The CUORE Detector: New Strategies

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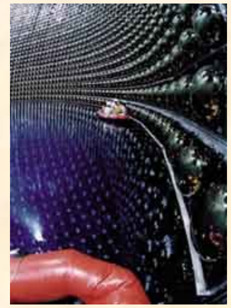
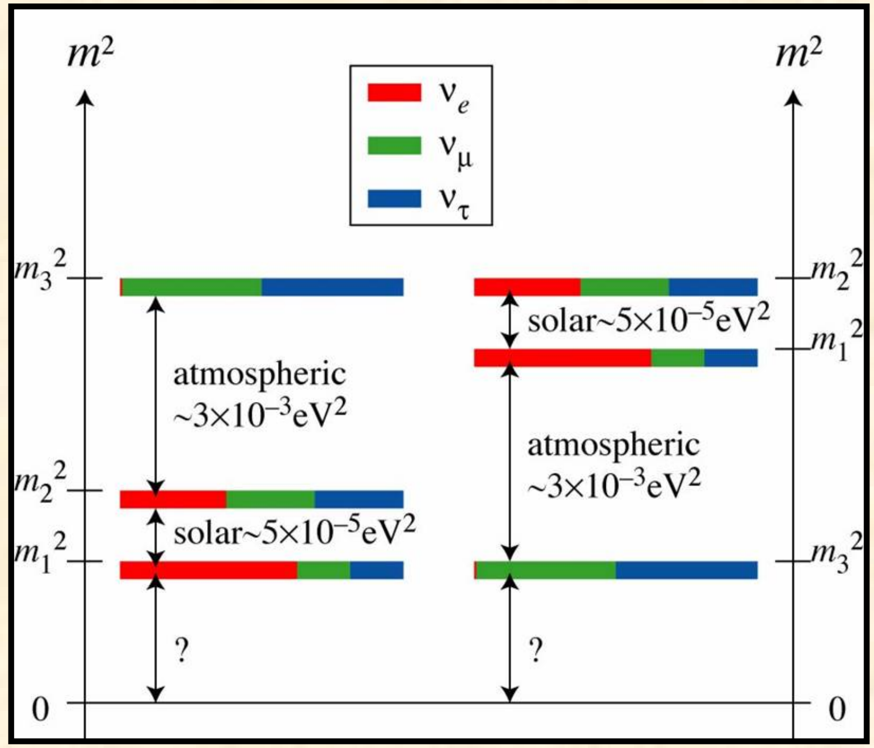
The context: Recent developments in ν Physics

Oscillation experiments:

SK, **SNO** and **KamLAND** have clearly demonstrated that:

- neutrinos (ν_e, ν_μ, ν_τ) do oscillate
- neutrinos (ν_1, ν_2, ν_3) are massive





Questions still open:

- neutrinos are Dirac or Majorana particles?
- what is the absolute mass scale?
- what is the mass hierarchy?

ββ0ν can answer to all this

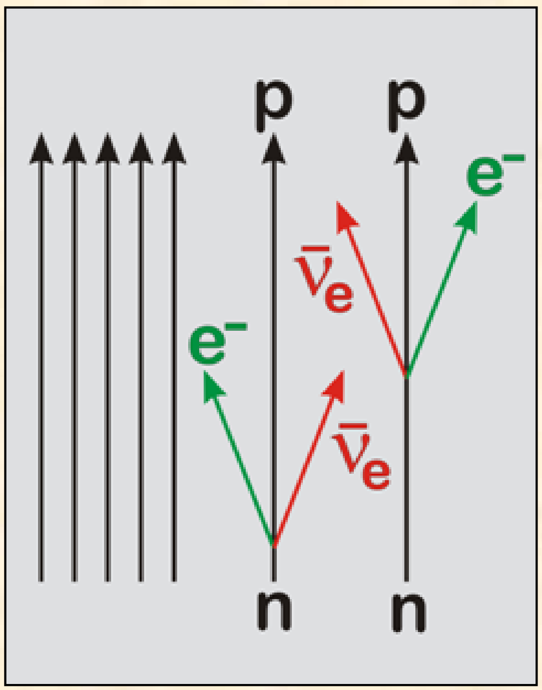
At least 1 ν has a mass > 55 meV

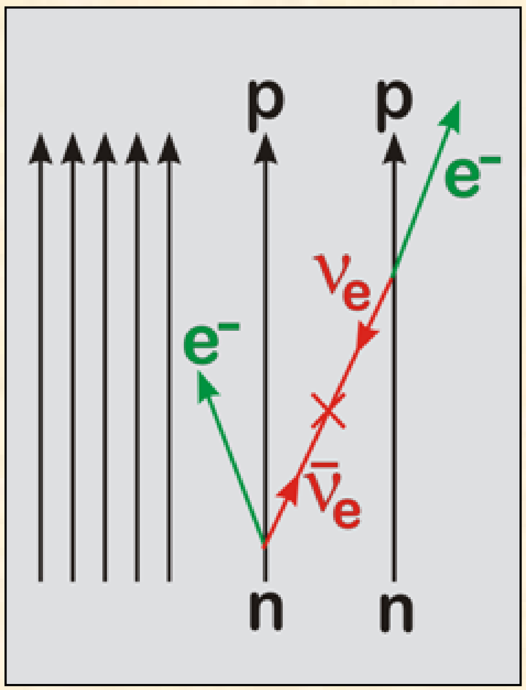
0ν Double Beta Decay

The **DBD** 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:

ββ**2**ν allowed by Standard Model	ββ**0**ν possible only with massive M. ν





Hyp: mass mechanism DOMINANT

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

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

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

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

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

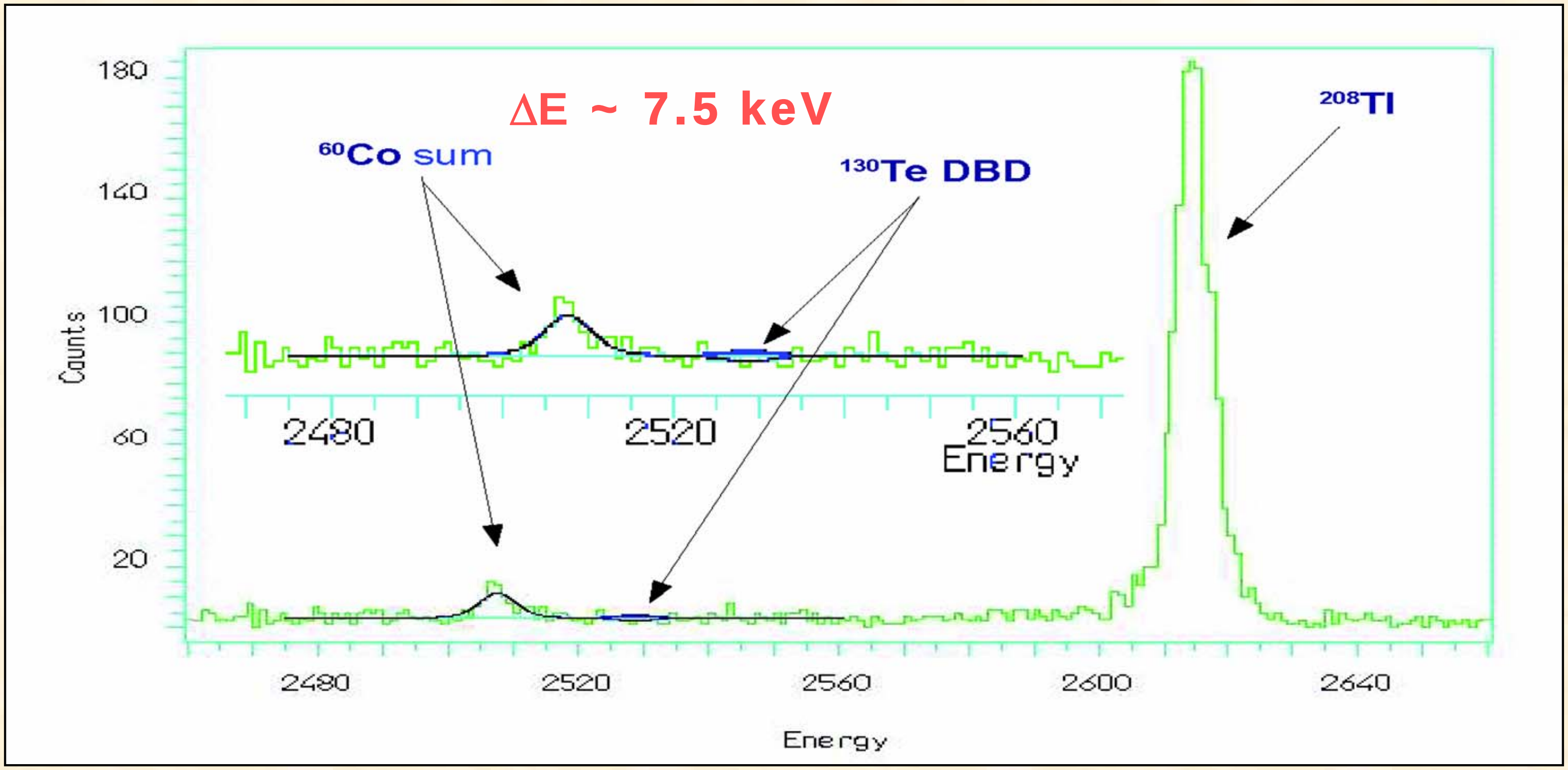
From where we start: CUORICINO

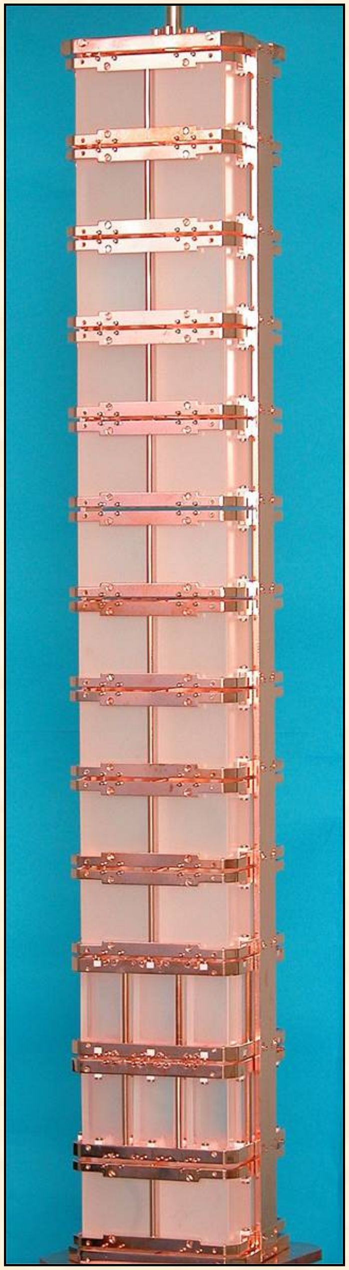
CUORICINO = tower of
- 11 modules, 4 detector (790 g) each
- 2 modules, 9 detector (330 g) each

Total Mass: 40.7 kg of TeO_2
(5×10^{25} Te-130 nuclei)

Background in $\beta\beta$ region
0.18 ± 0.02 c/keV·kg·y

Statistics: MT = 7.09 kg y ^{130}Te
$T_{1/2}(0\nu) > 2.2 \times 10^{24}$ y
$m_{\beta\beta} < 0.2 - 1.0$ eV

