Calibration of CUORE-0 and CUORE

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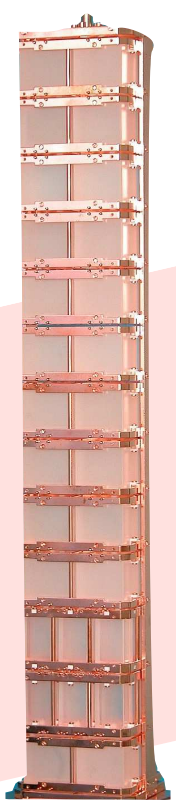
APS DNP Meeting, 10/29/15

Cuoricino to CUORE

Cuoricino
(2003-2008)



Astropart. Phys. **34**, 822–831 (2011)

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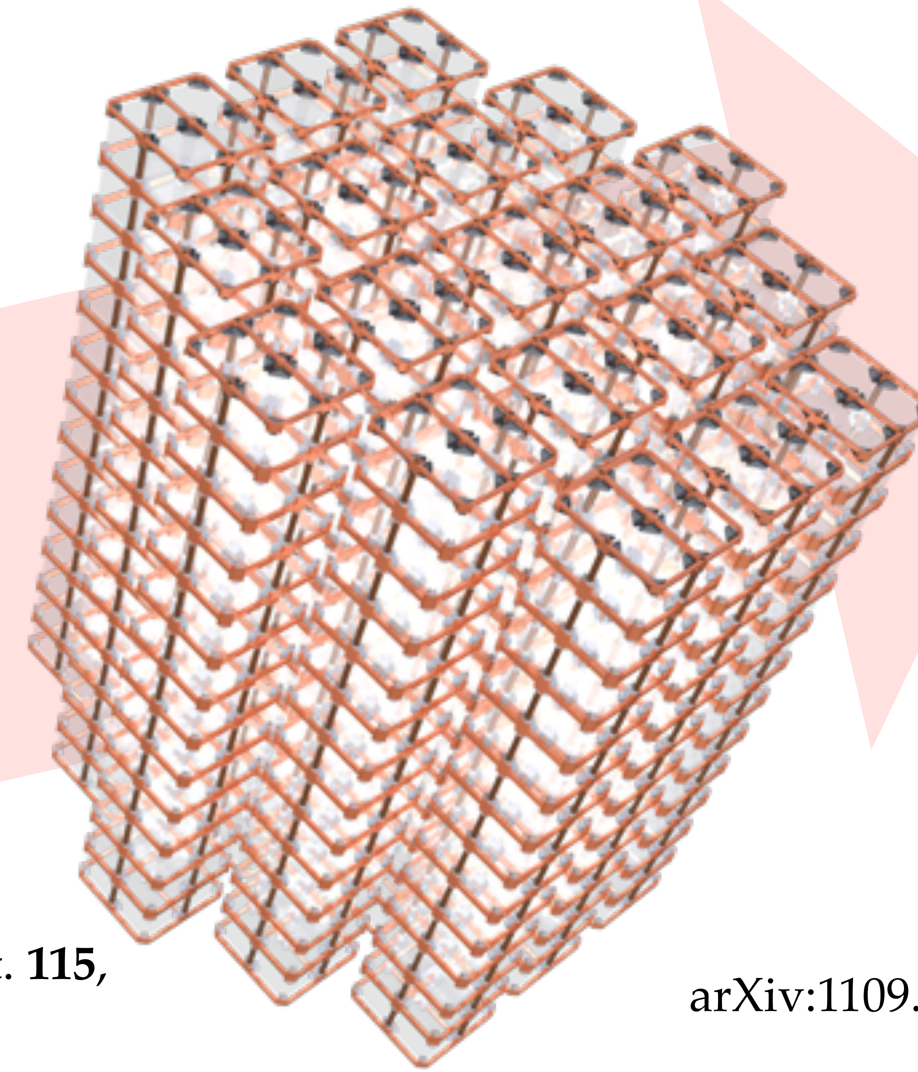
CUORE-0
(2013-2015)

Phys. Rev. Lett. **115**, 102502 (2015)

$T_{1/2}^{0\nu\beta\beta} > 4.0 \times 10^{24}$ y (90% C.L.)

CUORE
(2015-2020)

