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The road towards CUORE: latest Cuoricino results and CUORE-0

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Outline

- Looking for Neutrinoless Double Beta Decay
- Bolometers & TeO_2
- Cuoricino
- Towards CUORE
- The nearest step: CUORE-0

When thinking about the questions still open in the field of neutrino physics, there are three important -and complementary- tools of investigation:

$$\Sigma \equiv \sum_{i=1}^{3} M_i$$

Cosmological measurements

- Model dependant

$$\langle M_\beta \rangle \equiv \left[\sum_{i=1}^{3} M_i^2 \, |U_{ei}|^2 \right]^{1/2}$$

Single Beta Decay

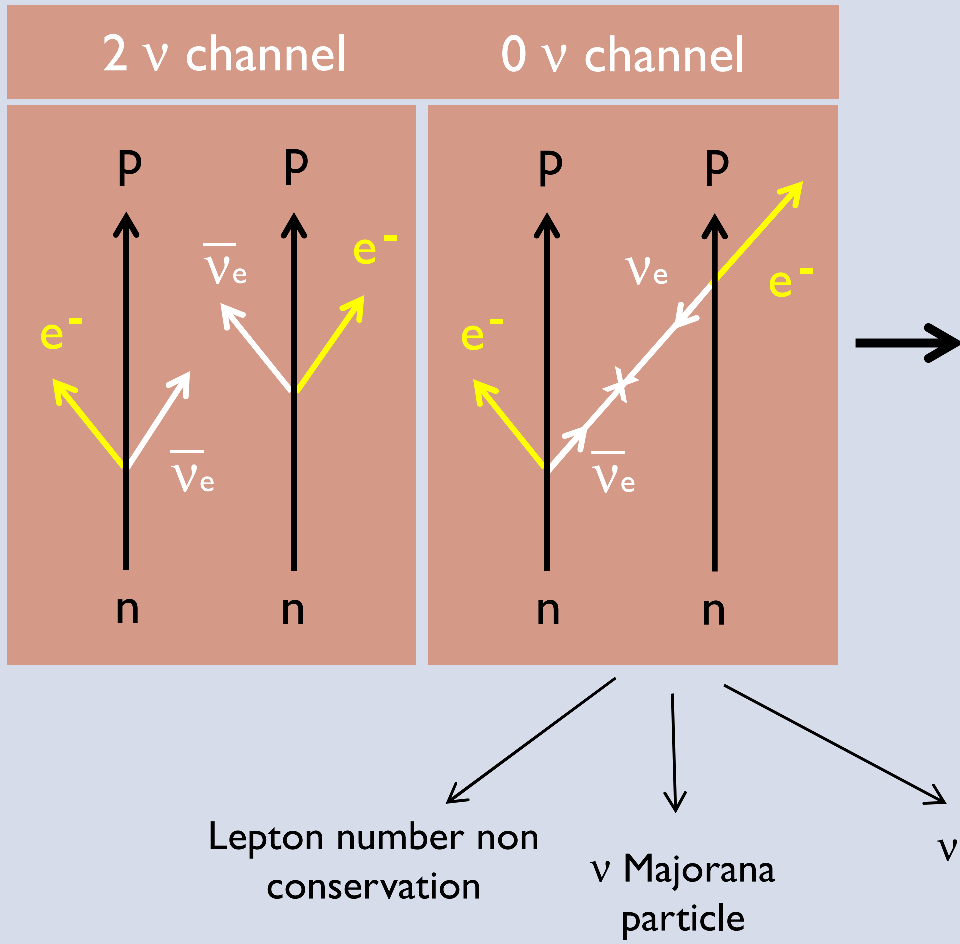
-Direct determination
-Laboratory measurement

Neutrinoless Double Beta Decay

-Model dependant
-Laboratory measurement

Double Beta Decay: rare, second order weak decay

$$(A,Z) \longrightarrow (A,Z+2)$$

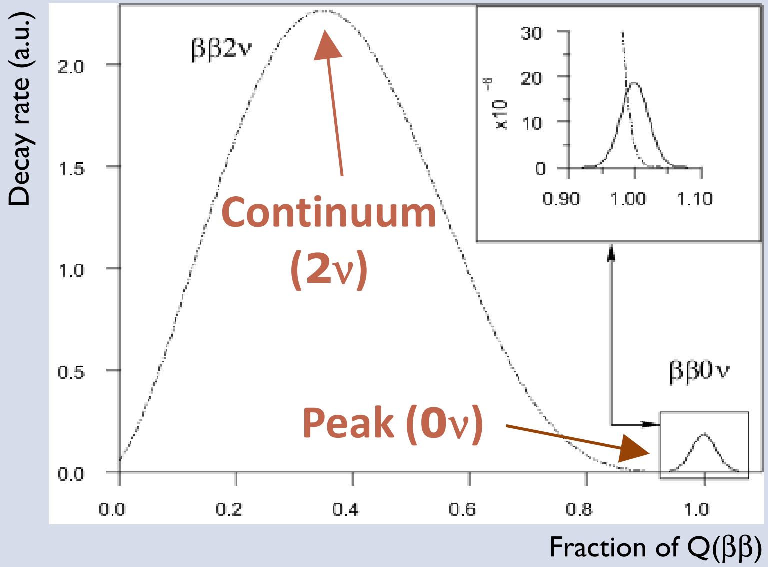


The observation of 0ν-DBD would give an answer to the questions regarding:

- The absolute ν mass scale
- The ν mass hierarchy
- The ν nature

0ν-DBD (2)

What we are looking for:



What kind of information we obtain:

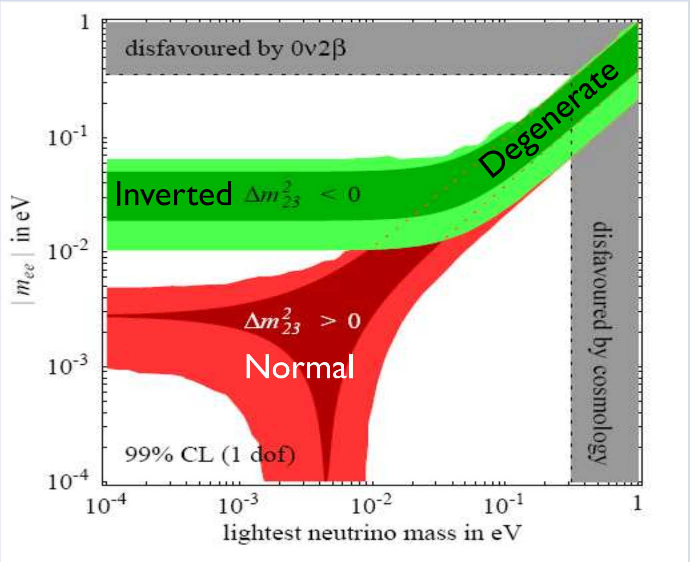
$$T^{0\nu}_{1/2} \sim \frac{1}{G^{0\nu}\,|M^{0\nu}|^2 \langle m_{ee}\rangle^2}$$

