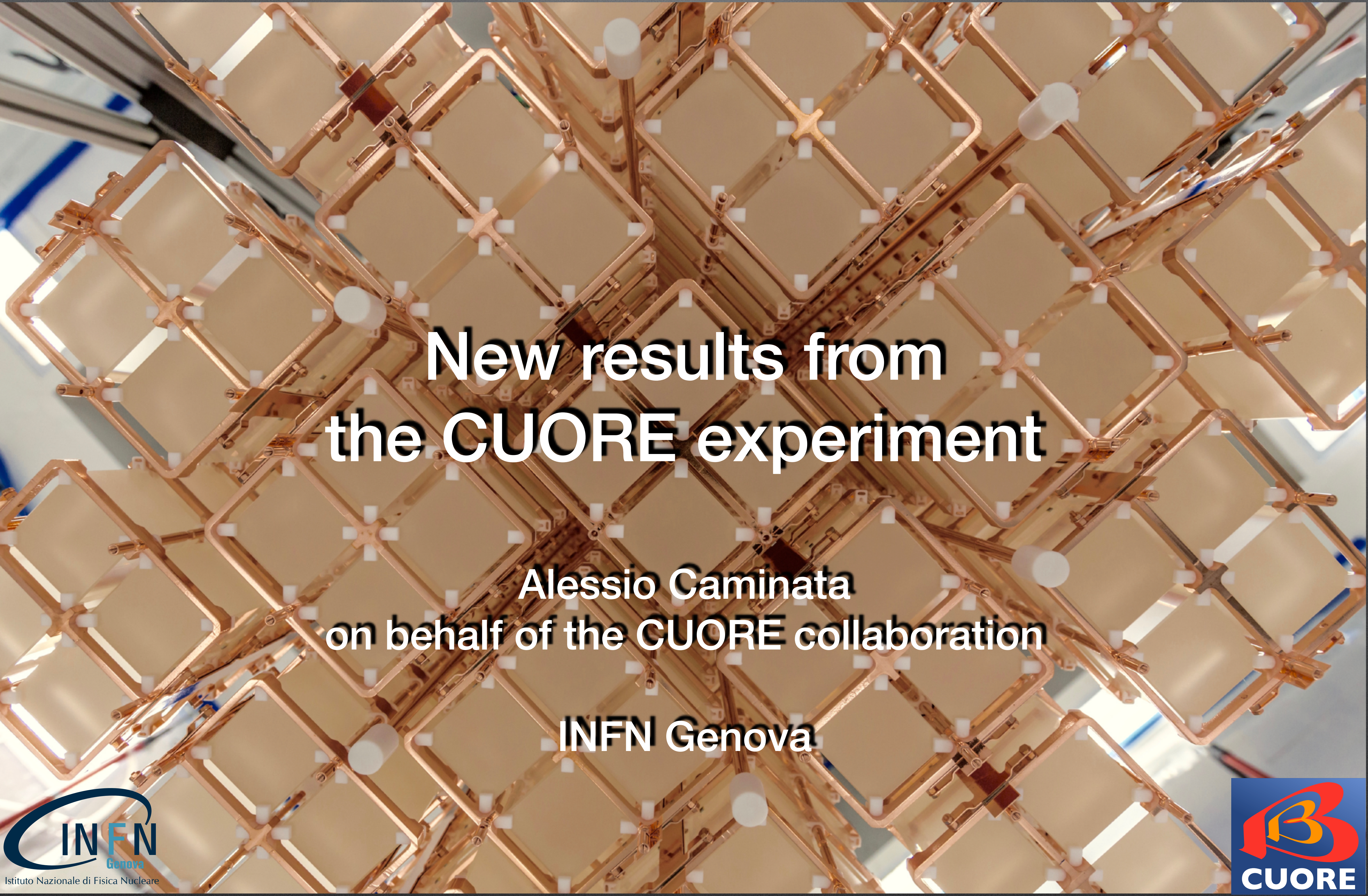


New results from the CUORE experiment

Alessio Caminata
on behalf of the CUORE collaboration

INFN Genova

Istituto Nazionale di Fisica Nucleare

Neutrinoless double beta decay (0νββ)

ββ alternative to β decay forbidden by mass difference for some even-even nuclei

2νββ

$(A,Z) \rightarrow (A,Z+2)+2e^{-}+2\,\overline{\nu}_e$

$T_{1/2}^{2\nu} \sim 10^{18\text{-}24}$ yr

The process is allowed by SM

0νββ

$(A,Z) \rightarrow (A,Z+2)+2e^{-}$

If observed ν Majorana particle

Physics beyond SM

Lepton number not conserved

$$T^{0\nu}_{1/2} \propto \eta a \sqrt{\frac{Mt}{b\Delta E}}$$

Detector Mass

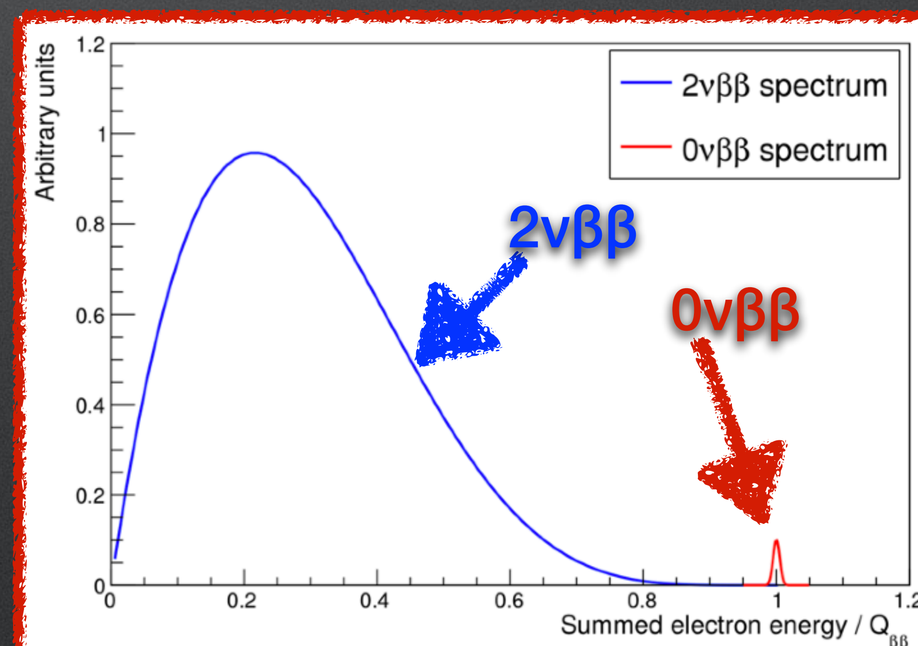
Livetime

Efficiency

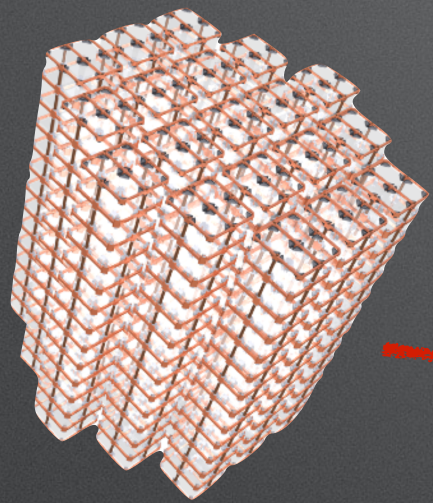
Isotopic abundance

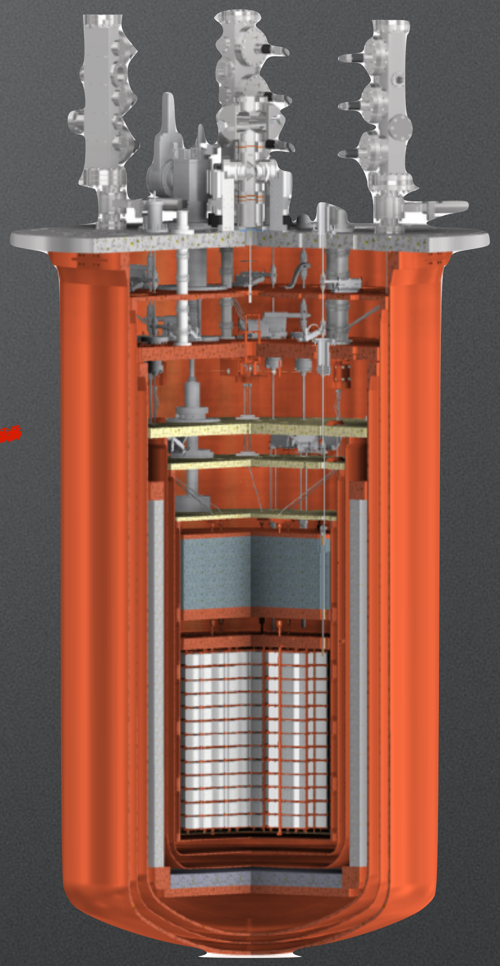
Energy resolution

Background rate



The CUORE experiment





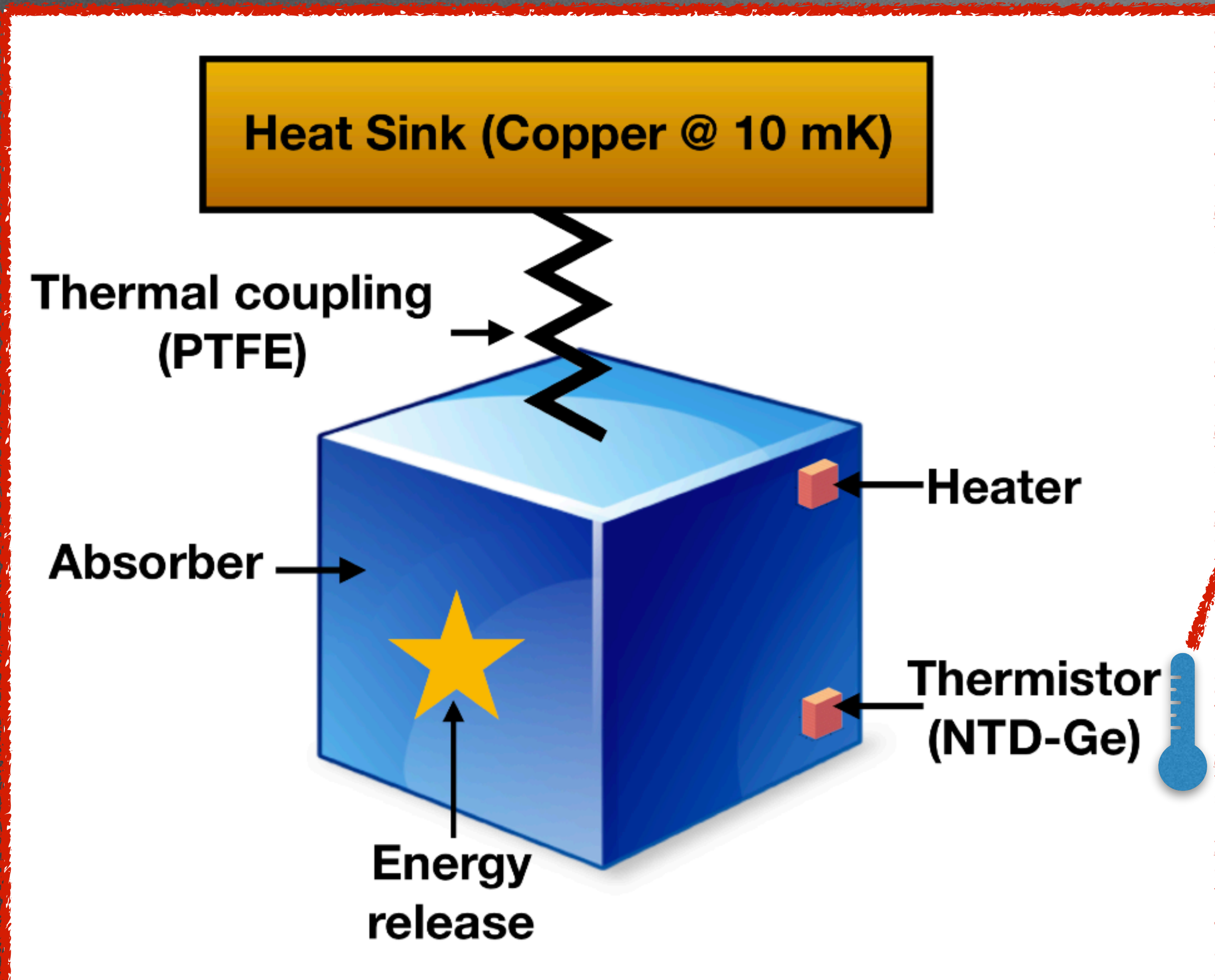
The CUORE experiment

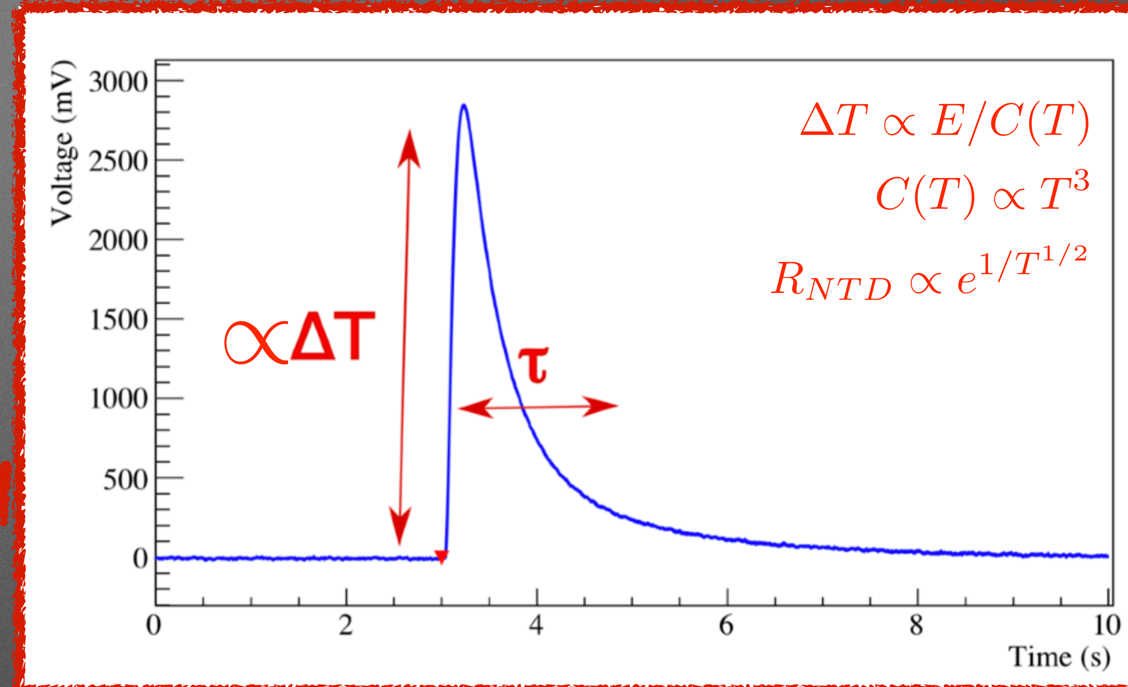
- Search for $0\nu\beta\beta$ of ^{130}Te: $^{130}Te \rightarrow {}^{130}Xe + 2e^-$
- Choice of the isotope:
  - High natural isotopic abundance (~ 34%)
  - Q-value (2527.515 ± 0.013 keV) above most of the natural radioactivity
  - Easy to mix (TeO_2)

