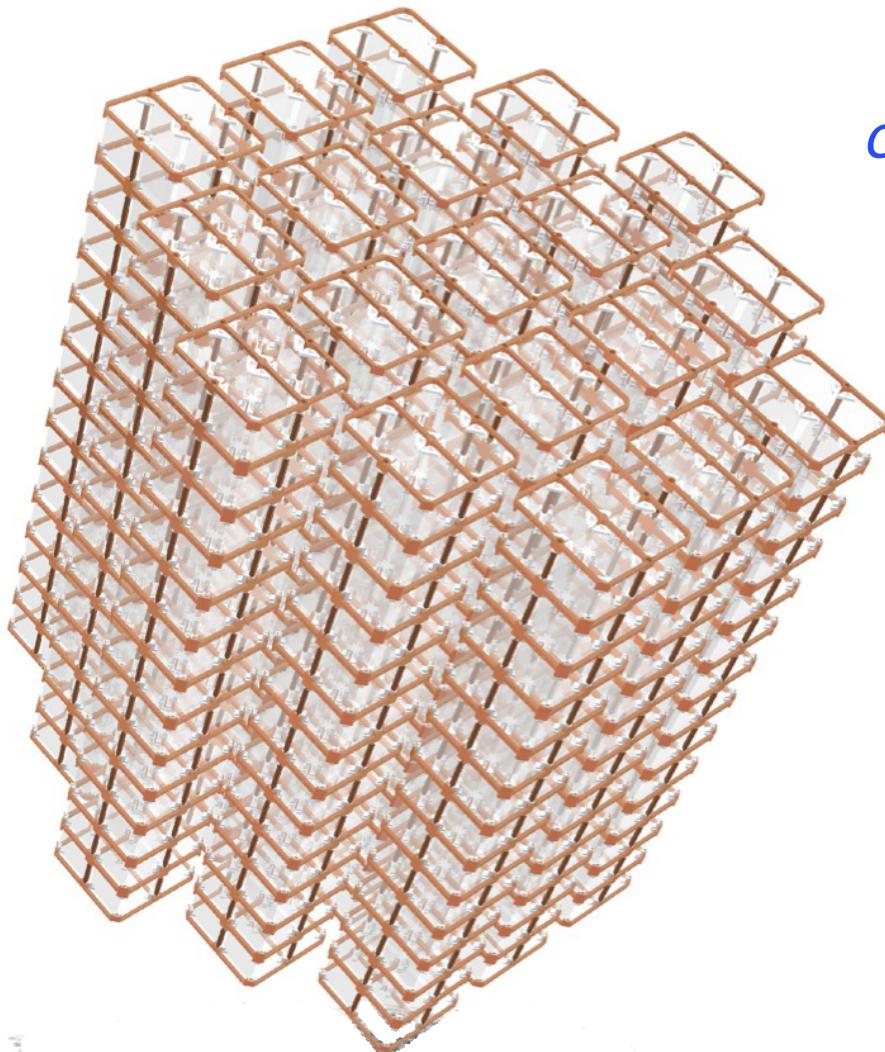


Status of CUORE and CUORE-0 experiments at Gran Sasso



*Fabio Bellini
on behalf of the CUORE Collaboration*



Isotta Meeting Orsay, 01/12/2014

Double beta decay with ^{130}Te

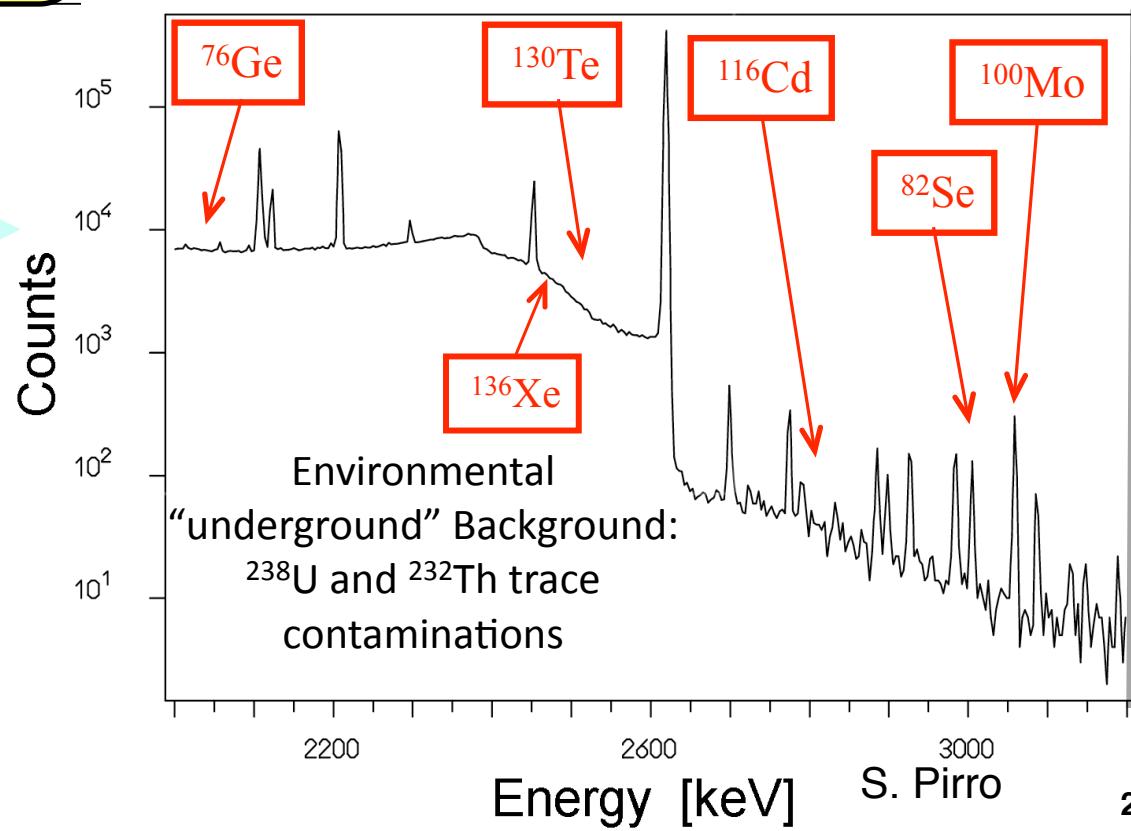
Parent Isotope	$Q_{\beta\beta}$ (KeV)	Ab(%)
^{48}Ca	4271	0.187
^{76}Ge	2039	7.8
^{82}Se	2995	9
^{100}Mo	3034	9.6
^{116}Cd	2902	7.5
^{130}Te	2530	33.9
^{136}Xe	2479	8.9
^{150}Nd	3367	5.6

Gain ~ 100
if

$Q_{\beta\beta} > 2615 \text{ keV}$

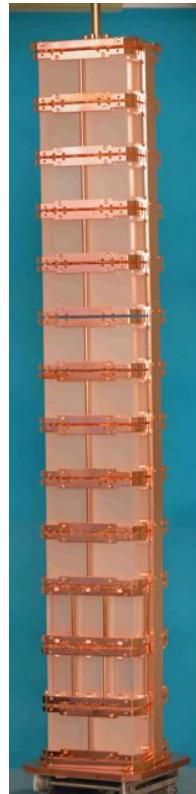
end of γ radioactivity (^{208}Tl)

Isotopic abundance:
 $<10\%$
only exception ^{130}Te



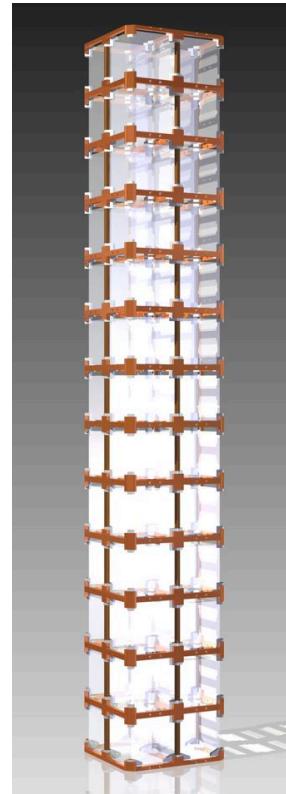
CUORE 0vDBD search

“Recent” past



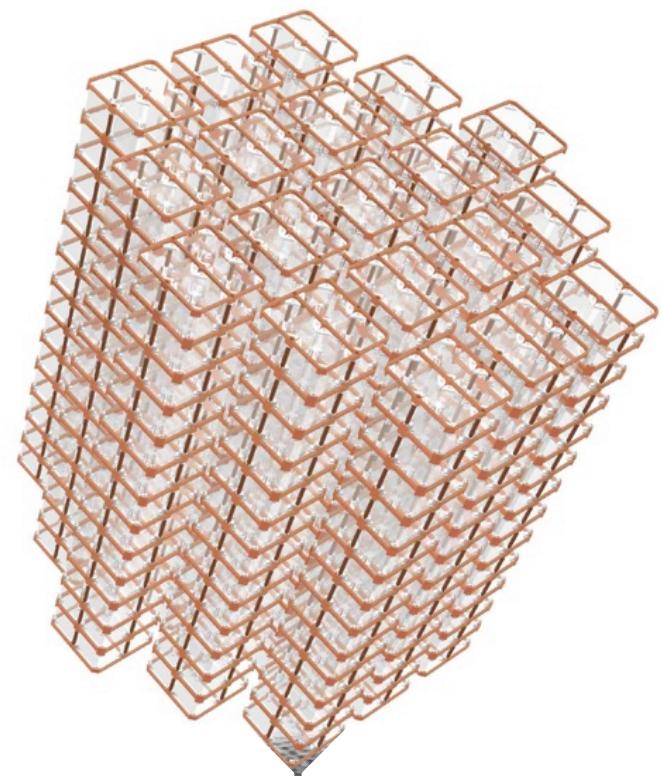
CUORICINO
2003-2008
11 kg ^{130}Te

Present



CUORE-0
2013-2015
11 kg ^{130}Te

“Near” feature



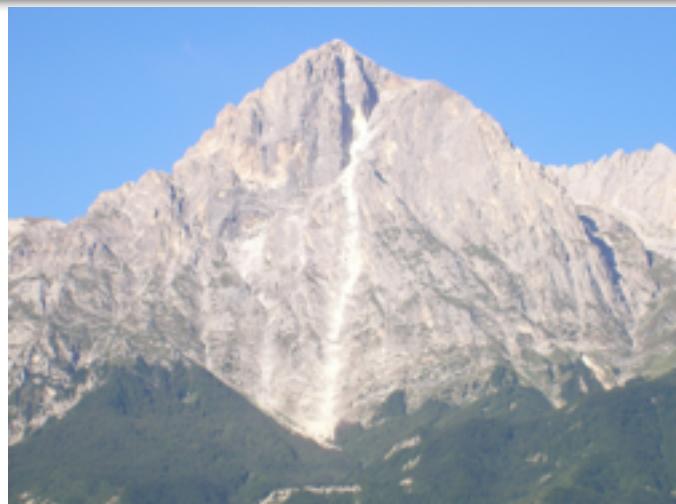
CUORE
2015-2020
206 kg ^{130}Te

$T^{0\nu}_{1/2} > 2.8 \times 10^{24} \text{ y (90\% CL)}$
 $\langle m_{\beta\beta} \rangle < 300\text{--}710 \text{ meV}$

will reach Cuoricino
sensitivity in few months

$T^{0\nu}_{1/2} > 9.5 \times 10^{25} \text{ y (90\% CL)}$
 $\langle m_{\beta\beta} \rangle < 50\text{--}130 \text{ meV}$

Gran Sasso lab in Italy

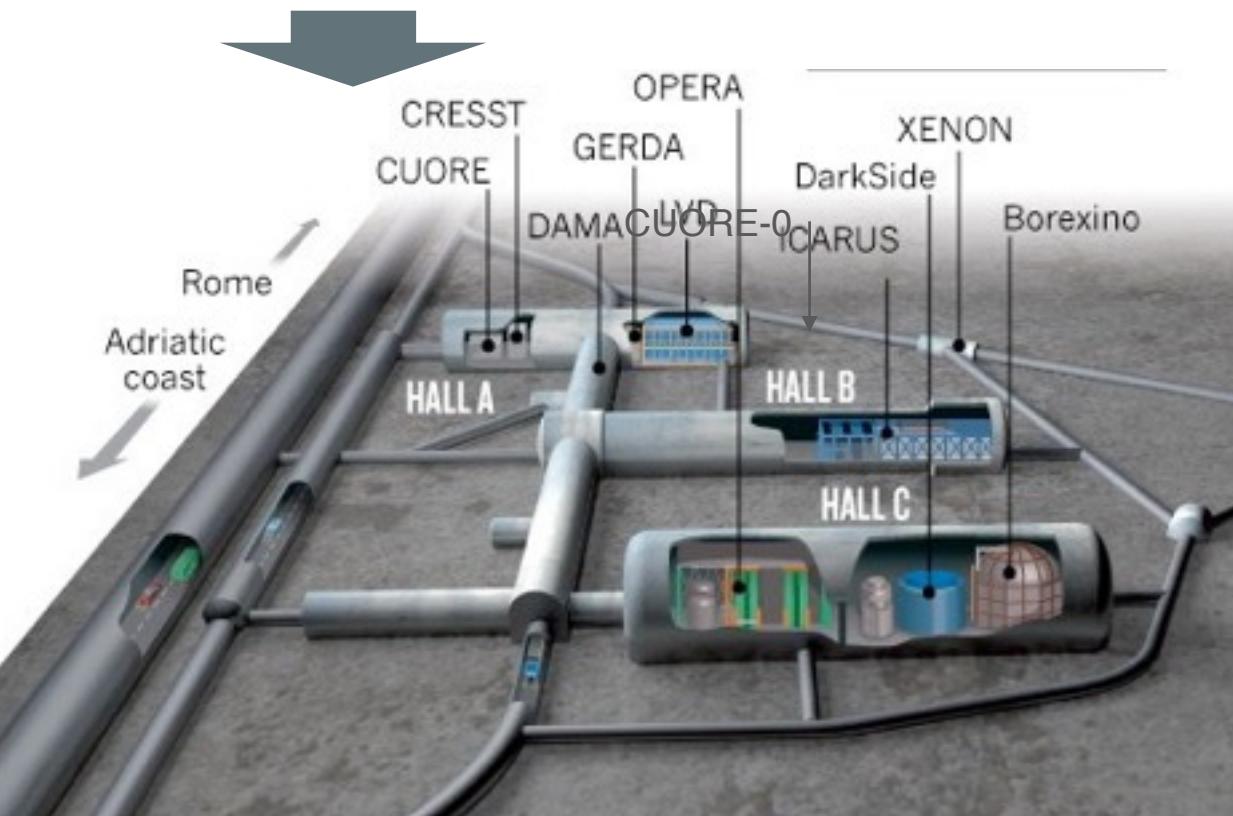


3650 m.w.e. deep

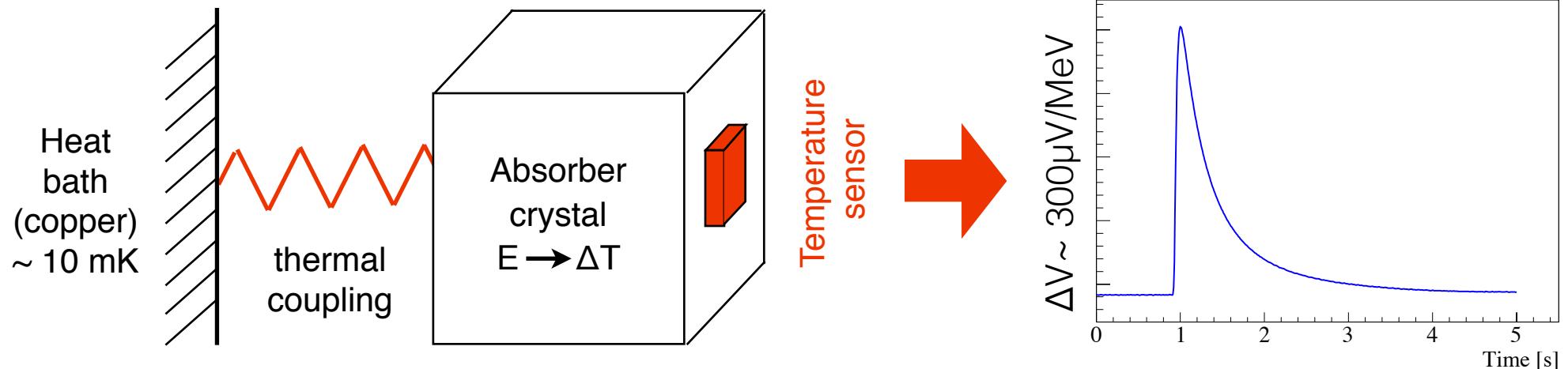
μs : $2.58 \times 10^{-8} / (\text{s cm}^2)$

