First results of Cuoricino and perspectives for CUORE

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First results of Cuoricino and perspectives for CUORE

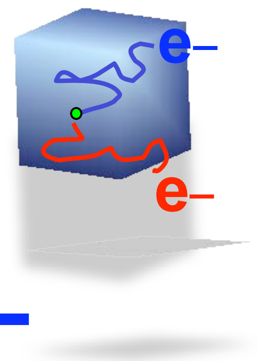
Outline

1. from Mi-DBD to CUORICINO and CUORE
2. the CUORE project
3. CUORICINO
4. CUORICINO construction
5. CUORICINO detector performances
6. CUORICINO background
7. perspectives for CUORE

From Mi-DBD to CUORICINO and CUORE

source = detector approach with bolometers

- wide choice of materials → *study new DBD candidates*
- detectors with an energy resolution comparable with that of Ge diodes



^{130}Te presents several nice features

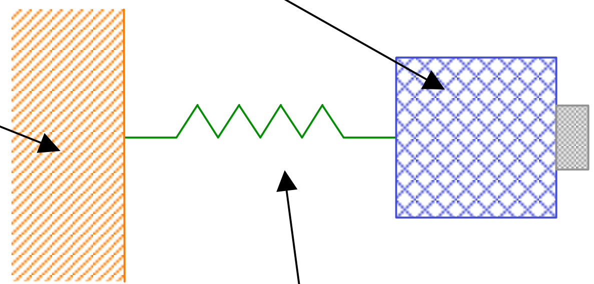
- high natural isotopic abundance (i.a. = 33.87 %) → *excellent feature for future reasonable-cosi expansion of Double Beta Decay experimer*
- high transition energy (Q = (2528.8 Ø1.3) keV) → *large phase space, lower background (clean window between full energy and Compton edge of ^{208}Tl photons)*
- encouraging theoretical calculations for 0ν–DBD lifetime → $m_{ee} \approx 0.1$ eV ⇔ $\tau \approx 10^{26}$ y

Te dominates in mass the compound
Excellent mechanical
and thermal properties

Energy absorber
TeO_2 crystal
C ≅ 2 nJ/K ≅ 1 MeV / 0.1 mK

Calorimetric approach
Good energy resolution
No limit to material choice

Heat sink
T ≅ 10 mK



Thermometer
NTD Ge-thermistor
R ≅ 100 MΩ
dR/dT ≅ 100 kΩ/μK

Thermal coupling
G ≅ 4 nW / K = 4 pW / mK

- Temperature signal: $\Delta T = E/C \cong 0.1$ mK for E = 1 MeV
- Bias: I ≅ 0.1 nA ⇒ Joule power ≅ 1 pW ⇒ Temperature rise ≅ 0.25 mK
- Voltage signal: $\Delta V = I \times dR/dT \times \Delta T \Rightarrow \Delta V = 1$ mV for E = 1 MeV
- Signal recovery time: $\tau = C/G \cong 0.5$ s
- Noise over signal bandwidth (a few Hz): $V_{rms} = 0.2\ \mu V$

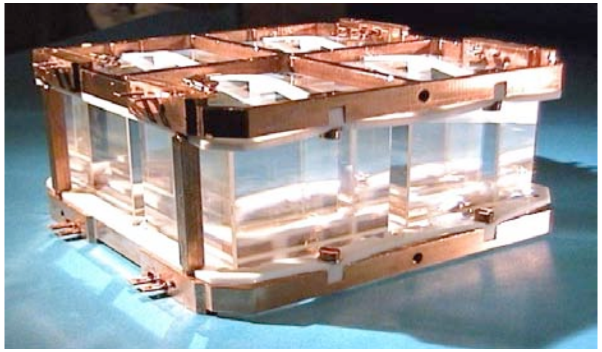
In real life signal about a factor 2 - 3 smaller

Energy resolution (FWHM): ≅ 1 keV

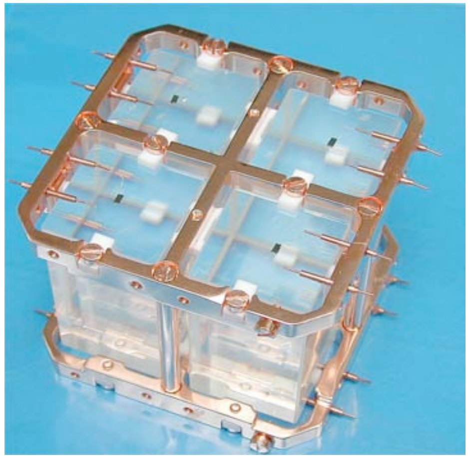
From Mi-DBD to CUORICINO and CUORE

1990: the first TeO_2 bolometer
1993: the first experiment with a 334 g TeO_2 detector

1997: the 20 (340 g) crystal array (Mi-DBD I)



1998-2002: tests on 750 g TeO_2 crystals



2001: the 20 crystal array is rebuild with a new structure and with cleaner materials (Mi-DBD II)

FWHM 15 keV
(0.33 +/- 0.11) c/keV/kg/y
$\tau_{1/2} > 2\ 10^{23}$ y at 90% C.L

The Mi DBD - II: experimental set-up

(a general test for the CUORICINO set-up)

5 modules, 4 detector each

(3x3x6 cm^3 TeO_2 crystals, 340 g)

are arranged in a tower-likecompact structure (6.8 kg)