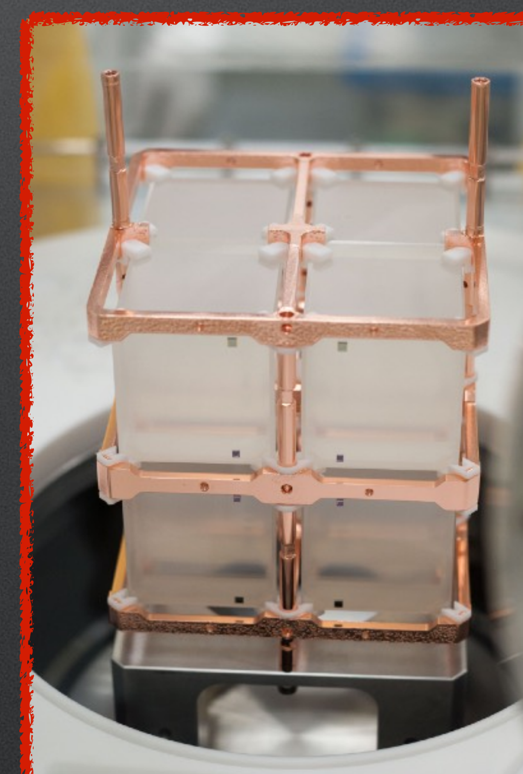
The CUORE collaboration

The CUORE experiment

The bolometric technique

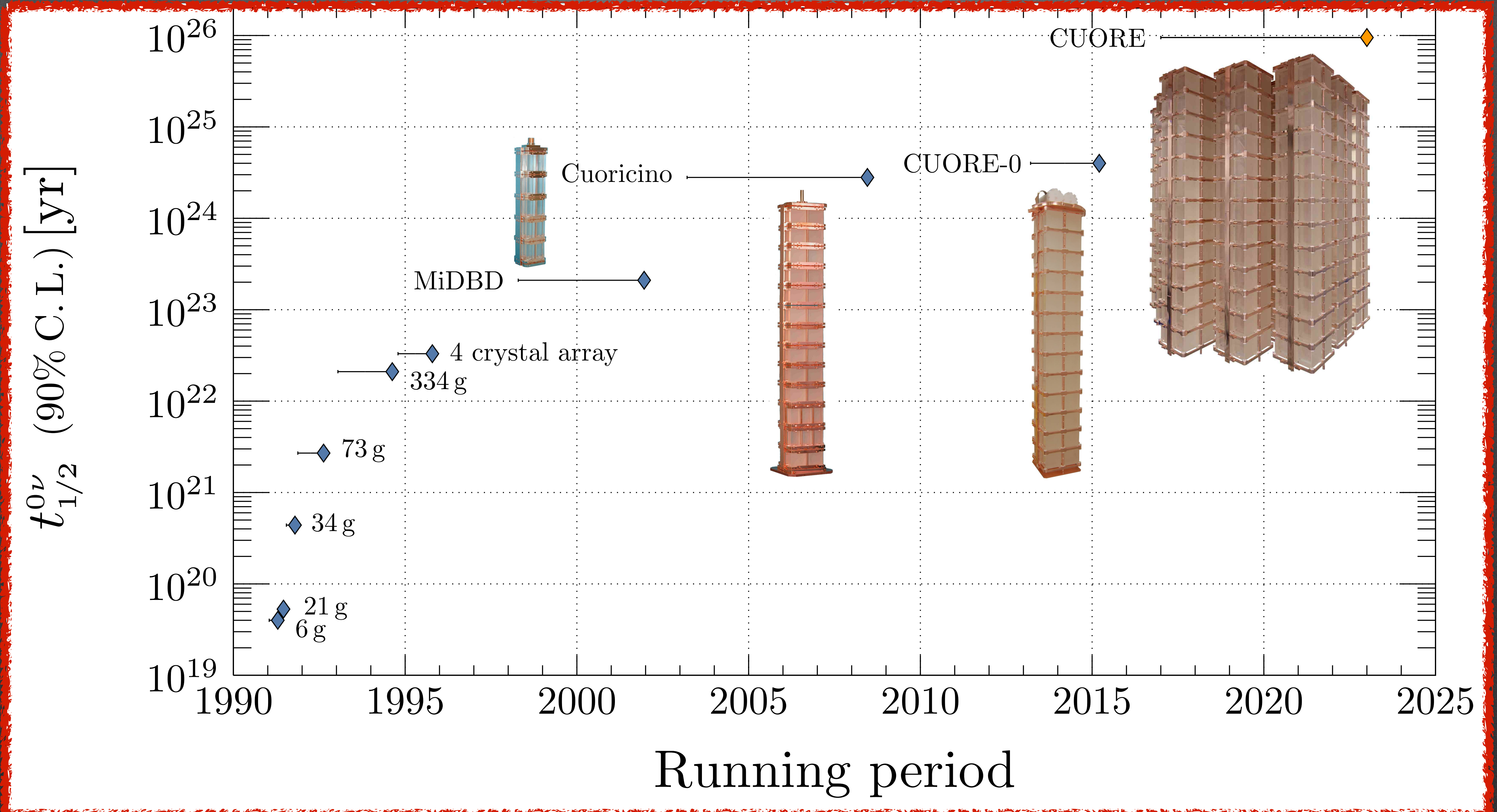






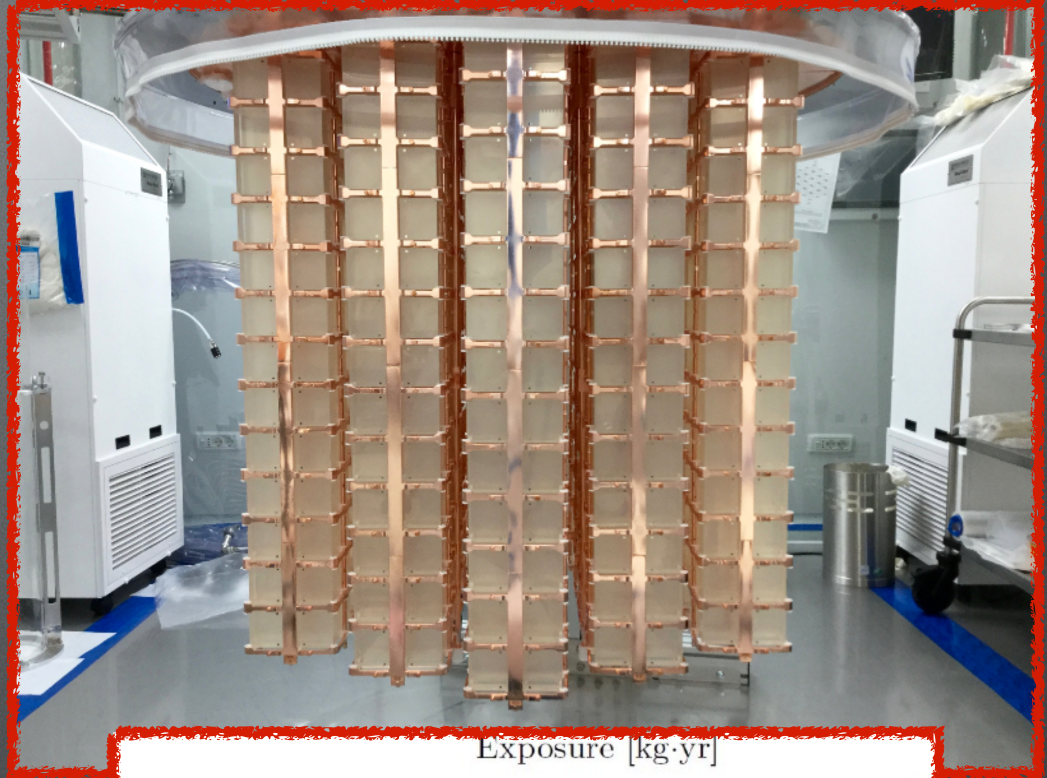
The temperature of the crystal rises due to the energy release and it is detected using a NTD-Ge thermistor

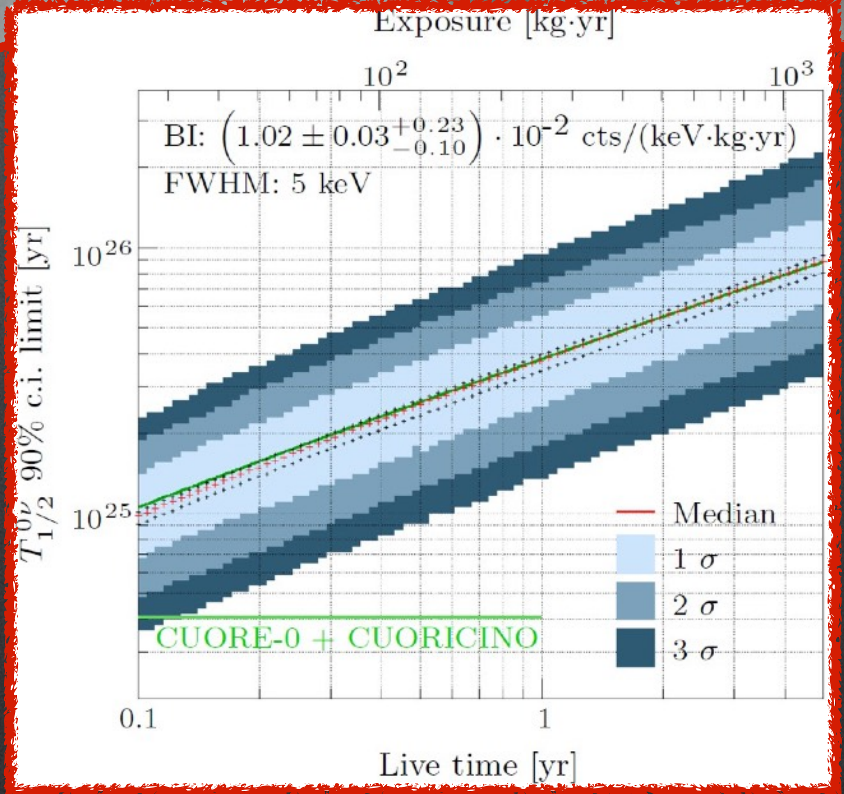
From a few grams to a ton-scale experiment



The CUORE experiment

- Primary goal: search for 0νββ in ^{130}Te
- 988 TeO_2 crystals in 19 towers
- Mass: 742 kg (206 kg of ^{130}Te)
- Background target: 10^{-2} cnts/(keV kg yr)
- Resolution target: 5 keV FWHM in the ROI
- Projected sensitivity (5yr, 90% CL): $T_{1/2}^{0\nu} > 9 \times 10^{25}$ yr*

