CUORICINO results &
status of CUORE

Fabio Bellini

Università di Roma "La Sapienza" & INFN Roma

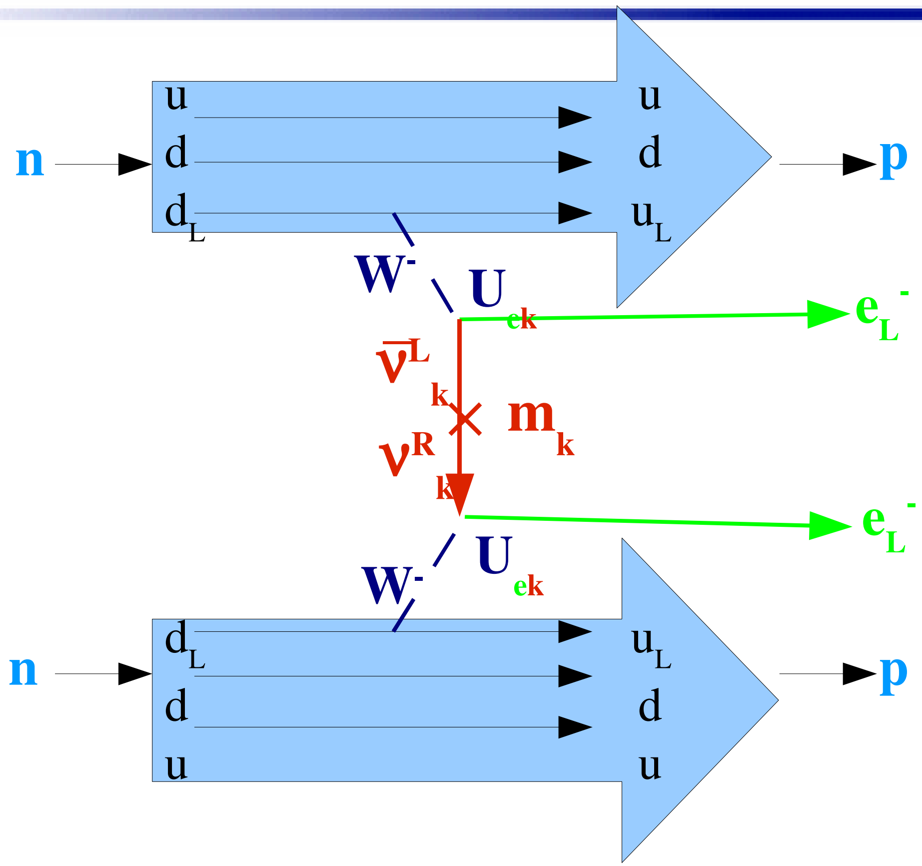
on behalf of the

CUORE Collaboration

1st Boulby Underground Science Workshop

York, England Oct. 21-22, 2006

Neutrino-less Double Beta Decay



- **Neutrino nature**

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

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

$$(Lepton\ number\ violation)$$

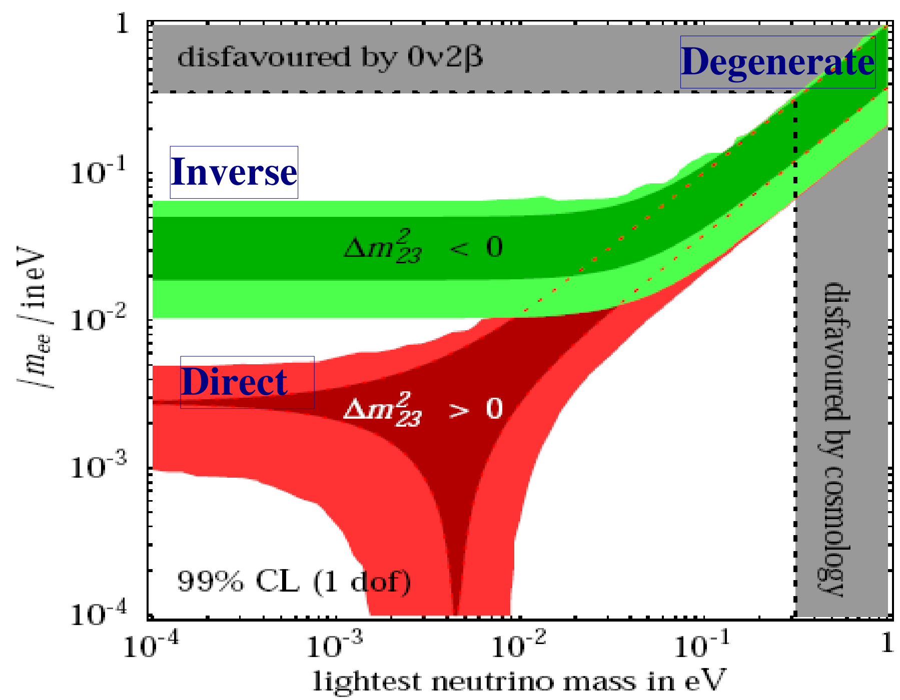
- **Absolute mass scale and hierarchy**

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

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

Effective neutrino mass

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



CUORICINO: the bolometric way

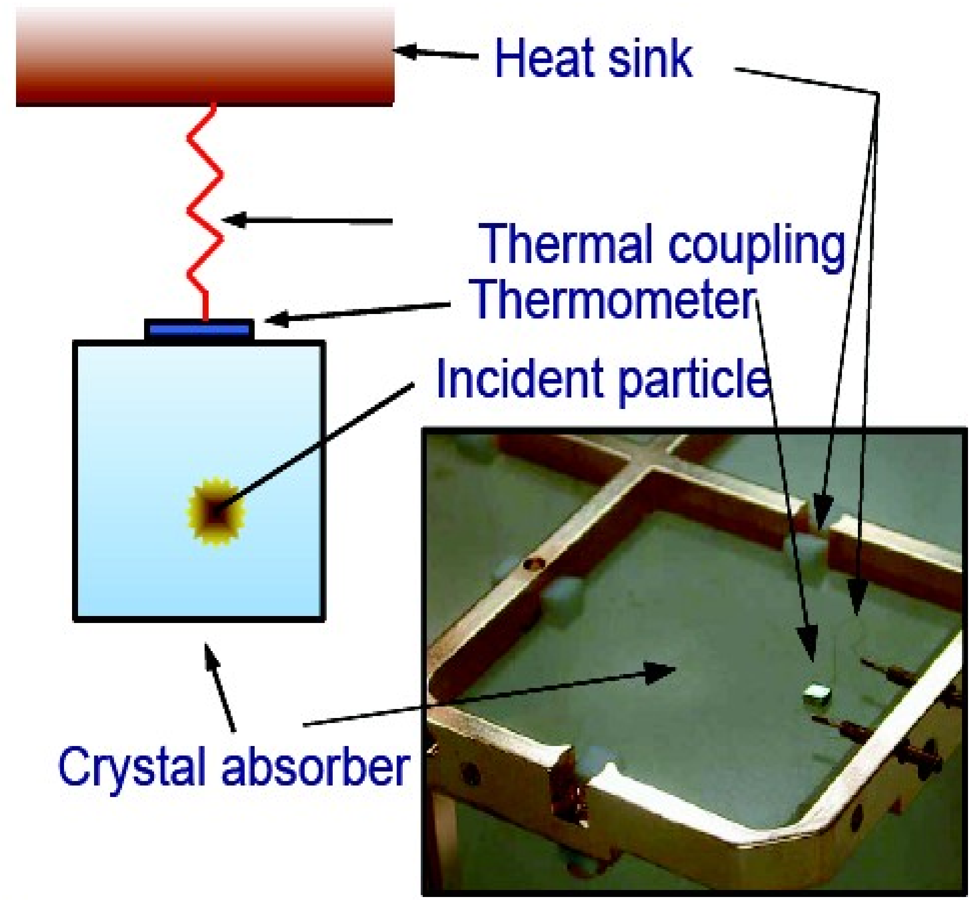
- **Bolometric technique: energy measured as a temperature increase in the detector**
- **Homogeneous detector: $\beta\beta0\nu$ source ≡ absorber**

- **(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

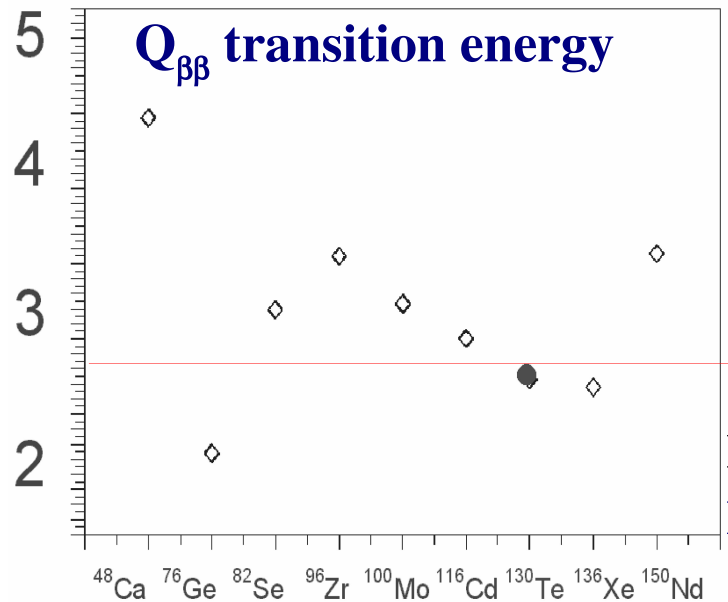
- **(Not for all) Typical pulse decay time: $t \sim C/G \sim 10^{2\text{-}3}$ ms**

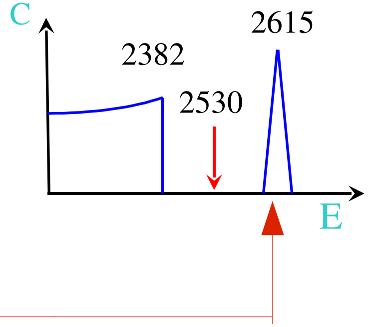
Why Tellurium?

