Cuoricino and CUORE detectors: developing big arrays of large mass bolometers for rare events physics

Paolo Gorla
Laboratori Nazionali del Gran Sasso of INFN
Università degli studi di Milano-Bicocca

On behalf of CUORE Collaboration

Outline

- Physical goal: search of neutrinoless DBD
- Bolometric approach in Cuoricino/CUORE
- Cuoricino detector
- Present performance

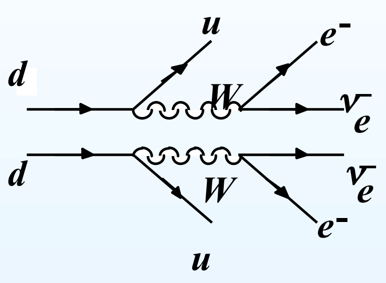
The Cuoricino results on neutrino physics

- Developments for Cuore
  - Background reduction
  - Resolution improvements
  - Detector reproducibility
- Conclusion

Neutrino proprieties and DBD

Nuclear ββ decay is a rare nuclear process; Two interesting decay modes are usually discussed:

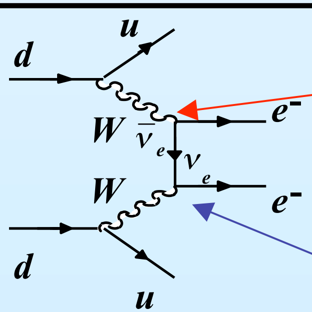
① DBD2ν: $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\,\bar{\nu}_e$



2ν - ββ decay

2nd order elettroweak process allowed by SM, has already been observed in various nuclei $\tau^{2\nu} \sim 1019 - 1021$ y

② DBD0ν: $(A,Z) \rightarrow (A,Z+2) + 2e^-$



0ν - ββ decay

a RH (L=1) antineutrino is emitted

a LH (L=-1) neutrino Is absorbed

In pre-oscillation standard particle physic (massless neutrino), the process is forbidden because neutrino has not the correct helicity/lepton number to be adsorbed at the second vertex

Neutrino proprieties and DBD

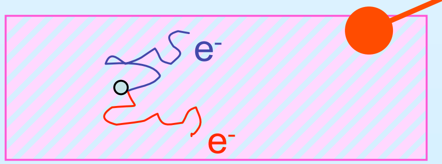
But from neutrino oscillation measures we know that $m_\nu \neq 0$.

IF neutrinos are massive Majorana particles ($\nu = (\nu)^c$) : helicity can be accommodate thanks to finite mass, AND Lepton number is not relevant.

Measuring 0ν-DBD is a very important test of neutrino nature

Experimental approach

Cuoricino (and CUORE) are experiments for measuring 0ν-DBD of ^{130}Te, using bolometric detectors with the, so called, calorimetric technique



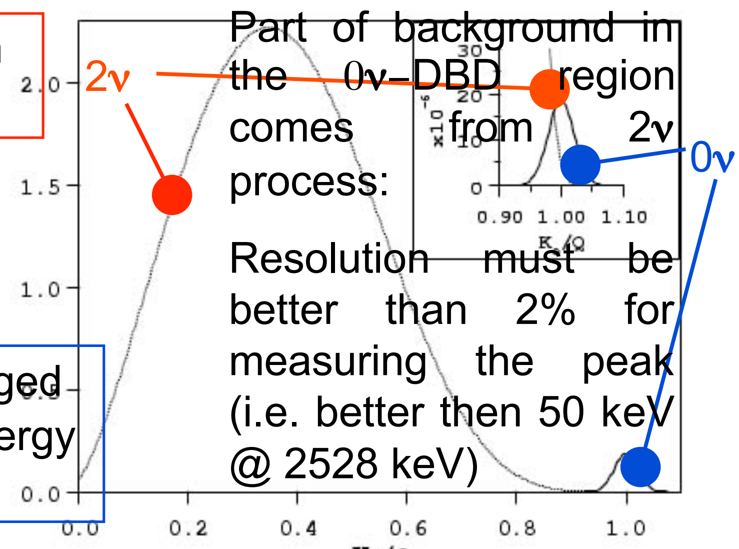
Source ≡ Detector
(calorimetric technique)

2ν- DBD continuum with max at ~1/3Q

An energy line is aspected at the the Q value of the reaction.

0ν- DBD peak enlarged only by detector's energy resolution

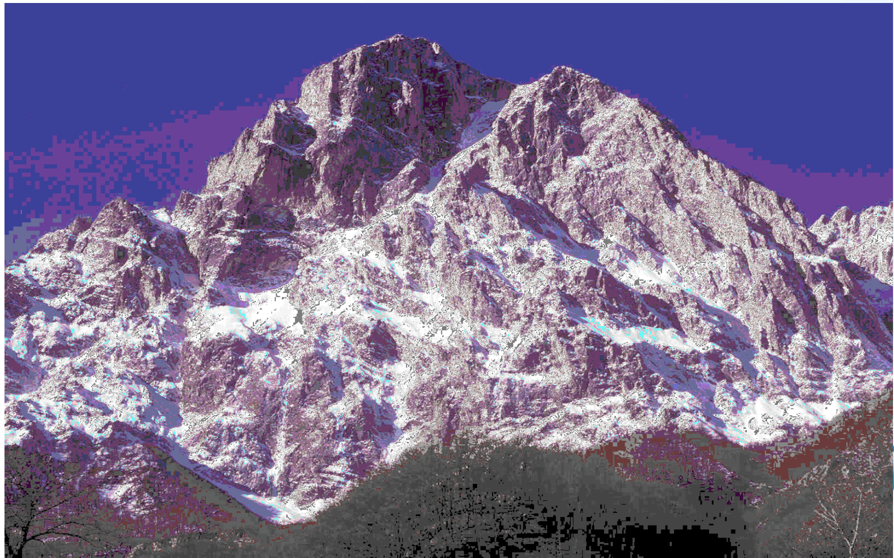
$Q(^{130}Te) = 2528$ keV



Part of background in the 0ν–DBD region comes from 2ν process:

Resolution must be better than 2% for measuring the peak (i.e. better then 50 keV @ 2528 keV)

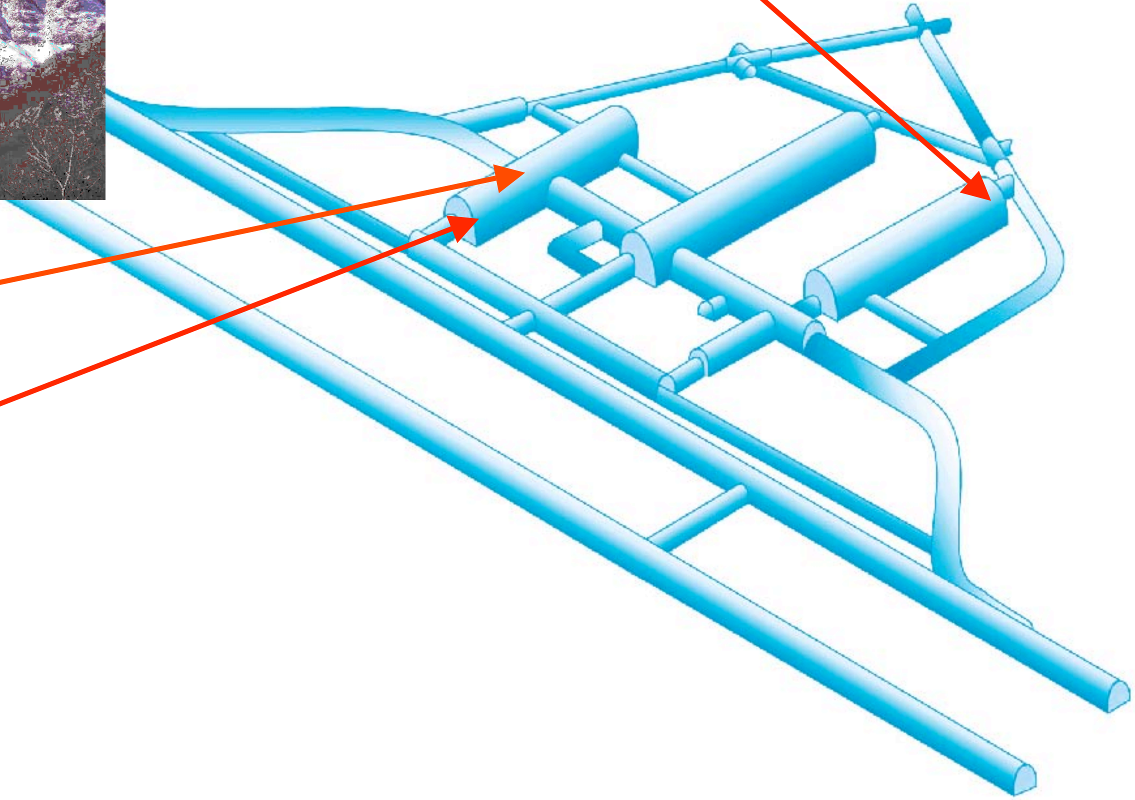
CUORE @ LNGS



CUORE R&D (Hall C)

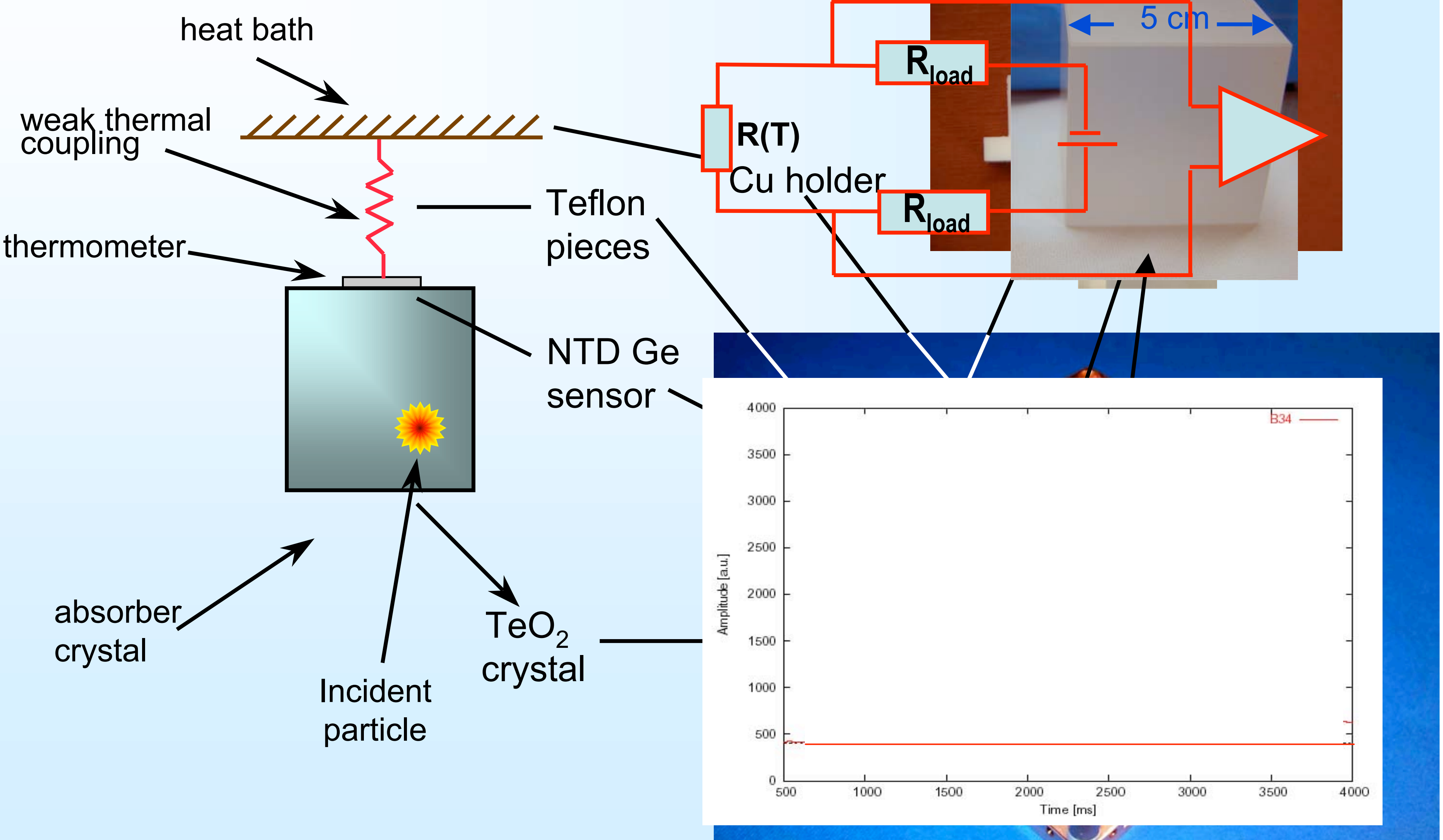
CUORE location (Hall A)

