CUORICINO and CUORE: Bolometric Experiments for Double Beta Decay Research

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- CUORICINO set-up, results and background
- CUORE-setup, perspectives ad sensitivity
- R&D for background reduction

Double Beta Decay Signature

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

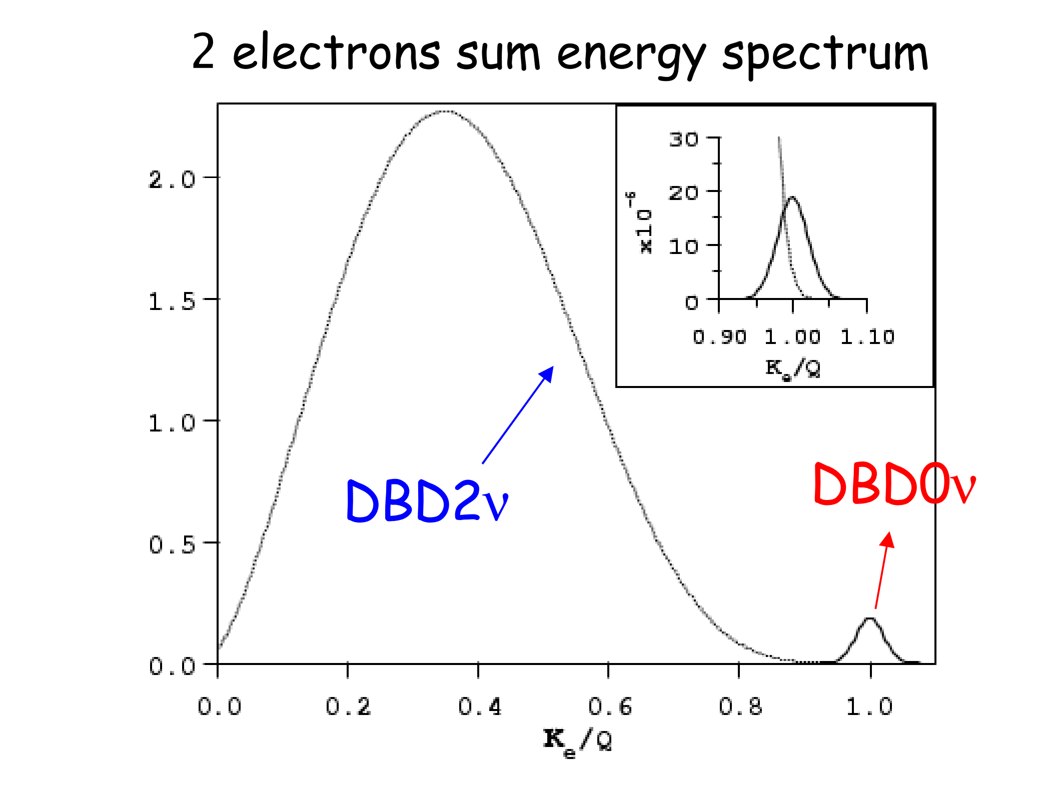
Phase space $\sim Q^5$ — NME UNCERTAIN

$$\left(T_{1/2}^{0\nu}\right)^{-1} = \sum_k G_k(Q,Z)\,|M_k|^2 \,|\langle m_\nu\rangle|^2$$

