Neutrinoless Double Beta Decay Search for ^{130}Te: CUORICINO status and CUORE prospects

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0ν Double Beta Decay for ^{130}Te

Neutrino nature:

- Dirac neutrino: $\nu_e \neq \bar{\nu}_e$
described by lepton number **L**
- Majorana neutrino: $\nu_e = \bar{\nu}_e$
described by helicity **H**

Neutrino masses:

- absolute value of neutrinos masses?
- mass hierarchy ?

» Neutrinoless Double Beta Decay

We recommend, as a high priority, a phased program of sensitive searches for neutrinoless nuclear double beta decay. *In this rare process, one atomic nucleus turns into another by emitting two electrons. Searching for it is very challenging, but the question of whether the neutrino is its own antiparticle can only be addressed via this technique. The answer to this question is of central importance, not only to our understanding of neutrinos, but also to our understanding of the origin of mass.*

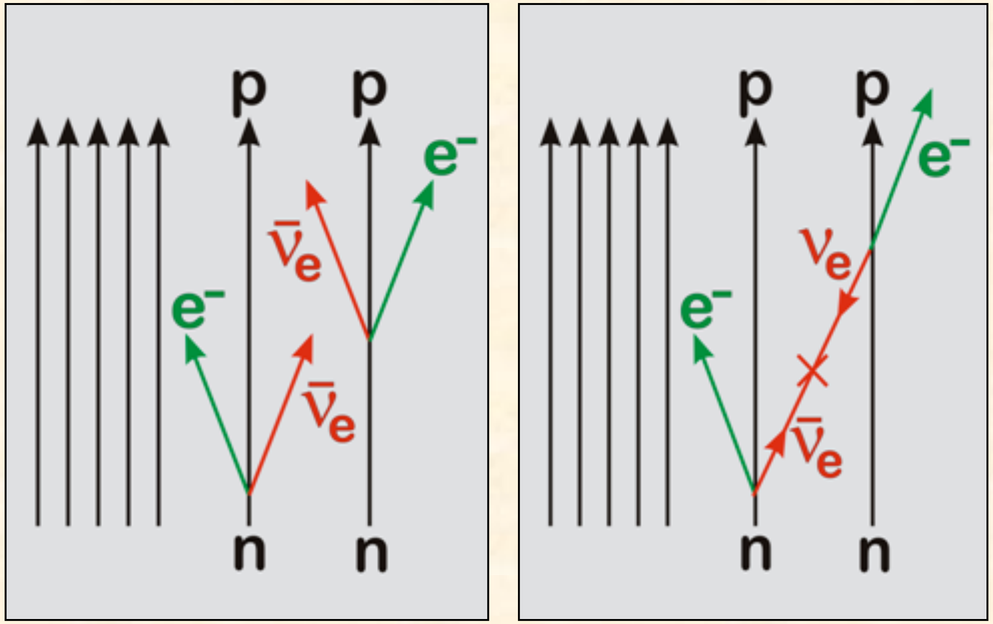
The Neutrino Matrix, Prepared by the members of the **American Physical Society Multidivisional Neutrino Study**, arXiv:physics/0411216

0ν Double Beta Decay for ^{130}Te

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:

ββ2ν allowed by Standard Model	ββ0ν possible only with Majorana ν



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

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

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

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

0ν Double Beta Decay for ^{130}Te

CUORE and CUORICINO are experiments that search for 0nDBD on 130Te

Why ^{130}Te

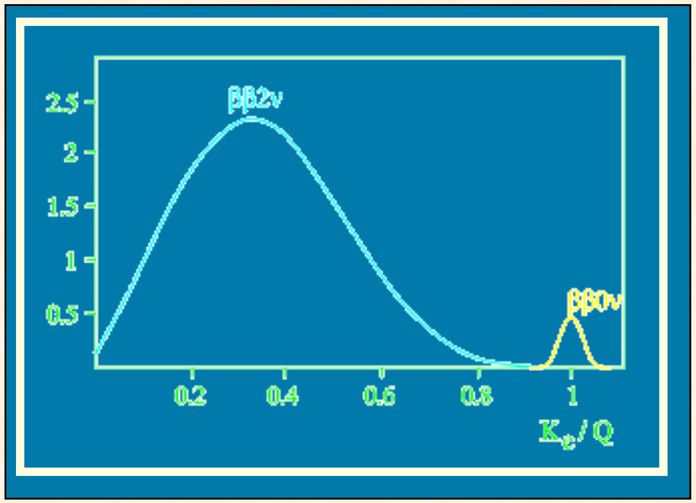
^{130}Te presents several nice features:

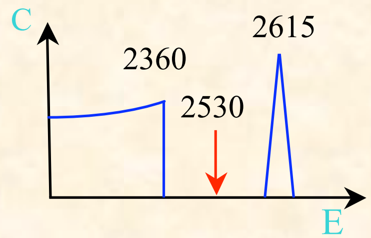
- high natural isotopic abundance (I.A. = 33.87 %)
- high transition energy (Q = 2530.30 ± 1.99 keV)
- encouraging theoretical calculations for 0ν–DBD lifetime

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

DBD spectrum

what are we looking for?





Experimental approach

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

Operated as perfect calorimeters: all energy converted into phonons

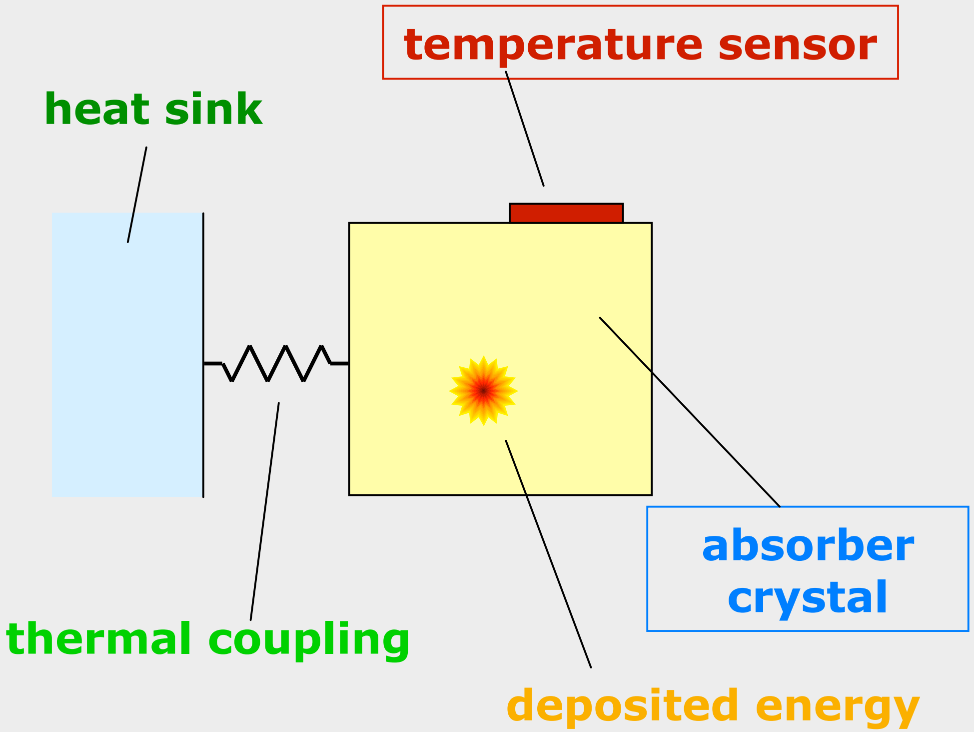
$$\Delta T = \frac{E}{C} \qquad \tau = \frac{C}{G}$$

complete and instantaneous thermalization

temperatures ~ 10mK

dielectric e diamagnetic materials

Bolometric technique:



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

CUORICINO bolometers

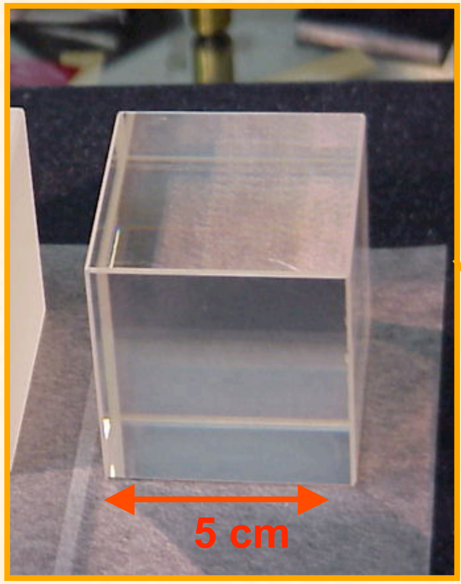
Absorber crystal

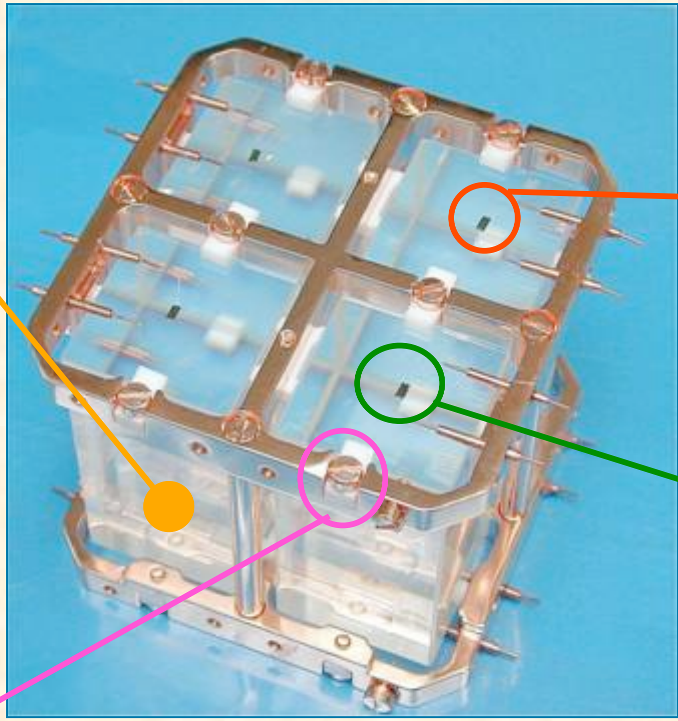
The absorber is a **5x5x5 cm^3** crystal of **TeO_2** which contains the neutrinoless DBD candidate **^{130}Te**