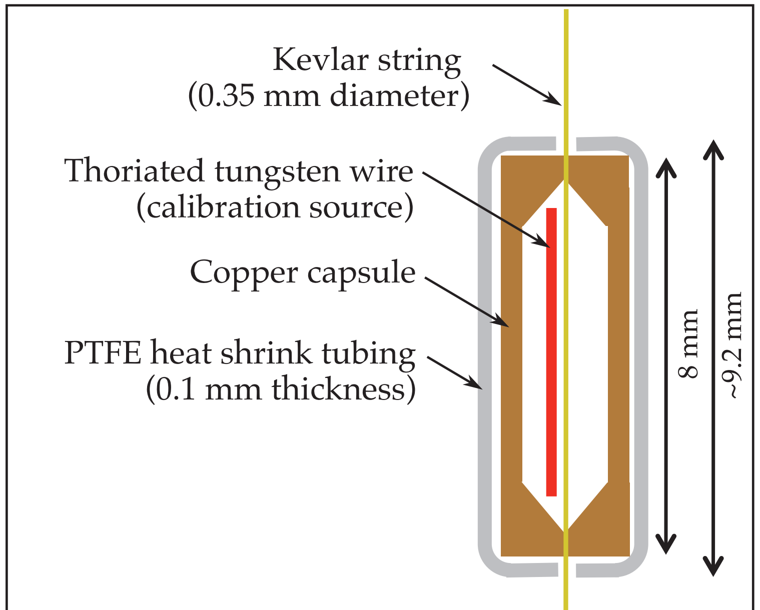


arXiv:1109.0494

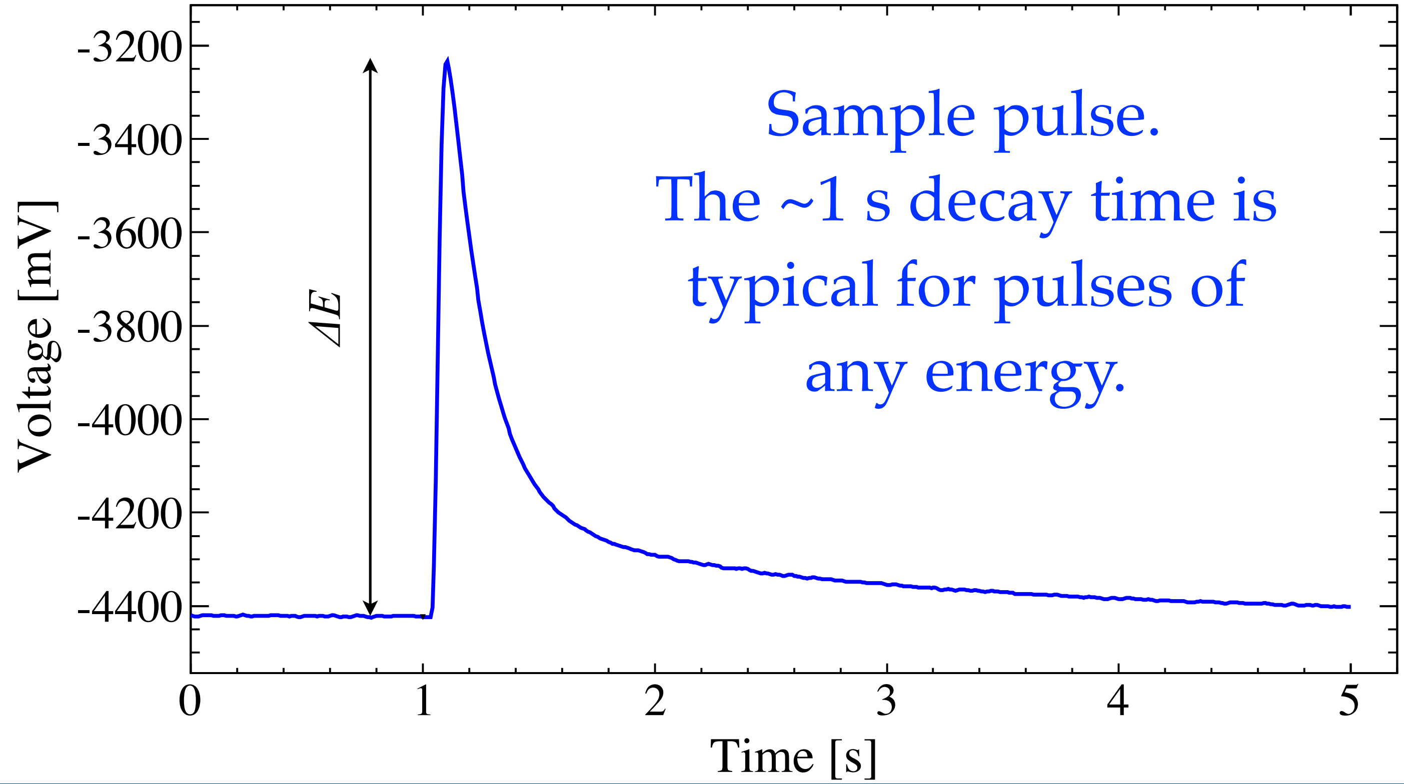
Projected:
$T_{1/2}^{0\nu\beta\beta} > 9.5 \times 10^{25}$ yr (90% C.L.)
$m_{\beta\beta} < 50 - 130$ meV

Bolometer calibration

- Voltage signals from the thermistors must be calibrated to convert temperature rises in the bolometers to true particle energies
- Bolometers require independent *in situ* energy calibration
- Monthly, the crystals are exposed to ^{232}Th γ-ray sources
- Gain and detector stability is measured between calibrations with a constant-energy pulser

