Neutrinoless double beta decay as a test of Majorana neutrinos: the CUORICINO experiment.

P. Gorla

Lab. of Nucl. and High En. Physics, Universidad de Zaragoza, Spain

INFN Laboratori Nazionali del Gran Sasso, Italy

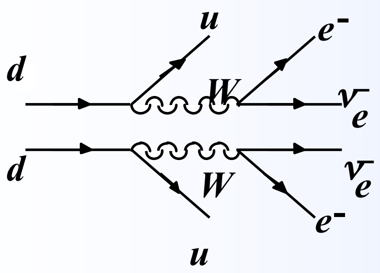
Outline

- Why DBD0ν experiment?
- Bolometric approach
- CUORICINO experiment
- New results
- Future
- Summary

Why Double Beta Decay experiment?

Nuclear ββ decay is a rare process

Two interesting decay modes are usually discussed:



2ν - ββ decay

1) DBD2ν (A,Z) → (A,Z+2) $+ 2e^- + 2\bar{\nu}_e$

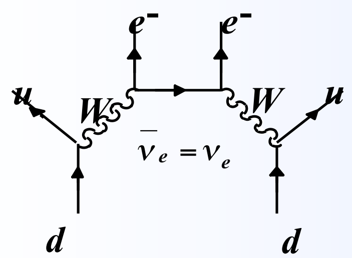
→ 2° order elettroweak process allowed by SM, has already been observed in various nuclei

→ $\tau^{2\nu} \sim 10^{19} - 10^{21}$ y

IF

$\nu = (\nu)^c$
$m_\nu \neq 0$

Majorana Neutrino



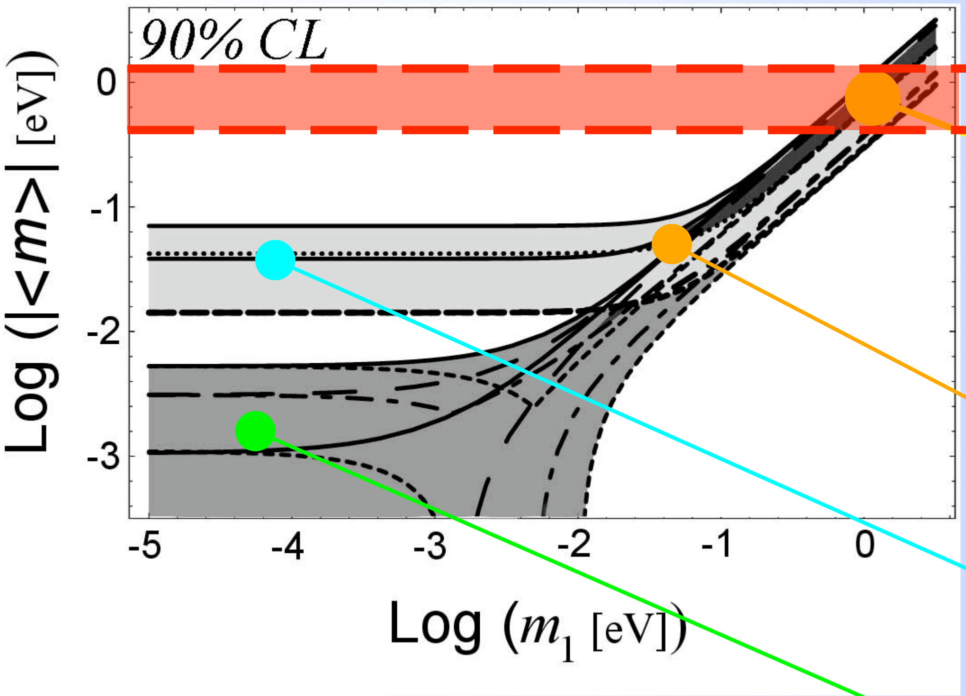
0ν - ββ decay

2) DBD0ν (A,Z) → (A,Z+2) $+ 2e^-$

→ This mode would imply physics BEYOND SM (Leptonic number violation, etc.)

Observation of DBD0v is the best test of Majorana nature of neutrino

Mass scale



Present limit *m<0.35 eV*

Possible evidence

"quasi" degeneracy $m_1 \approx m_2 \approx m_3$

Inverse hierarchy $\Delta m^2_{12} = \Delta m^2_{atm}$

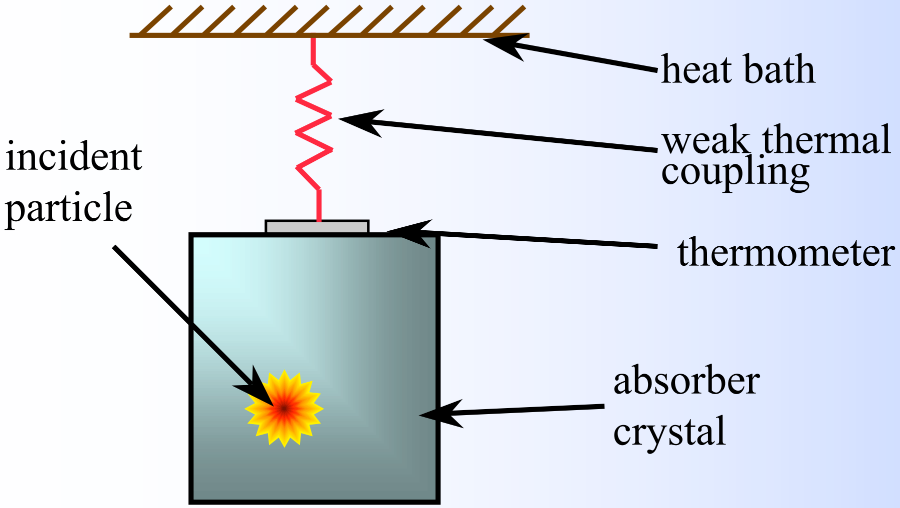
Direct hierarchy $\Delta m^2_{12} = \Delta m^2_{sol}$