the tower is mounted inside

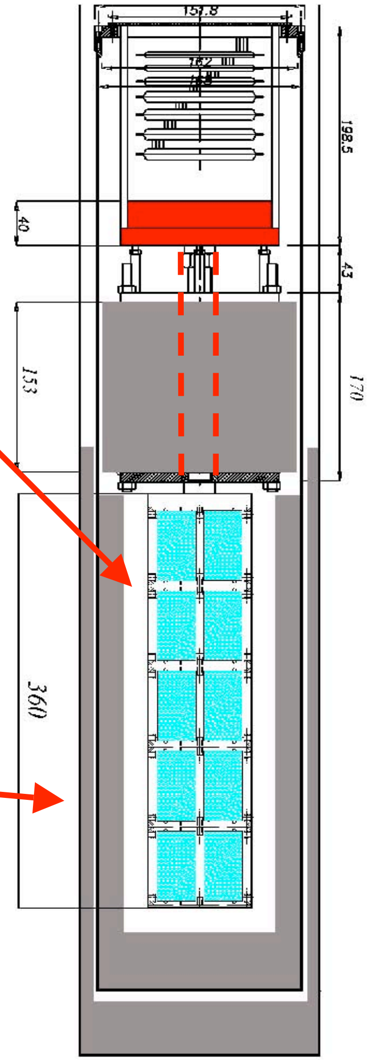
a dilution refrigerator

the tower is surrounded by

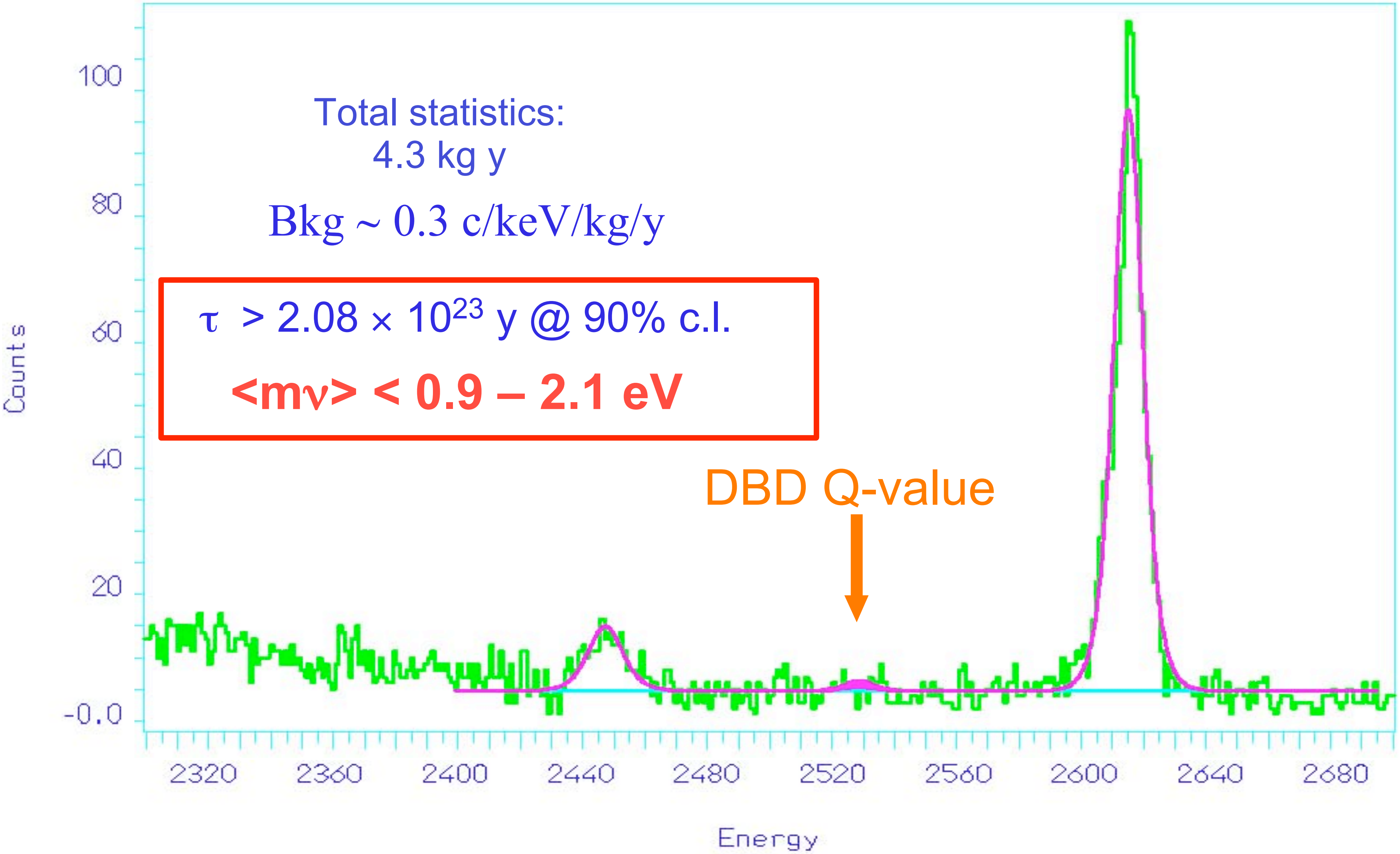
an inner Roman lead shield,

and all the refrigerator

by a 20 cm thick outer lead shield + borated PET shield



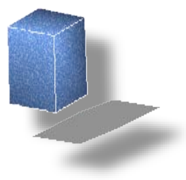
Mi DBD: limits on 0νDBD



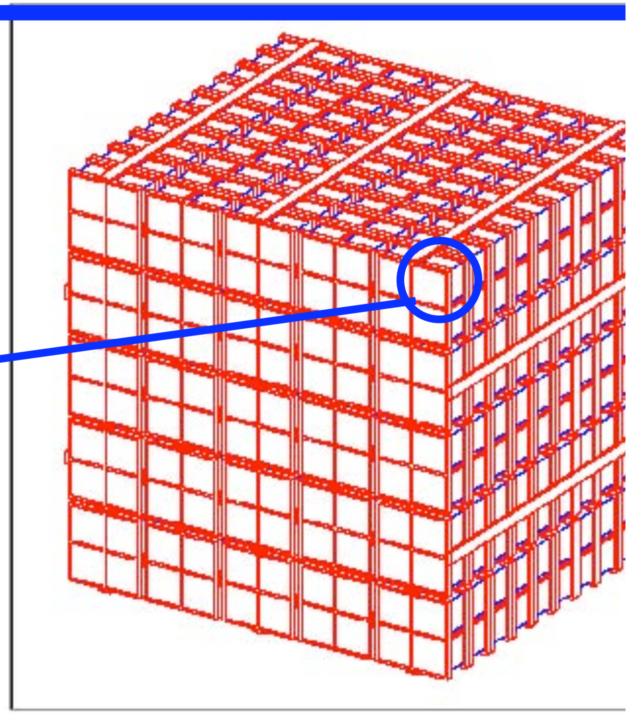
The CUORE project

CUORE is an array of ~ 1000 bolometers

750 kg TeO_2



x 1000



0.75 kg x 1000 = **750 kg TeO_2** = 600 kg Te = **203 kg ^{130}Te**

crystals are grouped in 250 modules of 4 crystals each, the modules are arrange
in 25 towers assembled in a 5x5 matrix

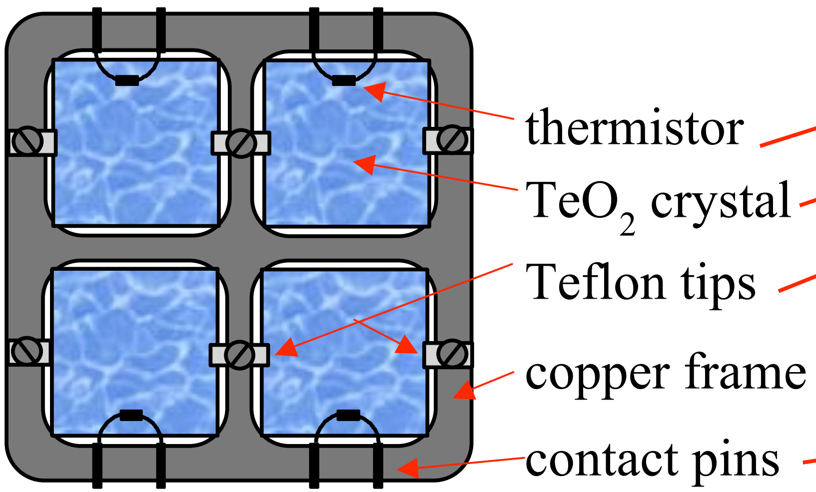
bolometers placed (in a single dilution refrigerator at ~ 10 mK) as close as possible with a minimum amount of material among them