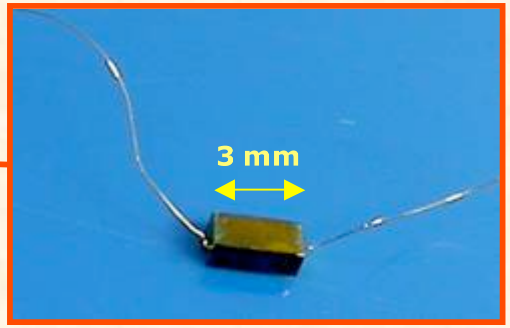
Temperature sensor

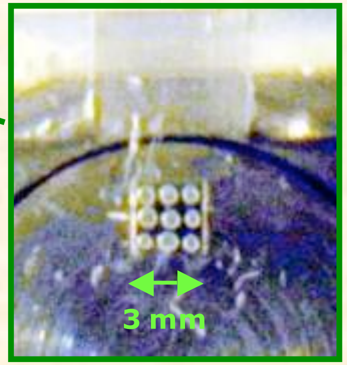
The thermal signal is measured by means of an **NTD Ge Thermistor**

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

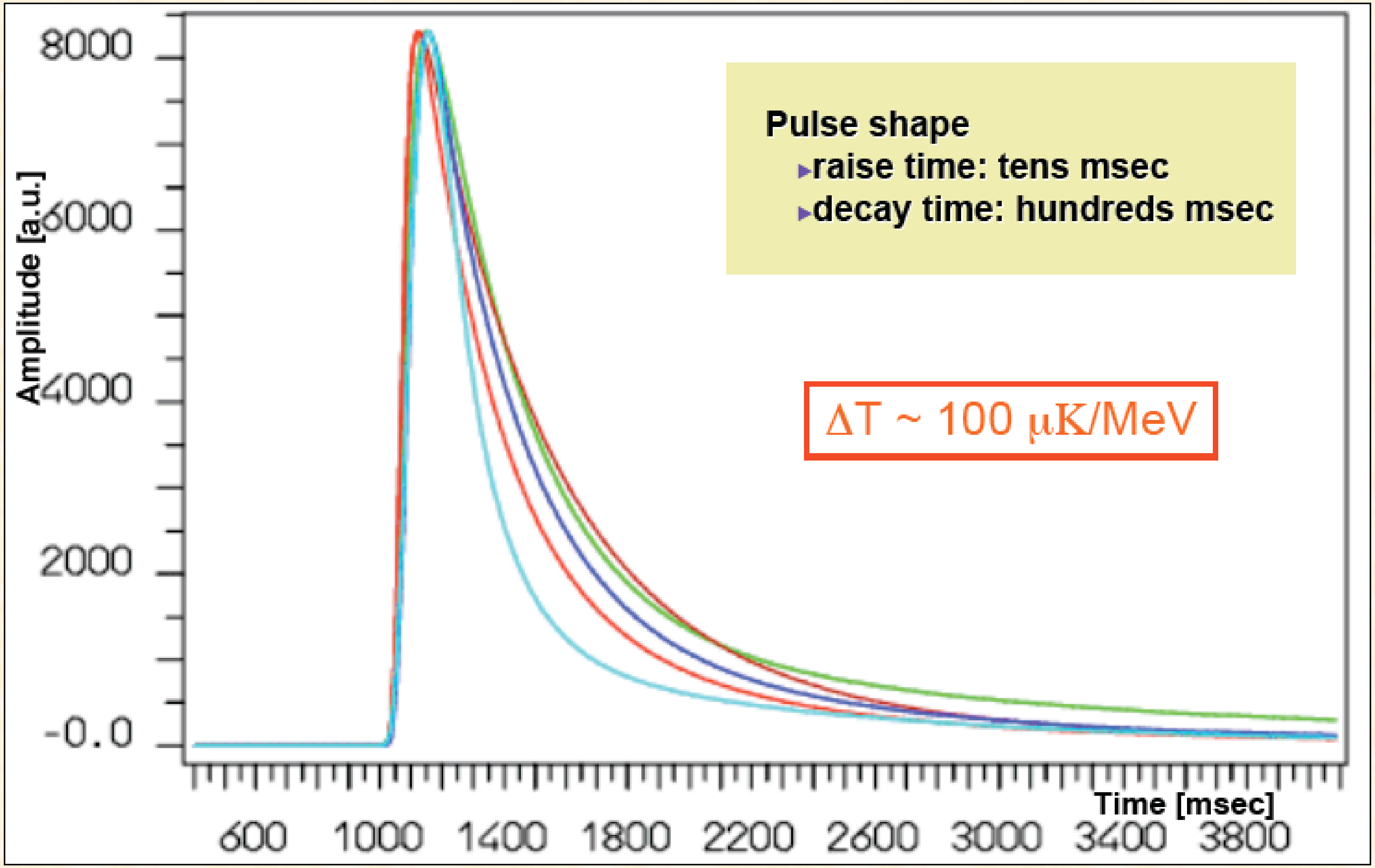








Detector response



Detector sensitivity

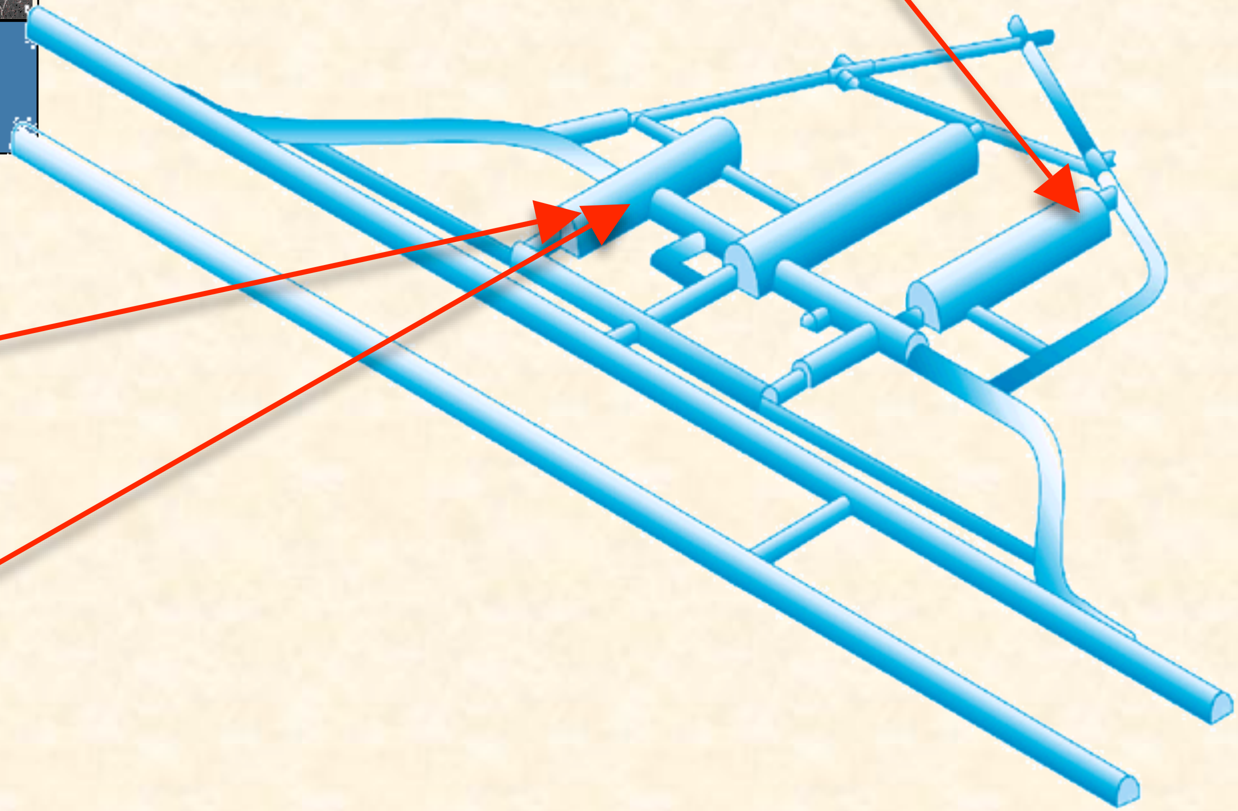
Sensitivity: Lifetime corresponding to the minimum number of detectable events above background at a given C.L.

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

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.



