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

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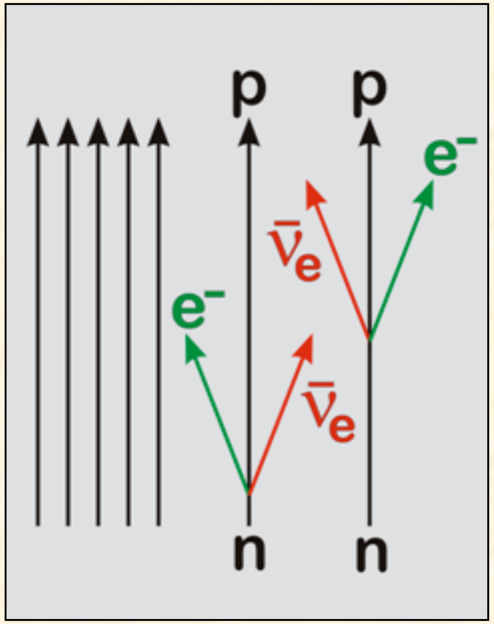
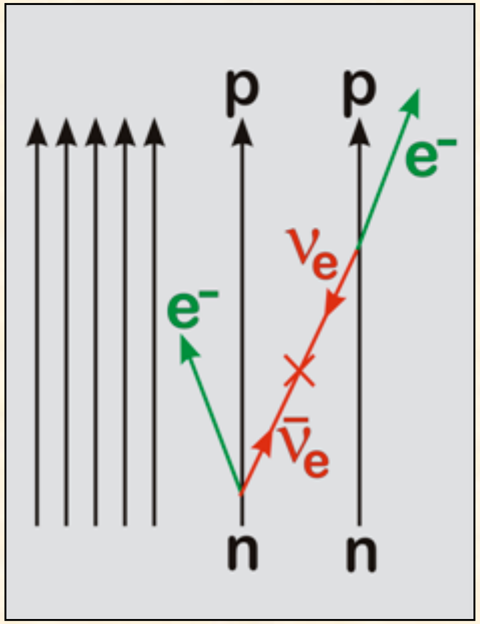
Neutrinoless Double Beta Decay

The **DDB** is a very rare nuclear decay process ($\tau \sim 10^{19} - 10^{21}$ y). This decay is detectable only when the single β decay is energetically forbidden or strongly suppressed.

Two main decay channels:

$\beta\beta2\nu$ allowed by Standard Model	$\beta\beta0\nu$ possible only with Majorana ν





Can give hints on:

- Neutrino nature: Dirac or Majorana
- Neutrino mass: absolute mass scale and hierarchy
- Neutrino CP-violation, …

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

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

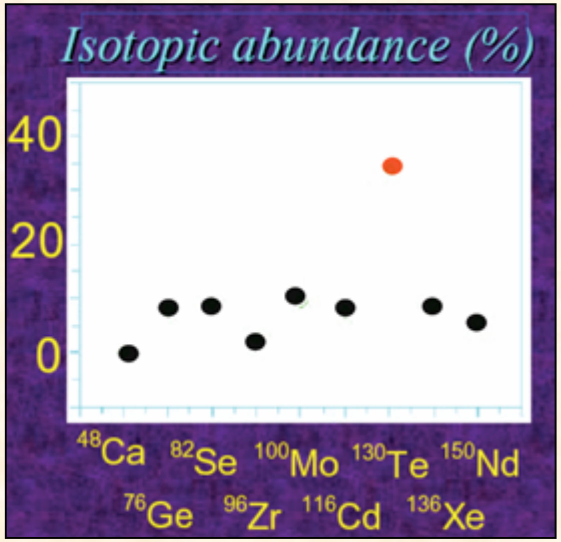
$M^{0\nu}$: nuclear matrix elements
» uncertainties

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

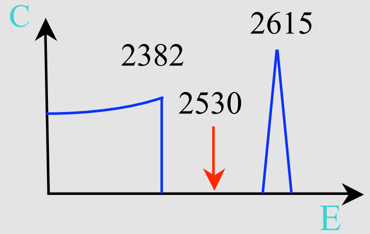
Why ^{130}Te

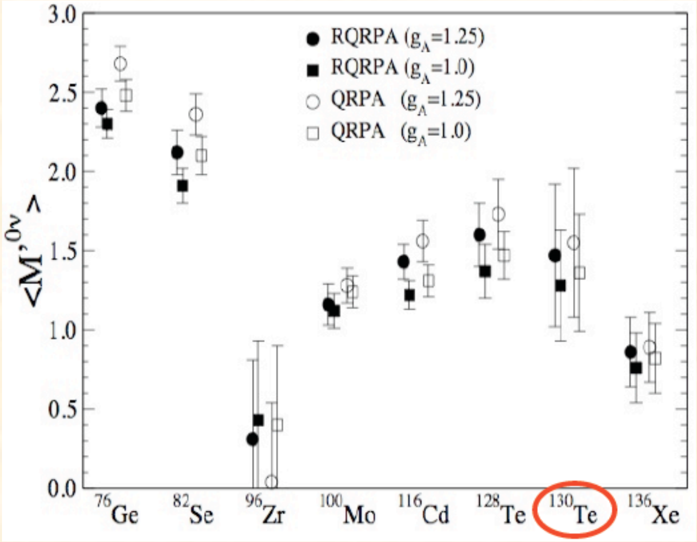
^{130}Te presents several nice features:

- 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)





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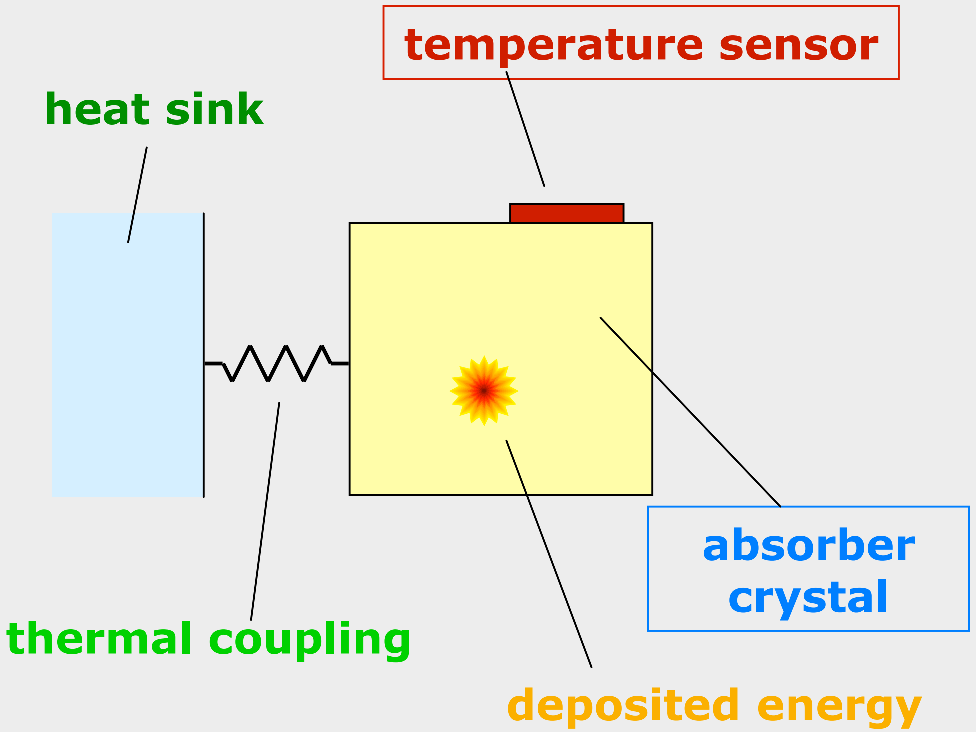
Experimental approach

Experimental needs:
- ❑ low background and big sources
- ❑ high energy resolution

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

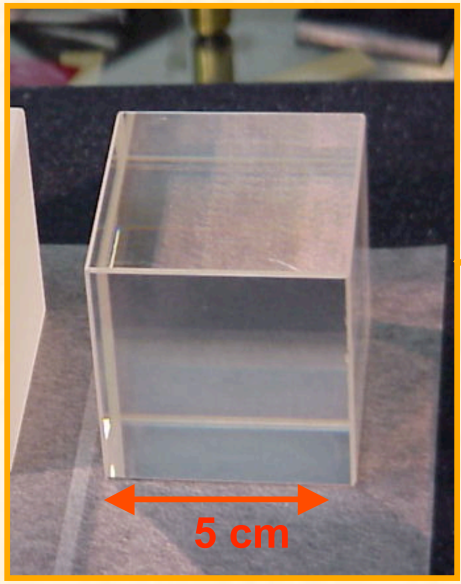
Absorber crystal

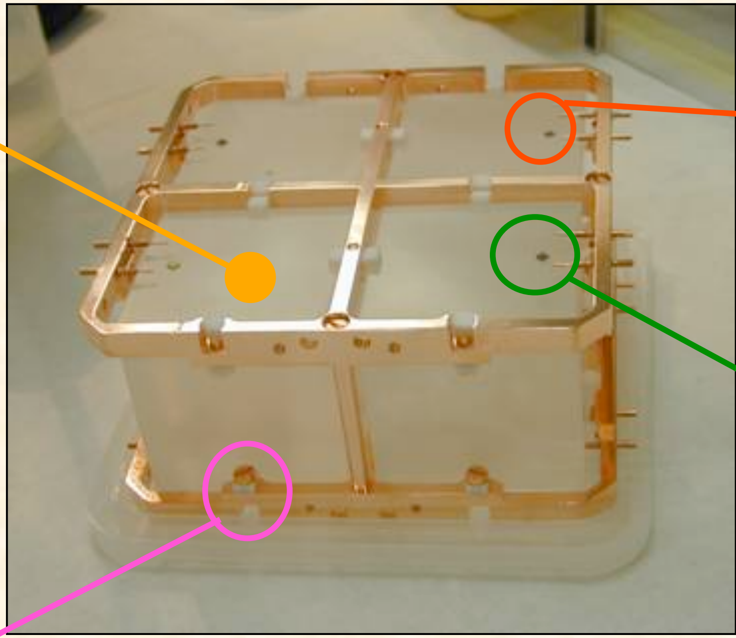
The absorber is a **5x5x5 cm^3** crystal of **TeO_2** which contains the neutrinoless DBD candidate **^{130}Te**

