Search for Neutrinoless Double Beta Decay with the CUORE Detector

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on the behalf of the CUORE Collaboration

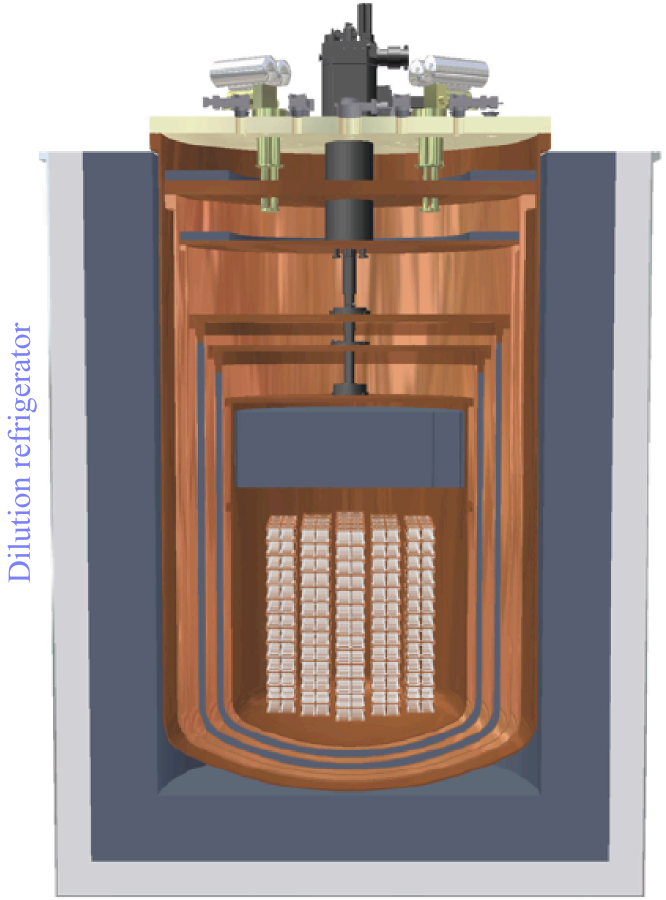
HEP Manchester 19th of July 2007

Outline

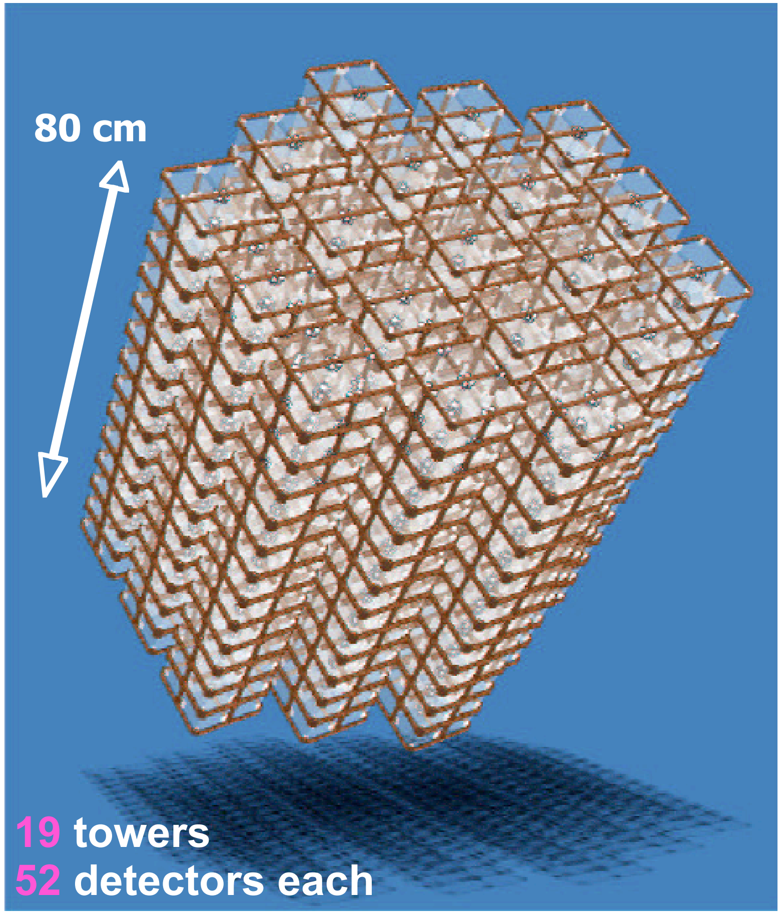
- The CUORE experiment
- Neutrino physics and the search for DBD0ν
- Searching for DBD0ν of ^{130}Te
- The TeO_2 bolometers
- Improving the experimental sensitivity
- A starting point: the CUORICINO experiment
- Background reduction via removal of surface radioactive contaminations
- Improving the performance: a new holder
- Conclusions

CUORE

CUORE (Cryogenic Underground Observatory for Rare Events) is an experiment to search for the neutrinoless Double Beta Decay (DBD0ν) of the ^{130}Te with bolometric detectors to be installed in the Laboratori Nazionali del Gran Sasso



988 detectors (cylindrically shaped)
$M = 741$ kg $TeO_2 \rightarrow 204$ kg Te



A single-tower test (CUORICINO) was started in 2002 and is presently running

CUORE

- Specially designed cryostat, will work at 10 mK
- Shielding:

  inside the cryostat

  6 cm Pb surrounding the array

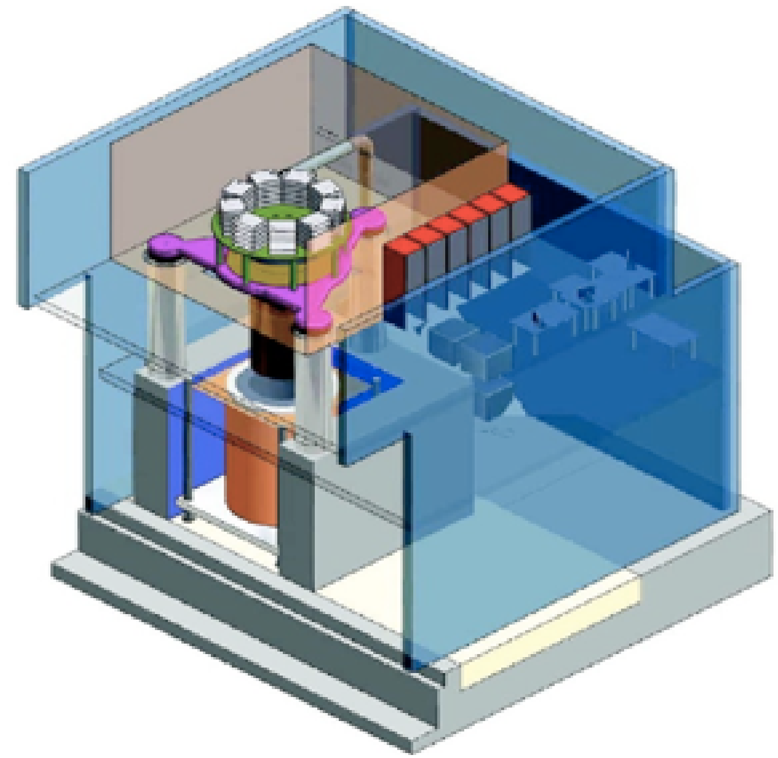
  24 cm Pb on the top

  outside the cryostat

  3 cm of Boric Acid for thermal n absorption

  25 cm Pb for gamma ray absorption

  18 cm of Polyethylene
- Muon veto: plastic scintillator



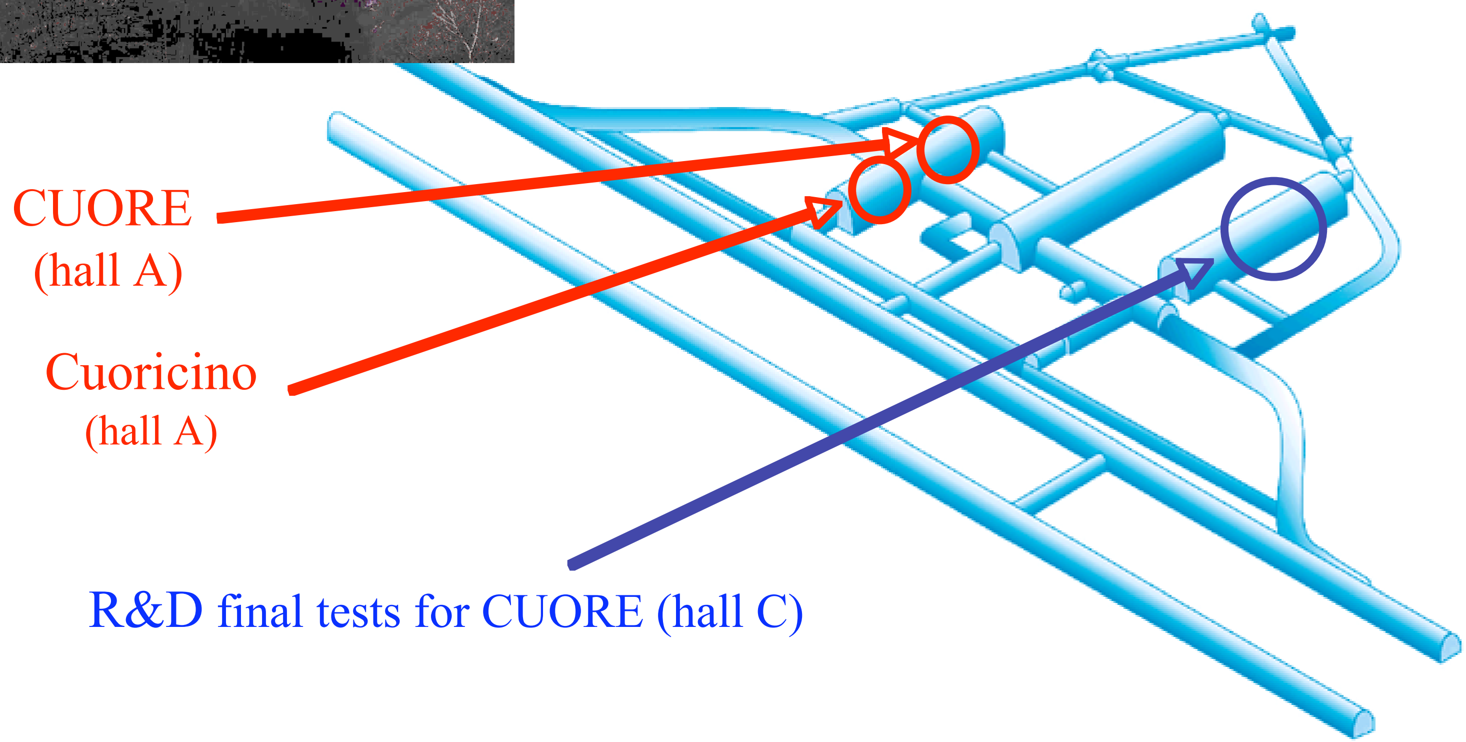
Hut+Cryostat+Shields bids
already started