Pascoli S Petcov ST hep-ph/0205022

→ New experiments must be designed to explore the region $< m_\nu > \; < 0.1$ eV

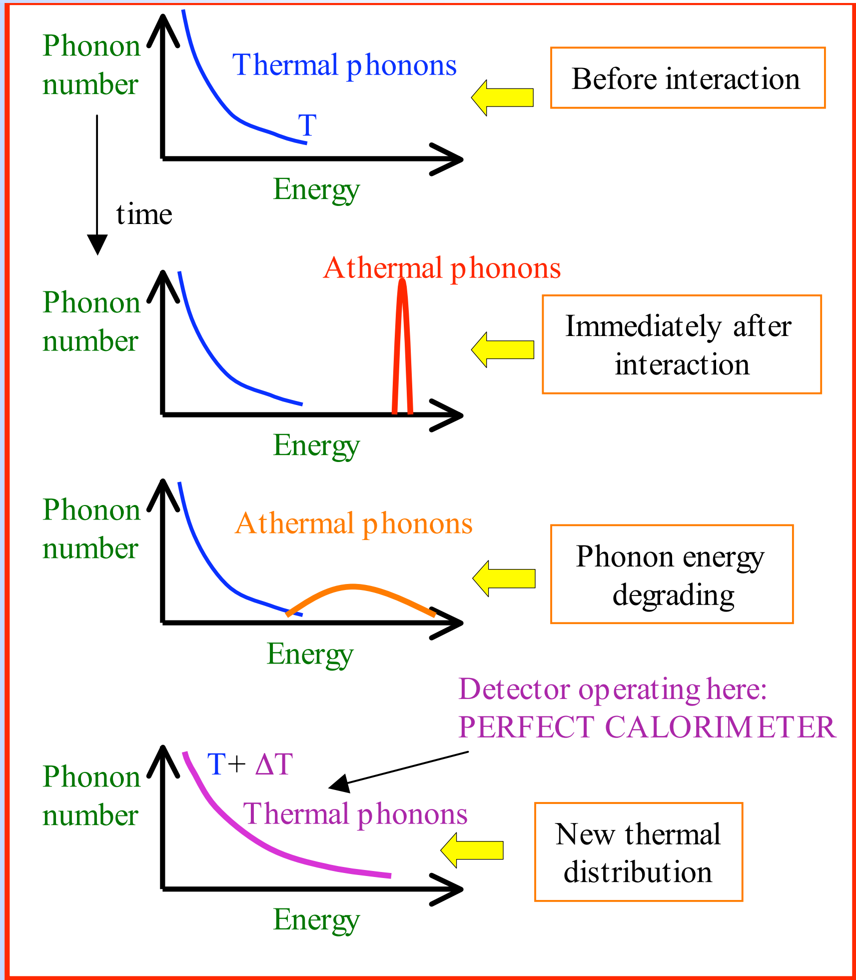
Bolometric detectors

The original idea is very simple:



This technique measures **all** the energy deposited by particle in form of increase of temperature in the absorber

$$\Delta T = E / C$$

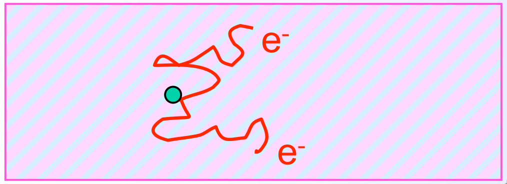


→ Need to work at very low temperature (~ 10 mK)

→ Use dielectric and diamagnetic materials

Radiation source

Source ≡ Detector



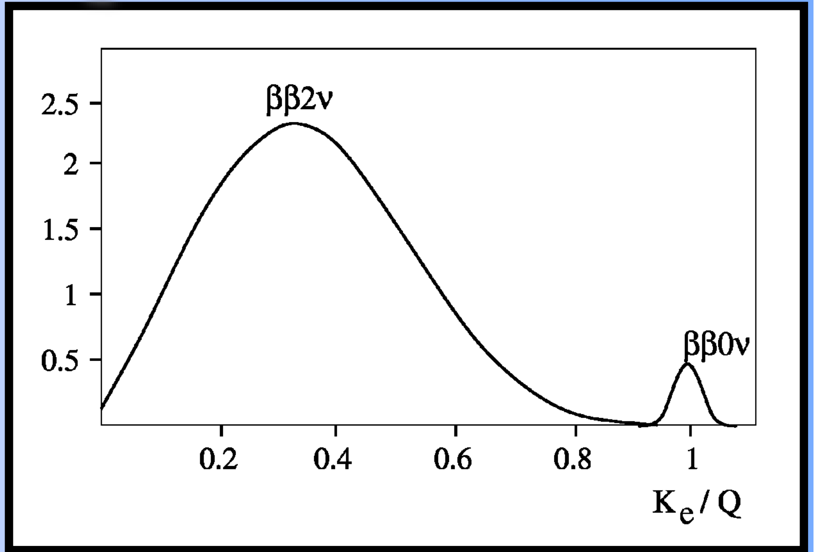
$$S = ln2\ N_A \frac{a.i.}{A}\ \varepsilon \sqrt{\frac{M\,t}{b\,\Delta E}}$$

No tracking

0.2 - 0.3 %

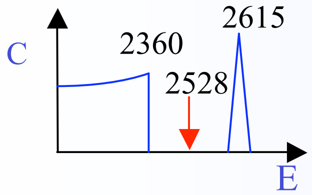
Germanium Diodes ^{76}Ge
Bolometers ^{130}Te

A line is expected in the spectrum at the energy corresponding to the Q value of the decay



TeO_2 bolometers

Research of DBD0ν of ^{130}Te



- high natural isotopic abundance (33.87 %)
- high transition energy ($Q = 2528.8 \pm 1.3$ keV)
- encouraging theoretical calculations for $\tau_{1/2}$ DBD0ν

$$\boxed{\tau \approx 10^{26}\ y \Rightarrow \langle m_\nu \rangle \approx 0.1\ eV}$$

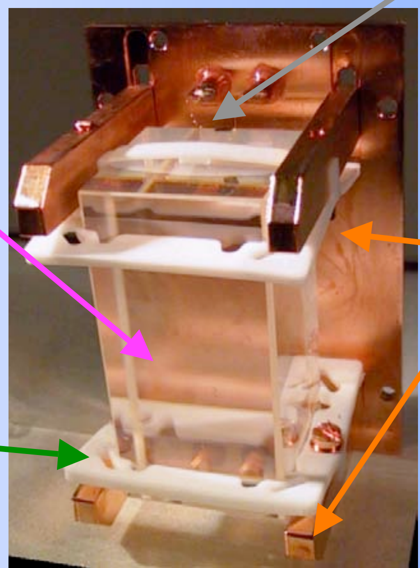
$$\langle m_\nu \rangle \propto 1/\sqrt{\tau}$$

TeO_2 crystals

- This solution guarantees good mechanical properties and the possibility of growing crystals of big size
- TeO_2 is a dielectric and diamagnetic material

