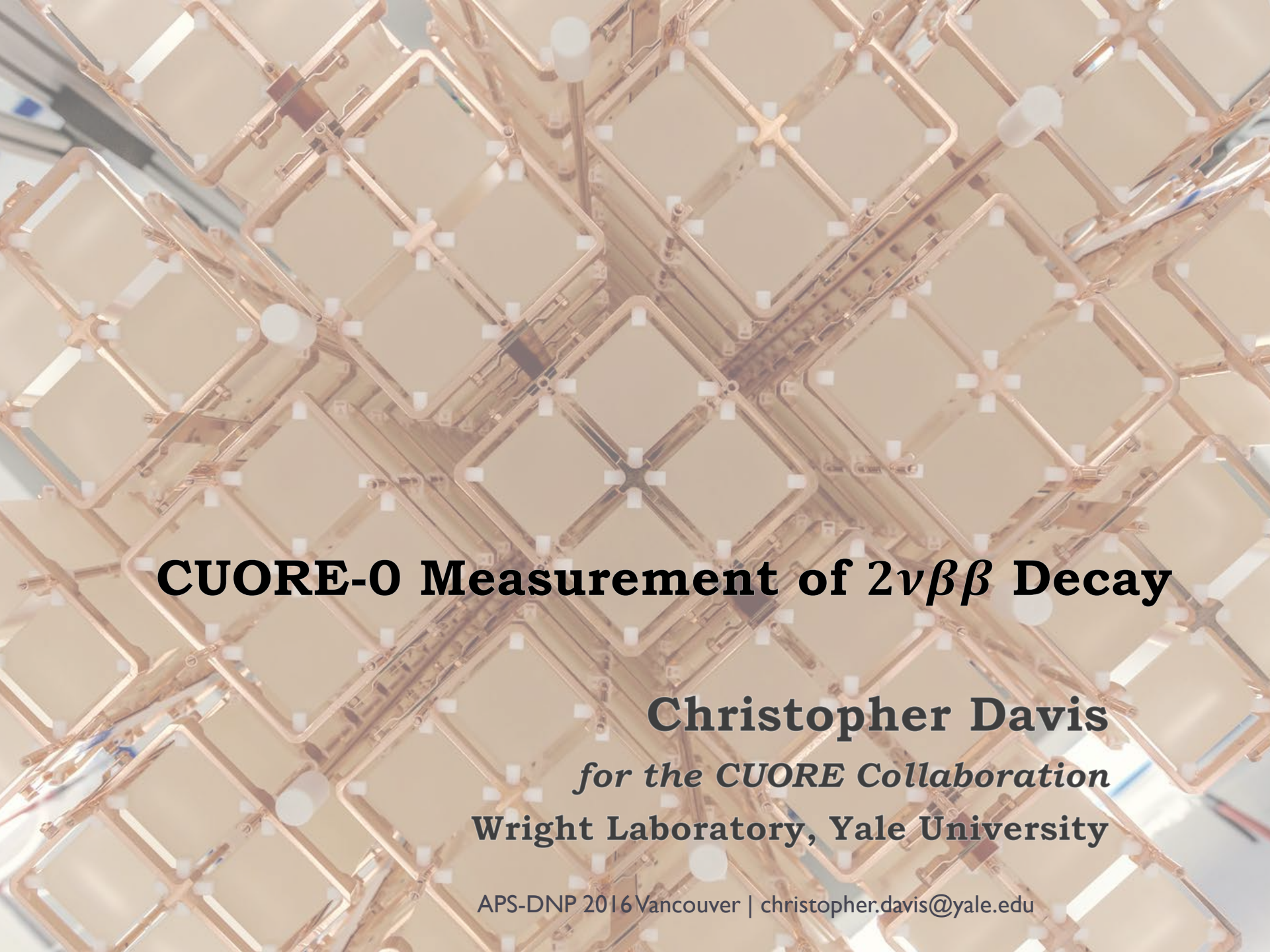

CUORE-0 Measurement of $2\nu\beta\beta$ Decay

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for the CUORE Collaboration

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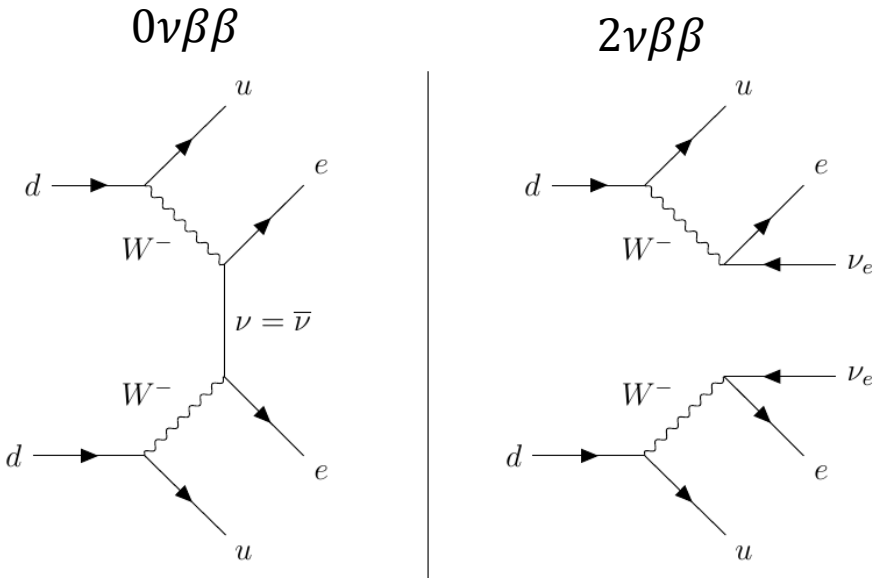
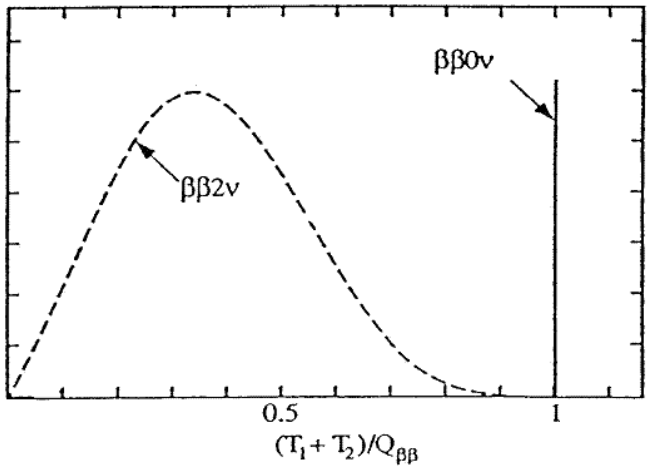
APS-DNP 2016 Vancouver | christopher.davis@yale.edu

