CUORICINO results & perspectives for CUORE

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on behalf of the CUORE Collaboration

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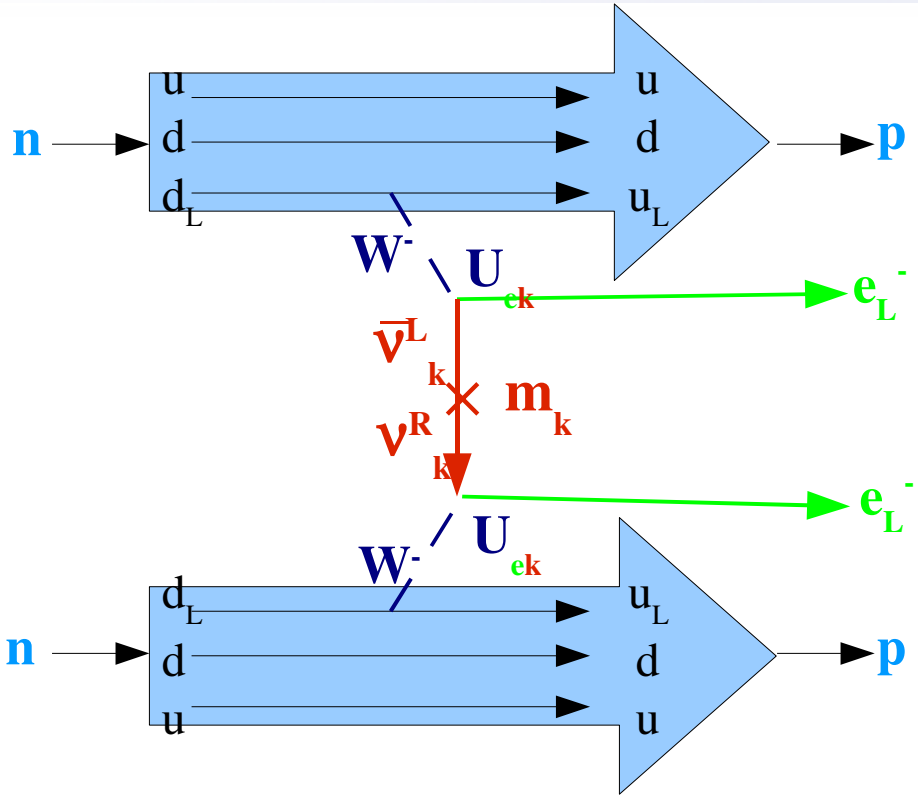
Neutrino-less Double Beta Decay



- **Neutrino nature**

$$chirality\ flip: m_\nu \neq 0$$

$$\nu_{majorana}: \nu \equiv \bar{\nu}$$

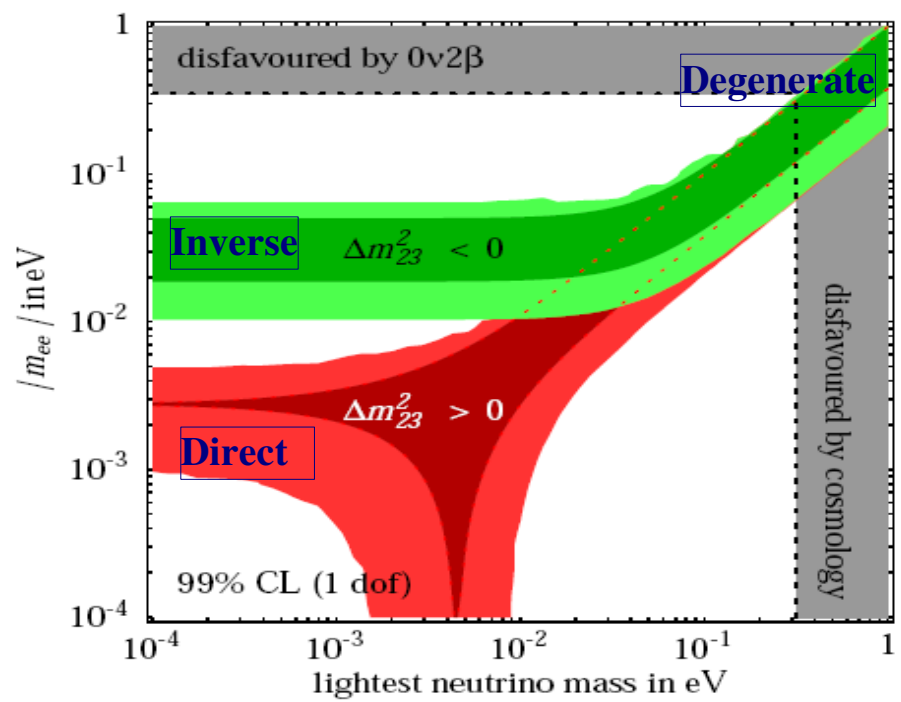
$$(Lepton\ number\ violation)$$

- **Absolute mass scale and hierarchy**

$$(\tau^{0\nu\beta\beta}_{1/2})^{-1} = G(Q,Z)|M_{nucl}|^2 |m_{\beta\beta}|^2$$

$$m_{\beta\beta} = \sum m_{\nu_k} U^2_{ek}$$

Effective neutrino mass



Strumia, Vissani Nucl.Phys.B726:294,2005

Cuoricino: the bolometric way

- Bolometric technique: energy measured as a temperature increase in the detector
- Homogeneous detector: $\beta\beta0\nu$ source ≡ absorber

- (Very) Low temperature calorimeter:
  - basic physics $\Delta T = E/C$

    ⇒ low C

    diamagnetic dielectrics @ low T (~ 10mK) :

    $C \sim T^3 \sim 10^{10}$ eV/K

- Thermometer: NTD Ge thermistor

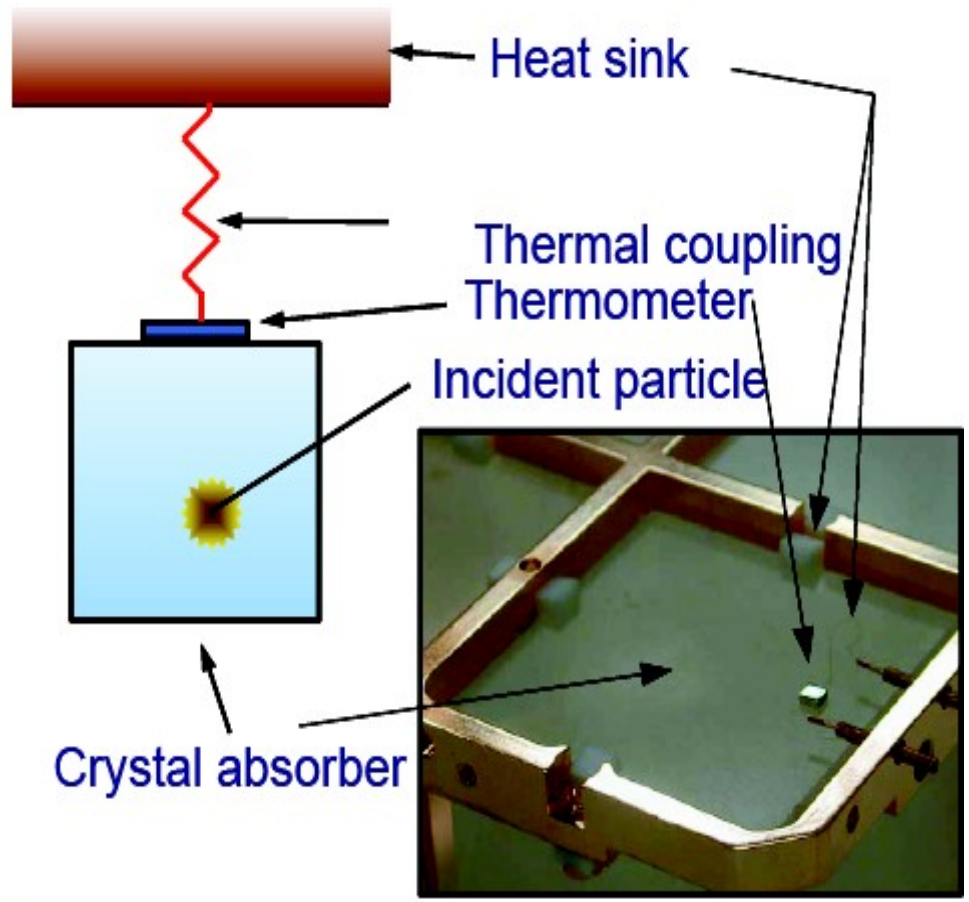
  $R \sim R^0 \exp(T^0/T)^{\sim 0.5}$

  $\Delta T \Rightarrow \Delta R$

  ⇒ 0.1 mK/MeV ⇒ 0.1mV/MeV

- Bonus: no intrinsic limit to $\sigma(E)$

  $\sigma(E) = (K_B C T^2)^{0.5} \sim 10$ eV



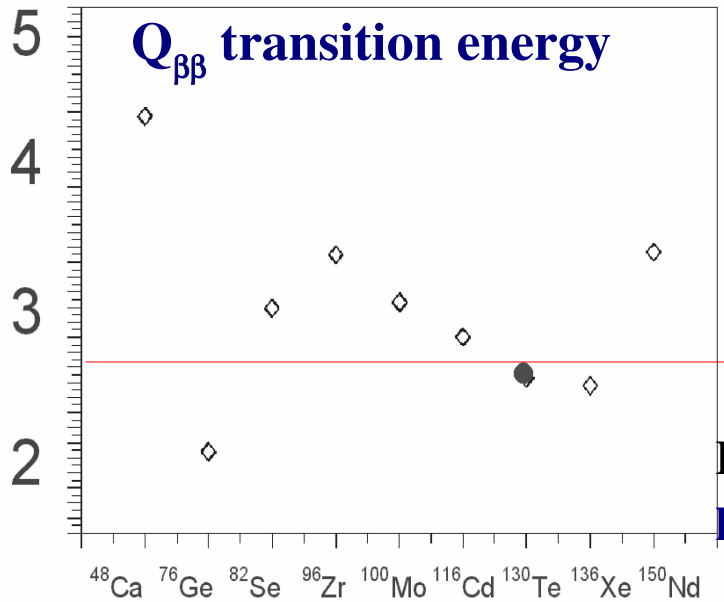
- (Not for all) Typical pulse decay time: $t \sim C/G \sim 10^{2\text{-}3}$ ms

