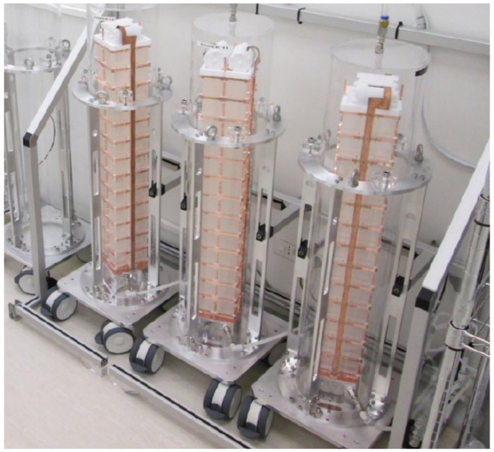
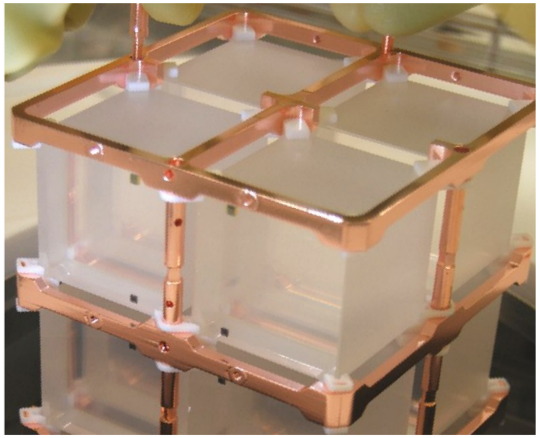
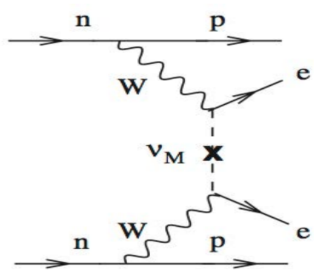
CUORE





$0\nu\beta\beta$ - ^{130}Te

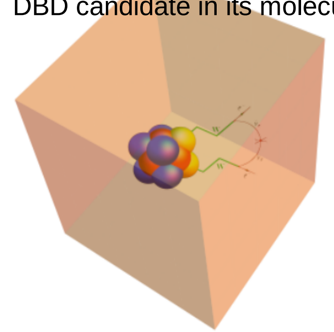
$(A,Z) \rightarrow (A,Z+2) + 2e^-$



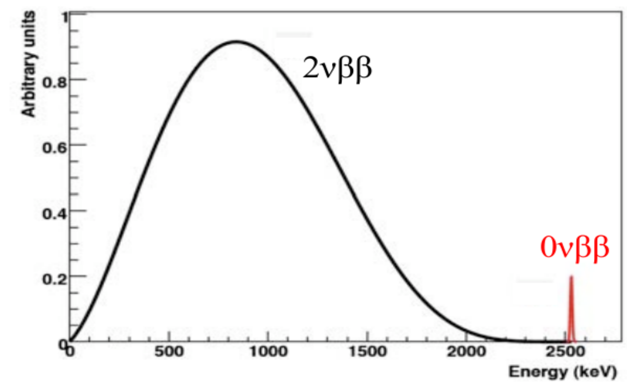
lepton violation
if observed ν is Majorana

Source = Detector

the detector is a crystal with the DBD candidate in its molecule



SIGNATURE

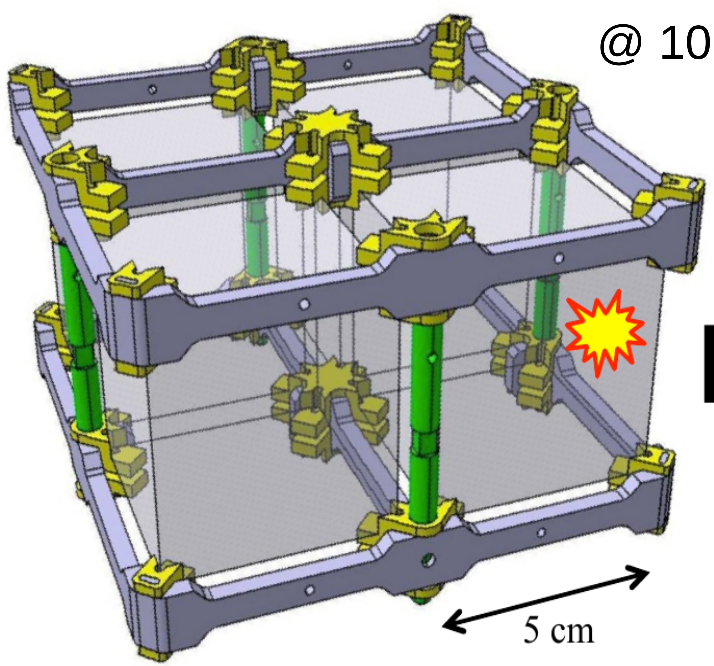


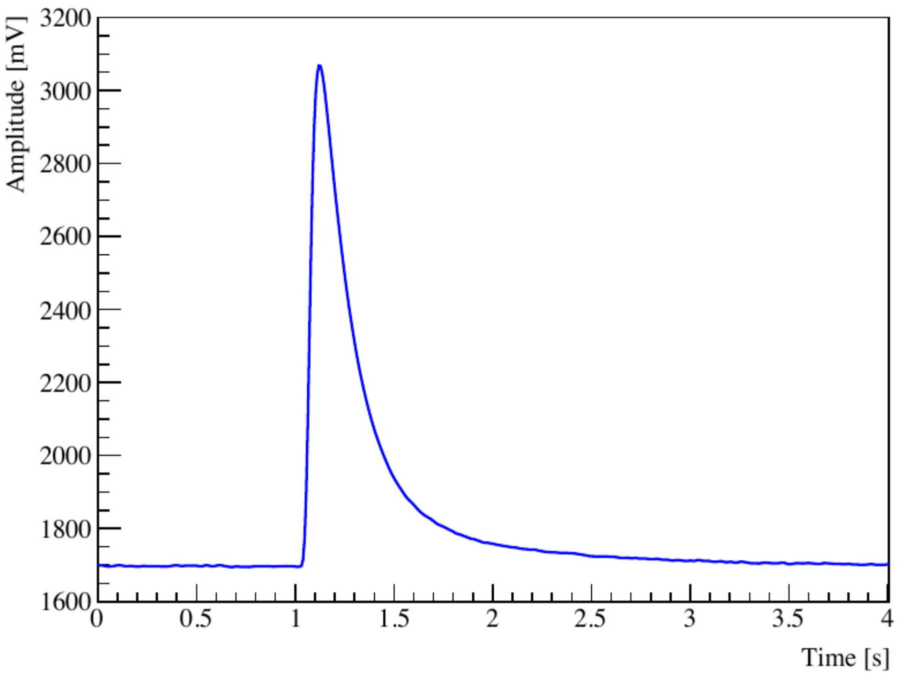
ISOTOPE CHOICE

^{130}Te

- High nat. isotopic abundance ~ 34.2% — NEED NO ENRICHEMENT
- High Q-value = 2527.518 ± 0.013 keV — LOW BACKGROUND
- Good Nuclear Factor of Merit

TeO_2 bolometers





Absorber: E → ΔT ~ E/C(T)

TeO_2 crystals ~ 750 g

Low heat capacity

High radio-purity

Temperature sensor ΔT → ΔV

NTD Ge thermistor

$R = R_0 \exp(T/T_0)^\gamma$ → high sensitivity

$0\nu\beta\beta$ - ^{130}Te

^{130}Te $\tau^{0\nu}_{1/2}$ SENSITIVITY i.e.

1) total mass / isotope mass

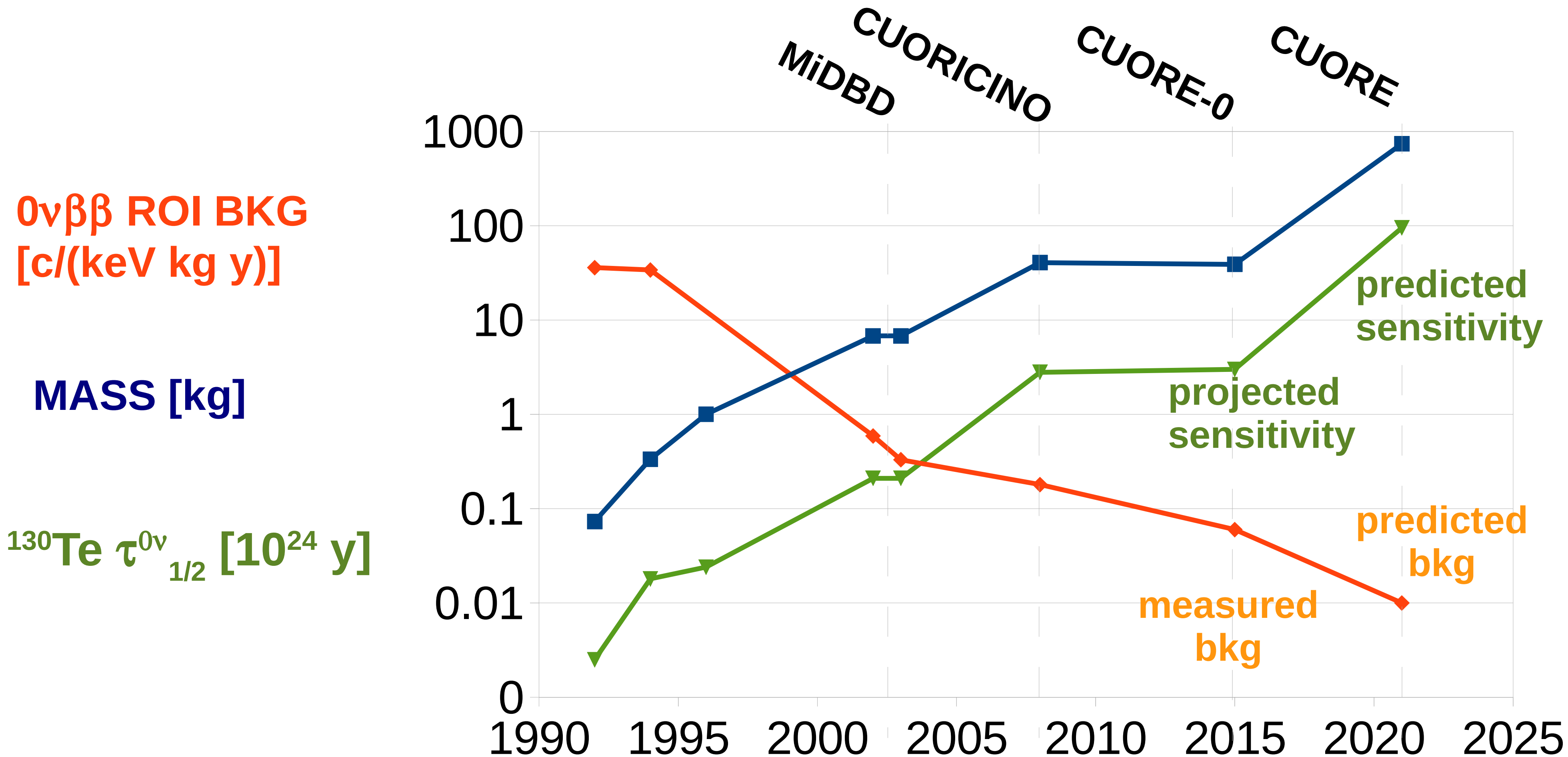
(1 kg TeO_2 ~ 0.28 kg of ^{130}Te)

