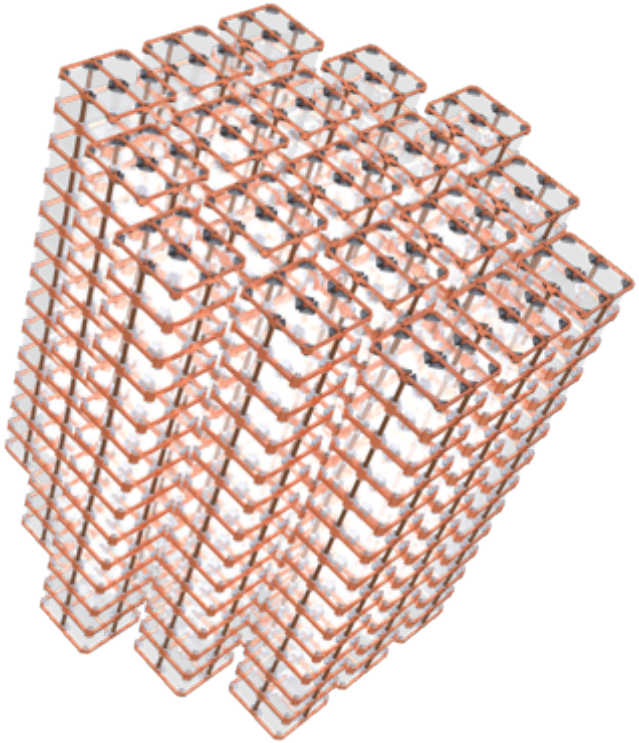
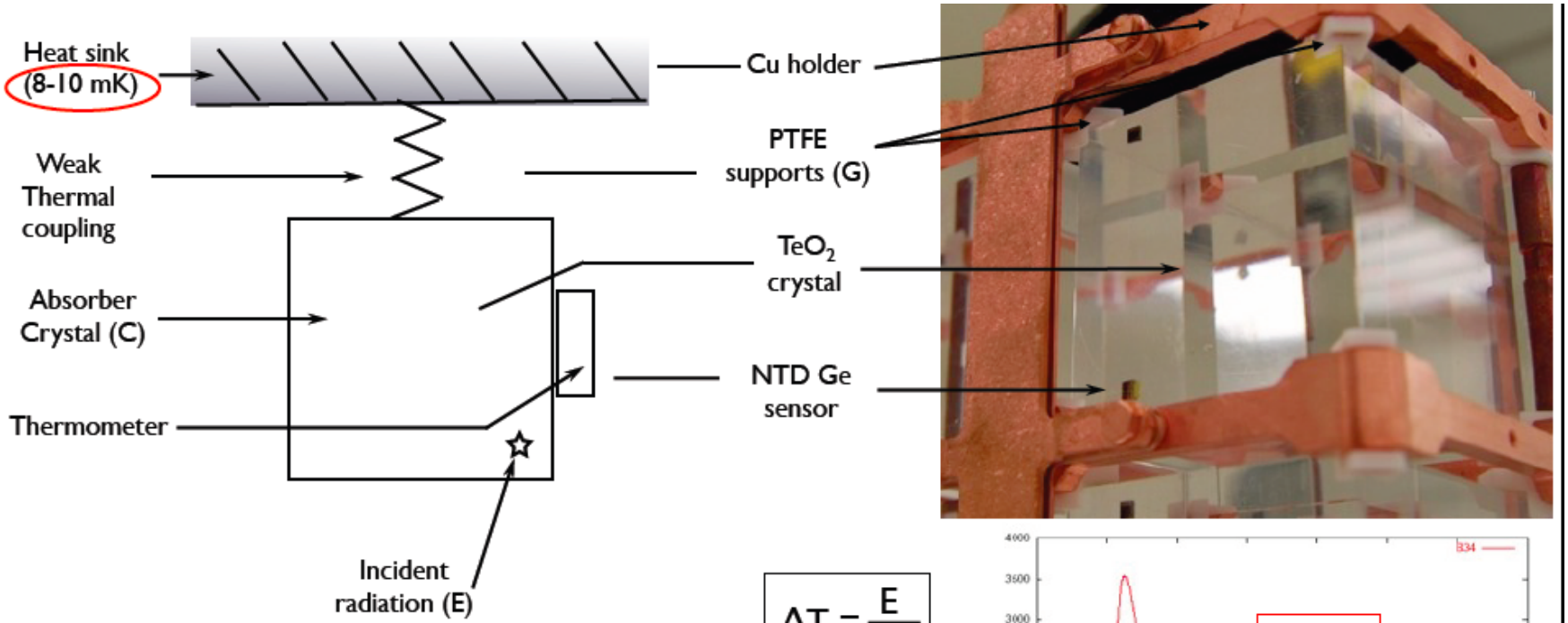
XV International Workshop on "Neutrino Telescopes"
Venice, March 11-15, 2013

CUORE-0 AND CUORE: AN UPDATE



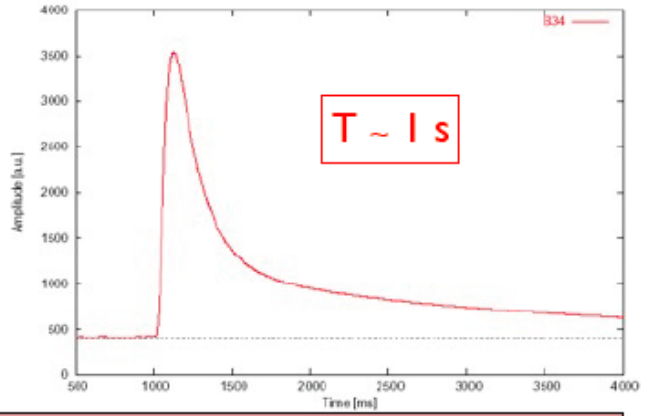
C. Brofferio
University and INFN, Milano Bicocca
on behalf of the CUORE Collaboration

