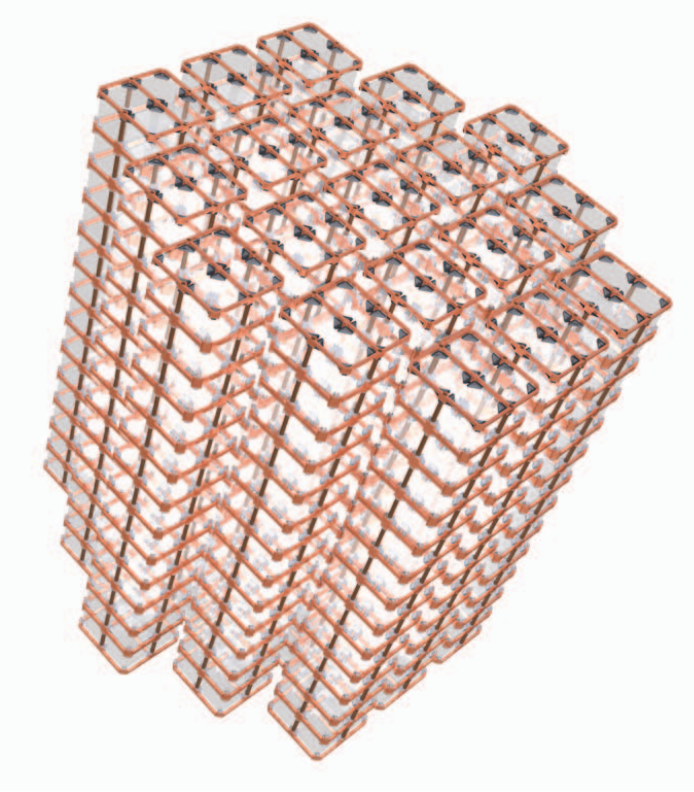
From Majorana to LHC: Workshop on the Origin of Neutrino Mass
Trieste, October 2-5, 2013

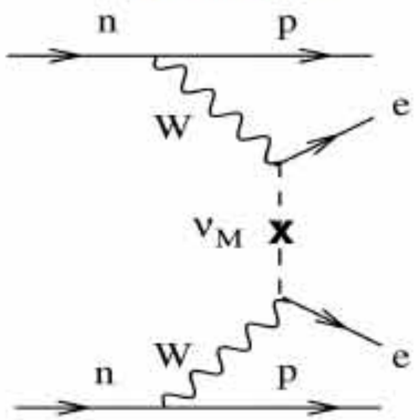
CUORE-0 AND CUORE



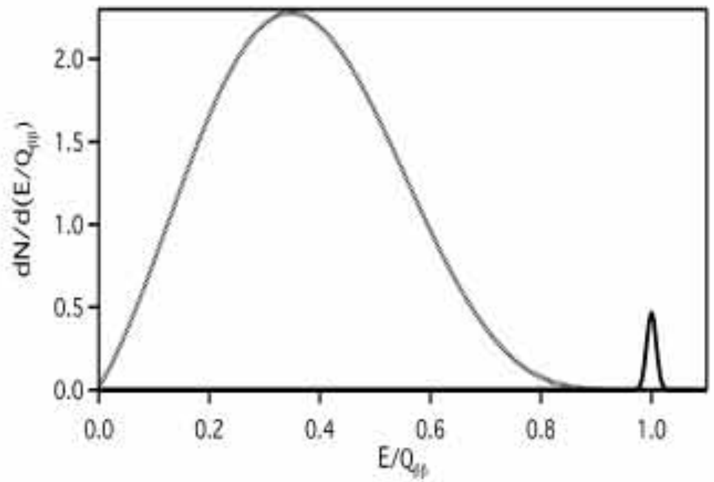
C. Brofferio
University and INFN, Milano Bicocca
on behalf of the CUORE Collaboration

A crowded summary slide…

Decay diagram



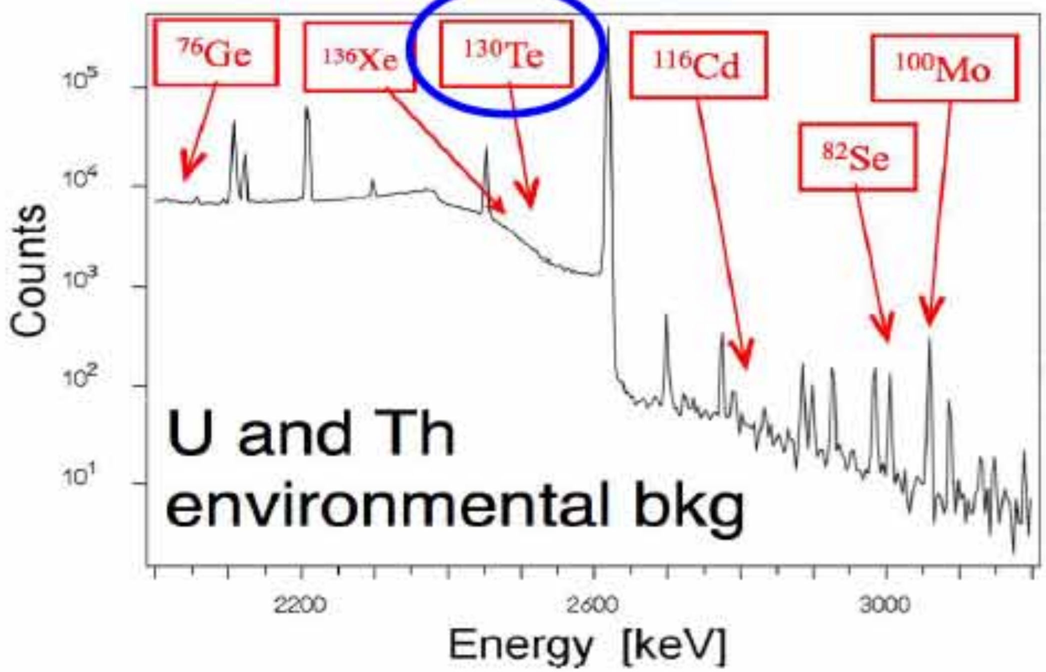
Energy spectrum



Interesting isotopes

$\beta\beta$ 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

Q-values and gamma background



Experimental sensitivity

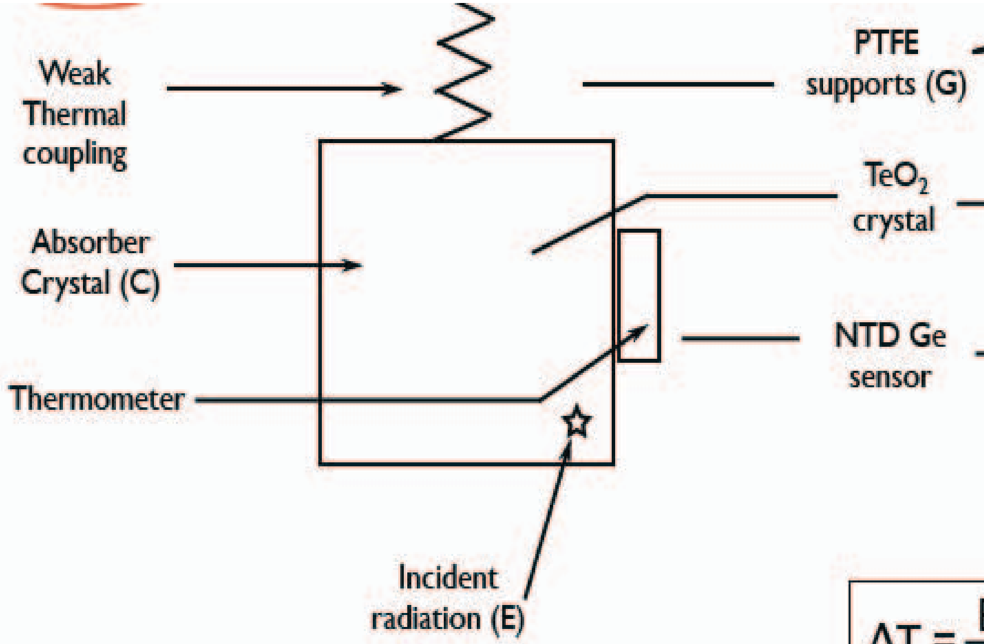
$$S^{0\nu} \propto i.a.\ \varepsilon \sqrt{\frac{M\ t}{b\ \Delta E}}$$

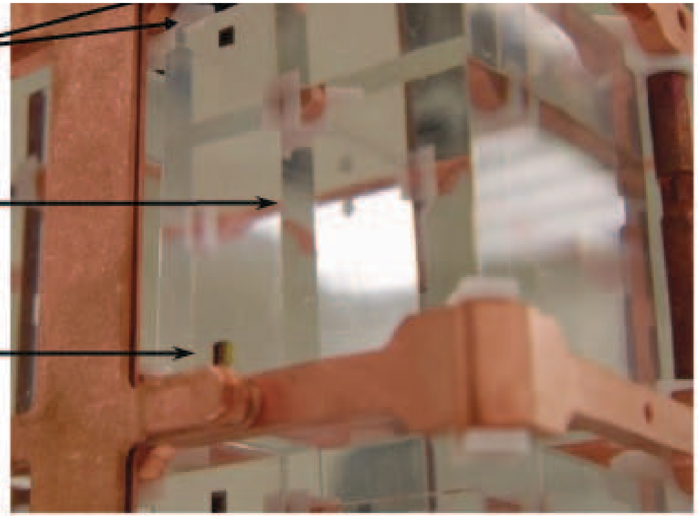
- Isotopic abundance → $i.a.$
- Detection efficiency → ε
- Detector mass → M
- Meas. time → t
- Background index counts/(keV kg y) → b
- Energy resolution → ΔE

The bolometric way to DBD

The key point when using a bolometer is that you can:

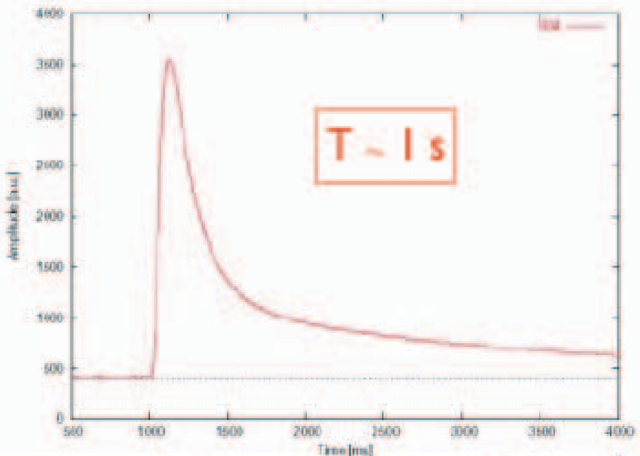
FIRST choose the isotope **THEN** define the compound





$$\Delta T = \frac{E}{C}$$

$$\tau = \frac{C}{G}$$



Pros:
- good energy resolution
- different sources could be investigated
- high efficiency (internal sources)

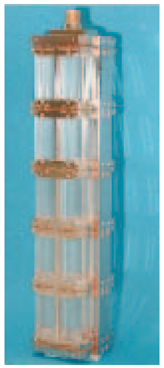
Cons:
- no dead layer
- low temperature tech required
- slow pulses

These advantages could be crucial in view of future experiments that aim to investigate all the inverted hierarchy region