Thermistor: Ge NTD glued on the crystal

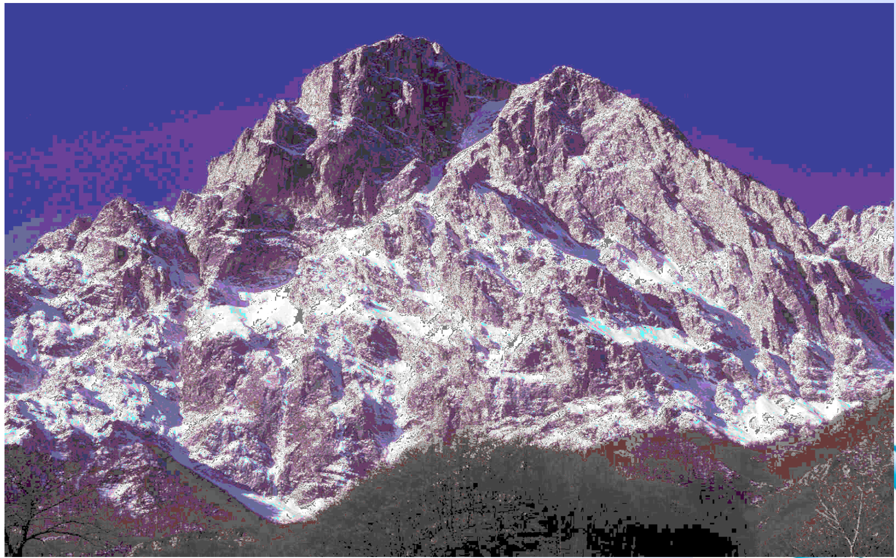
Absorber: crystal of TeO_2

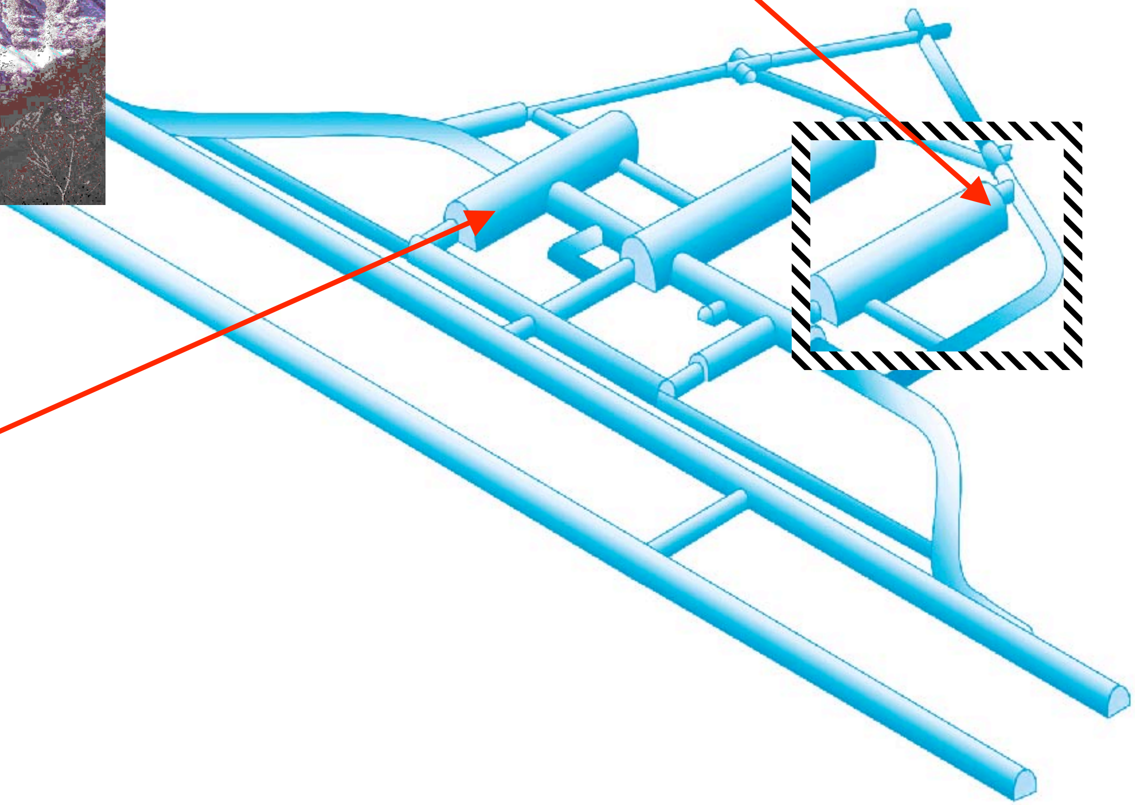


Heat bath: copper frames

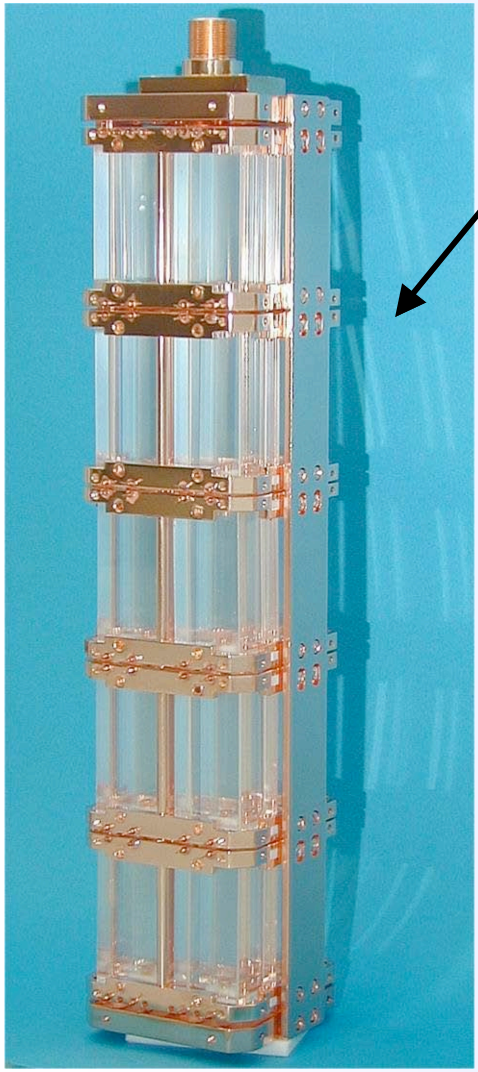
Crystal holders and thermal limks: teflon elements

Thermal detectors @ LNGS





Mibeta (^{130}Te)

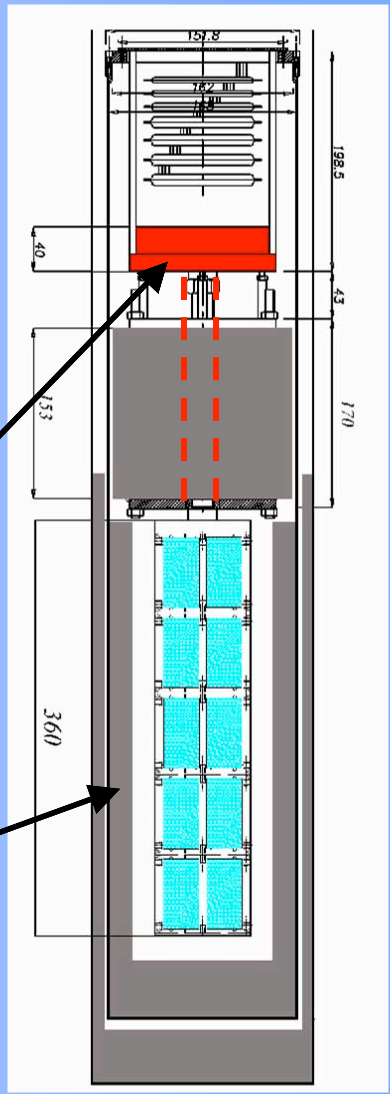


5 modules, 4 detectors each, arranged in a tower-like structure (6.8 kg)

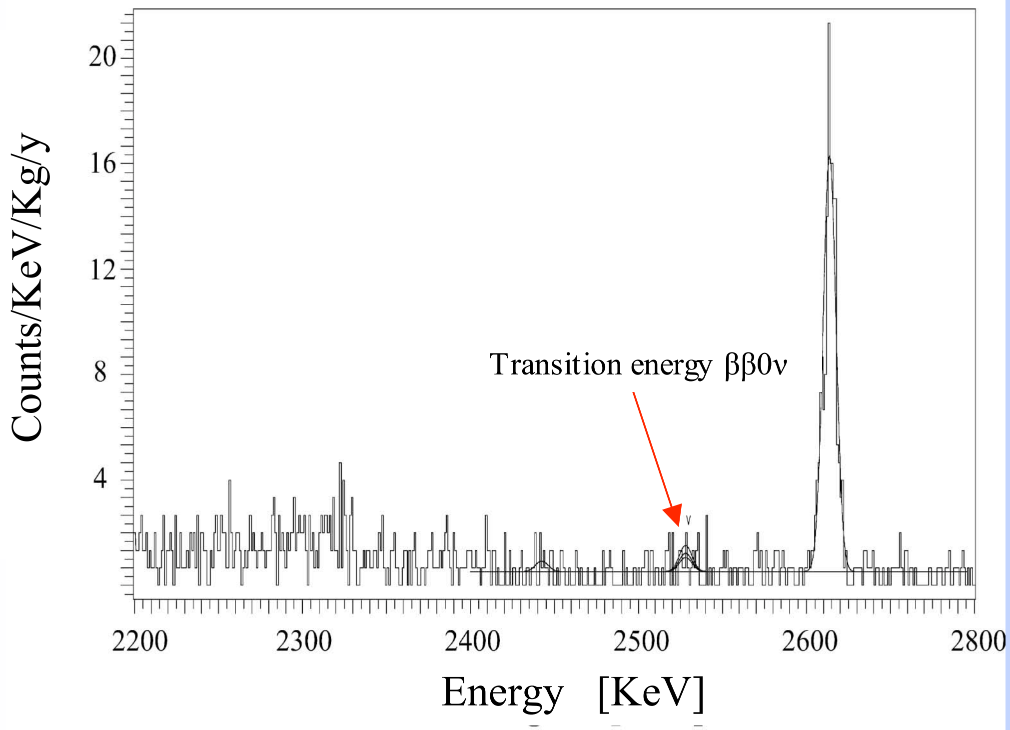
Every detector is a TeO_2 crystal $3x3x6\ cm^3$ (340 g)