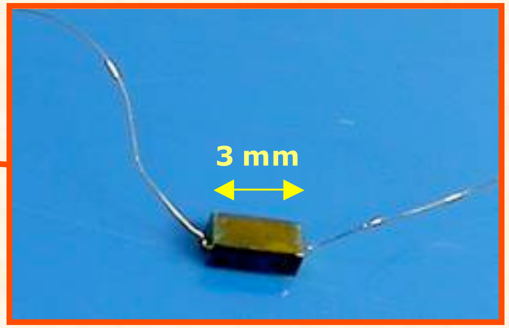
Temperature sensor

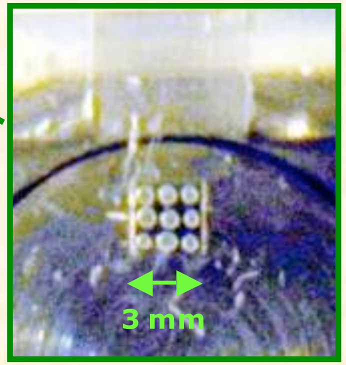
The thermal signal is measured by means of an **NTD Ge Thermistor**

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

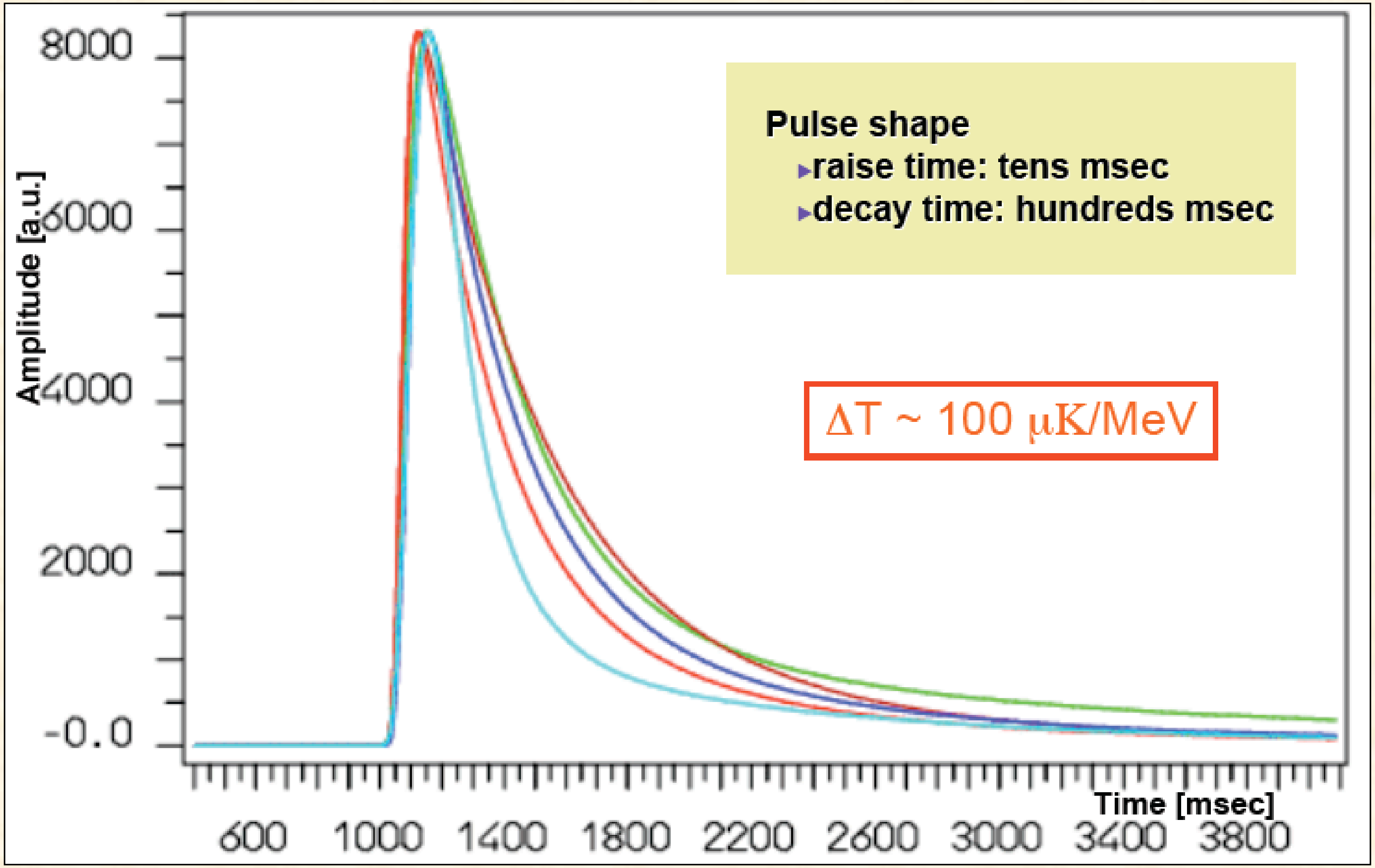








Detector response



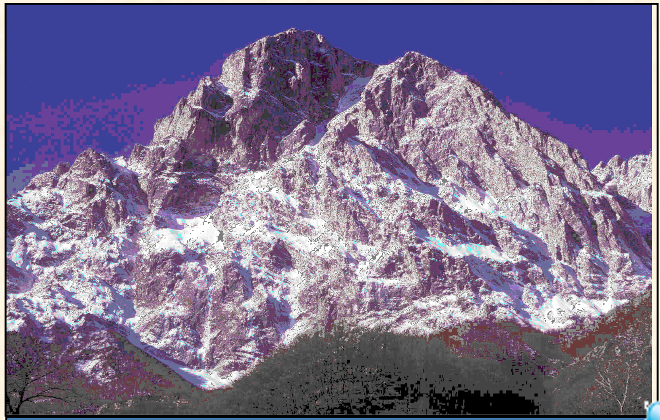
Detector sensitivity

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

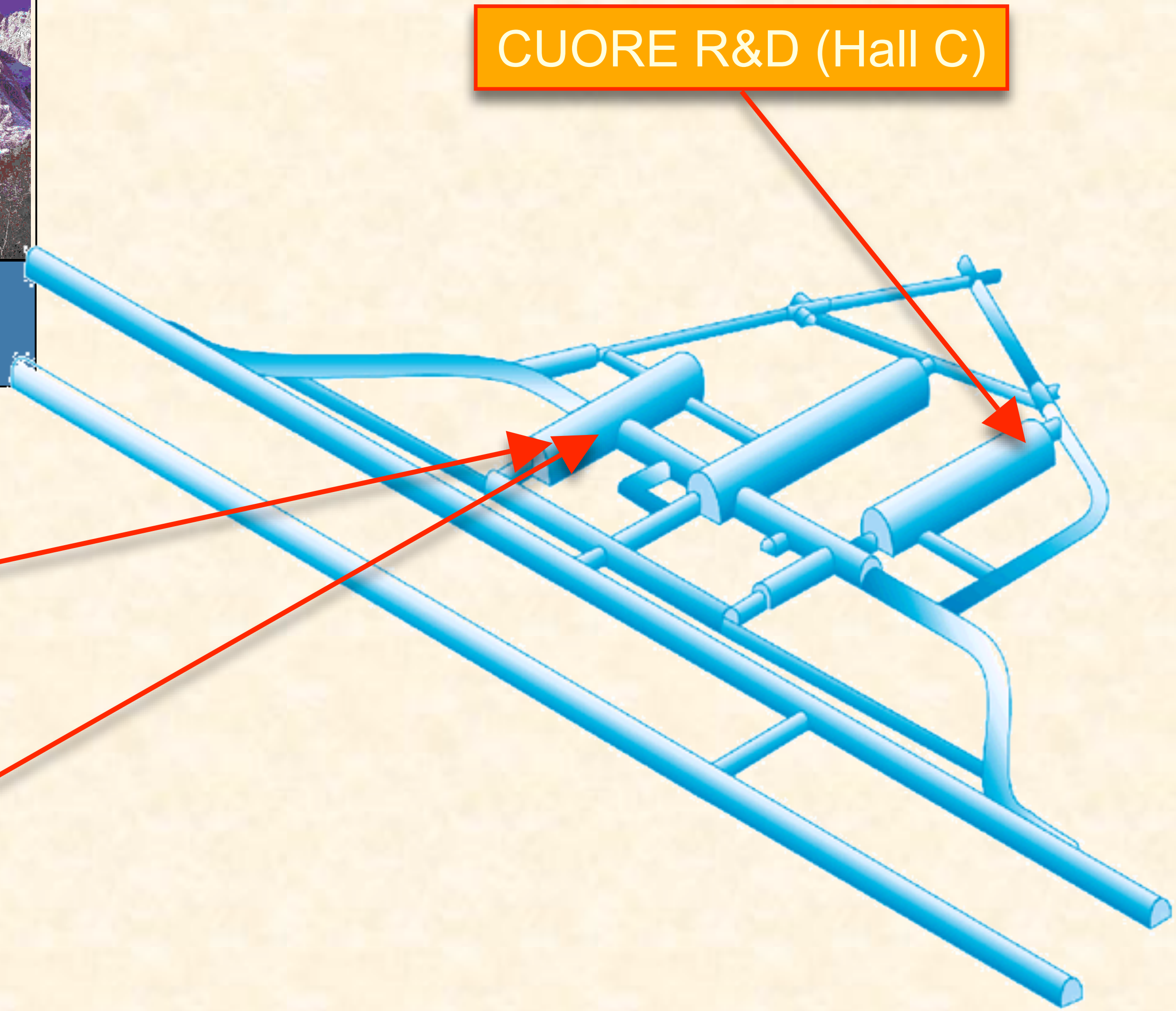
$$F^{0\nu} \sim \frac{a}{A}\sqrt{\frac{M \cdot T}{b \cdot \Gamma}} \cdot \varepsilon$$

