Analysis techniques for the search of neutrinoless double-beta decay of Te-130 with CUORE

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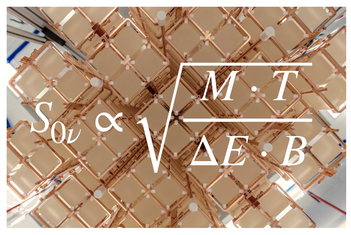
Cryogenic Underground Observatory for Rare Events

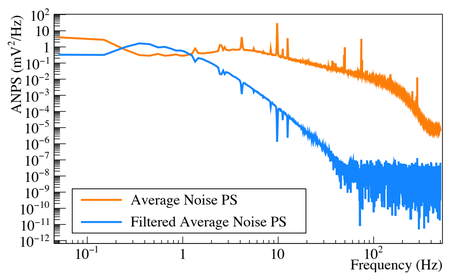


- 988 natural TeO_2 calorimetric detectors (19 towers, 13 floors, 2x2 detector modules)
- 742 kg TeO_2 (206 kg ^{130}Te)
- custom-built cryogen-free dilution refrigerator
- > 90% duty cycle since 2019
- ~10 mK, $C(T) \propto T^3$
- bolometric technique
- $\Delta T = \Delta E / C \ (100\,\mu K/MeV)$
- $\frac{\Delta E}{E} \simeq 0.3\% \ (2528\,keV)$
- LNGS, IT (3600 m.w.e)
- strict radio-purity controls
- passive shielding
- BI: ~10^{-2} ckky

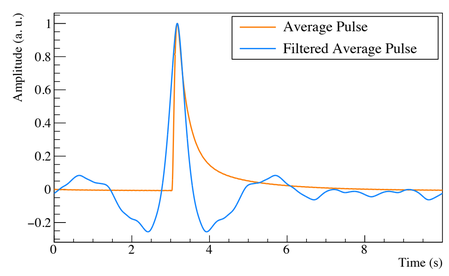
Energy reconstruction

- a digital filter designed to maximize the signal-to-noise ratio is applied to each pulse

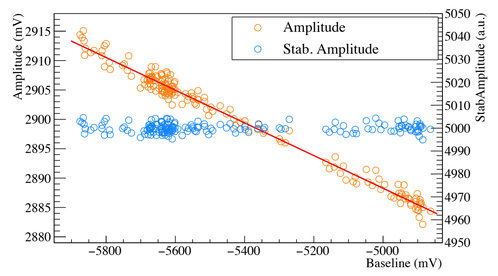
$$H(\omega) \sim \frac{S(\omega)}{N(\omega)}$$



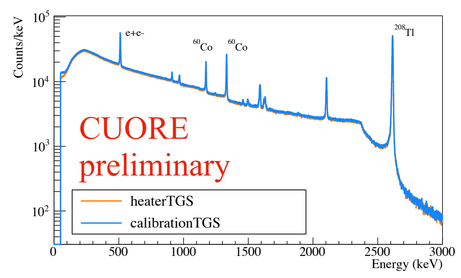
- the amplitude is determined by interpolating the maximum of the filtered pulse using a second order polynomial



- standardized heat and/or energy pulses are used to stabilize against thermal gain fluctuations

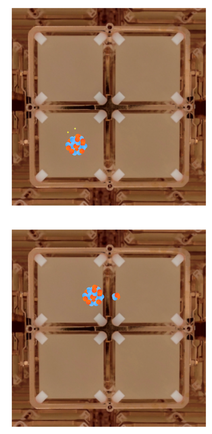


- energy calibration is based on measurements obtained during radioactive source deployment
- 2615 keV calibration peak is used to decide between thermal gain stabilizations