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

$Q_{\beta\beta}$ = (2530.30±1.99) keV

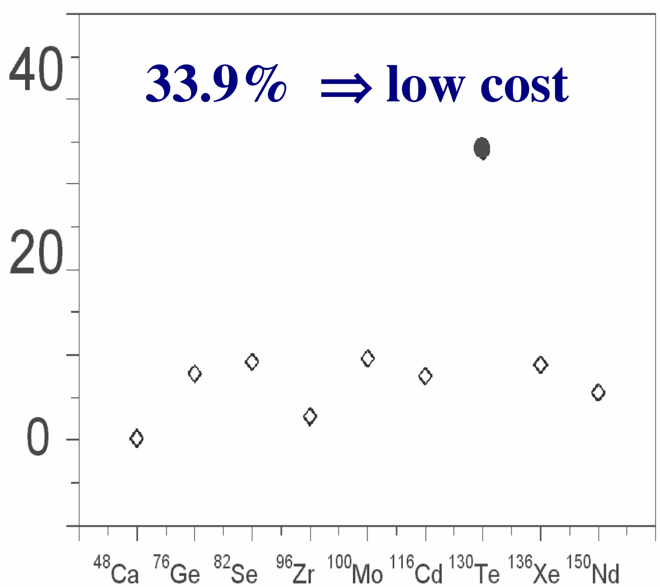
Nuclear Physics A 729 (2003) 337



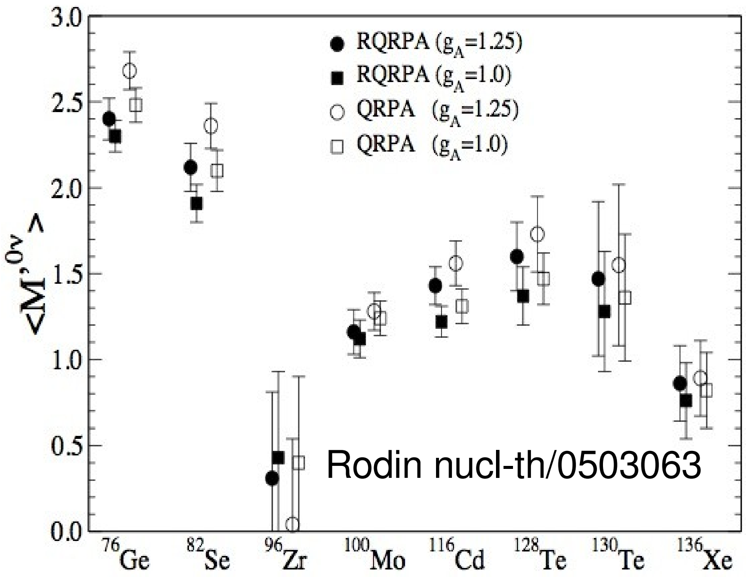


Between the highest natural γ line (^{208}Tl) and Compton edge

Natural abundance



Nuclear matrix element



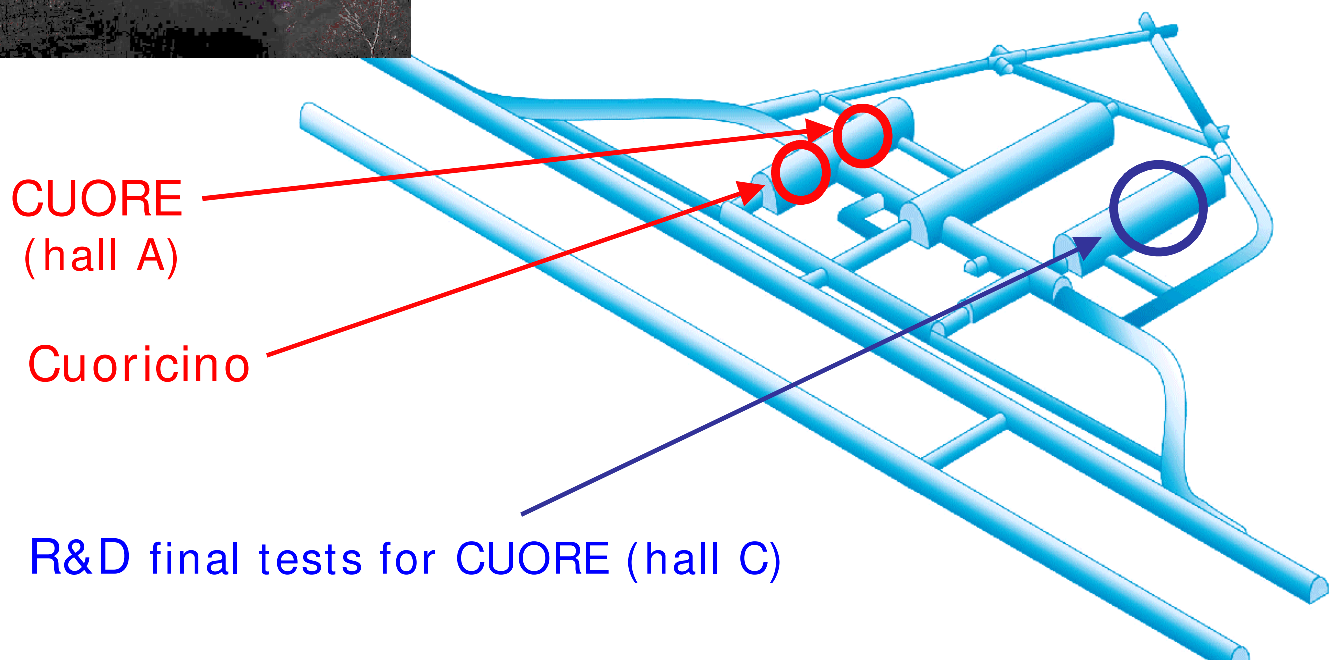
- **Absorber material: TeO_2**
  - **Low heat capacity**
  - **Possibility to grow large crystals**
  - **Good intrinsic purity**

CUOR(ICINO) @ LNGS

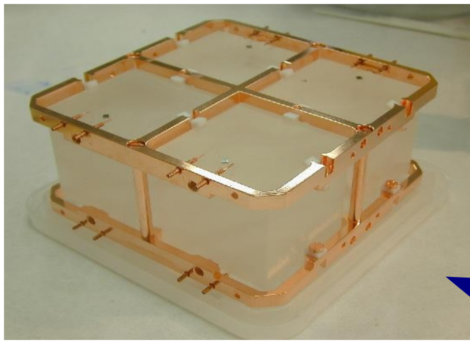
Cuoricino experiment is installed in the