$0\nu\beta\beta$ research with TeO_2

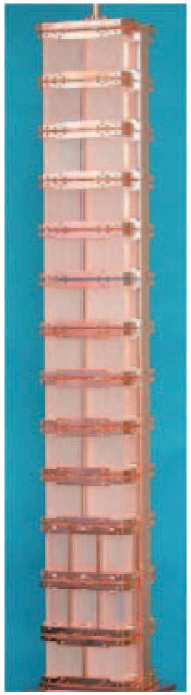
- ^{130}Te is a good DBD candidate ($^{130}Te \rightarrow {}^{130}Xe + 2\ e^-$) with high natural i.a. (34.2 %) and reasonably high Q-value (Q~2528 keV) leading to high G(Q,Z) and low background
- TeO_2 is a compound with good mechanical and thermal properties containing ^{130}Te
- 5x5x5 cm^3 TeO_2 crystals have a high detection efficiency for $0\nu\beta\beta$ events: ~87.4%

MiDBD
1.8 kg ^{130}Te



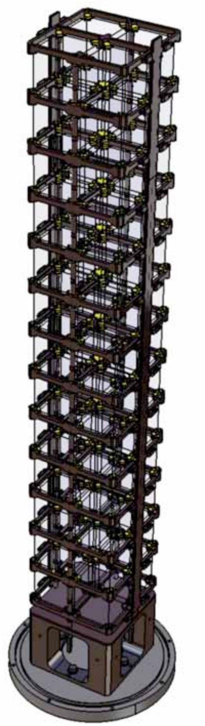
1997-2001

Cuoricino
11.3 kg ^{130}Te



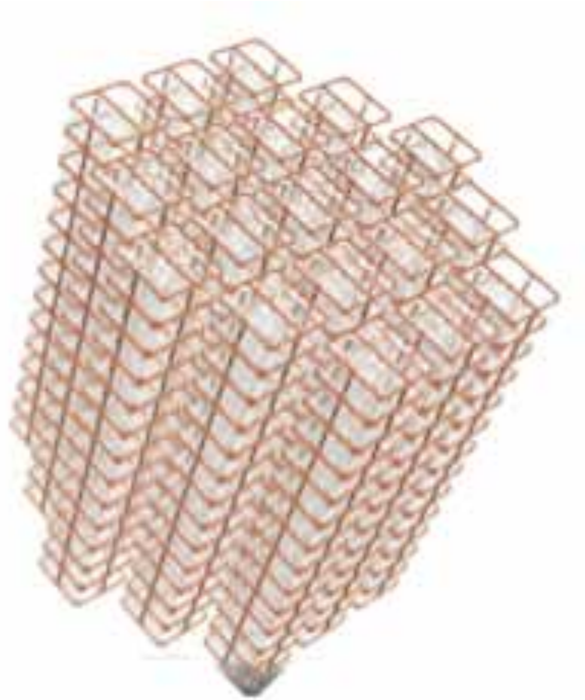
2003-2008

CUORE-0
11 kg ^{130}Te



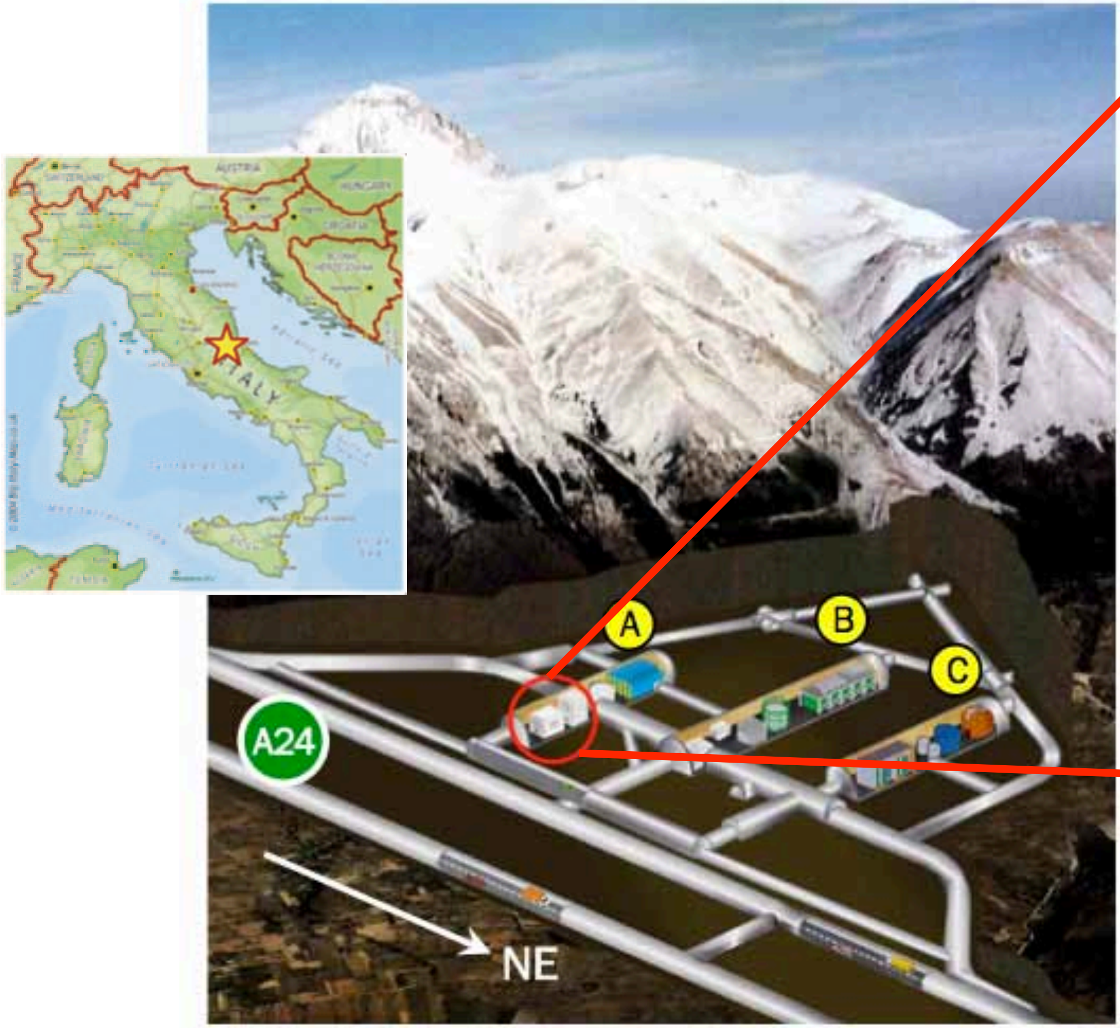
2012...2014

CUORE
206 kg ^{130}Te



2014...

Location



In Hall A of LNGS, Italy
(Laboratori Nazionali del Gran Sasso)

Average depth ~ 3650 m.w.e.

μ flux: $(2.58 \pm 0.3)\cdot 10^{-8}$ μ/s/cm^2

n flux <10 MeV: $4\cdot 10^{-6}$ n/s/cm^2

γ flux < 3 MeV: 0.73 γ/s/cm^2

From Cuoricino to CUORE

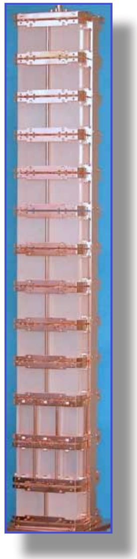
988 TeO_2 5x5x5 cm^3 crystals (750 g each)
Detector Mass: 741 kg TeO_2
^{130}Te mass (natural i.a.) : 206 kg of ^{130}Te
Array: 19 towers, each with 13 planes of 4 crystals each

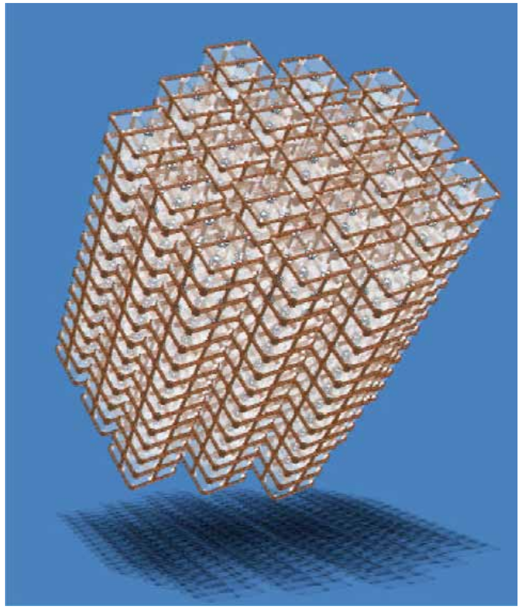
Sensitivity improvement:

$$S^{0\nu} \propto \frac{\epsilon\, a.i.}{A} \left(\frac{MT}{b\, \Delta E} \right)^{1/2}$$

(Mx20) + (ΔE/1.5) + (Tx2) + (b/20)

