The quest for neutrinoless double beta decay with the CUORE and Cuoricino bolometric experiments

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The key formulas

$$T_{1/2}^{0\nu} \sim \frac{1}{G^{0\nu}\left|M^{0\nu}\right|^2 \langle m_{ee} \rangle^2}$$

$G^{0\nu}$: ~ Q^5 phase space factor

$M^{0\nu}$: nuclear matrix elements
» uncertainties

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

Sensitivity: Lifetime corresponding to the minimum number of detectable events above background at a given C.L.

$$F^{0\nu} \sim \frac{a}{A}\sqrt{\frac{M \cdot T}{b \cdot \Gamma}} \cdot \varepsilon$$

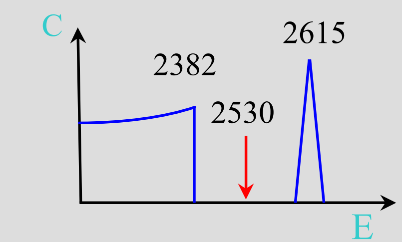
M: active mass [kg]
T: live time [y]
a: isotopic abundance
b: background [c/keV/kg/y]
Γ: energy resolution [keV]
A: atomic mass
ε: efficiency

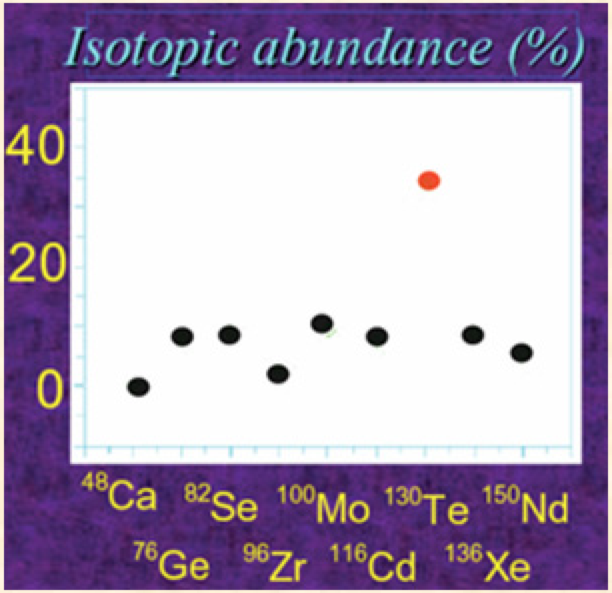
Why ^{130}Te

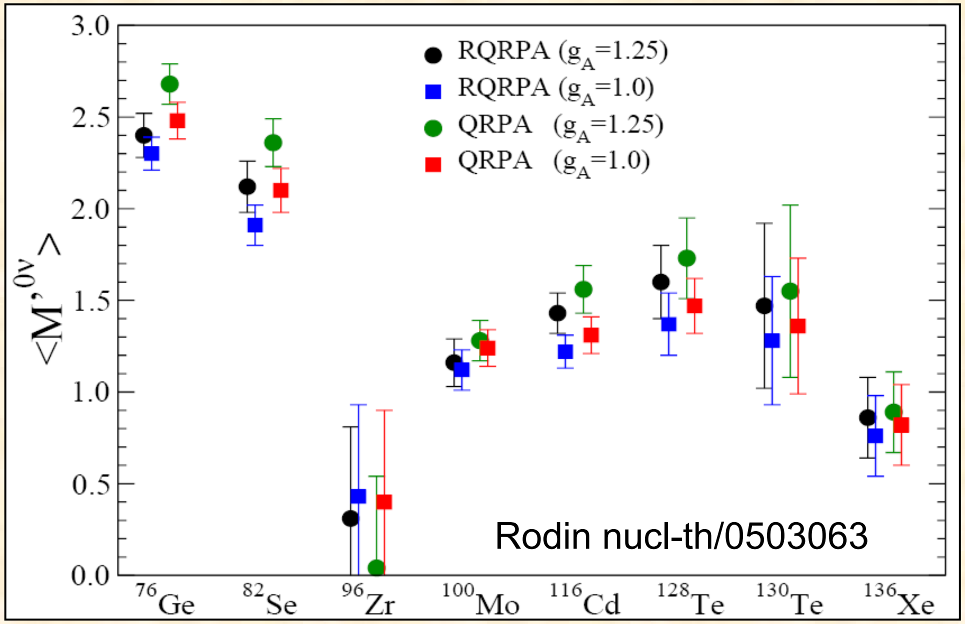
^{130}Te presents several nice features:

- high natural isotopic abundance (I.A. = 33.87 %)
- high transition energy (Q = 2530.30 ± 1.99 keV)
- encouraging theoretical calculations for 0ν-DBD lifetime

large phase space, lower background (clean window between full energy and Compton edge of ^{208}Tl photons)

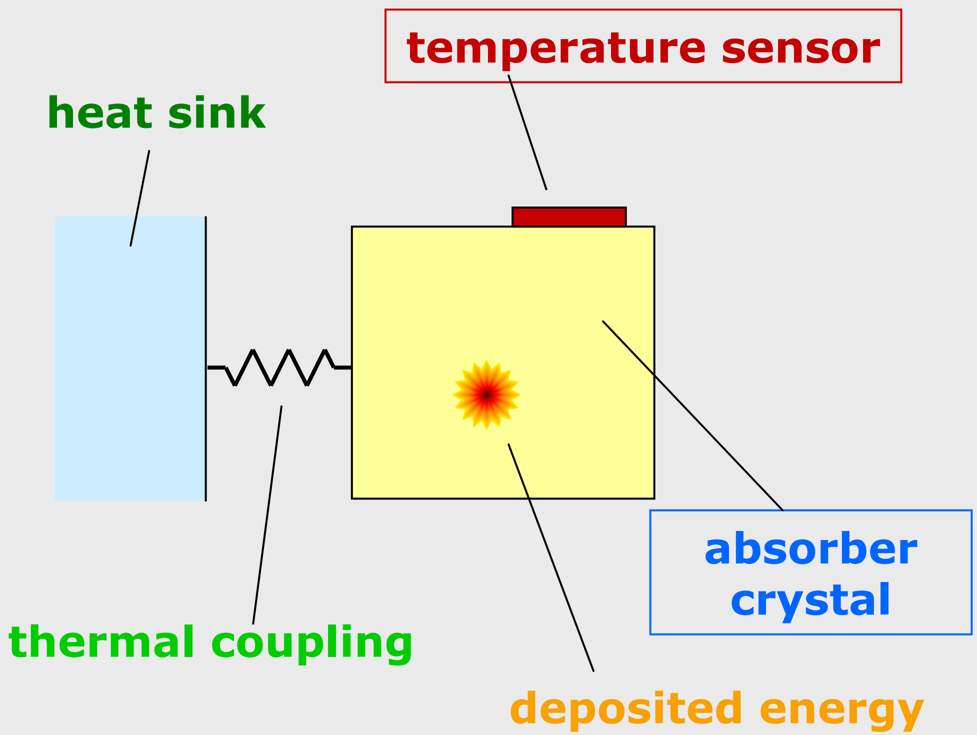






Experimental approach

Bolometric technique:



Operated as perfect calorimeters: all energy converted into phonons

$$\Delta T = \frac{E}{C} \qquad \tau = \frac{C}{G}$$

complete and instantaneous thermalization

temperatures ~ 10mK

dielectric e diamagnetic materials

Main advantages:

- high energy resolution
- wide versatility (few constrains on absorber material)

Cuoricino bolometers

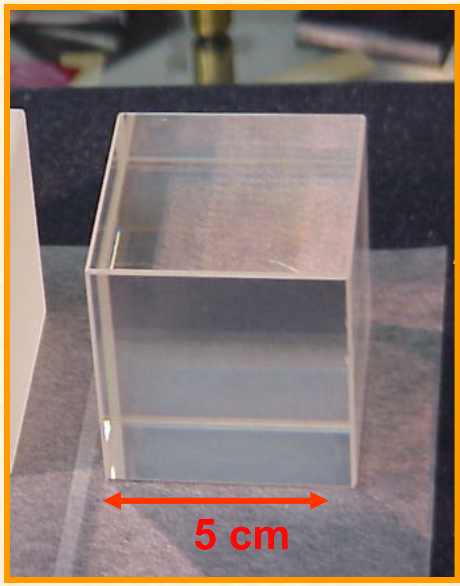
Absorber crystal

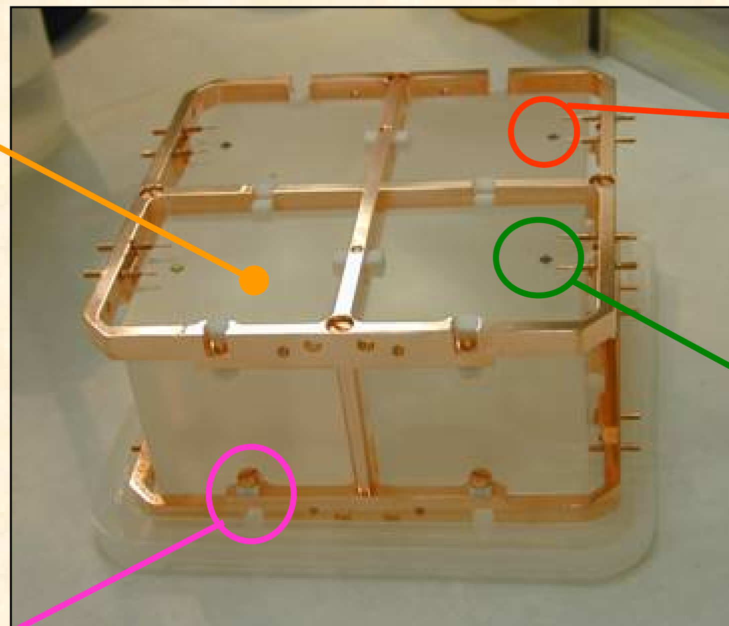
The absorber is a **$5x5x5\ cm^3$** crystal of **TeO_2** which contains the neutrinoless DBD candidate **^{130}Te**