Underground National Laboratory
of Gran Sasso
L'Aquila – ITALY

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



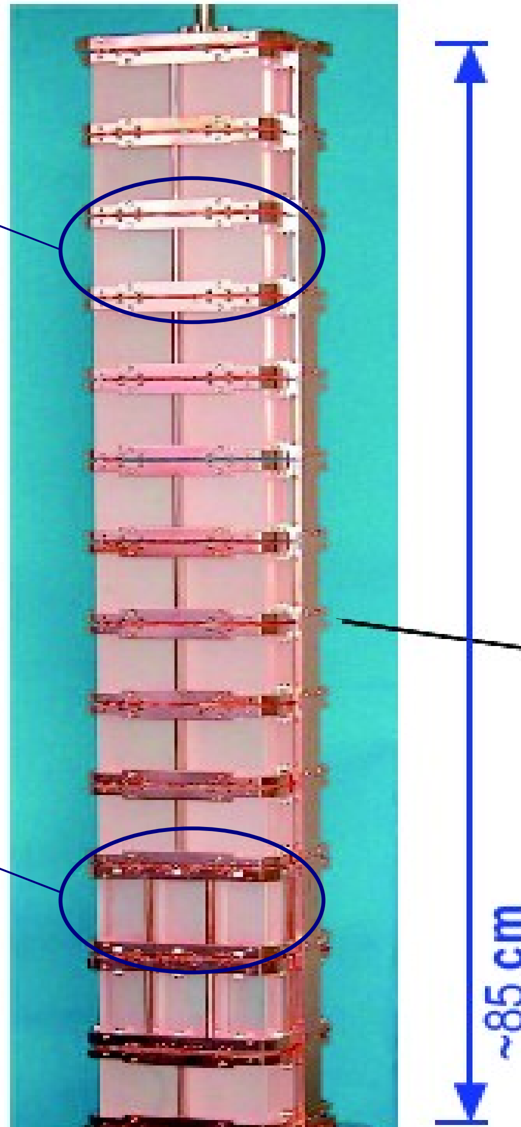
CUORICINO: the demonstrator



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

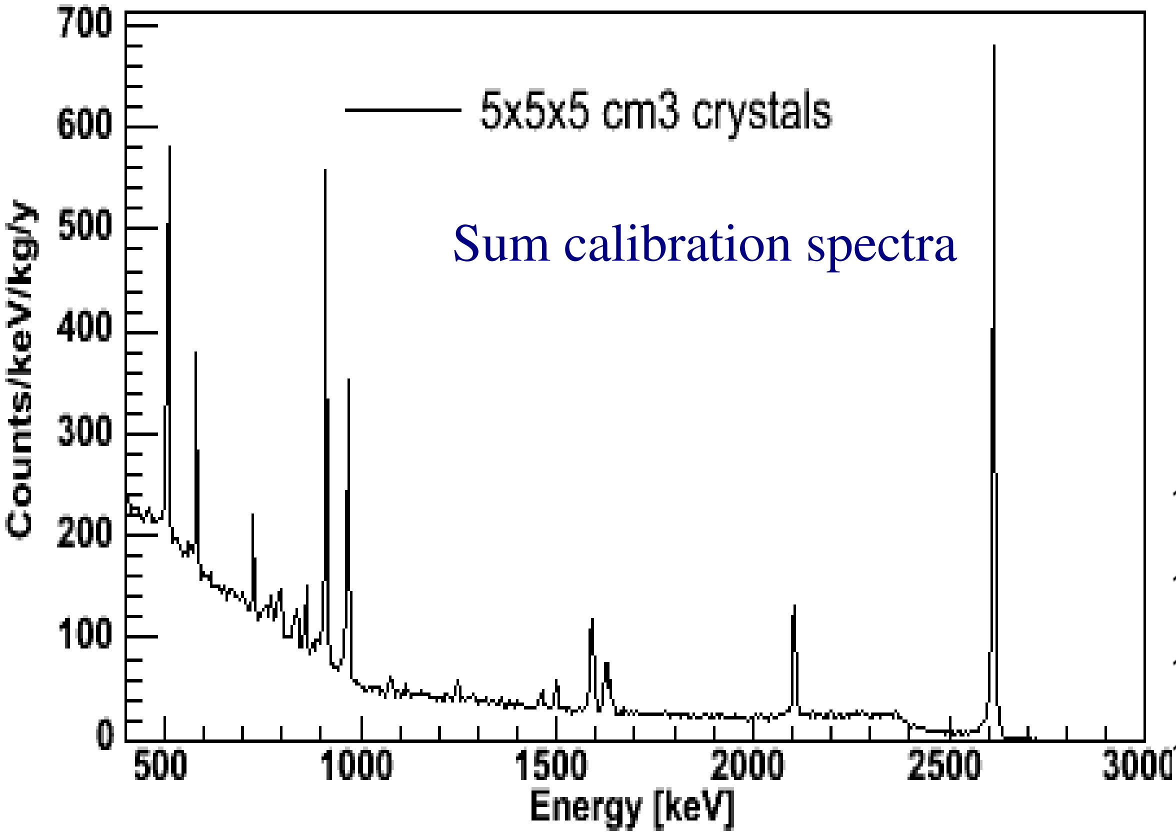
Total Active mass:

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

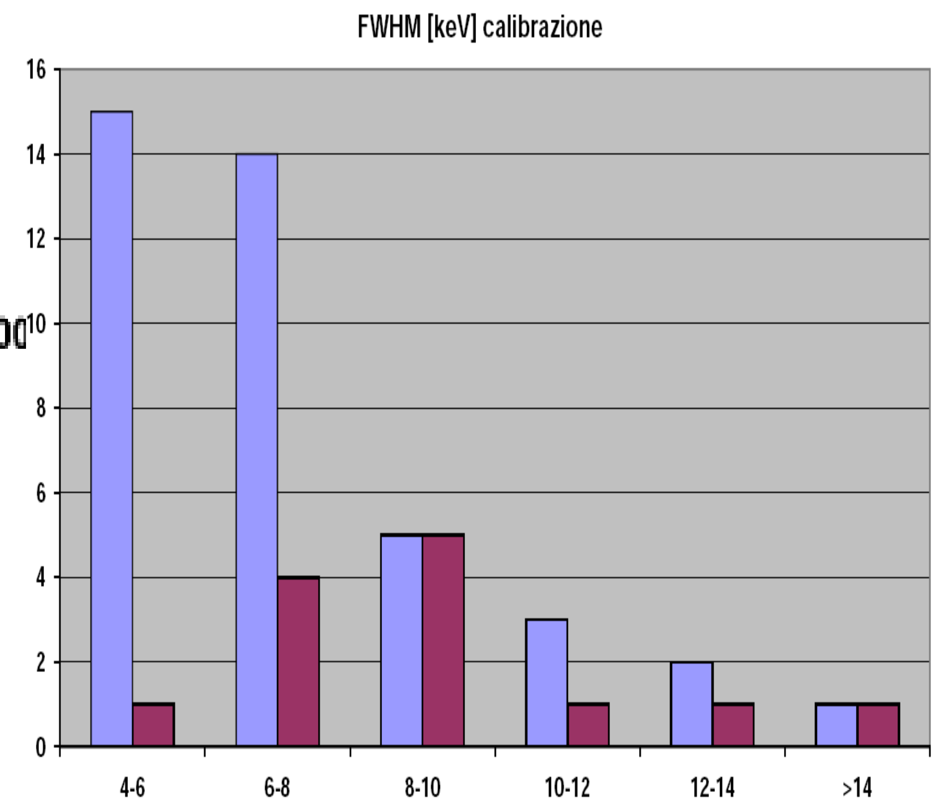
Installed in a dilution refrigerator (10 mK) surrounded by:

- 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

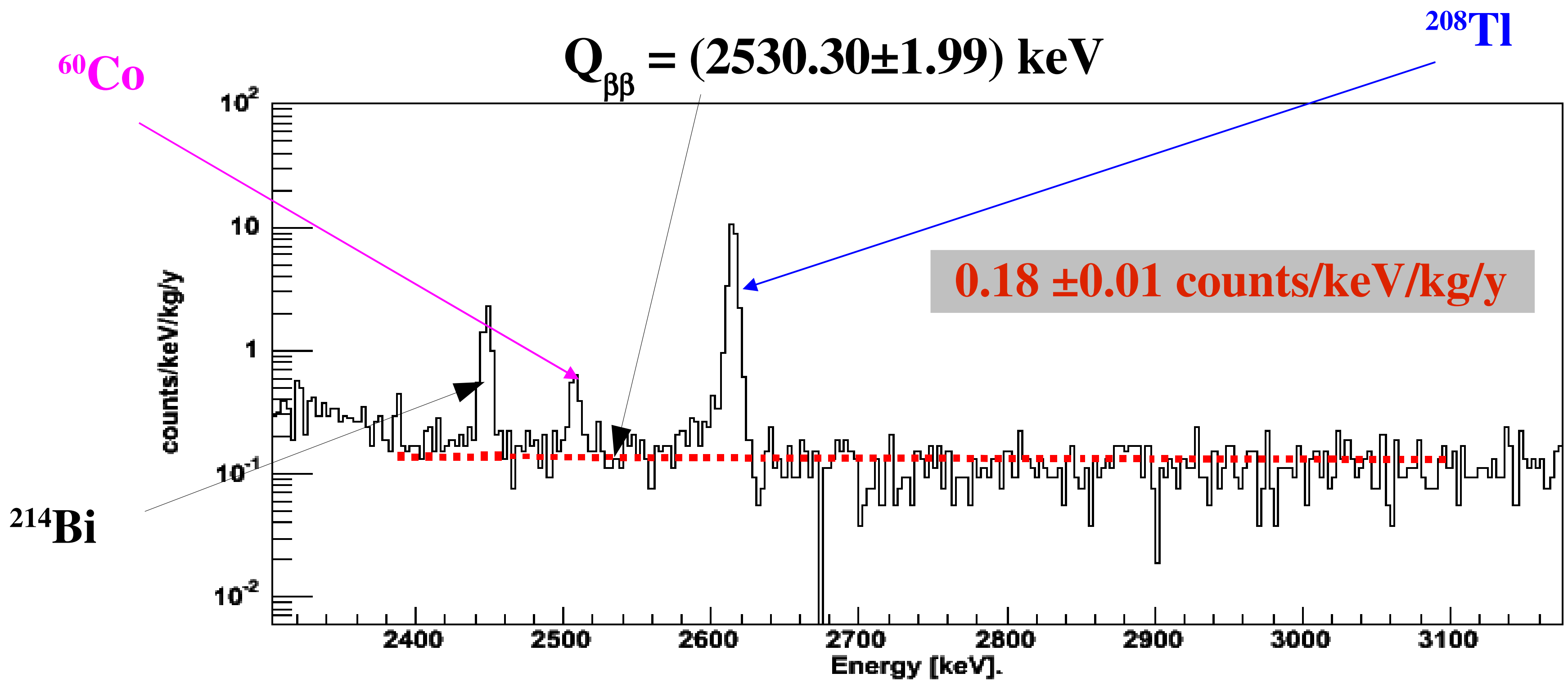
5x5x5 cm^3 crystal: FWHM 7.5±2.9 keV

3x3x6 cm^3 crystal: FWHM 9.6±3.5 keV

CUORICINO bkg in the 0$\nu\beta\beta$ region

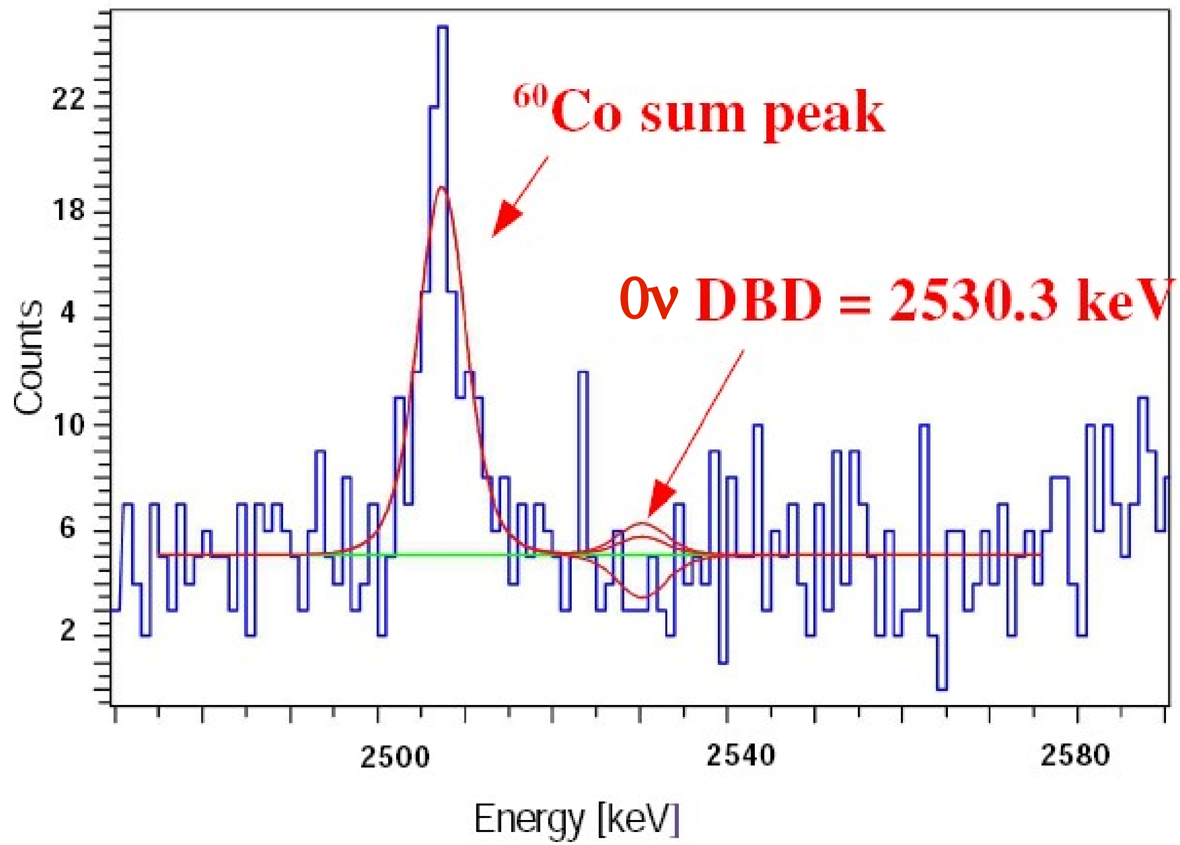
- ***All lines identified all over the whole spectrum***: **U & Th chains, ^{40}K, ^{207}Bi, ^{60}Co**

- **In 0$\nu\beta\beta$ 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**
- Bkg (ββ0ν region):
  0.18 ±0.01 counts/keV/kg/y
- FWHM measured on bkg spectrum
  @ 2.6 MeV **~ 8 keV**
- Detector efficiency: ~**86.4%**
- ML fit in **2475-2550 keV** region



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

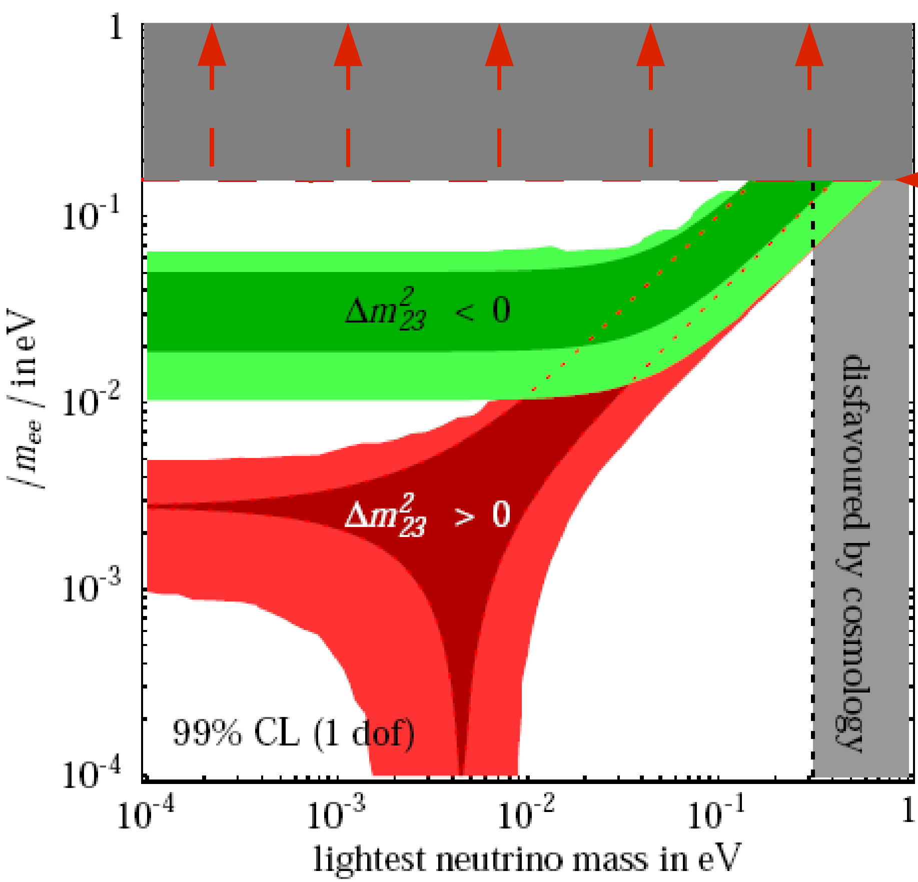
$$\tau_{1/2}^{\beta\beta 0\nu} > 2.4 \cdot 10^{24}\, y\, @\, 90\, C.L. \quad \Rightarrow \quad \langle m_{\beta\beta 0\nu} \rangle < [0.18 \div 0.94]\, eV$$

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

In the parameter space

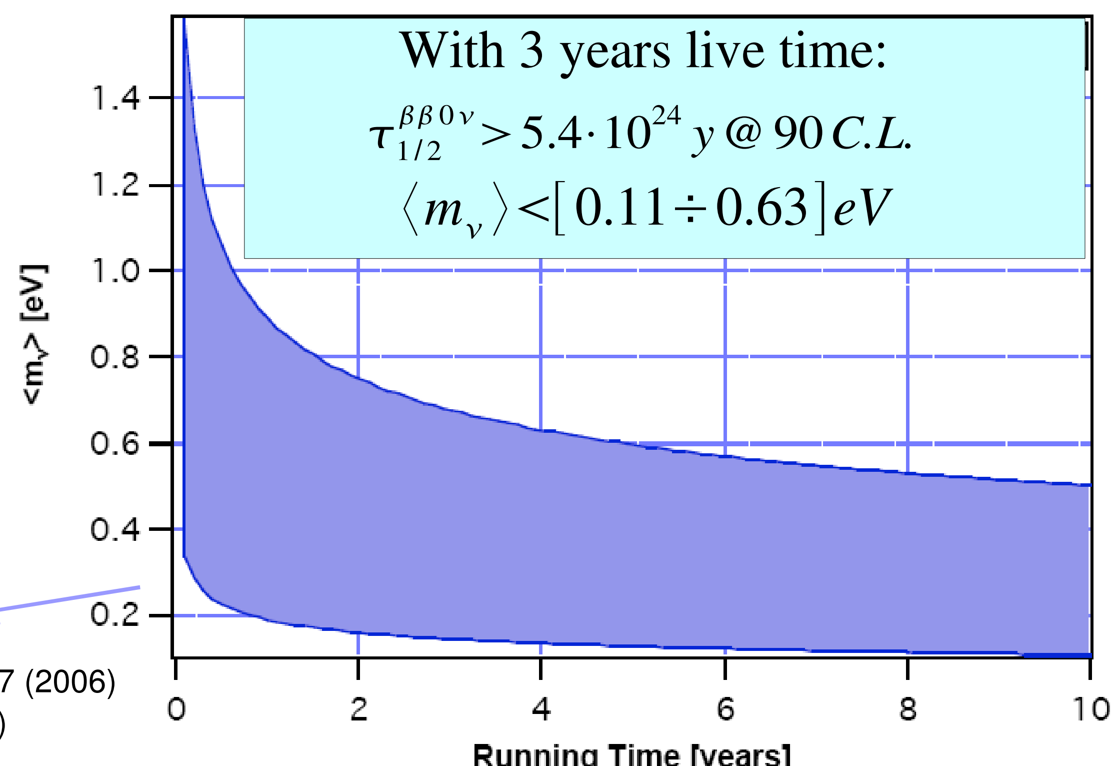
KK-HM: $0.24\,eV < m_{\beta\beta} < 0.58\,eV \Leftrightarrow m_{\beta\beta}^{best} = 0.44\,eV$

Klapdor-Kleingrothaus et al. Phys. Lett. B 586, 198-212



CUORICINO:

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

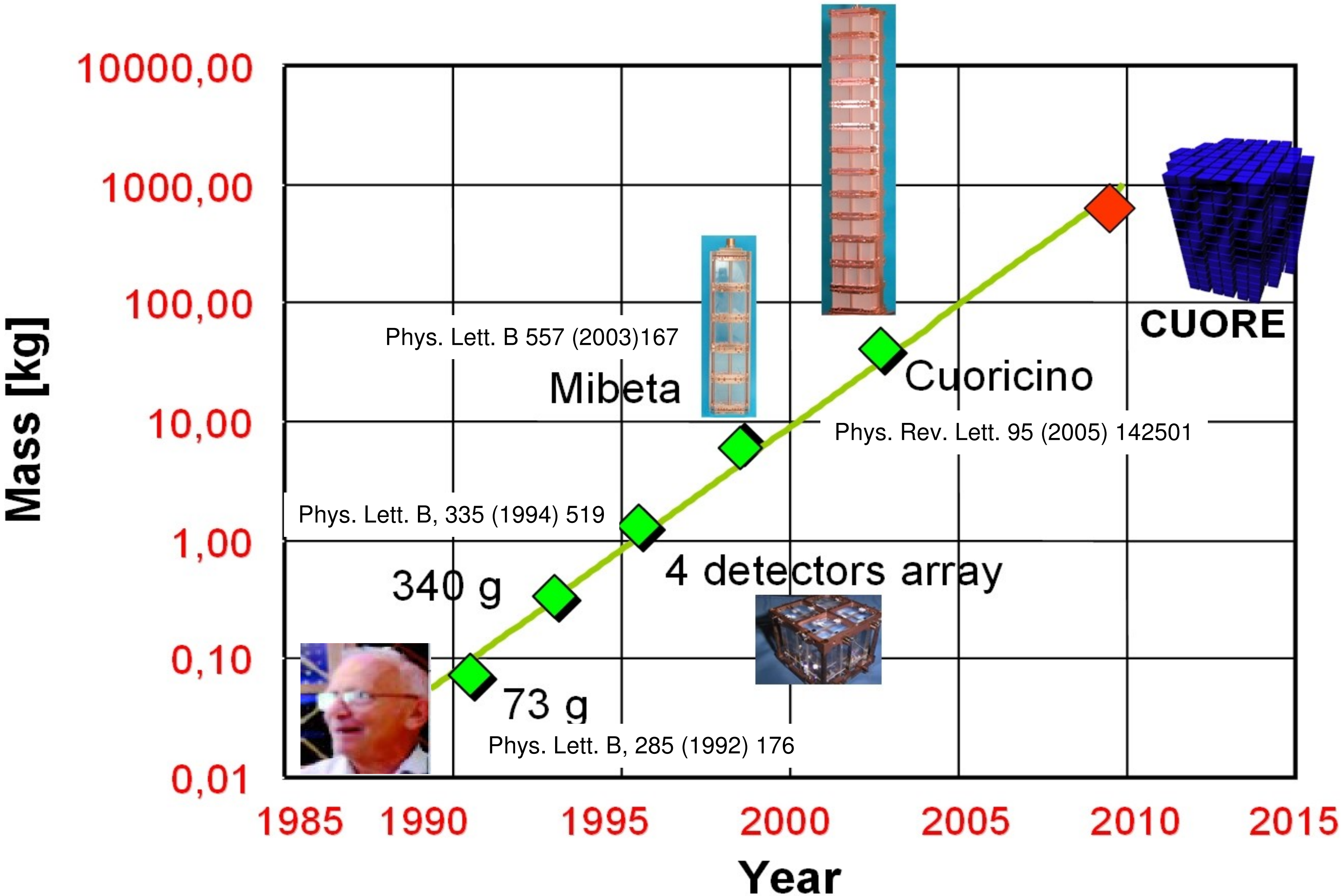


<m> range from various QRPA calculations:

Rodin, Faessler, Simkovic, & Vogel Nucl. Phys. A **766** 107 (2006)

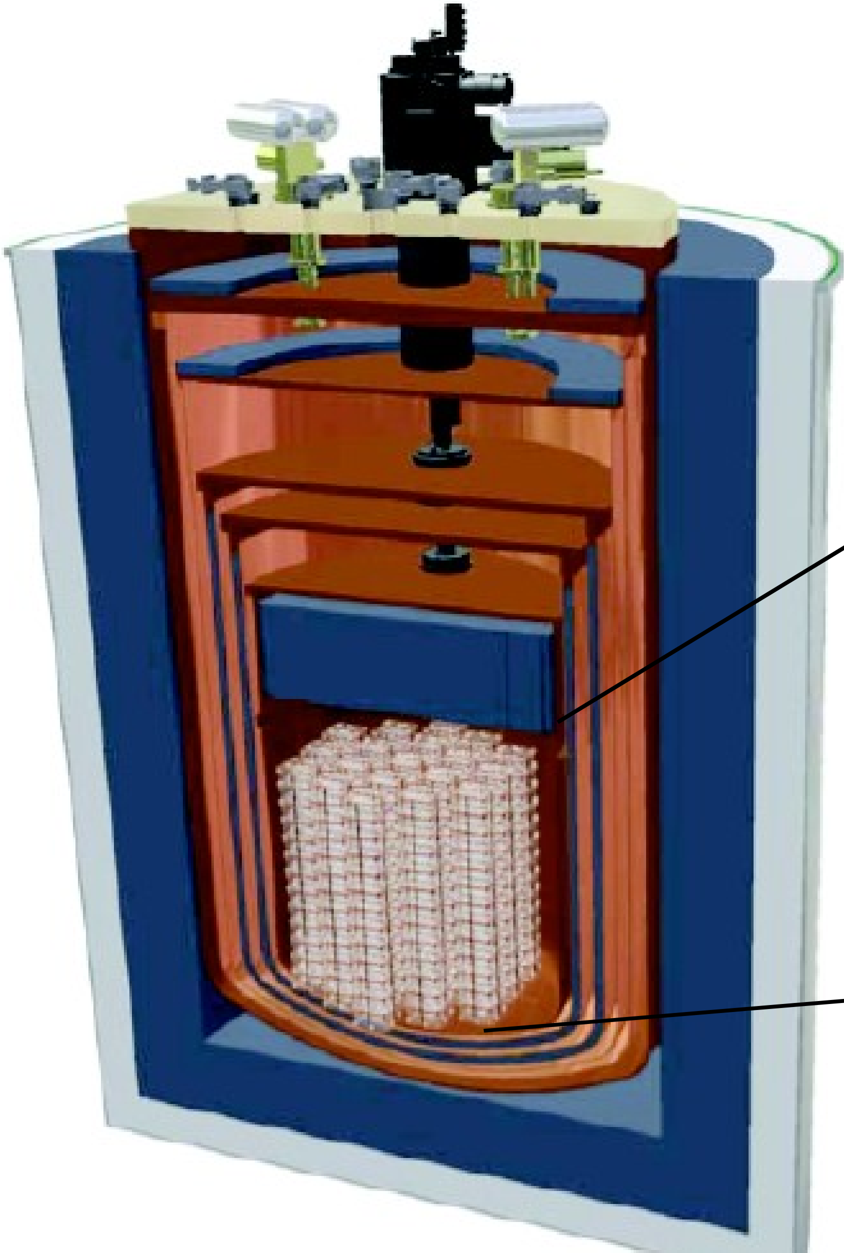
Staudt, Kuo & Klapdor-Kleingrothaus, PRC **46** 871 (1992)

