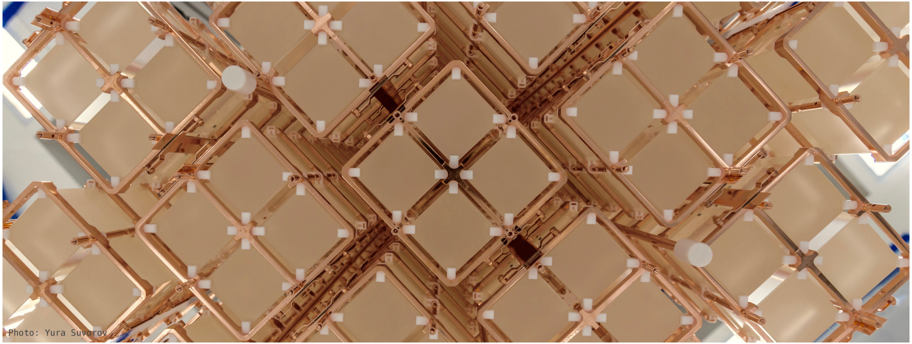


Latest results from the CUORE experiment

Giovanni Benato for the CUORE Collaboration
UC Berkeley

TeVPA, Berlin, 27-31 August 2018

$0\nu\beta\beta$ decay: what and why?

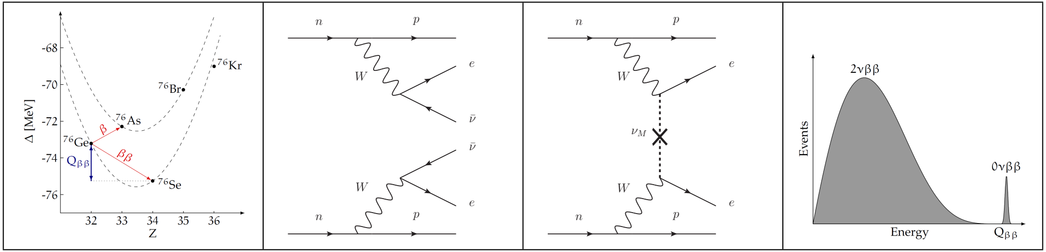
Open questions

- What is the origin of our matter-dominated Universe?
- Is $(B-L)$ conserved?
- What's the origin of neutrino masses?
- Are neutrinos Dirac or Majorana particles?

If we measure $0\nu\beta\beta$ decay:

- We would have an example of a matter-creating process
- $(B-L)$ and L would not be conserved
- Neutrinos would have a Majorana mass component

$0\nu\beta\beta$ decay: what and why?



$\beta\beta$ decay signature

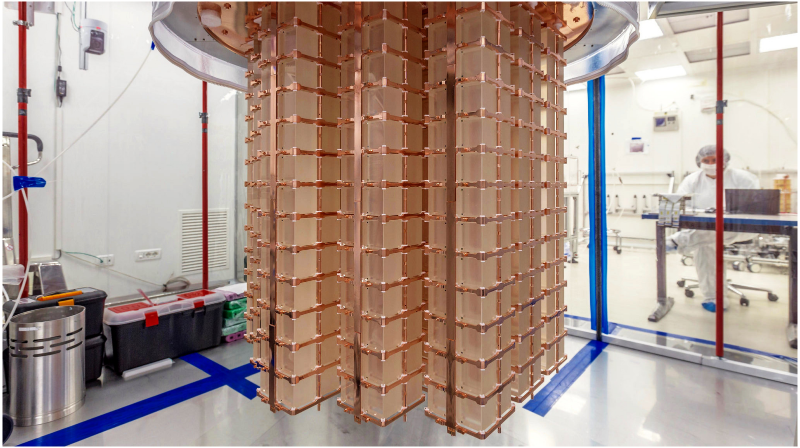
- Continuum for $2\nu\beta\beta$ decay, peak at $Q_{\beta\beta}$ for $0\nu\beta\beta$ decay
- Additional signatures from signal topology, pulse shape discrimination, ...