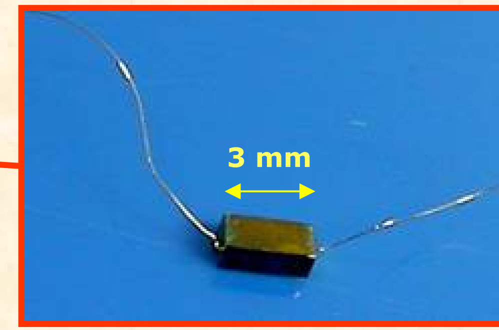
Temperature sensor

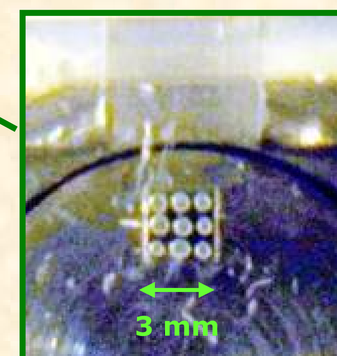
The thermal signal is measured by means of an **NTD Ge Thermistor**

$$R(T) = R_0 \exp \sqrt{\frac{T_0}{T}}$$





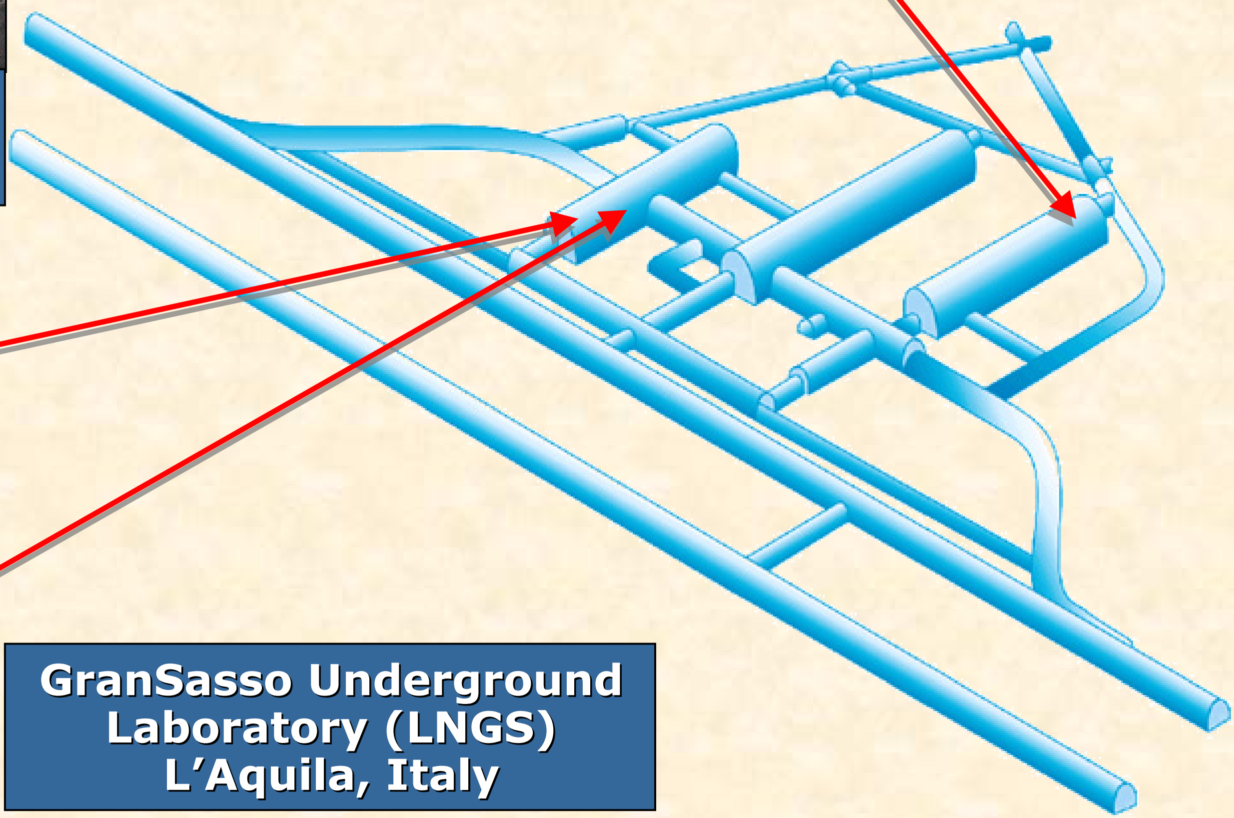




Experiments location

Depth ~ 3500 m.w.e.

CUORE R&D (Hall C)



Cuoricino (Hall A)

CUORE (Hall A)

GranSasso Underground Laboratory (LNGS) L'Aquila, Italy

Cuoricino assembling

All the operations done in clean room and nitrogen atmosphere

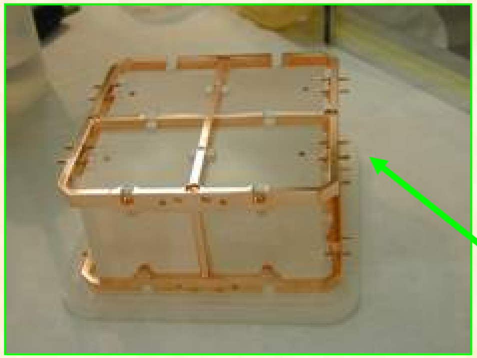
Cuoricino setup

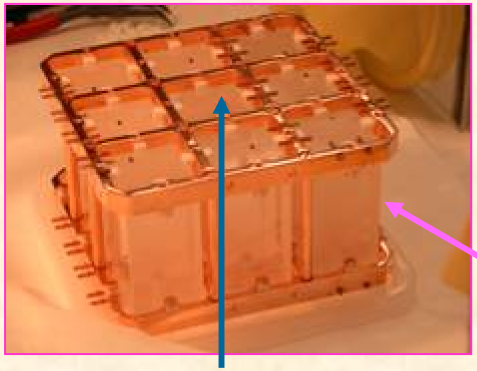
CUORICINO = tower of
11 modules, 4 detector (790 g) each
2 modules, 9 detector (330 g) each

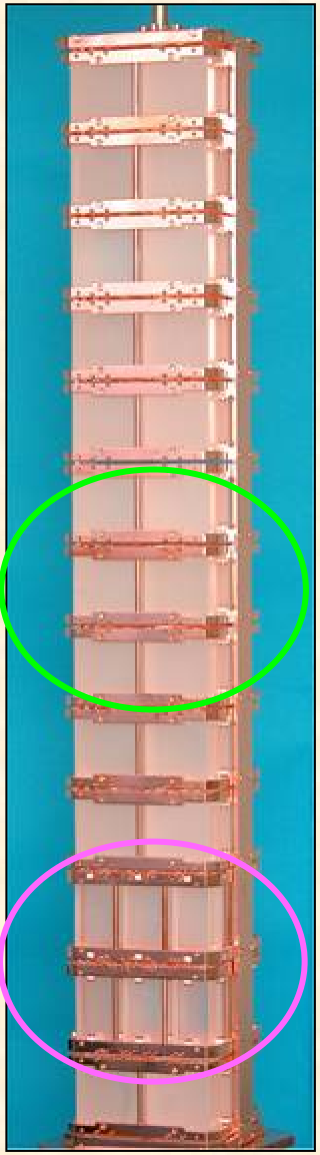
Total detector mass:
M ~ 40.7 kg TeO_2 ~ 5 x 10^{25} ^{130}Te nuclides