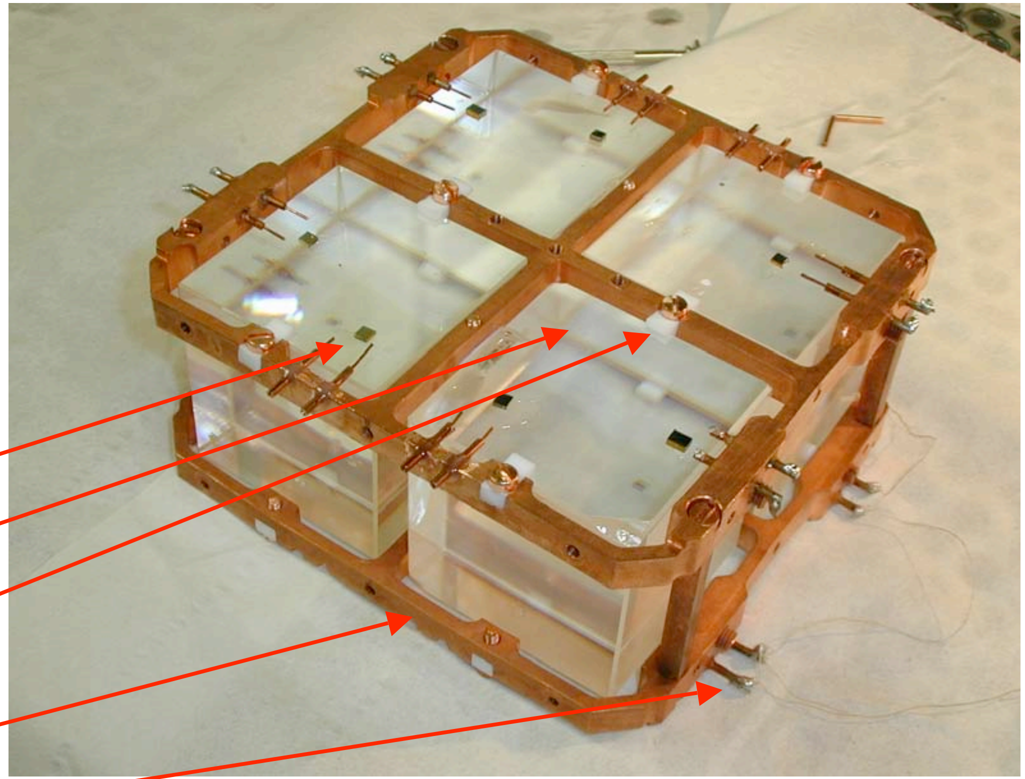
A SINGLE, HIGH GRANULARITY DETECTOR

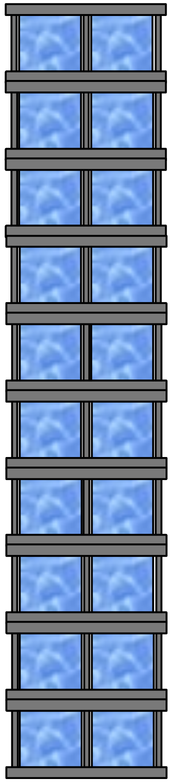
the elementary module:

a 4-crystal plane is a mechanically independent module made of 4 crystals, various 4-crystal planes have been tested with good results on both reproducibility and reliability

energy resolution	~ 1 keV at threshold
	5 - 10 keV at 3 MeV
nuclear recoil quenching factor	~ 1



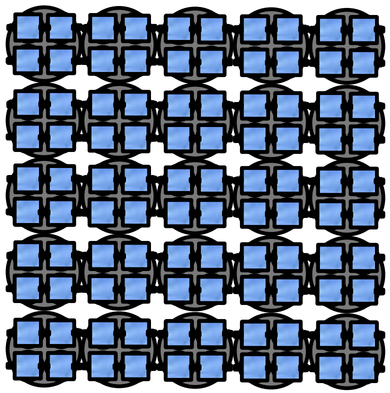


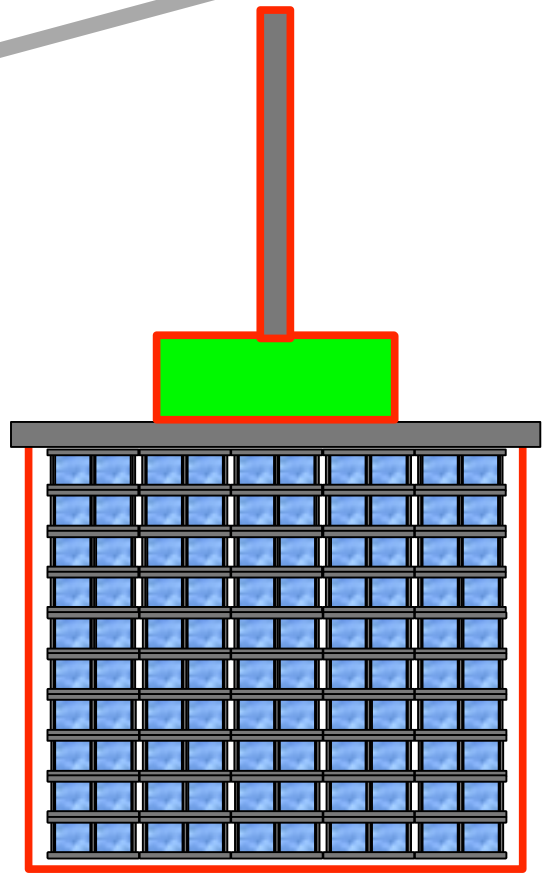


the tower

a tower contains 10 modules, as in the case of the 4-crystal modules also towers are indipendent structures

a single tower of CUORE has been already built and is installed in Hall A





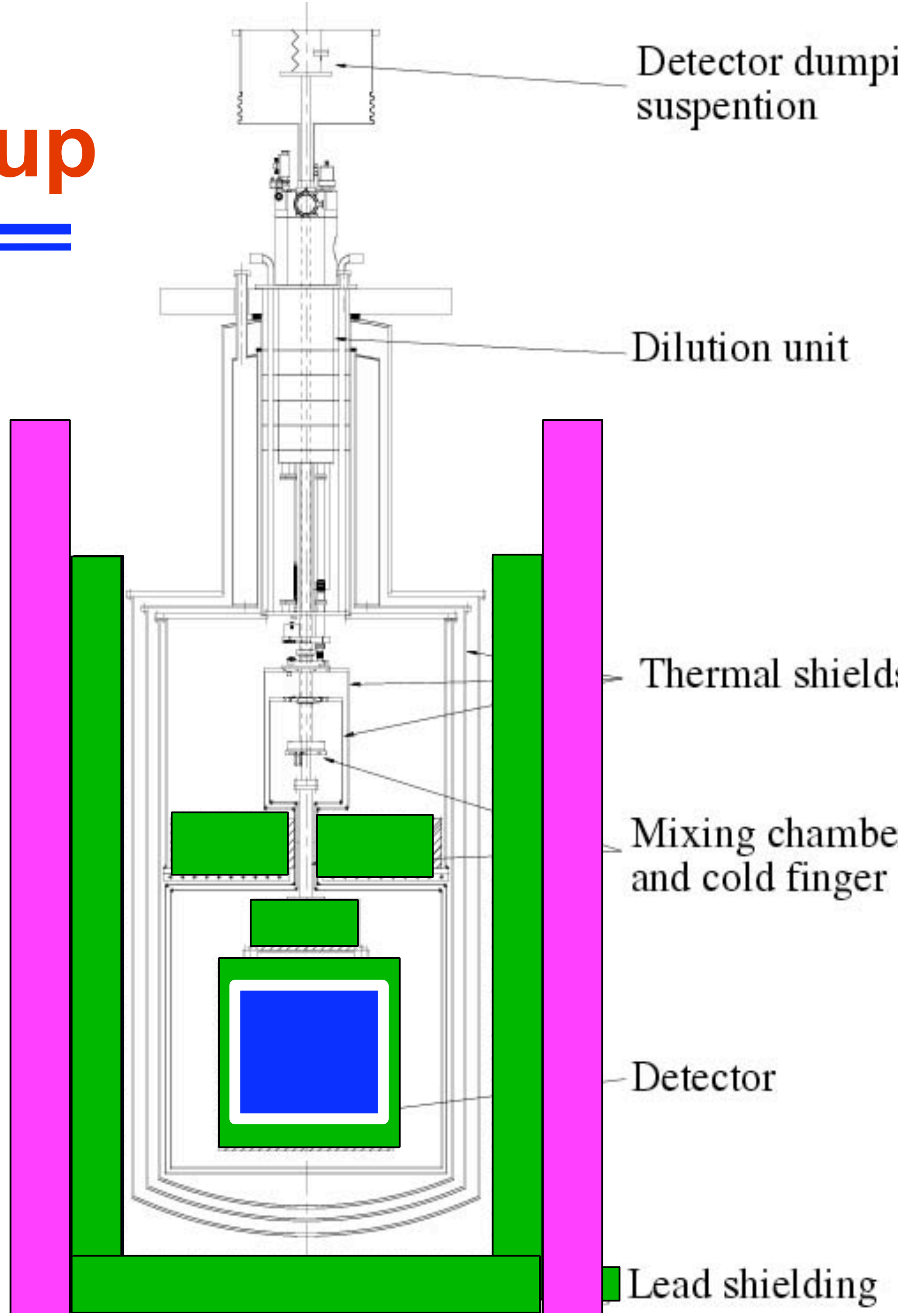
the array

the 25 towers are organized in a square structure (a 5x5 matrix), the towers will be suspended from a large square copper plate suspended with a vertical spring

the experimental set-up

the **CUORE** array:

- closed inside a cubic copper box
- surrounded by 3 cm of **roman lead**
- an additional 20 cm layer of **low activity lead** will be used to shield the array from the refrigerator dilution unit
- a **lead shield** and a **borated PET** neutron shield will surround completely the cryostat



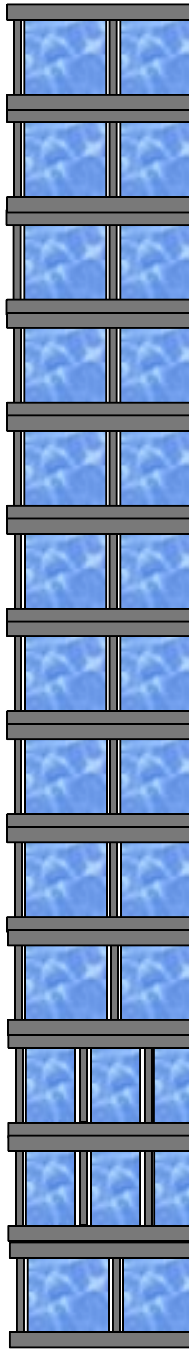
CUORICINO

44 TeO_2 crystals 5x5x5 cm^3 + 18 TeO_2 crystals 3x3x6 cm^3

array with a tower-like structure similar to the single tower of CUORE
(the only difference is that it contains 2 planes of 3x3x6 crystals)

mounted inside the Hall A refrigerator
where the Mi-DBD 20 array worked

CUORICINO is a self-consistent experiment
will give significant results concerning
Dark Matter and Double Beta Decay

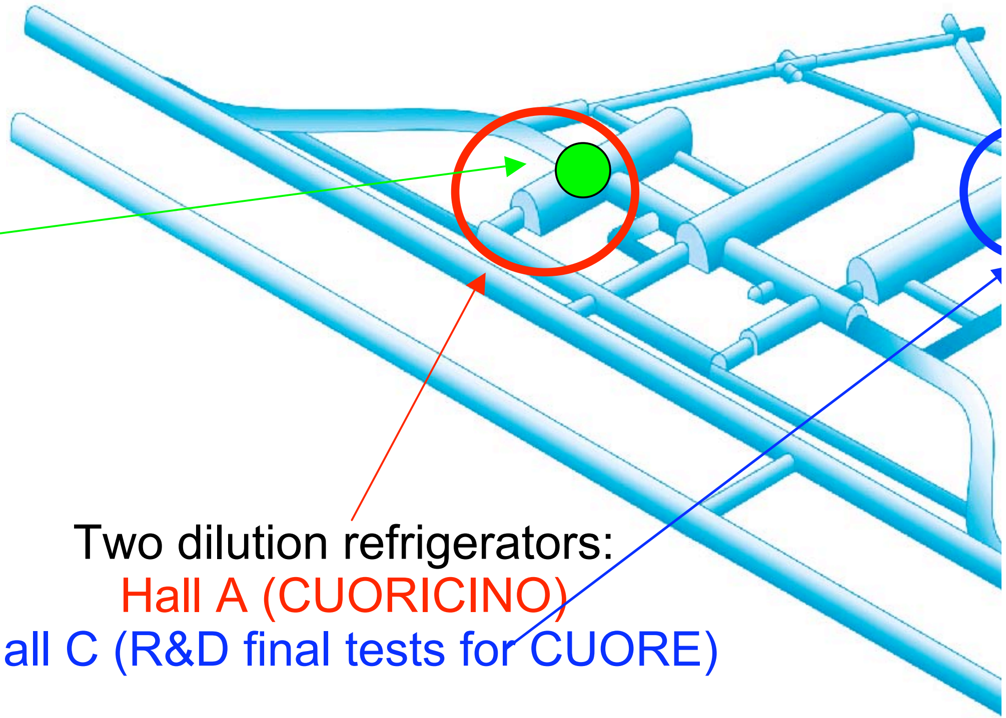


CUORICINO and CUORE location

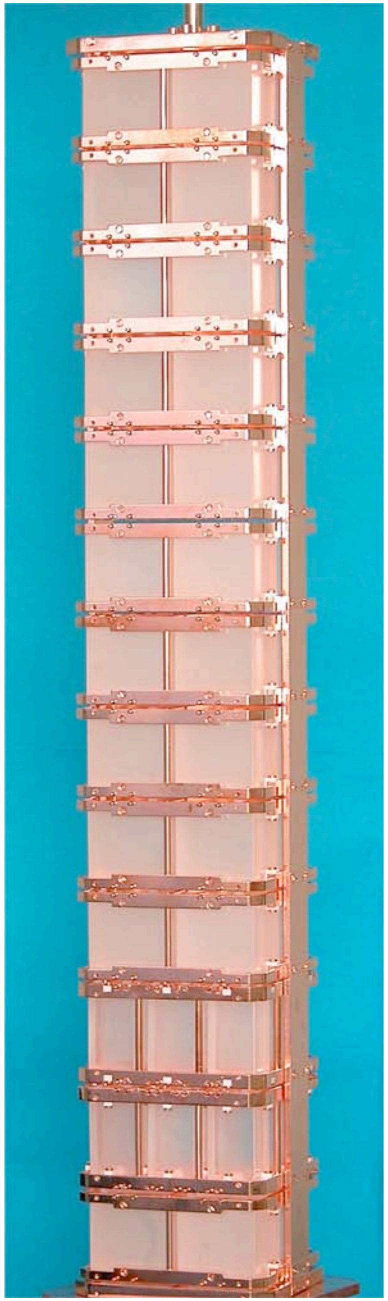
CUORE experiment will be installed in the

Underground National Laboratory
of Gran Sasso
L'Aquila – ITALY

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



Two dilution refrigerators:
Hall A (CUORICINO)
Hall C (R&D final tests for CUORE)

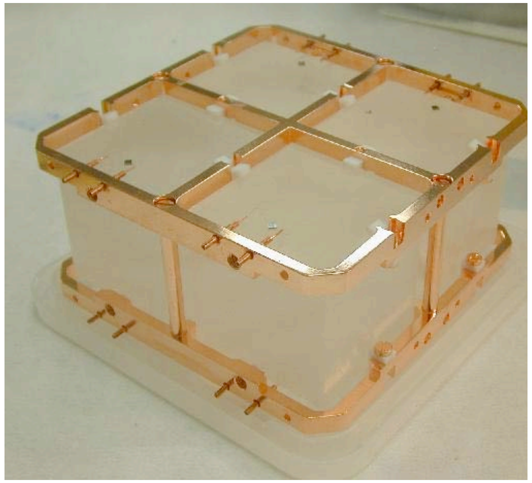


11 modules, 4 detector each,

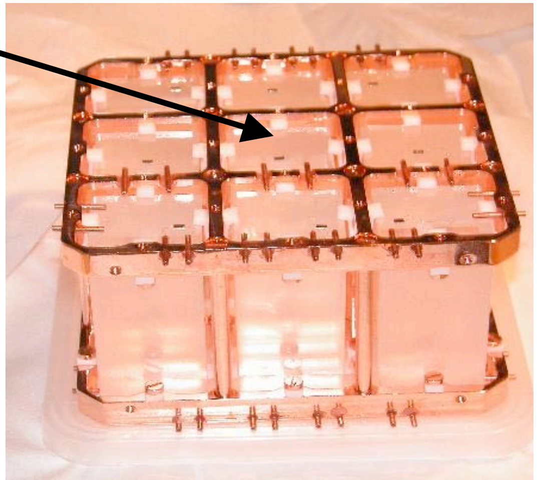
crystal dimension $5x5x5\ cm^3$

crystal mass 790 g

$4 \times 11 \times 0.79 = 34.76$ kg of TeO_2



this detector is completely surrounded by active materials. substantial improvement in BKG reduction