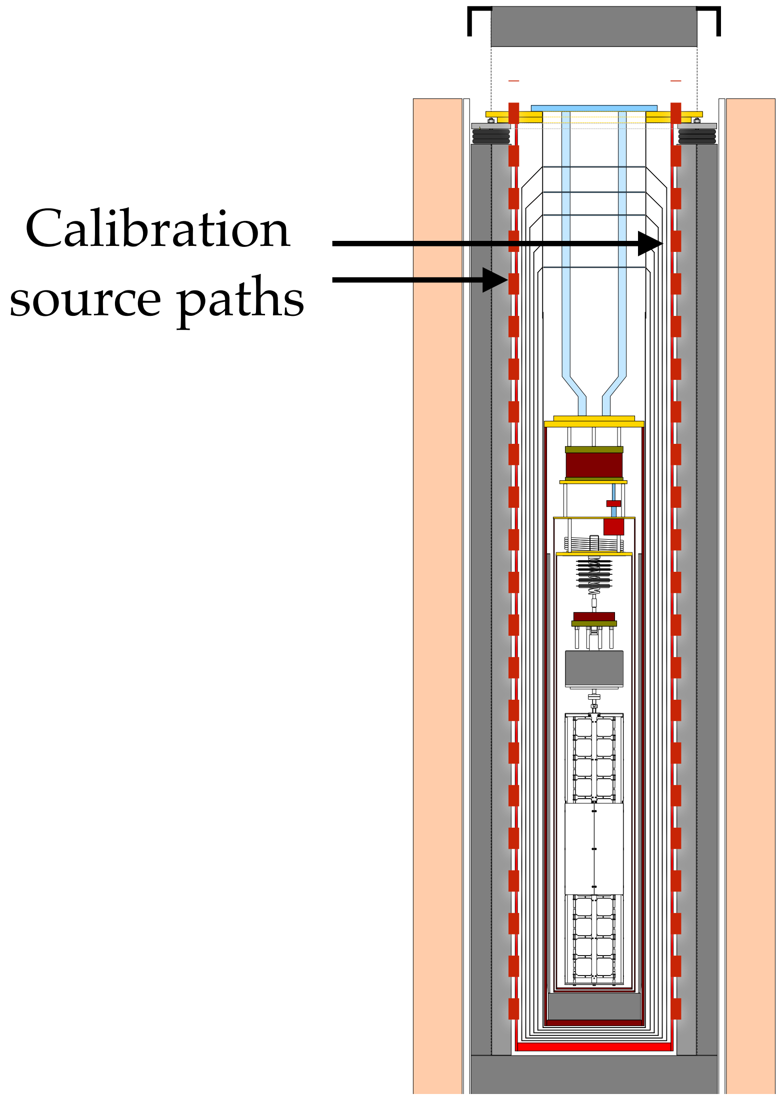


Source string and capsule



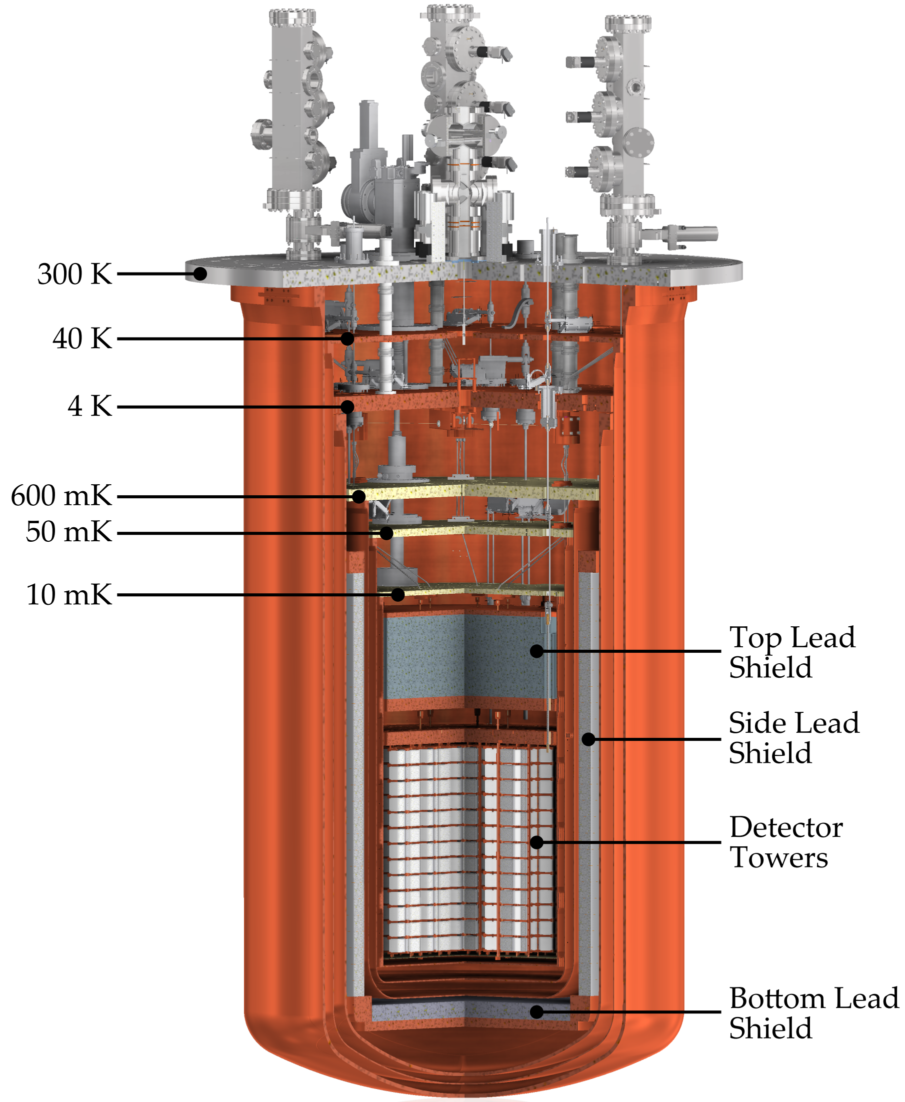
Calibration hardware

CUORE-0



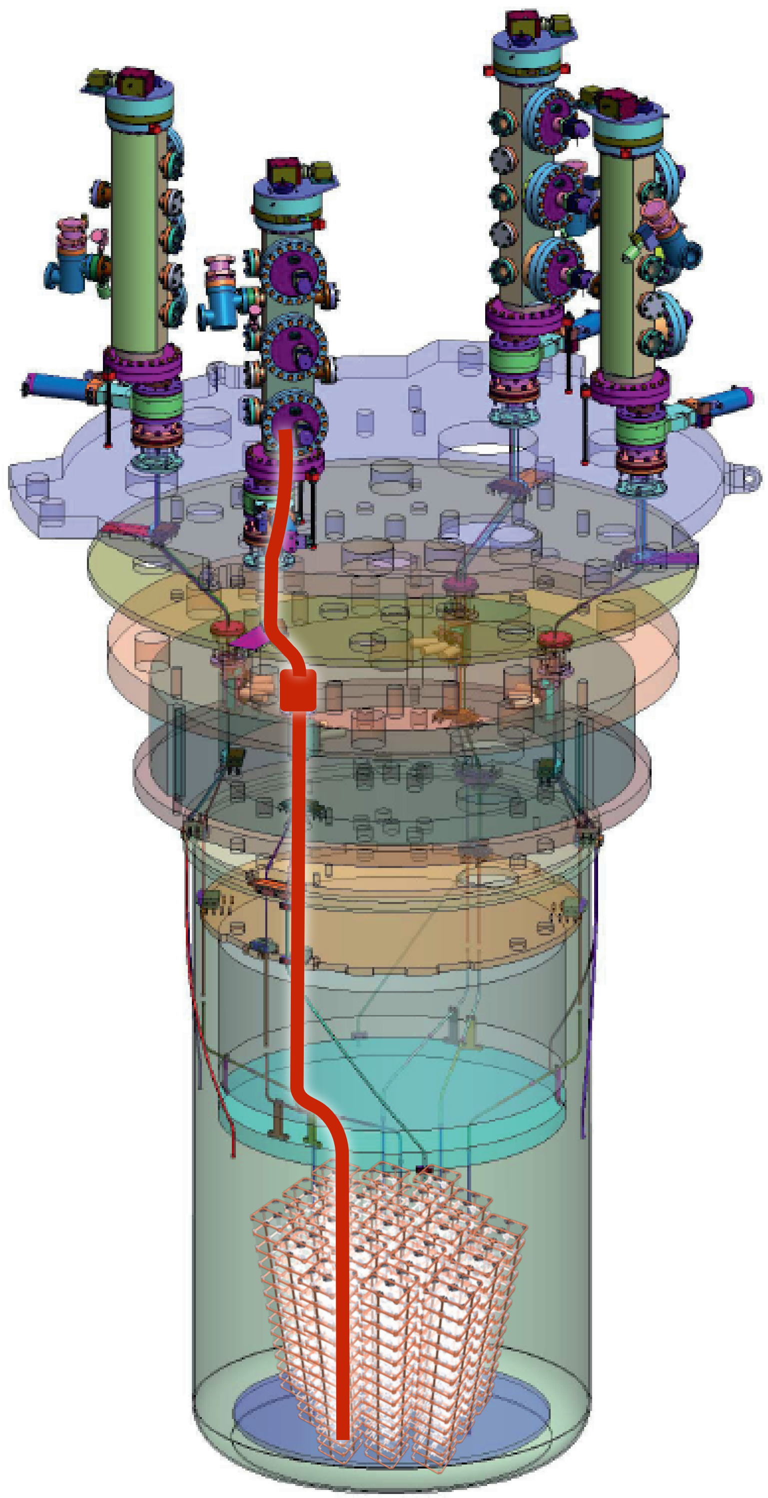
- Only one tower
- Sources can be placed outside cryostat but inside shielding
- Sources can be positioned by hand

