

# Latest results from the CUORE experiment



Paolo Gorla

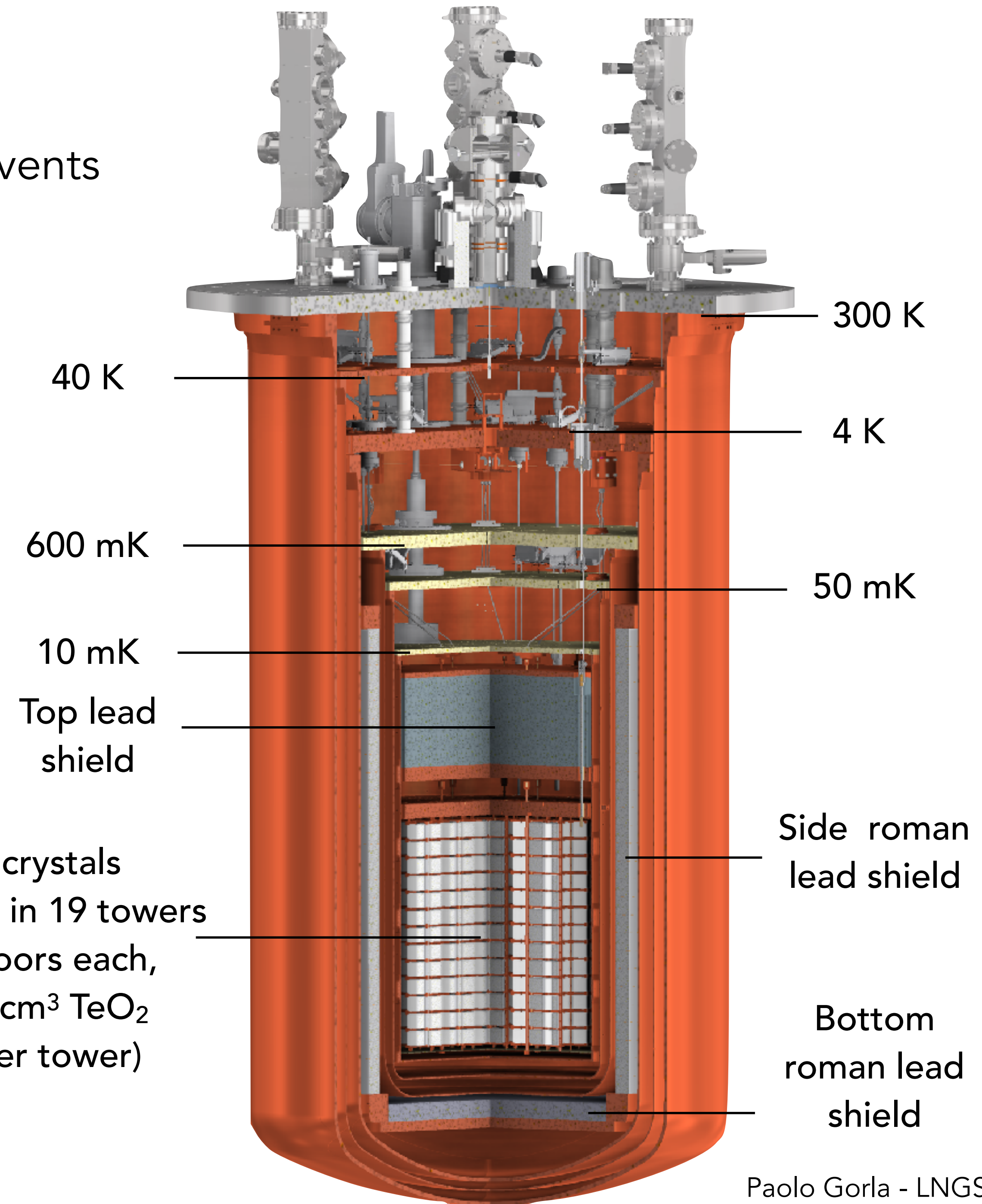
Laboratori Nazionali del Gran Sasso - INFN



Main goal: detect  $0\nu\beta\beta$  in  $^{130}\text{Te}$ , in cryogenic  $\text{TeO}_2$  bolometers, to prove the Majorana nature of the neutrino

- The CUORE detector is hosted in a cryogen-free cryostat (mass < 4K: ~15 tons of Pb, Cu and  $\text{TeO}_2$ )
- Operating temperature 11 mK (base T~7 mK)
- Designed to guarantee extremely low radioactivity and low vibrations environment
  - Energy resolution: goal of 5 keV at  $Q_{\beta\beta}$
  - Low background: goal of  $10^{-2}$  cts/ (keV·kg·yr) at  $Q_{\beta\beta}$

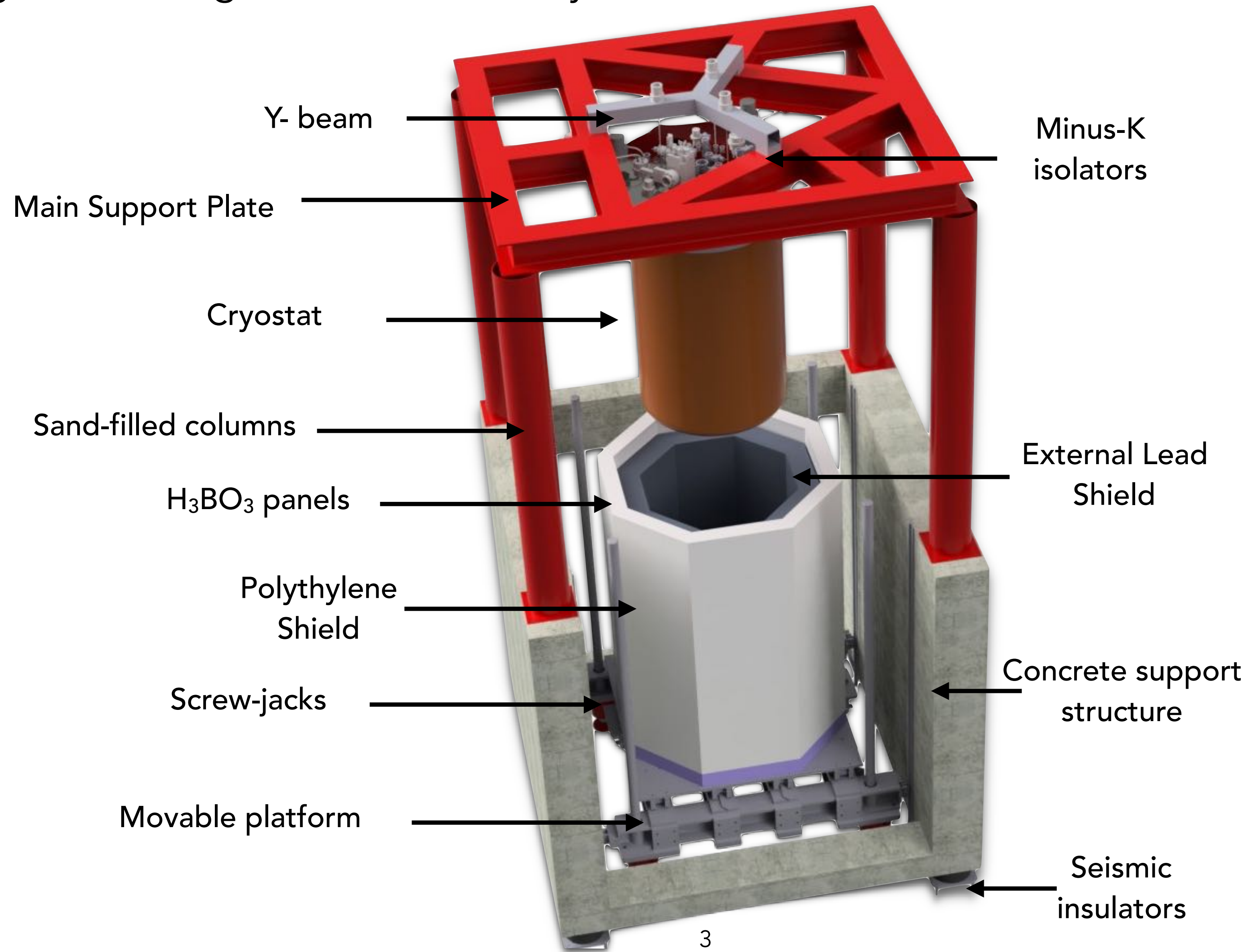
988  $\text{TeO}_2$  crystals (arranged in 19 towers with 13 floors each, 52  $5\times 5\times 5$  cm<sup>3</sup>  $\text{TeO}_2$  crystals per tower)



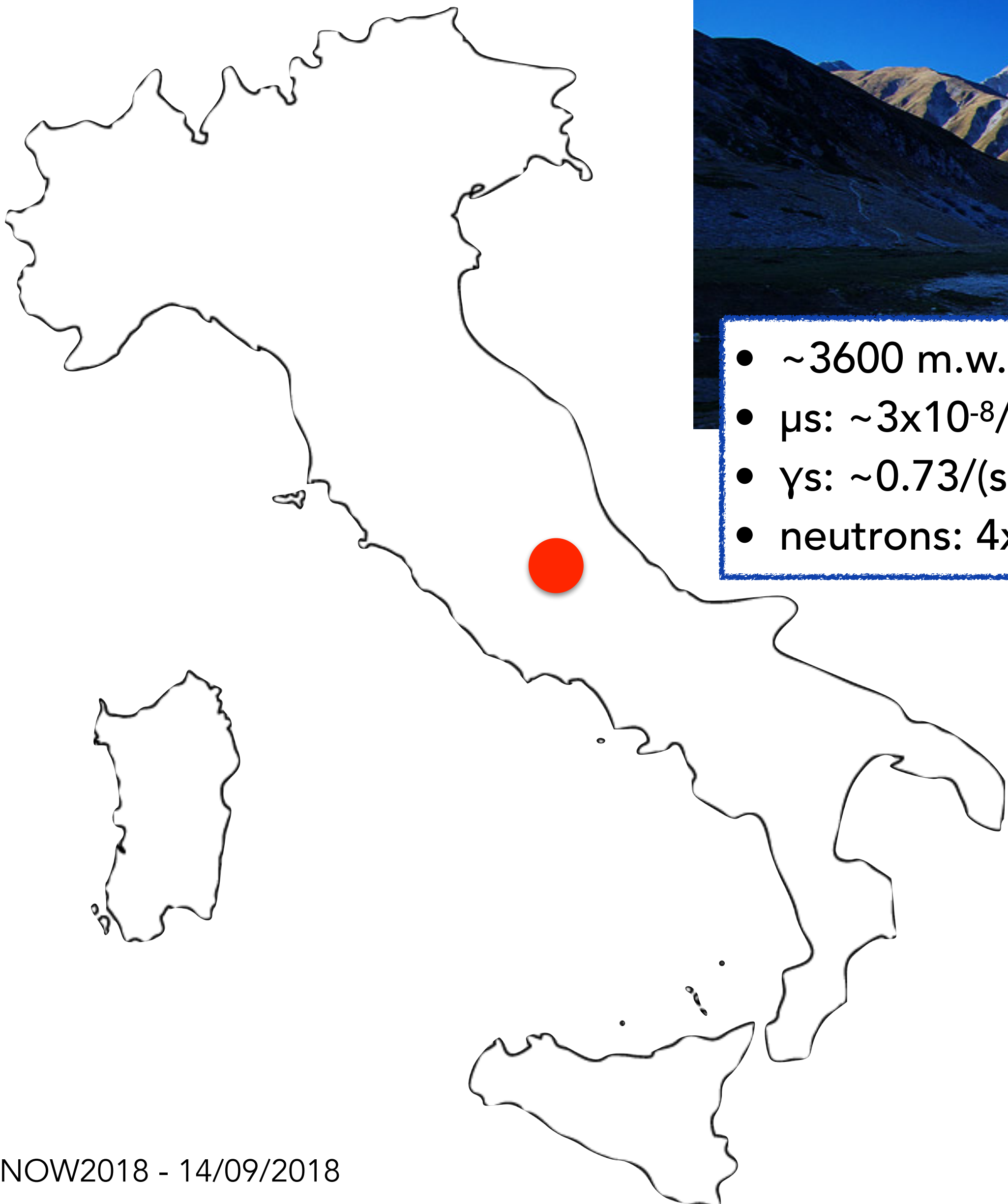


# CUORE

Cryogenic Underground Observatory for Rare Events



# CUORE @ LNGS

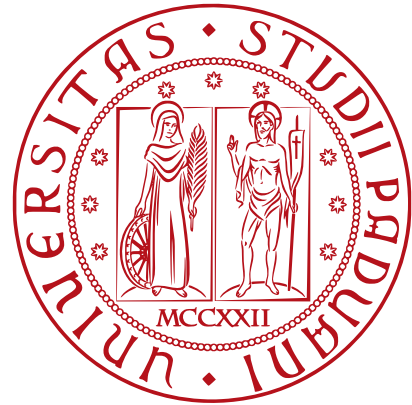


- ~3600 m.w.e. deep
- $\mu$ s:  $\sim 3 \times 10^{-8} / (\text{s cm}^2)$
- $\gamma$ s:  $\sim 0.73 / (\text{s cm}^2)$
- neutrons:  $4 \times 10^{-6} \text{ n} / (\text{s cm}^2)$

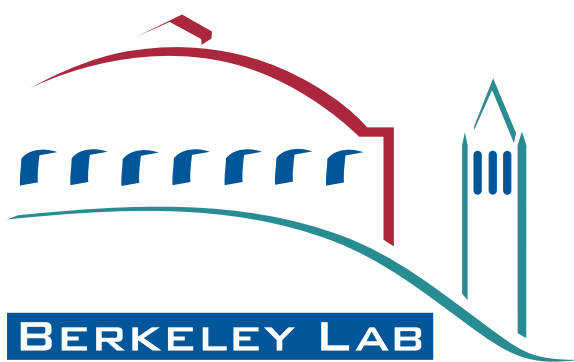


INFN  
Istituto Nazionale di Fisica Nucleare  
Laboratori Nazionali  
del Gran Sasso

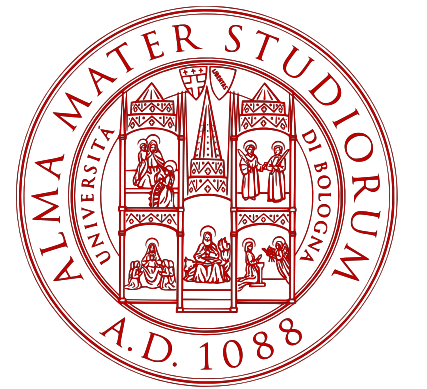
CUORE



Yale



CAL POLY  
SAN LUIS OBISPO



UCLA



SAPIENZA  
UNIVERSITÀ DI ROMA

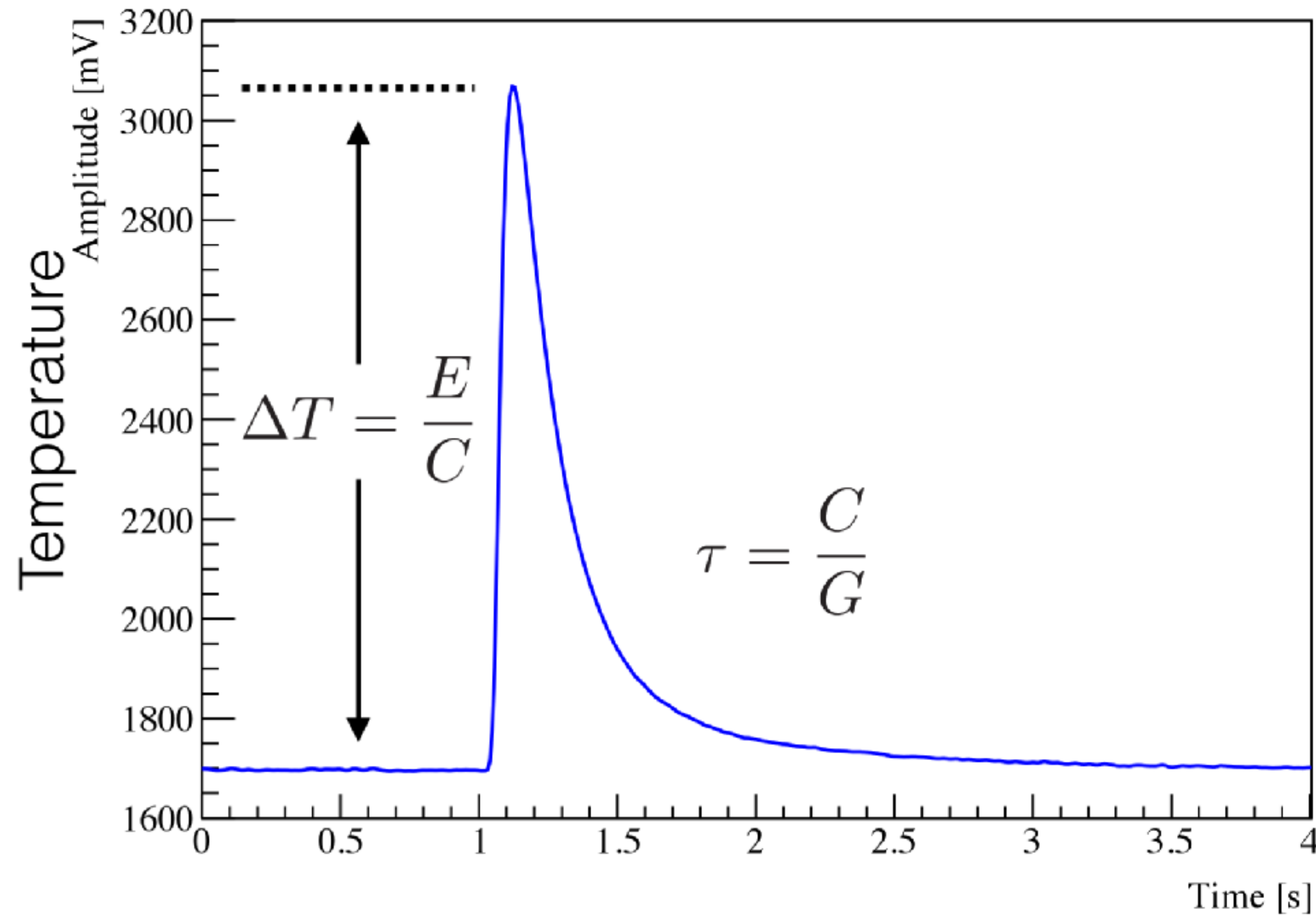


The CUORE  
collaboration





# CUORE working principle



$$\Delta T = \frac{\Delta E}{C} \sim \frac{100 \mu K}{MeV}$$

$$\tau = \frac{G}{C} \sim 1 s$$

$$C(T) \propto T^3$$

$$R(T) = R_0 e^{\sqrt{T_0/T}}$$

C: absorber capacity  
 $\Delta T$ : temperature variation  
 $\Delta E$ : energy deposition  
G: thermal conductance  
t: signal decay time

