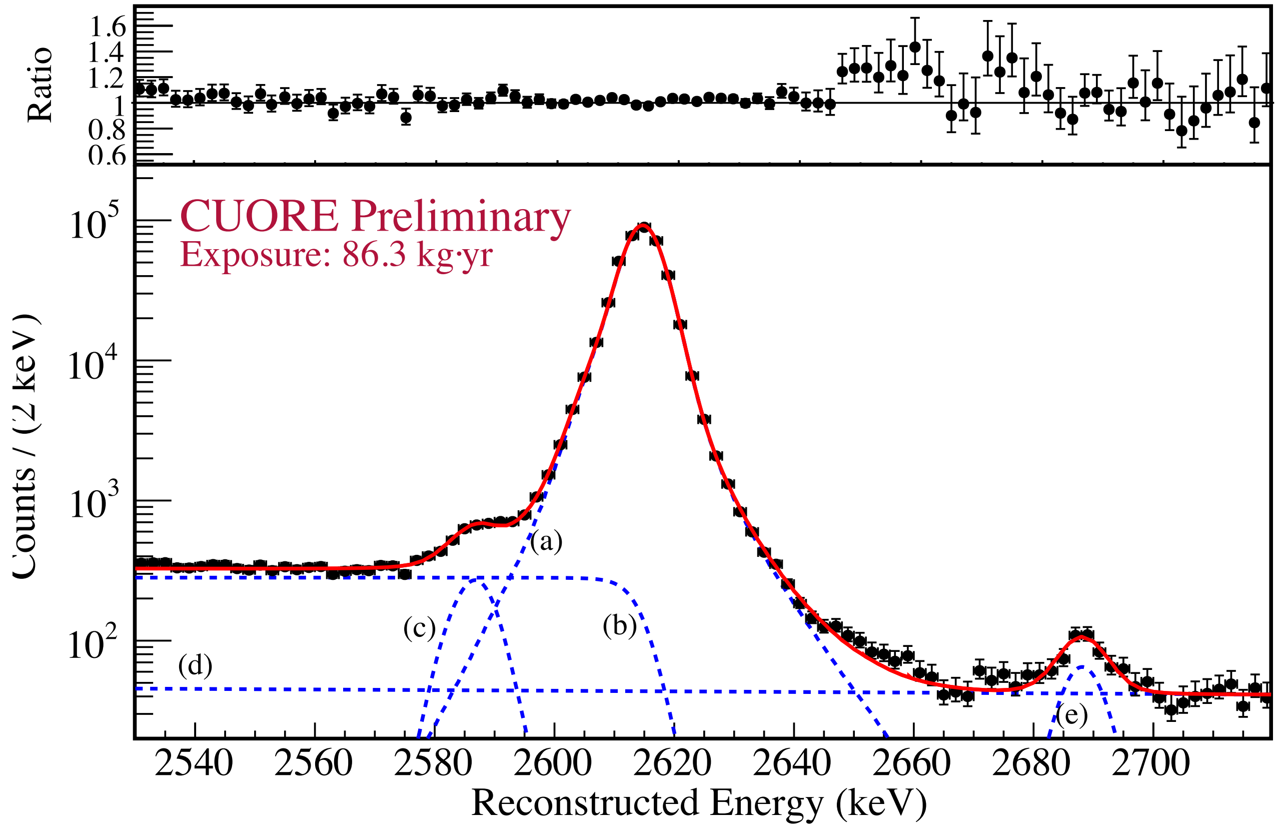
- 6 lines from the ^{232}Th decay chain are used to calibrate the detector



- Sets energy scale
- Used to study detector line shape

Line shape

- Line shape modeled from 2615-keV gamma line from calibration
  - Mono-energetic electron-like energy deposition, as $0\nu\beta\beta$ decay would be



