Background analysis techniques in the CUORE experiment

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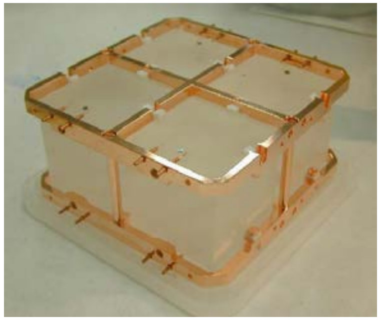
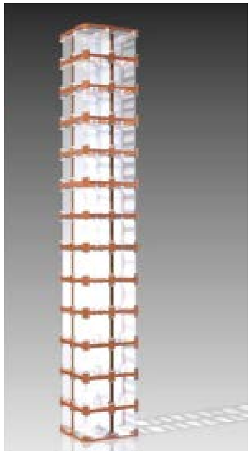
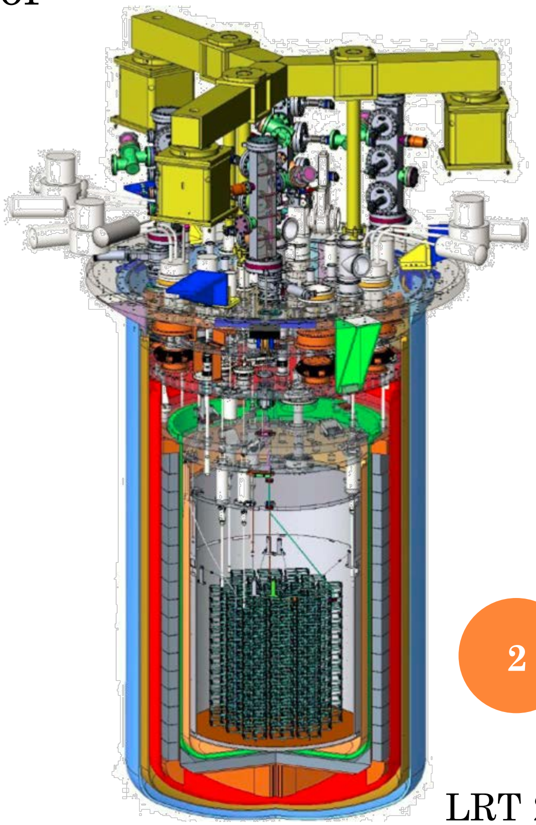
CUORE DETECTOR

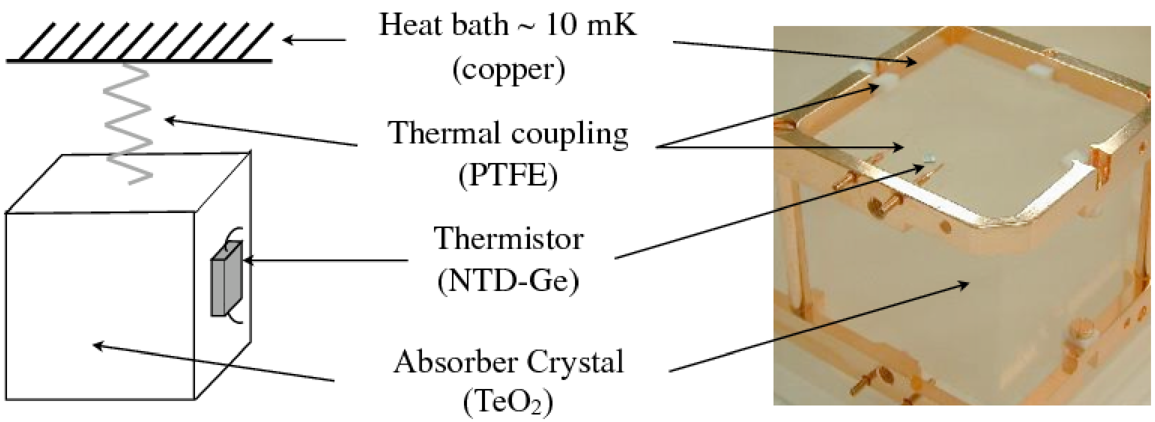
- Cryogenic Underground Observatory for Rare Events (CUORE)
  - Will search for $0\nu\beta\beta$ decay of ^{130}Te (Q-value = 2528 keV)
  - Detector is an array of 988 natural TeO_2 bolometers:
    - 19 towers; 13 floors/tower; 4 bolometers/floor
    - 741 kg total; 206 kg ^{130}Te
    - Isotopic abundance of ^{130}Te is 34%
    - Array will be held in a cryostat and cooled to ~10 mK
  - Data taking to start in late 2015.