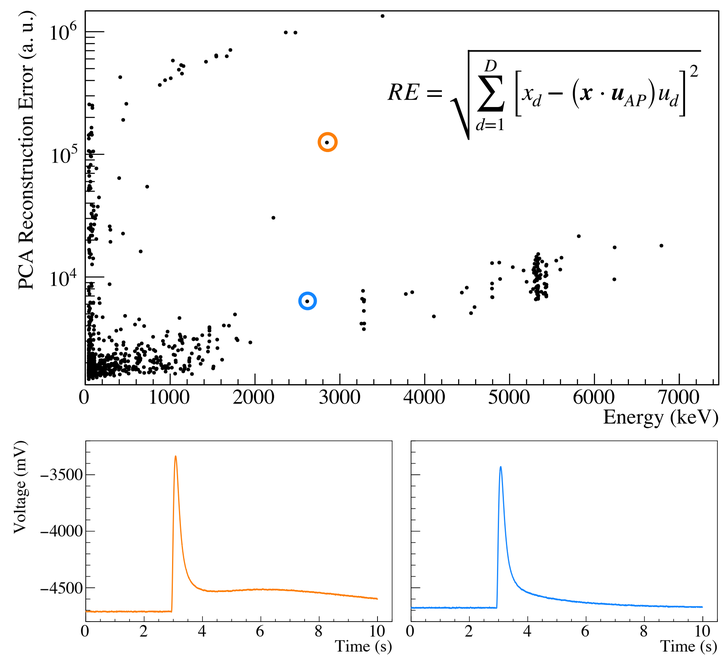
Coincidences

- ~88% of double-beta decay events deposit energy in a single crystal (MC)
- coincidence events correspond to energy depositions > 40 keV in multiple crystals within 5 ms
- synchronization, based on coincidence events, is used to correct for the characteristic rise time of each crystal and achieve a narrow coincidence time window
- anti-coincidence (AC) selection reduces background from multi-site events originating from crystal surface contamination, muons, etc.



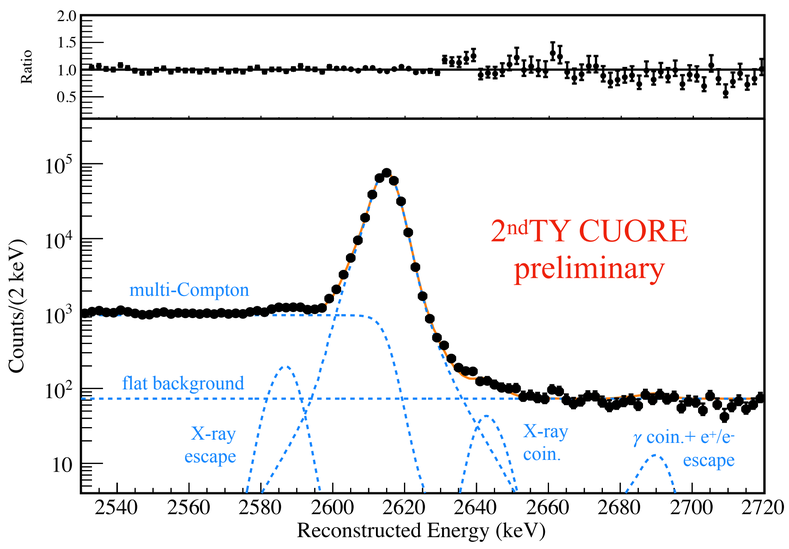
Pulse shape discrimination (PSD)

- principal component analysis (PCA) is sensitive to outliers in data
- the average pulse is used as a proxy for the leading principal component that reflects physical pulse shape
- PCA reconstruction error is used to discriminate physical and nonphysical (pileup, noise, etc.) events
- event selection is based on the figure-of-merit: $\frac{\epsilon_{2615keV}}{\sqrt{\epsilon_{bkg}}}$ with respect to the normalized (energy-independent) PCA reconstruction error