γs : $\sim 0.73 / (\text{s cm}^2)$

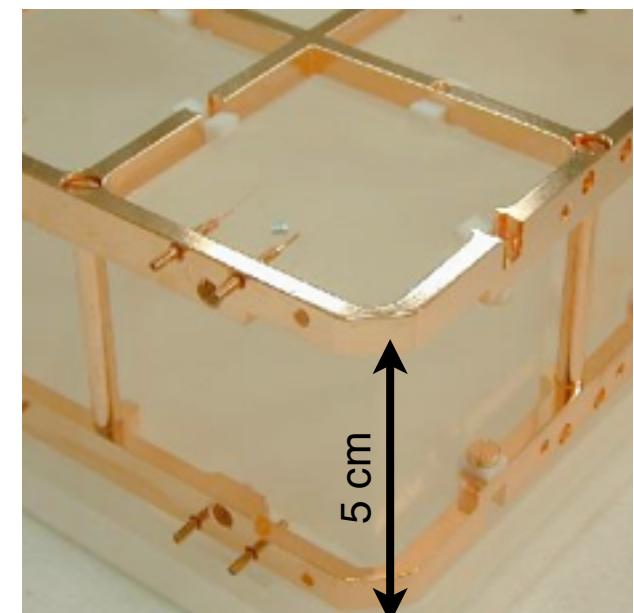
neutrons: $4 \times 10^{-6} \text{ n}/(\text{s cm}^2)$



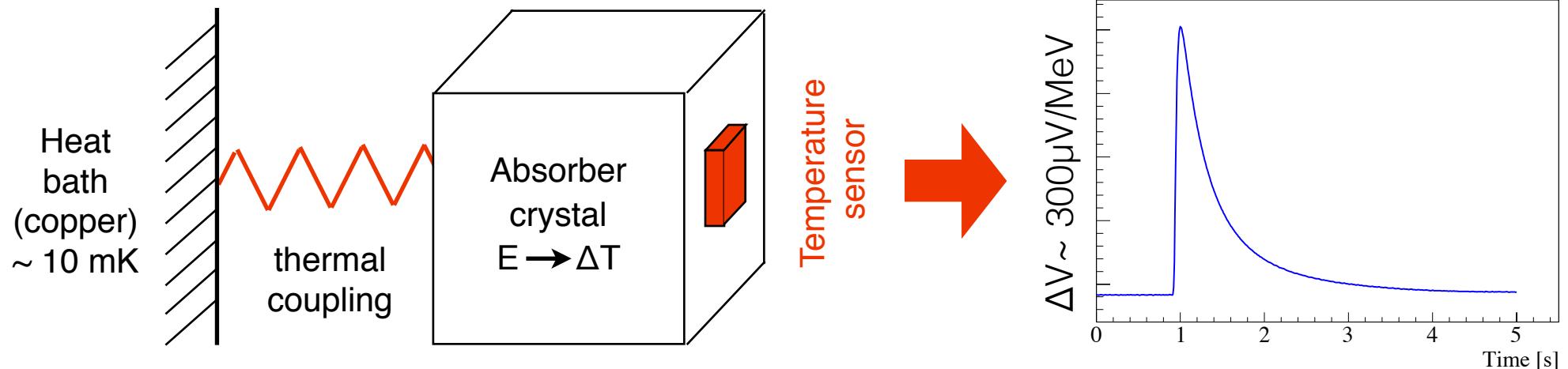
Bolometric technique in CUORE



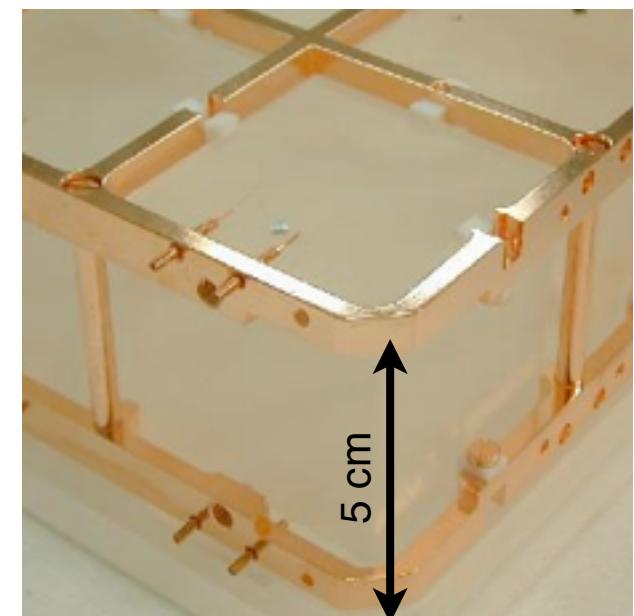
- 0.75 Kg $^{nat}\text{TeO}_2$ crystals:
 - ▶ $C \sim 10^{-9} \text{ J/K} \rightarrow \Delta T / \Delta E \sim 100 \mu\text{K/MeV}$
- NTD-Ge thermistor: $R = R_0 \exp(T_0/T)^{1/2}$
 - ▶ $R \sim 100 \text{ M}\Omega \rightarrow \Delta R / \Delta E \sim 3 \text{ M}\Omega/\text{MeV}$
- Joule heater to correct thermal gain



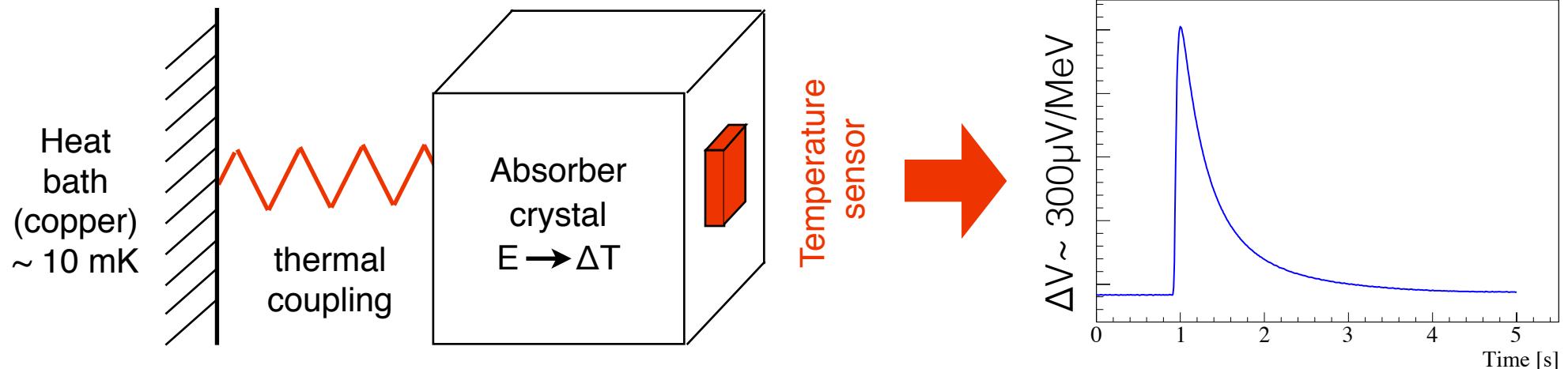
Bolometric technique in CUORE



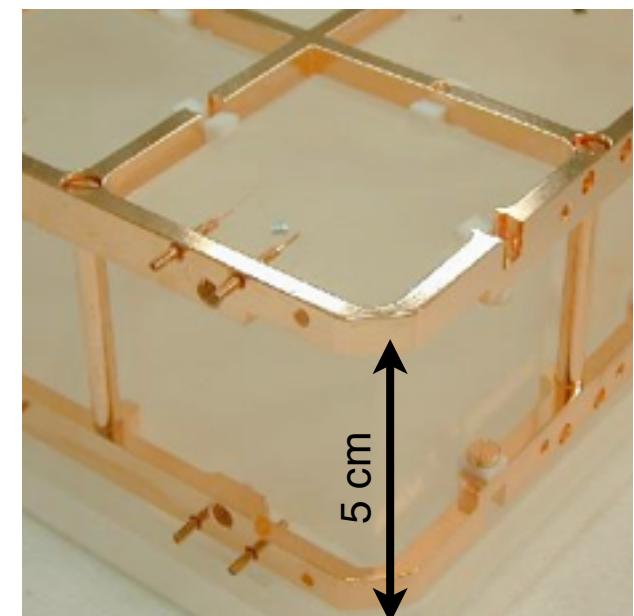
- Excellent resolution @ $0\nu\beta\beta$ energy: $\Delta E_{\text{FWHM}} \sim 5 \text{ keV}$
- Fully sensitive up to the surface
- No α vs β/γ discrimination in the heat channel



Bolometric technique in CUORE

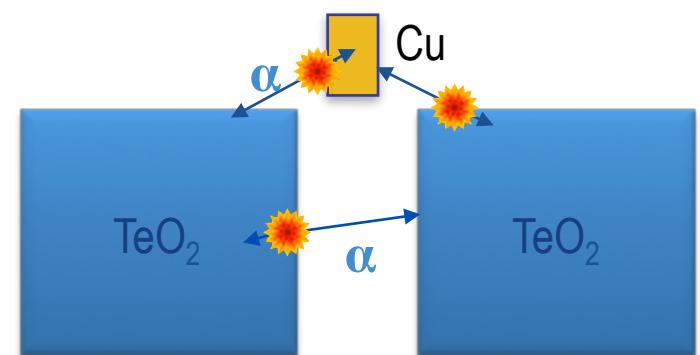
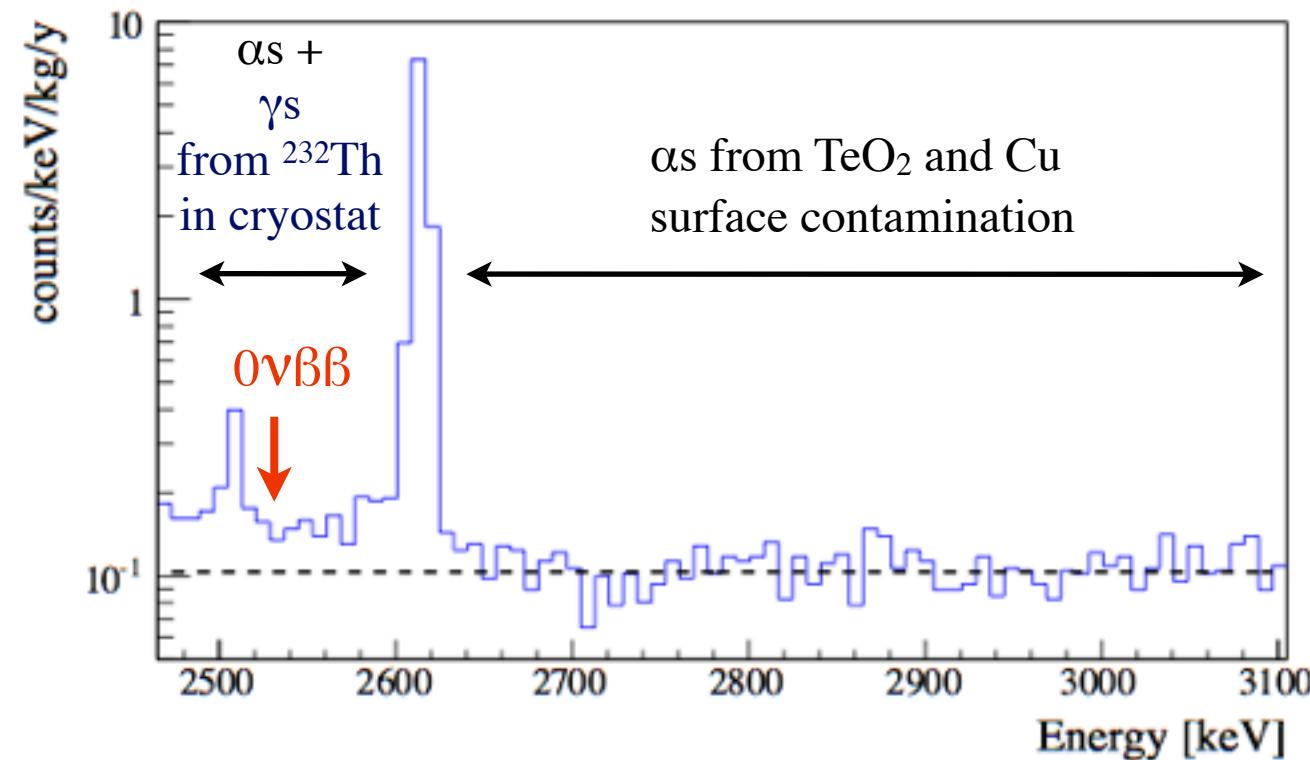
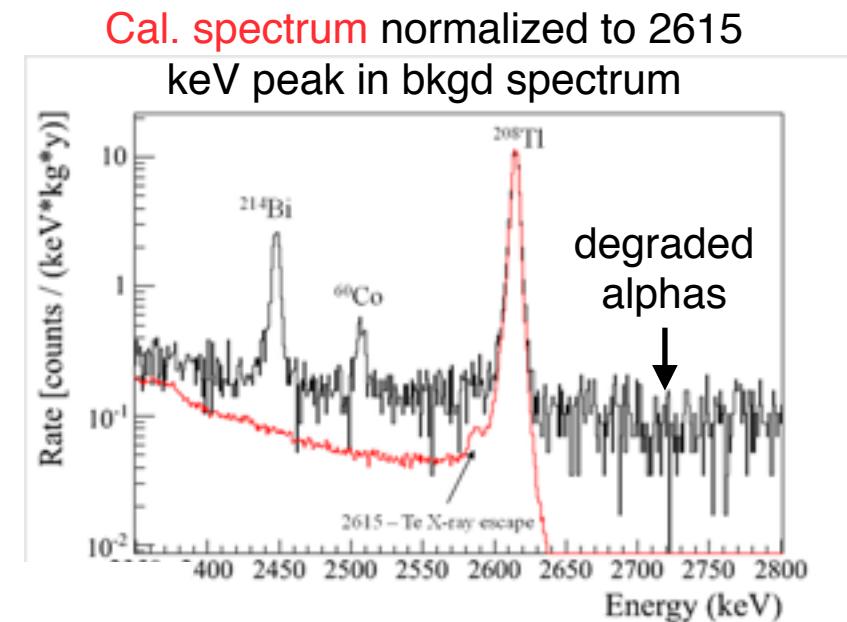


- Excellent resolution @ $0\nu\beta\beta$ energy: $\Delta E_{FWHM} \sim 5$ keV
 - Fully sensitive up to the surface
 - No α vs β/γ discrimination in the heat channel
- ⇒ radio-purity control: CUORE primary effort



The CUORICINO experience

- Exposure: $19.75 \text{ kg} \cdot \text{y}$ ^{130}Te
- $T^{0\nu}_{1/2} > 2.8 \times 10^{24} \text{ years}$ (90% CL)
 $\langle m_{\beta\beta} \rangle < 300 \sim 710 \text{ meV}$
- Background level (790g only):
0.15 counts/keV/kg/year