- low heat capacity @  $T_{\text{work}}$
- excellent energy resolution ( $\sim 1 \%$  FWHM)
- huge number of energy carriers (phonons)
- equal detector response for different particles
- slowness (suitable for rare event searches)

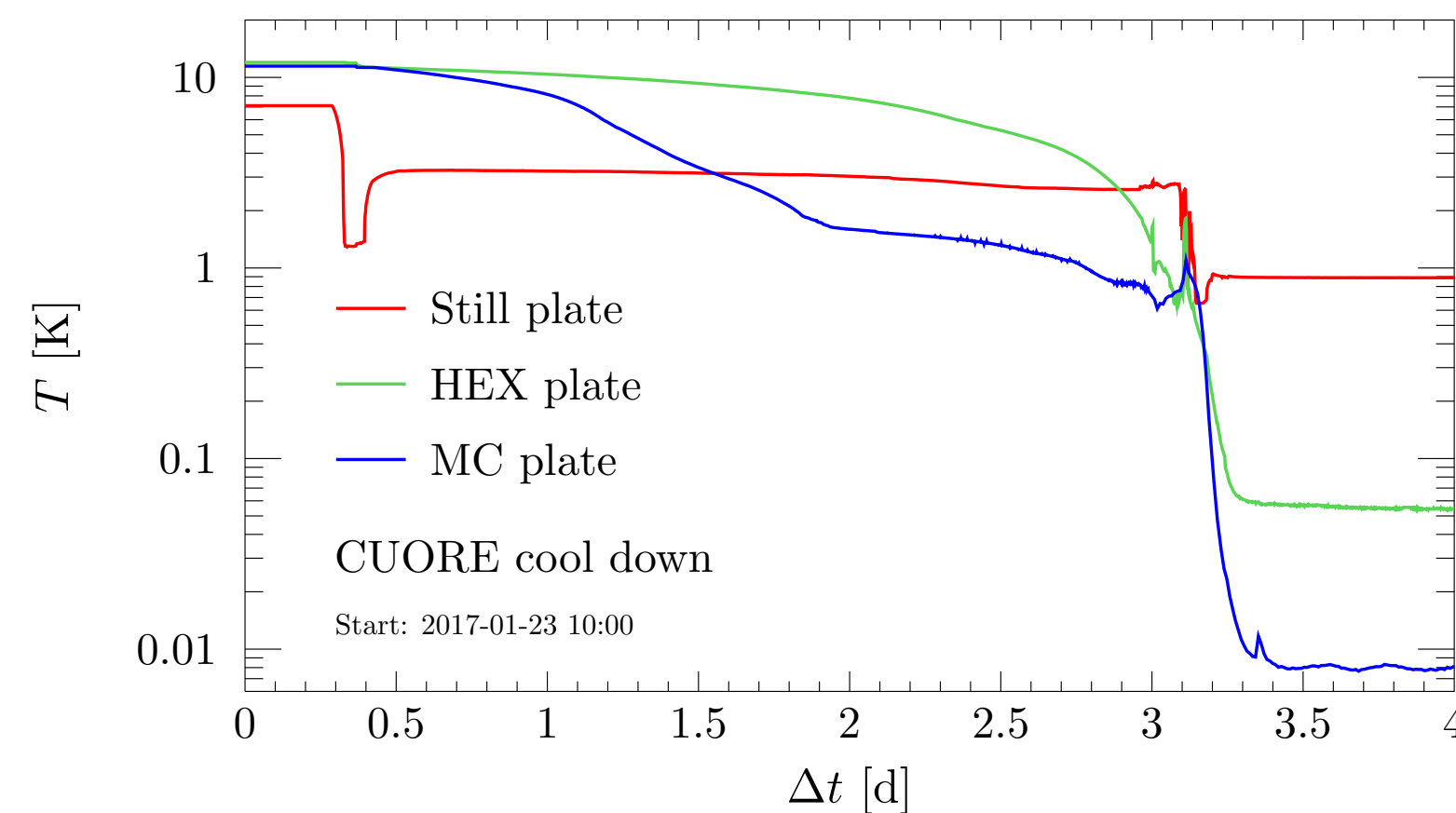
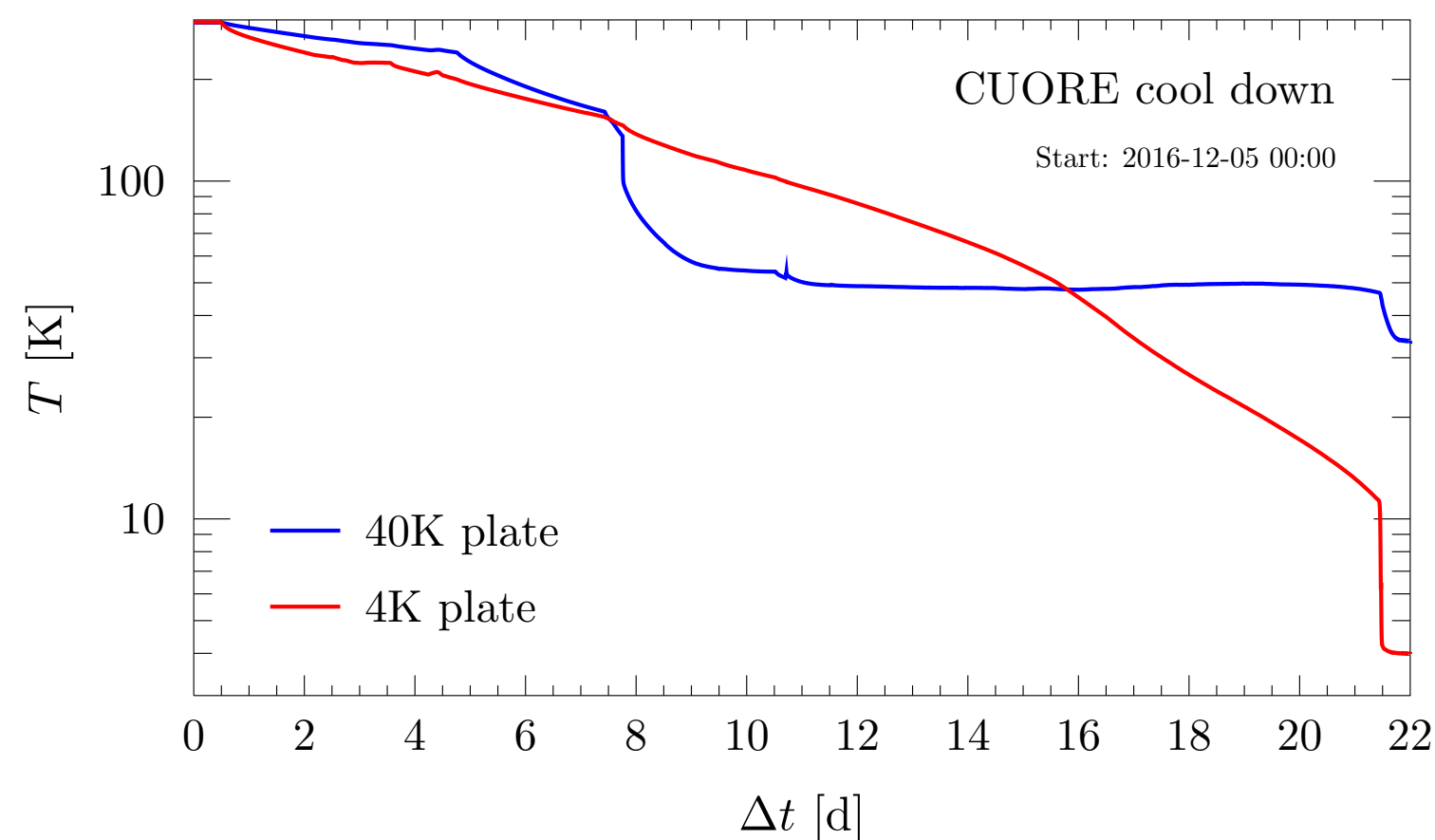
# CUORE cryostat

## Requirements

- Stable operating at  $\sim 10\text{mK}$
- Low vibrations
- Run for 5 yr

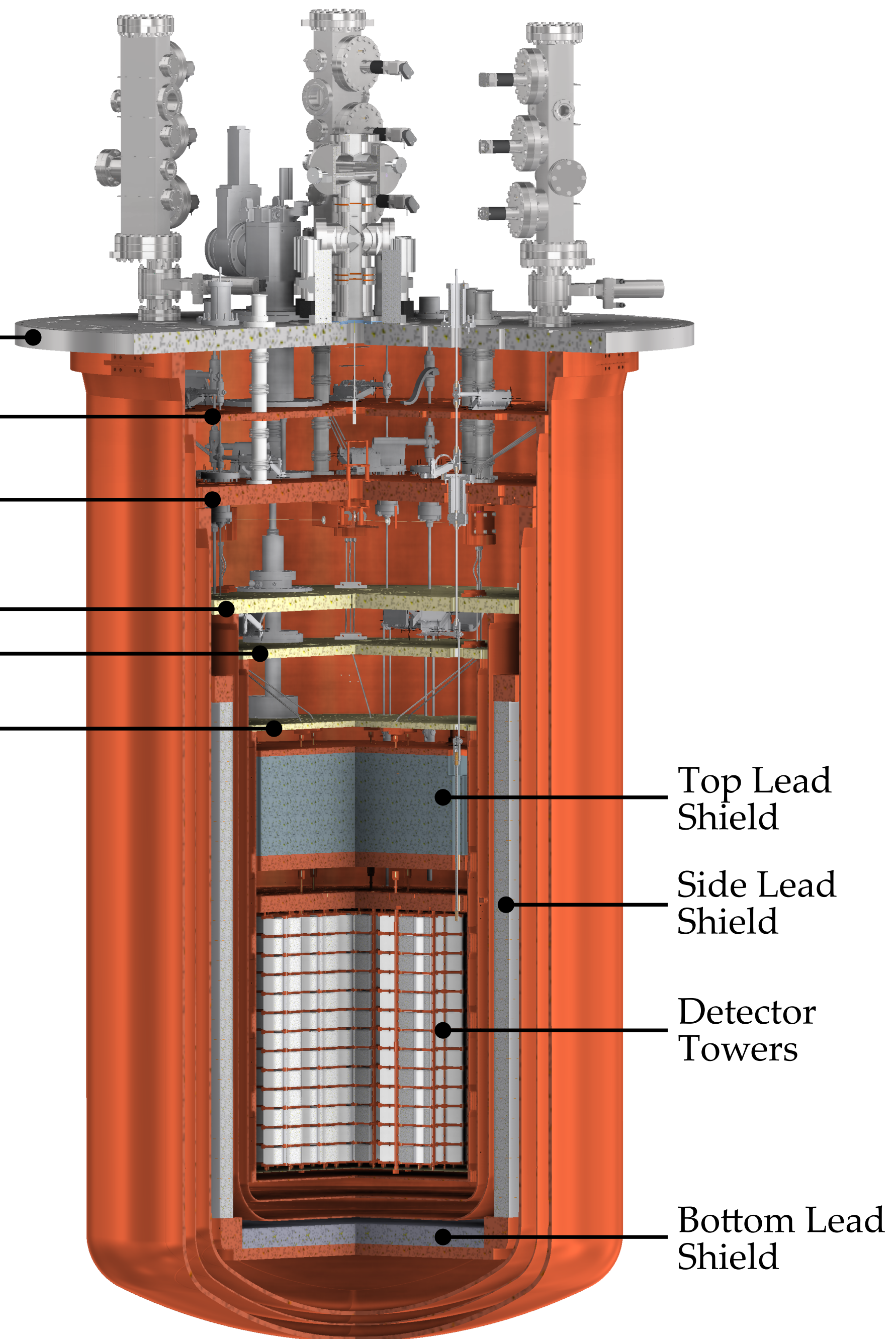
## Solutions

- Cryogen free cryostat  $\rightarrow$  Lower downtime
- 5 (4) Pulse Tubes (PT) down to  $\sim 4\text{K}$
- Dilution Unit (DU) down to  $\sim 7\text{mK}$
- PT phase cancellation