The bolometric way to DBD



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

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



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

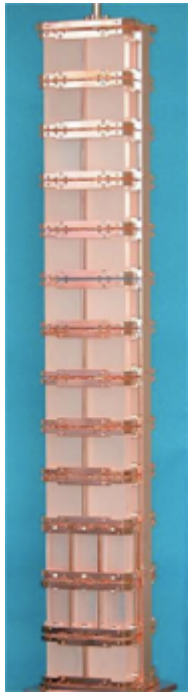
$0\nu\beta\beta$ research with TeO_2

- ^{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

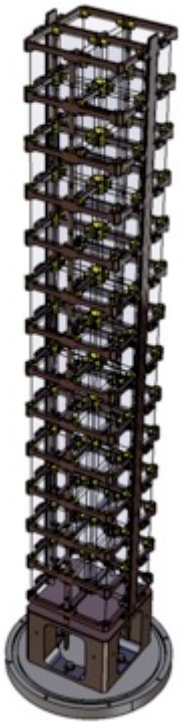
1997-2001

Cuoricino
11 kg ^{130}Te



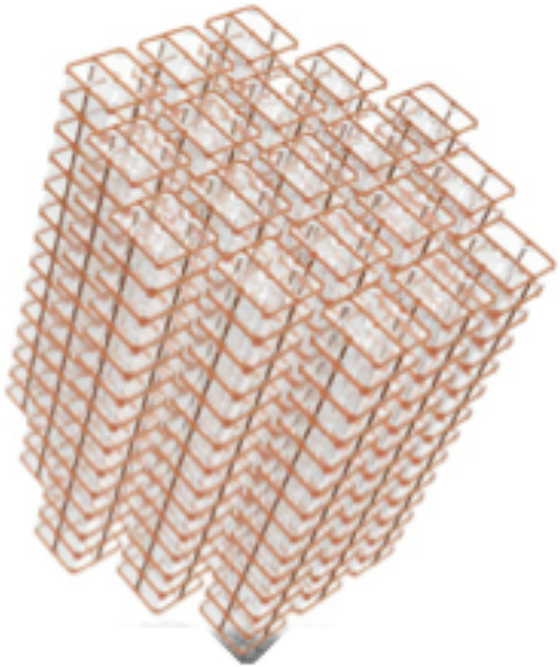
2003-2008

CUORE-0
11 kg ^{130}Te



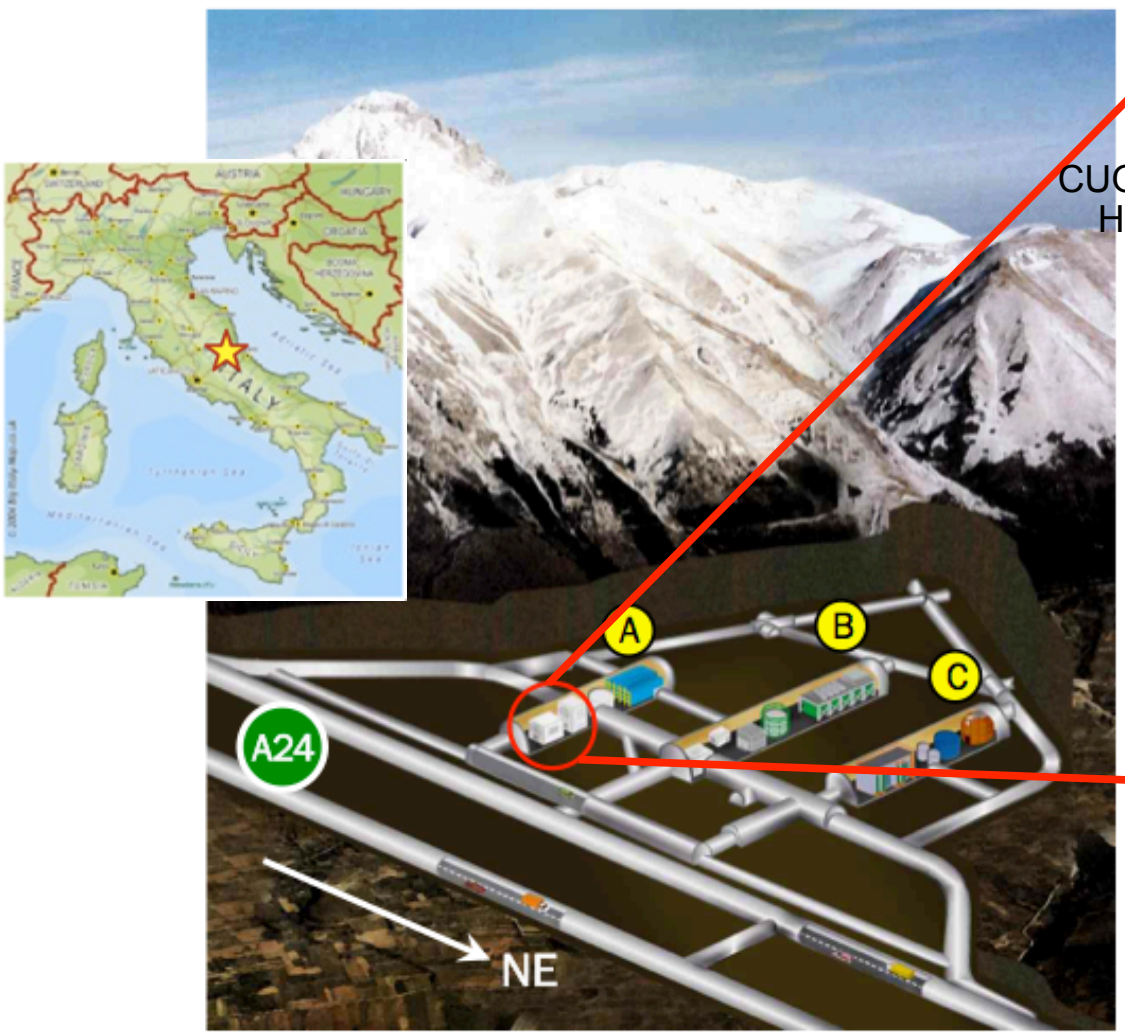
2012...2014

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

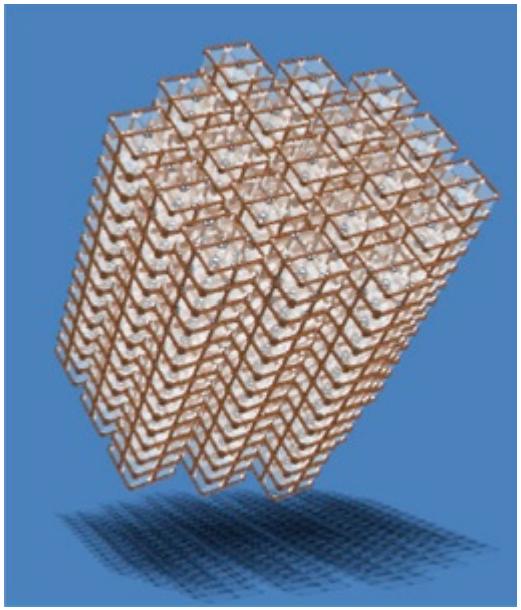
988 TeO_2 5x5x5 cm^3 crystals (750 g each)
Detector Mass: 741 kg TeO_2
^{130}Te mass (natural i.a.) : 206 kg of ^{130}Te
Array: 19 towers, each with 13 planes of 4 crystals each

Sensitivity improvement:

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

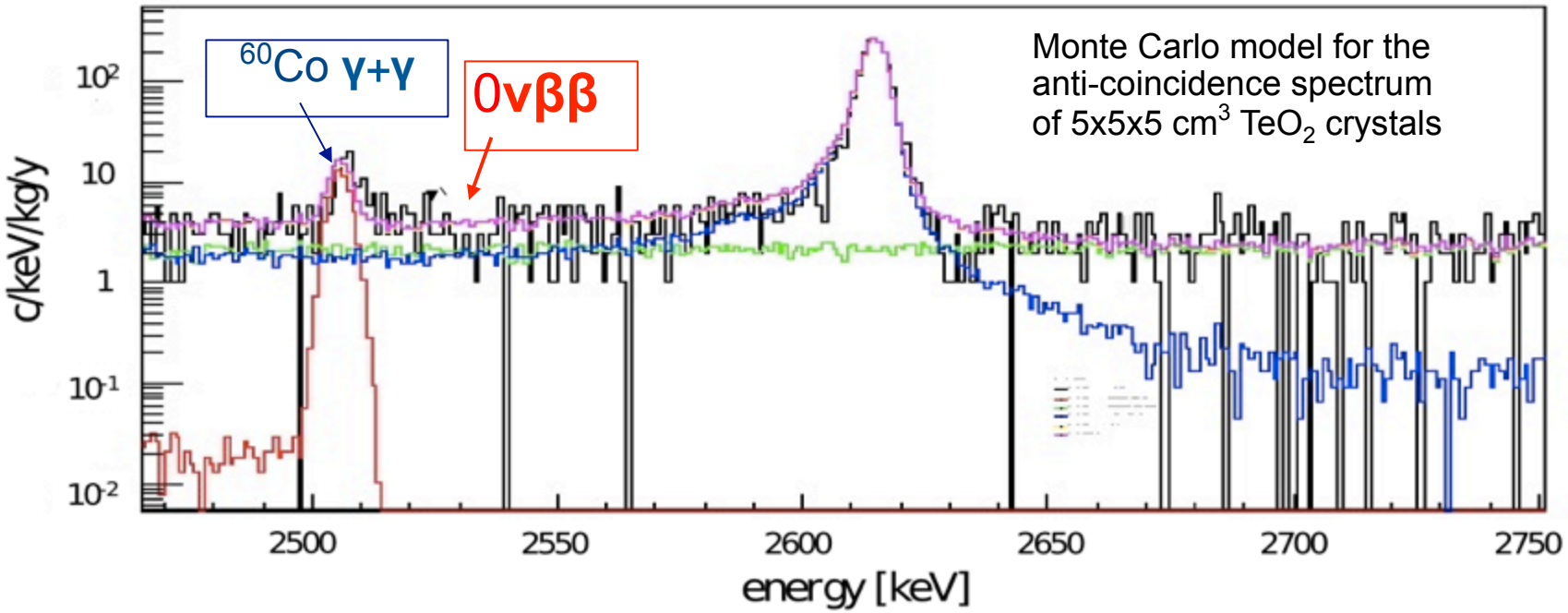
(Mx19) + (ΔE/1.5) + (Tx2) + (b/17)

=> CUORE $S^{0\nu}$ ~ 30 Cuoricino $S^{0\nu}$



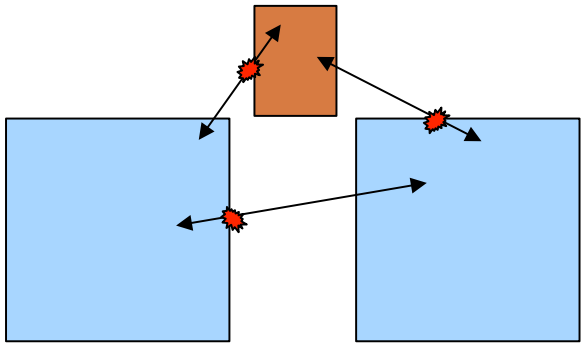
the most challenging issue is background reduction