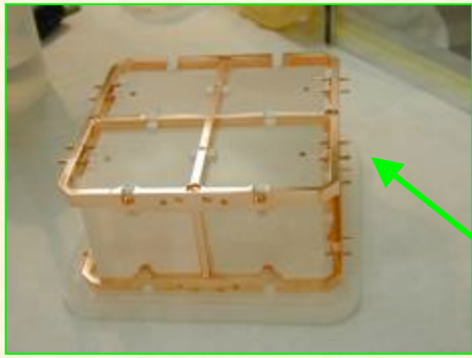
CUORICINO setup

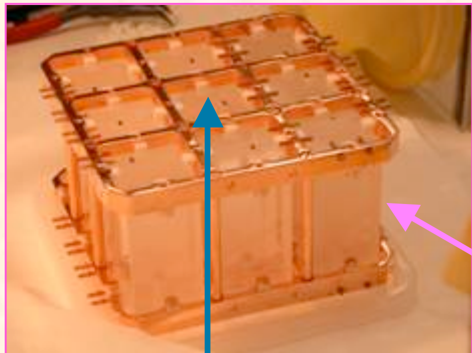
CUORICINO = tower of 11 modules, 4 detector (790 g) each
2 modules, 9 detector (330 g) each

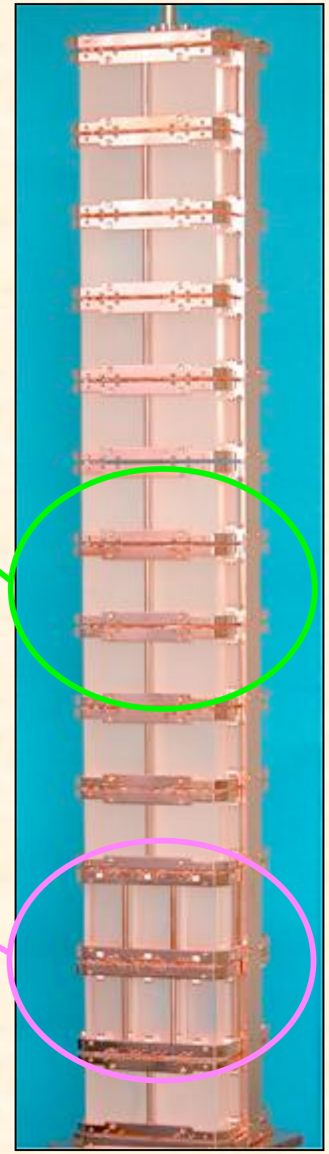
Statistics:
M ~ 40.7 kg TeO_2 ~ 5 x 10^{25} ^{130}Te nuclides

Run I (Feb 2003 – Oct 2003):
Working detectors: 73%
Live Time: 23%

Run II (from May 2004):
Working detectors: 94%
Live Time: ~60% (+ ~10% calib time)







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

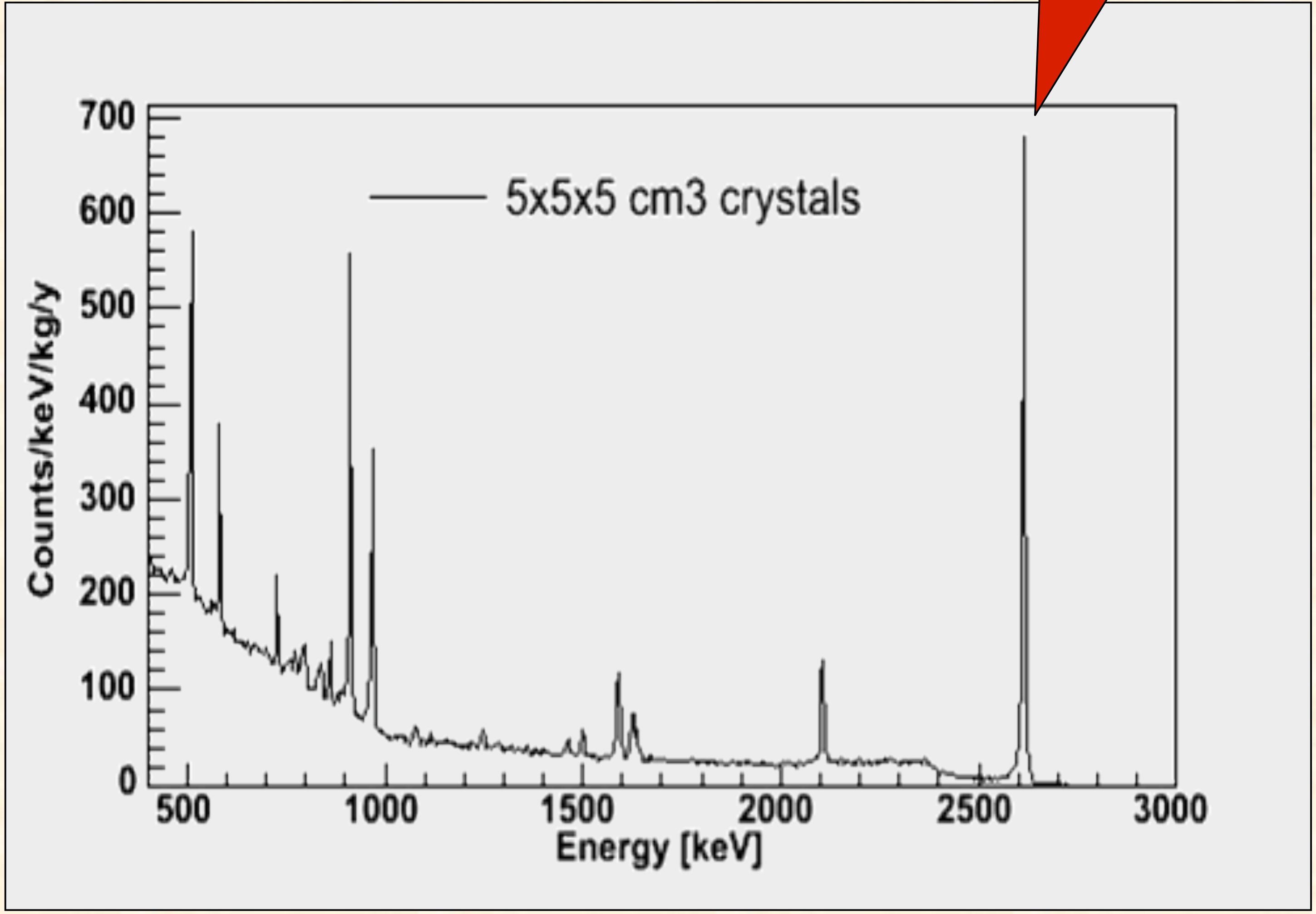
CUORICINO assembling

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±2.4 keV

3x3x6 cm^3 crystals ~ 11.0±4.7 keV

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

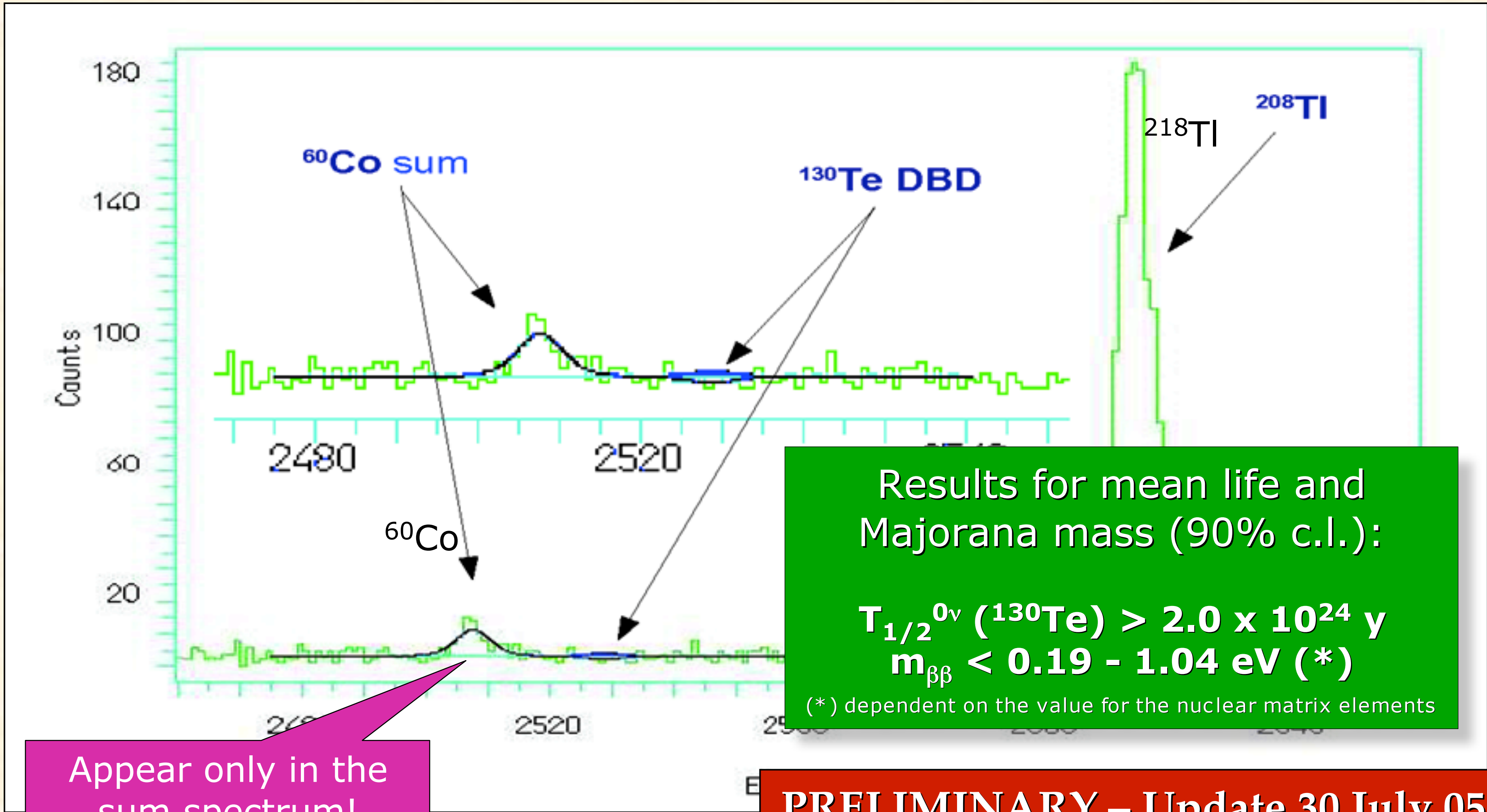
Resolution data for RUN II up to April 2005

CUORICINO results

Cuoricino is successfully acquiring data from April 2003 (MT = 5.87 kg y ^{130}Te)

Background in $\beta\beta$ region (anticoincidence spectrum, only 5x5x5 cm^3 crystals)

0.18 ± 0.02 c/keV/kg/y



Appear only in the sum spectrum!