Double Beta Decay: $0\nu\beta\beta$ and $2\nu\beta\beta$

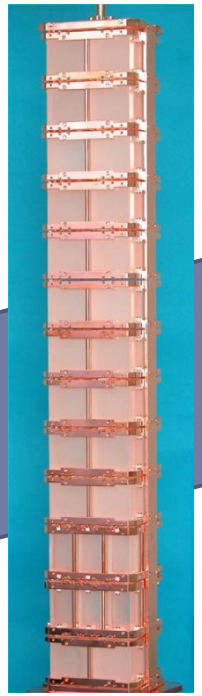
- $2\nu\beta\beta$ is an irreducible background in $0\nu\beta\beta$ experiments
- Slowest observed nuclear process
  - $T_{1/2}^{2\nu} \sim 10^{18} - 10^{21}$ yr
- Unlike $0\nu\beta\beta$, $2\nu\beta\beta$ energy is continuous, not a peak
  - Requires detailed understanding of backgrounds





Cryogenic Observatory for Rare Events (CUORE)

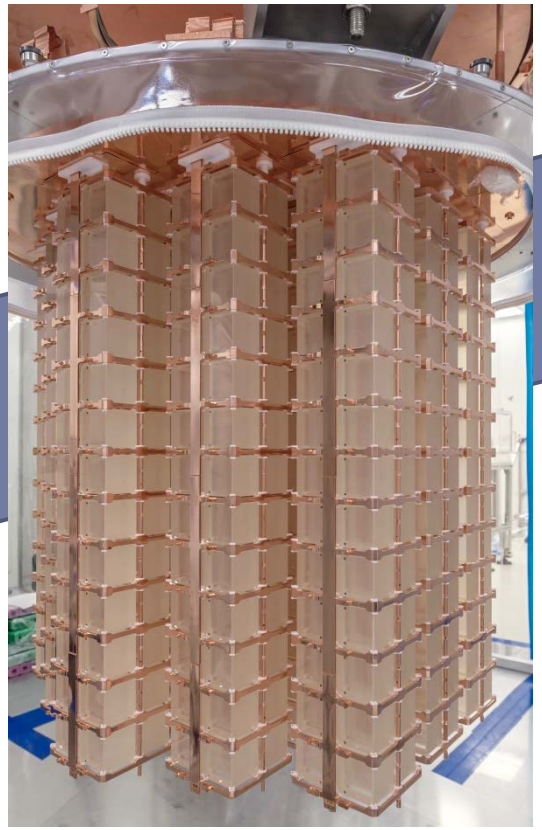
Cuoricino
2003 - 2008



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

CUORE-0
2013 - 2015

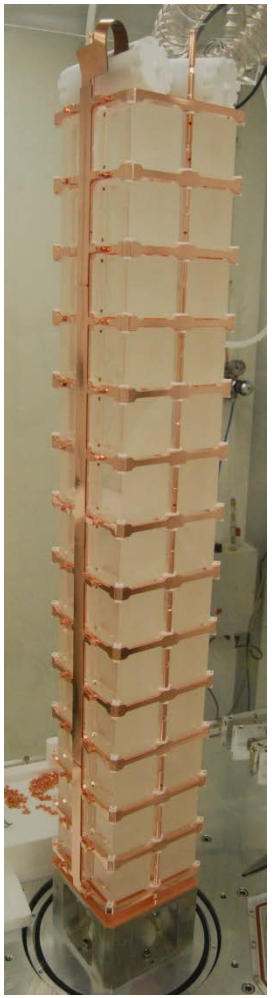
CUORE
Late 2016 -



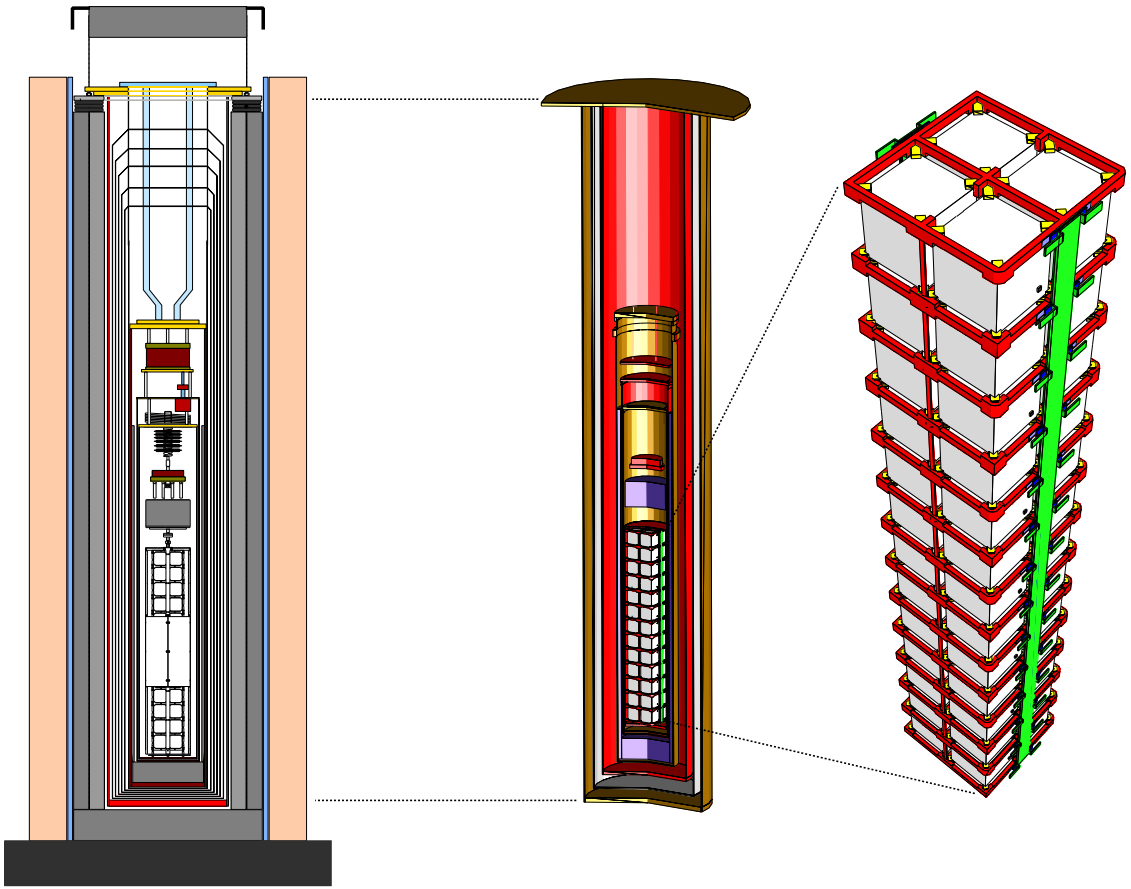
$T_{1/2}^{0\nu} > 9.5 \times 10^{25}\ yr$ 90% C.L. (Projected)

CUORE-0

- Completed experiment that searched for $0\nu\beta\beta$ in ^{130}Te
  - Successful test of CUORE methods
    - Detector assembly
    - DAQ and analysis methods