$0\nu\beta\beta$ decay rate

$$\frac{1}{T_{1/2}^{0\nu}} = G_{0\nu} \cdot |M_{0\nu}|^2 \cdot \frac{|f|^2}{m_e^2}$$

- $T_{1/2}^{0\nu}$ = $0\nu\beta\beta$ decay half life
- $G_{0\nu}$ = phase space (known)
- $M_{0\nu}$ = nuclear matrix element (NME)
- f = new physics

CUORE: the Cryogenic Underground Experiment for Rare Events



CSNSM
UCLA
Yale
INFN
Berkeley Lab
Cal Poly San Luis Obispo
Massachusetts Institute of Technology
VirginiaTech Invent the Future®
Lawrence Livermore National Laboratory
Sapienza Università di Roma
Università degli Studi di Milano Bicocca
SINAP
University of South Carolina

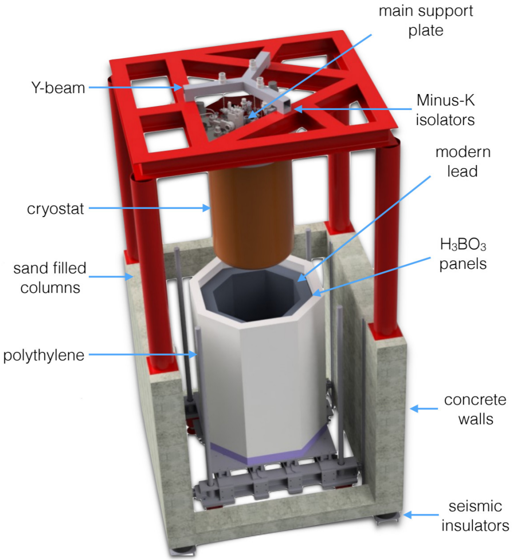
The CUORE experiment

Main features

- Goal: search for $0\nu\beta\beta$ decay of ^{130}Te
- Array of 988 TeO_2 crystals (206 kg of ^{130}Te) operated as cryogenic calorimeters at ~ 10 mK
- Energy resolution: goal of 5 keV at $Q_{\beta\beta}$
- Low background: goal of 10^{-2} cts/(keV·kg·yr) at $Q_{\beta\beta}$

Mitigation of external backgrounds

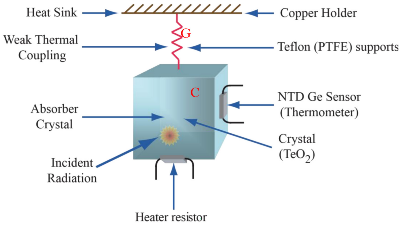
- Located at the Gran Sasso National Laboratory (3600 m.w.e. overburden): $3 \cdot 10^{-8}$ μ/cm^2/s
- Polyethylene and H_3BO_3 neutron shielding
- 70 tons of external lead shielding
- 6.5 tons of Roman Pb inside the cryostat
- Copper cryostat absorbs Pb X-rays



Detector principles

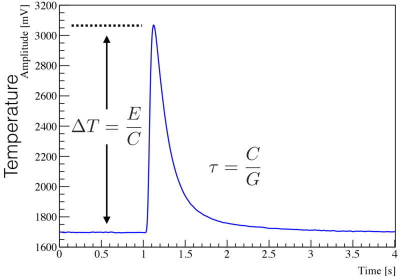
Why cryogenic calorimeters?

- Detect temperature variation due to phonon contribution of released energy
  $\rightarrow$ High energy resolution: currently $\sim 0.3\%$ FWHM at $Q_{\beta\beta}$
- Allow to change crystal and isotope

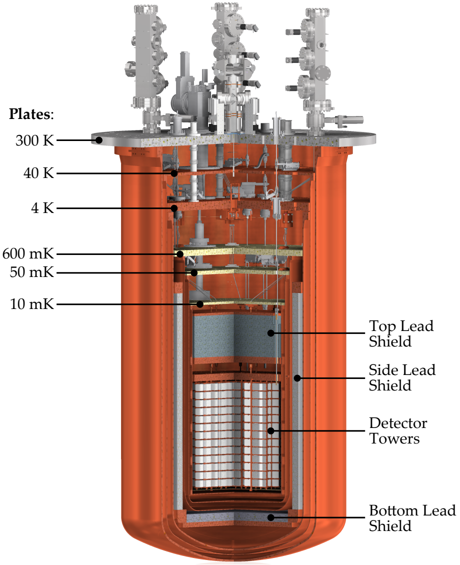


How do cryogenic calorimeters work?