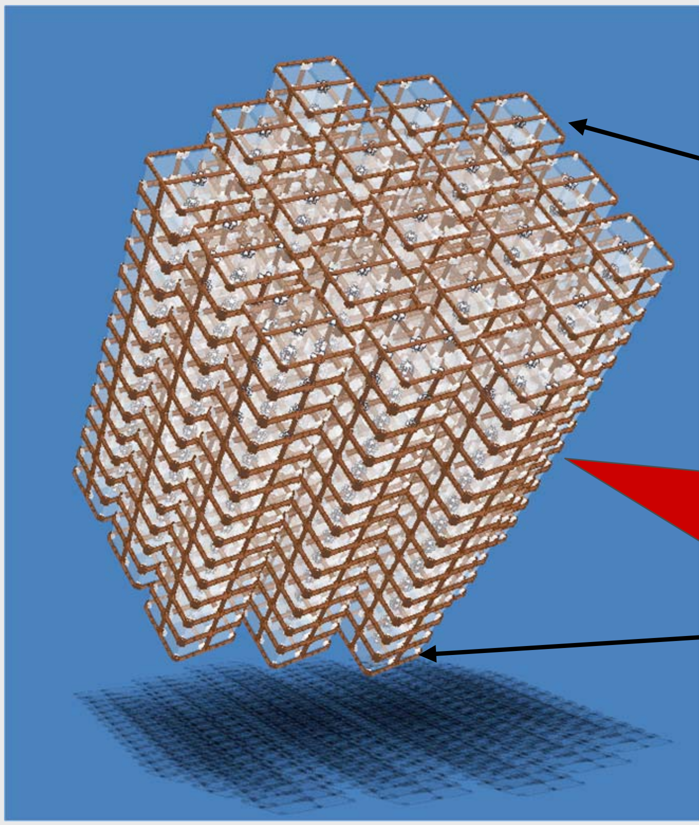




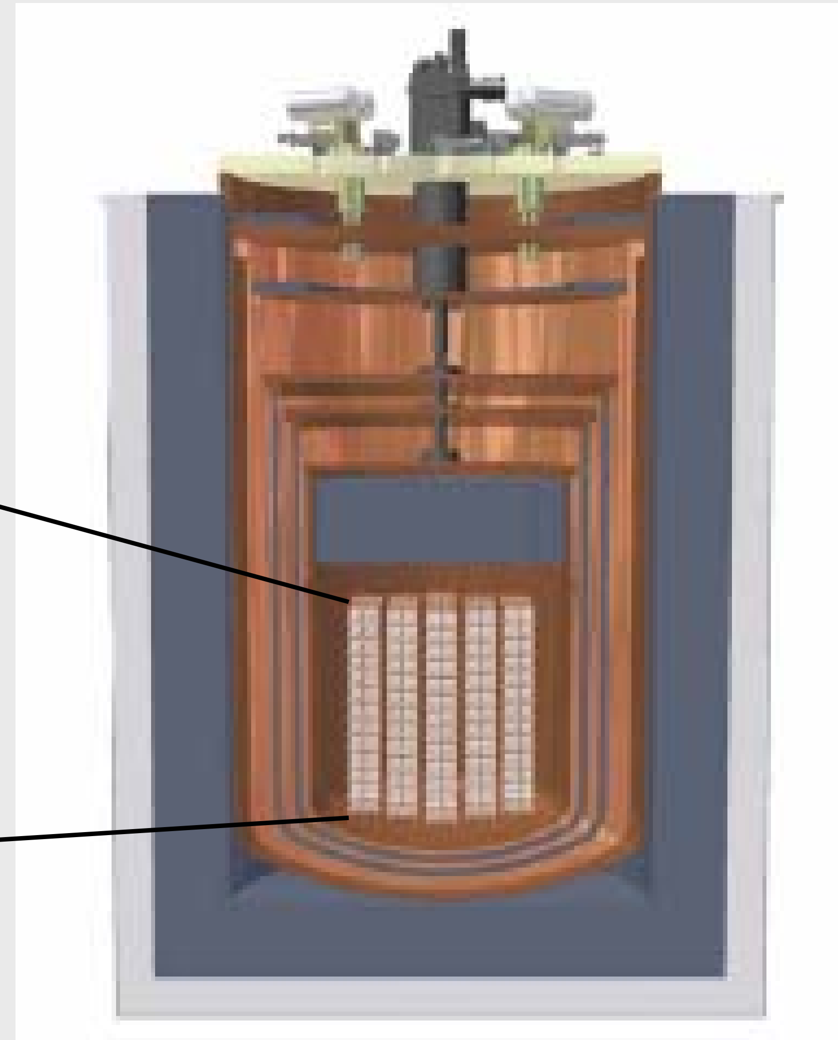
The evolution: CUORE

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



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



Next-generation experiment – Already approved and funded

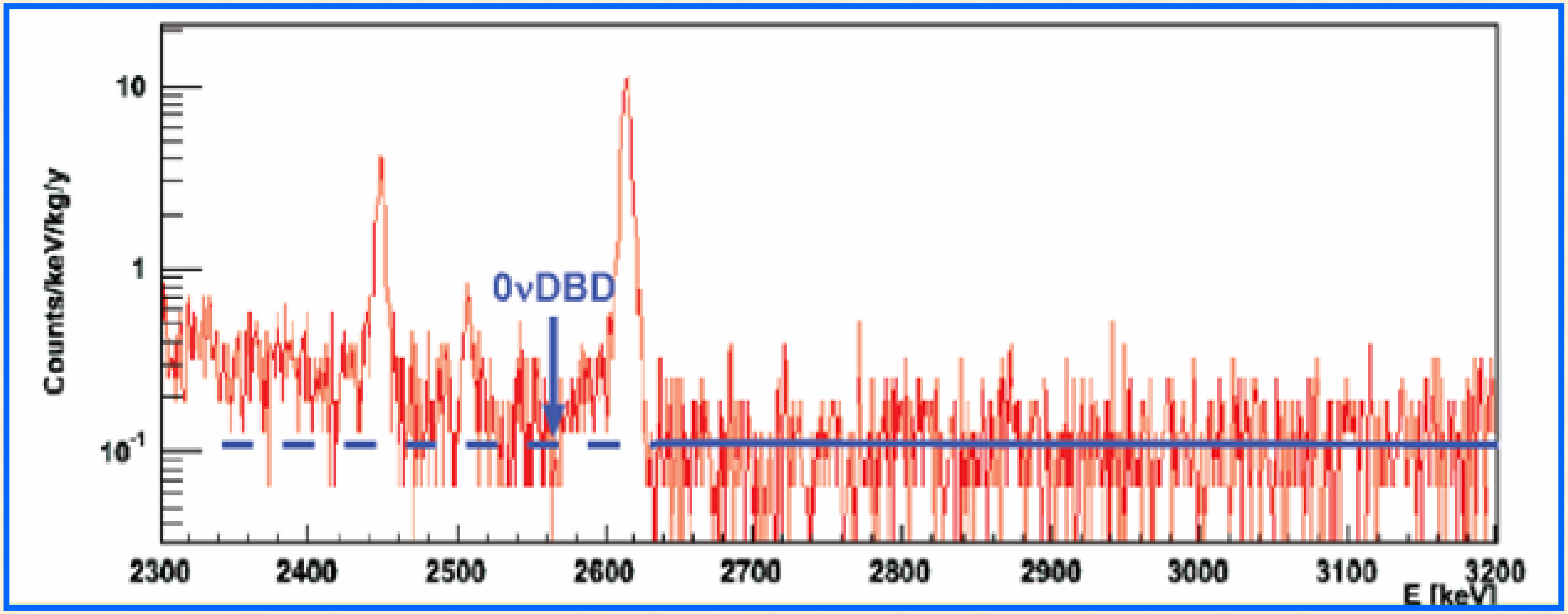
The background reduction

From CUORICINO and CUORE R&D we know that:

- **bulk bkg** of the detector is not crucial (<2 c/keV/ton/y)
- Crystals **surface bkg** can be reduced
- γ **bkg** can be eliminated and/or shielded
- **cosmogenic activity** can be controlled
- **neutrons** can be shielded/identified

MonteCarlo simulations show that the most dangerous component of the bkg is probably due to **energy degraded alfa and beta emitted from the surfaces facing the detector**