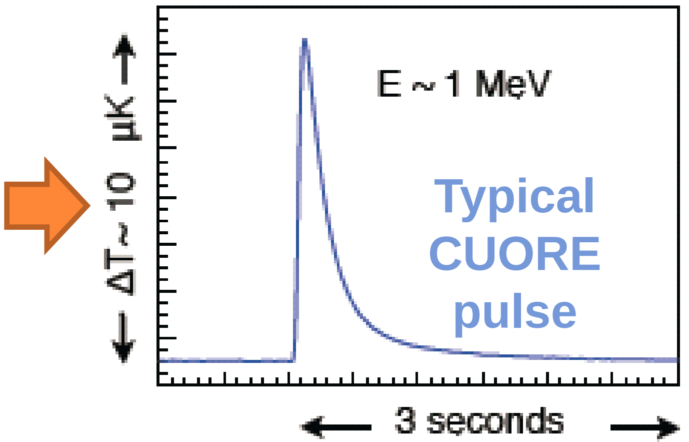




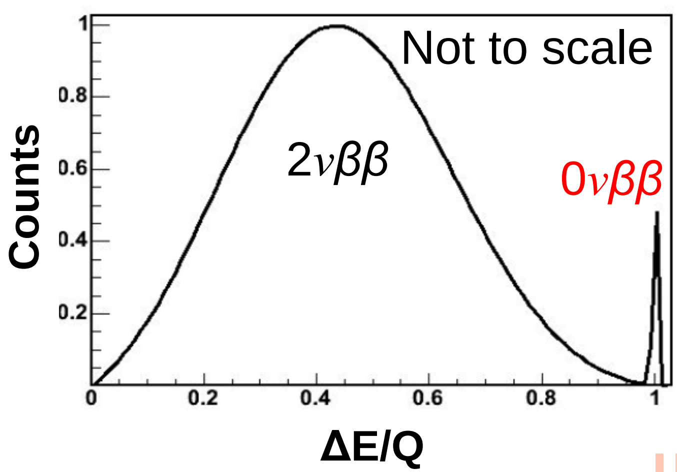


BOLOMETRIC TECHNIQUE





- TeO_2 bolometers:
  - Particle interaction deposits energy in crystal.
  - Resulting temperature rise (ΔT) measured.
  - Energy deposition determined from $E = C\,\Delta T$ (C is heat capacity).
- $0\nu\beta\beta$ decay signature: **peak at Q-value**
  - Energy resolution at 2528 keV:
    FWHM ~ 5-7 keV



HALF-LIFE SENSITIVITY

$$\hat{T}_{1/2}^{0\nu\beta\beta}(n_\sigma) \propto \frac{\varepsilon \cdot a}{n_\sigma}\sqrt{\frac{M \cdot t}{B \cdot \delta E}}$$