2) background in the ROI :

FWHM at $Q_{\beta\beta}$ (ROI width)

background rate at $Q_{\beta\beta}$

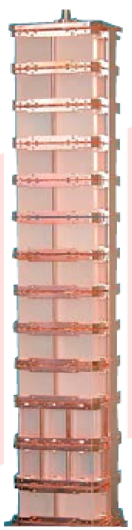
TeO_2 bolometers a story of successes



growing in mass & improving bkg

Cuoricino

~ 41 kg TeO_2
0.15 c/(keV kg y)



Astropart. Phys. 34 (2011) 822–831

CUORE-0

~ 39 kg TeO_2
0.06 c/(keV kg y)

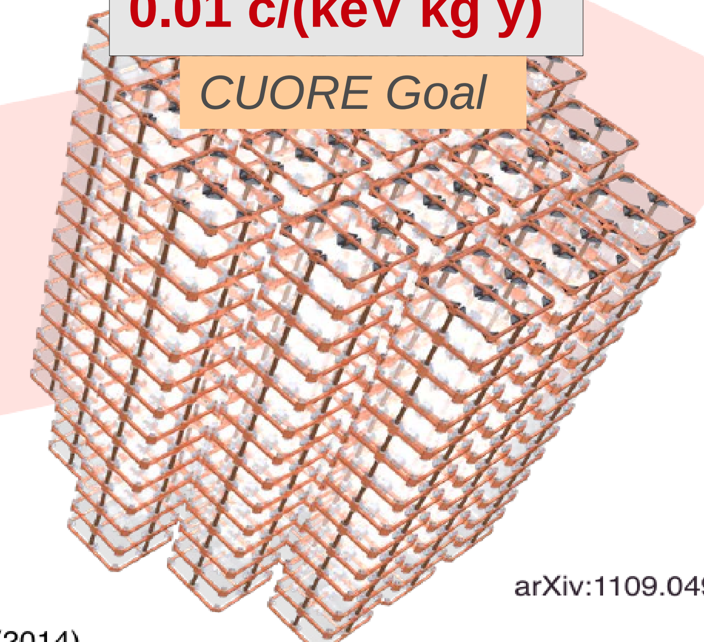
CUORE-0 Preliminary

EPJC 74, 2956 (2014)

CUORE

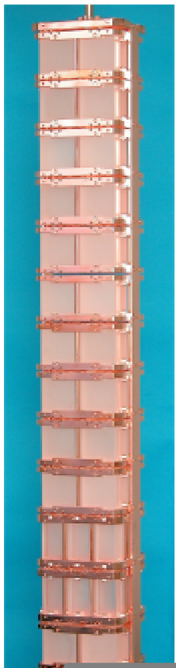
~ 741 kg TeO_2
0.01 c/(keV kg y)

CUORE Goal



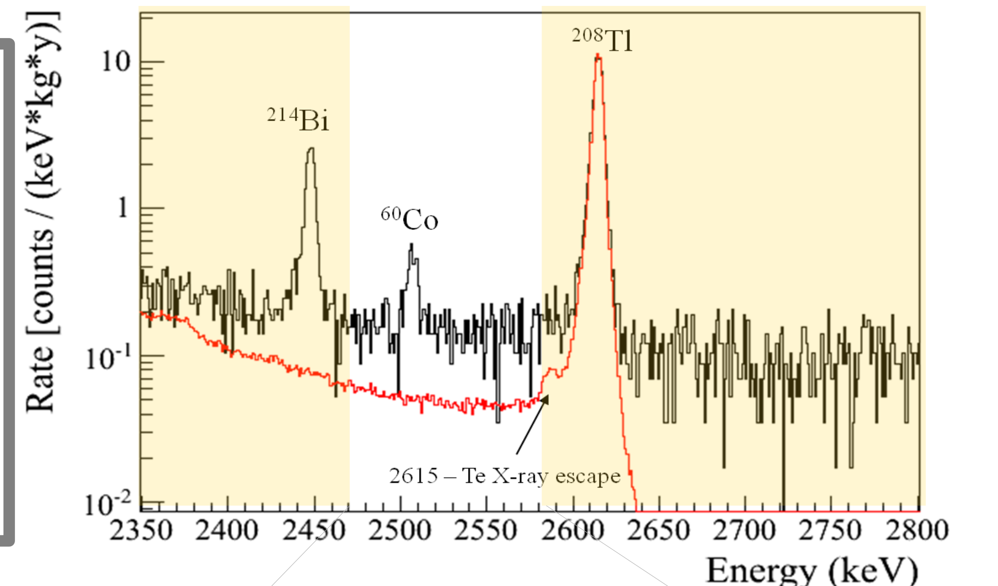
arXiv:1109.0494

Cuoricino



TeO_2 mass:	40.7 kg
Running:	2003 – 2008
FWHM	~ 7 keV
Exposure	19.75 kg(^{130}Te) y
Result	no 0νββ peak !

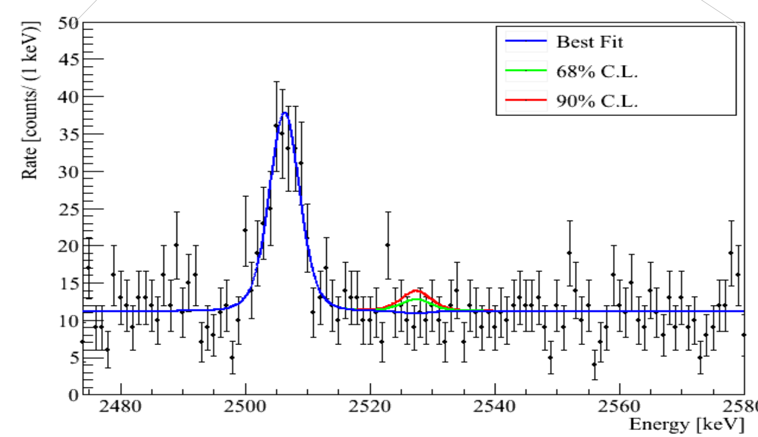
Astropart. Phys. 34 (2011) 822–831



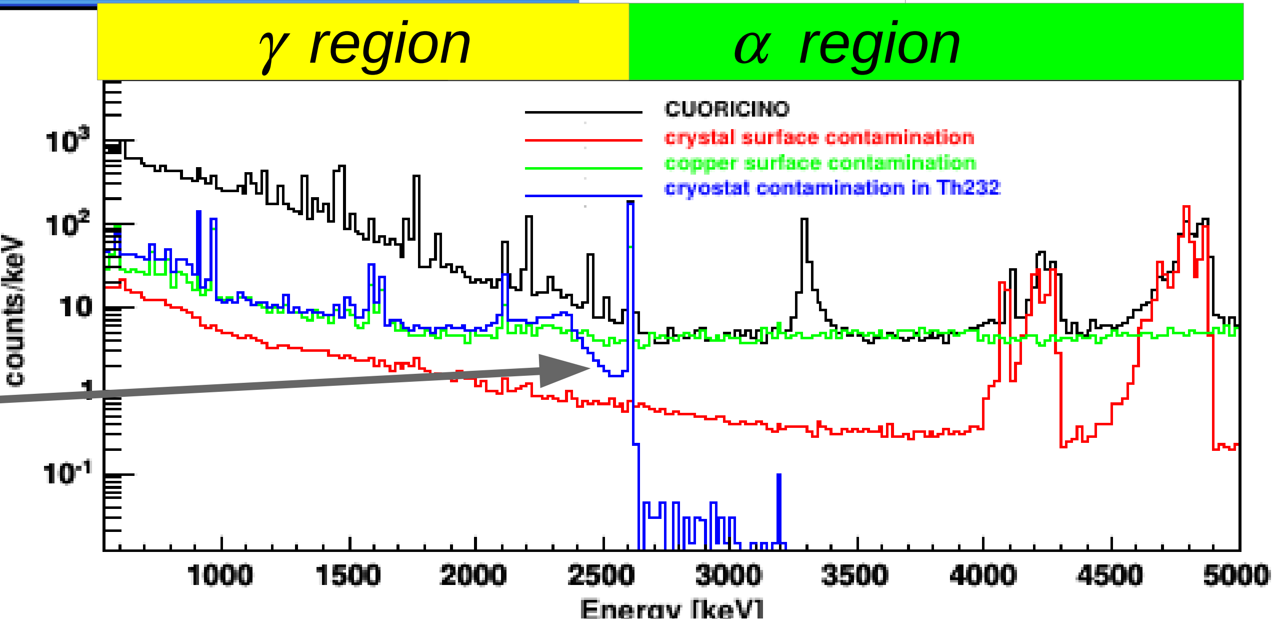
^{130}Te $\tau^{0\nu}_{1/2}$ > 2.8 x 10^{24} y (90 % C.L.)

*

Background :
0.169 ± 0.006 counts/(keV kg y)
on 5x5x5 cm³ crystals :
0.153 ± 0.006 counts/(keV kg y)



Cuoricino bkg model



0νββ ROI Counting Rate
0.153 ± 0.006 counts/(keV kg y)

degraded α's

10 +/- 5 %
surface contamination of TeO_2 crystals in ^{238}U and ^{232}Th

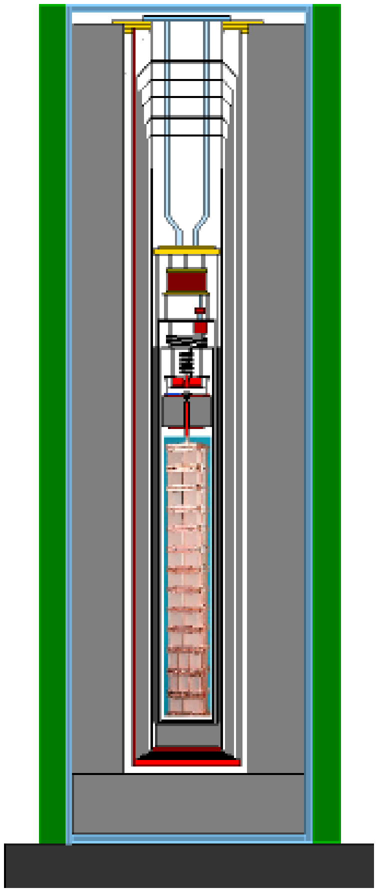
50 +/- 20 %
surface contamination of Cu Holder
(or any other element facing the crystals such as PTFE spacers)