Cold finger: 7 mK

The tower was surrounded by a Roman lead inner shield



Mibeta Results



Total background spectrum of the 20 crystal array around the DDB0ν region

Stopped December 2001

Total statistic ~ 4.3 kg · y

Background $_{\mathbf{2498 - 2558\ keV}}$

0.33 ± 0.11 [c/keV/kg/y]

$$\tau^{0\nu}_{1/2} \geq 2.08 \cdot 10^{23}\, y\,(90\%\, CL)$$

$$\Rightarrow$$

$$\langle m_\nu \rangle \leq 0.9 - 2.3\, eV \quad (90\% \ \ CL)$$

DDB-0ν Sensitivity

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

Detector mass (kg)

Measurement Time (y)

Isotopic abundance

Efficiency

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

Atomic mass

Background (counts/keV/kg/y)

Energy resolution (keV)

The 780 g detectors

R&D on new detectors 5x5x5 cm^3 of TeO_2 (780 g)

The best 780 g detector:

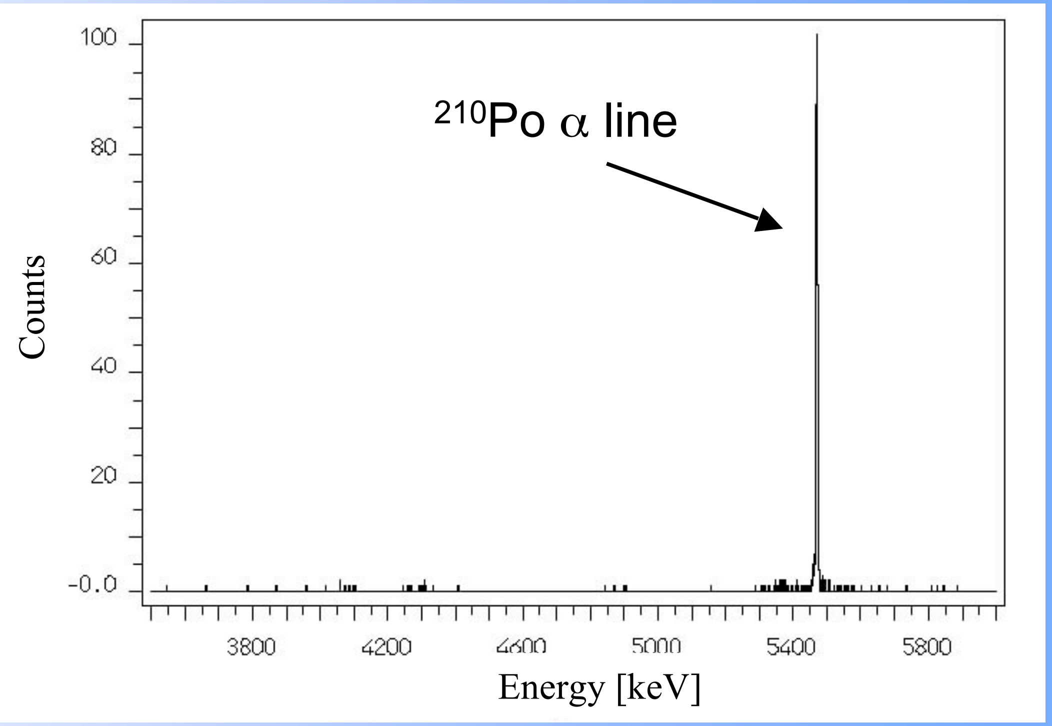
1.4 keV FWHM @ 0.351 MeV

2.1 keV FWHM @ 0.911 MeV

2.6 keV FWHM @ 2.615 MeV

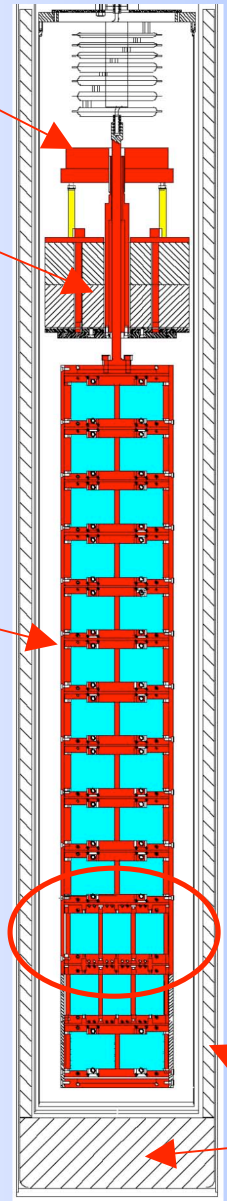
3.2 keV FWHM @ 5.407 MeV

(the best α spectrometer realized)
A.Alessandrello et al, NIM A440 (2000) 397-402



Better design of the 780 g detectors allowed performances comparable with the 340 g crystals