Detector efficiency

Isotope mass fraction

Detector mass

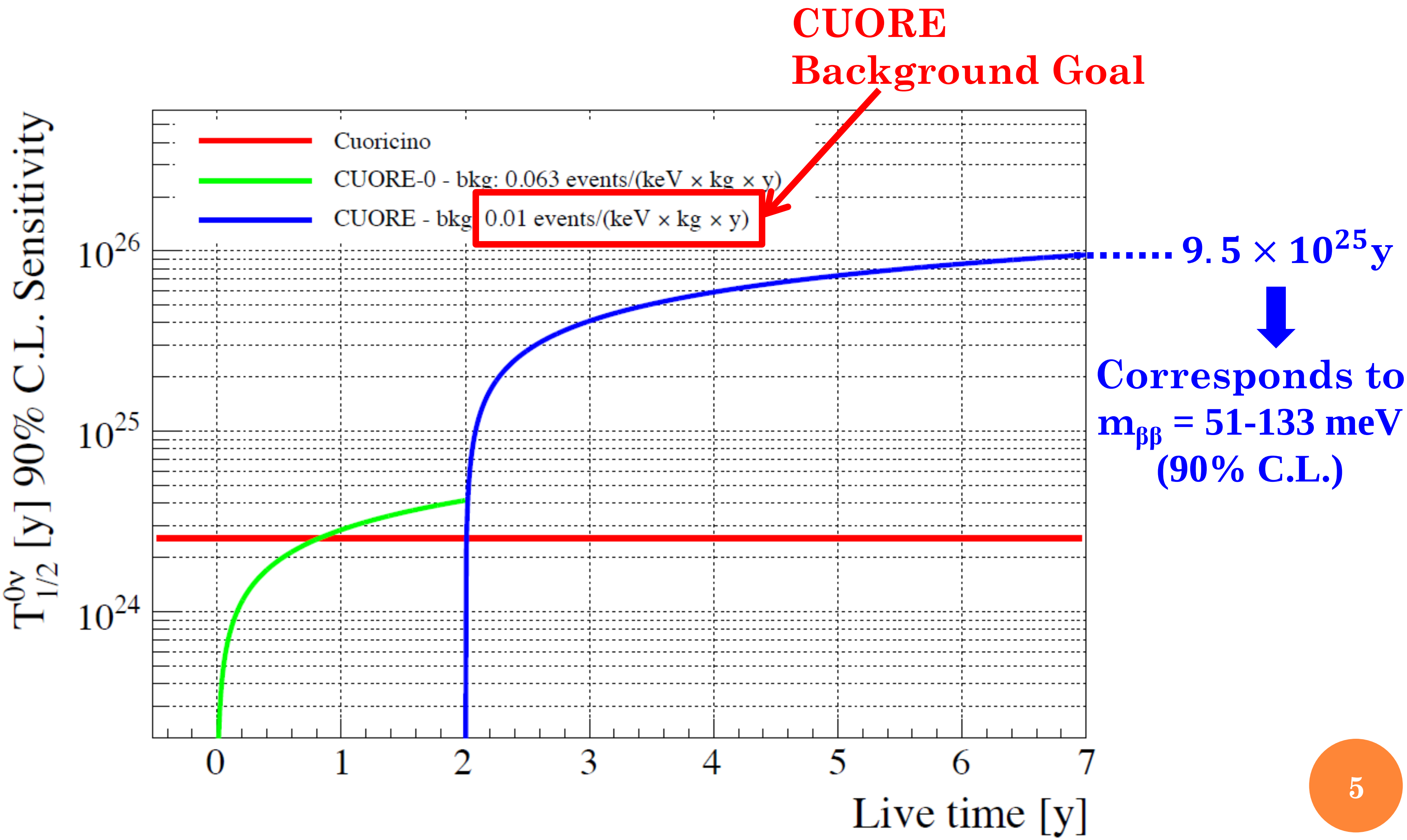
Exposure time

Confidence level

Background

Energy resolution

HALF-LIFE SENSITIVITY



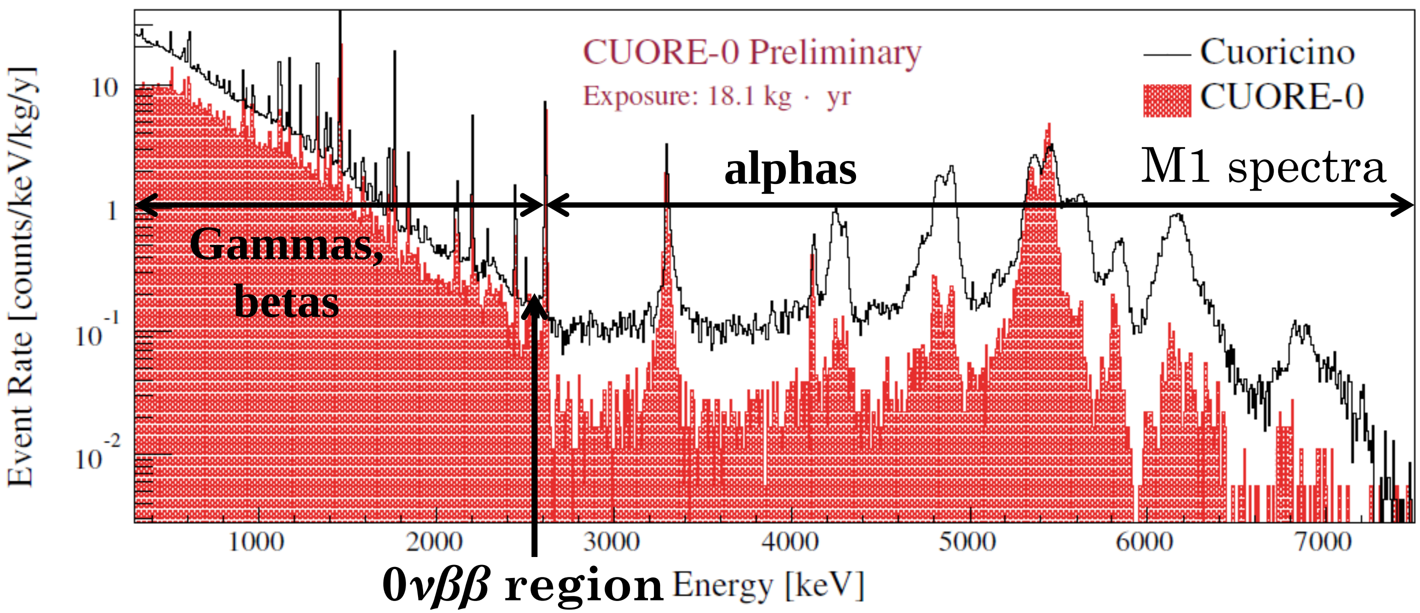
BACKGROUND ANALYSIS TECHNIQUES

- Gamma spectroscopy w/ HPGe detectors
- Neutron activation analysis
- Alpha spectroscopy w/ Si surface barrier detectors
- ICP-MS
- Bolometry w/ TeO_2
- Cross-section measurements for cosmogenic-isotope production in detector materials (e.g., Te)
- Data-analysis cuts
- Monte Carlo simulations

