CUORE: neutrinoless double beta decay with bolometers

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On behalf of the CUORE Collaboration

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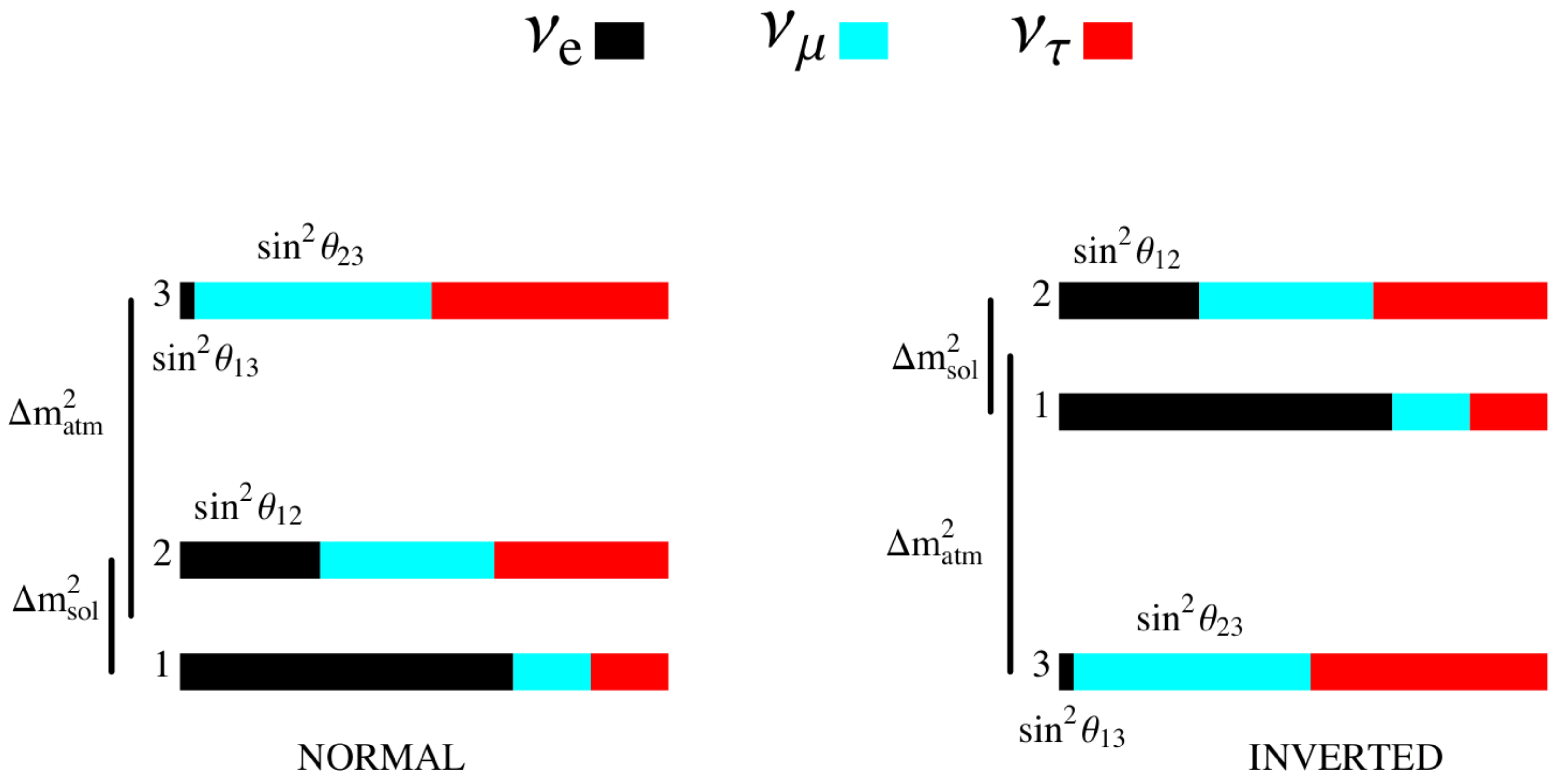
Neutrino Open Questions



- ➔ θ_{13}
- ➔ CP violation
- ➔ Absolute mass scale
- ➔ Mass hierarchy
- ➔ Dirac / Majorana neutrinos

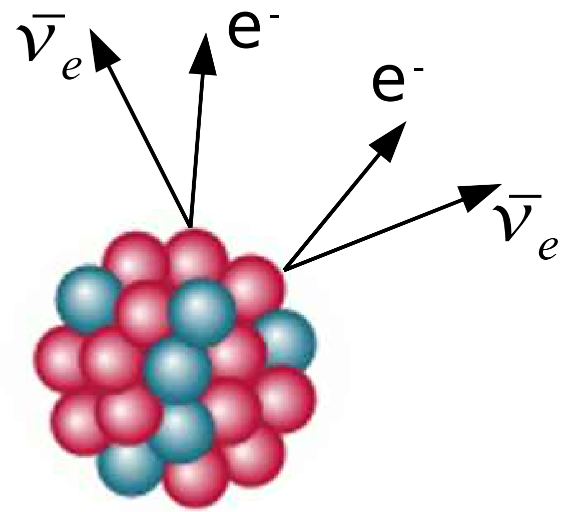
} **Can be addressed by double beta decay experiments**

Double Beta Decay

DBD is a rare process in which a nucleus changes its atomic number by 2 units

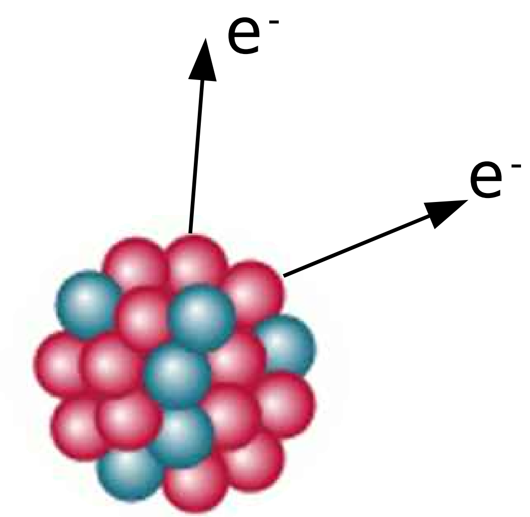
$\beta\beta 2\nu$: $(A,Z) \rightarrow (A,Z+2) + 2e^{-} + 2\bar{\nu}$

- Allowed by SM
- Observed for several isotopes

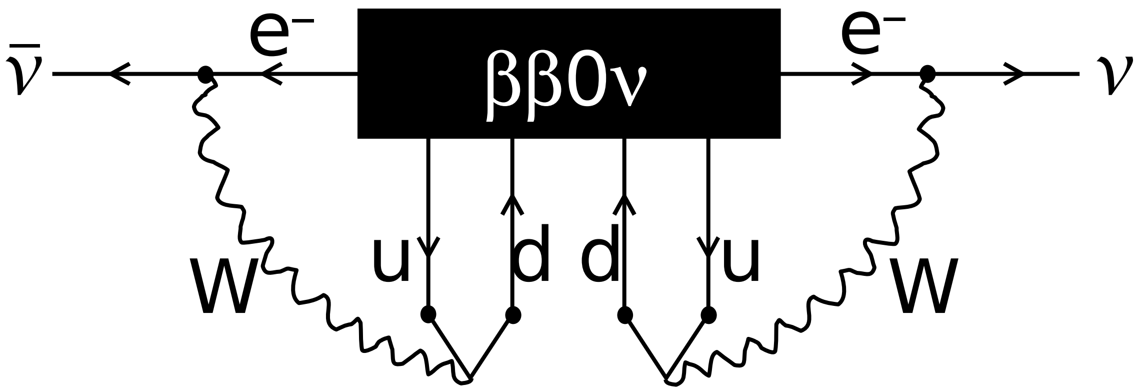


$\beta\beta 0\nu$: $(A,Z) \rightarrow (A,Z+2) + 2e^{-}$

- Forbidden in SM
- Requires Majorana neutrinos
- $\Delta L = 2$
- Never observed