=> CUORE $S^{0\nu}$ ~ 35 Cuoricino $S^{0\nu}$

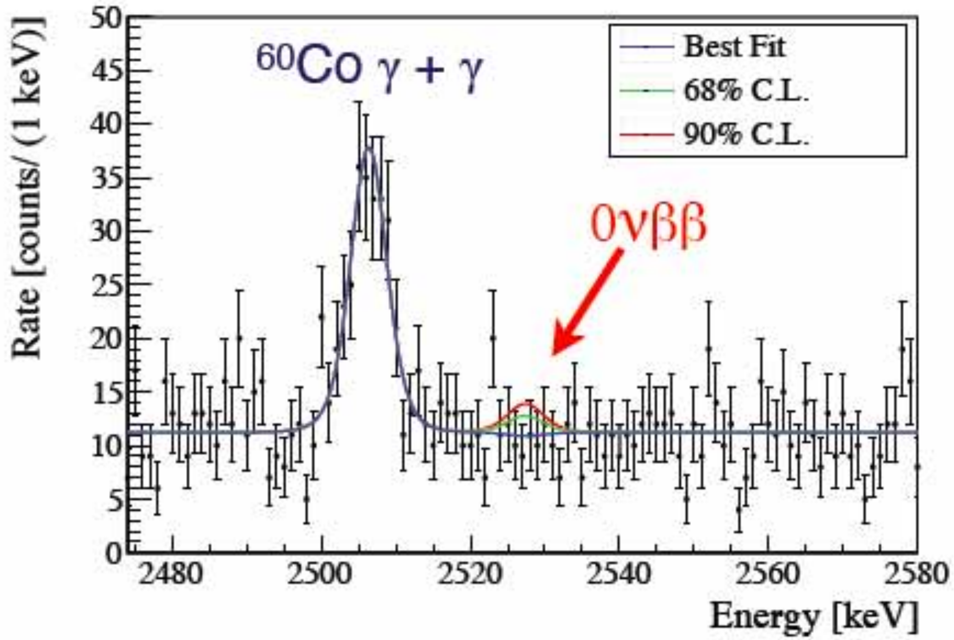


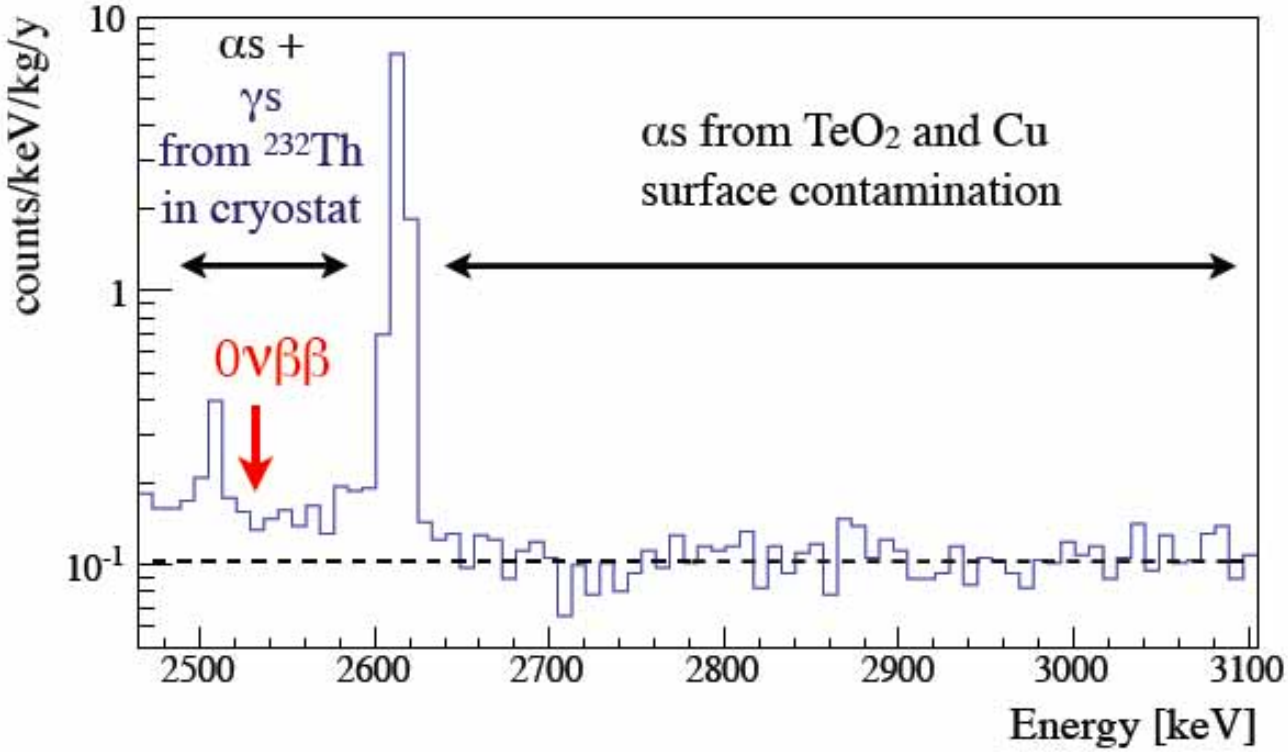


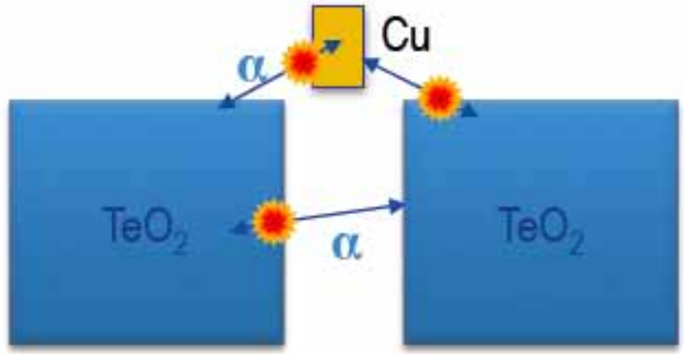
the most challenging issue is background reduction

Cuoricino Lesson: The Bkg origin

- 44x790g + 18x330g bolometers: 11 kg (^{130}Te)×2y
- $T^{0\nu}_{1/2} > 2.8\times10^{24}$ years (90% CL) $\langle m_{\beta\beta}\rangle < 300\sim710$ meV
- Background level (790g crystals): 0.15 counts/keV/kg/year







Background reduction

Passive methods adopted for CUORE

while testing different active methods (i.e. Surface sensitive bolometers, scintillating bolometers) for future improvements

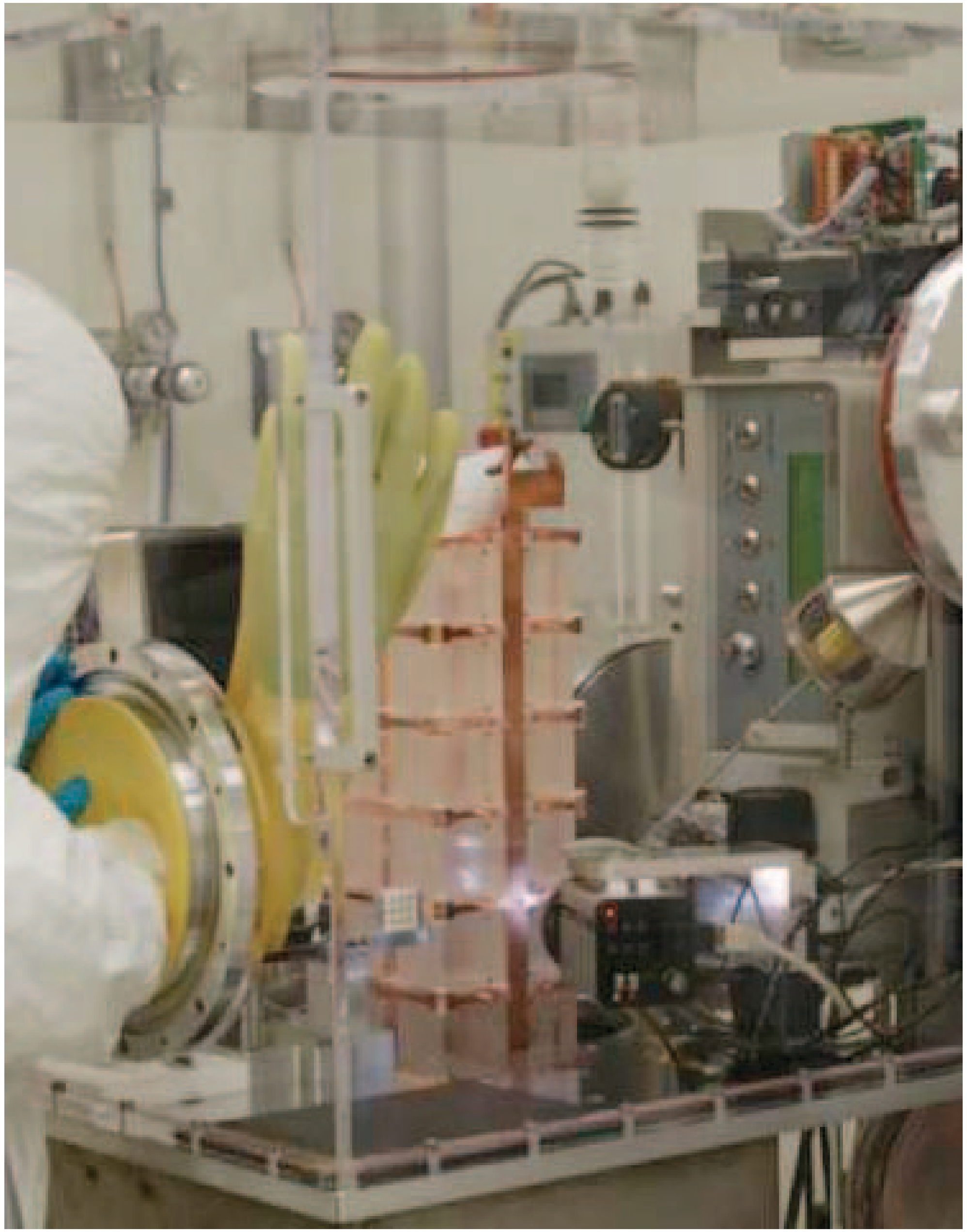
- **Pb Shields design** (36 cm minimum) **and strict materials selection**
- **New holder design** to reduce the amount of copper facing the crystals
- **TeO_2 crystals bulk contamination control**: strict protocol for TeO_2 production
  J. Cryst. Growth 312 (2010) 2999–3008
- **Crystals surface contamination reduction:** new treatment developed
  Astrop. Phys. 35, (2012), 839-849
- Reduction of **surface contamination of the copper facing the crystals:**
  Astroparticle Physics (2013), doi: http://dx.doi.org/10.1016/j.astropartphys.2013.02.005
- Further improvement thanks to **high detector granularity** (anticoincidence)
  Astrop. Phys. 33 (2010) 169