Background spectra

Cuoricino
2003-2008

CUORE-0
March 2013-Spring 2015

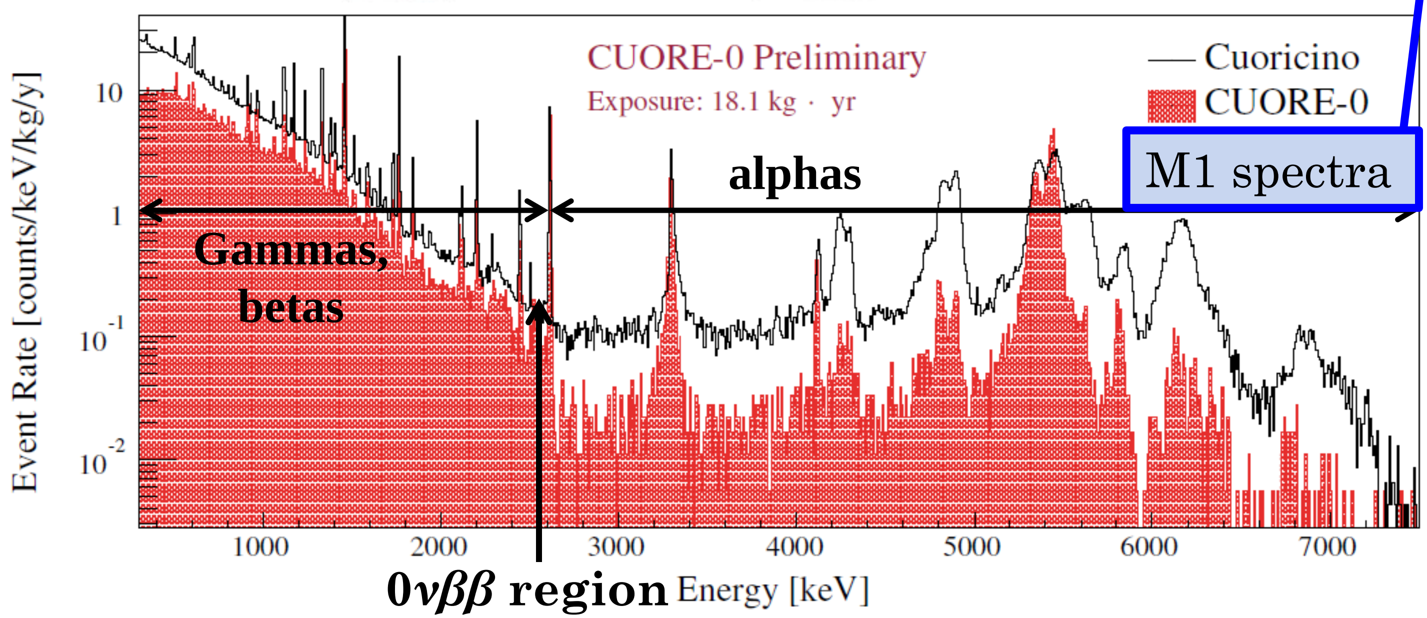


BACKGROUND SPECTRA

Cuoricino
2003-2008

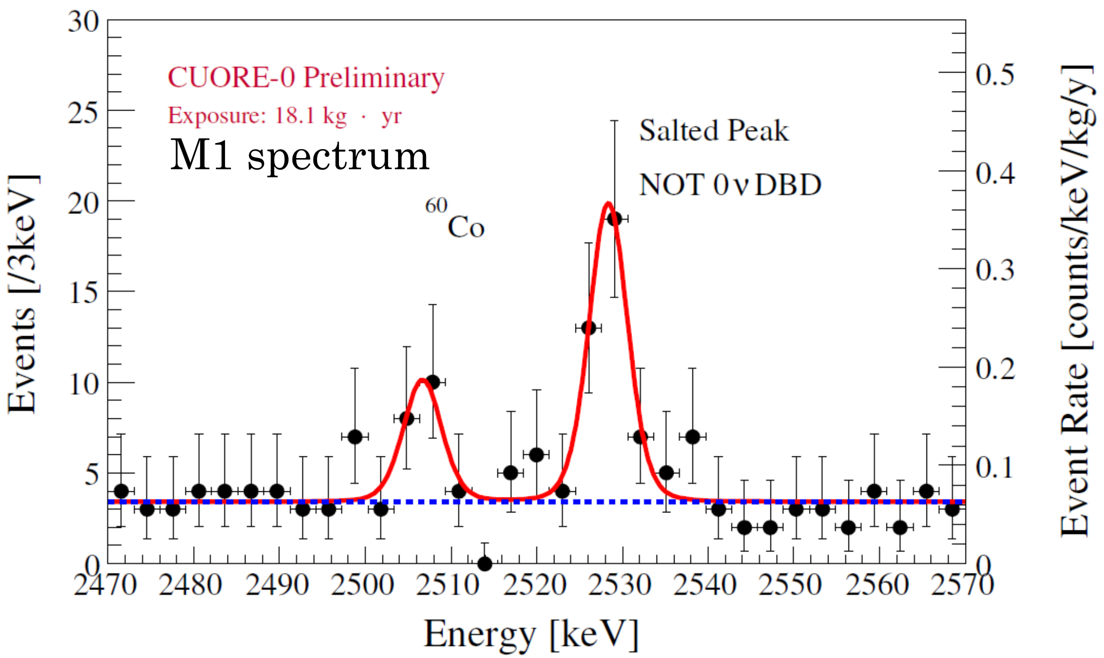
CUORE-
March 201

Only events that occur in a single crystal are plotted. These are known as **multiplicity 1 (M1)** events.



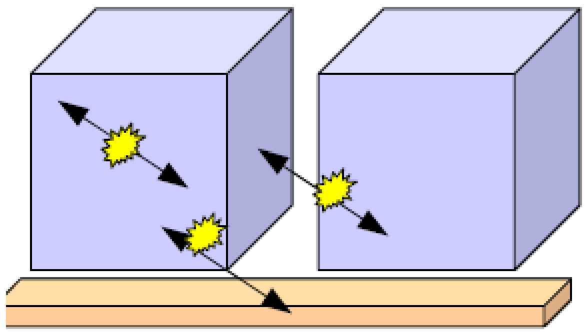
NEUTRINOLESS DOUBLE-BETA DECAY REGION

- $0\nu\beta\beta$-decay region:



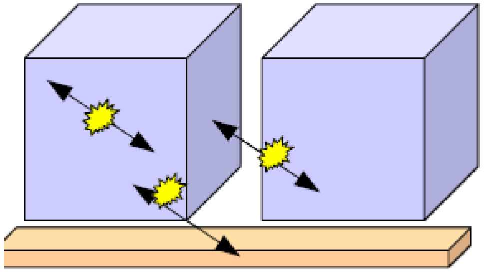
- Excellent energy resolution (~5 keV) at 2528-keV Q value allows the $0\nu\beta\beta$-decay peak to be unambiguously distinguished from the ^{60}Co sum peak.