Cuoricino (Hall A)



Cuoricino and CUORE

Cuoricino is an array of 62 bolometers:



Detector sensitivity for DDB-0ν

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

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

- *Isotopic abundance* (a)
- *Atomic mass* (A)
- *Detector mass (kg)* (M)
- *Measurement Time (y)* (T)
- *Background (counts/keV/kg/y)* (b)
- *Energy resolution (keV)* (Γ)
- *Efficiency* (ε)

Detector improvements must be on:

- Increase detector mass
- Background reduction (and if possible rejection)
- Increase energy resolution

Increasing the mass

Two ways:

1. Increasing the absorber crystal of the single detector
2. Increasing number of detectors

Temperature variation measure by NTD

BUT

Energy release

$\Delta T = E / C$

Absorber heat capacity

①

1991 : first TeO2 bolometer, 73 g of mass

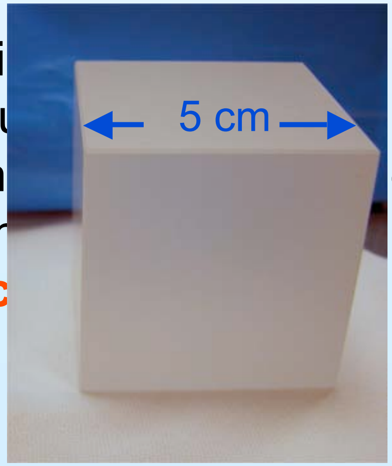
1993 : first 340 g TeO_2 bolometer, 3x3x6 cm^3

2000 : first 790 g TeO_2 bolometer, 5x5x5 cm^3

2004 : first 1300 g TeO_2 bolometer, 6x6x6 cm^3

the only limitation is given by the heat capacity of the crystal that is proportional to volume.

Thermal noi … i.e. baseline oscillation du … pation on the crystal (main … e amplitude of this type of r … the increasing of C. **S/N is c**