Cuoricino Lesson: The Bkg origin



b = 0.169 ± 0.006 c/keV/kg/y

^{232}Th in the cryostat (γ)	**30 ± 10 %**
Contamination on **crystal surface**	**10 ± 5 %**
Contamination on **Cu surface**	**50 ± 20 %**



MC: the residual background in CUORICINO, apart from the cryostat, is due to degraded particles which release only part of their energy in the detector (surface contamination)

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

  => bolometric tests on 4 sample crystals from each batch: **CCVR tests**

  Astrop. Phys. 35, (2012), 839-849
- Reduction of **surface contamination of the copper facing the crystals:**

  => bolometric test of three different surface treatments: **Three Tower Test (TTT)**

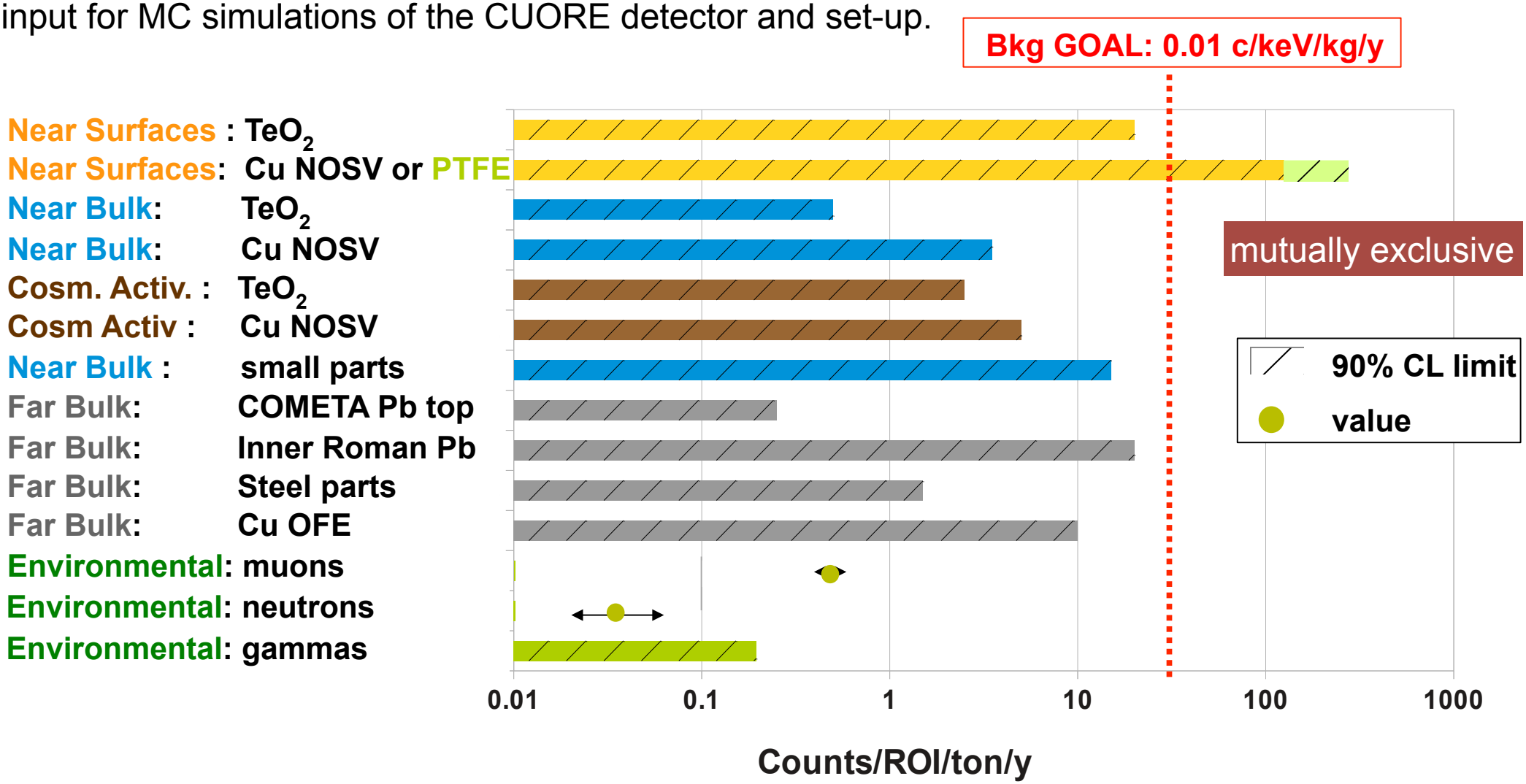
  Astroparticle Physics (2013), doi: http://dx.doi.org/10.1016/j.astropartphys.2013.02.005
- Further improvement thanks to **high detector granularity** (anticoincidence)

  Astrop. Phys. 33 (2010) 169

CUORE background budget

Contributions of the main background sources to the ROI of CUORE

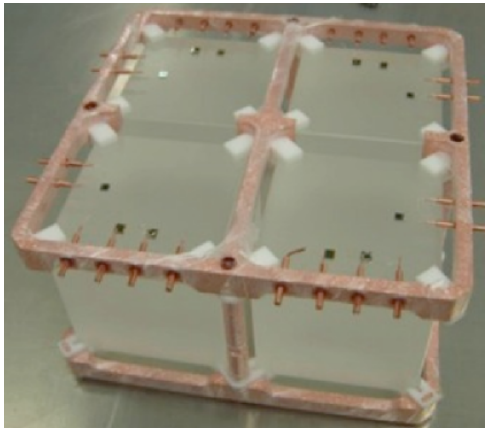
The computation is performed using contamination limits/values obtained from measurements as input for MC simulations of the CUORE detector and set-up.



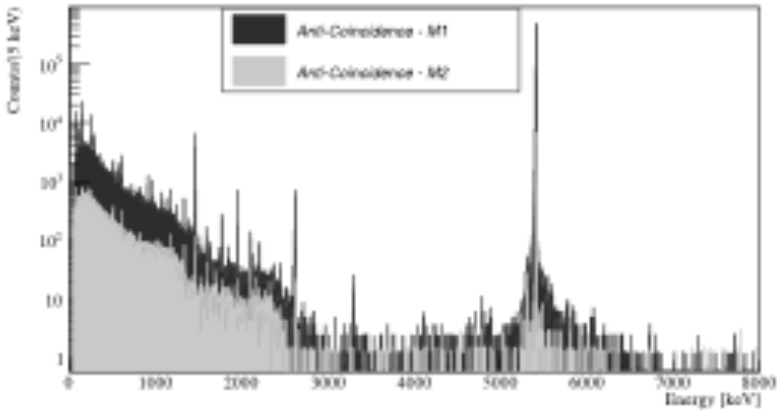
Pessimistic hyp: we assumed that all the flat bkg contribution observed in the R&D tests is coming from a source that will not improve with the geometry of CUORE.

Background from TeO_2: CCVR test

CUORE Crystal Validation Run: a dedicated cryogenic setup in Hall C at LNGS to test crystal radioactivity and performances (4 crystal samples from each CUORE batch since 2008)



CCVR 1-5 sum spectra



- Improved performance with respect to CUORICINO: **ΔE FWHM @ 2615 = 4.6 ± 1.2 keV**
- **Background** in the (2.7 ÷ 3.9) MeV region **reduced by a factor of ~2 with respect to CUORICINO**

Bulk/surface activities within contract specifications:

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)

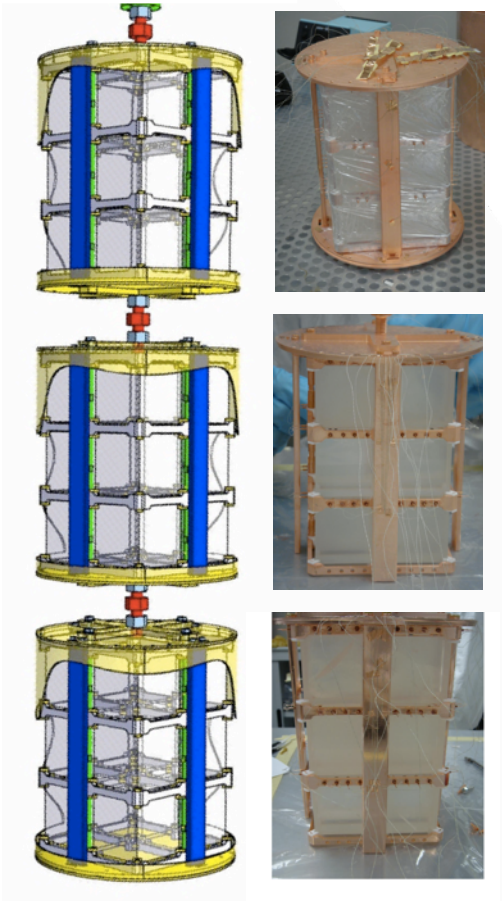
Surface activity 90% C.L. upper limits:

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

Background from Cu: TTT test

Bolometric test to compare the effect in the ROI of **3 different copper surface treatments**

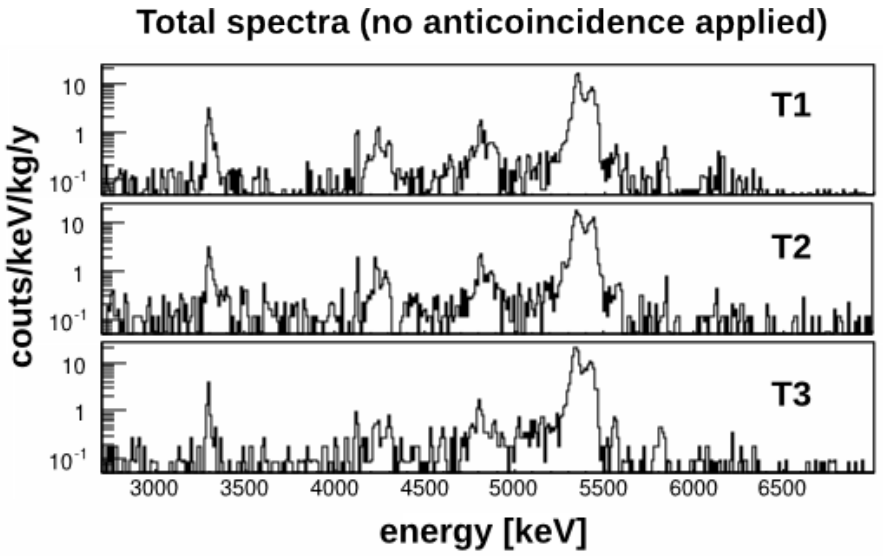
Crystals from Cuoricino array **fully reprocessed** according to the new CUORE standards



T1: Polyethylene
- Soap
- H_2O_2+ H_2O + citric acid
- 70 mm of polyethylene

T2: Chemical treatment
- Soap
- Electro-erosion
- Chemical etching
- H_2O_2+ H_2O + citric acid

T3: Plasma cleaning
- Tumbling
- Electro-polishing
- Chemical etching
- Magnetron Plasma etching



Best result obtained for T1 and T3

Bkg in the (2.7÷3.9) MeV region after anti-coincidence cut:

=> 0.052 ± 0.008 c/keV/kg/y

^{232}Th / ^{238}U on Cu: < 7·10^{-8} Bq/cm^2

CUORE Status

Assembly clean room area

Underground Storage Area

300 K shield installation

- **Hut and clean room:** fully equipped
- **Detector assembly line:** fully ready
- **Radon abatement system:** installed
- **Cryostat:** commissioning of first 3 vessels (of 6) on-going at LNGS
- **Cryostat Dilution Unit**: commissioning started, T<~~8~~ mK reached in stable conditions in a test cryostat

5.5 mK now!!

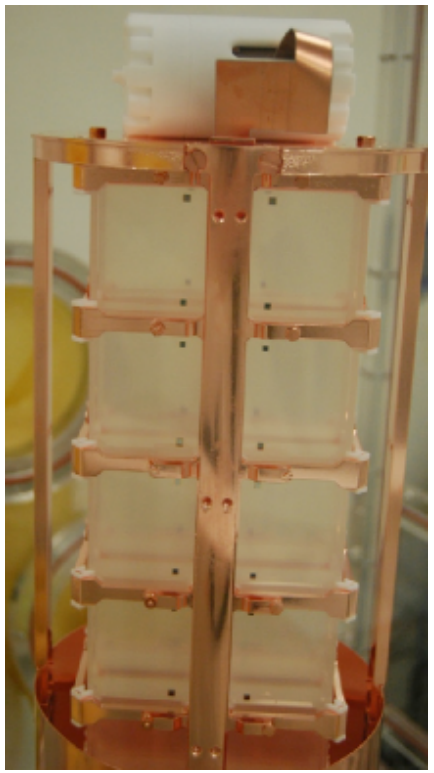
- **Calibration system:** commissioning started
- **Copper parts:** being machined and cleaned, delivered by end 2013
- **Crystals:** all stored underground at LNGS. Some will be reconditioned
- **Thermistors:** production on-going, final delivering in the next few months

Dilution Unit Commissioning

Meanwhile… CUORE-0

1 CUORE-like tower of 13 planes - 4 crystals each
52 TeO_2 5x5x5 cm^3 crystals (750 g each)
Detector Mass: 39 kg TeO_2
^{130}Te mass (natural i.a.): 11 kg of ^{130}Te

- All detector components manufactured, cleaned and stored with protocols defined for CUORE
- Assembled with the same procedures foreseen for CUORE

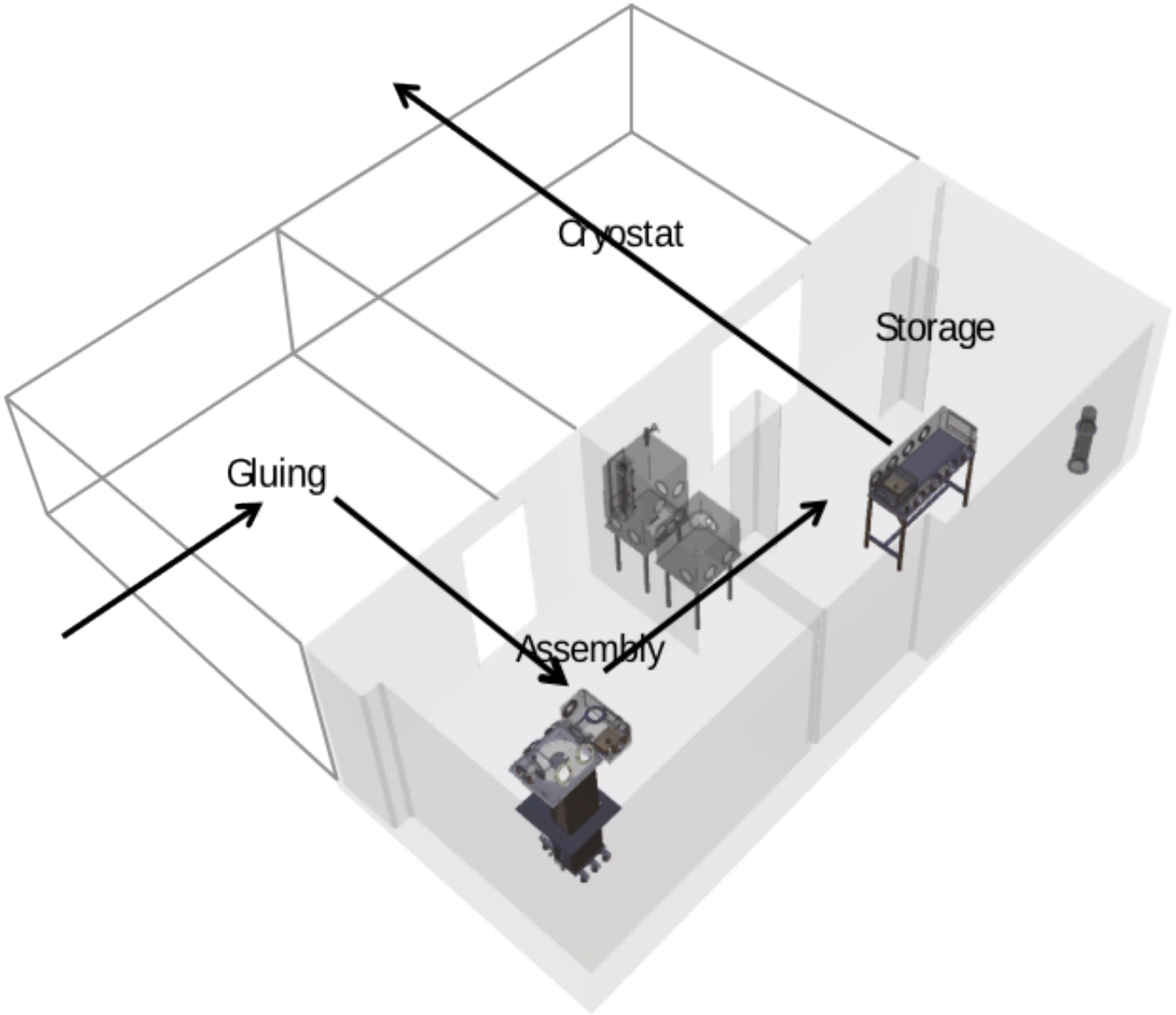


GOALS:

- Proof of Concept for CUORE detector in all stages
- Test and debug the CUORE assembly line
- Test of the CUORE DAQ and analysis framework
- High statistics check of the improved uniformity of bolometric response
- High statistics test of the background reduction achievable
- Extend the physics reach beyond CUORICINO while CUORE is being assembled and confirm the potential of CUORE for DM and Axion detection

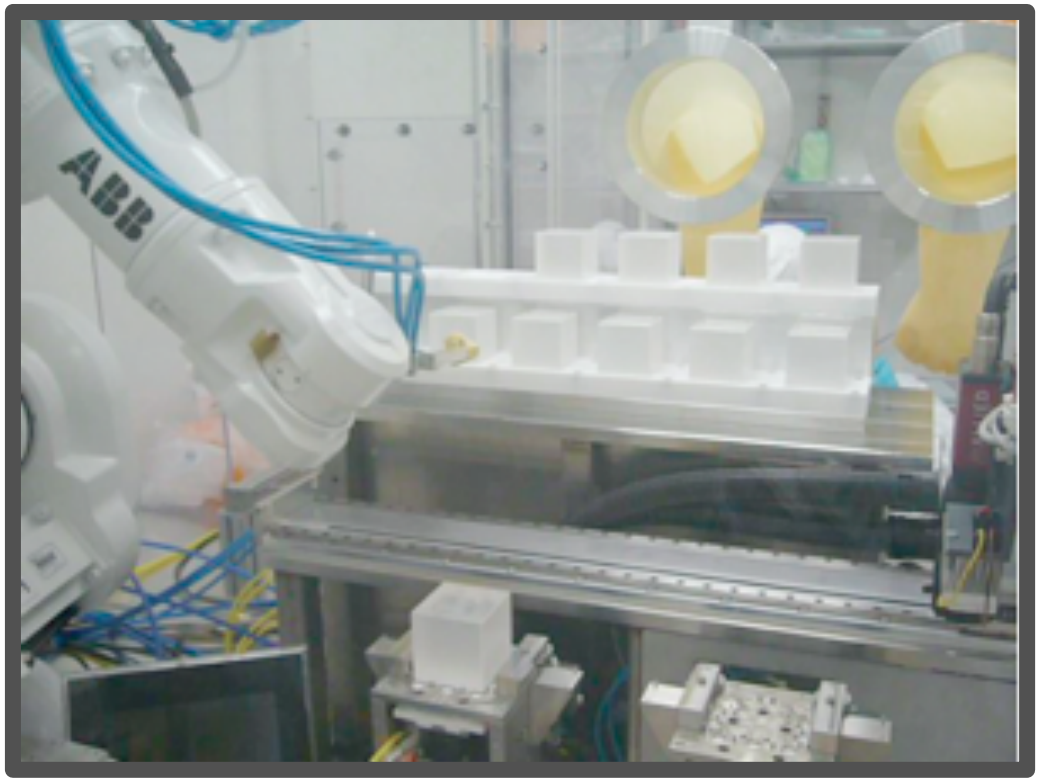
CUORE-0: assembly procedure

CUORE-0 assembly was performed in the new CUORE clean room following all the stages and using **all the equipment developed for CUORE**

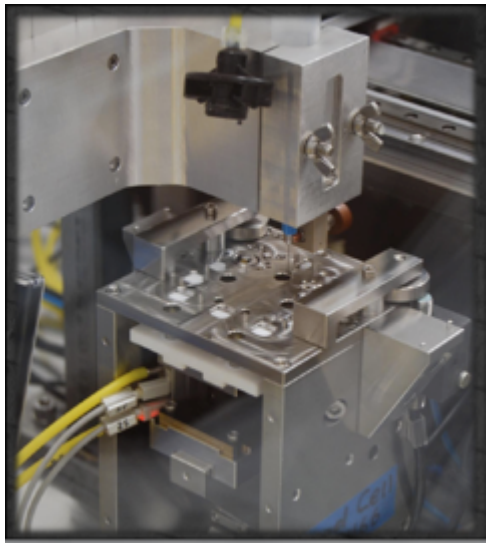


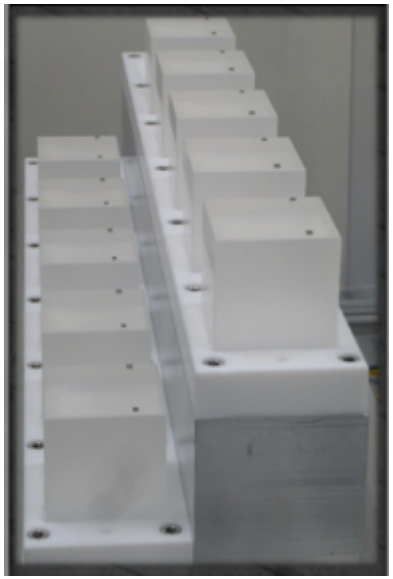
CUORE-0: thermistor gluing

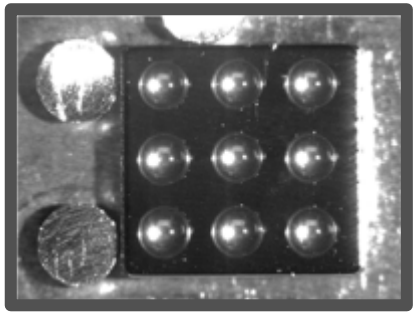
The gluing of CUORE-0 thermistors and heaters to crystals was performed with the **new CUORE gluing semi-automatic machine** in a N_2 flushed glove box: fast, almost operator independent, minimizes radioactive (re)contaminations, makes this stage more reproducible thus improving detector uniformity.



The detector performances (e.g. energy resolution) are driven by the sensor-to-crystal coupling (glue spots)







NTD thermistor

heater

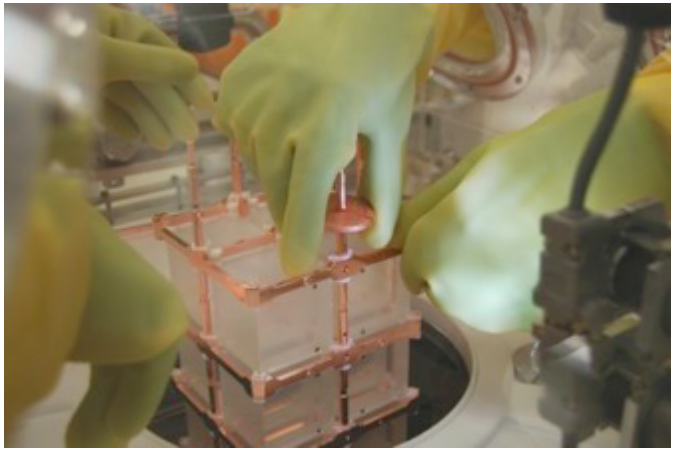
CUORE-0: tower assembly

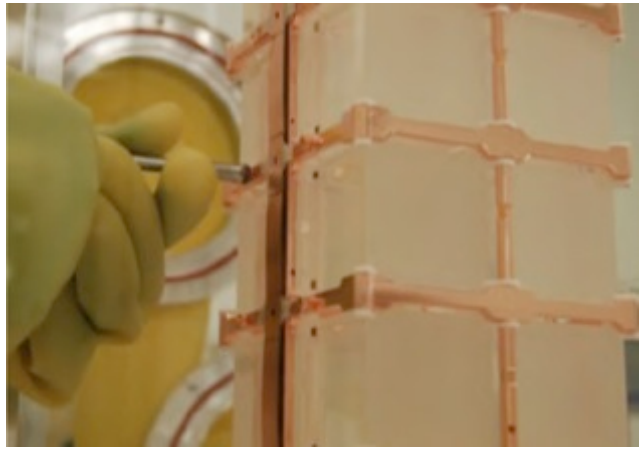
The assembly of the CUORE-0/CUORE towers must follow very strict prescriptions, because of the extraordinary level of radio-purity required

- assembly realized inside nitrogen fluxed glove boxes (recontamination-free)
- strict control on all materials and tools touching the tower elements
- simple, fast, reproducible protocols