- Heat capacity: $C = C(T) \propto T^3 \rightarrow$ Need to work at ~ 10 mK
- Temperature response (pulse height): $\Delta T = \Delta E / C$
- Relaxation through weak link with thermal conductivity G
- Pulse decay constant: $\tau = C/G$



How do we keep the crystals cold?

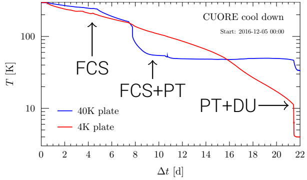


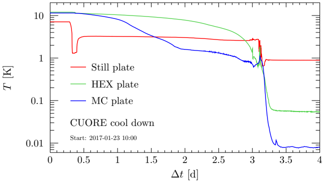
Requirements

- Cool down in $\lesssim 1$ month
- Stay stable at ~ 10 mK
- Run for 5 yr

Solutions

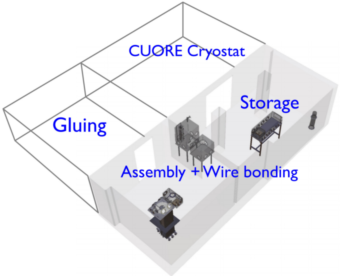
- Cryogen free cryostat $\rightarrow$ Lower down time
- Fast cooling with He vapor down to ~ 40 K
- 5 Pulse Tubes (PT) down to ~ 4 K
- Dilution Unit (DU) down to ~ 10 mK

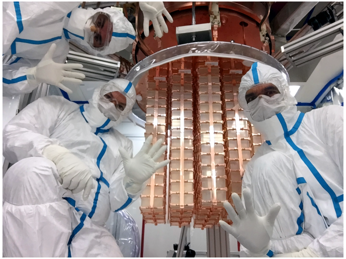




How to avoid recontamination?

- Screening of all parts
- Underground storage to avoid cosmic activation
- Tower assembly in underground class 1000 clean room
- Towers stored in N_2 atmosphere to minimize Rn contamination
- Dedicated clean room with Rn-free air for tower installation
  $\rightarrow$ Rn level kept $\lesssim 50$ mBq/m^3 for the entire duration of the installation





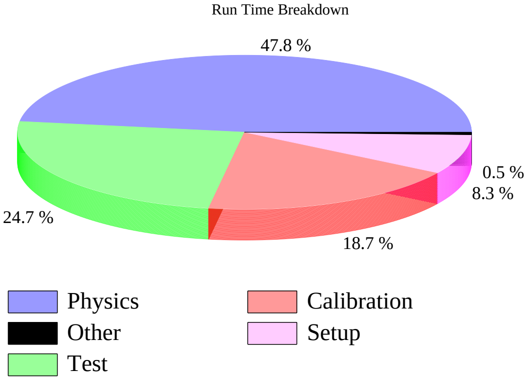
2017 data collection

Data sets

- Dataset 1: May-Jun. 2017
- Dataset 2: Aug.-Sep. 2017
- Calibration at beginning and end of each data set

Performance

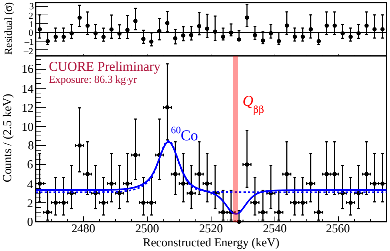
- 984/988 operational channels
- $\sim 3\%$ of channels without heater
- More stable wrt Cuoricino/CUORE-0
- Thr.: from 20 to few hundreds keV
  $\rightarrow$ Optimal trigger available soon
- Per-channel trigger rate:
  6 mHz physics / 50 mHz calibration

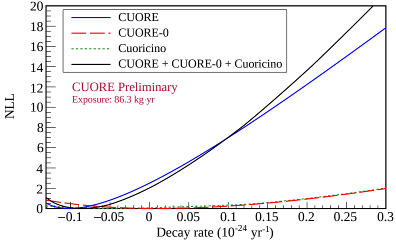


Collected statistics

- TeO_2 exposure: 86.3 kg·yr
- ^{130}Te exposure: 24.0 kg·yr

2017 $0\nu\beta\beta$ decay analysis[1]





ROI fit

- Fit region: $[2465, 2575]$ keV
- Flat bkg + $0\nu\beta\beta$ peak + ^{60}Co peak
- Channel-dependent line shape
- Simultaneous unbinned max-$\mathcal{L}$ fit (negative rates allowed)
- Cross-check with fully Bayesian fit