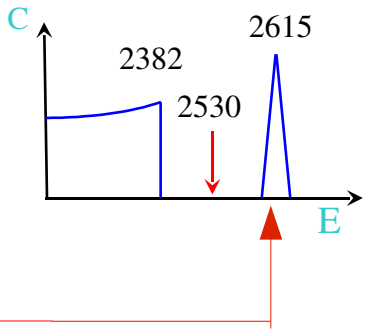
Why Tellurium?

- **Active isotope: ^{130}Te**
  - **Transition energy**

    $Q_{\beta\beta}$ = (2530.30±1.99) keV

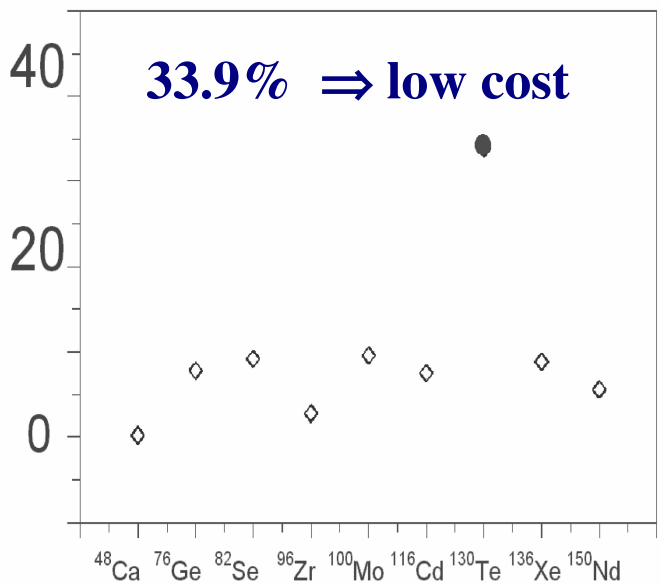
    Nuclear Physics A 729 (2003) 337

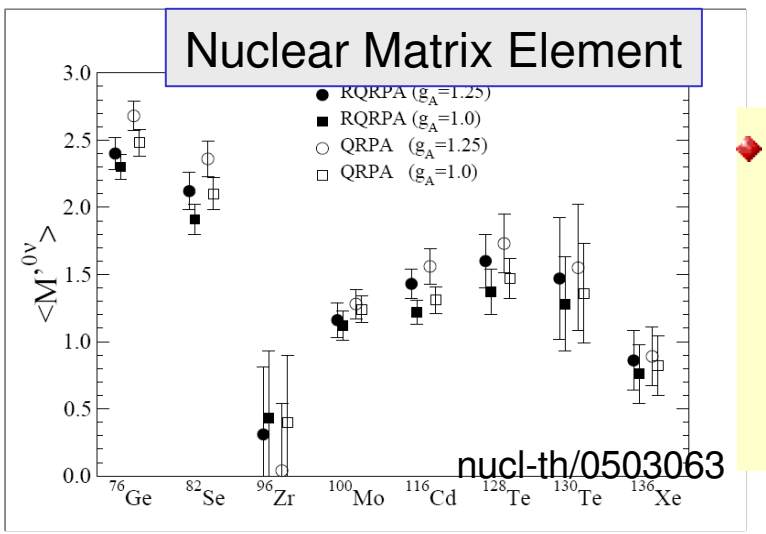




Between the highest natural γ line (^{208}Tl) and Compton edge

Natural abundance





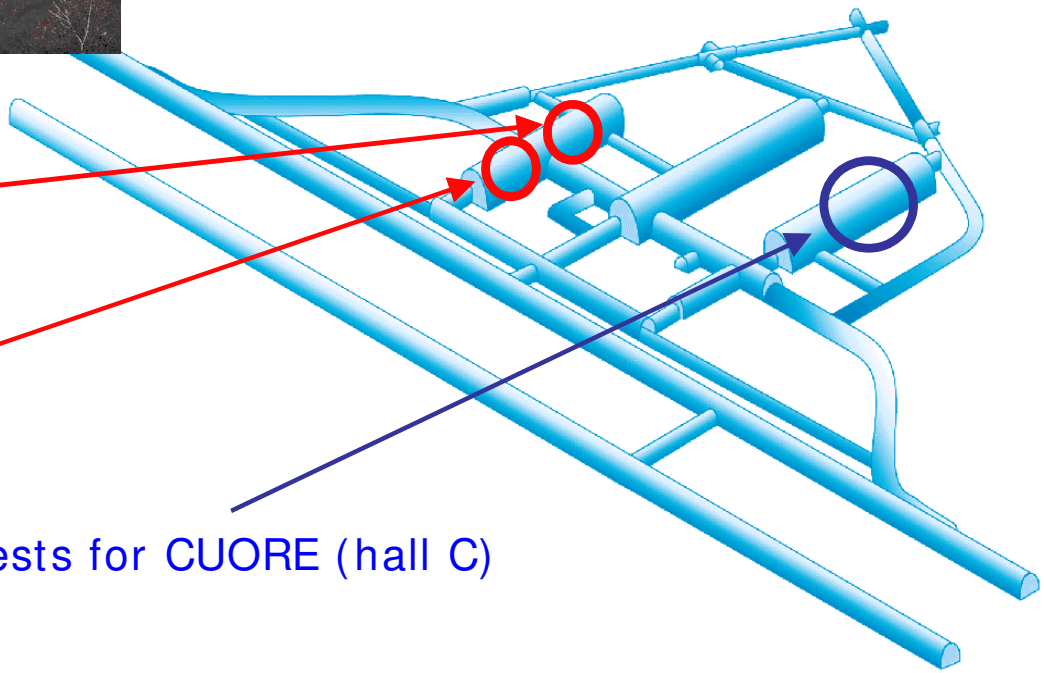
- **Absorber material: TeO_2**
  - **Low heat capacity**
  - **Possibility to grow large crystals**
  - **Good intrinsic purity**

CUOR(ICINO) @ LNGS

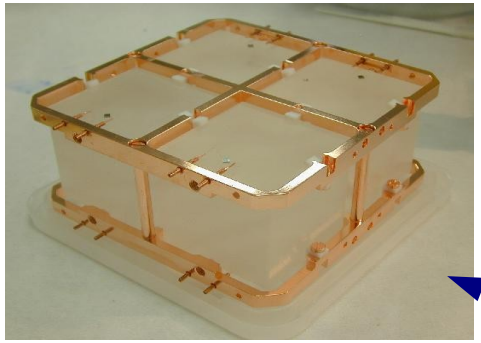
Cuoricino experiment is installed in the

Underground National Laboratory
of Gran Sasso
L'Aquila – ITALY

the mountain providing a 3500 m.w.e. shield against cosmic rays



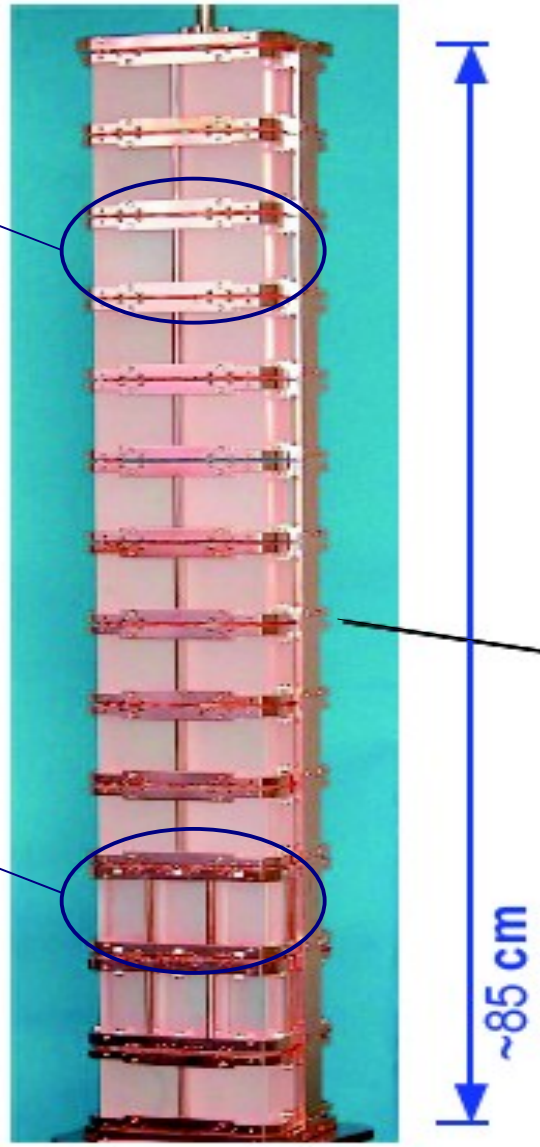
CUORICINO: the demonstrator



11 modules: 4 detector
5x5x5 cm^3=790 g each

2 modules 9 detector
3x3x6 cm^3=330 g each

4 enriched: 2 @75% ^{130}Te
2 @82.3% ^{128}Te



Started on April 2003

- long stop between run 1 and run 2
- various stops due to maintenance and interferences with Safety upgrade works

