First results from CUORE

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INFN Roma
for the CUORE Collaboration

Moriond EW, La Thuile, 15 March 2018

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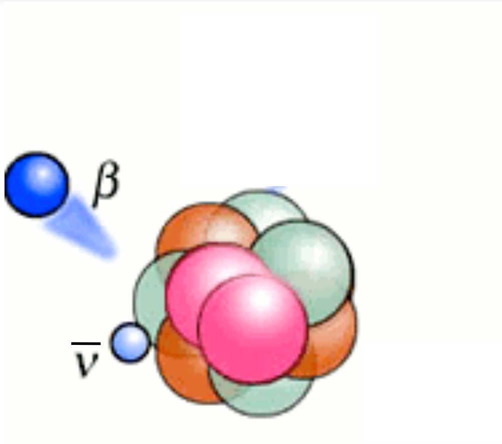
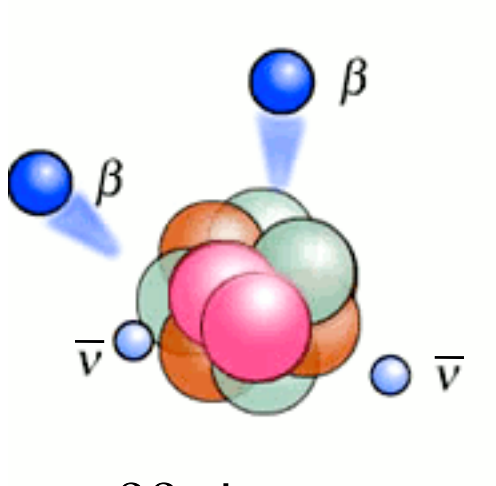
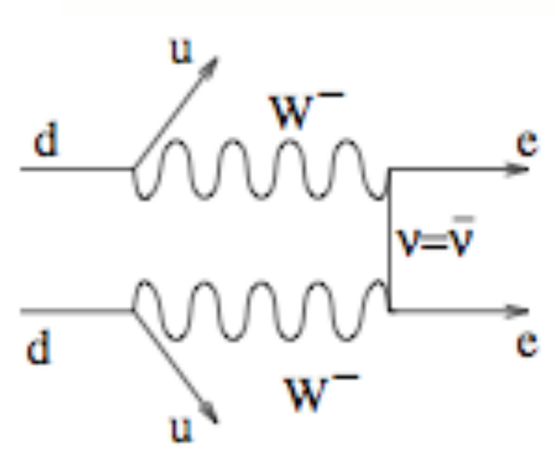
Double β decay



β-decay

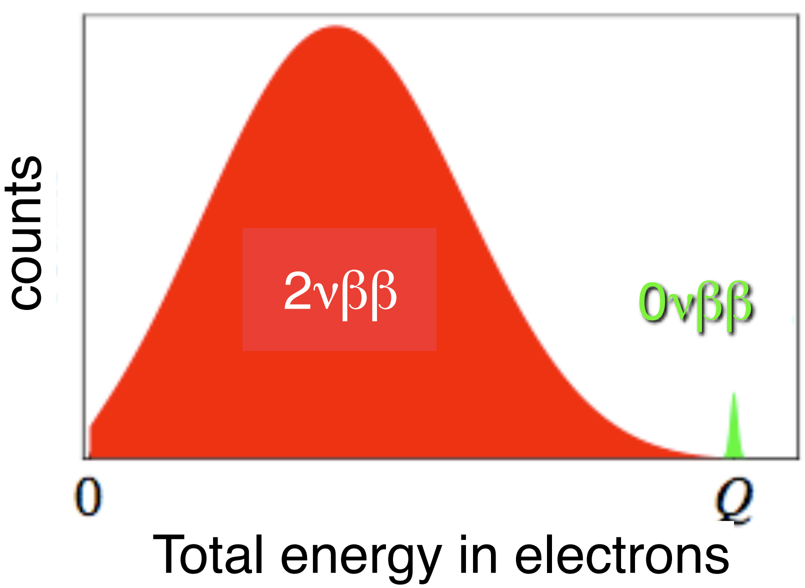


ββ-decay



0νββ-decay

possible only if *νs* have Majorana nature



0νββ can occur only in a few natural isotopes, e.g.: ^{130}Te, ^{76}Ge, ^{136}Xe, ^{100}Mo, ^{82}Se.

Present half-life limits are: $\tau > 10^{24\text{-}26}$ years.

Several nuclei (100 - 1000 kg) are needed.

Almost Zero background is needed

Sensitivity challenges

Isotopic abundance (%)

Detector mass (~100 kg)

Measurement time (5y)

$$S^{0\nu} = \ln 2 N_A \cdot \frac{a}{A} \left(\frac{Mt}{B \Delta E} \right)^{1/2} \cdot \epsilon$$

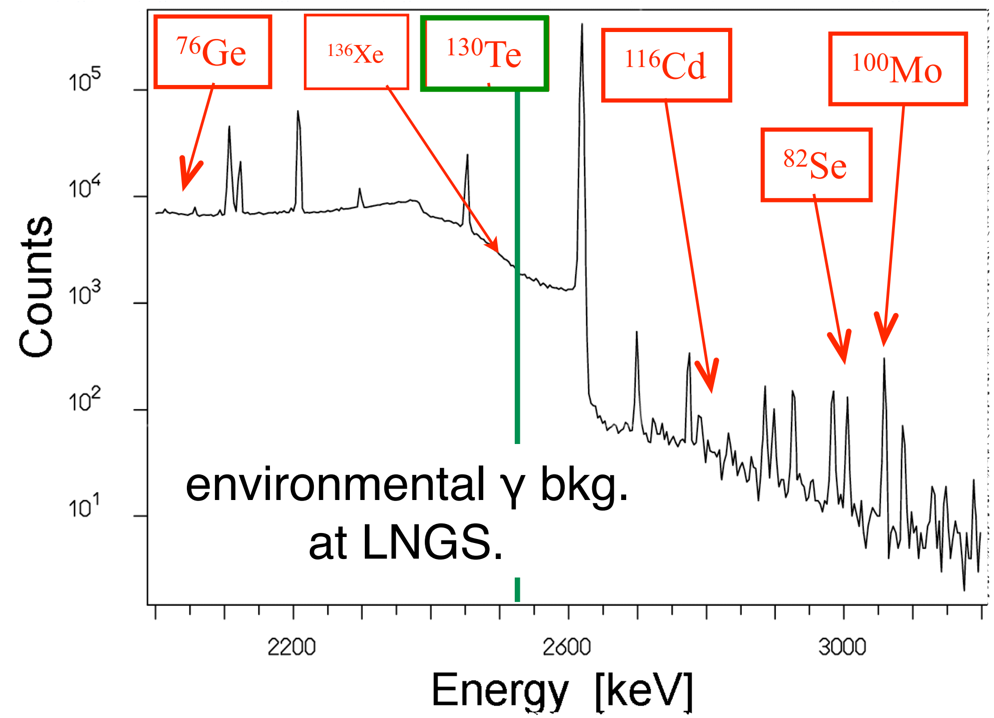
Detection efficiency

Atomic mass

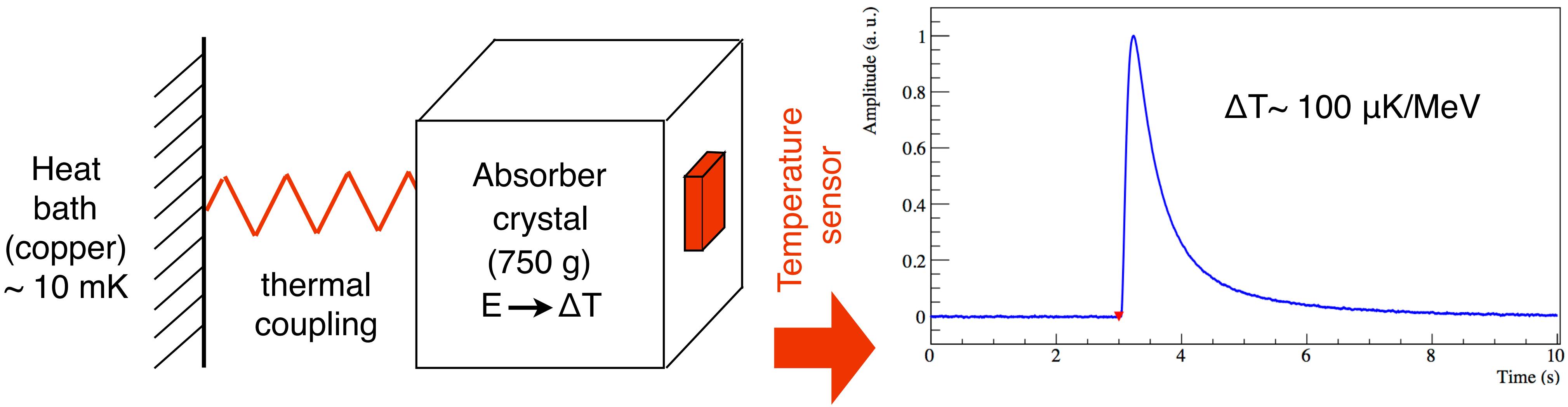
Energy Resolution (keV)