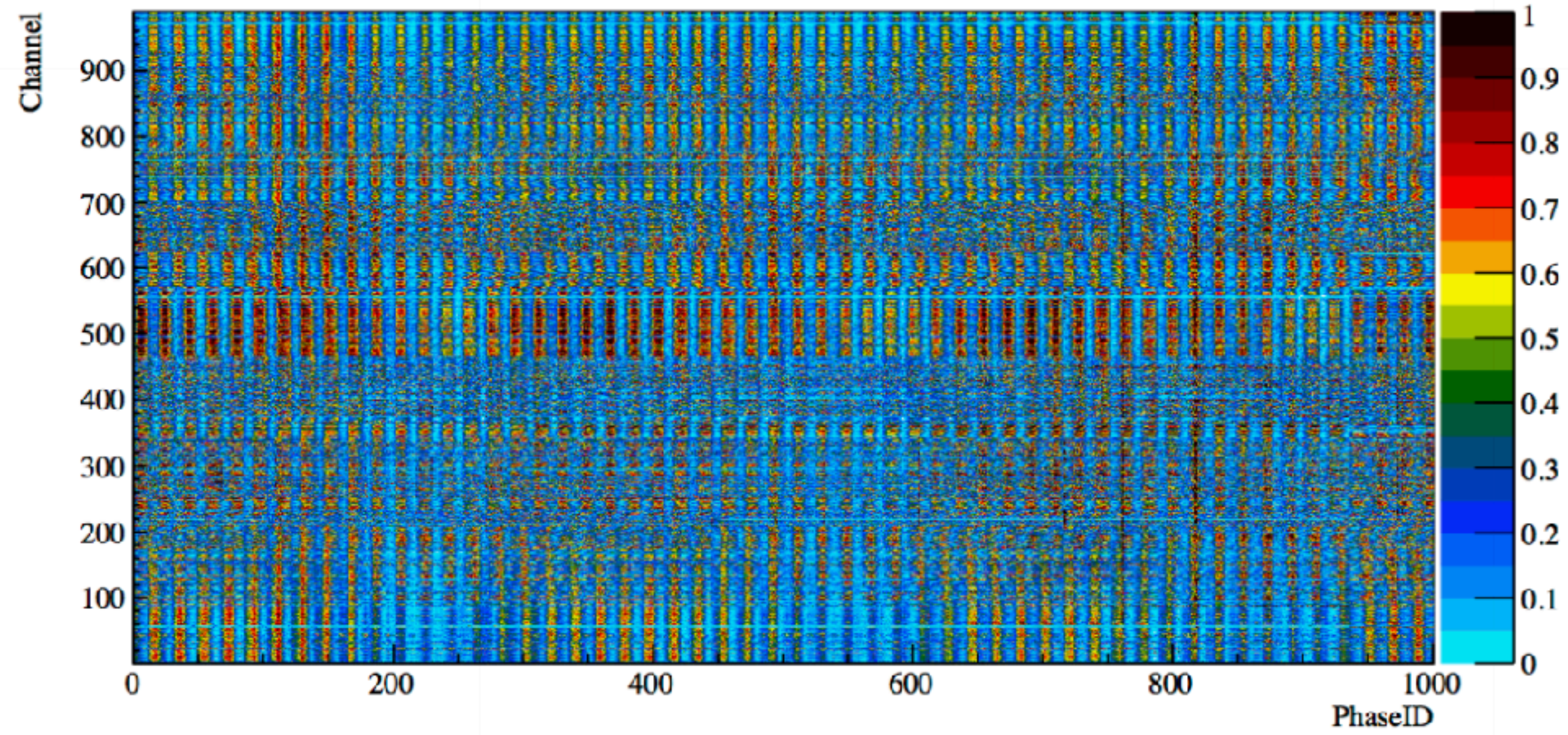


## Plates:

- 300 K
- 40 K
- 4 K
- 600 mK
- 50 mK
- 10 mK



# PT phase cancellation

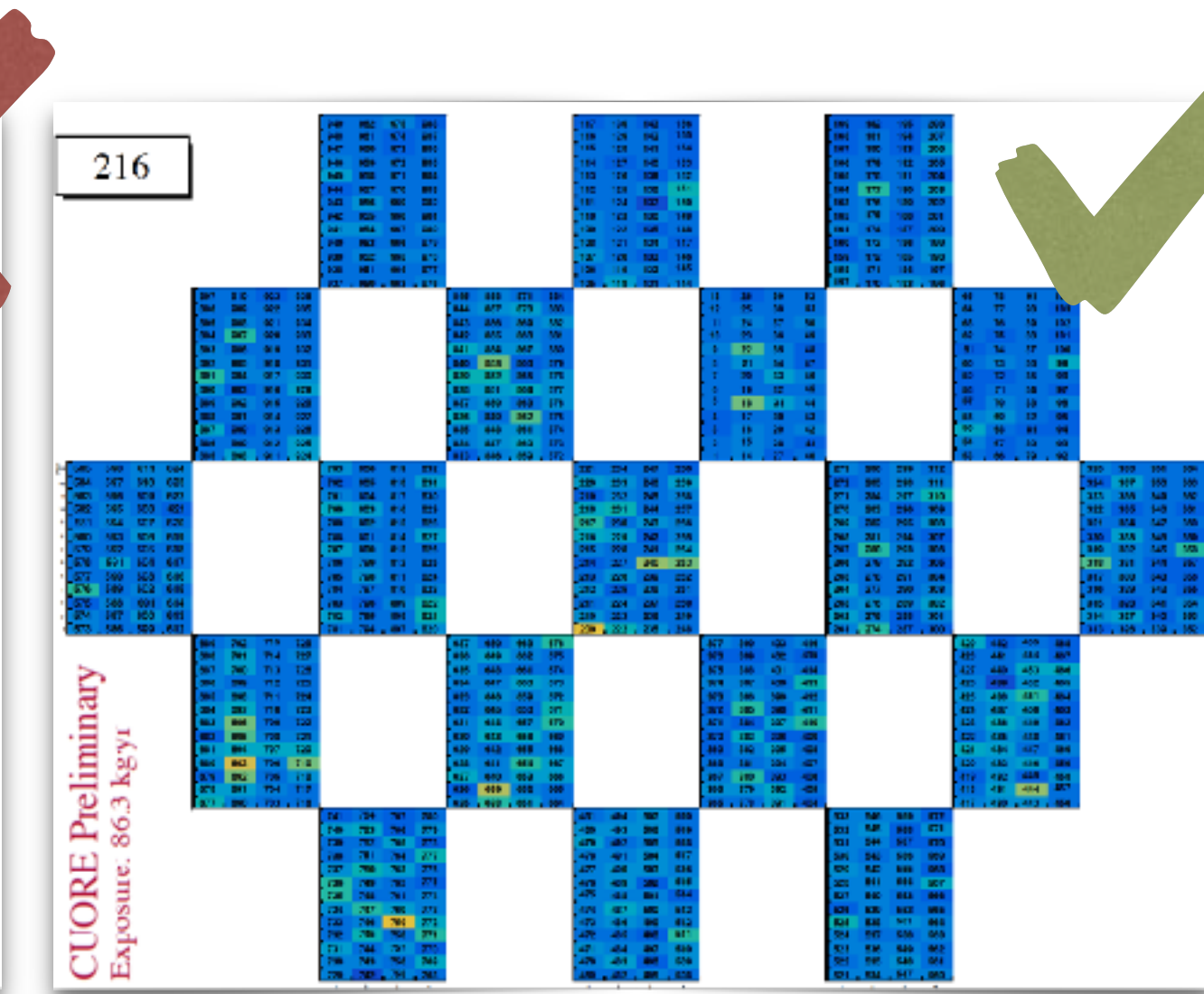
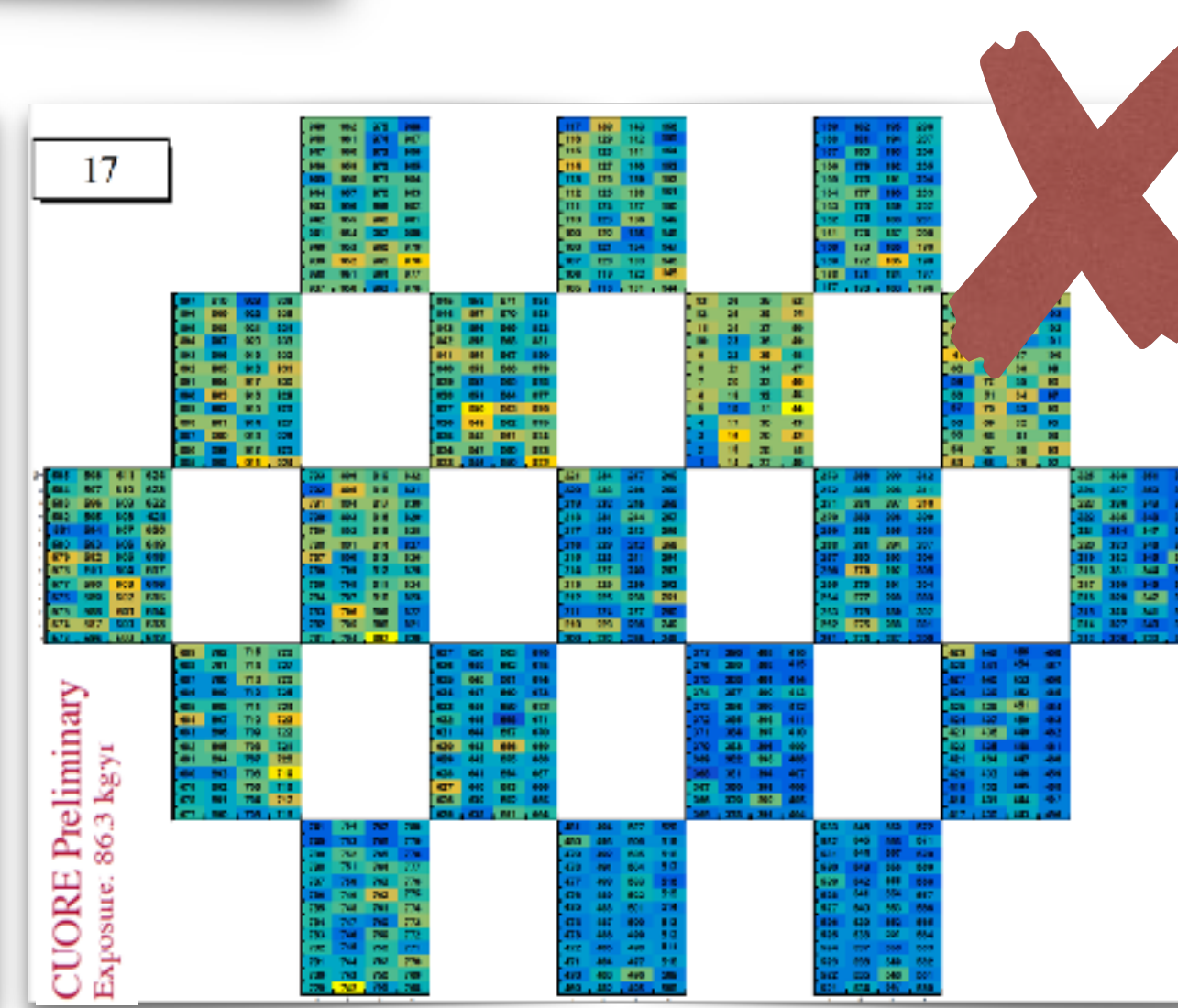
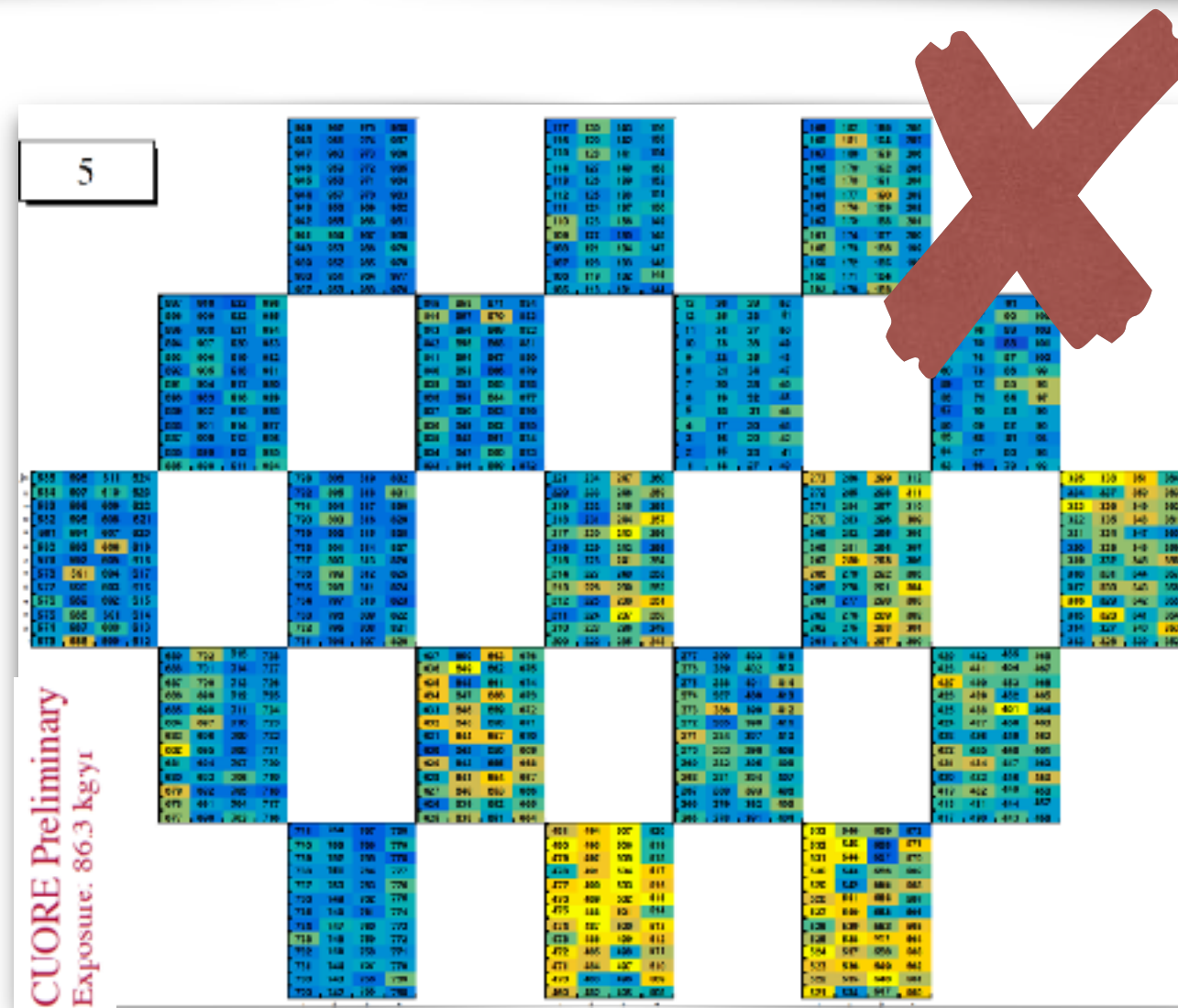


Attenuation of Pulse tube induced vibrations:

- (1) Switch to Linear Drives to control PT motor heads -> reduce temperature variations on the Mixing Chamber
- (2) PT phase scan to find the phase configuration that actively minimize the PT induced vibrations

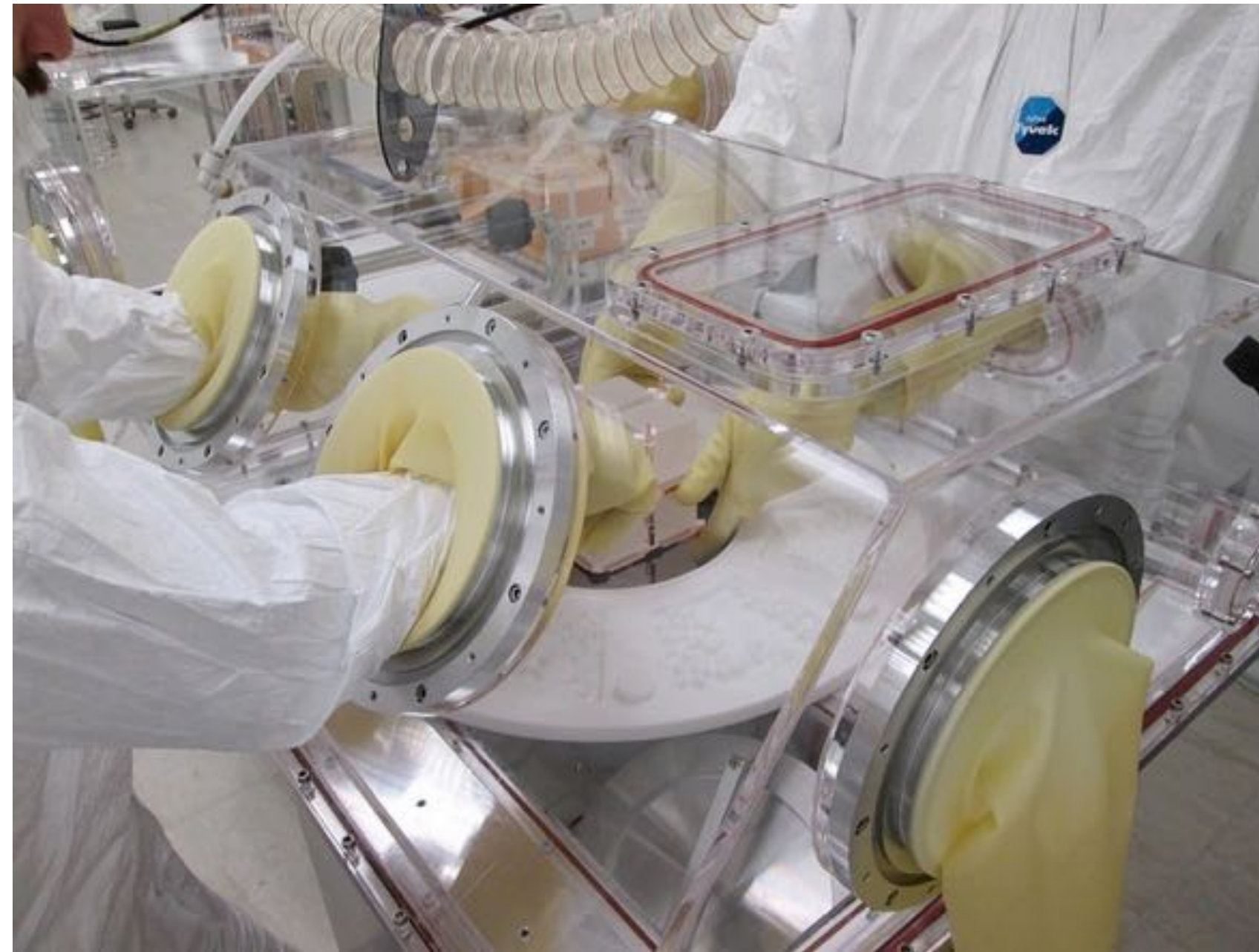
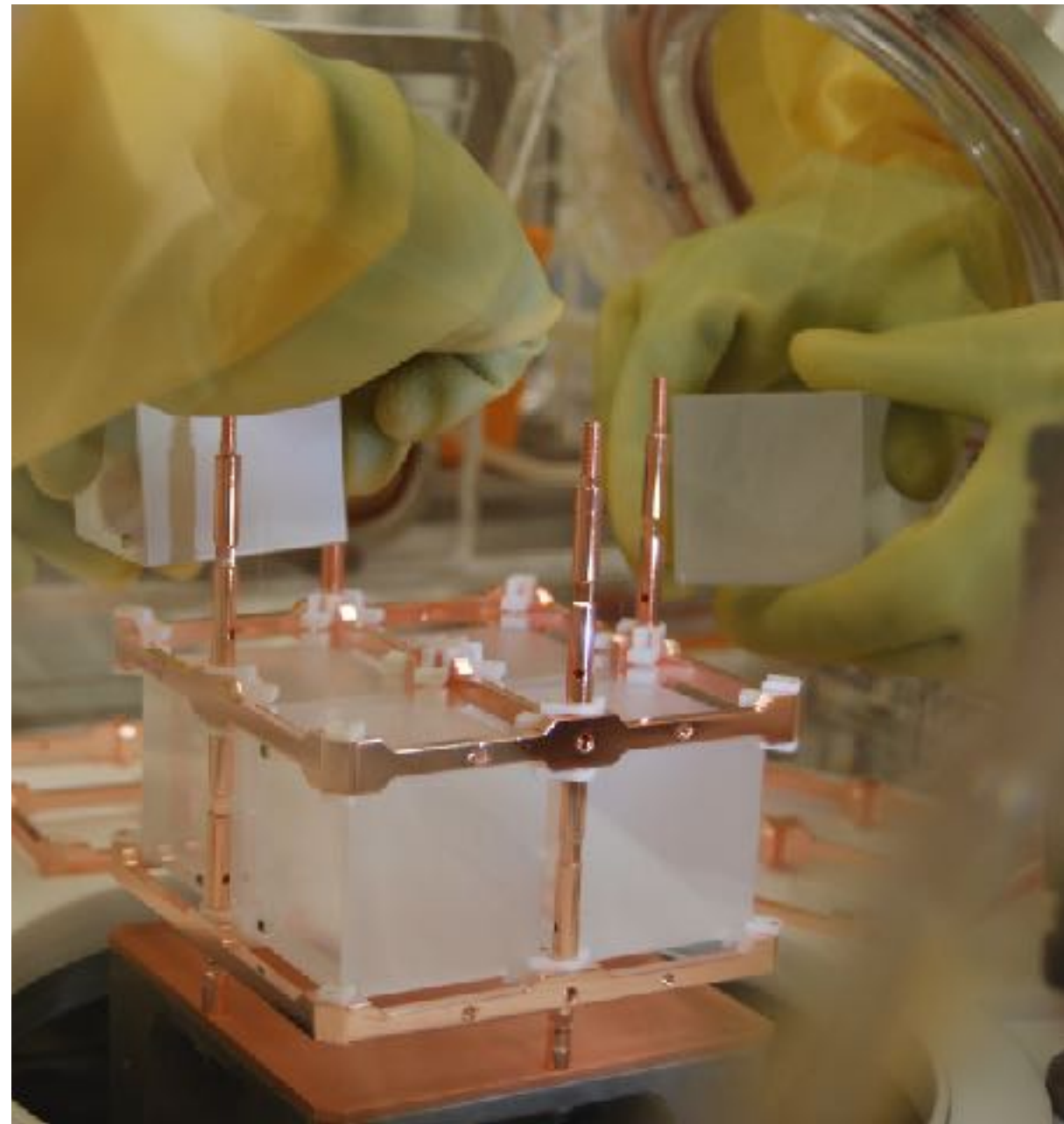
Cryogenics 93 (2018) 56–65  
arXiv:1712.02753