CUORICINO and CUORE location

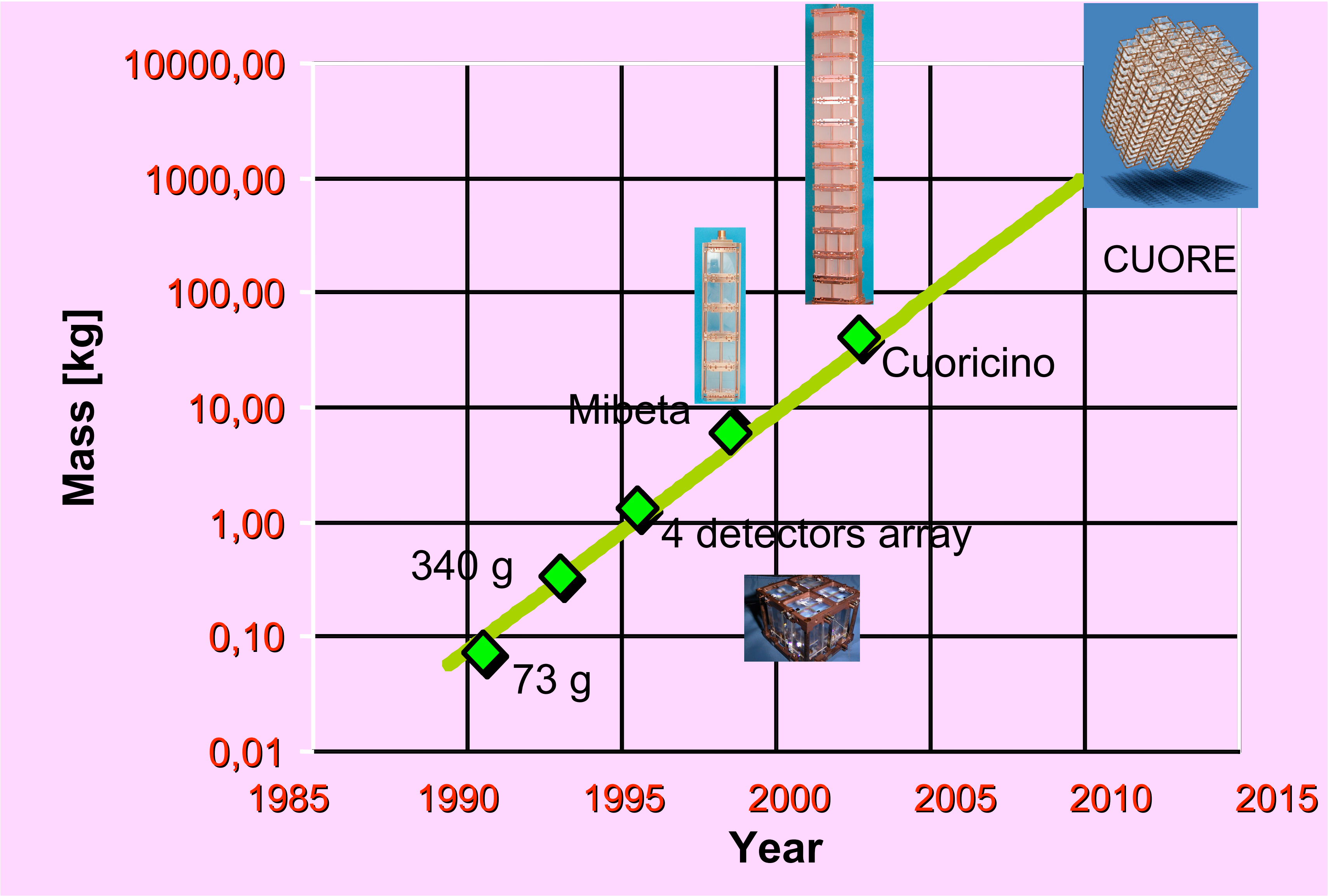
Cuoricino experiment is installed in

Underground National Laboratory
of Gran Sasso
L'Aquila – ITALY

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



TeO_2 bolometers



Present scenario

In the past years many new discoveries were done in neutrino physics:

What we know:

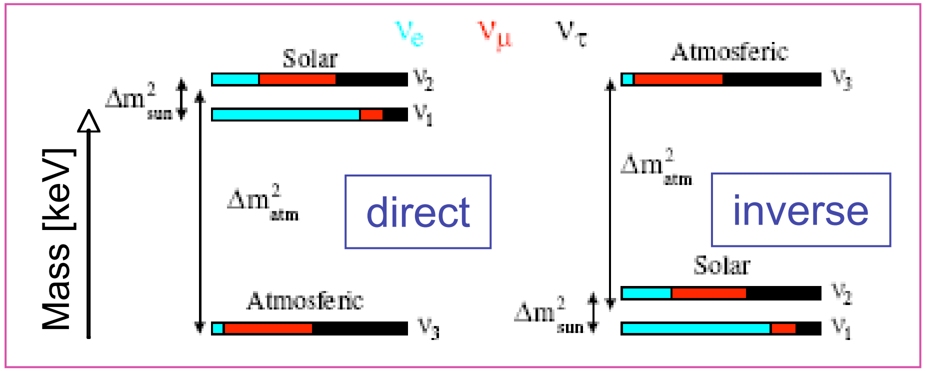
① Oscillations take place. Neutrinos have non-zero masses.

② We have rough measurements of two $\Delta m_{ij}^2 = m_i^2 - m_j^2$ between the three eingenvalues of mass m_1, m_2, m_3.

③ We have rough measurements of the three mixing angles that parameterize the mixing matrix.

What we do not know:

① The mass hierarchy →



② The absolute mass scale

③ The DIRAC or MAJORANA nature of the neutrino

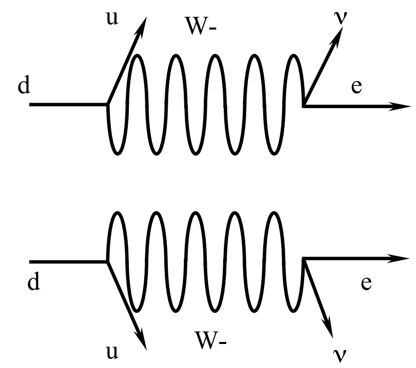
Double Beta Decay

Double beta decay is a rare nuclear process. Two channels are usually discussed:

1) $2\nu\beta\beta$ - decay mode

$$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\overline{\nu}_e$$

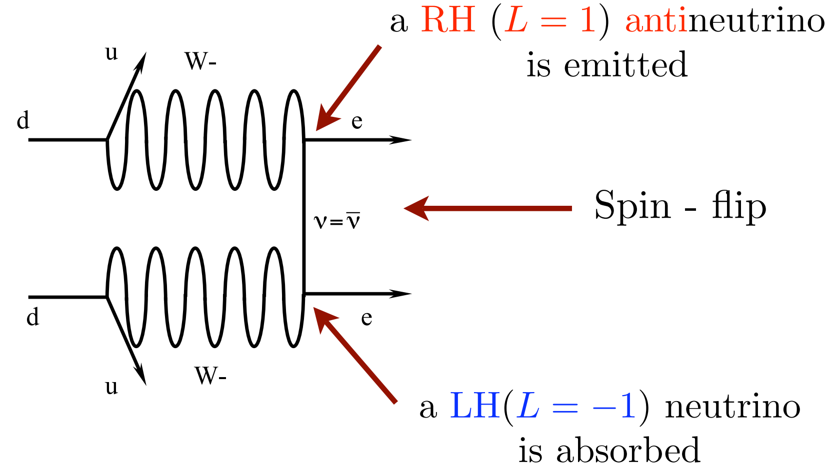
2^{nd} order electroweak process allowed by the SM, already observed in several nuclei with $T^{2\nu} \geq 10^{19}$ y

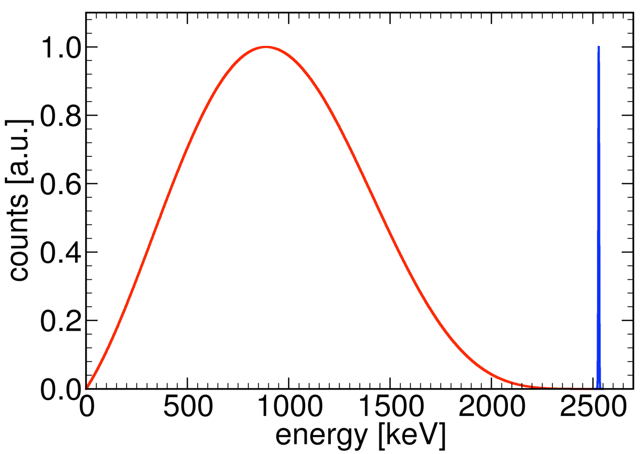


2) $0\nu\beta\beta$ - decay mode

$$(A,Z) \rightarrow (A,Z+2) + 2e^-$$

The process is allowed for a Majorana type neutrino ($\nu = \bar{\nu}$)