CUORE

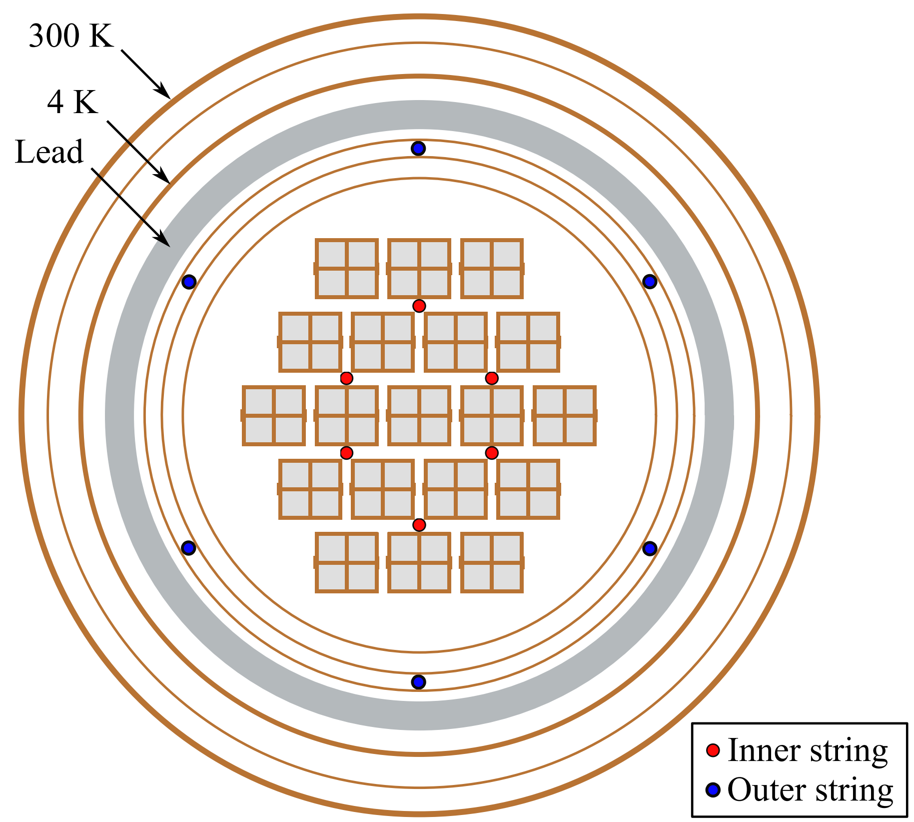


- Outer towers shield inner towers
- Sources must be cold and placed among towers inside cryostat
- Source deployment must be automated

CUORE calibration source deployment



- Source strings are outside cryostat during physics data-taking
- Lowered into cryostat for calibration (~monthly) and cooled from 300 K to 10 mK inside guide tubes
- Strings move under their own weight



6 inner source strings

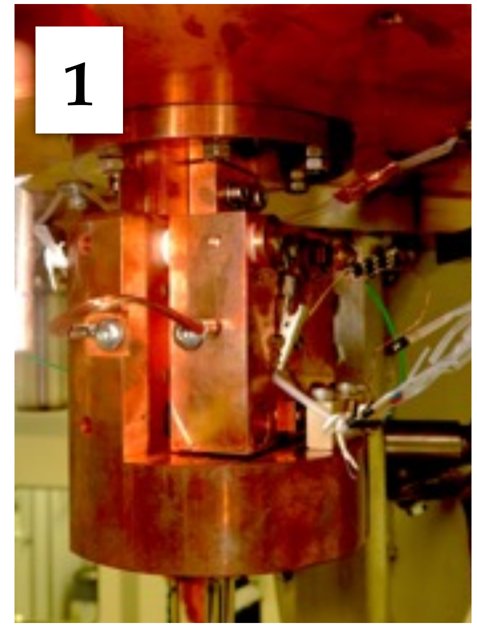
- 3.5 Bq each
- Guided between the bolometer towers to illuminate the inner detectors

6 outer source strings

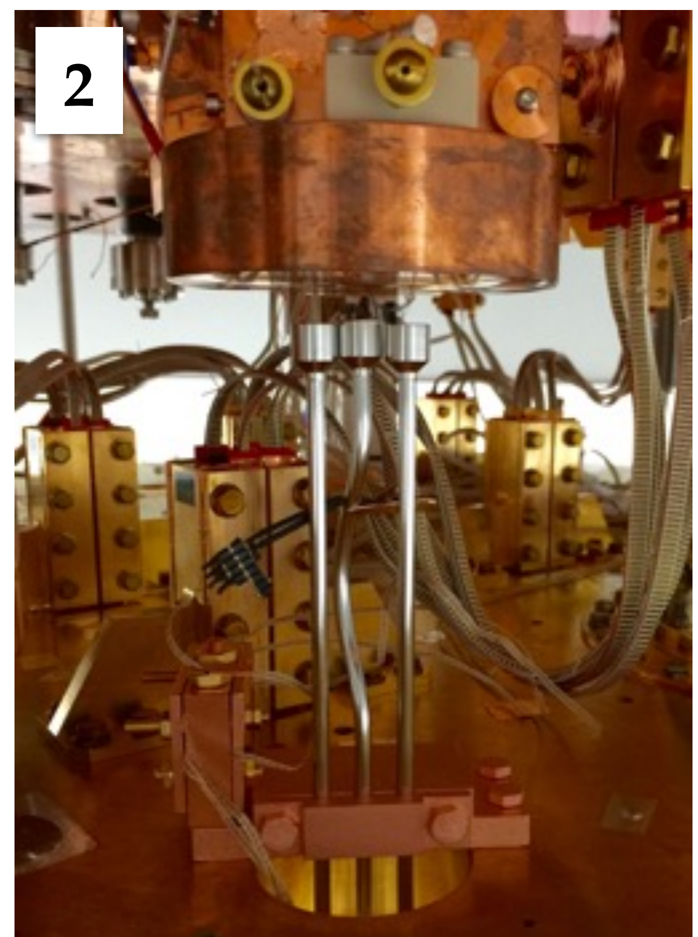
- 19.4 Bq each
- Guided to outside of detector region and allowed to hang freely