Background (< counts/keV/kg/y)

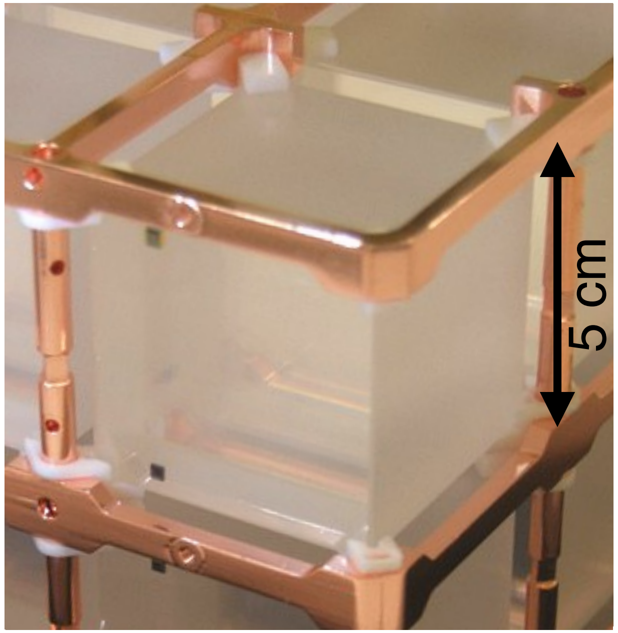
$\beta\beta$ Decay Reaction	Isotopic Abundance [atomic %]	Q-value [keV]
$^{48}Ca \rightarrow ^{48}Ti$	0.2	4274
$^{76}Ge \rightarrow ^{76}Se$	7.6	2039
$^{82}Se \rightarrow ^{82}Kr$	8.7	2996
$^{96}Zr \rightarrow ^{96}Mo$	2.8	3348
$^{100}Mo \rightarrow ^{100}Ru$	9.6	3034
$^{116}Cd \rightarrow ^{116}Sn$	7.5	2814
$^{124}Sn \rightarrow ^{124}Te$	5.8	2288
$^{128}Te \rightarrow ^{128}Xe$	31.8	866
$^{130}Te \rightarrow ^{130}Xe$	34.2	2528
$^{136}Xe \rightarrow ^{136}Ba$	8.9	2458
$^{150}Nd \rightarrow ^{150}Sm$	5.6	3368



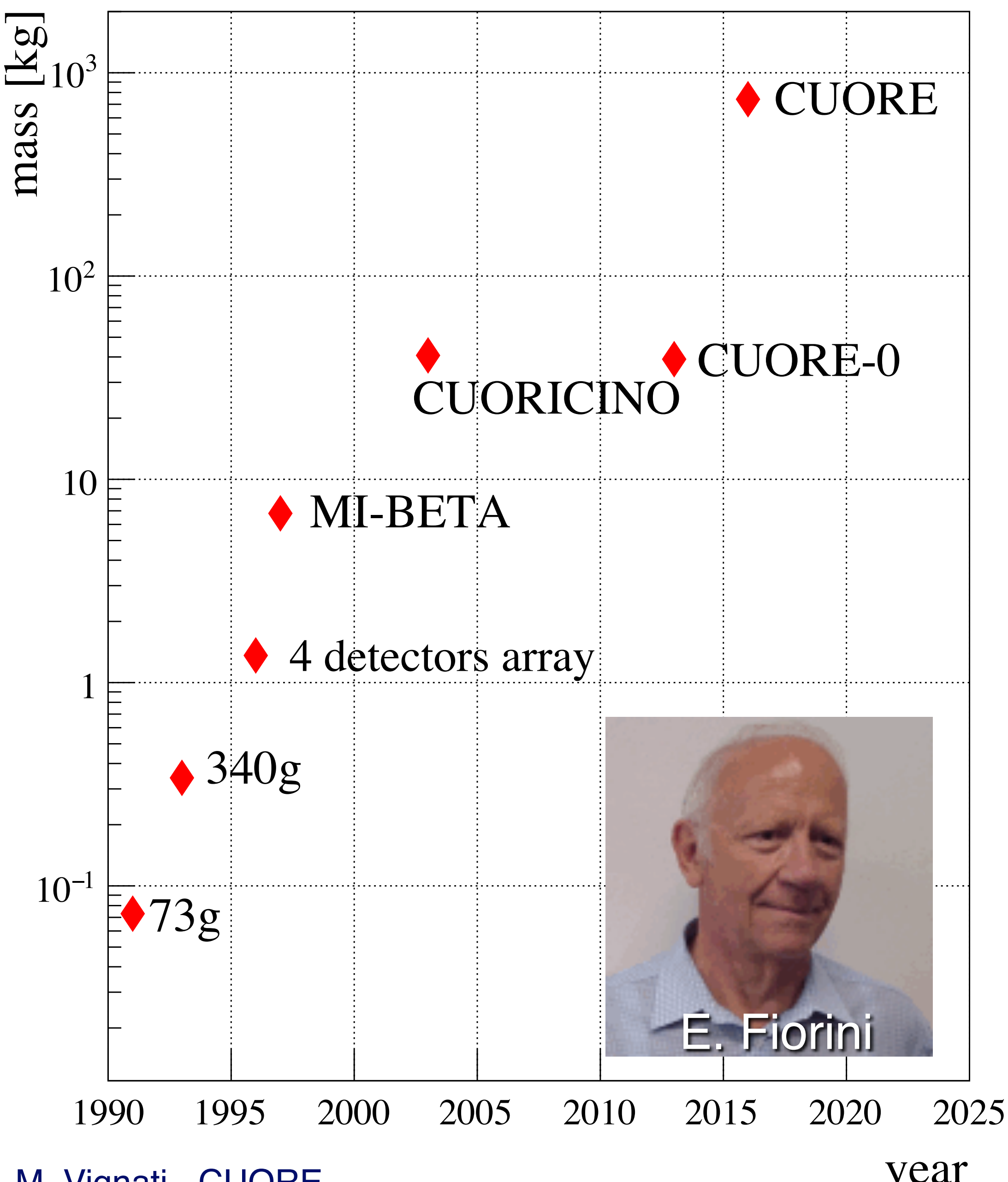
Bolometric technique in CUORE



- $^{nat}TeO_2$ crystals (low heat capacitance) source embedded in the detector
- NTD-Ge thermistor: $R(T) \simeq 1\,\Omega \cdot \exp\left(\frac{3\,\mathrm{K}}{T}\right)^{\frac{1}{2}}$
- Resolution @$0\nu\beta\beta$ energy (2528 keV): ΔE = 5 keV FWHM
- Detection efficiency ~ 80%



Arrays of TeO_2 bolometers



Cryogenic **U**nderground **O**bservatory for **R**are **E**vents

- Hosted at LNGS in Italy.
- 988 $^{nat}TeO_2$ bolometers
  19 towers, 13 floors.
- Active mass: 742 kg.
- Isotope mass: 206 kg ^{130}Te.
- Expected background:
  10^{-2} c/keV/kg/year
- Sensitivity to $0\nu\beta\beta$ in 5y
  $T_{1/2} = 9 \times 10^{25}$ y @90% C.L.
- Sensitivity to $m_{\beta\beta}$ in 5y:
  56 - 160 meV @90% C.L.