The Moore's law of TeO_2 bolometers

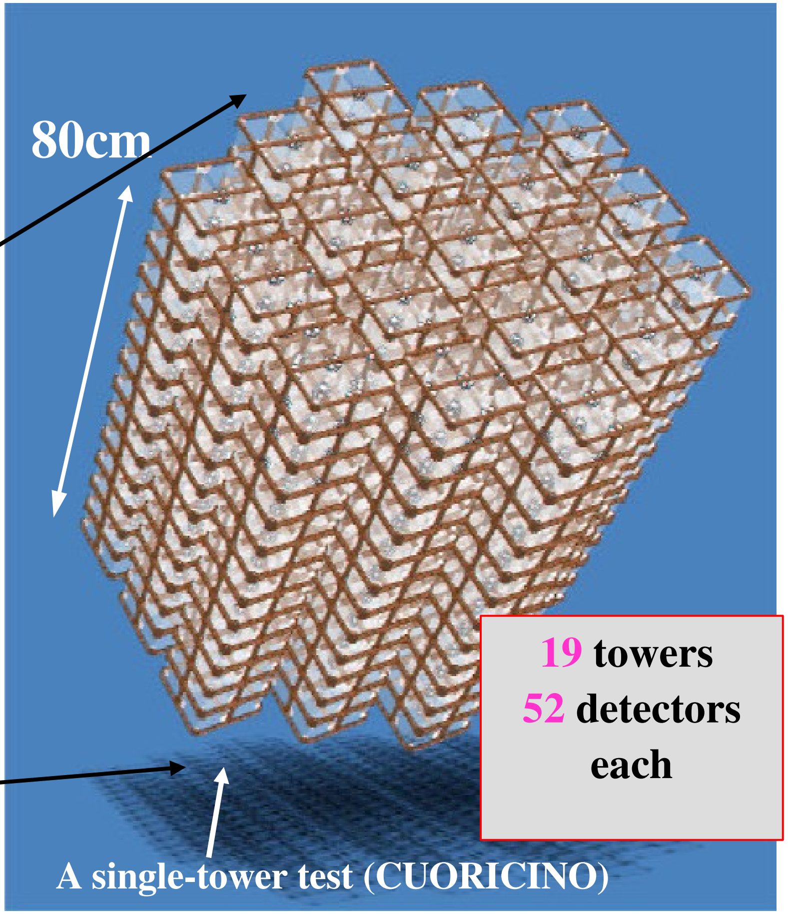


Cryogenic Underground Observatory for Rare Events

Single dilution refrigerator ~10 mk

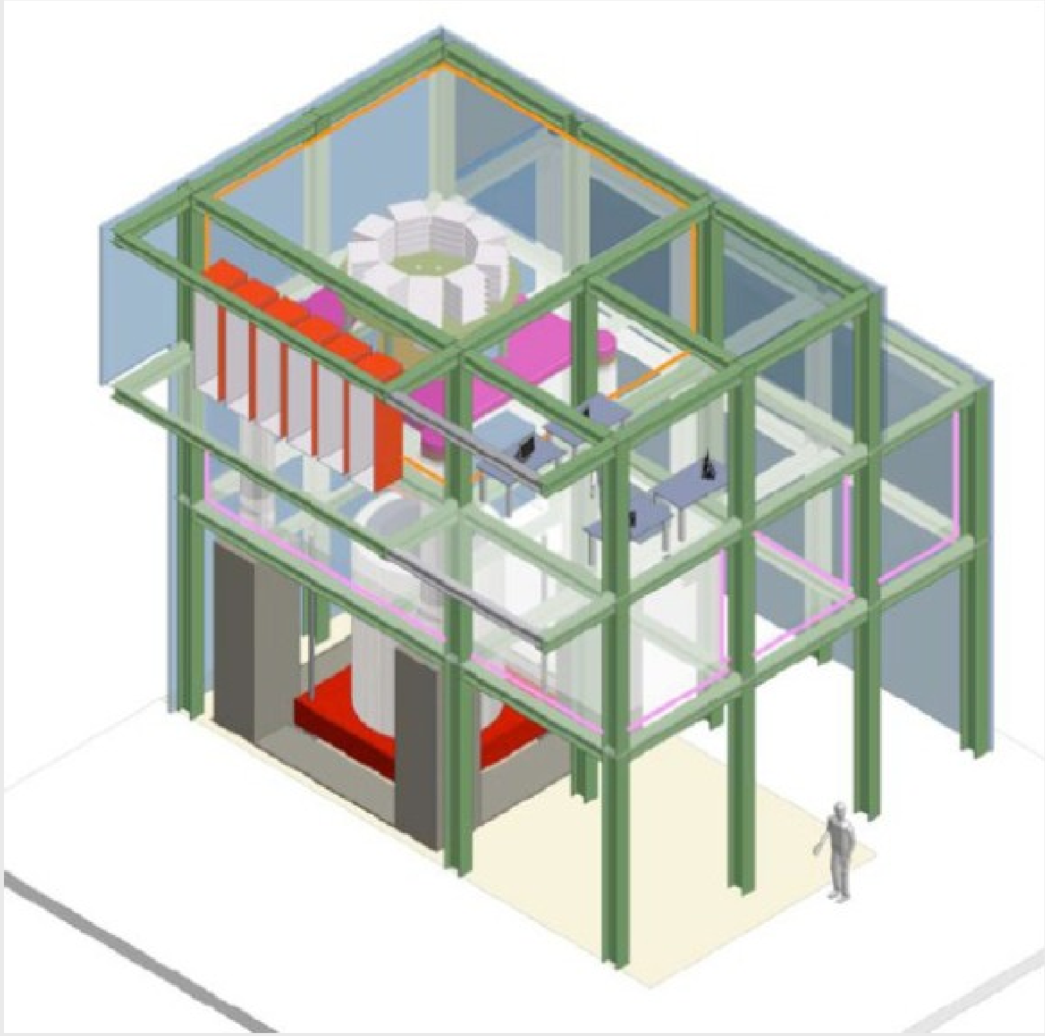


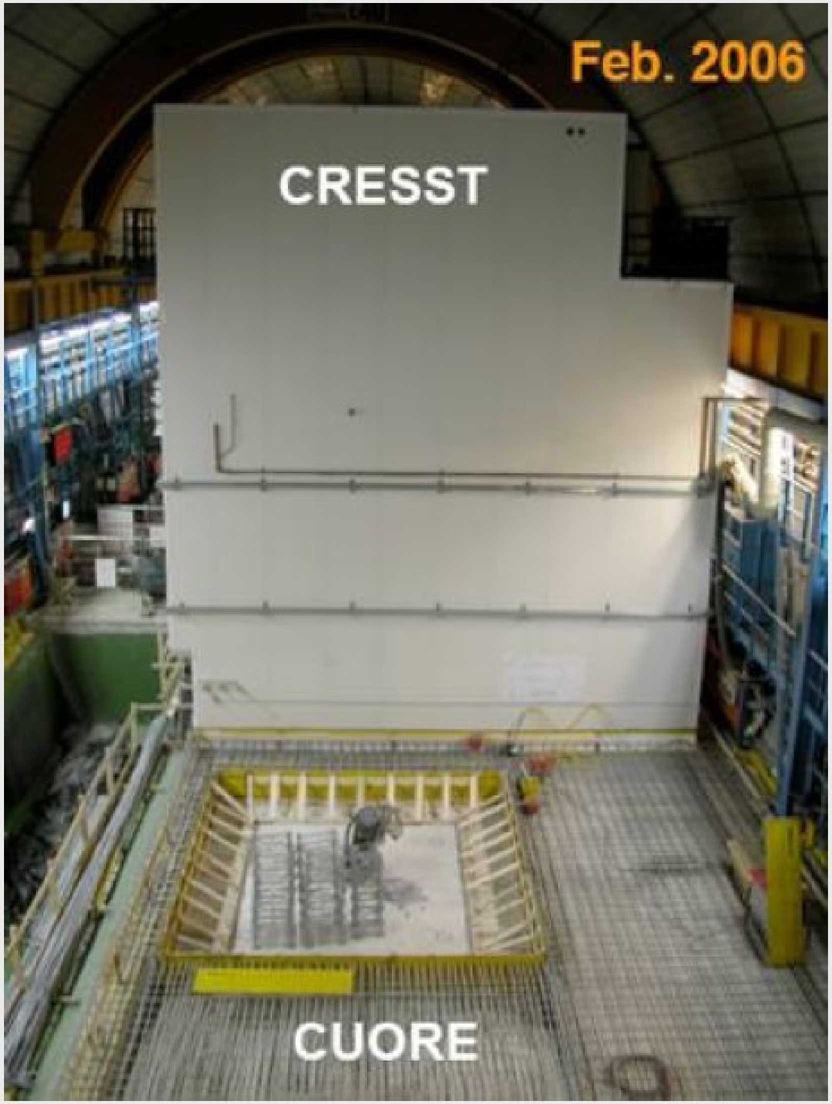
- **ββ0ν, Cold Dark Matter, Axion searches**
  proposal hep/ph 0501010



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

CUORE Housing





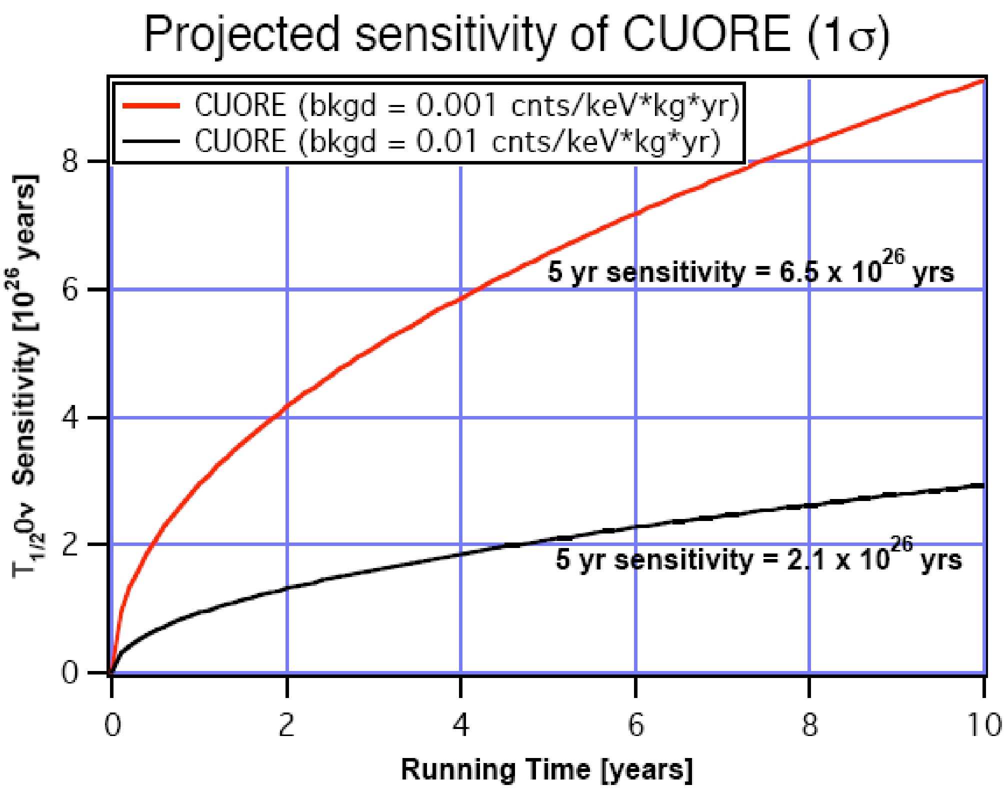
Basement already completed ... the rest is coming