Total Active mass:

- TeO_2 = 40.7 Kg
- ^{130}Te = 11.34 Kg

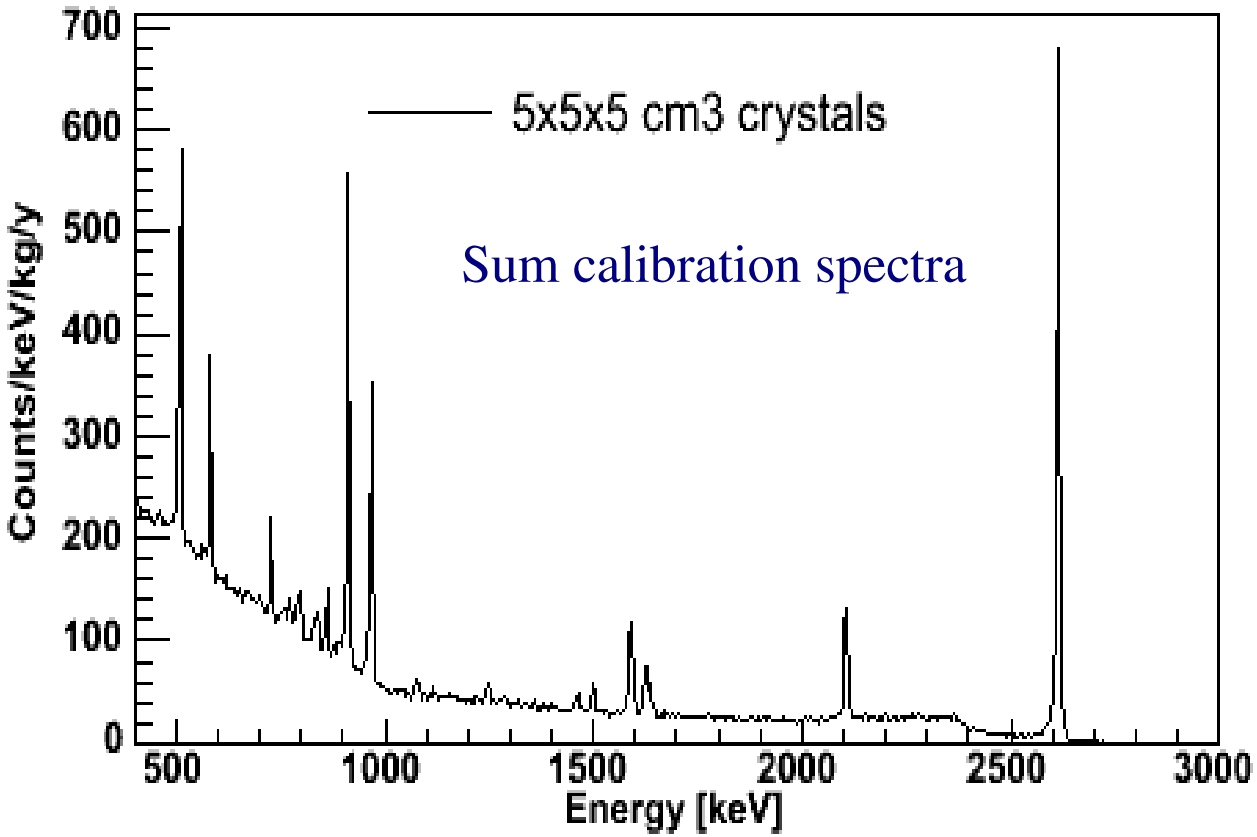
Installed in a dilution refrigerator (10 mK) surrounded by:

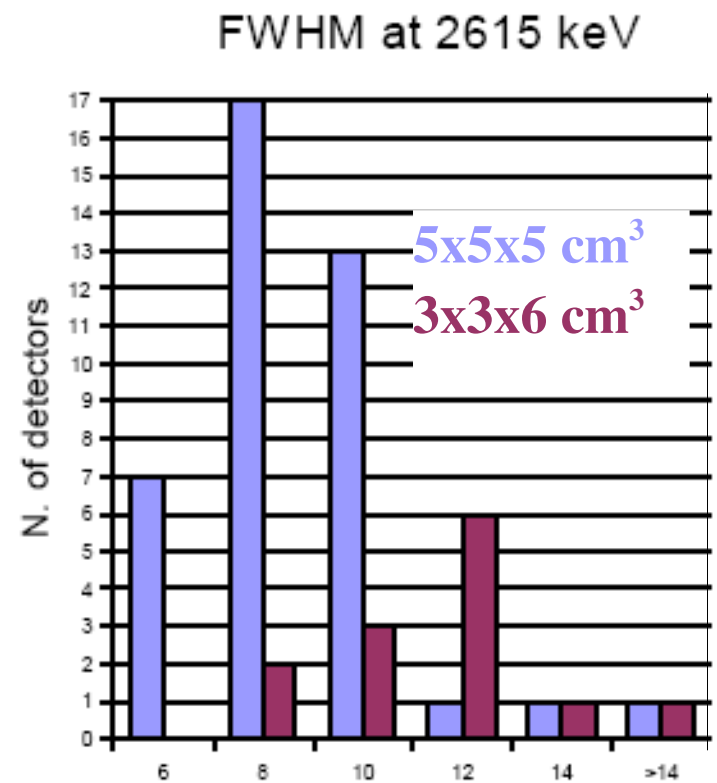
- Cu shield
- Roman Pb inner shield
  1.5 cm lateral, 10 cm top&bottom
- 20 cm Pb external shield
- Neutron shield:
  ~10 cm B(10%)-polyethylene
- Anti-radon box:nitrogen overpressure

Calibration spectra: energy resolution

- ^{232}Th γ–source external to the cryostat: 3 days measurement every month

FWHM @ 2615 keV ^{208}Tl γ–line
average 5x5x5 cm^3 crystal: FWHM 7.5±2.9 keV
average 3x3x6 cm^3 crystal: FWHM 9.6±2.5 keV