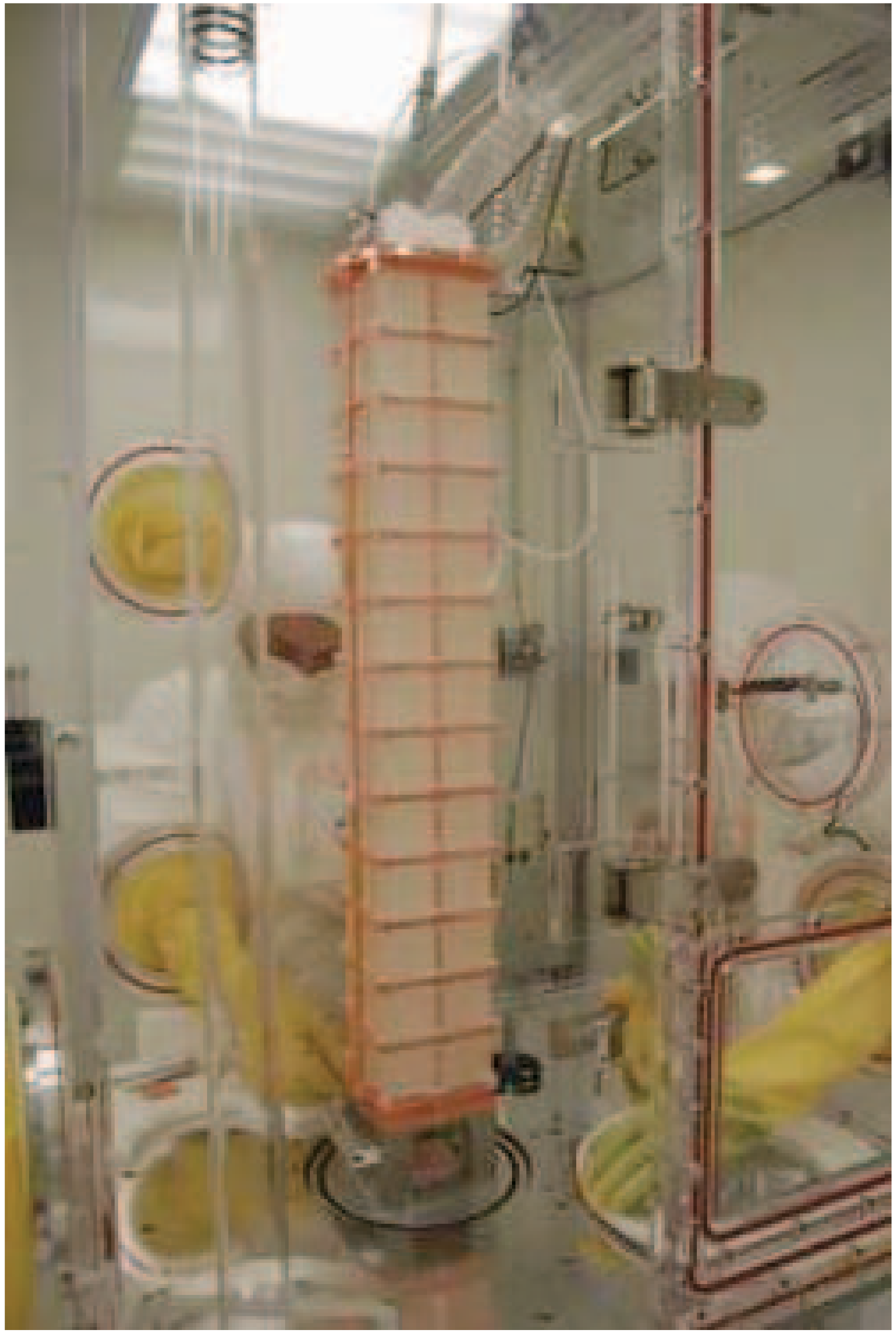
Detector assembly approach

A ZERO-CONTACT APPROACH

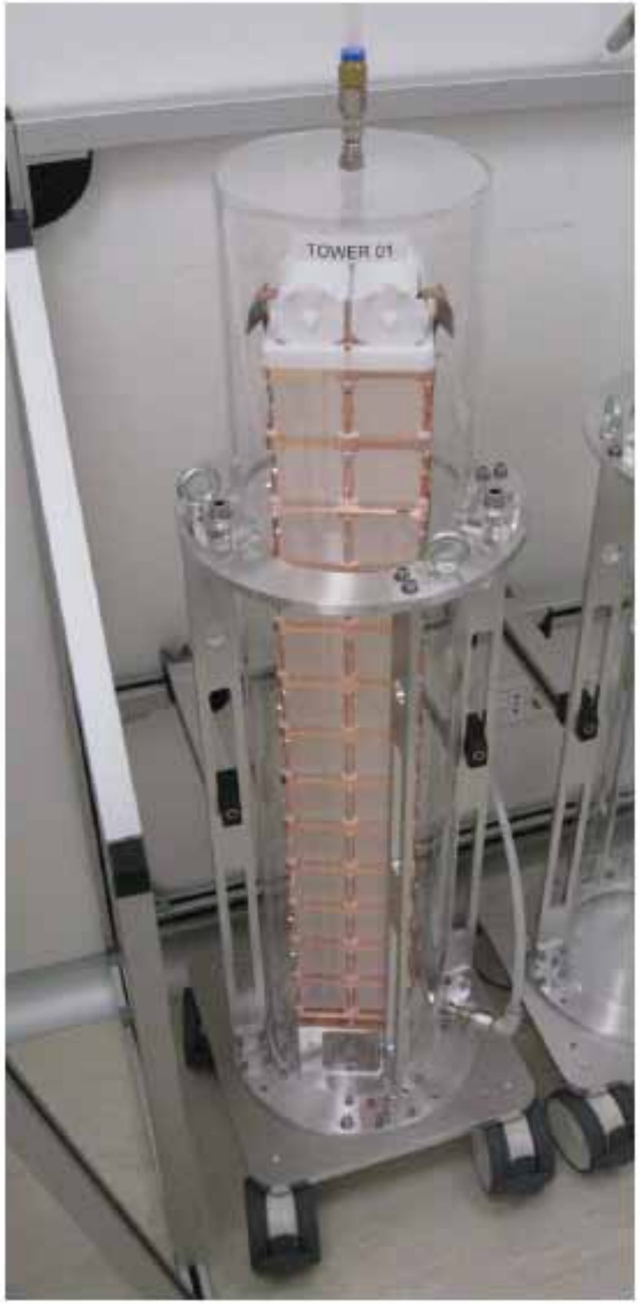
Once the detector parts are clean…

- No more contact with air (Rn)
- No contact with tools or parts not validated
- Detector always kept under nitrogen flush





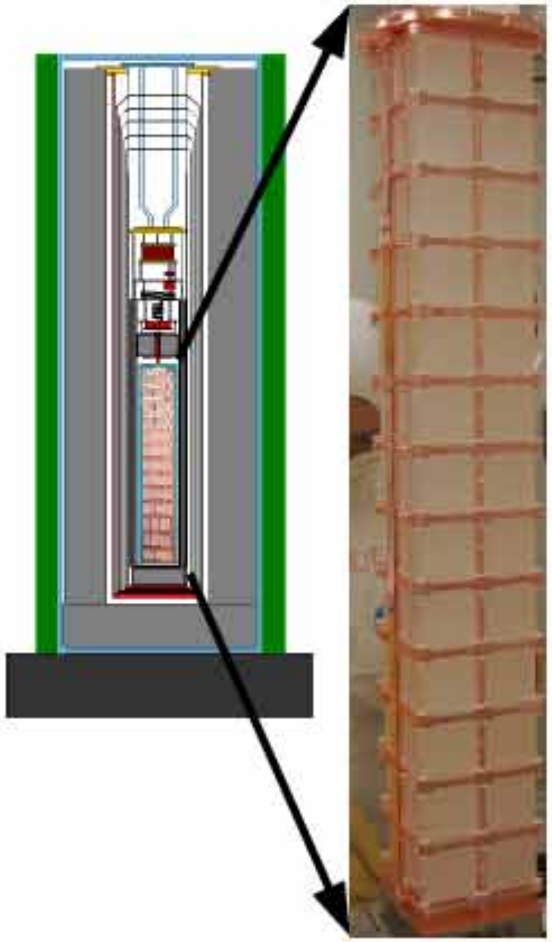
CUORE Status and schedule



- Detector assembly started in February 2013 and will finish in June 2014
  - Crystals for 10 towers already glued with heaters and thermistors
  - 9 towers assembled
  - 4 towers already bonded and put to storage
- Cryostat commissioning and tests are ongoing and will be completed in June 2014
- Detector installation and commissioning will take place in the second half of 2014
- Cooldown foreseen before the end of 2014

Meanwhile….

CUORE-0: the Demonstrator



- A single CUORE-like tower:
  - 52 5x5x5 cm^3 TeO_2 bolometers

- Test of the CUORE cleaning procedures
- Test of the CUORE assembly procedures
- A sensitive 0vDBD experiment

- Same detector mass as CUORICINO:
  - TeO2 mass: 39 kg
  - 130Te mass: 11 kg

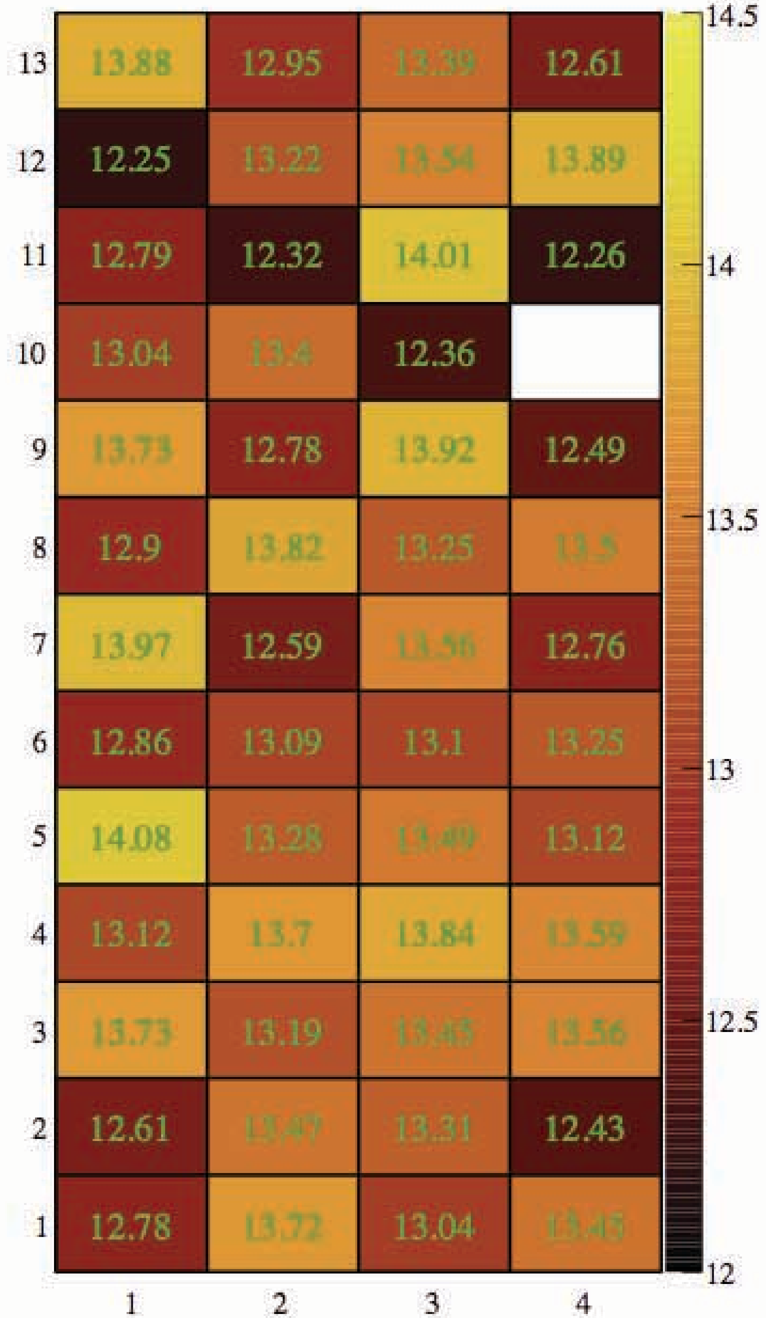
- Shielding:
  - Internal and external lead shield
  - Borated Polyethylene shield
  - Anti radon box

Started data taking in March 2013

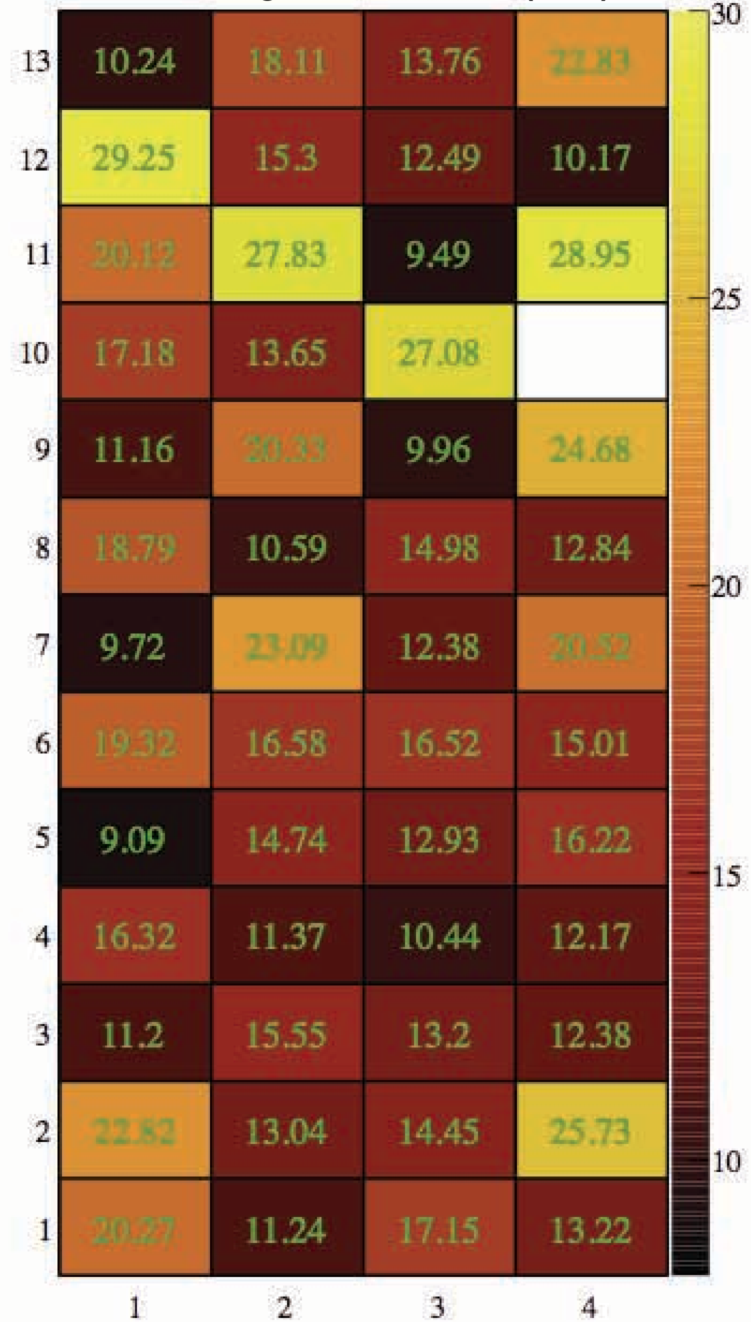
Operated in the CUORICINO cryostat:
γ background not expected to change → study α background

