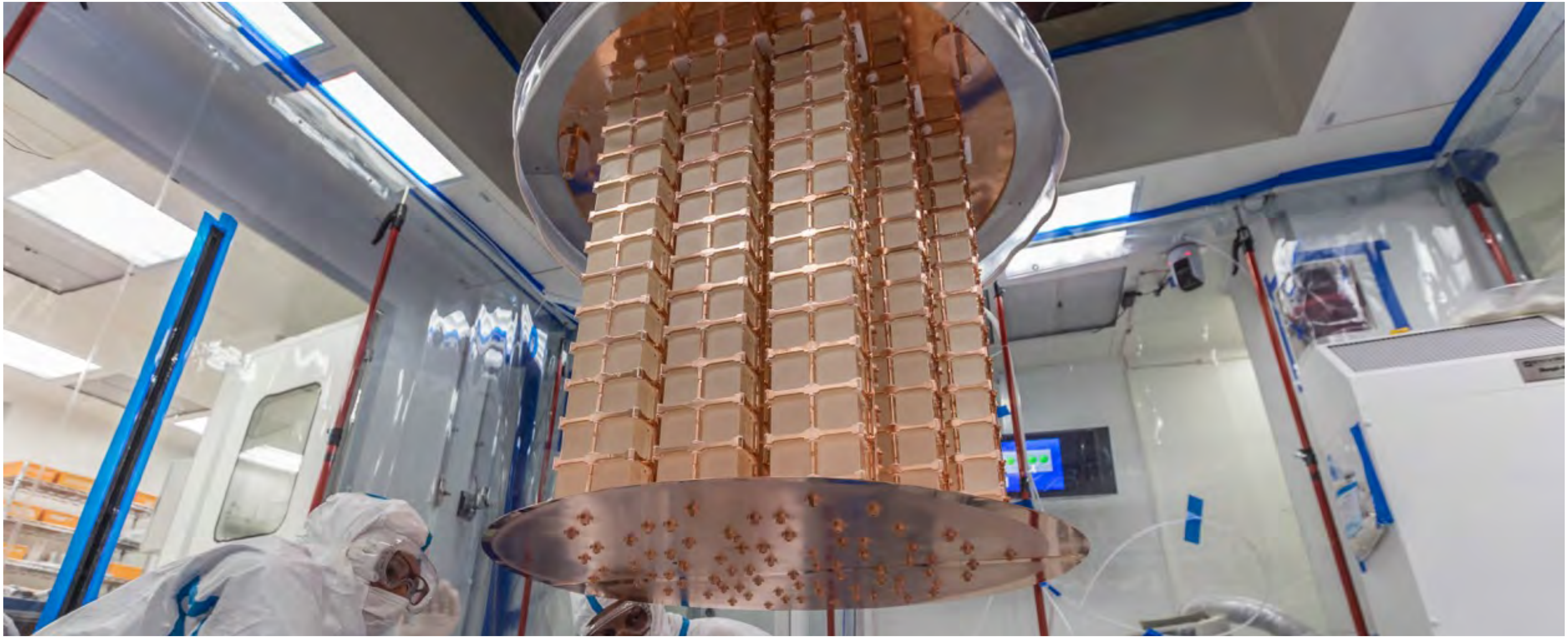

CUORE

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INFN - Sez. Milano Bicocca

October 2, 2017 - Meeting of the LNGS Scientific Committee

Outline

- Status
- First results
- Plans

CUORE
(Cryogenic Underground Observatory for Rare Events)

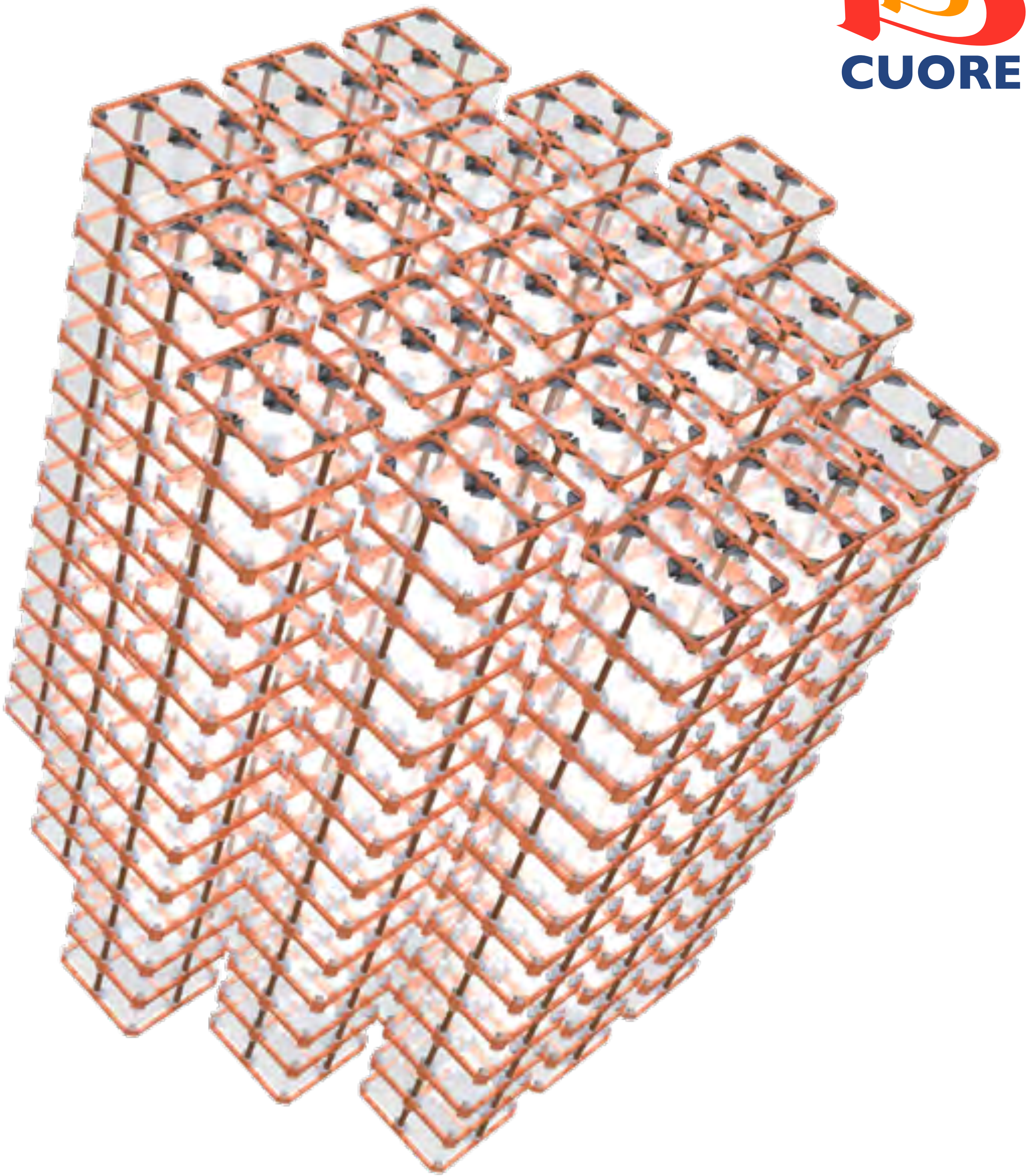
CUORE

Primary goal: search for 0νββ decay in ^{130}Te

Closely packed array of 988 TeO_2 crystals arranged in 19 towers

^{130}Te:
- large transition energy: $Q_{\beta\beta}$ (^{130}Te) 2527.5 keV
- highest natural isotopic abundance (33.8%)

CUORE design parameters:
- mass of TeO_2: **742 kg** (206 kg of ^{130}Te)
- low background aim: **10^{-2} c/(keV·kg·yr)**
- energy resolution: **5 keV** FWHM in the Region Of Interest (ROI)
- high granularity
- deep underground location
- strict radio-purity controls on materials and assembly