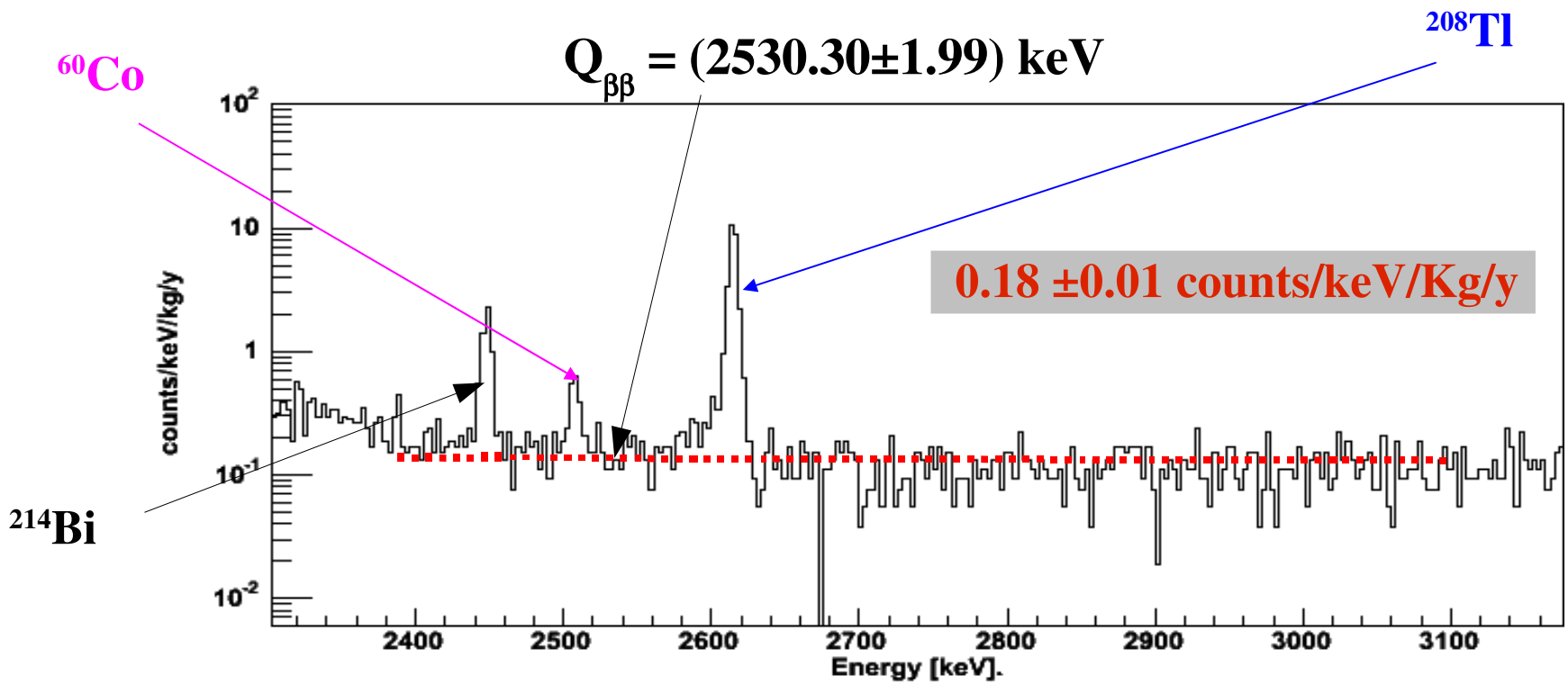




Cuoricino bkgd in the 0νββ region

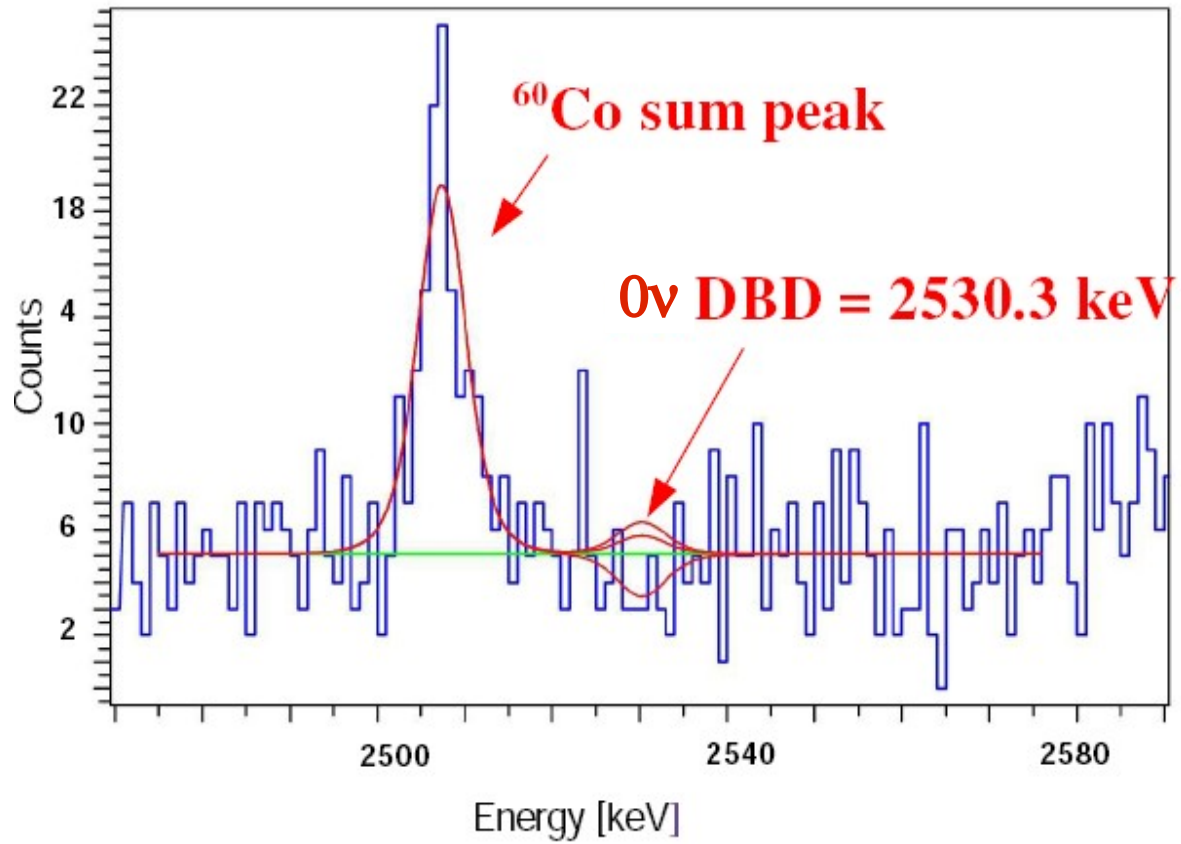
- ***All lines identified all over the whole spectrum***: U & Th chains, ^{40}K, ^{207}Bi, ^{60}Co

- **In 0νββ region:**
  - **30 ± 10%** ^{208}Tl (2614.5 keV line) via multi-Compton events from ^{232}*Th* in *cryostat shields*
  - **10 ± 5%** from crystals surface ^{238}*U and* ^{232}*Th contamination*
  - **50 ± 20%** from degraded α produced by ^{238}U and ^{232}Th contaminations of *mounting structure* main candidate the *copper surface*
  - negligible contribution from 2505 (1173γ+1332γ) keV ^{60}Co tail due *Cu cosmogenic activation*



CUORICINO 0νββ result

- Total statistics: **8.38 Kg ^{130}Te•y**
- Bkgd (ββ0ν region):
  0.18 ±0.01 counts/keV/Kg/y
- FWHM measured on bkgd spectrum
  @ 2.6 MeV **~ 8 keV**
- Detector efficiency: ~**86.4%**
- ML fit in **2475-2550 keV** region



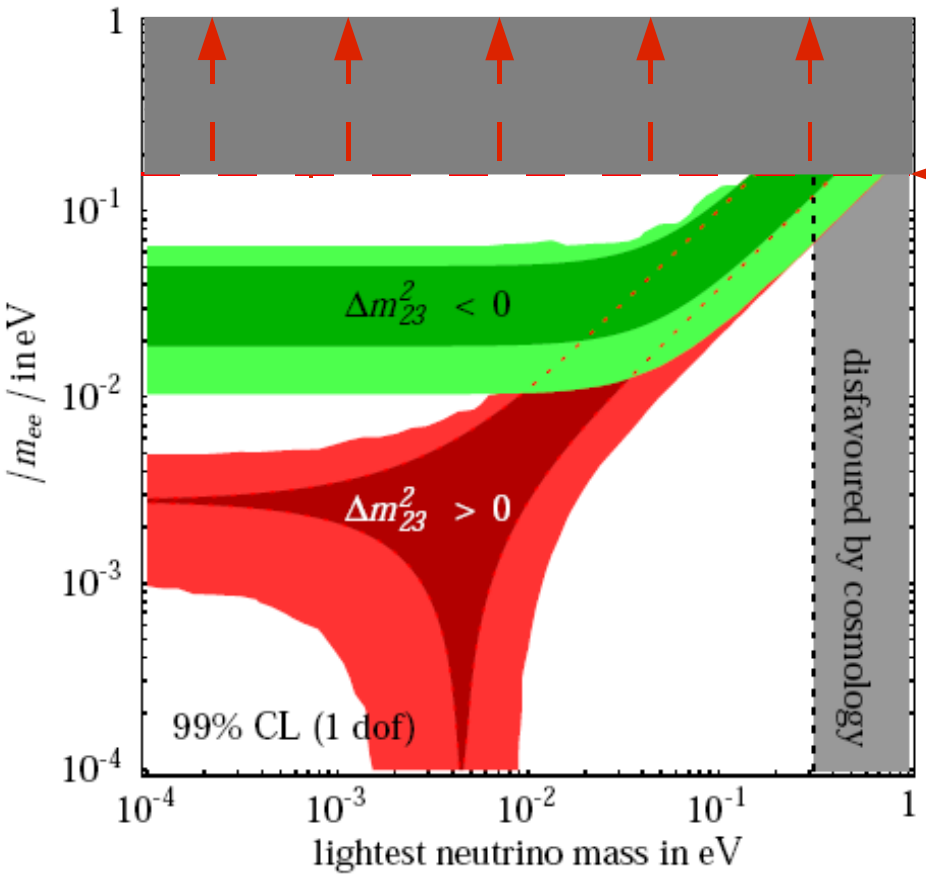
- flat bkgd + 2505 keV peak
- peak shape = N-gaussian
  to account for the different – measured - energy resolutions
- best fit yields negative effect

$$\tau_{1/2}^{\beta\beta 0\nu} > 2.4 \cdot 10^{24}\, y \,@\, 90\, C.L. \quad \Rightarrow \quad \langle m_{\beta\beta 0\nu} \rangle < [0.18 \div 0.94]\, eV$$

NMA from *"New Limit on the Neutrino-less ββ Decay of ^{130}Te"*, C.Arnaboldi et al., PRL 95, 142501 (2005)

In the parameter space

KK-HM: $0.24\,eV < m_{\beta\beta} < 0.58\,eV \Leftrightarrow m_{\beta\beta}^{best} = 0.44\,eV$ *Klapdor-Kleingrothaus et al. Phys. Lett. B 586 (198)*