- Data collection from March '13 to July '15
  - 35.2 kg·yr TeO_2 exposure
  - 9.3 kg·yr of ^{130}Te data
  - 5 keV resolution at 2528 keV Q-value of $0\nu\beta\beta$
    - Resolution allows for detailed analysis of peaks.
- Limit on $0\nu\beta\beta$:
  - (90% C.L.): 4.0×10^{24} yr
  - C. Alduino et al., Physical Review C Volume 93, 045503 (2016)



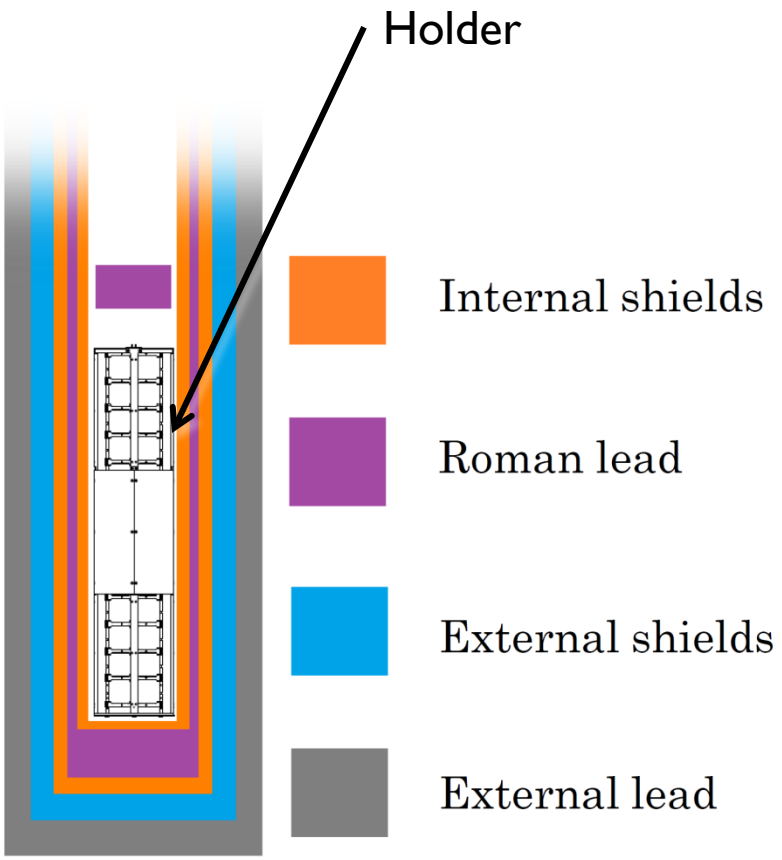
CUORE-0 Monte Carlo in Geant4



- Highly detailed geometries
- Detector effects added to geant4 output
- Main backgrounds:
  - Bulk sources from far components
  - Surface and bulk sources from nearby components

Background Sources

- Volumes grouped into categories, including
  - Shielding
  - Holder
  - Crystals
- Identical background spectra in each category
  - Similar composition
  - Similar placement
- Greatly simplifies fit
  - 57 source spectra to fit
  - ^{238}U, ^{232}Th, ^{60}Co, ^{40}K, etc.