Example of the PT induced noise for three different PT phase configurations



# CUORE background mitigation

- Screening of all parts
- Underground storage to avoid cosmic activation
- Towers assembled and stored in N<sub>2</sub> atmosphere to minimize Rn contamination
- Tower assembly in underground class 1000 cleanroom
- Dedicated clean room with Rn-free air for tower installation
  - Rn level kept <50 mBq/m<sup>3</sup> for the entire duration of the installation

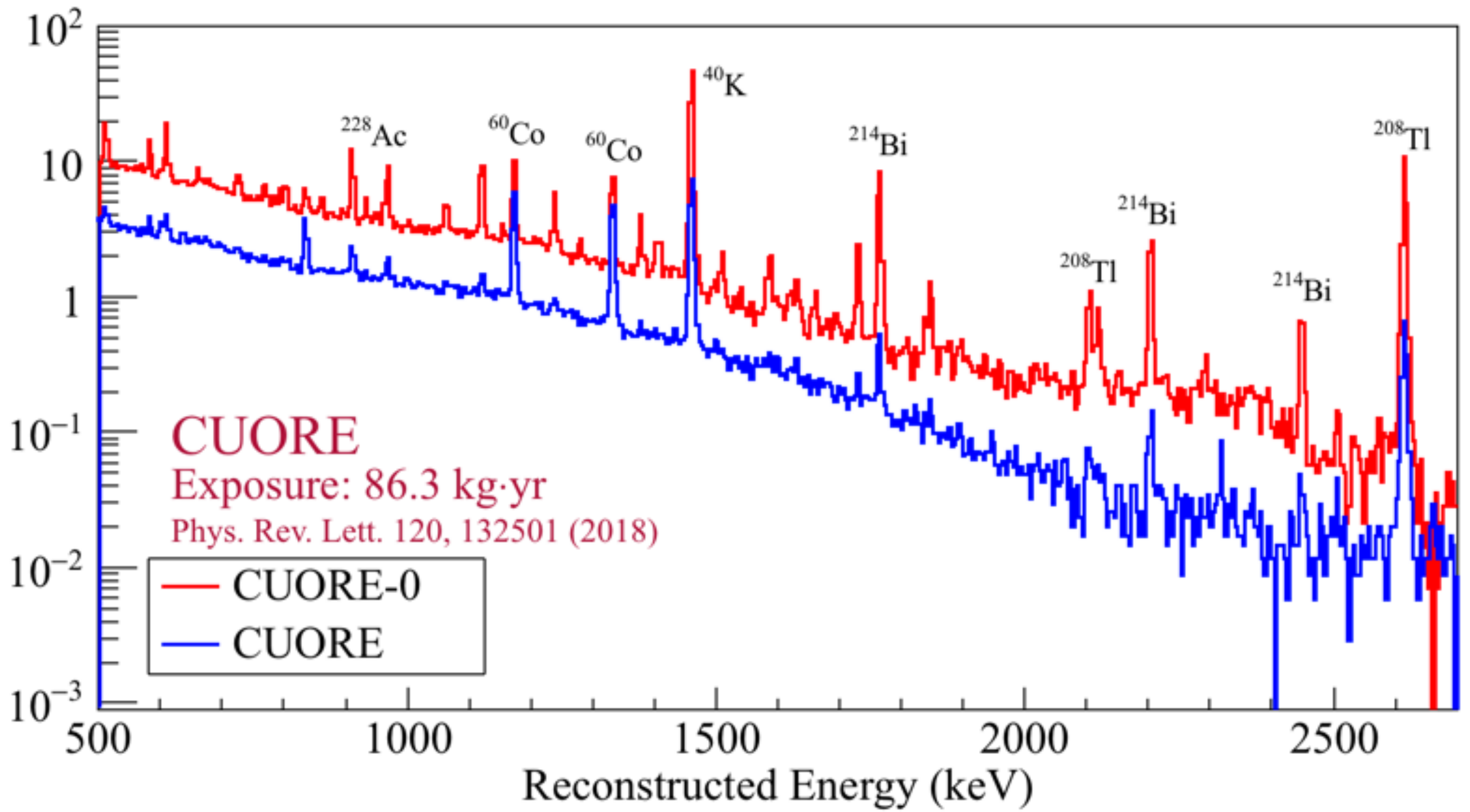
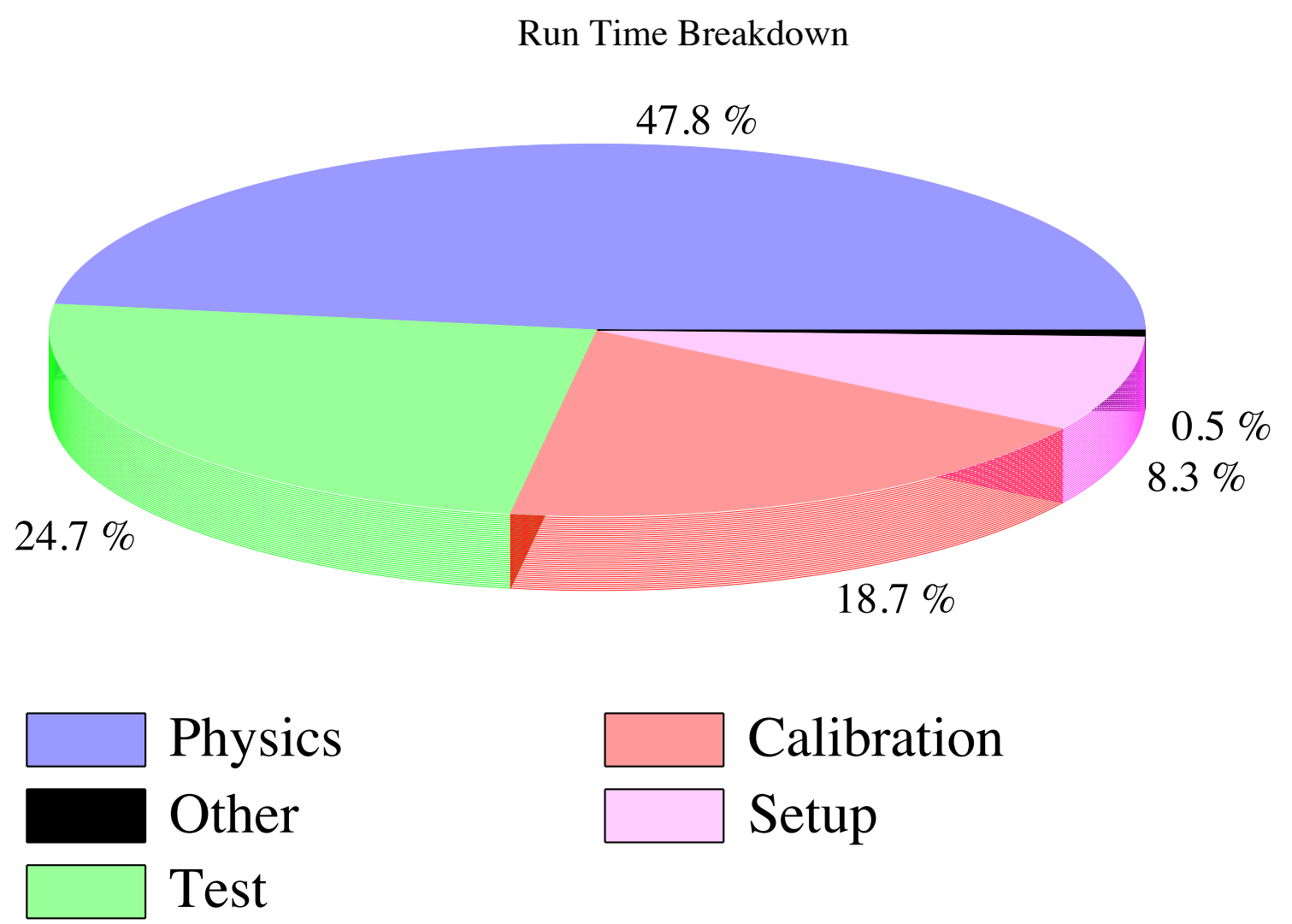
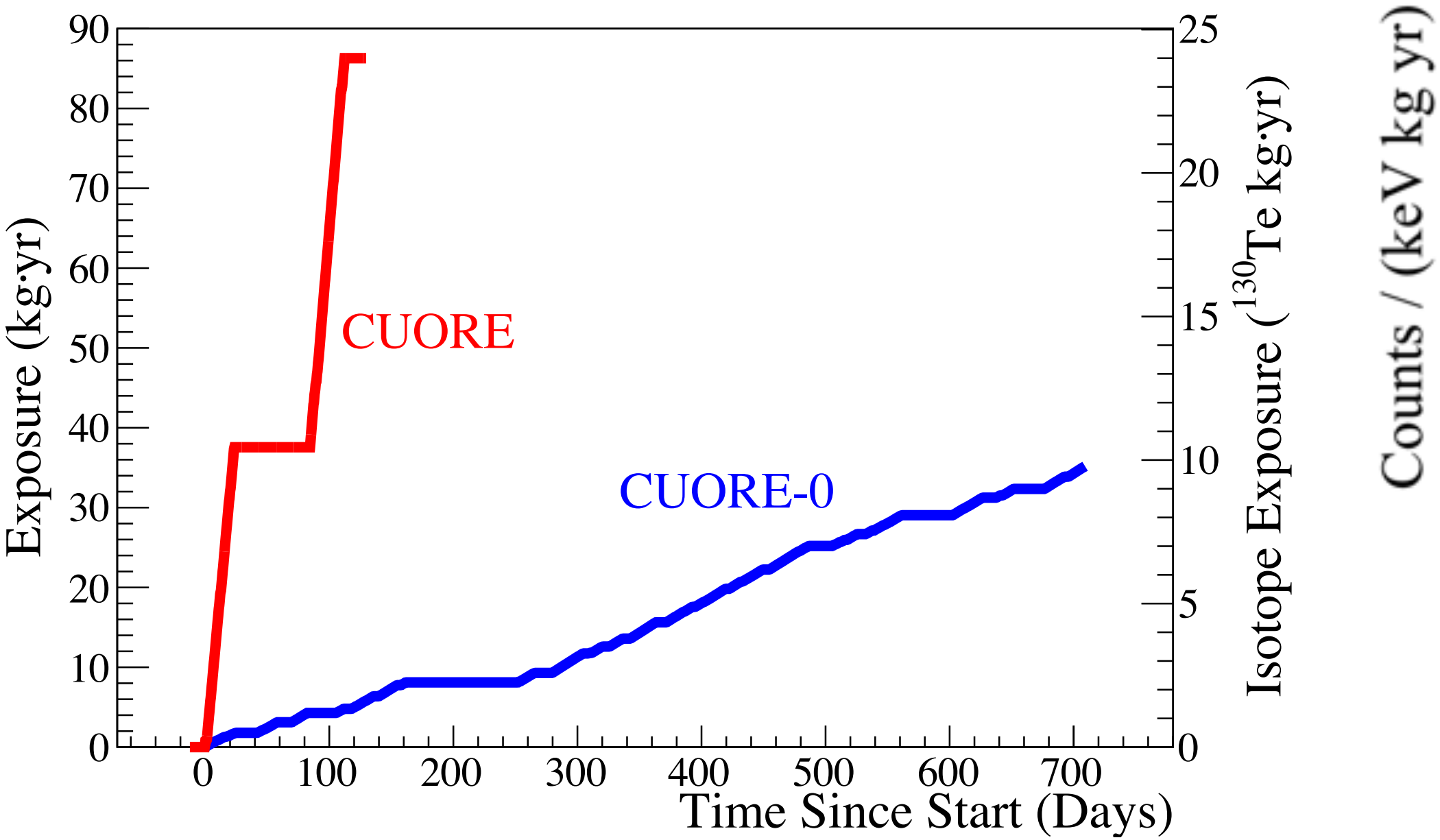




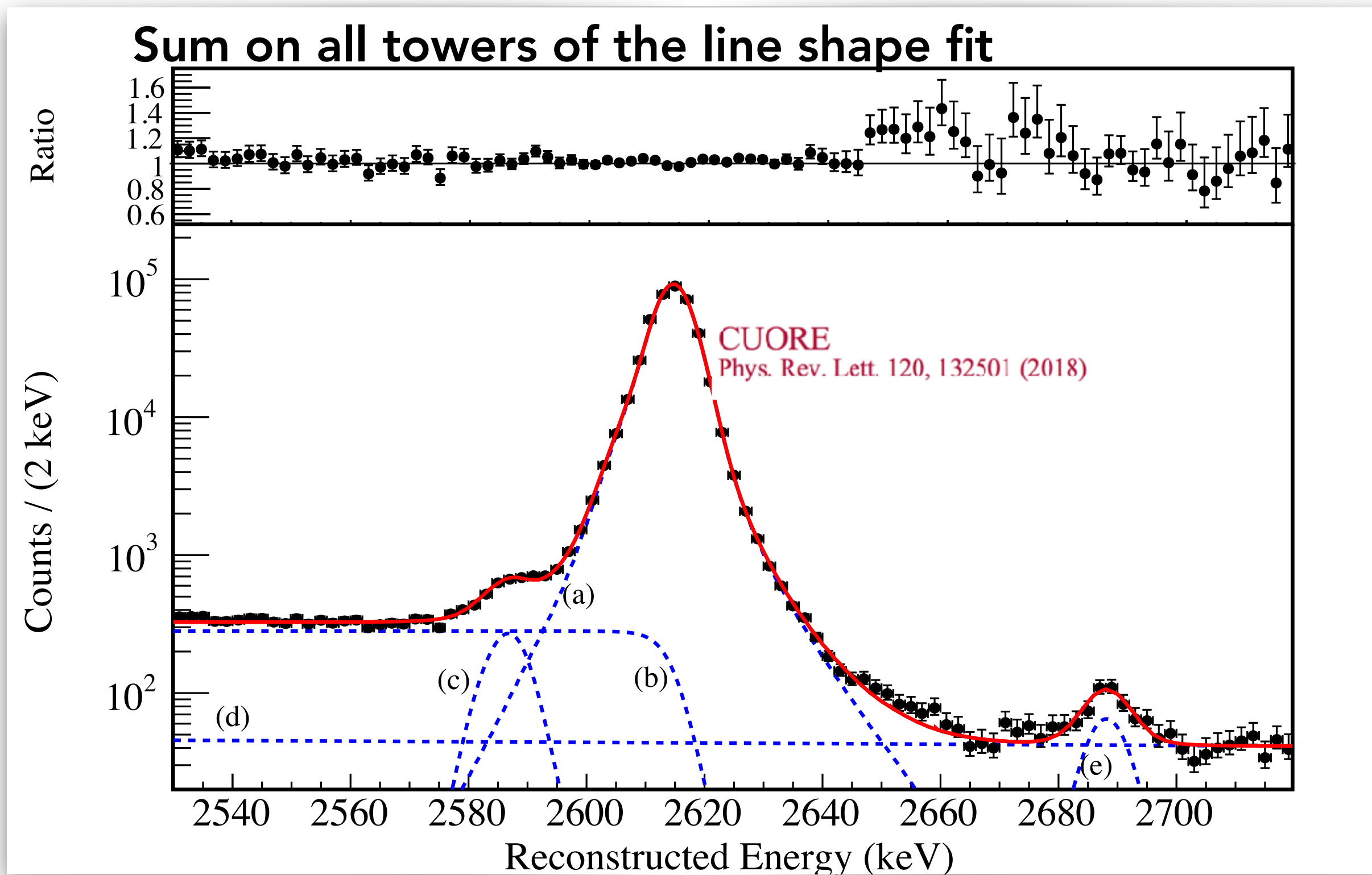
# The CUORE Detector

# CUORE Data Taking

- ▶ In summer 2017, collected 86.3 kg·yr of TeO<sub>2</sub> over 7 weeks (24.0 kg·yr of <sup>130</sup>Te)
- ▶ 99.6% of channels active (984/988)
- ▶ 92% of channels passing analysis cuts
- ▶ Characterized by an energy resolution of 7.7 keV FWHM
- ▶ Signal efficiency of ~80%