0ν-DBD half life

$$m_{ee} = \left| \sum_{i=1}^{N} U_{ei}^2 \, m_i \right|$$

Effective Majorana mass

Where we are working now and where we want to go:

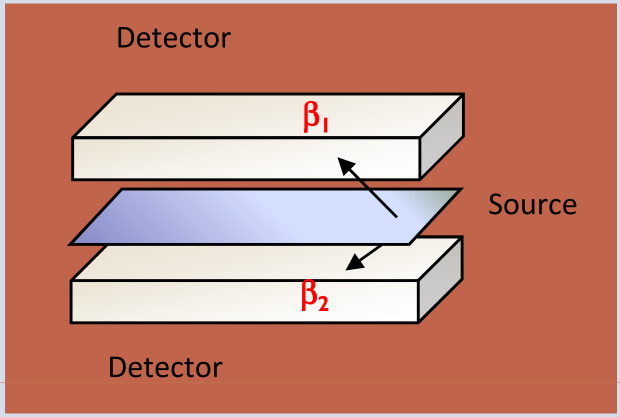


A. Strumia, F. Vissani, hep-ph/0503246

Experimentally, one can approach the search by following two different paths:

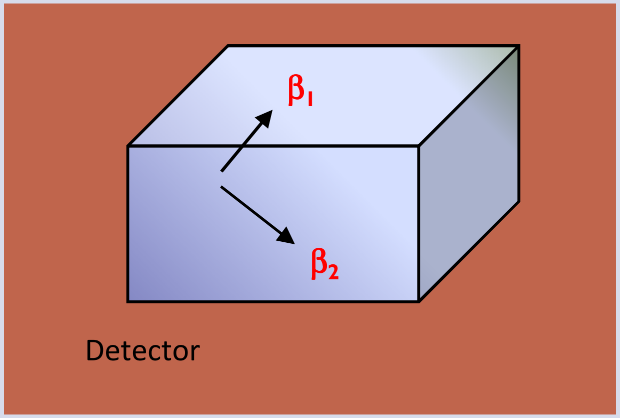
Source ≠ detector

- Event shape reconstruction
- Low energy resolution



Source = Detector → The calorimetric approach

- No event topology
- High energy resolution



Exp. approaches

Sensitivity

The experimental parameters to play on are evidenced by introducing the sensitivity $S^{0\nu}$ as the half life corresponding to the minimal number of detectable events above background, for a given confidence level:

$$S^{0\nu} \propto \frac{a}{A} \sqrt{\frac{M \cdot T}{b \cdot \Delta E}} \times \varepsilon$$

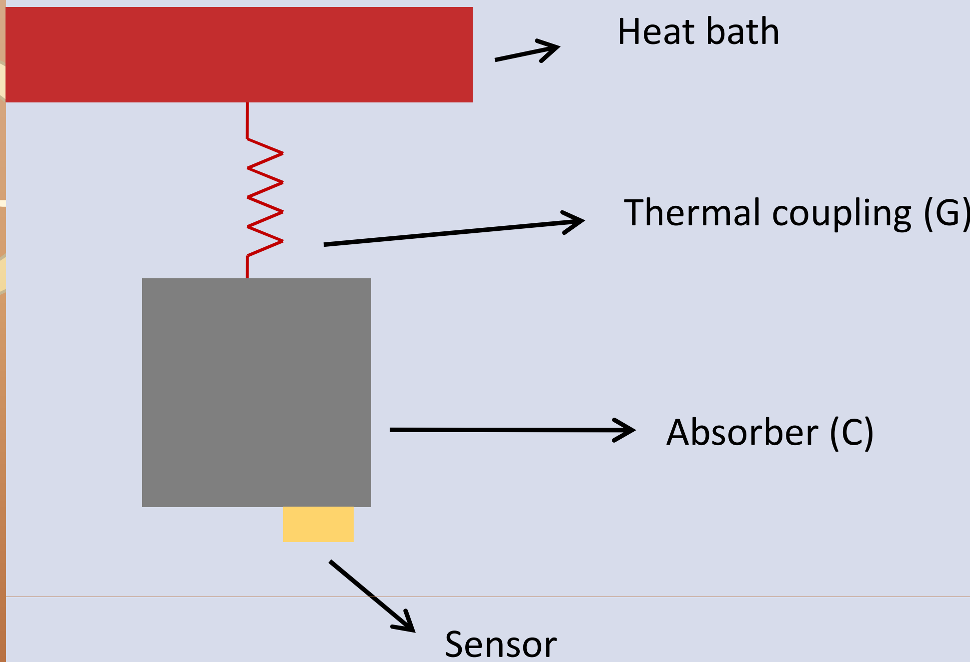
- a → Isotopic abundance
- M → Detector mass [kg]
- T → Measurement time [y]
- ε → Efficiency
- ΔE → Energy resolution [keV]
- b → Background level [counts/keV/kg/y]
- A → Atomic mass

$$m_{ee} \propto \sqrt{\frac{1}{T^{0\nu}_{1/2}}}$$

Not all of the parameters can be tuned effectively…

Bolometers

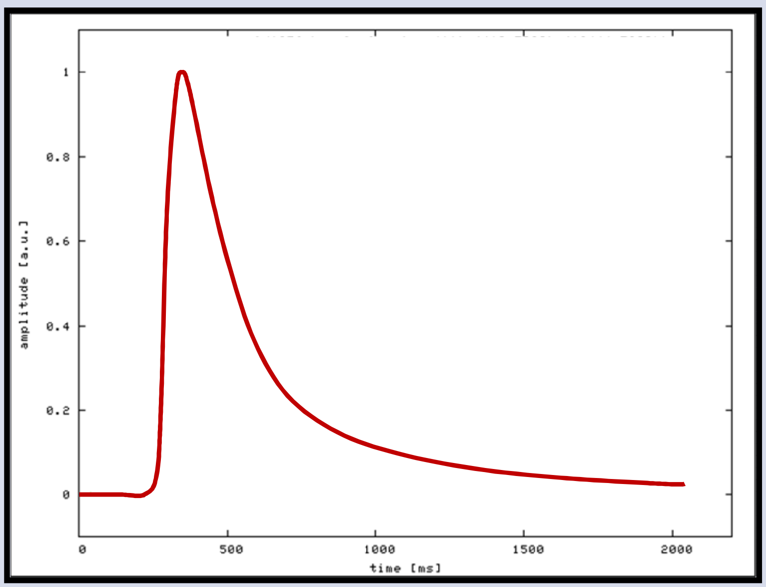
The basic principle is very simple.