$\Rightarrow$ **we need to** reduce this kind of bkg of a factor 10-100



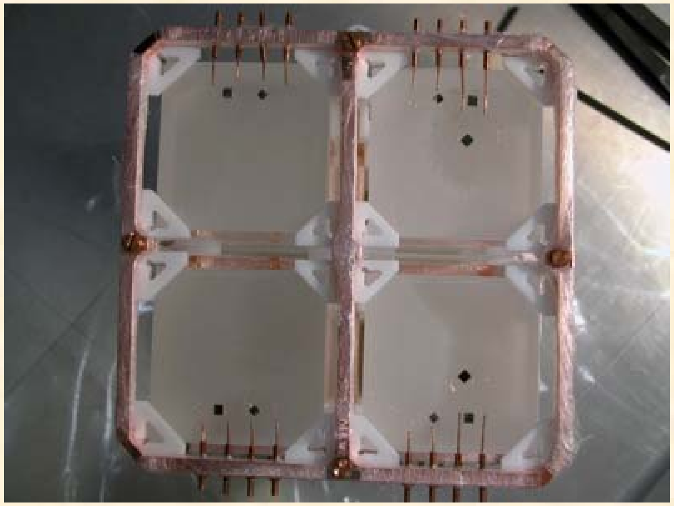
Surface contamination challenge

Possible solutions

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

» Reduce material contamination increasing quality of surface treatment

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



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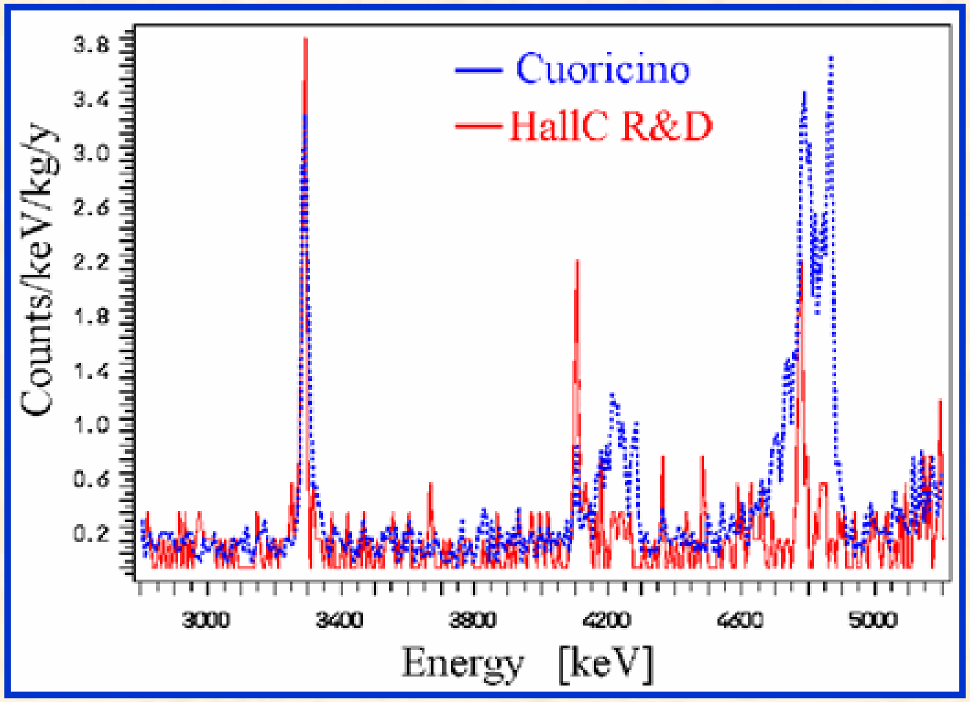
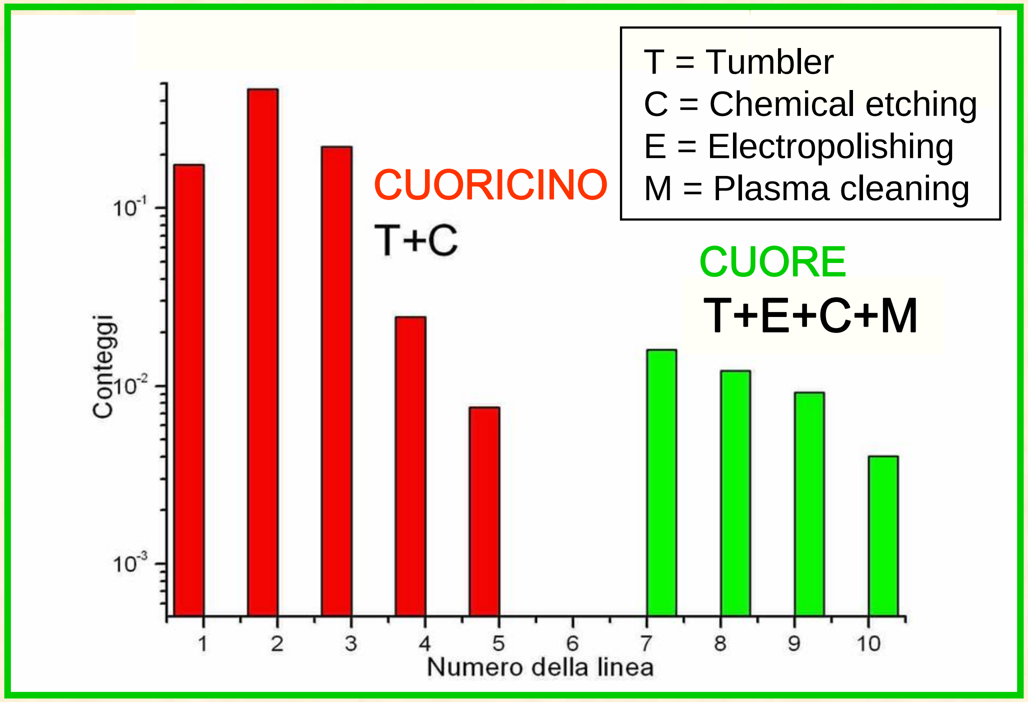


The Idea:

use the surface treatments know-how for Superconducting accelerating cavities



~ 4 on TeO_2 surface contaminations

~ 2 on Cu surface contaminations

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SURFACE SENSITIVE BOLOMETERS

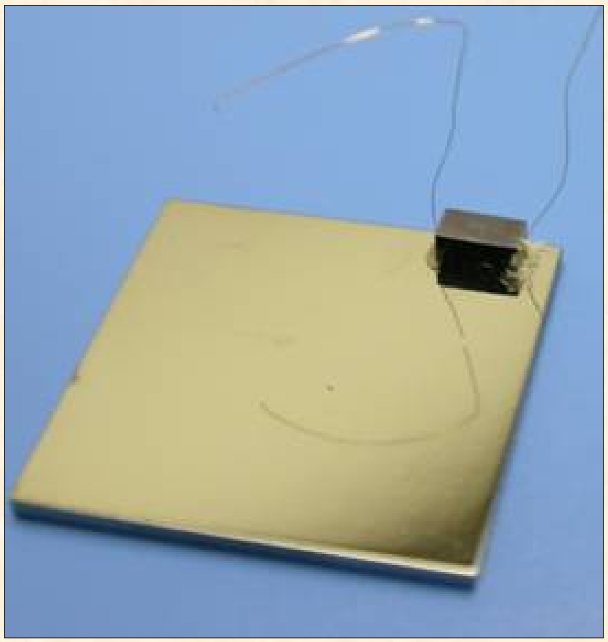
SCINTILLATING BOLOMETERS

Surface Sensitive Bolometers (SSB)

An active shielding of the main bolom. by means of thin instrumented foils that provide full coverage.

New idea: the thin bolometers are glued on the main absorber, to form a single *composite bolometer*