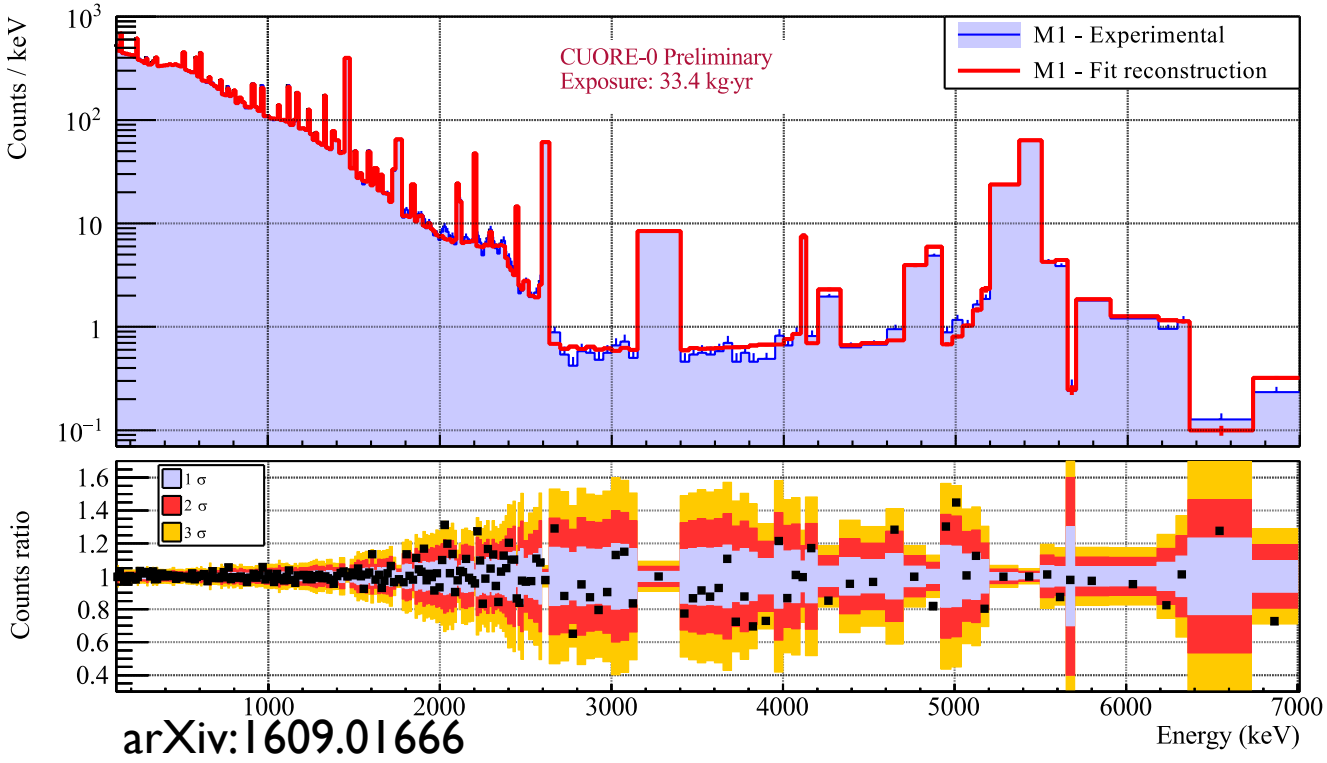


Fitting the Background Spectrum

- Use both a priori measurements and CUORE-0 data
  - Radio-assay measurements
  - γ, α peaks
  - Neutron activation
  - Coincidence analysis
- Fit each of the peaks with a Gibbs sampler (JAGS)
  - $\left\langle C_{i,\alpha}^{exp} \right\rangle = \sum_{j=1}^{57} N_j \left\langle C_{ij,\alpha}^{MC} \right\rangle$
  - α separates different event types
    - Events that interact with a single crystal only (M_1)
    - Events that interact with multiple crystals (M_2 and Σ_2) in backup

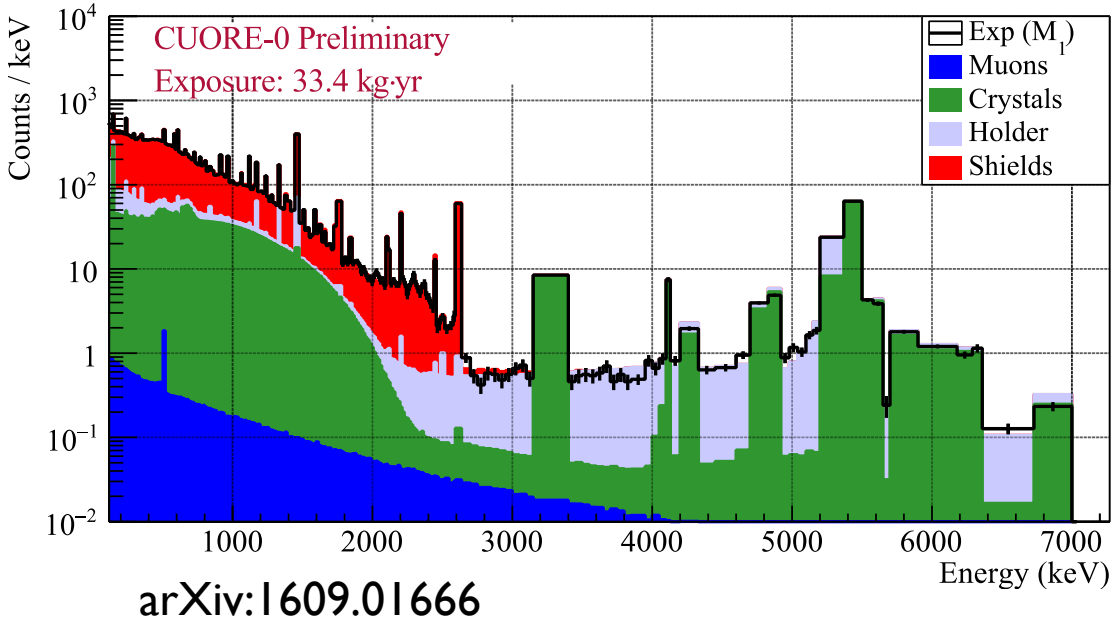
Background Fit (M_1)