ALPHA BACKGROUND

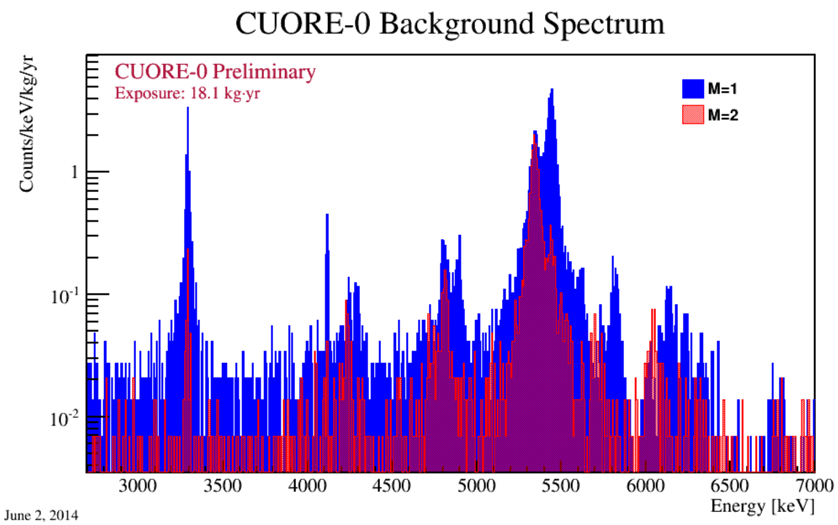


- Alpha decay: $Q_\alpha = E_\alpha + E_R$
- Alpha background comes from
  - Bulk contamination of TeO_2 crystals
    - Deposits Q_α in crystal
  - Surface contamination of TeO_2 crystals
    - Fully contained event: deposits Q_α in crystal.
    - Partially contained event: alpha (or recoil) loses energy in crystal before escaping completely or depositing remaining energy in an adjacent crystal
  - Surface contamination of the copper frames
    - Alpha loses energy in copper before depositing remaining energy in TeO_2 crystal
- "Degraded" alphas:
  - Alphas that deposit partial energy in the crystals
  - Background extends from Q_α or E_α down to zero

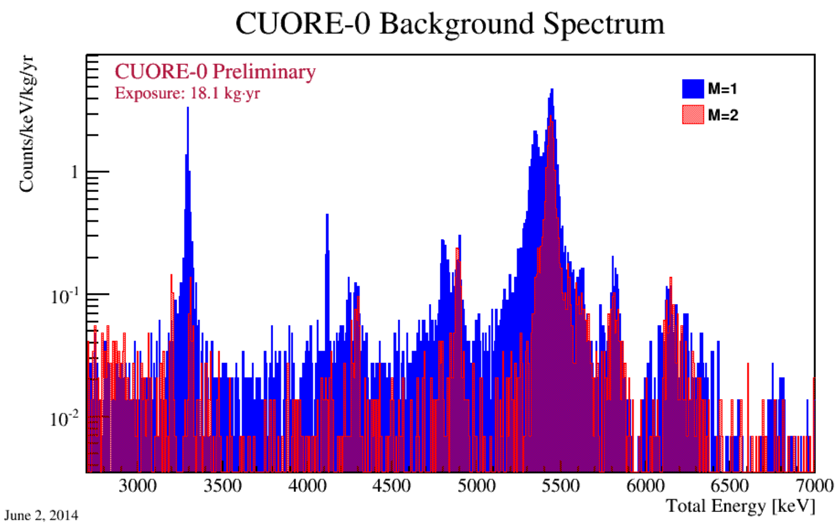
ALPHA BACKGROUND



- Crystal bulk and surface events can be disentangled by comparing spectra for single-crystal events (M1) with those for two-crystal events (M2)

