Bayesian Analyses in CUORE and CUPID

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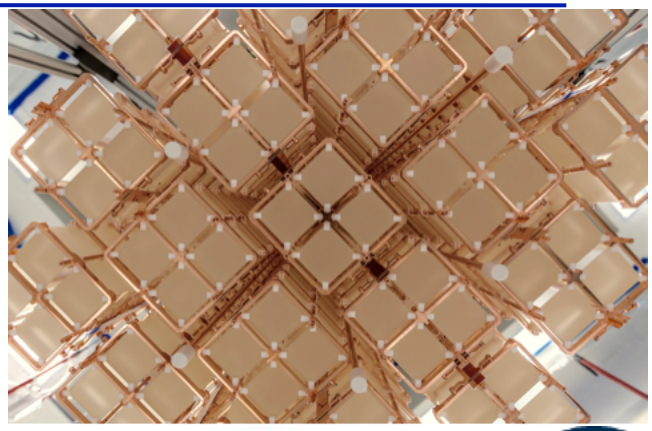


CUORE and CUPID

CUORE: Array of 988 TeO_2 crystals

- **19** towers suspended in a cylindrical structure
- **13** levels, **4** crystals each
- Operating now to ~2024 at LNGS

CUPID: next-generation upgrade

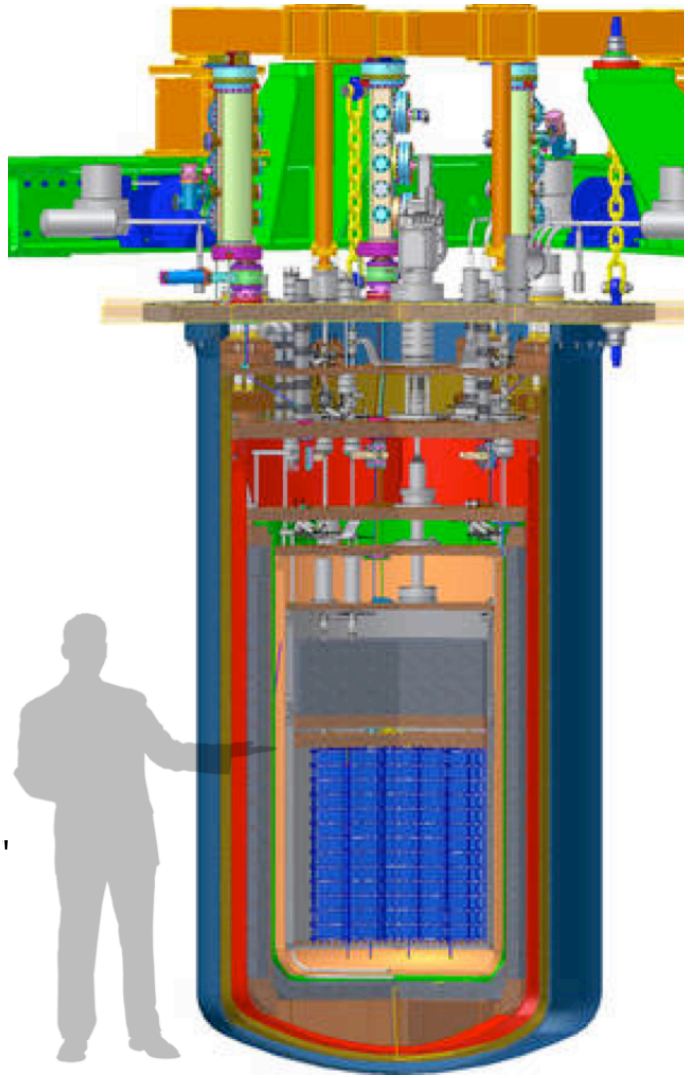
- Array of 1596 crystals, dual readout of heat and light (3306 channels in total)

Low event rates (~3 mHz/channel)

- Operating 24x7 for ~10 years
  - Would still expect O(10^9) events when all is said and done

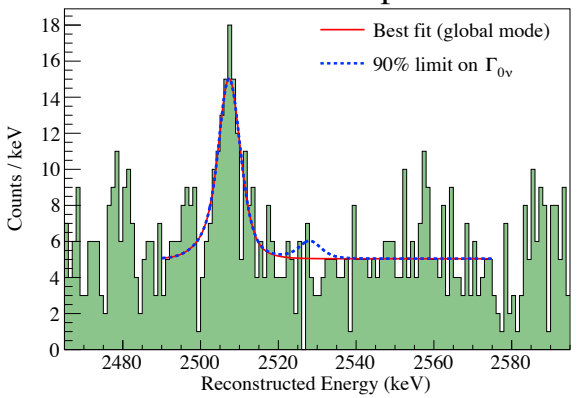
Bayesian analysis by default

- E.g. $0\nu\beta\beta$ and background model
- LOTS of nuisance parameters

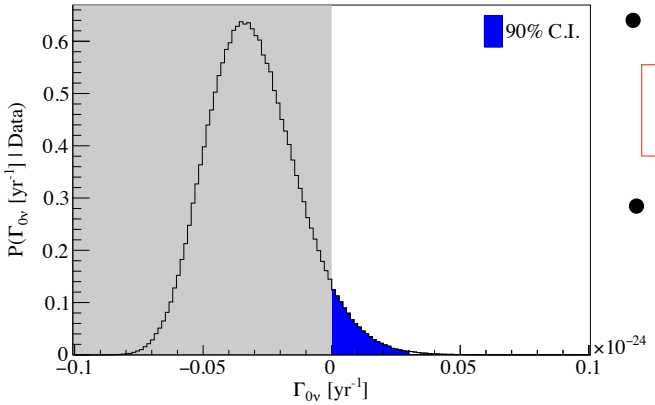


Example: CUORE: 0νββ Search

CUORE ROI Spectrum



Posterior for $\Gamma_{0\nu}$



- No evidence for 0νββ decay

$$T^{0\nu}_{1/2} > 3.2 \times 10^{25}\ \text{yr}\ (90\%\ \text{C.I.})$$

- Interpretation in context of light Majorana neutrino exchange

$$m_{\beta\beta} < 75 - 350\,\text{meV}$$

Phys. Rev. Lett. 124, 122501 (2020)