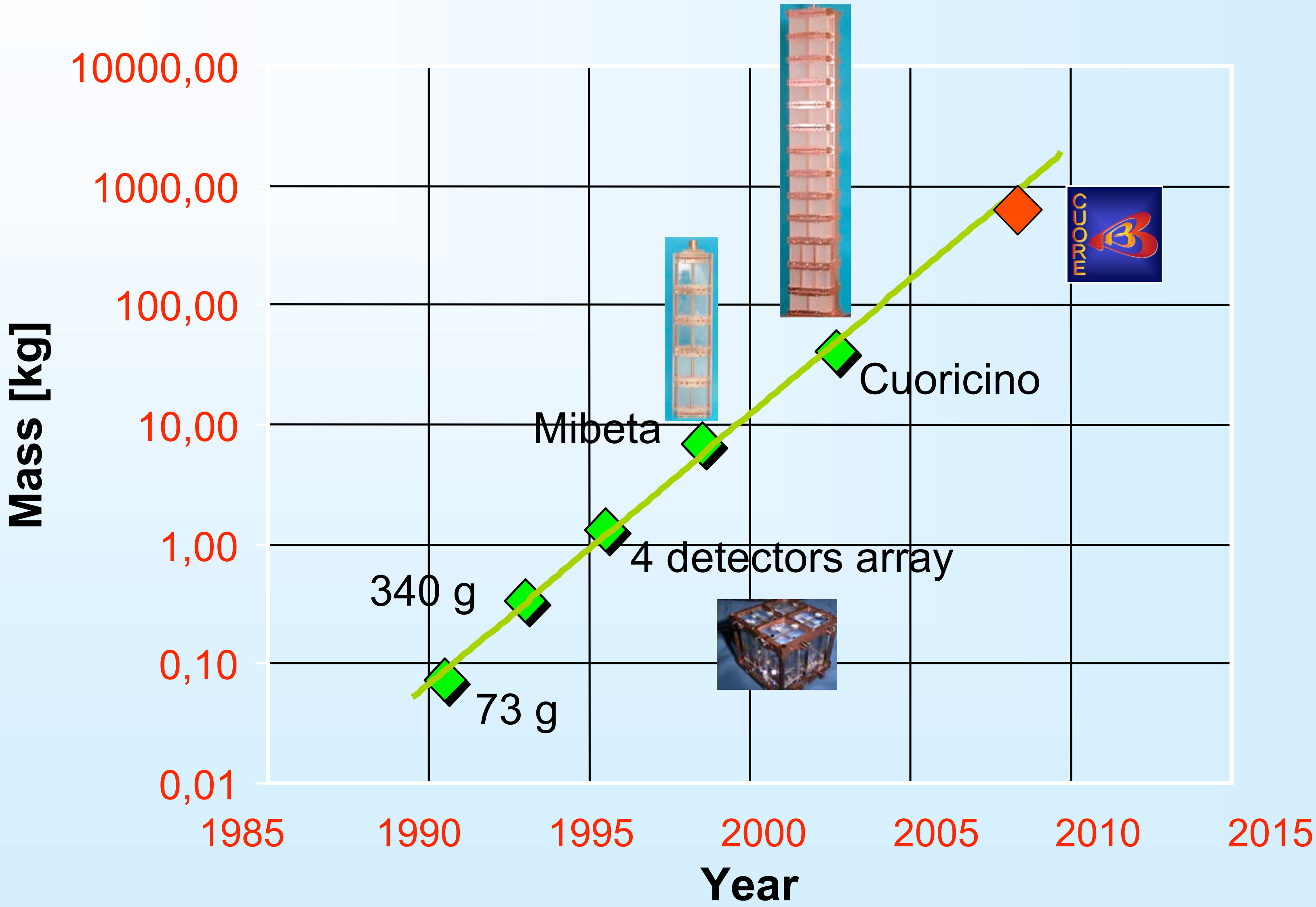


The real limitation is given by growing crystals of big dimensions.