Currently the largest operated bolometer

First cooldown: Feb 2003







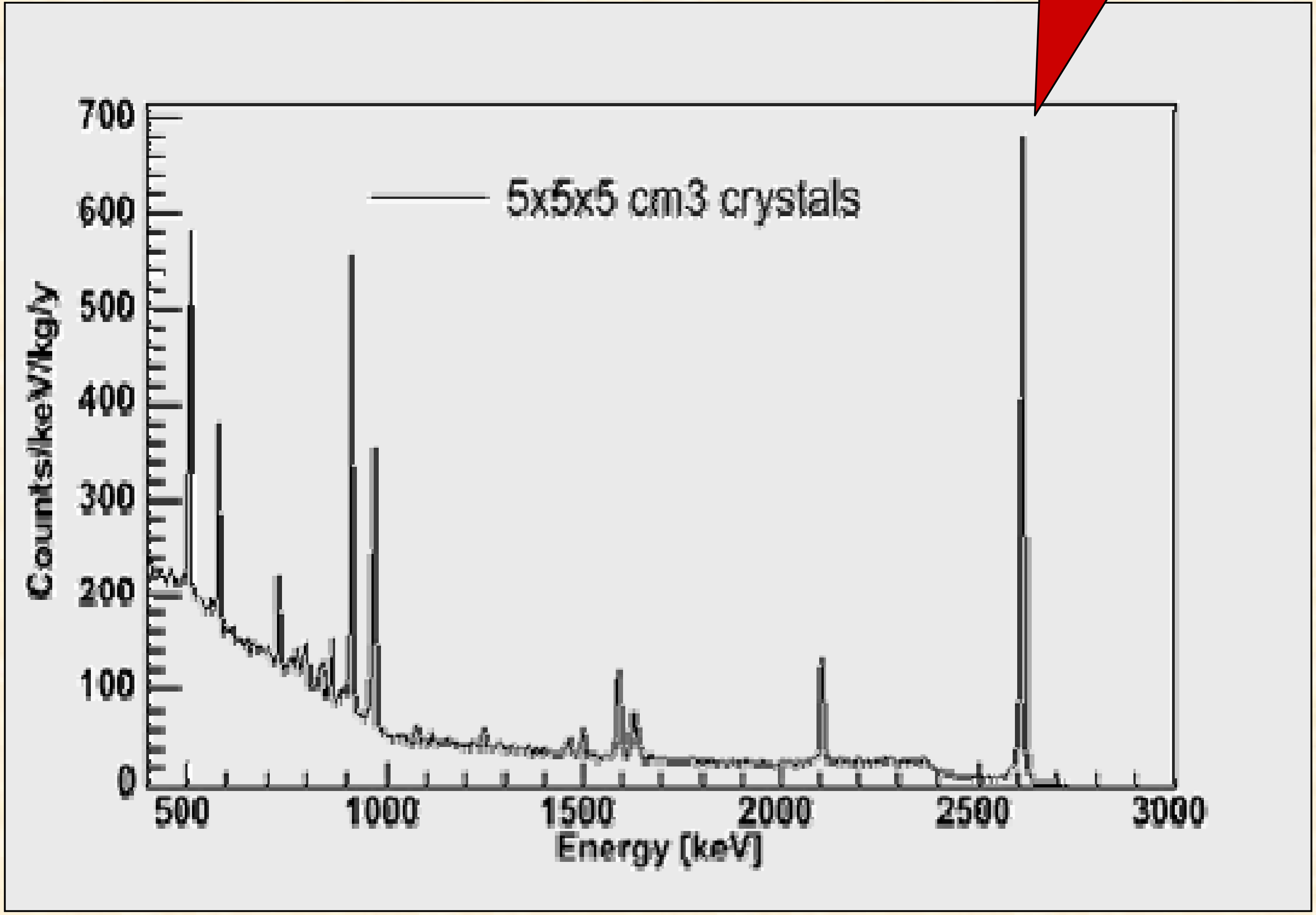
Shielding:
- Cu box + Roman Pb inside cryostat
- 20 cm Pb & 10 cm borated polyethylene outside
- Faraday Cage
- Nitrogen overpressure

This detector is completely surrounded by active materials. Useful for bkg origin models

Cuoricino performances

Sum calibration spectrum (U+Th)

2615 keV ^{208}Tl



Mean energy resolution @ 2615 keV

5x5x5 cm^3 crystals ~ 7.8 keV

3x3x6 cm^3 crystals ~ 9.1 keV

Best energy resolution (790 g) @ 2615 keV is 3.9 keV

Resolution data for RUN II up to April 2005

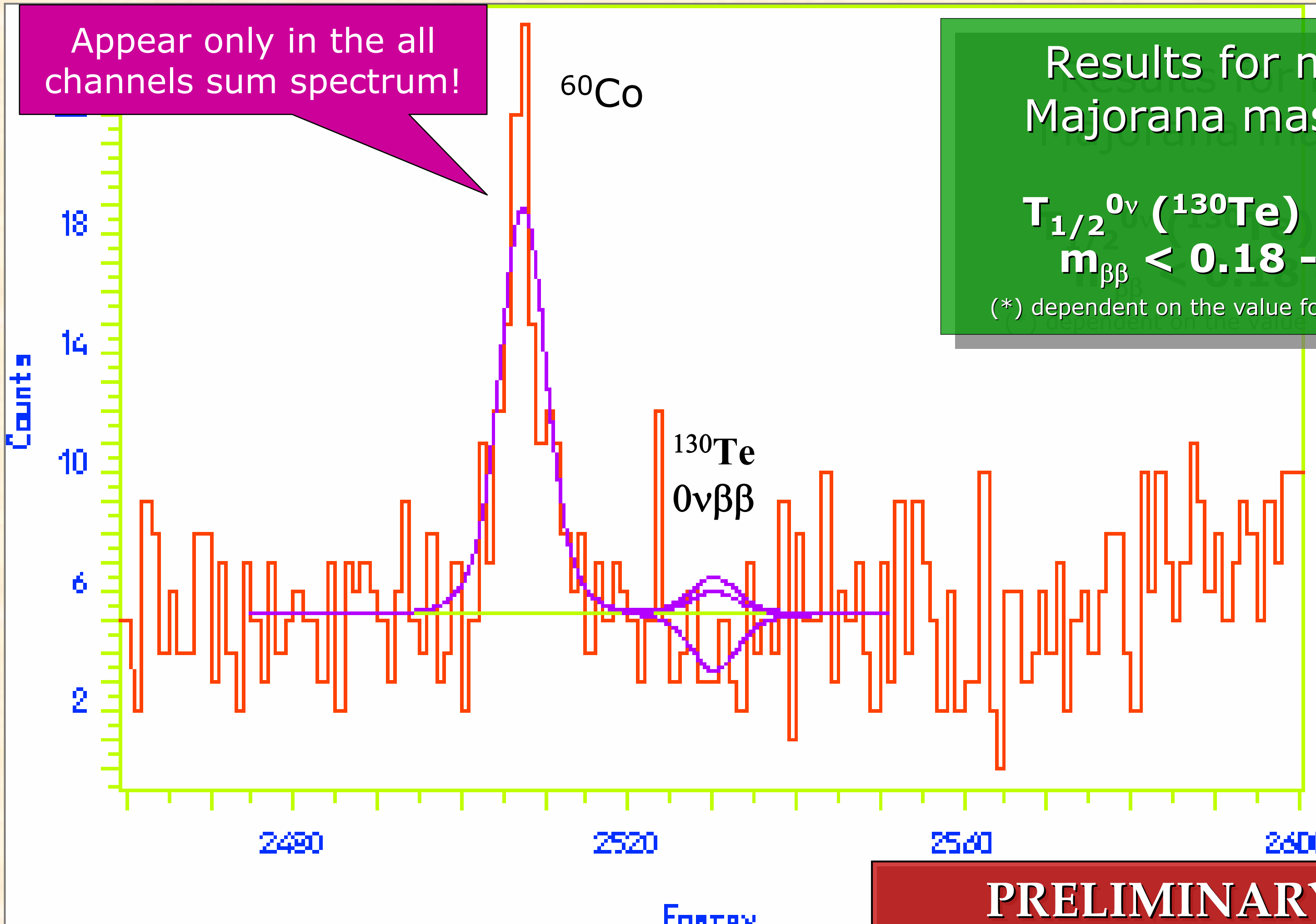
Cuoricino results

Cuoricino is successfully acquiring data from April 2003 (MT = 8.38 kg y ^{130}Te)

Background in ββ region (anticoincidence spectrum, only 5x5x5 cm^3 crystals)

0.18 ± 0.01 c/keV/kg/y

Appear only in the all channels sum spectrum!



Results for mean life and Majorana mass (90% c.l.):

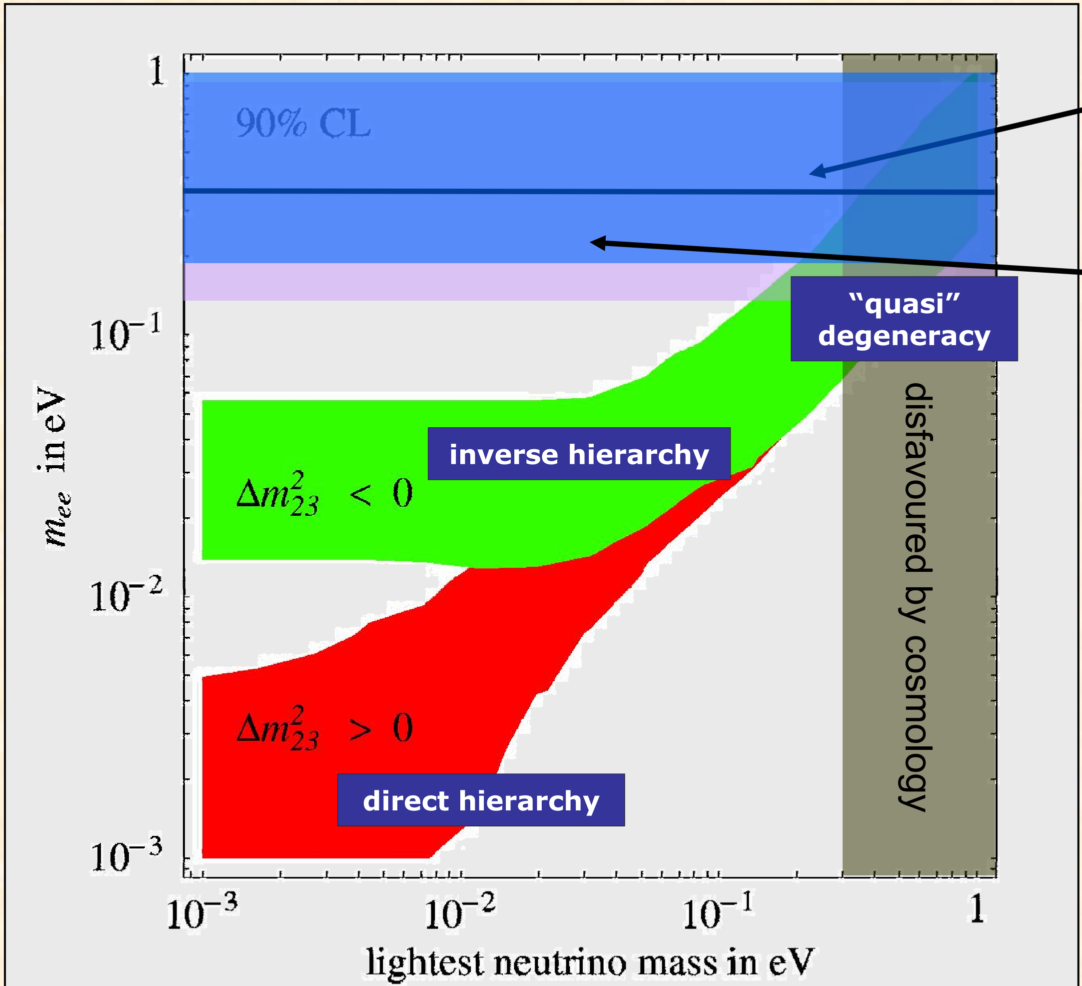
$T_{1/2}^{0\nu}$ (^{130}Te) > 2.4 x 10^{24} y