Cuore0 - operation conditions

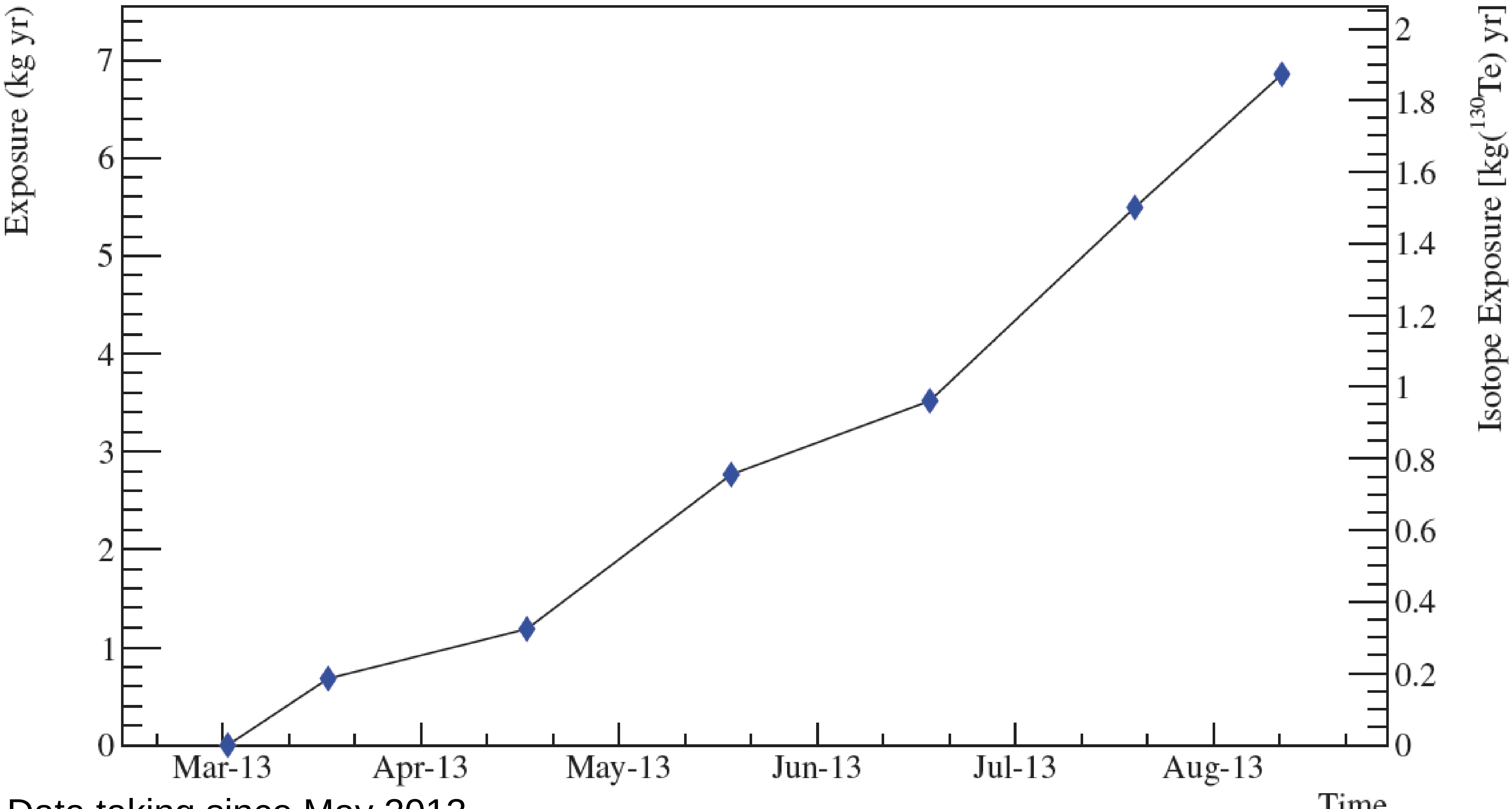
Operating temperatures (mK)



Working resistances (MΩ)