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

Experiments location



LNGS - ~ 3500 m.w.e.



Cuoricino setup

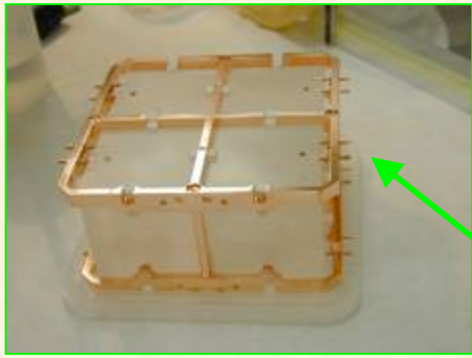
CUORICINO = tower of 11 modules, 4 detector (790 g) each
2 modules, 9 detector (330 g) each

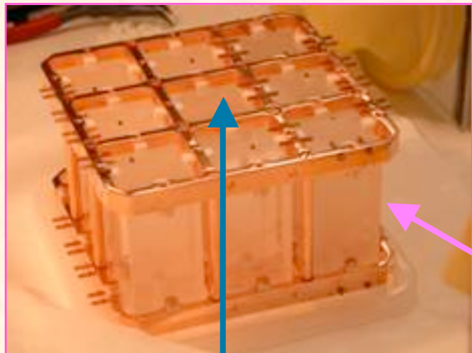
Total detector mass:
M ~ 40.7 kg TeO_2 ~ 5 x 10^{25} ^{130}Te nuclides