- Variable bin size for sensitivity to source strengths
  - Removes detector features such as resolution
  - Decreases statistical effects



Background Model

- The fit reveals information about which sources are contributing most to the background
- Useful for understanding background at 2528 keV Q-value



arXiv:1609.01666

Component	% at 2528 keV
Shields	74.4 ± 1.3
Holder	21.4 ± 0.7
Crystals	2.64 ± 0.14
Muon	1.51 ± 0.06

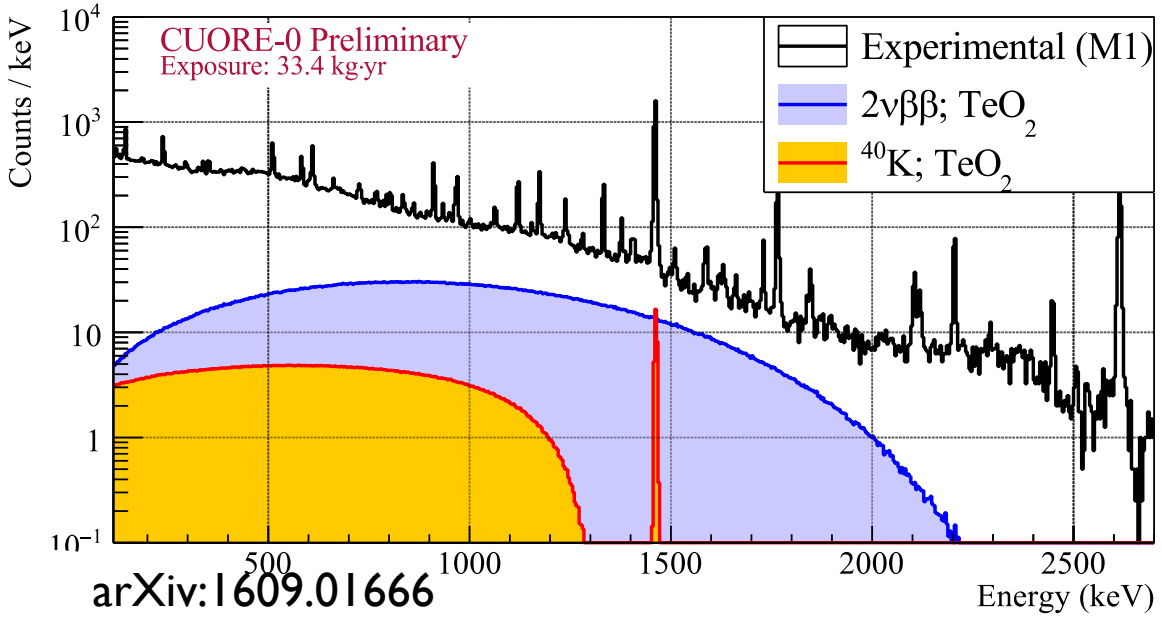
Fit Results

Preliminary

- The $2\nu\beta\beta$ half life of Te-130 is measured to be: (arXiv:1609.01666)

$$T_{1/2}^{2\nu} = [8.2 \pm 0.2\ (stat.) \pm 0.6\ (syst.)] \times 10^{20}\ yr$$

  - MiDBD: $\left[6.1 \pm 1.4\ (stat.)\ ^{+2.9}_{-3.5}\ (syst.)\right] \times 10^{20}\ yr$
  - NEMO: $[7.0 \pm 0.9\ (stat.) \pm 1.1\ (syst.)] \times 10^{20}\ yr$



Conclusion and CUORE $2\nu\beta\beta$

- Have fit and reconstructed the background sources in CUORE-0
- Measured half-life of $2\nu\beta\beta$
  - Most accurate measurement in Te-130 to date
  - Paper in preparation
- Allows us to estimate contributions to the $0\nu\beta\beta$ ROI
- CUORE cooldown expected to start shortly
  - Will take data for 5 years with 19 times the mass of ^{130}Te
  - Lower backgrounds, new cryostat