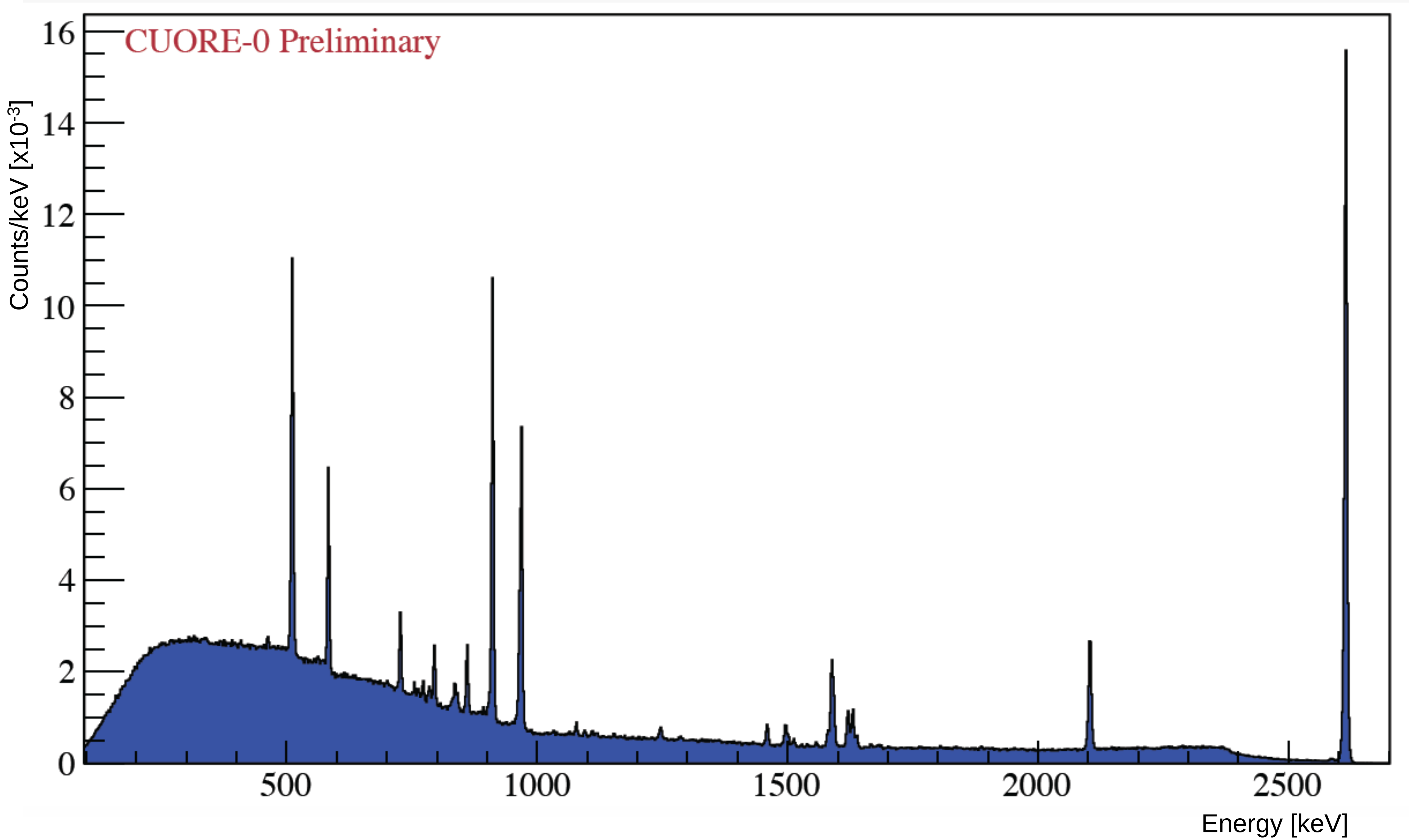


Data taking

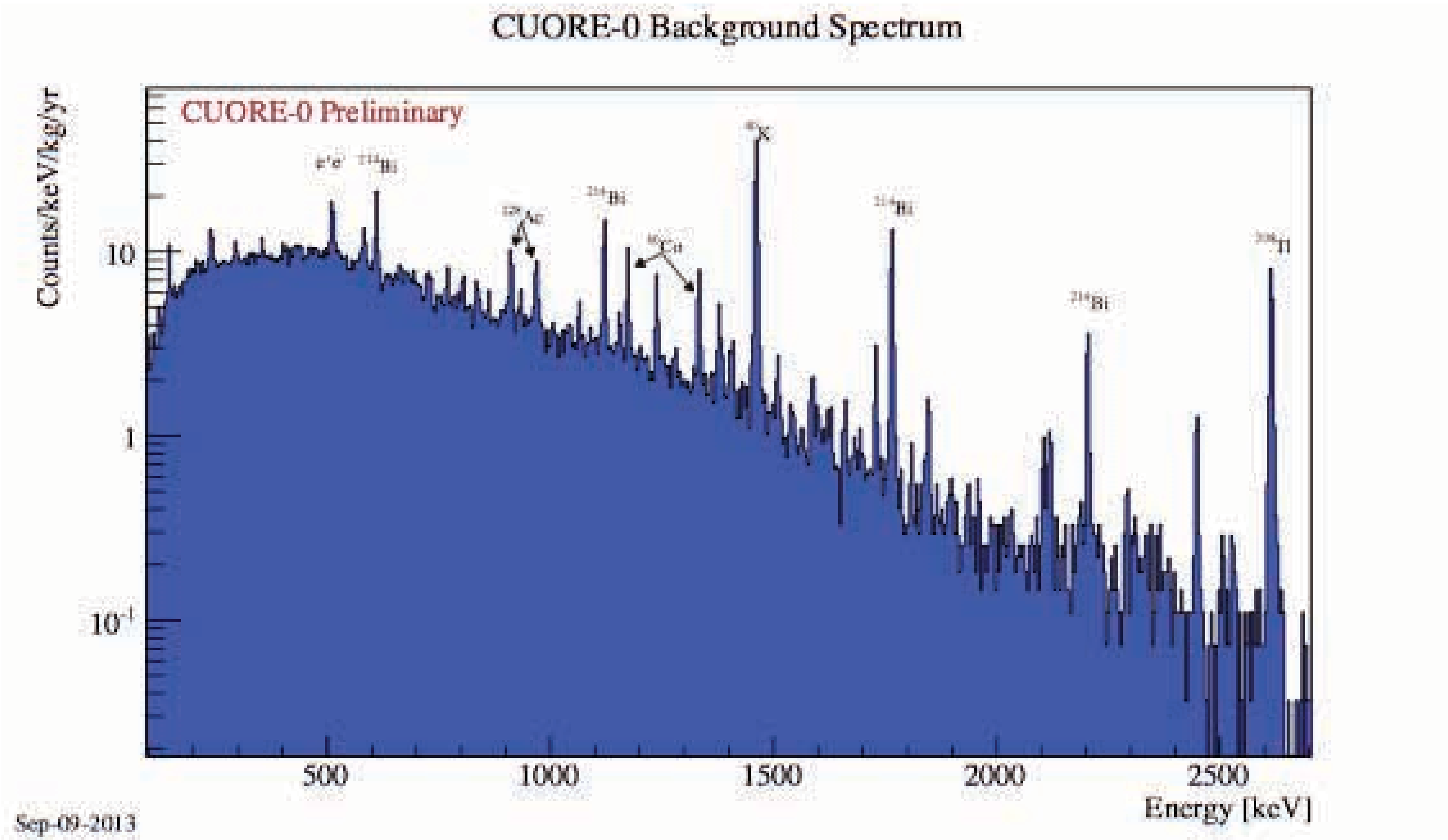


Data taking since May 2013

Calibration sum spectrum

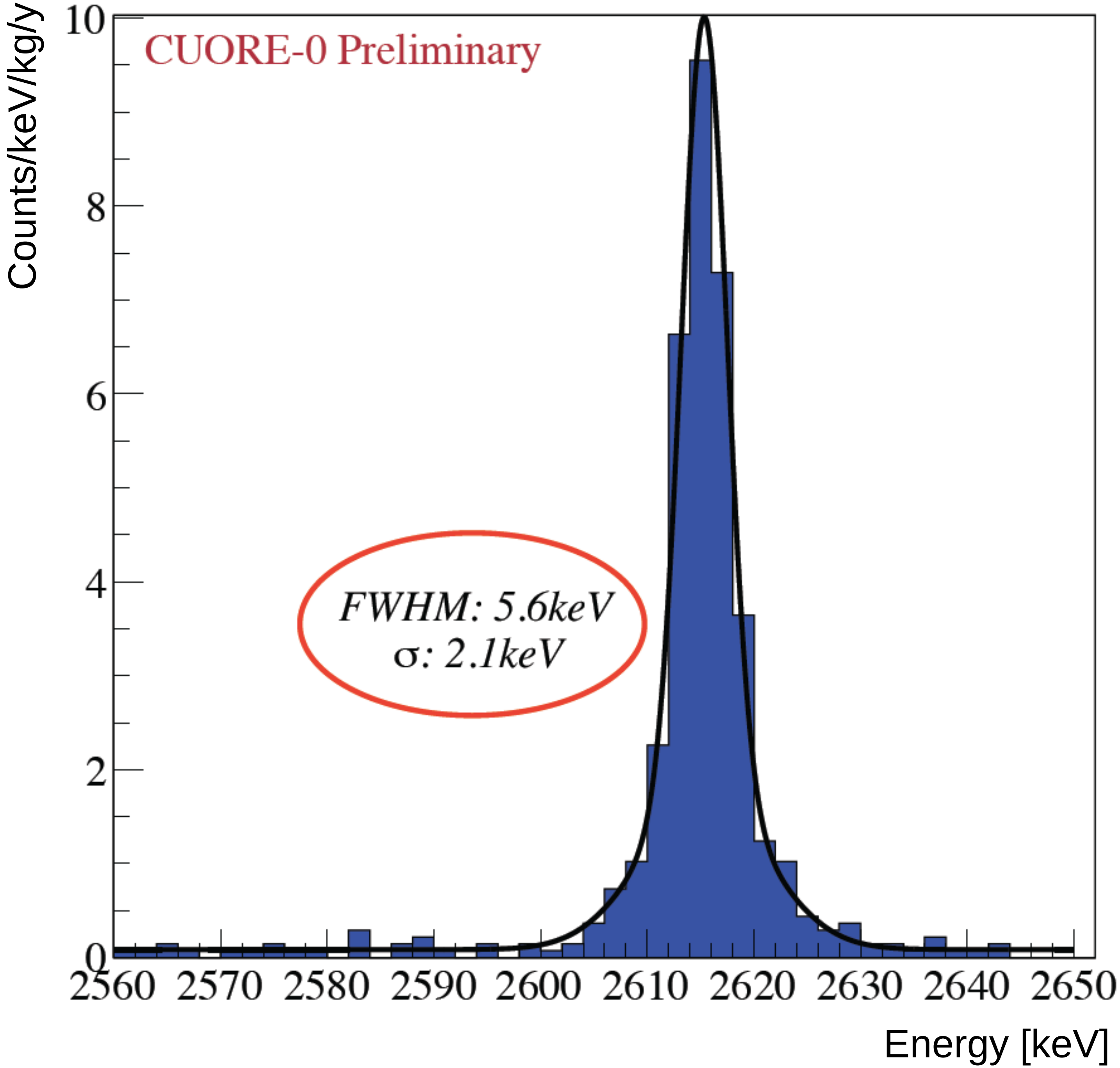


Background sum spectrum

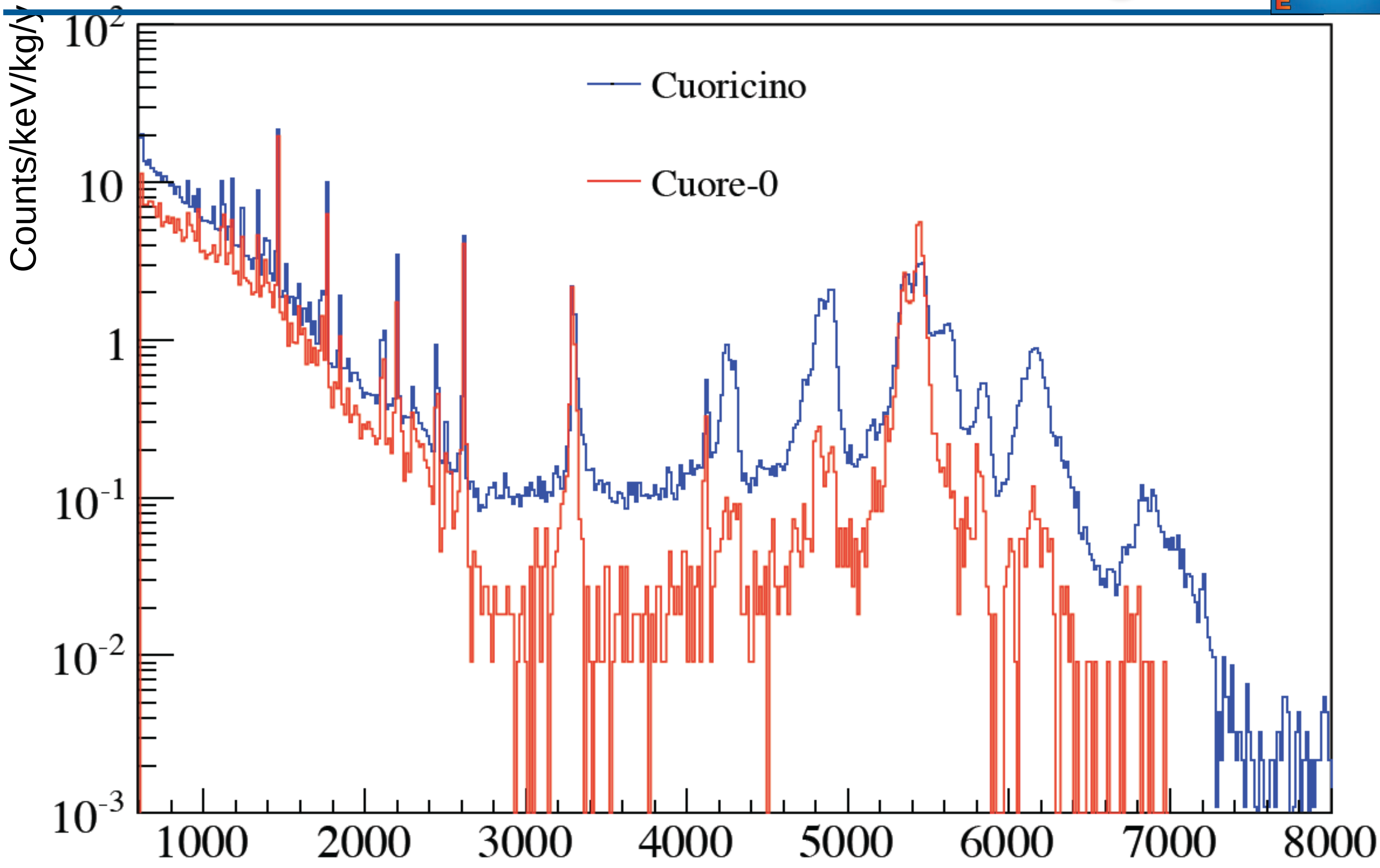


Energy resolution

Energy resolution at the ^{208}Tl peak: background spectrum



Cuore-0 vs Cuoricino bkg

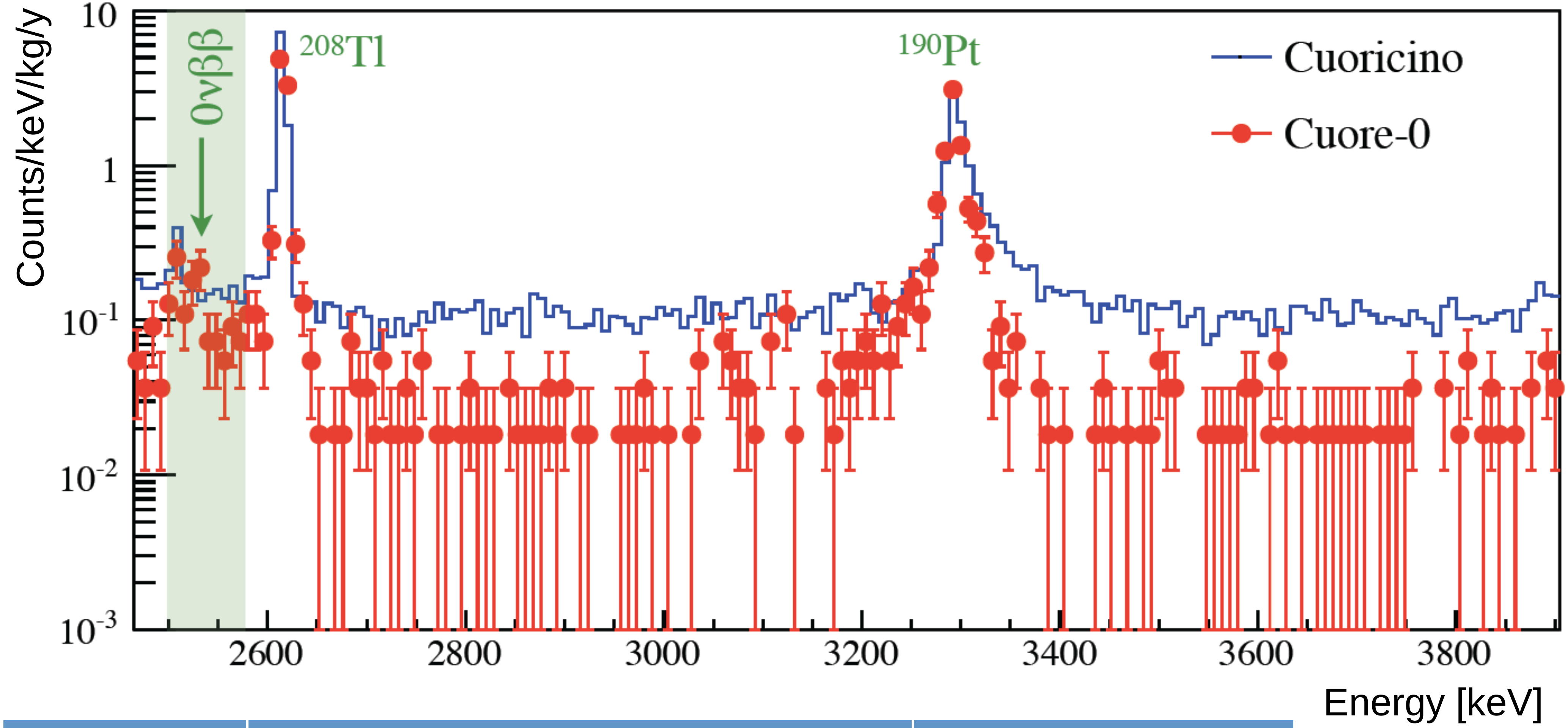


^{238}U γ lines reduced by a factor 2 (better radon control),

^{232}Th γ lines not reduced (originate from the cryostat).