LNGS Gran Sasso Laboratory

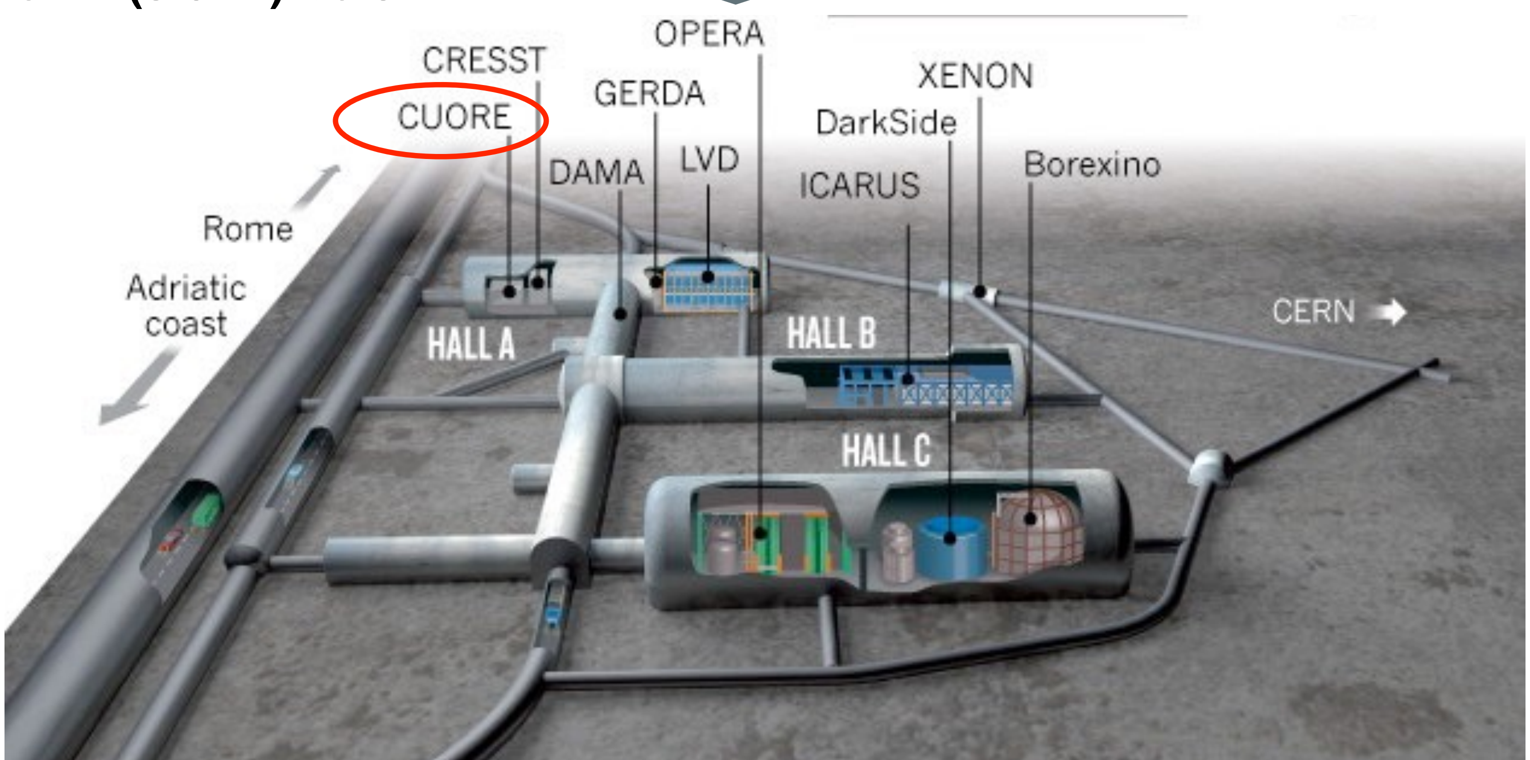
120 km from Rome

~ 3600 m.w.e. deep

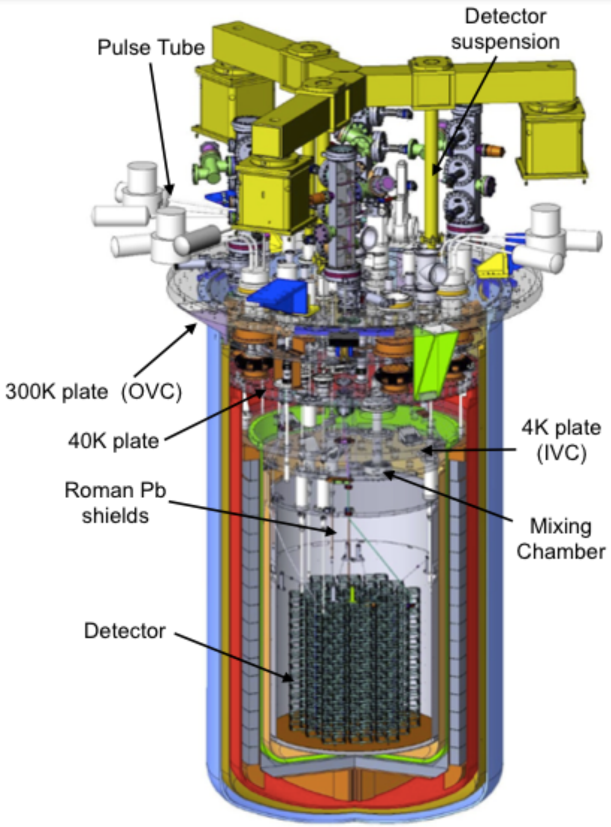
μ flux: ~ 3×10^{-8}/(s cm^2)

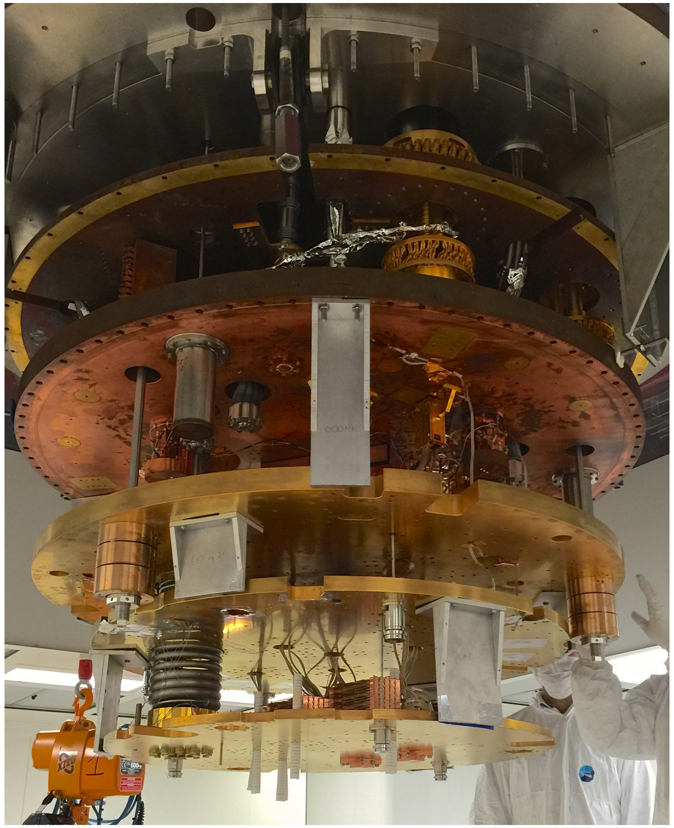
γ flux: ~ 0.73/(s cm^2)