With this technique, we measure all of the energy deposited by a particle in form of an increase in the temperature of the absorber.

- Signal $\Delta T = E/C$

- Time constant C/G



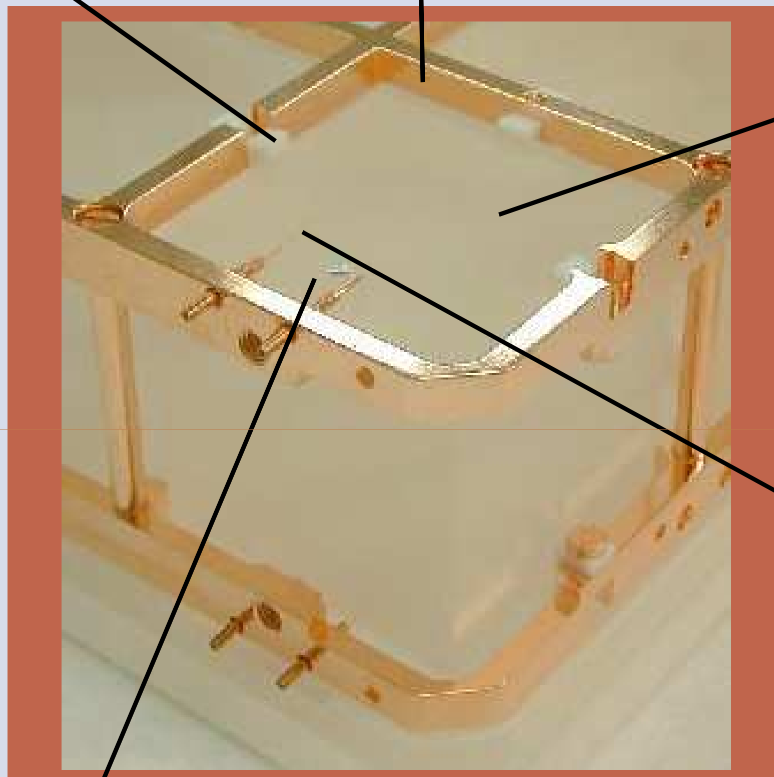
Low temperatures & Dielectric diamagnetic crystals

TeO_2 Bolometers (I)

@~10 mK

Weak thermal coupling to the heat bath (PTFE holders)

Heat bath (copper frame)



Absorber (TeO_2 5x5x5 cm^3cubic crystal, C~10^{-9} J/K)

Gold wires for signal read-out (ϕ=50μm)

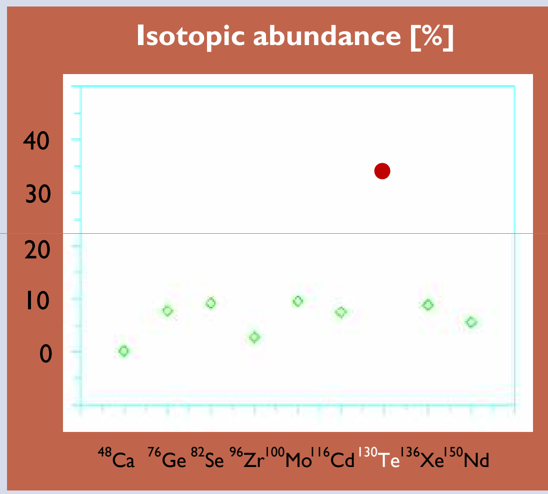
Sensor for temperature/electric signal conversion (Ge NTD thermistor, R~100 MΩ)

In this configuration,
ΔT~0.2 mK/MeV, τ_r~50 ms and τ_d~500 ms

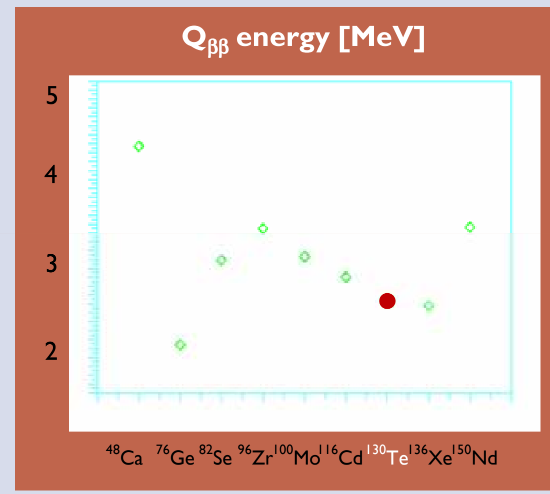
Why use ^{130}Te as 0ν-DBD source and TeO_2 as energy absorber?