Underlying process

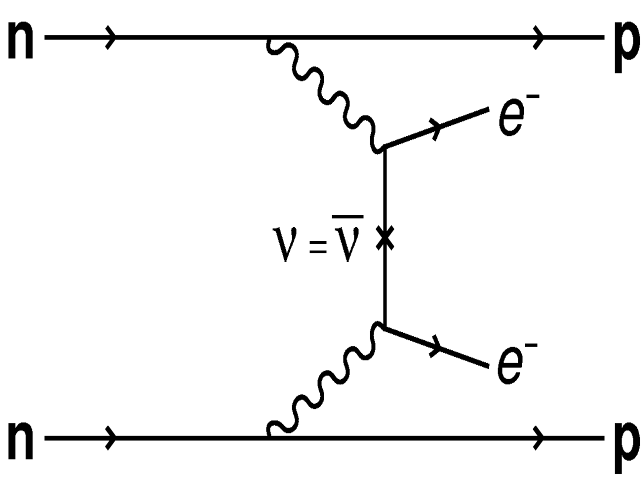


Observation of ββ0ν would prove with no doubt that neutrinos are Majorana particles

(Schechter and Valle, 1982)

Inference on neutrino mass requires assumptions on the decay mechanism

Simplest assumption:
light Majorana ν exchange



Phase space

Nuclear matrix element

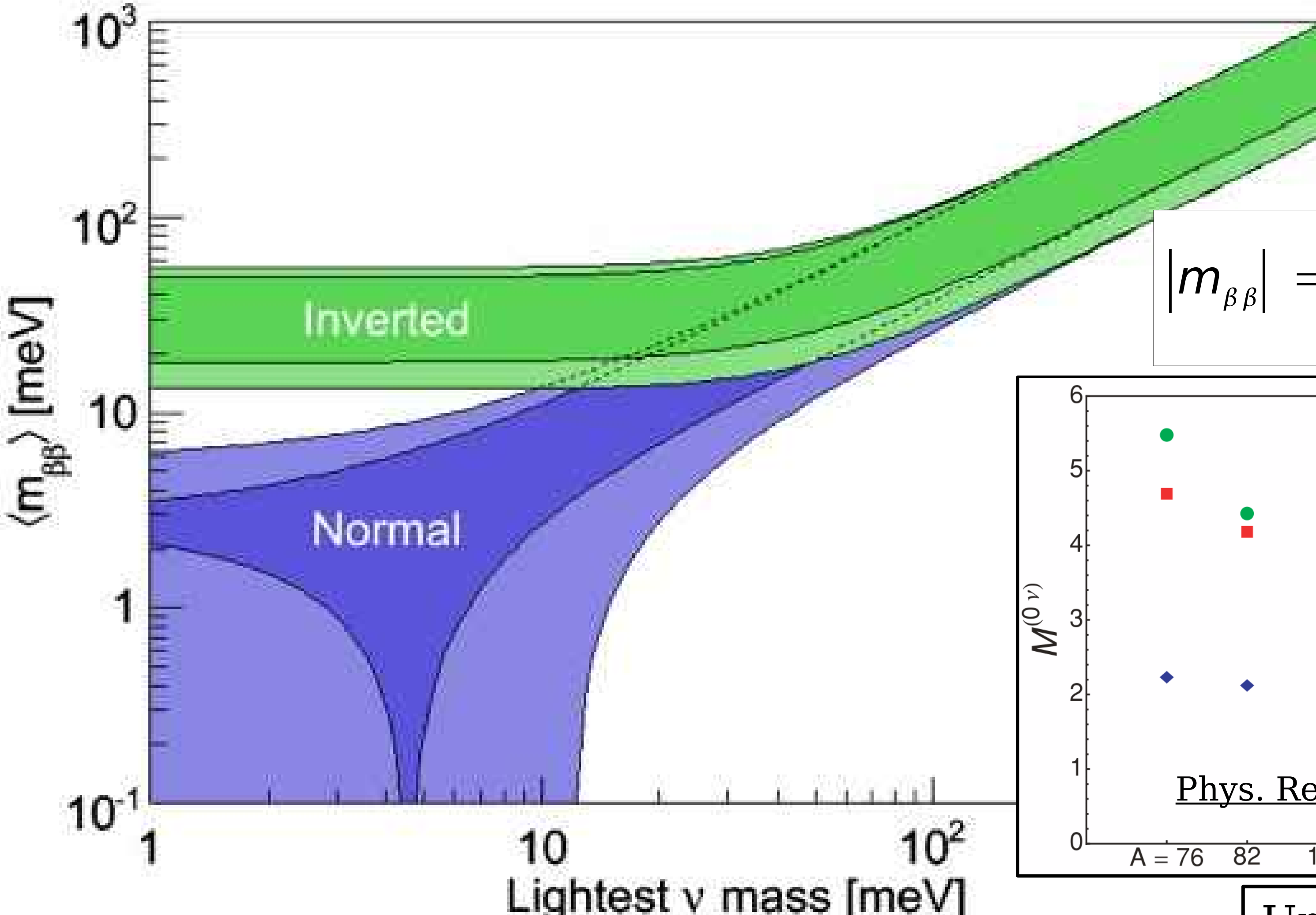
$$\Gamma^{0\nu} = \frac{1}{T_{1/2}^{0\nu}} = G(Q,Z)\ \left|M^{0\nu}\right|^2\ \left|m_{\beta\beta}\right|^2$$

Effective Majorana mass

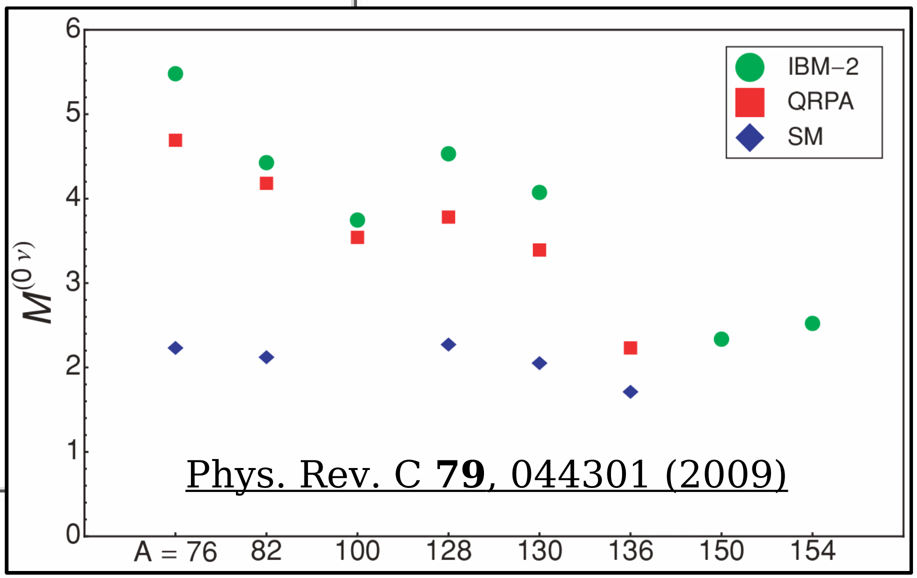
$$\left|m_{\beta\beta}\right| = \left|\sum_j \left|U_{ej}\right|^2 e^{i\phi_j} m_j\right|$$

Light Majorana neutrino exchange

$m_{\beta\beta}$ can be expressed as a function of the mass of the lightest neutrino using the measured values of the mixing angles and of the two mass splittings



$$|m_{\beta\beta}| = \frac{1}{|M^{0\nu}|\sqrt{T^{0\nu}_{1/2}\ G(Q,Z)}}$$



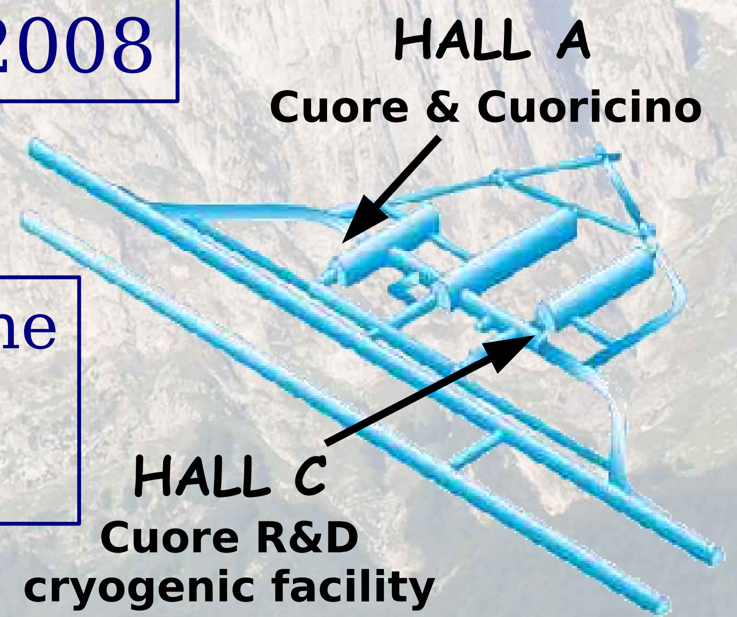
Uncertainties from NME

CUORE and CUORICINO

CUORE and **CUORICINO** use the bolometric technique to search for ββ0ν in ^{130}Te