neutrons: 4×10^{-6} n/(s cm^2) below 10 MeV



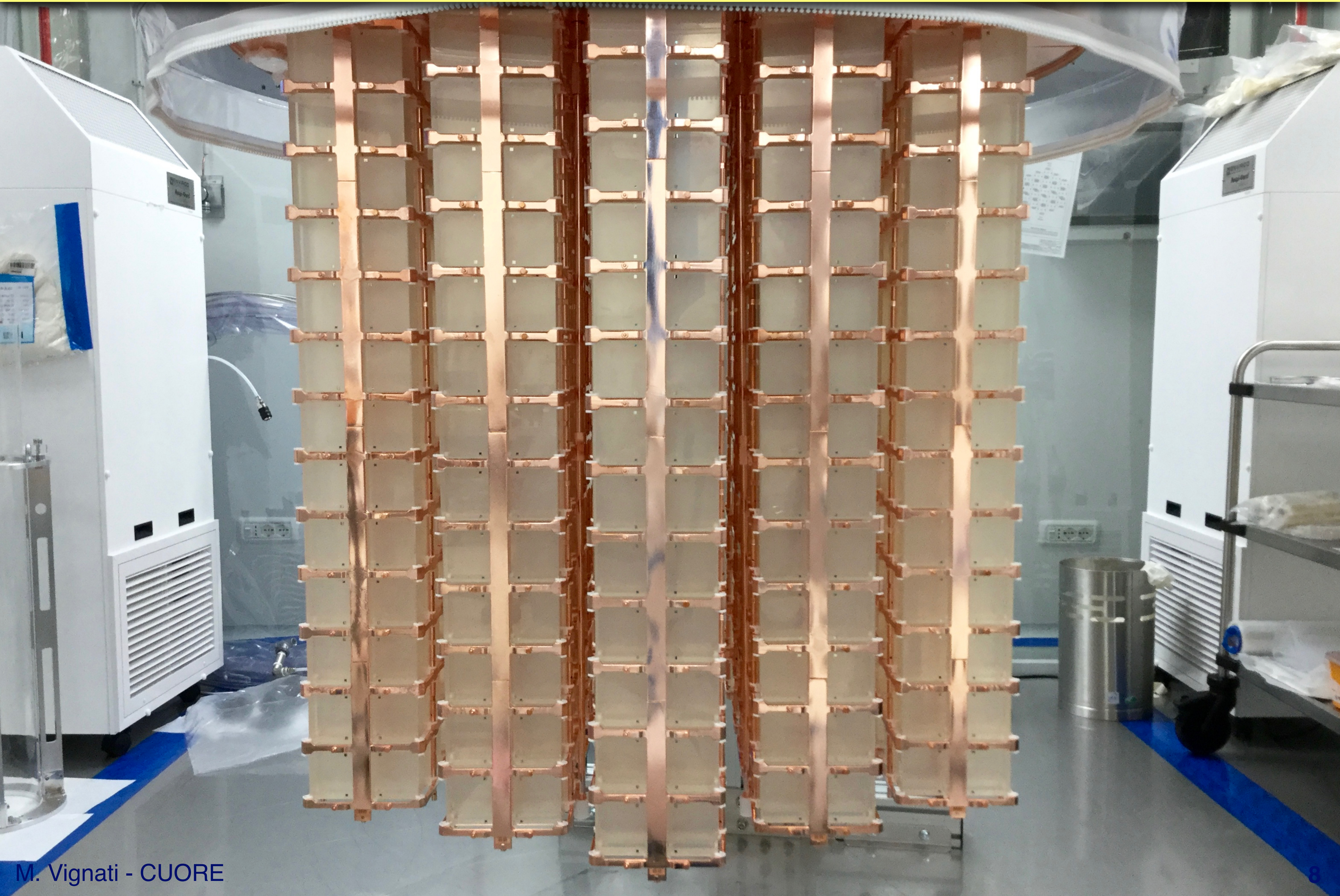
CUORE cryostat



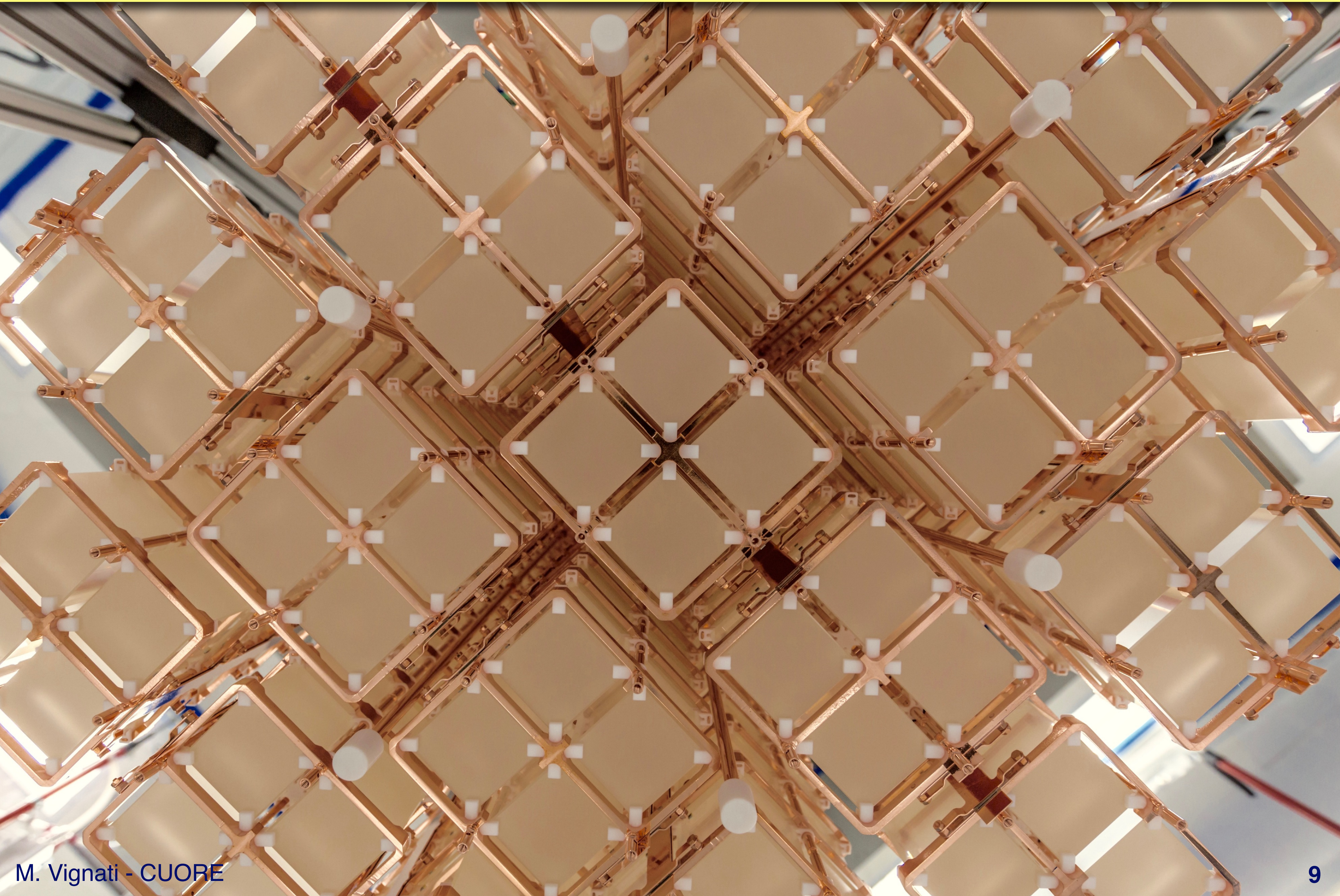


- **Goals:** Cool down ~1 ton detector to ~10 mK. Mechanically decoupled for extremely low vibrations. Low background environment.
- Minimum base temperature of 6.3 mK reached, detector optimal performance @ 10-15 mK. Cool down time: 20 days to 3.4 K, 1.5 more days to base temperature.
- Cryostat total mass ~30 tons. Mass to be cooled < 4K: ~15 tons. Mass to be cooled < 50 mK: ~3 tons (Pb, Cu and TeO2).
- Detector calibration system: ^{232}Th calibration sources at base temperature