γ's

30 +/-10%
multiCompton events induced by the ^{208}Tl (2615 keV peak)
due to cryostat contamination in ^{232}Th

from Cuoricino to CUORE

Cuoricino/CUORE-0

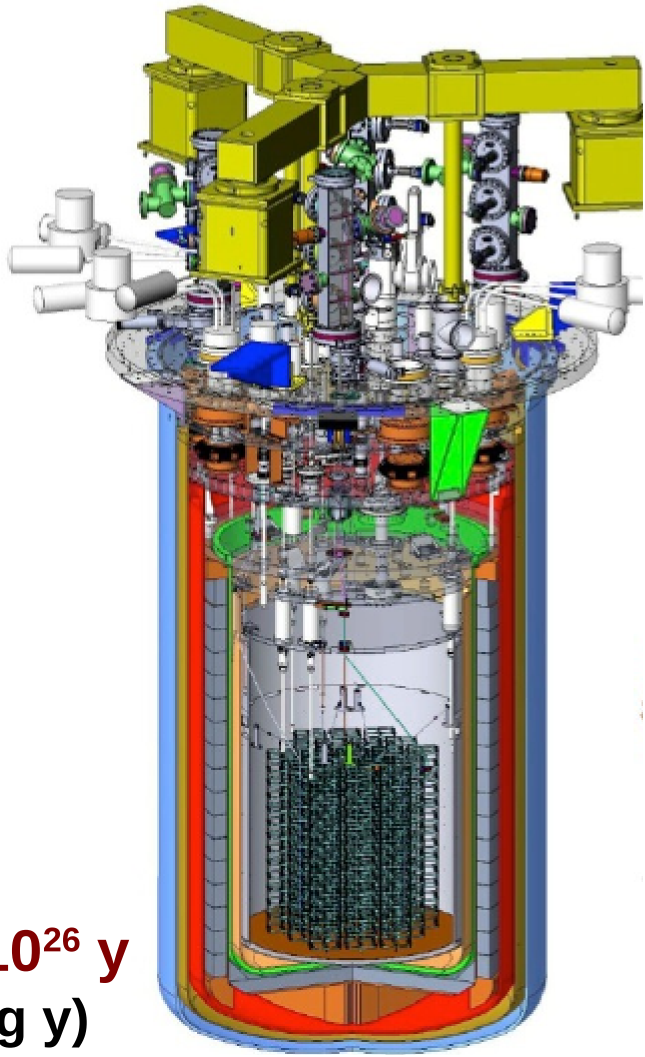


MAIN CONCEPTS:

- **increase the mass**
  ~20 times the mass of Cuoricino
- **improve detector performances**
  5 keV FWHM
- **reduce the background**
  ~20 times lower than Cuoricino

achieve a sensitivity of ~ 10^{26} y
bkg goal 0.01 counts/(keV kg y)

CUORE

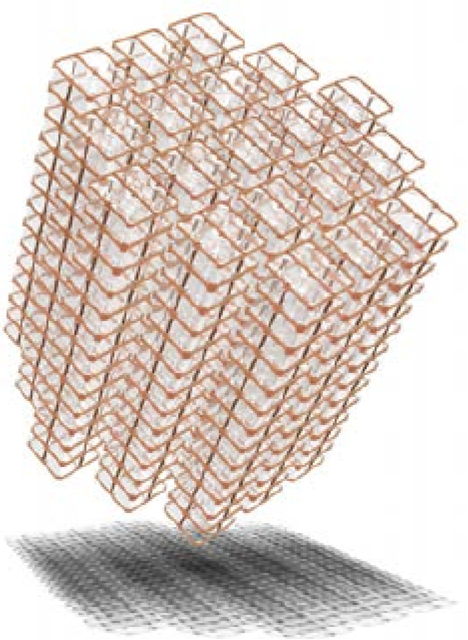


CUORE

Cryogenic Underground Observatory for Rare Events

740 kg TeO_2 ~200 kg ^{130}Te

- 988 TeO_2 ultra-clean crystals run as bolometers
- 19 towers assembled in an ultra-clean environment
- a new cryostat with optimized internal (Roman Lead) and external (Lead + Polyethylene+Boron) shields



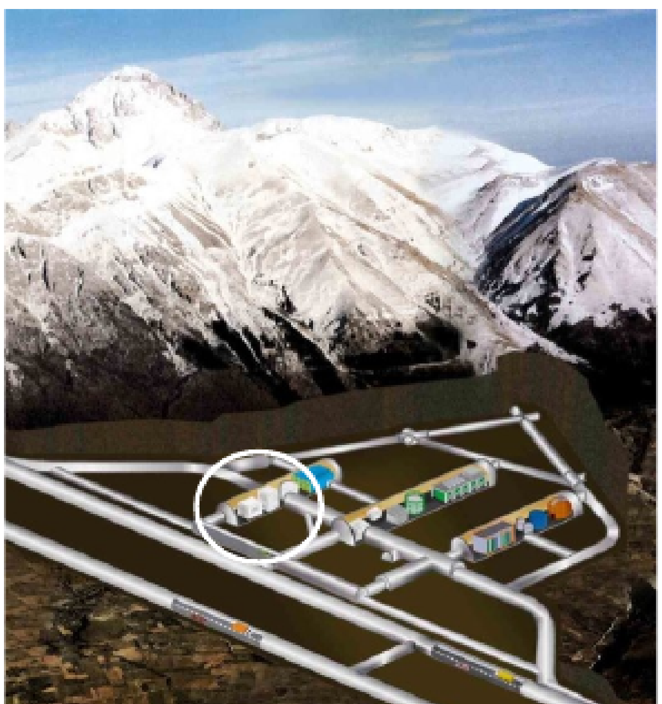
CUORE

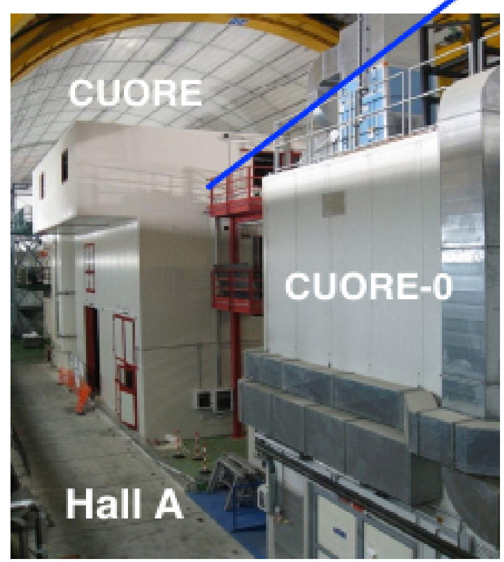
Cryogenic Underground Observatory for Rare Events

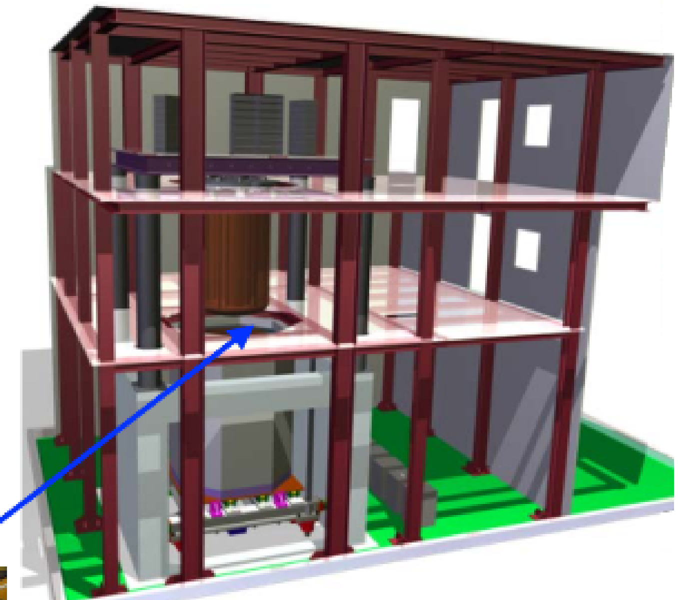
Gran Sasso National Laboratory

Average depth ~ 3600 m.w.e.

μ: 3 x 10^{-8} μ/s/cm^2
n < 10 MeV: 4 x 10^{-6} n/s/cm^2
γ < 3 MeV: 0.73 γ/s/cm^2







CUORE Hut

CUORE: ultraclean bolometers

done!

TeO_2 Crystals

Astroparticle Physics 35 (2012) 839–849

Bulk activity 90% C.L. upper limits:

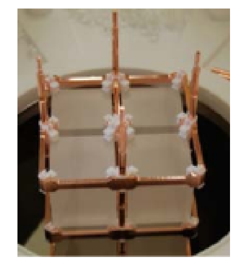
$8.4 \cdot 10^{-7}$ Bq/kg (^{232}Th), $6.7 \cdot 10^{-7}$ Bq/kg (^{238}U), $3.3 \cdot 10^{-6}$ Bq/kg (^{210}Po)

Surface activity 90% C.L. upper limits:

$2 \cdot 10^{-9}$ Bq/cm^2 (^{232}Th), $1 \cdot 10^{-8}$ Bq/cm^2 (^{238}U), $1 \cdot 10^{-6}$ Bq/cm^2 (^{210}Po)

Cu Crystal Holder

Astroparticle Physics 45 (2013) 13–22



- Crystal holder design optimized to reduce passive surfaces (Cu) facing the crystals

- Developed ultra-cleaning process for all Cu components:
  - Tumbling
  - Electropolishing
  - Chemical etching
  - Magnetron plasma etching