$m_{\beta\beta}$ < 0.18 - 0.94 eV (*)

(*) dependent on the value for the nuclear matrix elements

PRELIMINARY – May 2006

Cuoricino discovery potential



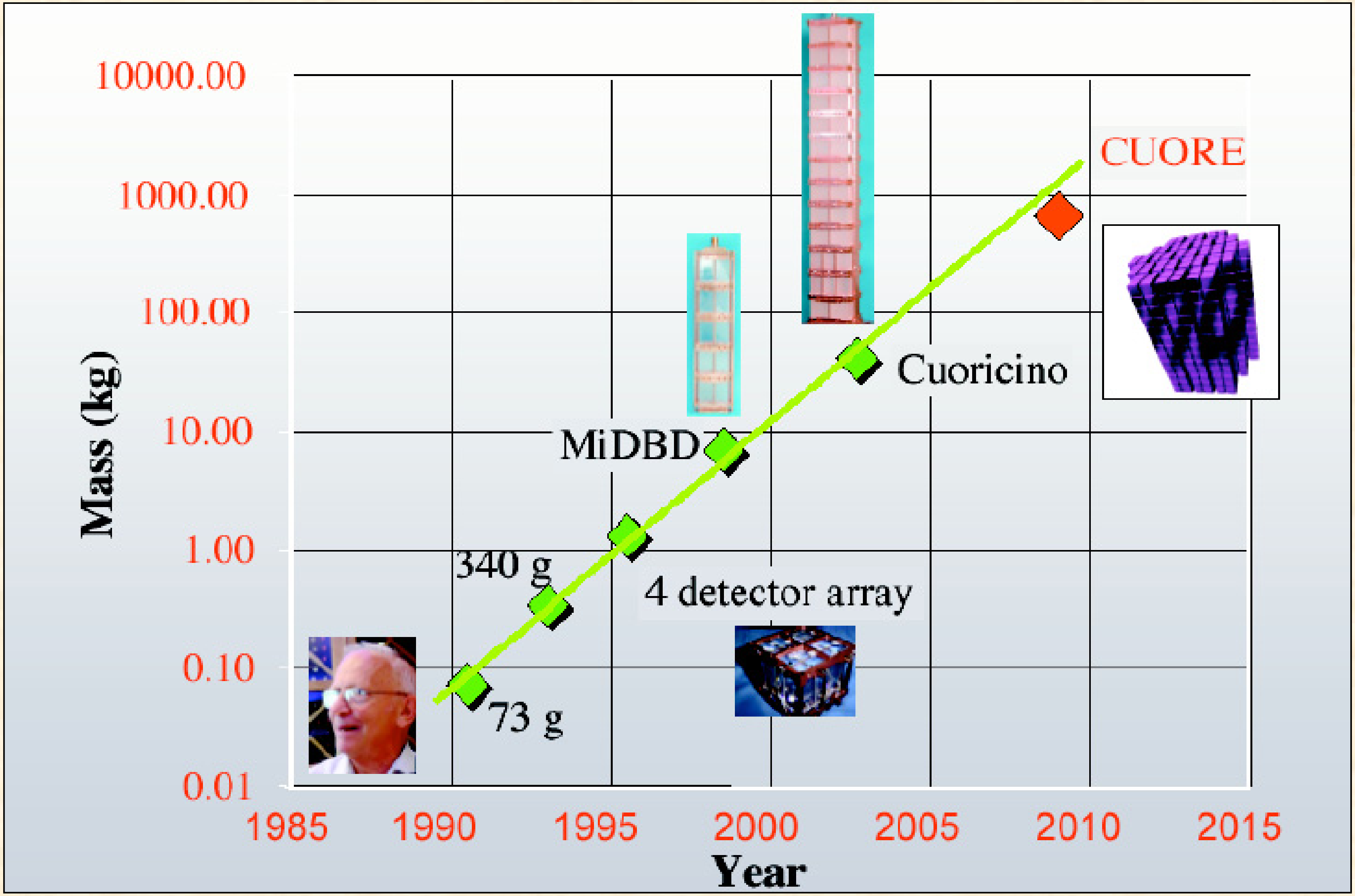
Strumia, Vissani, Nucl.Phys. B726 (2005) 294

KK-HM possible evidence
Physics Letters B 586 (2004) 198

Present CUORICINO limit
Phys.Rev.Lett. 95 (2005) 142501

good chance to have a positive indication in a short time (3 y) but cannot falsify KK if no signal is seen

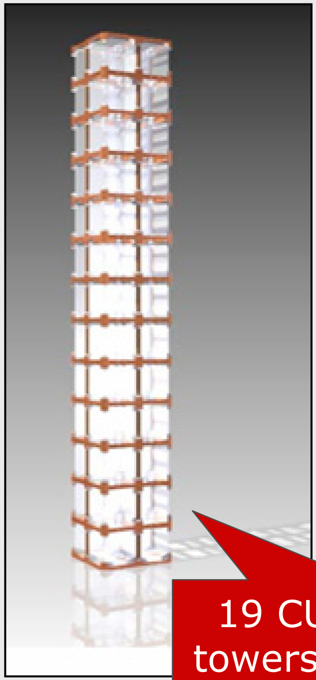
The Moore's Law of bolometry



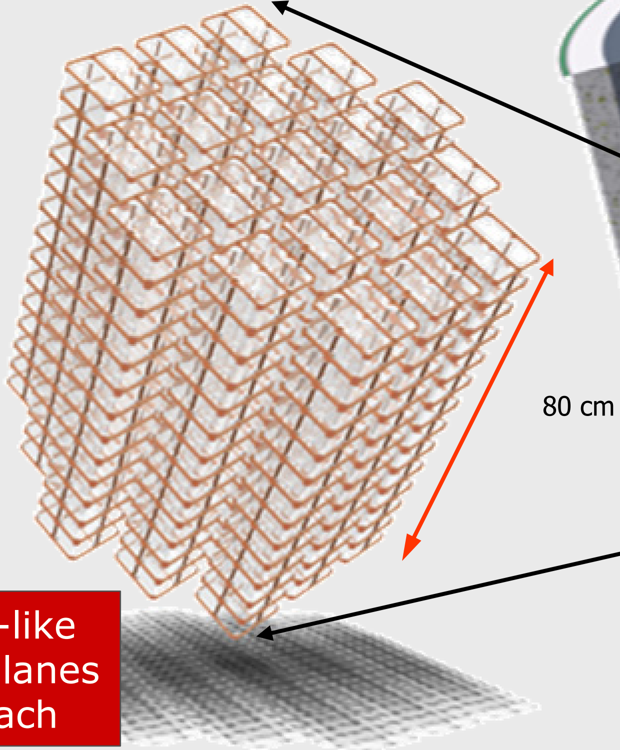
The evolution: CUORE

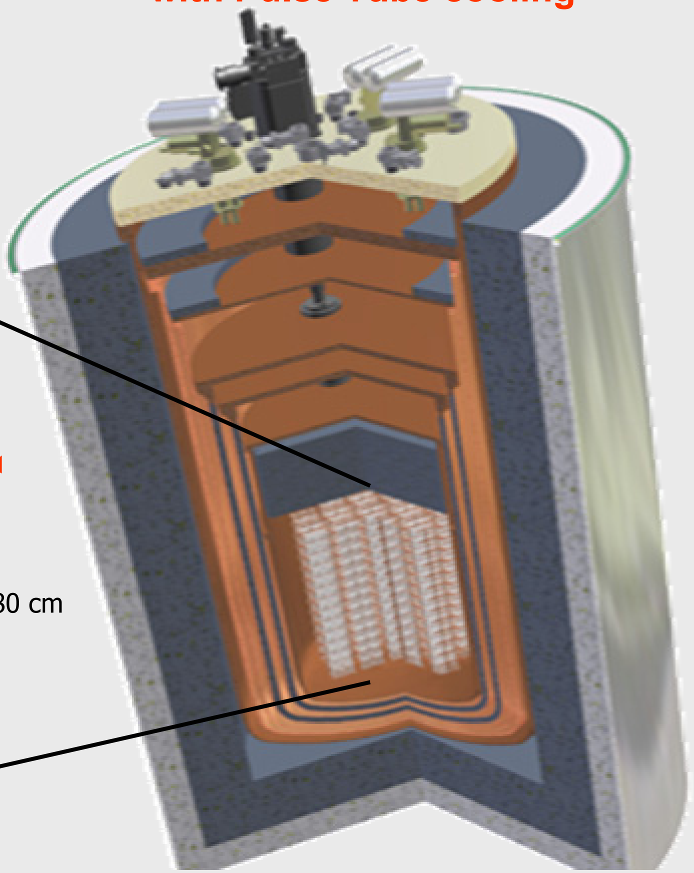
CUORE (Cryogenic Underground Observatory for Rare Events) will be a closely packed array of 988 detectors - M ~ 741 kg of TeO_2