# CUORE performance



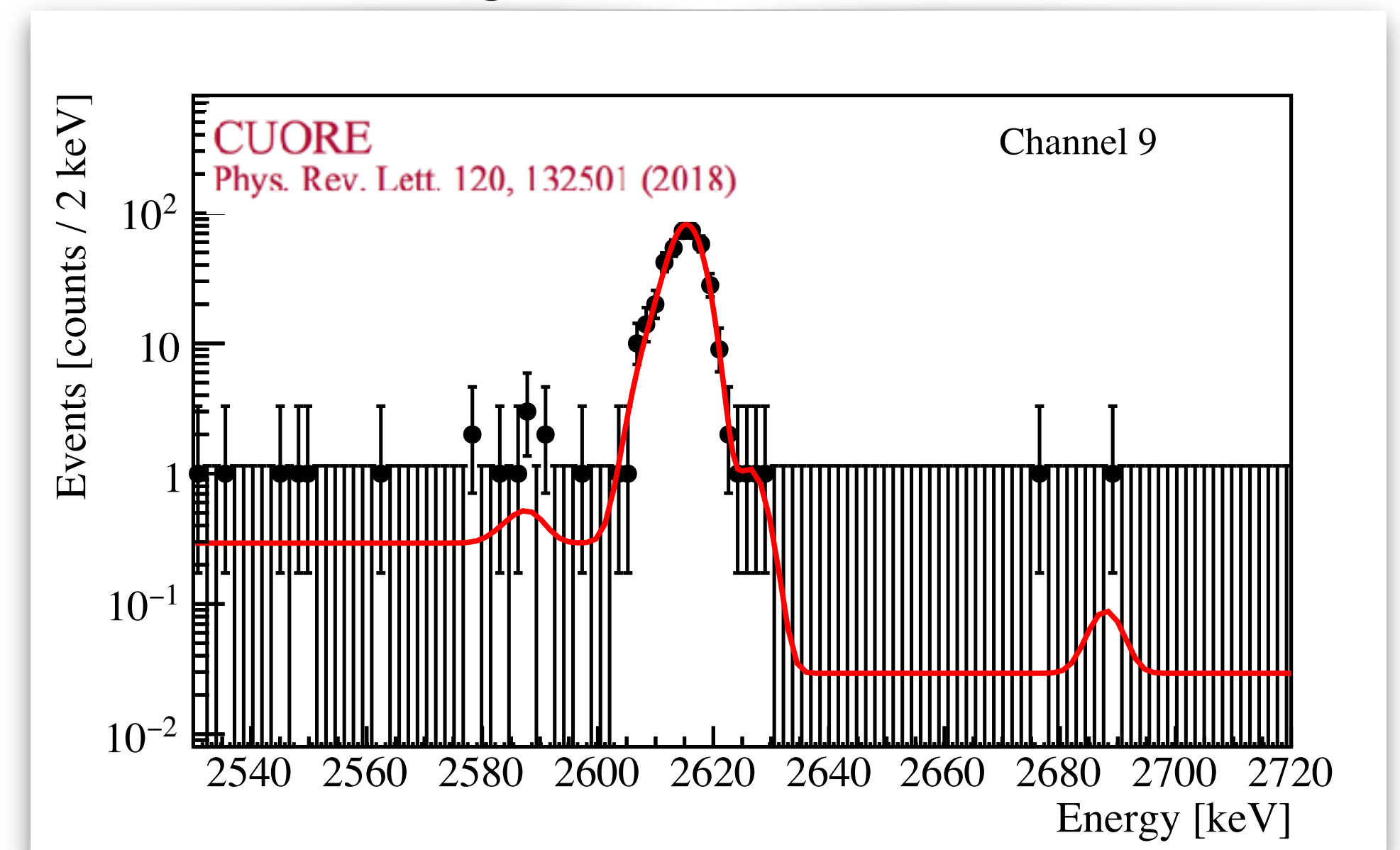
- (a) Photopeak
- (b) Compton
- (c) 30 keV X-Ray escape
- (d) Linear background
- (e) (2615 + 538 - 511) keV coincidence

Detector response of each channel studied by fitting the 2615 keV  $^{208}\text{Tl}$  calibration line.

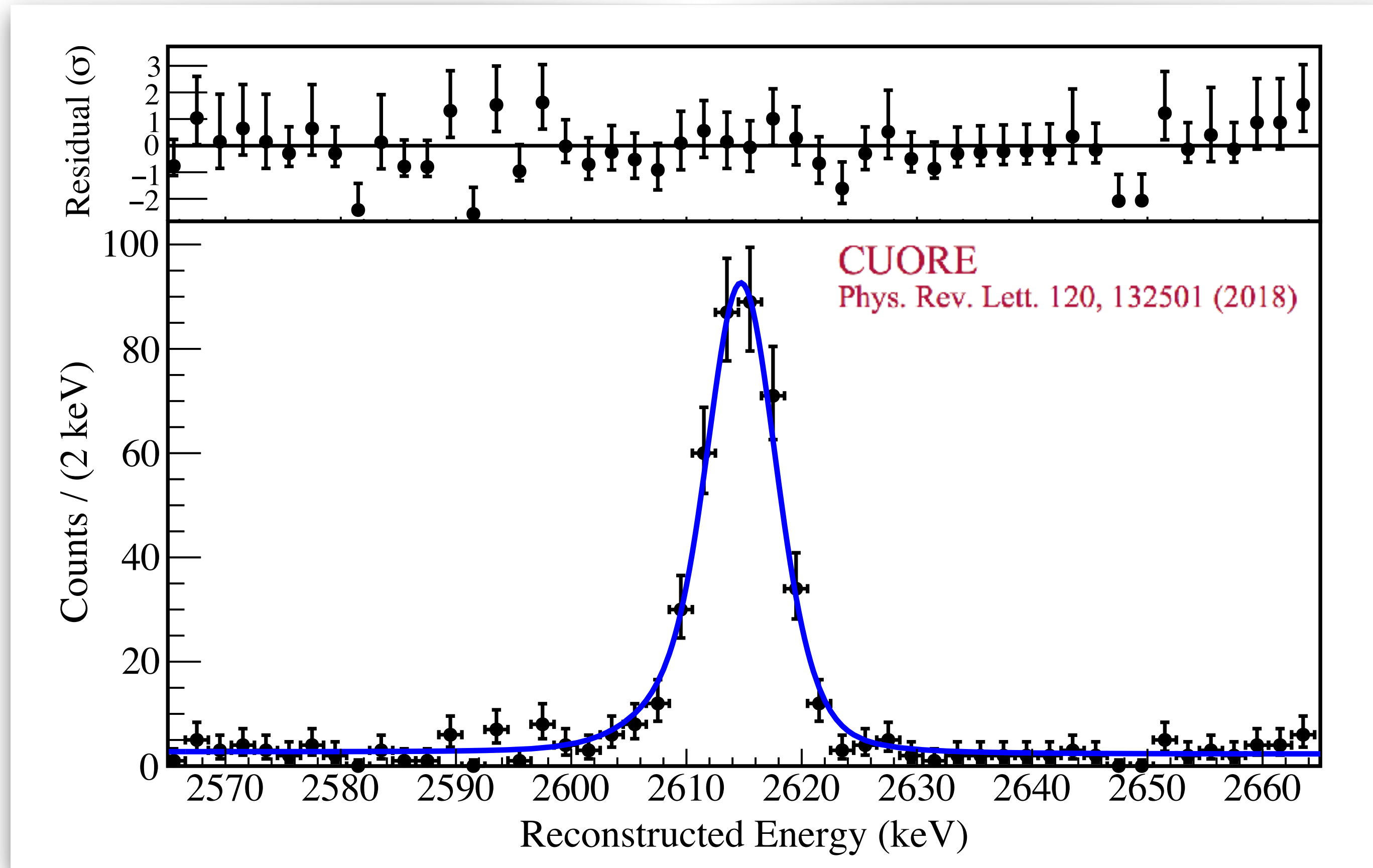
UEML simultaneous fit performed over all the channel-dataset.

The detector response is given by the photo-peak component of the fit, modelled by the sum of 3 Gaussians.

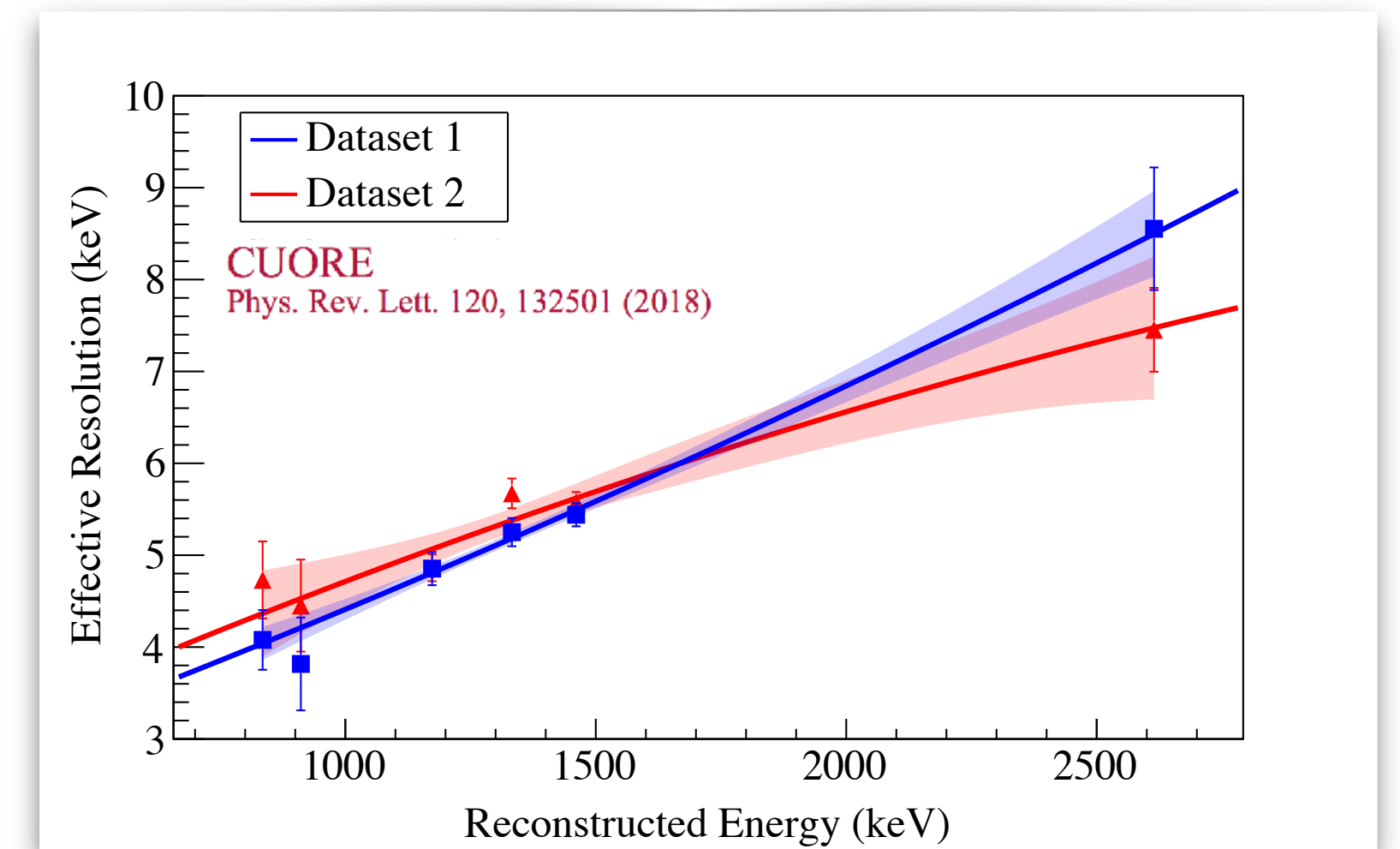
## Single channel-dataset



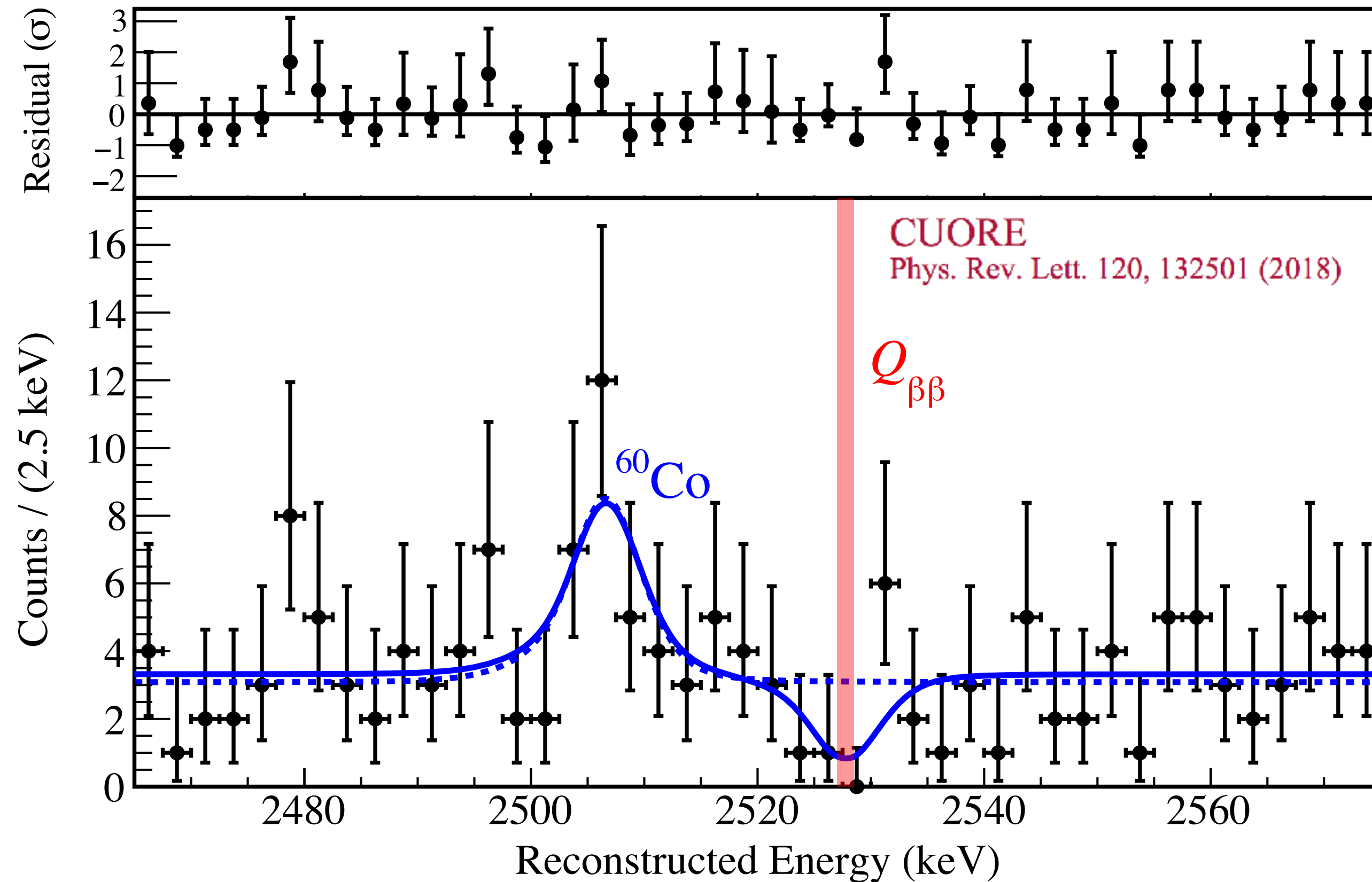
# CUORE resolution



**FWHM in the ROI for dataset 1:  $(8.3 \pm 0.4)$  keV**  
**FWHM in the ROI for dataset 2:  $(7.4 \pm 0.7)$  keV**



# $0\nu\beta\beta$ result



## ROI fit

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

Half-life limit: integrated the profile likelihood in the physical region (decay rate  $> 0$ )