CUORE Detector Calibration System

Installing the calibration system in the cryostat

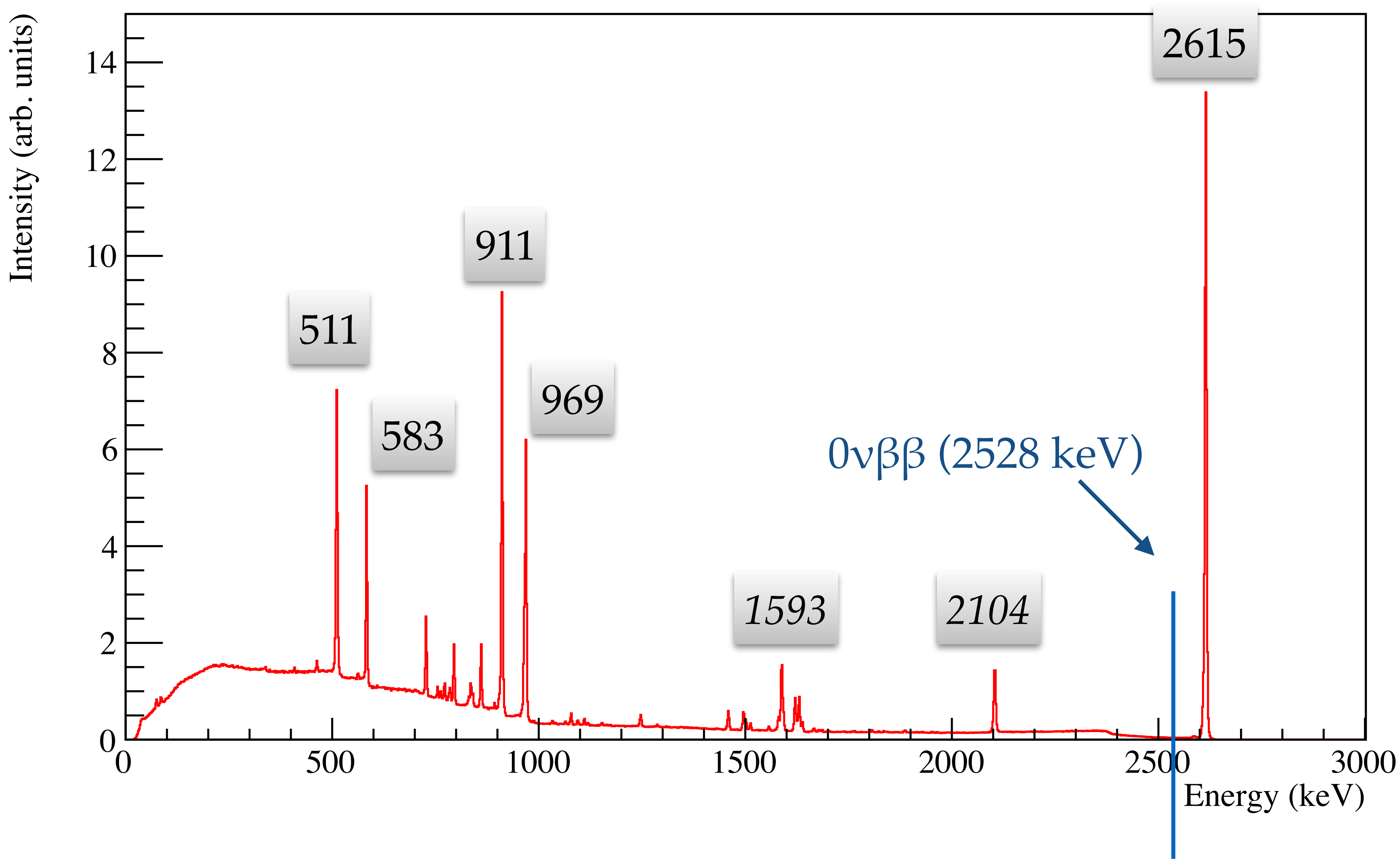


1. **4-Kelvin thermalization mechanism**
2. **Stainless steel guide tubes**
3. **Source string hanging near test tower**