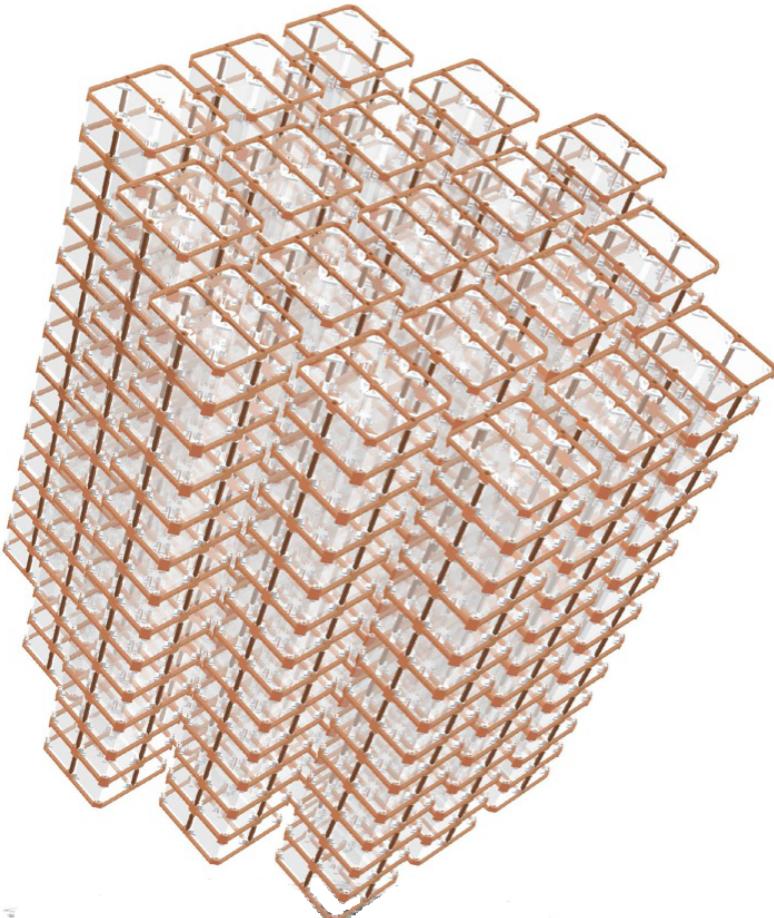
The CUORE goal

- Start to probe the inverted hierarchy:

$$\frac{1}{|m_{\beta\beta}|^2} \sim F_N \cdot \text{I.A.} \times$$

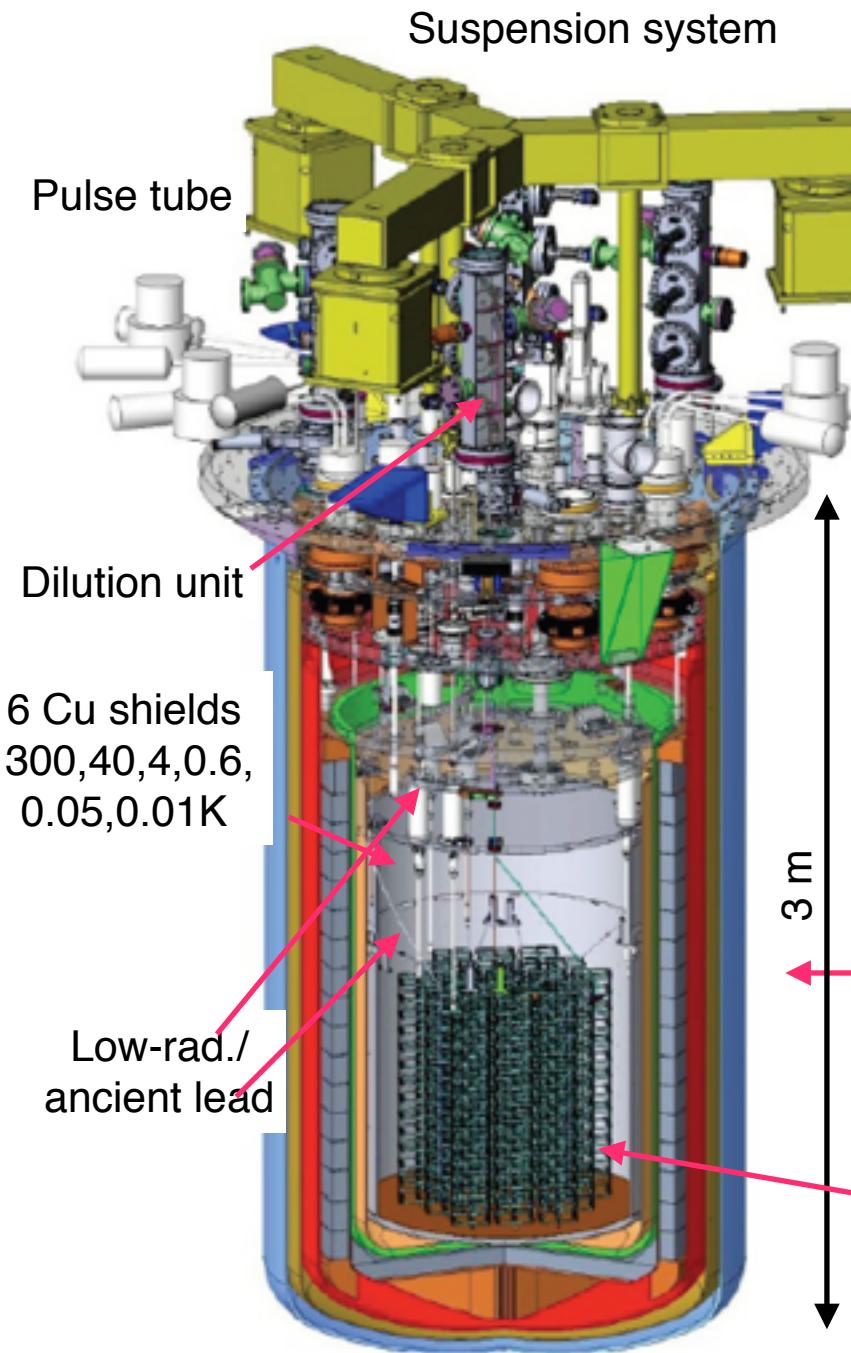
- Scale up Mass by 19X: 741(206) kg (^{130}Te)
- Reduce bkgd by ~15X: 0.01 counts/keV/kg/year

$$\sqrt{\frac{\text{Mass} \cdot \text{livetime}}{\text{bkg.} \cdot \Delta E}}$$



- New cryogenic system
- Better shielding
- Cleaner crystals
- Cleaner copper and less of it per kg of TeO₂
- Cleaner assembly environment & more robust assembly procedure

Cryogenic system & shielding



- Pulse tube dilution refrigerator & cryostat:
~3 Ton @ 10 mK (~20 Ton@various stages)
- Stringent radioactivity constraints on materials and clean assembly
- Independent suspension of detectors from dilution unit

Not shown in the figure:
external Lead shield >25 cm

+
18 cm PET + 2 cm H_3B0_3

passive and active bolometers self-shielding

Crystals

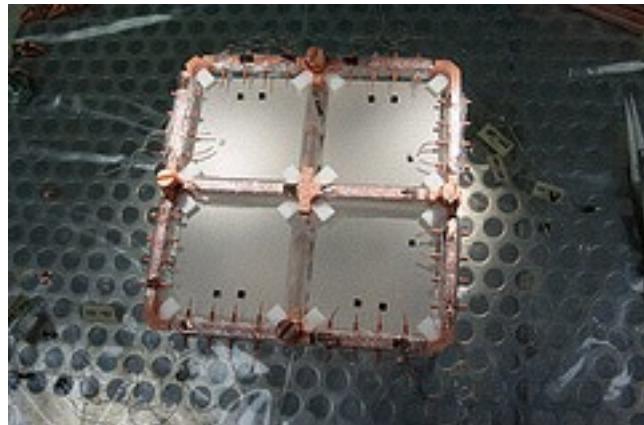
- Radio-purity control protocol to limit bulk & surface contaminations in crystal production

J. Crys. Growth 312 (2010) 2999-3008

Isotope	Allowed Contamination
^{238}U	$< 3 \cdot 10^{-13} \text{ g/g}$
^{232}Th	$< 3 \cdot 10^{-13} \text{ g/g}$
^{210}Pb	$< 1 \cdot 10^{-5} \text{ Bq/kg}$
^{210}Po	$< 0.1 \text{ Bq/kg}$

- Benchmarked in dedicated runs at LNGS

Astropart. Phys. 35 (2012) 839–849

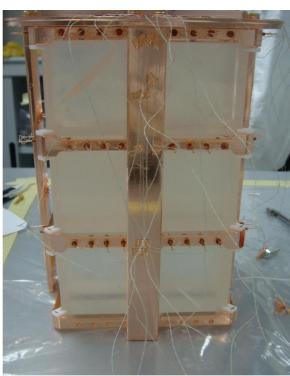


	Bulk(90% C.L. U.L.)	Surface(90% C.L.U.L)
^{238}U	$5 \cdot 10^{-14} \text{ g/g}$	$1 \cdot 10^{-9} \text{ Bq/cm}^2$
^{232}Th	$2 \cdot 10^{-13} \text{ g/g}$	$2 \cdot 10^{-9} \text{ Bq/cm}^2$
^{210}Pb	$3.3 \cdot 10^{-6} \text{ Bq/kg}$	$9.8 \cdot 10^{-7} \text{ Bq/cm}^2$
^{210}Po	0.05 Bq/kg	

- CUORE: bkgd $< 1.1 \cdot 10^{-4}$ ($4.2 \cdot 10^{-3}$) counts/keV/kg/y from **bulk** (surface)

Copper

- Crystal holder optimised to reduce passive Cu surfaces facing crystals

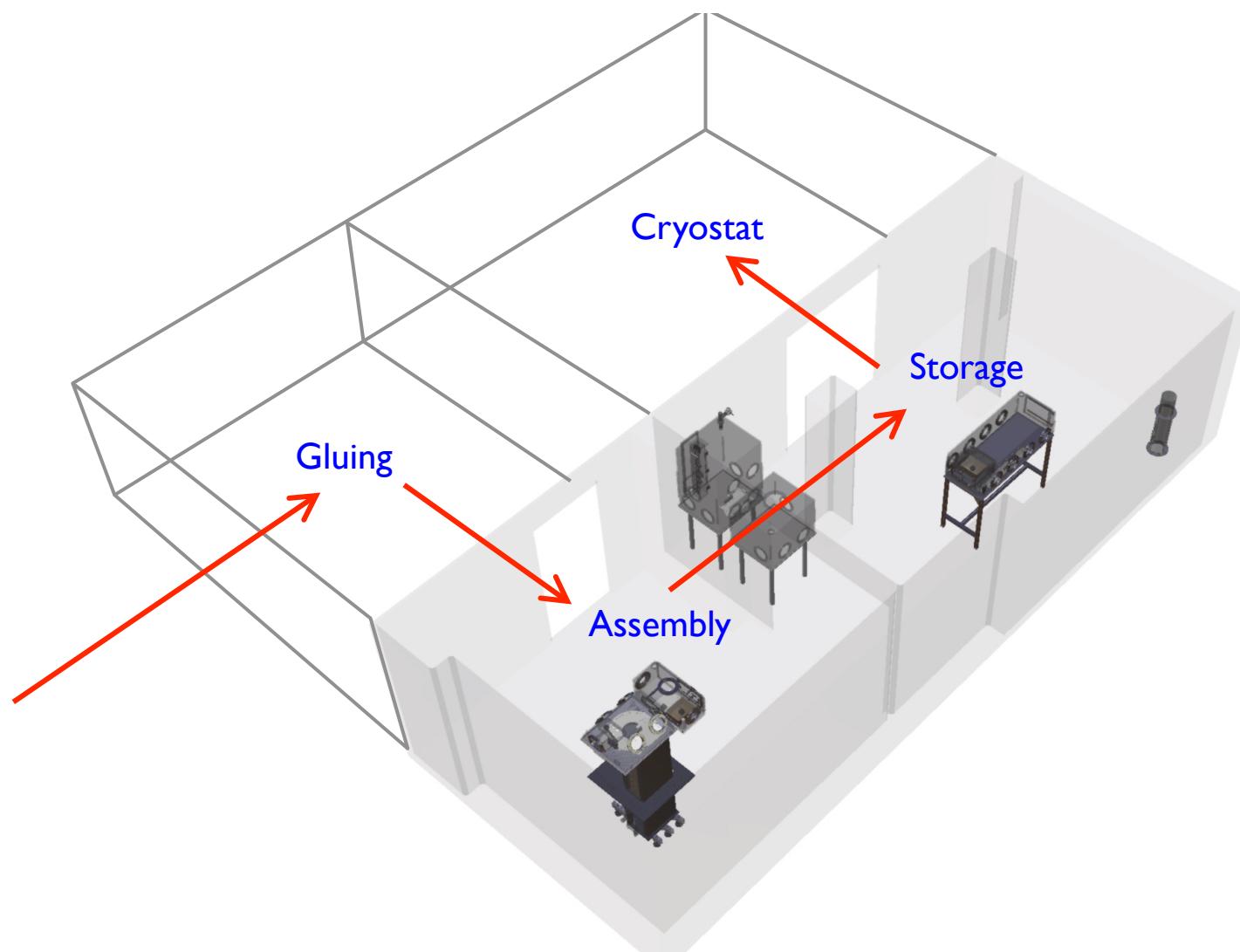


- Ultra-cleaning process for all Cu components:
 - ▶ Tumbling
 - ▶ Electropolishing
 - ▶ Chemical etching
 - ▶ Magnetron plasma etching
- CUORE: $\text{bkgd} < 2 \cdot 10^{-2} \text{ counts/keV/kg/y}$
- All Cu parts cleaned & stored underground, under N_2 atmosphere

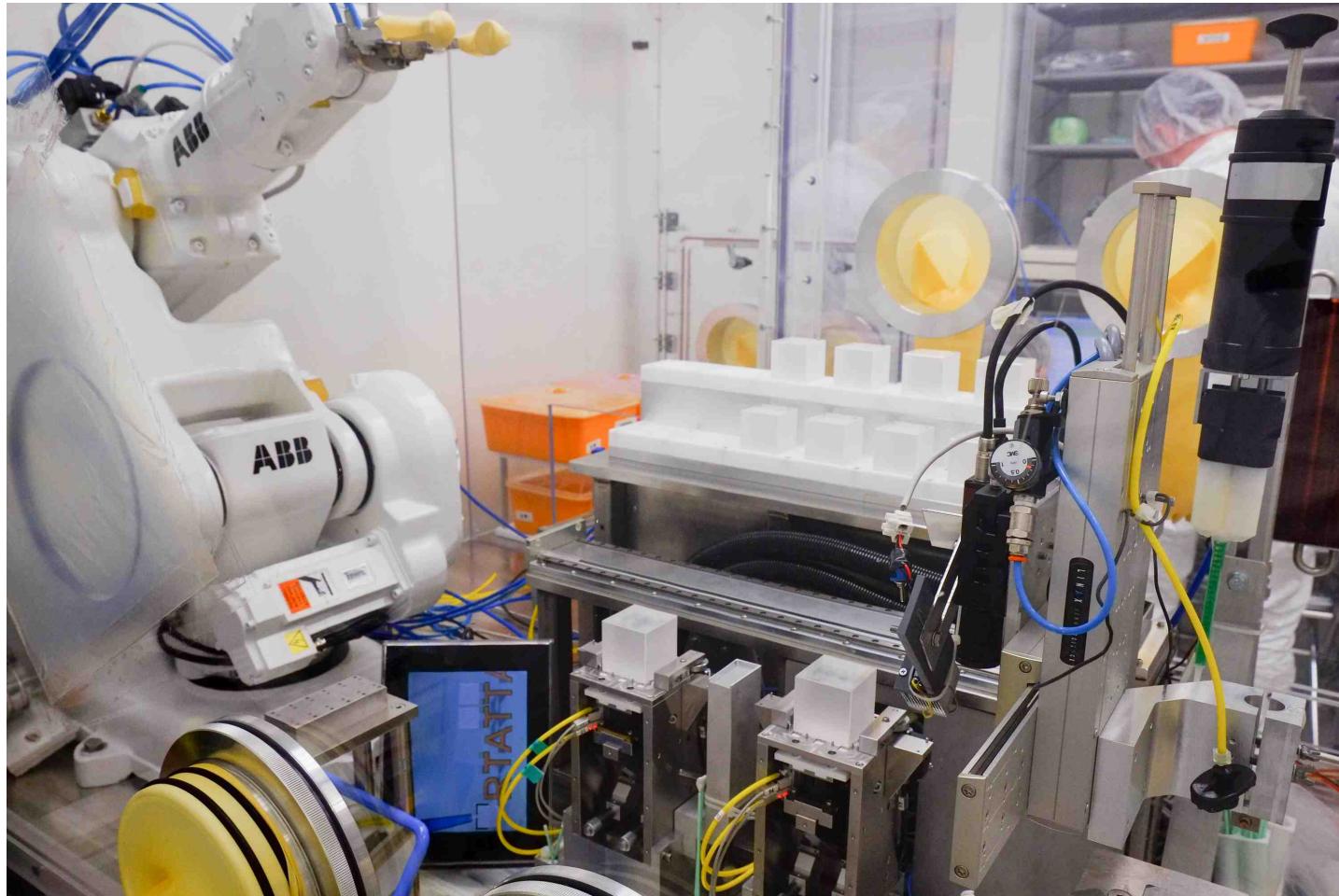
	Surface (90% C.L.U.L)
^{238}U	$7 \cdot 10^{-7} \text{ Bq/cm}^2$
^{232}Th	$7 \cdot 10^{-8} \text{ Bq/cm}^2$
^{210}Po	$9 \cdot 10^{-7} \text{ Bq/cm}^2$