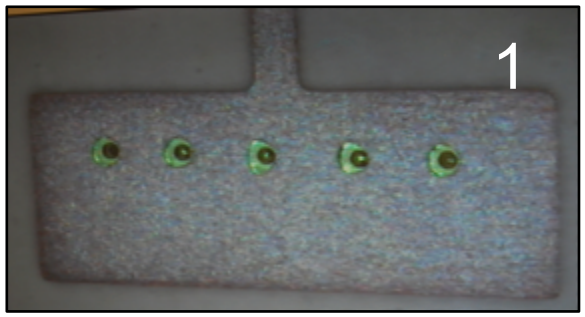


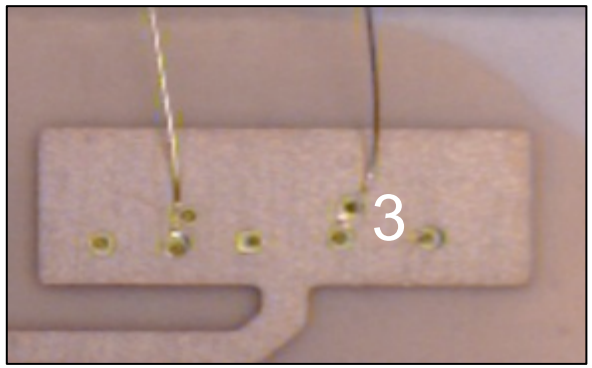


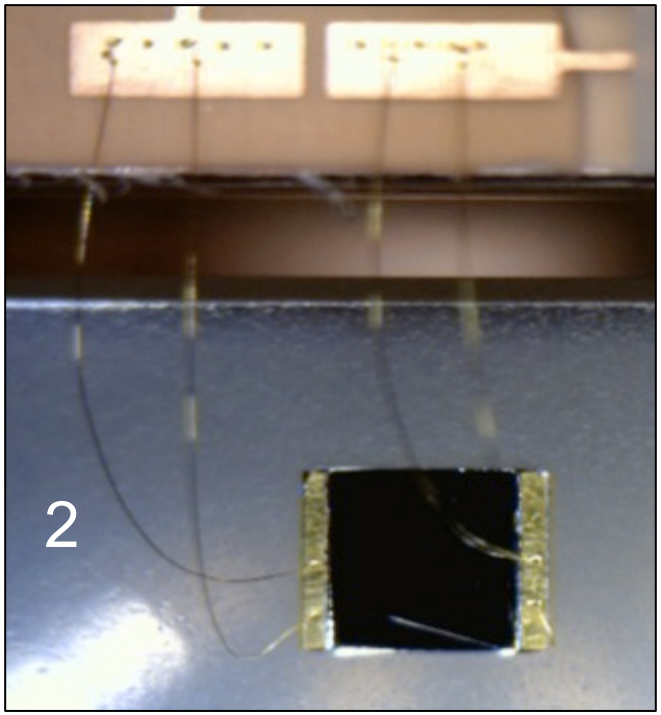


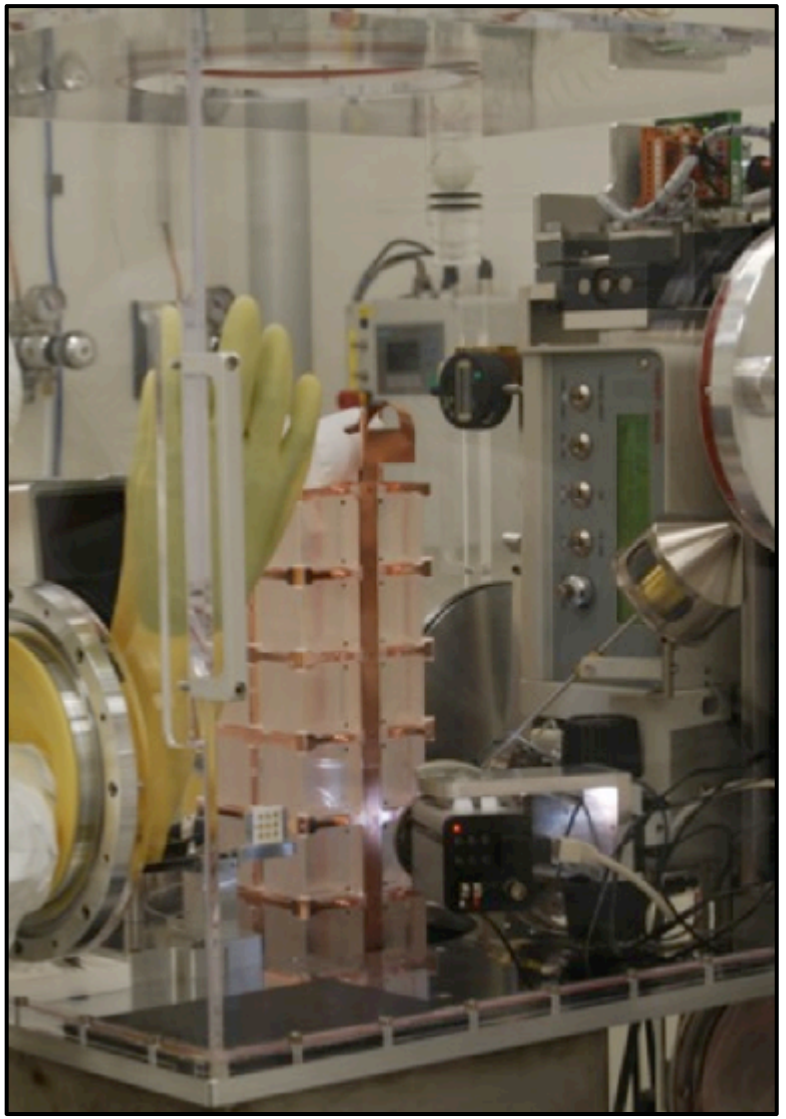
CUORE-0: Signal wires connection

The signal readout is provided by **gold wires directly bonded** on the assembled tower in a N_2 fluxed glove box. The bonding proceeds in **3 main steps**: 1. single ball bonding on the Cu pad; 2. bonding of the wire from chip to a Au ball on the Cu pad; 3. reinforcing ball bond.









416 25 μm dia. gold wires, 15 mm long

More than 2000 bonding steps

Aprox 100 hours for the complete procedure

CUORE-0 status

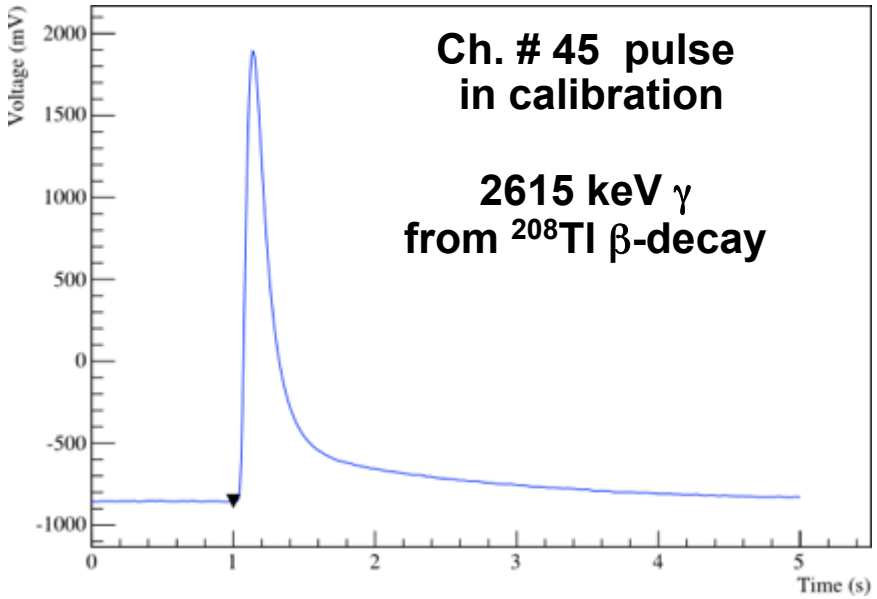
- We have been fighting since May 2012 with the Dilution Unit and the cryogenic system (**24 years old**). Several problems showed up. Each “stop” required between 1 month and 4 months delay