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

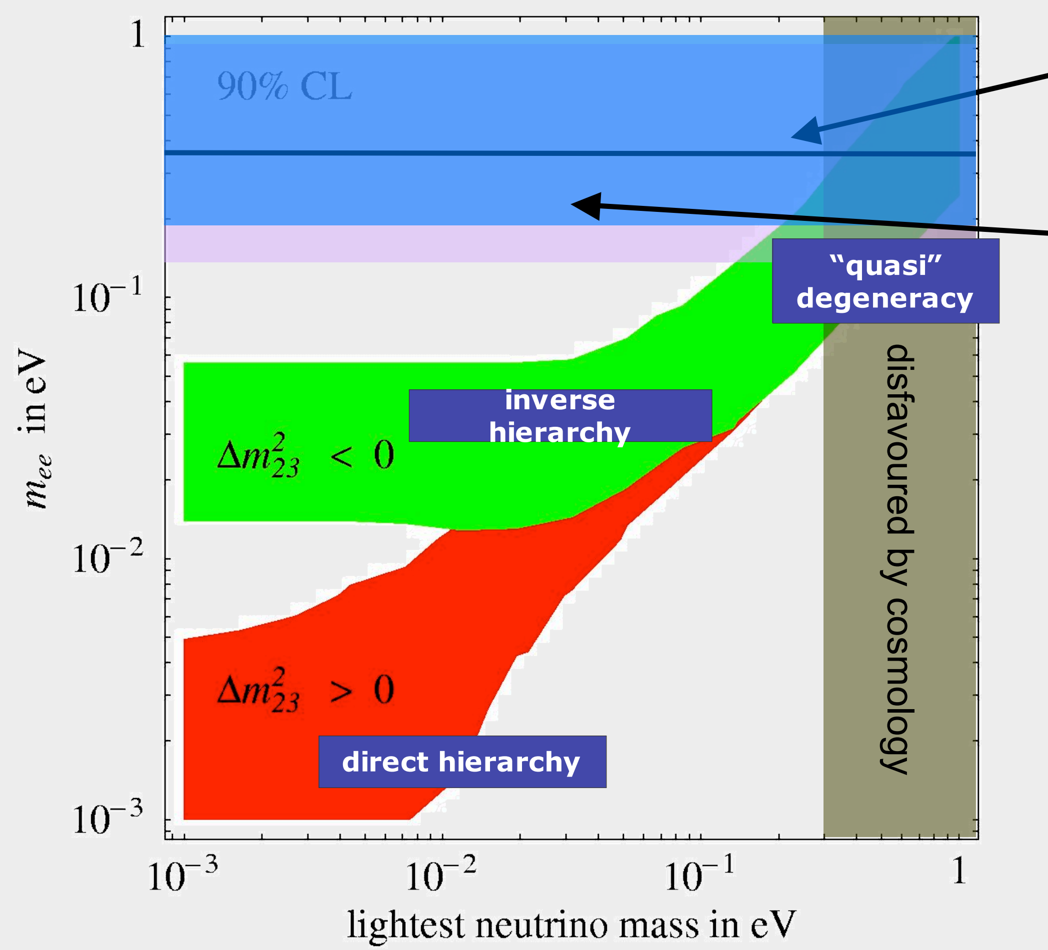
$T_{1/2}^{0\nu}$ (^{130}Te) > 2.0 x 10^{24} y

$m_{\beta\beta}$ < 0.19 - 1.04 eV (*)

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

PRELIMINARY – Update 30 July 05

CUORICINO discovery potential



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

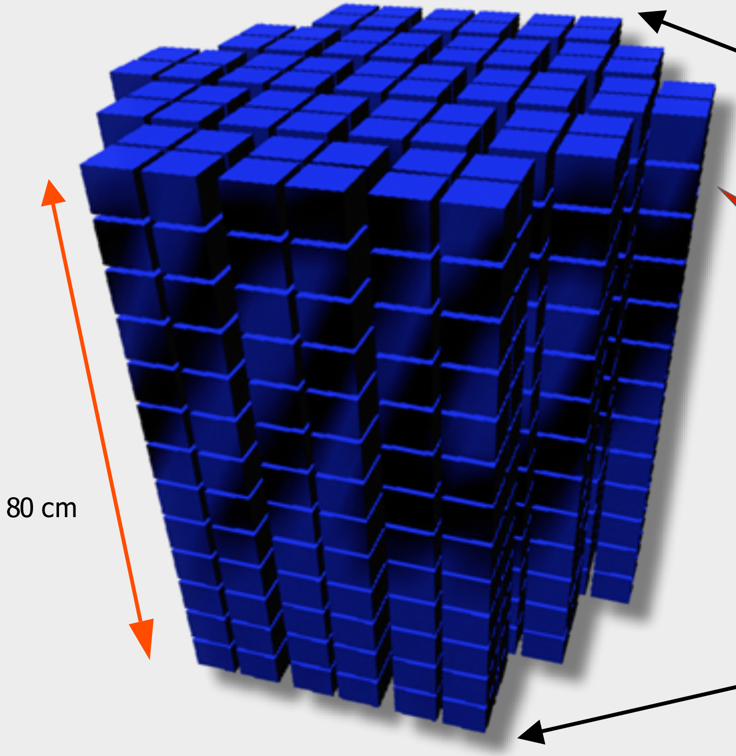
KK-HM possible evidence
hep-ph/0201231

Present CUORICINO limit
Arnaboldi et al, **Phys.Rev.Lett.**, hep-ex/0501034 (2005)

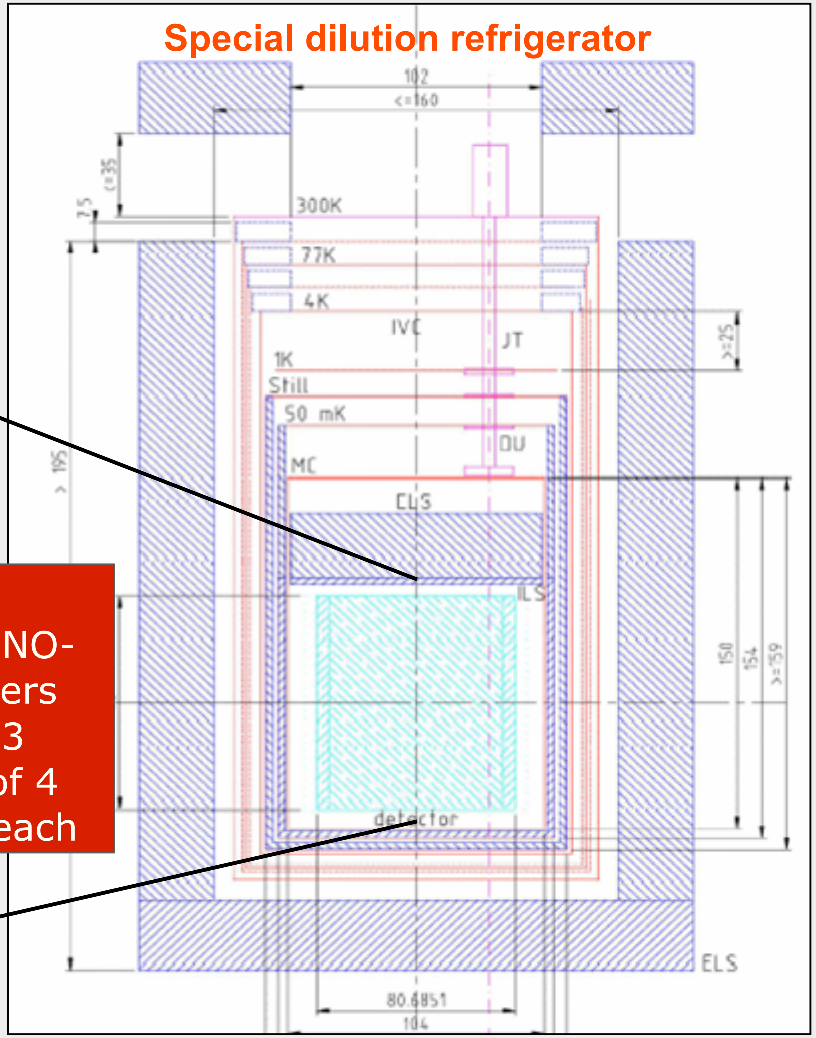
good chance to have a positive indication in a short time (3 y) but cannot falsify KK if no signal is seen