CUORE-0 calibration spectrum

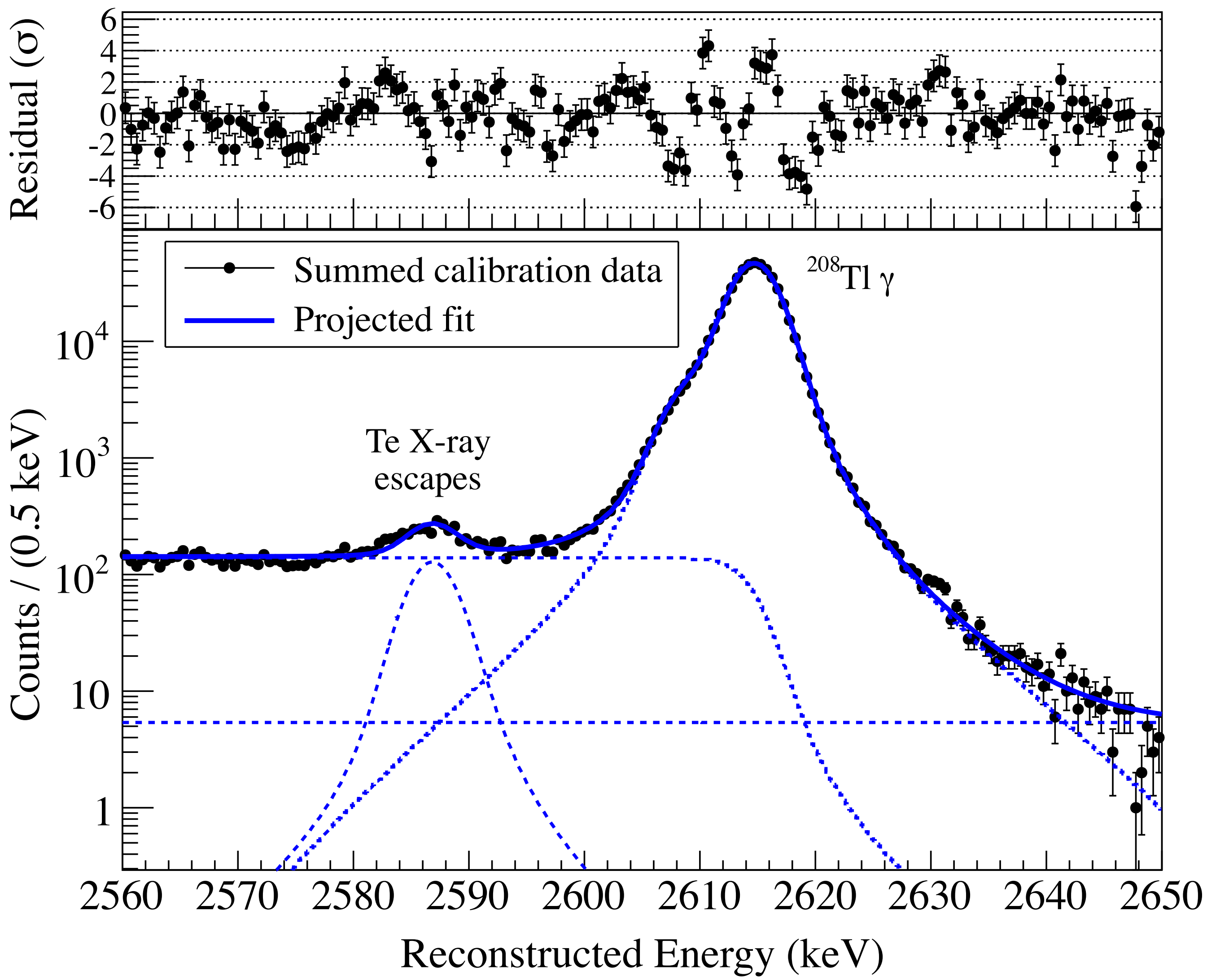
- ^{232}Th decay chain gives a wide variety of gamma lines (7 strong lines)



- Also visible are the single and double escape lines from 2615 keV, at 2104 keV and 1593 keV, respectively

Detector resolution

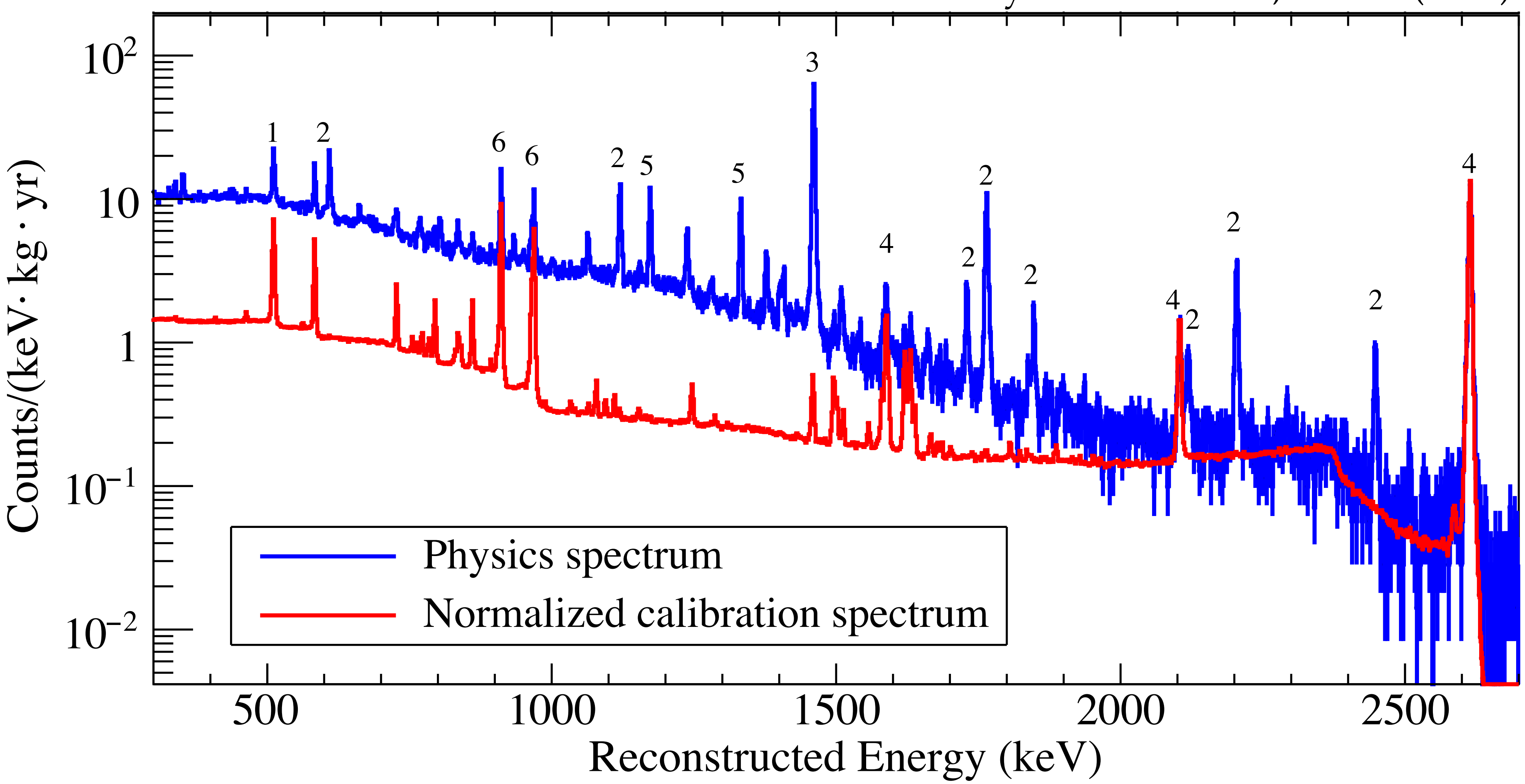
- 2615 keV gamma peak used to measure detector resolution near *Q*-value (2528 keV)
- Fit contains full energy peak, secondary peak due to Te X-ray escape, Compton multiscatter continuum, and flat background



- Each channel is fit independently
- Exposure-weighted harmonic mean of FWHM values gives 5.1 ± 0.3 keV resolution at 2615 keV (0.2%)
- Resolutions of physics and calibration data are consistent