Decay: $^{130}Te \longrightarrow {}^{130}Xe + 2e^-$

High natural isotopic abundance (~33.9%), which makes enrichment not a priority



High transition energy ($Q_{\beta\beta}$= 2530 keV), between the 2615 keV ^{208}Tl γ line and the Compton edge, almost above the background of natural radioactivity

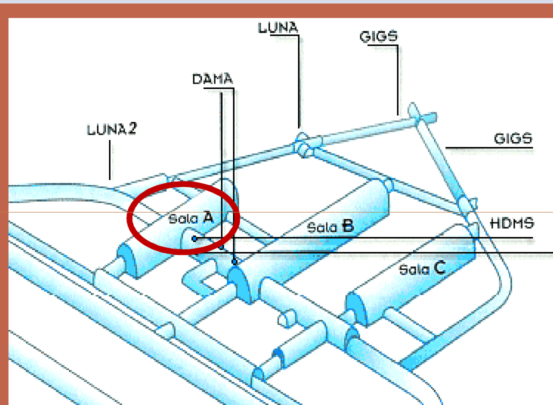


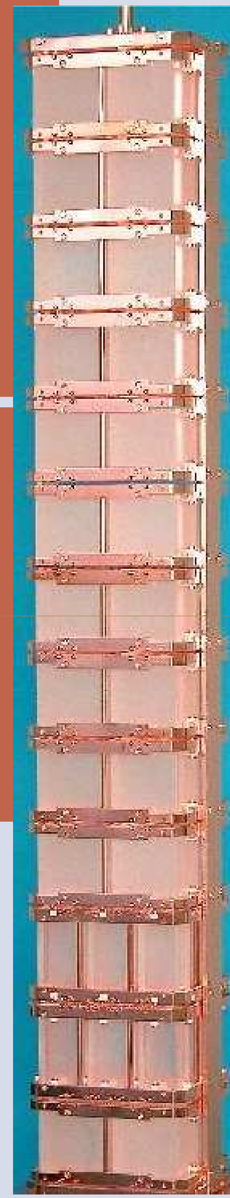
The 2ν-DBD for ^{130}Te was measured by geochemical experiment, MIBETA and NEMO3 with $T^{2\nu}_{1/2}$ = (7.6±1.5±0.85) x 10^{20} y

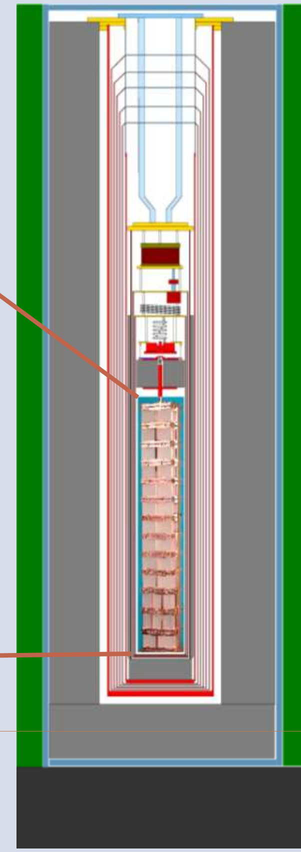
Using TeO_2 allows one to have bolometric absorbers with low heat capacity as well as to grow with good radiopurity large crystals resistant to thermal cycles

Cuoricino

@ Gran Sasso National laboratory, Italy – 3500 m.w.e







Active mass:
- 40.7 kg of TeO_2
- 11.3 kg of ^{130}Te (~$5x10^{25}$ nuclides)

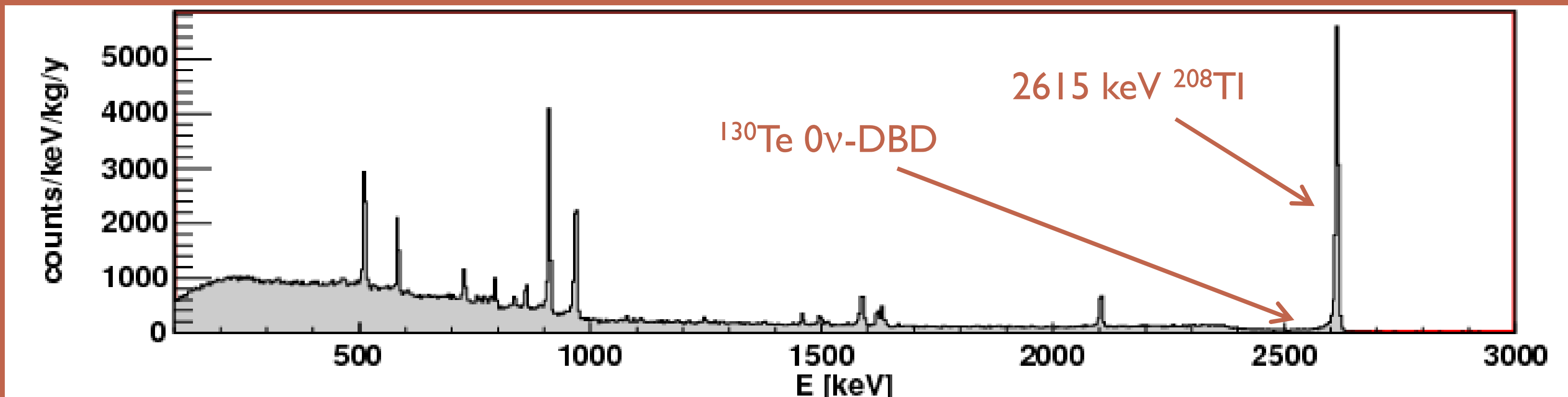
Modules:
- 11 modules each with 4 crystals $5x5x5\ cm^3$
- 2 modules each with 9 crystals $3x3x6\ cm^3$
  2 enriched in ^{128}Te (82%)
  2 enriched in ^{130}Te (75%)

- Inner shield: 1 cm Roman Pb, $A(^{210}Pb) < 4$ mBq/kg
- External shield: 20 cm Pb + 10 cm borated polyethilene
- Nitrogen flushing to avoid Rn contamination

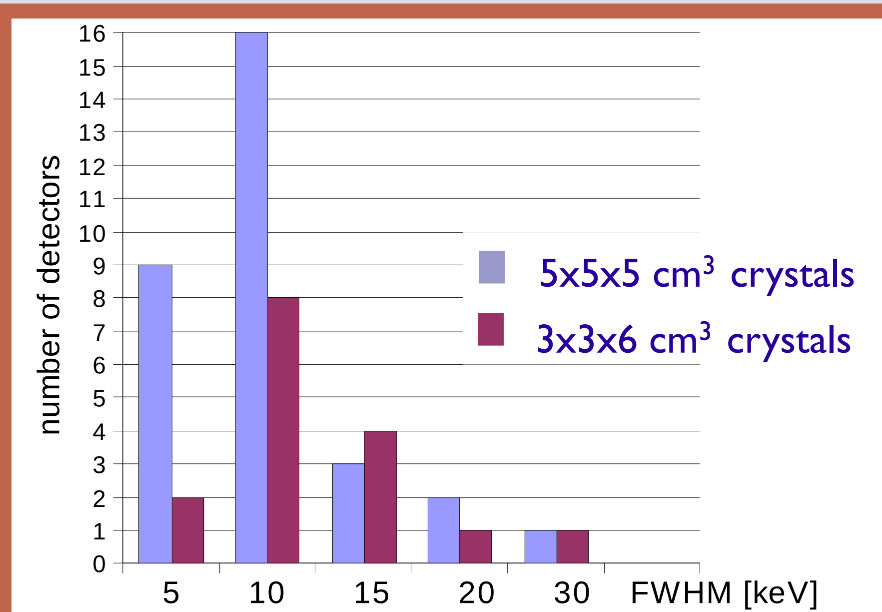
Started in 2003, data taking ended in June 2008