Special dilution refrigerator with Pulse Tube cooling



19 CUORICINO-like towers with 13 planes of 4 crystals each

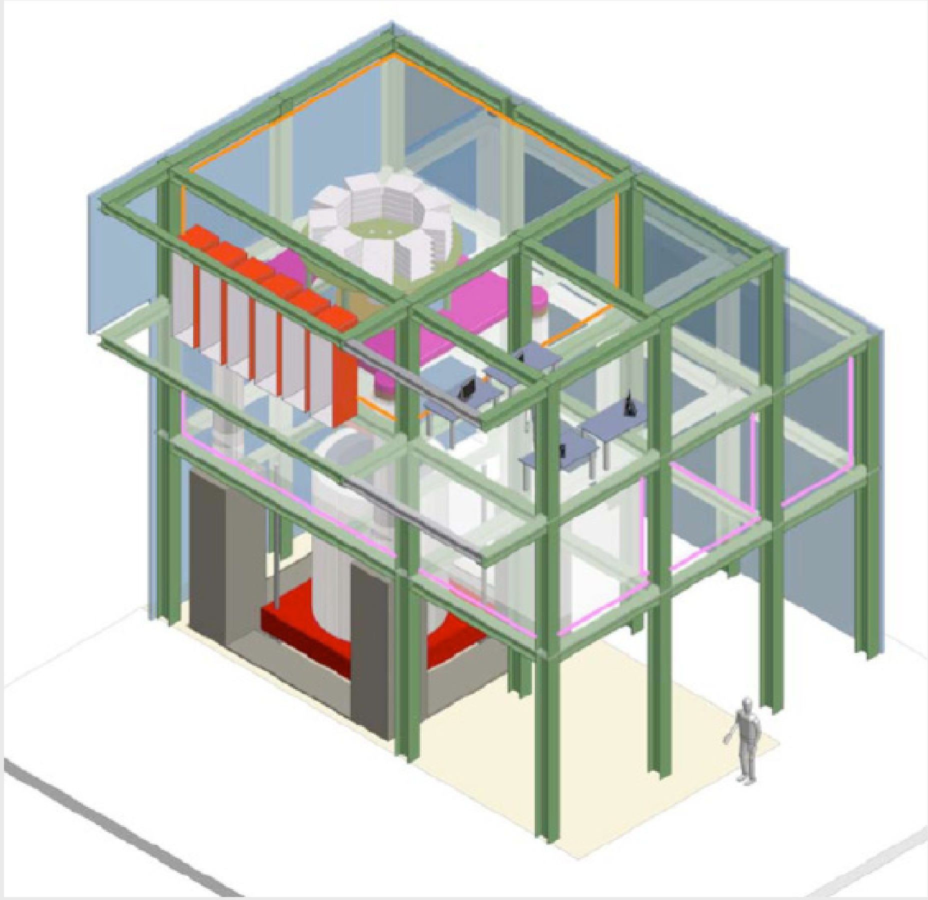


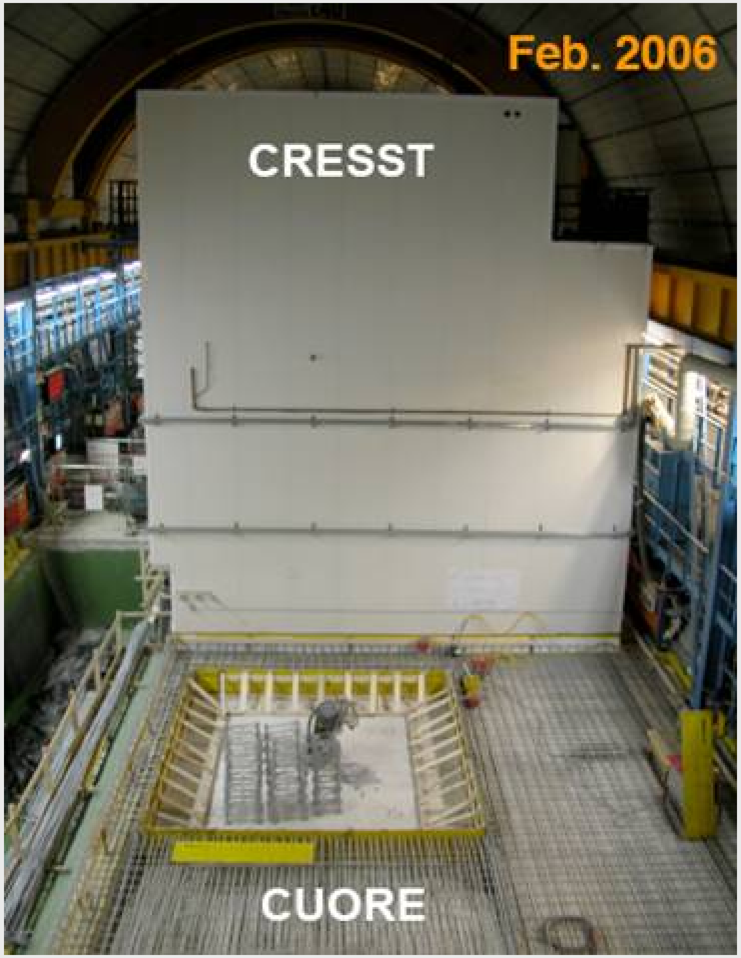


Next-generation experiment

Approved by INFN
Advanced design status

CUORE Housing





The basement of the hut is completed and the hut is being built in GranSasso HallA

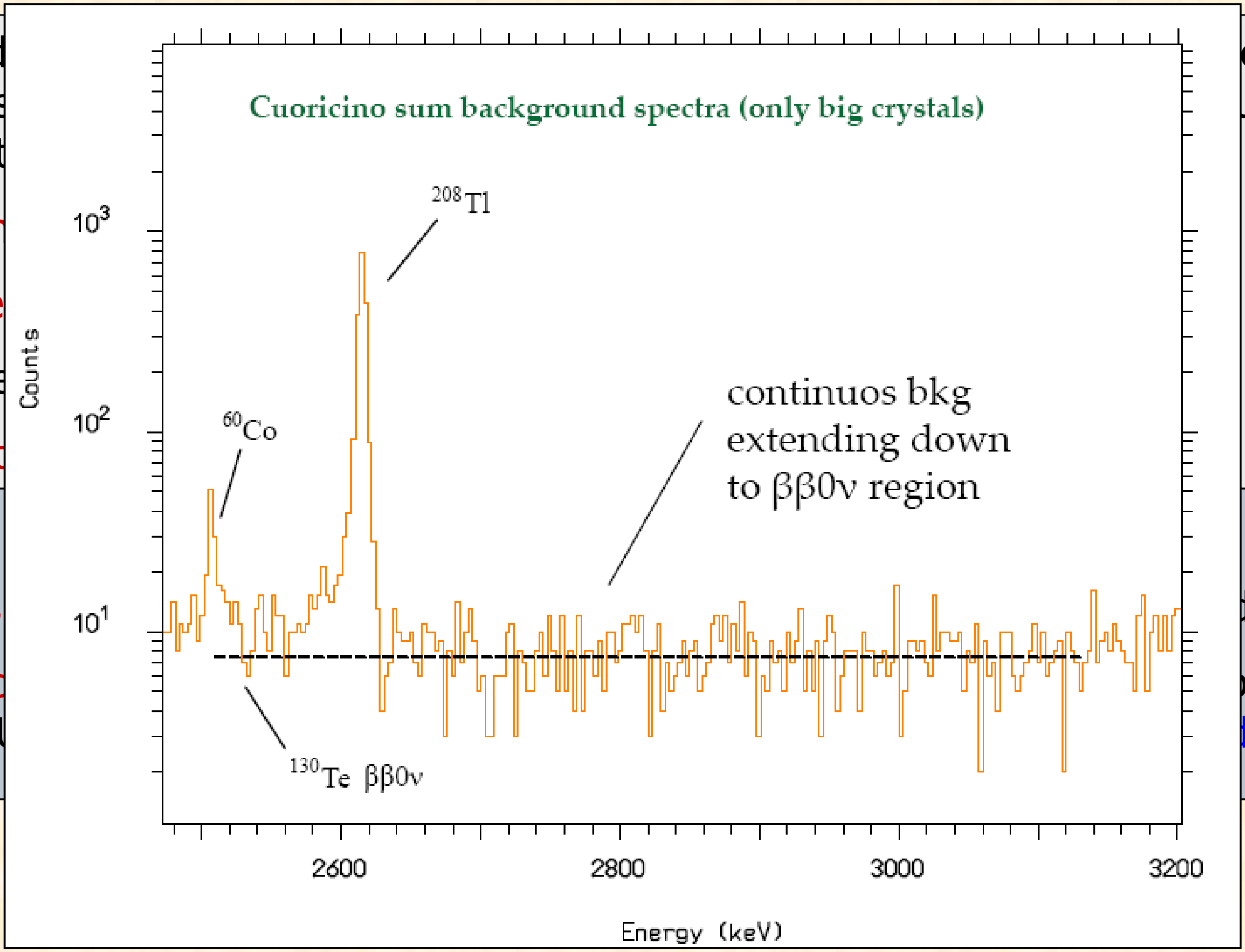
The background reduction issue

We have id... carlo evaluations ...ulk contaminat...