CUORE-0 physics spectrum

Phys. Rev. Lett. **115**, 102502 (2015)



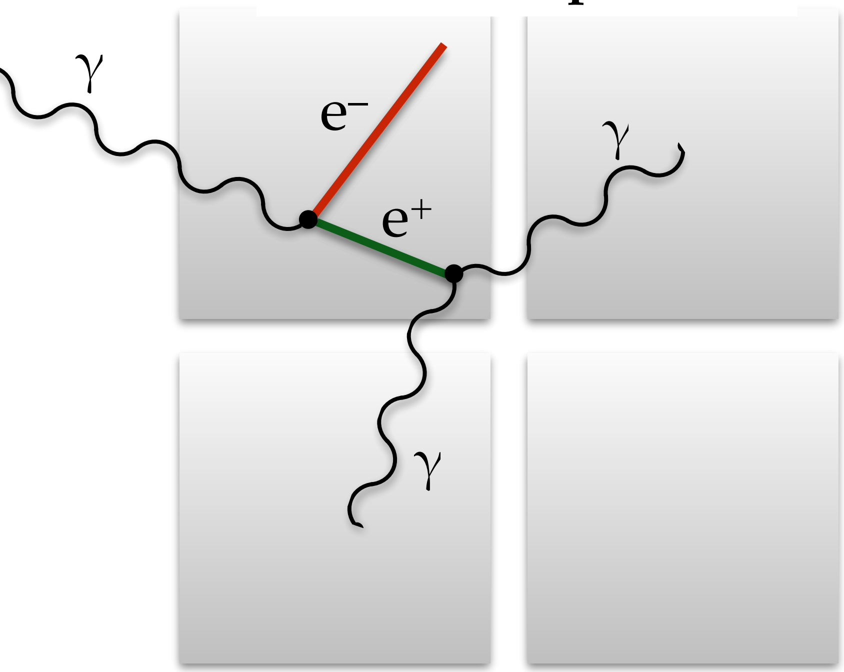
(1) e^+e^-
(2) ^{214}Bi
(3) ^{40}K
(4) ^{208}Tl
(5) ^{60}Co
(6) ^{228}Ac

- Calibration performance is tested by measuring residuals (i.e., reconstructed energy – true energy) in the physics data
- The measured single-gamma energy scale uncertainty is 0.1 keV

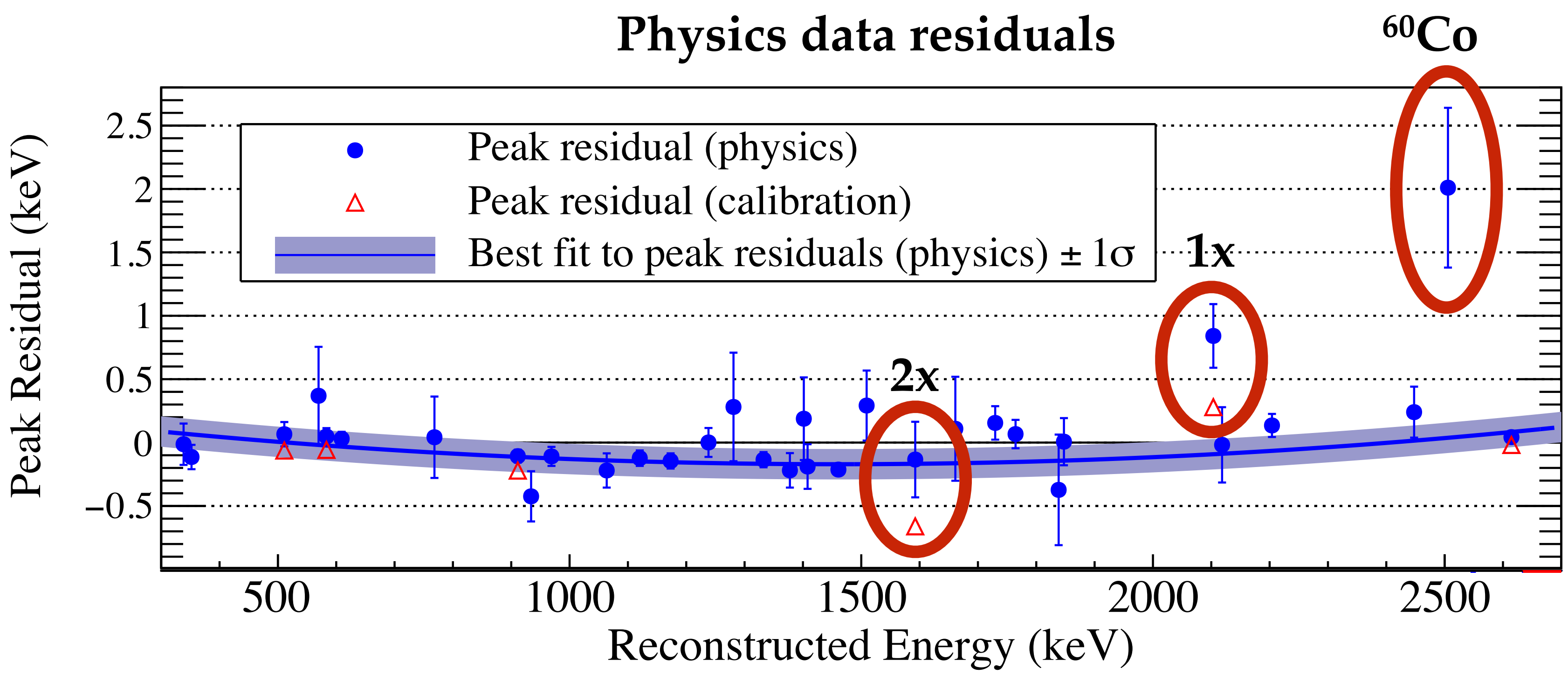
Calibration challenges

- Coincident gammas and single and double escape peaks can be reconstructed with different energies

Double escape event:



Physics data residuals

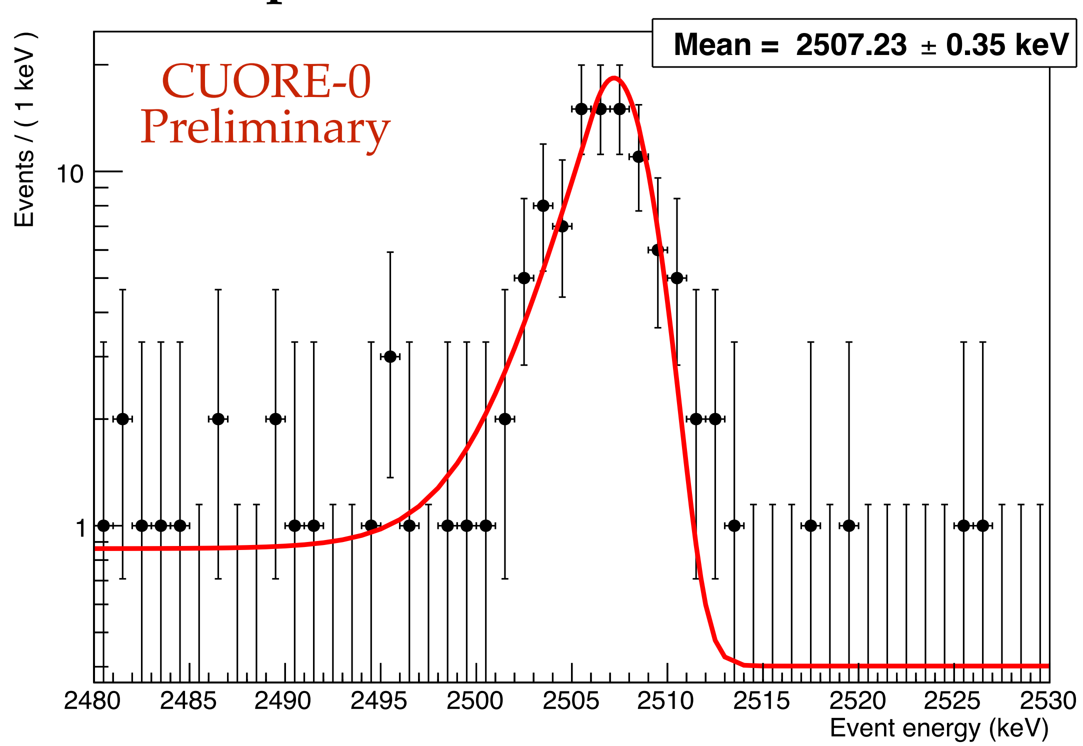


- Peak at 2505 keV is the result of coincident 1173 and 1332 keV gammas from ^{60}Co, and it is reconstructed 1.9 ± 0.7 keV too high
- Double escape events most resemble neutrinoless double beta decay ($0\nu\beta\beta$) events, so understanding their energy reconstruction is crucial

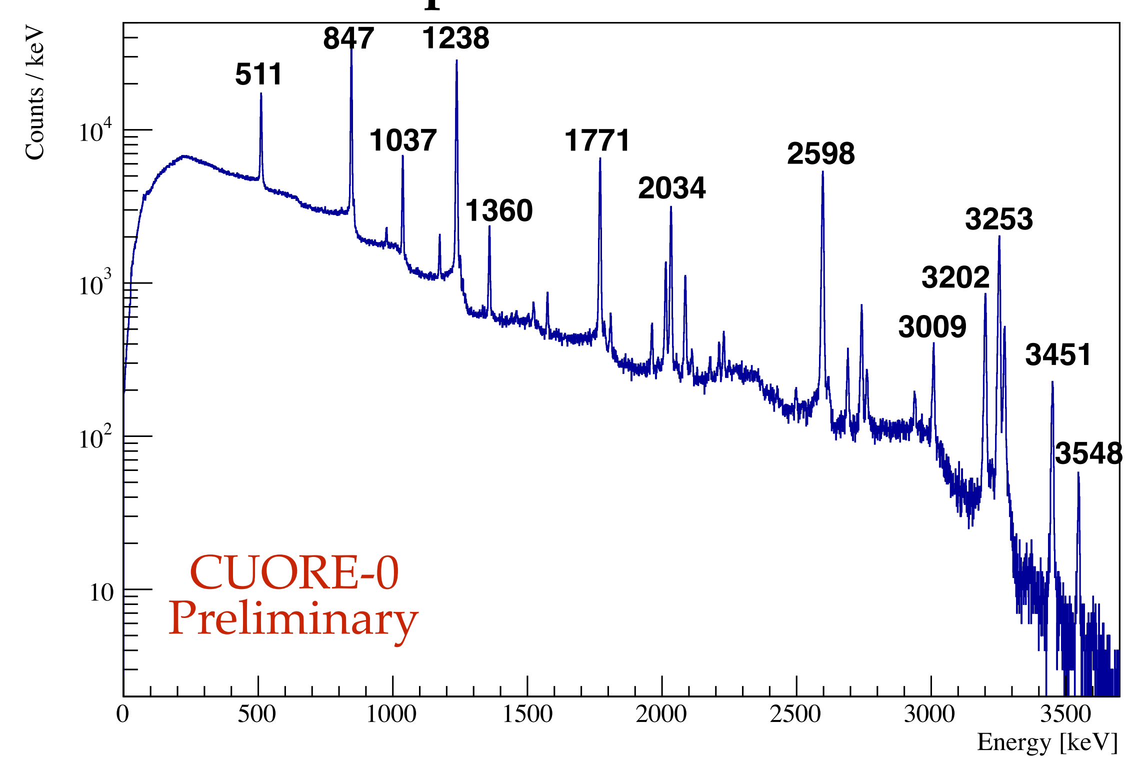
Measurements with ^{56}Co and ^{60}Co

- Dedicated calibrations were performed with ^{60}Co and ^{56}Co sources, and a similar effects were observed
- Higher-statistics ^{56}Co calibration in CUORE is being explored
  - ^{56}Co offers higher energy gammas with many single and double escape peaks
- Physical origin of the residuals is being studied

Coincident peak from dedicated ^{60}Co calibration



^{56}Co spectrum in CUORE-0



Conclusions

- We have constructed the Detector Calibration System to meet the challenges of calibrating 988 individual channels in CUORE
- CUORE-0 and CUORE are calibrated with ^{232}Th, with constant-energy pulsers to measure gain and stability between calibrations
- CUORE-0 energy resolution: 5.1 ± 0.3 keV FWHM at 2615 keV (0.2%)
- CUORE-0 single-gamma energy scale uncertainty: 0.1 keV
- Studies are ongoing to better understand the energy reconstruction of other event types (e.g. coincident gammas, single and double escape peaks)

CUORE

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SINAP

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