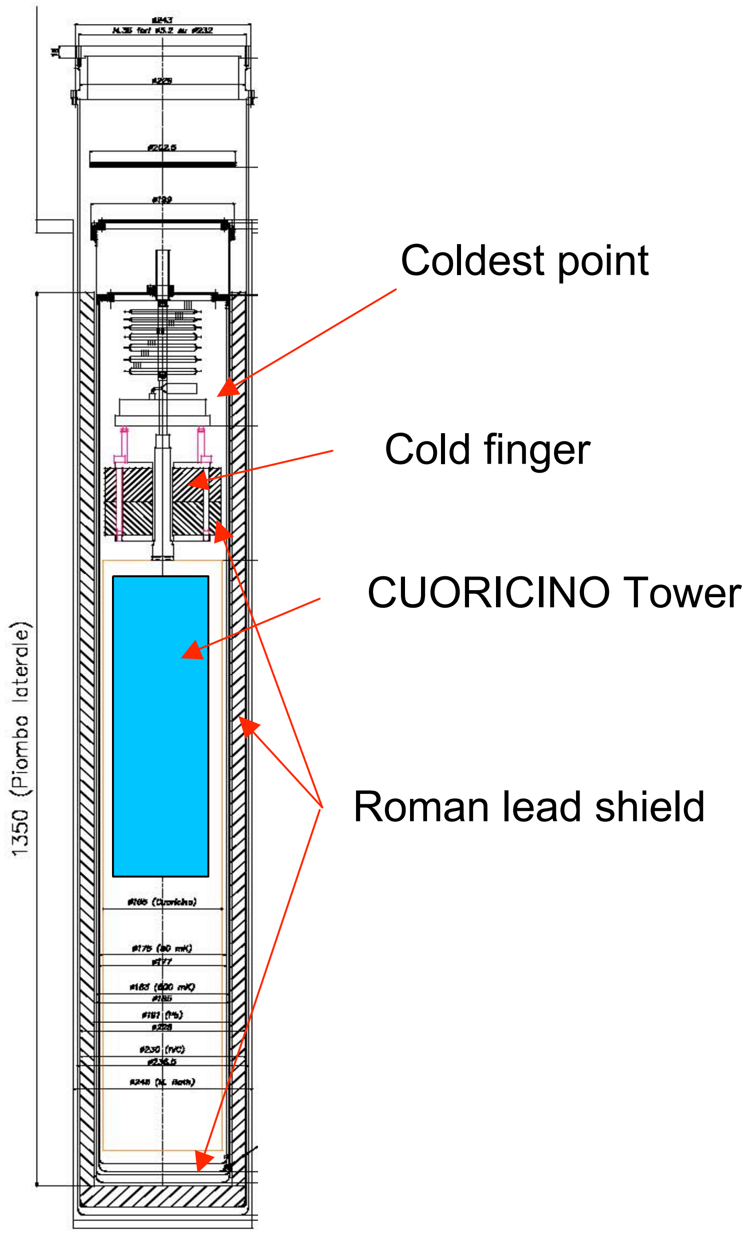
2 modules, 9 detector each,

crystal dimension $3x3x6\ cm^3$

crystal mass 330 g

$9 \times 2 \times 0.33 = 5.94$ kg of TeO_2

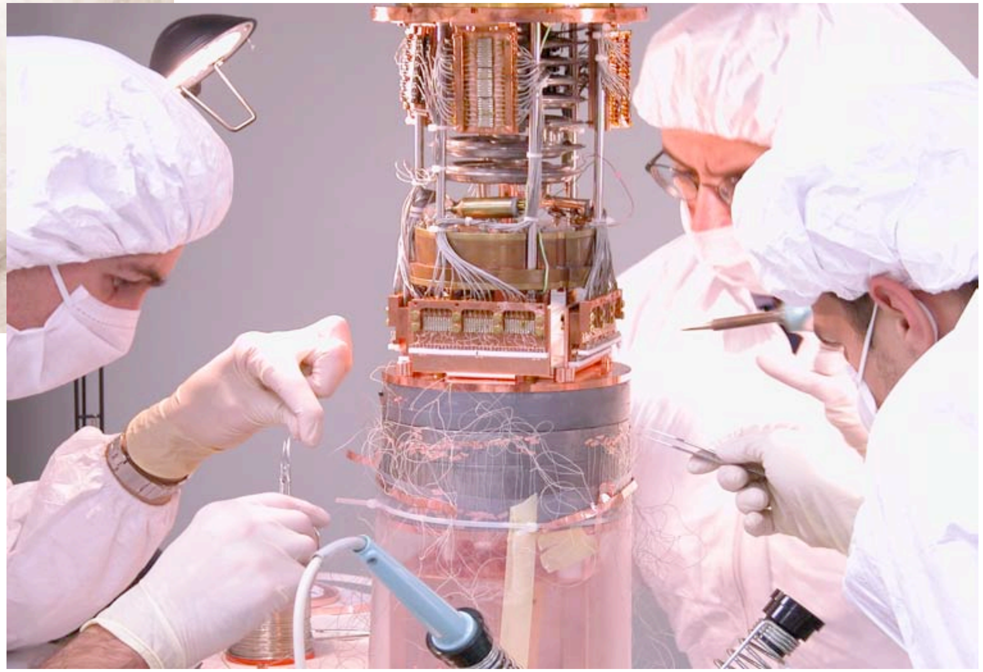
CUORICINO TOTAL ACTIVE MASS = 40.7 kg of TeO_2


Coldest point
Cold finger
CUORICINO Tower
Roman lead shield
1350 (Piombo laterale)

Assembling the detectors

All the operations done in
nitrogen atmosphere

Assembling the tower



Almost completely done in nitrogen atmosphere

First results of CUORICINO

february - june 2003

Cool down: february 2003

Detectors: some electrical connection were lost during the cooling of the tower, as a result some detectors cannot be read-out (to recover the electrical connections it is necessary to warm up the cryostat)

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 during this run:

32 x 0.790 = 25.28 kg

12 x 0.330 = 3.96 kg

} 29.24 kg = 9.9 kg ^{130}Te - 72%

2 (^{130}Te-enriched) x 0.330 = 0.660 kg = 0.495 kg ^{130}Te

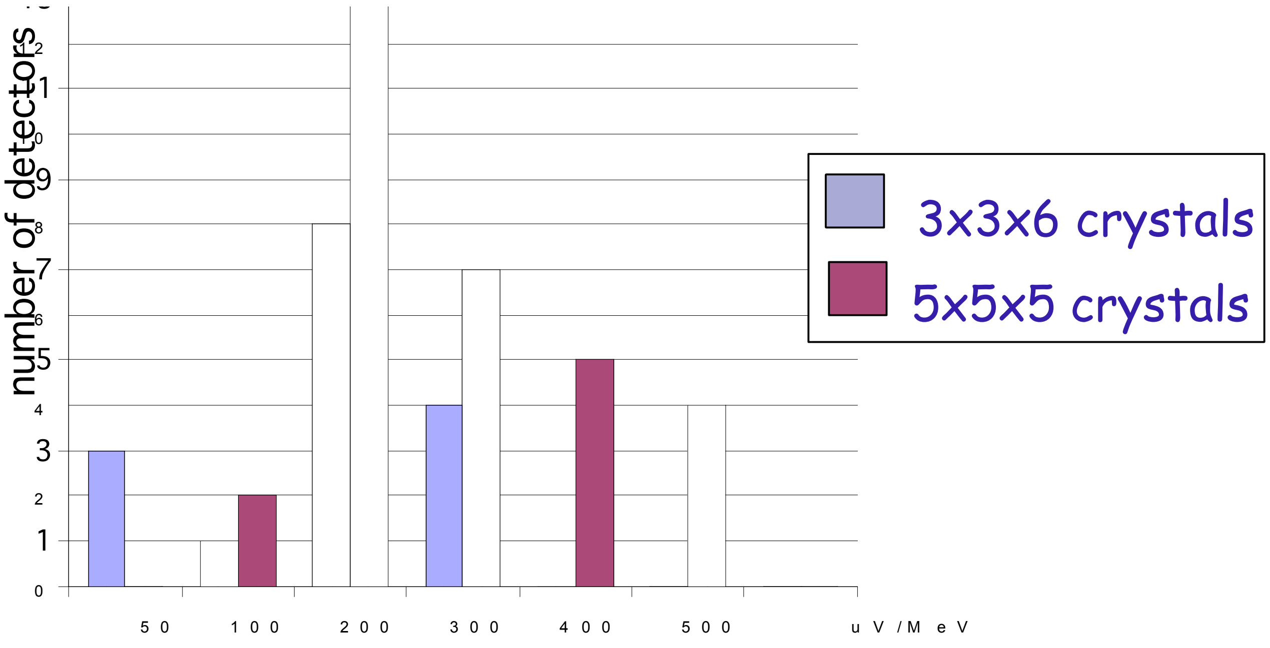
2 (^{128}Te-enriched) x 0.330 = 0.660 kg = 0.543 kg ^{128}Te

Detector performances: pulse height

average pulse height for 5x5x5 crystals = 340 μV/MeV

average pulse height for 3x3x6 crystals = 440 μV/MeV

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

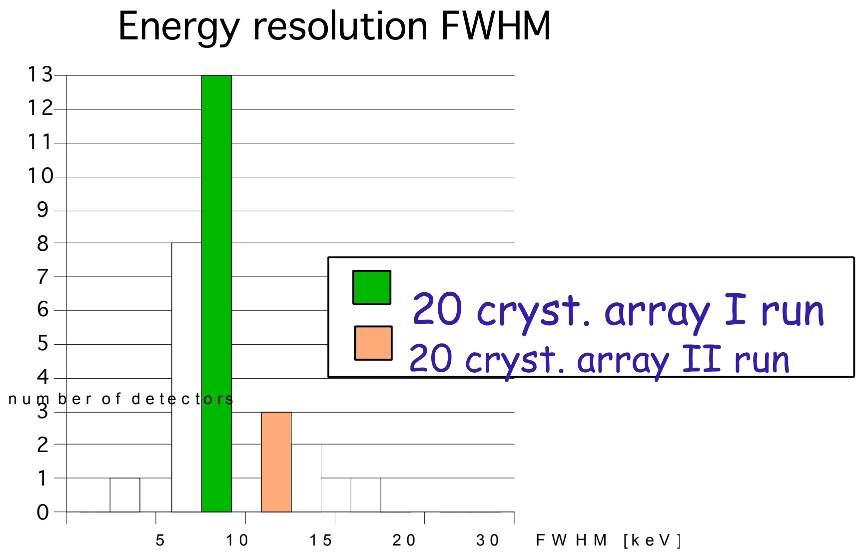


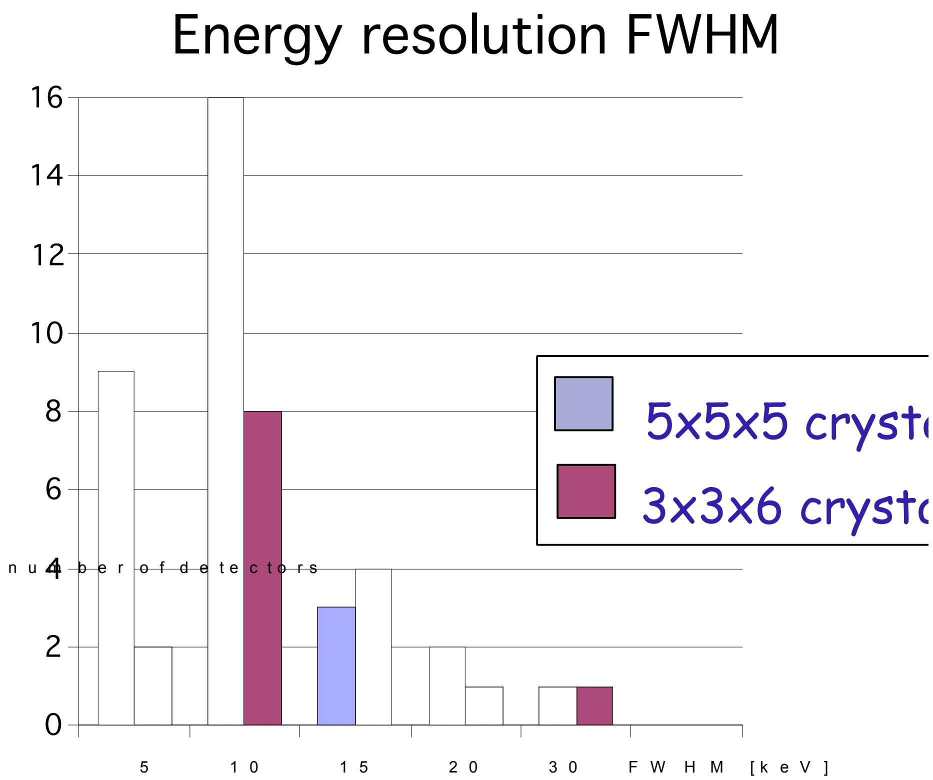
Detector performances: energy resolution