$Q_{\beta\beta}(^{130}Te) = 2530.3 \pm 2.0$ keV

Double Beta Decay

$$(2\nu\beta\beta) - \text{decay}$$

$$\left[T^{2\nu}_{1/2}\right]^{-1} = G^{2\nu}(Q,Z)|M^{2\nu}_{\text{nucl}}|^2$$

$$(0\nu\beta\beta) - \text{decay}$$

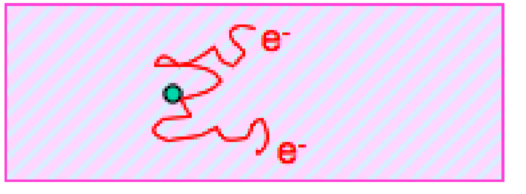
$$\left[T^{0\nu}_{1/2}\right]^{-1} = G^{0\nu}(Q,Z)|M^{0\nu}_{\text{nucl}}|^2\langle m_\nu\rangle^2$$

$G \rightarrow$ phase space factor $\propto Q^5$

$M_{\text{nucl}} \rightarrow$ nuclear matrix element

$|\langle m_\nu\rangle| \rightarrow$ effective Majorana neutrino mass

CUORE (CUORICINO) are experiments for measuring $0\nu\beta\beta$-decay of ^{130}Te using bolometric detectors



source = detector

no tracking of electrons $\rightarrow$ calorimetric technique

Signature: an energy line is expected at the Q value of the reaction

Sensitivity

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

$$S^{0\nu} = \ln 2 \times N_A \times \frac{a}{A} \left(\frac{MT}{b\Gamma} \right)^{1/2} \times \epsilon$$

$a \rightarrow$ isotopic abundance

$A \rightarrow$ atomic mass

$M \rightarrow$ detector active mass [kg]

$T \rightarrow$ live time [y]

$b \rightarrow$ background [c/keV/kg/y]

$\Gamma \rightarrow$ energy resolution [keV]

$\epsilon \rightarrow$ efficiency

We can increase the sensitivity by decreasing the bkg and increasing the measuring time.

Our bkg prediction for Cuore is based on the measured Cuoricino bkg, on the model we have drawn for that and on MonteCarlo simulations that use as input measured values or limit for the different possible bkg sources

CUORE Expected Sensitivity

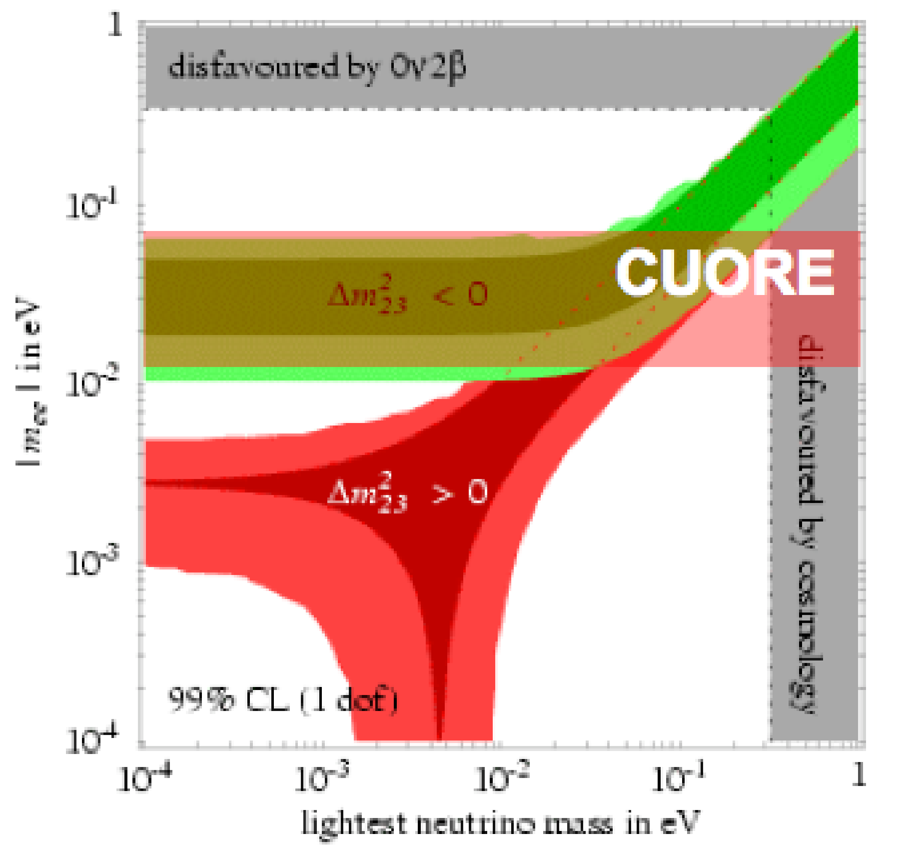
CUORE ββ-0ν sensitivity will depend strongly on the background level and detector performance.

In five years:

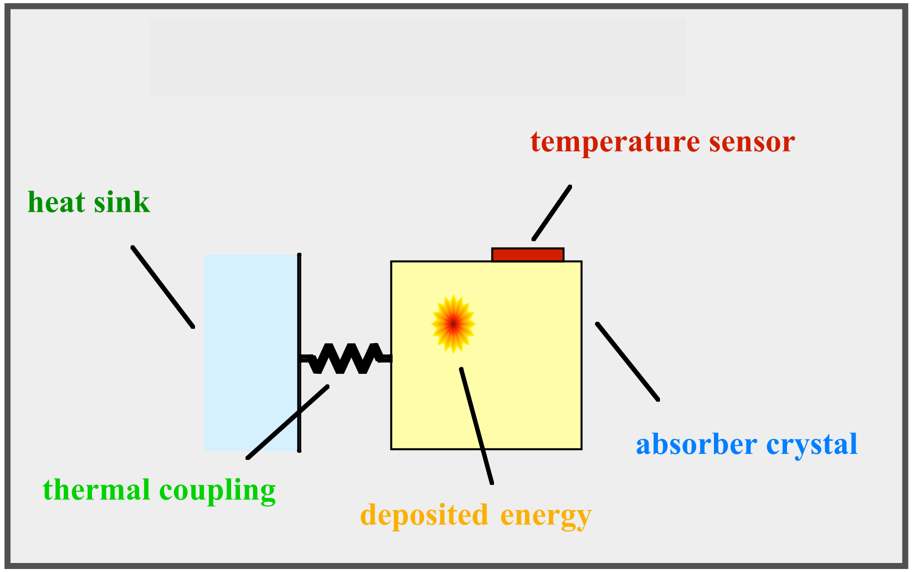
B(counts/keV/kg/y)	Δ(keV)	$T_{1/2}$(y)	$\lvert\langle m_\nu\rangle\rvert$ (meV)
0.01	10	1.5×10^{26}	23–118
0.01	5	2.1×10^{26}	19–100
0.001	10	4.6×10^{26}	13–67
0.001	5	6.5×10^{26}	11-57