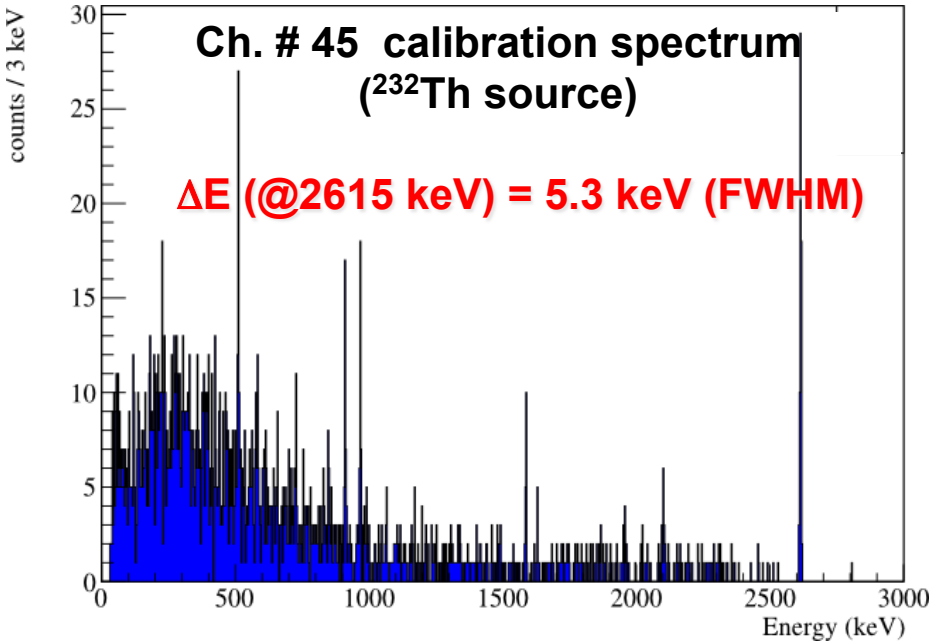
- In **August 2012** we reached at least for some days a base T **~ 8 mK** and we were able to perform a short **calibration** despite the leaks, showing good detector performance

- The **last (hopefully) leak has been fixed** at the beginning of February

- We are **NOW** in the pre-operation and optimization phase (a calibration run is on going). Will the cryostat survive this time?

THINK POSITIVE!!





While waiting for real data…

- The CUORE **assembly procedures successfully tested** and defined
- Demonstrated that **a complete CUORE tower** can be assembled in **less than 4 weeks**
- The totally new bonding approach has survived several thermal cycles: **all detectors are still alive**.The only missing one was not even bonded.
- **Based on CUORE-0 experience** a detailed plan for the assembly of the 19 CUORE towers has been prepared, aiming at:
  - Minimize manpower, cost, and duration
  - Maximize efficiency
  - Preserve quality control

The full plan for the CUORE towers assembly has started in February

THE FIRST 2 TOWERS WILL BE GLUED, ASSEMBLED AND BONDED BY MAY

CUORE cooldown foreseen by the end of 2014

CUORE-0 and CUORE sensitivity

Assumptions

	CUORE-0	CUORE
M [kg]	11 of ^{130}Te	206 of ^{130}Te
ΔE [keV] *	~5	~5
b [c/keV/kg/y] **	**0.05**	**0.01**
Live-T [y]	2	5

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

ε = 87.4% (Monte Carlo calculation)
i.a. (^{130}Te) = 34.2 % (ICP-MS)

* Data from Cuoricino and CUORE-0
** Data from measurements + bkg model in the hypothesis that surface contaminations are negligible with respect to cryostat ones

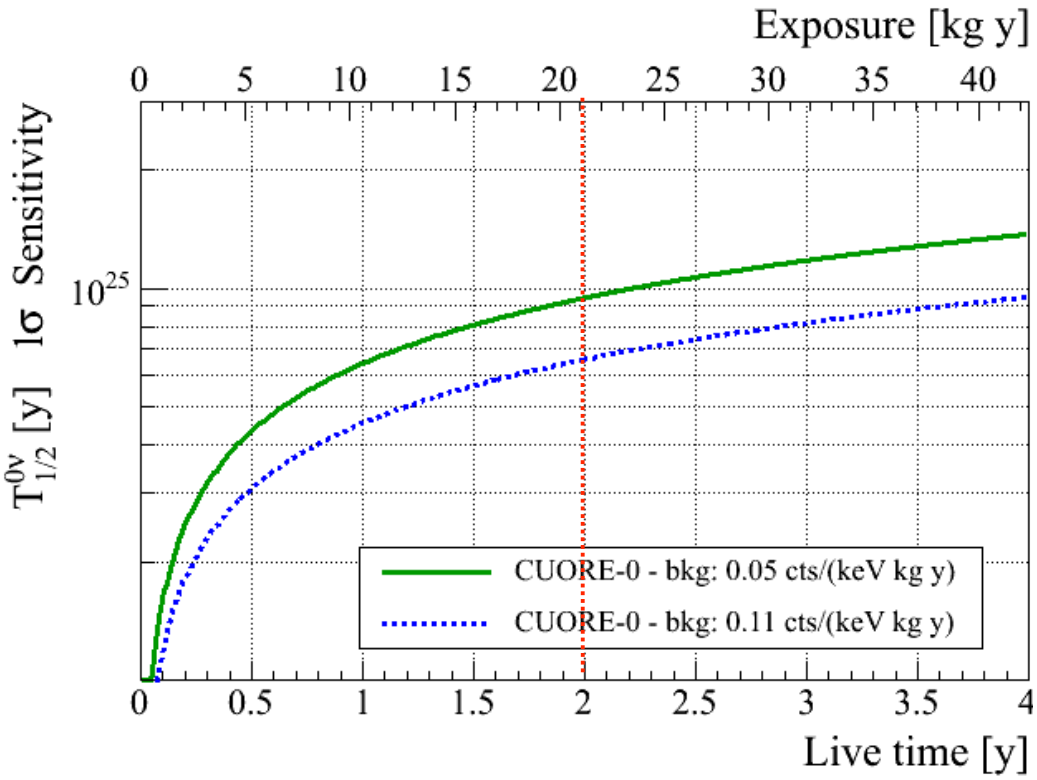
Sensitivity

		CUORE-0	CUORE
$T_{1/2}$	1σ CL	9.4 x 10^{24} y	1.6 x 10^{26} y
	90% CL	**5.9 x 10^{24} y**	**9.5 x 10^{25} y**
$\langle m_{ee} \rangle$ ***	1σ CL	162 – 422 meV	39 – 102 meV
	90% CL	**204 – 533 meV**	**51 – 133 meV**

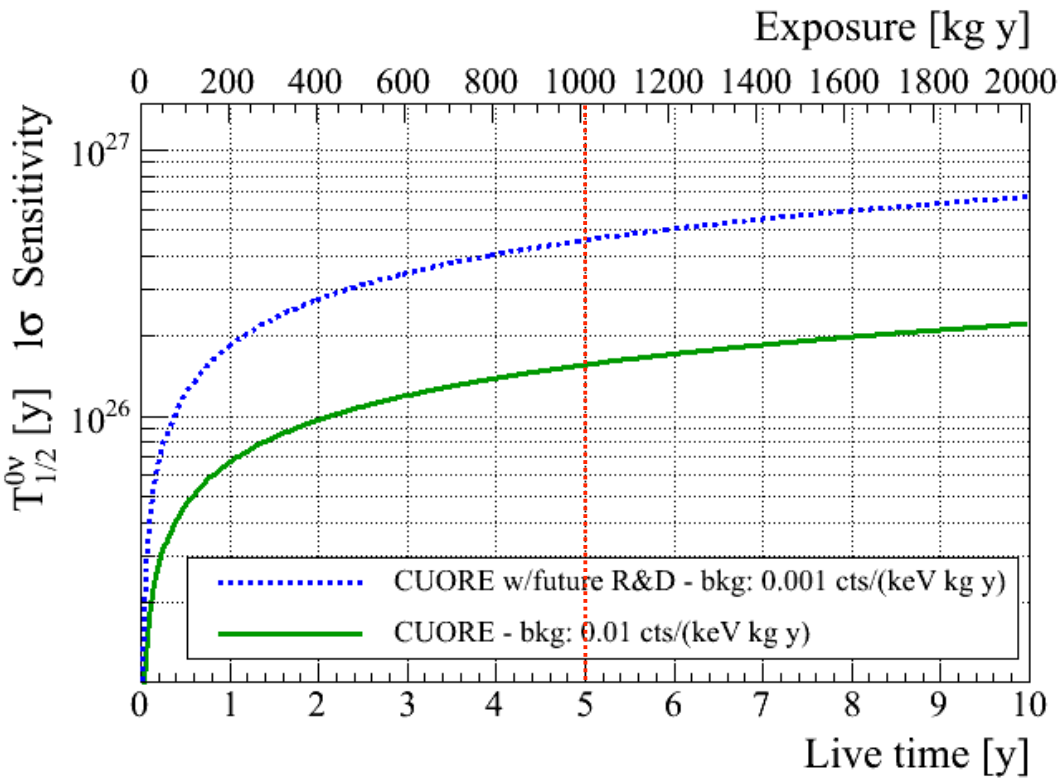
*** Computation performed with PSF and NME from J Barea et al., PRC 87 (2013) 014315 and references therein