Sum calibration spectrum (for 5x5x5 cm^3 crystals)

Calibration performed with a ^{232}Th source
~ 3 days every month



Average FWHM [keV] of the 2615 keV line of ^{208}Tl for 5x5x5 cm^3 crystals = **7 keV**



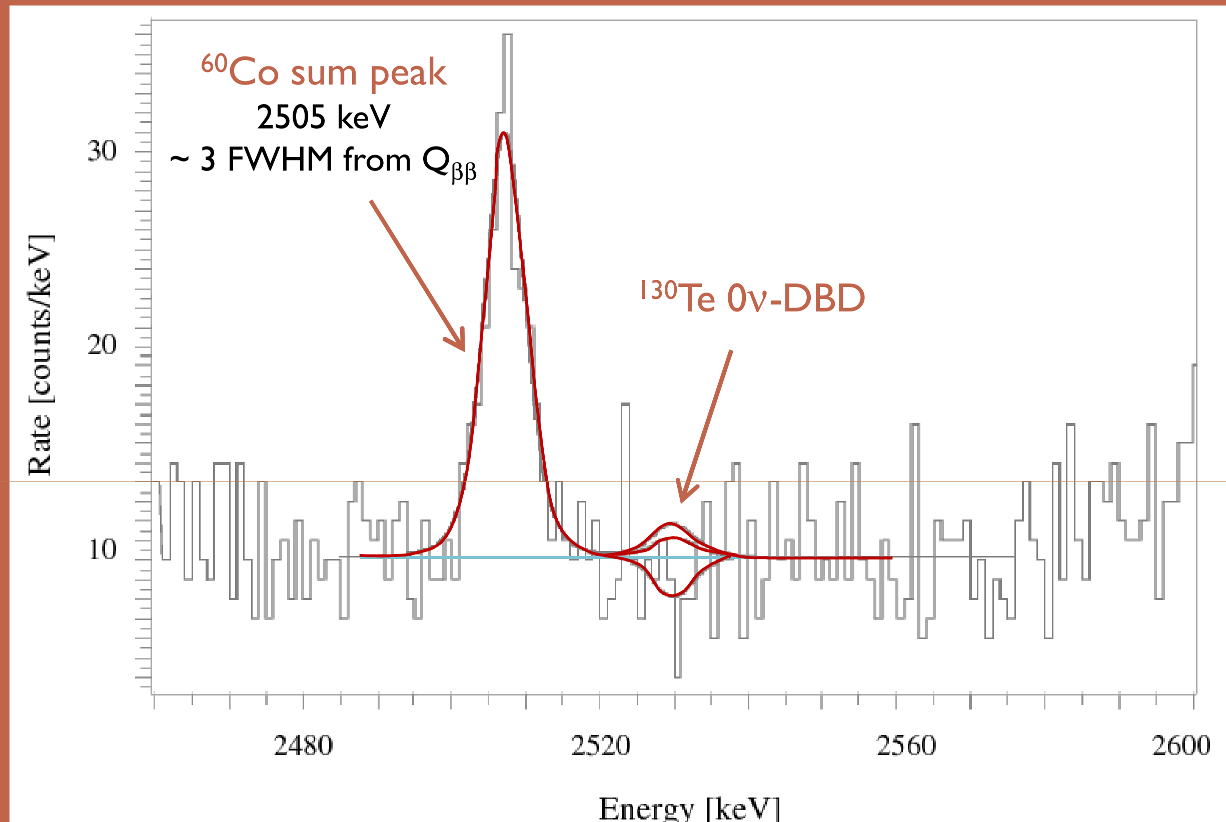
Distribution of energy resolution FWHM

The physics result: statistics updated to **August 2007**

No peak appears @ $Q_{\beta\beta}$ value.
An upper limit for the ^{130}Te 0ν-DBD is set.

- M · T = 15.53 kg ^{130}Te · y
- Background level b= (0.18±0.01) c/keV/kg/y

0ν-DBD ^{130}Te limit



$T_{1/2}^{0\nu}(^{130}\text{Te}) > 3.1 \times 10^{24}$ y @ 90% C.L.

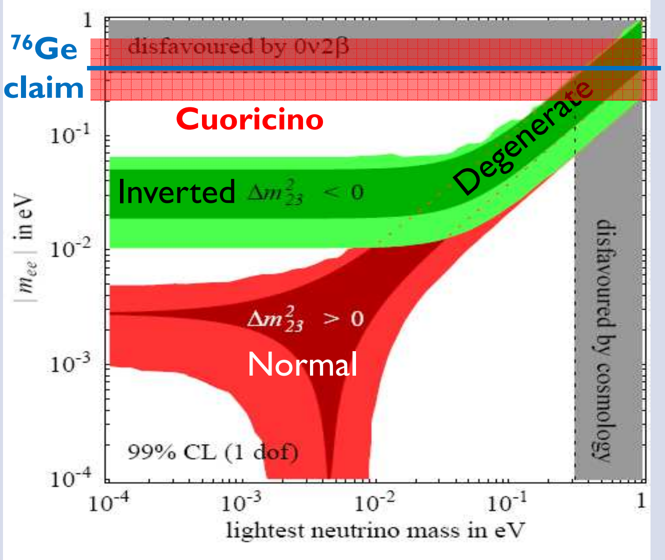
⇕

m_{ee} < 200-680 meV

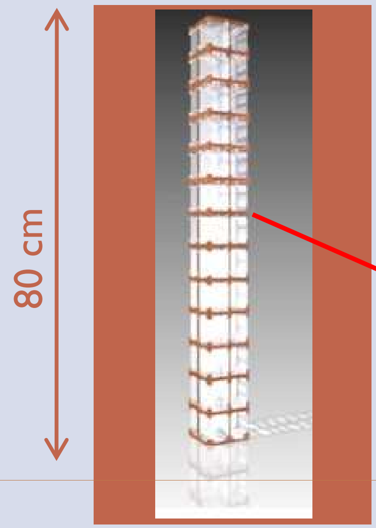
[NME from the review table of QRPA calculation in Rodin et al Nucl. Phys. A 766,107 (2006) + Erratum nucl-th:0706.4304v1]