- Environm...
- Cosmoge...
- ββ2ν » ne...
- Bulk cont...

Flat bkg

- Neutrons ...d
- Surface c... ...act and granular CU...



Possible solutions

» Review detector holder structure to minimize surfaces facing directly the absorber

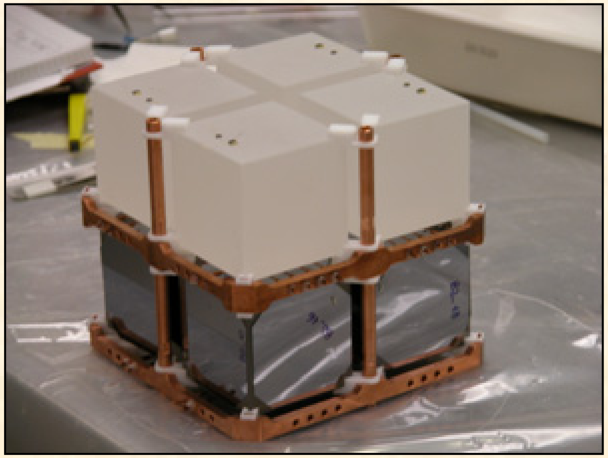
» Reduce material contamination increasing quality of surface treatment

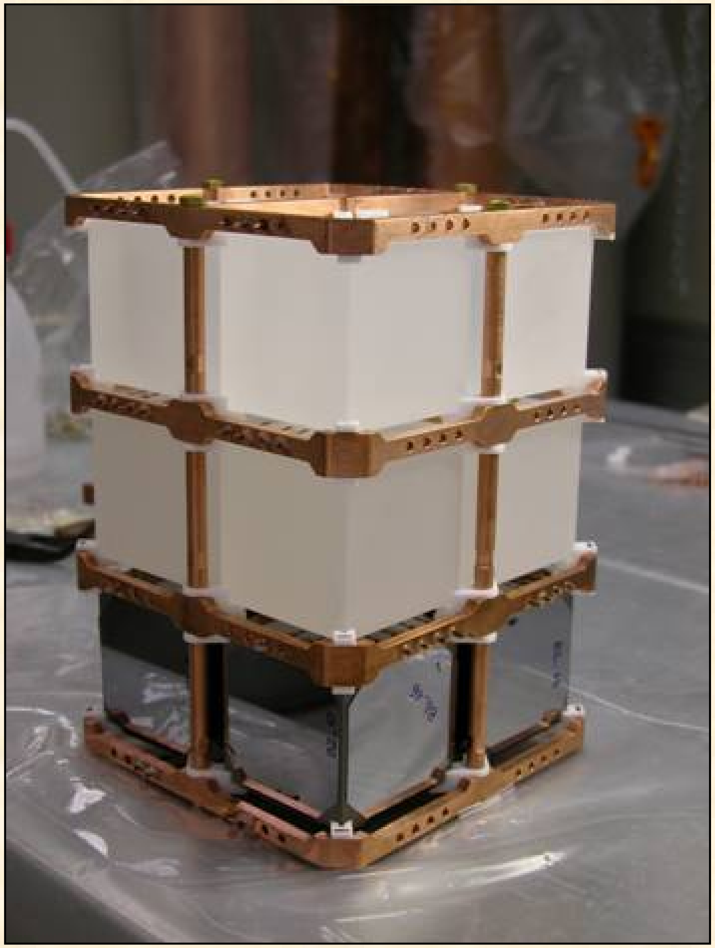
» Develop "clever" calorimeters to discriminate the origin of an event

New mounting structure

Goals:
- Contribute to bkg reduction
- Improve resolution
- Improve reproducibility
- Improve the detector standardization
- Fast and standard assembling procedure

Results:
- resolution comparable with Cuoricino (FWHM 5.5 ± 0.9 keV @ 2615keV)
- vibration analysis under way



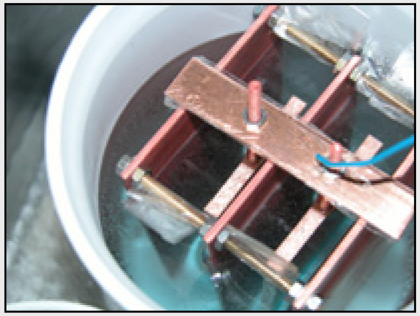


RAD tests

An array of **8 detectors cleaned** with **ultrapure materials** and **procedures**

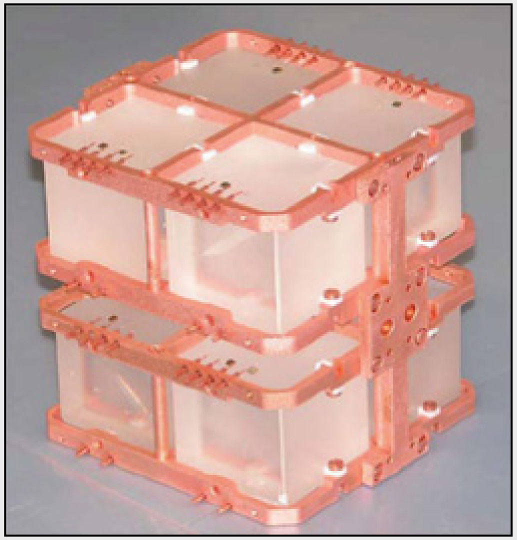
Copper

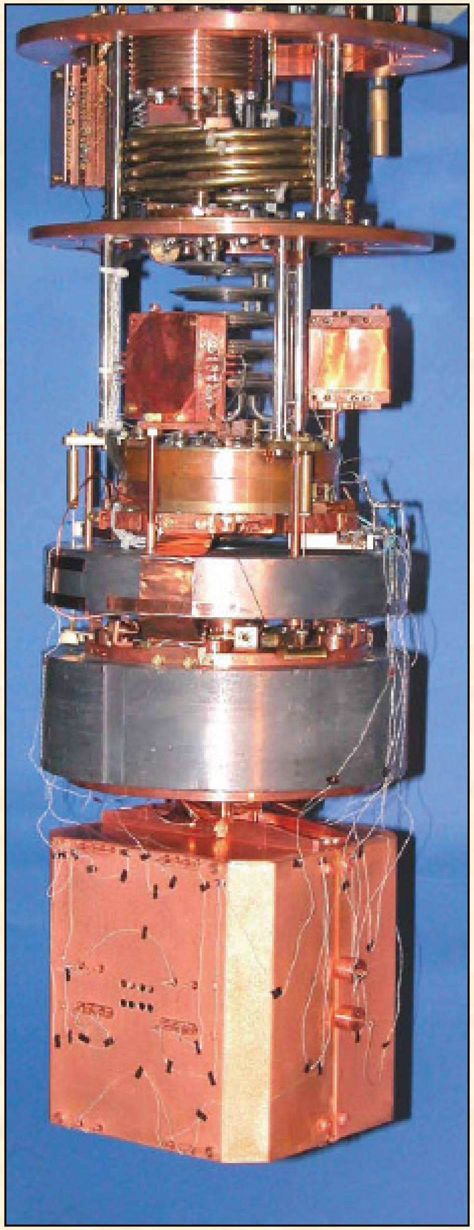
- Etching
- Electro polishing
- Passivation procedure