Currently the largest operated bolometer

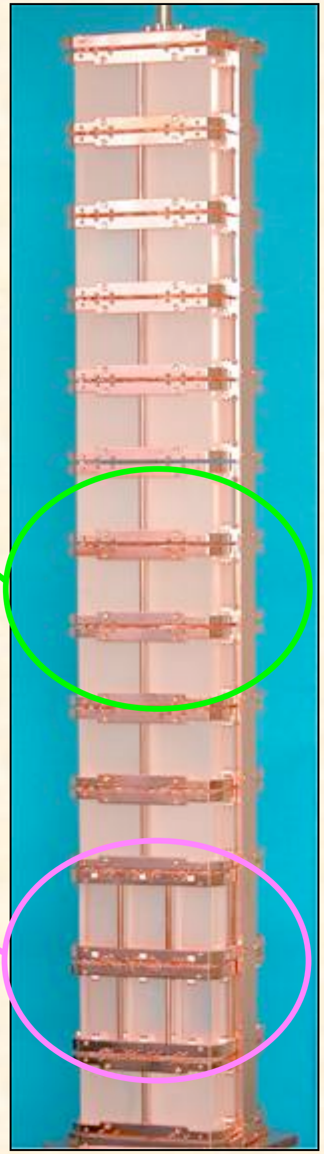
First cooldown: Feb 2003

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



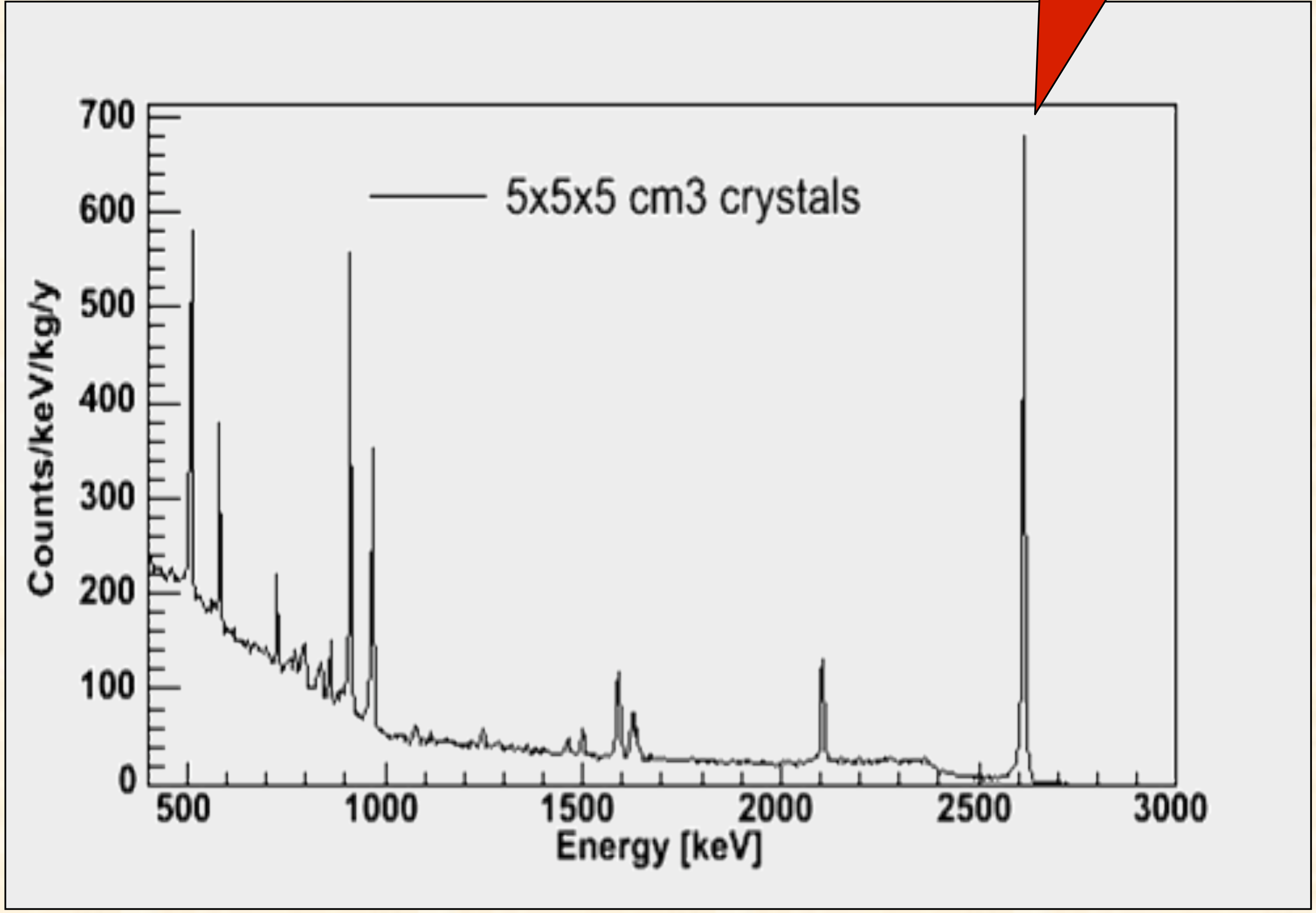
Cuoricino assembling

All the operations done in clean room and nitrogen atmosphere

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

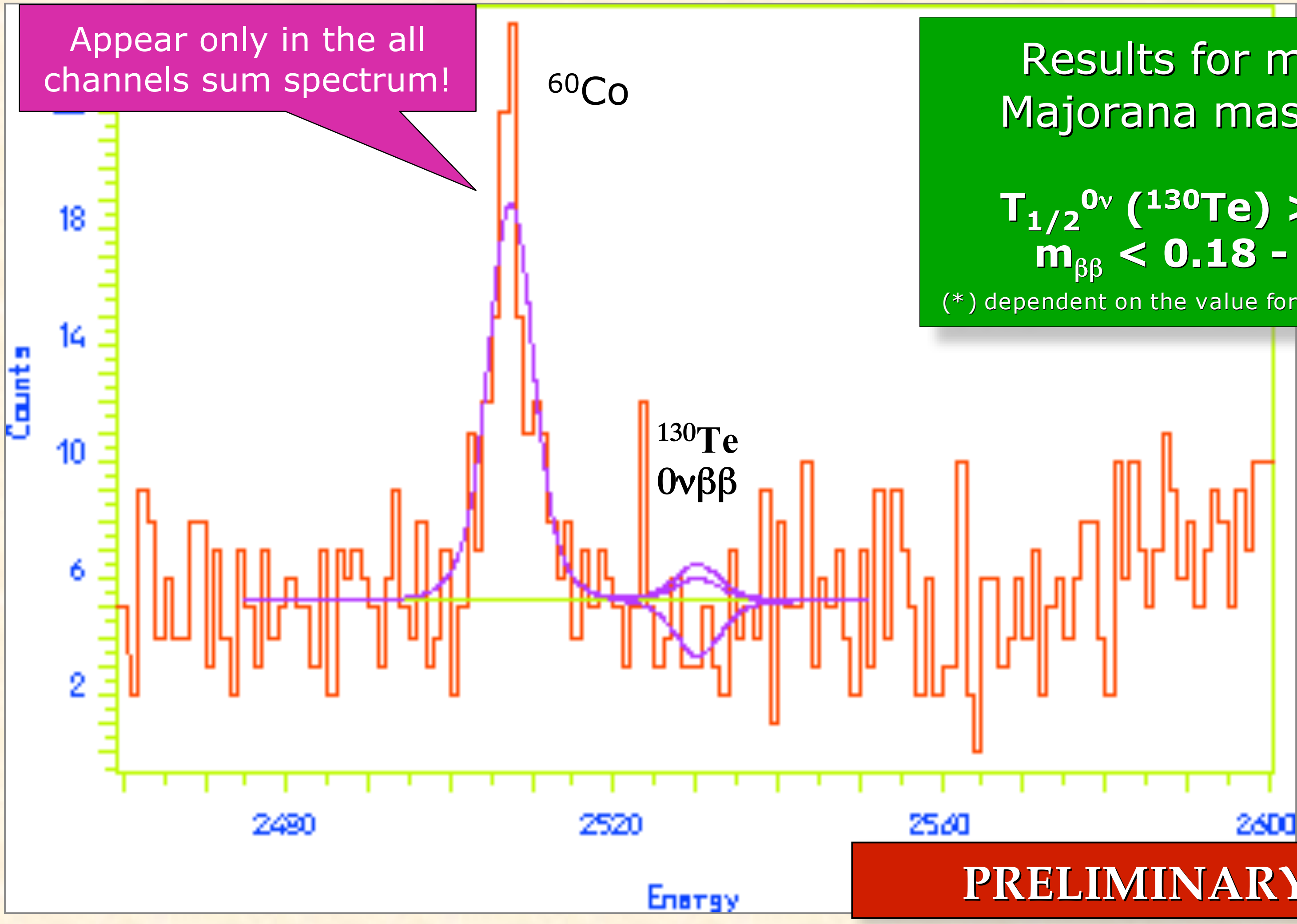
Resolution data for RUN II up to April 2005

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



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

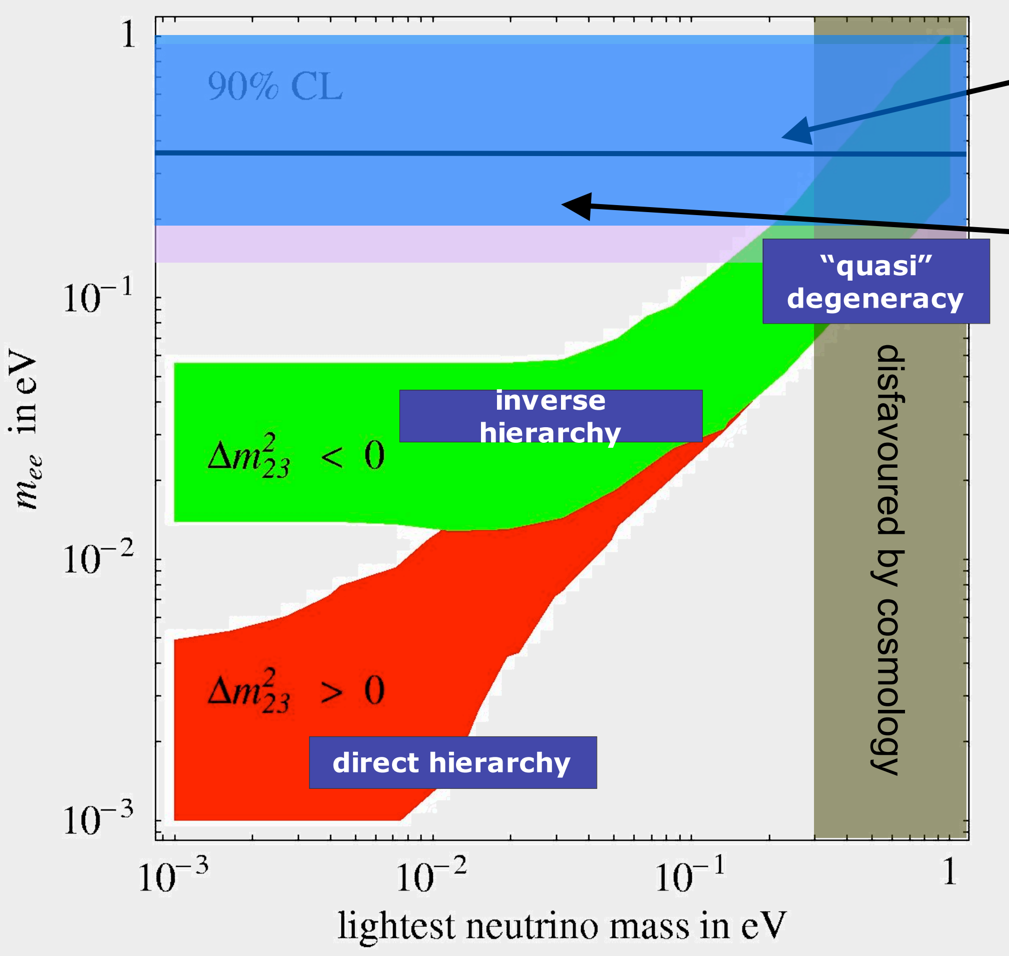
$$T_{1/2}^{0\nu}\,(^{130}Te) > 2.4 \times 10^{24}\ y$$

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

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

PRELIMINARY – May 2006

Cuoricino discovery potential



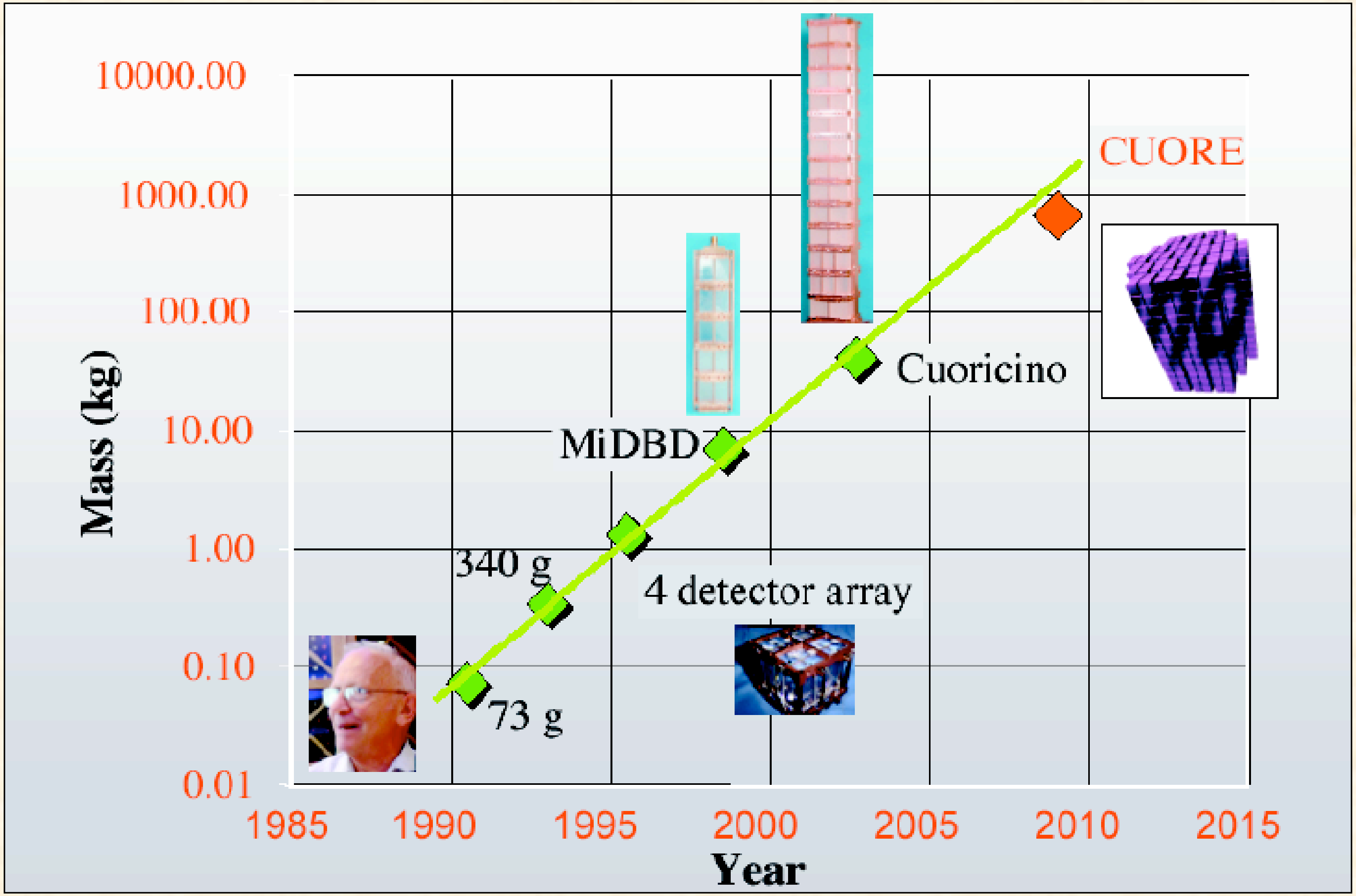
Strumia, Vissani, Nucl.Phys. B726 (2005) 294