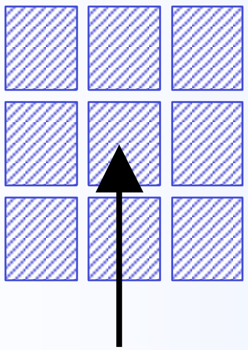
CUORICINO



11 modules
4 detectors each
Dimension: 5x5x5 cm^3
Mass: 790 g

2 modules
9 detectors each,
Dimension: 3x3x6 cm^3
Mass: 340 g

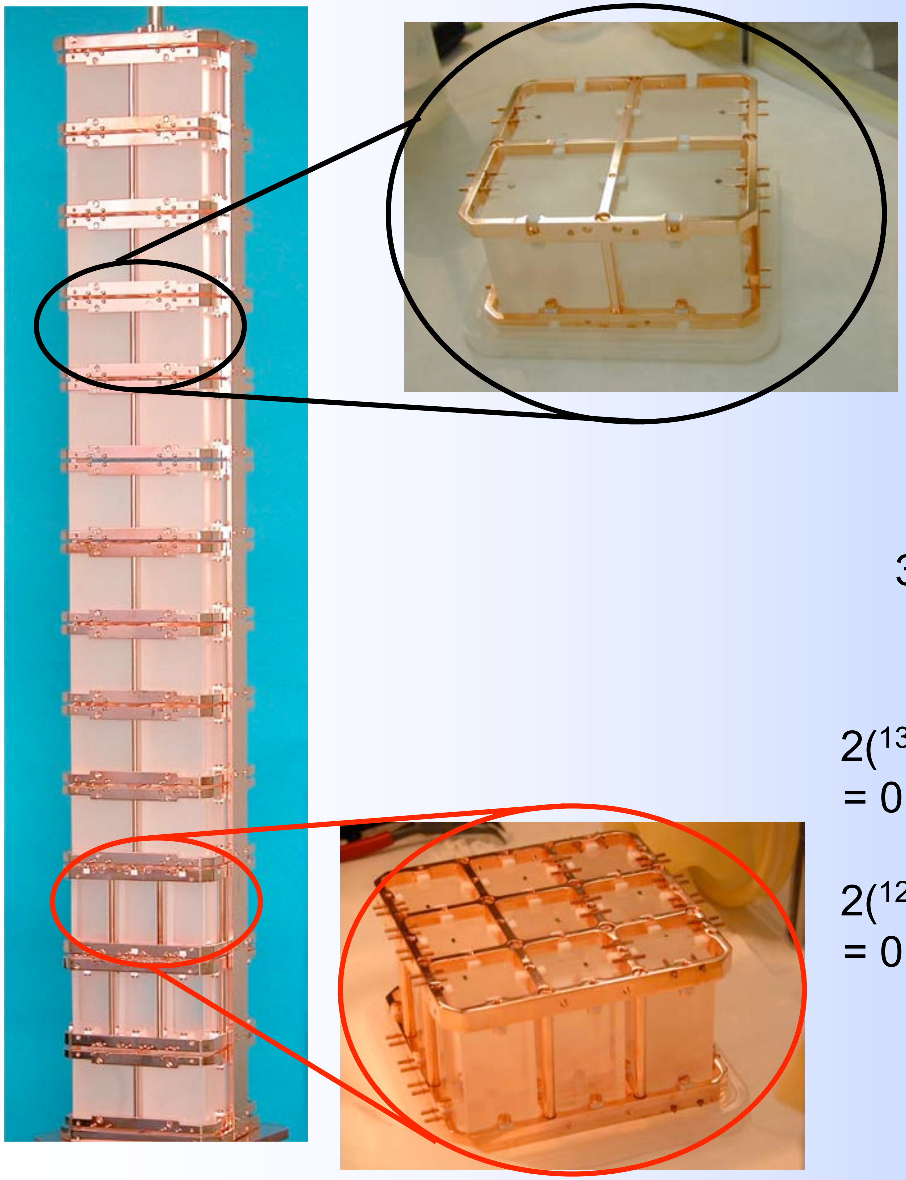
Planar Section



This detector is completely surrounded by active materials. Substantial improvement in BKG reduction

Total mass
40.9 kg

CUORICINO mass



Detectors:

4x11 = 44 large size crystals
(~5x5x5 cm^3 av. mass = 790 g)
32 working

9x2 = 18 small size crystals
(~3x3x6 cm^3 av. mass 330 g)
16 working

Active mass:

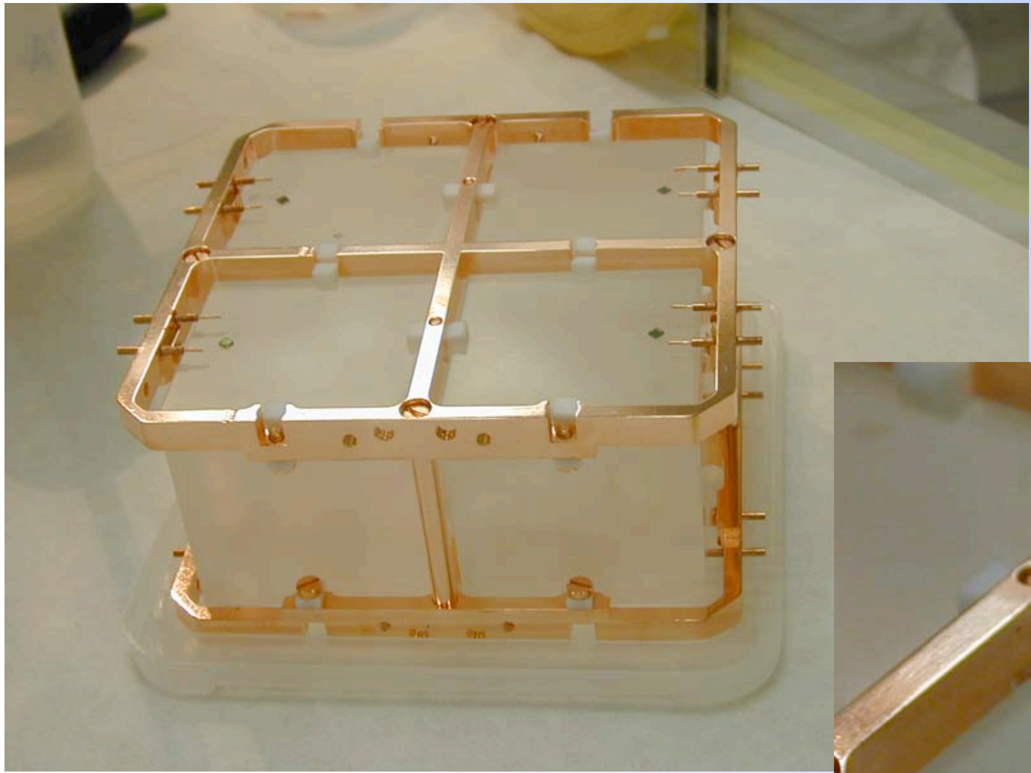
32 x 0.790 = 25.28 kg

12 x 0.330 = 3.96 kg

$$\left.\begin{array}{l} 2(^{130}\text{Te-enriched}) \times 0.330 = \\ = 0.660 \text{ kg} = 0.495 \text{ kg } ^{130}\text{Te} \\ \\ 2(^{128}\text{Te-enriched}) \times 0.330 = \\ = 0.660 \text{ kg} = 0.543 \text{ kg } ^{128}\text{Te} \end{array}\right\} 29.24 \text{ kg} = 9.9 \text{ kg } ^{130}\text{Te}$$

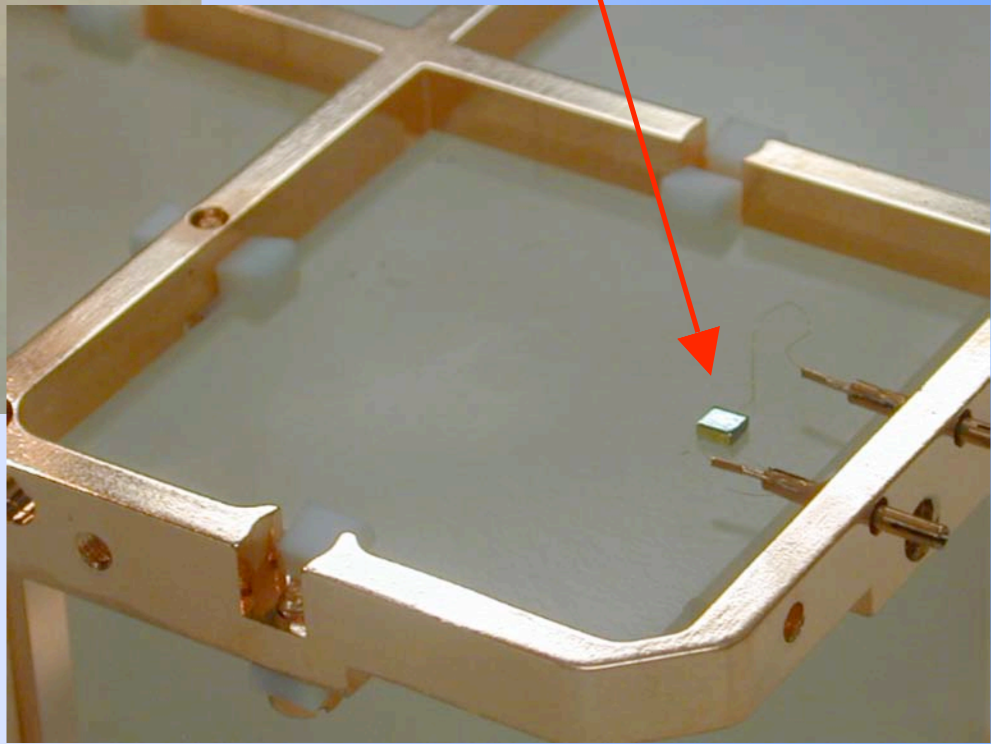
$\boxed{10.4 \text{ kg } ^{130}\text{Te}}$