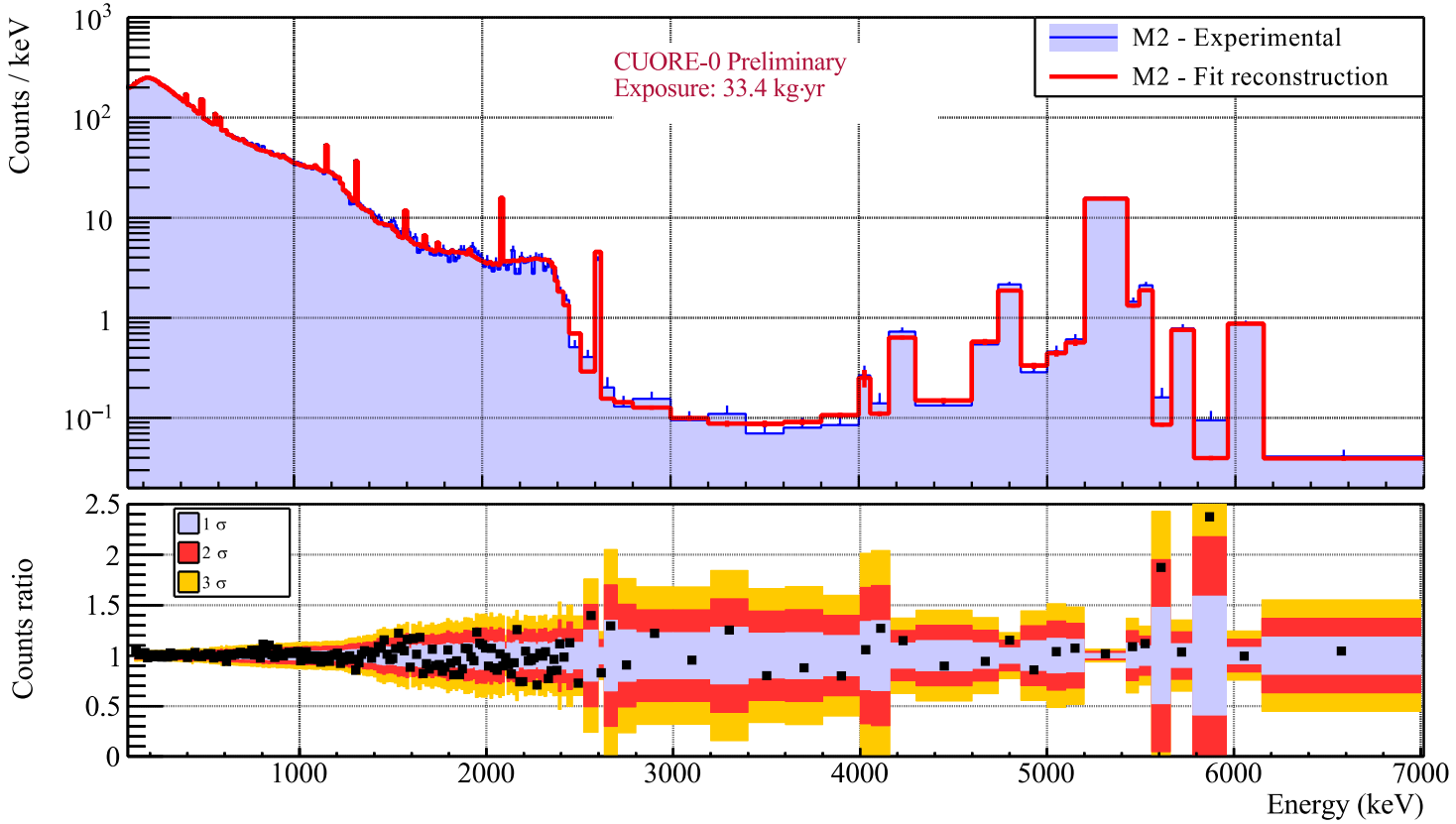
CUORE Collaboration

DD.00003 Search for Neutrinoless Double Beta Decay with CUORE – Vivek Singh
EA.00080 Slow Monitoring Systems for CUORE – Suryabrata Dutta
EA.00081 Simulations towards Effective Calibrations of the CUORE Detector – Byron Daniel
FD.00004 Search for WIMP-Induced Annual Modulation with the CUORE-0 Experiment – Kyungeun Lim
NF.00005 Optimizing the CUORE data processing in search for $0\nu\beta\beta$ decay – Ben Schmidt
NF.00006 Online Data Quality and Bad Interval Detection for the CUORE Neutrinoless Double Beta Decay Search – Bradford Welliver
NF.00010 Improving the energy calibration of CUORE-0 and CUORE – Jeremy Cushman
HH.00004 CUPID: CUORE Upgrade with Particle IDentification – Raul Hennings-Yeomans