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

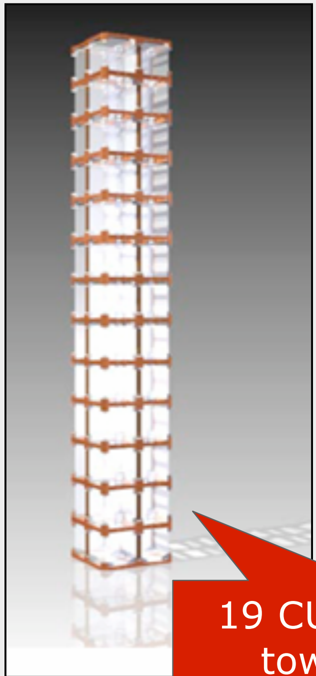
The Moore's Law of bolometry

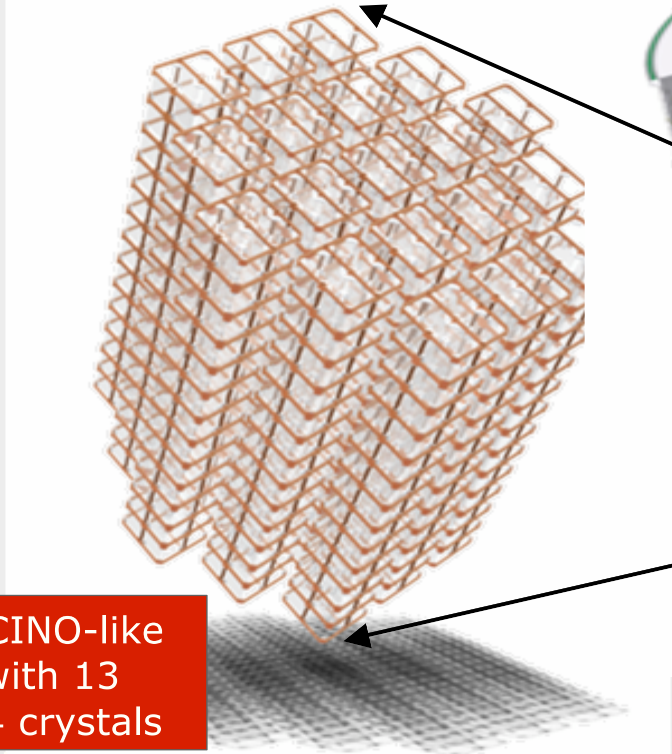


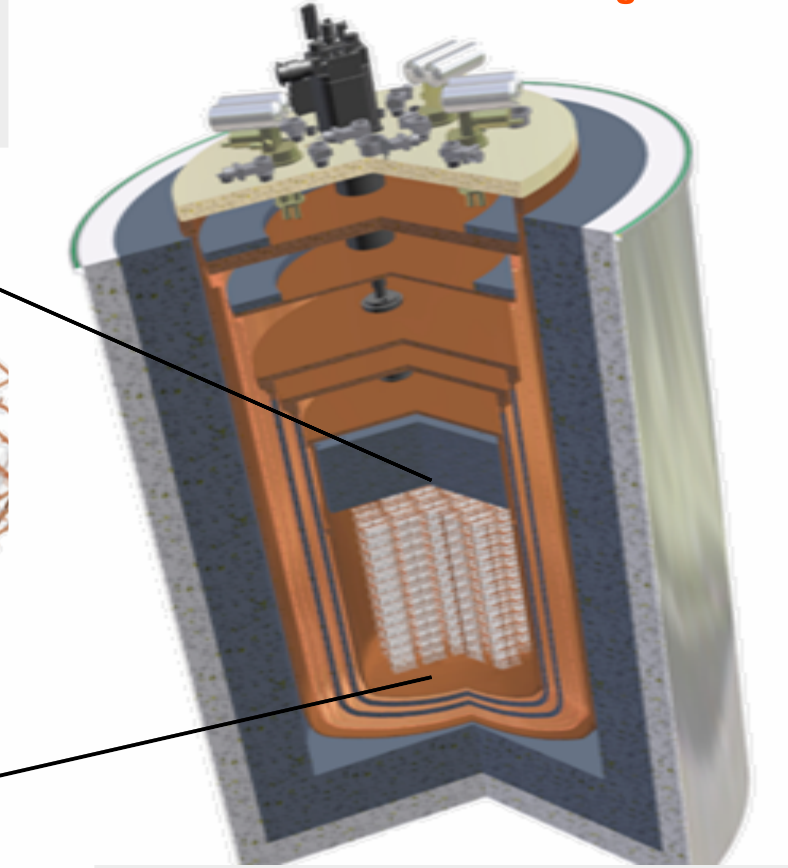
The evolution: CUORE

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



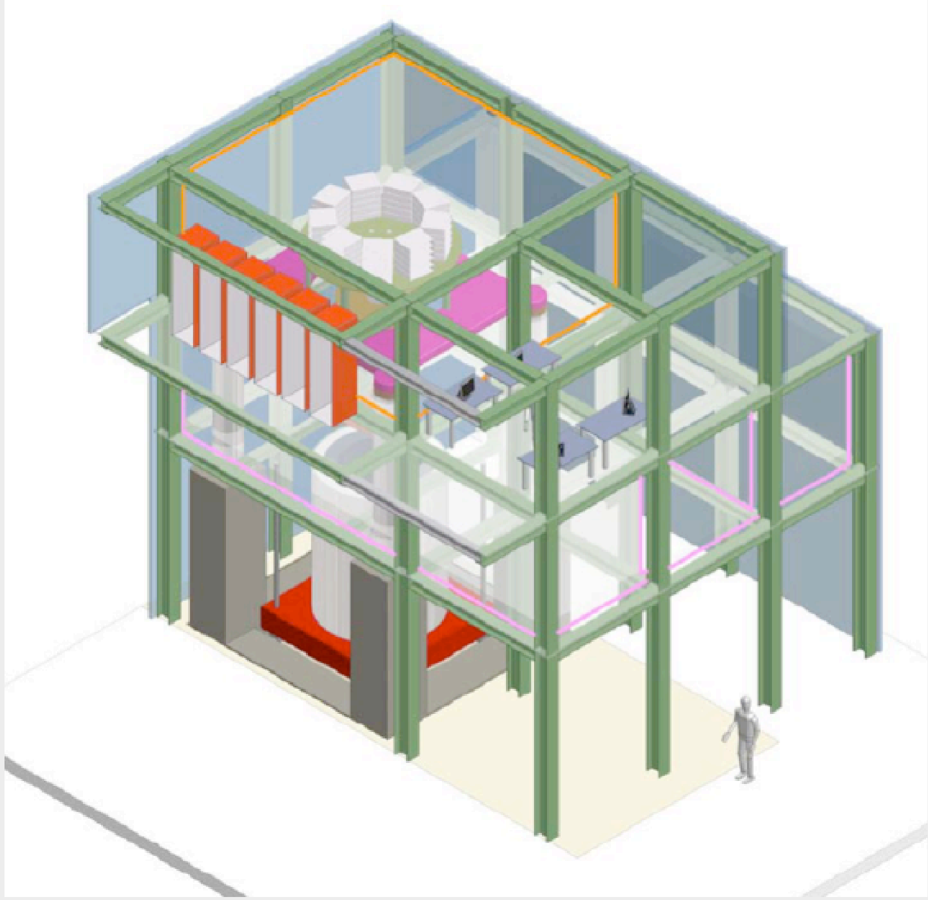




19 CUORICINO-like towers with 13 planes of 4 crystals each

Next-generation experiment

CUORE Housing



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

The background reduction

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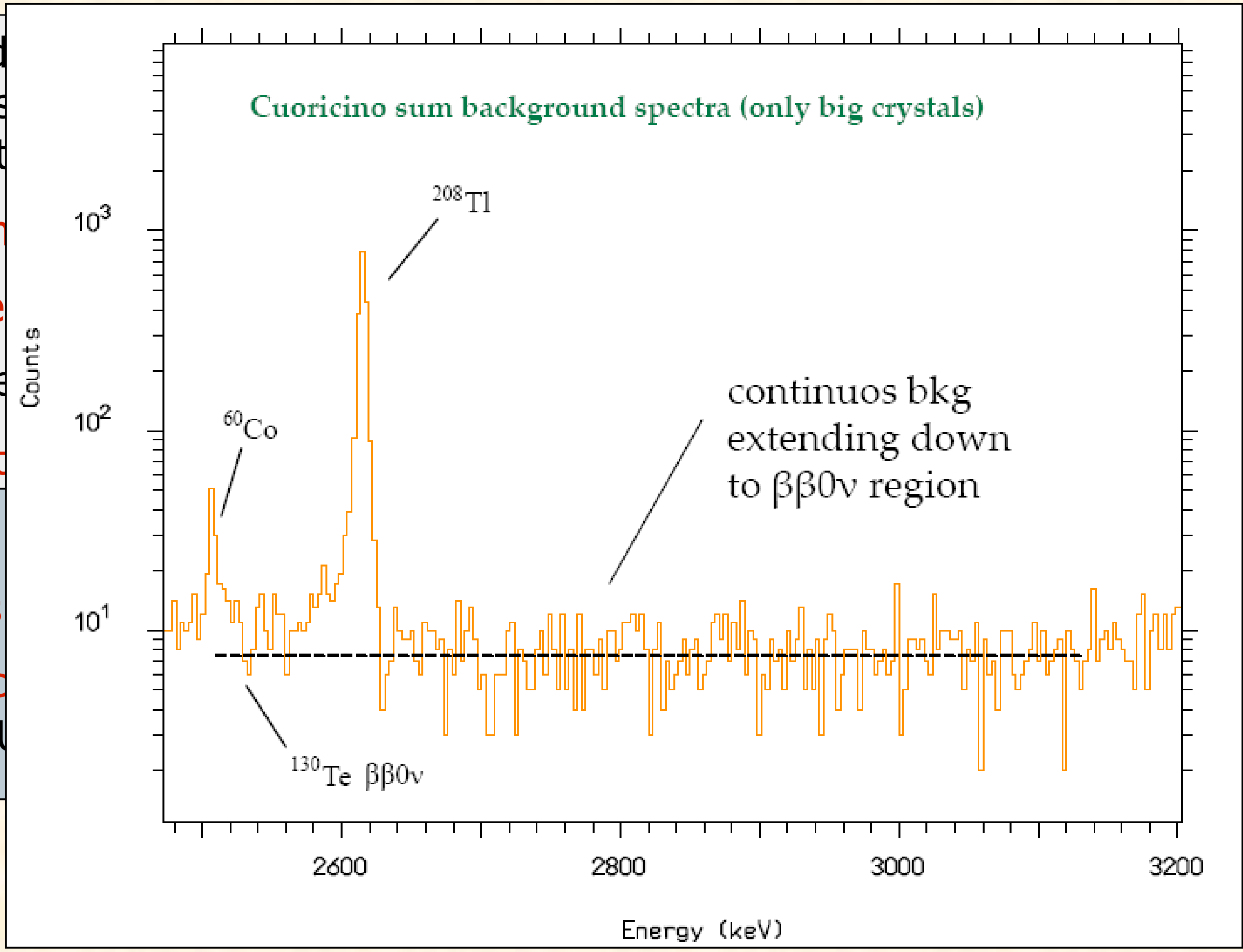
evaluations ... ulk
contaminat