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



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



Next-generation experiment – Already approved and funded

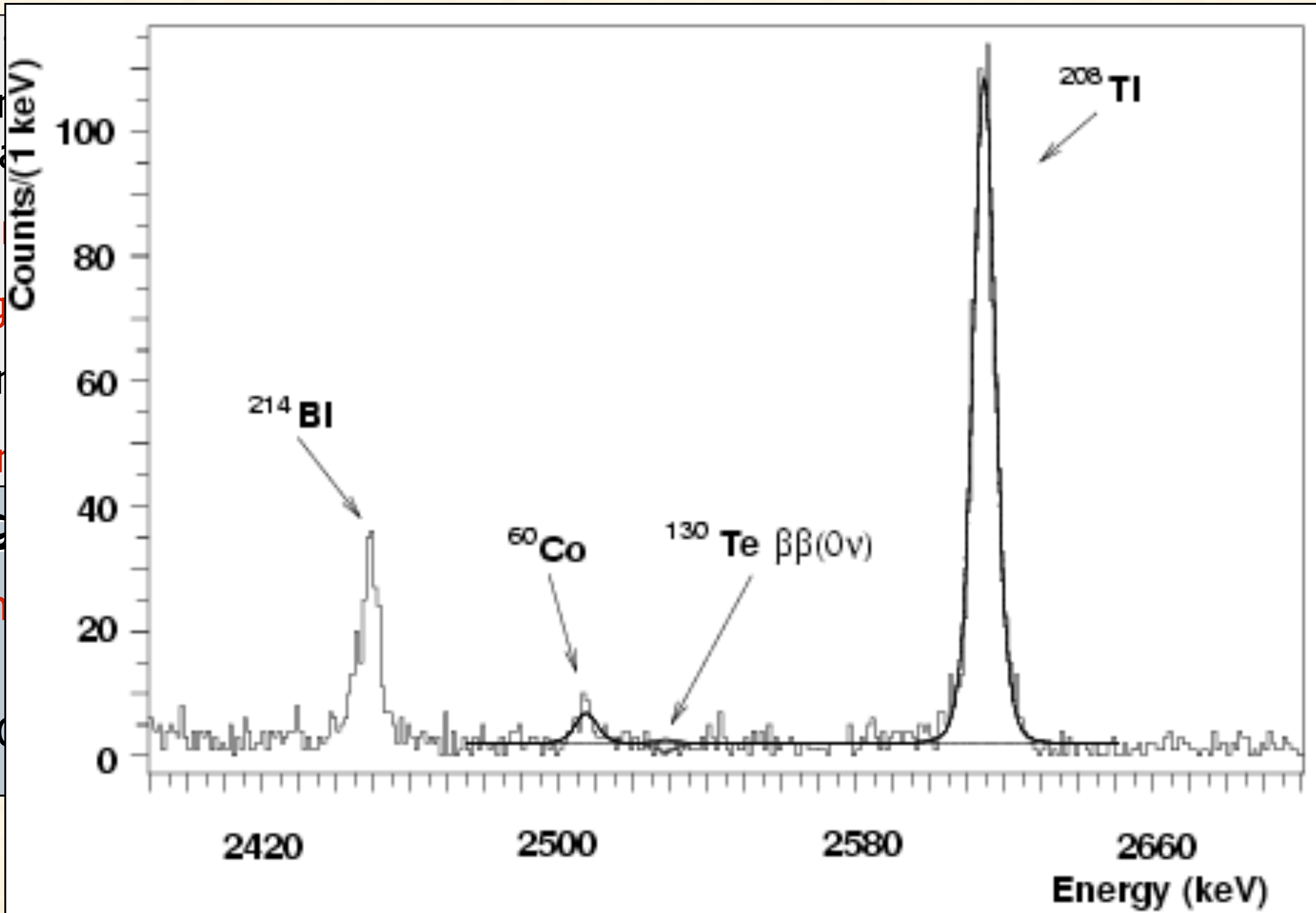
The background reduction

We have … rlo
evaluatio…
contamin…

- Environ…
- Cosmog…
- $\beta\beta2\nu$ » r…
- Bulk co…

Flat bkg…

- Neutron…
- Surface … t and
granular (…



Possible solutions

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

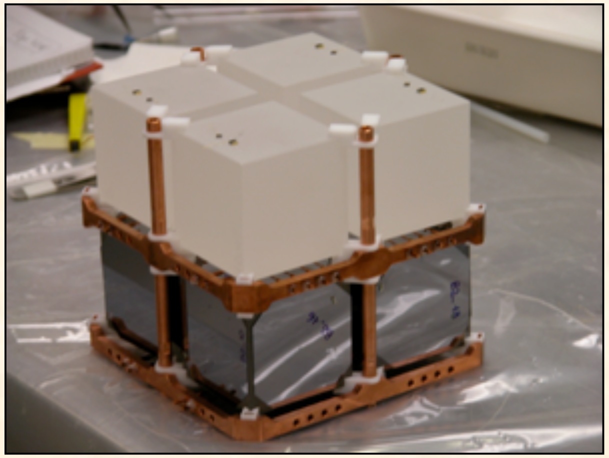
» Reduce material contamination increasing quality of surface treatment

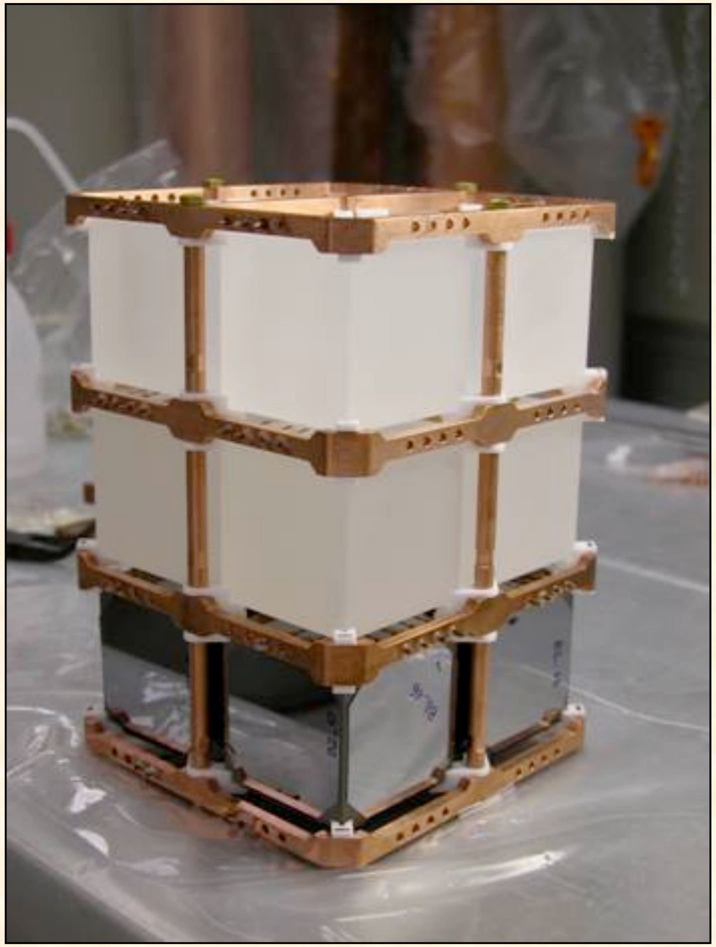
» Develop "clever" calorimeters to discriminate the origin of an event

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



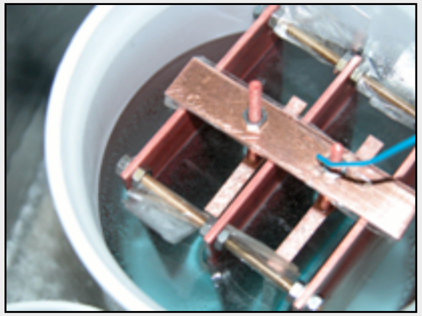


RAD tests

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

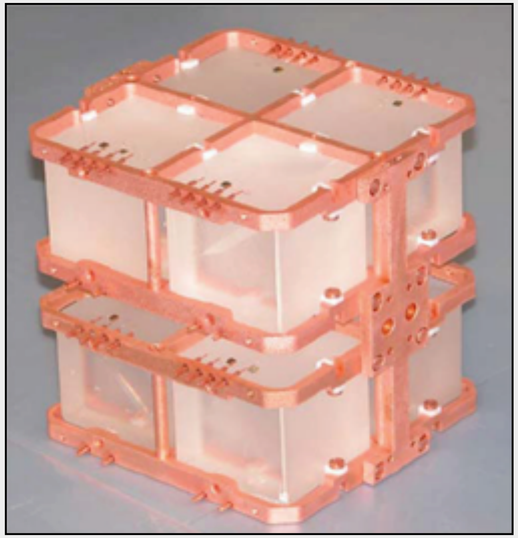
Copper

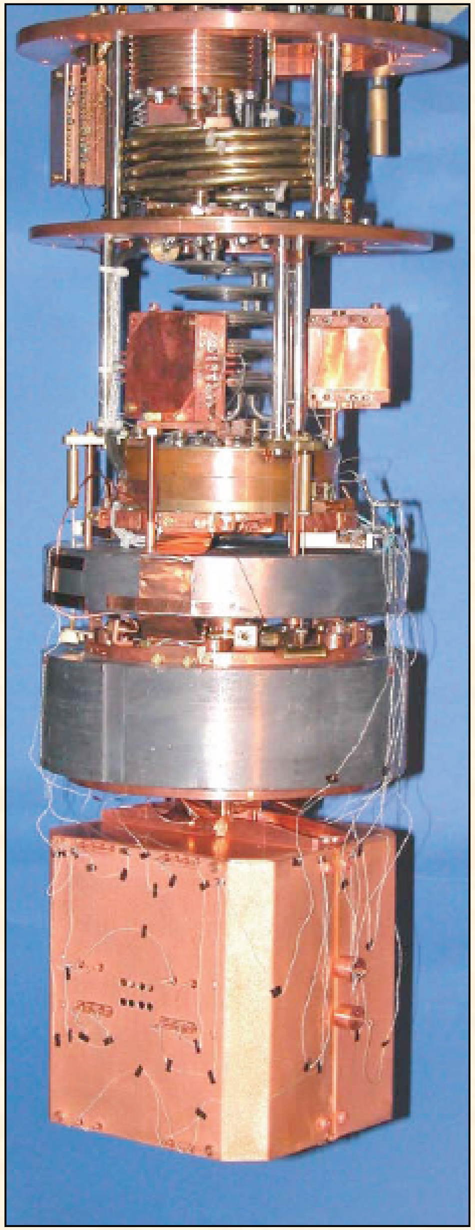
- Etching
- Electro polishing
- Passivation procedure