T1

T2

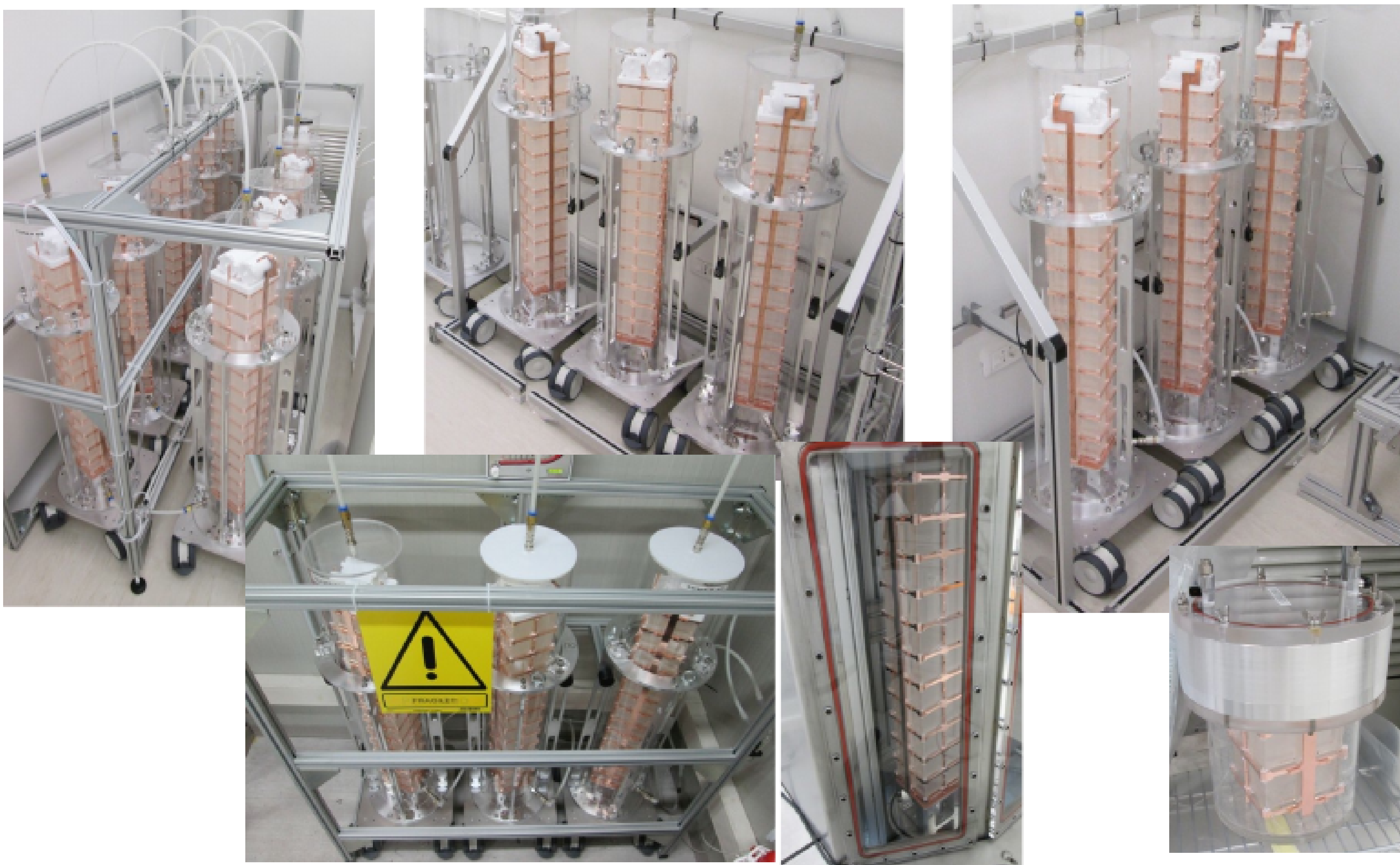
T3

- Benchmarked in dedicated bolometer run at LNGS
  - Residual ^{232}Th / ^{238}U surface contamination of Cu: $< 7 \cdot 10^{-8}$ Bq/cm^2
- Validated by CUORE-0

- All parts stored underground, under nitrogen after cleaning

CUORE:
19 detector towers

done!



CUORE: refrigerator commissioning *in progress*

Phased Commissioning

Phase I: 4K system check

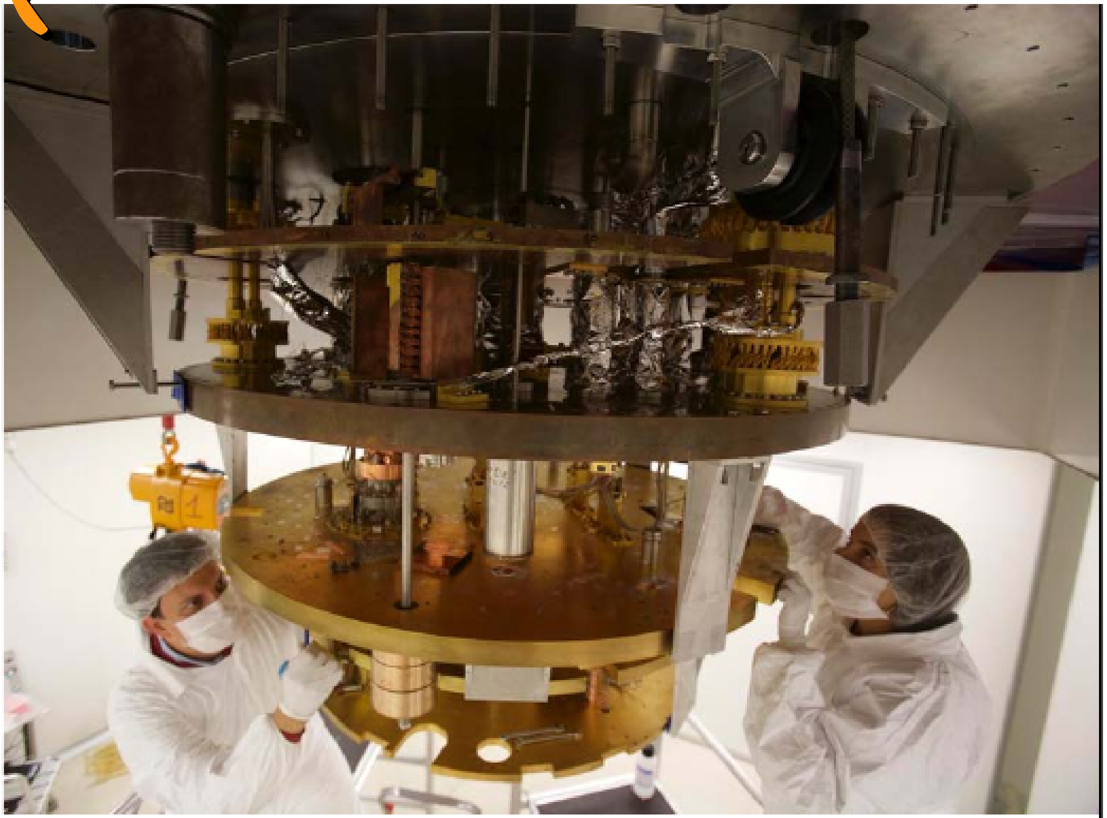
- Outer/Inner vacuum chamber test
- Cryogenic verification of detector calibration system
- Commissioning test of DU

Phase II: full cryostat vessel check

- Full assembly of cryostat
- Cool down of cryostat
- Integration of test tower
- Detector wiring
- calibration system

Preparing for Phase III: integrated cryogenic test

- with lead shield
- wiring
- full calibration system



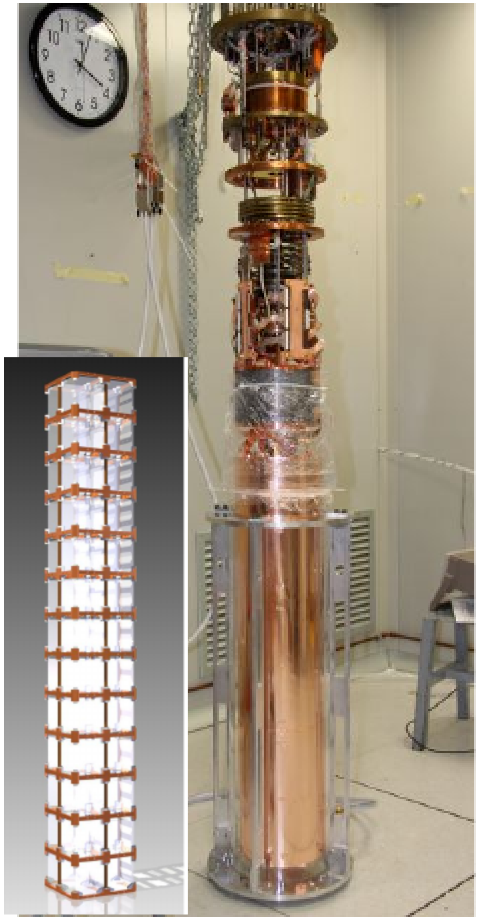
6mK stable base temperature achieved in October 2014

meanwhile …

CUORE-0 !

52 TeO_2 crystals
39 kg TeO_2
~ 11 kg of ^{130}Te

first CUORE-like tower installed in Cuoricino cryostat



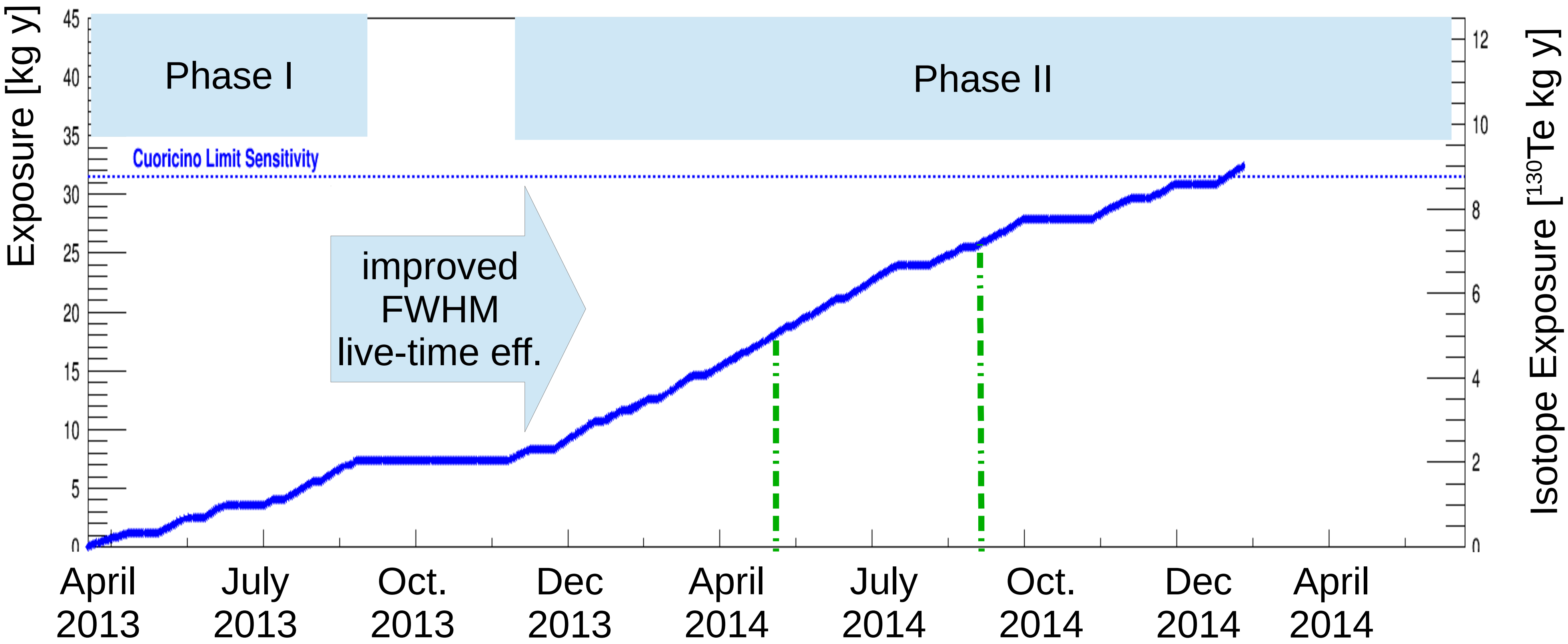
PURPOSE

validate cleaning and assembly procedures for CUORE
- TeO_2 crystal contaminations
- Cu holder surface contamination

stand-alone 0νββ experiment
- phase I data *EPJC 74, 2956 (2014)*
- phase II ongoing
- 0νββ ROI blinded

unblinding when reached Cuoricino sensitivity very soon !