What experiments try to measure

What nuclear theorists try to calculate

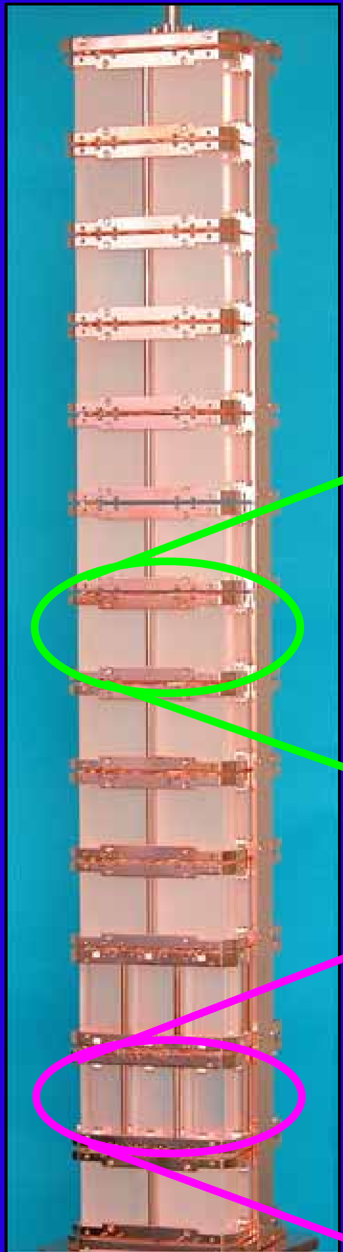
Parameter containing the physics



Mixing matrix — ±1 if CP conserved

$$|\langle m_\nu\rangle| \equiv m_{ee} = \left|\sum_k U_{ek}^2 m_k\right| = \left|\sum_k |U_{ek}|^2 e^{i\alpha_{ek}} m_k\right|$$

CUORICINO (start April 2003)

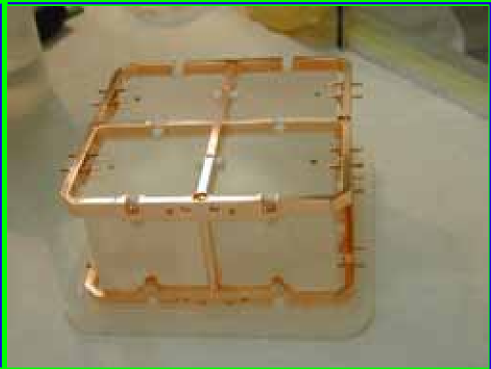


Bolometric technique (source = detector)

TeO_2 crystals (DBD0ν candidate ^{130}Te)

Energy deposition => $\Delta T = E/C \div T^{-3}$ (T ~ 10 mK)

Smc thermometer => $\Delta T \rightarrow \Delta R$ $\Delta V/\Delta E \cong 1$ mV/MeV



11 modules, 4 detector each

crystal dimension: 5x5x5 cm^3

crystal mass: 790 g

Total mass:

40.7 kg of TeO_2

11.34 kg ^{130}Te

2 modules, 9 detector each

crystal dimension: 3x3x6 cm^3

crystal mass: 330 g

2 enriched in ^{128}Te @ 82.3%

2 enriched in ^{130}Te @ 75%

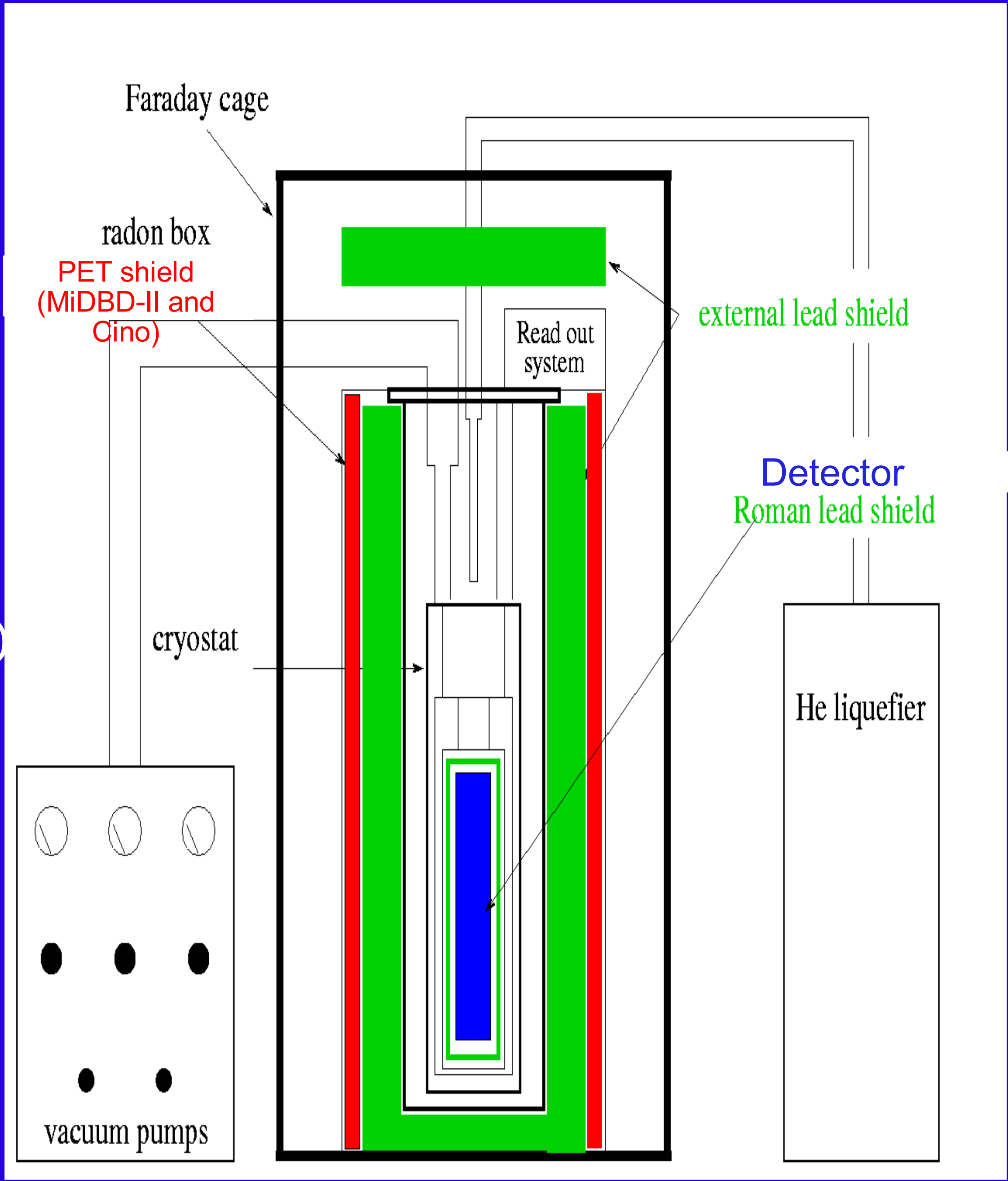
CUORICINO shields

Located at LNGS (3200 mwe) in a He^3/He^4 dilution refrigerator (T~10 mK)

- Cu shields
- Internal Roman Lead

(1.5 cm on side + 10 cm on top and bottom)

- 20 cm external Lead
- Nitrogen overpressure
- 10 cm (10%) Borated PET
- Faraday Cage



CUORICINO latest results

- Statystics: 8.38 kg y ^{130}Te
- FWHM measured on bkg spectrum at 2.6 MeV ~ 8 keV
- bkg counting rate = 0.18 +/- 0.01 cnts/keV/kg/y
- best fit yields NEGATIVE effect

➔ peak shape = N-gaussian (to account for the different - measured - energy resolutions)