Detector assembly

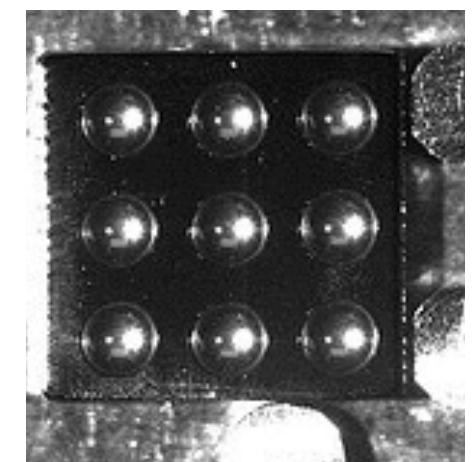
- Crystals are prepared & assembled into towers inside a N₂-flushed glove box in a class 1000 clean room



Chip Gluing

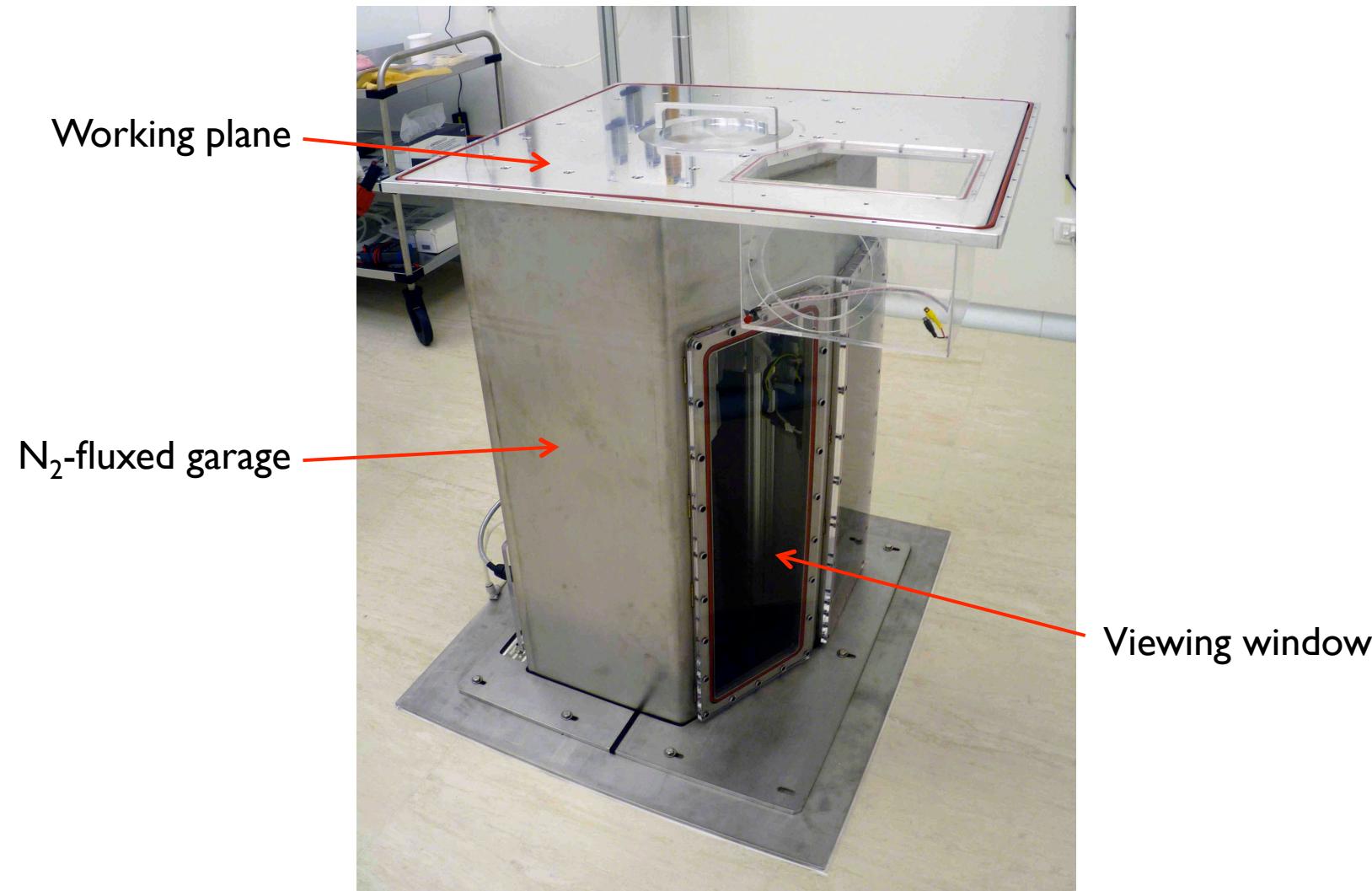


Semi-automated,
glovebox-
enclosed system
for gluing sensor
to crystals



Tower assembly line

Detectors towers built using this workstation, with task-specific glove box

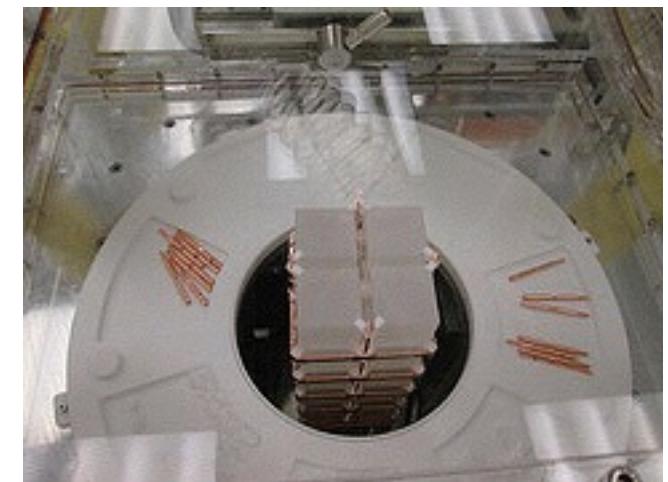


Tower assembly line

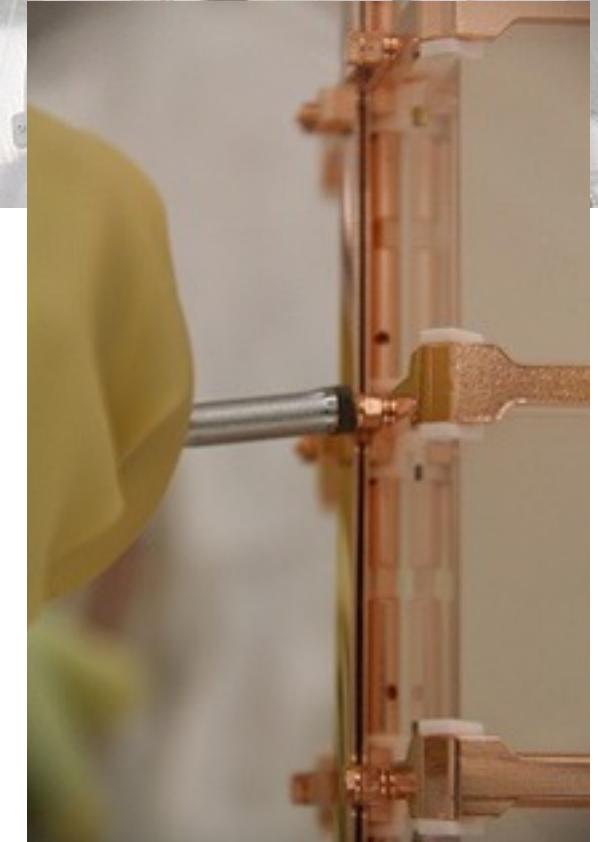
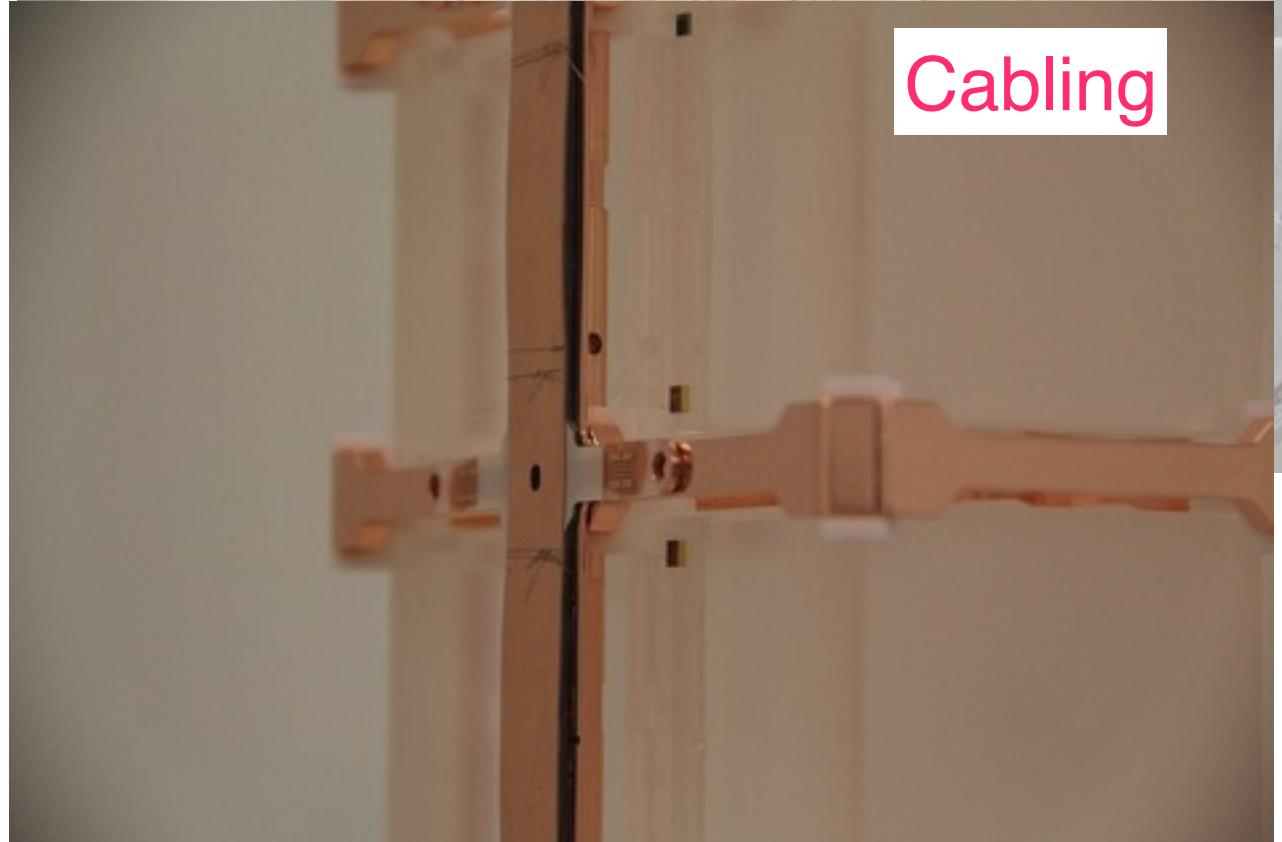
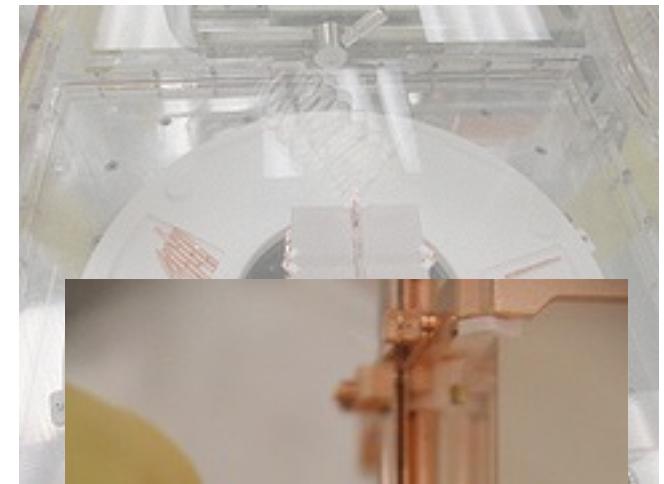
Tower assembly line