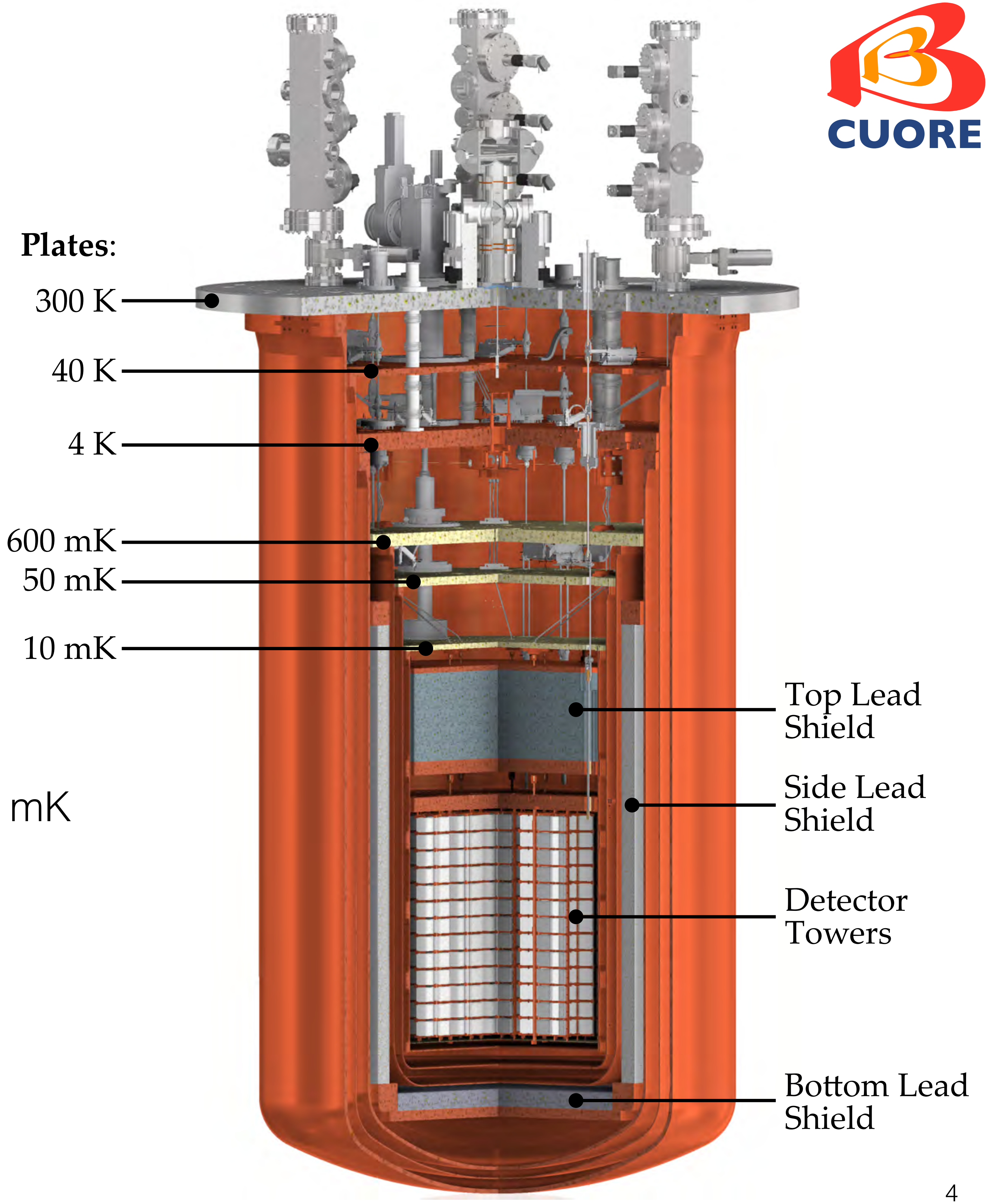


CUORE projected sensitivity (5 years, 90% C.L.):

$T_{1/2} > 9 \times 10^{25}$ yr

The CUORE cryostat

- Designed to cool down ~1 ton detector to ~10 mK
- Mechanically decoupled for extremely low vibrations
- Low background environment

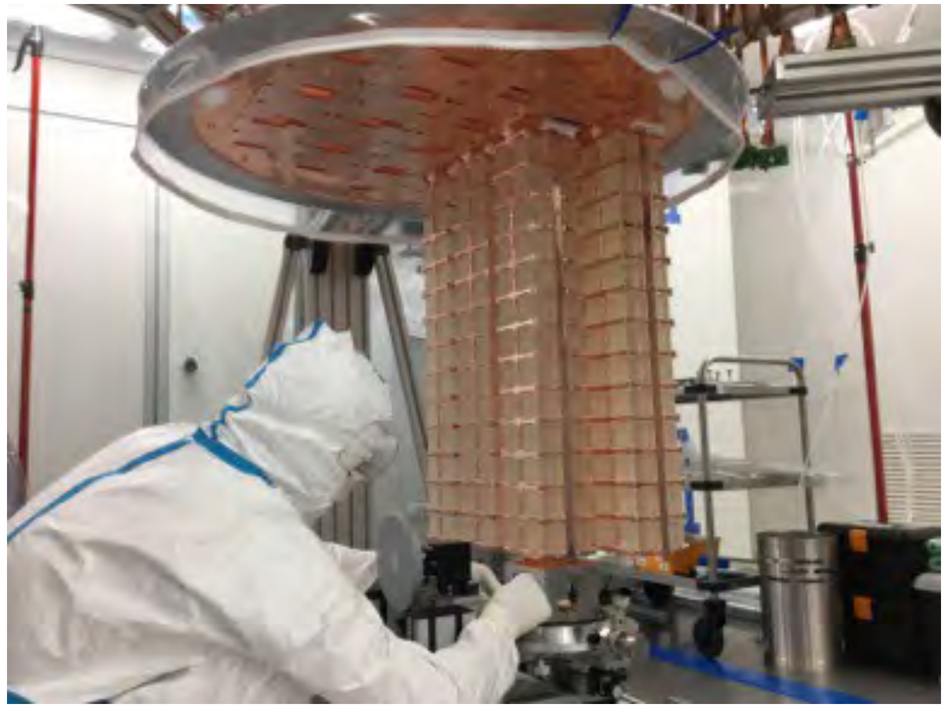


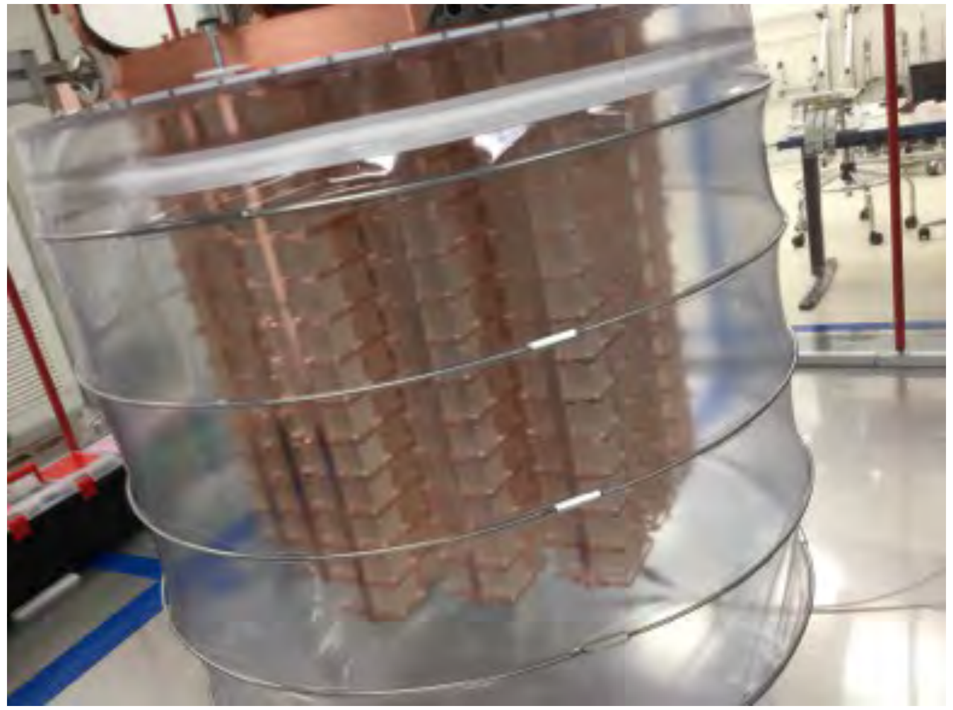
- Cryogen-free cryostat
- Fast Cooling System (^{4}He gas) down to ~50K
- 5 pulse tubes cryocooler down to ~4K
- Dilution refrigerator down to operating temperature ~10 mK
- Nominal cooling power: 3 μW @ 10mK
- Cryostat total mass ~30 tons
- Mass to be cooled < 4K: ~15 tons
- Mass to be cooled < 50 mK: ~3 tons (Pb, Cu and TeO_2)

The CUORE Collaboration

CUORE construction

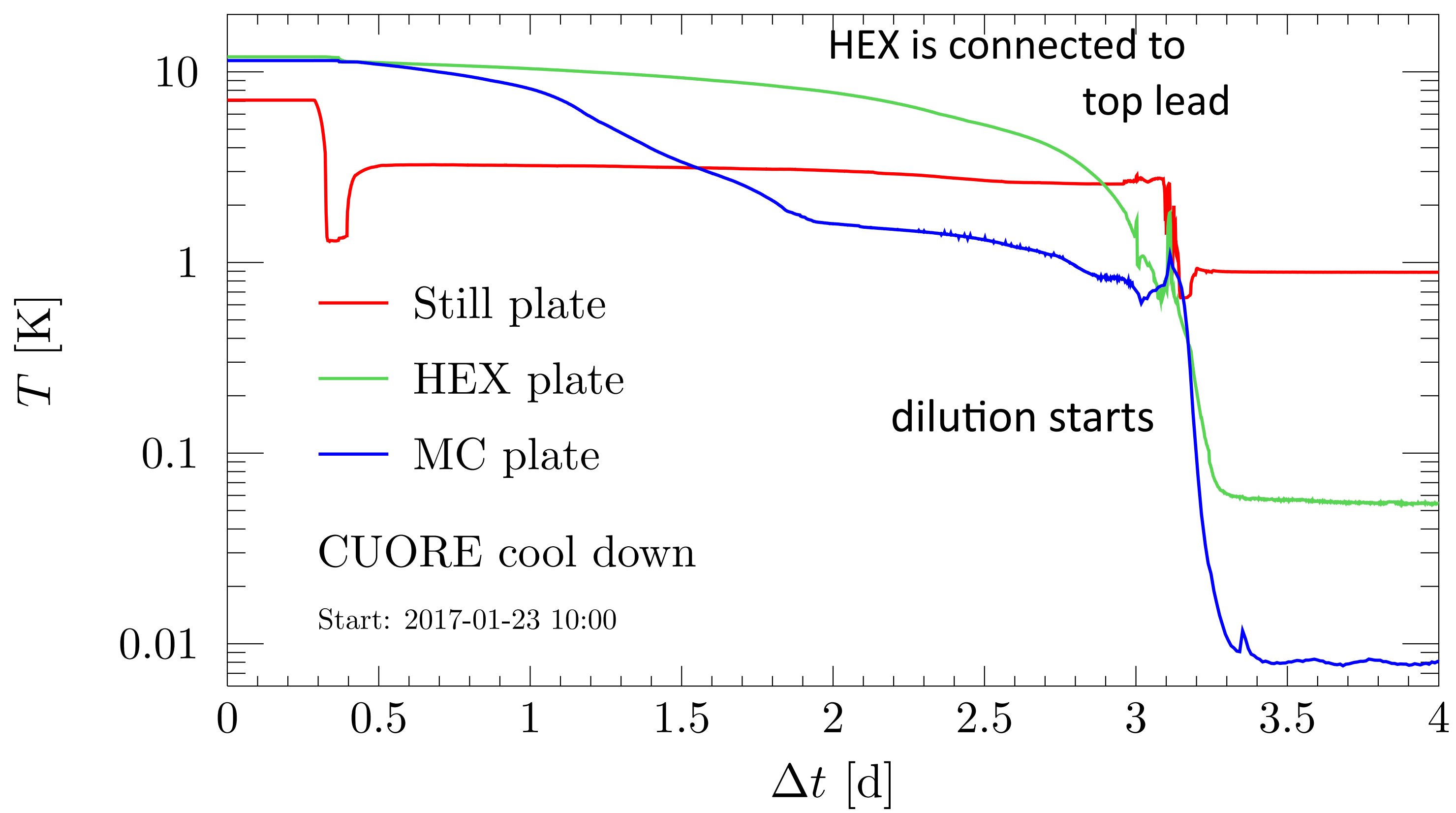
- June 2016: last steps of the CUORE construction process
  - Installation of the front-end electronics (2nd floor)
  - Installation of the DAQ (2nd floor)
  - Detector installation preparation
- August 2016: detector installation
- September-November 2016:
  - Installation of cryostat interfaces
  - Test of readout wires
  - Close-out of the cryostat vessels
  - IVC eventually closed in October 2016
- December 2, 2016: system close-out complete
- December 5, 2016: cool-down start