CUORICINO modules

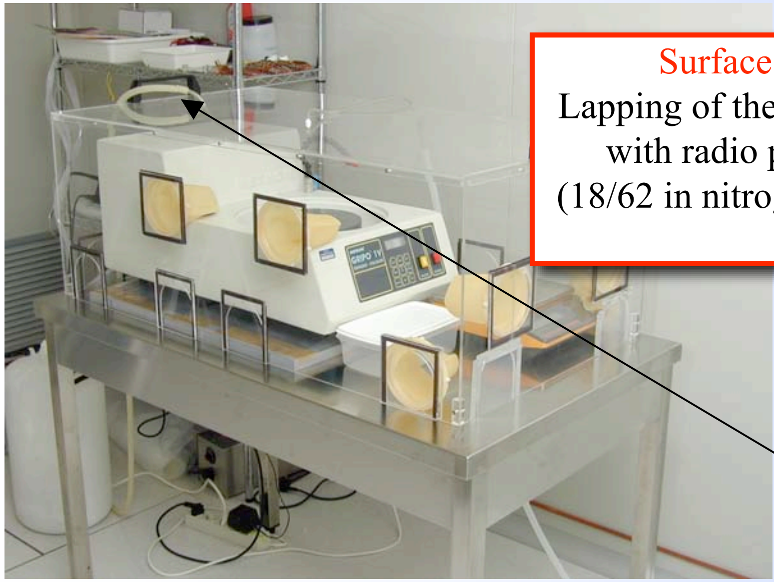


CUORICINO module of 4 detectors

Termistore Ge NTD



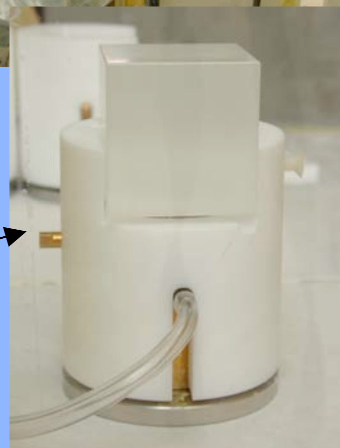
Detector preparation



Surface cleaning:
Lapping of the crystals surface
with radio pure powders
(18/62 in nitrogen atmosphere)

Nitrogen

Detector assembly:
Gluing thermistors and heaters:
all done in nitrogen atmosphere



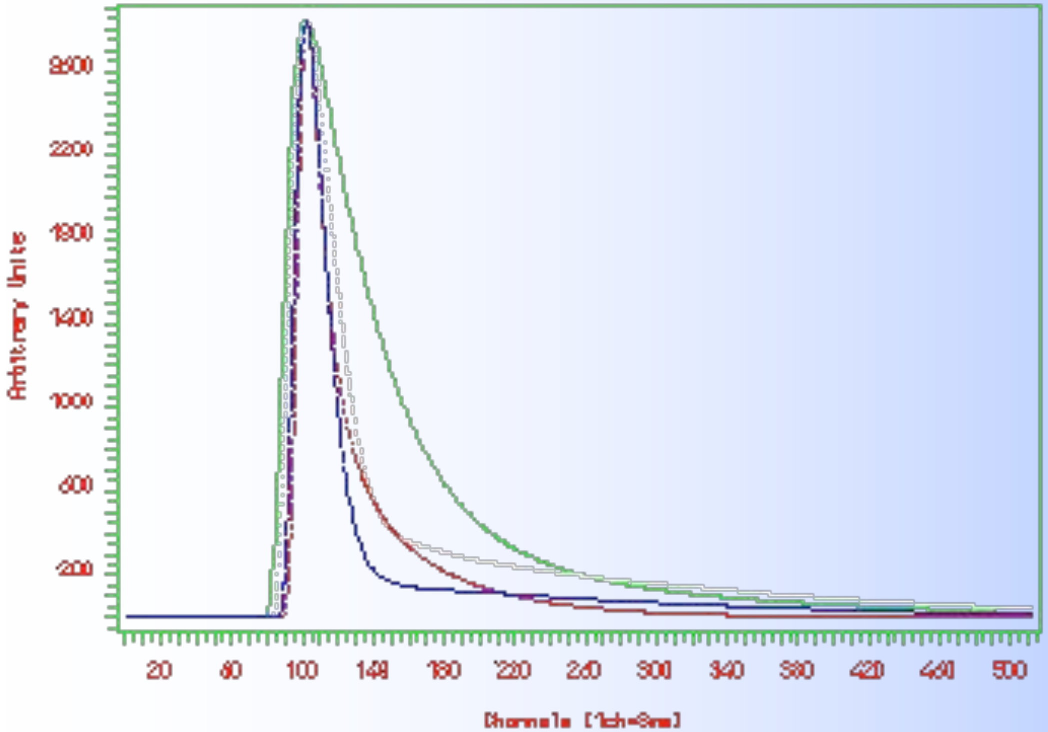
Gluing tool

Modules assembling

All the operations done in nitrogen atmosphere

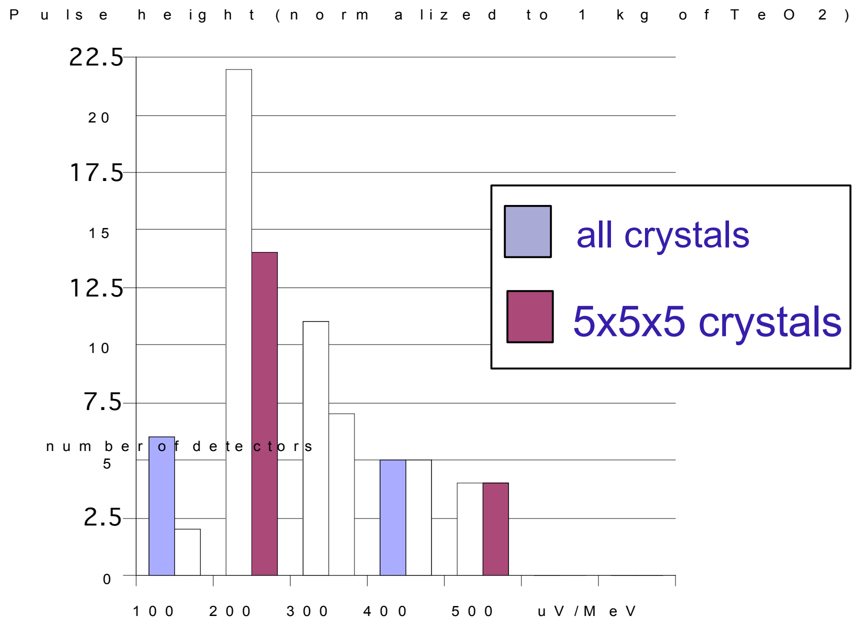
Tower assembling

Performances of the detectors



average pulse height
for 5x5x5 crystals = 340 uV/MeV
average pulse height
for 3x3x6 crystals = 440 uV/MeV