(a) Main photopeak, modeled as the sum of 3 Gaussians

(b) Step-wise smeared multi-Compton background

(c) Te X-ray escape following a 2615 keV deposition

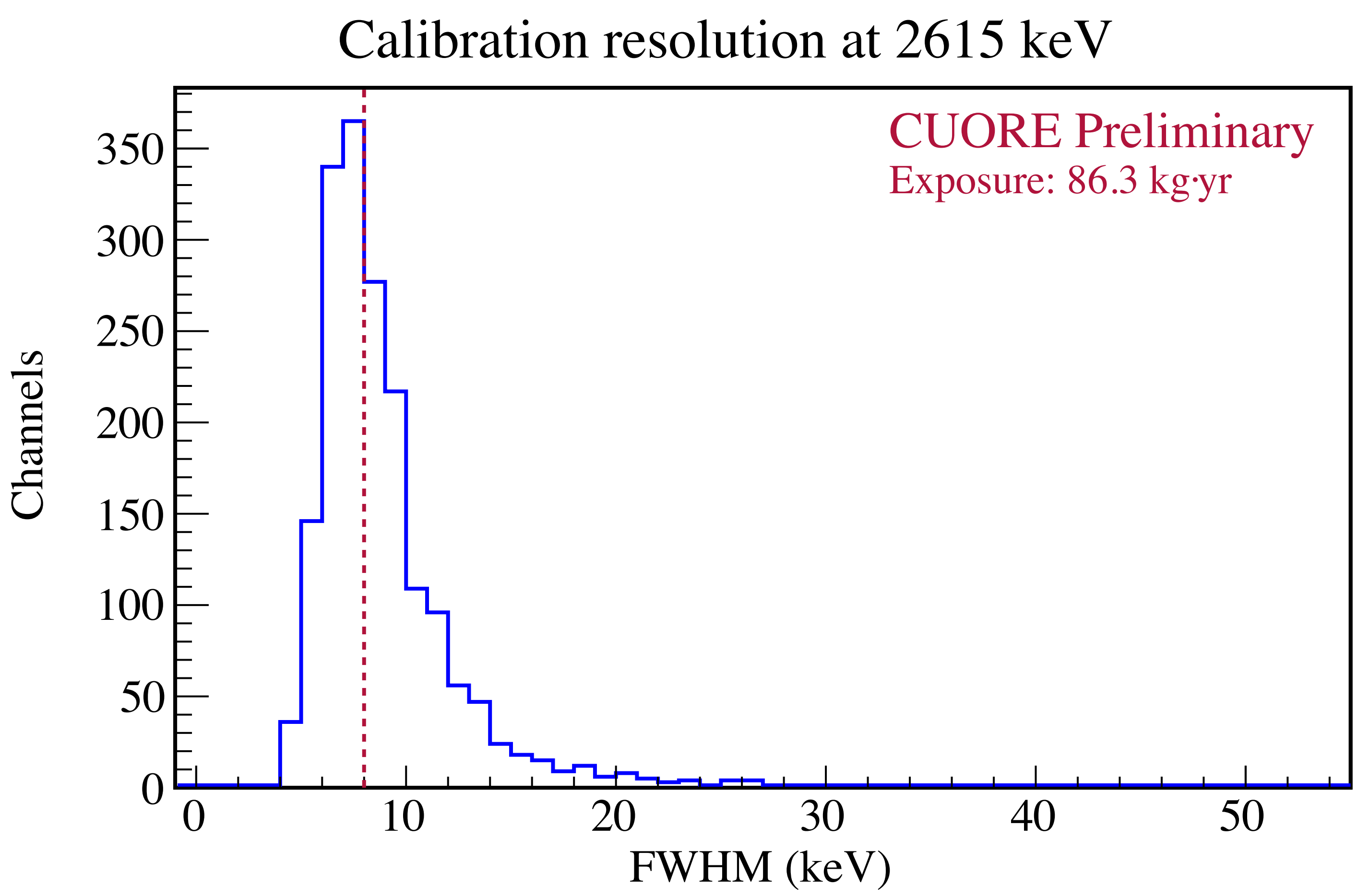
(d) Linear background

(e) Gaussian line for the coincident absorption of 2615 keV and 583 keV followed by a single 511 keV escape

- Channel-dependent shape of the 2615-keV line is used for the spectrum fit in the $0\nu\beta\beta$ decay region of interest