Backup Slides

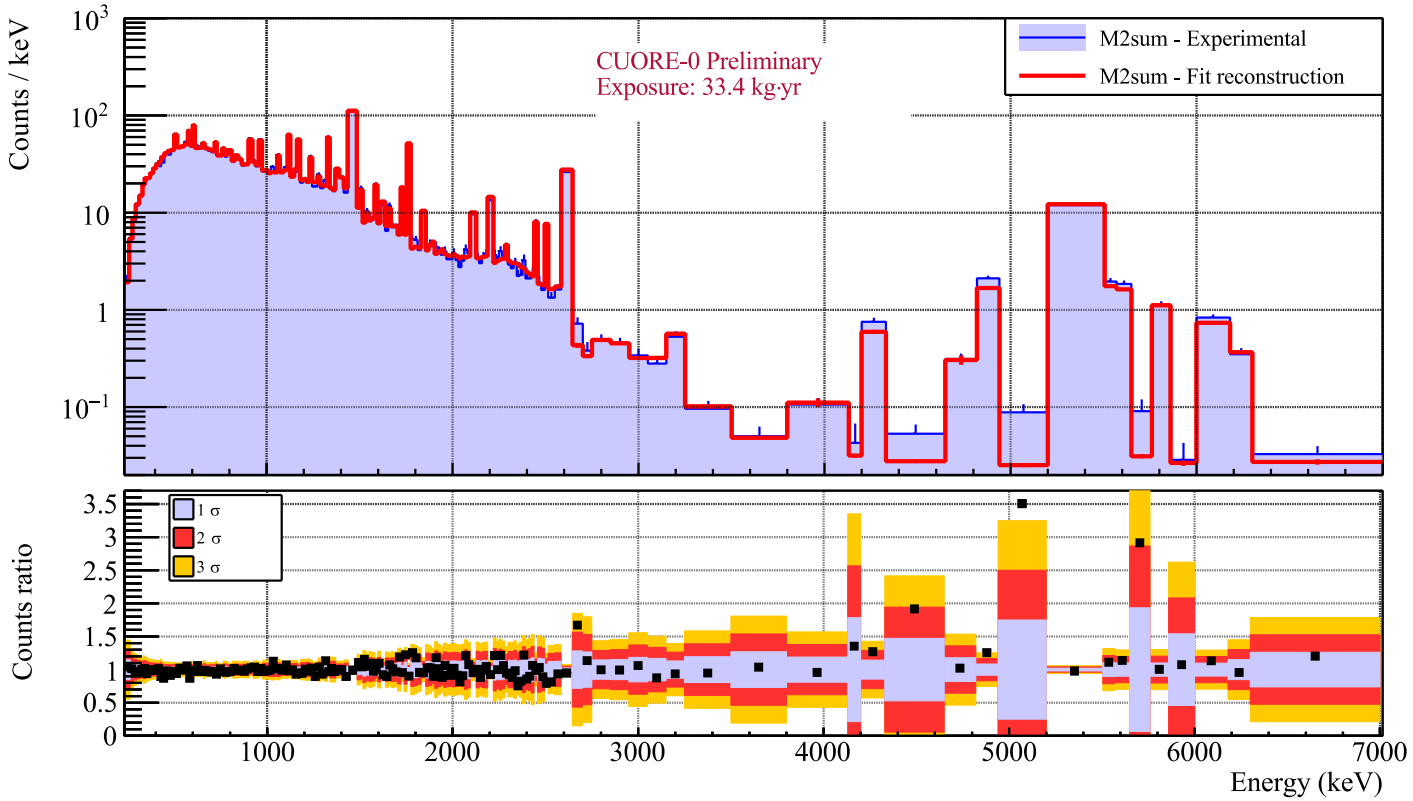
Fit Model (M_2)

- Events where two crystals record simultaneously (M_2)

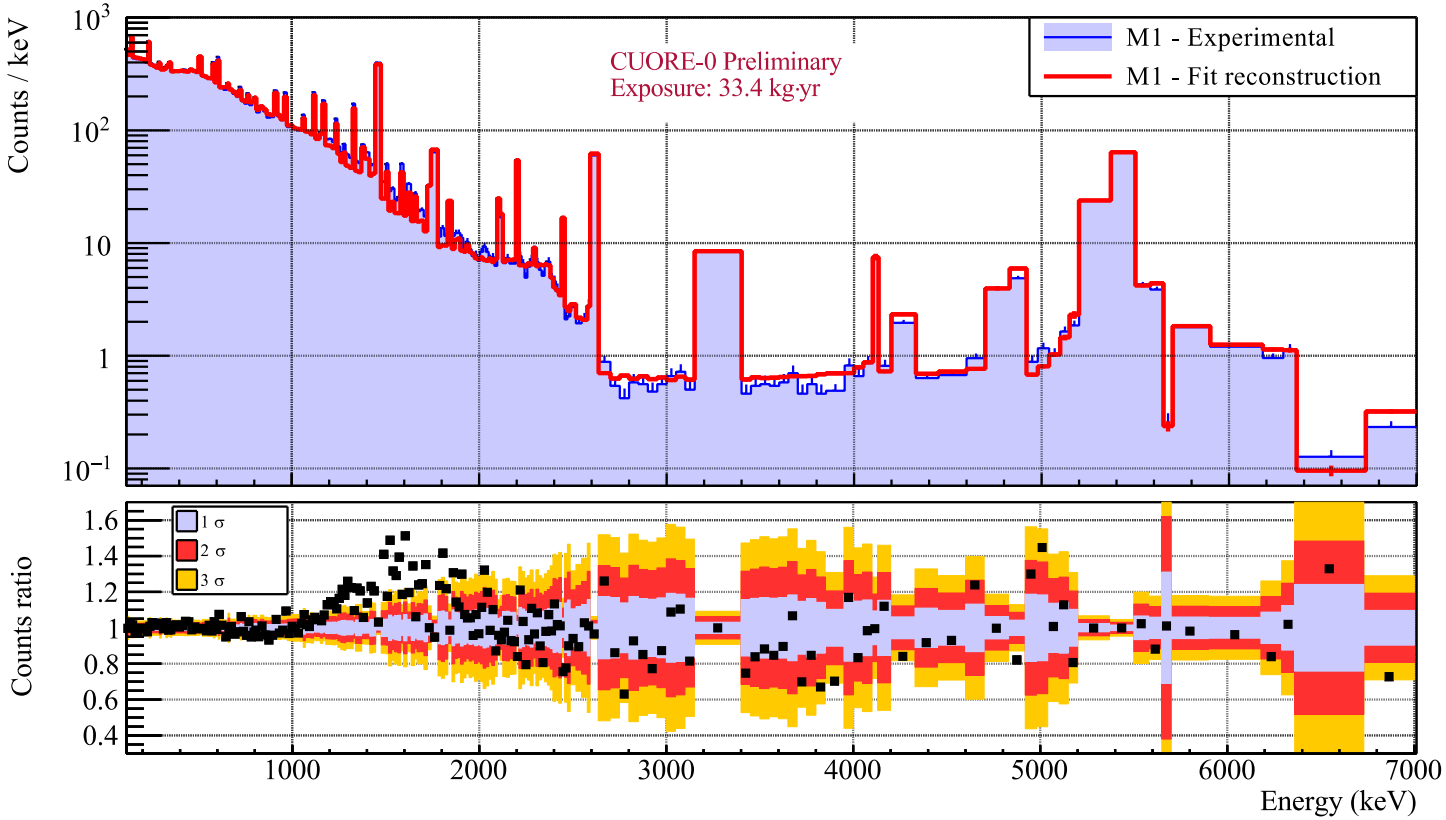


Fit Model (Σ_2)