Spread in $<m_\nu>$ from nuclear matrix element uncertainty

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



Bolometric Technique



From a very simple thermal model

Signal: $\Delta T = E/C$

-> to develop high pulses the detector has to work at low temperature (10mk)

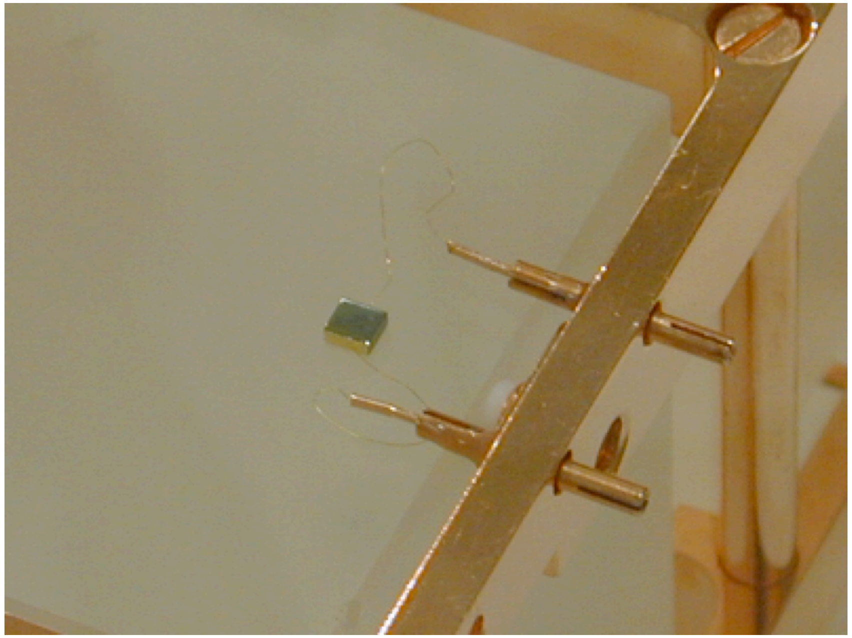
Main advantages:

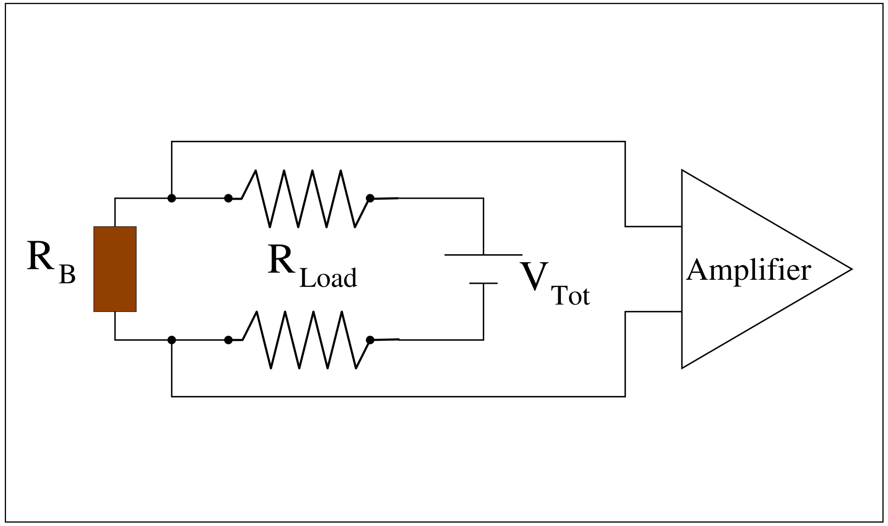
- **high energy resolution**
- **wide flexibility (few constraints on absorber material)**
- **the detector is fully sensitive (no dead layer)**

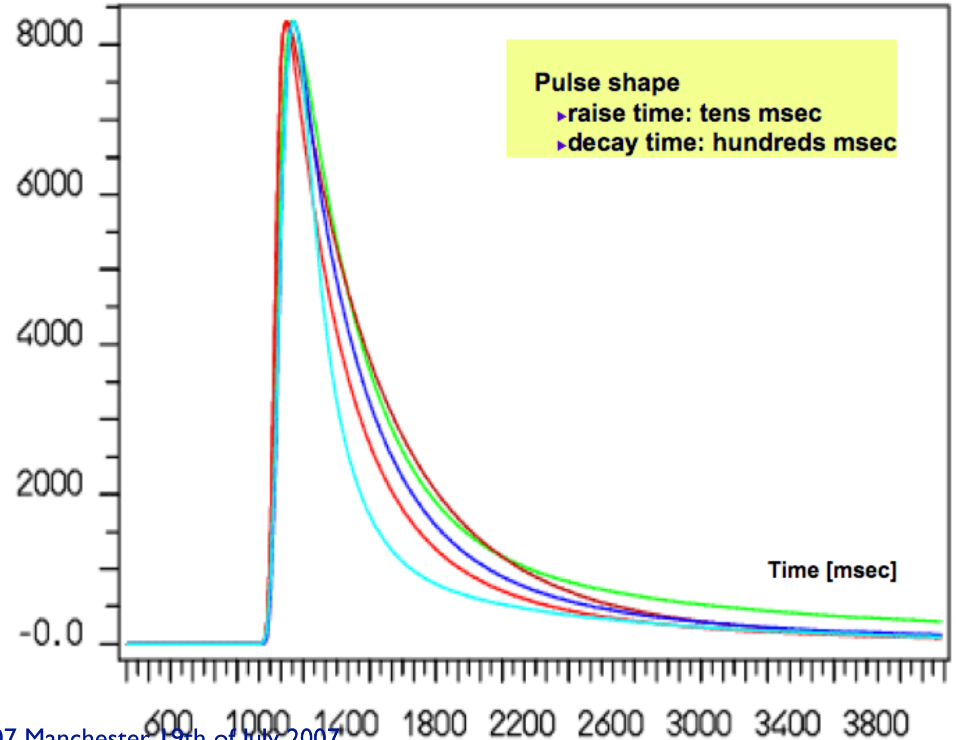
WHY ^{130}Te ?