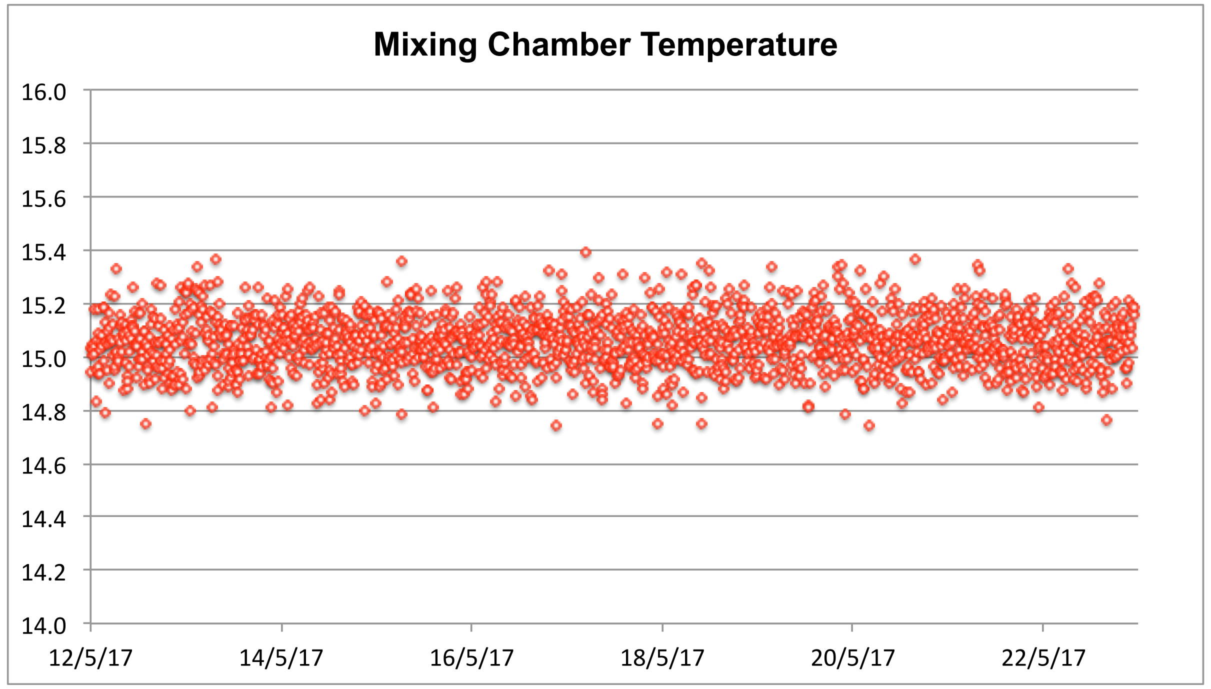


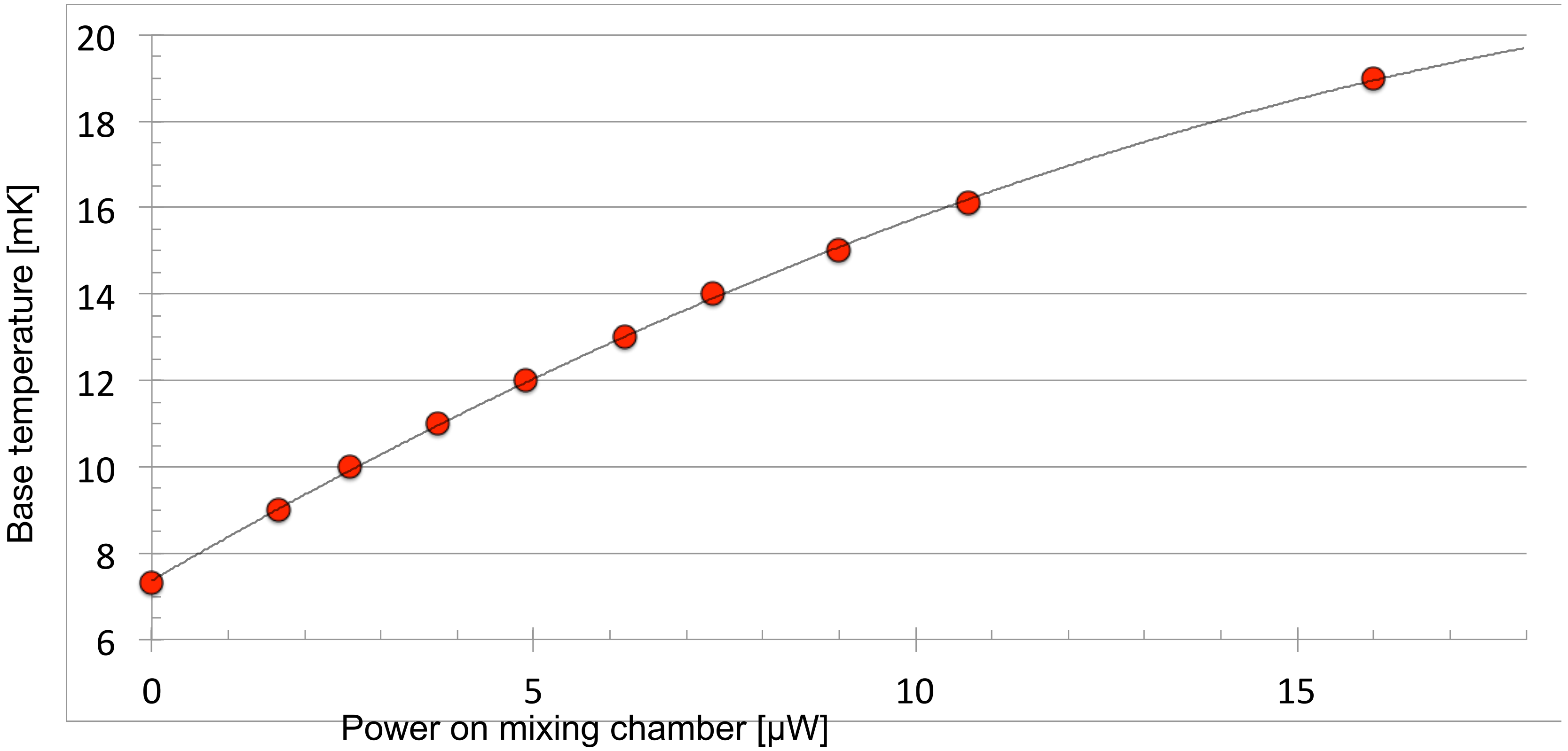
CUORE cooldown

- Reached a stable base temperature of ~7 mK on Jan 27, 2017
- Cooldown to base T: ~ 3 days
- Lowest temperature reached: 6.7 mK
- 984/988 working detectors
- Excellent performance @ full load



- Stable operation





Pre-operation

After the successful cool-down, we faced with the challenge of operating a thousand bolometers in a completely new system

A long list of activities

- DAQ and front-end electronics optimization
- Detector working points
  - Select representative subset
  - Load curves
  - Temperature scan for the best operating conditions
- Noise reduction
  - vibration induced
  - electrically induced

End of March 2017:

- optimization not yet complete
- decision to start calibrations and science runs
- selected working temperature: 15 mK

Transition to operation

Detector Performance

- The key parameters expected from CUORE are:
  - energy resolution
  - backgrounds in ROI
- Prioritary to obtain informations on both
- **CUORE has opted for a gradual transition to operation, alternating science runs to technical measurements aiming to achieve better performance and to demonstrate improvements towards the ultimate performance.**