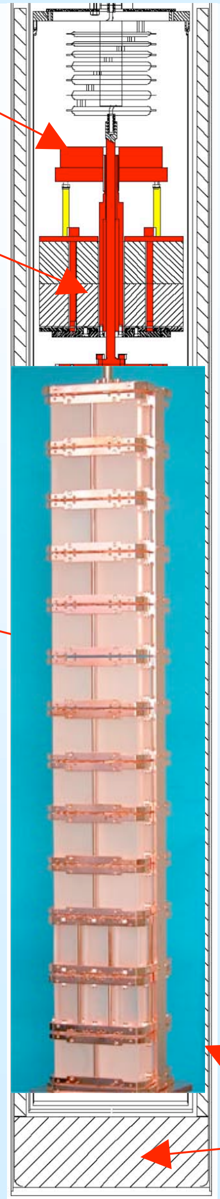
Best choice: 5x5x5 cm^3

Increasing the mass

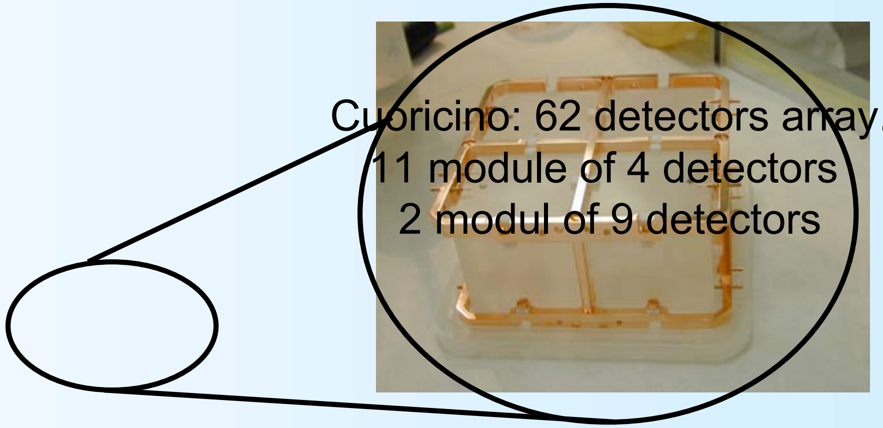
②



Cuoricino



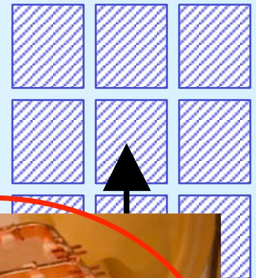
Total mass
40.9 kg

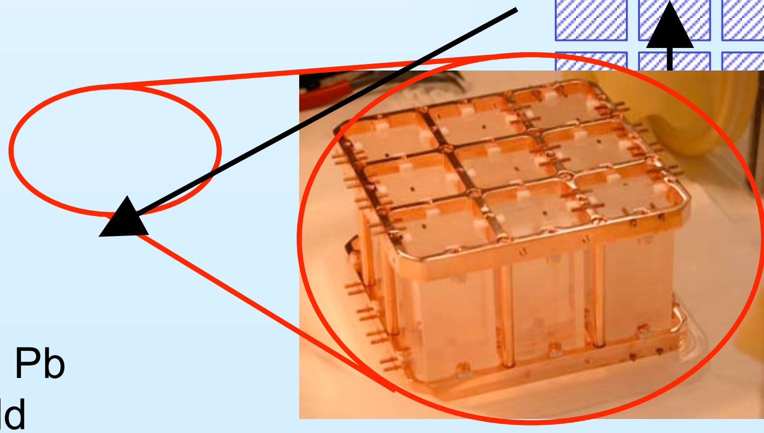


Cuoricino: 62 detectors array.
11 module of 4 detectors
2 modul of 9 detectors

4 detectors 5x5x5 cm^3, 790 g each

Planar Section





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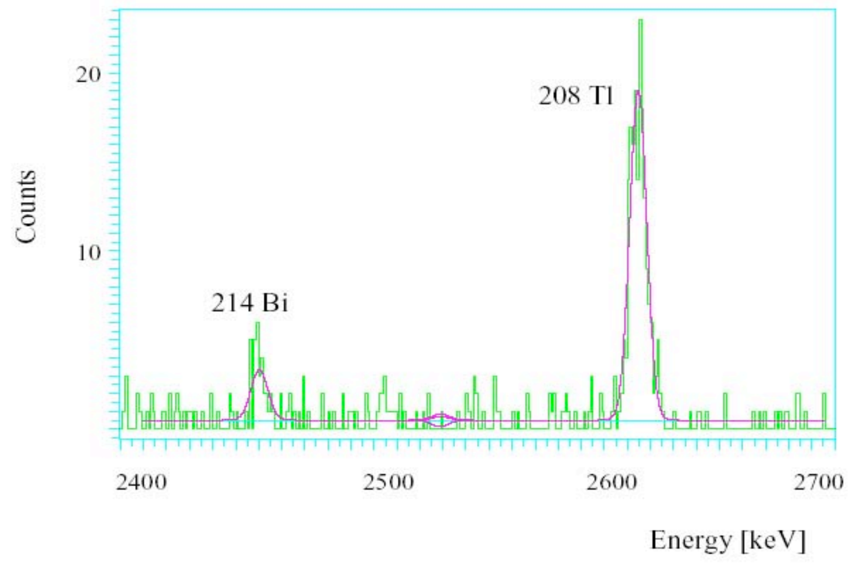
9 detectors 3x3x6 cm3, 340 g each

Background

Bkg sources in the DBD region:

• Degraded α particles from material surface

• Multicompton effects and other gamma process



Coincidence detection on faced crystals allows:

• Reconstruction of the sum energy of the event

• Rejection of the events in anticoincidence

Surface contamination from non active material (Cu, Teflon,…) cannot be rejected with anticoincidence.

• Reduce material possible source of contamination: no mater how clean is the material you use, treatment always introduce surface contamination.

• Clean surfaces with special techniques

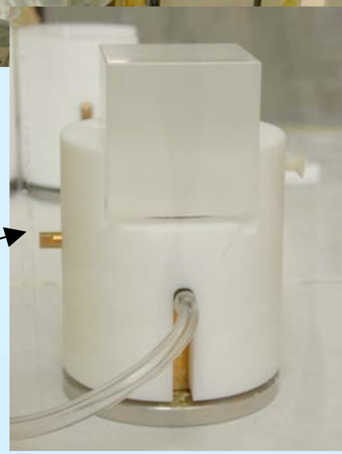
Detector preparation

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



Clean procedures

Completely done in nitrogen atmosphere

Resolution: 790 g detector performance

In the past years a big effort was made in R&D on the 5x5x5 cm^3 TeO_2 detectors (790 g)

The best 790 g detector:

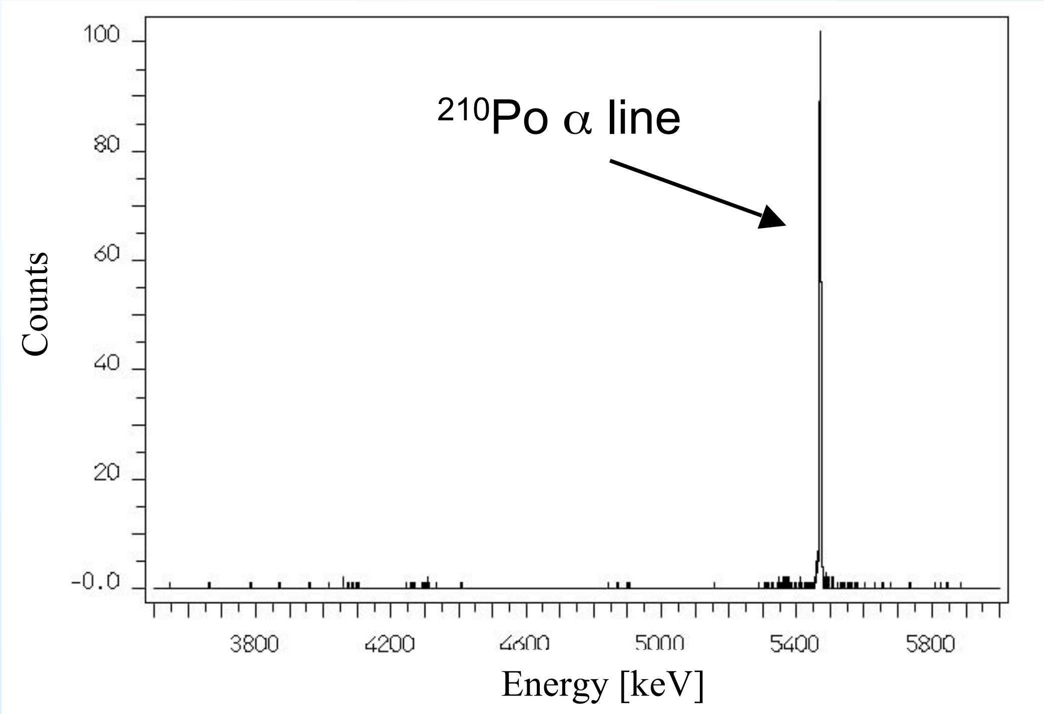
1.4 keV FWHM @ 0.351 MeV

2.1 keV FWHM @ 0.911 MeV

2.6 keV FWHM @ 2.615 MeV

3.2 keV FWHM @ 5.407 MeV

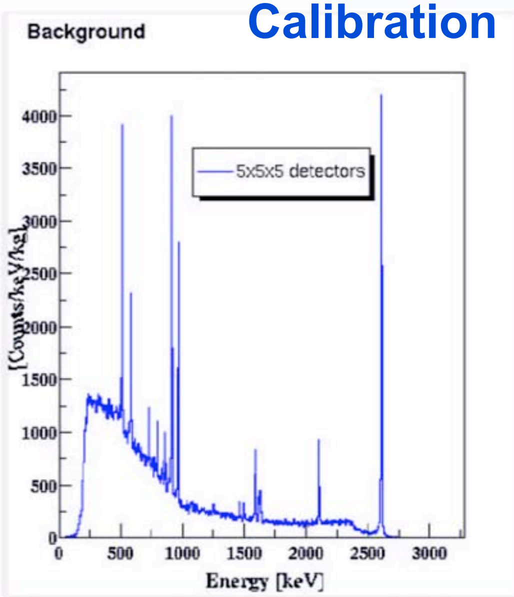
(the best α spectrometer ever realized)
A.Alessandrello et al, NIM A440 (2000) 397-402