CUORE-0 Exposure



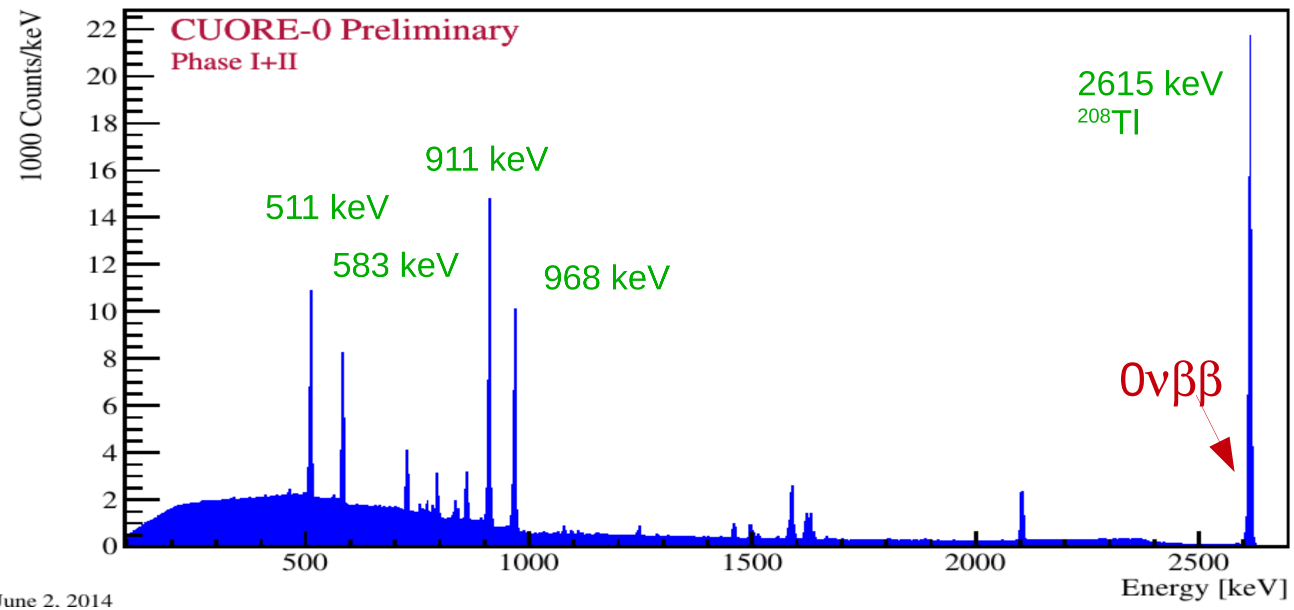
bkg numbers *refer to this Exposure (18.1 kg y)*

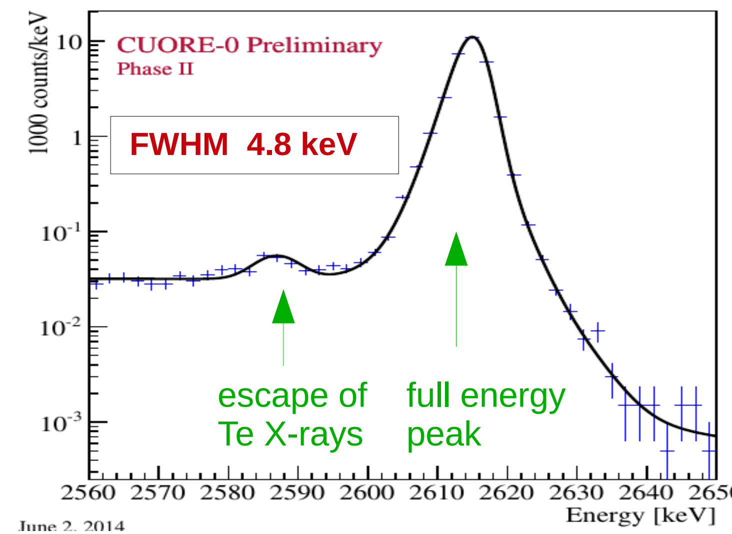
plots *refer to this Exposure (25.81 kg y)*

CUORE-0 resolution

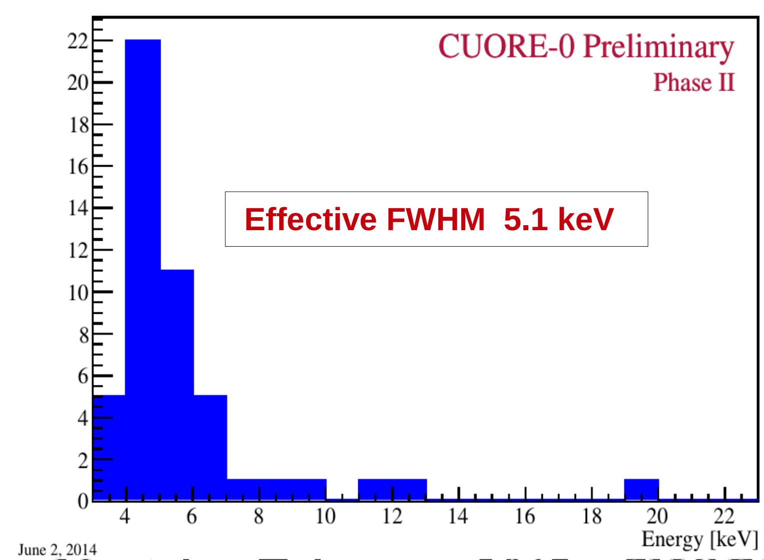
done!

CUORE-0 calibration spectrum -sum over all the detectors





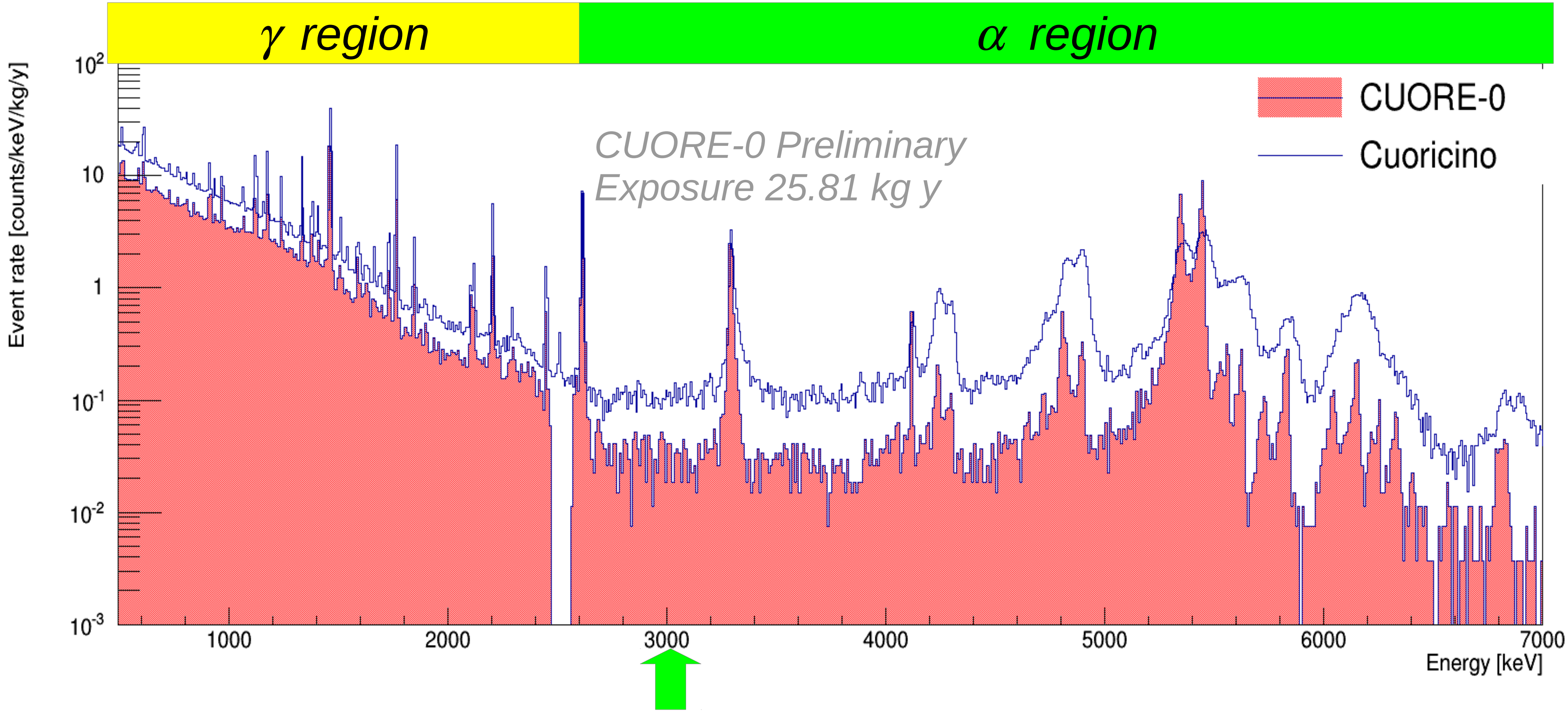
CUORE-0 Calibration Resolution by Channel (Phase II)



- ^{232}Th source (thoriated wires outside the cryostat)
- improved detector operation in phase II