First Physics Result

- **With few weeks of data CUORE can report the world's best limit on $0\nu\beta\beta$ from ^{130}Te with a high degree of confidence.**
- A preliminary physics result can demonstrate the successful operation of CUORE and be worth publishing by itself.
- Milestones:
  - Preliminary results for TAUP 2017
  - First CUORE physics paper by October 2017

Schedule for Early Physics with CUORE

2017:
- Feb-Mar: system optimisation
- Apr-May: science runs
- Jun-Jul: system optimisation
- Aug-Sep: science runs
- Oct-Nov: system optimisation

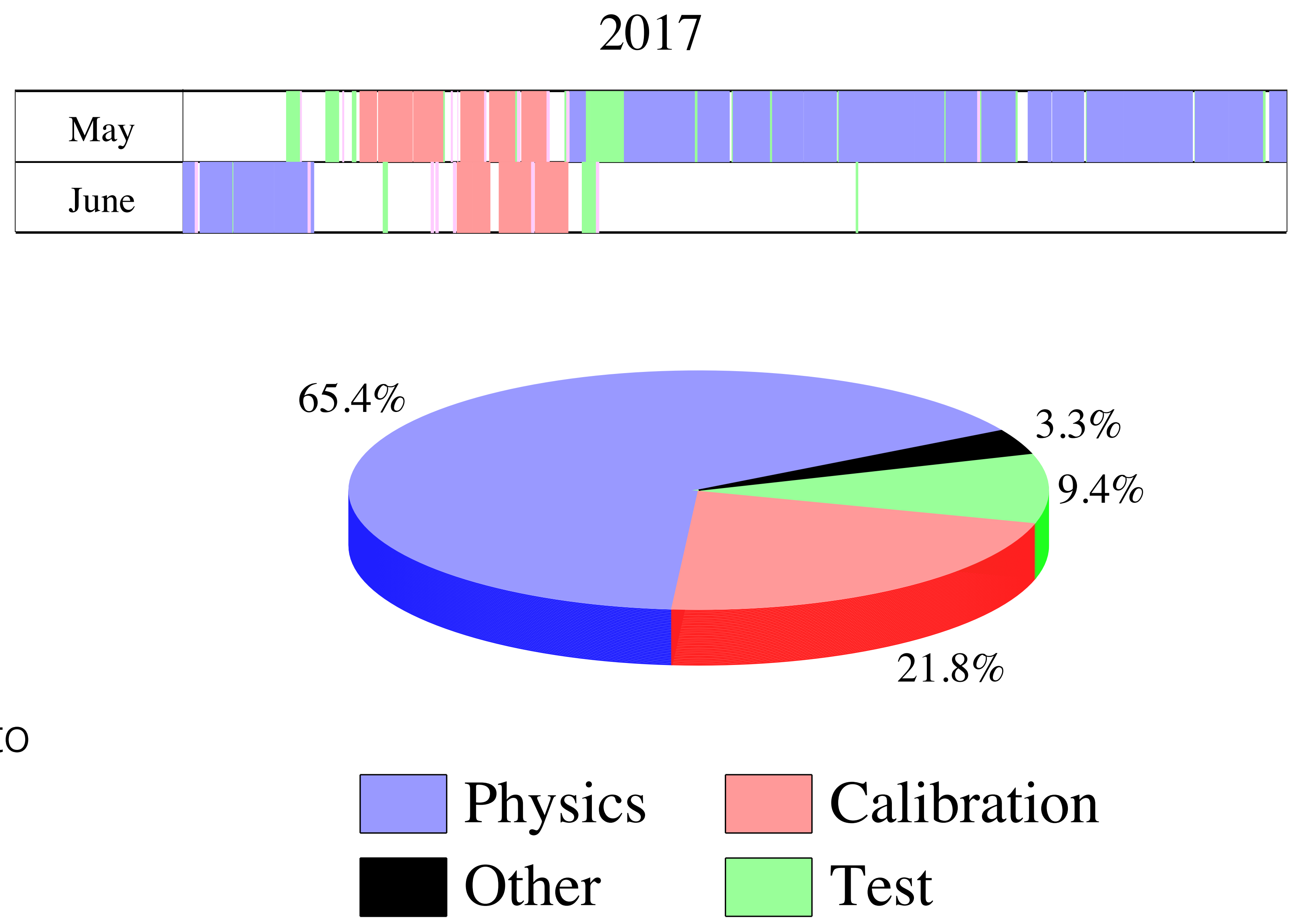
2018:
- **Science runs**

First results:
Apr-May 2017 (ds 3018)

Science runs

- Science operations started on April 14, 2017
  - **Dataset 1**: very short (identified issue with the thermistor bias on about 1/3 of the channels)
  - Reoptimization of the detector working point
  - **Dataset 2**: 3 weeks of physics data bracketed by 2 calibration periods (May 4 - June 11)
  - Second optimization campaign
  - Dataset 3: August - September 2017

Dataset 2 time breakdown



Operational performance:

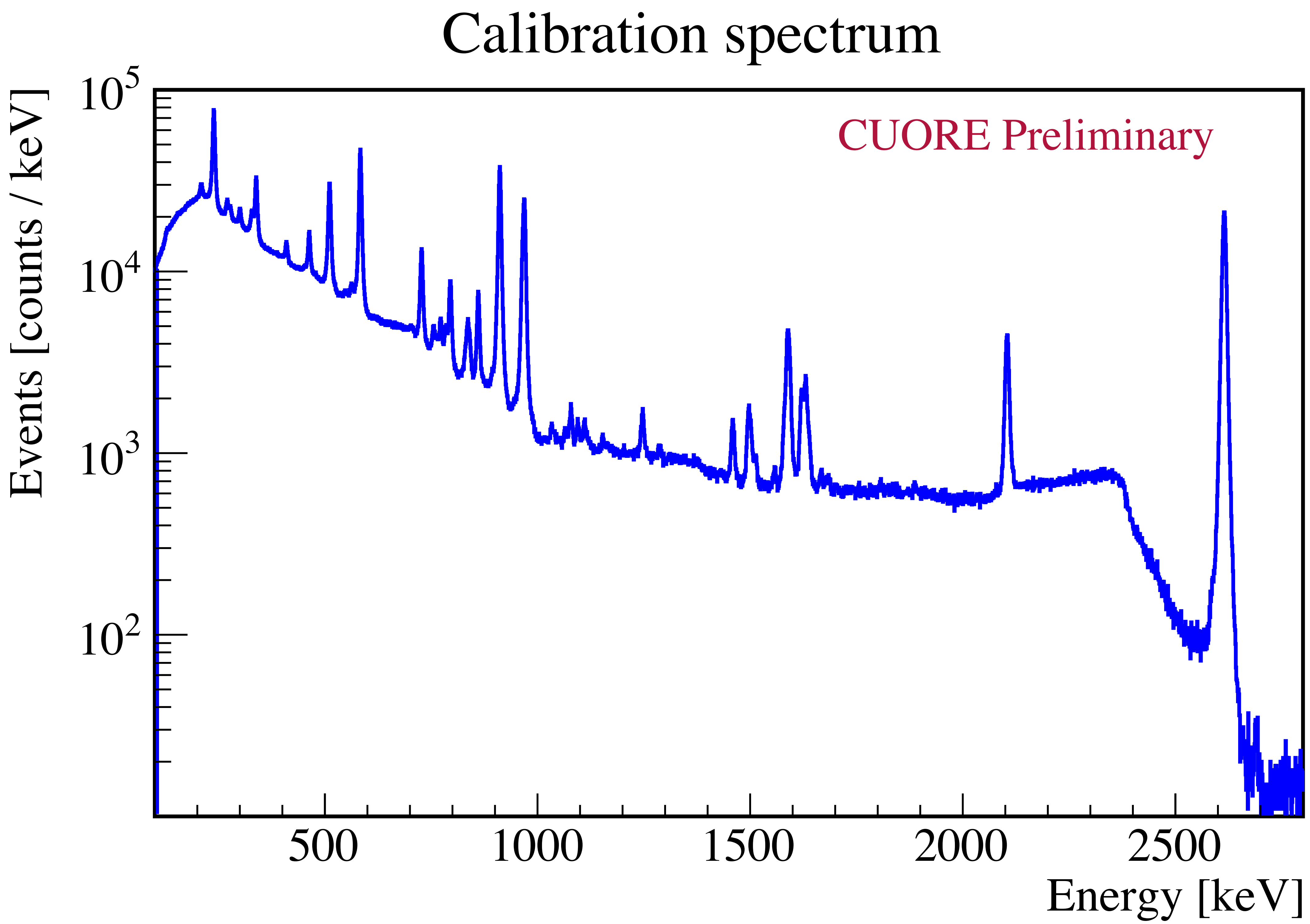
- **984/988 operational channels**
- Excellent data-taking efficiency when in operations
- Much improved detector stability, compared to Cuoricino/CUORE-0
- Calibrations/physics ratio data still to be optimized to maximize $0\nu\beta\beta$ sensitivity

Acquired statistics for 0vDBD decay search:

- **$^{nat}TeO_2$ exposure: 38.1 kg yr**
- **^{130}Te exposure: 10.6 kg yr**

Calibration spectrum

- ^{232}Th sources deployed inside the CUORE detector
- Energy spectrum of all the CUORE detectors