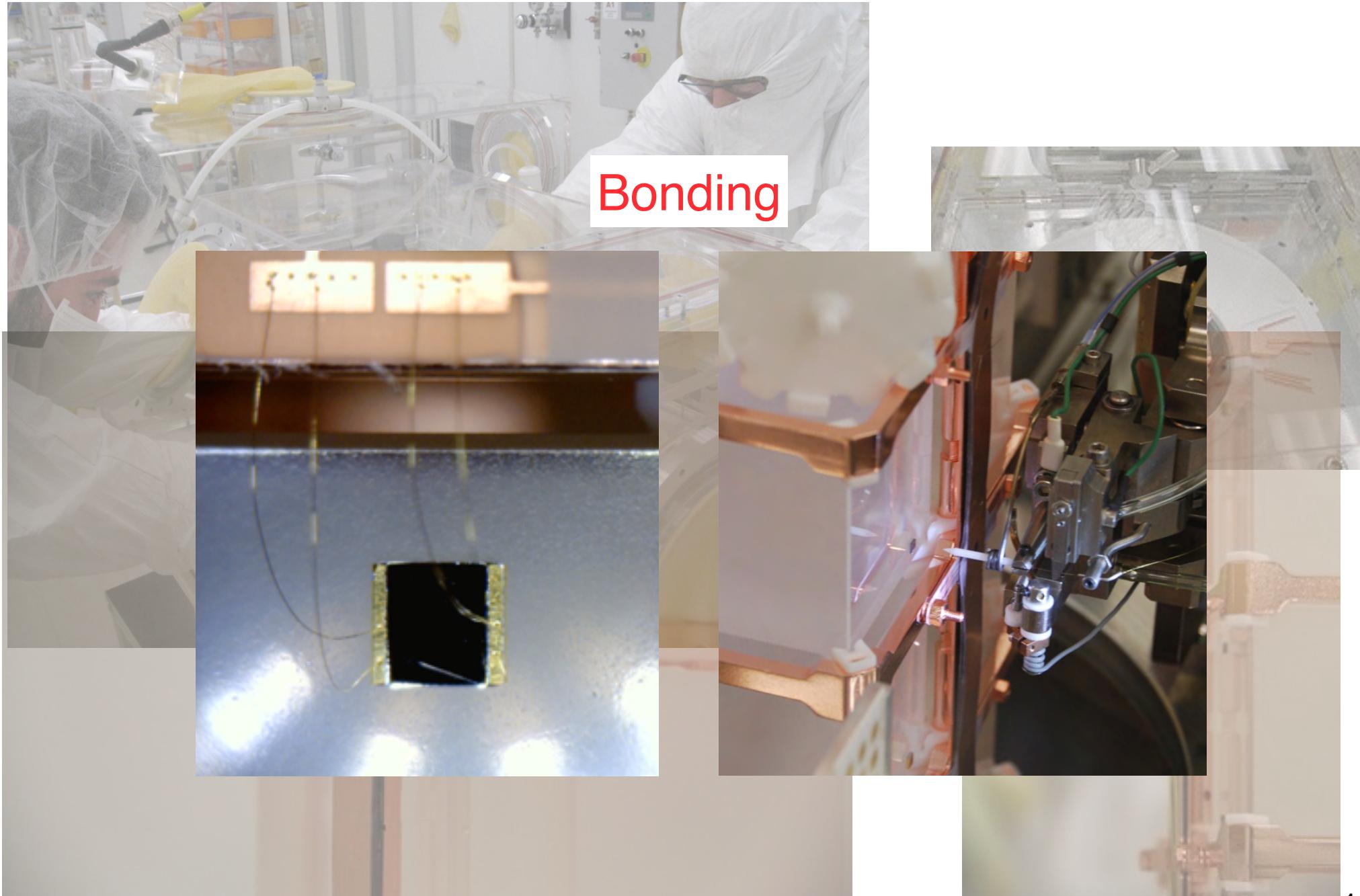
Assembly



Tower assembly line



Tower assembly line



Towers in storage

All 19 towers are complete! Await in N₂-flushed storage



CUORE-0

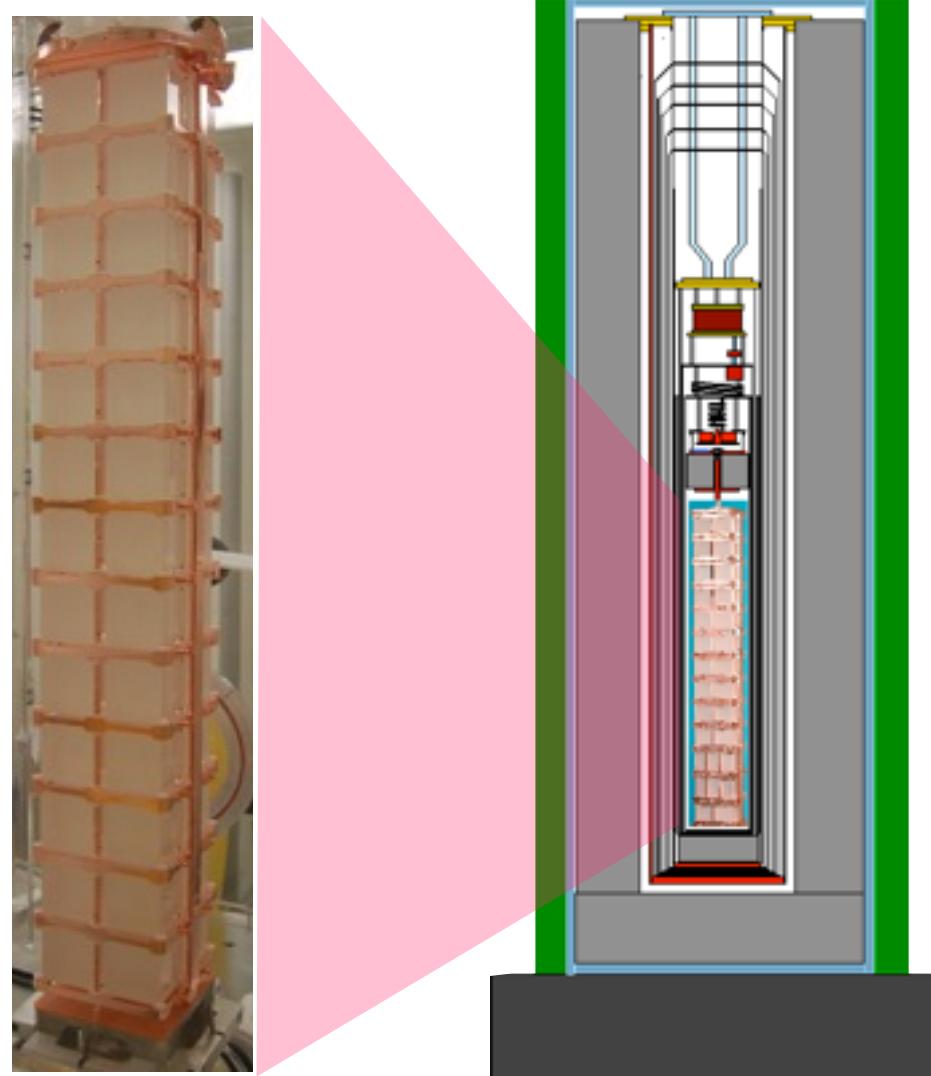
A single CUORE-like tower to test cleaning & assembly

Size similar to CUORICINO:

- 52x750g crystals
- 13 floor of 4 crystals each

Active mass:

- TeO_2 : 39 kg
- ^{130}Te : ~11 kg



Cryostat:

- Inner shield:
1cm Roman Pb
 $A(^{210}\text{Pb}) < 4 \text{ mBq/Kg}$
- External Shield:
20 cm Pb
10 cm Borated polyethylene
- N_2 flushing to avoid Rn contamination.

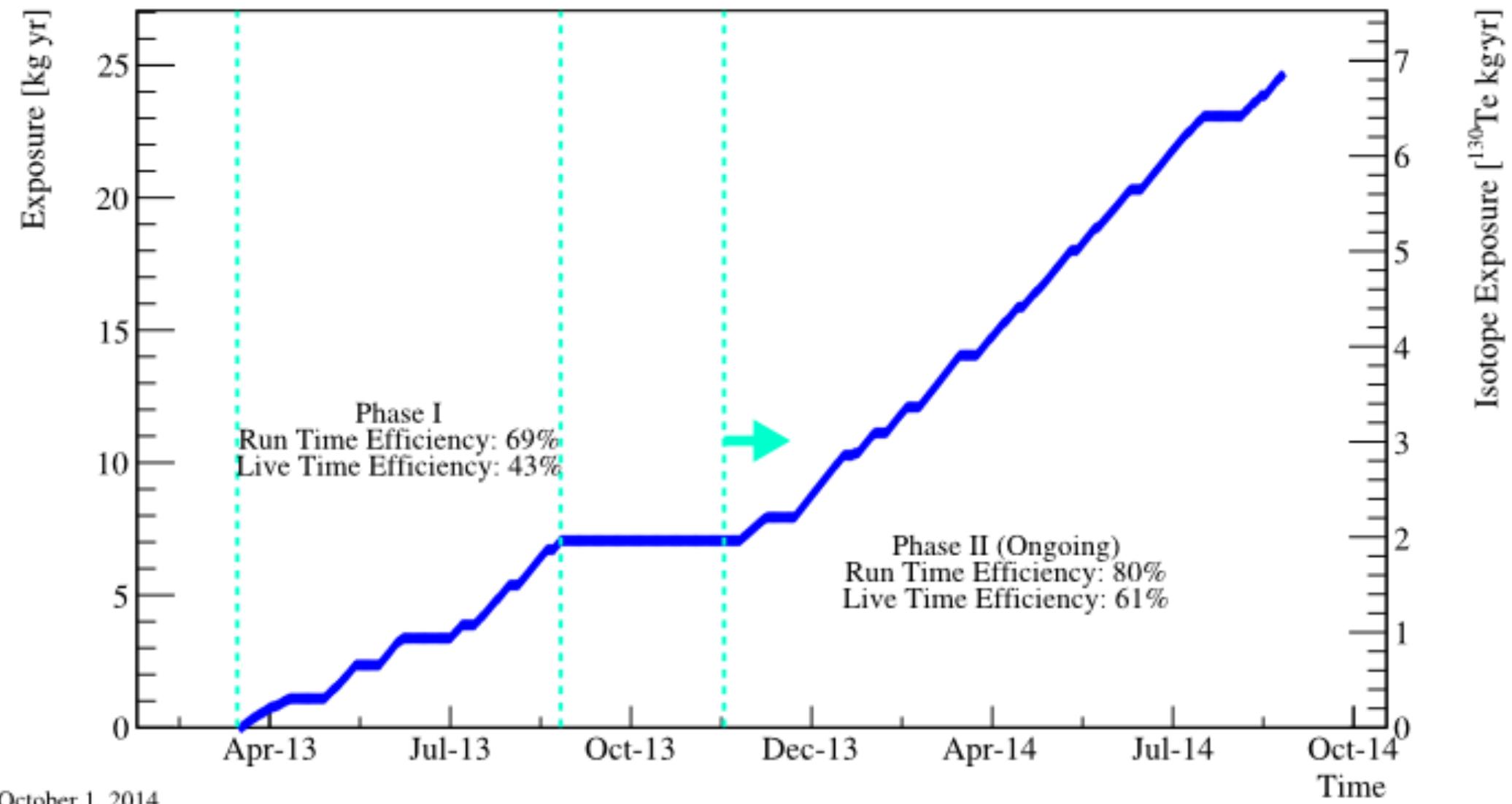
Same cryostat as CUORICINO:

γ background (^{232}Th) not expected to change \Rightarrow test the α background

Data Taking

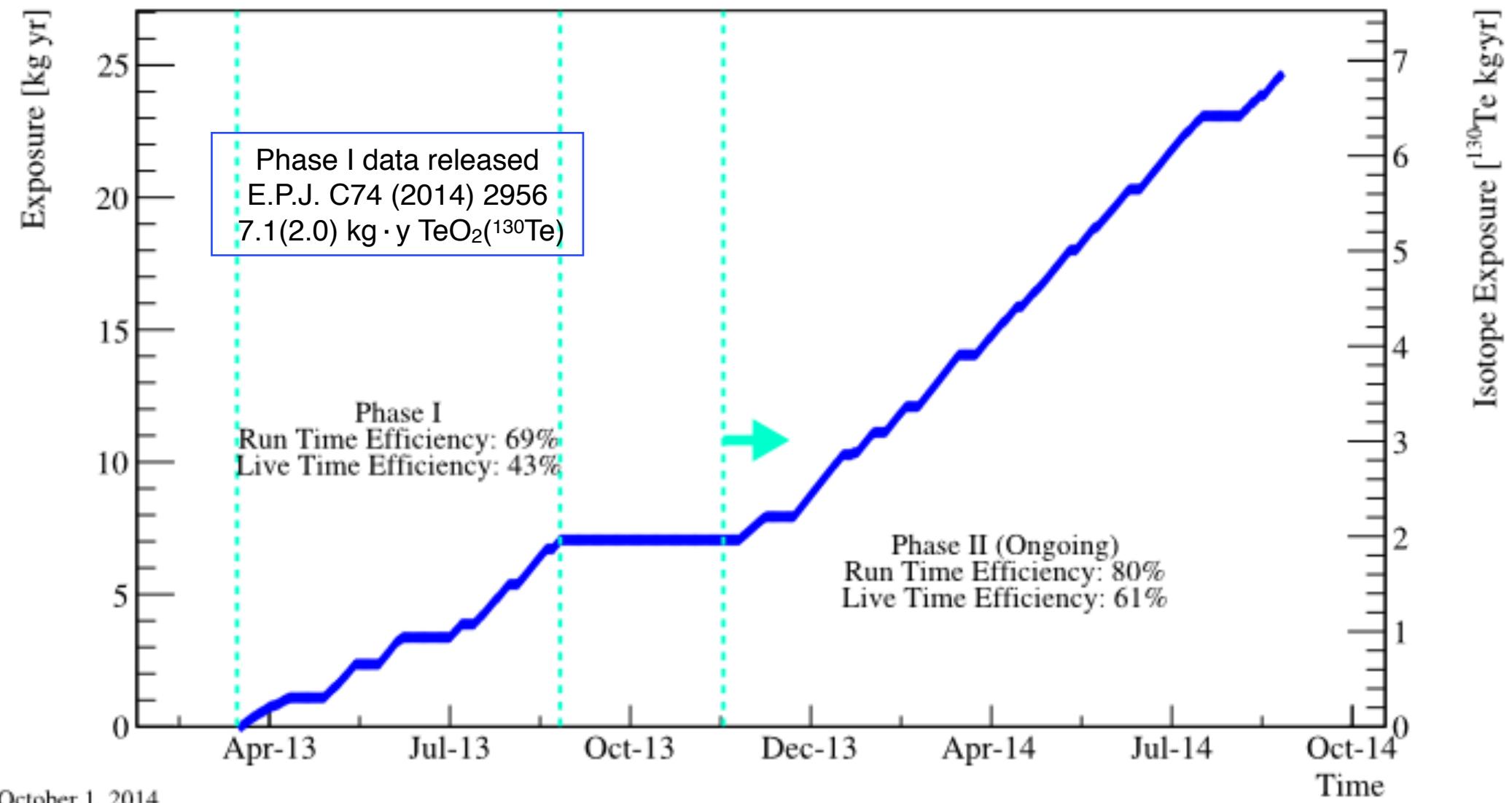
Data Taking

Cuore-0 Exposure



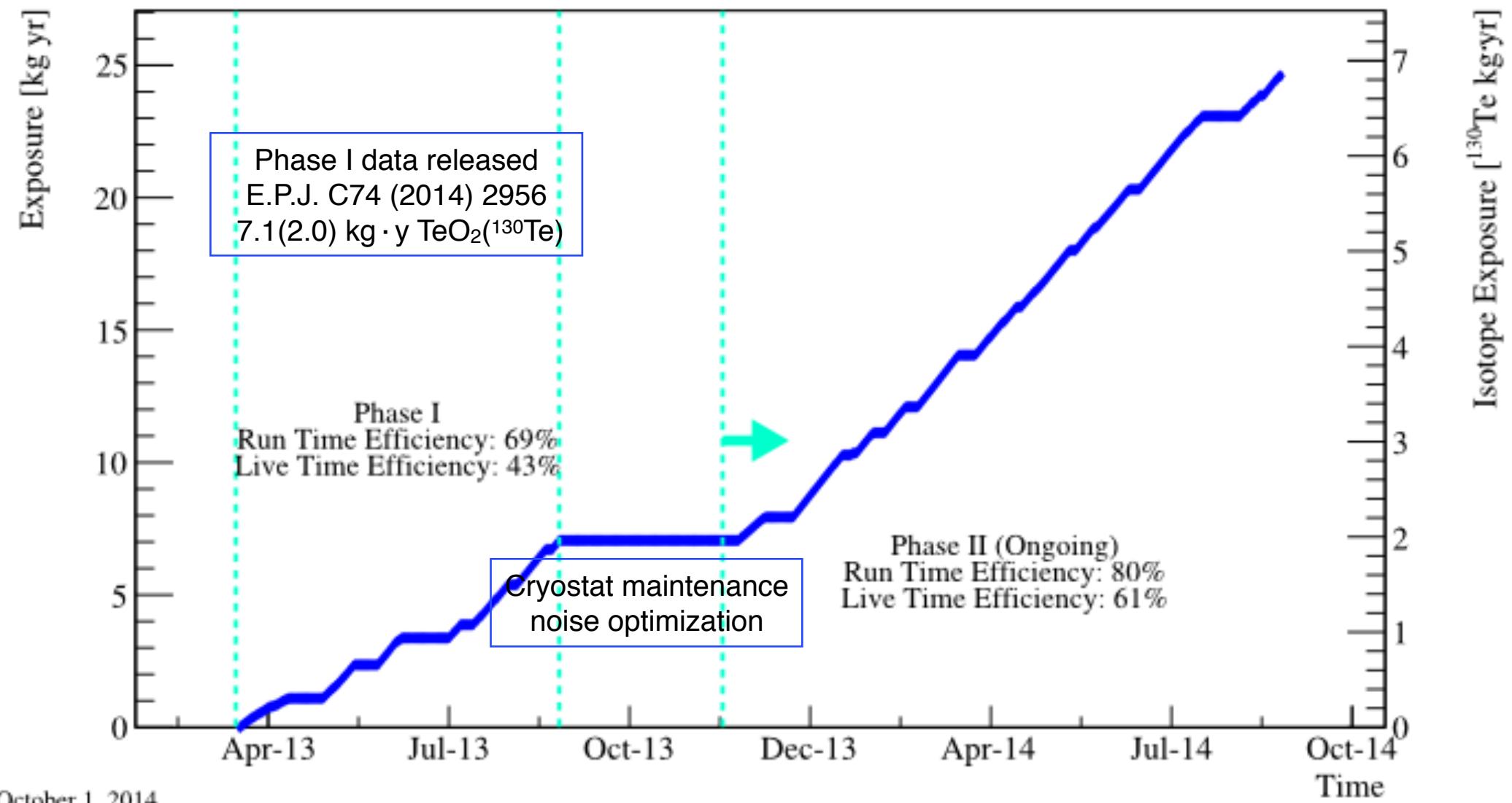
Data Taking

Cuore-0 Exposure



Data Taking

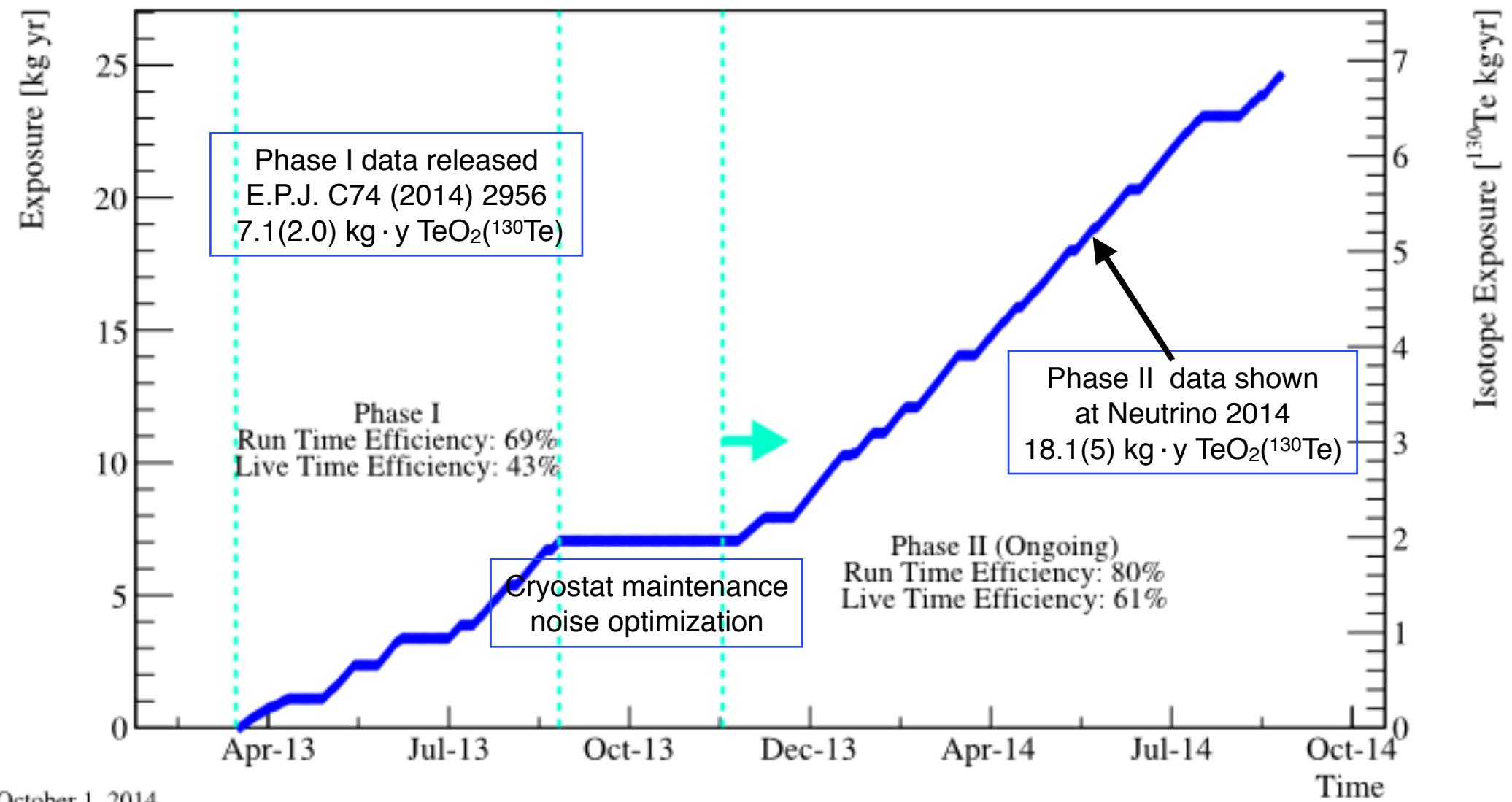
Cuore-0 Exposure



October 1, 2014

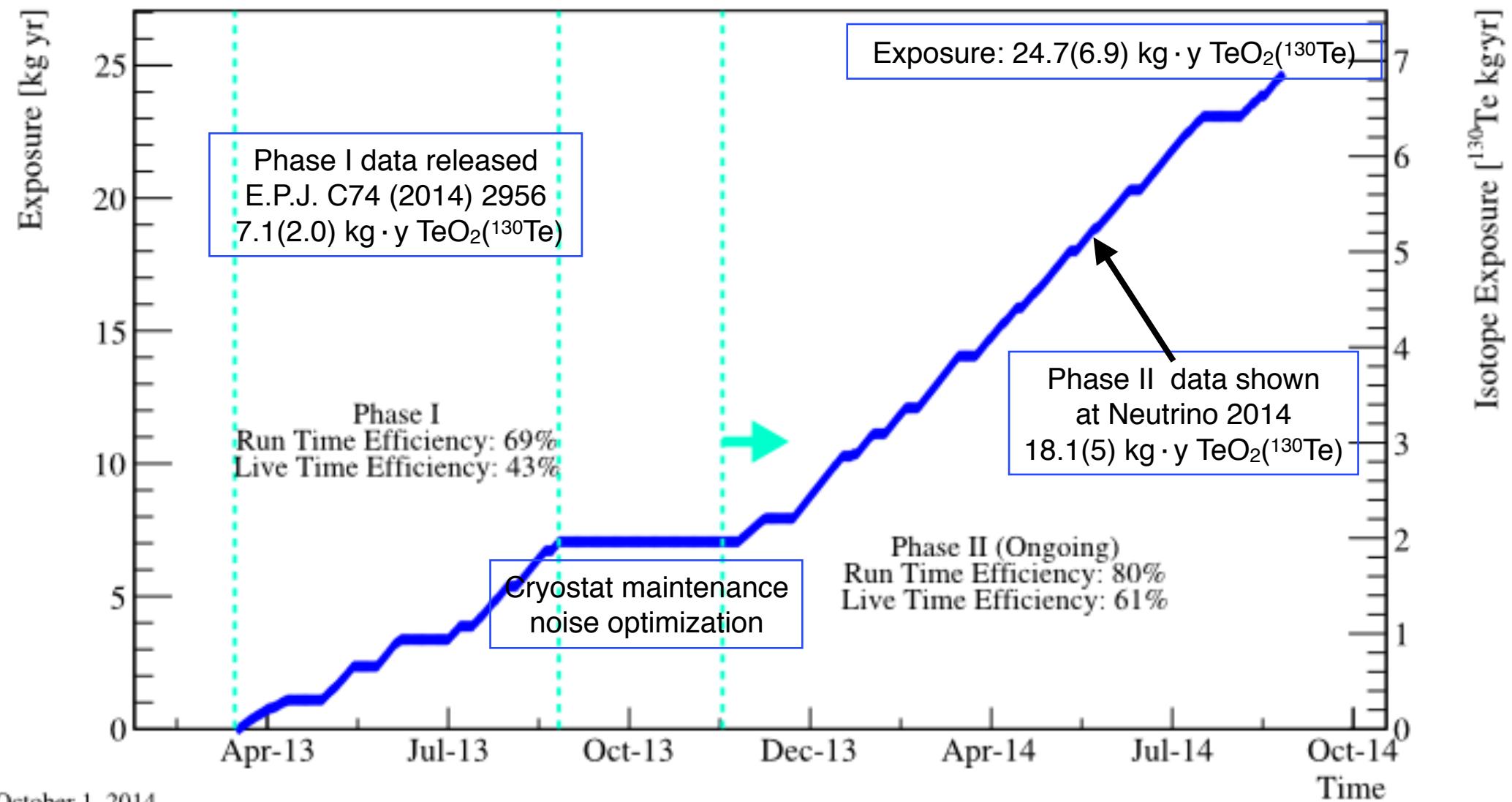
Data Taking

Cuore-0 Exposure



Data Taking

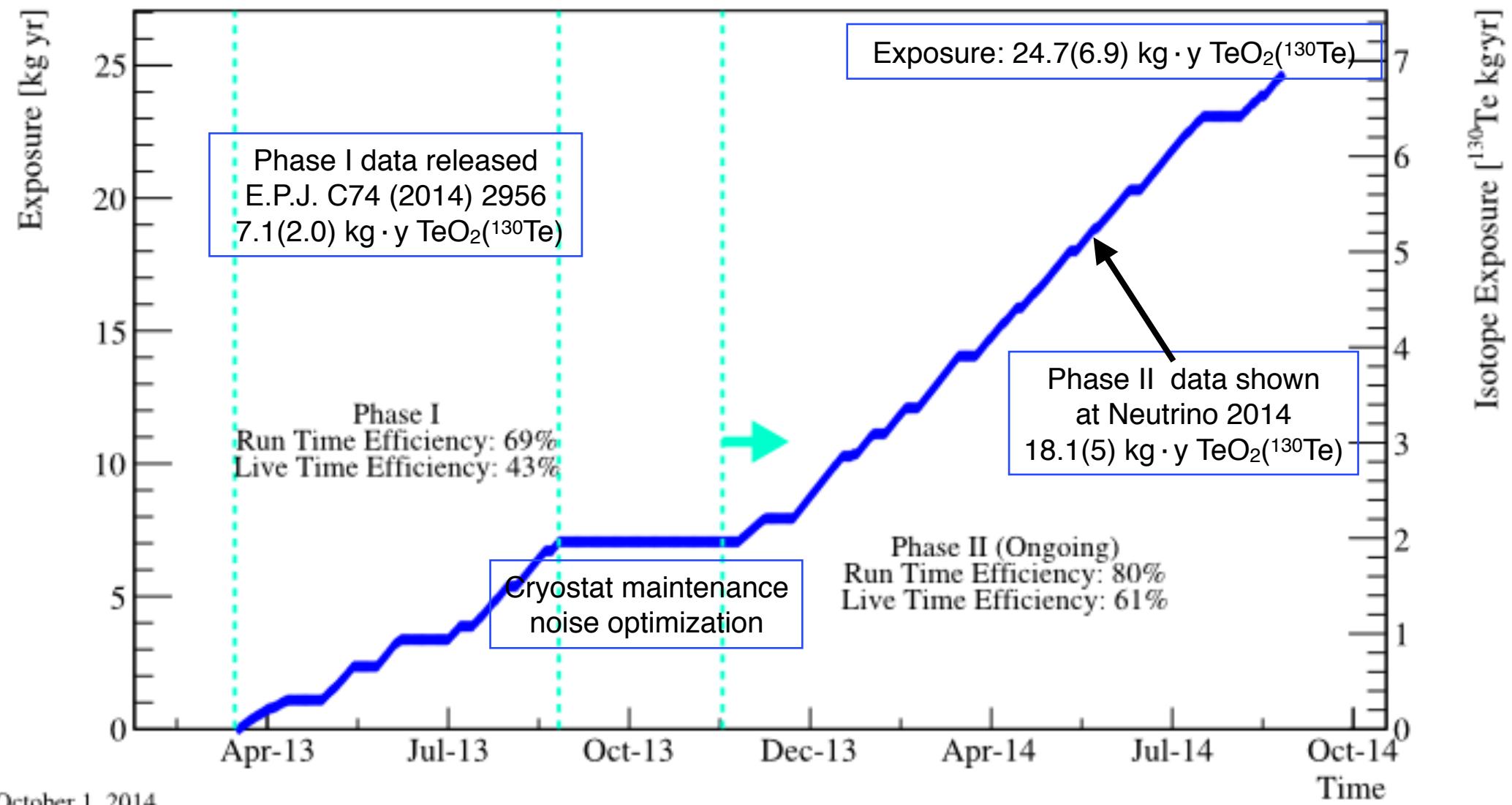
Cuore-0 Exposure



October 1, 2014

Data Taking

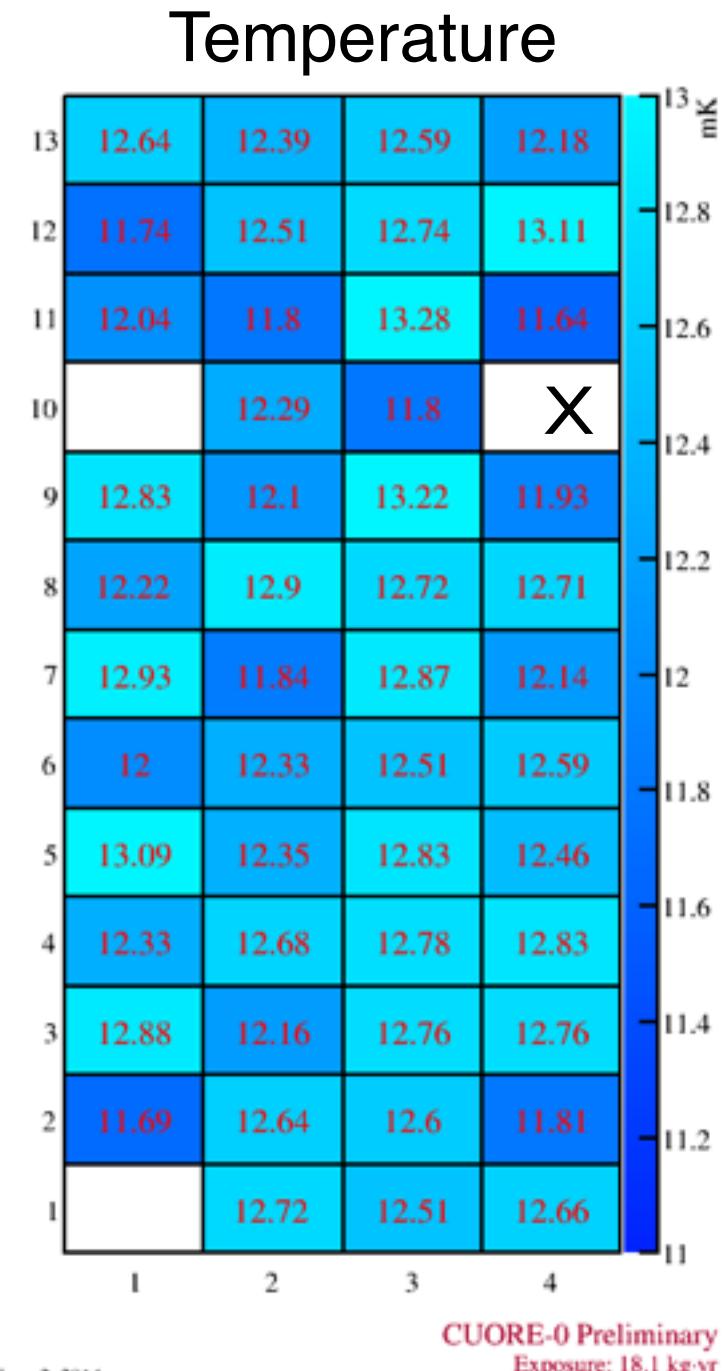
Cuore-0 Exposure



Expect to release final data in spring 2015

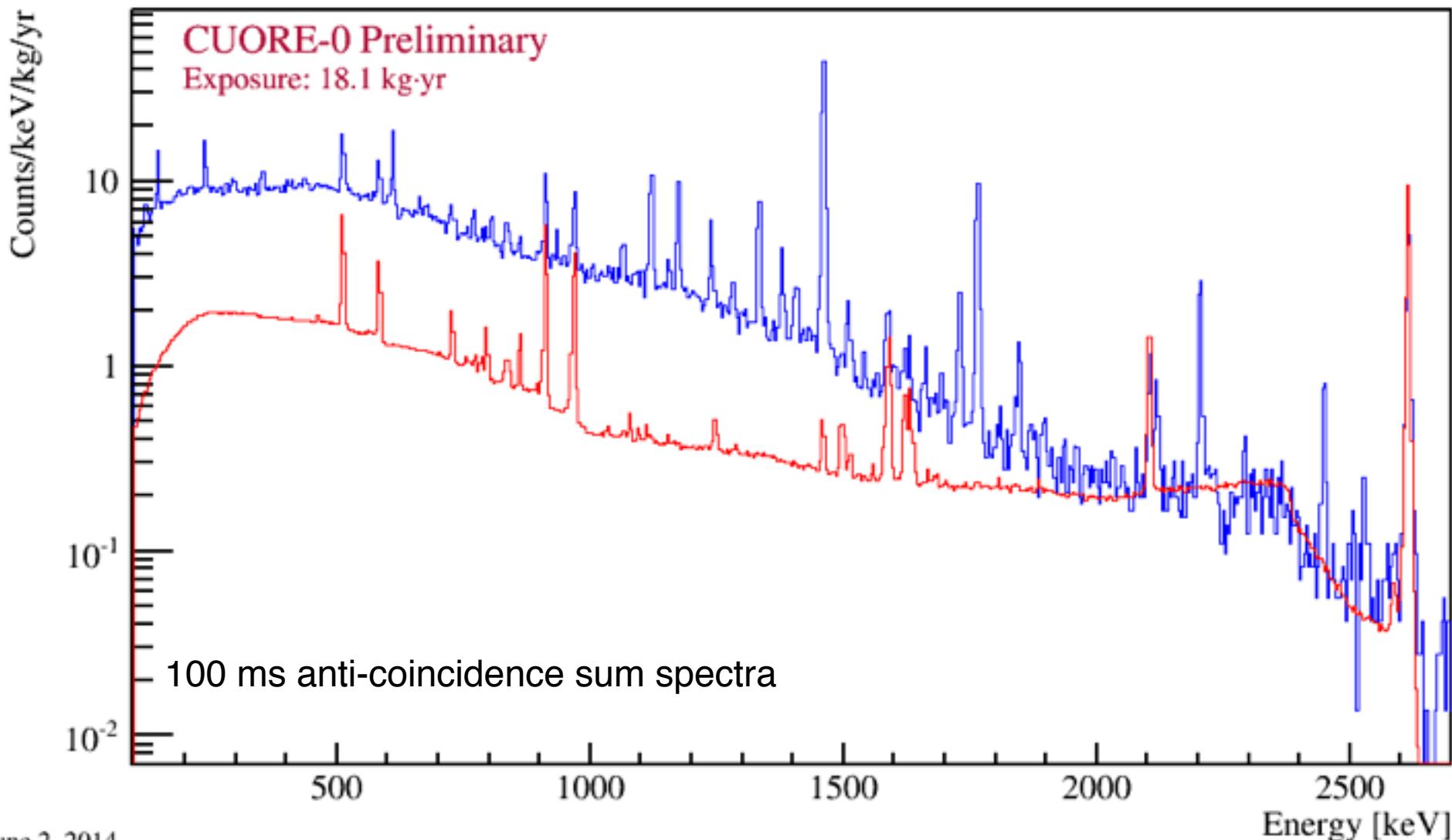
CUORE-0 Performance

- 51 crystals instrumented with thermistors:
 - ▶ all survived cool-down
- 51 crystals instrumented with heaters
 - ▶ 50 survived cool-down
- 49/52 crystals have both an active thermometer and heater