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

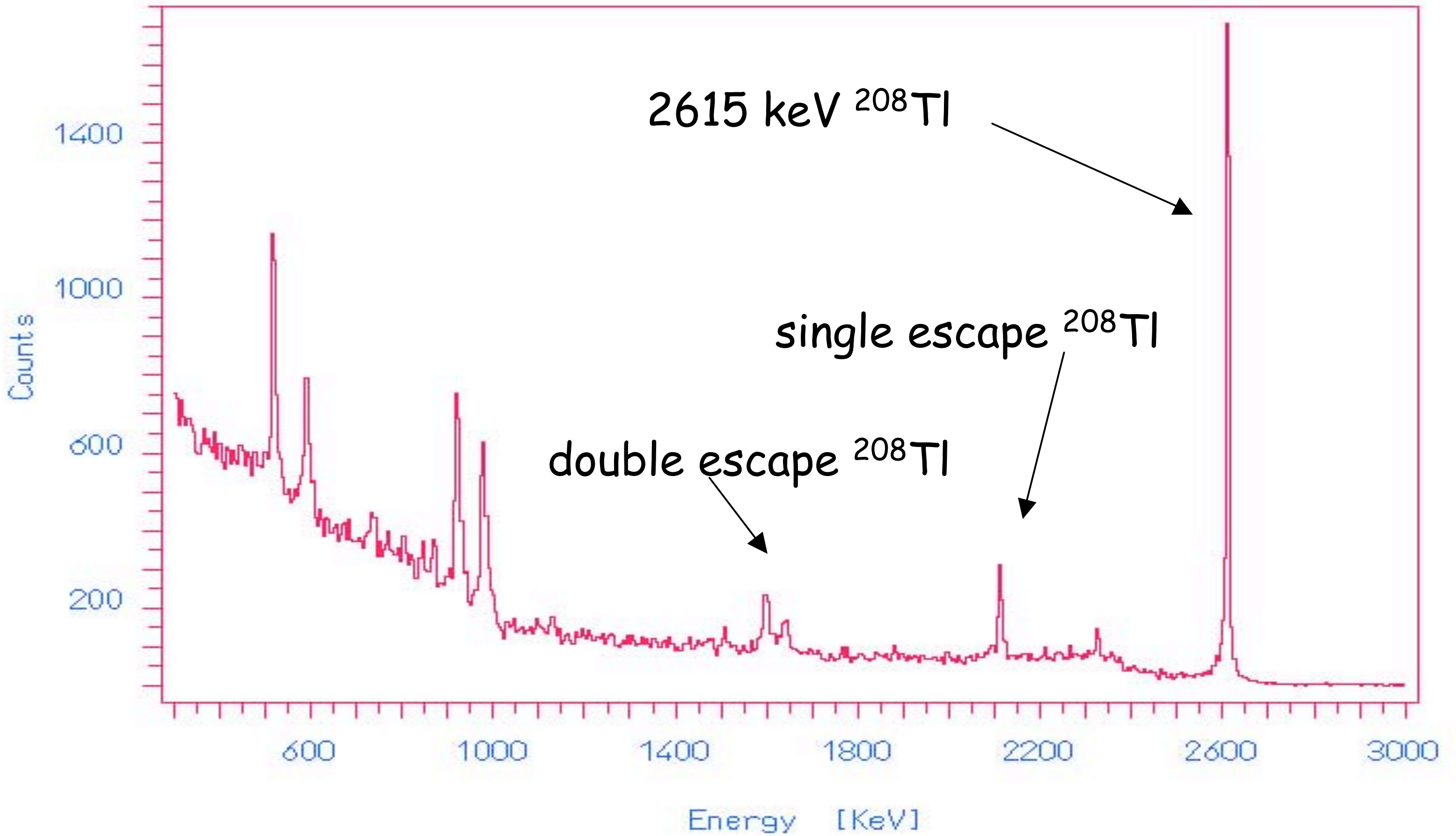
average 3x3x6 cm^3 crystals ~ 9 keV



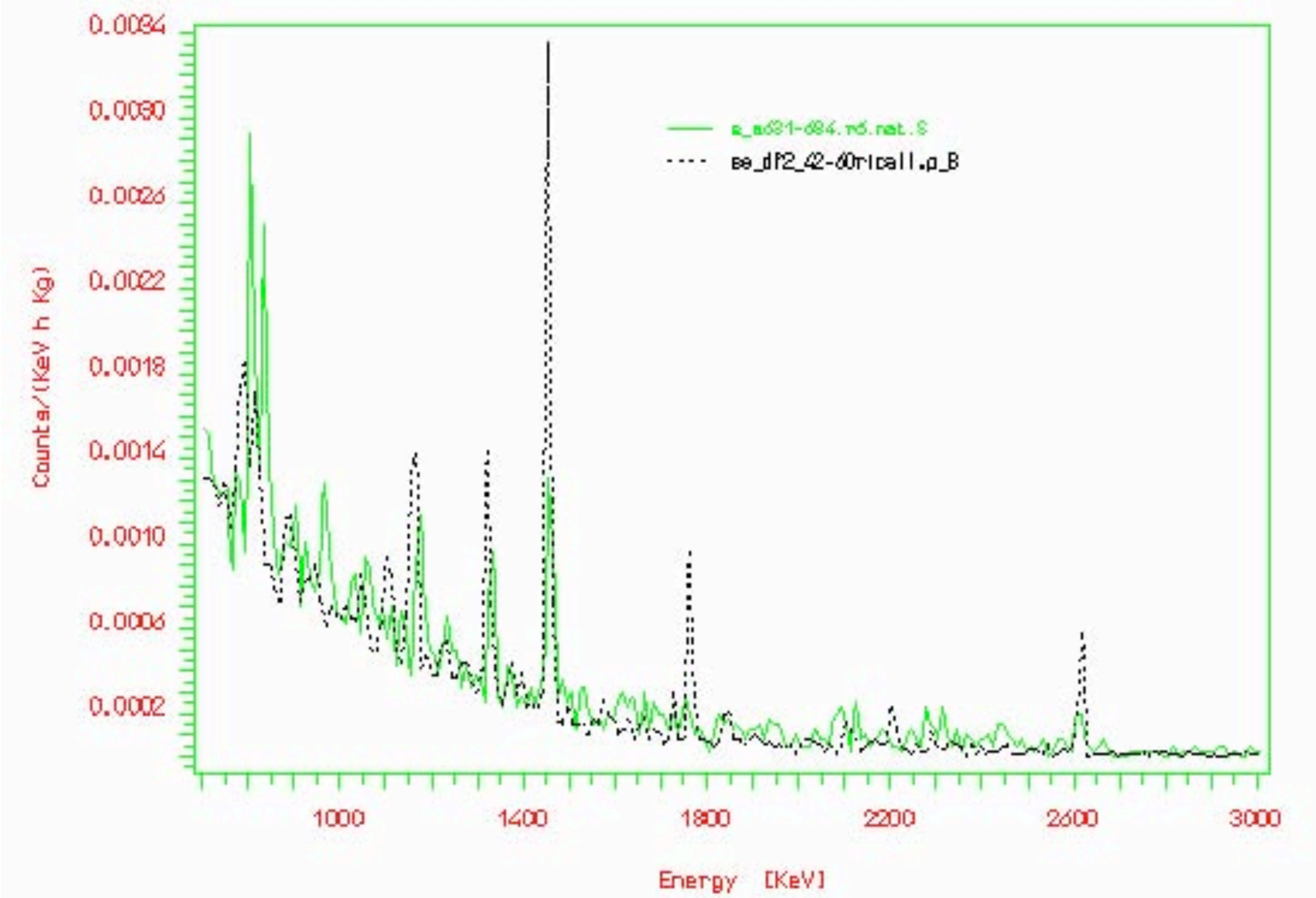


Th calibration

5x5x5 cm^3 crystals



Background: MiDBD II and CUORICINO



Background: MiDBD II vs CUORICINO

- gamma peaks of ^{60}Co, ^{40}K, ^{207}Tl have a higher intensity in CUORICINO but the internal roman lead shield has a lateral thickness much reduced (2 cm less)

- continuum background in the 2-3 MeV region is reduced

- alpha peaks due to surface contamination of the crystals are reduced

	1000-2000 c/keV/kg/y	2000-3000 c/keV/kg/y	3000-4000 c/keV/kg/y	4000-5000 c/keV/kg/y
MiDBD-II (11666 h)	3.07+/-0.10	0.533+/-0.004	0.243+/-0.003	1.84+/-0.008
Cuoricino 5x5x5 (12200 h)	3.39+/-0.05	0.38+/-0.02	0.23+/-0.02	0.55+/-0.02
Cuoricino 3x3x6 (4806 h)	3.16+/-0.13	0.29+/-0.04	0.28+/-0.04	1.17+/-0.08