CUORE goal of 5 keV FWHM @ ROI achieved

CUORE-0 background degraded alphas

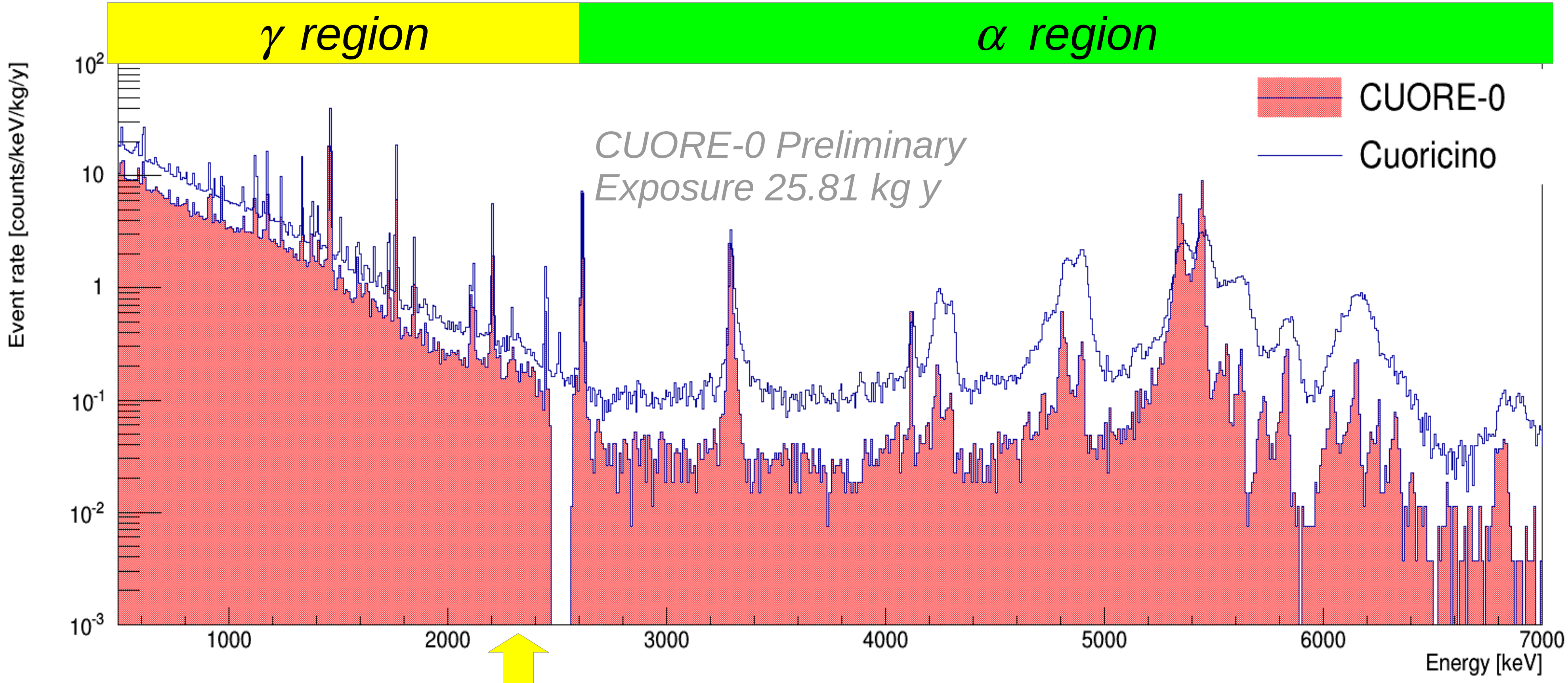


degraded α's background is reduced by a factor 6 !!

ultra-cleaning of Cu surfaces

+ use of radiopure materials for TeO_2 crystal polishing

CUORE-0 background gamma's

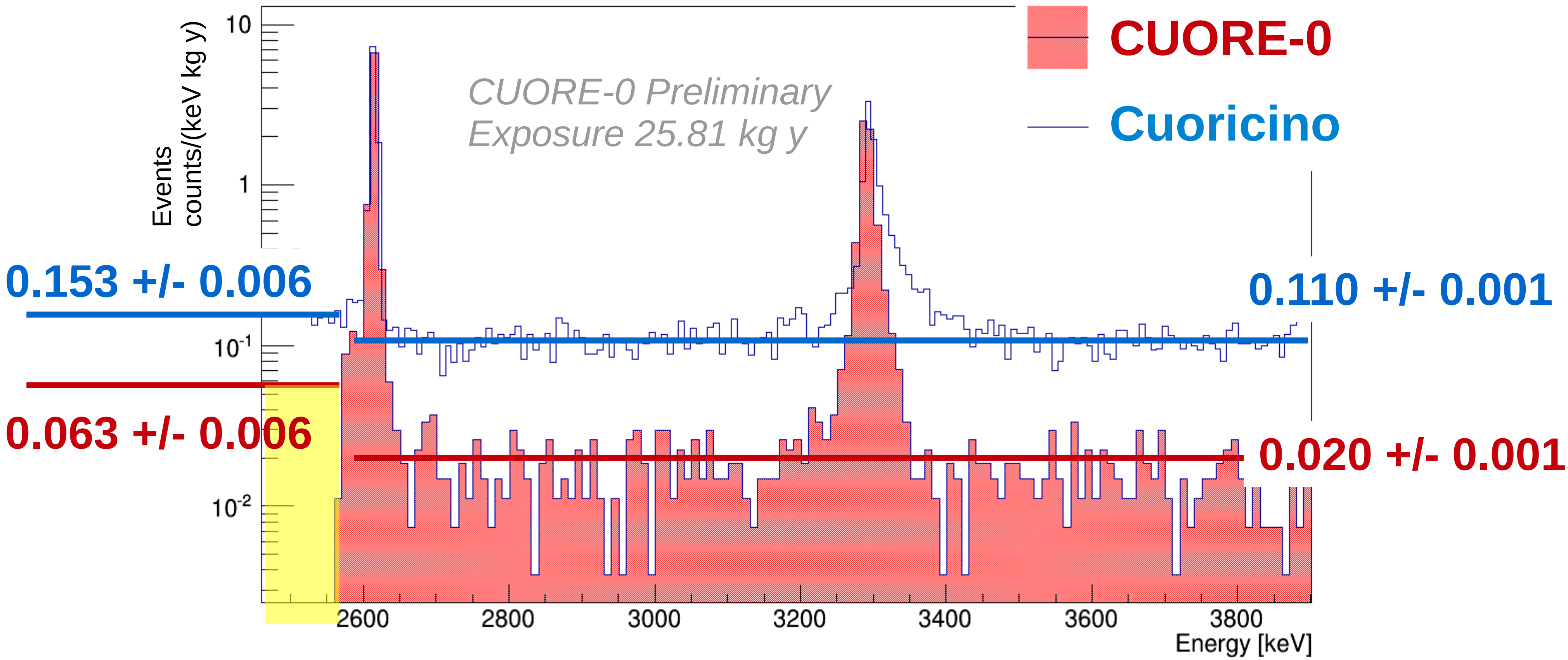


multi-Compton γ's from ^{208}Tl unchanged

^{208}Tl 2615 keV line has the same intensity as in Cuoricino

irreducible ^{232}Th bkg from cryostat

CUORE-0 background



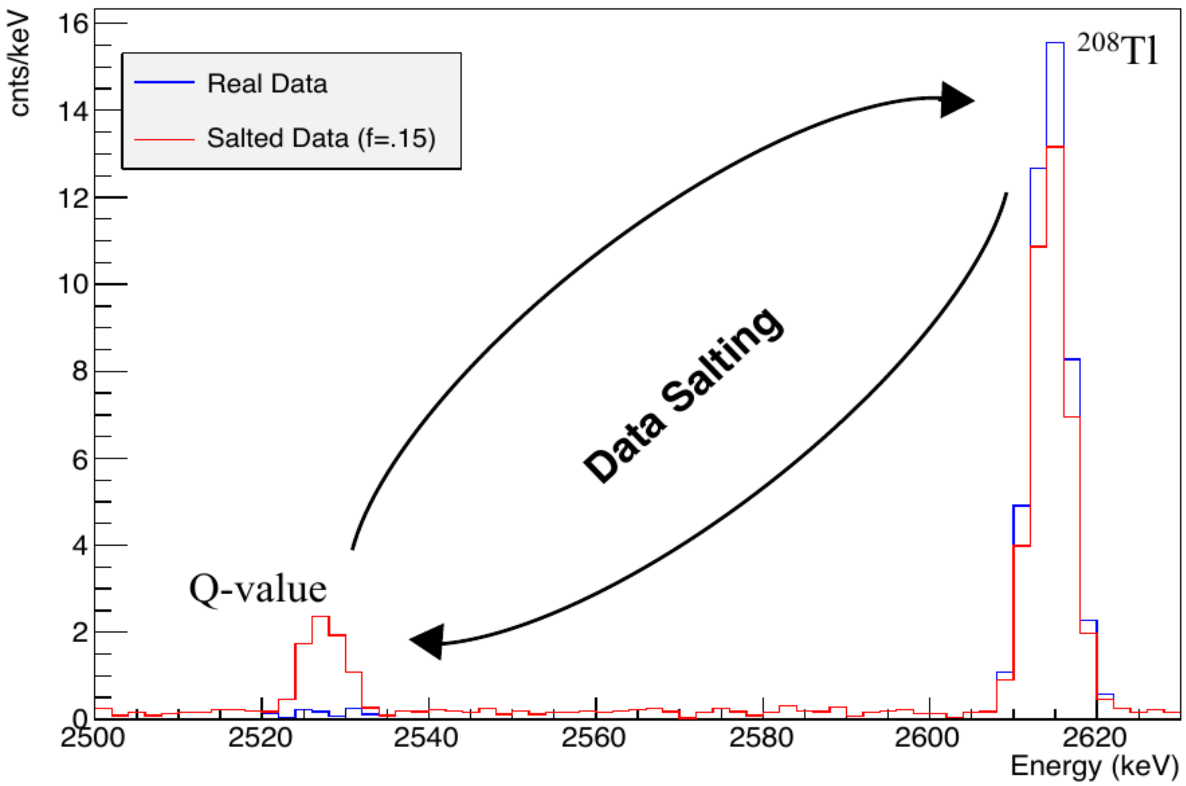
	0νββ region [c/keV/kg/yr]	2700-3900 keV * [c/keV/kg/yr]
CUORICINO ε=83%	0.153 +/- 0.006	0.110 +/- 0.001
CUORE-0 ε =78%	**0.063 +/- 0.006**	**0.020 +/- 0.001**

* excluding the ^{190}Pt peak region

These numbers refer to 18.1 kg y exposure not updated to present Exposure

CUORE-0 blinding

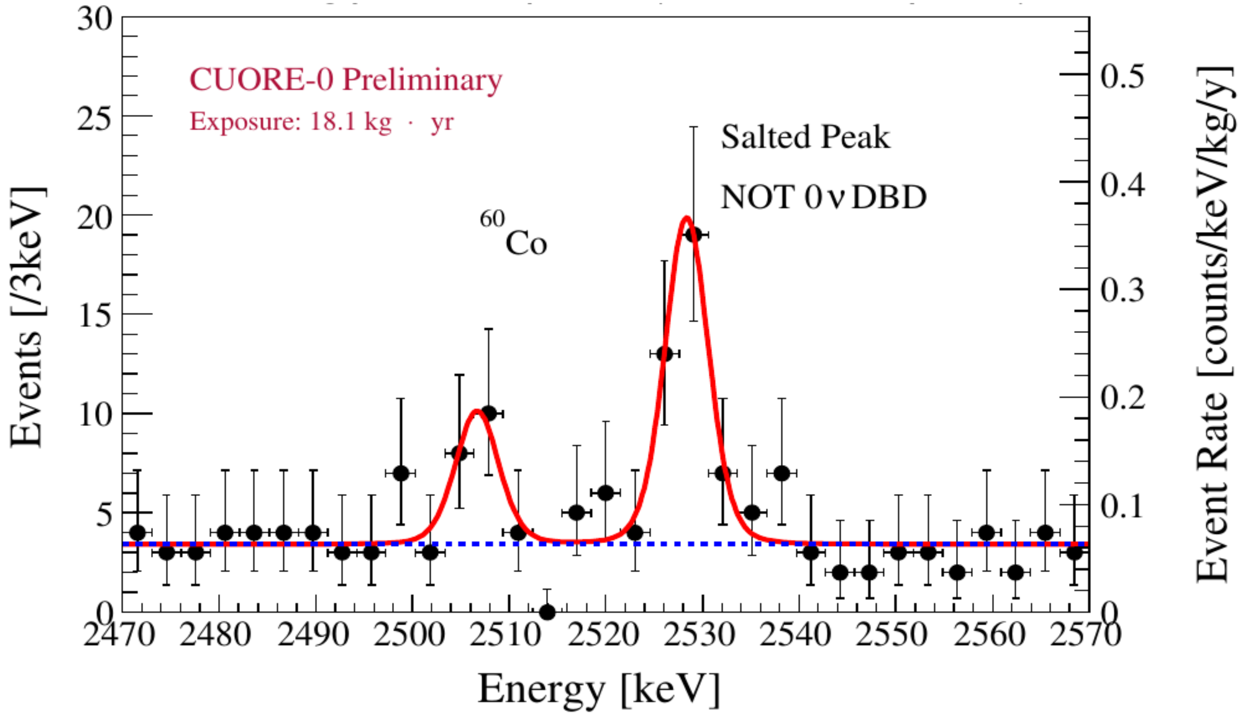
Illustration of *salting* technique



Small (and blinded) fraction of events within ±10 keV of ^{208}Tl photopeak are moved to within ±10 keV of ^{130}Te $0\nu\beta\beta$ decay Q-value, and vice versa