Shield bolometer

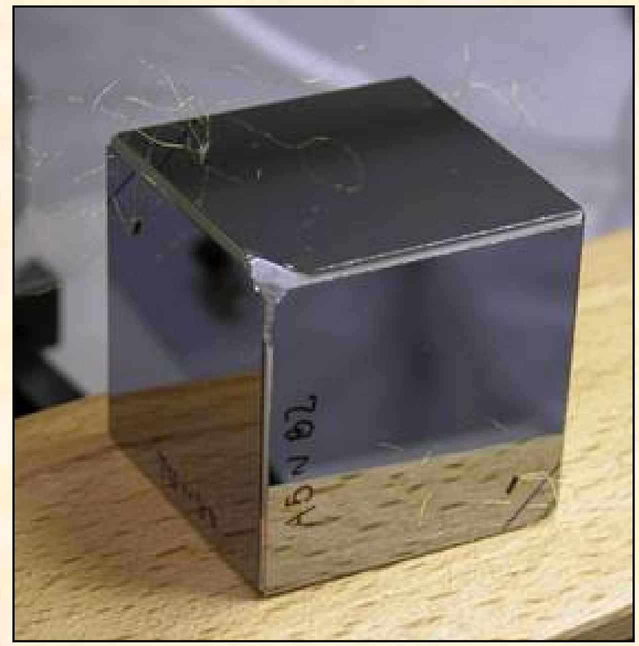


+

TeO_2 bolometer

=

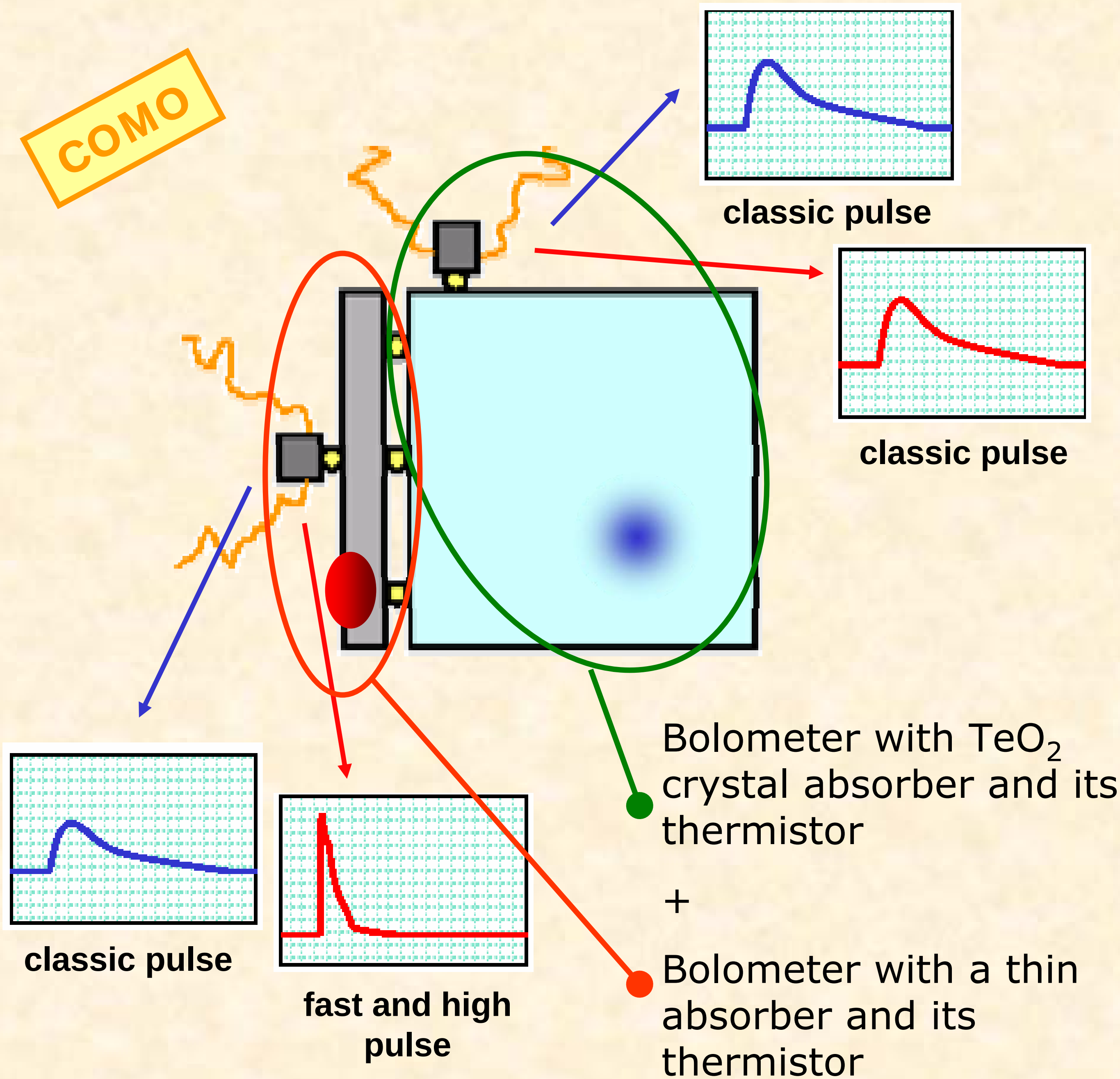
Composite bolometer



SO, HOW DOES IT WORK?

L.Foggetta et al., APL 86(2005)134106

Dynamic behavior of SSBs



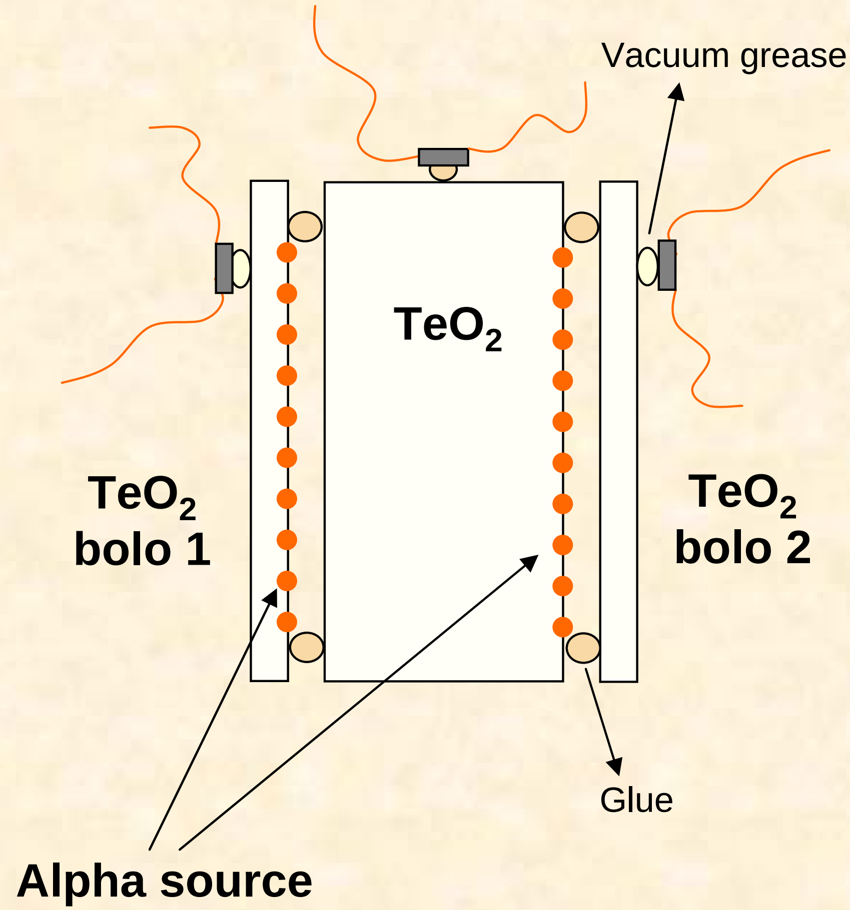
The presence of the auxiliary bolometers changes the thermal dynamic behavior of the detector giving rise to pulses with different amplitudes and shapes.

Different impact points means different pulses on thermistors

Recent LNGS tests – Run 2

Features:

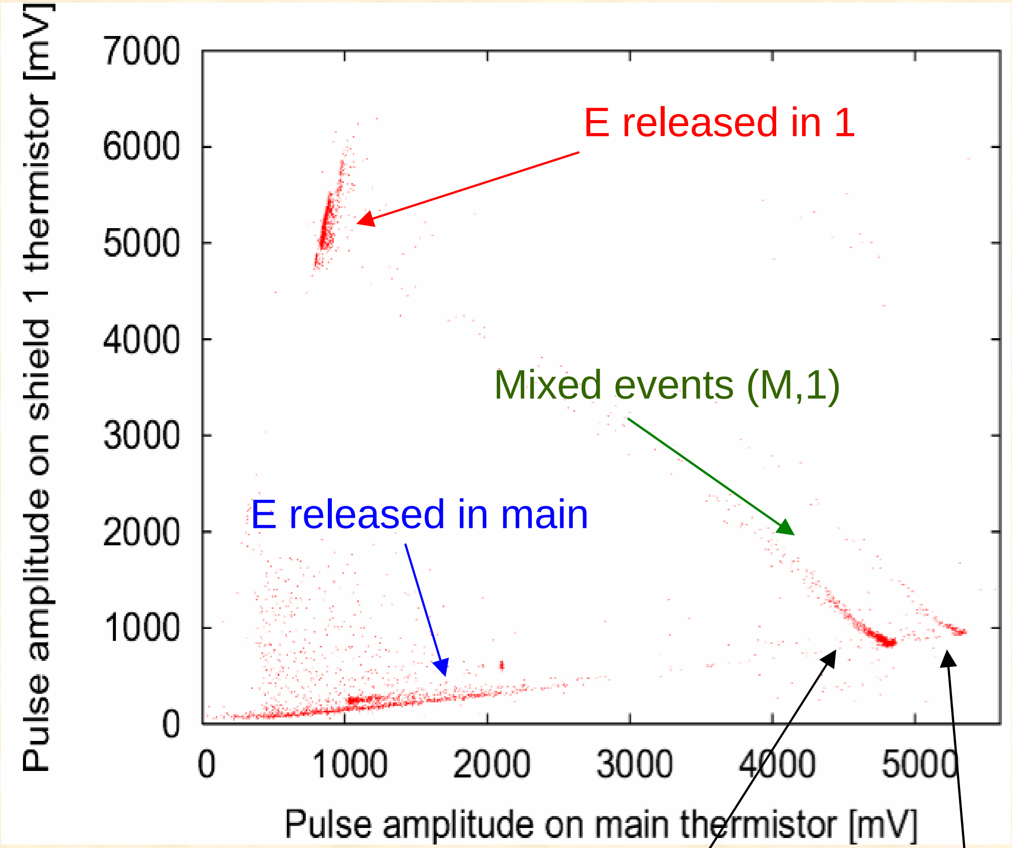
- 1 TeO_2 Main absorber (2 cm^3)
- 2 TeO_2 active shields (no full coverage)
- 3 Independent thermistors read-out
- Alpha source implanted in two different points of the detector