Latest article: **"Results from a search for the 0νββ-decay of ^{130}Te", Physical Review C 78, 035502 (2008)**

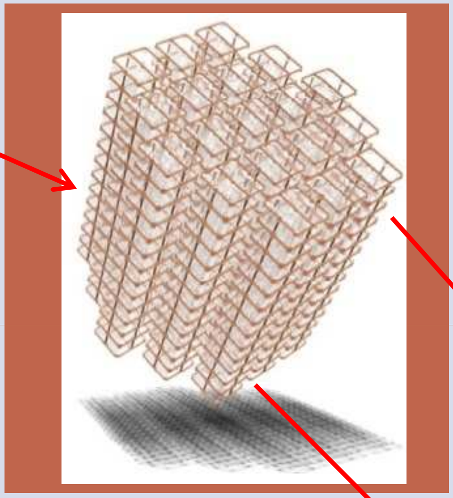
CUORE (Cryogenic Underground Observatory for Rare Events): a next generation experiment for investigating the inverted hierarchy region



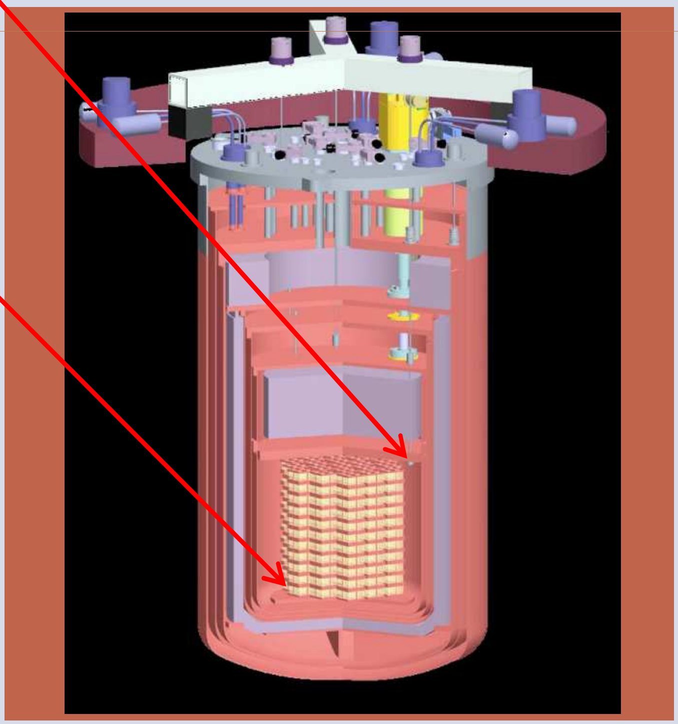
It will be a high granularity detector with 741 kg of TeO_2 (230 kg of ^{130}Te)



13 layers, each with 4 "big" crystals ($5x5x5\ cm^3$)



19 towers arranged in a cylindrical structure



988 bolometers working in a closed pack array put in a LHe-free dilution refrigerator

Start of data taking: 2012

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From Cuoricino to CUORE: remembering the sensitivity $S^{0\nu}$,

$$m_{ee} \propto \frac{1}{(a \cdot \varepsilon \cdot G)^{1/2} |M^{0\nu}_{nucl}|} \sqrt[4]{\frac{1}{M \cdot T}} \sqrt[4]{\Delta E \cdot b}$$

Difficult to modify: requires fundings and R&D efforts

From "*Qino to Q*" we gain a factor $\sim(200/10)^{1/4}$: however further improvements are not easy to reach

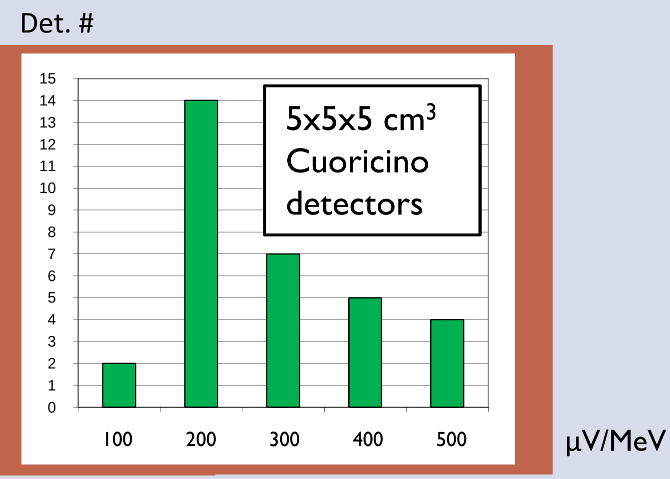
CUORE will take data for 5 years: but afterwards, to get a factor 2 on that, one should run for other 75 years…

The improvements on this factor have a negligible influence

The background level is the only factor here that can be tuned with a real impact on the m_{ee} sensitivity