- Total exposure in TeO_2: 372.5 kg*y
- Bayesian Analysis (BAT)
- Likelihood model: flat continuum (BI), posited peak for 0νββ (rate), peak for ^{60}Co (rate + position)
- Unbinned fit on physical range (rates non-negative), uniform prior on $\Gamma_{0\nu}$
- Systematics: repeat fits with nuisance parameters, allow negative rates (<0.4% impact on limit)
- Nuisance parameters for each channel-dataset (>10^4)

Detector Performance Parameters

Background Index

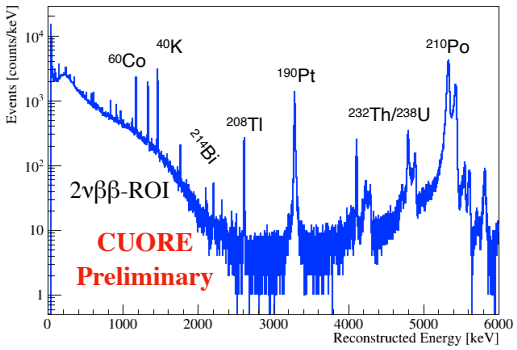
$$(1.38 \pm 0.07) \times 10^{-2} \text{cnts}/(\text{keV} \cdot \text{kg} \cdot \text{yr})$$

Characteristic FWHM ΔE at $Q_{\beta\beta}$

$$7.0 \pm 0.3\ \text{keV}$$

2νββ decays, Background Model

Summed CUORE Spectrum

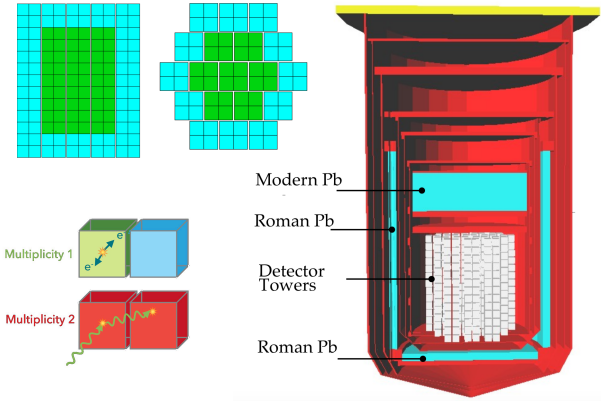


Reconstruct CUORE continuum background

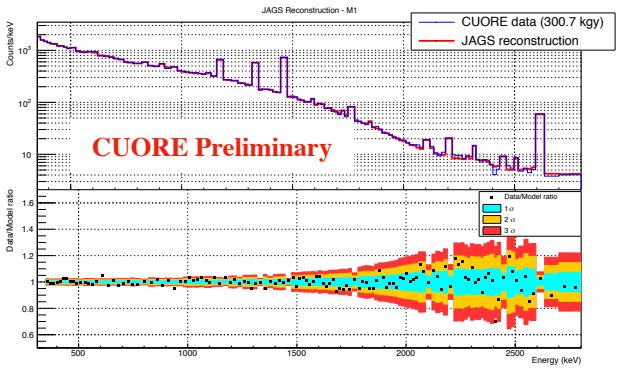
GEANT4 simulation + measured detector response function to produce expected spectra

62 sources considered, Bayesian fit with flat priors (JAGS)

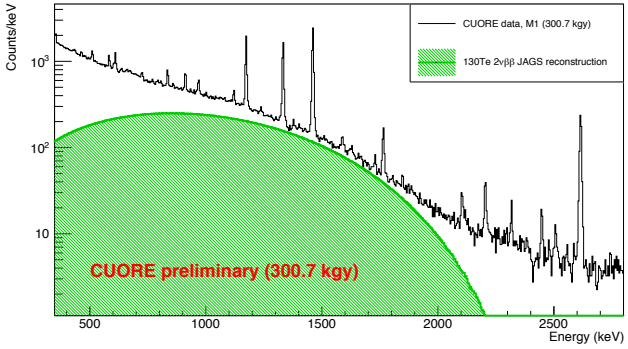
Exploit coincidences & detector self-shielding to constrain location of sources



Reconstructed Spectrum (Multiplicity 1)



Reconstructed Spectrum (Multiplicity 1)



Systematic Uncertainties

- Data selection:
  - geometric splitting, time splitting, fit range
- Choice of 2νββ spectrum (single state vs. higher state dominance*)
- Unconstrained fallout products (^{90}Sr)

[* Phys. Rev. C. 85, 034316 (2012)]

CUORE Preliminary

$$T^{2\nu}_{1/2} = [7.71^{+0.08}_{-0.06}(\text{stat.})\,^{+0.17}_{-0.15}(\text{syst.})] \times 10^{20}\ \text{yr}$$

CUORE/CUPID Issues

- In full glory, O(10^9) events, perhaps O(10^6) nuisance parameters
  - Bayesian analysis is most natural here
- Fully Bayesian fits, with the full evaluation of systematic errors due to the uncertainties of the nuisance parameters quickly become untenable
  - Would be interested in optimization of MCMC, but clearly need a qualitative change in how these fits are done
  - Would also be interested in development of common tools and frameworks for applications for NP