CUORE-0 ROI

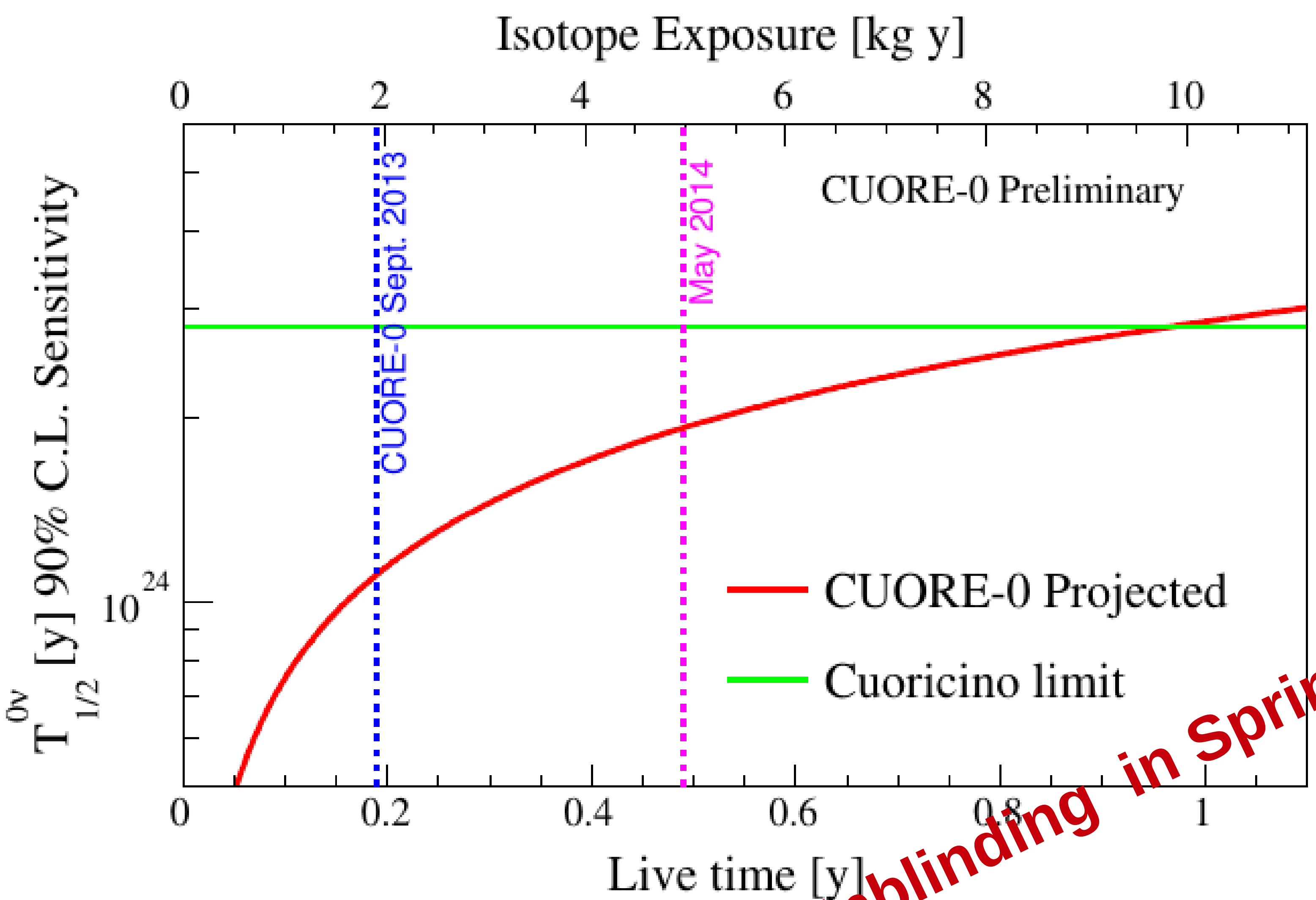
5.0 kg-yr ^{130}Te exposure (Mar 2013 – May 2014)



Signal detection efficiency = 77.6 ± 1.3%
(~87% containment efficiency & ~89% identification efficiency)

D.R.Artusa et al. (CUORE-0 Collaboration) EPJC 74, 2956 (2014) [arXiv:nucl-ex/1402.0922].

CUORE-0 Sensitivity



Unblinding in Spring 2015

… toward CUORE

CUORE-0 confirms

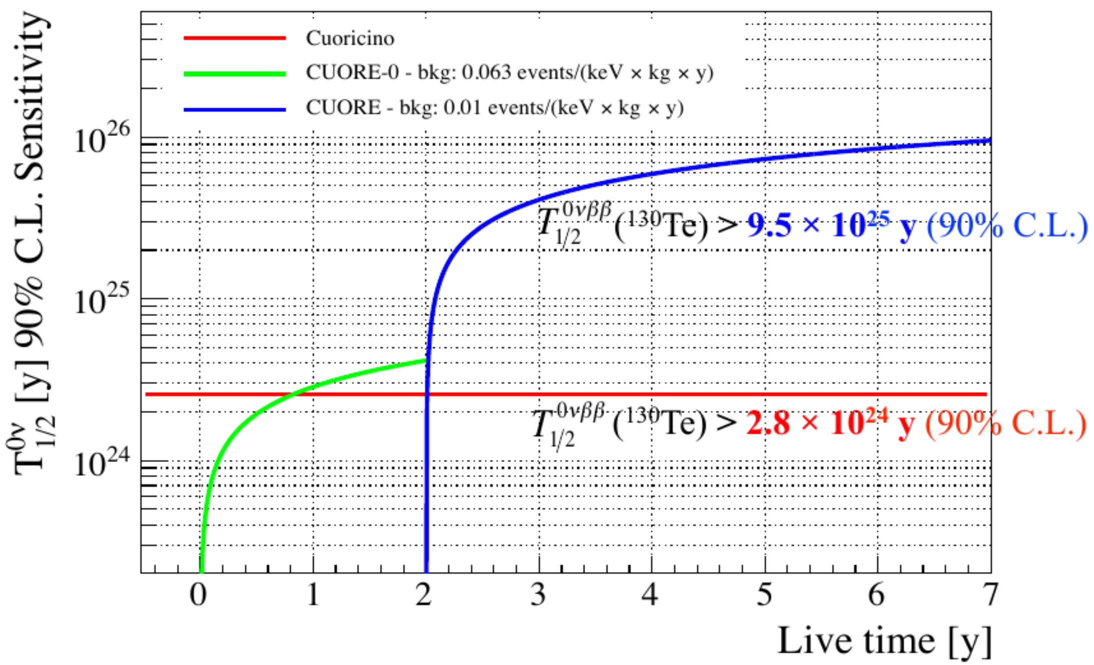
detector performance improvement:
energy resolution 5 keV FWHM

Cuoricino background model:
degraded α + Tl multiCompton

successful results of ultre-clean procedures
TeO_2 surface contribution reduced
Cu surface contribution reduced

CUORE background goal is achieved !

CUORE



Time Shedule

- cryostat commissioning concluded in Spring
- tower installation Spring/Summer
- CUORE operation end of 2015

See "Sensitivity and Discovery Potential of CUORE to Neutrinoless Double-Beta Decay" [arXiv:nucl-ex/1109.0494v3]

CUORE SENSITIVITY GOAL :

^{130}Te $\tau^{0\nu}_{1/2}$ 9.5 x 10^{25} y @ 90% C.L.

Assumptions : 5 keV FWHM + 0.01 c/(keV kg y) + 5 y live-time

Beyond CUORE

GOAL: 10^{27} – 10^{28} y 0νββ Sensitivity

D.R. Artusa et al., Eur.Phys.J. C74 (2014) 3096 - *Exploring the neutrinoless double beta decay in the inverted neutrino hierarchy with bolometric detectors*

STRATEGIES:

use CUORE → know-how
use CUORE → cryogenic facility

work on → $N_{\beta\beta}$ candidates → **isotopic enrichment**
work on → background → **0 counts/ton/y**

Beyond CUORE: what is going on today

CRYSTAL CHOICE + ISOTOPIC ENRICHEMENT

DETECTORS able to suppress a relevant fraction of background (main focus on a particle from surfaces)

OPTIONS
- remove *surface* events
- discriminate α from β/γ

BOLOMETER + PSA

in Scintillating Crystals ***α vs.β***

in TeO_2 with proper coating ***surf. vs. bulk***

BOLOMETER + LIGHT

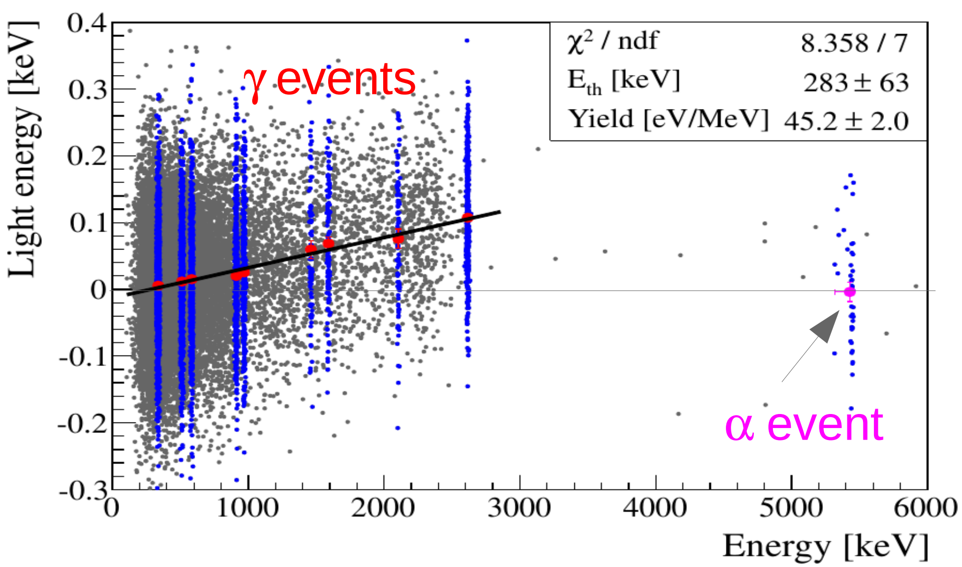
in TeO_2 Cerenkov ***α vs.β***

in Scintillating Crystals ***α vs.β***

Holder Scintillation ***bulk vs. surf.***

^{130}Te option

- CRYSTAL : TeO_2 well known !!
- ENRICHMENT: easy and cheap – positive results from first tests
- ISOTOPE: low $Q_{\beta\beta}$ (2530 keV) environmental γ's are important (2615 keV)
- DETECTOR: no scintillation observed – one possibility is **Cerenkov light**



requires a ~ 20 eV resolution light detector development on the way

TES
Si/Ge Luke effect
mKIDS
...