CUORE will be able to span the inverted mass-hierarchy region

CUORICINO is a small prototype that took data in the years 2003-2008

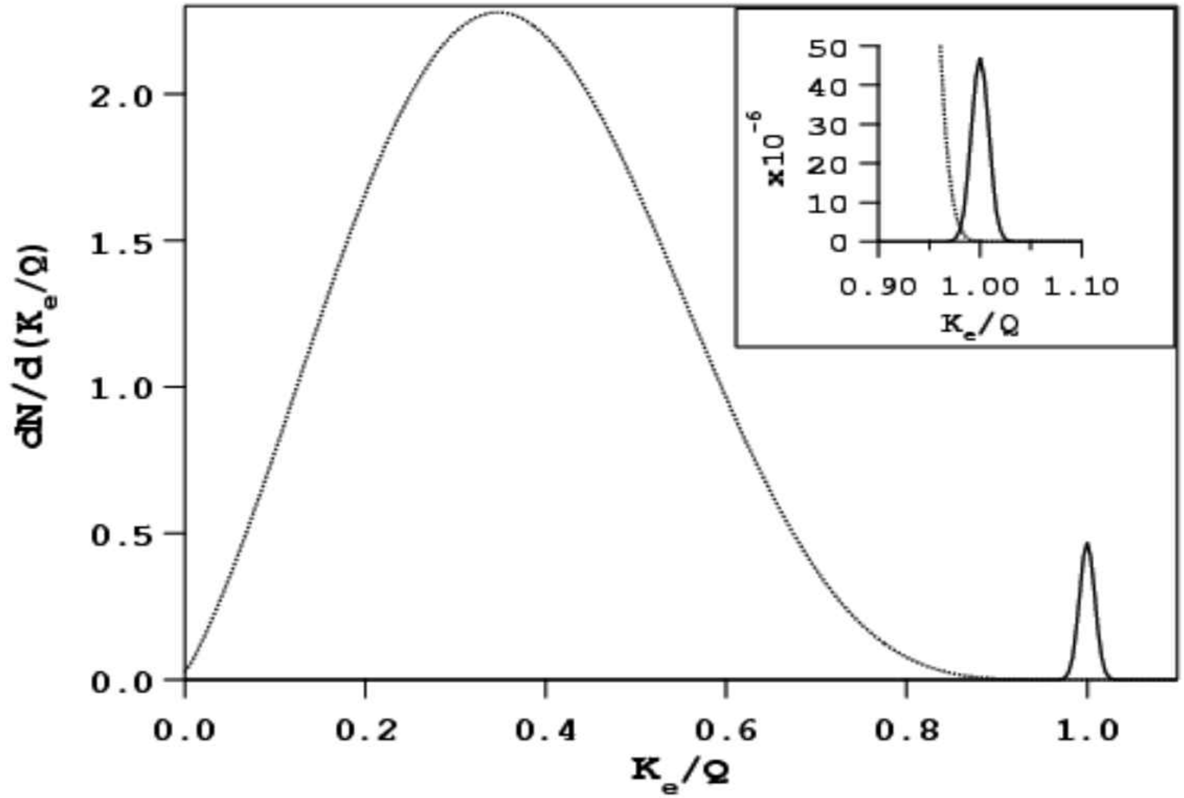


Experiments located underground at the Laboratori Nazionali del Gran Sasso
3400 m w.e. rock shield against CR

$\beta\beta 0\nu$ experimental features

Signature:

monochromatic line at the Q-value of the decay



Sensitivity:

$T_{1/2}$ corresponding to the minimum number of detectable events above background

detector mass

isotopic abundance

live time

$$S^{0\nu} \propto a \cdot \sqrt{\frac{M\,t}{b\,\Delta E}}$$

Background counts

energy resolution

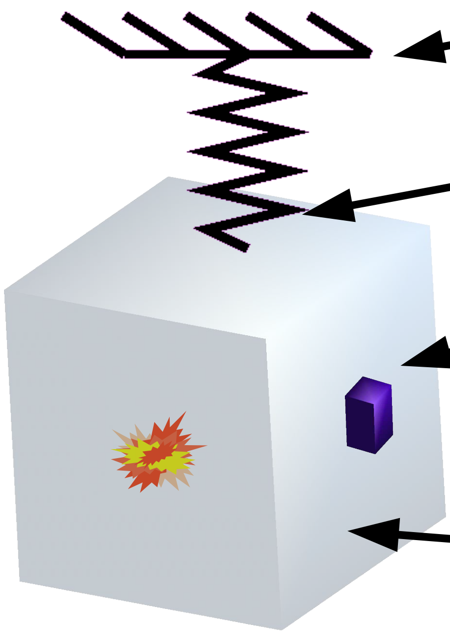
Key features:

- good energy resolution
- big mass
- low background

Bolometers

Working Principle:
measure the temperature rise of the energy absorber

$$\Delta T = \frac{E}{C}$$ requires low temperature and low heat capacity

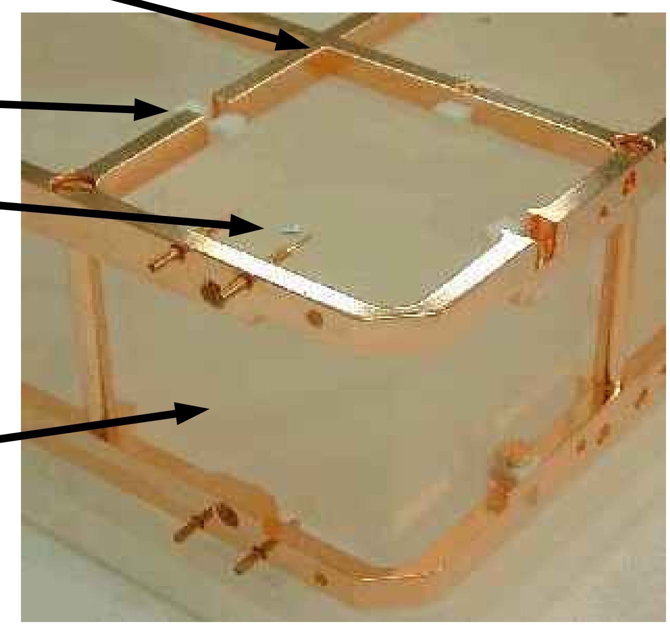


Heat bath
(~ 8 mK)

Thermal coupling

Sensor
NTD Ge thermistor
R ~ 100 MΩ
dR/dT ~ 0.1MΩ/μK

Absorber
TeO_2 crystal
m ~ 790 g
ΔT/E ~ 0.2 mK/MeV



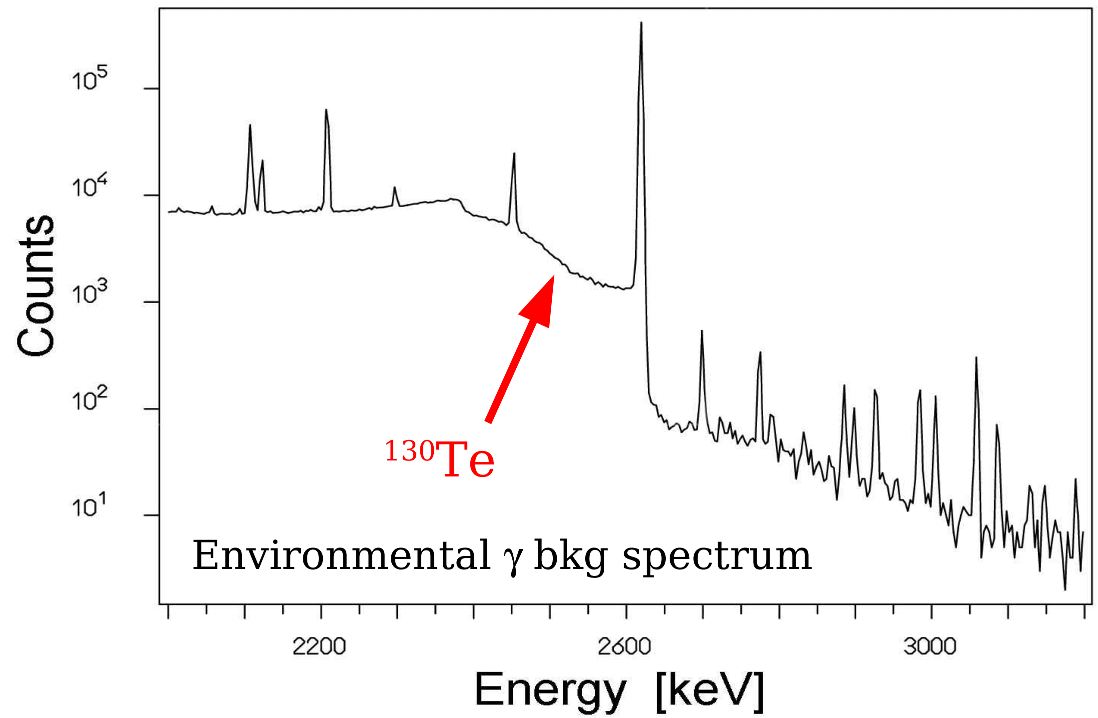
Typical ouptut signal: 100 μV per MeV of released energy