26/8/16: CUORE detector completed



Bottom view



Detector installation

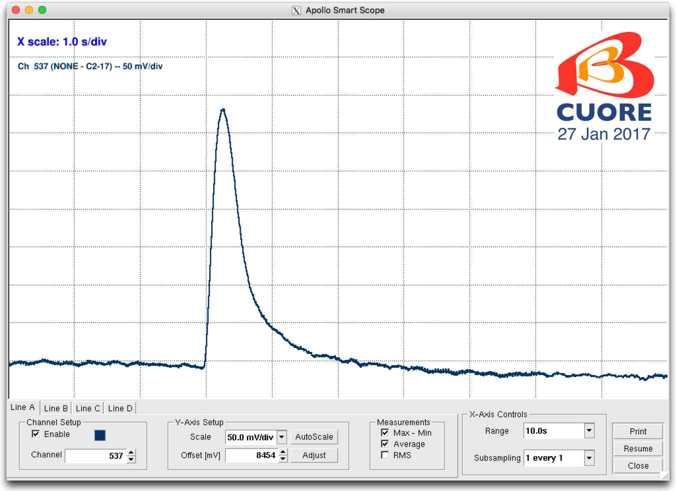
Performed in a radon-free environment:

- protected area inside the CUORE clean room flushed with radon-free air (Rn concentration < 0.1 Bq/m^3)
- protective bags flushed with nitrogen for overnight and emergency storage
- teams composed of 3 operators spending the minimum amount of time in the cleanroom, following strict protocols developed during months of training and test with mockup components.

September-October 2016:

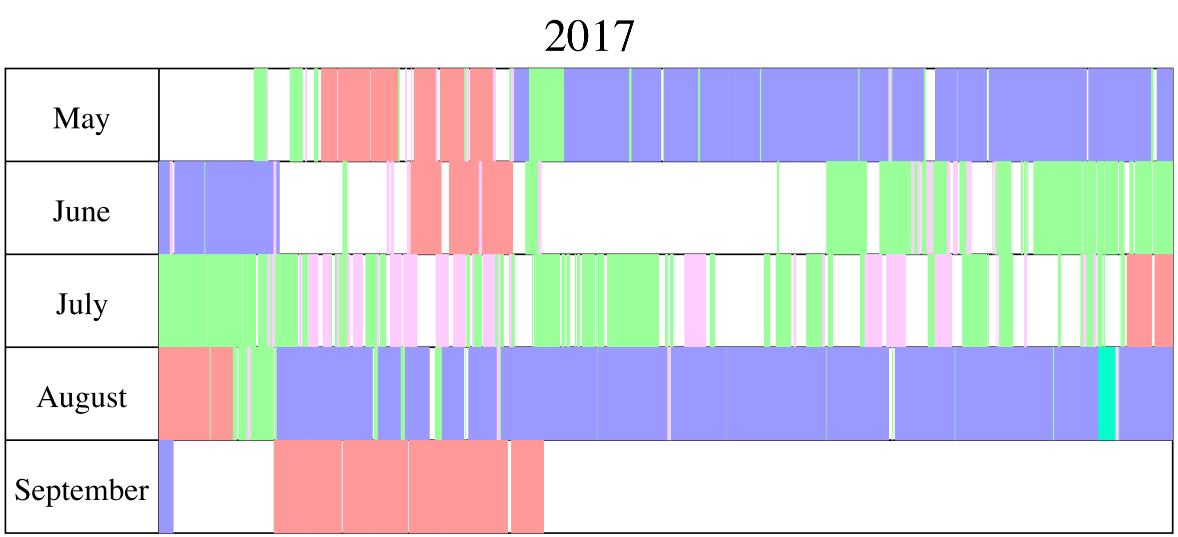
- installation of the cryostat interfaces (protective tiles) and radiation shields
- read-out tests.

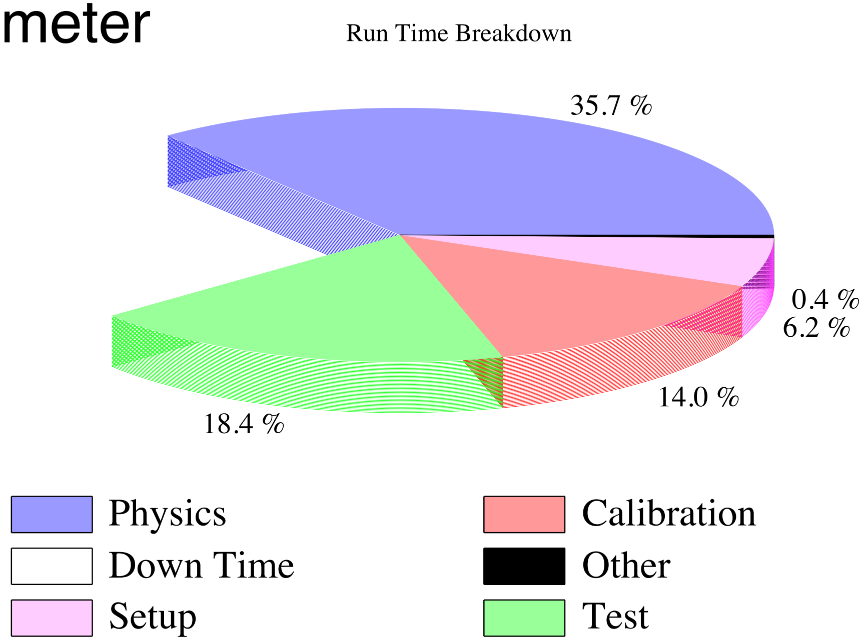
Observed first detector pulses just after the cool down on January 27, 2017.



Science runs (May-September '17)

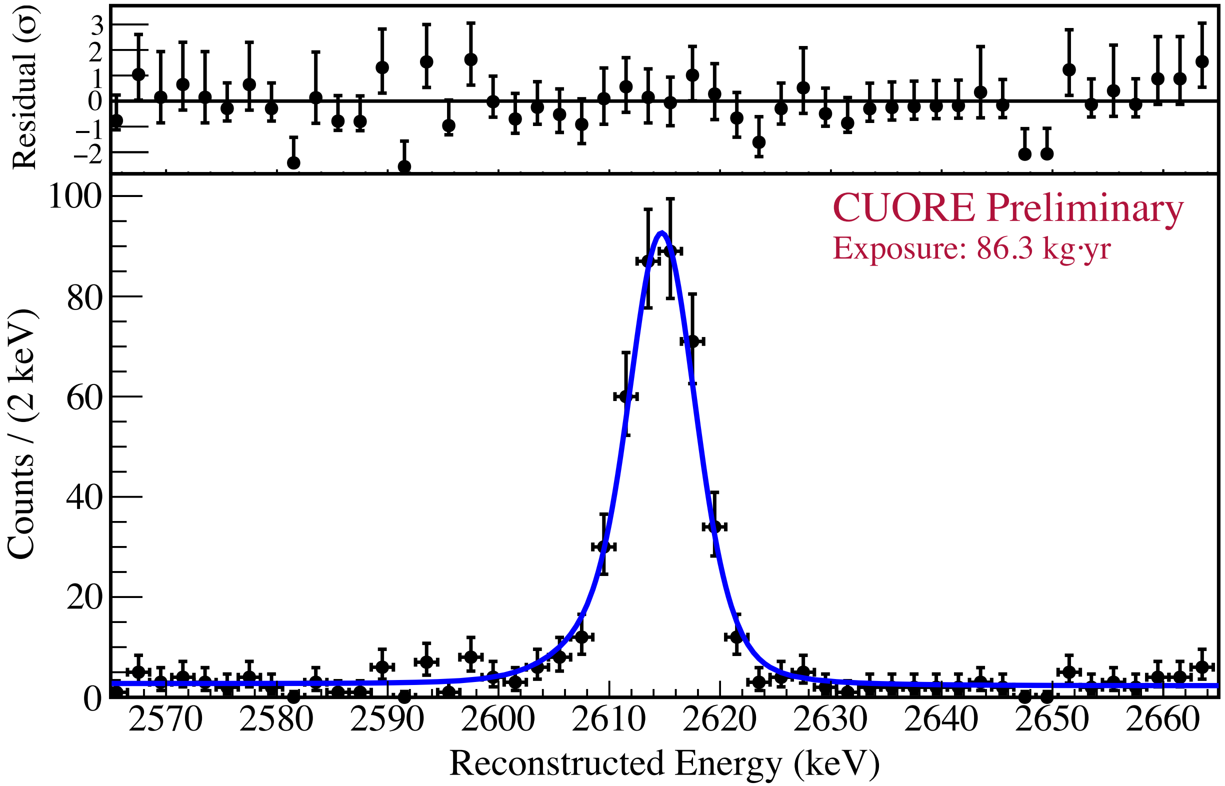
- 2 periods of physics data
  - Dataset 1: May – Jun 2017 → 37.6 kg yr of TeO_2
  - Dataset 2: Aug – Sep 2017 → 48.7 kg yr of TeO_2
- Total exposure: TeO_2 → 86.3 kg yr , ^{130}Te → 24.0 kg yr
- 984/988 bolometers are operational
- Trigger rate in physics runs: 6 mHz / bolometer