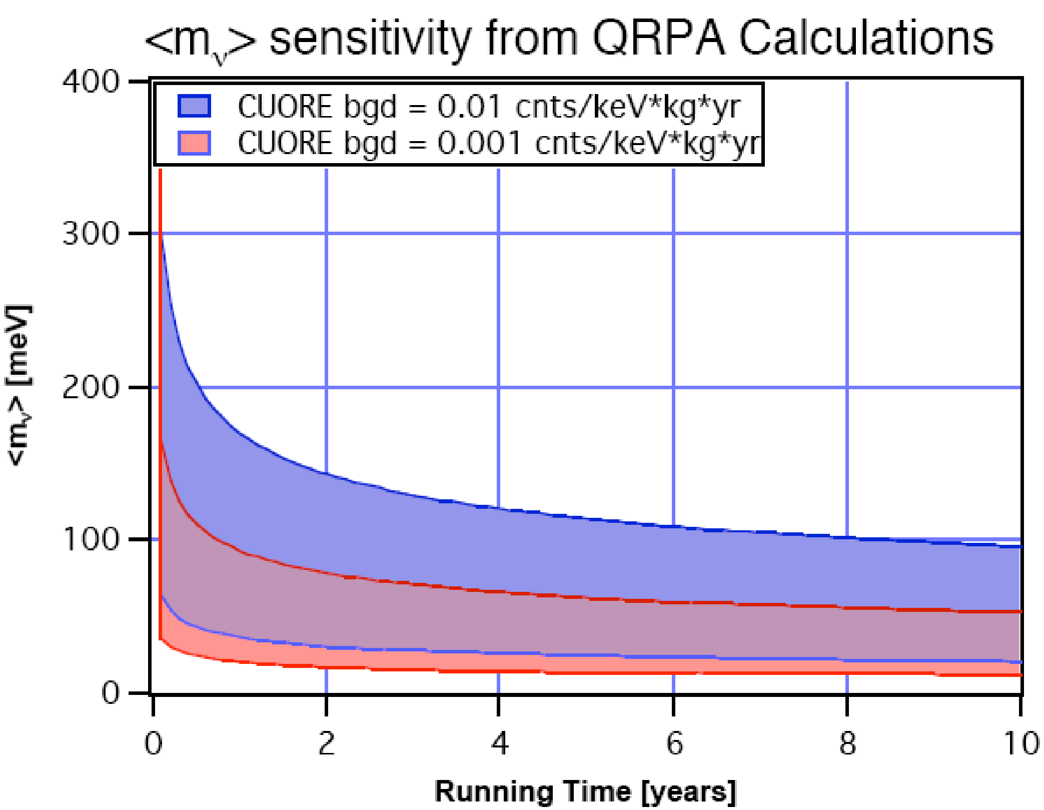
CUORE sensitivity

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

1st generation exp: proof of technology
2nd generation exp: explore inverted hierarchy

CUORE GOAL:
test inverse hierarchy: 19-50 meV



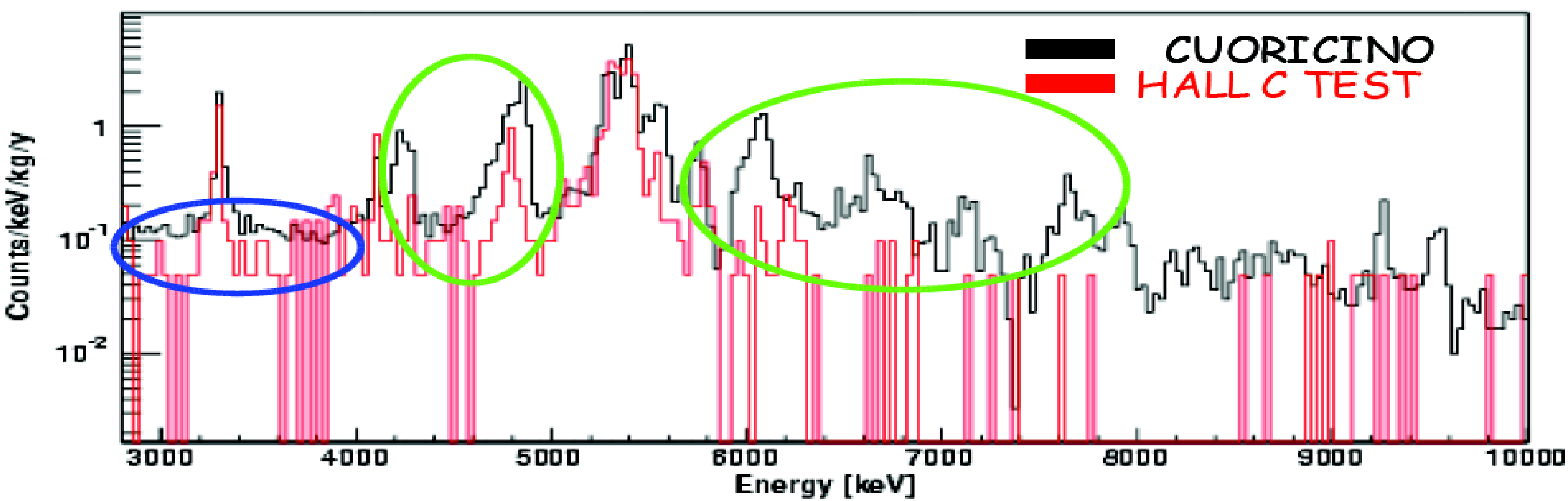


Spread due to NME uncertainties: main obstacle to answer ν mass question

Background reduction

- **Cryostat ^{232}Th bulk contamination contribution reduced by properly shielding in CUORE cryostat + selection of construction materials: bkg= < 10^{-3} c/keV/kg/y**
- **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



Hall C cryostat has different shielding than CUORICINO resulting in higher rates < 2.6 MeV. Possible to study α bkg only