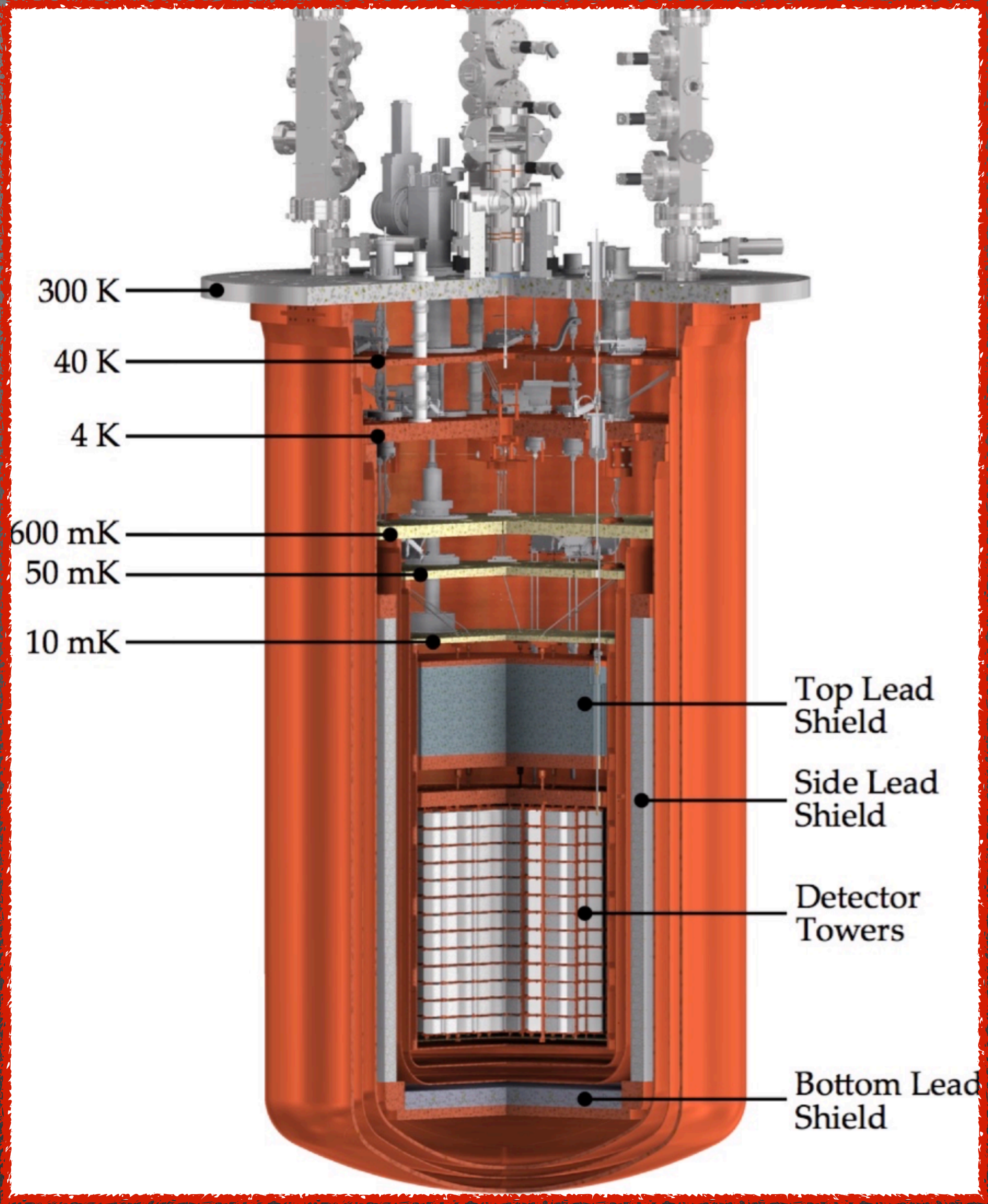




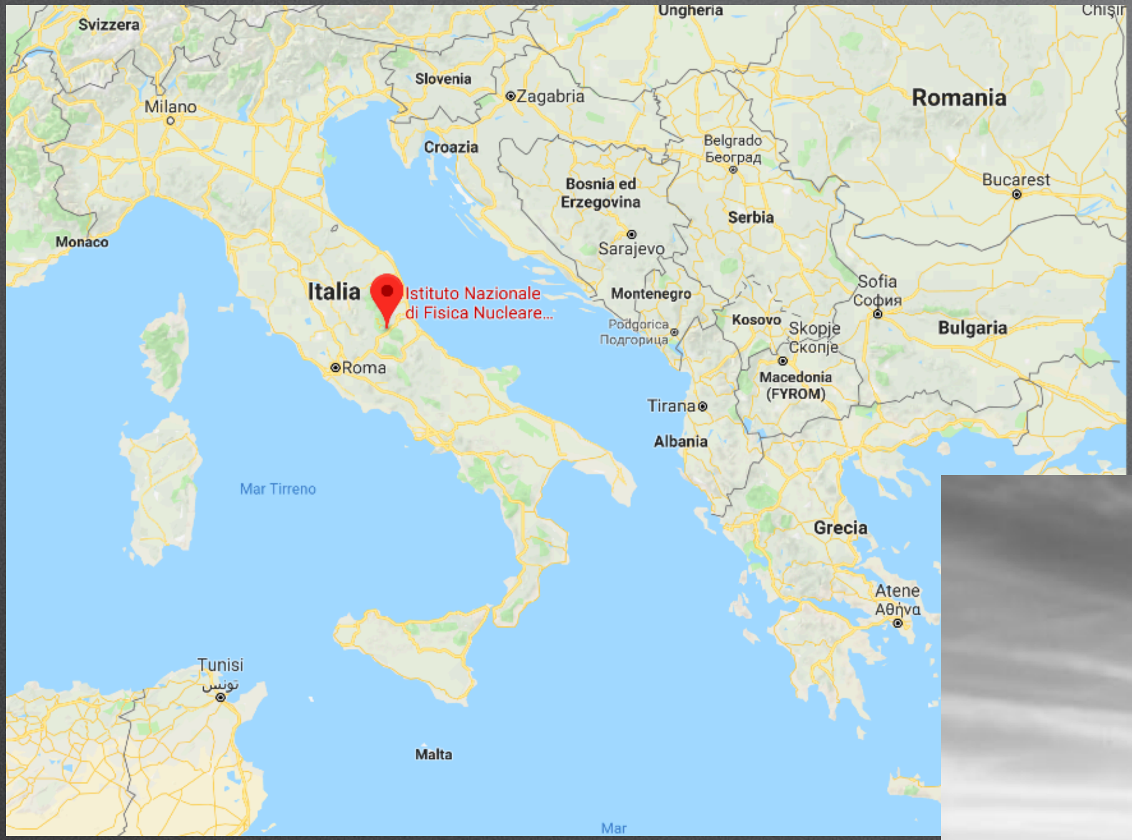
*Eur. Phys. J. C (2017) 77:532

The CUORE Cryostat

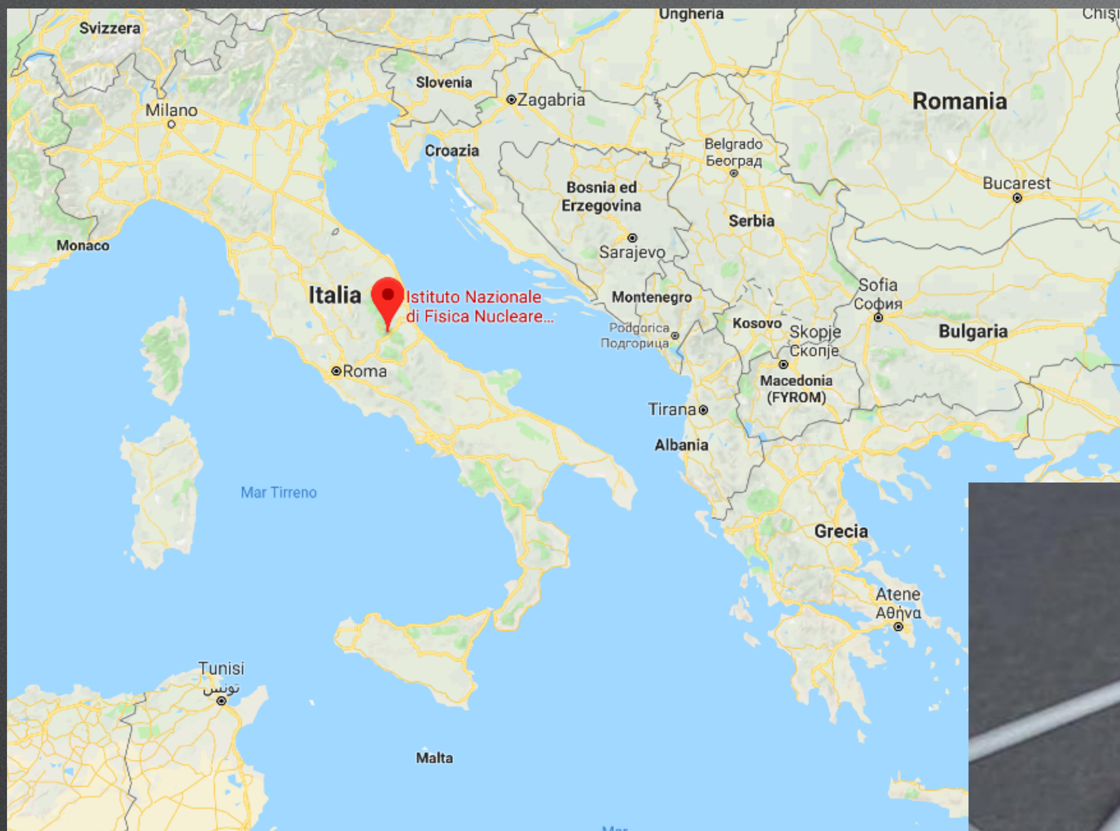
- Cooling
  - Cools the detector at 10 mK
  - PT-cryocoolers + Dilution refrigerator
  - Stable temperature over long periods of time
- Shielding
  - Clean low radioactivity copper
  - Ancient Roman lead on the 4K stage



CUORE@LNGS


Svizzera
Ungheria
Slovenia
Zagabria
Romania
Milano
Croazia
Belgrado
Београд
Bosnia ed
Erzegovina
Bucarest
Serbia
Monaco
Sarajevo
Sofia
София
Italia
Istituto Nazionale
di Fisica Nucleare...
Montenegro
Kosovo
Skopje
Скопје
Bulgaria
Roma
Podgorica
Подгорица
Macedonia
(FYROM)
Tirana
Albania
Mar Tirreno
Grecia
Atene
Αθήνα
Tunisi
Malta

CUORE@LNGS



depth: ~ 3600 m.w.e.

$\mu \sim 3 \times 10^{-8}\ \mu/(\mathrm{s\ cm^2})$

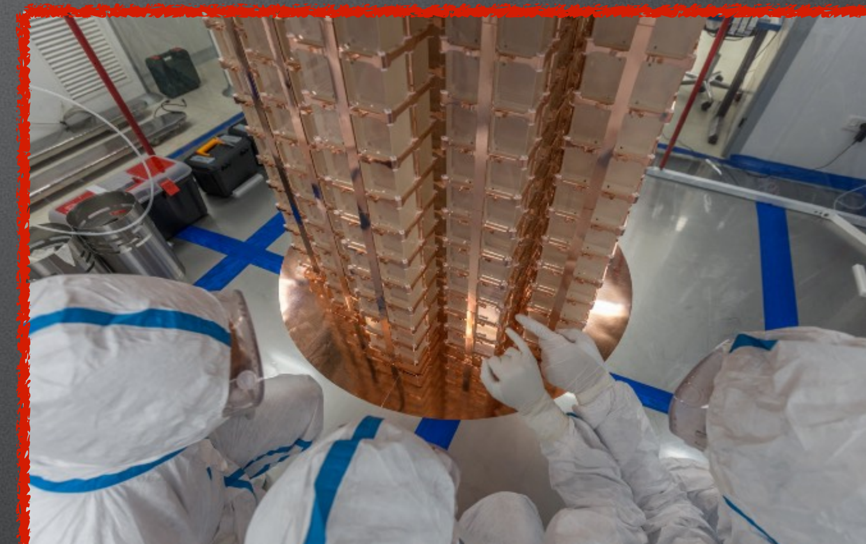
$\gamma \sim 0.73\ \gamma/(\mathrm{s\ cm^2})$*

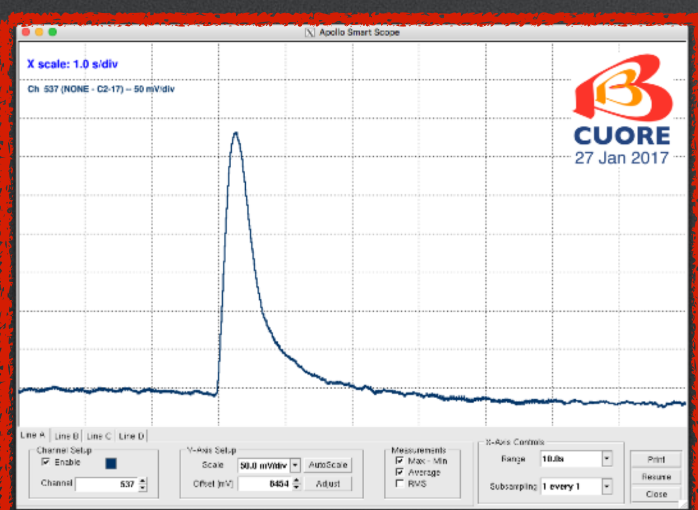
$n < 4 \times 10^{-6}\ n/(\mathrm{s\ cm^2})$**

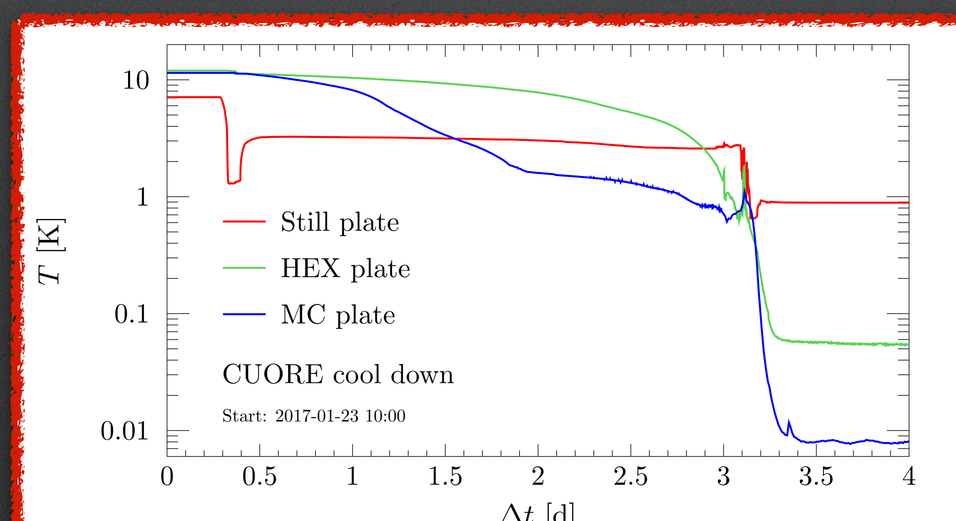
* below 3 MeV, ** below 10 MeV

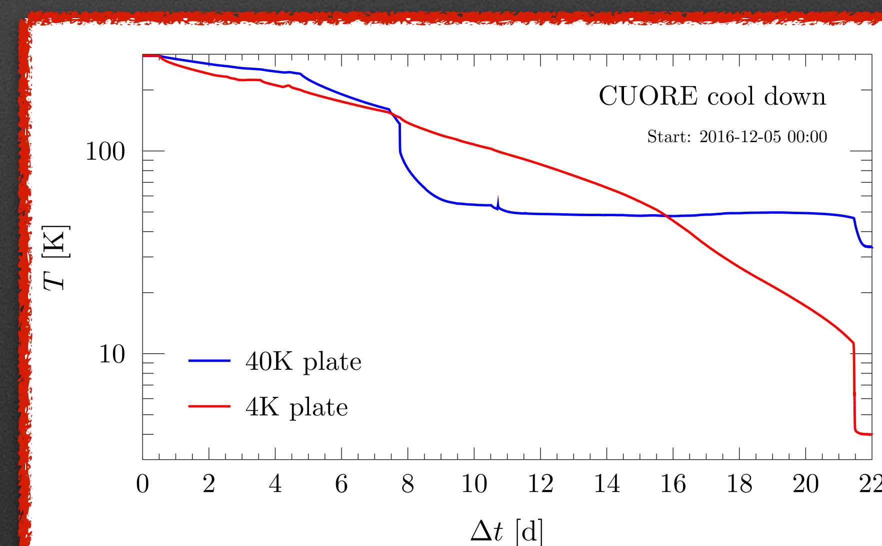
Detector commissioning

June 2013	End of crystal production
2015	CUORE cryostat commissioning
July-August 2016	CUORE towers installation
December 2016	CUORE cooldown
January 2017	First pulses from CUORE
April 2017	End of commissioning