CUORICINO:

$$m_{\beta\beta} < [0.18 - 0.94]\,eV$$

with KK-HM NME $m_{\beta\beta}$ = 0.46 eV

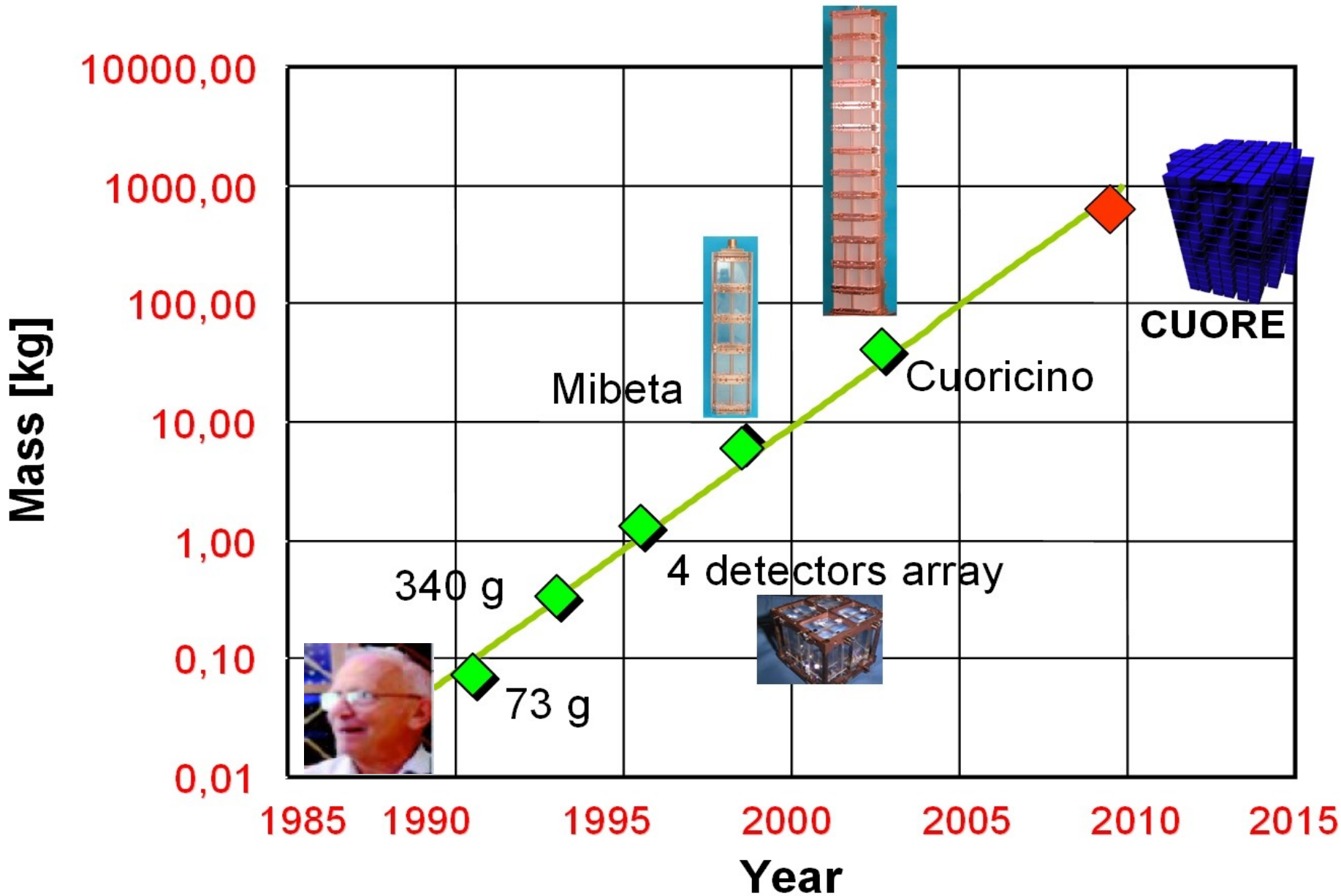
With 3 years live time:

$$\tau_{1/2}^{\beta\beta 0\nu} > 7.1 \cdot 10^{24}\,y \text{ @ } 90\,C.L.$$

$$\langle m_\nu \rangle < [0.1 \div 0.6]\,eV$$

- **Good chances to have a positive indication**
- **But : cannot falsify HM if no signal is seen**

The Moore's law of TeO_2 bolometers

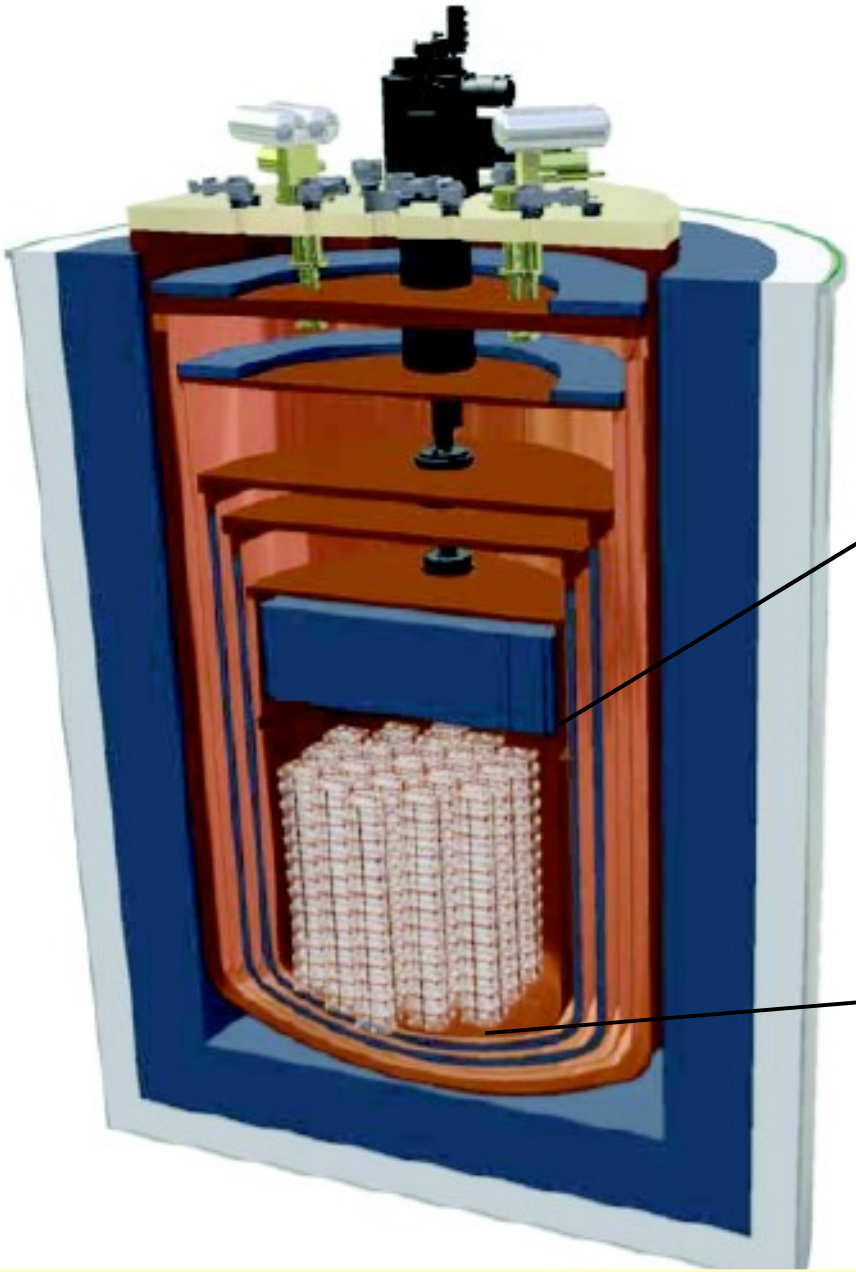


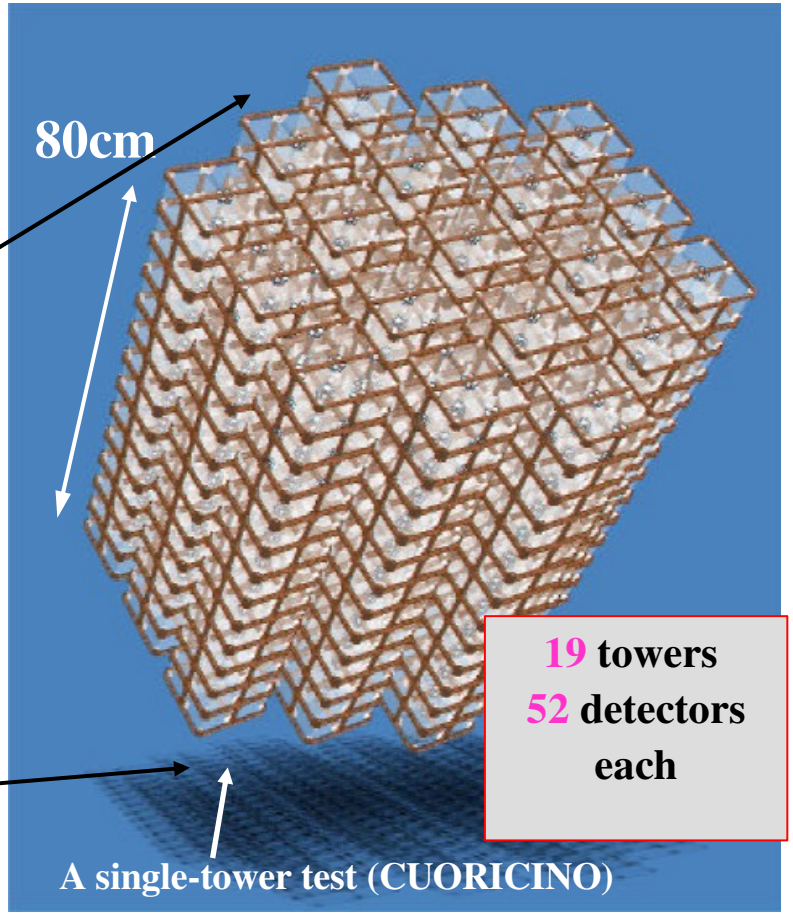
Cryogenic Underground Observatory for Rare Events