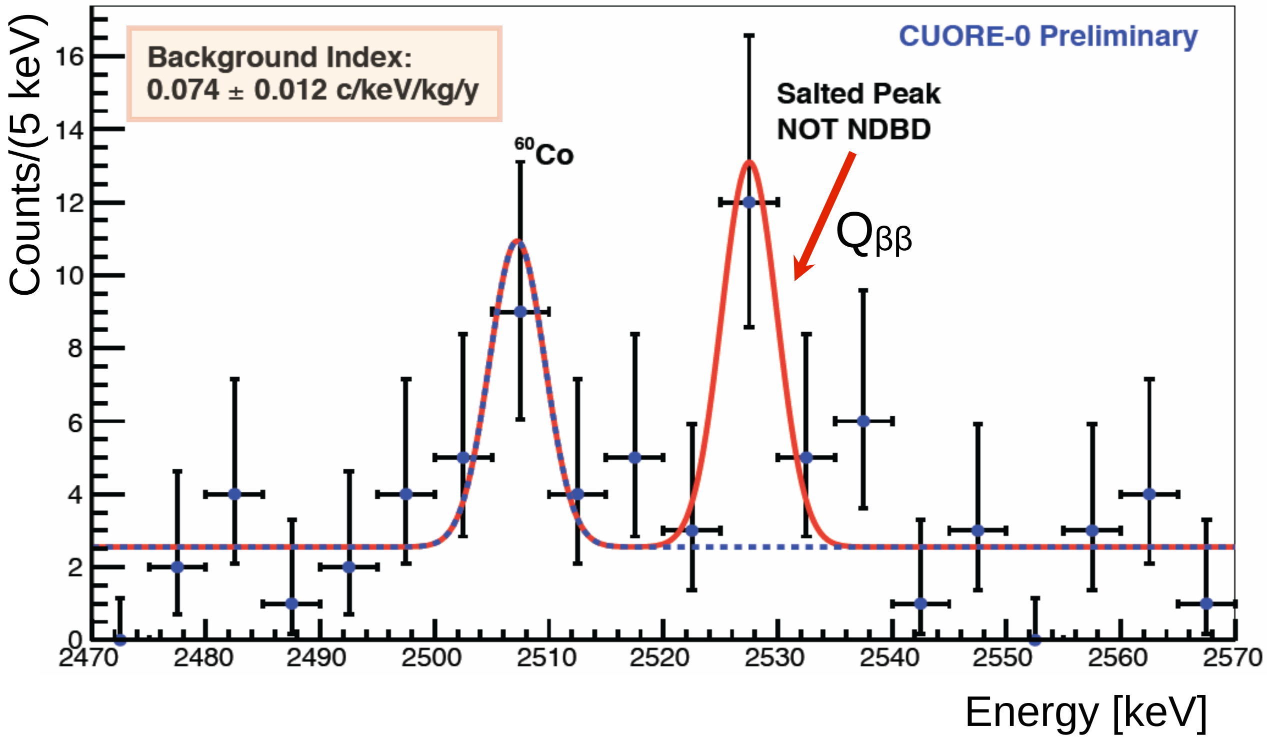
^{238}U and ^{232}Th α lines reduced thanks to the new detector surface treatment.

Flat alpha background



	Avg. flat bkg. [counts/keV/kg/y]		Signal eff. [%]
	0νββ region	2700-3900 keV	(detector+cuts)
CUORICINO	0.153 ± 0.006	0.110 ± 0.001	83 ± 1
CUORE0	0.074 ± 0.012	0.019 ± 0.002	78 ± 1

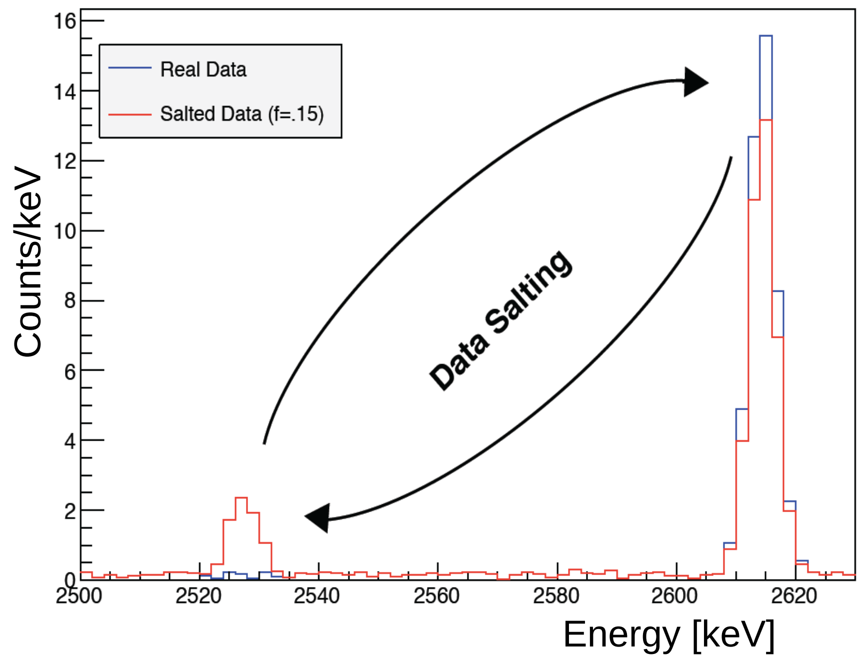
0νββ region (blinded)



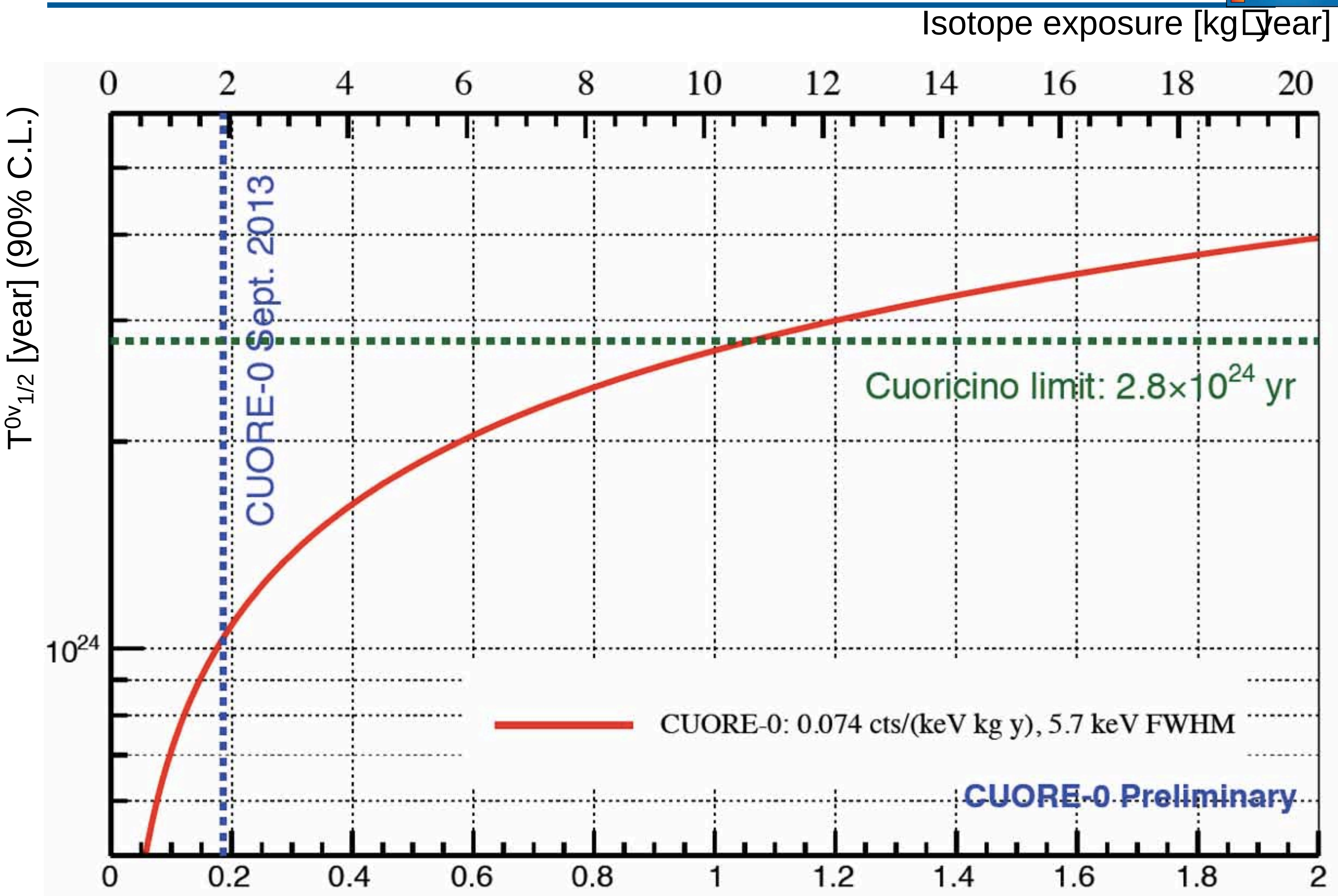
PRELIMINARY:
Pulse shape cuts
not yet optimized

Our way of blinding is to **salt the data**:

Exchange a small (and blinded) fraction of ^{208}Tl events (2615 keV) with events in the 0νββ region, producing a **fake peak**