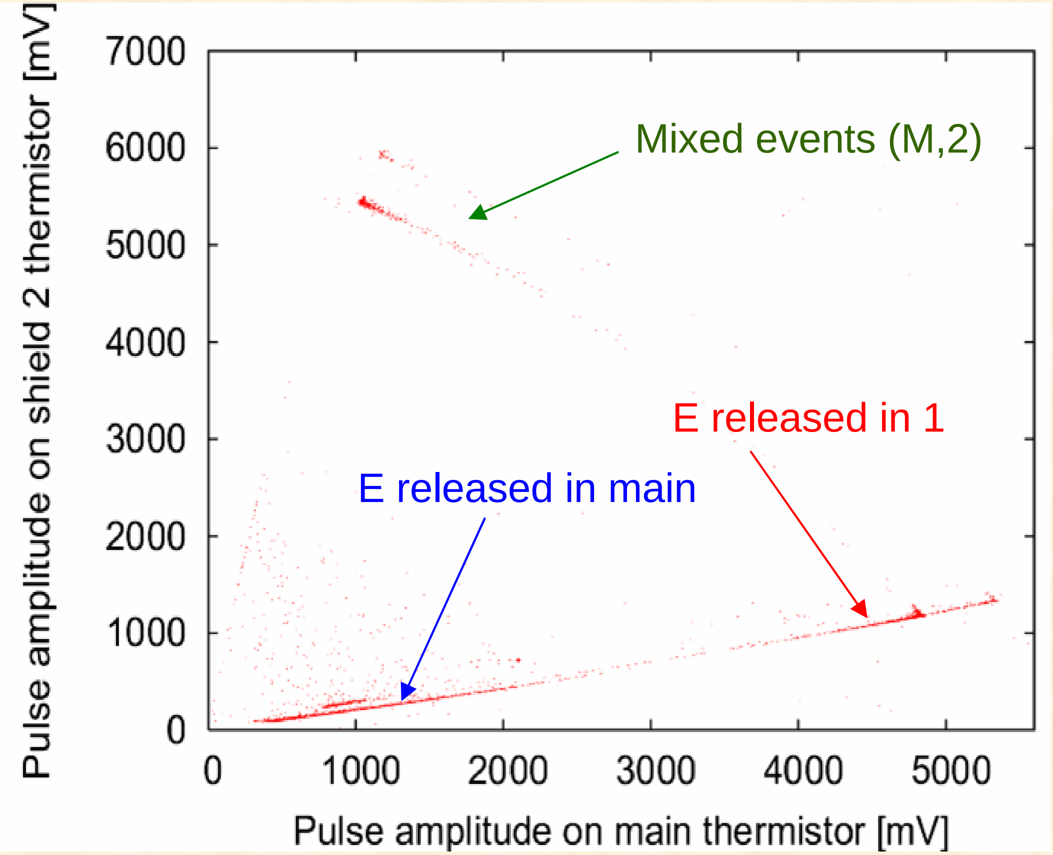


Run 2: scatter plots (1)

Bolo 1 (implanted)

Bolo 2 (facing the implanted side of the main crystal)



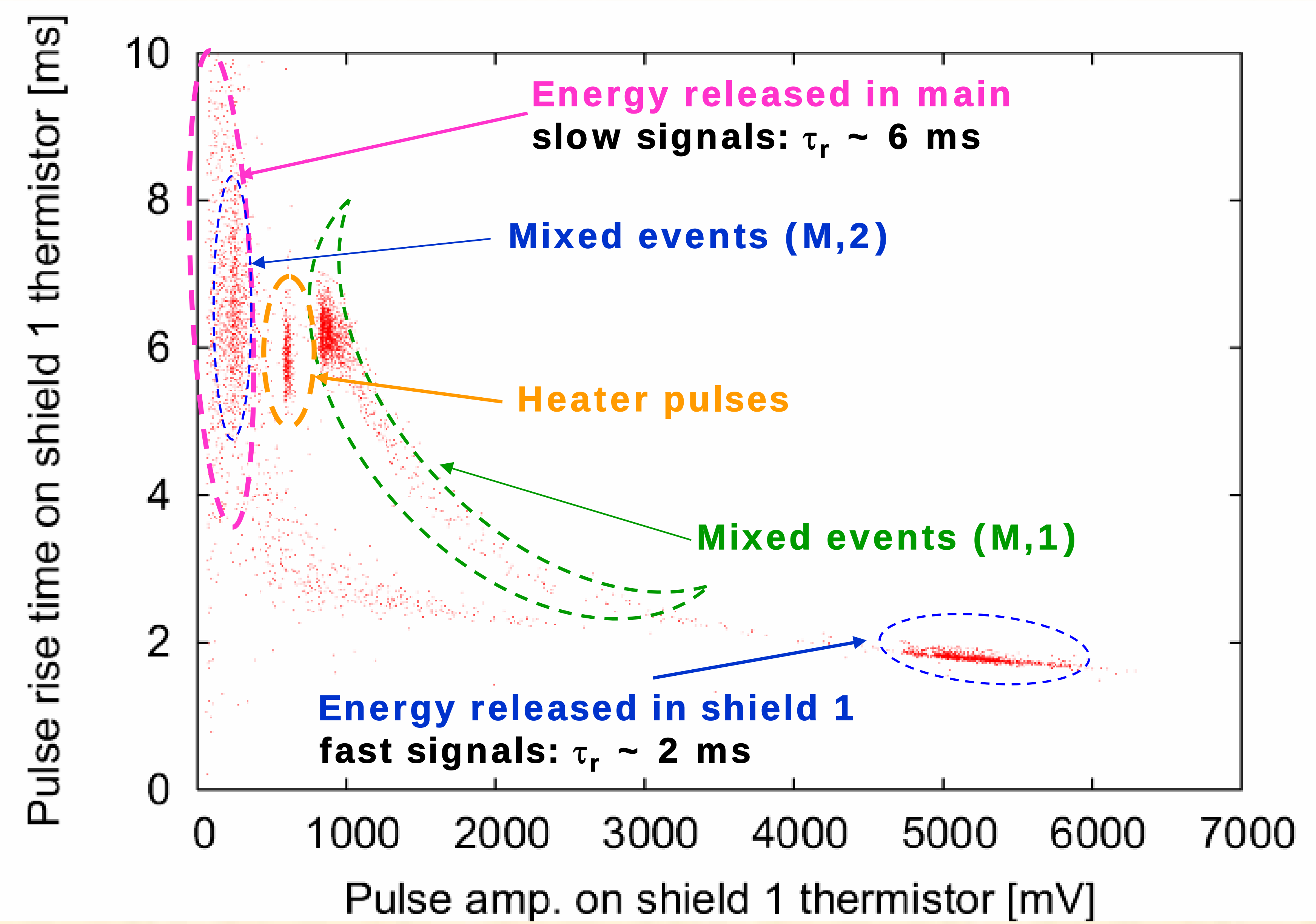


^{238}U α's (~4.2 MeV)

^{234}U α's (~4.7 MeV)

Run 2: rise time on shield thermistors

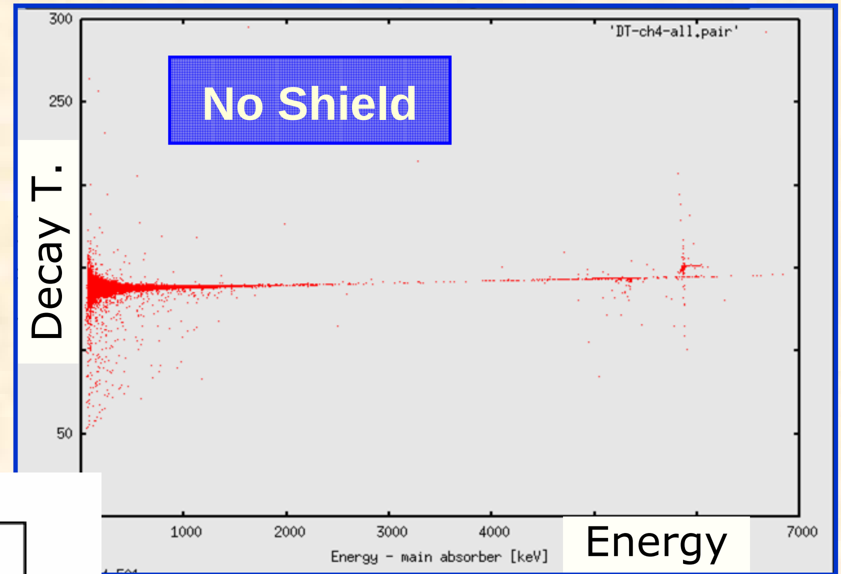
Shield 1 (implanted)