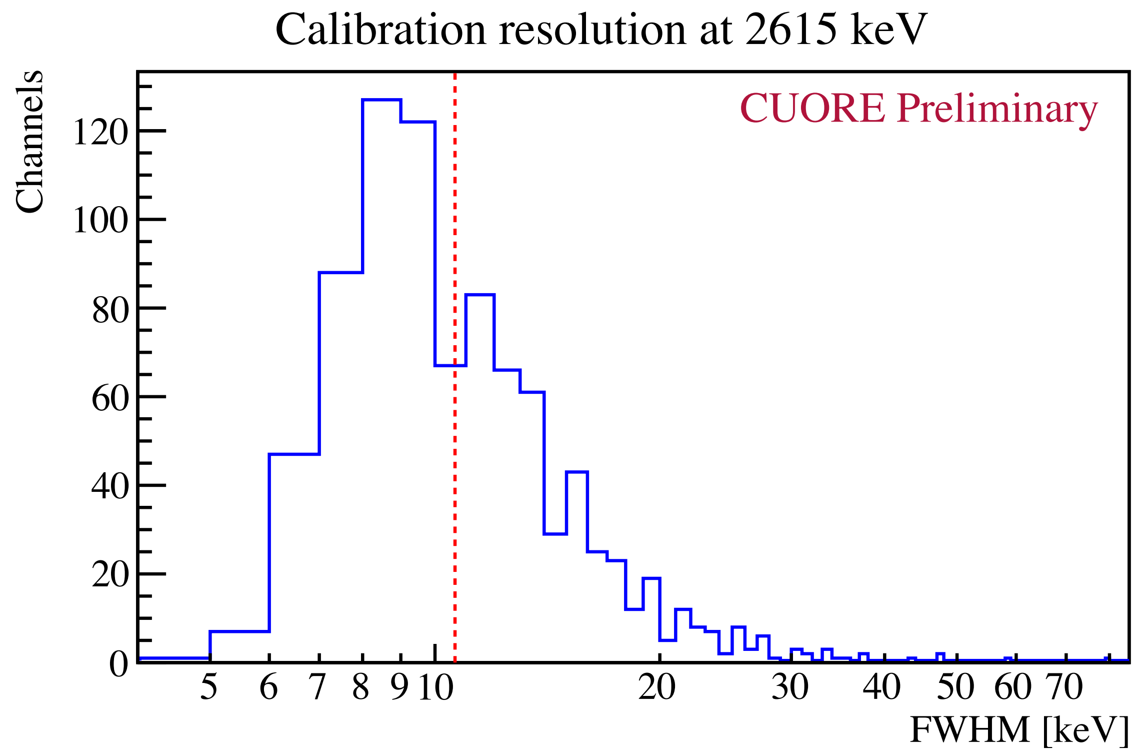


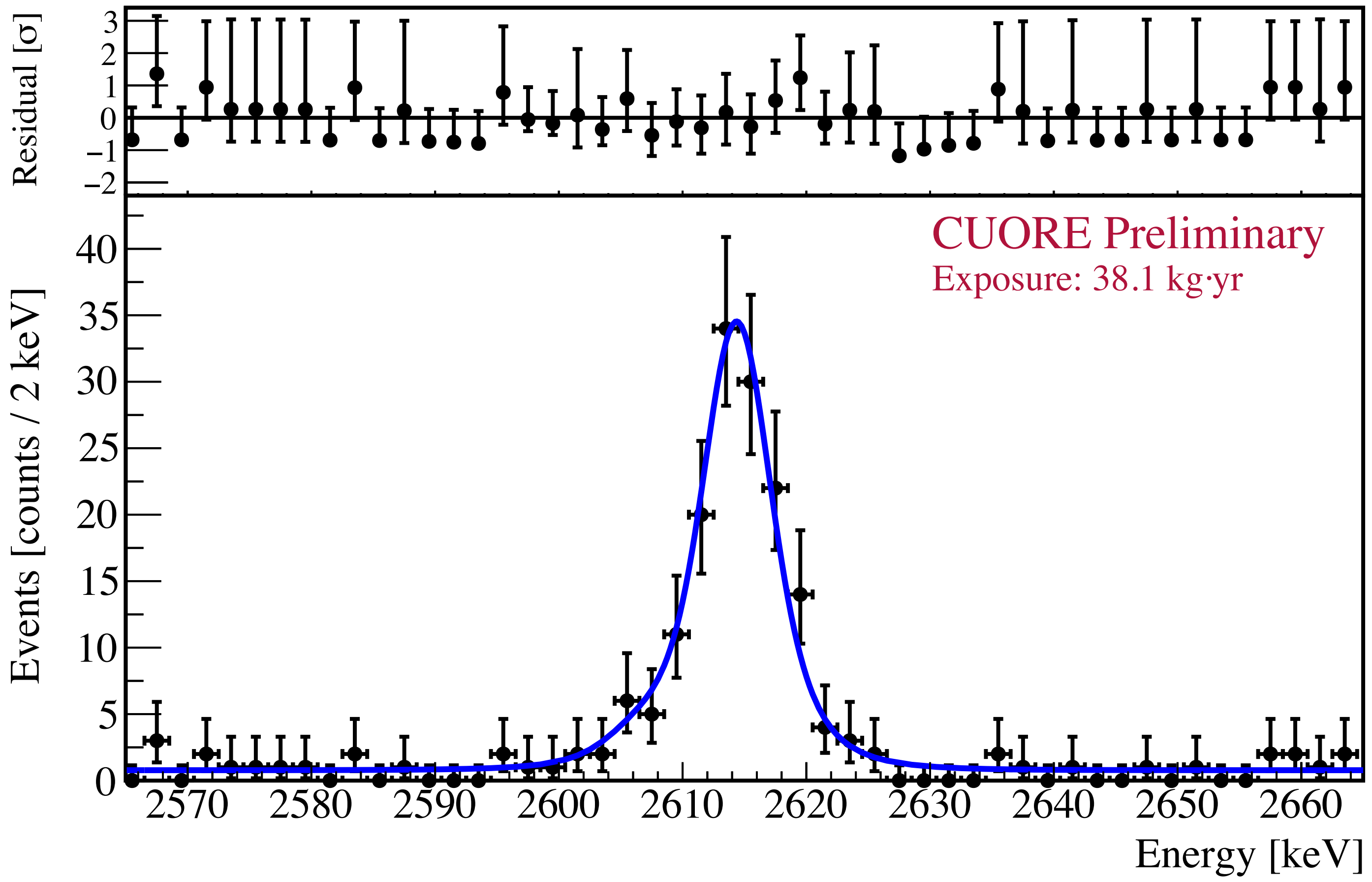
Detector performance: energy resolution

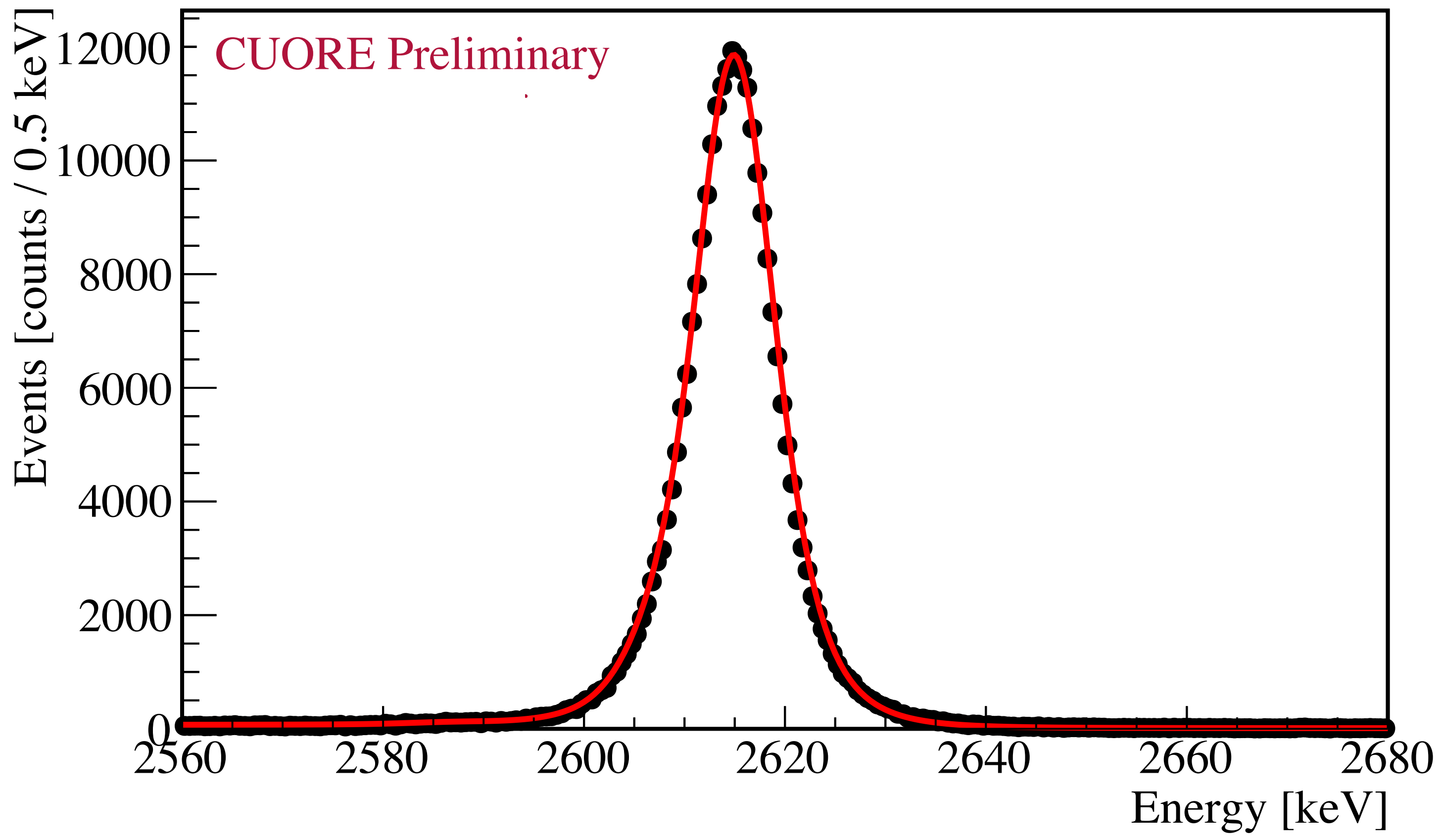
CUORE

- 899 (90%) best performing channels used for initial analysis; most discarded channels had poor line or pulse shapes, and should be recovered in future runs
- Average (“harmonic mean”) energy resolution in calibration runs: **10.6 keV FWHM @ 2615 keV**