Another issue: the reproducibility of the detectors…

Distribution of detector pulse heights



The challenge

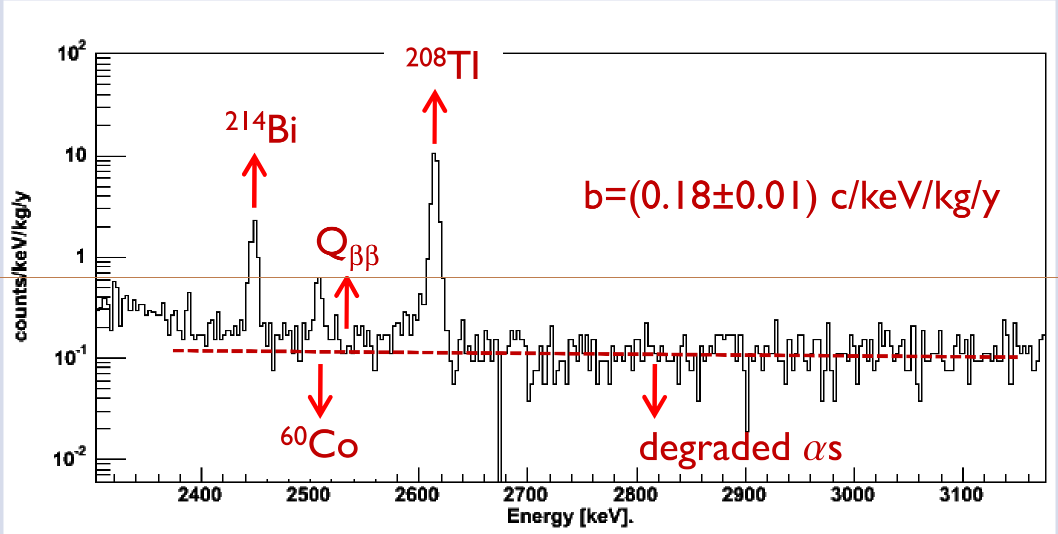
The expected sensitivity for CUORE, in 5 years:

b [c/keV/kg/y]	ΔE [keV]	$T_{1/2}$ [y]	m_{ee} [meV]
10^{-2}	5	$< 2.1 \cdot 10^{26}$	48-72
10^{-3}	5	$< 6.5 \cdot 10^{26}$	27-41

[NME from: -Rodin et al Erratum, nucl-th:0706.4304v1;
-Civitarese and Suhonen, Nucl. Phys. A 761, 313:
-Caurier, Nowacki and Poves, nucl-th:0709.0277v2]

What we know from Cuoricino:

- ~ 40% ^{208}Tl via multi-Compton events from ^{232}Th in the cryostat shields;
- negligible effect from the 2505 keV ^{60}Co tail due to Cu cosmogenic activation;
- muon induced background excluded;
- ~ 10% due to degraded αs from ^{232}Th & ^{238}U contaminations in the crystal surface;
- ~ 50% due to degraded αs from ^{232}Th & ^{238}U contaminations in the copper surface.



What we have already gained from R&D:

A reduction of ~ a factor 4 in the contribution due to contaminations on the crystal surface and of ~ a factor 2 for the Cu surface.

Extrapolating the contributions to CUORE:

- ~ 10^{-3} c/keV/kg/y contribution due to intrinsic contaminations
- $2\text{-}5 \cdot 10^{-2}$ c/keV/kg/y contributions due to surface contaminations

An upcoming test using the same setup of the already disassembled Cuoricino: the Three Towers run

Legnaro cleaning

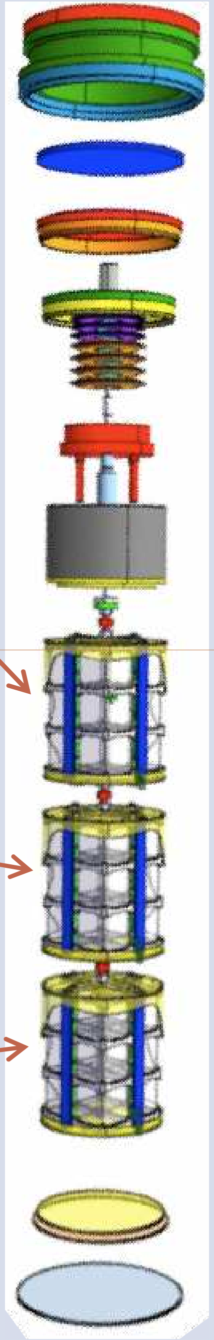
- Tumbling: mechanical barrel polishing
- Electropolishing: removal of ~100 μm of material
- Chemical etching: removal of ~10 μm of material
- Magnetron sputtering: removal of a few μm
- Ion beam cleaning: removal of a few nm

LNGS cleaning

- Electropolishing
- Chemical etching
- Passivation

LNGS alternative cleaning

- Chemical etching
- Passivation
- 50 μm PET coverage of Cu components

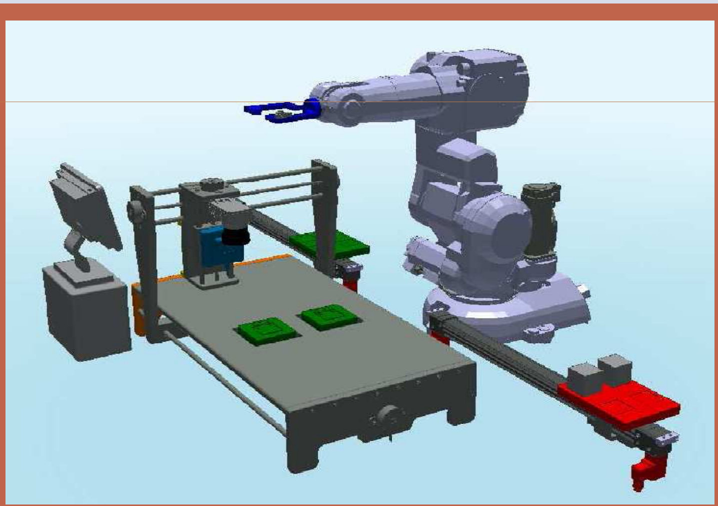


Background (2)

On the road towards CUORE, it is necessary to reduce the aspects which contribute in making the performances of the detectors not reproducible.

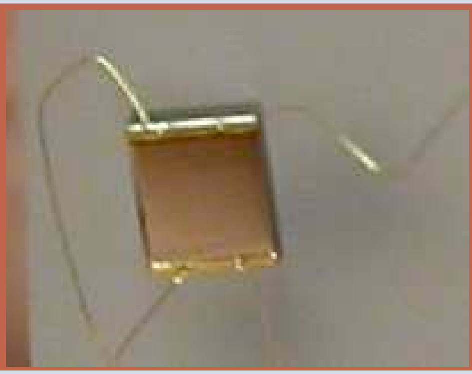
Concerning this aspect, the thermal and mechanical coupling between the thermistor and the crystal absorber is one of the most delicate points in the assembly procedure.

The coupling is performed – until now manually- by depositing spots of bicomponent epoxy glue, with 50 μm height, between the crystal and the sensor: the process is not trivial!



→ Development of a "gluing line" totally automatic able to produce a coupling fast, sure, low radioactivity, reproducible and independent from the actions of operators.

Moreover, study of thermistors with different shape which could greatly simplify the assembly procedure.