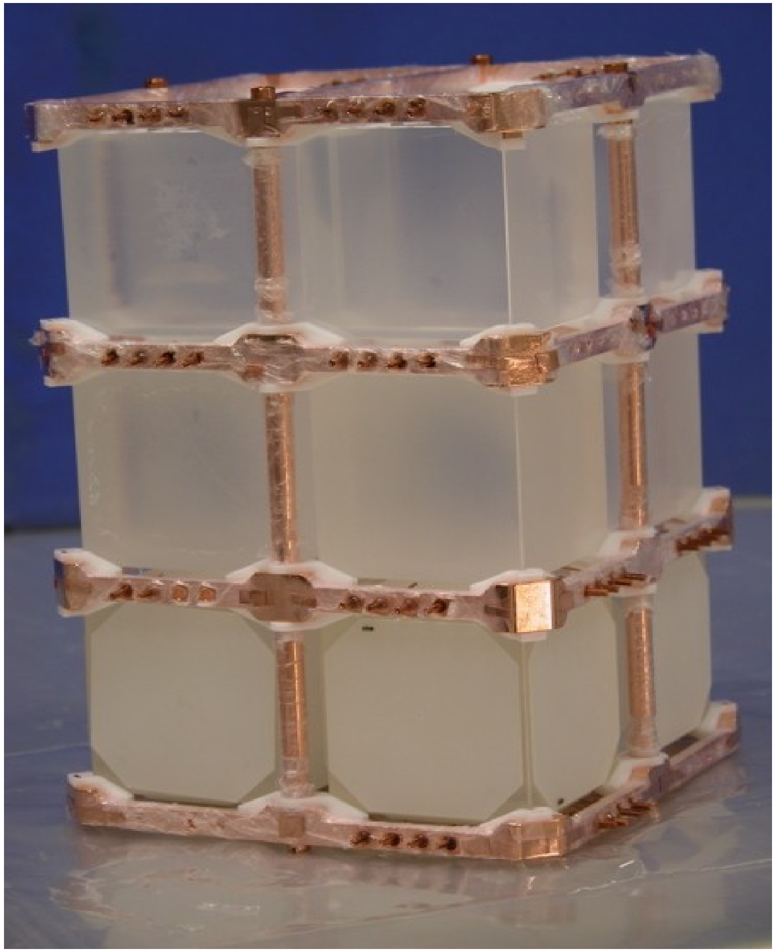
Background reduction

The extrapolated contribution to CUORE are

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

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

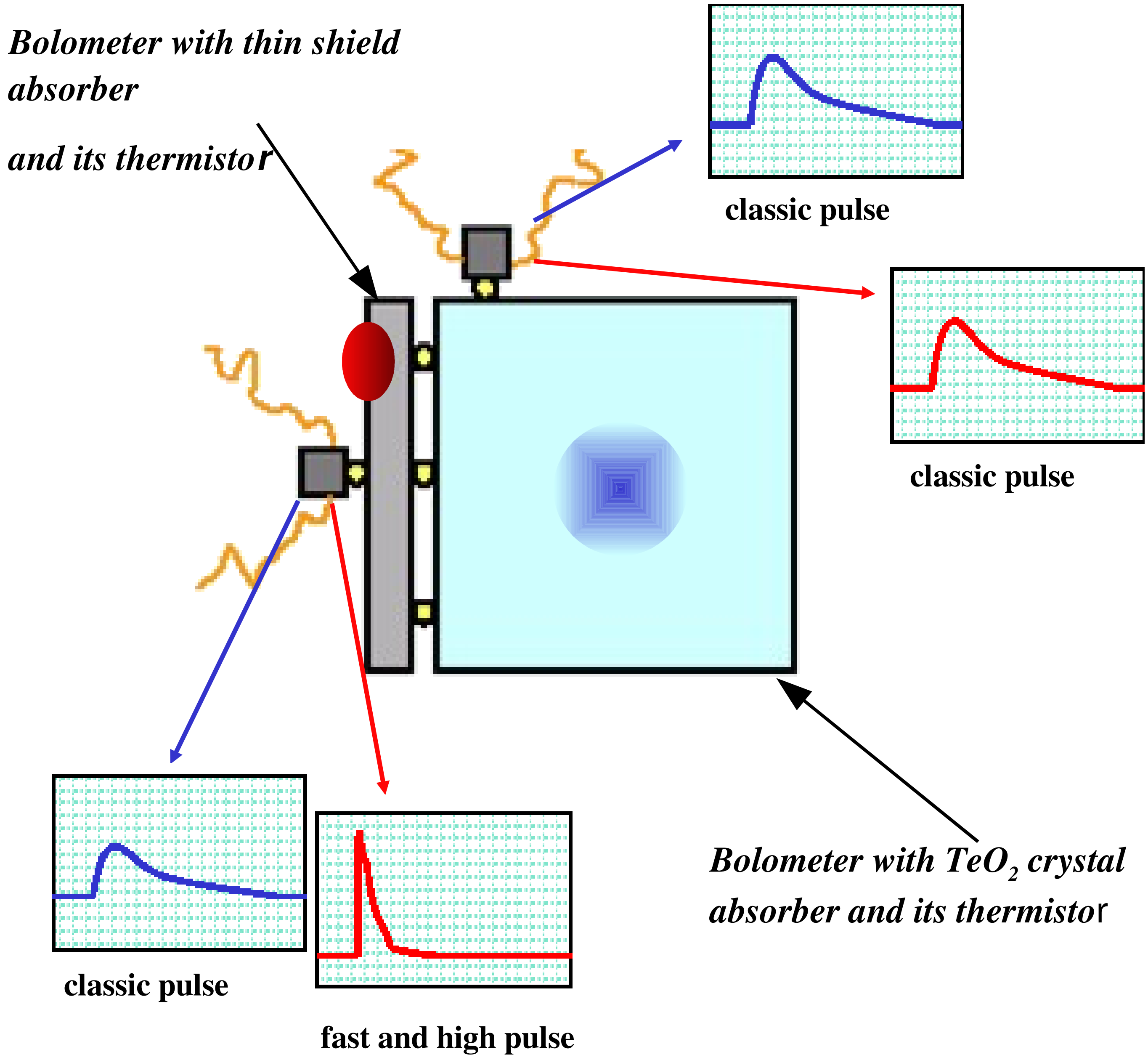
reduction of this kind of impurities

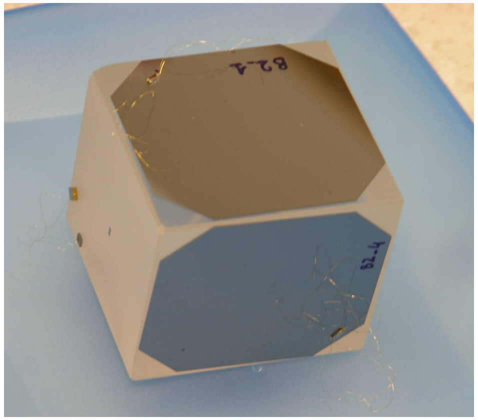
alternative viable way that guarantees

the bkg achievement= Surface Sensitive Bolometers

CUORE R&D:active bkg rejection

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

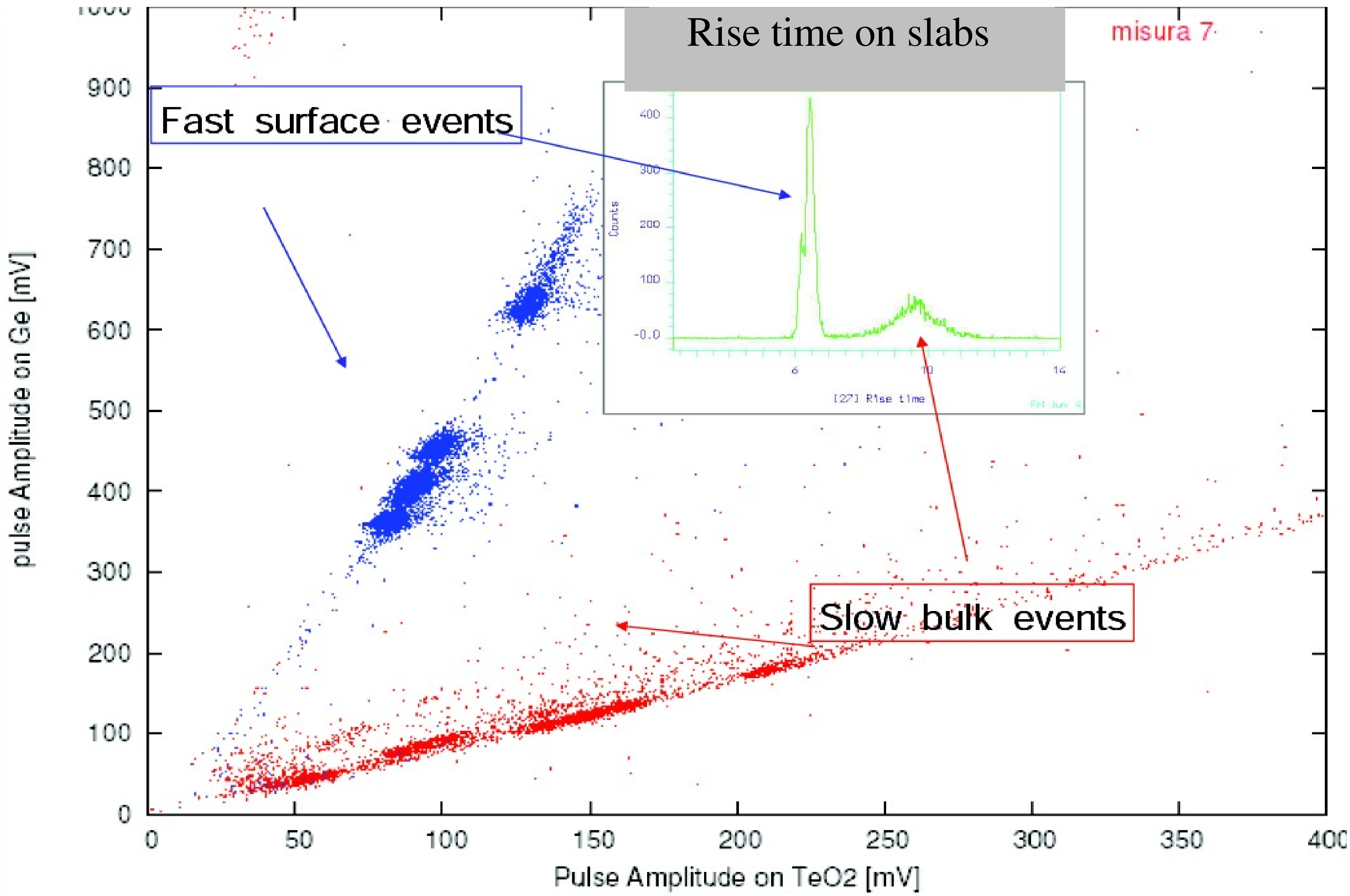




The presence of the shield changes the thermal dynamic behavior of the detector giving rise to pulses with different amplitudes and shapes.

Different impact points means different pulses on thermistors

CUORE R&D: active bkg rejection



neutron & γ background

- External neutron flux:
  - $\Phi=3.7\cdot10^{-6}$ n/s/cm^2 (measurement E<10MeV + μ-induced neutrons simulation in the rock)
  - Total anti-coicidence bkg~10^{-5} counts/keV/kg/y

- Muon-induced neutrons in the shieldings
  - muon flux $\Phi = (3.2+0.2)\cdot10^{-4}$ μ/s/m^2, induced neutron flux on detector $\Phi=(57.7\pm3.6)\cdot10^{-9}$ n/s/cm^2
  - total anti-coincidence bkg= $(1.5\pm0.3)\cdot10^{-4}$ counts/keV/kg/y

- External radiation: $\Phi=7.7\cdot10^{6}\,\gamma$/d/cm^2 measured with Ge detector

  bkg= $1.5\cdot10^{-5}$ counts/kg/keV/y with 24 cm external Pb shield

- External Pb shield contamination: 100 μBq/kg

  bkg = $2.4\cdot10^{-4}$ counts/kg/keV/y

- Internal shield
  - Roman lead contamination (6cm Pb):

    60 ± 17 μBq/kg bkg = $6\cdot10^{-3}$ counts/keV/kg/y
  - DownRun Pb <22 μBq/kg bkg < $2\cdot10^{-3}$ counts/keV/kg/y

    (but ^{60}Co contamination & 27 Bq/kg ^{210}Pb)

  - Cu shield contamination : <12 μBq

    bkg <$2.4\cdot10^{-3}$ counts/keV/kg/y

    (better for Th contamination.. worse for ^{60}Co contamination and neutron activation)

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**

CUORE Collaboration

Università di Milano-Bicocca - INFN Sez. di Milano
C. Arnaboldi, C. Brofferio,
S. Capelli, L. Carbone, M. Clemenza, O. Cremonesi,
E. Fiorini, C. Nones, A. Nucciotti, M. Pavan,
G. Pessina, S. Pirro, E. Previtali, M. Sisti, L. Torres,
L. Zanotti

Politecnico di Milano
R.Ardito, G. Maier

Laboratori Nazionali del Gran Sasso
M. Balata, C. Bucci, S. Nisi, C. Zarra

Università di Firenze e INFN, Firenze
M. Barucci, L. Risegari, G. Ventura

University of Zaragoza
S. Cebrian, P. Gorla, I.G. Irastorza

Università degli Studi dell'Insubria, Como
A. Giuliani, M. Pedretti, S. Sangiorgio

Università di Genova
S. Cuneo, S. Di Domizio, A. Giachero, E. Guardincerri,
M. Olcese, P. Ottonello, M. Pallavicini

Laboratori Nazionali di Legnaro
V. Palmieri

Università di Roma
F. Bellini, C. Cosmelli, I. Dafinei, M. Diemoz, F. Ferroni,
C. Gargiulo, E. Longo, S. Morganti, M. Vignati

University of California at Berkeley
S.J. Freedman,
Yu.G. Kolomensky, E.E. Haller

University of South Carolina
F.T. Avignone III, I. Bandac, R. J. Creswick,
H.A. Farach, C. Martinez, C. Rosenfeld

Lawrence Berkeley National Laboratory
J.W. Beeman, A.R. Smith, N. Xu

Lawrence Livermore National Laboratory
M.J. Dolinski, E.B. Norman

University of California, Los Angeles
H. Huang, C. Whitten Jr.

University of Wisconsin, Madison
K.M. Heeger, R.H. Maruyama

California Polytechnic State University
T.D. Gutierrez

Università di Milano-Celoria - INFN Sez. di Milano
F. Alessandria