Calibration resolution

- Resolution of each channel is determined from the fits to the 2615-keV line

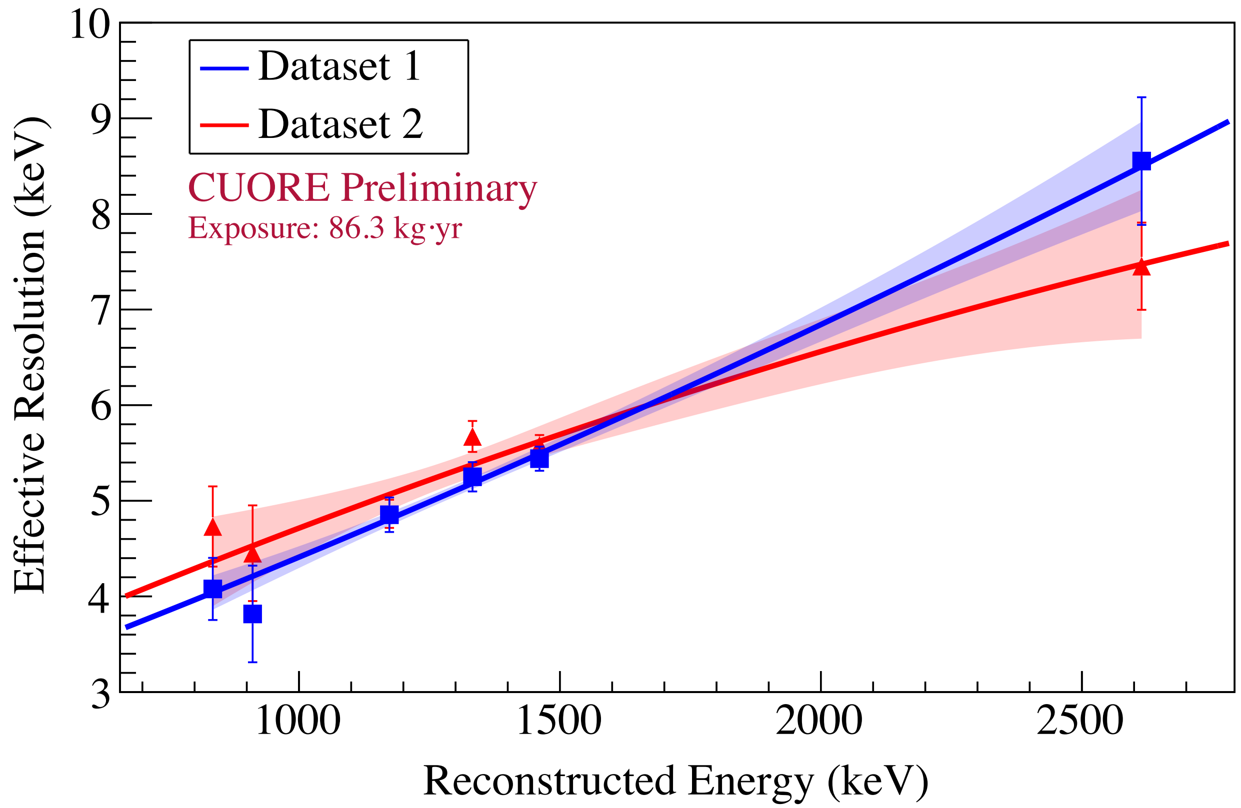


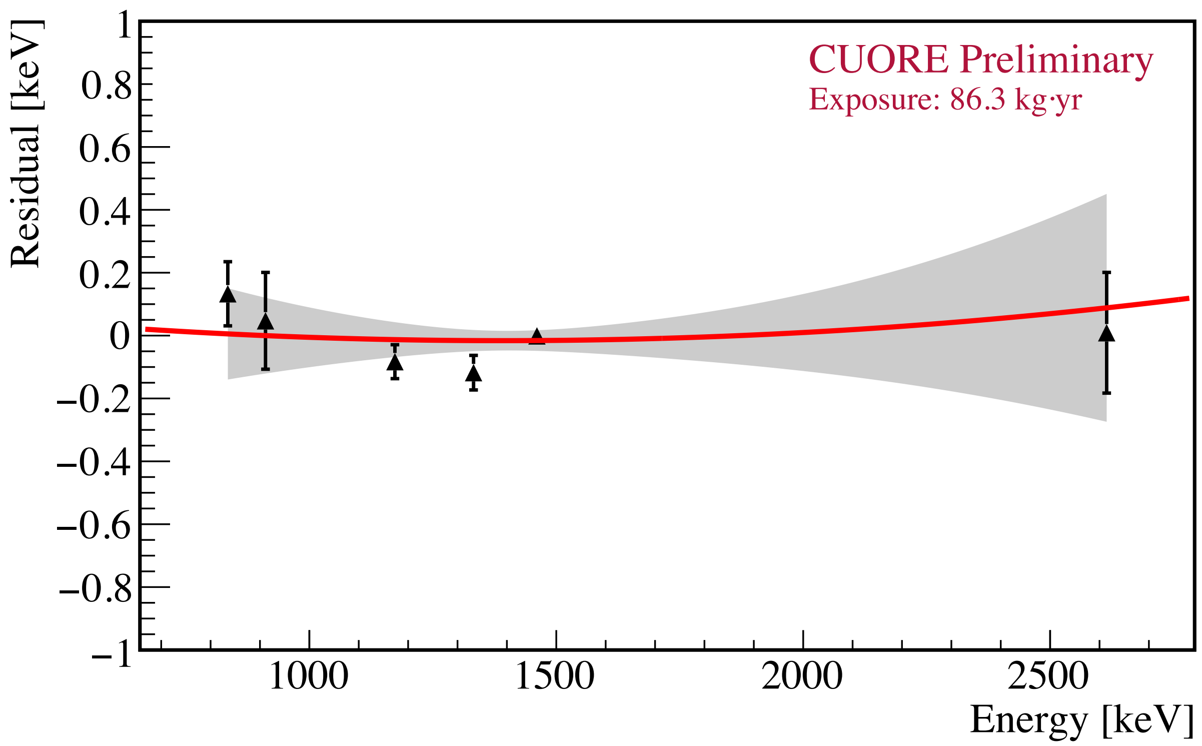
Harmonic mean resolution of all detectors at 2615 keV in calibration data:

8.0 keV

Resolution at Q-value

- We perform a fit to various lines in the physics spectrum to:
  - Estimate the resolution at the Q-value
  - Assess any possible energy reconstruction bias