TeO_2 Bolometers for $\beta\beta 0\nu$

CUORE and **CUORICINO** use TeO_2 crystals: source ≡ detector

- High isotopic abundance: 34%
- High Q-value: 2527 keV
- Easy to grow big crystals with low radioactive contaminations
- good mechanical properties at low temperature
- Low heat capacity

$$^{130}Te \rightarrow {}^{130}Xe + 2e^-$$



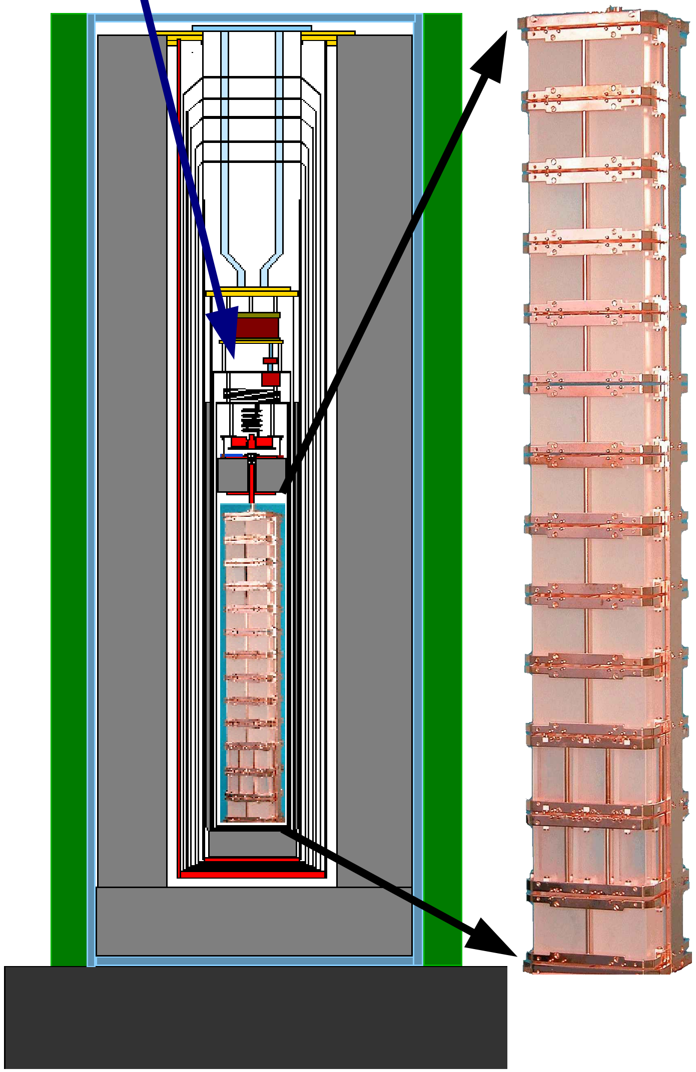
$Q_{\beta\beta}(^{130}Te)$

- 2530.3 ± 2.0 keV
- 2527.01 ± 0.32 keV   arXiv:0902.2376 (2009)
- 2527.518 ± 0.013 keV   PRL **102**, 212502 (2009)

CUORICINO detector

Diluition refrigerator

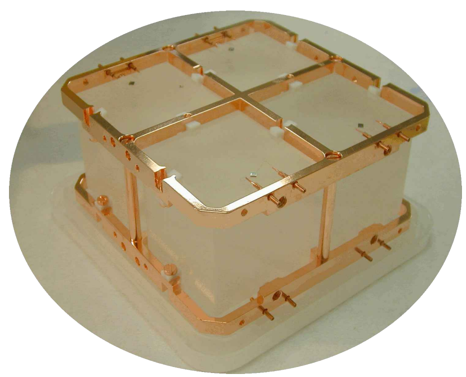
(Coldest point ~ 8mK)



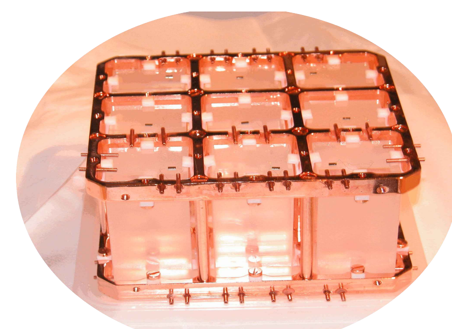
62 TeO_2 crystals

Total mass: 42 Kg (11.8 Kg in ^{130}Te)

11 floors of 4 crystals
- Mass: 790 g
- Dimensions: 5x5x5 cm^3
- not enriched



2 floors of 9 crystals
- Mass: 330g
- Dim: 3x3x6 cm^3
- 2 enriched in ^{128}Te (82%)
- 2 enriched in ^{130}Te (75%)



Shielding

Internal (600 mK):

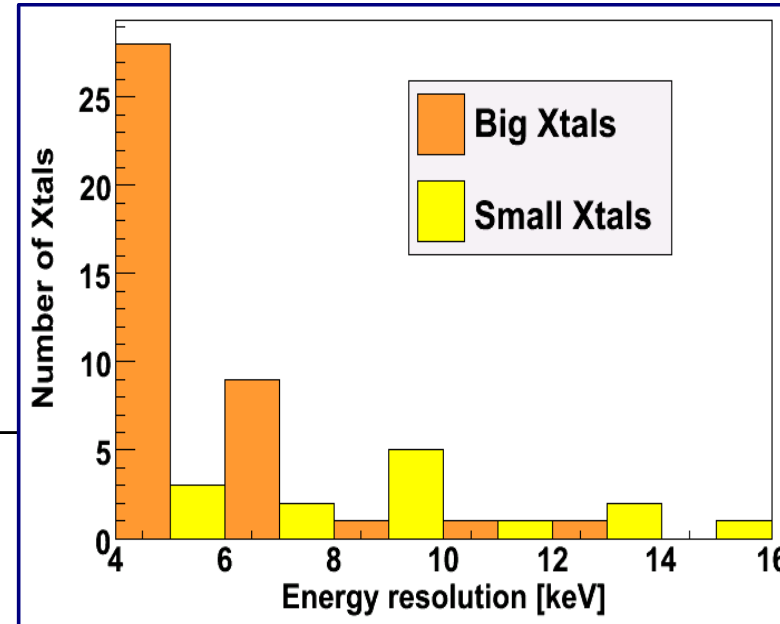
➔1cm low activity Pb
(A < 4 mBq/Kg in ^{210}Pb)

External:

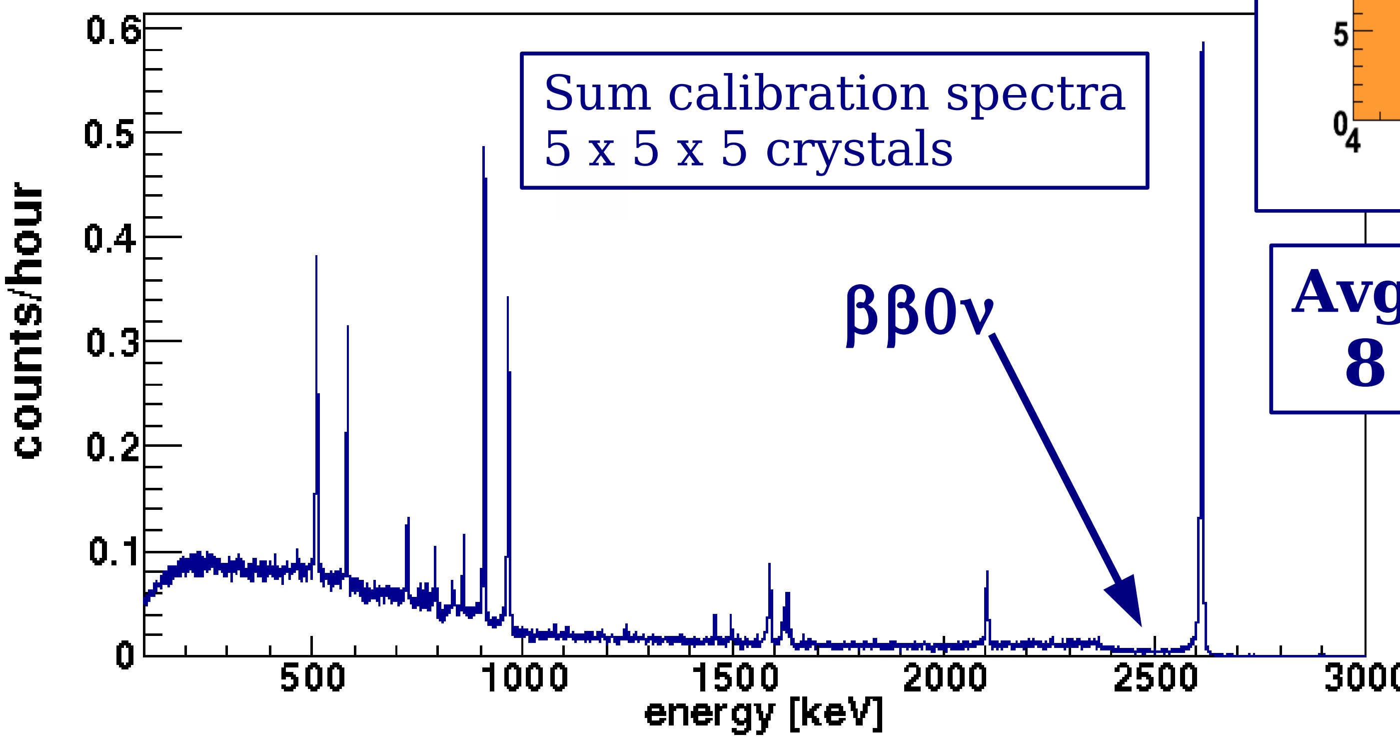
➔20cm Pb
➔20cm Borated Polyethylene
➔Anti-Rn box: Nitrogen overpressure