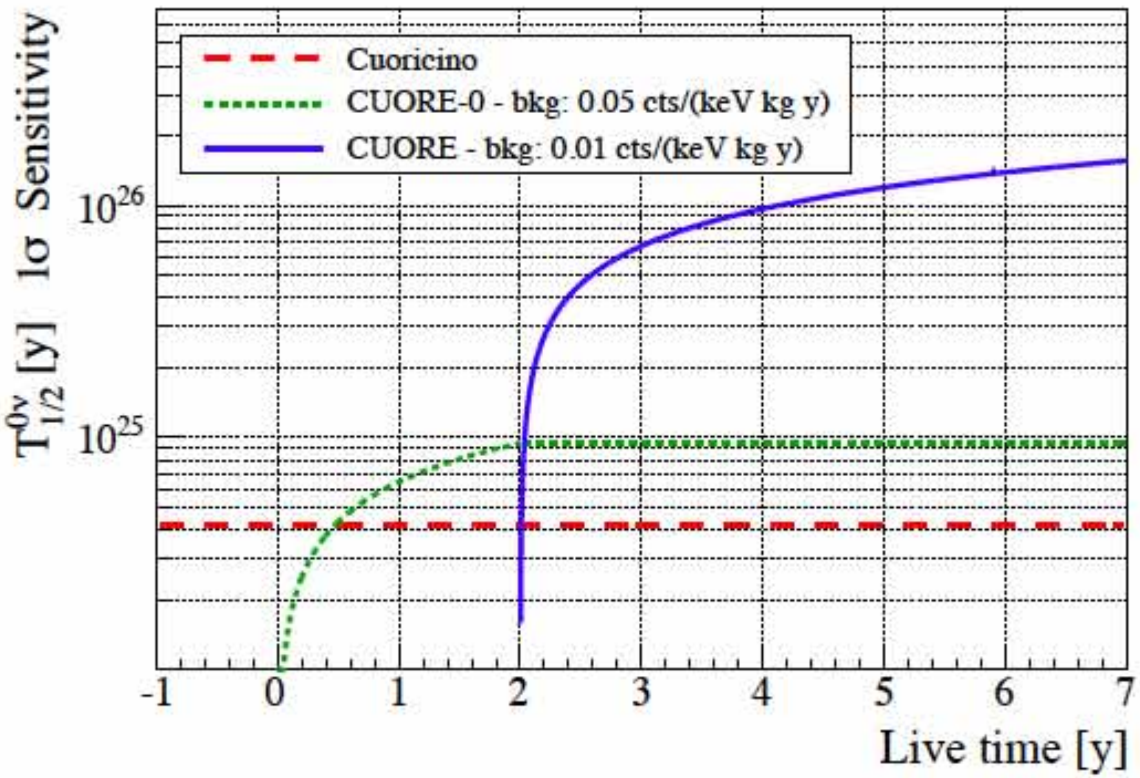


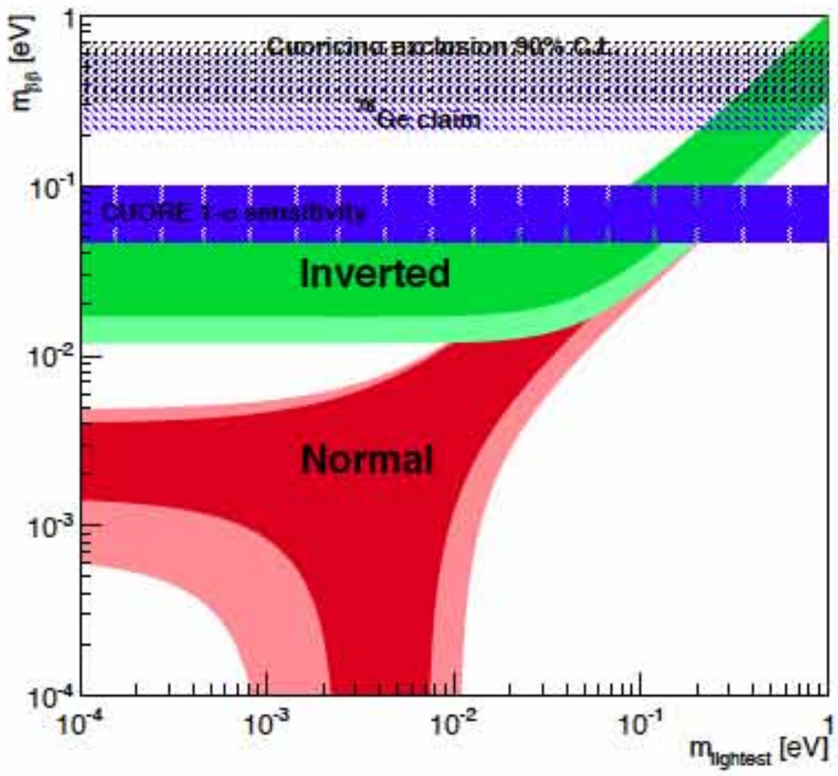
Cuore-0 Sensitivity



Cuore-0 and Cuore Sensitivities

- 1σ sensitivity $T_{1/2}^{0\nu\beta\beta} = 1.6 \times 10^{26}$ y; effective Majorana mass down to 39-102 meV.
  - Assuming a background rate of 10^{-2} counts/(keV kg y), and 5 keV FWHM
  - 5 years of live time
- Detector assembly will be finished by June 2014, followed by installation in July and commissioning by the end of 2014.





What beyond CUORE?

$$S^{0\nu} \propto \frac{\epsilon\, a.i.}{A} \left(\frac{MT}{b\, \Delta E} \right)^{1/2}$$

Extensions beyond CUORE are possible in order to increase sensitivity to cover the inverted hierarchy region of the neutrino mass spectrum

- Relatively inexpensive isotopic enrichment of ^{130}Te
- No change needed to the experimental infrastructure
- > 500 kg of ^{130}Te
- A factor 3 increase in i.a. => $S^{0\nu}_{enr} \sim 3\, S^{0\nu}_{nat}$

- Particle discrimination (R&D is being developed):

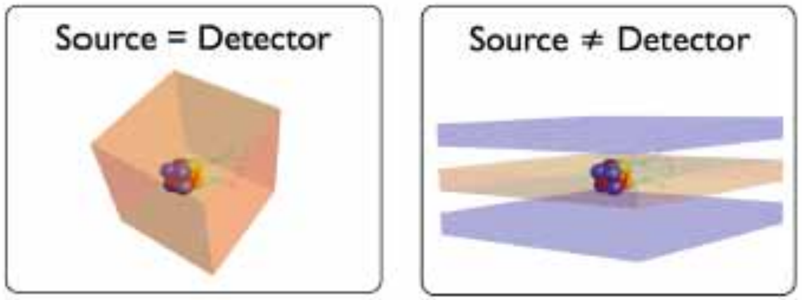
  signal shape, surface sensitive detectors,

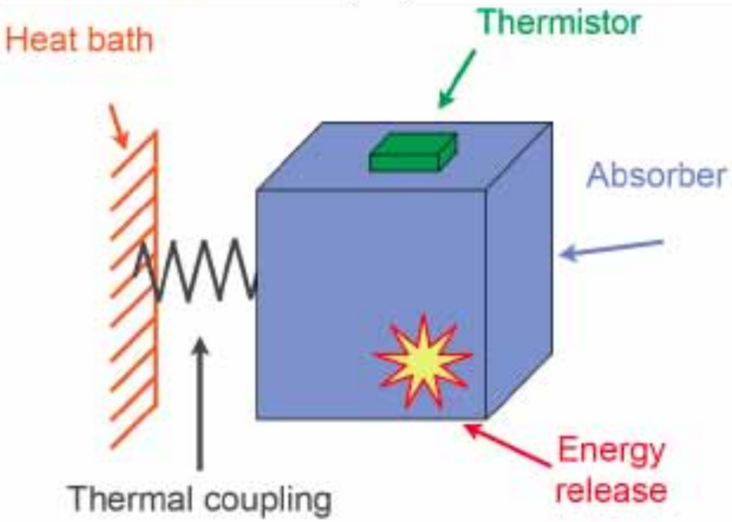
  Cherenkov light detection, scintillating bolometers…

Beyond CUORE: double read-out

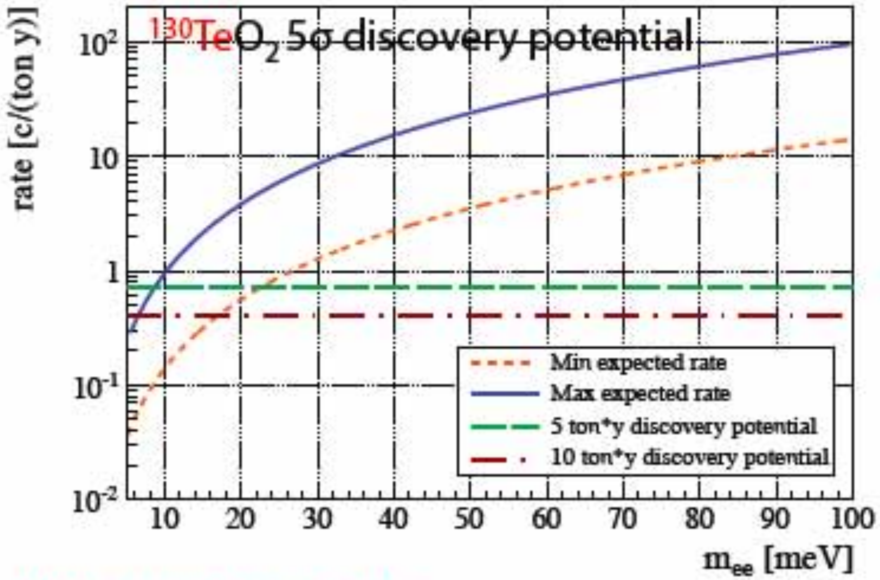
Bolometry - best of both worlds

- Bolometer utilizes only the low heat capacity of dielectric crystal.
- High efficiency and flexibility in candidate isotope choices.
- Especially valuable for discovery confirmations in different isotopes.





- Next generation Inverted Hierarchy Explorer (IHE) to fully cover the IH region
  - Phonon + photon
  - CUORE operations and scientific success are critical for the future bolometric program.



90% sensitivity limits

Crystal	Exposure [ton·y]	half-life sensitivity [10^{27}y]	$\lvert m_{ee}\rvert_S$ [meV]
ZnSe	5	3.3	9 - 26
	10	6.5	6 - 18
$CdWO_4$	5	1.5	14 - 26
	10	3.0	10 - 18
$ZnMoO_4$	5	0.9	11 - 32
	10	1.4	9 - 25
TeO_2	5	3.4	8 - 22
	10	6.8	6 - 16

Conclusions

- TeO_2 bolometers represent since many years a competitive detector for 0νββ research.
- After the CUORICINO lesson a strong R&D has been developed in order to reduce the background in the ROI. CUORE-0 is the answer to those studies: 6x improvement on alphas
- With a background at the 0νββ of **0.074±0.012** counts/keV/kg/y (surface + **cryostat**) it will overcome the CUORICINO sensitivity in less than 1 year of data taking.
- CUORE goal of 0.01 c/keV/kg/y is just behind the corner.
- CUORE is under construction: CUORE cool down is foreseen by end 2014.

The CUORE Collaboration

- INFN LNGS Laboratories
- INFN & University Milano Bicocca
- INFN Roma & Sapienza University
- INFN Roma Tor Vergata
- INFN & University Genova
- INFN & University Firenze
- INFN LNL Laboratories
- INFN LNF Laboratories
- INFN Padova
- INFN and University Bologna

- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- University of California Berkeley
- University of Califoria Los Angeles
- University of South Carolina
- California Politechnic state University
- University of Wisconsin Madison
- CNRS – CSNSM Orsay
- Shanghai Institute of Applied Physics
- University of Zaragoza