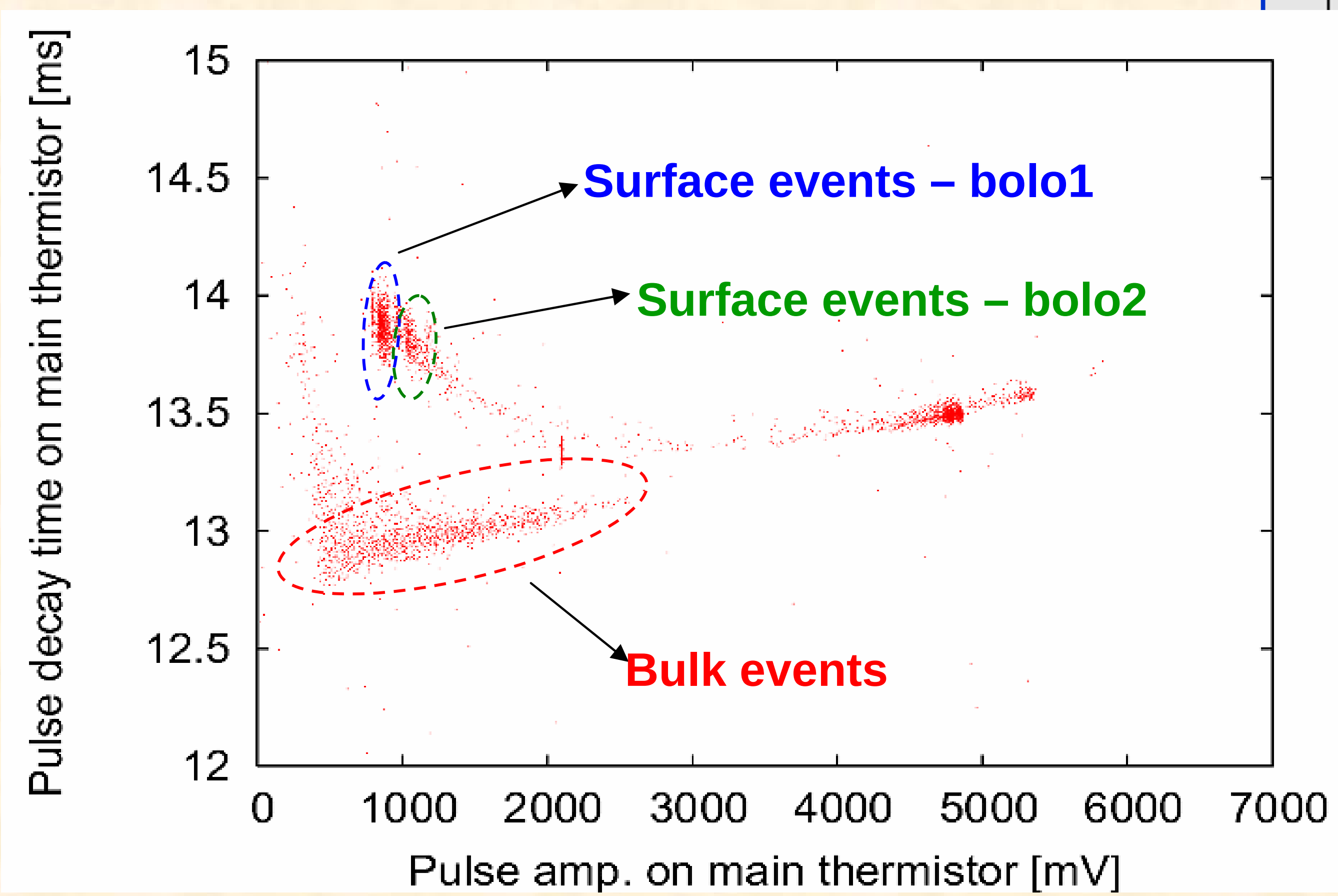


Run 2: decay time on main thermistor

AUX. B. OPERATE AS SIGNAL-SHAPE MODIFIERS

The decay time of the pulses read by the NTD on the main absorber allows the discrimination between surface and bulk events





Background reduction

Total background

Active discrimination by the decay time

α-bkg suppression: Light Detection

Scintillation may help to discriminate the type of interacting quantum with an immediate effect on background reduction

However some remarks are necessary:

1. "Large" scintillation yield from the main crystal — ROME

2. Feasible light detector setup

LNGS
- **Easily expandable to ~1000-channel scale**
- **Work at very low temperatures**
- **Low radioactive contaminations**

Scintillation of doped TeO_2

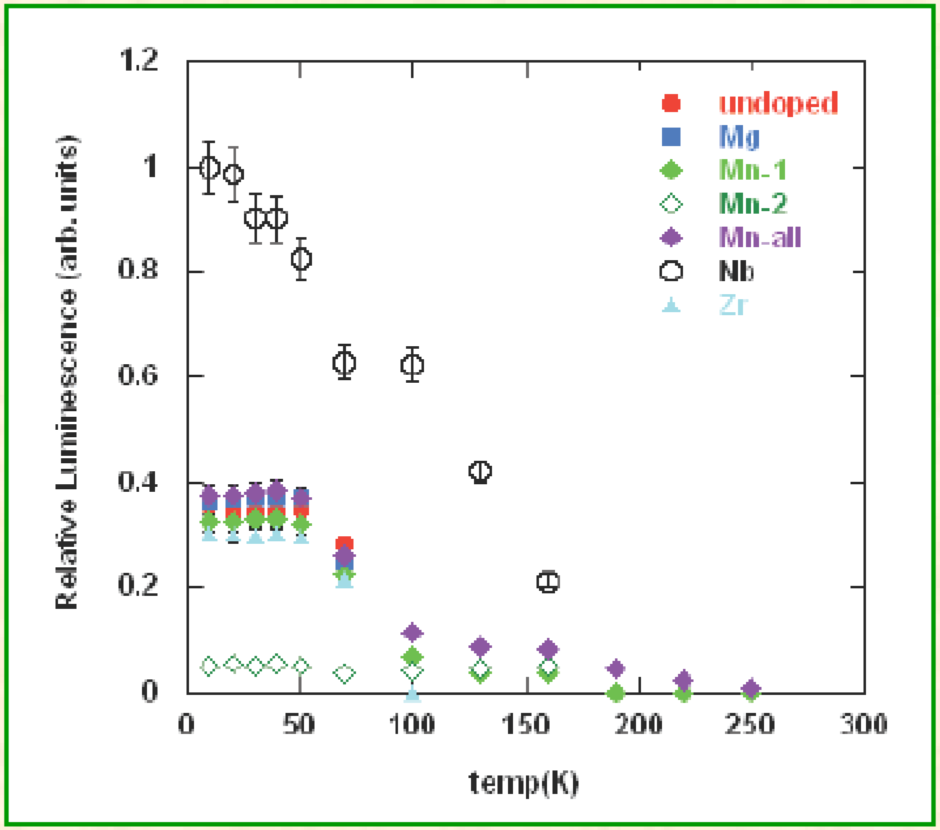
A first attempt to grow doped TeO_2 crystals to increase their scintillation was performed.