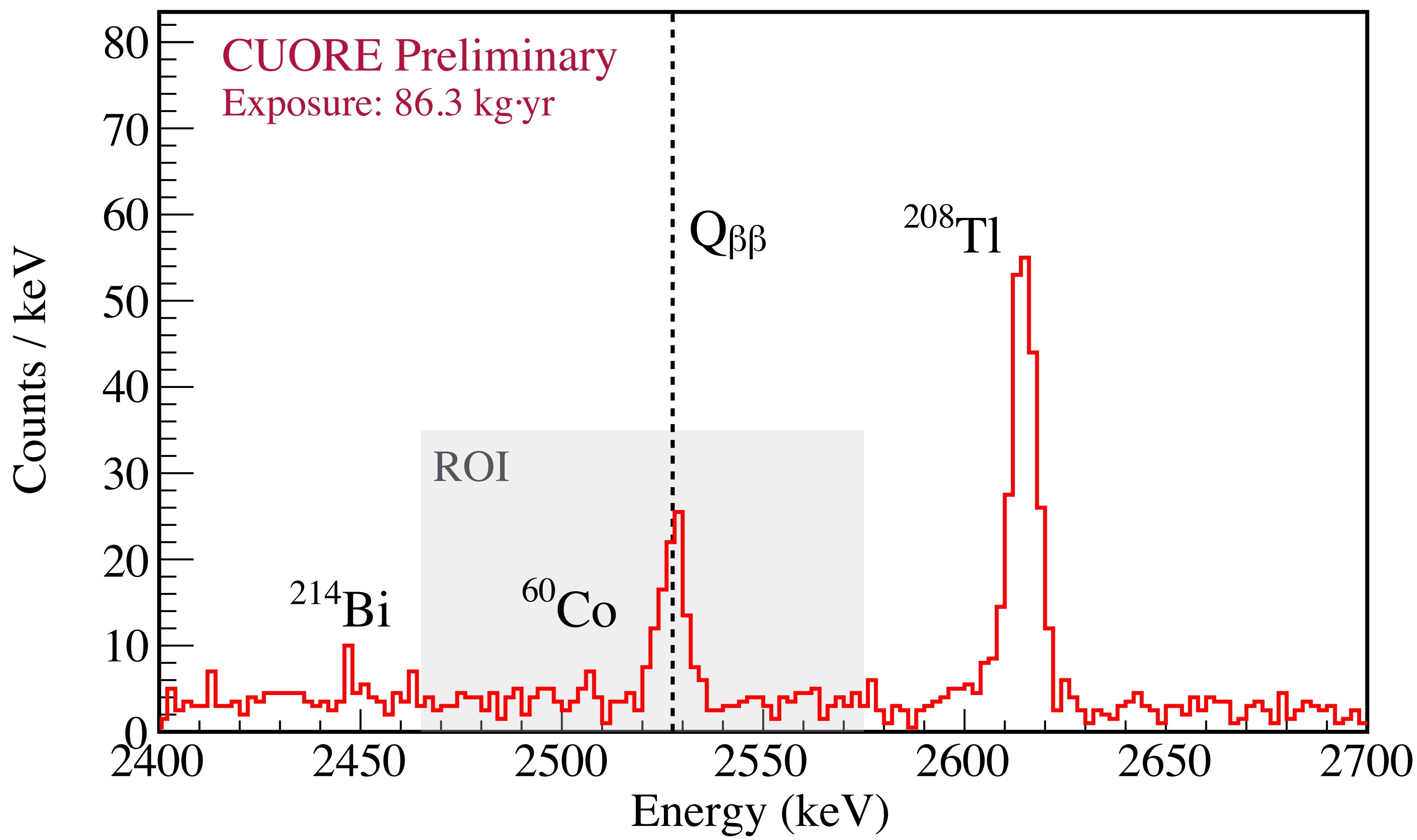
Energy resolution in physics data at Q-value:
- (8.3 ± 0.4) keV in Dataset 1
- (7.4 ± 0.7) keV in Dataset 2

- Energy bias is consistent with 0
- We conservatively take ±0.5 keV as a systematic uncertainty

Blinded spectrum

- The spectrum is blinded during data analysis by inserting a fake peak at the *Q*-value
- Events are swapped between the region around the *Q*-value and 2615 keV

CUORE physics spectrum (blinded)