- high natural isotopic abundance (33.87 %)
  - high transition energy (Q=2530.30 ± 1.99 keV)
    - this means large phase space for the decay
    - the Q-value is important with respect to the natural radioactive background
  - encouraging theoretical calculations for 0vDBD lifetime

Bolometric Technique



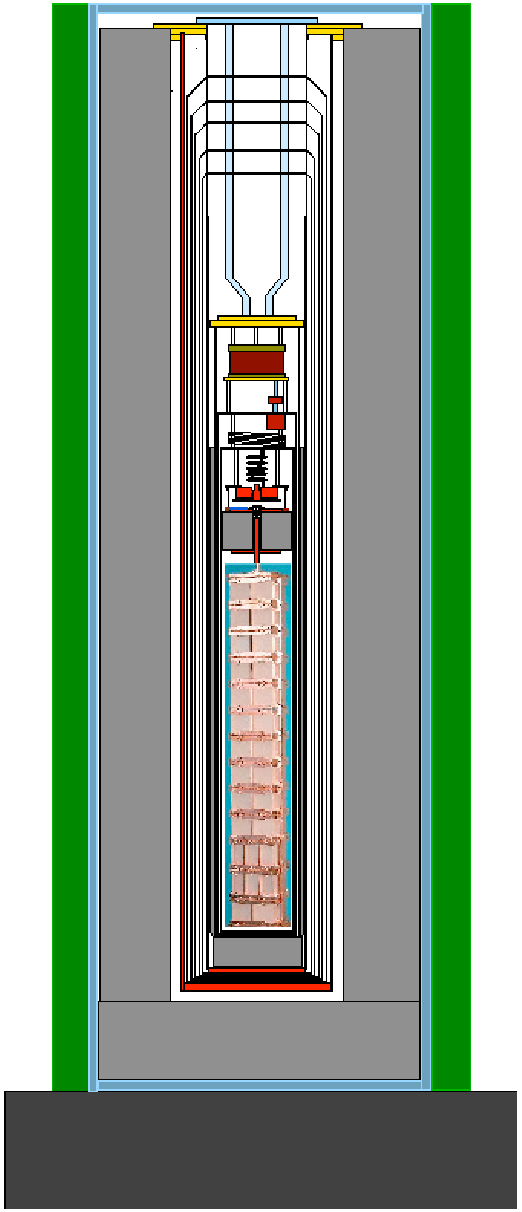




CUORICINO

It is a self-consistent experiment giving significant results on **Double Beta Decay.**

- 2 modules with 9 *small* detectors
  - 18 TeO_2 crystals
  - $3{\times}3{\times}6$ $cm^3 \Rightarrow 330$ g
  - TeO_2 mass $\Rightarrow 5.94$ kg
- 4 crystals are enriched
  - $2{\times}^{130}TeO_2 + 2{\times}^{128}TeO_2$



- 11 modules with 4 *big* detectors
  - 44 TeO_2 crystals
  - $5{\times}5{\times}5$ $cm^3 \Rightarrow 790$ g
  - TeO_2 mass $\Rightarrow 34.76$ kg