Pulse height distribution uV/MeV
(normalized to 1 kg of TeO_2)



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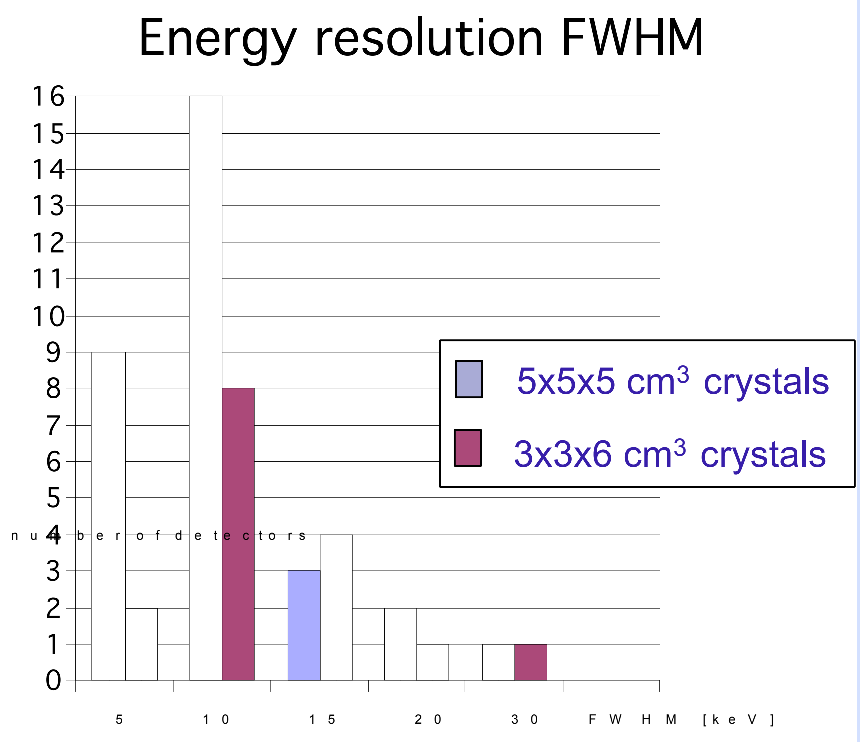
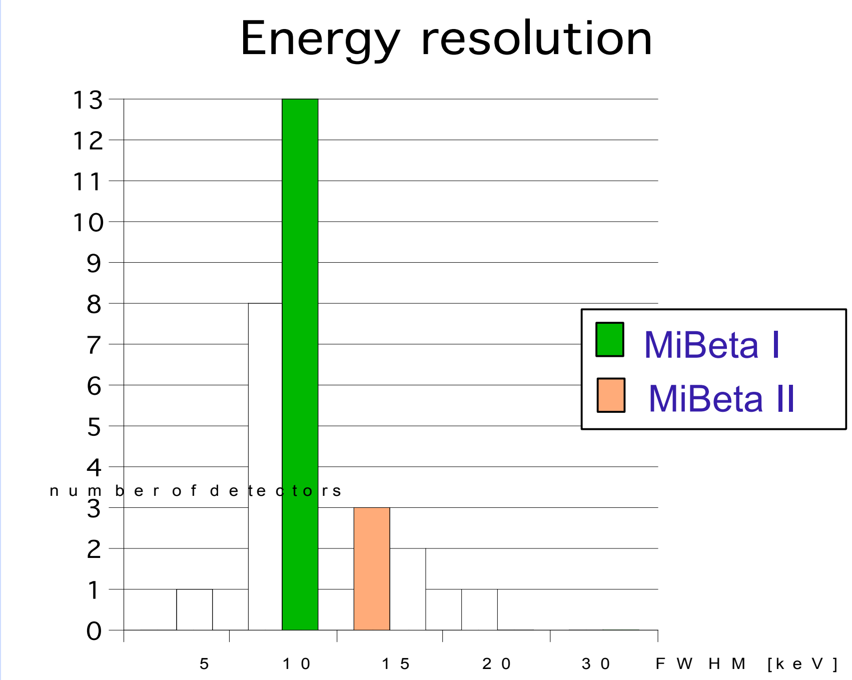
Performances of the detectors



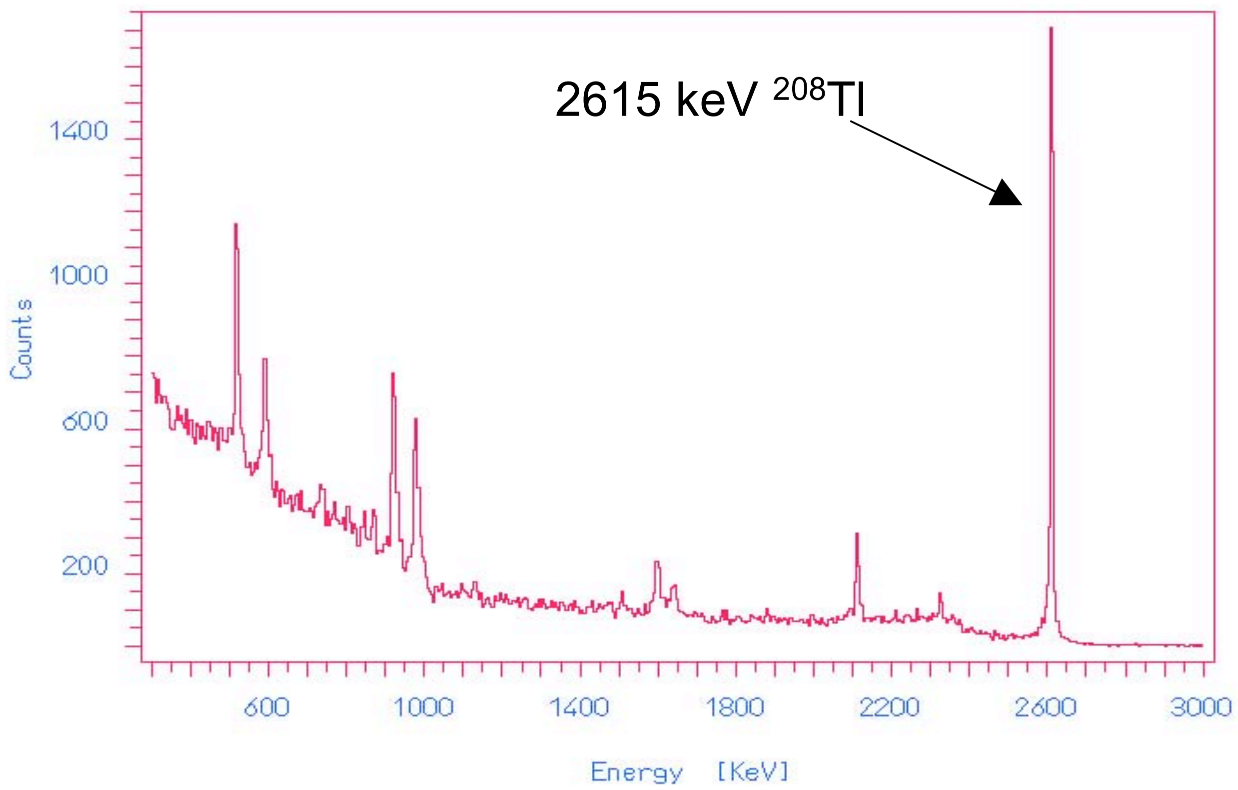
FWHM [keV] of the 2615 keV gamma line of ^{208}Tl (calibration with a ^{232}Th source ~ 3 days)

average 5x5x5 cm^3 crystals ~ 7 keV
average 3x3x6 cm^3 crystals ~ 9 keV



[keV] of the 2615 keV gamma line of ^{208}Tl

^{232}Th Calibration



Sum spectrum of all the 5x5x5 cm^3 detectors

ΔE_{FWHM} = 7 keV @ 2615 keV

FIRST RESULT

After ~1 month of measure:

Background ββ region

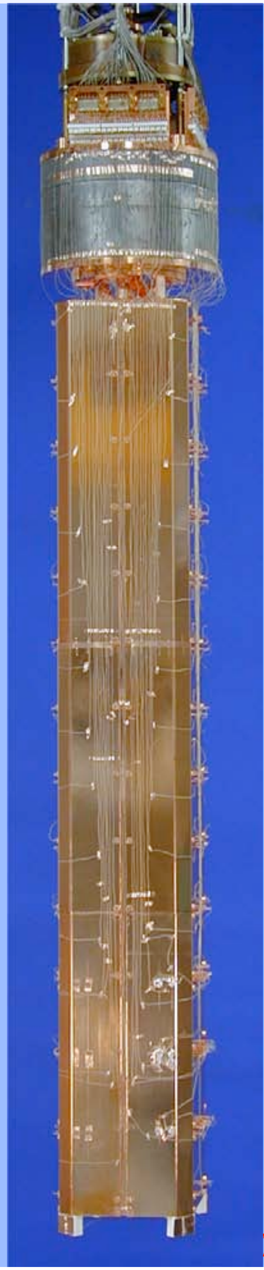
(anticoincidence spectrum, only 5x5x5 crystals)

= 0.26 +/- 0.06 c/keV/kg/y

Total results for life time and Majorana mass:

$$\tau^{0\nu}_{1/2} \geq 3.6 \cdot 10^{23}\, y\,(90\%\, CL)$$

$$\Rightarrow \quad \langle m_\nu \rangle \leq 0.7 - 1.6\, eV \quad (90\%\, CL)$$



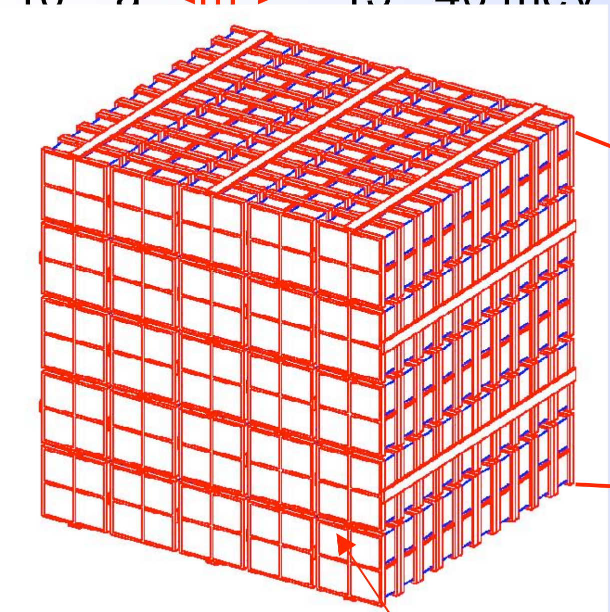
Cryogenic Underground Observatory for Rare Events

Array of 1000 detectors:
25 towers - 10 modules/tower -
4 detectors/module
⟹ M = 0.78 ton di TeO_2

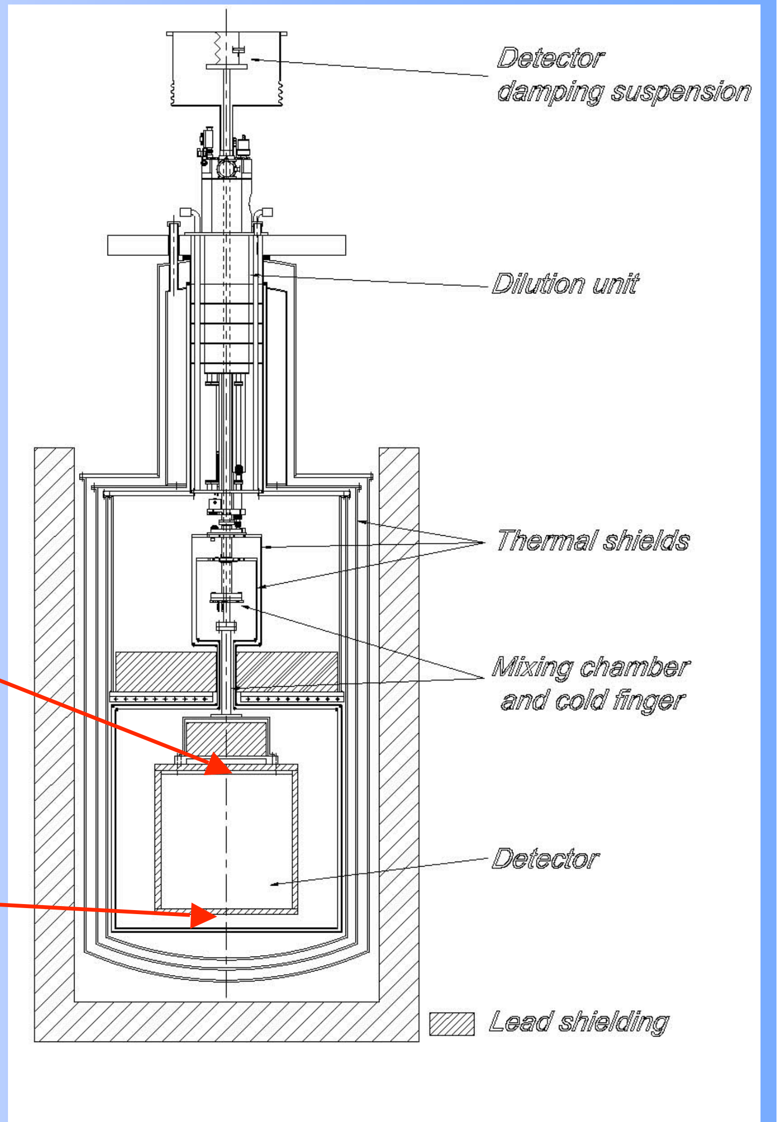
Sensitivity DDB-0ν *(ext. background 1 c/keV ton y)*

T^{5y} ~6.6 10^{26} a $\langle m \rangle$ ~ 15 - 40 meV

70 cm



25 towers CUORICINO-like



Conclusion

- DBD0ν search is a powerful way of improving our knowledge of neutrino proprieties
- Bolometric (source = detector) approach is up to now the best
- CUORICINO is a working prototype of a large mass experiment
- First CUORICINO results are very encouraging for the future