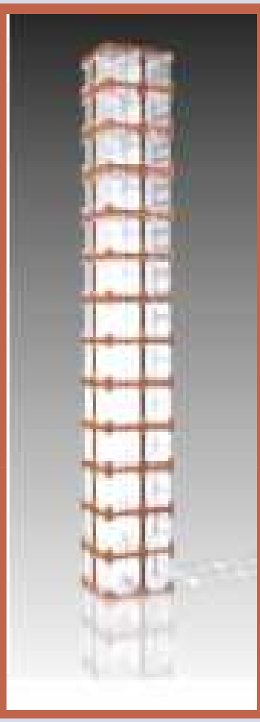
On the road

Hut construction: April 2008 status

- The hut of CUORE is under construction.
- The crystals are in production: the first batch will arrive in November 2008.
- Starting from 2009, the cryogenic system will be manufactured and then installed underground. Also: clean room.
- During 2010 all the components (lead shields, wires, detector suspensions and detector calibration system) will be integrated and tested. Also: front-end & DAQ, Faraday cage.

The beginning of CUORE data taking is foreseen in 2012.

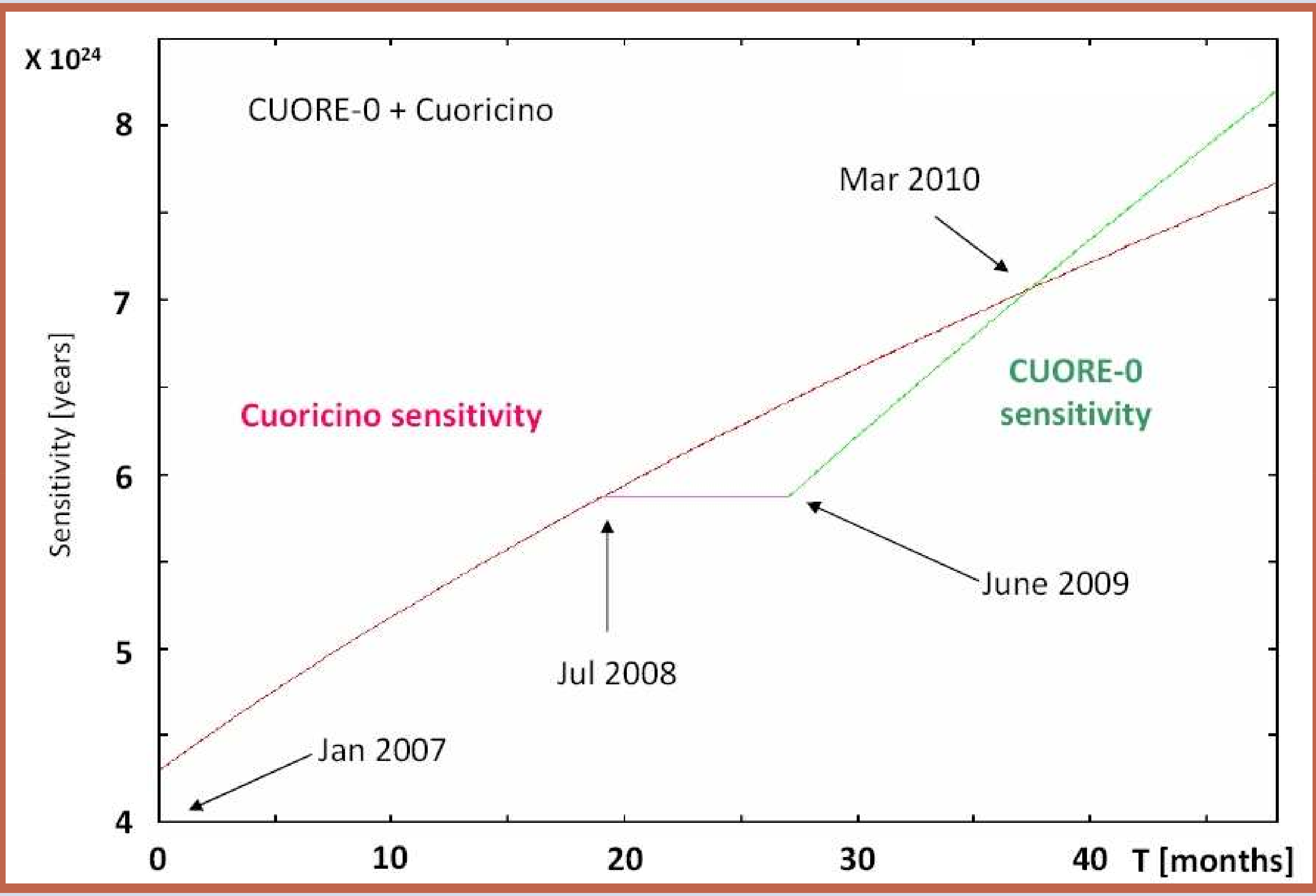
CUORE-0: the first CUORE tower to be assembled & installed in the Hall A dilution refrigerator (ex-Cuoricino)



CUORE-0 has its reasons!

- CUORE-0 will test with high statistics the assembly procedure, which has been largely improved during the R&D years (gluing, holder, zero-contact approach, wires, …)
- It will be possible to verify the background reduction expected, approximately 1/3 of the Cuoricino background in the DBD energy region: it should be close to the CUORE target in the energy degraded alpha region
- CUORE-0 will be a powerful experimnt that will overtake soon the Cuoricino sensitivity

CUORE-0 will be constructed and operated in 2009.


X 10^{24}
CUORE-0 + Cuoricino
Mar 2010
CUORE-0
sensitivity
Cuoricino sensitivity
Sensitivity [years]
June 2009
Jul 2008
Jan 2007
8
7
6
5
4
0
10
20
30
40
T [months]

Conclusions

The recently closed Cuoricino experiment demonstrated the feasibility of a large mass bolometric experiment, with good energy resolution and background.

The latest result from Cuoricino data analysis, updated to August 2007, gives for $T^{0\nu}_{1/2}$ a lower limit of 3.1×10^{24} y, corresponding – with given NME- to an upper limit for m_{ee} of 200-680 meV.

CUORE is on its way: the construction began.

The first CUORE tower, CUORE-0, will be assembled and operated in 2009: it will be a fundamental test for the future but also a powerful experiment in itself.

CUORE will have the capability to explore the inverse hierarchy region and will start taking data in 2012.