Energy resolution

2615 keV ^{208}Tl γ peak



Resolution FWHM in Physics runs:

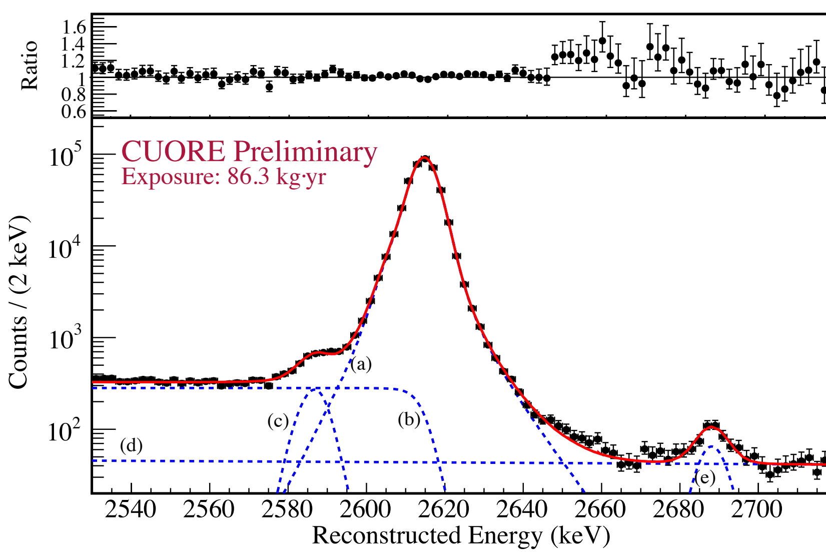
- Dataset 1: (8.3 ± 0.4) keV
- Dataset 2: (7.4 ± 0.7) keV
- Weighted avg: (7.7 ± 0.5) keV
- CUORE goal: 5 keV.

Line shape per bolometer (calibration runs)

- Triple gaussian

+ multi compton + linear background

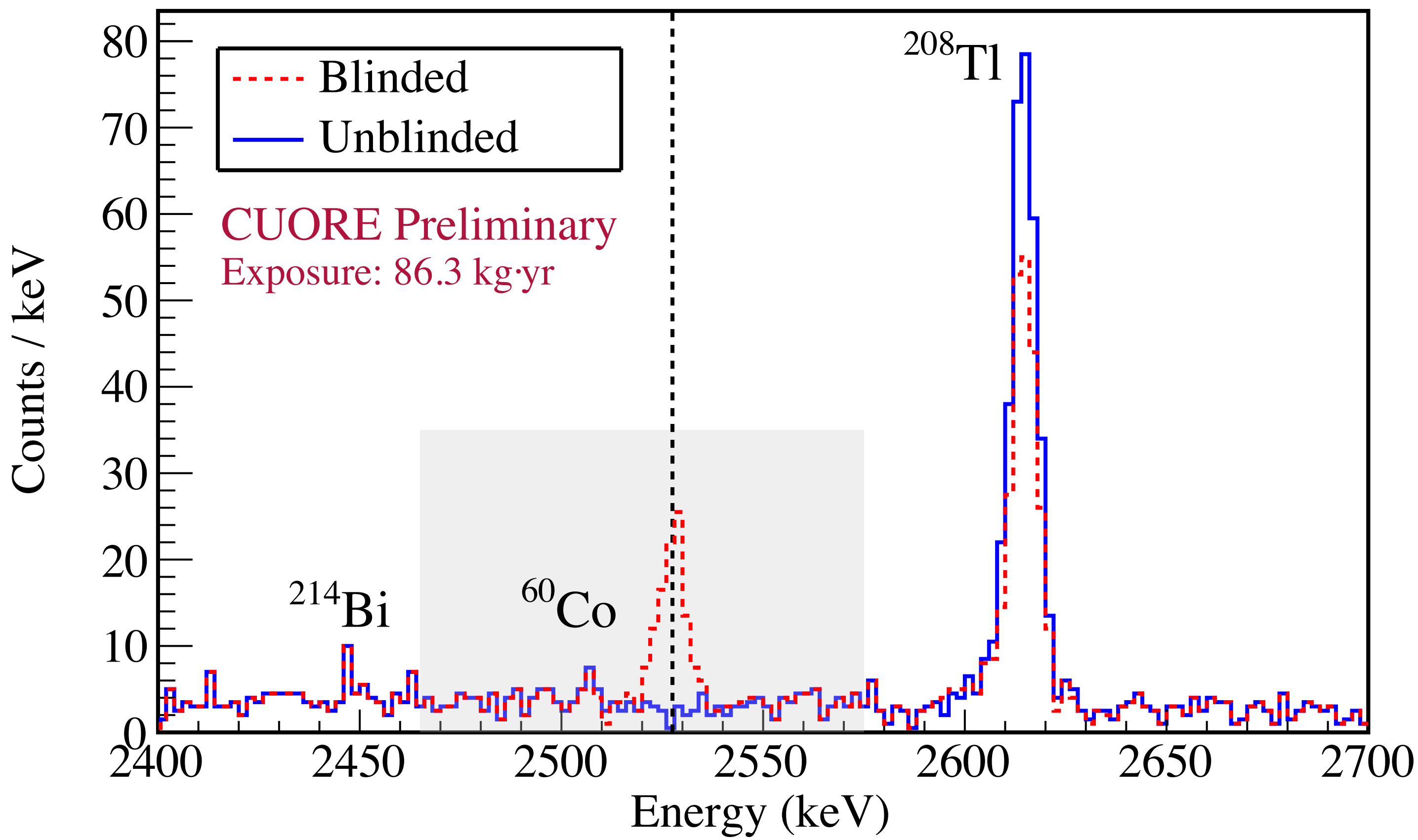
+ Tellurium X-ray escape peak + sum peak