CUORICINO Calibration

3 days per month:
^{232}Th source



Avg FWHM resolution
8 keV @ 2615keV



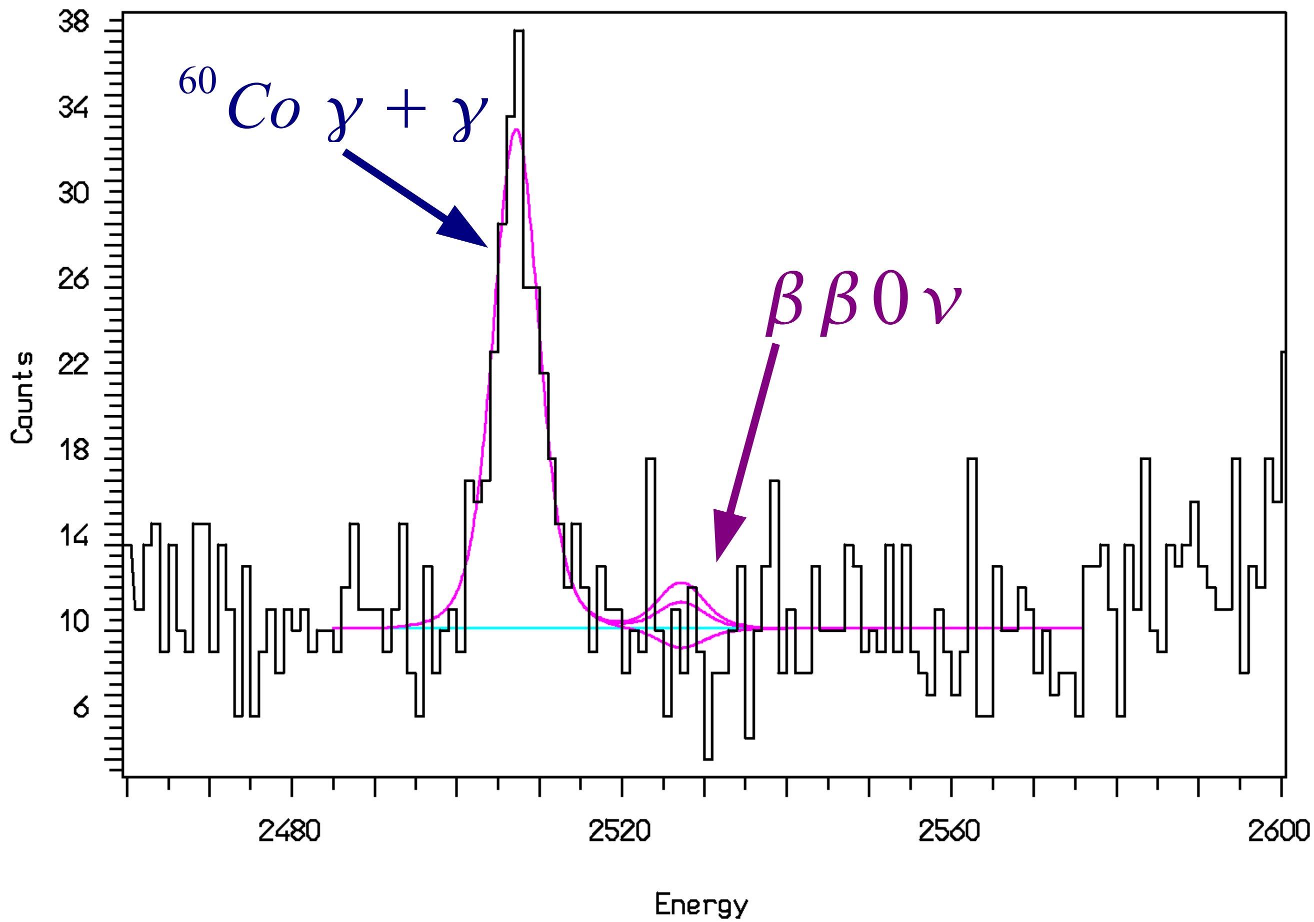
CUORICINO Results

Statistics

M·t = 18 kg·y in ^{130}Te

Background

0.18 counts/keV/kg/yr



No signal found

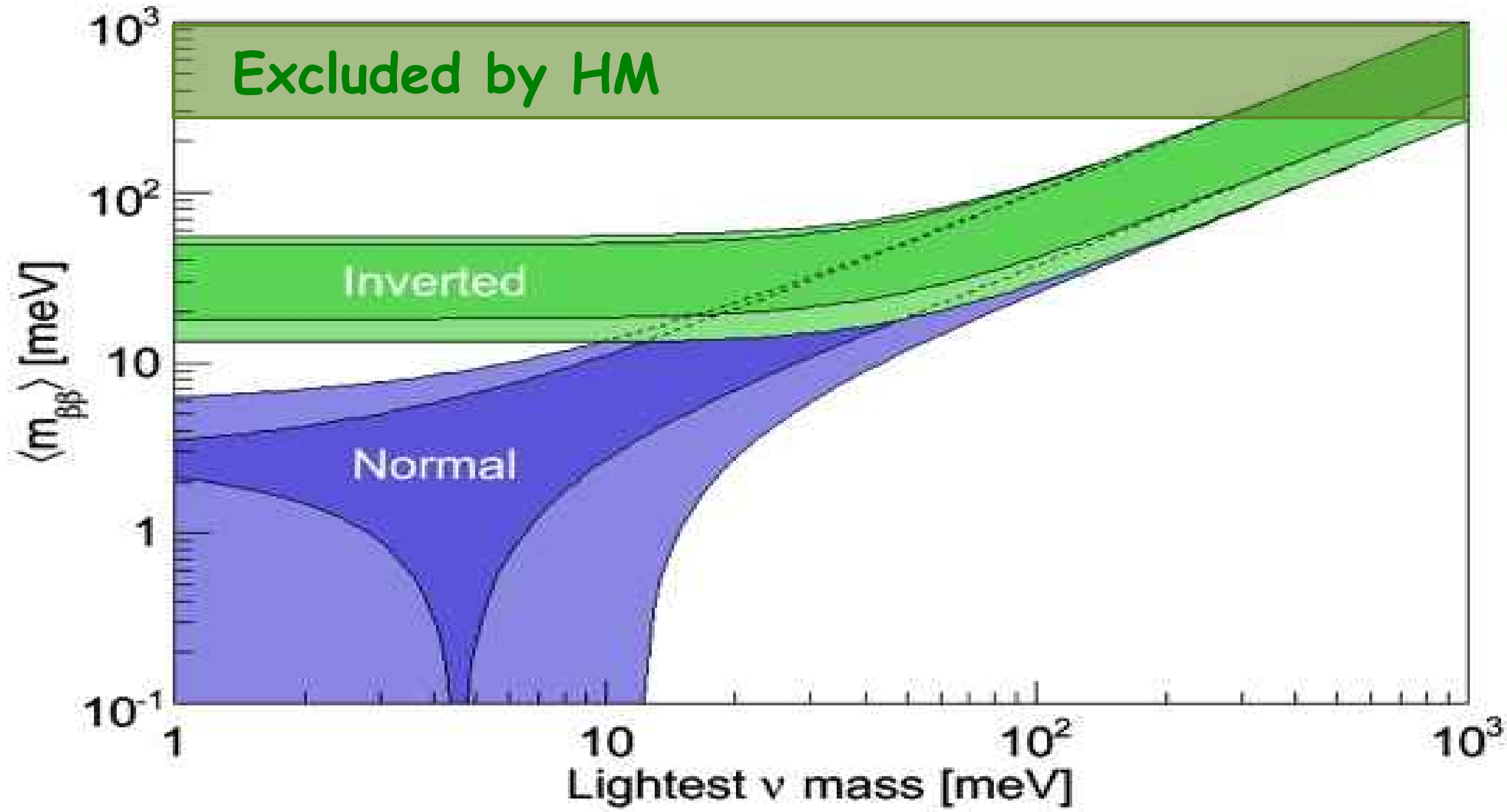
$$T_{1/2}^{0\nu} > 2.94 \cdot 10^{24}\ y\ @90\%\ C.L.$$

$$\langle m_{\beta\beta} \rangle < 0.21 \div 0.7\ \text{eV}$$