- Environm
- Cosmoge
- $\beta\beta 2\nu$ » 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

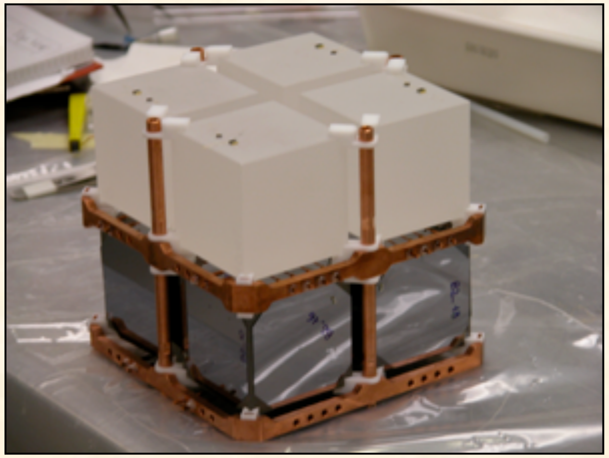
» Reduce material contamination increasing quality of surface treatment

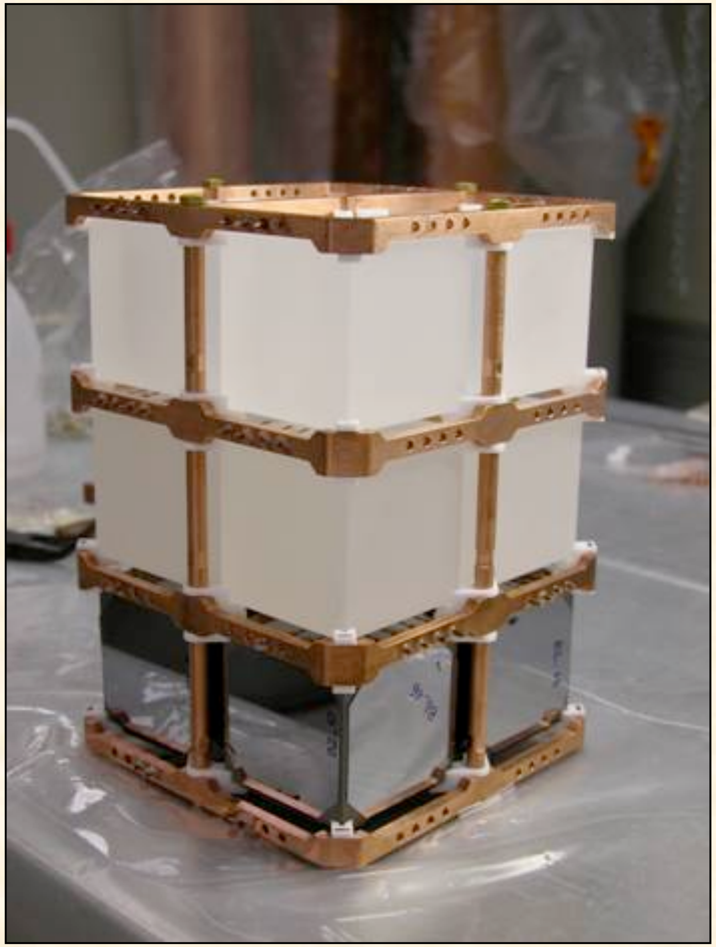
» Develop "clever" calorimeters to discriminate the origin of an event

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



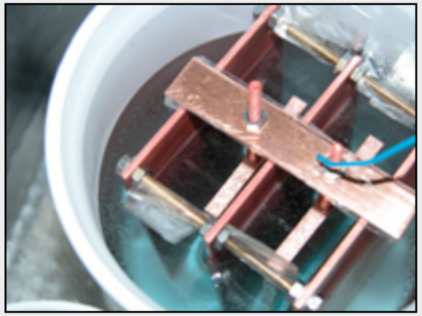


RAD tests

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

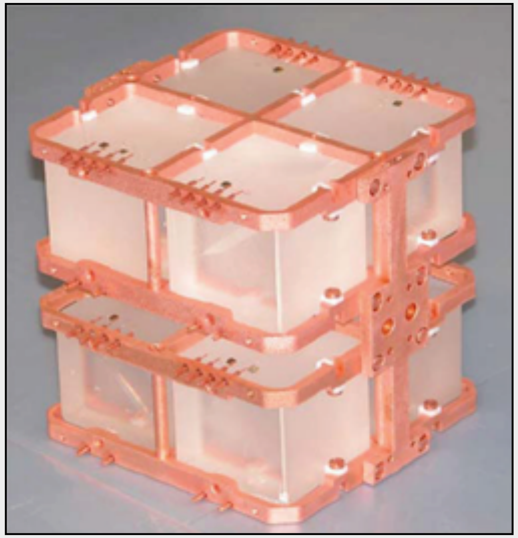
Copper

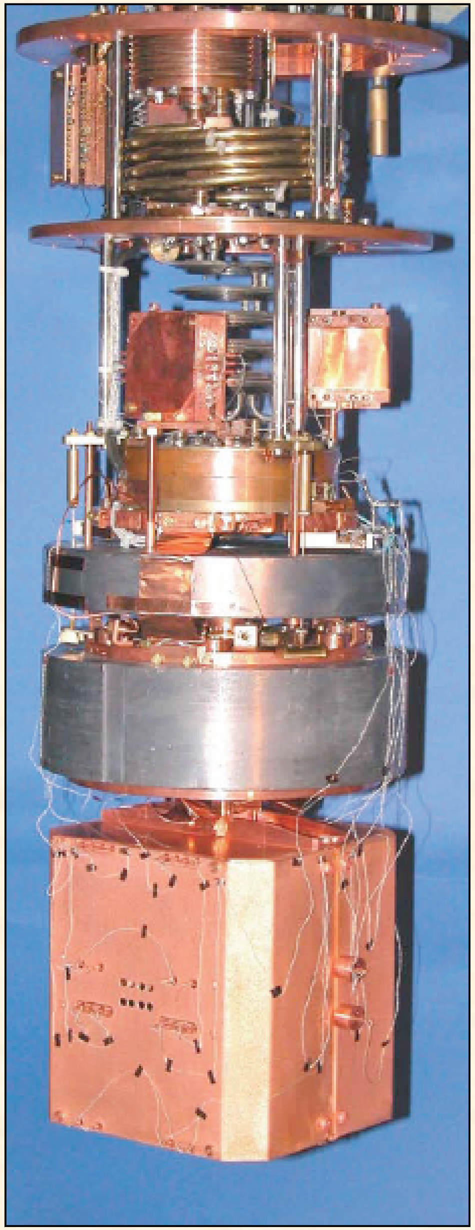
- Etching
- Electro polishing
- Passivation procedure