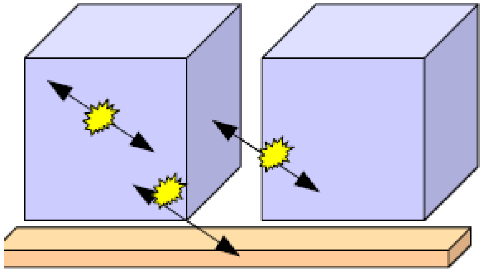


Energy deposited in individual crystals during each event is plotted

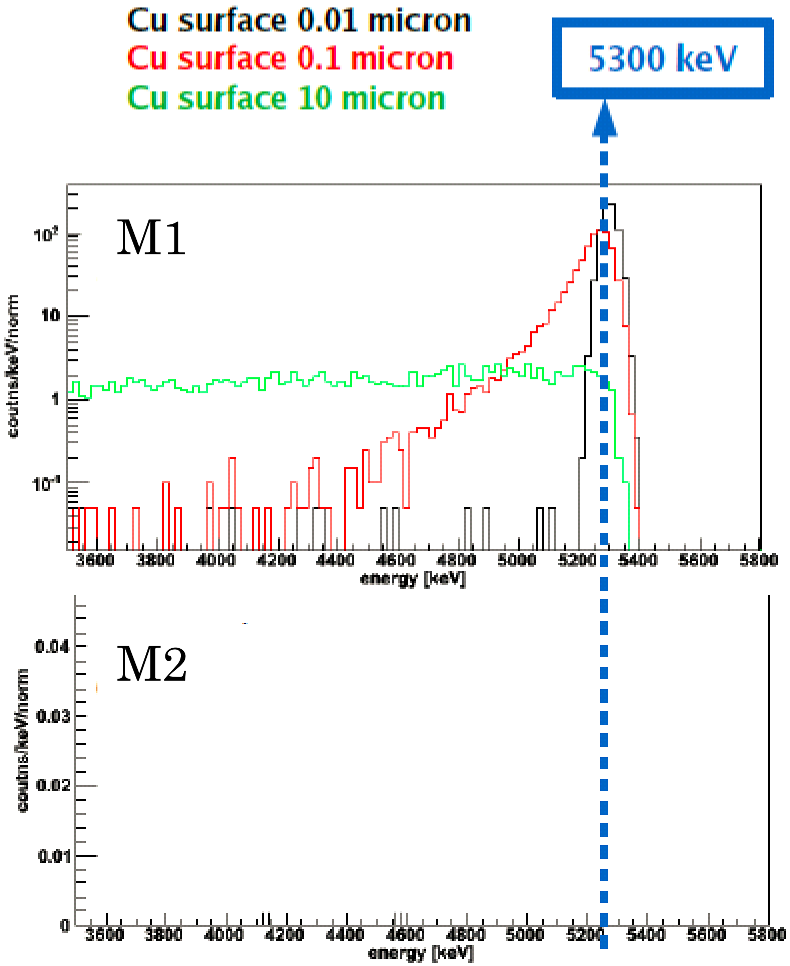


Energy deposited in entire detector array during each event is plotted

ALPHA BACKGROUND

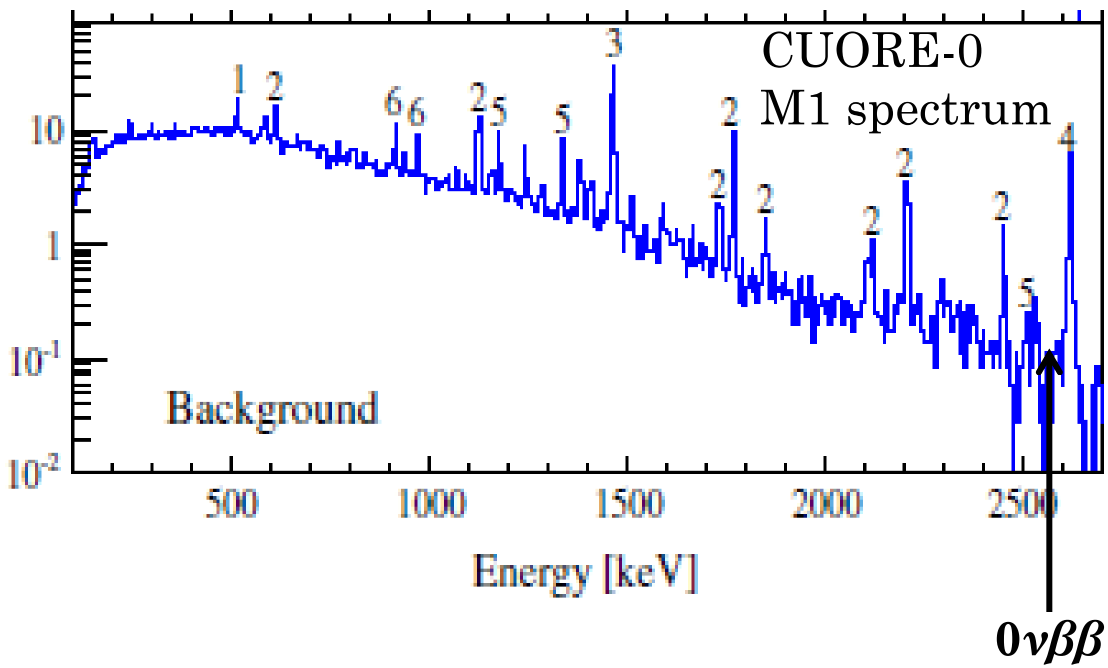


- Degraded-alpha signature from Po-210 surface contamination on copper
- Simulation results for different contamination thicknesses shown
- Energy deposited in individual crystals during each event plotted