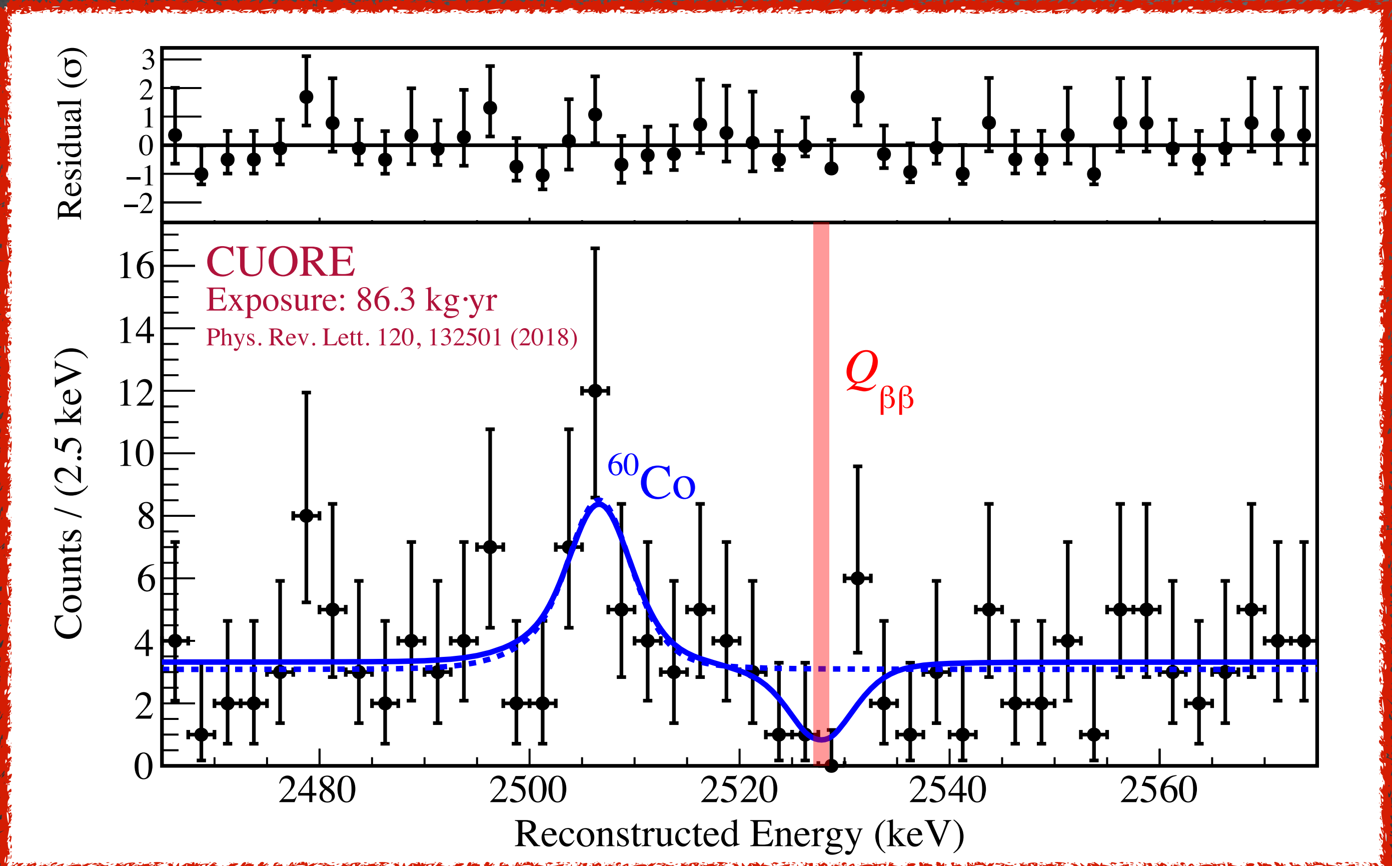


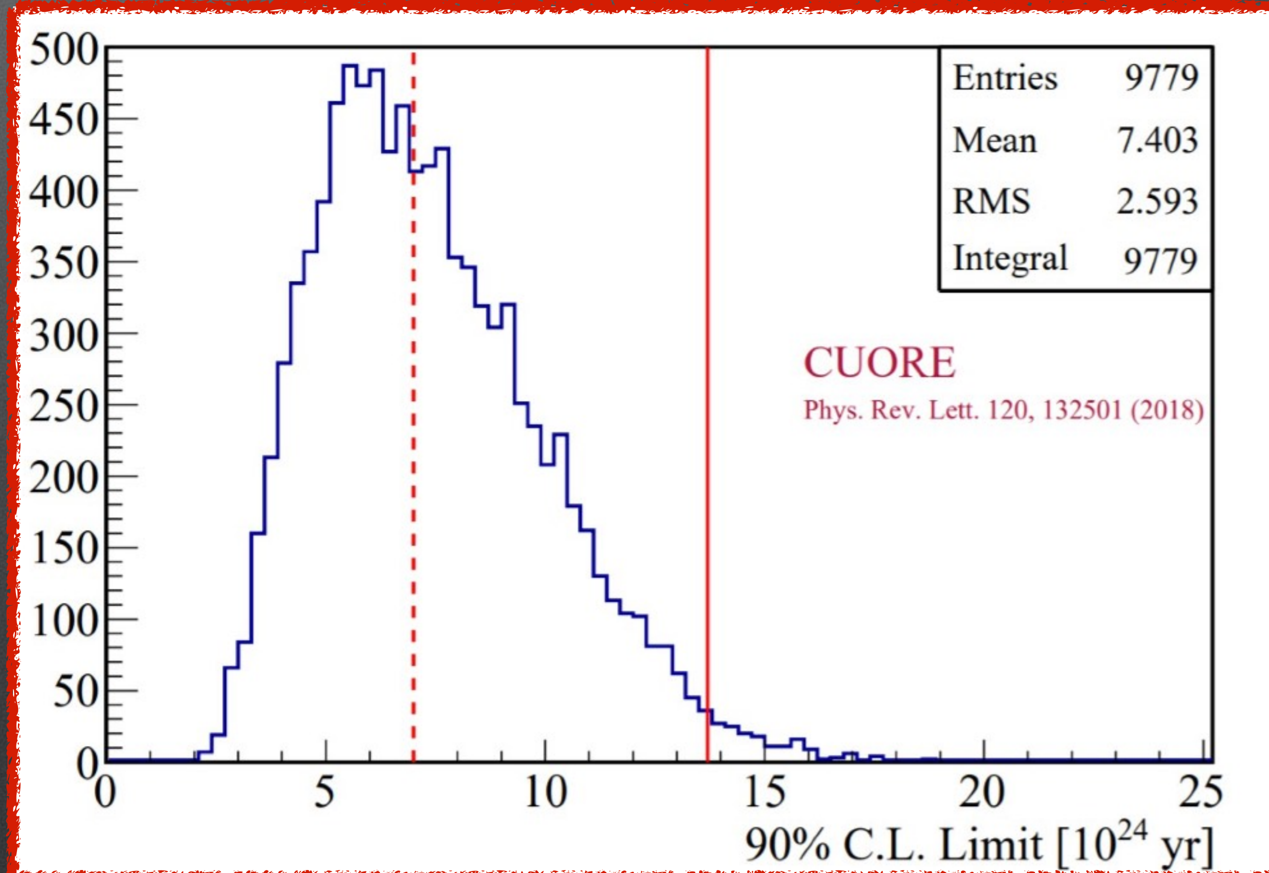




0νββ results - 2018

- Background index: (1.4 ± 0.2)x10^{-2} cnts/(keV kg yr)
- Median expected sensitivity: is $T_{1/2}^{0\nu}$=7.0 x 10^{24} yr
- Combined limit with CUORE-0 and CUORICINO*: $T_{1/2}^{0\nu}$>1.5x10^{25} yr (90% CL)





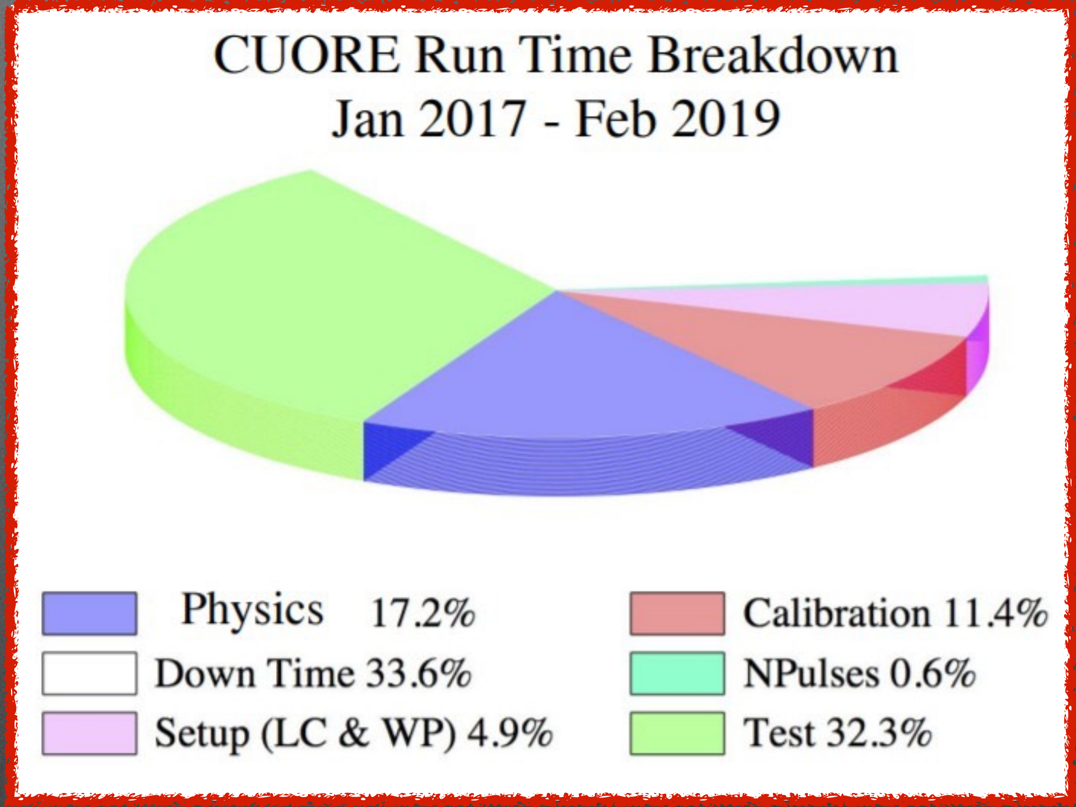
*PRL 120, 132501 (2018)

CUORE data taking: 2017-2019

Up to March 2019, the duty cycle was poor, dominated by down-time (short warm-ups and cool-downs) and technical runs

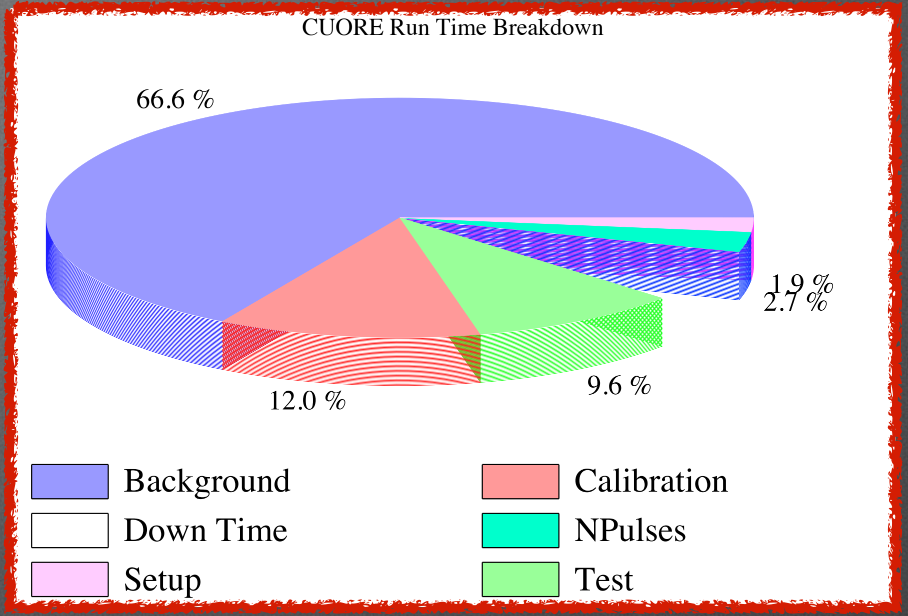
We concentrated our efforts in improving the reliability of the overall system and the stability of the data-taking:

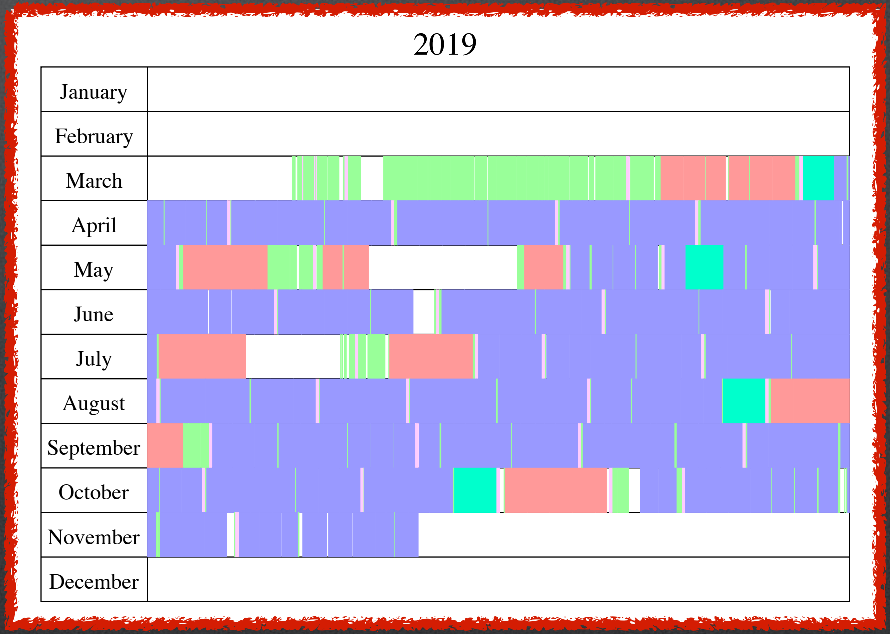
- Upgrade of the calibration system (2018)
- Major maintenance of the cryogenic system (early 2019)
- Improved the data processing and analysis techniques



CUORE data taking: 2019

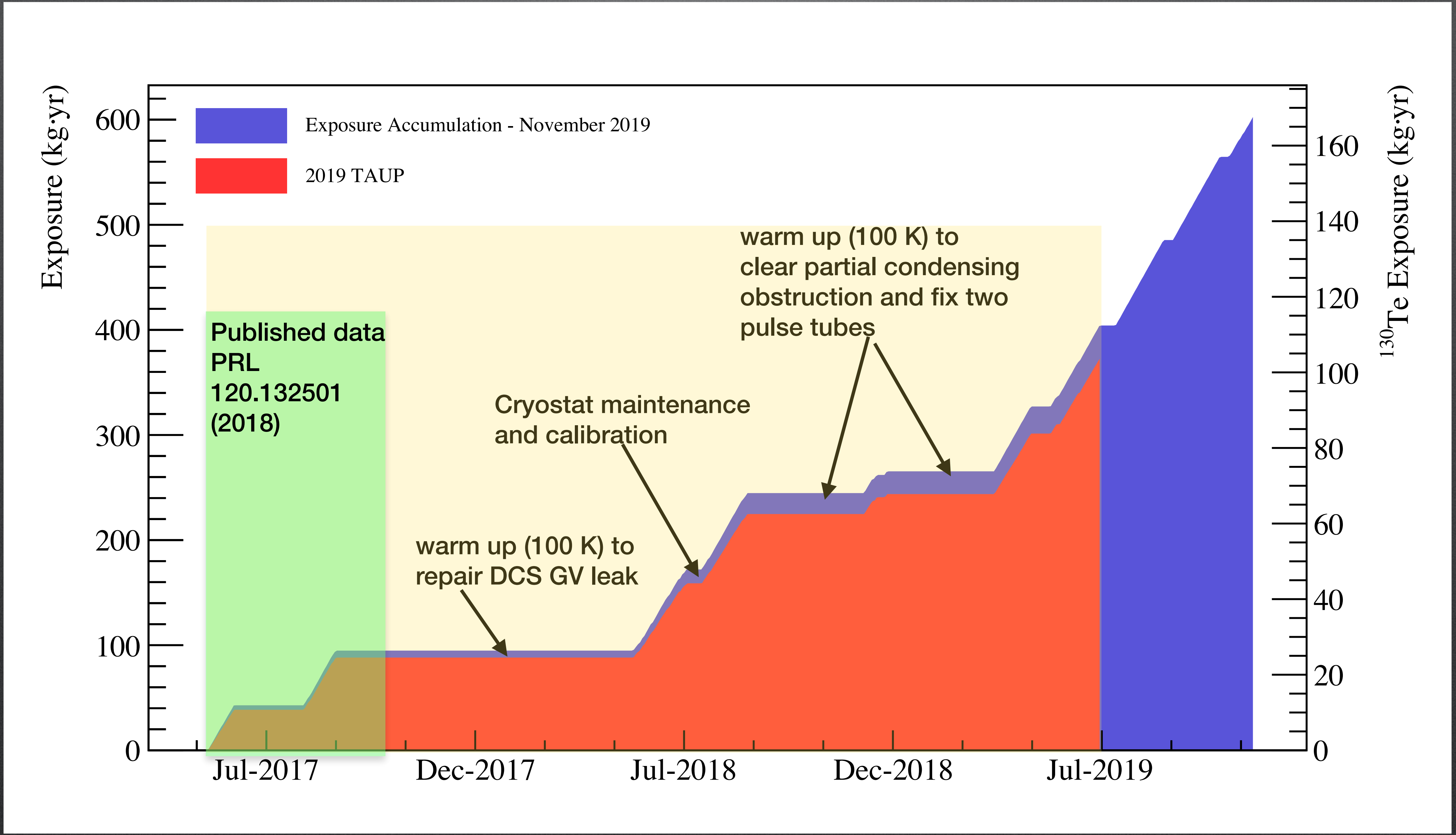
- Stable data taking with high duty cycle
- Short stops only for running consistency checks (noise, thermal response)
- Data-taking is ongoing, no further optimisation in the near future
- Analysed exposure: 369.9 kg yr





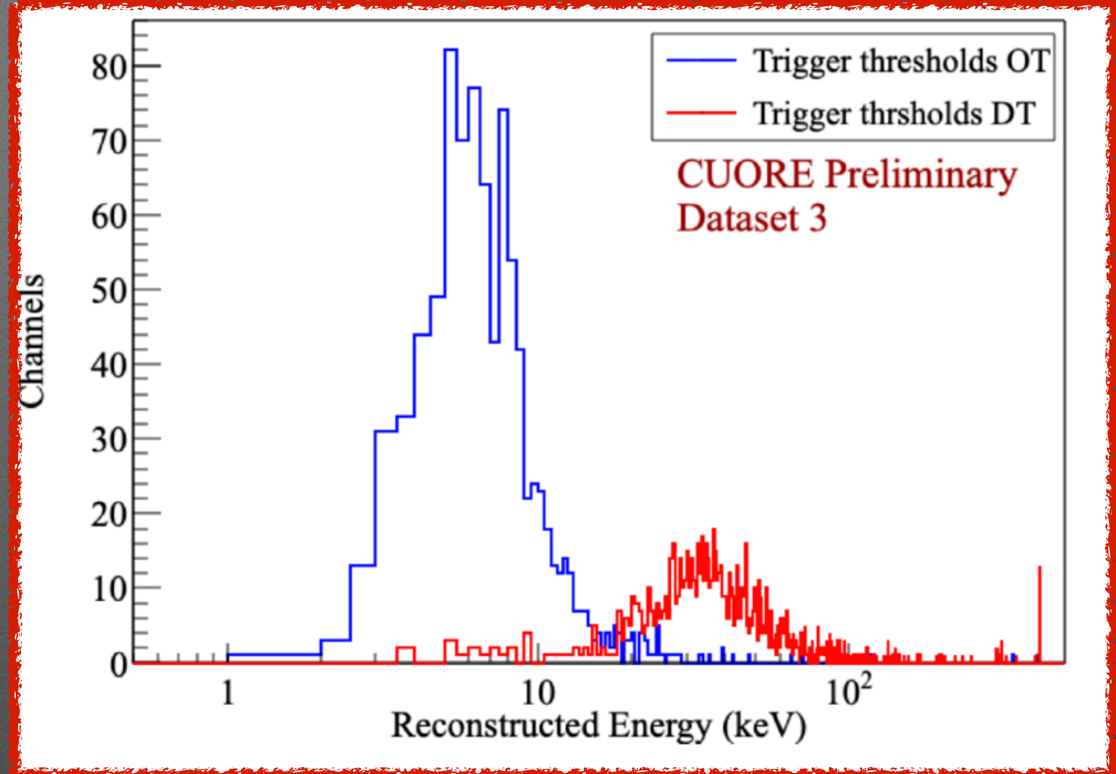
CUORE data taking

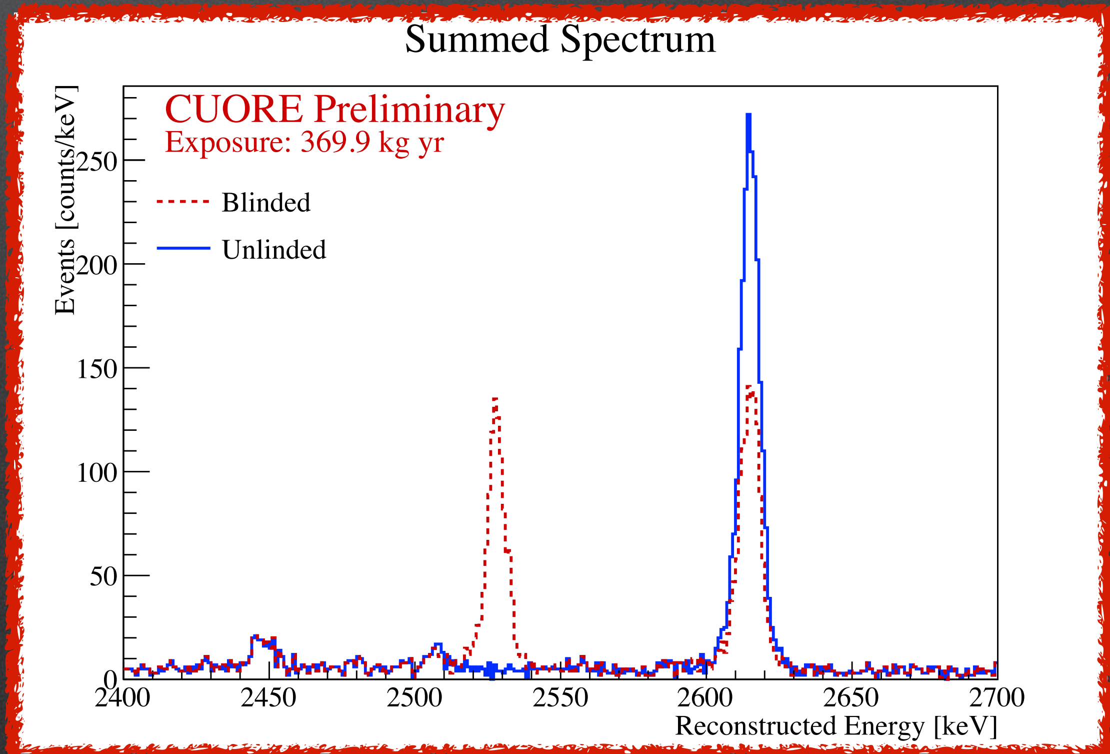
- We processed all data acquired up to July 2019 (369.9 kg y)



CUORE data processing

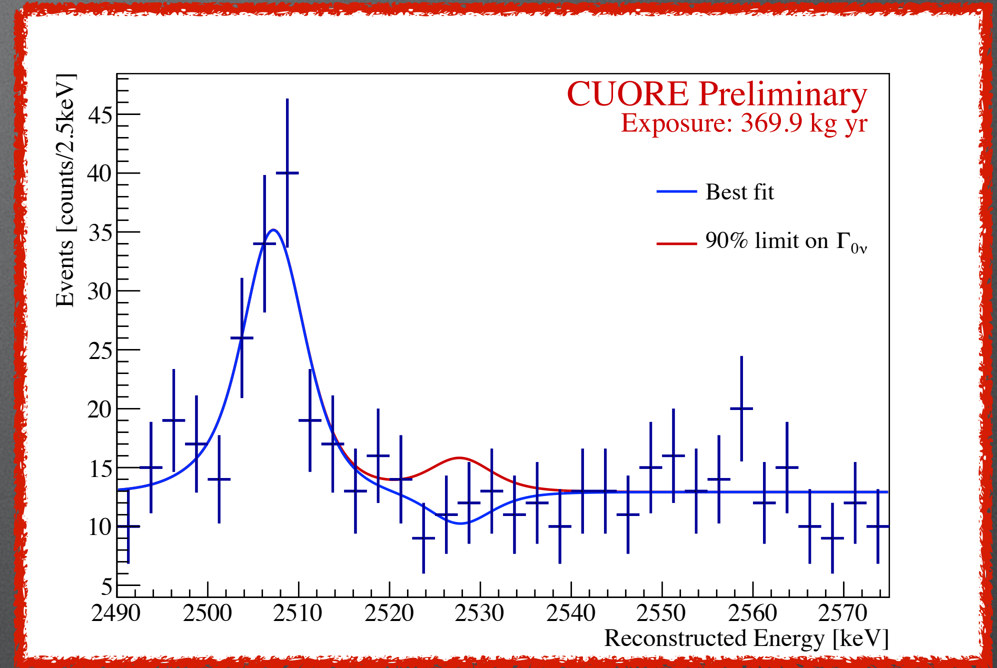
- Data are continuously acquired and triggered offline
- Retrigger all data with improved trigger algorithm (threshold < 10 keV)
- Run our whole processing sequence on retriggered data
- Blind the ROI by randomly swapping event at $Q_{\beta\beta}$ and 2615 keV peak
- Optimize cuts on blinded data
- Unblind and fit the ROI to look for $0\nu\beta\beta$