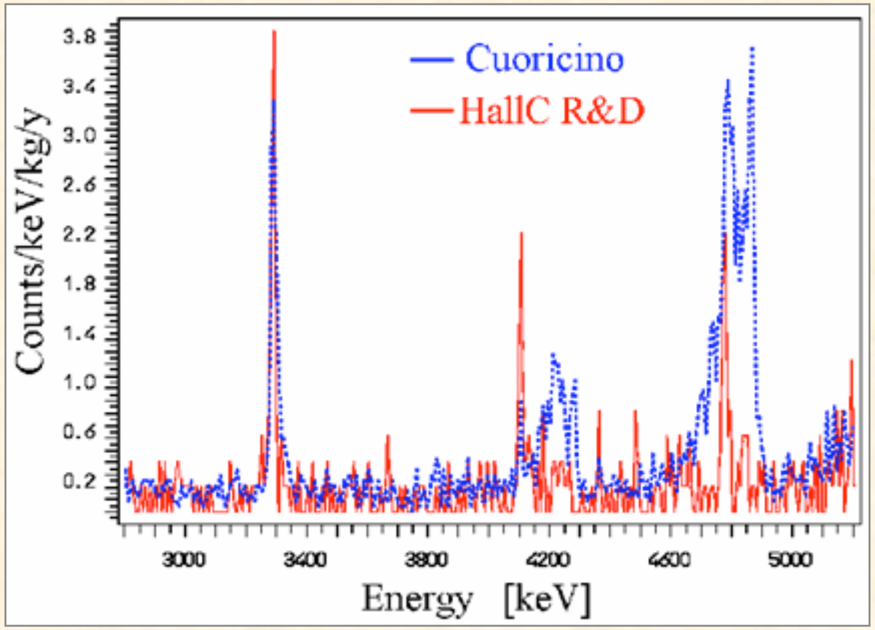
Crystals

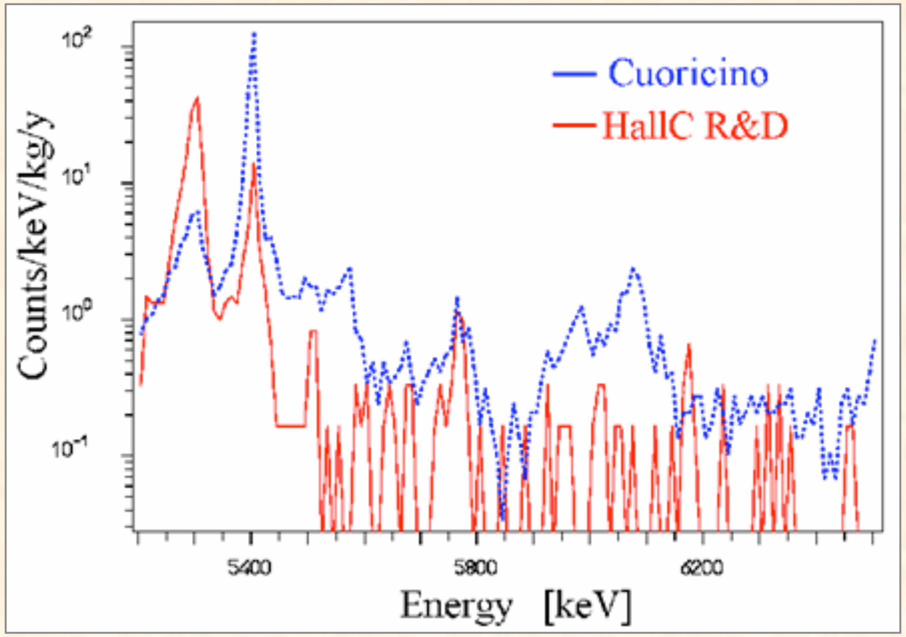
- Crystal etching (Nitric acid)
- Lapping with clean powder (2μ SiO_2)

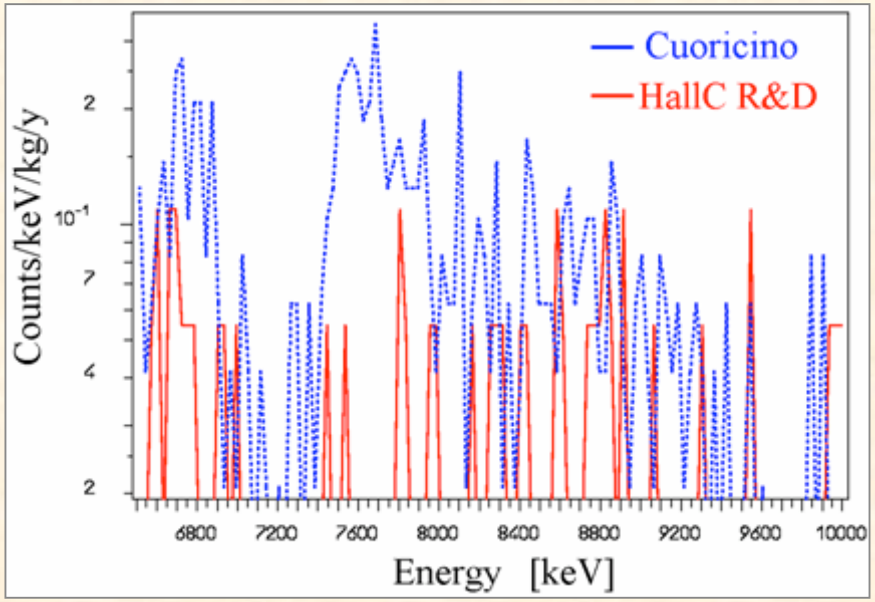




RAD tests results







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

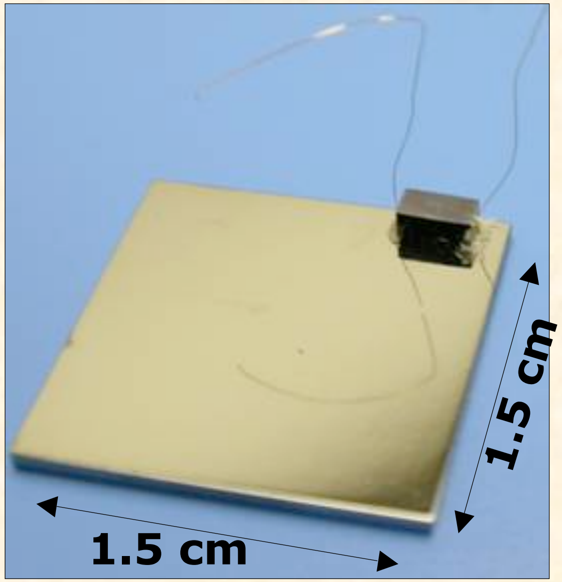
» new tests are on going in GranSasso

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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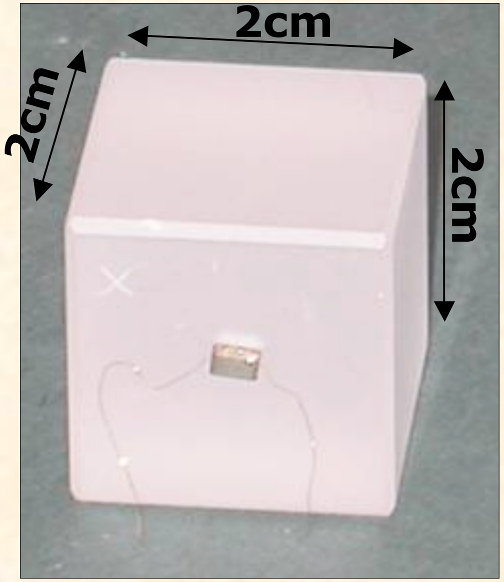
TeO_2 bolometer