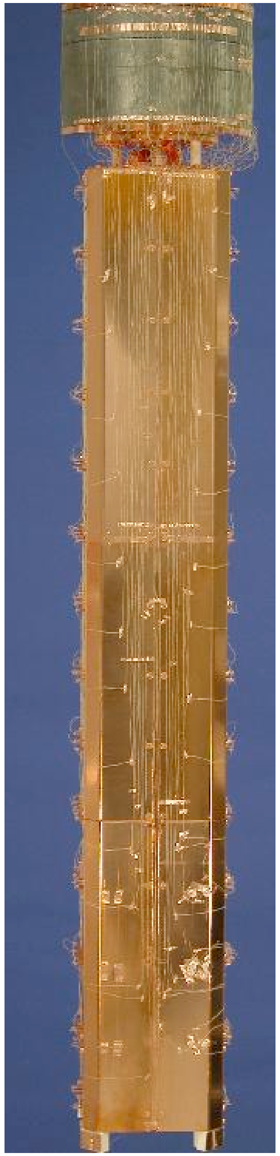
Total active mass

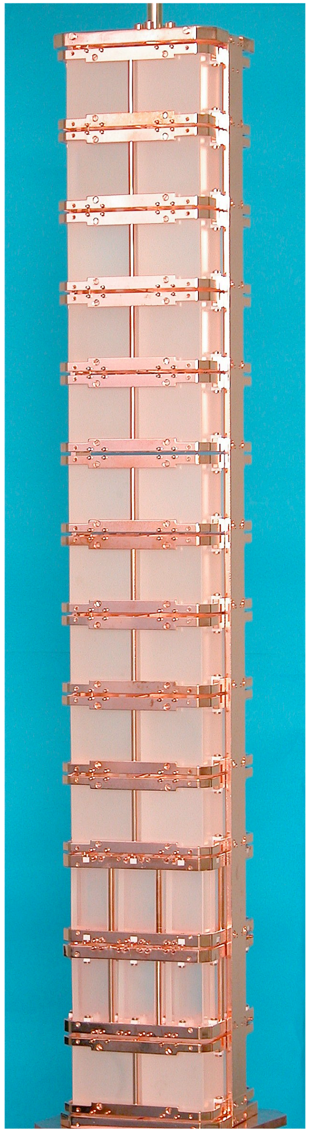
TeO_2 : 40.7 kg

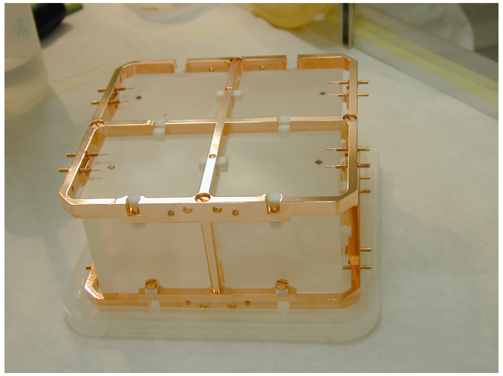
^{130}Te : 11.3 kg

^{128}Te : 10.5 kg

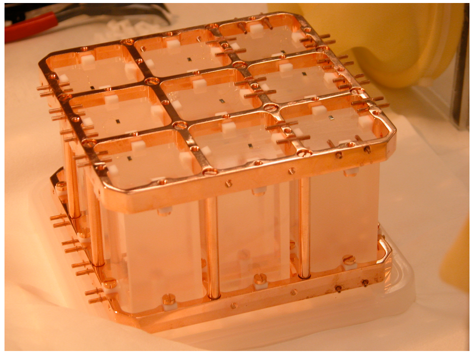
CUORICINO







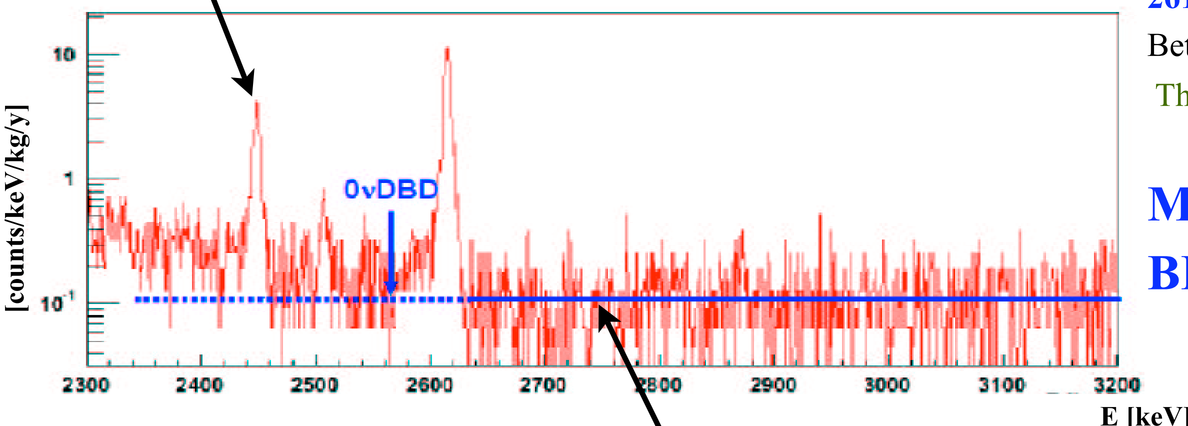
11 modules with 4 detectors $5 \times 5 \times 5$ cm^3
790 g each; total mass 34.76 kg



2 modules with 9 detectors $3 \times 3 \times 6$ cm^3
330 g each; total mass 5.94 kg

CUORICINO background

2505 keV line: sum of the 2 ^{60}Co gammas (1173 and 1332 keV)
Most probable source: neutron activation of the Copper
Contribution to the DBD background: neglijible



2615 keV Tl line

Between the inner Roman lead shield and the external lead shield.

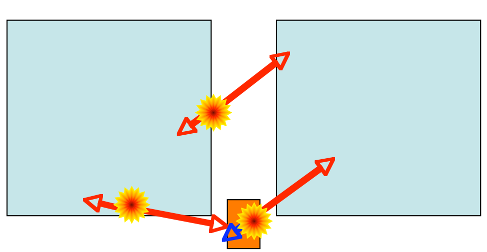
Th (Tl) contribution to DBD background: **~ 40%**

MORE ROMAN LEAD:
BETTER CRYOSTAT DESIGN

Flat background in the energy region above the ^{208}Tl 2615 line

Contribution to the counting rate in the 0νDBD region: ~ 60%

Origin: degraded alpha particles *(20 +/- 10) % crystal surface contamination*
(80 +/- 10) % "Cu" surface contamination ~

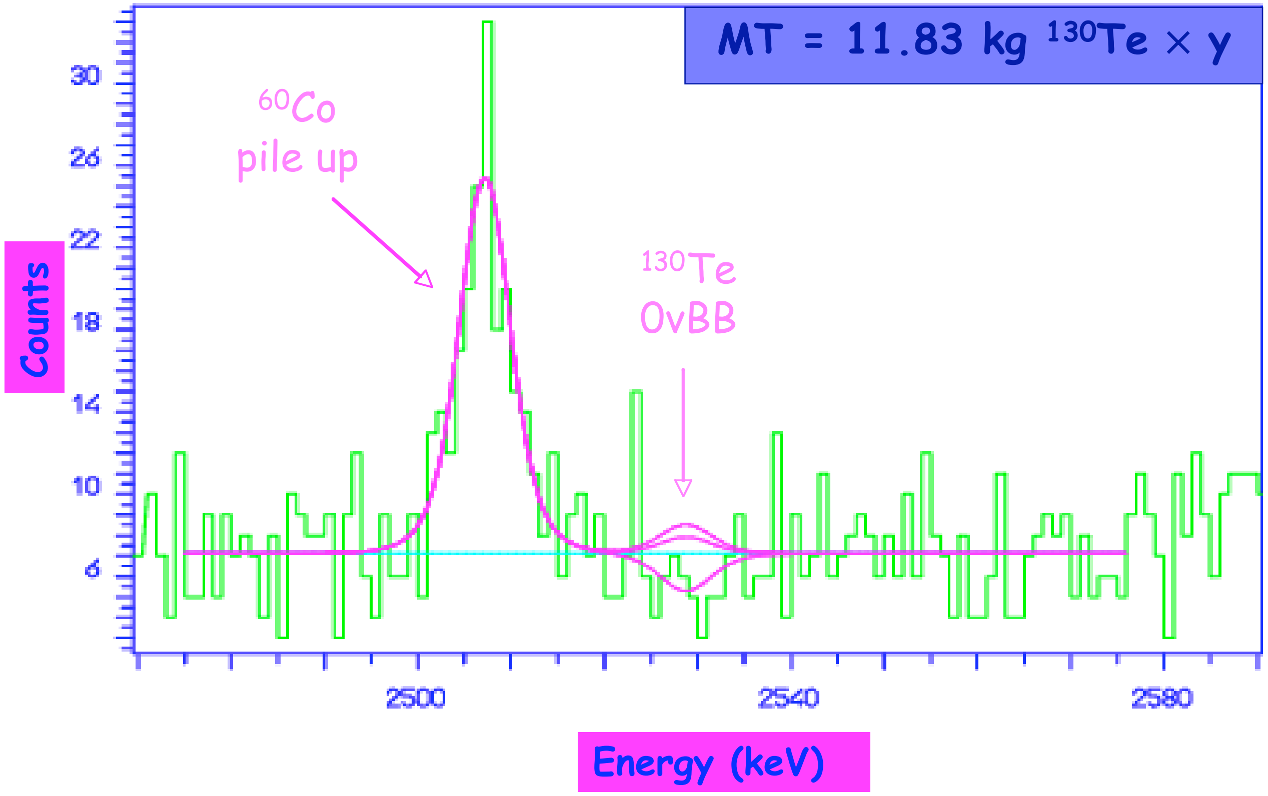


Results

Background model

~ 0.18 ev/y/kg/keV at $Q_{\beta\beta}$

$30\% \pm 10\%$	^{208}Tl (cryostat contamination)
$20\% \pm 10\%$	TeO_2 surfaces (α contaminations)
$50\% \pm 10\%$	Cu surfaces (α contaminations)
~ 0 from $2\nu\beta\beta$	< 0.01 from cosmic rays (n and ν)