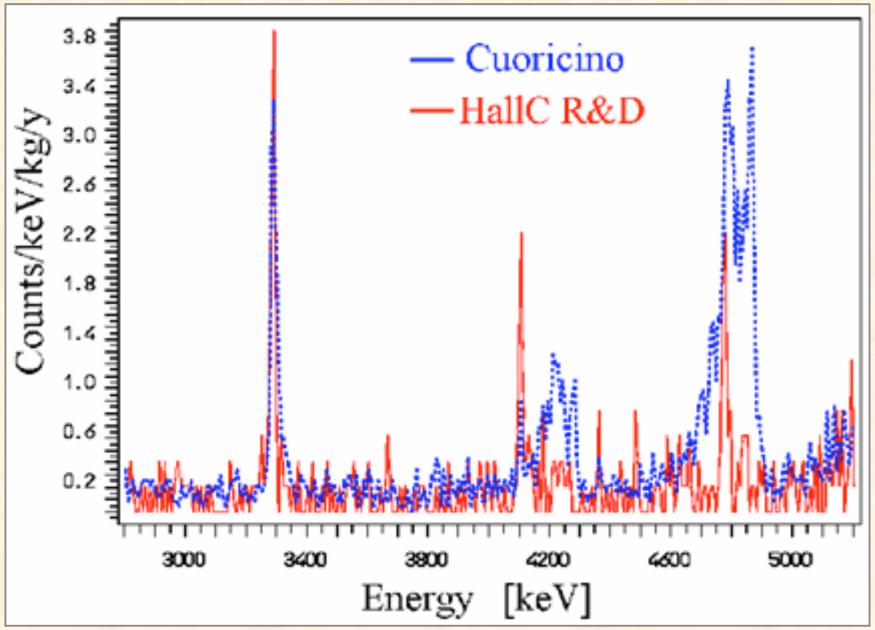
Crystals

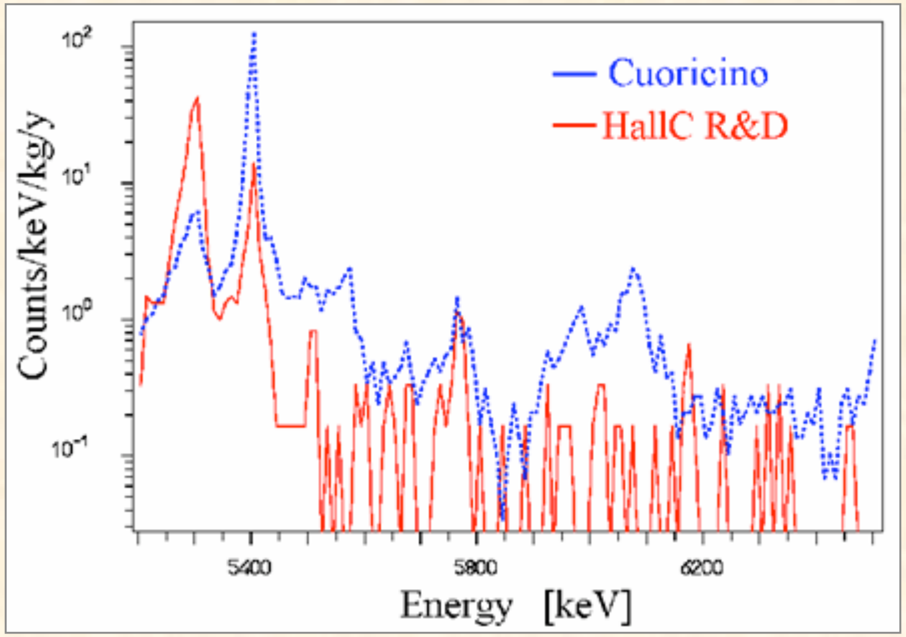
- Crystal etching (Nitric acid)
- Lapping with clean powder (2µ SiO_2)

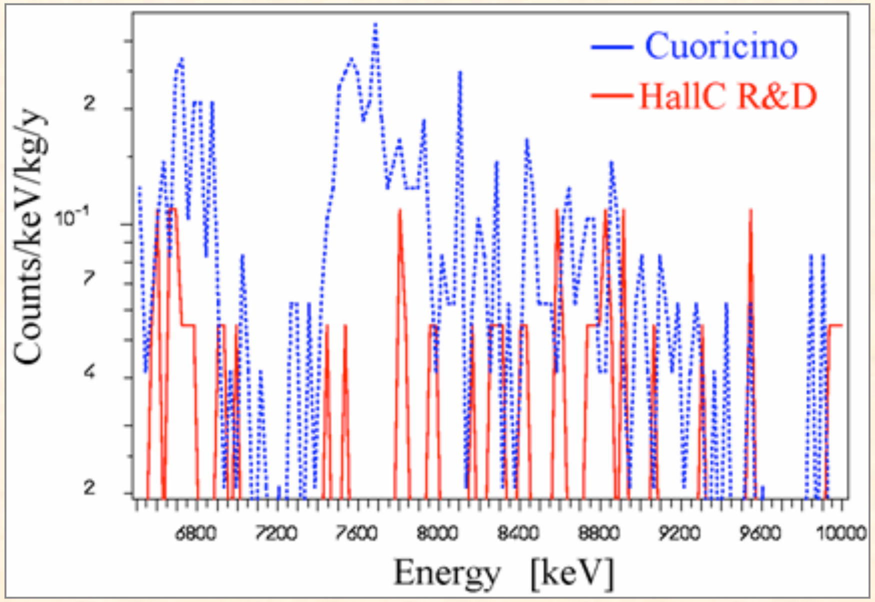




RAD tests results







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

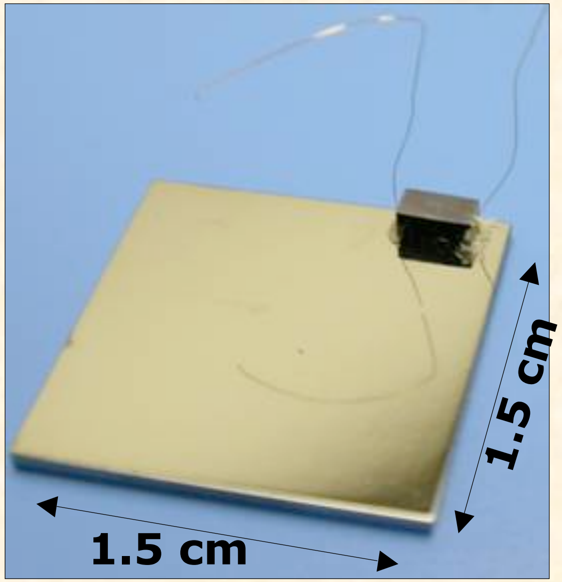
» new tests are on going in GranSasso

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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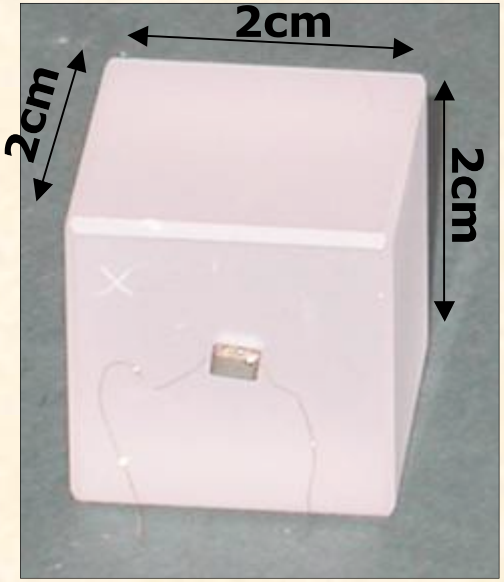
TeO_2 bolometer