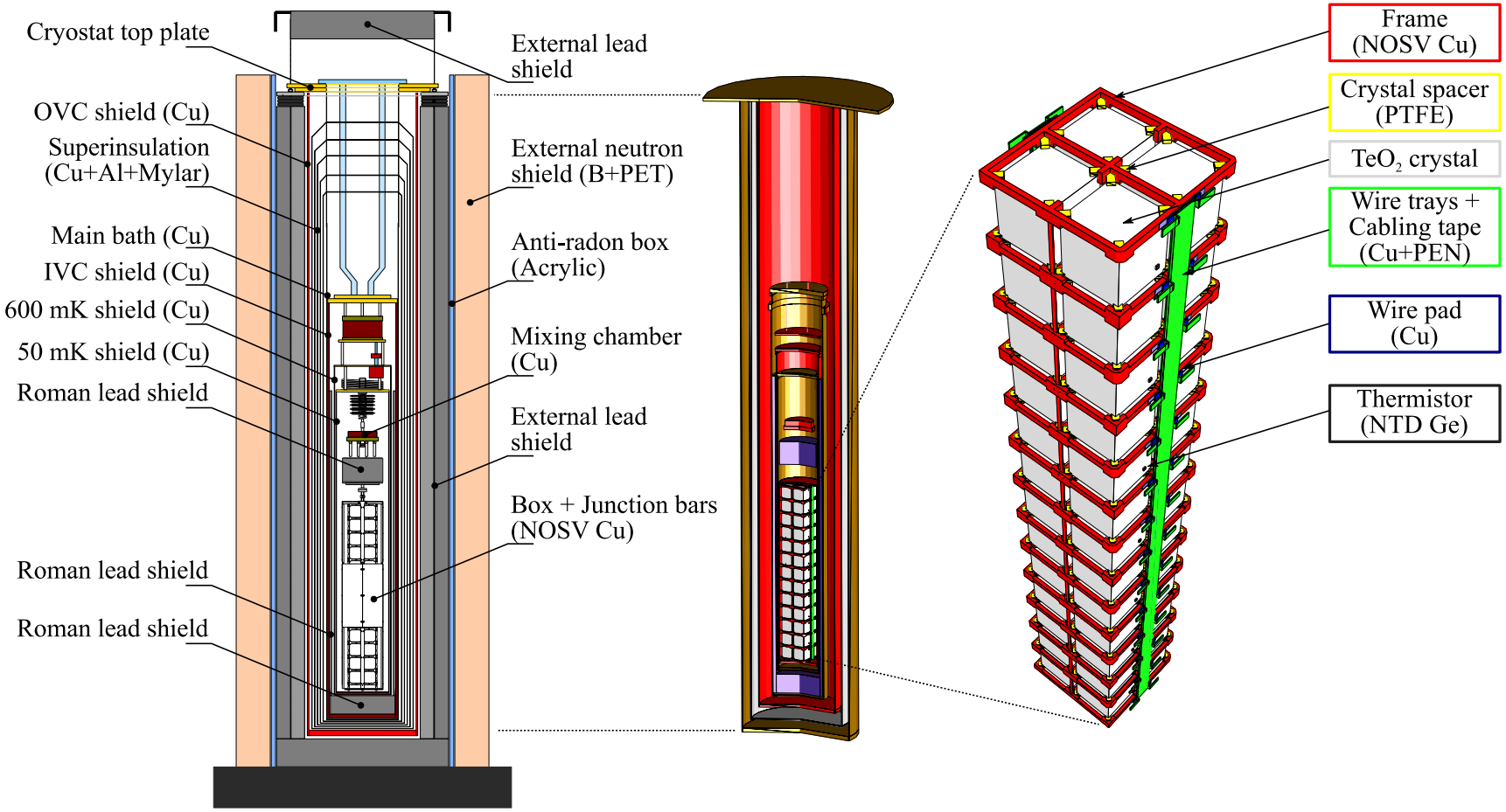
- Events where two crystals record simultaneously, summed energy (Σ_2)



Spectrum without $2\nu\beta\beta$



Cryostat in Monte Carlo



Bayesian Fitting

- $\left\langle C_{i,\alpha}^{exp} \right\rangle = \sum_{j=1}^{57} N_j \left\langle C_{ij,\alpha}^{MC} \right\rangle$
- $Posterior(N_j, \left\langle C_{ij,\alpha}^{MC} \right\rangle | C_{i,\alpha}^{exp}, C_{ij,\alpha}^{MC}$
- $= \prod_{i,\alpha} Pois(\, C_{i,\alpha}^{exp} | \left\langle C_{i,\alpha}^{exp} \right\rangle \times \prod_j Prior(N_j)$
- $\times \prod_{ij,\alpha} Pois(C_{ij,\alpha}^{MC} | \left\langle C_{ij,\alpha}^{MC} \right\rangle) \times Prior(\left\langle C_{ij,\alpha}^{MC} \right\rangle)$