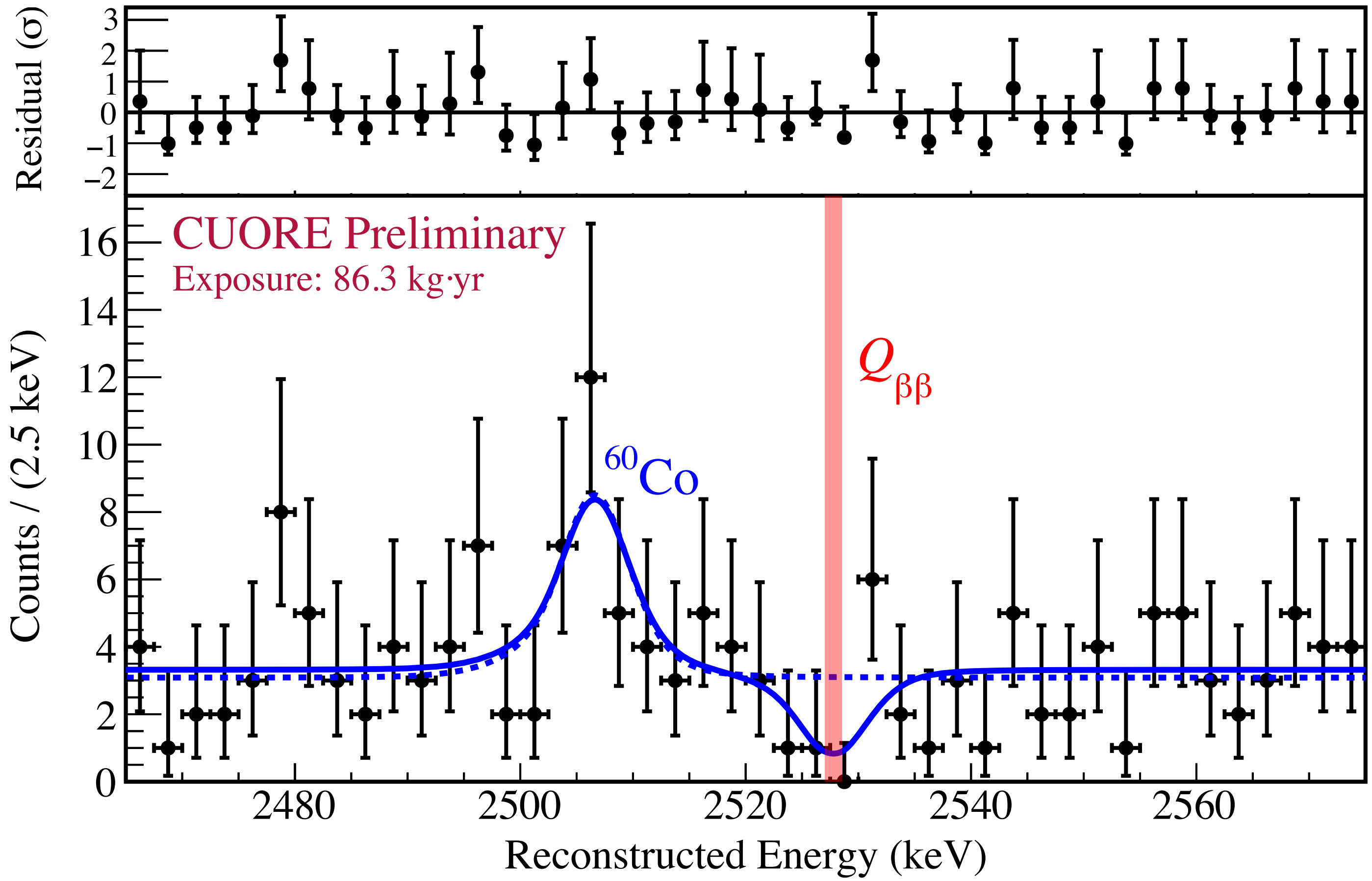
Blinding of the result

- Data at the Q-value are salted by randomly exchanging events with the nearby ^{208}Tl background line. This creates an artificial peak that hinders the true rate at the Q-value;
- Once the analysis procedures are fixed data are unblinded by exchanging back the events.

0νββ Q-value



Result: no evidence found



Fit components:

- Flat background
- ^{60}Co sum peak
- Peak at $Q_{\beta\beta}$

Half-life limit 90% CL:

- **$T^{0\nu} > 1.3 \times 10^{25}$ yr**

	Background (counts / keV / kg / y)	Efficiency (%)
Dataset 1	$1.49_{-0.17}^{+0.18} \cdot 10^{-2}$	75.7 ± 3.0
Dataset 2	$1.35_{-0.18}^{+0.20} \cdot 10^{-2}$	83.0 ± 2.6

Efficiency:

- Analysis cuts
- ββ single crystal containment (88%)

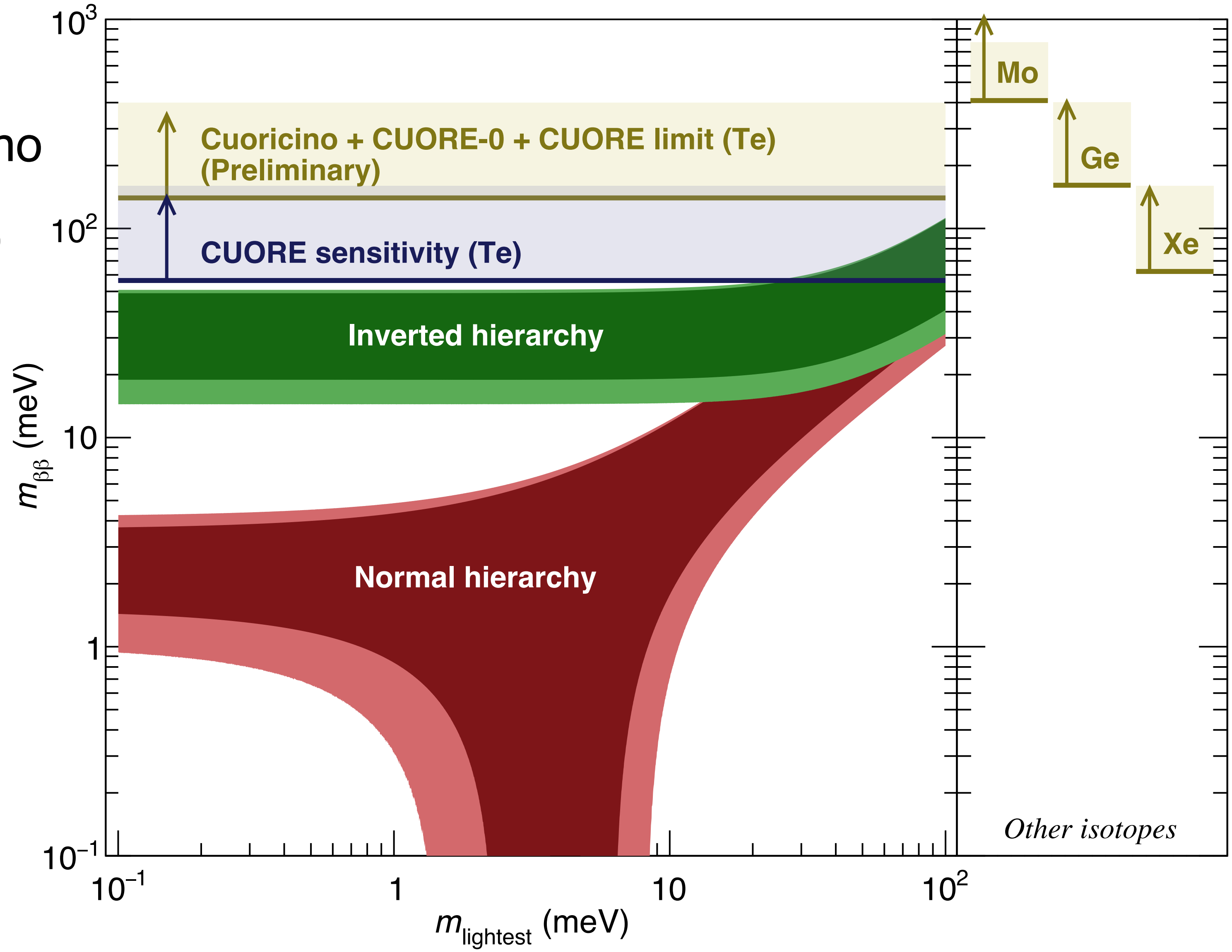
Combined with previous Te experiments

Exposure ^{130}Te:

- 19.75 kg yr Cuoricino
- 9.8 kg yr CUORE-0
- 24.0 kg yr CUORE

Combined 90% limit:

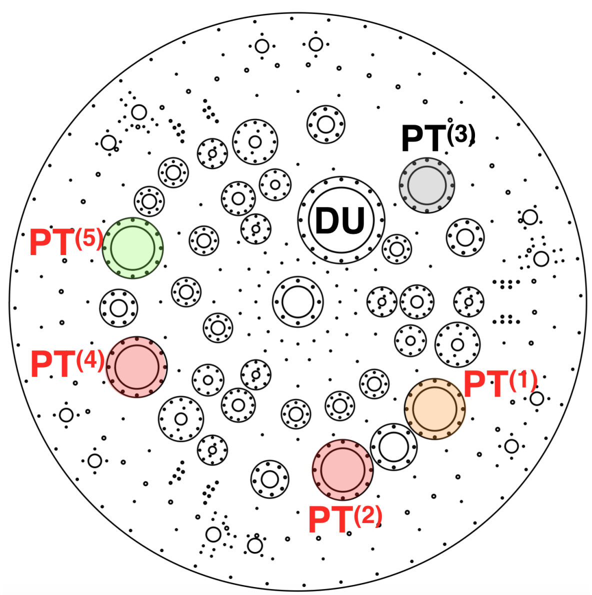
- **$T^{0\nu}$ > 1.5 × 10^{25} yr**
- **$m_{\beta\beta}$ < 140-400 meV**

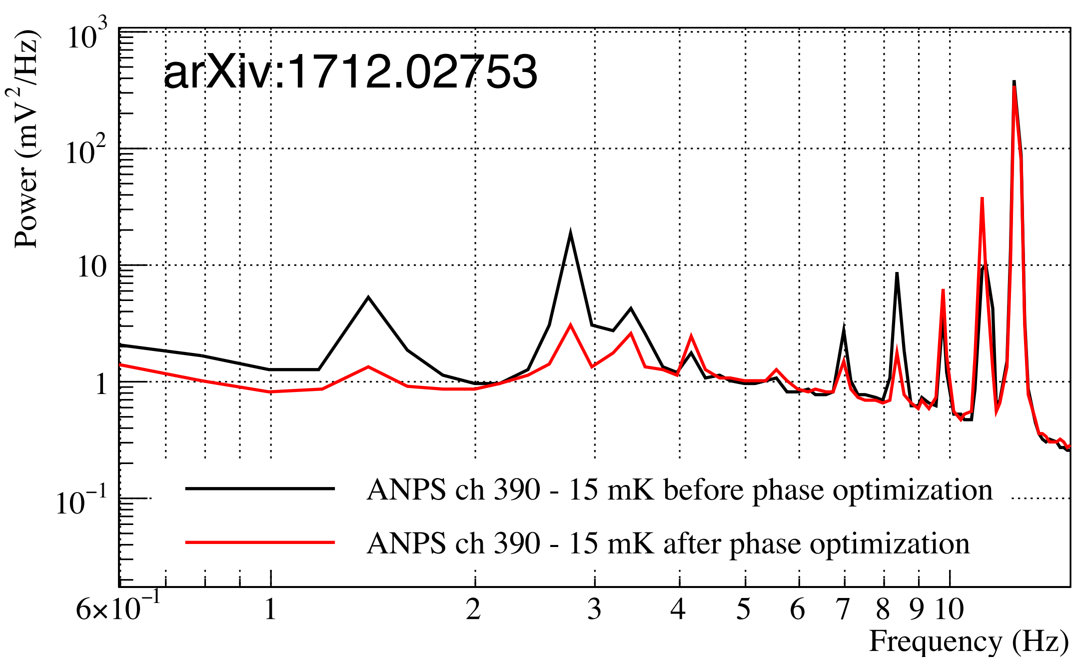


Experimental half lives:
^{130}Te: 1.5 × 10^{25} yr from this analysis
^{76}Ge: 5.3 × 10^{25} yr from Nature 544, 47–52 (2017)
^{136}Xe: 1.1 × 10^{26} yr from Phys. Rev. Lett. 117, 082503 (2016)
^{100}Mo: 1.1 × 10^{24} yr from Phys. Rev. D 89, 111101 (2014)
CUORE sensitivity: 9.0 × 10^{25} yr

Conclusions and perspectives

- CUORE is the first ton-scale $0\nu\beta\beta$ detector.
- Exceptional cryostat performance, more than a ton of material at 10 mK.
- First results from 2 months of collected physics data.
- CUORE is cooling back down, focus on energy resolution improvement:
  - Optimization of detector working conditions.
  - Noise cancellation via Pulse Tube phase optimization:





Thank you!

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INFN Istituto Nazionale di Fisica Nucleare

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CUORE

Backup slides

Fit in the ROI

CUORE

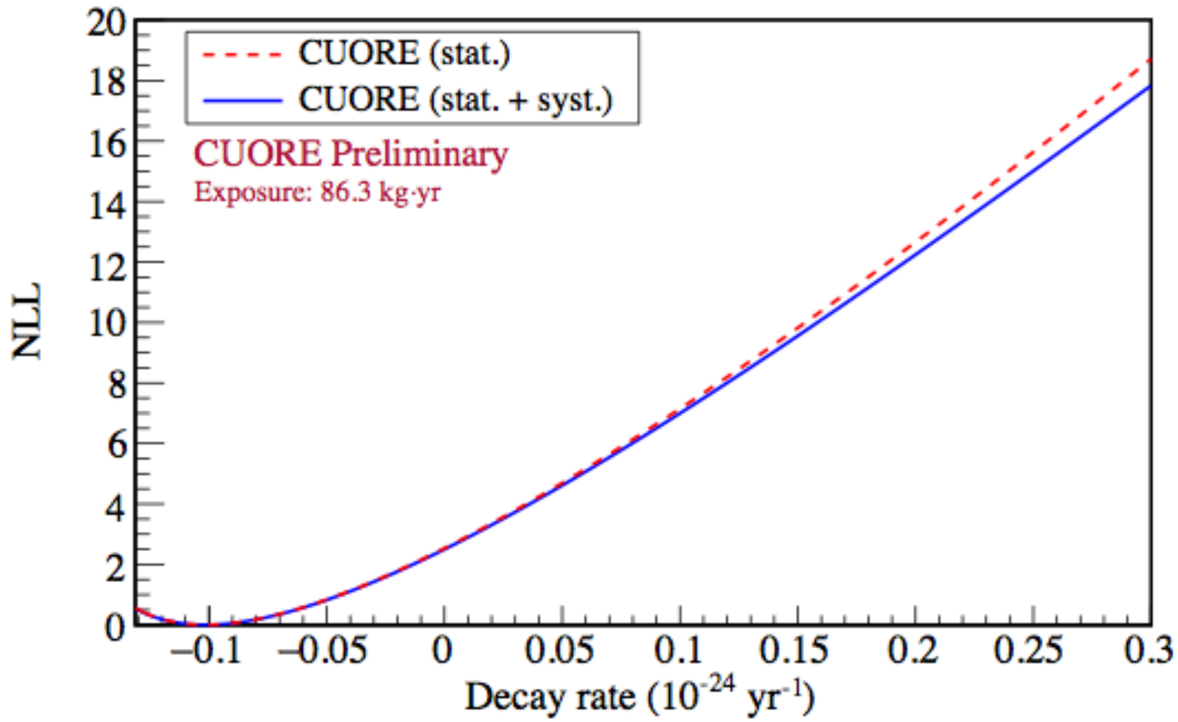
Best fit decay rate: $(-1.0_{-0.3}^{+0.4}$ (stat.) $\pm$ 0.1 (syst.)$)\times 10^{-25}$ / yr

No evidence of signal
Limit calculation
Profile likelihood integrated on the physical region ($\Gamma^{0\nu} > 0$)

Decay rate limit
(90% CL, including systematics):
< 0.52 × 10^{-25} / yr

Half-life limit
(90% CL, including systematics):
1.3 × 10^{25} yr

Median expected sensitivity:
7.0 × 10^{24} yr



(2% probability of a larger limit wrt the one observed)

Systematic errors

CUORE

The following nuisance parameters are considered:

- energy resolution (higher and lower by 1σ).
- Q-value (higher and lower by 0.5 keV from energy scale uncertainty)
- no sub-peak in the detector response (simple gaussian line shape)
- linear background (higher and lower by 1σ).

The systematic error associated to efficiency is computed directly from the statistical uncertainty on the efficiency.

Systematic	Absolute uncertainty [10^{-24} yr]	Relative uncertainty
Resolution	-	1.5%
Q-value location	-	0.2%
No subpeaks	0.002	2.4%
Efficiency	-	2.4%
Linear fit	0.005	0.8%