Background: ββ region

2480-2600 keV (ββ ^{130}Te transition energy = 2528.8 keV)

anticoincidence spectrum, only 5x5x5 crystals

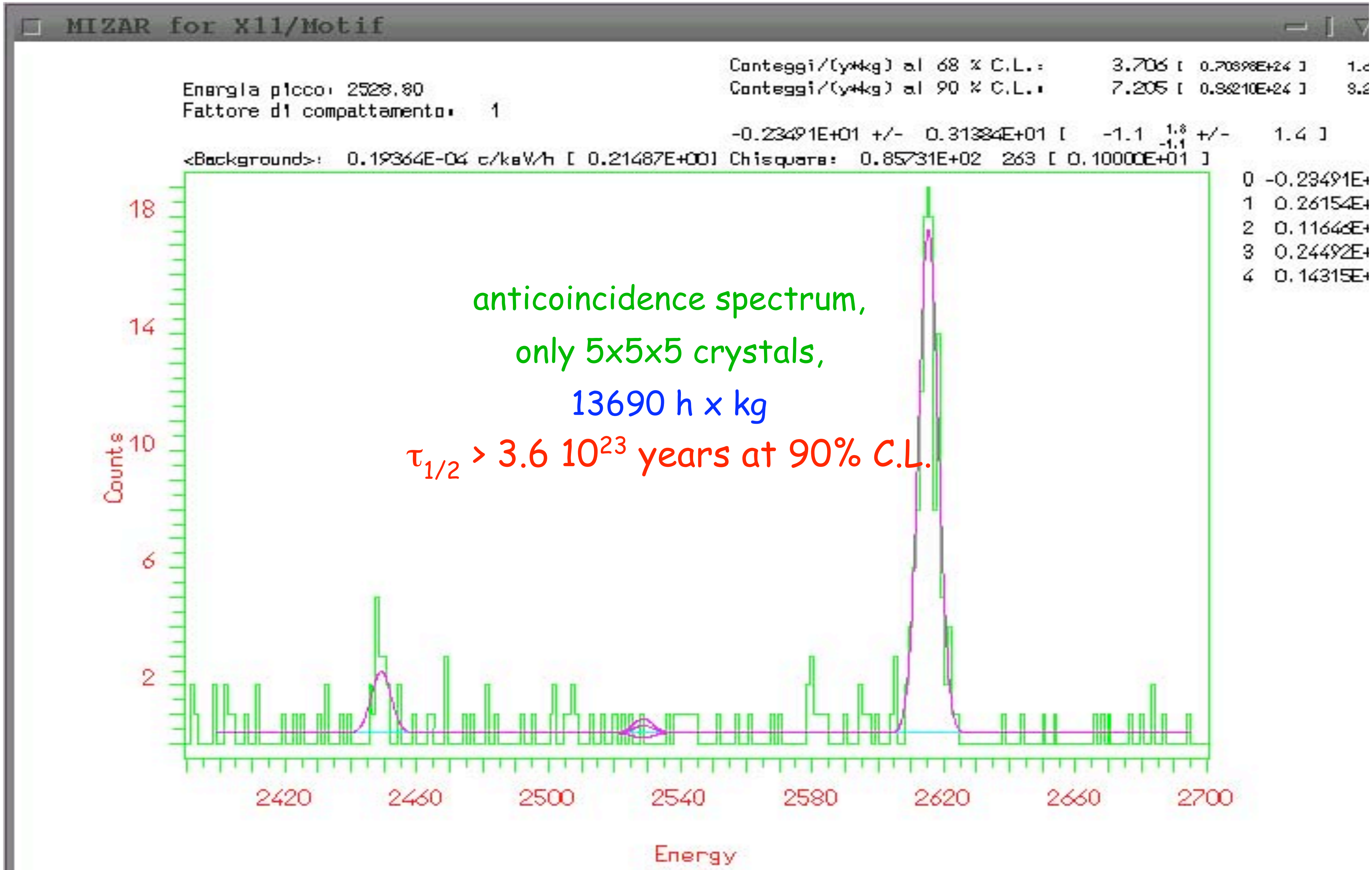
b = 0.23 +/- 0.04 c/keV/kg/y

3 year sensitivity CUORICINO (full mass): b=0.23 Γ=8 keV

$F^{0\nu}_{3\ years} = 1 \times 10^{25}\ T_{1/2}$ $\langle m_\nu \rangle \sim 0.15 - 0.38$ eV

Sensitivity: $F^{0\nu} = 4.17 \times 10^{26} \times \frac{a}{A} \left(\frac{M\,T}{b\,\Gamma} \right)^{1/2} \times \varepsilon$

Isotopic abundance (a), Atomic mass (A), Detector mass (kg) (M), Running time (y) (T), BKG (counts/keV/kg/y) (b), Energy resolution (keV) (Γ), Detector efficiency (ε)



Preliminar result on $0\nu-\beta\beta$ ^{130}Te decay

Perspectives for CUORE

CUORICINO:

- apparatus: proves the feasibility of a large bolometric array with the tower-like structure
- detectors: shows that detector performances are not affected by the increase in crystal size (from 340 g to 790 g)

CUORE:

- apparatus: it will contain 25 towers similar to the CUORICINO one, R&D will be dedicated to cryostat and mechanical apparatus design
- detectors: R&D to guarantee detector reproducibility and uniformity (pulse shape and resolution)

Perspectives for CUORE

CUORICINO:

- background achievements: MiDBD-II was used as a test bench to verify surface cleaning techniques, the improvement in bkg obtained in Cuoricino (despite the reduced shield) proves the reproducibility of cleaning and handling procedures

- background study: Cuoricino data will be used to further study bkg sources in view of Cuore

Perspectives for CUORE

- a completely new set-up will allow the optimization of shielding
- CUORE is specifically designed to reduce as far as possible the amount o materials interposed between the crystals.
- the high granularity of the CUORE detector will allow to use with hig efficiency the coincidence/anticoincidence technique to identify and reje background events
- the real challenge of CUORE will be the control and reduction of background
- *only low radioactivity materials will be employed to build the refrigerator and the entire mechanical set up for CUORE*
- *special techniques for surface cleaning will be applied*

CUORE sensitivity

MC simulation for BKG contributions:

- Bulk contamination is not a problem < 0.004 counts/keV/kg/y

  MC simulation with MEASURED 90% upper limits on material contaminations

- *Surface contamination from passive materials is potentially dangerous, but the amount of Cu facing the detector will be reduced by a factor 10 -1*
  with respect to now ~ 0.01 – 0.001 counts/keV/kg/y

- *Environmental radioactivity contribution is reduced to a minimum*
  thanks to the lead and neutron shields

- Cosmogenic activation of Cu and Te will be reduced to a minimum
  by the underground storage of materials

- Two neutrino double beta decay contribution < 0.0001 counts/keV/kg/y

CUORE sensitivity

$$0\nu \text{ sensitivity} = \ln 2 \; N_A \frac{a.i.}{A} \sqrt{\frac{M\,t}{b\,\Gamma}} \; \varepsilon = 2.1\; 10^{25} \sqrt{\frac{t}{b\,\Gamma}}$$

Pessimistic estimation: b = 0.01 - Γ = 5 keV

$F^{0\nu} = 9.4 \times 10^{25} \times (\, T[y\,]\,)^{1/2}$

$m_{ee} <$ 40 – 249 meV $\times (\, T[y\,]\,)^{1/4}$
(27-167 meV in 5 years)

Optimistic estimation: b = 0.001 - Γ = 5 keV

$F^{0\nu} = 2.96 \times 10^{26} \times (\, T[y\,]\,)^{1/2}$

$m_{ee} <$ 22.4 - 140.6 meV $\times (\, T[y\,]\,)^{1/4}$
(15-94 meV in 5 years)

CUORE cost estimation

Item	Cost (in today USA dollars)
Crystals	4.300.000
Refrigerator	600.000
Cryogenic equipment (liquefier, dewars etc)	300.000
Chemical materials (grinding powders etc)	200.000
Shielding materials (lead, neutron shield etc.)	600.000
Electronics	600.000
Installation	400.000
Contingency	1.000.000
TOTAL	8.000.000

CUORE temptative schedule