(NME from *Nucl. Phys. A* **766** *(2006)* + erratum *nucl-th/0706.4304*)

CUORICINO Sensitivity

CUORICINO sensitivity is comparable to the one obtained with HPGe semiconductor detectors (Heidelberg-Moscow)



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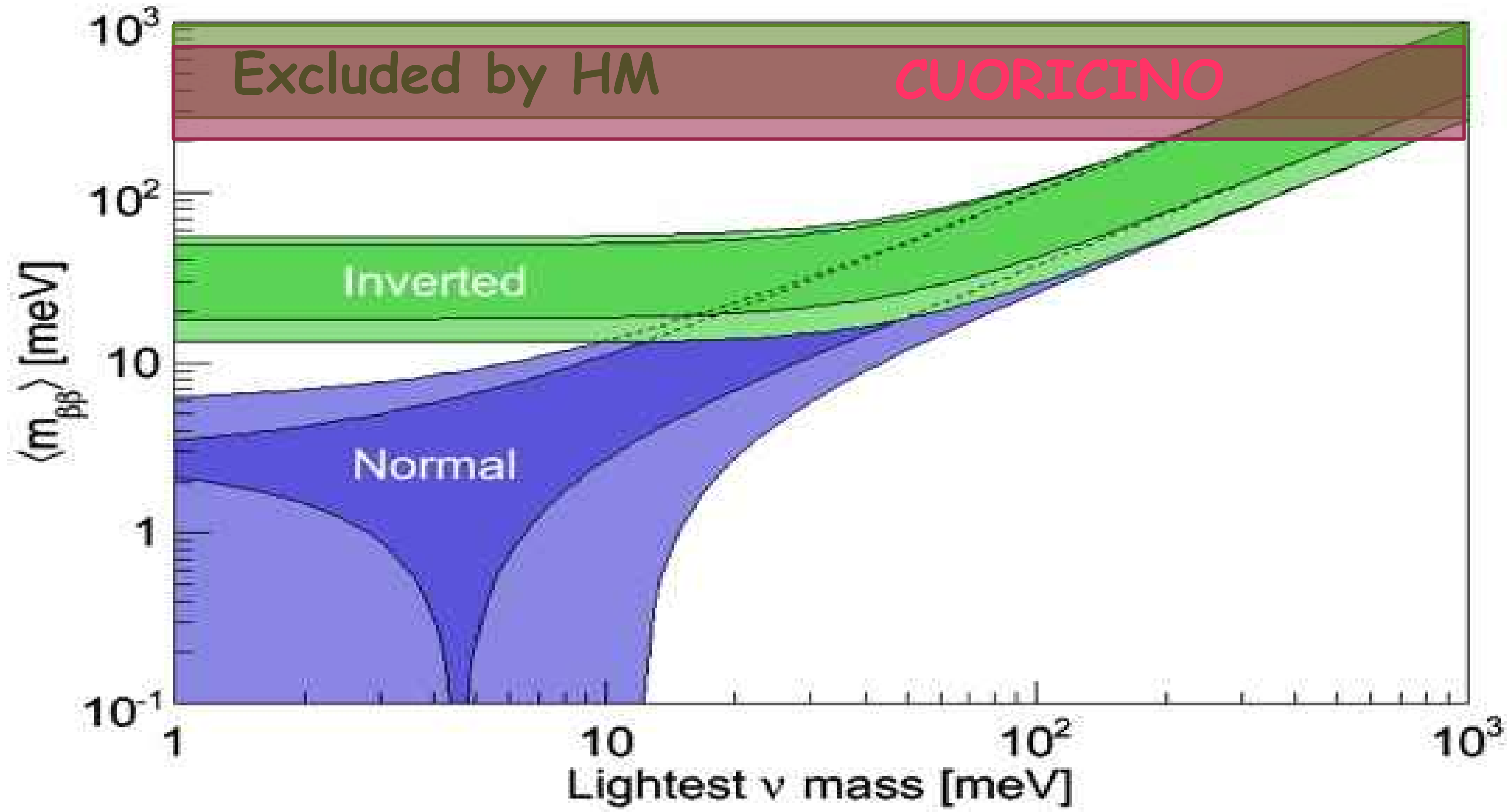
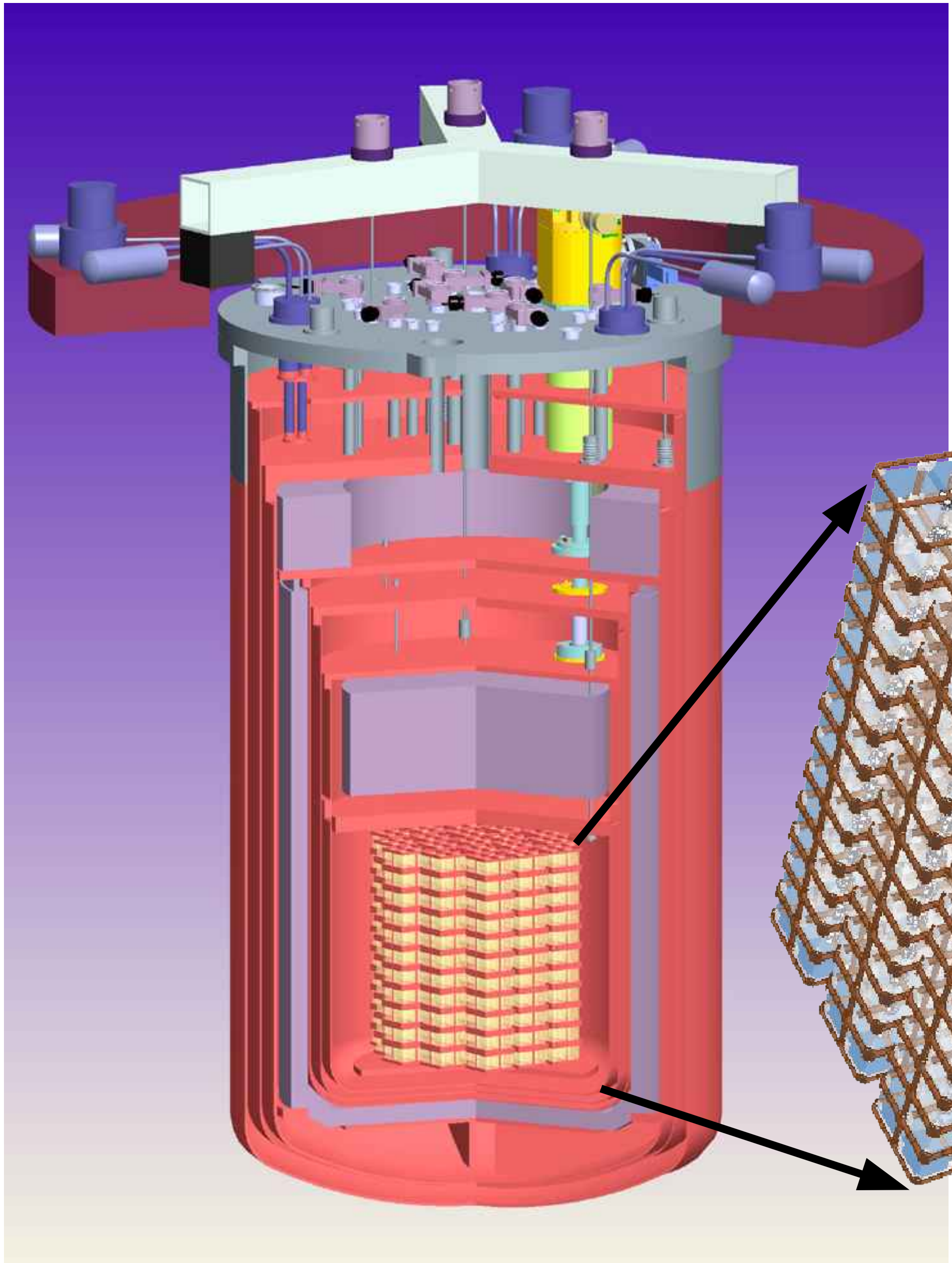
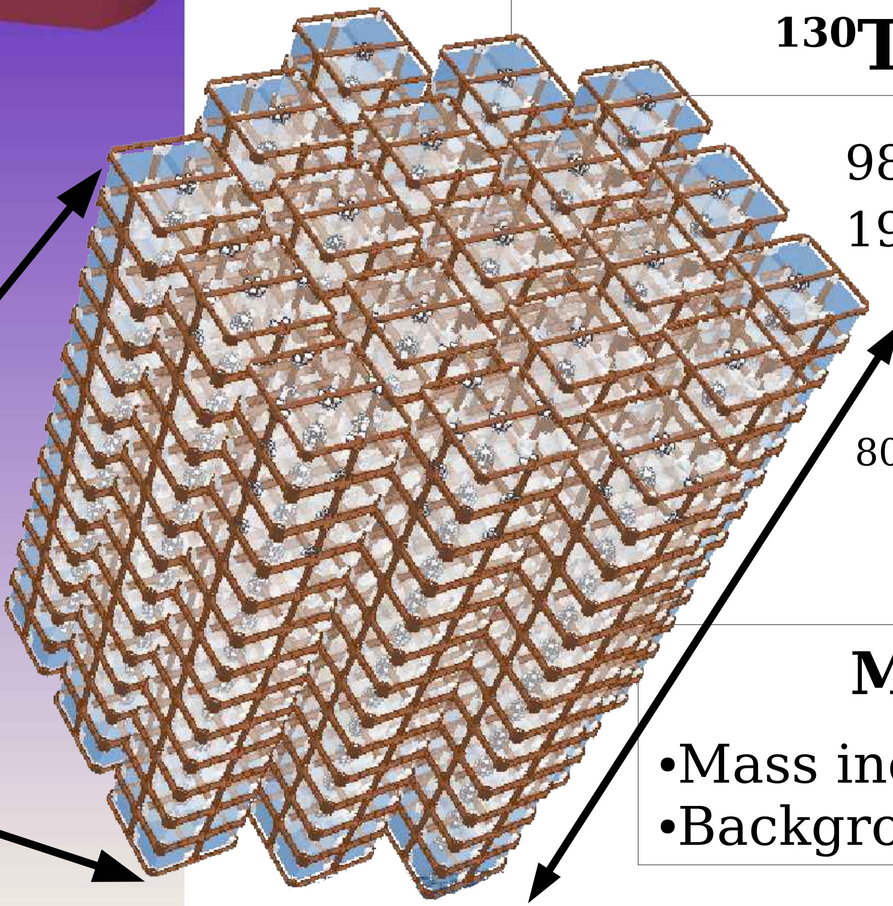