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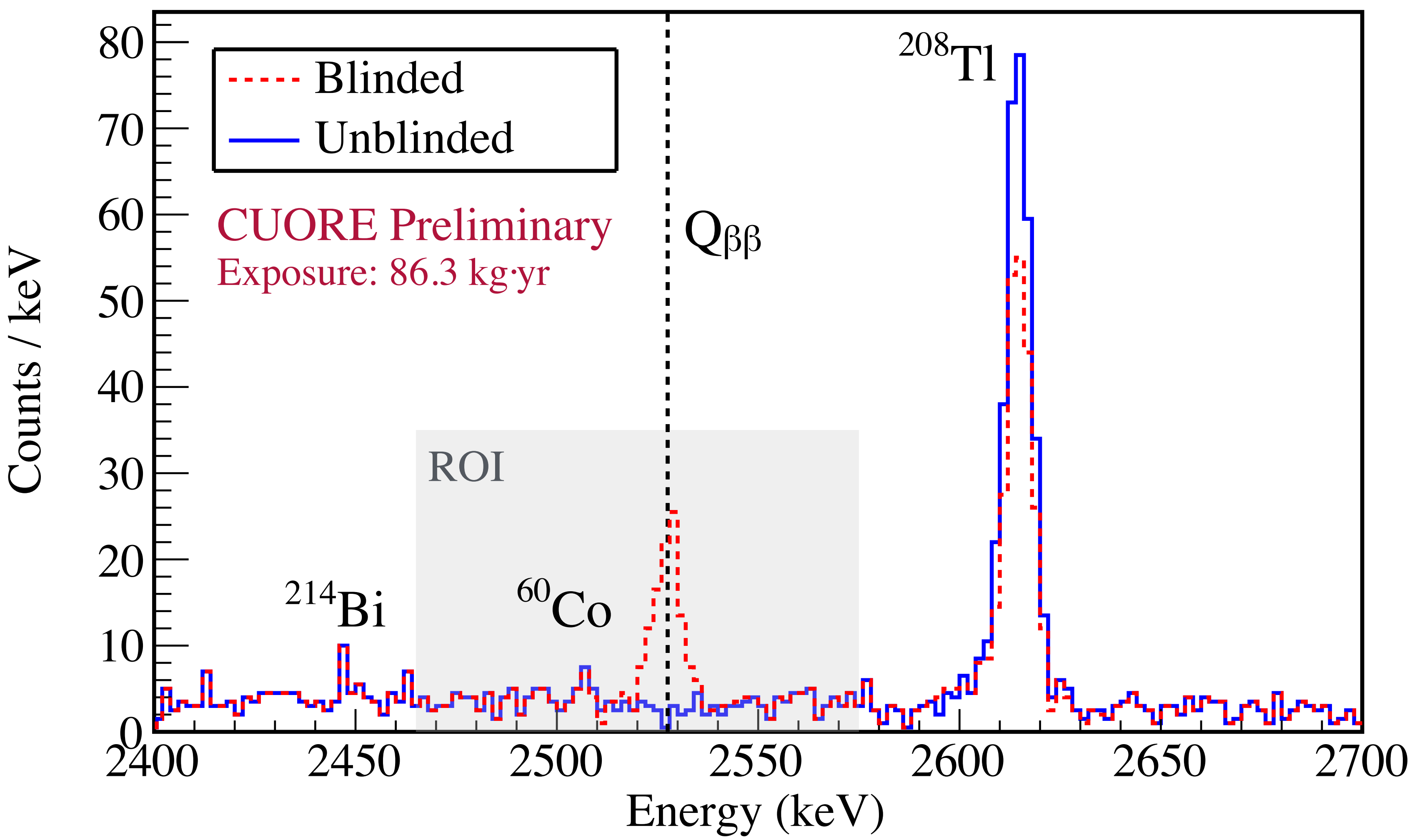
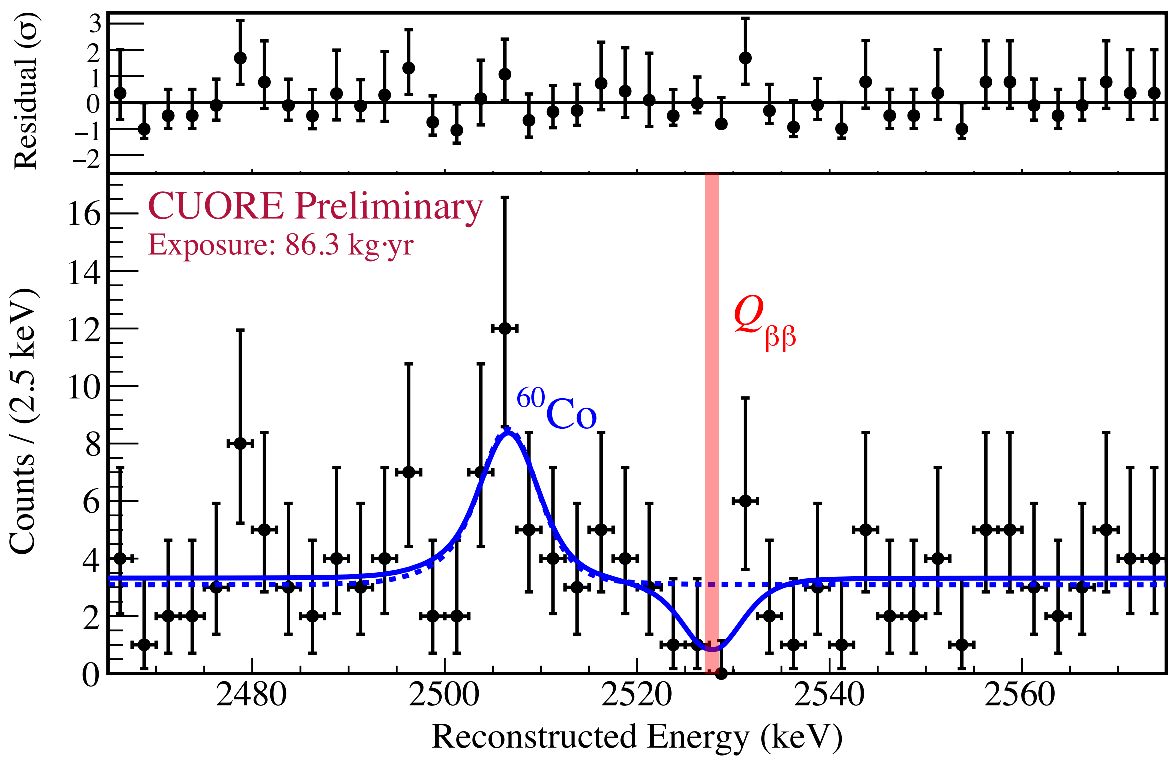