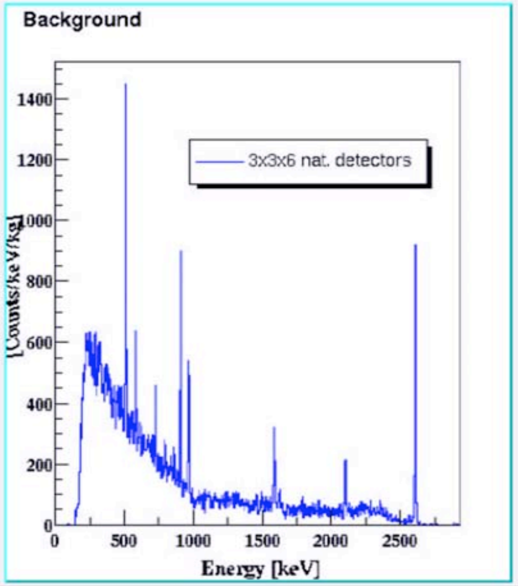


One of the best techniques for measuring very low radioactive contaminations

Resolution: Cuoricino

Calibration

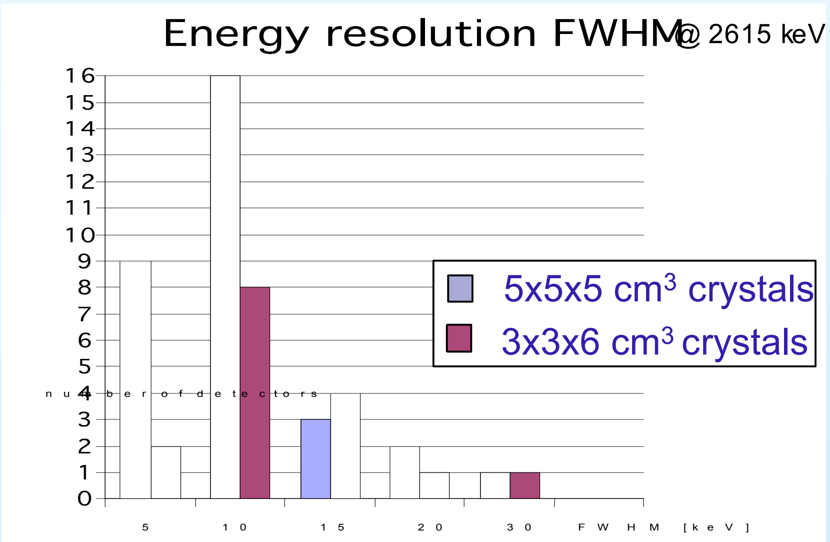


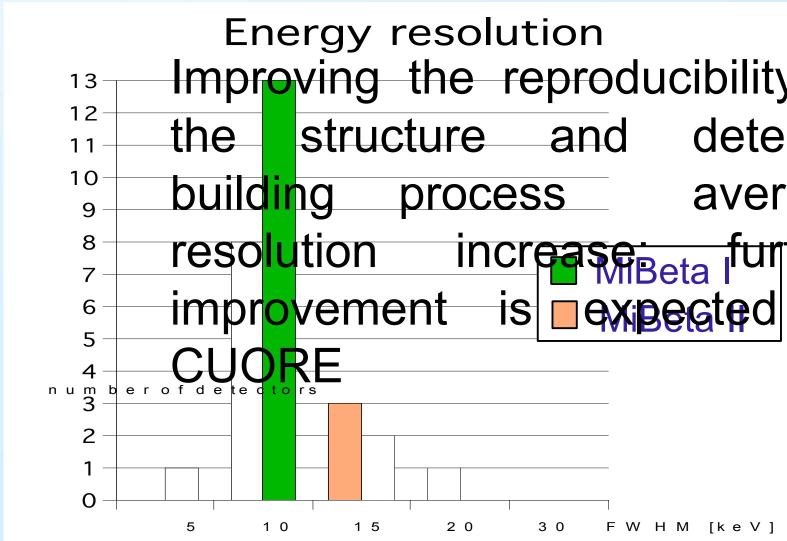


FWHM [keV] of the 2615 keV gamma line of ^{208}Tl (calibration with a ^{232}Th source ~ 3 days)

average 5x5x5 cm^3 crystals ~ 7 keV

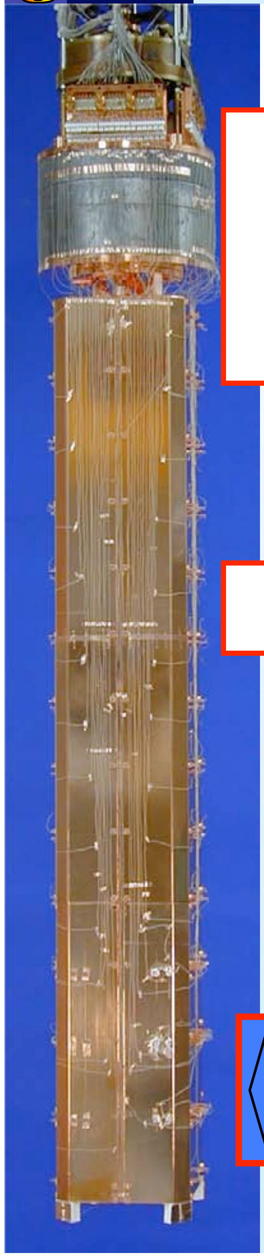
average 3x3x6 cm^3 crystals ~ 9 keV





Improving the reproducibility of the structure and detector building process average resolution increase; further improvement is expected in CUORE