GAMMA/BETA REGION

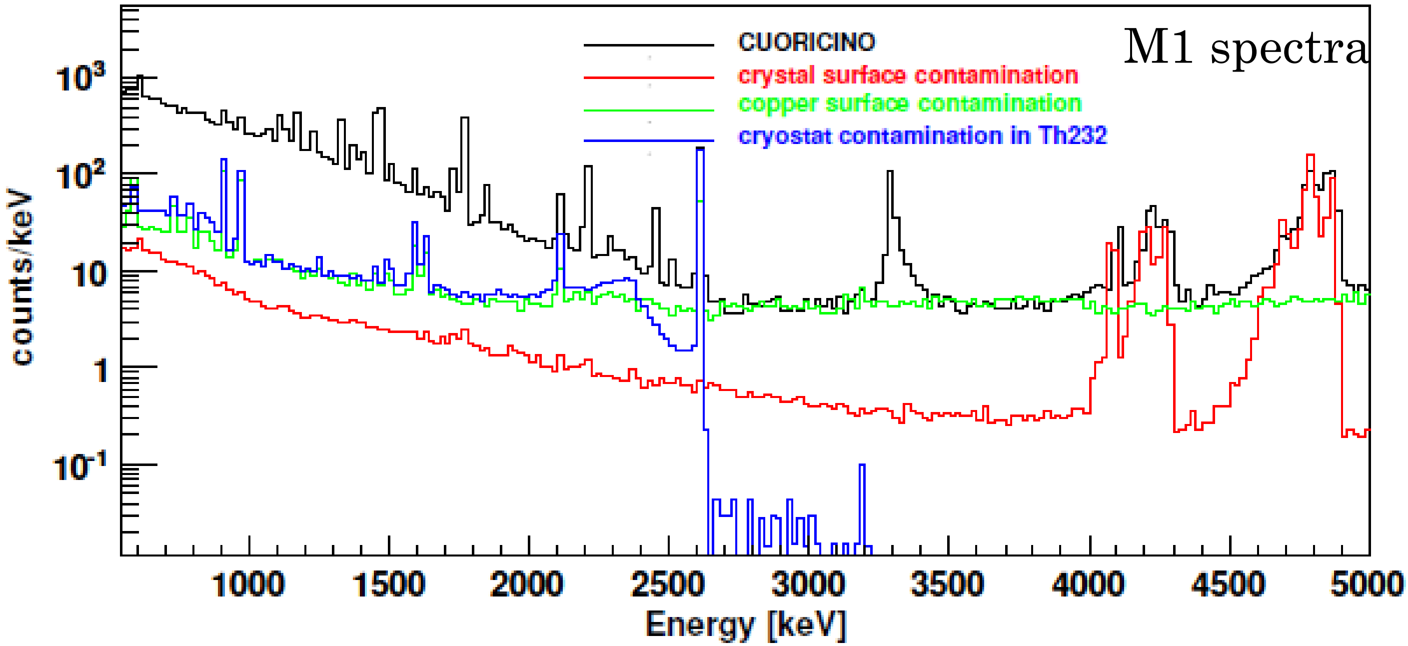
- Dominated by Th-232 and U-238 contaminations in the cryostat and/or its shields.



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

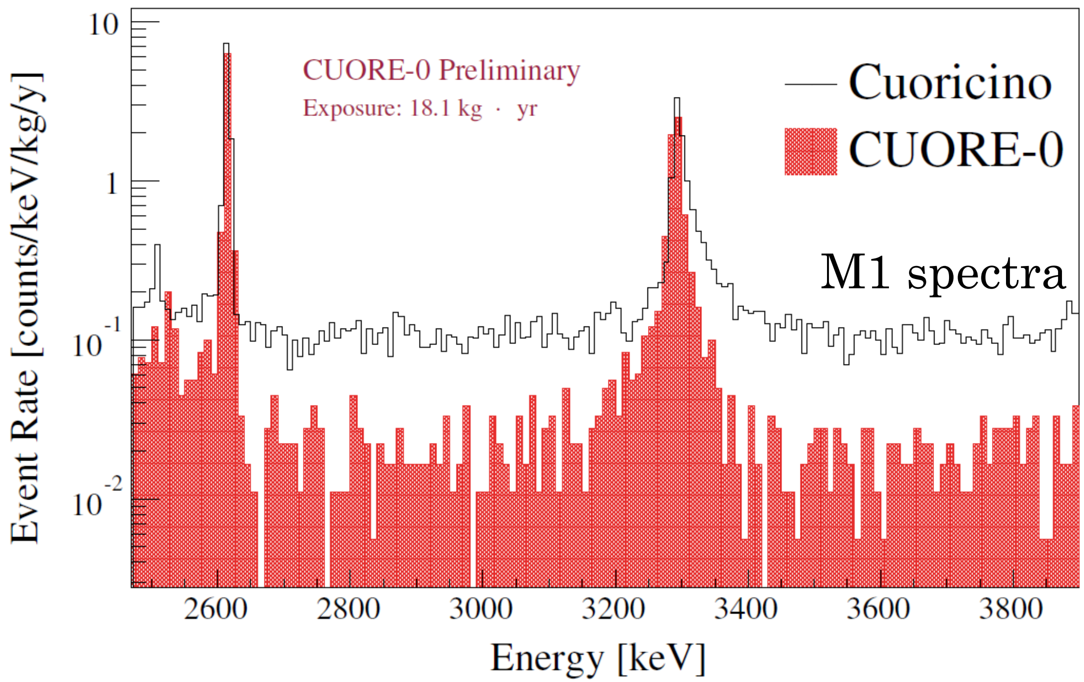
Background model and Monte Carlo simulations

- Three major contributors to $0\nu\beta\beta$-decay region:
  - **10 ± 5%: U-238 and Th-232 surface contaminations of crystals**
  - **50 ± 20%: Th-232 surface contaminations of copper (or any other component facing crystals)**
  - **30 ± 10%: multi-Compton events from Tl-208 2614 keV line (due to Th-232 contamination in cryostat)**



Improving the alpha background

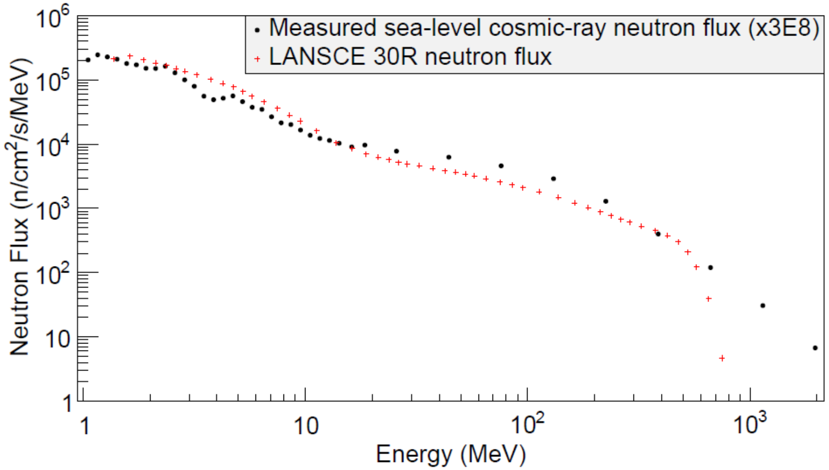
- CUORE-0 has achieved an overall background **2 times lower** than Cuoricino and an alpha background **6 times lower.**
- Due largely to more rigorous copper cleaning methods and more consistent cleaning protocol for crystals.