- Significantly better performance in physics data: **(7.9 ± 0.6) keV FWHM @ 2615 keV**



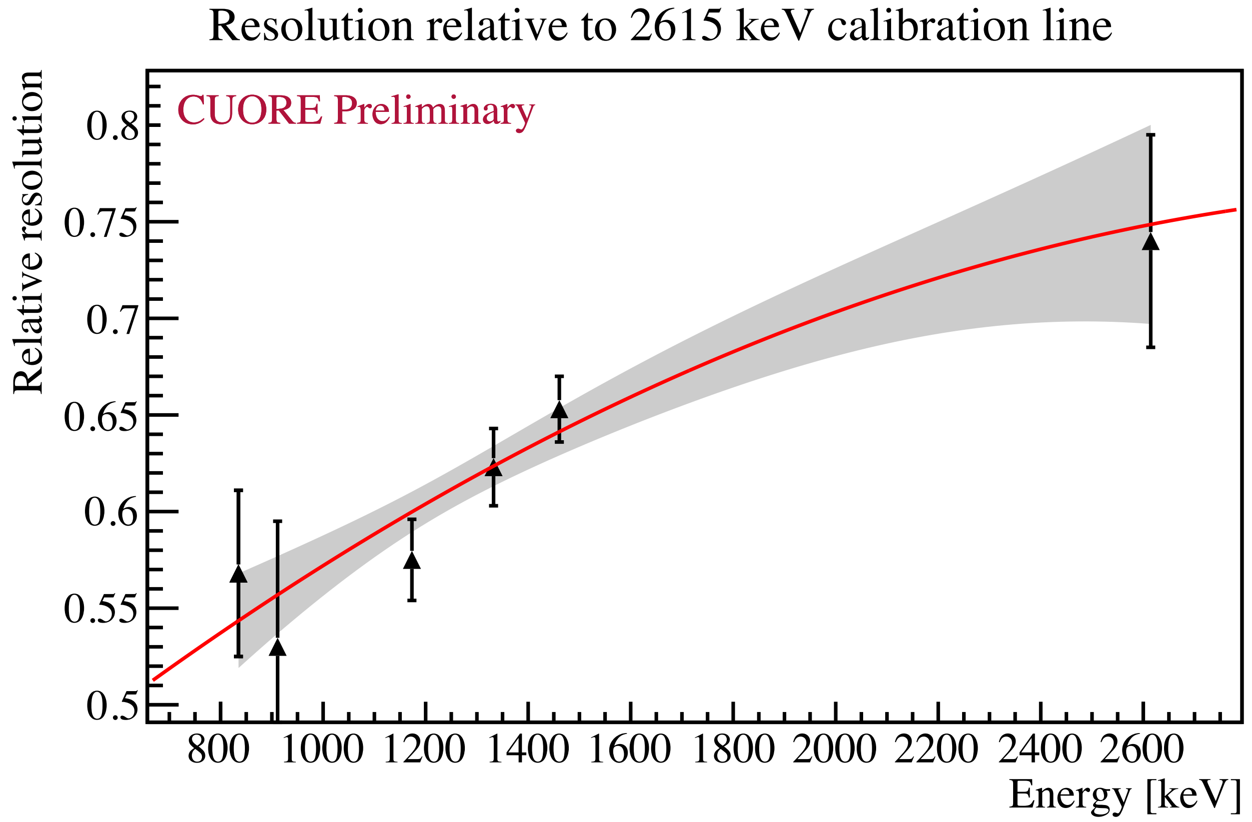


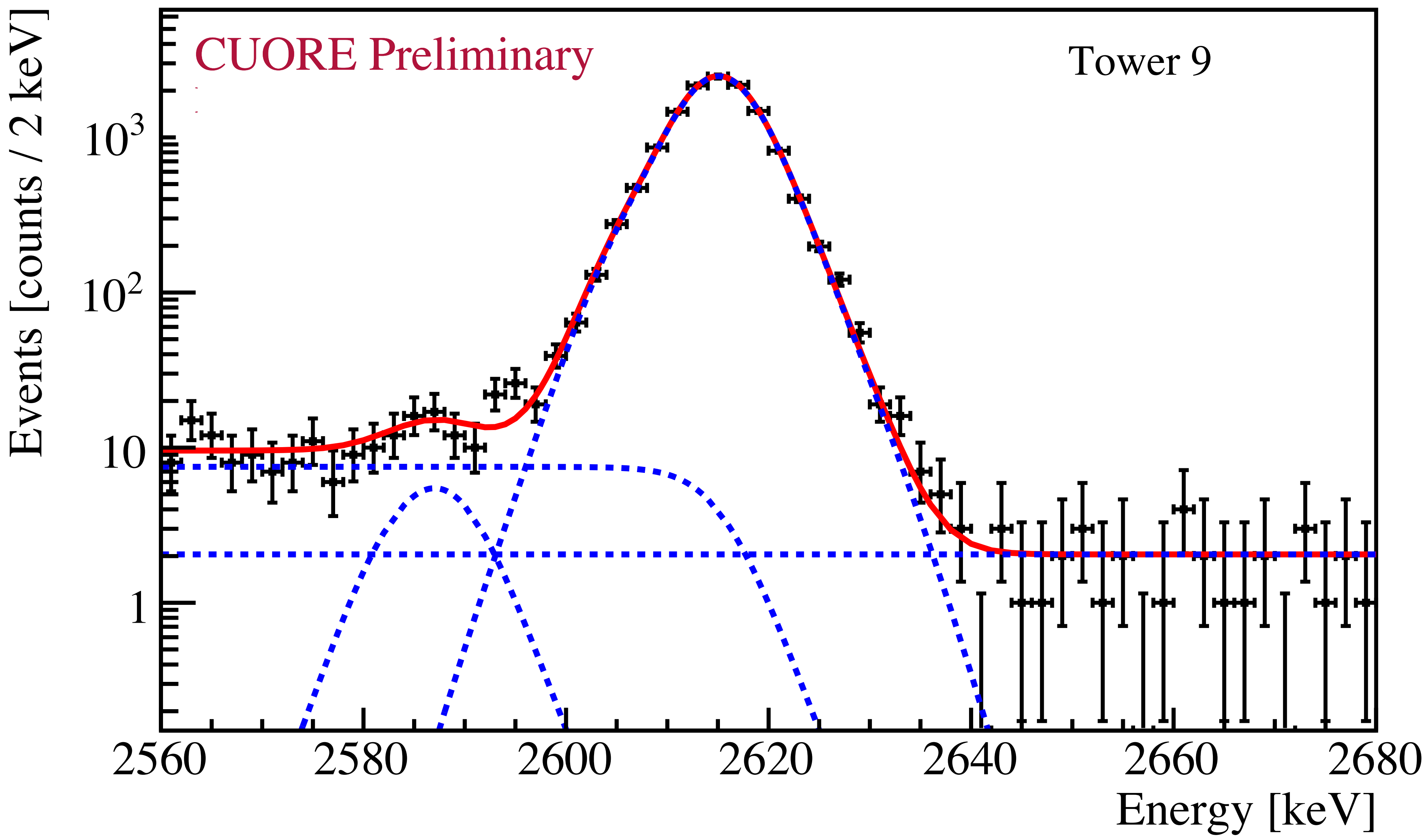


Detector performance: line shape

- Fit components:
    - a flat background
    - a step-wise smeared background
    - a double gaussian for the main peak
    - a combination of gaussian escape lines

- A quadratic dependence of the energy resolution is determined from gamma lines in the physics spectrum