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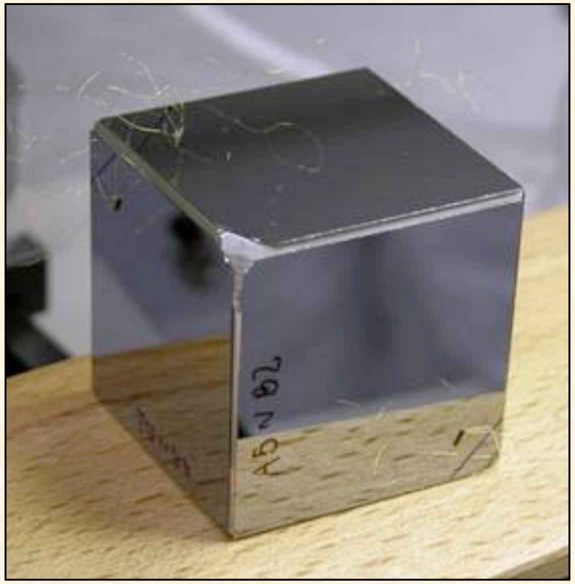
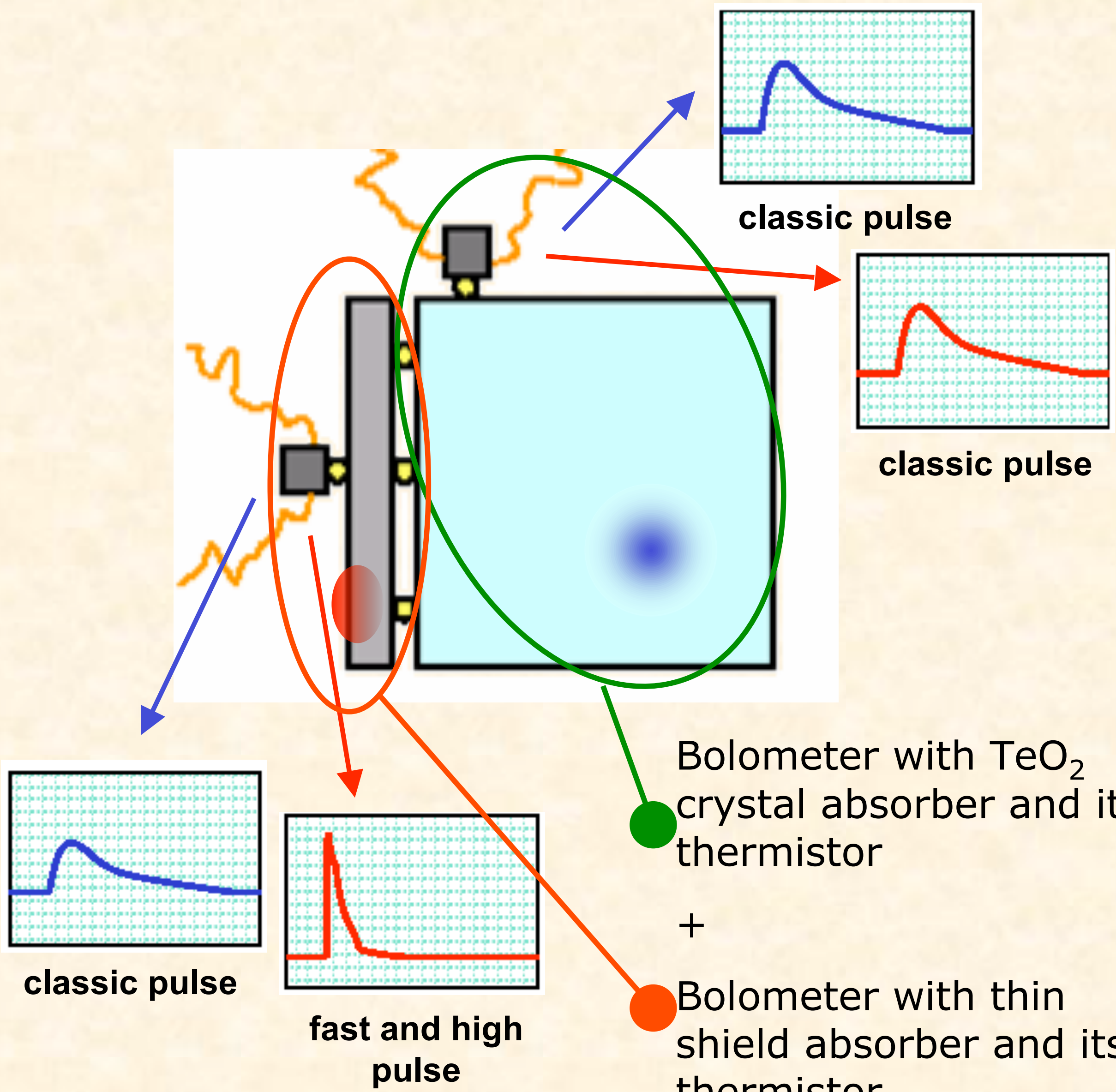
Composite bolometer



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.

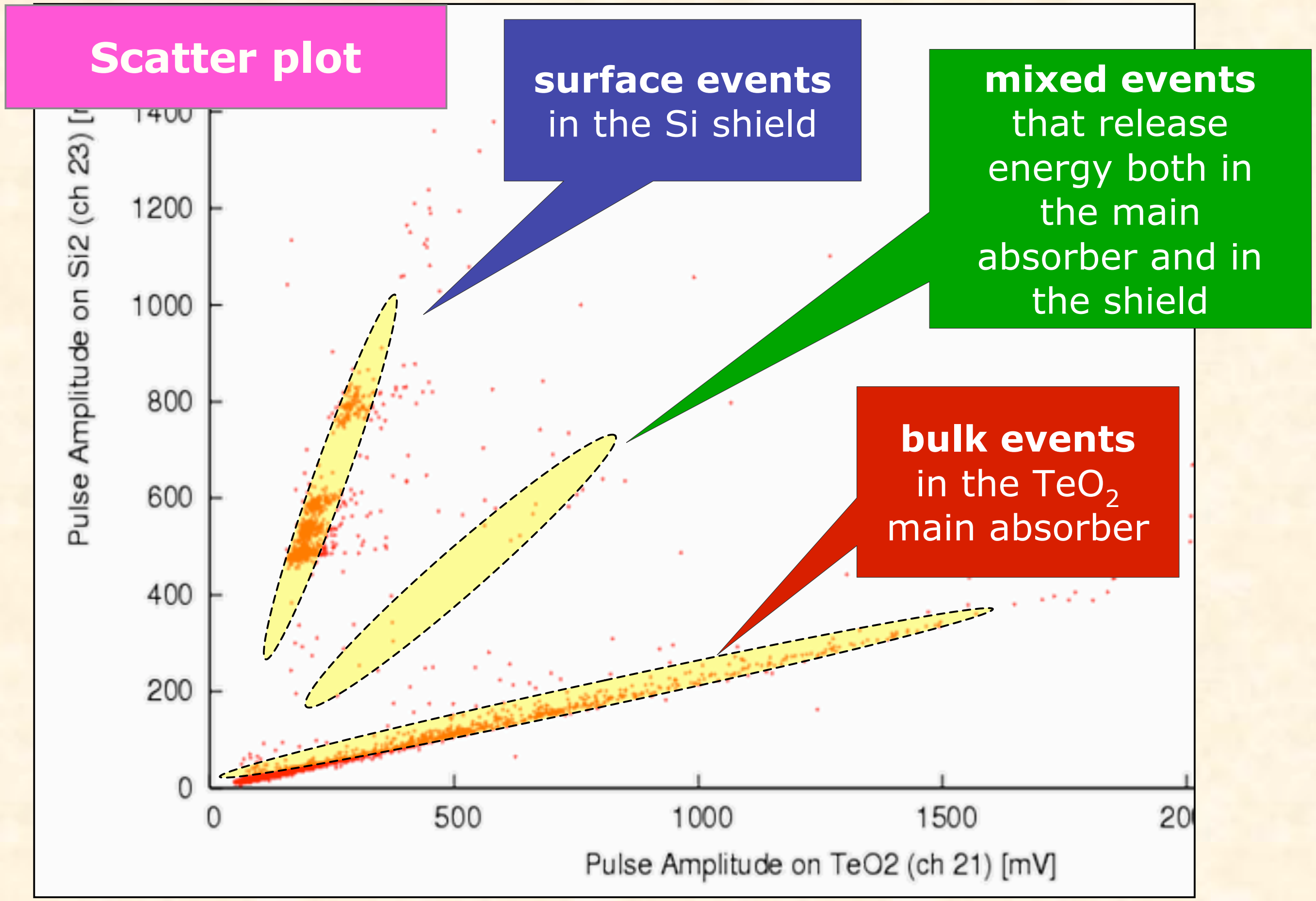
Different impact points means different pulses on thermistors

SSBs results

Identification of surface events:

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

- pulse amplitude discrimination (scatter plot)



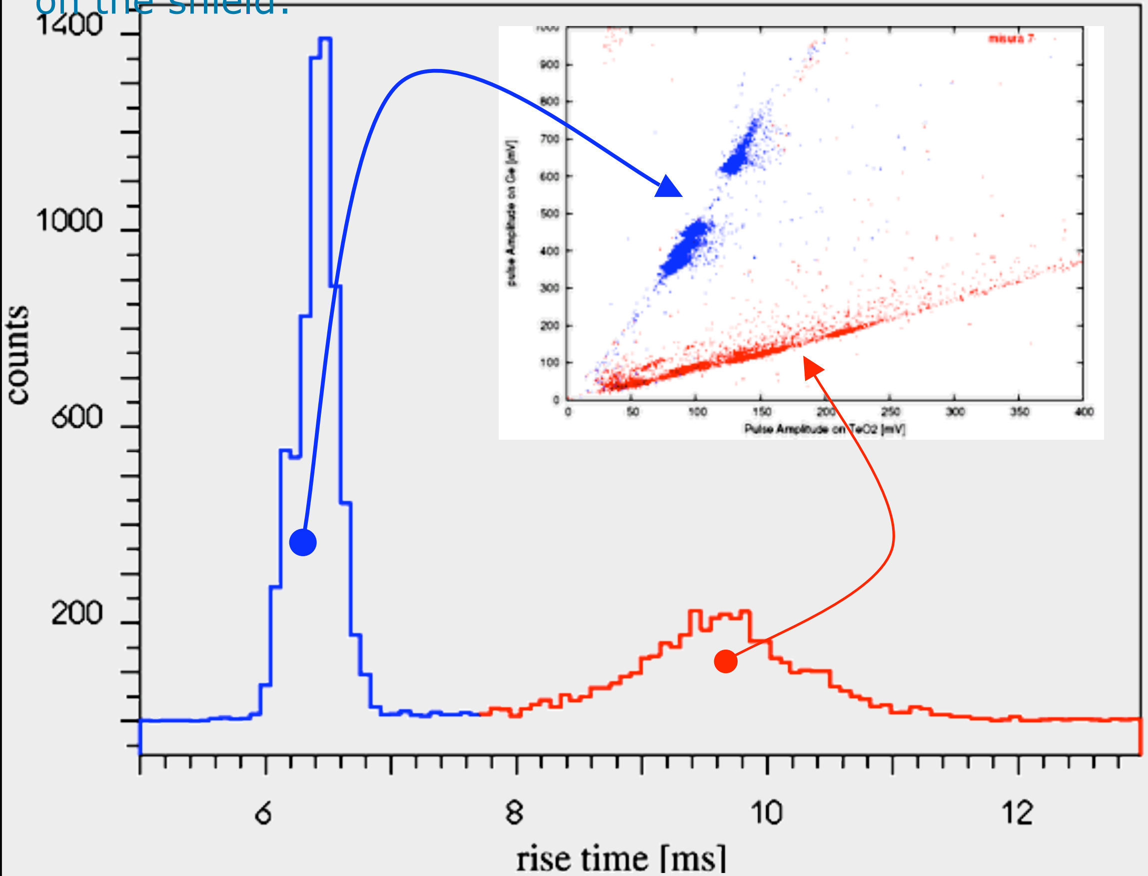
SSBs results

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

Identification of surface events:

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

Rise time distribution of the pulses read by the thermistor on the shield:



SSBs results

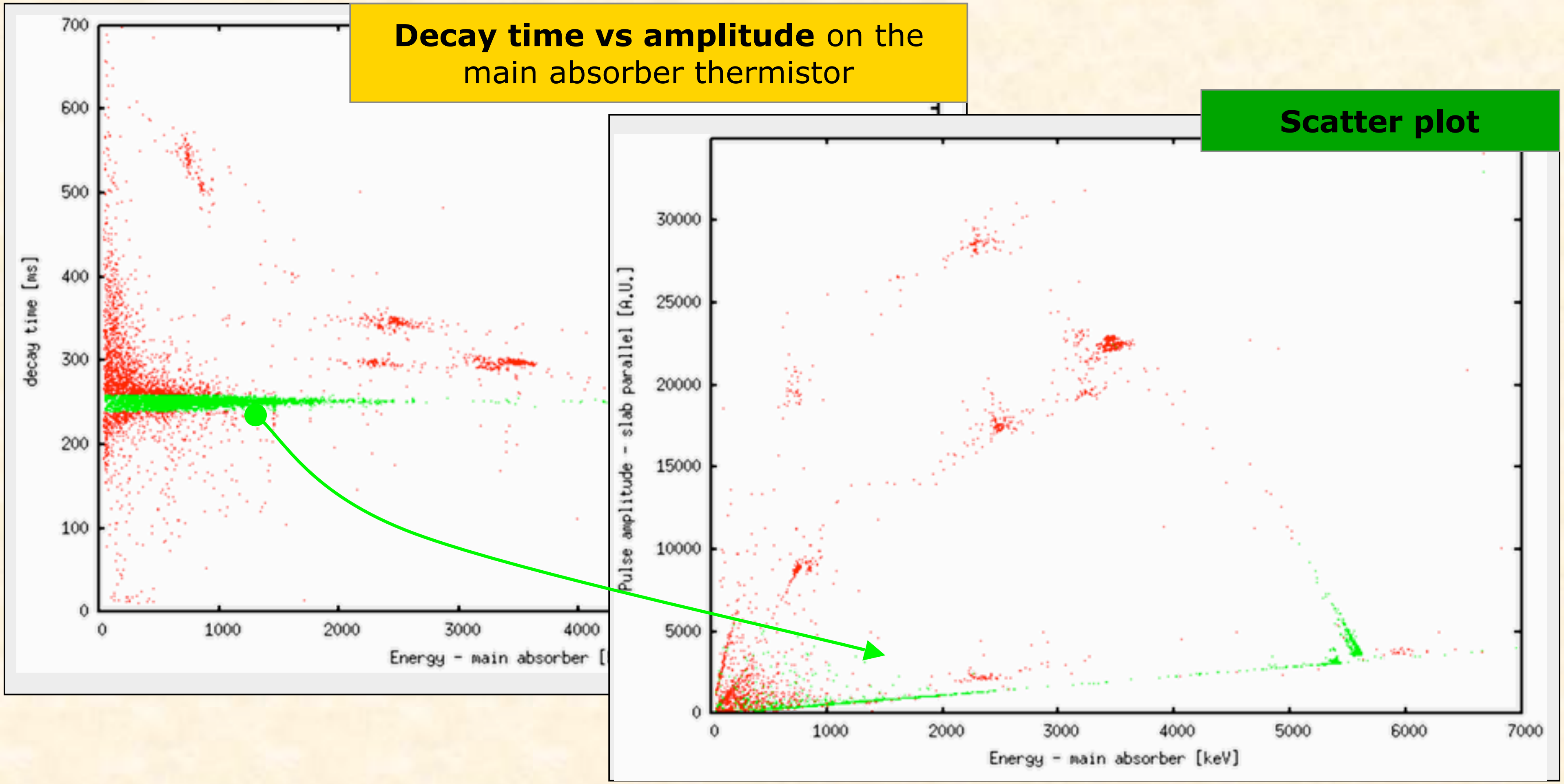
Appl. Phys. Lett. **86**, 134106 (2005)

Identification of surface events:

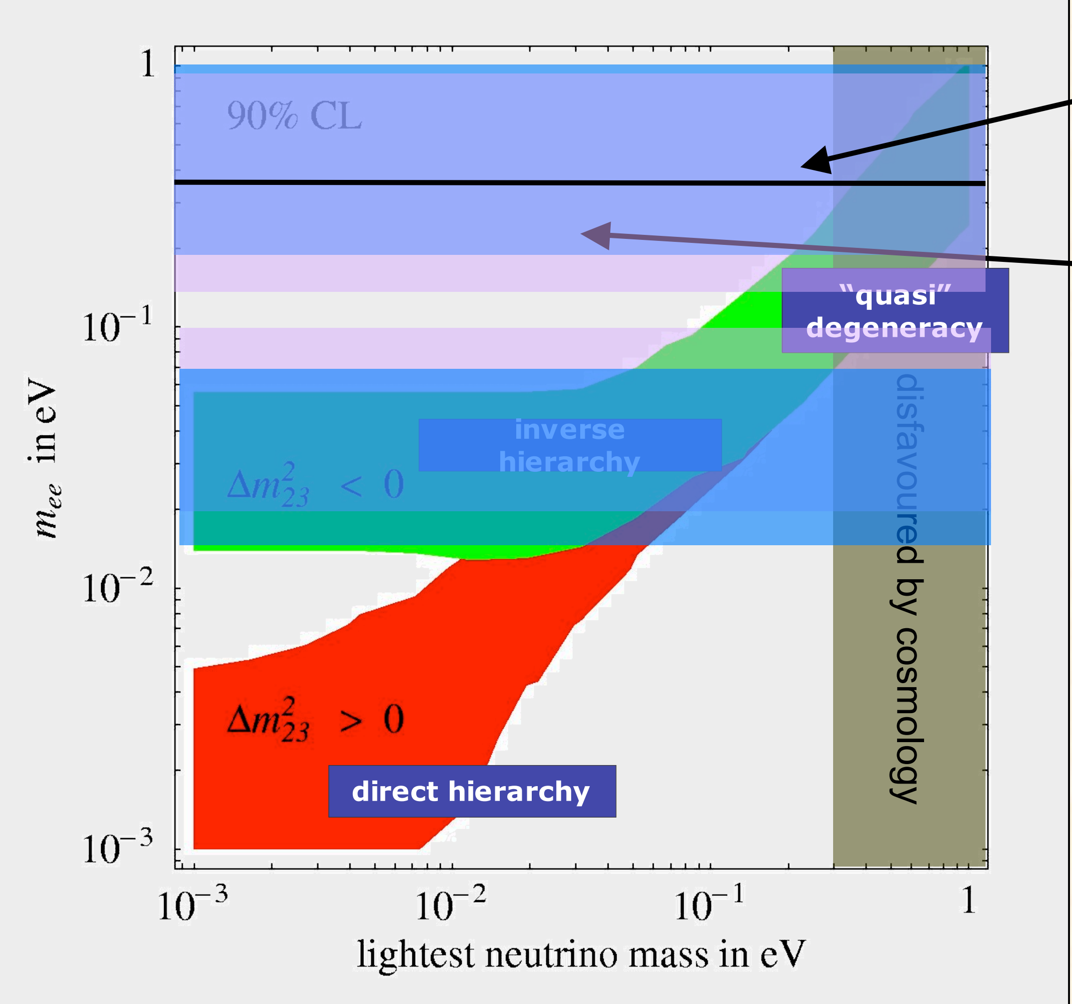
- pulse amplitude discrimination (scatter plot)
- rise time of the pulses of thermistor on the shield
- decay time of the pulses of thermistor on the shield

Decay time vs amplitude on the main absorber thermistor

Scatter plot



CUORE expected sensitivity



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

KK-HM possible evidence
hep-ph/0201231

Present CUORICINO limit
*Arnaboldi et al, **Phys.Rev.Lett.**, hep-ex/0501034 (2005)*

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 (togheter 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 BKG, in order to permit to CUORE experiment to investigate the inverse hierarchy region of the neutrino mass pattern
- The costruction of CUORE, a second generation detector, is started and we will start taking data in 5 years from now.

CUORE Collaboration

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14 institutions – 4 countries - ~ 60 physicists