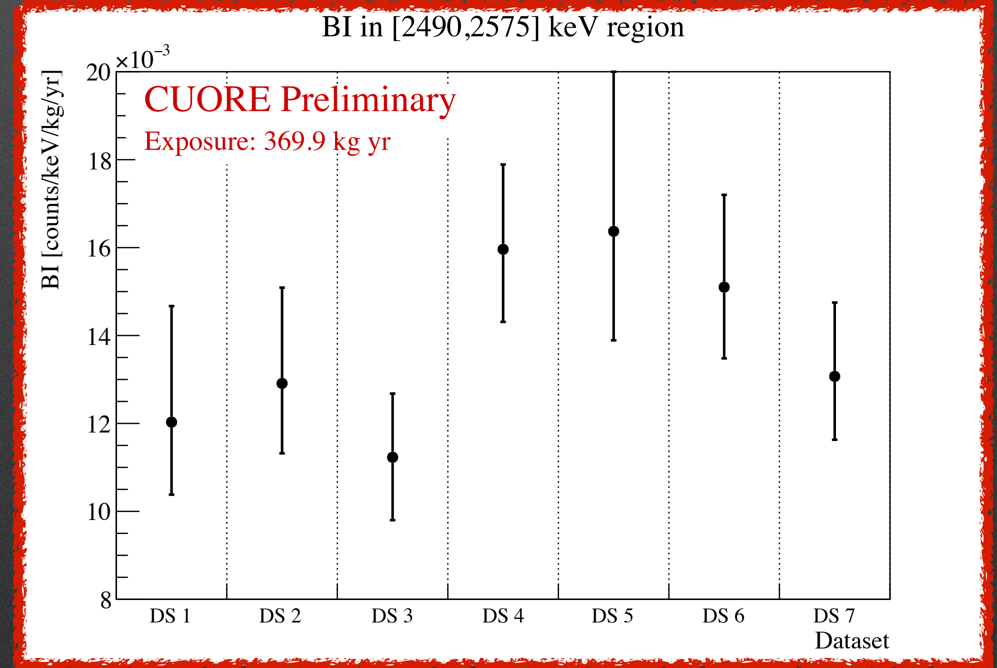




Fit in the region of interest

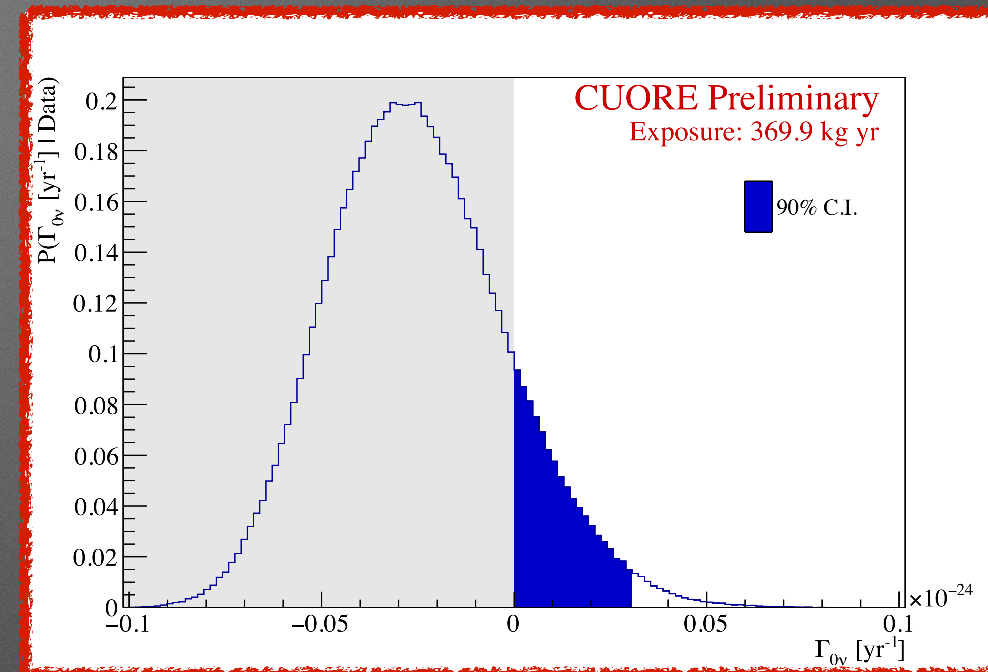
- Bayesian fit on the region of interest (2490 - 2575) keV
- Free parameters: ^{60}Co rate and position, background, $\Gamma_{0\nu}$
- bkg: (1.37 ± 0.07) x 10^{-2} cnts/(keV kg yr)
- No evidence of $0\nu\beta\beta$

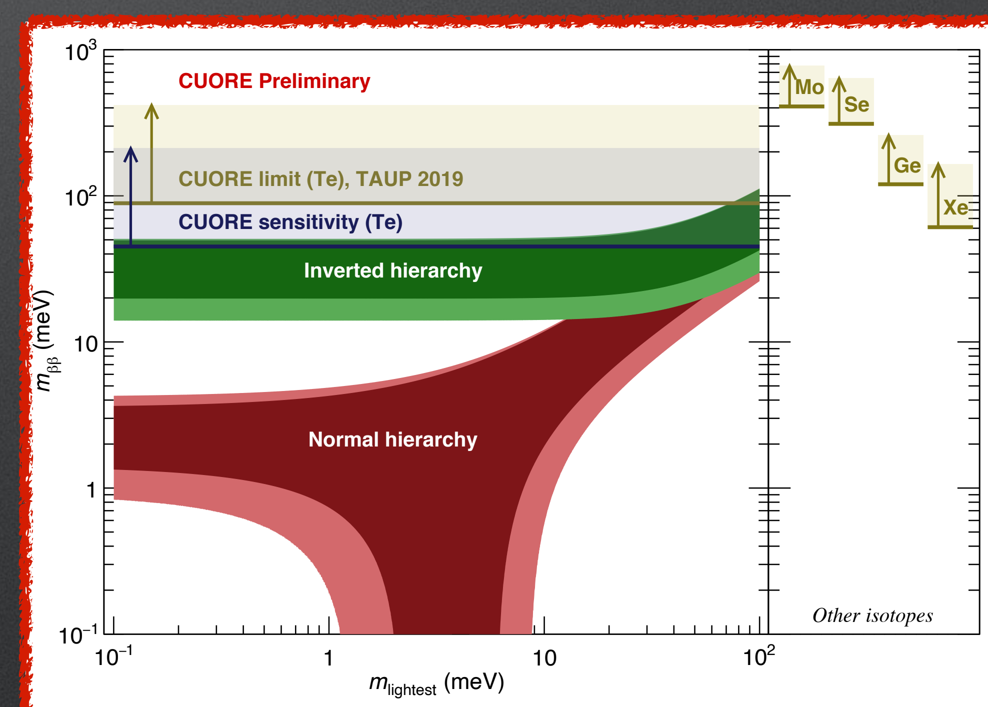




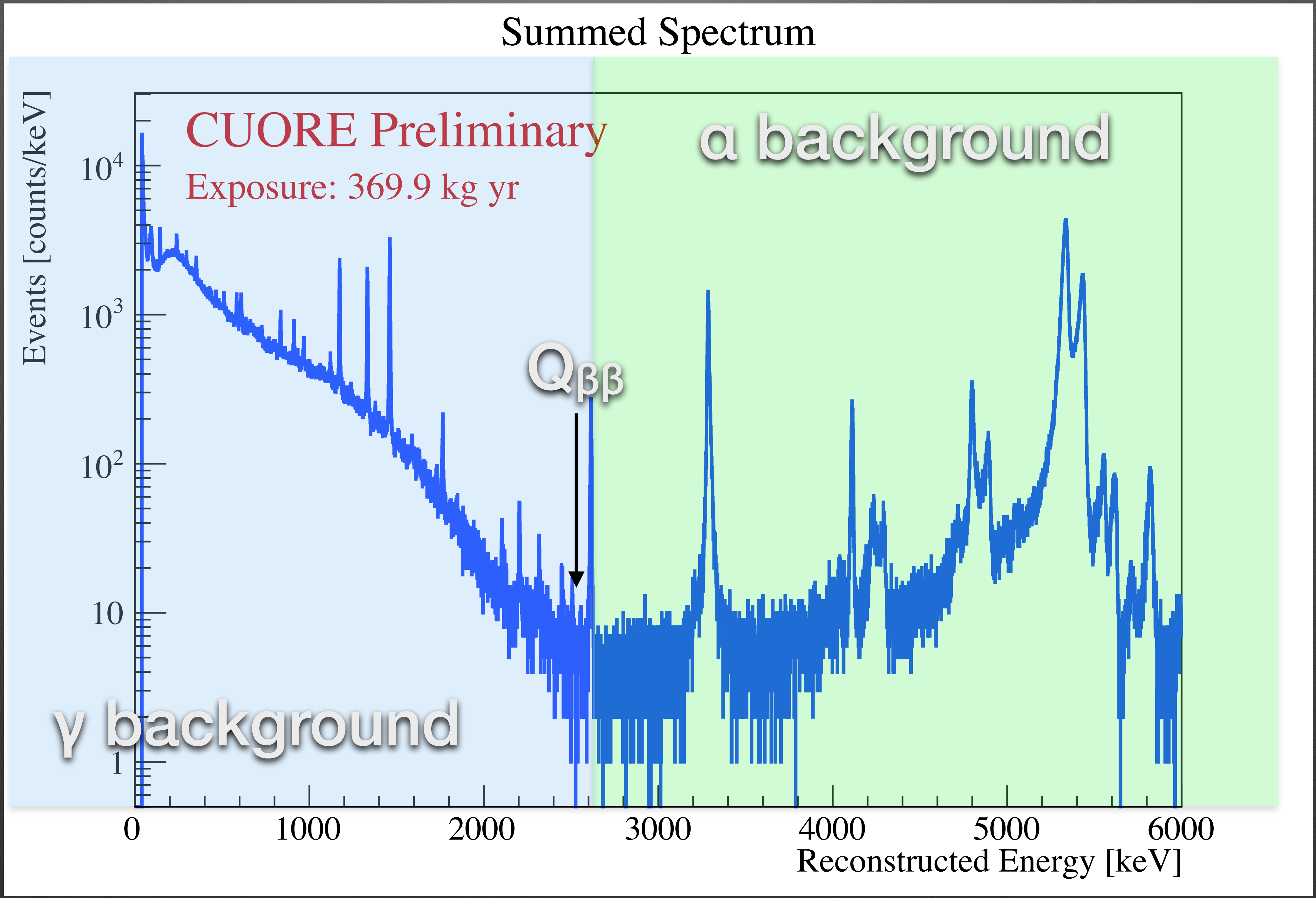
0νββ

- Limit on 0νββ half life computed on physical range:
- $T_{1/2}^{0\nu} > 2.3 \times 10^{25}$ yr (90% CL) PRELIMINARY
- $(T_{1/2}^{0\nu})^{-1} = G^{0\nu} |M^{0\nu}|^2 <m_{\beta\beta}>^2$
  $<m_{\beta\beta}>^2 = |\Sigma\, m_i\, U_{ei}^2|^2$
  $m_{\beta\beta} < (0.09 - 0.42)$ eV (90% CL)