I. Dafinei et al., NIMA 554 (2005) 195

SAMPLES

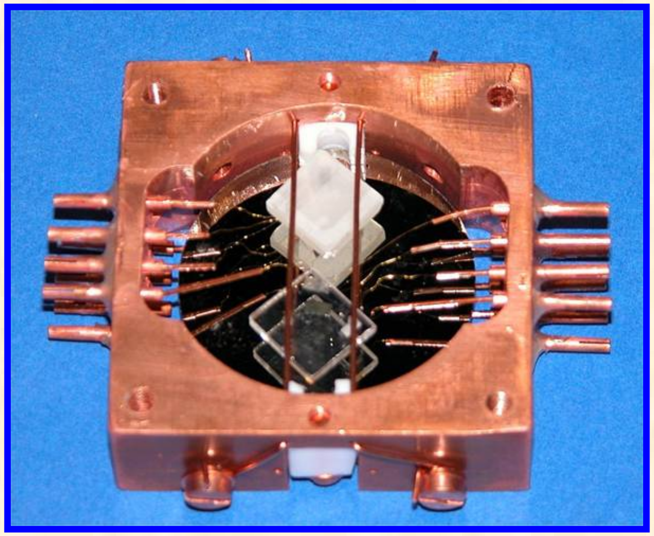
1. TeO_2 undoped
2. TeO_2+MgO (10^{-4} mol/mol)*
3. $TeO_2+Nb_2O_5$ (10^{-4} mol/mol)*
4. TeO_2+ZrO_2 (10^{-4} mol/mol)*
5. TeO_2+MnO_2 (10^{-4} mol/mol)*

* in the melt



The scint-bolo studies: $CdWO_4$

MEANWHILE.... S.Pirro et al., arxiv:nucl-ex/0510074

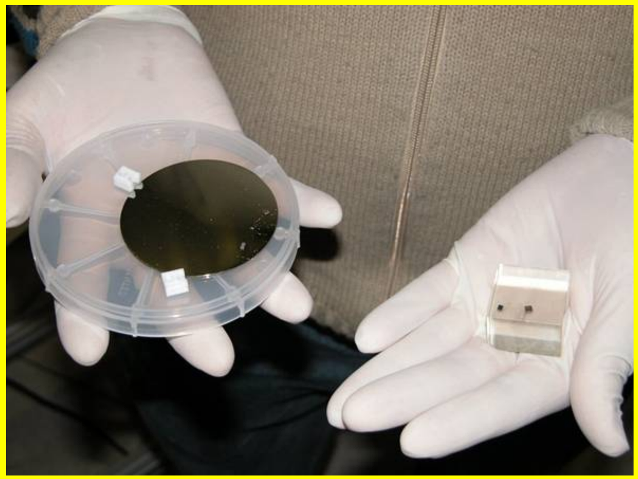


Optimization of a BOLOMETER light detector

Study of several scintillators as bolometers

$PbWO_4$, $PbMoO_4$, $CaMoO_4$, CaF_2, $SrMoO_4$, $MgMoO_4$, ZnSe, **$CdWO_4$**

6.3 cm dia 1 mm thick Ge

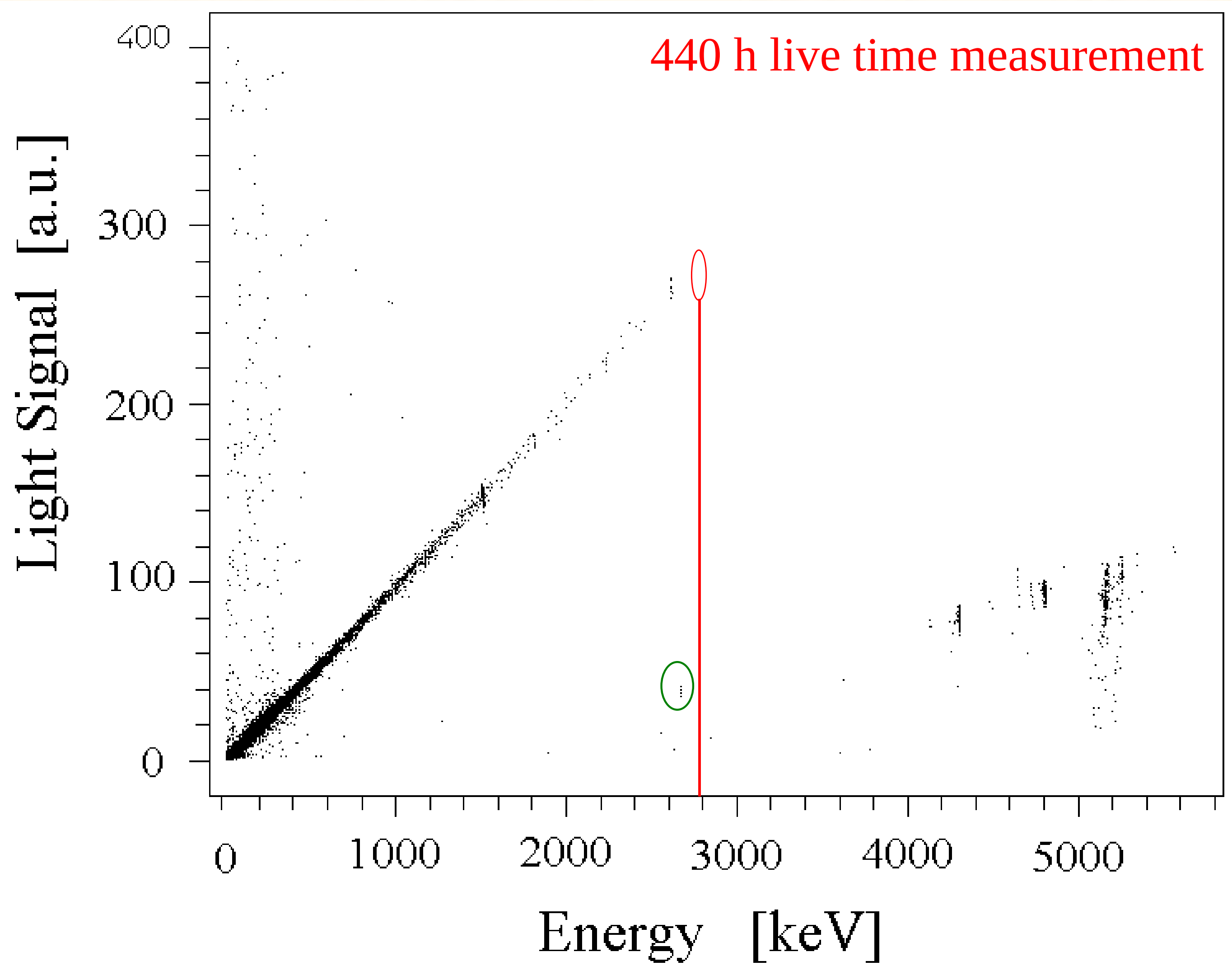


$3x3x2\ cm^3$ $CdWO_4$ (140g)

Heat: 0.3 % ΔE @ 2.6 MeV

Light: 3 % ΔE @ 2.6 MeV

Bkg measurement: scatter plot



Clear identification of alphas and gammas

No gammas above 2615 keV (Tl-208)

⇨ No counts at $Q_{\beta\beta}$

$Q_{\beta\beta}(^{116}Cd)$=2802 keV

Above 2.6 MeV clear α-peak of W-180, well out of γ-region

Conclusions

- CUORE will be a competitive II-generation DBD detector

- An intense R&D work is still going on to reduce the BKG, in order to permit the investigation of the inverse hierarchy region of the neutrino mass pattern

- New and already used bolometer techniques are under study, with very promising results that could open new strategies also in other fields

- CUORE will start data taking in 2010

CUORE Collaboration

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14 institutions – 4 countries - ~ 60 physicists