Limit on $T_{1/2}^{0\nu}$ and $|m_{\beta\beta}|$

- Integrate profile likelihood in the physical region $(\Gamma_{0\nu} > 0)$
- For bkg-dominated case, equivalent to Bayesian construction with flat prior on all rates
- CUORE only: $T_{1/2}^{0\nu} > 1.3 \cdot 10^{25}$ yr $(90\%$ C.I.)
- With Cuoricino and CUORE-0: $T_{1/2}^{0\nu} > 1.5 \cdot 10^{25}$ yr $(90\%$ C.I.)
- Median sensitivity: $\hat{T}_{1/2}^{0\nu} = 7.4 \cdot 10^{24}$ yr
- Limit on effective mass: $m_{\beta\beta} < (140 - 400)$ meV $(90\%$ C.I.)

[1]CUORE Collaboration, Phys. Rev. Lett. 120 (2018) 132501

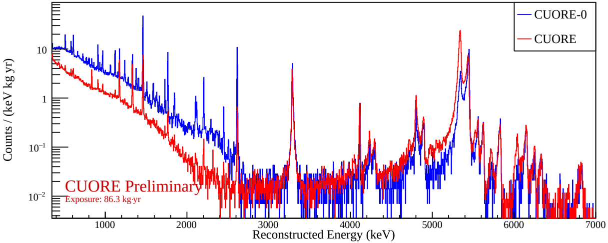
Understanding the CUORE background

Some history

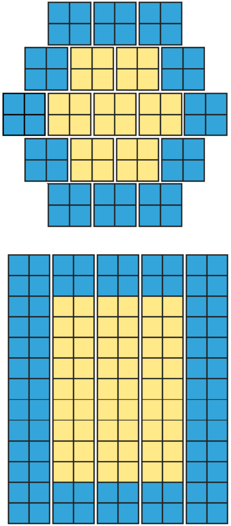
- $\sim 65\%$ of CUORICINO bkg from surface α contaminants, remaining was γ's from ^{232}Th in cryostat
- CUORE-0: test CUORE tower construction on CUORICINO cryostat
- α background in CUORE-0 reduced by factor 10 wrt CUORICINO

CUORE background

- γ bkg strongly reduced
- Most α bkg consistent with CUORE-0
- Bkg generally consistent with expectations
- ^{210}Po excess (probably) from shallow contamination in copper $\rightarrow \sim 10^{-4}$ cts/(keV·kg·yr) at $Q_{\beta\beta}$



Building the CUORE background model

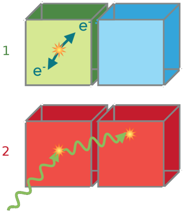


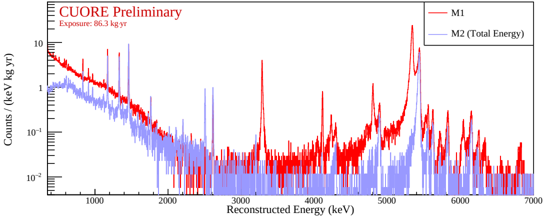
Maximize use of available information

- Split the data into inner and outer layers
- Split data into Multiplicity 1 (M1), Multiplicity 2 (M2) and Multiplicity 2 Sum ($\Sigma 2$)

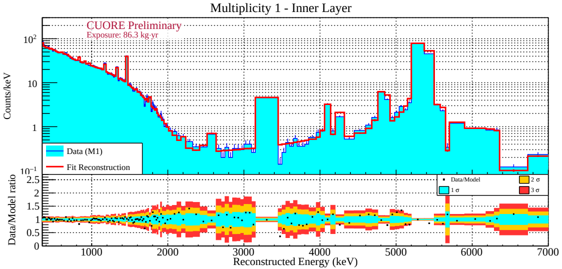
Background model

- Geant4 simulation of contaminants in different cryostat components (~ 60 independent fit parameters)
- Bayesian fit using a MCMC Gibbs sampler (JAGS)
- Flat priors for all parameters except muons