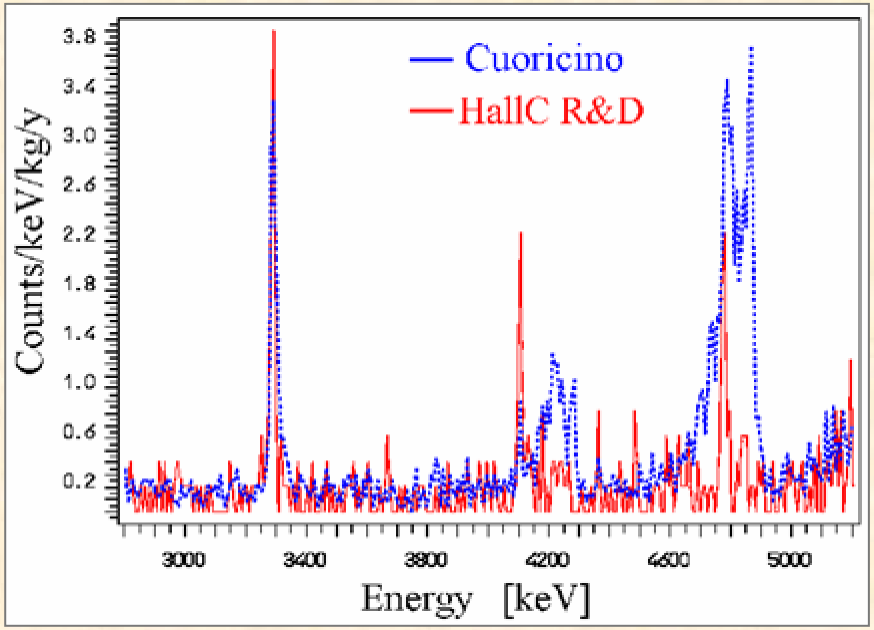
Crystals

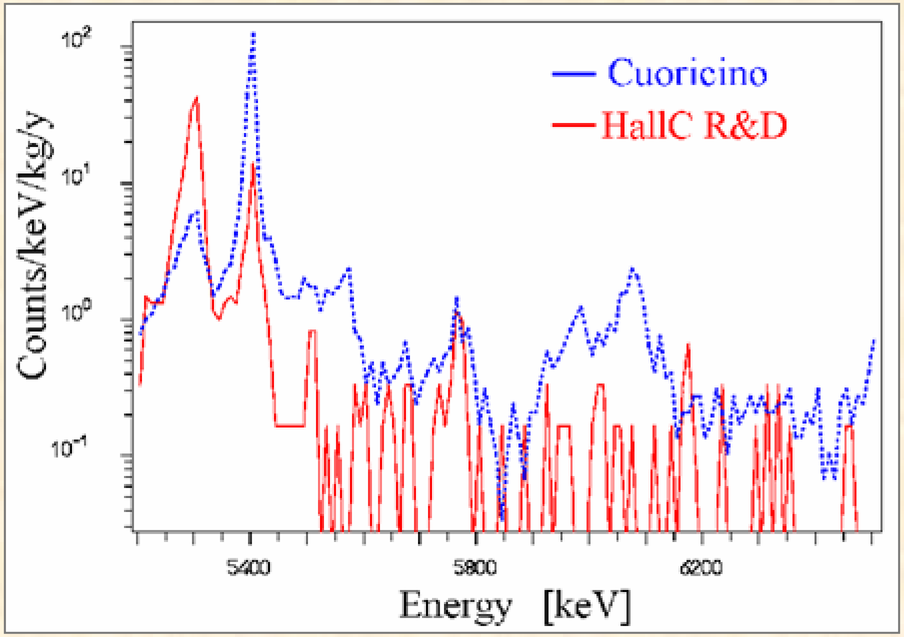
- Crystal etching (Nitric acid)
- Lapping with clean powder (2μ SiO_2)

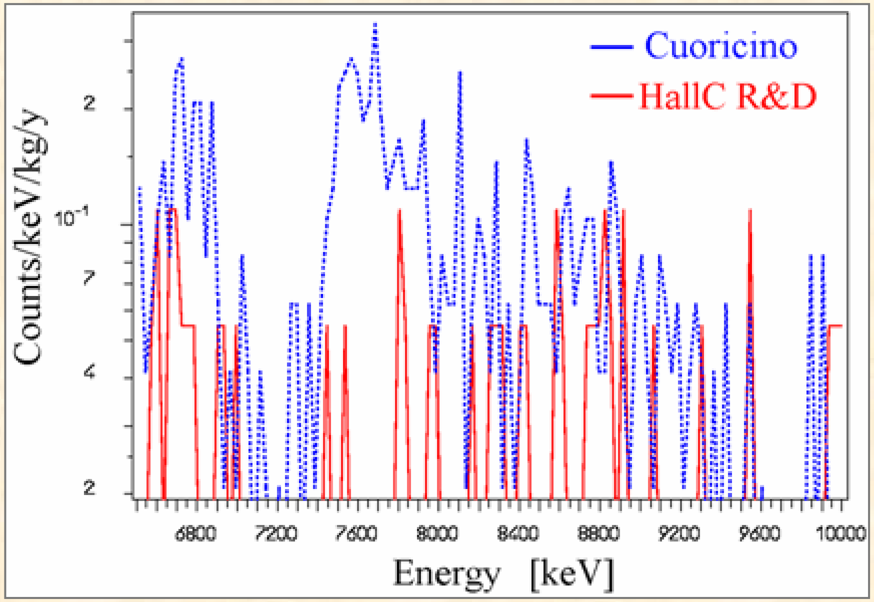




RAD tests results







- Reduction of a factor ~ 4 on **crystal** surface contaminations
- Reduction of a factor ~ 2 on **copper** surface contaminations

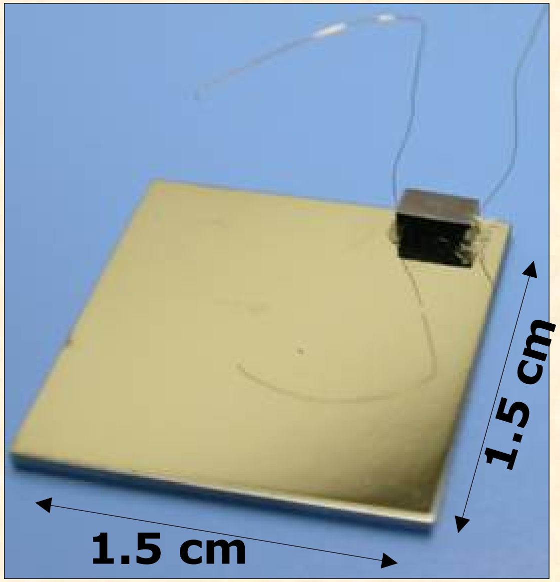
» new tests are on going in GranSasso

Surface Sensitive Bolometers (SSB)

Active shielding of the main bolometer by means of thin foils of other absorber materials that provide full coverage.

New idea: the shields are thermally coupled with glue to the main absorber to form a single *composite bolometer*

Shield bolometer



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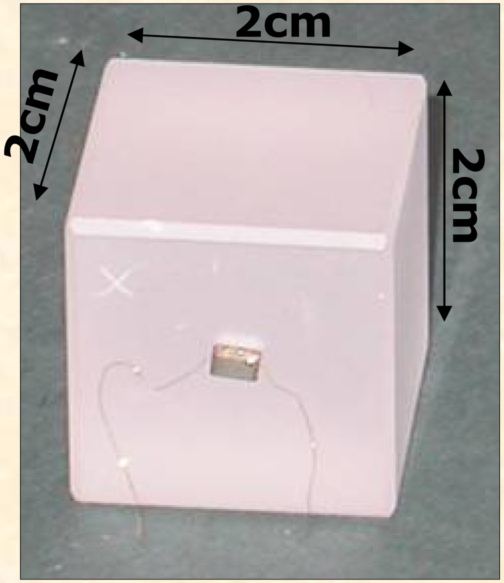
TeO_2 bolometer



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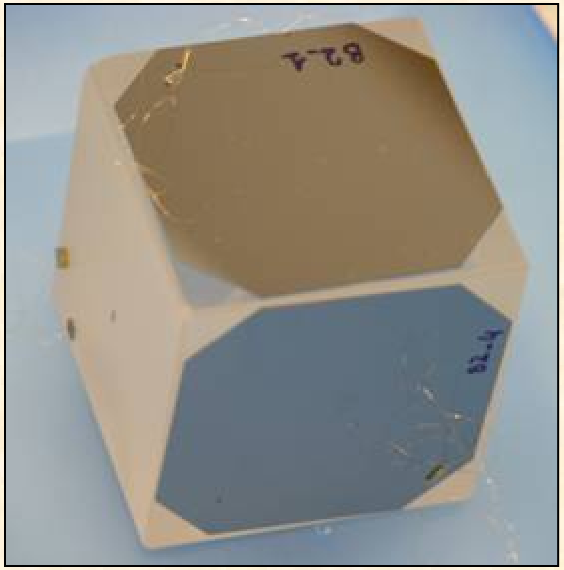
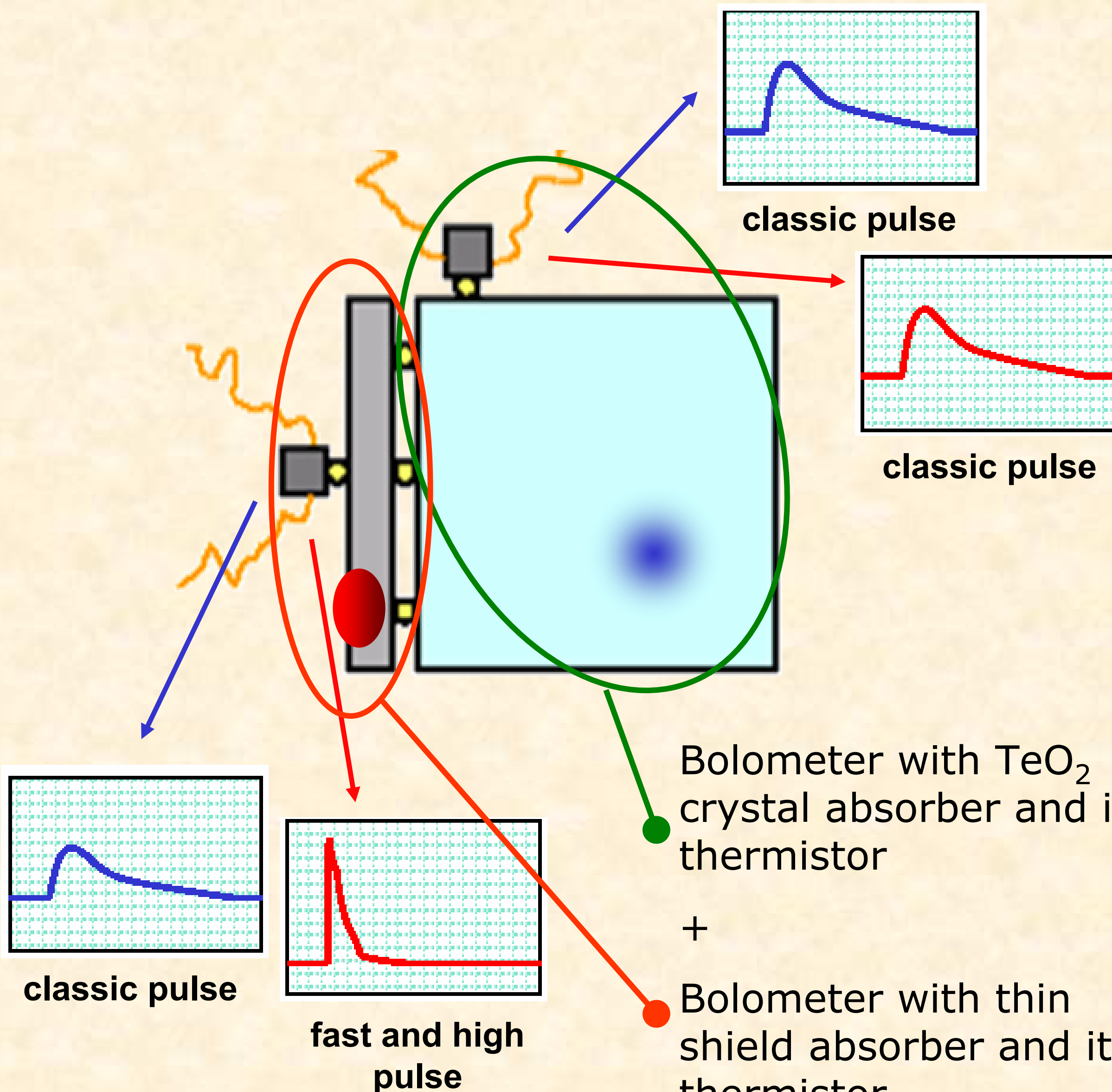
Composite bolometer



In this way the conventional anticoincidence technique is not very useful because particles releasing energy in the detector heat up each element of this composite bolometer. How does it work?