Cuoricino results



After ~4 month of measure, 5.4 kg·y:

Background ββ region

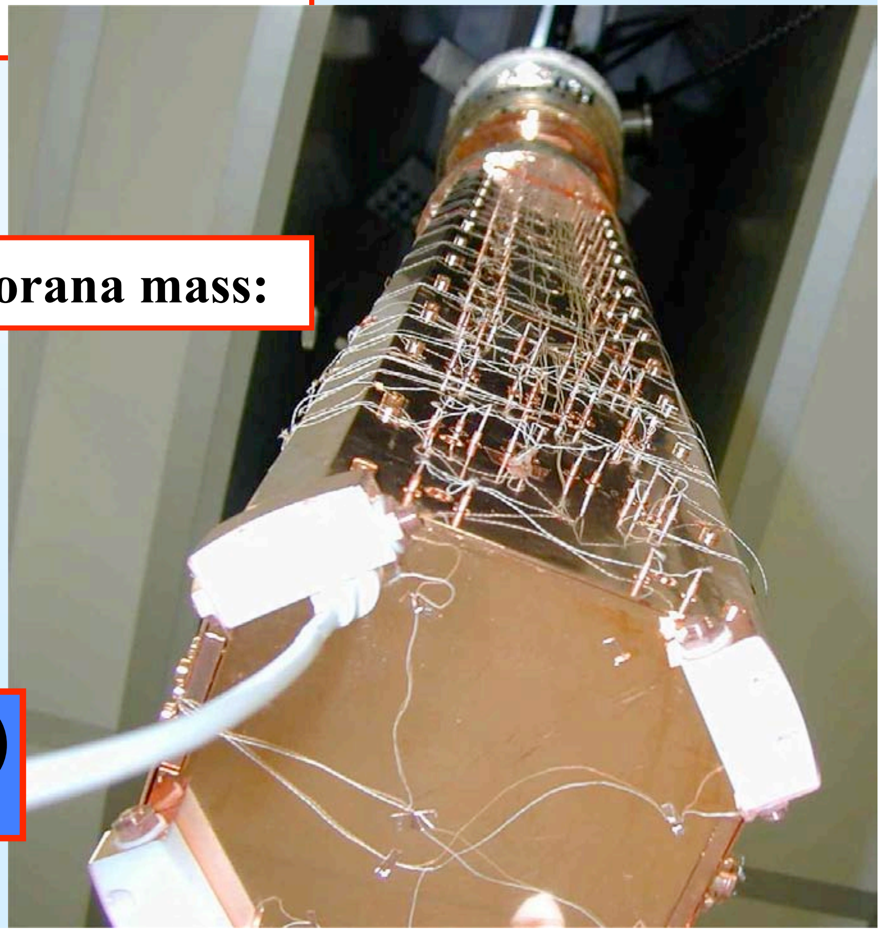
(anticoincidence spectrum)

= 0.19 c/keV/kg/y

Total results for life time and Majorana mass:

$$\tau_{1/2}^{0\nu} \geq 7.5 \cdot 10^{23}\, y \,(90\%\, CL)$$

$$\langle m_\nu \rangle \leq 0.31 - 1.63\, eV \quad (90\%\, CL)$$



Cryogenic Underground Observatory for Rare Events

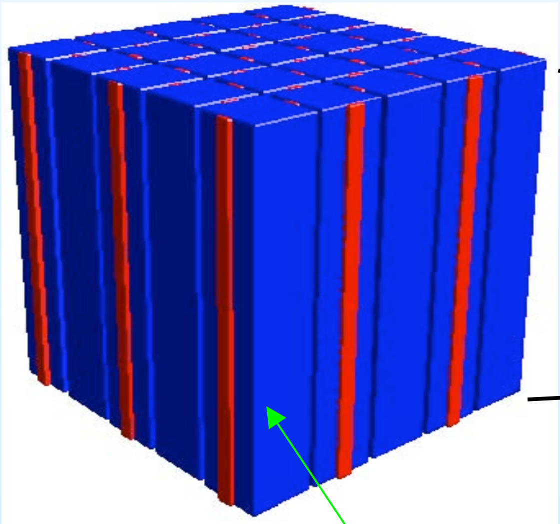
Array of 1000 detectors:
25 towers - 10 module/tower - 4 detectors/module