CUORE-0 energy spectrum

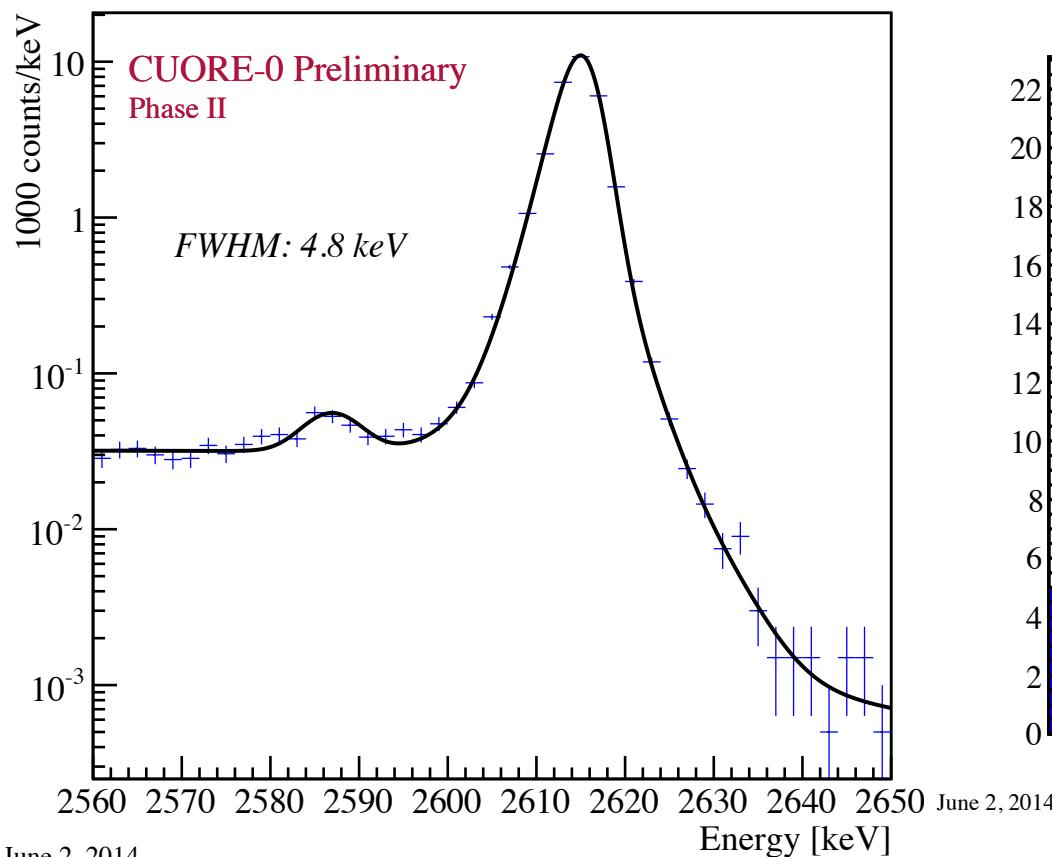
Calibration spectrum from Th source normalized to ^{208}TI peak in background data



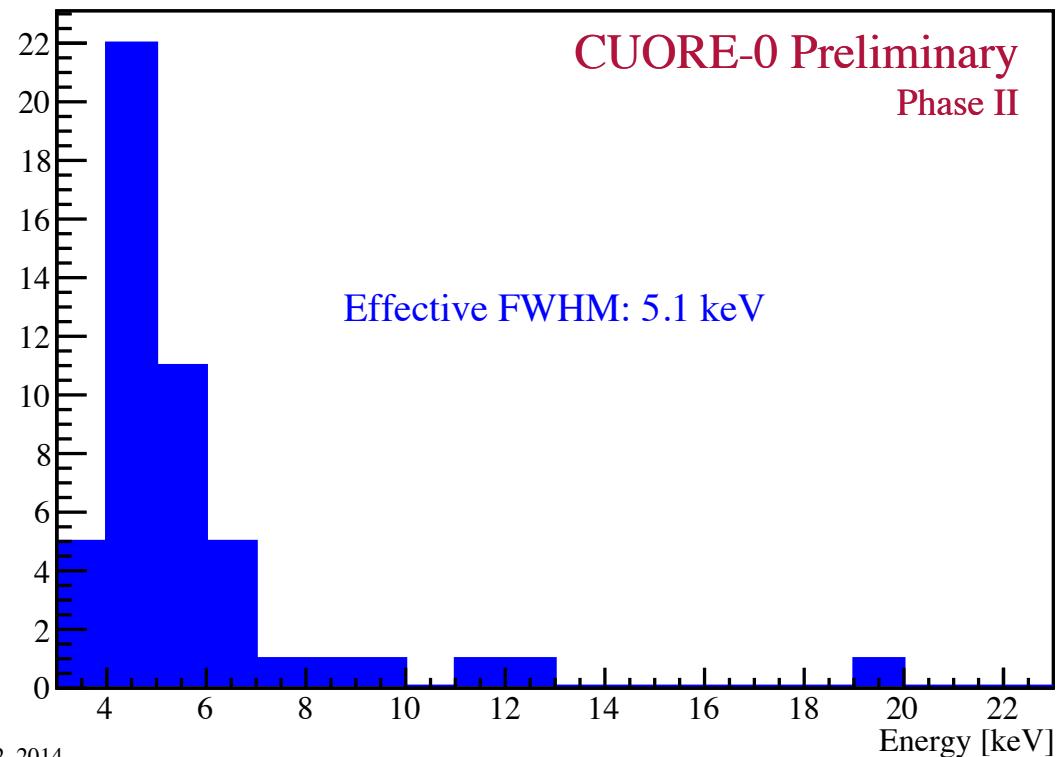
CUORE-0 Energy resolution

- Resolution evaluated on ^{208}TI line @ 2615 keV
- Overall ΔE_{FWHM} in Phase I was 5.7 keV, in Phase II 4.8 keV

CUORE-0 Calibration Spectrum (Phase II)

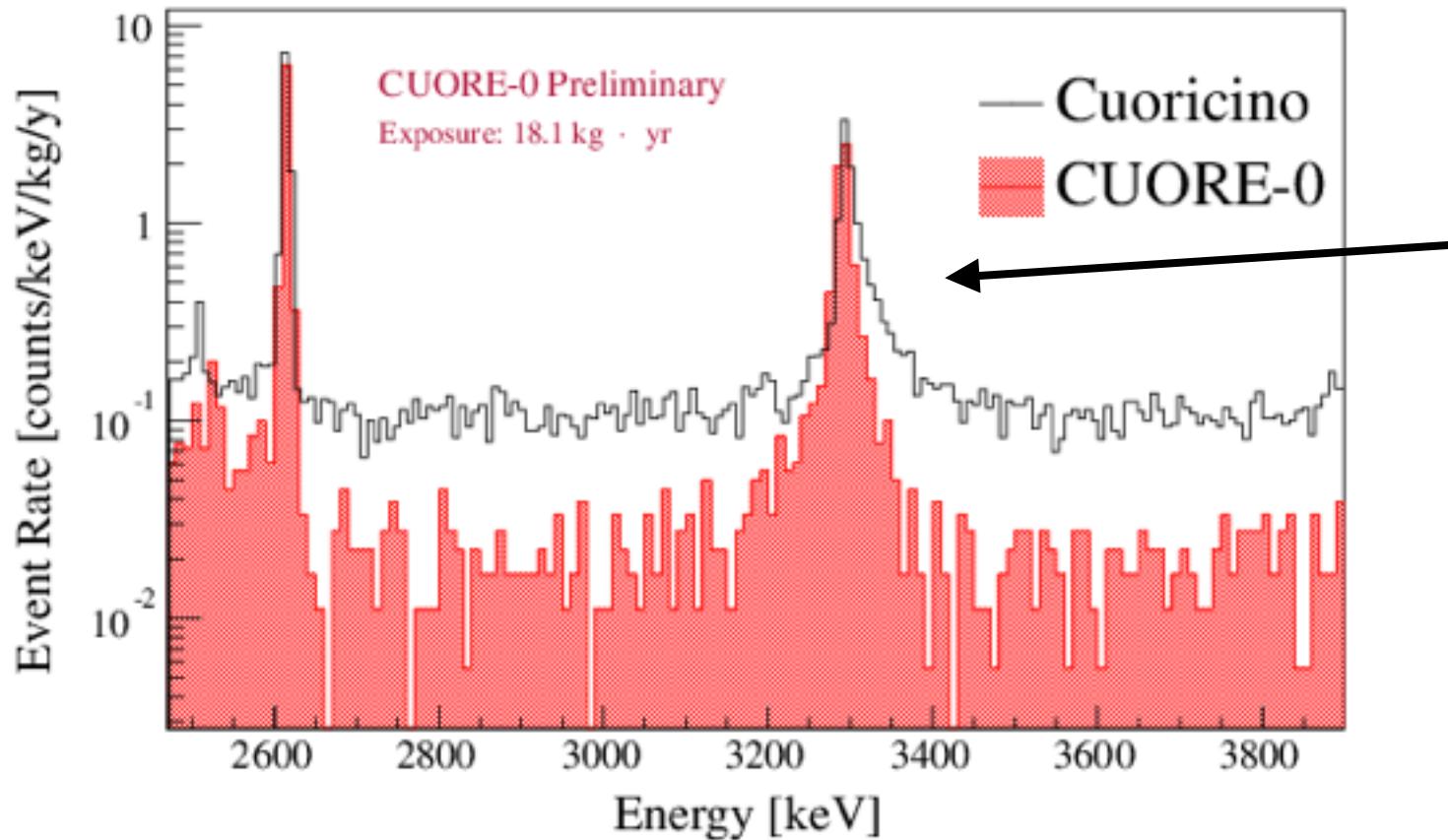


CUORE-0 Calibration Resolution by Channel (Phase II)



effective \equiv harmonic mean

CUORE-0 bkgd: a region

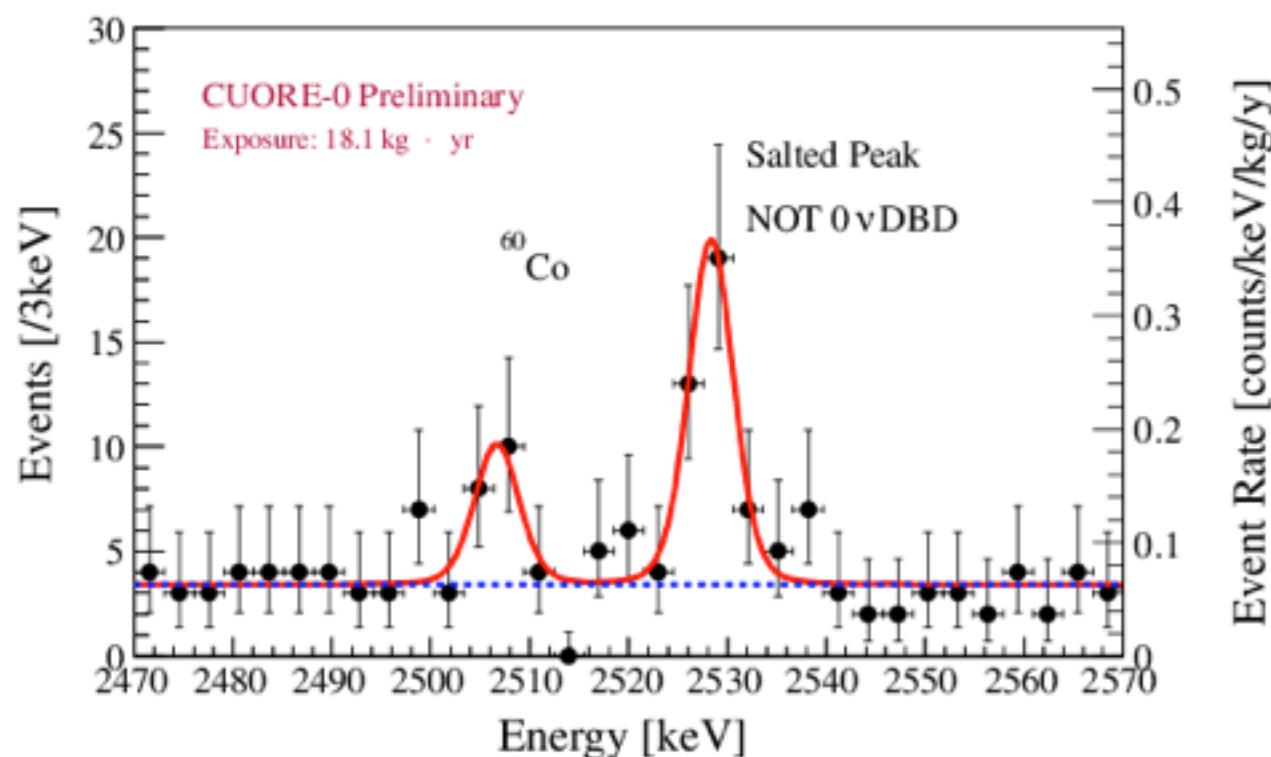


^{190}Pt alpha peak, due to Pt inclusions from the crucible during crystal growth

Bkgd in a region evaluated in the intervals (2.7-3.1)MeV + (3.4-3.9)MeV (excluding ^{190}Pt peak)

0.020 ± 0.001 counts/keV/kg/y reduction by ~6 w.r.t. CUORICINO

CUORE-0 bkgd: DBD region(blinded)

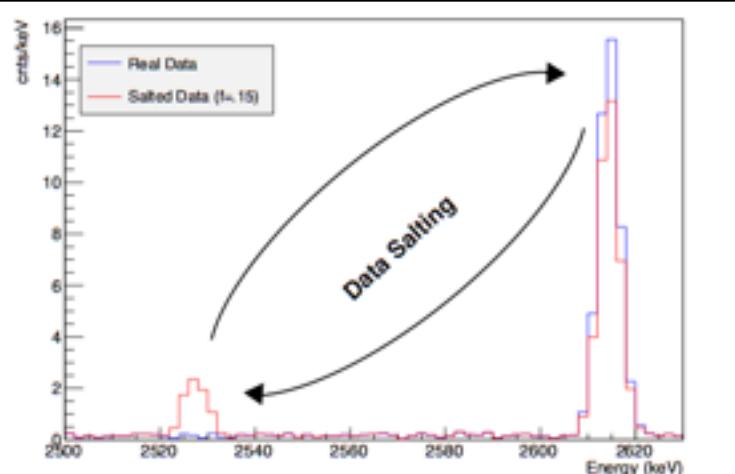


Flat background in ROI:

0.063 ± 0.006 counts/keV/kg/y

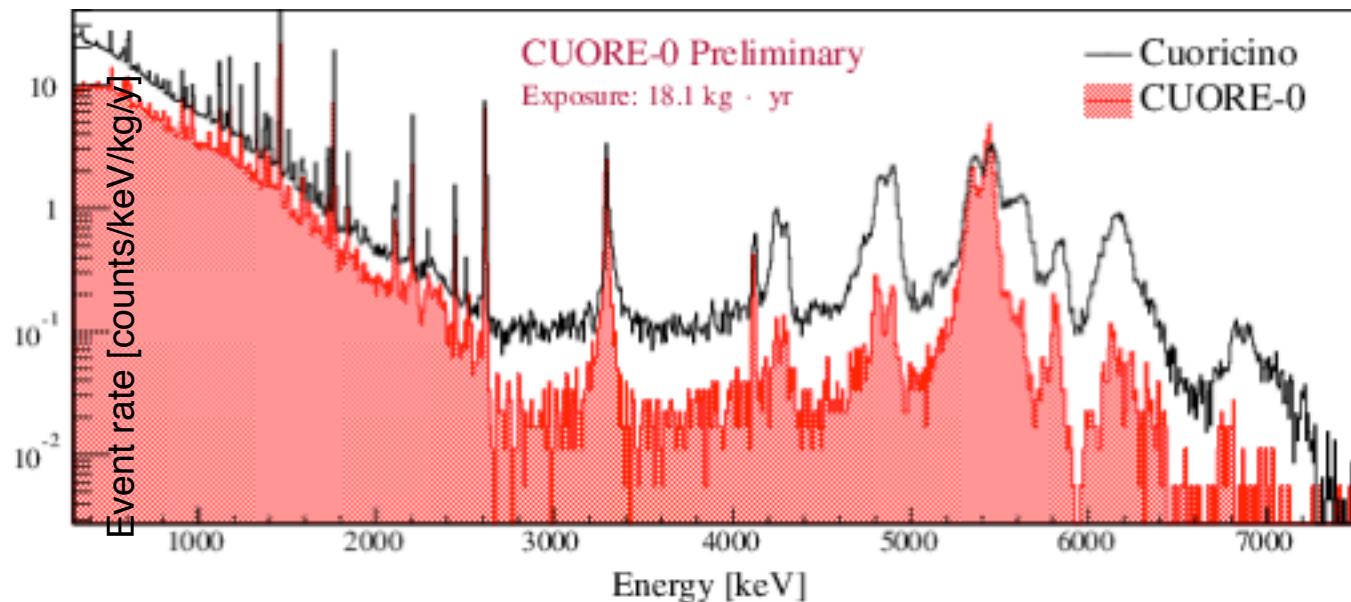
Our way of **blinding** is to **salt** the data:

exchange a small (and blinded) fraction of ^{208}TI events (2615 keV) with events in the $0\nu\beta\beta$ region, producing a **fake peak**.



CUORE-0 vs CUORICINO

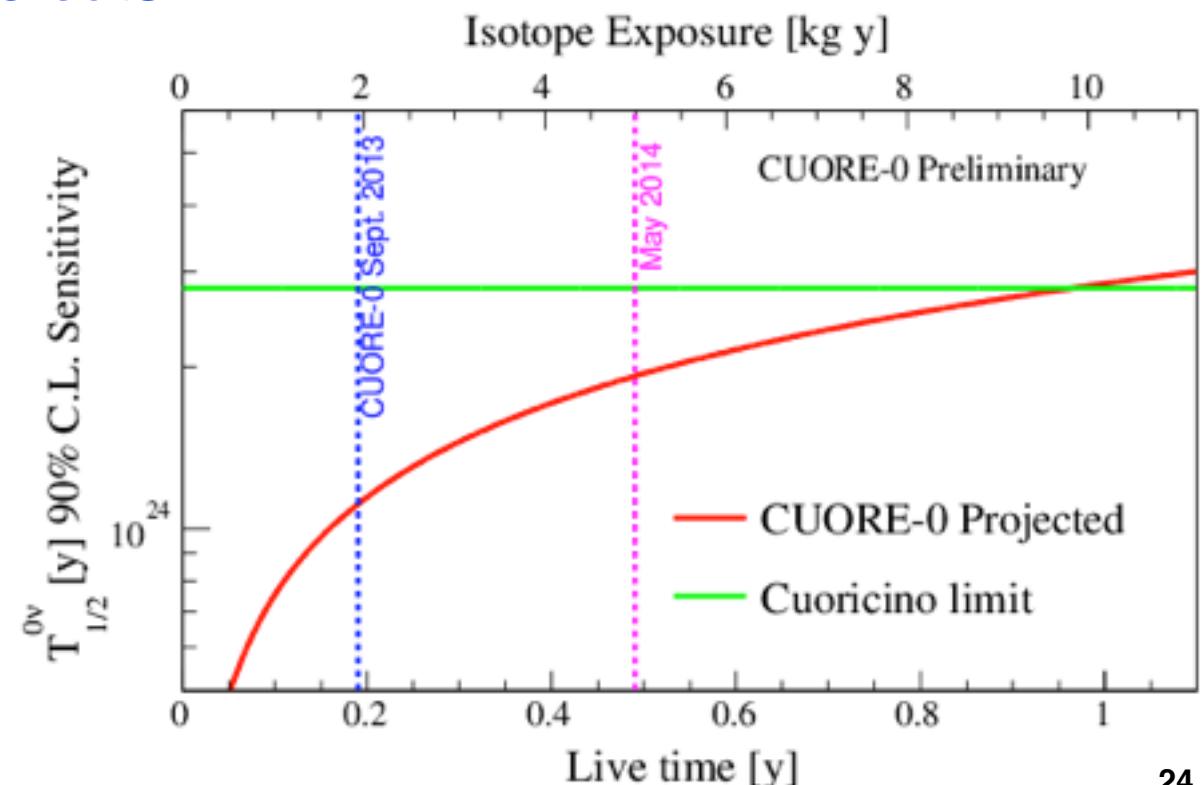
- ▶ ^{238}U γ lines reduced by ~ 2 (better radon control)
- ▶ ^{232}Th γ lines not reduced (originate from the cryostat)
- ▶ $^{238}\text{U}/^{232}\text{Th}$ α lines reduced (detector surface treatment)



	Avg. flat bkg. [counts/keV/kg/y] $0\nu\beta\beta$ region	2700-3900 keV	signal eff. [%] (detector+cuts)
CUORICINO	0.153 ± 0.006	0.110 ± 0.001	82.8 ± 1.1
CUORE-0	0.0063 ± 0.006	0.020 ± 0.001	77.6 ± 1.3

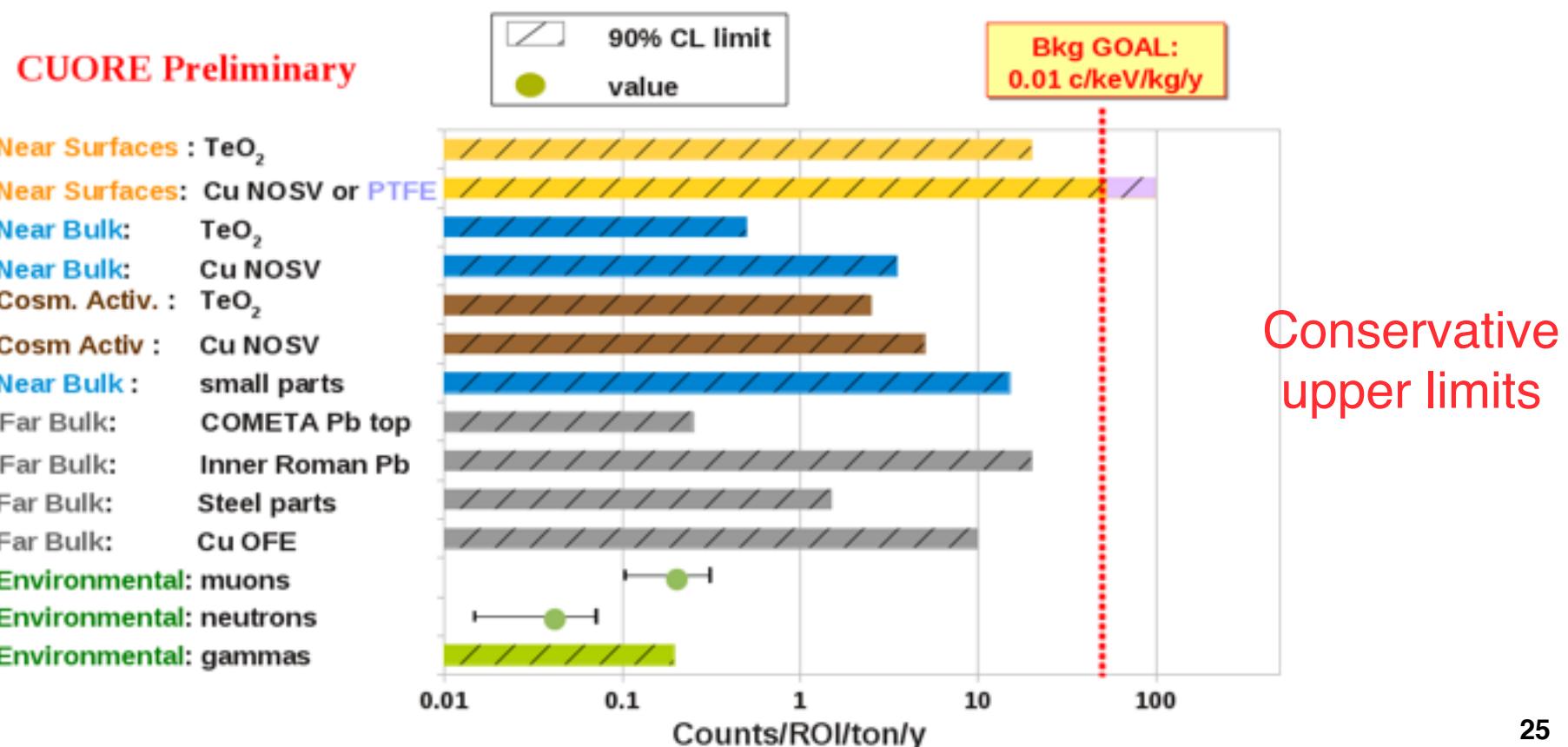
CUORE-0

- Successful demonstrator of: **radio-purity, resolution, bkgd model**
- Data analysis ongoing with improvements in
 - ▶ noise decorrelation
 - ▶ heater-less gain stabilization
 - ▶ pulse shape & coincidence cuts
 - ▶ background model
 - ▶ more accurate calibration
- **Expect to unblind & publish in 2015**

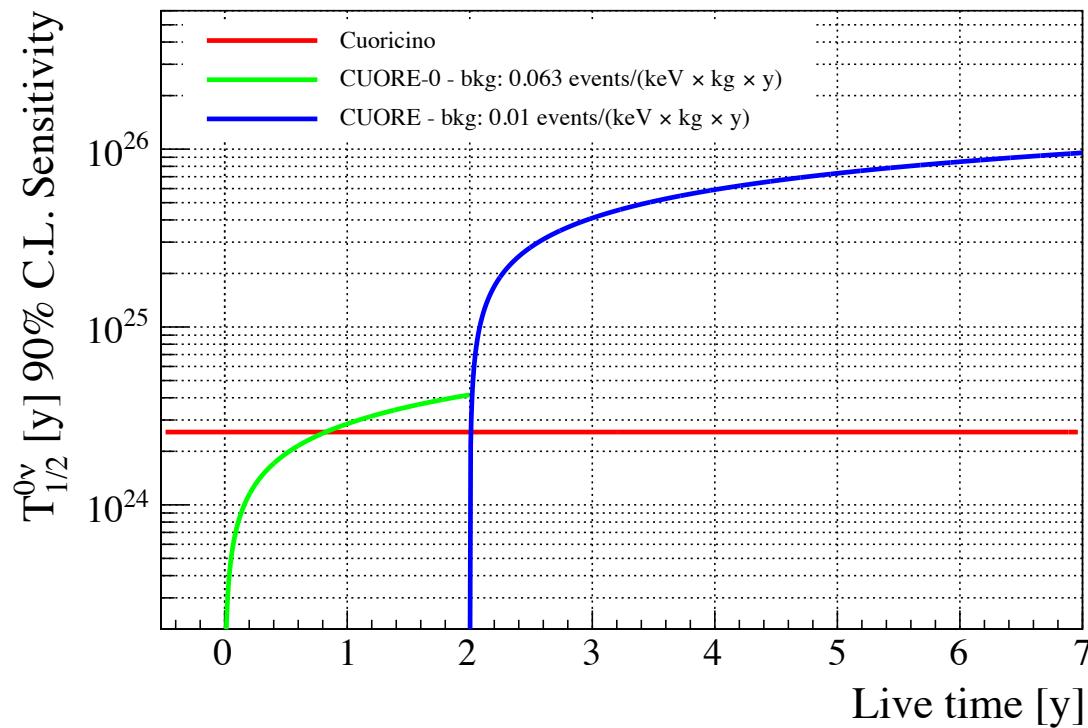


CUORE Background

- New cryostat with radio-pure materials: γ contribution negligible
- Less copper facing the crystals: a from Cu surface reduced
- Enhanced granularity: negligible a bkgd from crystals surface



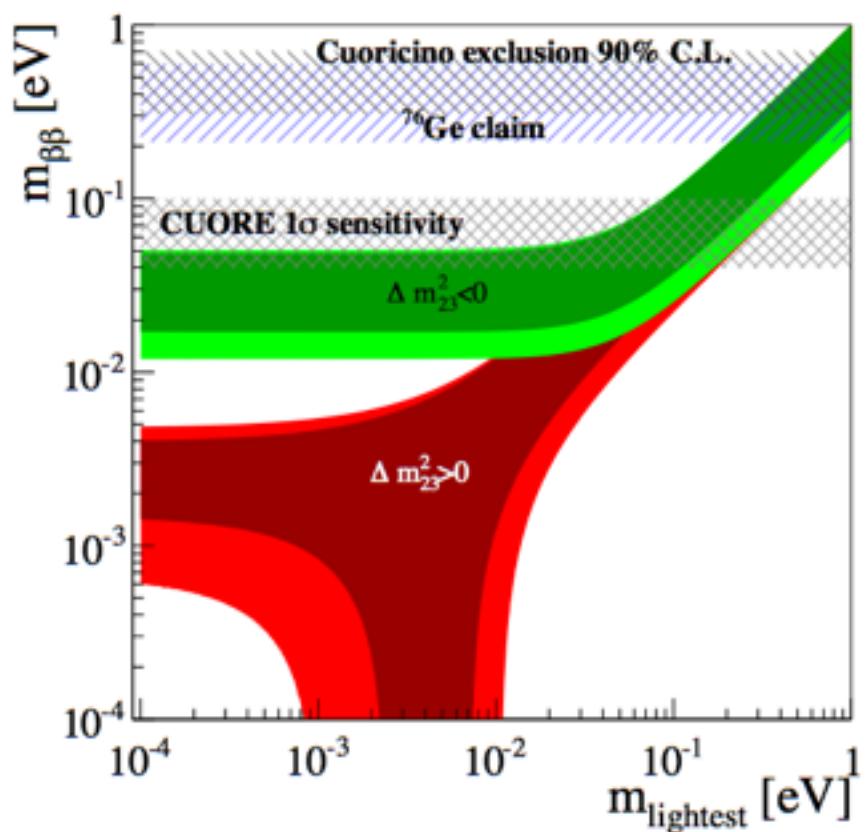
CUORE sensitivity



Projected half-life sensitivity:
 $9.5 \cdot 10^{25}$ y (90 % C. L.)

Effective Majorana neutrino mass sensitivity:
50 - 130 meV (90 % C. L.)

CUORE
Background: 0.01 counts/keV/kg/y
FWHM resolution: 5 keV
Live time: 5 y



Cryostat commissioning

- September 2014: 6 mK base temperature reached with all vessels
- Integration of a test tower ongoing
- Physics run expected in 2015



Beyond CUORE