Decay rate

- Unbinned extended maximum likelihood fit in the region of interest
- Using the line shapes in each channel obtained from calibration data
- Resolution of $0\nu\beta\beta$ peak is determined from visible lines in physics spectrum
- Q-value is fixed

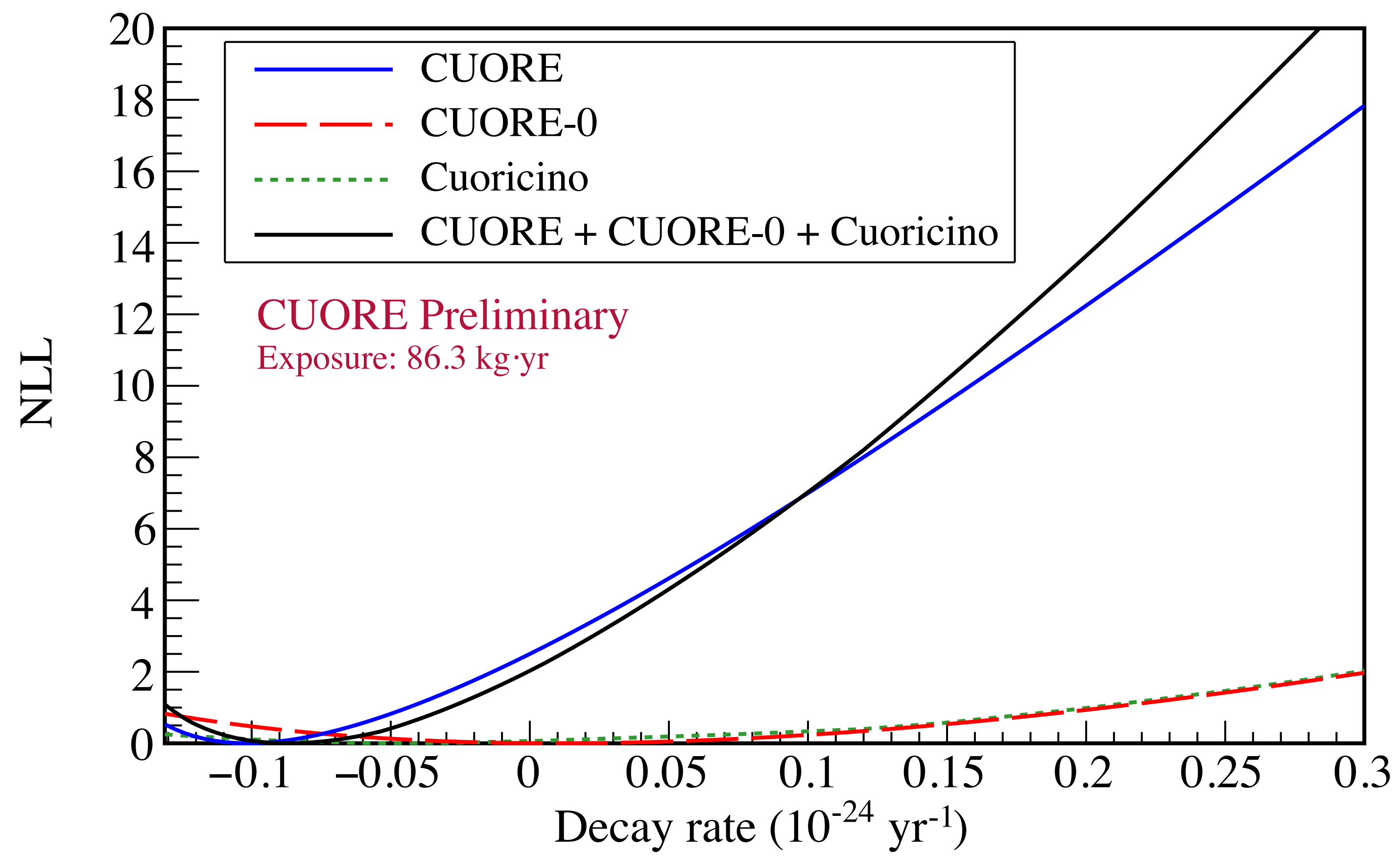


Best-fit decay rate: $(-1.0\ ^{+0.4}_{-0.3}\ (\text{stat.}) \pm 0.1\ (\text{syst.})) \times 10^{-25}\ \text{yr}^{-1}$