⇨ M = 0.79 ton di TeO_2

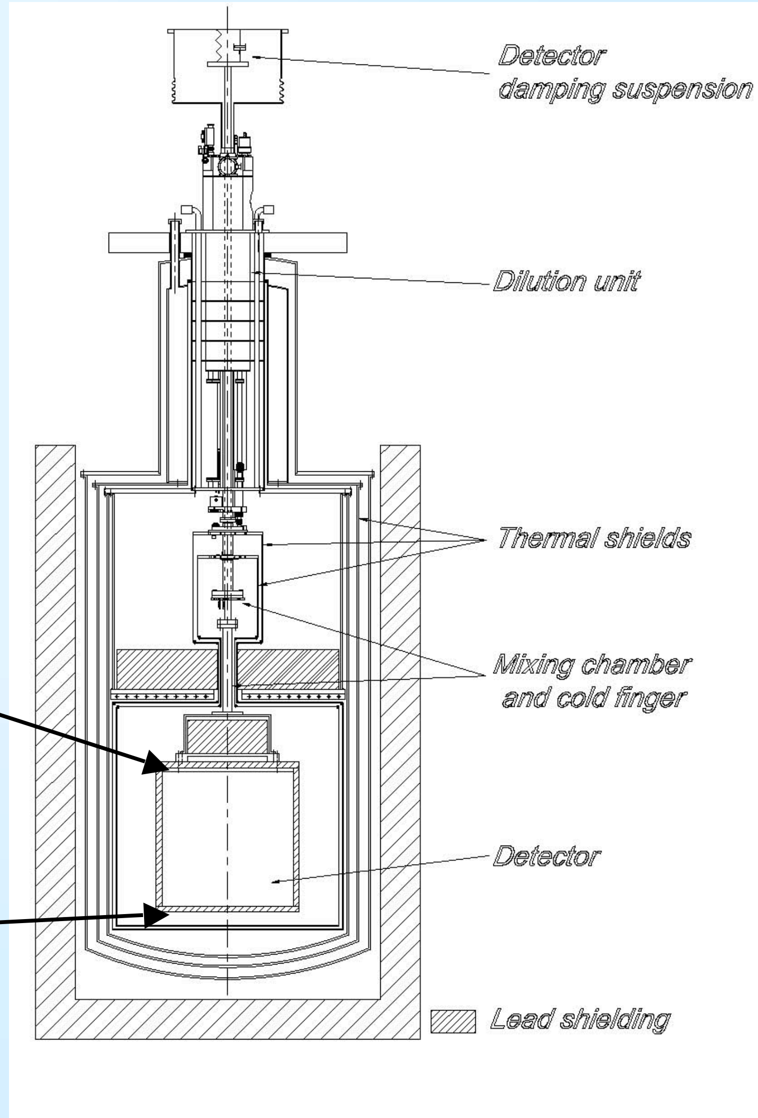
Sensitivity on DBD-0ν *(extimated bg 1 c/keV ton y)*

$T^{5y} \sim 6.6\ 10^{26}$ y $<m_\nu> \sim$ 15 - 40 meV

70 cm

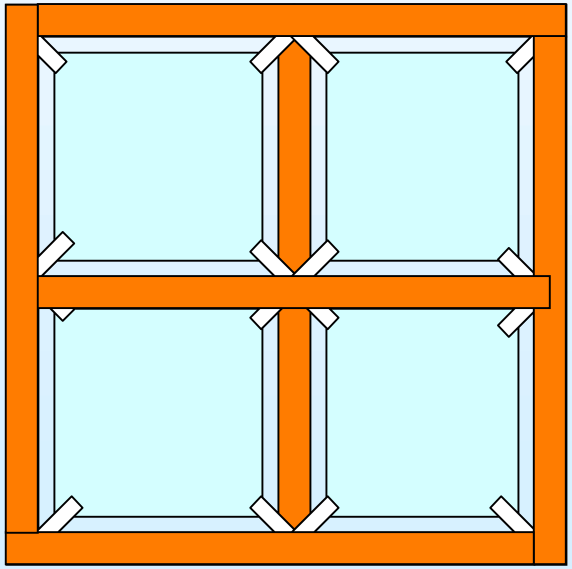


25 CUORICINO-like towers

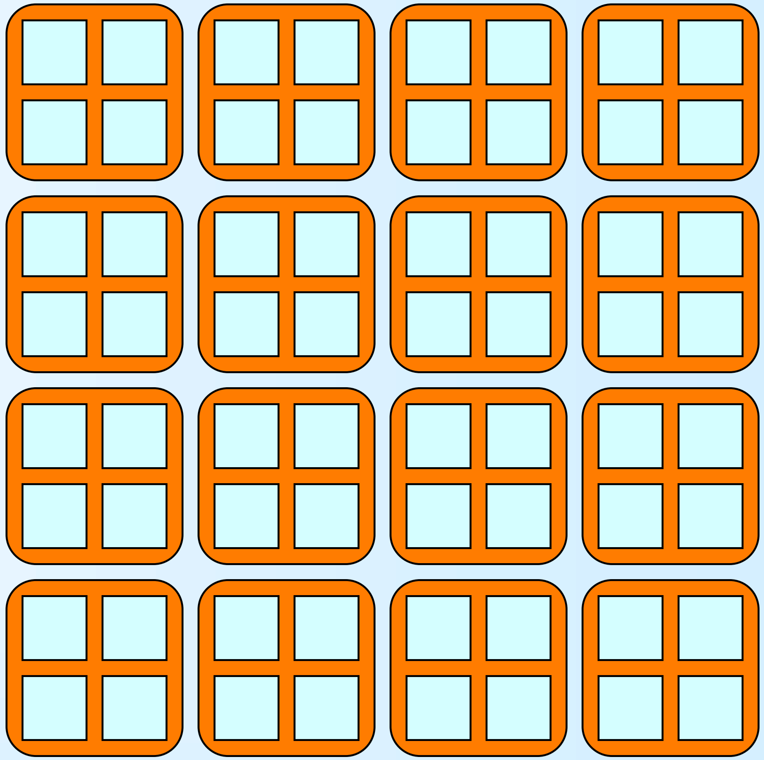


Cryogenic Underground Observatory for Rare Events

Cuore is a huge improvement not only in mass but in segmentation (anticoincidence) and modularity (resolution)



More stable older



A CUORE slice

Conclusion

- Big arrays of macrobolometers are reliable detectors for rare events physic
- Cuoricino demonstrate the possibility of having an average good energy resolution on many detector and tested the improvements of anticoincidence technique
- CUORE, a second generation detector developed on this new approaches will be build in the next 5 years.