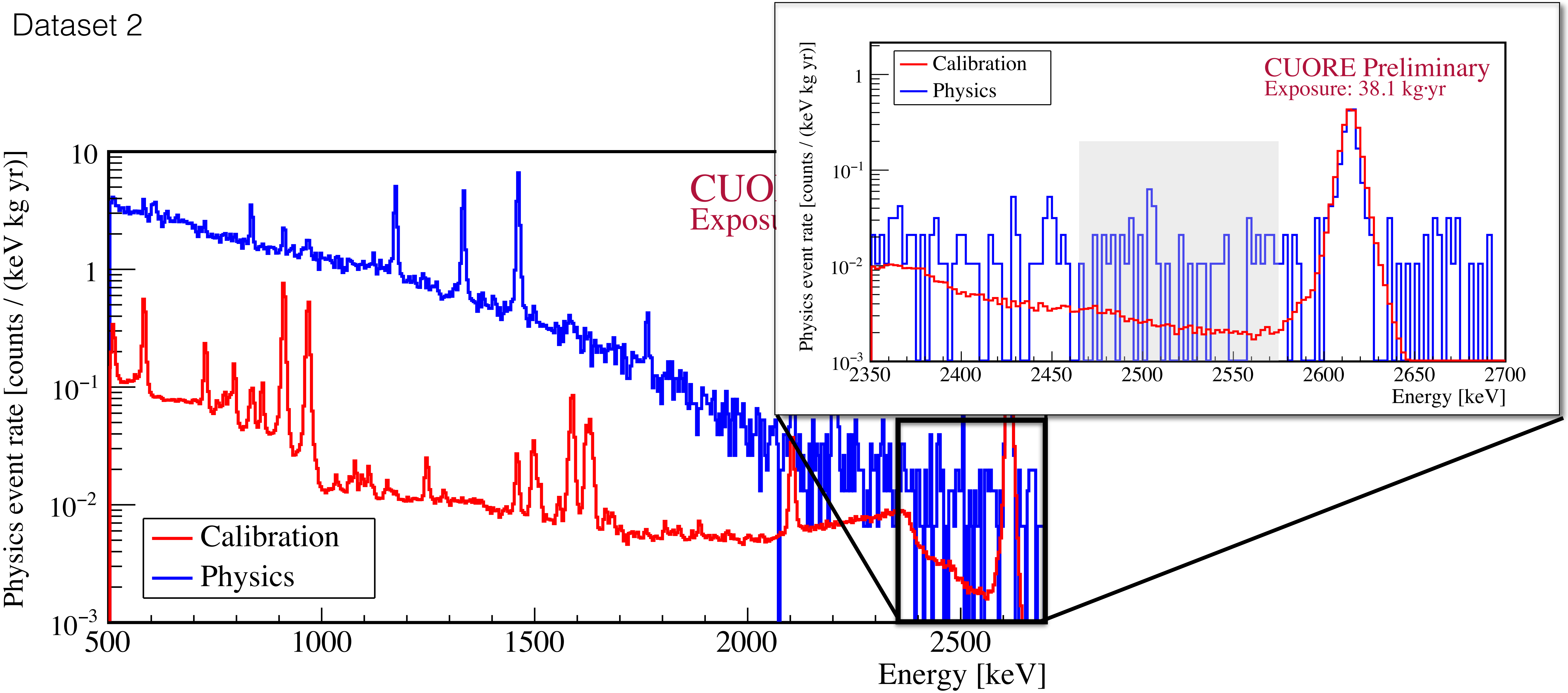
Analysis steps

- Acquisition of triggered signals
- Data preprocessing: estimation of raw parameters
- Pulse filtering
- Thermal Gain Stabilization (TGS)
- Energy calibration
- Particle event selection
- Coincidence analysis
- Energy spectrum

Essentially the same steps and procedures developed and used for CUORE-0 (Phys. Rev. C 93, 045503 (2016) - arXiv:1601.01334)

Background spectrum: γ region

Dataset 2

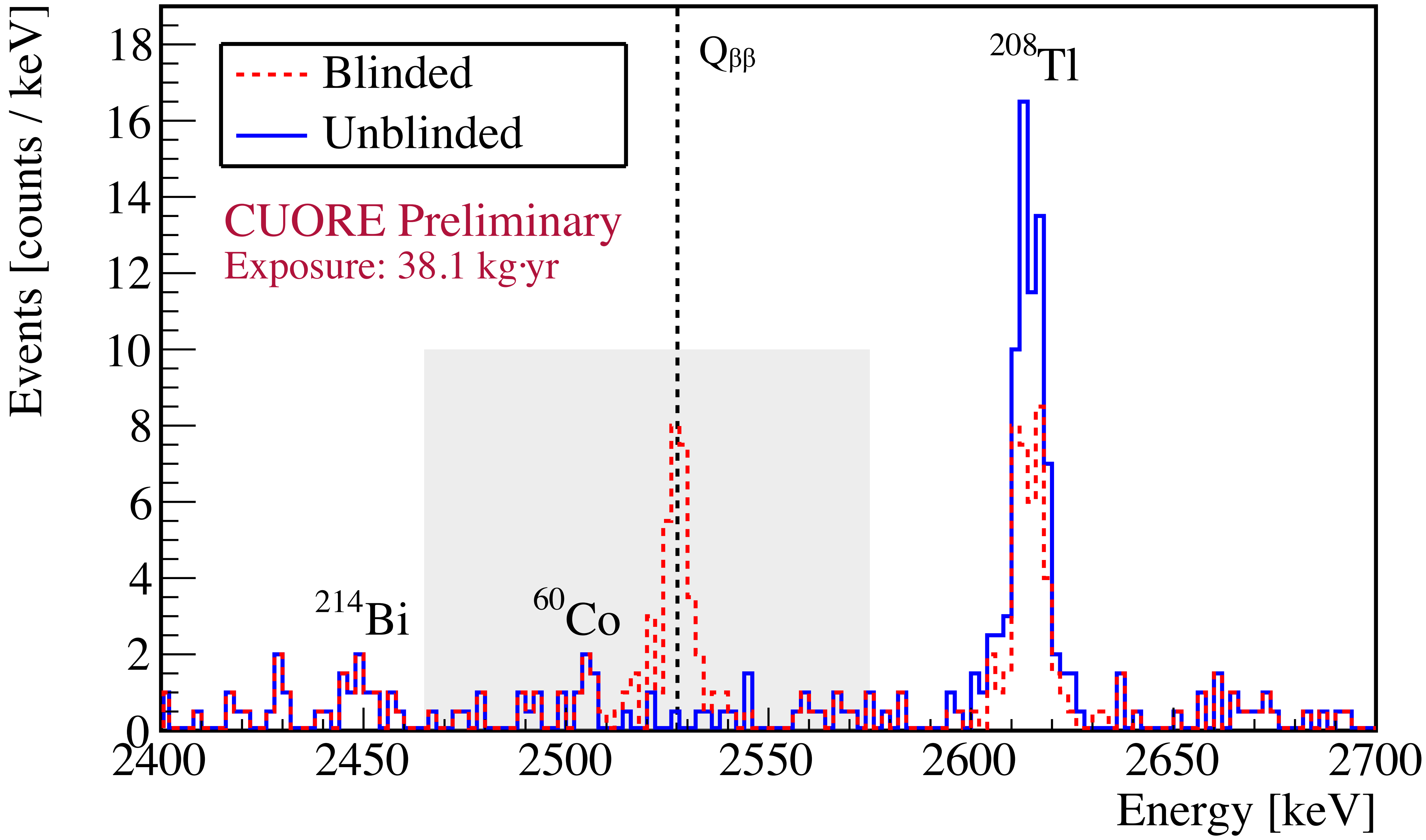


Blinded spectrum

- To blind our data we randomly move a fraction of events from +/- 20 keV of 2615 keV to the Q-value and vice versa
- The blinding algorithm produces an artificial peak around the 0vDBD Q-value and blinds the real 0vDBD rate of ^{130}Te.
- This method of blinding the data preserves the integrity of the possible 0vDBD events while maintaining the spectral characteristics with measured energy resolution and introducing no discontinuities in the spectrum.

- When all data analysis procedures are fixed the data are eventually unblinded

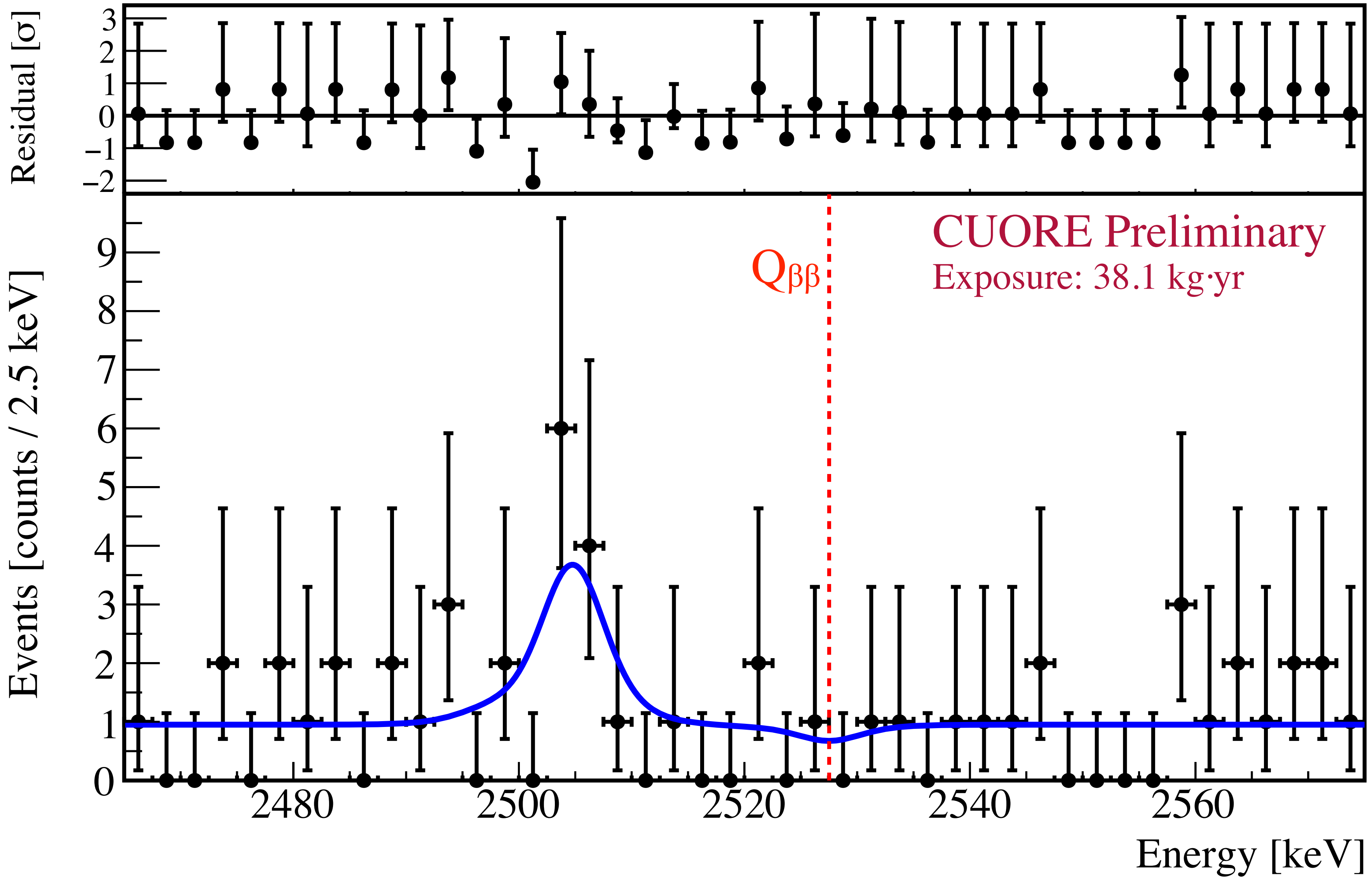
- The blinding procedure is more evident by comparing directly the two spectra