$$T^{0\nu}_{1/2} > 1.3 \times 10^{25} \text{ yr (90\% CL, syst. included)}$$

Combine CUORE result with CUORE-0 and Cuoricino

$$T^{0\nu}_{1/2} > 1.5 \times 10^{25} \text{ yr (90\% CL, syst. included)}$$

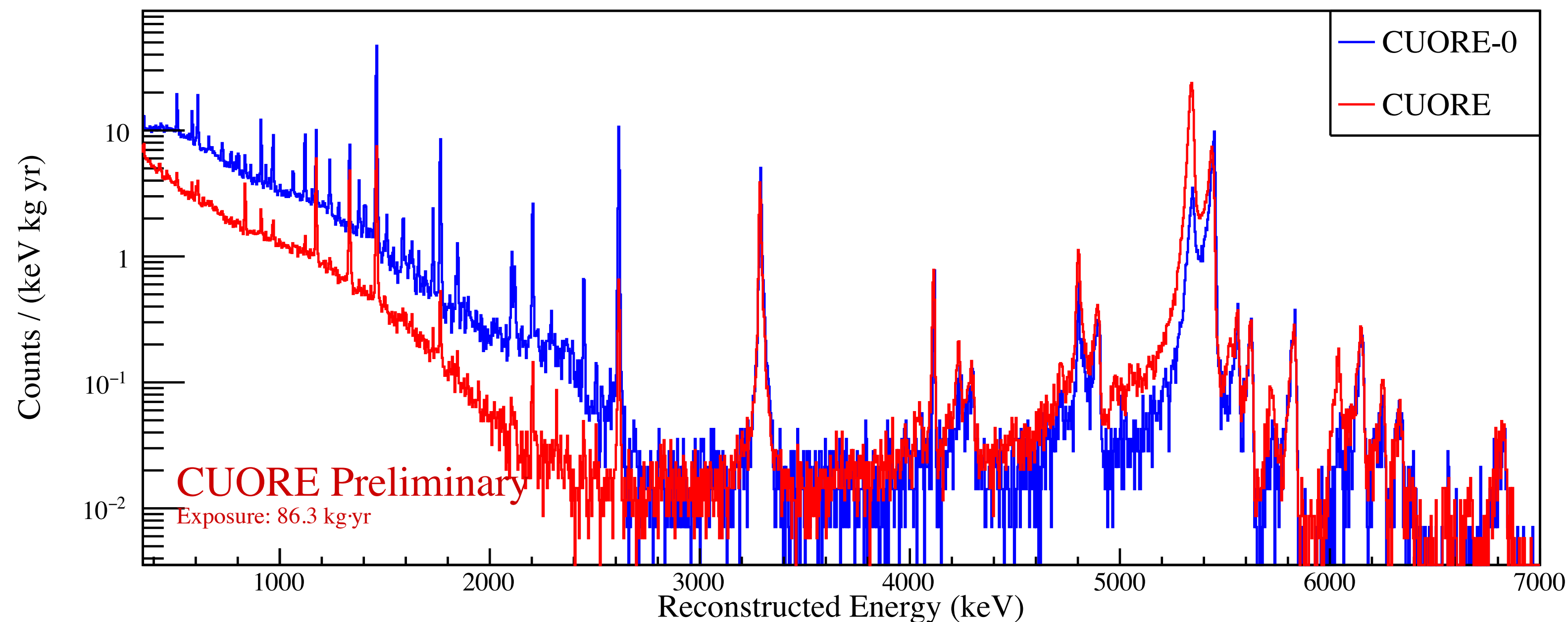
# CUORE background

## Some history

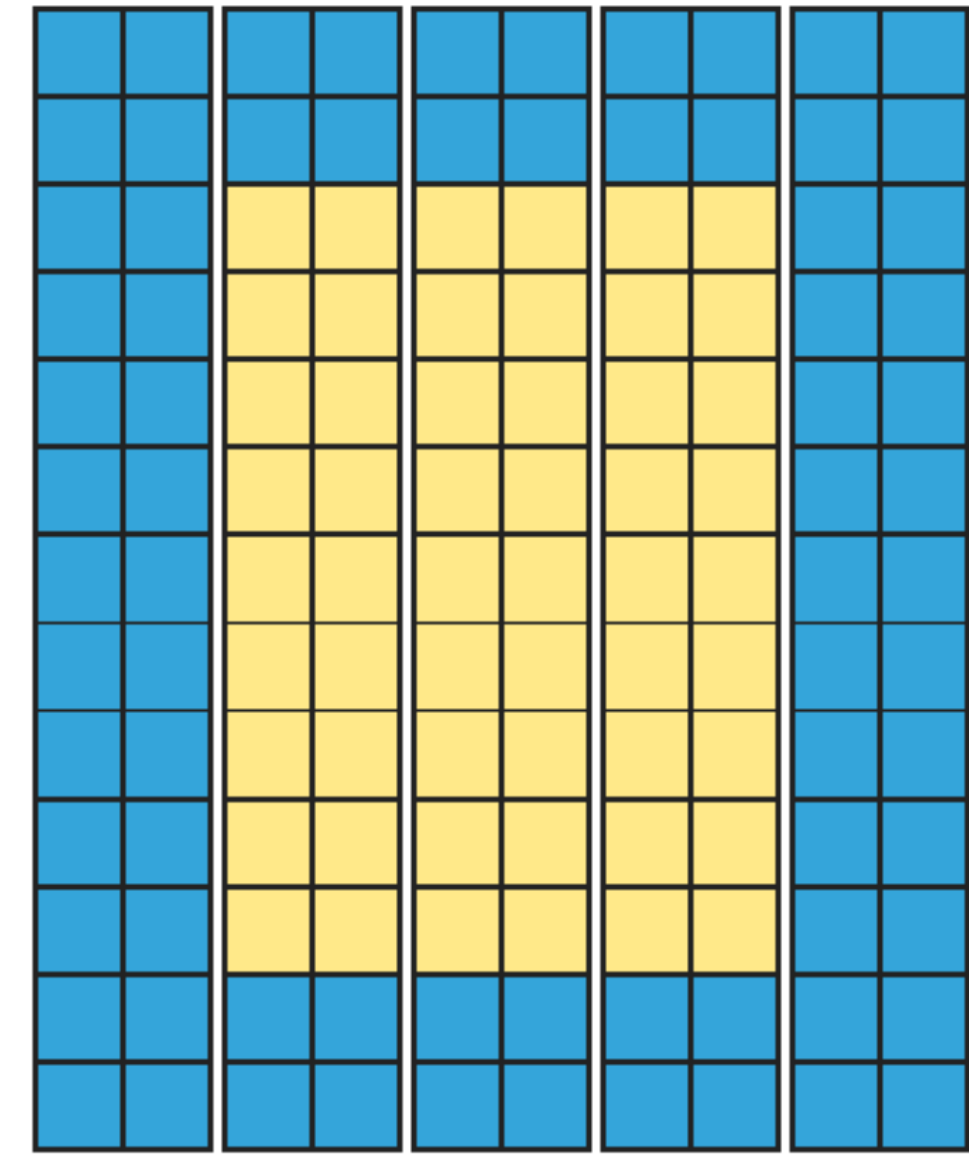
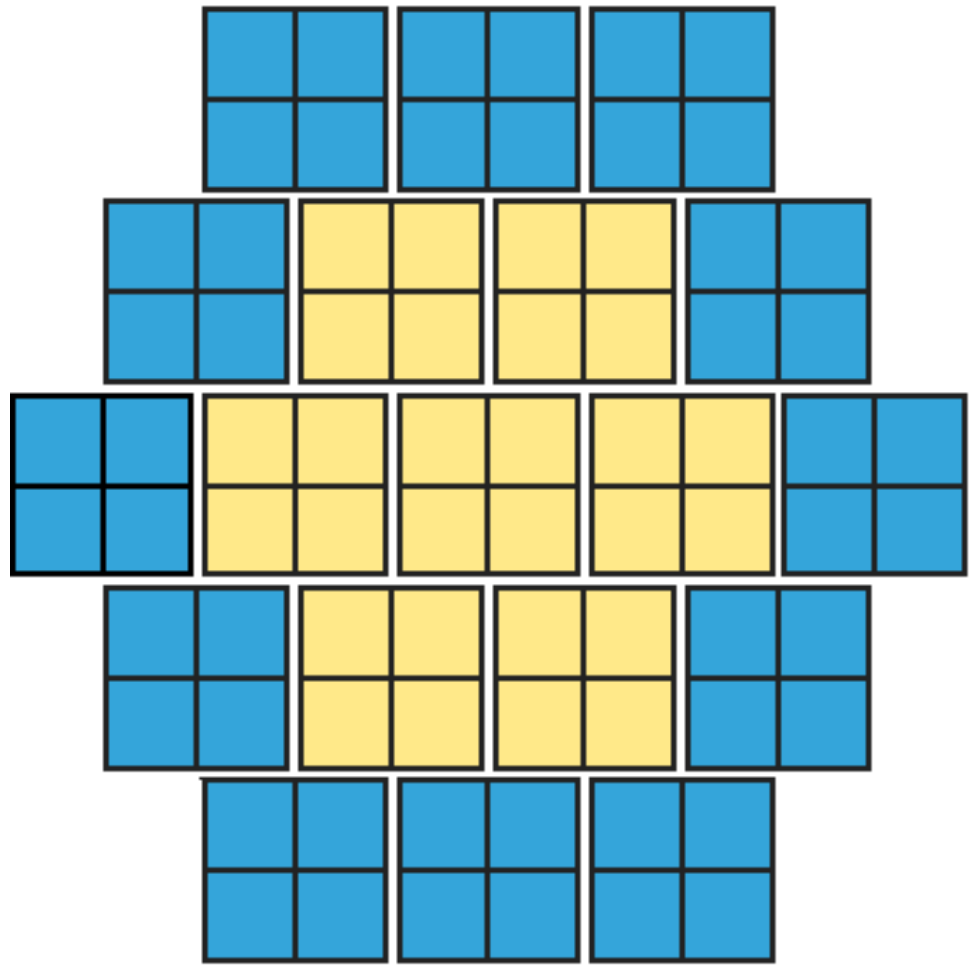
- ~ 65% of CUORICINO bkg from surface  $\alpha$  contaminants, remaining was  $\gamma$ 's from  $^{232}\text{Th}$  in cryostat
- CUORE-0: test CUORE tower construction on CUORICINO cryostat
- $\alpha$  back ground in CUORE-0 reduced by factor 10 wrt CUORICINO

## CUORE background

- $\gamma$  bkg strongly reduced
- Most  $\alpha$  bkg consistent with CUORE-0
- Bkg generally consistent with expectations
- $^{210}\text{Po}$  excess under investigation, contribution not relevant in the ROI  
→  $\sim 10^{-4}$  cts/(keV·kg·yr) at  $Q_{\beta\beta}$



# CUORE background model

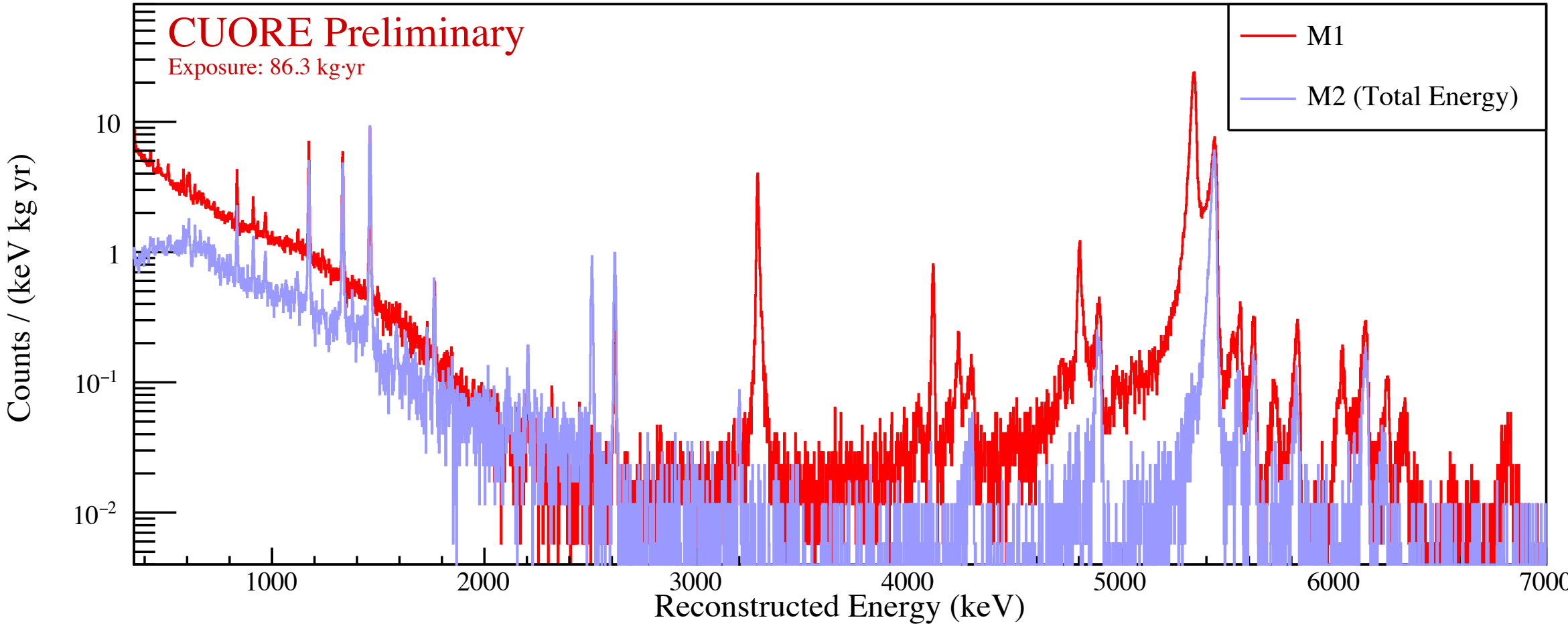
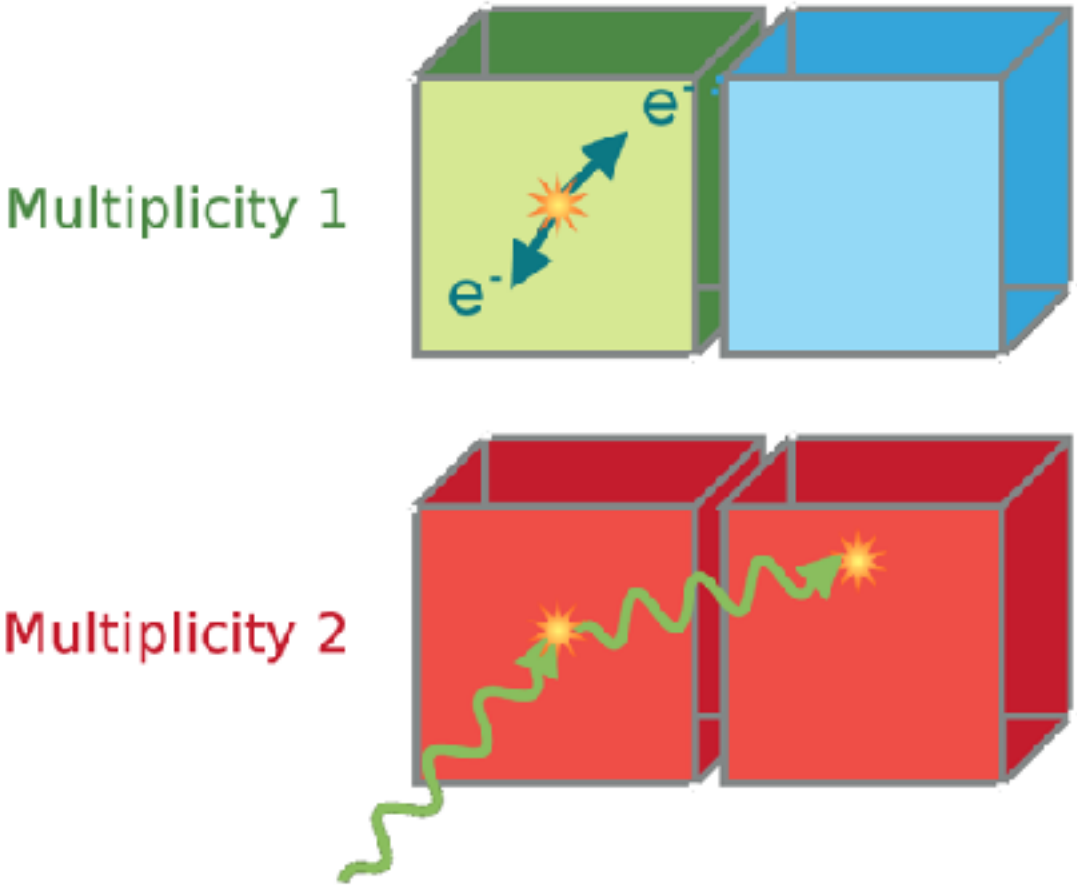