CUORE

Cryogenic Underground Observatory for Rare Events





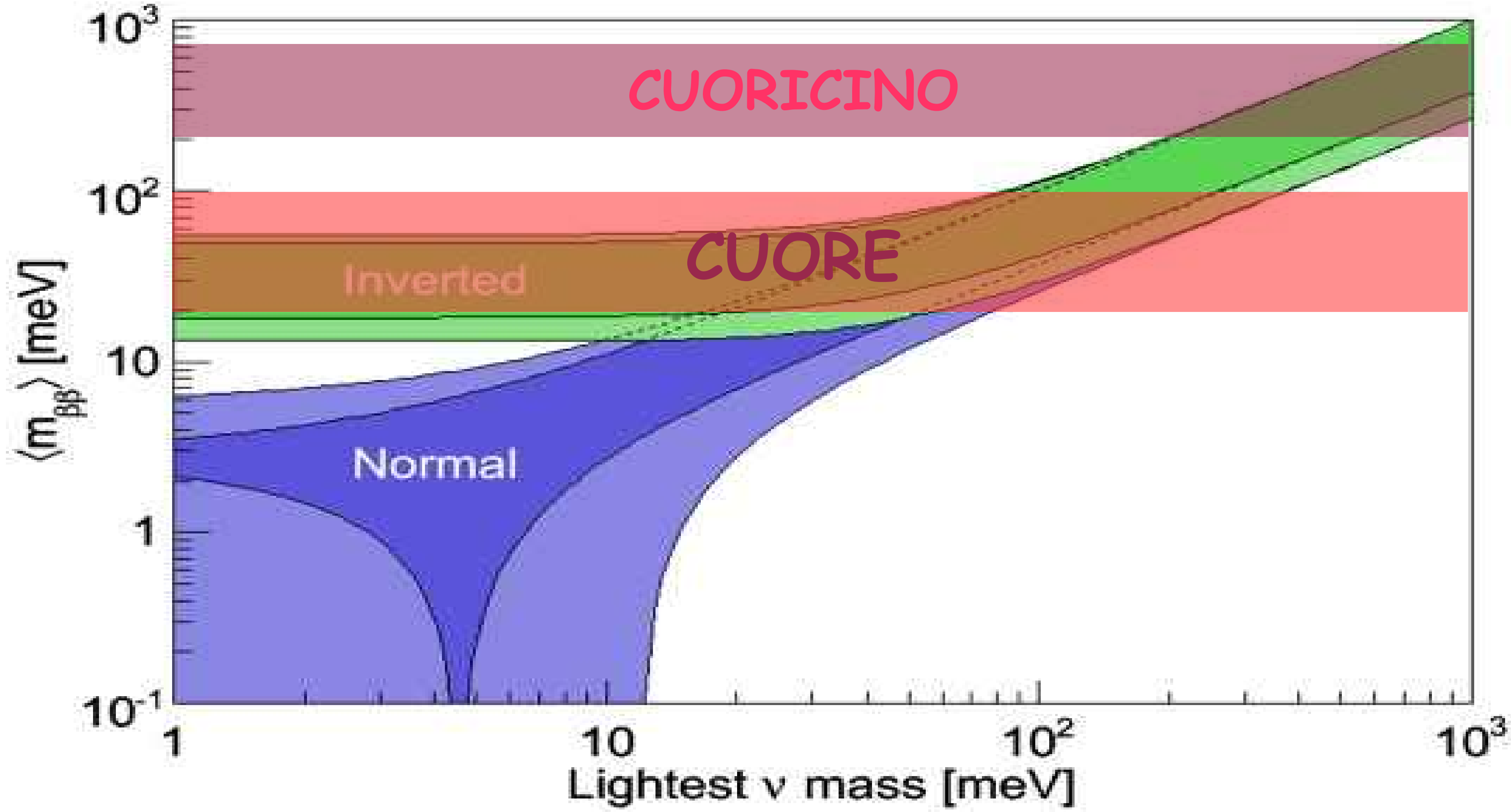
Total mass: 741 Kg
^{130}Te: 203 Kg

988 TeO_2 crystals
19 towers

Major efforts

- Mass increase
- Background reduction

CUORE Sensitivity

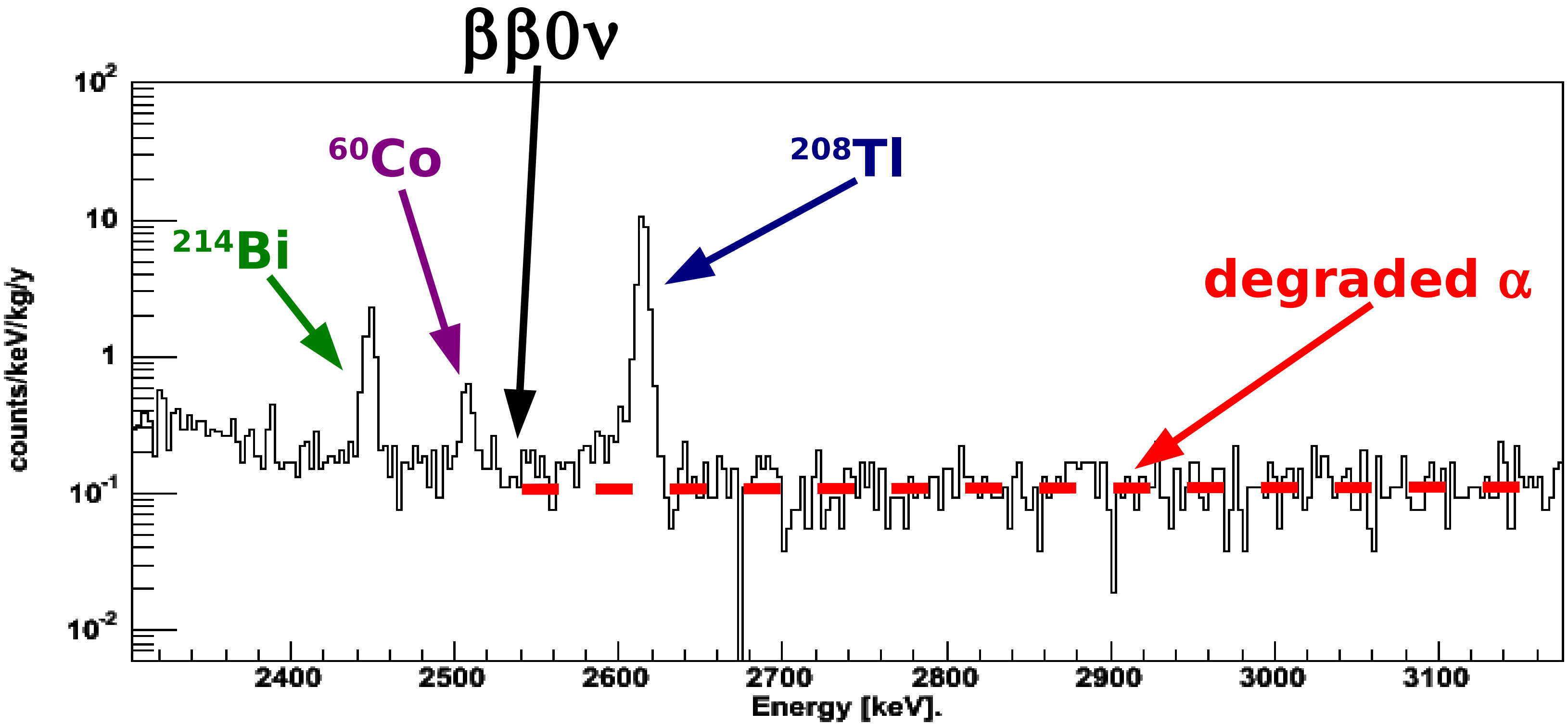


- **Measurement time: 5 years**
- **bkg: 0.01 counts/keV/kg/y**
- **Avg FWHM resolution: 5 keV**

$$T_{1/2}^{0\nu} > 2.1 \cdot 10^{26}\, y\, @\, 90\ C.L.$$

$$m_{\beta\beta} < 20 \div 100\, meV$$

CUORICINO Background



Background contributions

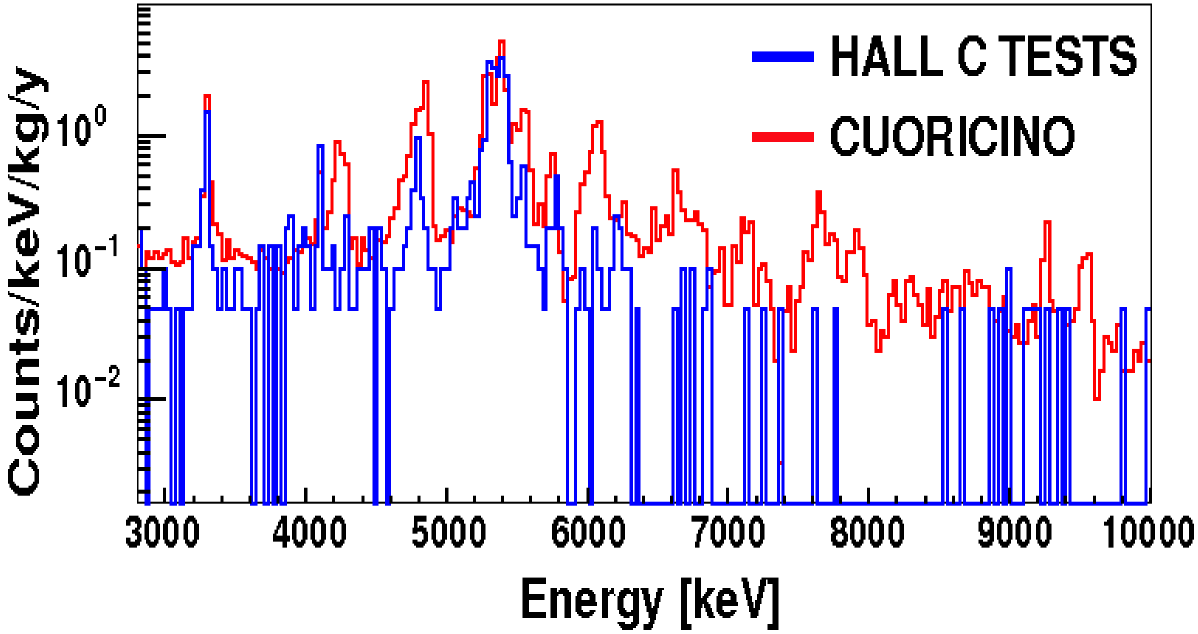
- ^{60}Co from cosmogenic activation: negligible
- Multi-Compton from ^{208}Tl (^{232}Th cont. in cryostat shields): ~40%
- Degraded α from crystal surfaces: ~10%
- Degraded α from Cu holders surfaces: ~50%
- Muon-induced background: negligible

CUORE Background

Improved cleaning procedures tested in the HALL C R&D facility

- reduction by a factor 4 on Crystal surf. contaminations
- Reduction by a factor 2 on Cu frames surf. contaminations

Projection to CUORE
(goal: 10^{-2} c/keV/kg/y)



Component	Bkg in DBD region [10^{-2} c/keV/kg/y]
Environmental γ	< 0.1
Apparatus γ	< 0.1
Crystal bulk	< 0.01
Crystal surface	< 0.3
Cu frames bulk	< 0.1
Cu frames surface	~ 2 ÷ 4
Neutrons	< 0.01
Muons	< 0.01

CUORE Status

CUORE

- Hut construction started
- Copper procured
  - Cryostat
  - Detector holders
- Crystal production is ongoing
  - ~100 xtals already stored underground at LNGS
- Dilution refrigerator is being built

CUORE-0

The first tower of CUORE will be assembled and operated in 2010

- Will be hosted in the CUORICINO cryostat
- Same mechanical design of the CUORE towers
- Test of the detector assembling procedure

CUORE data taking is foreseen to start in 2012

Conclusions

- Bolometers are a powerful technique for the search of Double Beta Decay
- **CUORICINO** has demonstrated the feasibility of **CUORE** and has set a limit on the $\beta\beta0\nu$ decay time of ^{130}Te
- **CUORE** will be able to span part of the inverted mass-hierarchy region
- **CUORE** construction is ongoing: data taking is foreseen in 2012