Background sum spectrum of all detectors in the DBD region

Results

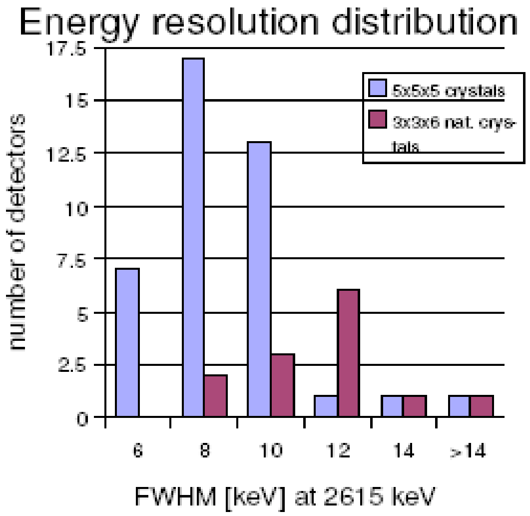
$$MT = 11.83 \text{ kg } ^{130}Te \times y$$

$$T^{0\nu}_{1/2} > 3 \times 10^{24} \text{ y @ 90\% C.L.}$$

→

$$\langle m_\nu \rangle < (0.2 - 0.98) \text{ [eV]}$$

Bkg = 0.18±0.02 c/keV/kg/y



FWHM measured on sum bkg spectrum @ 2.6 MeV ~ **7 keV**

CUORE background

For the background in the DBD region we clearly identified 2 sources and we are not so sure about the third one:

Source 1 = 2615 keV Tl line: just a problem of shielding

CUORE Tl line bkg $< 10^{-3}$ c/keV/kg/y

Source 2 = U and Th crystal surface contaminations: the contamination can be controlled with proper surface treatments (including chemical etching and polishing with "clean" powders). A recent test on 8 crystals (CUORE-like) proved that the new surface treatment studied at LNGS reduces the contamination by a factor of 4.

In Hall C measured the contamination projected on CUORE $< 3\times10^{-3}$ c/keV/kg/y

Source 3 = something to explain the 3-4 MeV flat bkg: unknown source candidates are surface contamination of the inert part of the detector.

In Hall C measured the contamination projected on CUORE $\sim 2 - 4 \times 10^{-2}$ c/keV/kg/y

a dedicated array of 8 $5 \times 5 \times 5$ cm^3 crystals operated in Hall C

bulk and surface measurement

low bkg Ge spectroscopy

some more investigation on neutron contribution

All the other sources are presently non-relevant

CUORE background

	$\times 10^{-3}$ c/keV/kg/y	
External gamma	<1	MEASURED
Exp. apparatus	<1	MEASURED
Detector structure bulk	<1	MEASURED
Crystal bulk	<0.1	MEASURED
Detector structure surfaces	~20-40	extrapolated from our bkg model
Crystal surfaces	<3	MEASURED
Neutrons	<0.1	MC simulation
Muons	~2	MC simulation without veto

Limiting factor to 0.01 c/keV/kg $\Rightarrow$ 24-120 meV range

Limiting factor to 0.001 c/keV/kg $\Rightarrow$ 14-66 meV range

MEASURED=experimentally measured contamination extrapolated to CUORE

CUORE R&D

Ongoing activities:

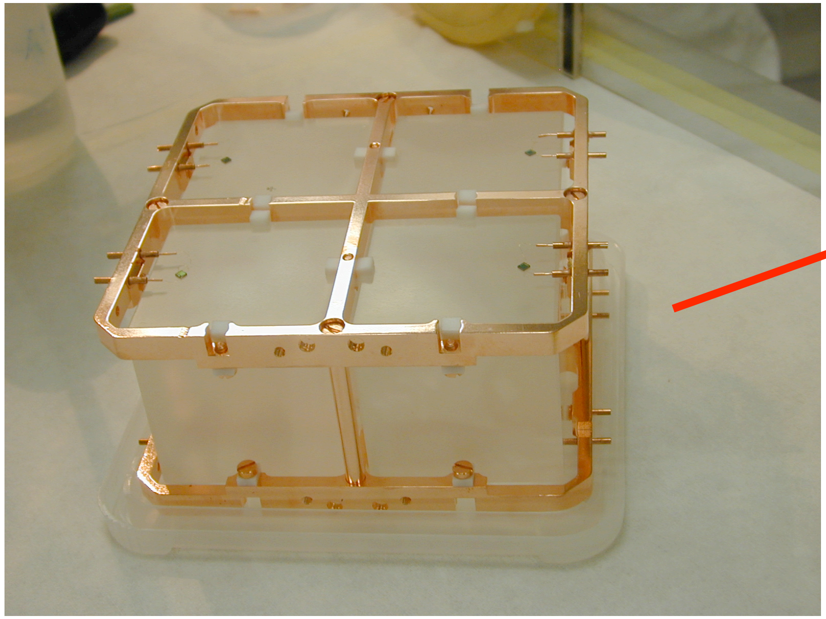
- Underground Laboratory (hut) design, material selection and site preparation
- Dilution refrigerator tender and final design
- Shieldings final design and material selection
- Best TeO_2 producer selection
- Germanium irradiation for NTD thermistor preparation
- Detector structure optimization for
  - lower background contribution
  - decoupling from setup vibrations
  - Better performance and reproducibility
  - Detector standardization
  - easier and Fast assembling procedure
  - Front-end electronics prototypes

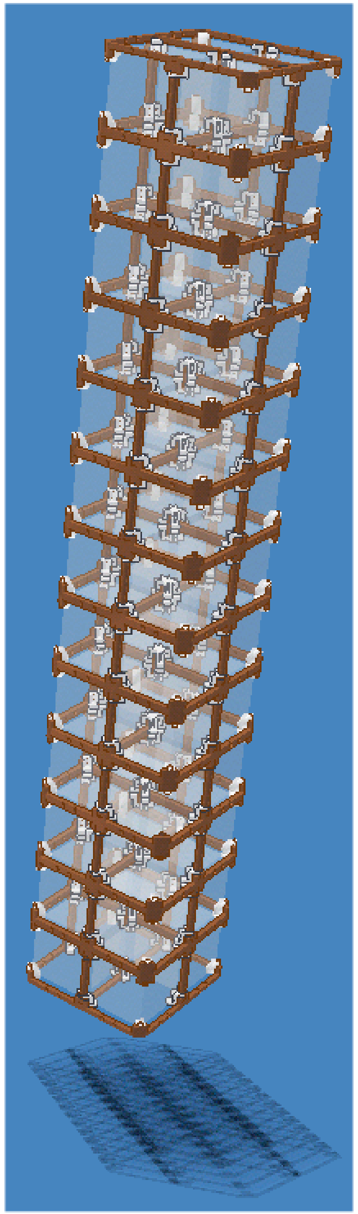
and, to be preliminarly tested on CUORICINO

- DAQ prototype
- DAQ + online analysis software

CUORE R&D

The SuperModule structure:
•is more compact
•reduces the amount of copper,
•improves the visibility between the different detectors
•it is easier to assemble.
•the resolution uniformity is very good
This holder was adopted for the final CUORE design





Conclusions

•Cuoricino demonstrated feasibility of a large scale bolometric detector (CUORE) with good energy resolution and bkg on many detectors.

•CUORE, a second generation detector developed on this new approaches, will be build and start up in 2011.

•Recent results on background suppression confirm the capability to explore the inverse hierarchy mass region.