Dynamic behaviour of SSBs



- Bolometer with TeO_2 crystal absorber and its thermistor

+

- Bolometer with thin shield absorber and its thermistor

The presence of the shield changes the thermal dynamic behavior of the detector giving rise to pulses with different amplitudes and shapes.

Different impact points means different pulses on thermistors

SSBs results

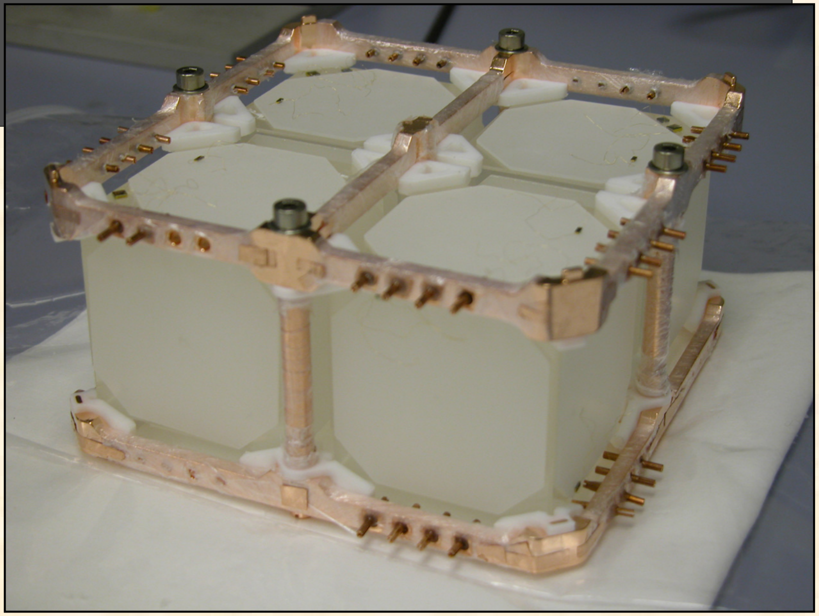
Appl. Phys. Lett. **86**, 134106 (2005)

We perform **several tests** on small prototypes and on full scale CUORICINO-size bolometers.

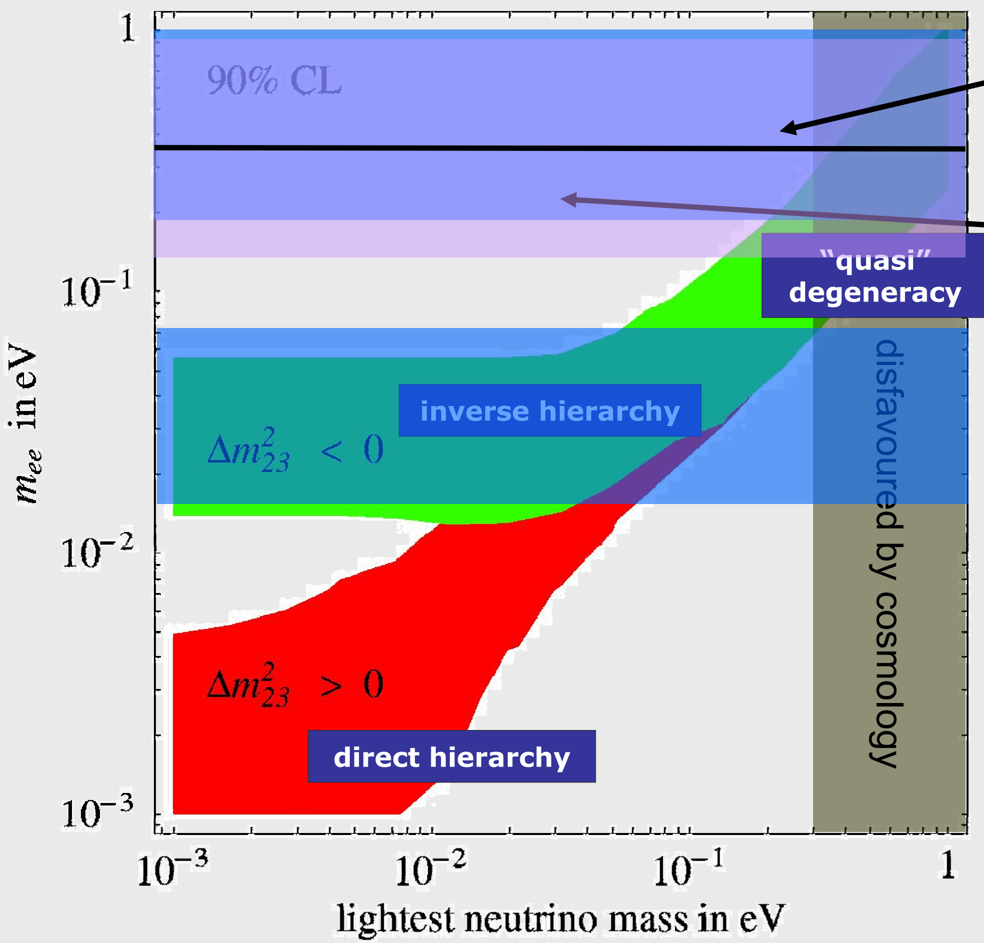
Identification of surface events:

- pulse amplitude discrimination (scatter plot)
- rise time of the pulses of thermistor on the shield
- decay time of the pulses of thermistor on the main

Powerful **background reduction**



CUORE expected sensitivity



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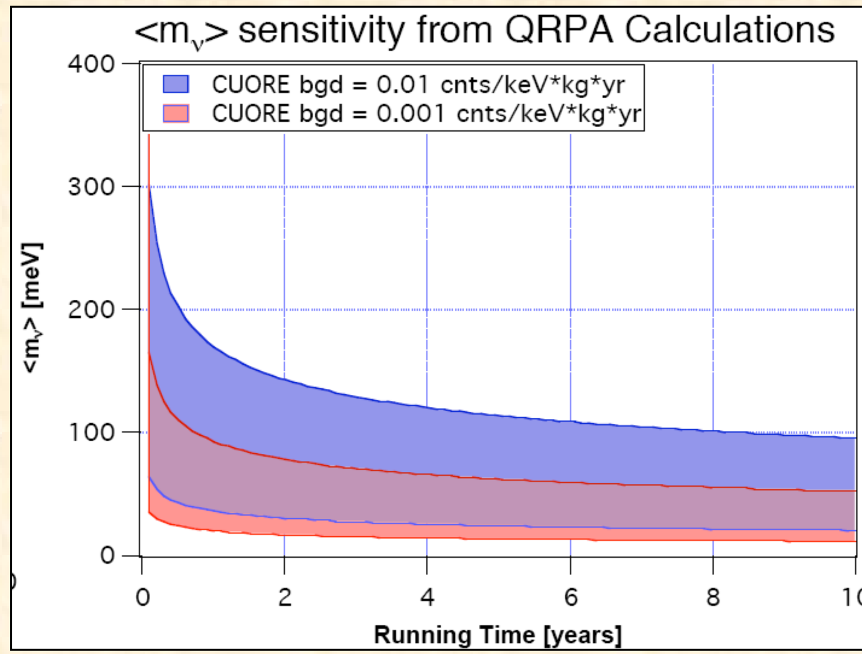
Present CUORICINO limit
Phys.Rev.Lett. 95 (2005) 142501



* <m> range from various QRPA calculations:
high: Rodin, Faessler, Simkovic, & Vogel Nucl. Phys. A **766** 107 (2006)
low: Staudt, Kuo & Klapdor-Kleingrothaus, PRC **46** 871 (1992)

Conclusions

- **Cuoricino** is presently the most sensitive 0νDBD running experiment (together with NEMO3)
- Cuoricino demonstrate the **feasibility** of a large scale bolometric detector with good energy resolution and background.

- **CUORE** is designed to probe the neutrino inverted hierarchy.
- The construction of CUORE **is started** and data taking scheduled in 4 years from now.
- Background reduction is well underway

- CUORE can be **enriched** at a very low cost due to its large natural isotopic abundance and other compounds of **other double beta active nuclei** (e.g. ^{48}Ca, ^{100}Mo, ^{116}Cd) can be used (also in the heat-scintillation approach).

CUORE Collaboration

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