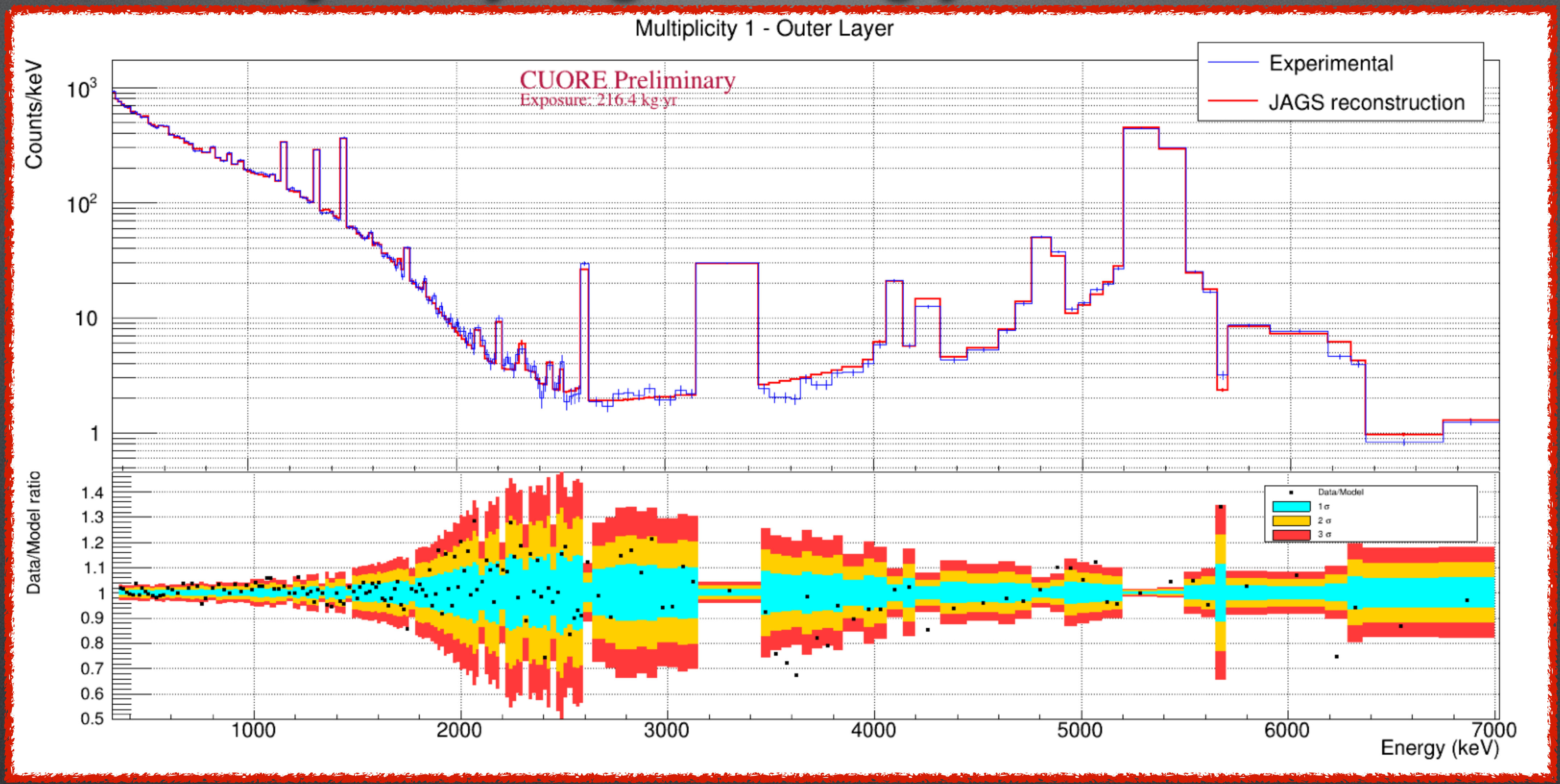


The CUORE background



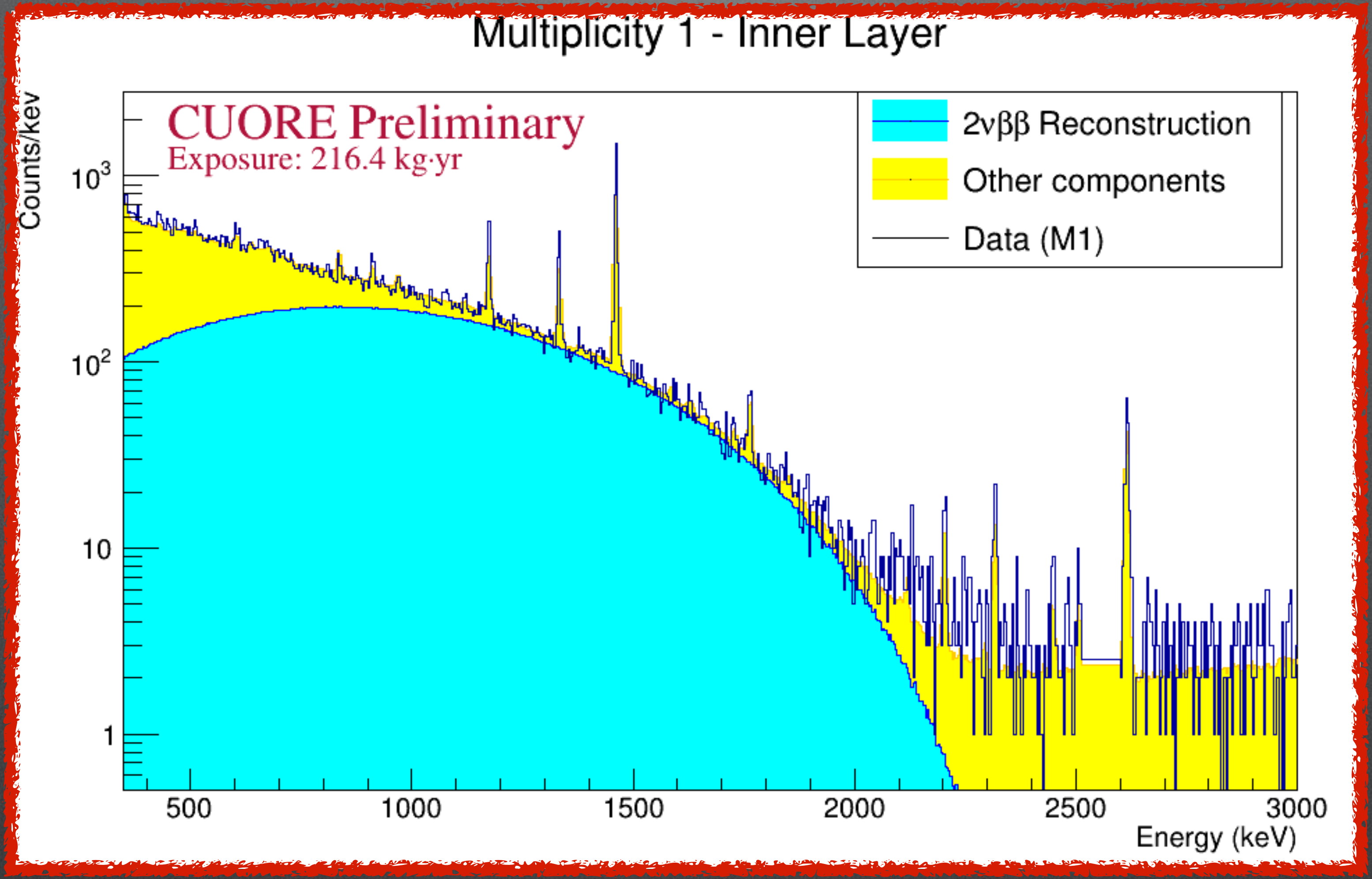
Cuore background model

Currently analysing 216.4 kg yr of data available



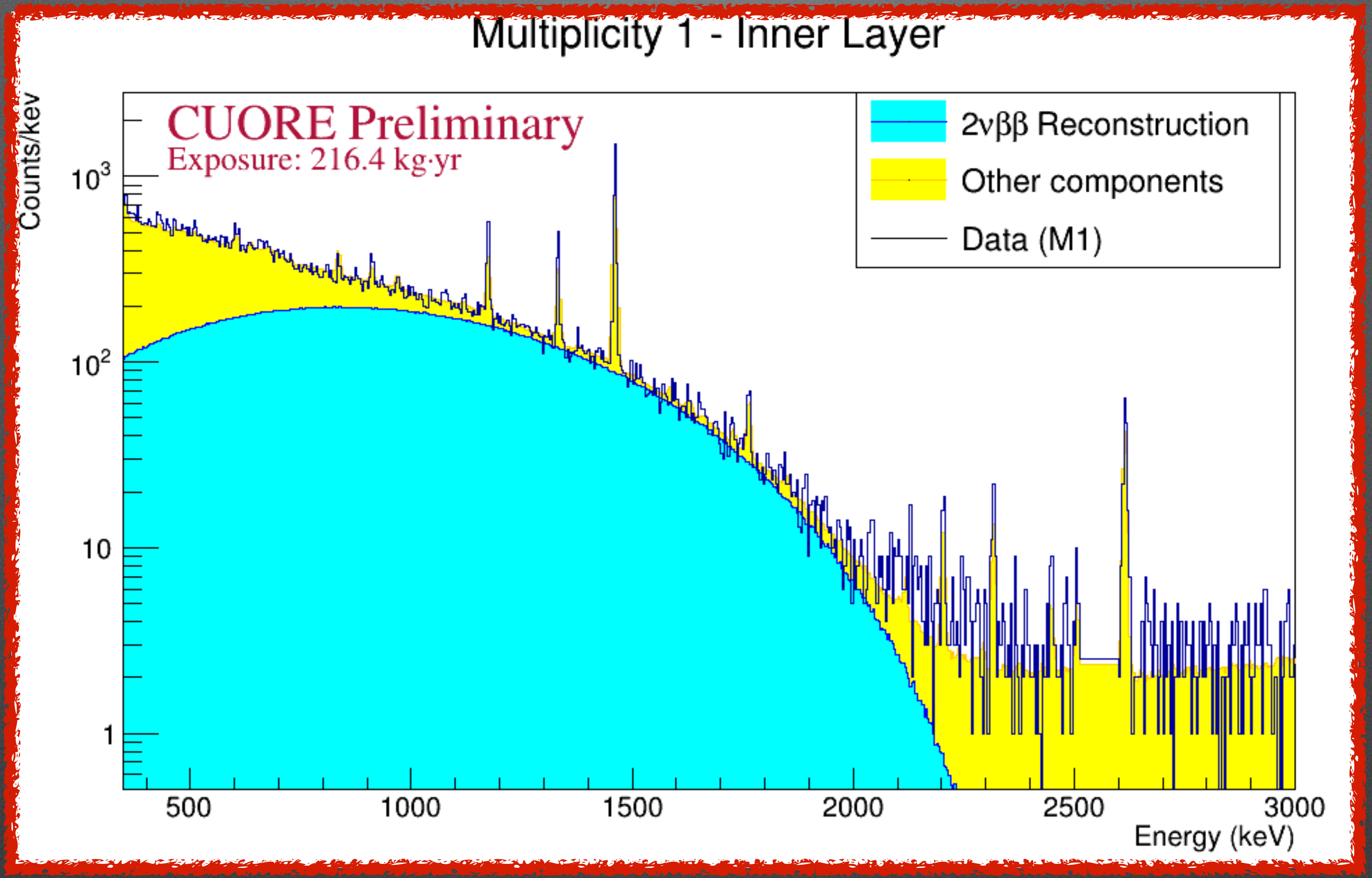
We are able to reconstruct most features of the CUORE spectrum

^{130}Te $2\nu\beta\beta$



$2\nu\beta\beta$ decay accounts for nearly all the events in the range (1, 2) MeV of the spectrum after requiring events deposit energy in a single crystal (Multiplicity 1)

^{130}Te 2νββ



$T_{1/2}^{2\nu}$ =[8.2± 0.1 (stat)] x10^{20} yr (90% CL) PRELIMINARY

CUORE-0: $T_{1/2}^{2\nu}$ =[8.2 ± 0.2 (stat) ± 0.6 (sys)]x10^{20} yr (90% CL)

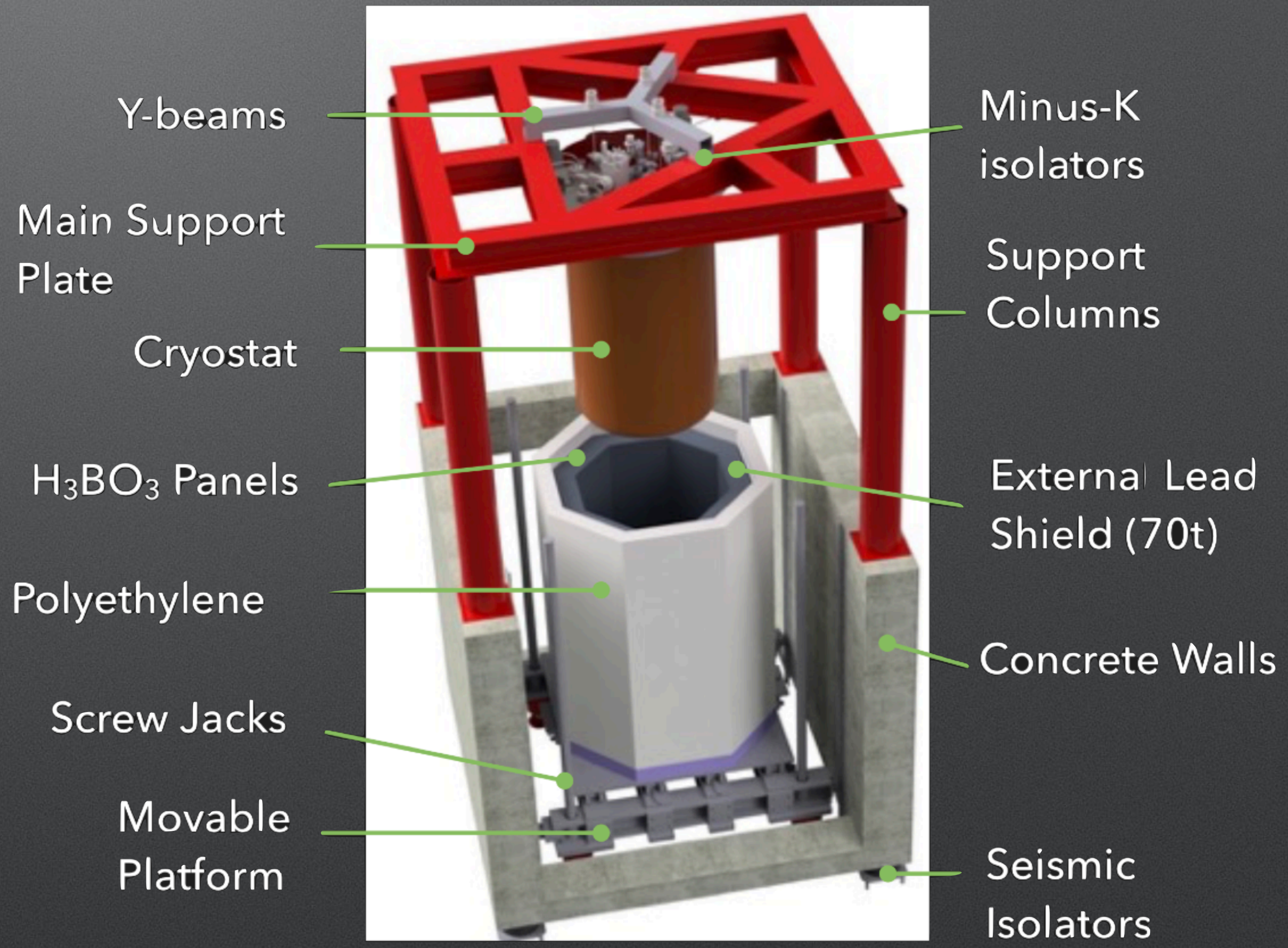
NEMO-3: $T_{1/2}^{2\nu}$ =[7.0 ± 0.9 (stat) ± 1.1 (sys)]x10^{20} yr (90% CL)

Conclusions and outlook

- CUORE is now in a stable data taking phase since March 2019
- Accumulated over 500 kg yr exposure and new data is being acquired
- Updated physics results for both $0\nu\beta\beta$ and $2\nu\beta\beta$