Single dilution refrigerator ~10 mk

- ββ0ν, Cold Dark Matter, Axion searches

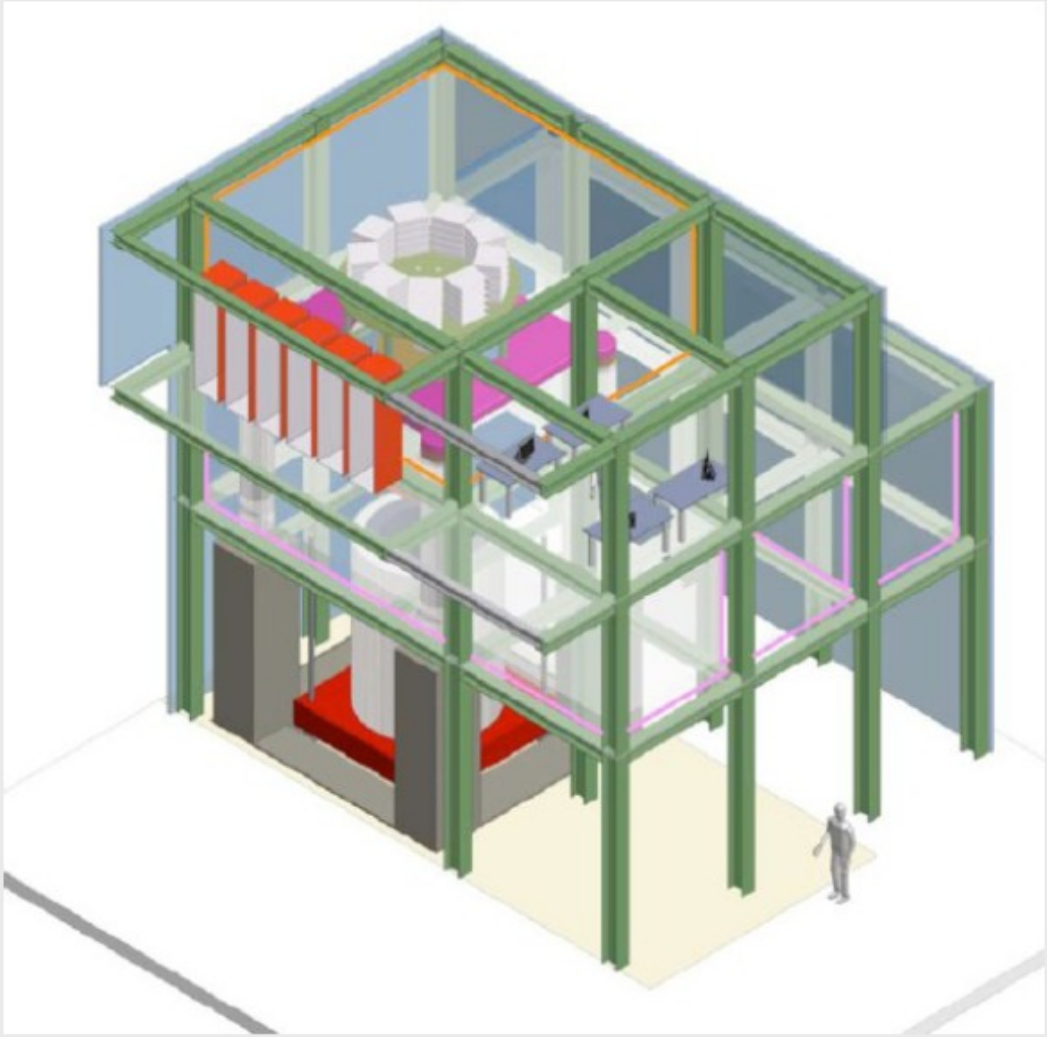
proposal hep/ph 0501010

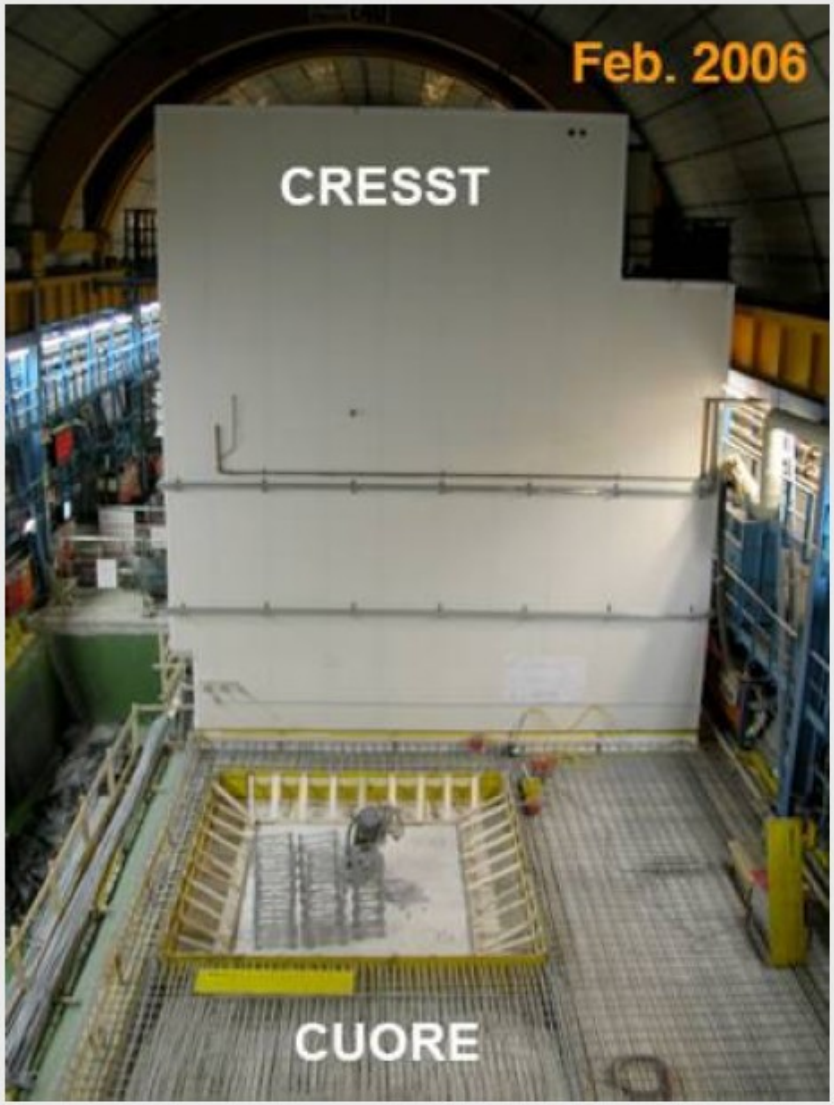




Closed packed array of 988 TeO_2 5x5x5 cm^3 crystals ⇒741 Kg TeO_2 ⇒ 204Kg ^{130}Te

CUORE Housing

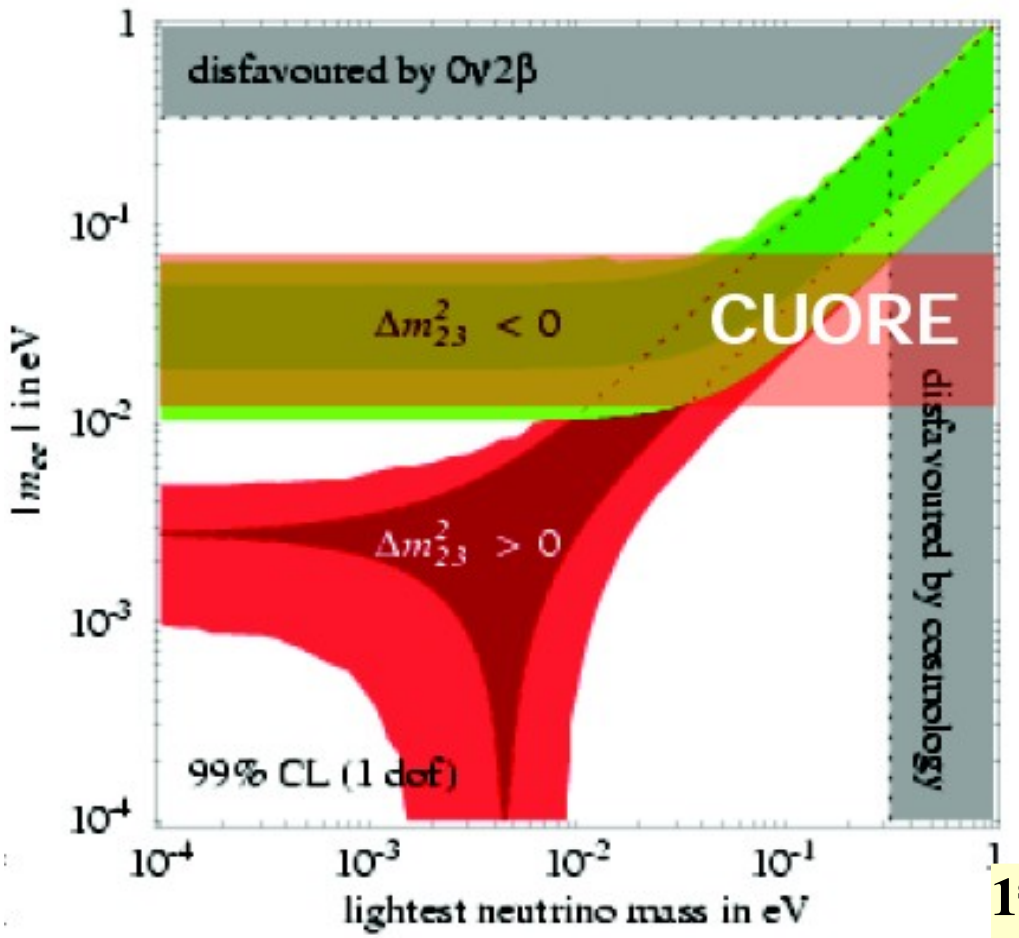




Basement already completed ... the rest is coming

CUORE sensitivity

CUORE ββ0ν sensitivity will depend strongly on the bkgd level and detector performance