$T_{1/2}$ sensitivity versus Time

CUORE-0

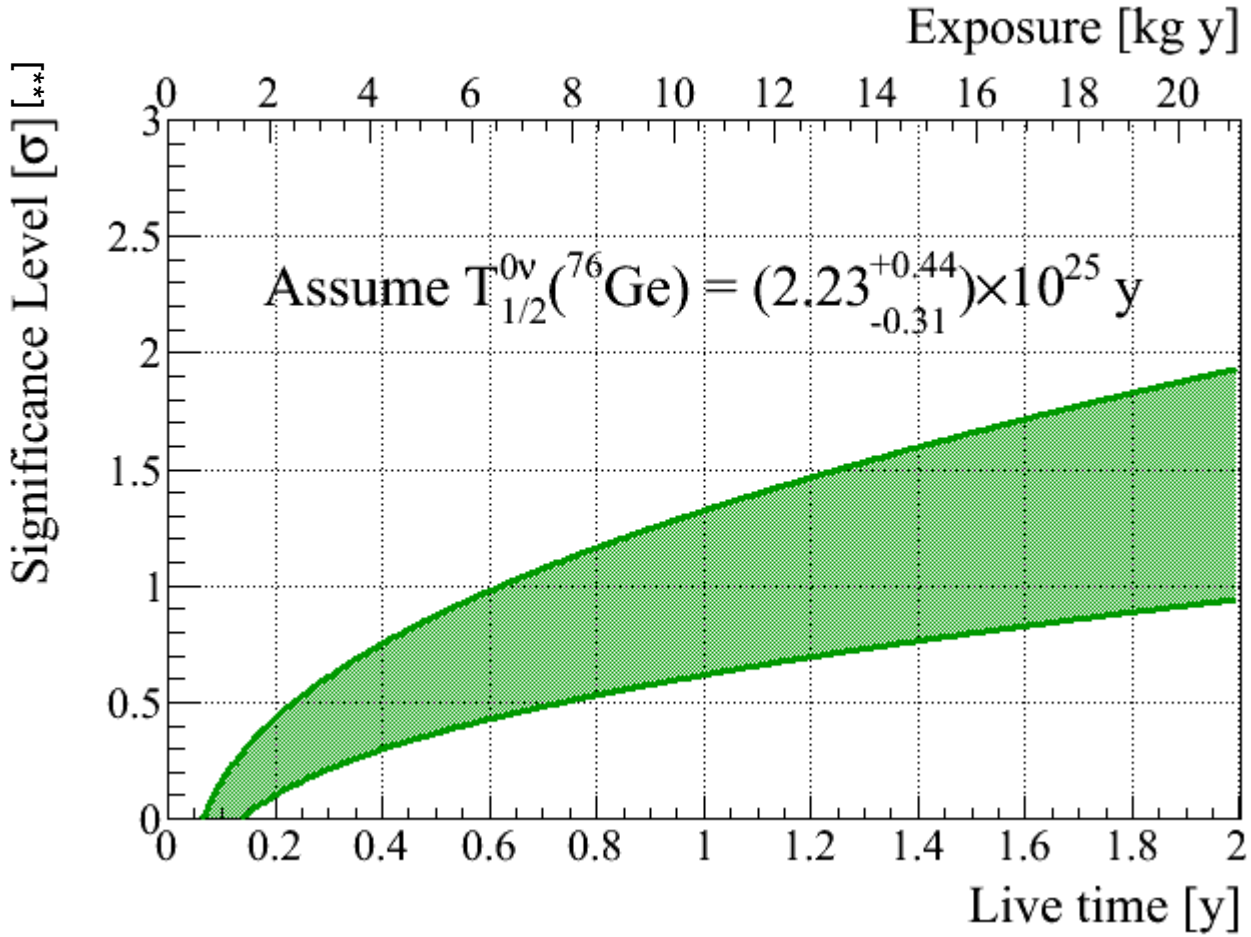


CUORE



- Bkg scaled from CUORICINO taking into account the improvement in the cleaning of surfaces
- Bkg in the hypothesis that surface contaminations are negligible with respect to cryostat contamination
- Bkg evaluated from measured values/limits for CUORE materials and geometry (bkg budget)
- Optimistic background

CUORE-0 Sensitivity to ^{76}Ge claim



Significance level at which CUORE-0 can observe a **ββ0ν signal consistent with the claim in ^{76}Ge** [*] , with b=0.05 c/keV/kg/y

Spread due to the NMEs + the 1 σ error on the reported ^{76}Ge measurement

[*] *H.V. Klapdor-Kleingrothaus et al., Mod. Phys. Lett. A 21 (2006) 1547*
[**] *Computation performed with PSF and NME from [6]*

What beyond CUORE?

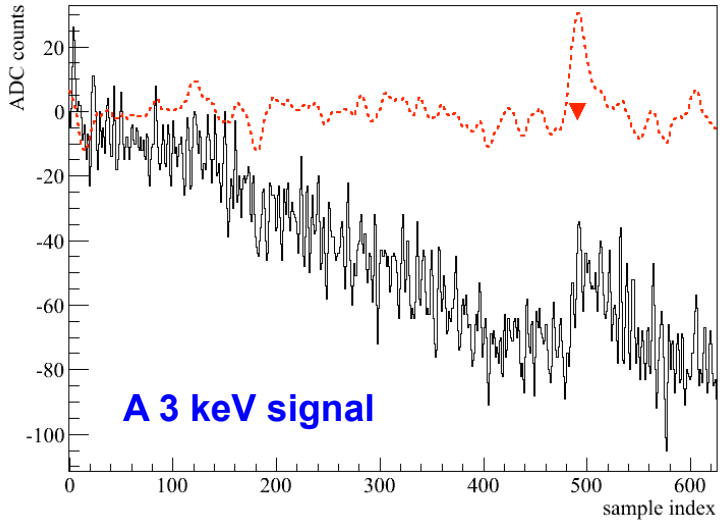
$$S^{0\nu} \propto \frac{\epsilon\, a.i.}{A} \left(\frac{MT}{b\,\Delta E} \right)^{1/2}$$

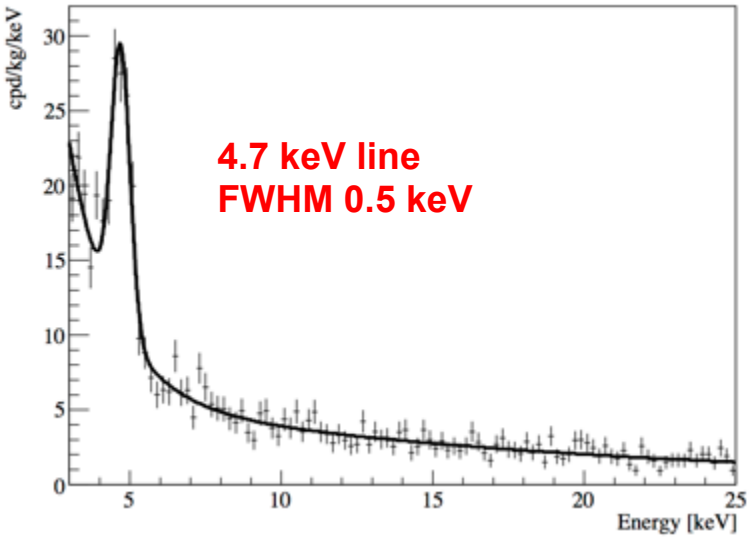
Extensions beyond CUORE are possible in order to increase sensitivity to cover the inverted hierarchy region of the neutrino mass spectrum

- Relatively inexpensive isotopic enrichment of ^{130}Te
- No change needed to the experimental infrastructure
- 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 or scintillating bolometers (i.e. ZnSe, $CdWO_4$, $ZnMoO_4$...)

Other Measurements with CUORE

Reduction in the background levels, especially at low energy, make other physics measurements possible





- Dark matter search à la DAMA
- Solar axions through the axio-electric effect
- Supernova watch
- Rare nuclear transitions

Look for a 14.4 keV line

This could be made possible by a new trigger algorithm that can lower the energy threshold at a few keV

Energy resolution has also showed to be good: 0.5 keV at 4.7 keV (origin of the peak presently unknown)

VISIT CUORE POSTER TONIGHT!

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 (the **main challenge being surface contaminations** of detector and facing parts)
- Bolometric tests after improving surface treatments demonstrate that the **CUORE goal of 0.01 c/keV/kg/y** is just **behind the corner**.
- **CUORE** is **under construction.** The assembly of the CUORE towers started in February.
- CUORE **cool down** is foreseen **by end 2014**

- **CUORE-0**, the first CUORE tower, was **successfully assembled** using CUORE assembly tools and procedures
  - **Measurements** performed in pre-operation/optimization phase show **good detector performances**
  - Official data-taking experienced some delay due to cryogenic problems. **Foreseen to start in a short time**

The CUORE Collaboration

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