### Maximize use of available information

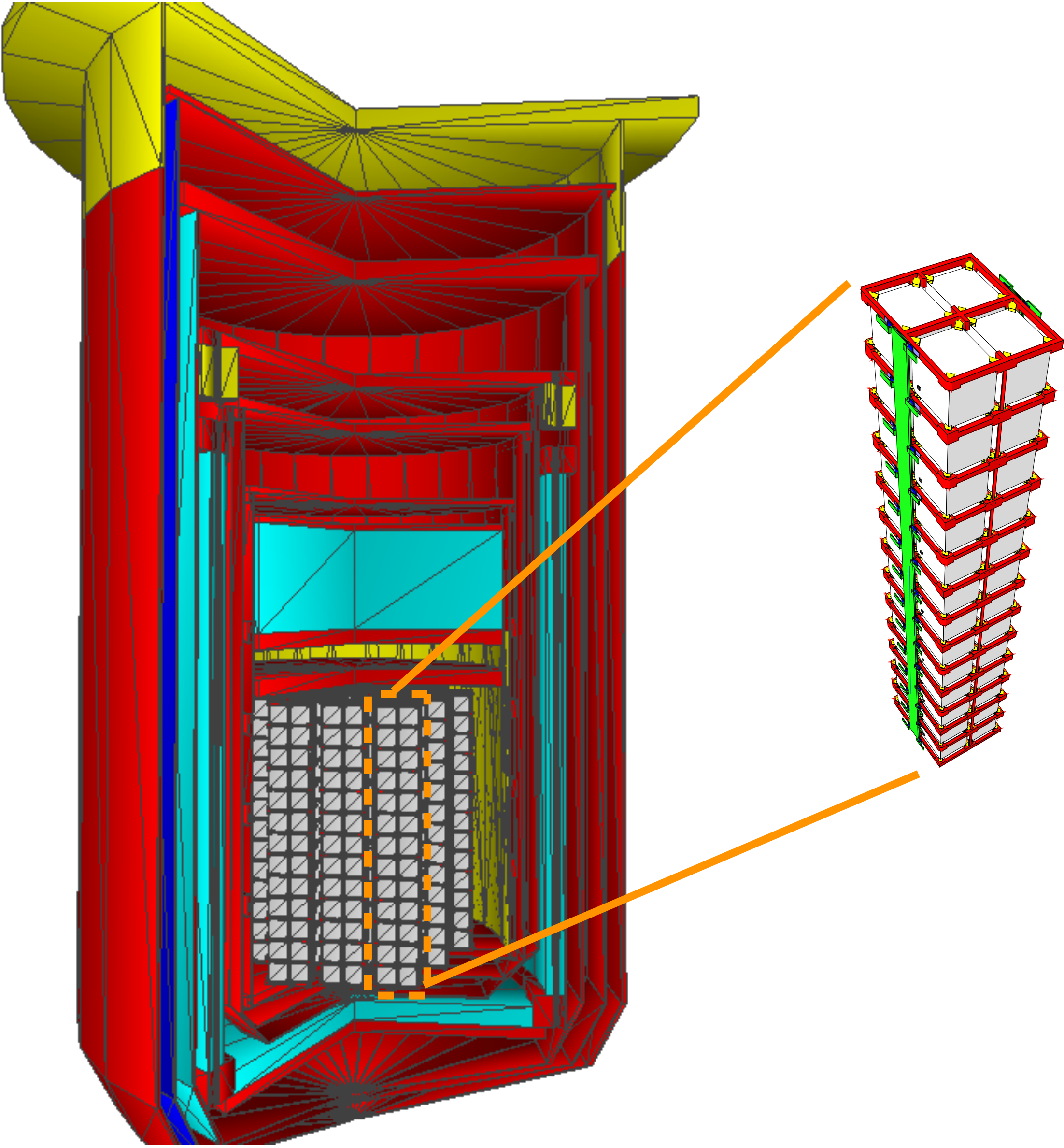
- Split the data into inner and outer layers
- Split data into Multiplicity1 (M1), Multiplicity2 (M2) and Multiplicity 2 Sum ( $\Sigma 2$ )

### Background model

- Geant4 simulation of contaminants in different cryostat components (~ 60 independent fit parameters)
- Full background reconstruction with a Bayesian fit
- Flat priors for all parameters except muons



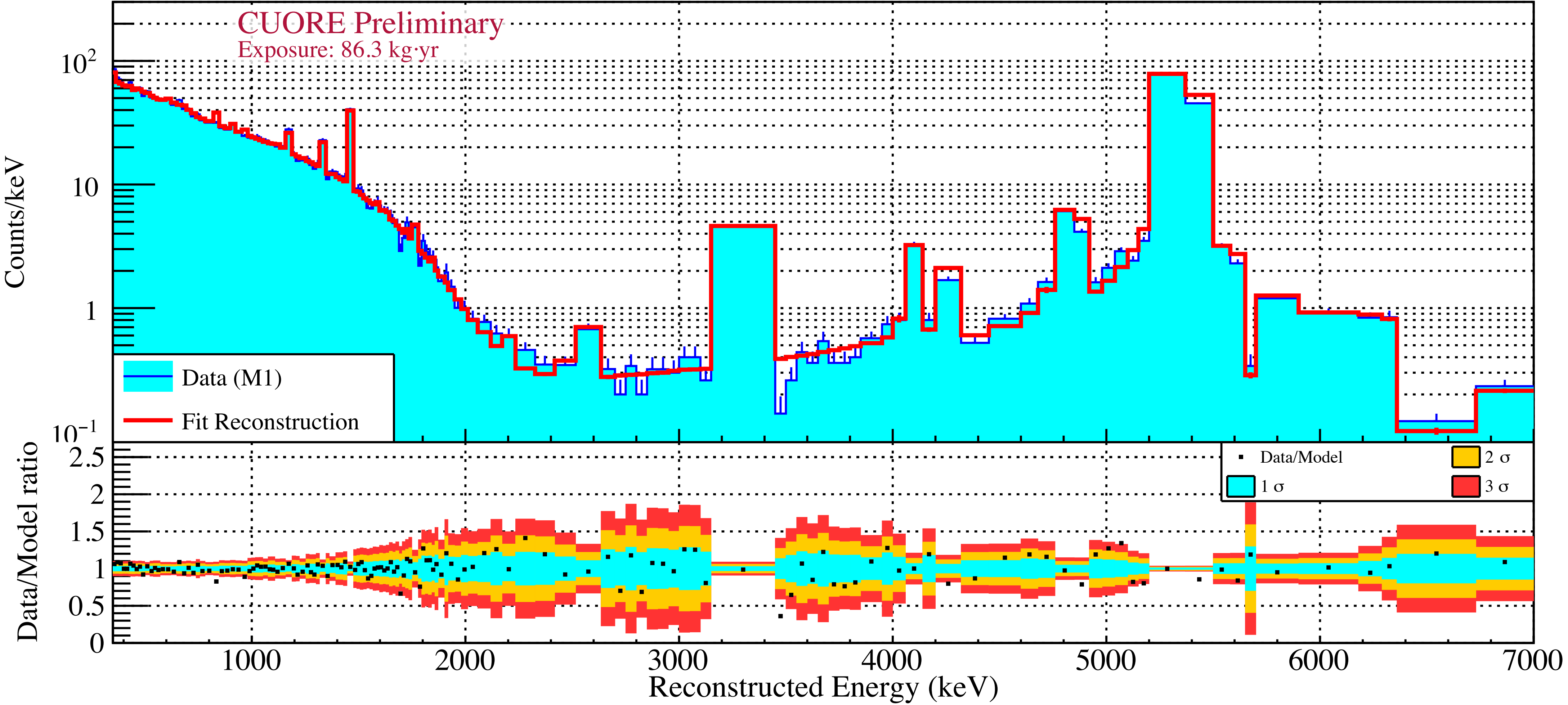
# CUORE background model



Volume	Type	Components
TeO <sub>2</sub>	Bulk	$2\nu\beta\beta$ , <sup>210</sup> Pb, <sup>232</sup> Th, <sup>228</sup> Ra- <sup>208</sup> Pb, <sup>238</sup> U- <sup>230</sup> Th, <sup>230</sup> Th, <sup>226</sup> Ra- <sup>210</sup> Pb, <sup>40</sup> K, <sup>60</sup> Co, <sup>125</sup> Sb, <sup>190</sup> Pt
TeO <sub>2</sub>	Surface (0.01 μm)	<sup>232</sup> Th, <sup>228</sup> Ra- <sup>208</sup> Pb, <sup>238</sup> U- <sup>230</sup> Th, <sup>226</sup> Ra- <sup>210</sup> Pb, <sup>210</sup> Pb
TeO <sub>2</sub>	Surface (1 μm)	<sup>210</sup> Pb
TeO <sub>2</sub>	Surface (10 μm)	<sup>210</sup> Pb, <sup>232</sup> Th, <sup>238</sup> U
CuNOSV	Bulk	<sup>232</sup> Th, <sup>238</sup> U, <sup>40</sup> K, <sup>60</sup> Co, <sup>54</sup> Mn
CuNOSV	Surface (0.01 μm)	<sup>210</sup> Pb, <sup>232</sup> Th, <sup>238</sup> U
CuNOSV	Surface (1 μm)	<sup>210</sup> Pb, <sup>232</sup> Th, <sup>238</sup> U
CuNOSV	Surface (10 μm)	<sup>210</sup> Pb, <sup>232</sup> Th, <sup>238</sup> U
Roman lead	Bulk	<sup>232</sup> Th, <sup>238</sup> U, <sup>108m</sup> Ag
Top lead	Bulk	<sup>232</sup> Th, <sup>238</sup> U, <sup>210</sup> Bi
Ext. lead	Bulk	<sup>210</sup> Bi
CuOFE	Bulk	<sup>232</sup> Th, <sup>238</sup> U, <sup>60</sup> Co
External	-	Cosmic muons