CUORE GOAL:

test inverse hierarchy: 19-50 meV

In 5 years of data taking

B(counts/keV/kg/y)	Δ(keV)	$T_{1/2}$(y)	$\lvert\langle m_\nu\rangle\rvert$ (meV)
0.01	10	1.5×10^{26}	23–118
0.01	5	2.1×10^{26}	19–100
0.001	10	4.6×10^{26}	13–67
0.001	5	6.5×10^{26}	11-57

1st generation exp: proof of technology

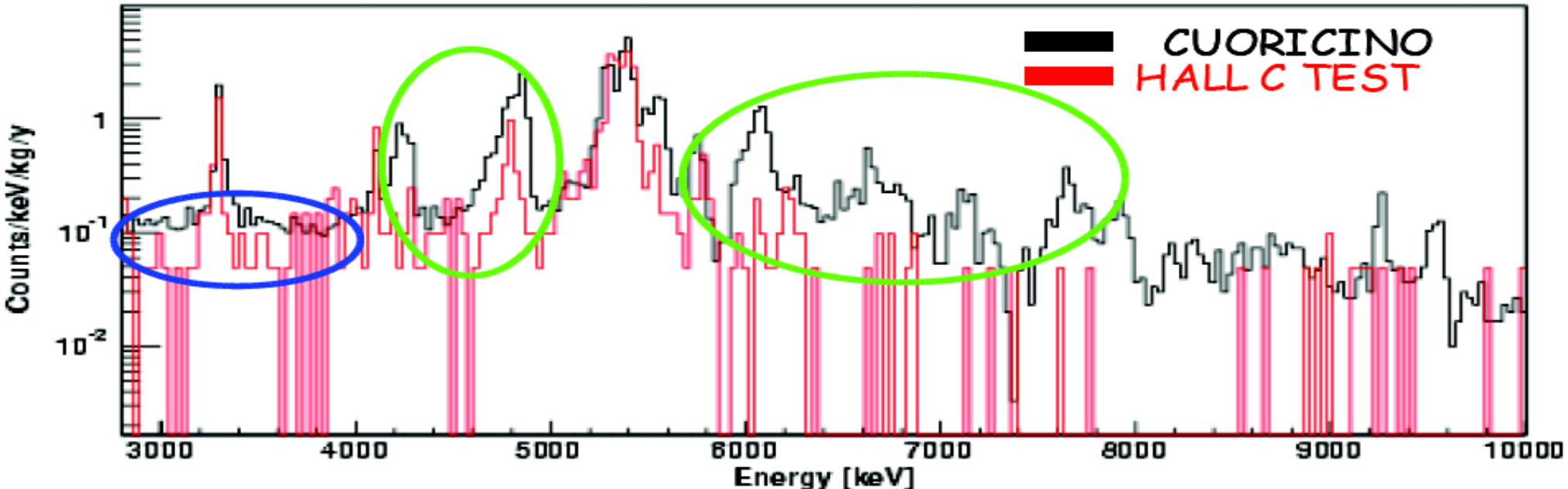
2nd generation exp: explore inverted hierarchy

Spread due to NME uncertainties: main obstacle to answer ν mass question

Background reduction

- **Cryostat ^{232}Th bulk contamination contribution reduced by properly shielding in CUORE cryostat + selection of construction materials**
- **Neutron & environmental** background reduced by **lead and neutron shield**
- **Cosmogenic Cu and Te activation** reduced by **underground storage of materials**

- **Surface contribution:**
  - **test wih new crystals surface cleaning (etching, lapping with 2μm SiO_2 clean powder)**
    reduction of a factor 4
  - **test wih new Cu cleaning (etching, electro-polishing, passivation) and complete coverage of Cu facing the crystal with ~50μm PET film**
    reduction of ~40% of flat continuum background



Background reduction

The extrapolated contribution to CUORE are

- **Crystal Surface contamination contribution** **$<3 \bullet 10^{-3}$ counts/Kg/keV/y**
- **Copper Surface contamination contribution** **$<5 \bullet 10^{-2}$ counts/Kg/keV/y**
- **New structure with reduced Cu amount is being tested right now**

  MC simulation Cu contribution **$< 2.5 \bullet 10^{-2}$ counts/Kg/keV/y**

still a factor no less than 2.5 to go

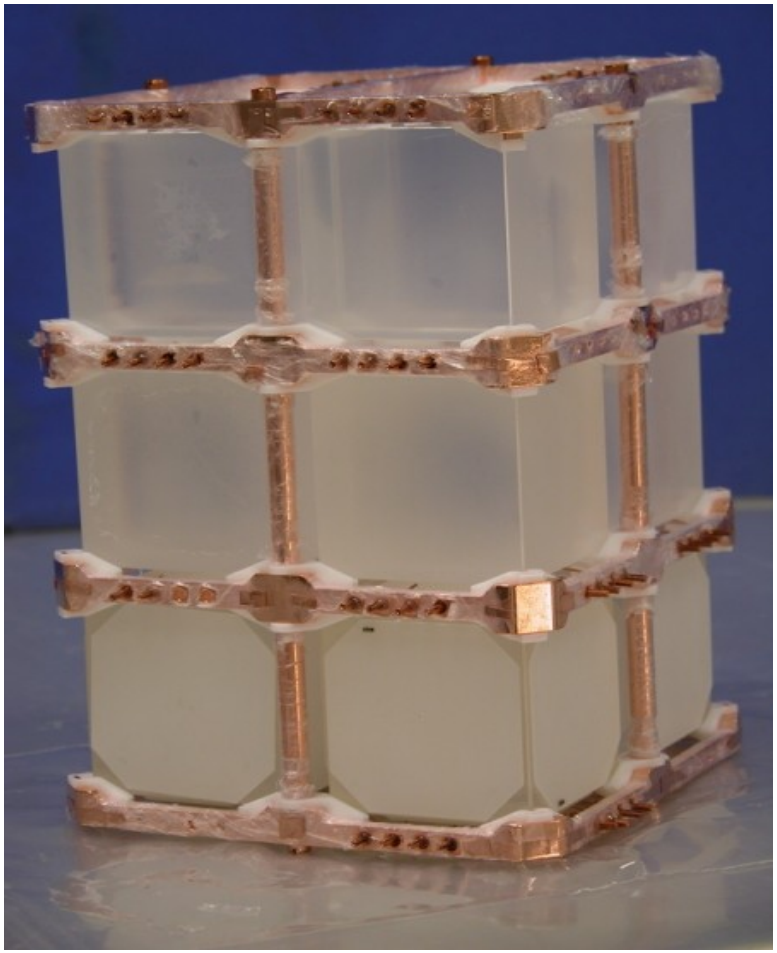
New passive procedure (plasma cleaning) under test