First results from CUORE-0 published in The European Physical Journal C 74, 2956 (2014)

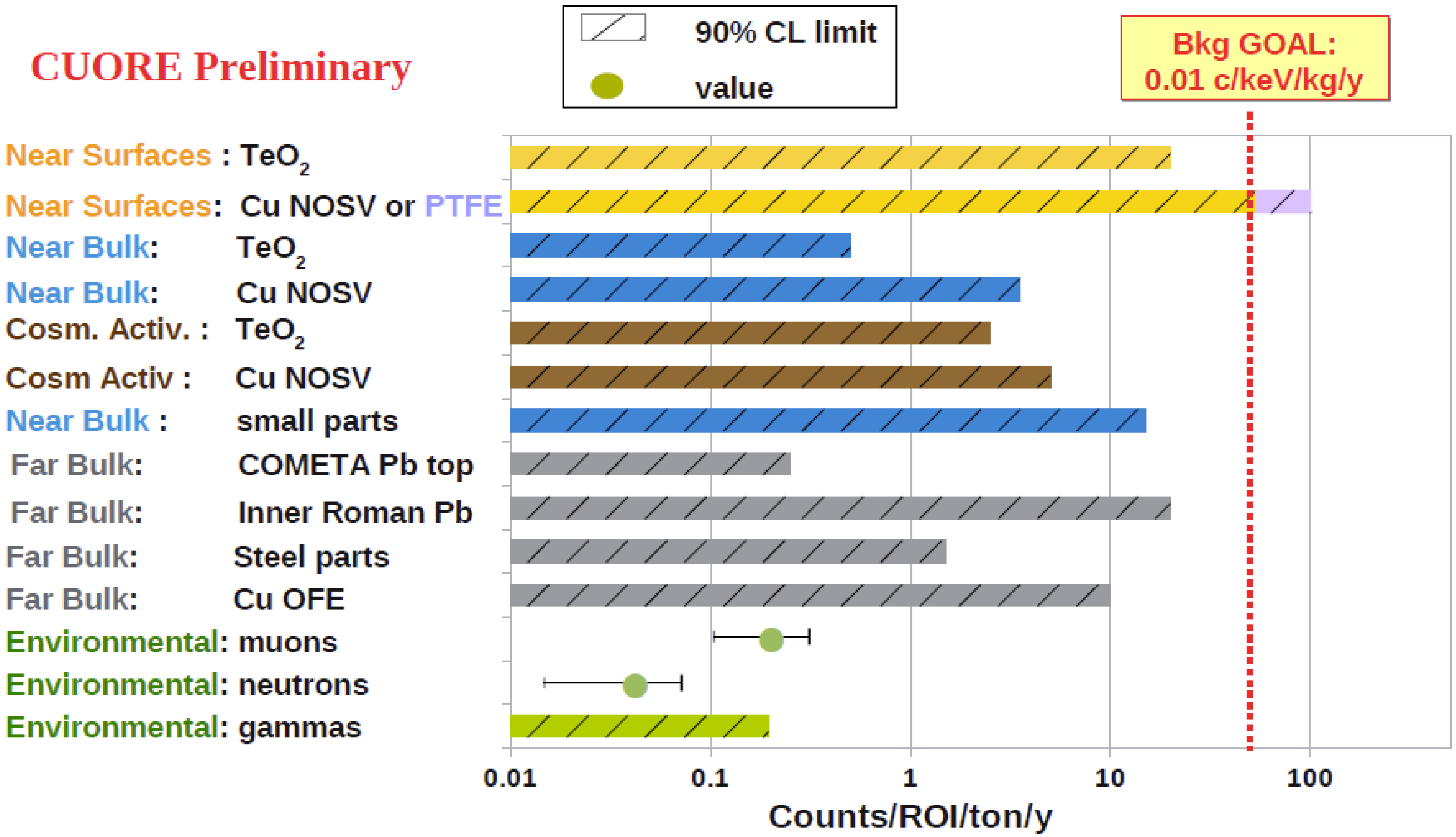
COSMOGENIC BACKGROUND

- Background from ^{110m}Ag and ^{60}Co present due to **cosmogenic activation** of TeO_2 crystals.
- Background estimated using radioisotope-production cross sections measured at the Los Alamos Neutron Science Center (LANSCE).
  - TeO_2 powder irradiated w/ a neutron spectrum similar in shape to the cosmic-ray neutron spectrum at sea-level.
  - Cross sections obtained[1]: **^{110m}Ag: 0.28 ± 0.04 mb**, **^{60}Co: < 0.0016 mb**



[1] Paper on the cross-section measurement submitted to Physical Review C. Preprint may be found here: http://arxiv.org/abs/1503.02095

BACKGROUND BUDGET



Thank you for listening. Questions?

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