# CUORE background model

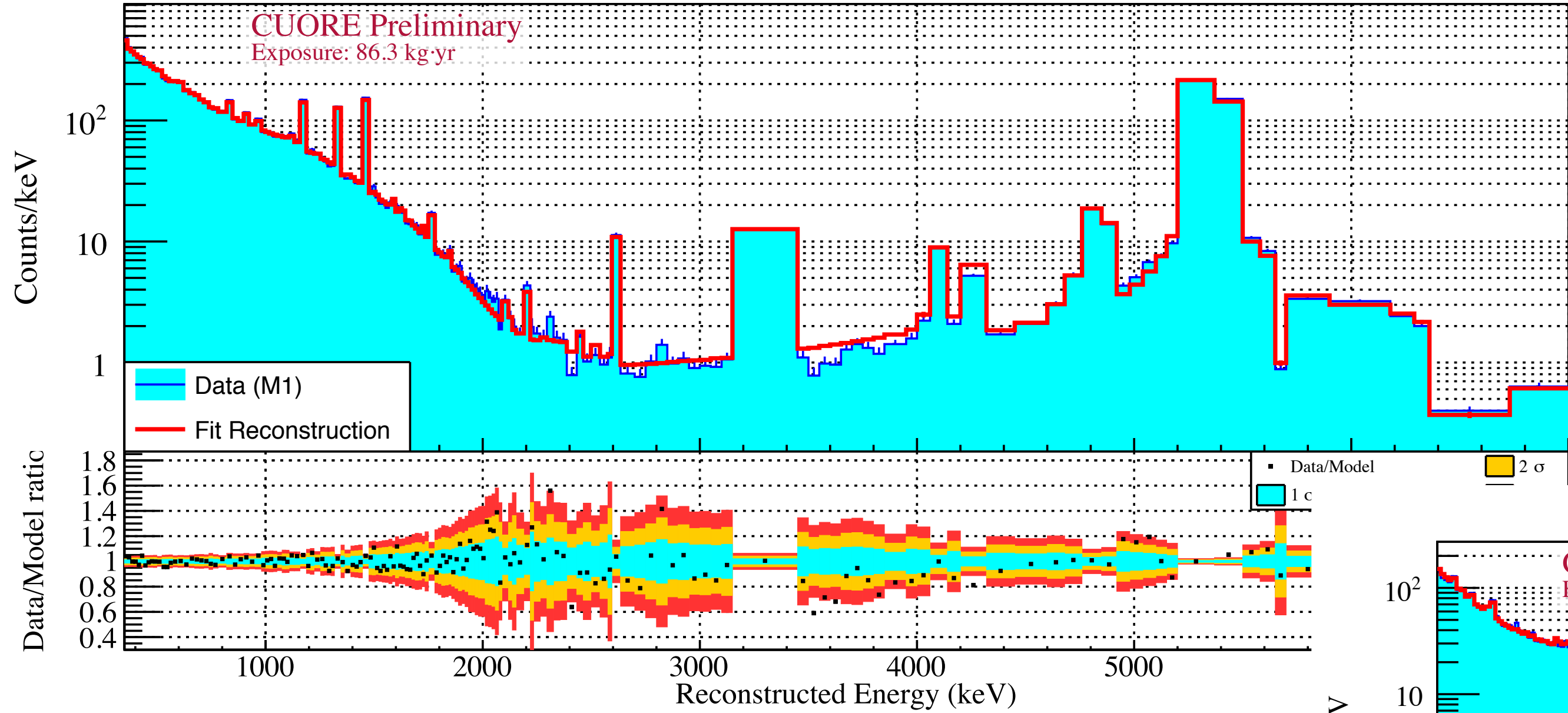
Multiplicity 1 - Inner Layer



Spectrum reconstruction extremely accurate

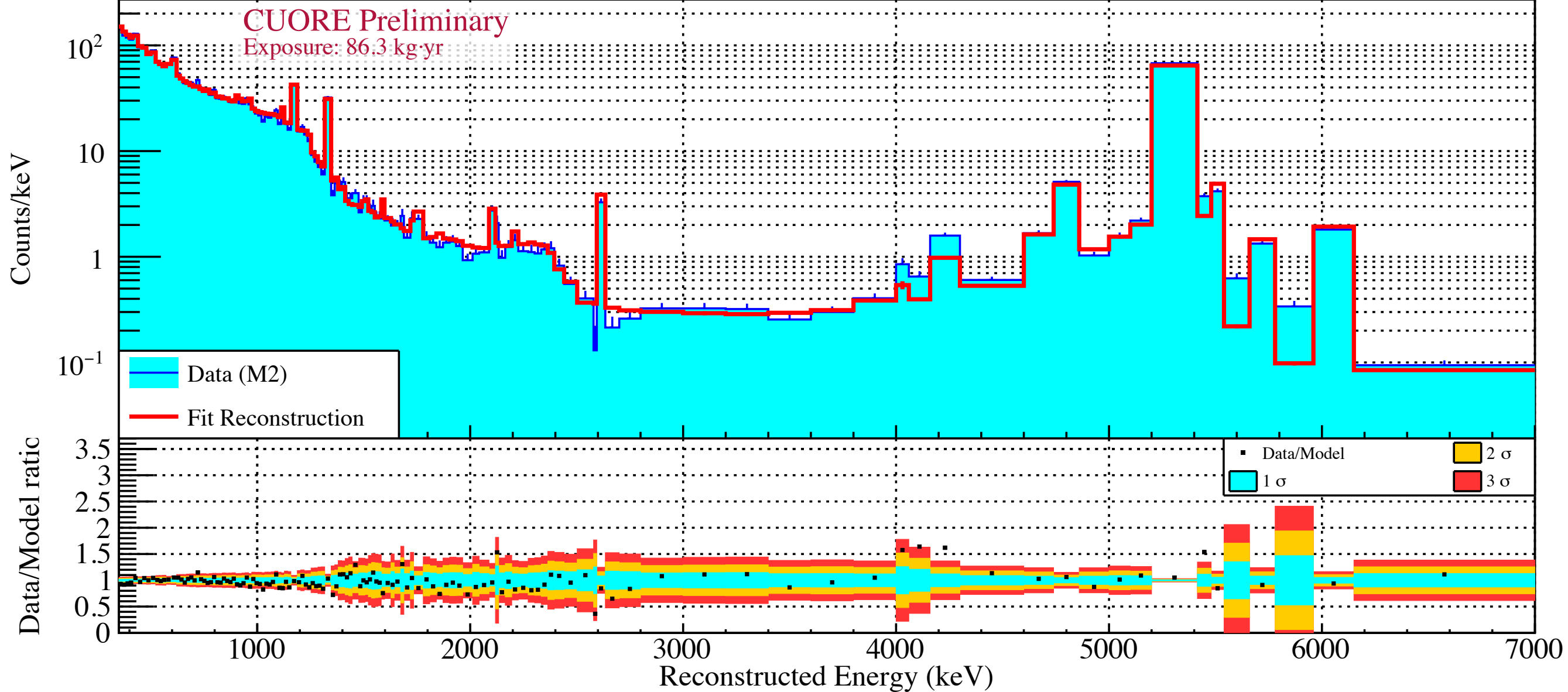
# CUORE background model

Multiplicity 1 - Outer Layer



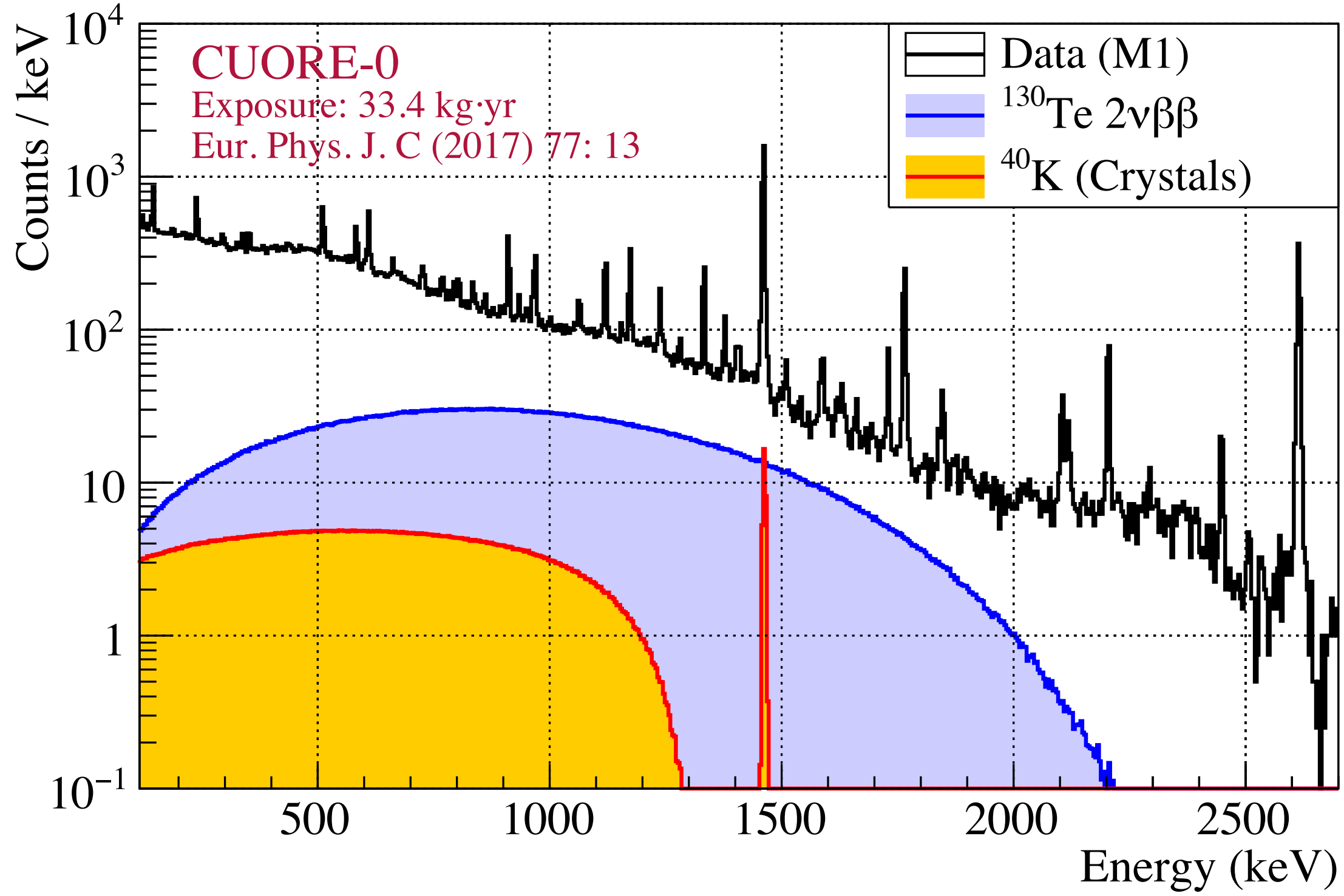
Outer layer sensitive to external backgrounds

Multiplicity 2



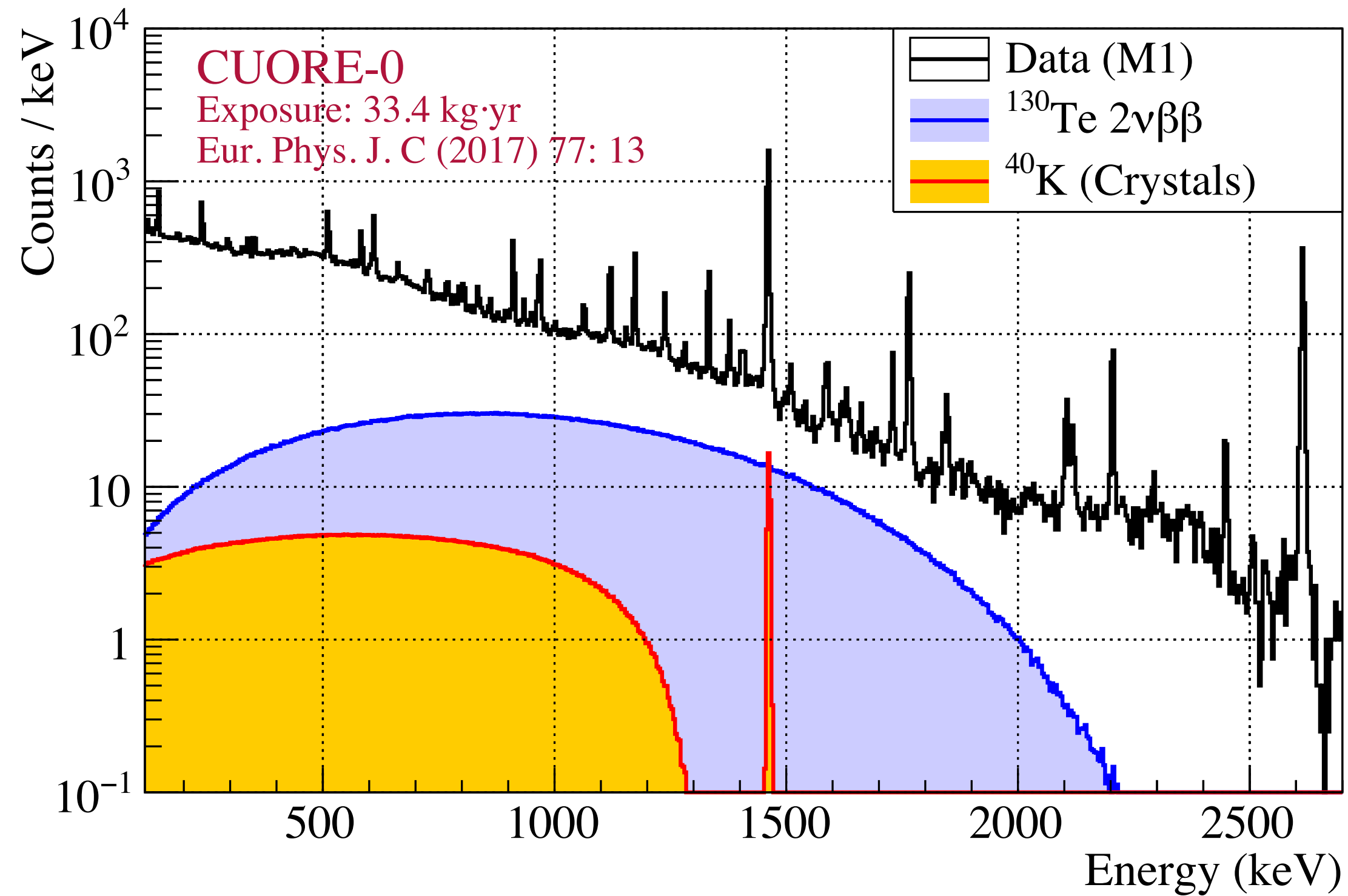
M2 and  $\Sigma$ 2 spectra constrain a subset of the backgrounds

# $2\nu\beta\beta$ result



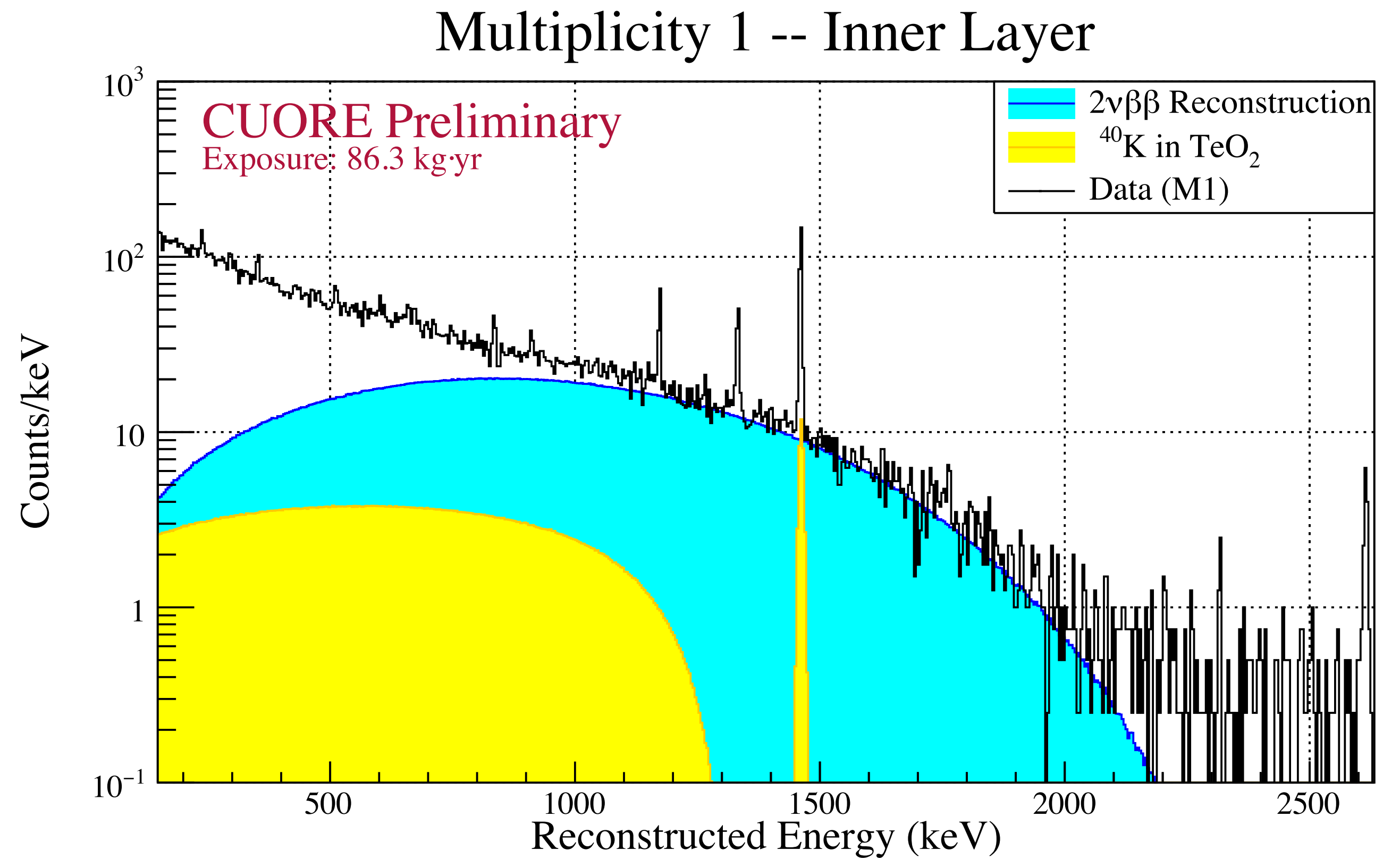
In CUORE0,  $2\nu\beta\beta$  accounted for about 10% of the events in the 1-2 MeV region...

# $2\nu\beta\beta$ result



...but now, thanks to the improved background, it accounts for almost 100% of events.

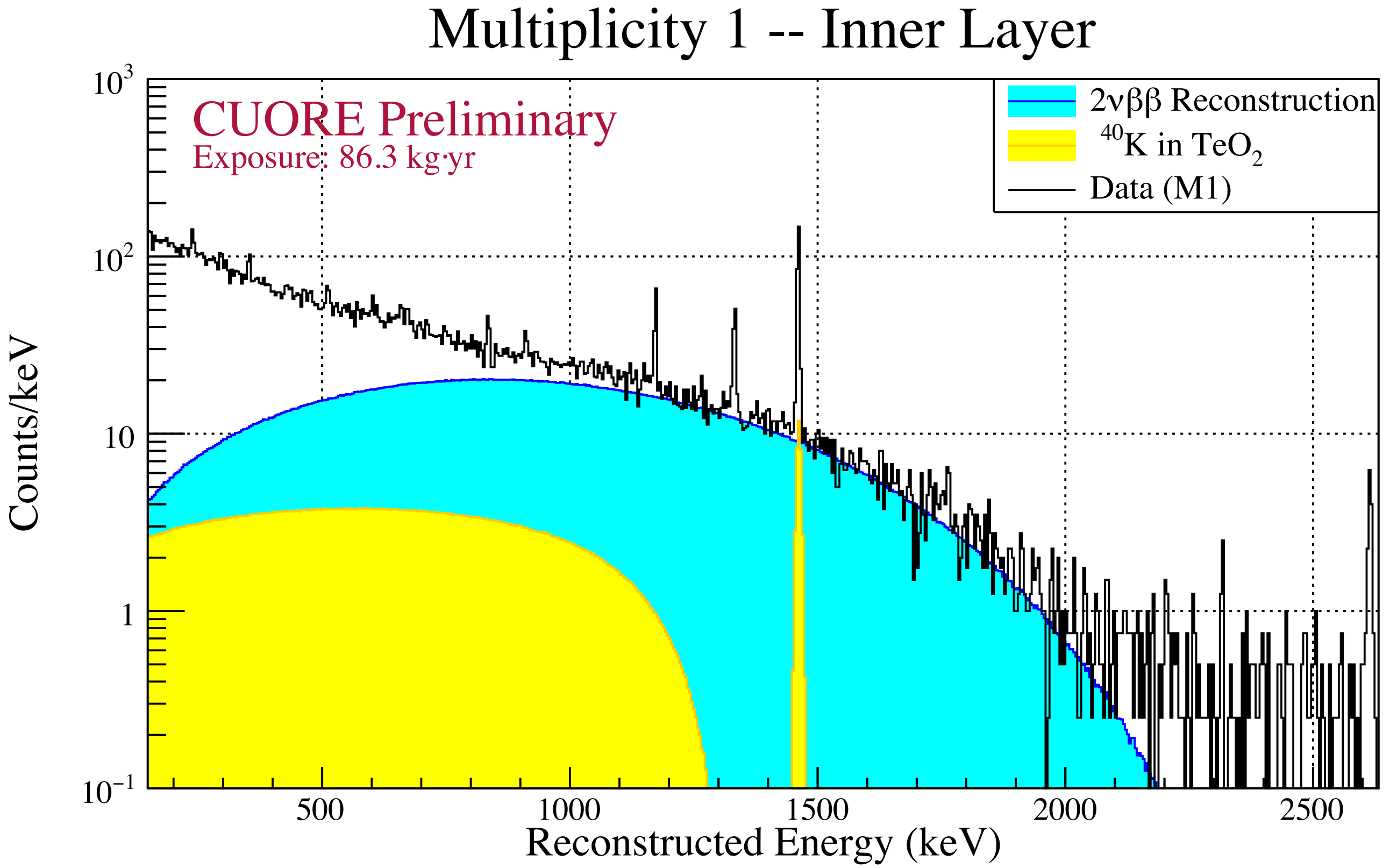
In CUORE0,  $2\nu\beta\beta$  accounted for about 10% of the events in the 1-2 MeV region...



# $2\nu\beta\beta$ result

Results:

- $T_{1/2}^{2\nu} = [7.9 \pm 0.1(\text{stat}) \pm 0.2(\text{syst})] \cdot 10^{20} \text{ yr}$  (PRELIMINARY)
- CUORE-0:  $T_{1/2}^{2\nu} = [8.2 \pm 0.2(\text{stat}) \pm 0.6(\text{syst})] \cdot 10^{20} \text{ yr}$
- NEMO:  $T_{1/2}^{2\nu} = [7.0 \pm 0.9(\text{stat}) \pm 1.1(\text{syst})] \cdot 10^{20} \text{ yr}$



# Status and outlook

## 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

- Improvements ongoing to achieve the 5 keV goal
- Physics data collection since May 2018: goal collect 10 times more statistics
- Analysis of new data on going: exploring the full potential of CUORE
- More results to come