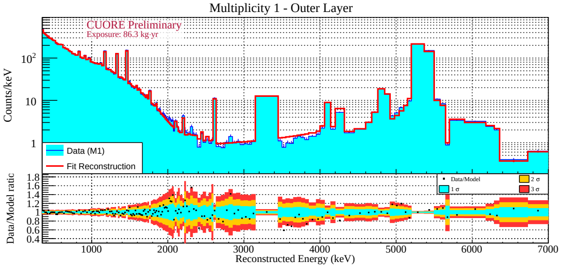


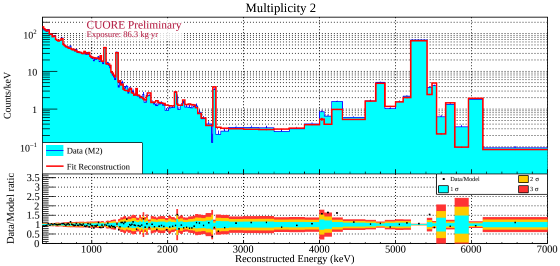
Building the CUORE background model



Why separate spectra?

- Inner layer very sensitive to signal (lower background)
- Outer layer sensitive to external backgrounds
- M2 and Σ2 spectra constrain a subset of the backgrounds





$2\nu\beta\beta$ decay analysis

"Ein Abdruck ihrer Formen
In Gamma-Strahlenhintergrund"

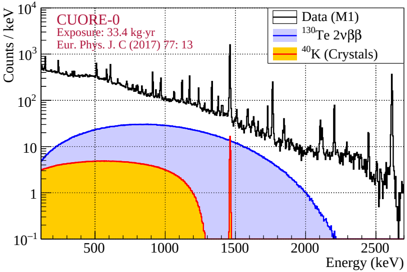
Einstürzende Neubauten
Die Explosion im Festspielhaus

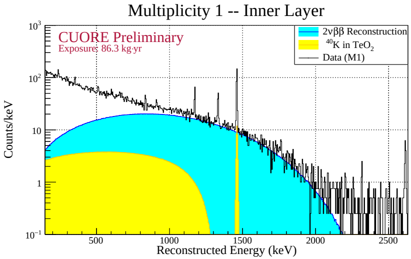
Results

- Almost all events in 1-2 MeV range are $2\nu\beta\beta$ events (compare to $\sim 20\%$ in CUORE-0)
- $T^{2\nu}_{1/2} = [7.9 \pm 0.1(\text{stat}) \pm 0.2(\text{syst})] \cdot 10^{20}$ yr (PRELIMINARY)
- CUORE-0: $T^{2\nu}_{1/2} = [8,2 \pm 0.2(\text{stat}) \pm 0.6(\text{syst})] \cdot 10^{20}$ yr
- NEMO: $T^{2\nu}_{1/2} = [7.0 \pm 0.9(\text{stat}) \pm 1.1(\text{syst})] \cdot 10^{20}$ yr

Systematics

- Primary systematic from geometric splitting
- No dependence on fit threshold over the range 100-750 keV



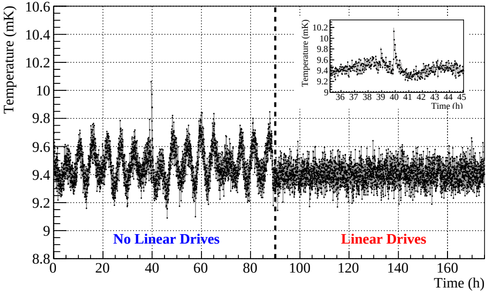


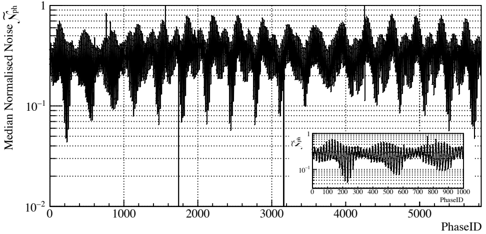
System optimization

- Oct.–Dec. 2017: scan of detector performance vs temperature
  → Selected 11 mK as optimal temperature
- Jan.–Mar. 2018: warmed up to 100 K to replace a set of gate valves
- Mar. 2018: back to base temperature
- Mar. 2018: Pulse Tube phase scan to minimize noise

Current status

- April calibration still shows 7.6 keV FWHM
  → Still working to achieve the 5 keV goal
- Stable physics data collection since May 2018
- Analysis of new data ongoing





Thank you!