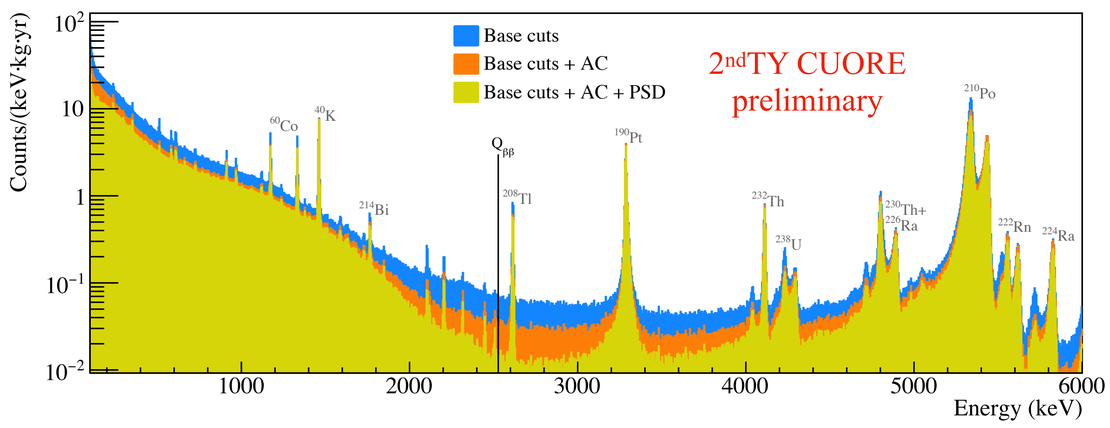


Detector response

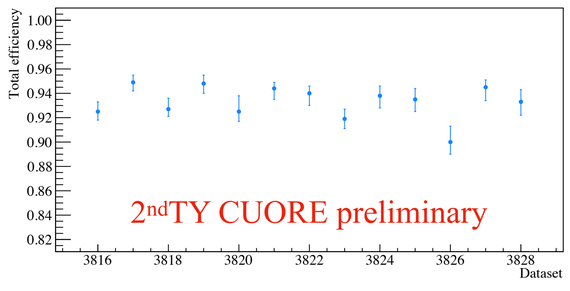
- peak shape model (3 Gaussians) is fit to the 2615 keV gamma line from the *calibration spectrum*
- simultaneously fit with:
  - multi-Compton shoulder
  - flat background
  - ^{130}Te X-ray (~30 keV) escape/ coincidence peaks
  - γ coincidence (583 keV) + e^+/e^- (511 keV) escape peak



- peaks in the *background spectrum* are fit with the 2615 keV-calibration-based line shape to determine the detector response parameters in the region of interest (ROI)



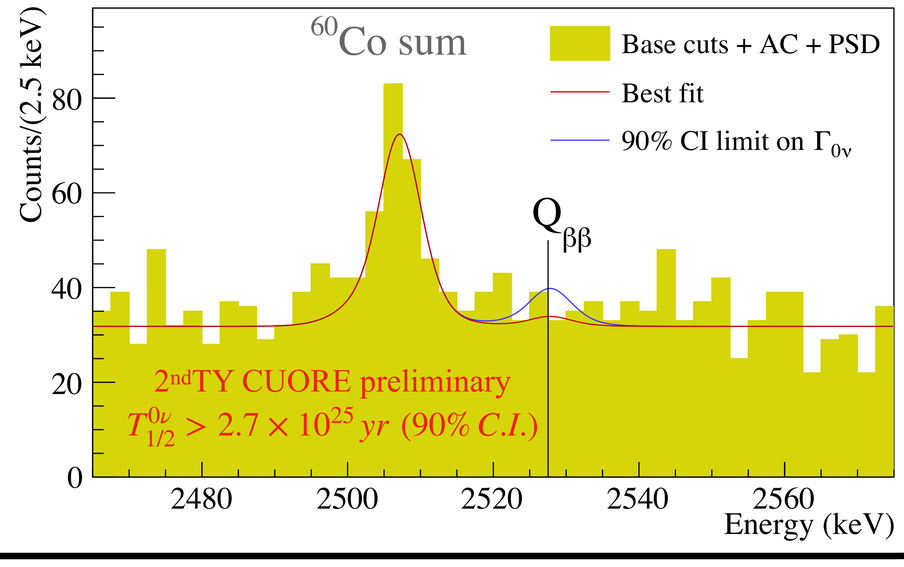
Efficiencies



- Base Cuts: probabilities of accurate detection, energy reconstruction, and pile-up rejection (heater pulses)
- AC: probability of identifying single crystal event (^{40}K)
- PSD: probability of keeping a physical event ($\gamma_{i,BG}$)

ROI fit

- UEML fit in ROI: [2465,2575] keV
- likelihood model: ^{130}Te $Q_{\beta\beta}$ peak $(\Gamma_{0\nu})$ + ^{60}Co sum peak (Γ_{Co}) + flat background (BI)
- flat priors on BI and $\Gamma_{0\nu}$
- informative priors for efficiencies, energy bias, resolution, $Q_{\beta\beta}$, and isotopic abundance
- fit procedure determined using blinded data, where events are exchanged between posited $Q_{\beta\beta}$ and the ^{208}Tl 2615 keV peak



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