most exp. efforts now concentrated in the

reduction of this kind of impurities

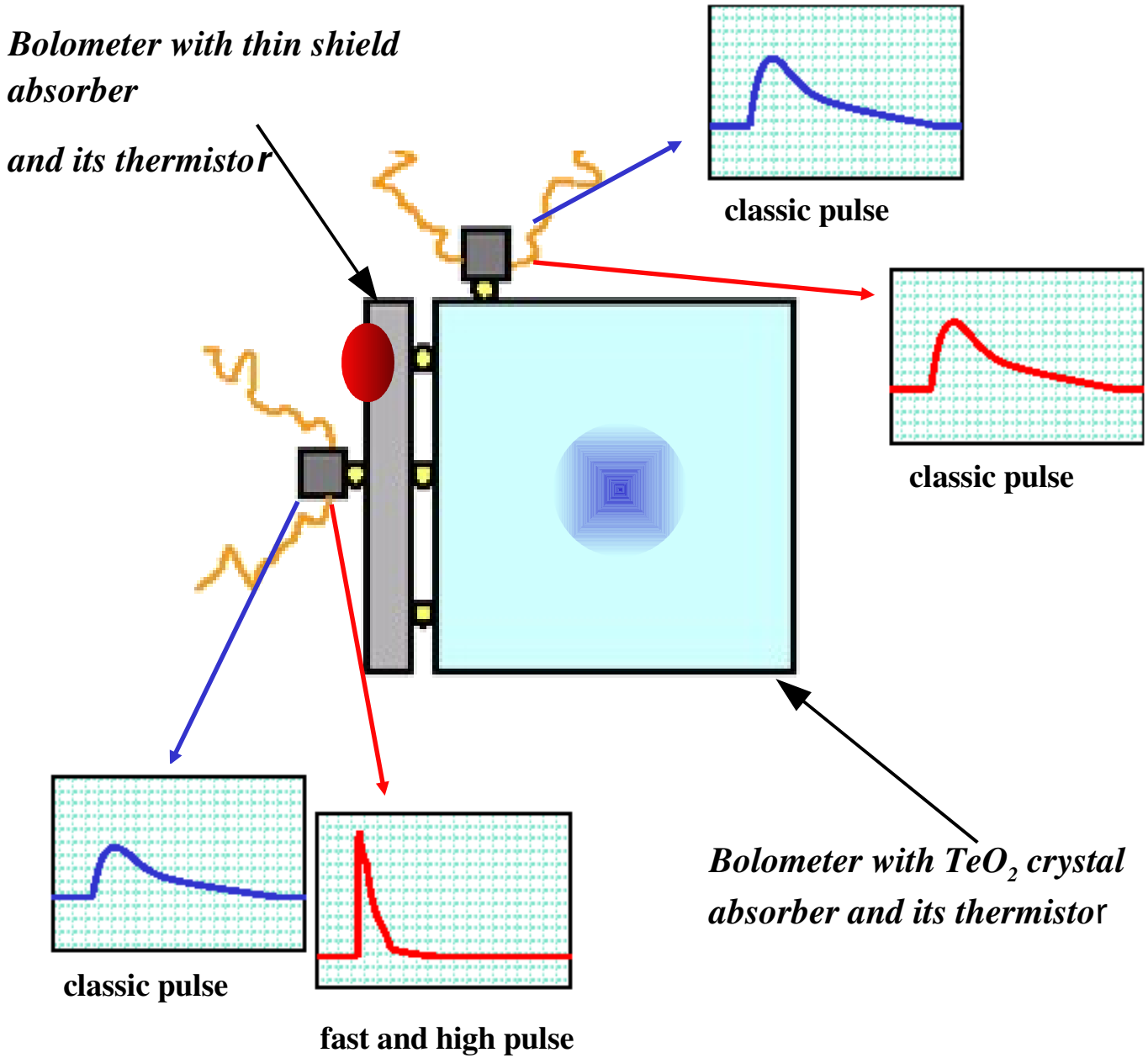
alternative viable way that guarantees

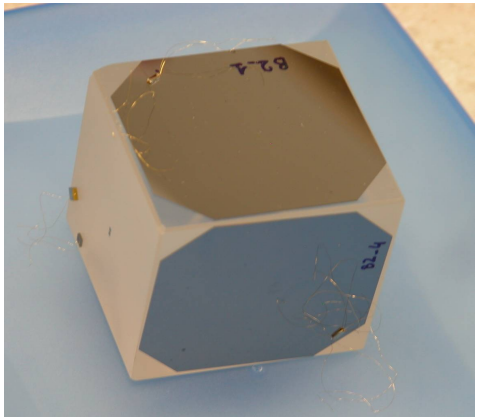
the bkgd achievement= Surface Sensitive Bolometers



CUORE R&D:active bkgd rejection

Surface sensitive detectors: ***composited bolometer with a thin Ge, Si, TeO_2 crystal***

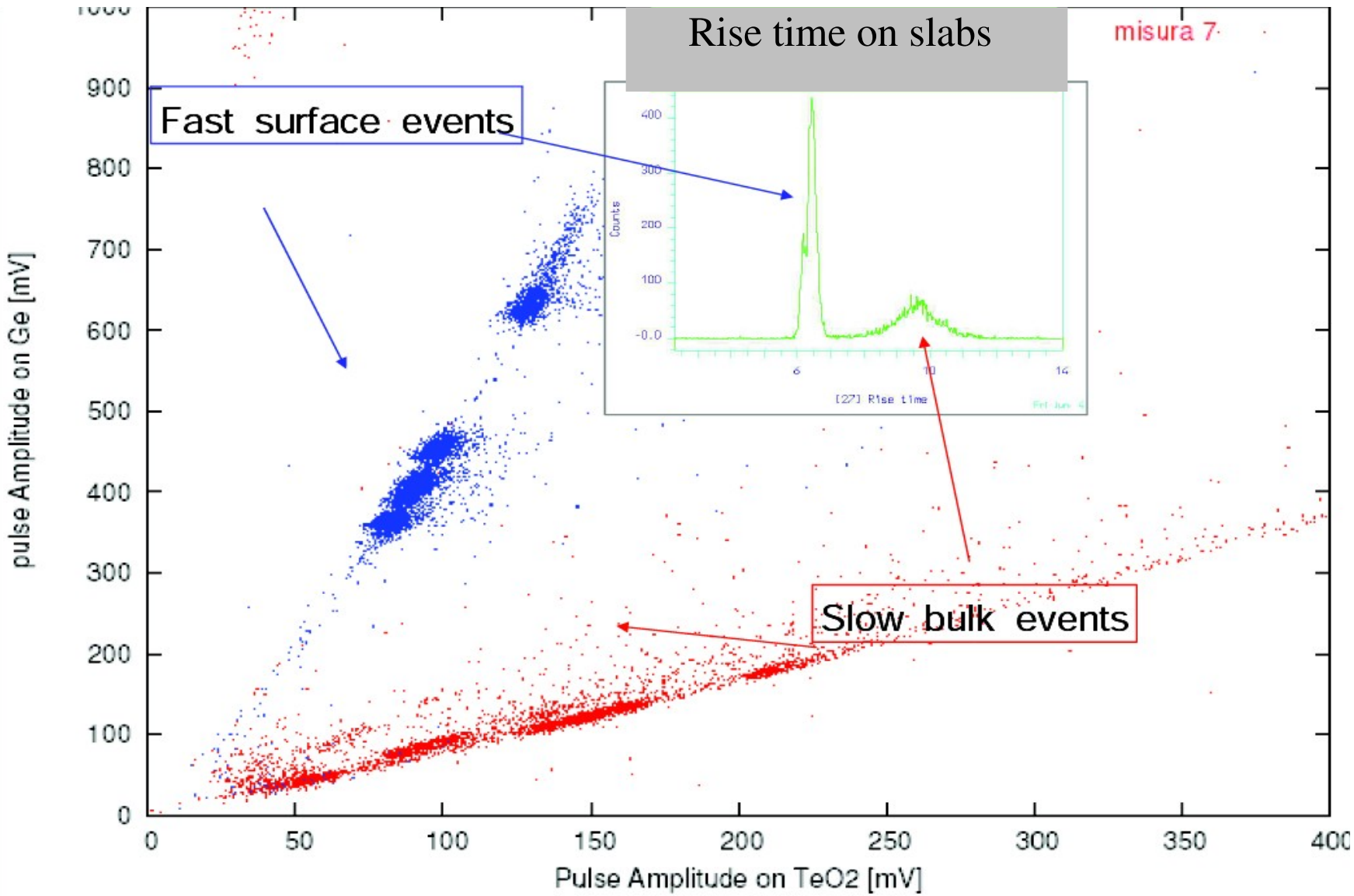




The presence of the shield changes the thermal dynamic behavior of the detector giving rise to pulses with different amplitudes and shapes.

Different impact points means different pulses on thermistors

CUORE R&D: active bkgd rejection



More details in C. Nones ' poster "Cuore and the inverted hierarchy region: the reduction of surface background"

Conclusion

- **CUORICINO:**
  - **The most sensitive ββ0ν decay running experiment:**

$$\tau_{1/2}^{\beta\beta 0\nu} > 2.4 \cdot 10^{24}\, y \,@\, 90\, C.L. \quad \Rightarrow \quad \langle m_{\beta\beta 0\nu} \rangle < [0.18 \div 0.94]\, eV$$

  - **Good chances to confirm KK-HM experiment**
  - **CUORICINO proved the feasibility of CUORE**
  - **Crucial informations for background identification**

- **CUORE:**
  - **Hut construction already started**
  - **Intense R&D activity to reduce background and optimize construction and assembly**
  - **Enrichment or alternative options (^{48}Ca,^{100}Mo,^{116}Cd,^{150}Nd) still open**
  - **The inverse hierarchy will be explored**
  - **Start data taking: 1st January 2010**

Neutron bkgd @ Cuore in ββ0νregion

- from thermal to 1keV → absorbed by a "thin" n shield
- from 1keV to 10 MeV → flux from measures + simulation of radiation in the rock
  - total $7 \cdot 10^{-3}$ counts/Kg/keV/y
  - global anticoincidence $2 \cdot 10^{-4}$ counts/Kg/keV/y

Can be further reduced by a n shield

- from 10 MeV to 2 GeV → flux simulation of muon interaction in the rock
  - total $3 \cdot 10^{-5}$ counts/Kg/keV/y
  - global anticoincidence $6 \cdot 10^{-7}$ counts/Kg/keV/y
- from 1keV to 2 GeV →flux simulation of muon interaction in the muon shield
  - total $3 \cdot 10^{-3}$ counts/Kg/keV/y
  - global anticoincidence $2 \cdot 10^{-4}$ counts/Kg/keV/y

Can be further reduced by a muon veto

Same background in Dark Matter search region

No limit to CUORE sensitivity due to neutron flux in LNGS

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