Backup

Building CUORE

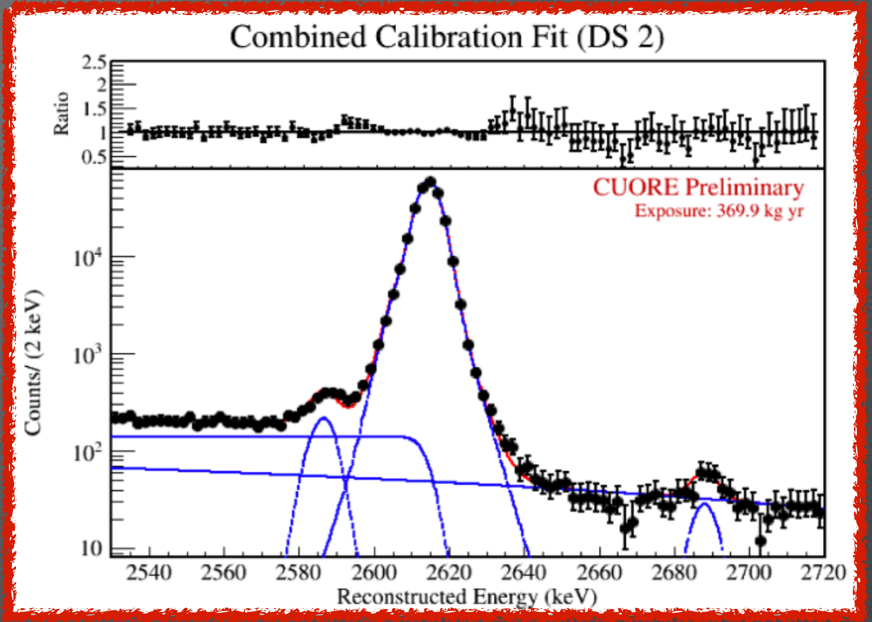


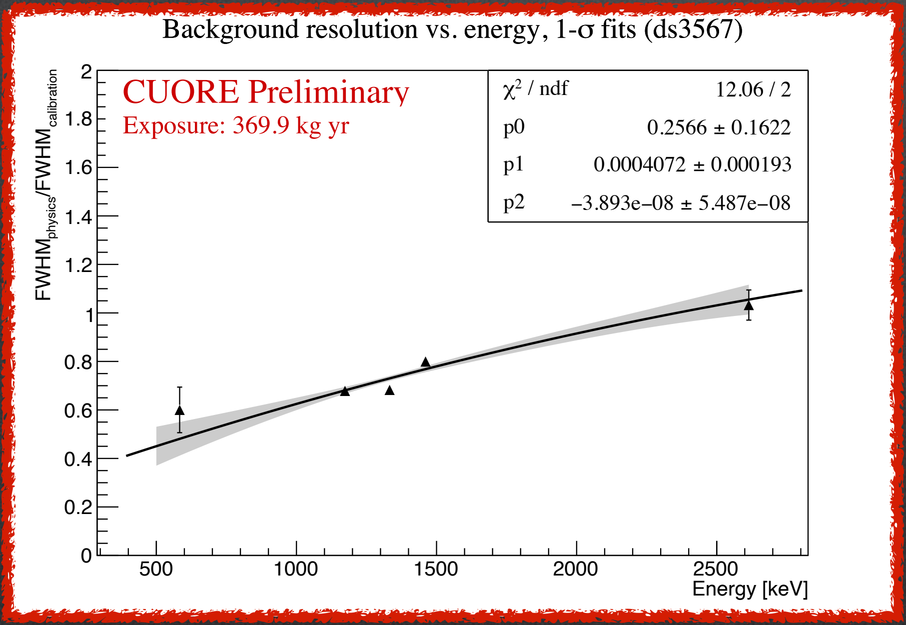
Shielding the detector

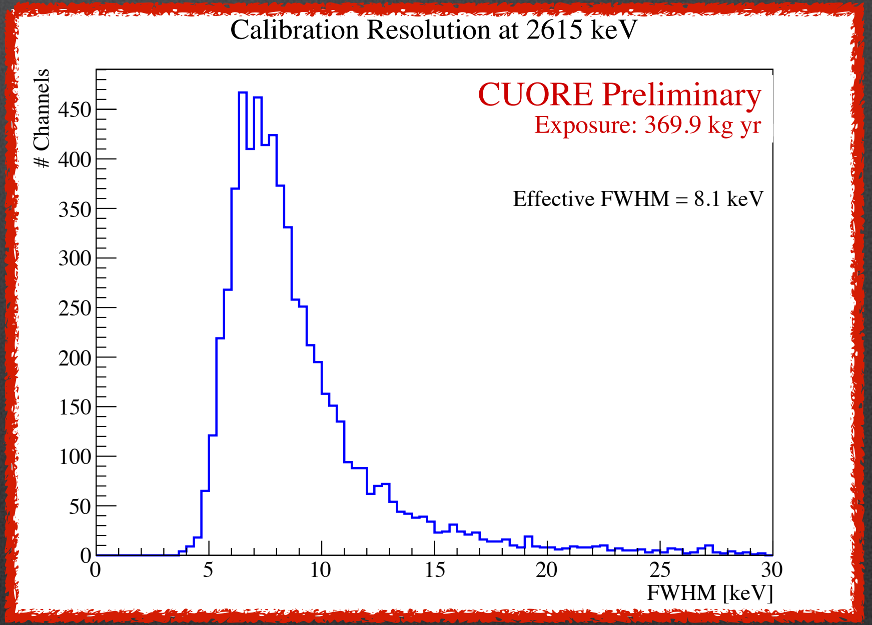
- External background:
  - 70 tons of lead+H_3BO_3
- Building materials:
  - Material selection:
    - NOSV copper
    - Ancient roman lead

Energy resolution

- Lineshape from 2615 keV peak in calibration data
- Main peak parametrized with the sum of 3 Gaussians
- Average FWHM @2615: 8.1 keV
- The background is fitted with the same line shape to get resolution scaling





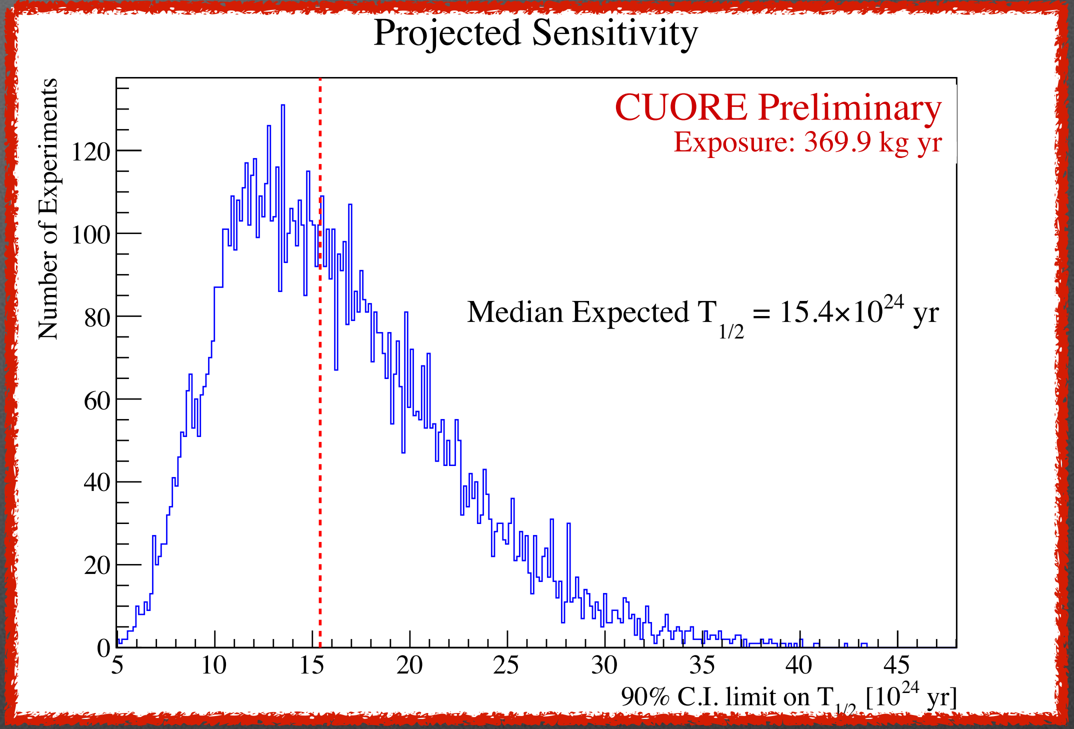


Detection efficiency

Reconstruction: probability that a signal is triggered, its energy reconstructed and no pileup	95.958 ± 0.003 %
Anti-coincidence: rejection of multi-crystal events	98.954 + 0.151 - 0.161 %
Pulse-shape: combination of 6 pulse-shape parameters to select only signal-like events	92.037 ± 0.108 %
Total	87.412 ± 0.175 %
$0\nu\beta\beta$ containment	88.350 ± 0.090 %

0νββ Sensitivity

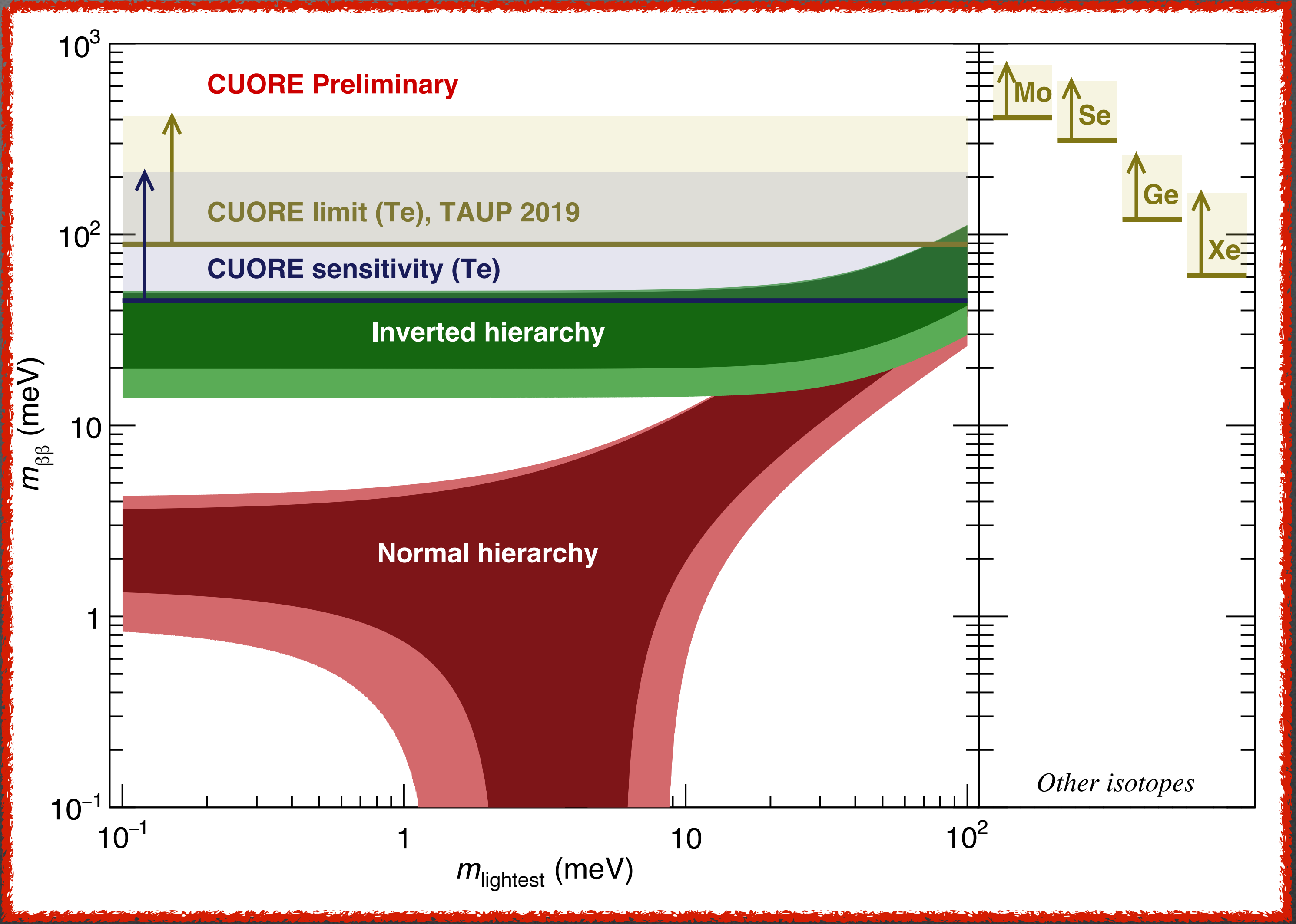
- Fit ROI with background and ^{60}Co only (no 0νββ)
- Generate 10^4 toy-MC according to background-only model
- Fit toy-MC with background+signal model
- Extract distribution of 90% CL limits



- 13% probability of getting a stronger limit with $T_{1/2}^{0\nu} > 2.3 \times 10^{25}$ yr

NMEs

- JHEP02 (2013) 025
- Nucl. Phys. A 818, 139 (2009)
- Phys. Rev. C 87, 045501 (2013)
- Phys. Rev. C 87, 064302 (2014)
- Phys. Rev. C 91, 034304 (2015)
- Phys. Rev. C 91, 024613 (2015)
- Phys. Rev. C 91, 024309 (2015)
- Phys. Rev. C 91, 024316 (2015)
- Phys. Rev. Lett. 105, 252503 (2010)
- Phys. Rev. Lett. 111, 142501 (2013)



CUORE background model

- Exploit a priori information from previous experiments and radioassay
- Analysis of α and γ lines in the spectra
- PDFs built from Geant4-based MC
- 60 independent sources representing various contaminations in CUORE materials
- Split crystals into inner and outer layers
- Split data into Multiplicity 1 (M1), Multiplicity 2 (M2) and Multiplicity 2 Sum

Near sources

Far sources

Volume	Type	Components
TeO_2	Bulk	$2\nu\beta\beta$, ^{210}Pb, ^{232}Th, ^{228}Ra-^{208}Pb, ^{238}U-^{230}Th, ^{230}Th ^{226}Ra-^{210}Pb, ^{40}K, ^{60}Co, ^{125}Sb, ^{190}Pt
TeO_2	Surface (0.01 μm)	^{232}Th, ^{228}Ra-^{208}Pb, ^{238}U-^{230}Th, ^{226}Ra-^{210}Pb, ^{210}Pb
TeO_2	Surface (1 μm)	^{210}Pb
TeO_2	Surface (10 μm)	^{210}Pb, ^{232}Th, ^{238}U
CuNOSV	Bulk	^{232}Th, ^{238}U, ^{40}K, ^{60}Co, ^{54}Mn
CuNOSV	Surface (0.01 μm)	^{210}Pb, ^{232}Th, ^{238}U
CuNOSV	Surface (1 μm)	^{210}Pb, ^{232}Th, ^{238}U
CuNOSV	Surface (10 μm)	^{210}Pb, ^{232}Th, ^{238}U
Roman lead	Bulk	^{232}Th, ^{238}U, ^{108m}Ag
Top lead	Bulk	^{232}Th, ^{238}U, ^{210}Bi
Ext. lead	Bulk	^{210}Bi
CuOFE	Bulk	^{232}Th, ^{238}U, ^{60}Co
External	-	Cosmic muons