Background index: (0.014 ± 0.02) counts/(keV kg yr)
(no-signal model)

Half-life limit

- Integrate the negative log-likelihood in the physical region (decay rate > 0) to obtain a 90% C.L. limit on 0νββ decay



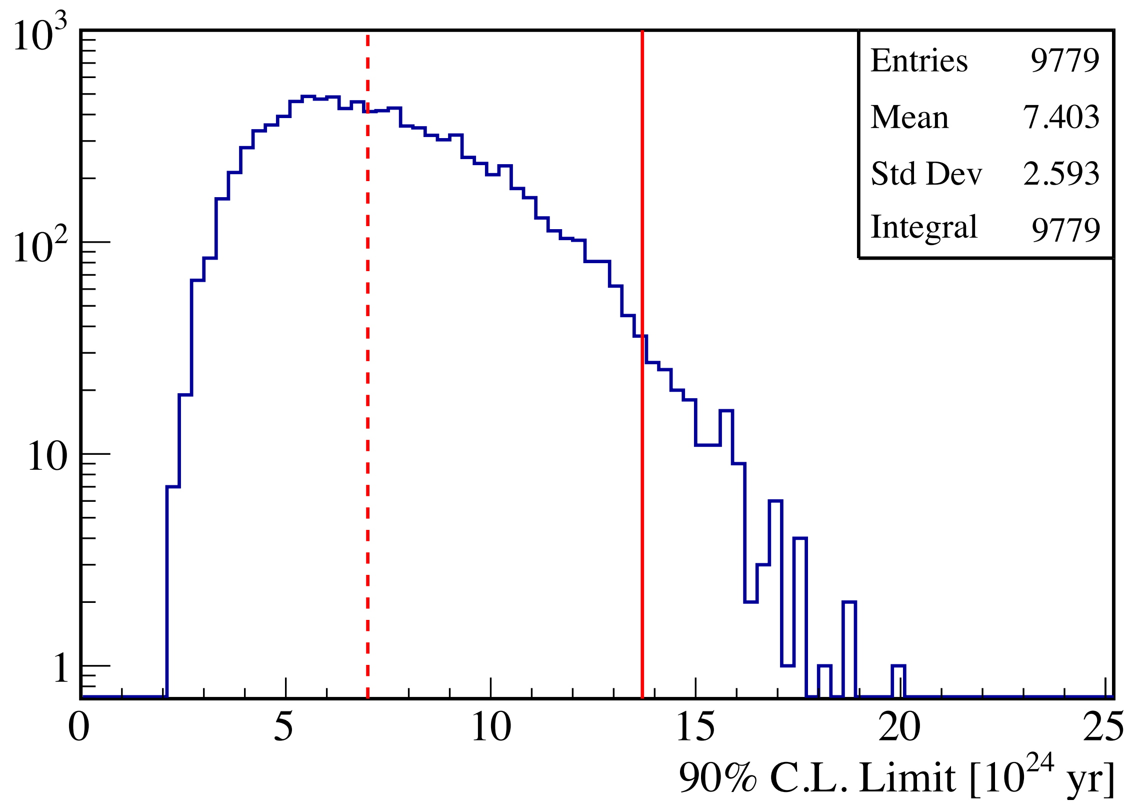
CUORE Half-life limit (90% CL): $T_{1/2}^{0\nu} > 1.3 \times 10^{25}$ yr