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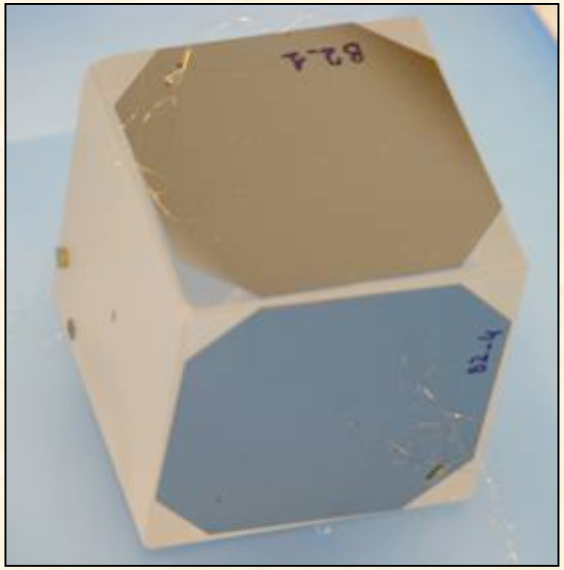
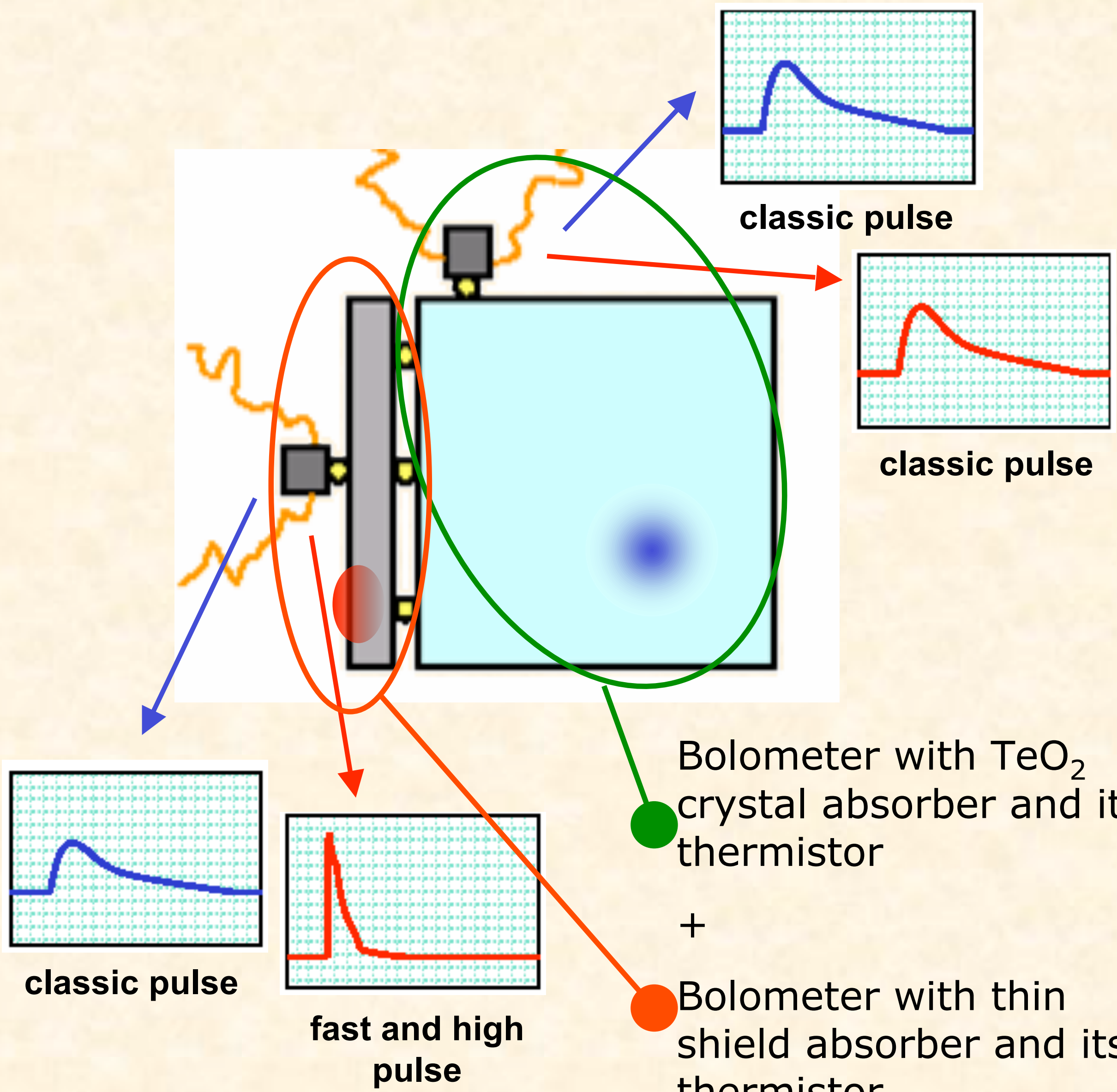
Composite bolometer



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.

We tested different **materials** as shields, each with different pros and cons:

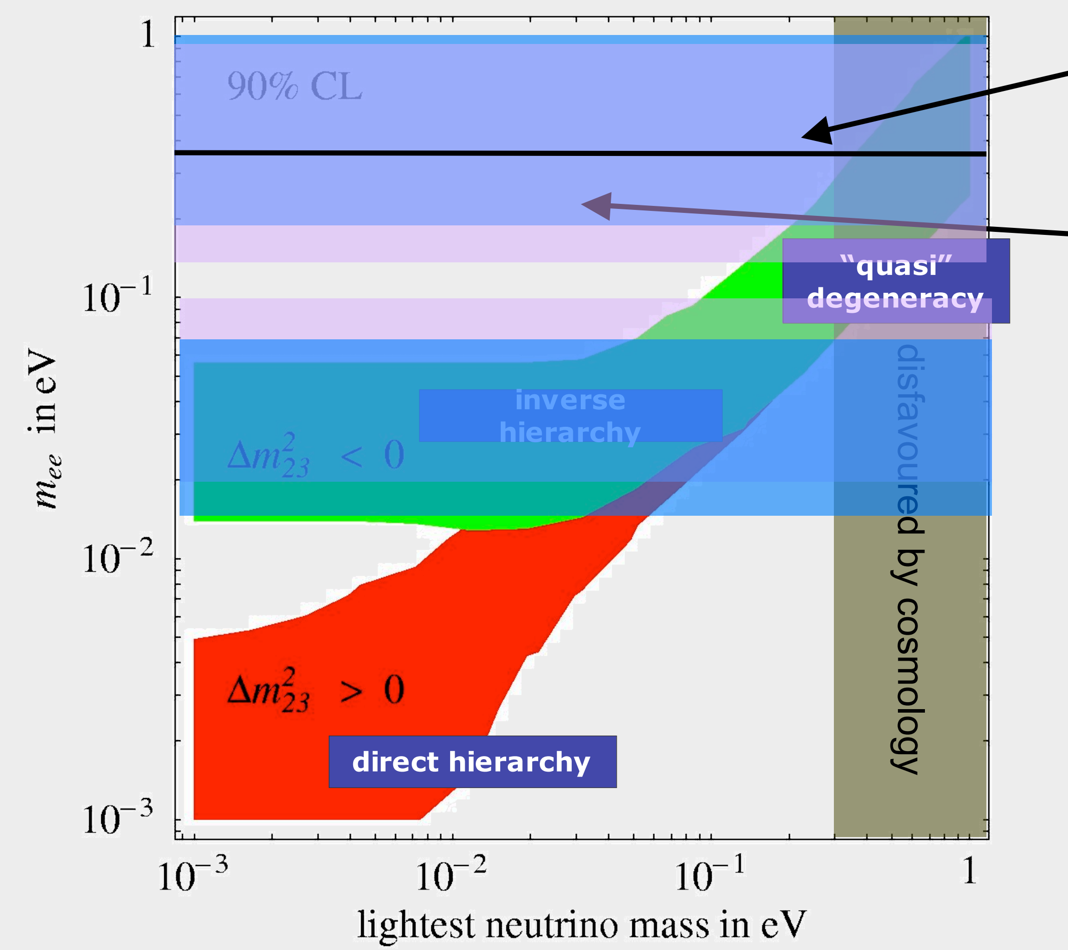
- **ultrapure Ge**
- **ultrapure Si**
- **TeO_2**

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



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

KK-HM possible evidence
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Present CUORICINO limit
Phys.Rev.Lett. 95 (2005) 142501

In 5 years:

b (counts/keV/kg/y)	Γ [keV]	$T_{1/2}$ [y]	$<m_\nu>$ [meV]
10^{-2}	5	2.1 _ 10^{26}	19-100
10^{-3}	5	6.5 _ 10^{26}	11-57

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.

- An intense **R&D work** is going on to **reduce the background**, in order to permit to CUORE experiment to investigate the inverse hierarchy region of the neutrino mass pattern

- CUORE can be **enriched** at a very low cost due to its large natural isotopic abundance. The use of other compounds of **other double beta active nuclei** (e.g. Ca-48, Mo-100, Cd-116) have been proved in the heat-scintillation approach which is capable to decrease dramatically the background.

- The costruction of **CUORE**, a second generation detector, is started and we will start taking data in 4 years from now.

CUORE Collaboration

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