Fit in the ROI

- We determined the yield of 0νββ events by performing a simultaneous UEML fit in the energy region 2465-2575 keV
- The fit has 3 components:
  - a posited peak at the Q-value of ^{130}Te
  - a floating peak to account for the ^{60}Co sum gamma line (2505 keV)
  - a constant continuum background, attributed to multi scatter Compton events from ^{208}Tl and surface alpha events

Unblinded spectrum fit



Fit in the ROI

CUORE

- Profile likelihood
- Integrated on the physical region

- Region of interest: **2465 to 2575 keV**
- ROI background index: **$(9.8_{-1.5}^{+1.7}) \times 10^{-3}$ c/(keV·kg·yr)**
- Events in the region of interest: **50**
- Best fit for ^{60}Co mean: **(2504.8 ± 1.2) keV**

Efficiencies

Trigger and energy reconstruction	(98.469 ± 0.009) %
Anti-coincidence	(99.3 ± 0.3) %
Pulse shape analysis	(64 ± 3) %
All cuts except containment	**(62.6 ± 3.4) %**
0νββ containment	(88.345 ± 0.085) %
Total 0νββ efficiency	**(55.3 ± 3)%**

- Best fit decay rate: **$(-0.03_{-0.04}^{+0.07}$ (stat.) ± 0.01 (syst.)$)\times 10^{-24}$ / yr**
- Decay rate limit (90% CL, including systematics): **0.15×10^{-24} yr^{-1}**
- Half-life limit (90% CL, including systematics): **4.5×10^{24} yr**
- Median expected sensitivity: **3.6×10^{24} yr (arXiv:1705.10816)**

We have also evaluated limits according to "W. Rolke et al., Nucl. Instrum. Meth. A 551, 493-503 (2005)":

- Half-life limit (90% CL, including systematics): 6.1×10^{24} yr
- Decay rate limit (90% CL, including systematics): 0.11×10^{-24} / yr
- Median expected sensitivity: 3.7×10^{24} yr

Combination with previous results

- We combined the CUORE result with the existing ^{130}Te
  - 19.75 kg·yr of Cuoricino
  - 9.8 kg·yr of CUORE-0

- The combined 90% C.L. limit is

$T_{0\nu}$ > 6.6 × 10^{24} yr

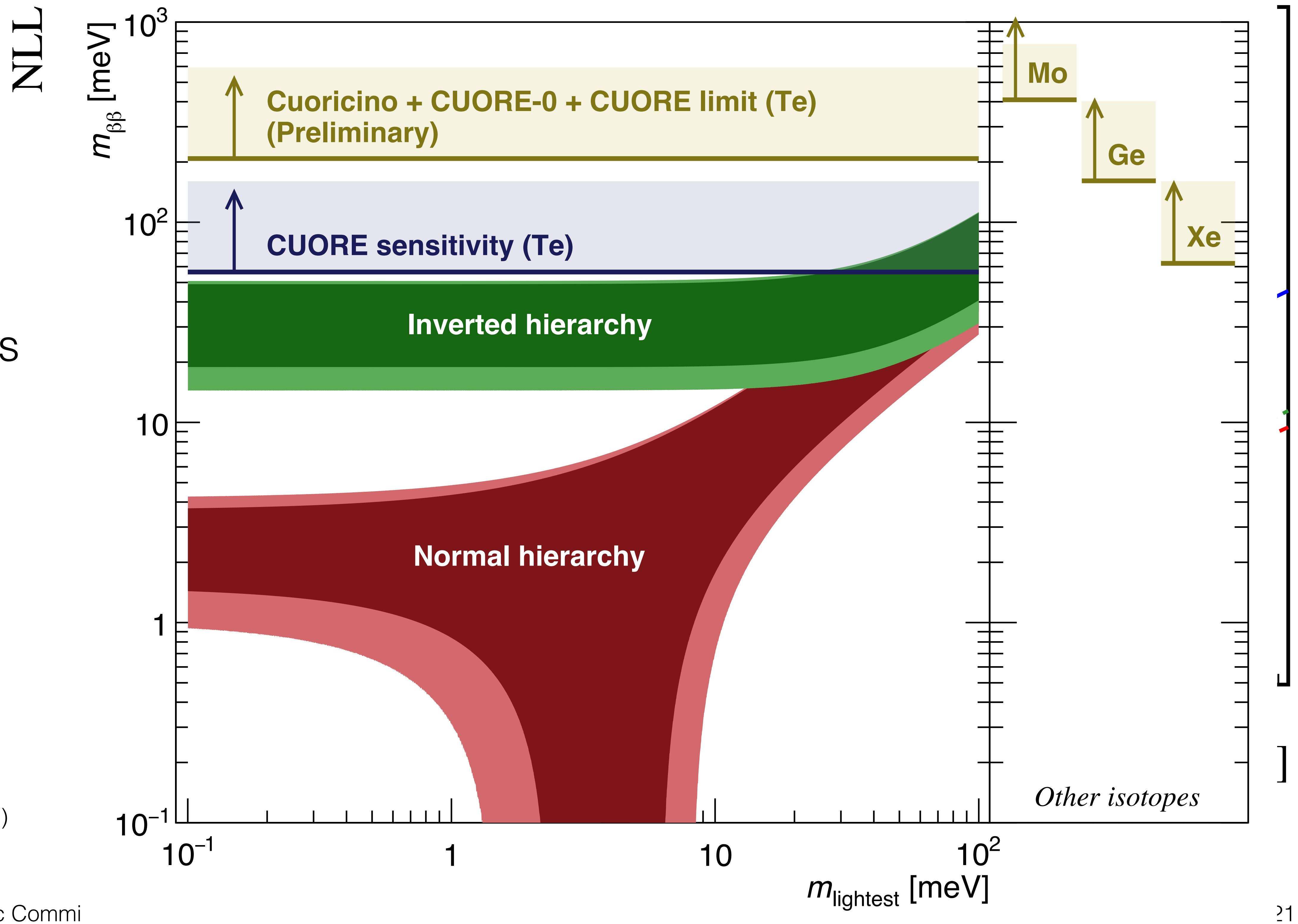
$m_{\beta\beta}$ < 210–590 meV

NME:

Phys. Rev. C 91, 034304 (2015)
Phys. Rev. C 87, 045501 (2013)
Phys. Rev. C 91, 024613 (2015)
Nucl. Phys. A 818, 139 (2009)
Phys. Rev. Lett. 105, 252503 (2010)

Experiments:

^{130}Te: 6.5 × 1024 yr from this analysis
^{76}Ge: 5.3 × 1025 yr from Nature 544, 47–52 (2017)
^{136}Xe: 1.1 × 1026 yr from Phys. Rev. Lett. 117, 082503 (2016)
^{100}Mo: 1.1 × 1024 yr from Phys. Rev. D 89, 111101 (2014)
CUORE sensitivity: 9.0 × 10^{25} yr



Additional physics run: Aug 2017 (ds 3020)

Science runs

- Total statistics doubled with respect to June 2017
  - All the available data have been fully reprocessed
  - Adopted the usual blinding procedure
  - Data analysis almost complete
  - Expected release of results: Oct. 23,2017
- In the meantime ….

System optimization

- Further optimization steps:
  - Detector commissioning stopped in April to start science runs
  - Still room for improvements
  - Mainly directed to: **detector performance** and **noise abatement**

- Detector optimization campaigns: **June-July** and **fall** 2017 ← just started
    - Careful investigation/upgrades to the electronics grounding in the CUORE Faraday cage
    - Active cancellation of the PT-induced noise
    - Optimization of the operating temperature and detector working points
    - System upgrades
    - Software and analysis upgrades

Conclusions

- The cryostat is working extraordinarily well.
- With 3 weeks of physics data we have accumulated higher exposure than CUORE-0/Cuoricino and surpassed their limit.
    - Total exposure: 38.1 kg·y
    - Invaluable operational experience
    - Important information on detector performance, noise, resolutions, background levels
- Developed and debugged physics tools, stress-tested end-to-end data processing with quality appropriate for science results
- Background rates are consistent with the background model
- New data taken during the summer (still embargoed)
- Available data have been fully reprocessed
- Further improvements possible:
    - Detector optimization campaigns have been scheduled, focused on improving the resolution through noise reduction.
    - First results already available
- More to come