CUORE + CUORE-0 + Cuoricino: $T_{1/2}^{0\nu} > 1.5 \times 10^{25}$ yr

Strongest limit on 0νββ decay in ^{130}Te to date

Sensitivity

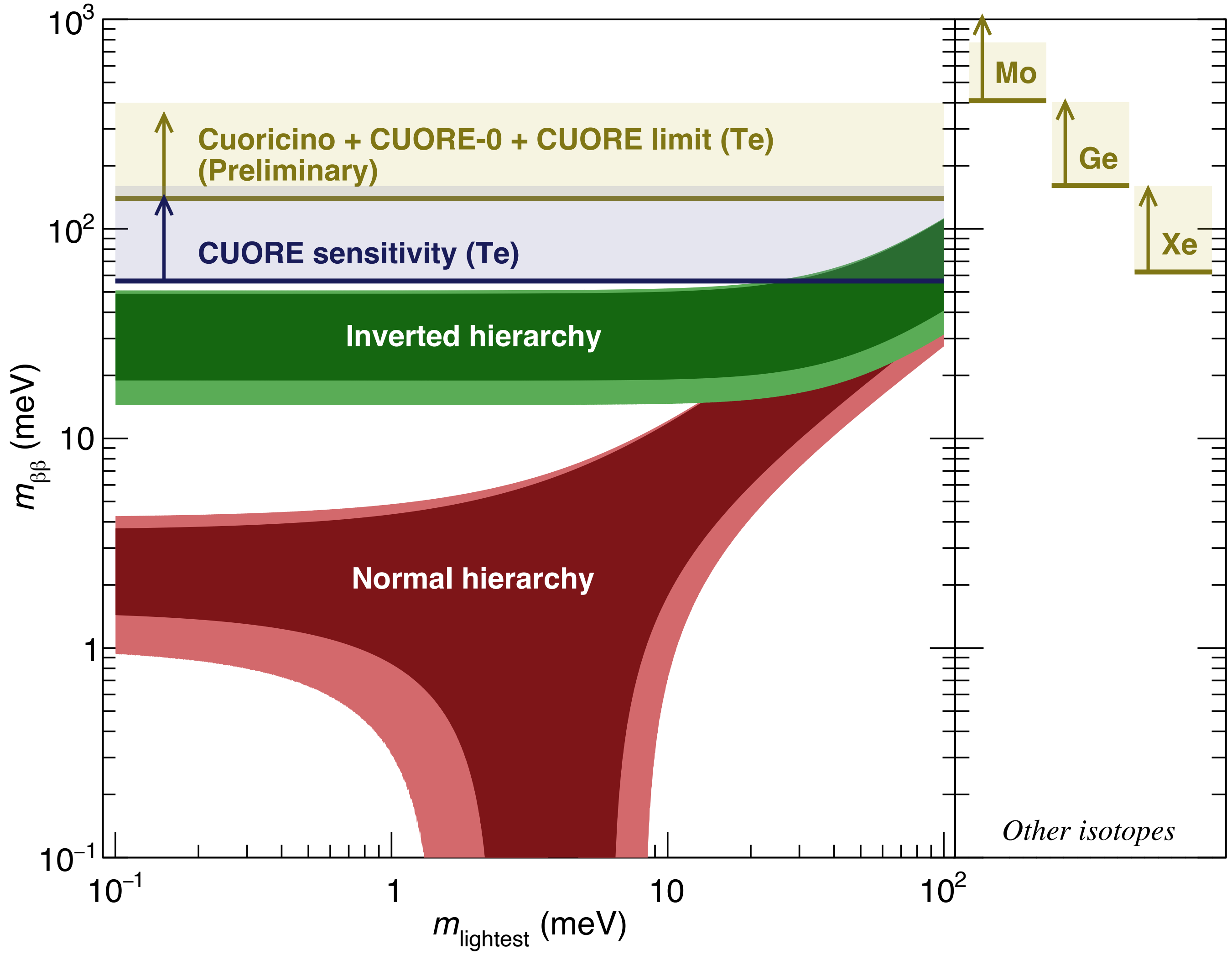
- We evaluate the sensitivity of this search by fitting a large number of pseudo-experiments generated with the null (no-signal) hypothesis



- Median 90%-C.L. limit obtained in these pseudo-experiments (the sensitivity of this search) is 7.0×10^{24} yr
- 2% chance of obtaining a more stringent limit than the one we obtained before accounting for systematic uncertainties

Effective Majorana mass

- We evaluate our result as a limit on the effective Majorana neutrino mass in the context of the model of light Majorana neutrino exchange



Nuclear matrix elements:

- Phys. Rev. C 91, 034304 (2015)
- Phys. Rev. C 87, 045501 (2013)
- Phys. Rev. C 91, 024613 (2015)
- Nucl. Phys. A 818, 139 (2009)
- Phys. Rev. Lett. 105, 252503 (2010)

Half-life limits:

- ^{130}Te: 1.5 × 10^{25} yr from this analysis
- ^{76}Ge: 5.3 × 10^{25} yr from Nature 544, 47–52 (2017)
- ^{136}Xe: 1.1 × 10^{26} yr from Phys. Rev. Lett. 117, 082503 (2016)
- ^{100}Mo: 1.1 × 10^{24} yr from Phys. Rev. D 89, 111101 (2014)
- CUORE sensitivity: 9.0 × 10^{25} yr

- We obtain $m_{\beta\beta} < 140 – 400$ meV, depending on the nuclear matrix elements used

Summary

- We have collected almost 100 kg yr of exposure with CUORE
- CUORE has set a limit on ^{130}Te $0\nu\beta\beta$ decay greater than 10^{25} years: arXiv:1710.07988
- The CUORE cryostat, a huge engineering feat, has been operating smoothly and reliably in these first datasets
- With 5 years of live time, the sensitivity of CUORE will improve by over an order of magnitude from its current value
- Thanks to the DOE Office of Science, Nuclear Physics, and Yale University for funding this research
- More physics results are on the way!