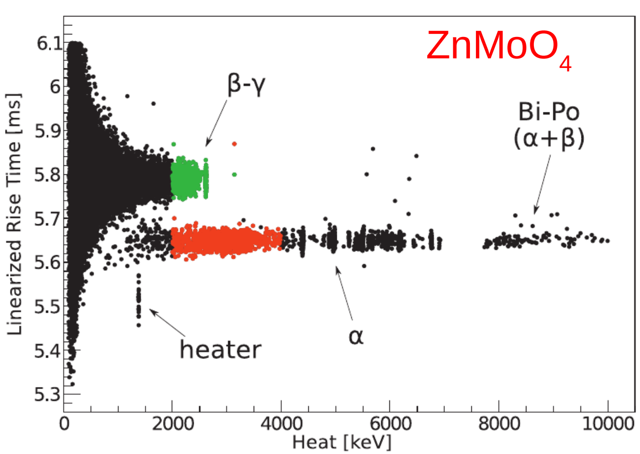
N. Casali, et al., Eur. Phys. J. C 75 (2015) 12

^{82}Se – ^{116}Cd – ^{100}Mo

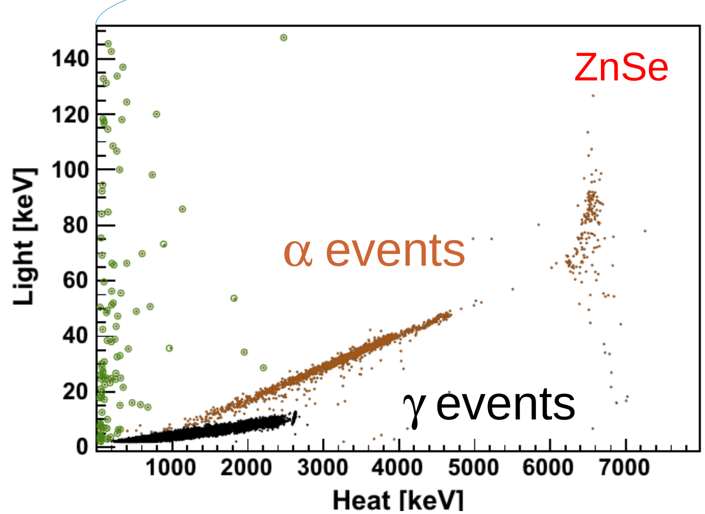
- ✔ choice of crystal and assessment of crystal grow issues (purity, reproducibility …)
- ✔ enrichment feasible but expensive or very expensive
- ! high $Q_{\beta\beta}$ (>2615 keV) environmental γ are nearly irrelevant
- ! scintillating crystals provide a powerful alpha rejection technique

PSA (no light detector)

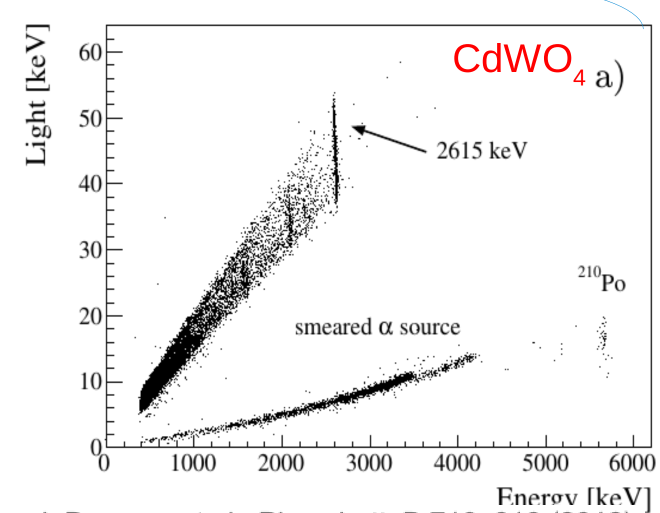
Scintillation (light detector coupled to the main bolometer)



C. Arnaboldi et al. / Astroparticle Physics 34 (2011) 797–804



C. Arnaboldi et al. / Astroparticle Physics 34 (2011) 344–353



J. Beeman et al., Phys. Lett. B 710, 318 (2012)

Conclusions

CUORE-0 running, unblinding is quite near

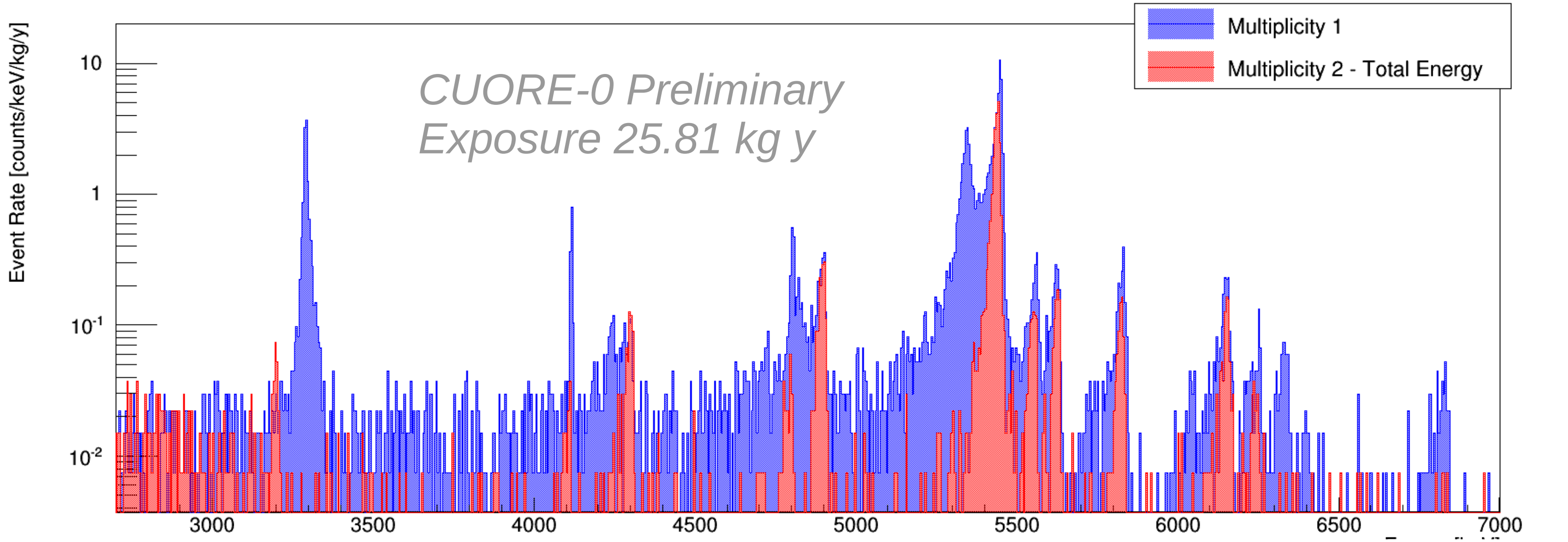
- Cuoricino sensitivity almost reached
- confirms achievement of CUORE energy resolution @ $Q_{\beta\beta}$ = 5 keV FWHM
- confirms Cuoricino background model and proves achievement of background reduction

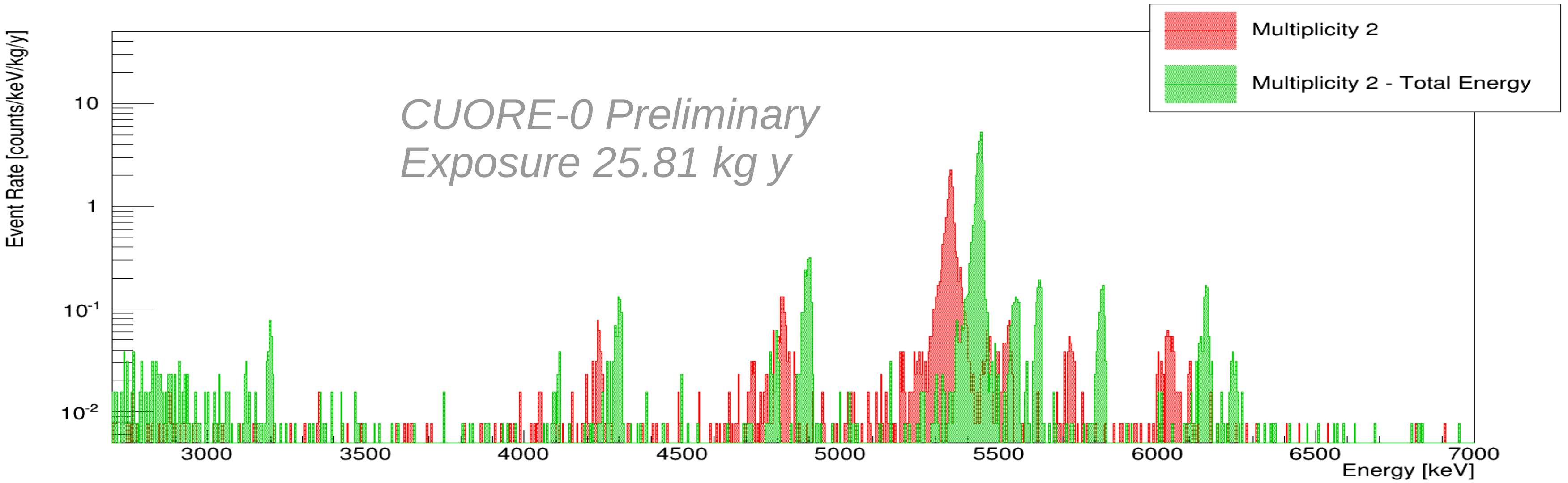
CUORE under construction

- 19 towers already assembled
- first two phases of cryostat commissioning succesful
- switch on by end 2015 !!

BEYOND CUORE …

Cuore-0 α region





CUORE Bkg Budget