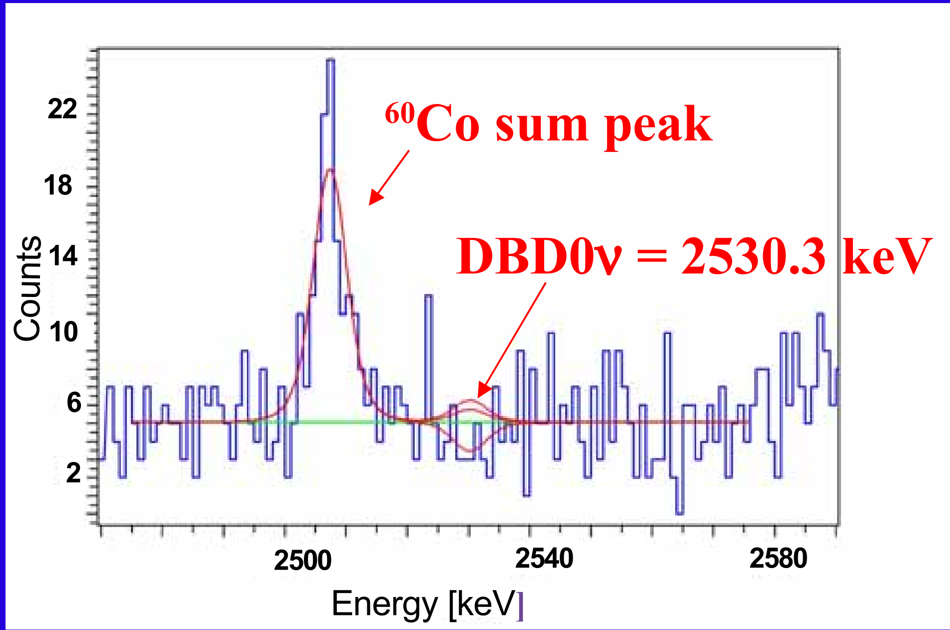
➔ flat bkg + 2505 keV peak

➔ fit interval = 2475 - 2550 keV

$\tau_{1/2}$ > 2.4 10^{24} [y] @ 90% C.L

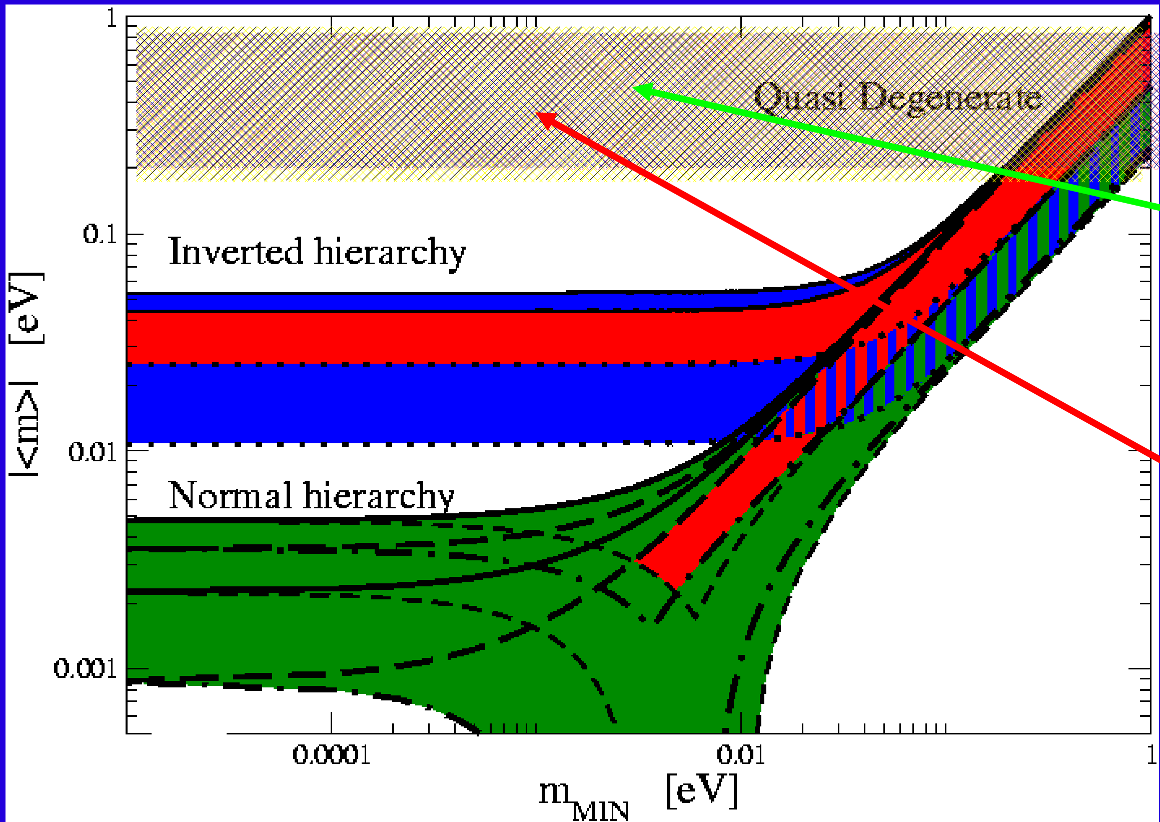
<m_ν> < (0.18 ÷ 0.94) eV

NME from
"New Limit on the Neutrinoless bb Decay of ^{130}Te",
C.Arnaboldi et al., PRL 95, 142501 (2005)



New statistics (reaching 11.8 kg y of ^{130}Te) is being analysed in these days

CUORICINO sensitivity



With the same matrix elements the Cuoricino limit is **0.46 eV**

Ge evidence

(best value 0.39 eV)

Klapdor-Kleingrothaus HV et al. hep-ph/0201231

Sensitivity: half life corresponding to the minimal number of detectable events above background, for a given C.L.

$$S^{0\nu} = \ln 2 \times N_A \times 10^3 \times \frac{\text{ia.}}{A} \left(\frac{M\,T}{B\,\Delta E} \right)^{1/2} \times \varepsilon$$

Background level

With 3 y live time:

$T_{1/2} \geq 7\times10^{24}$ y

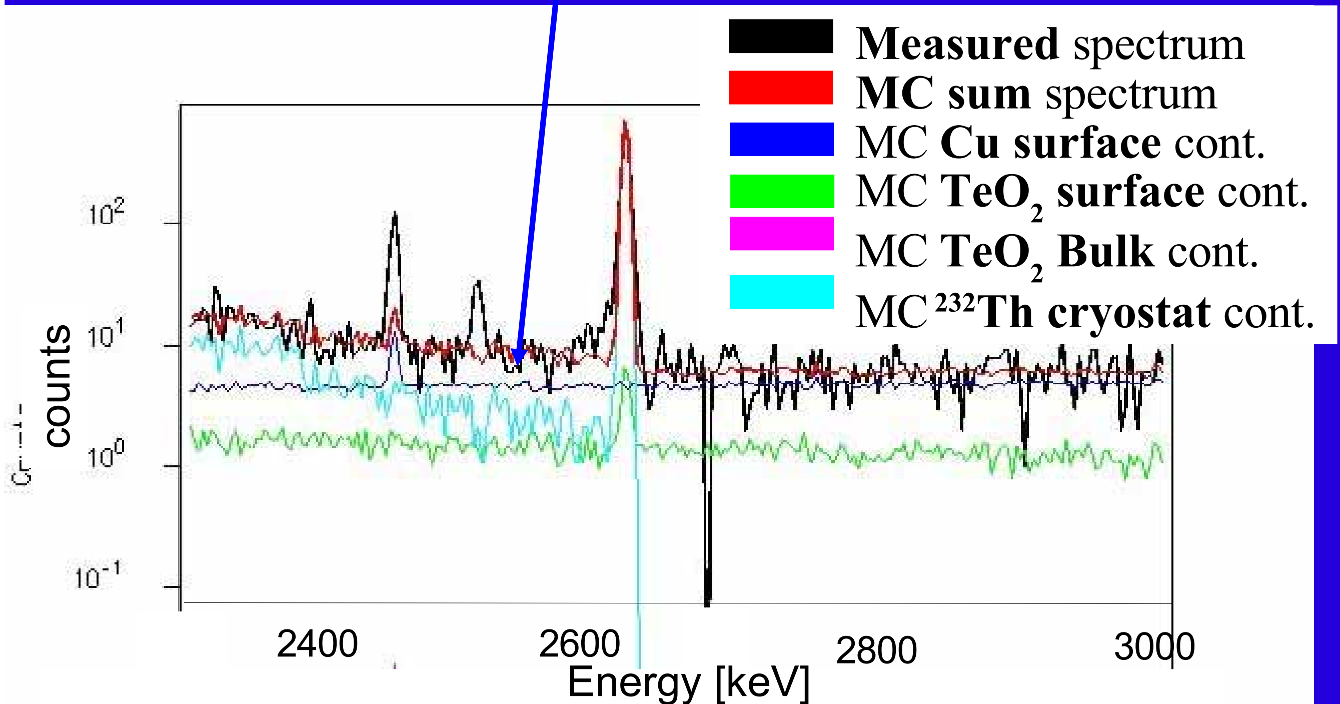
$\langle m_\nu \rangle \leq 0.1 \div 0.6$ eV

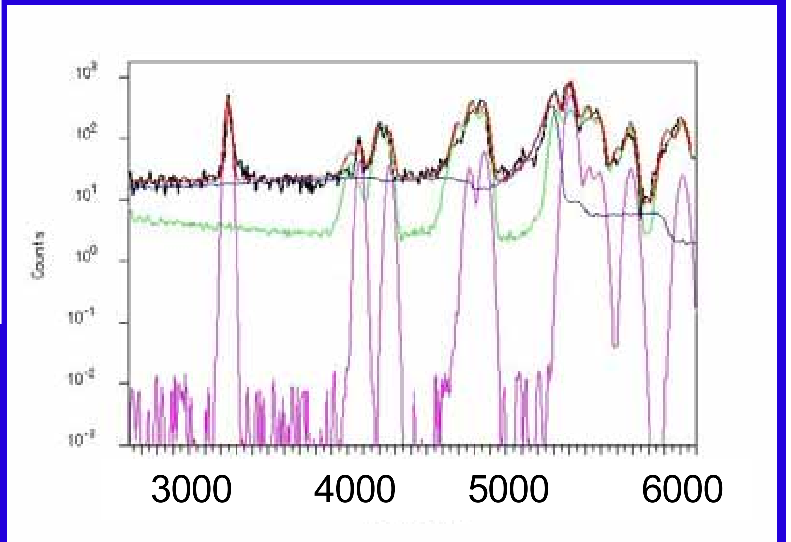
Bkg sources in the DBD0ν region

DBD0ν REGION

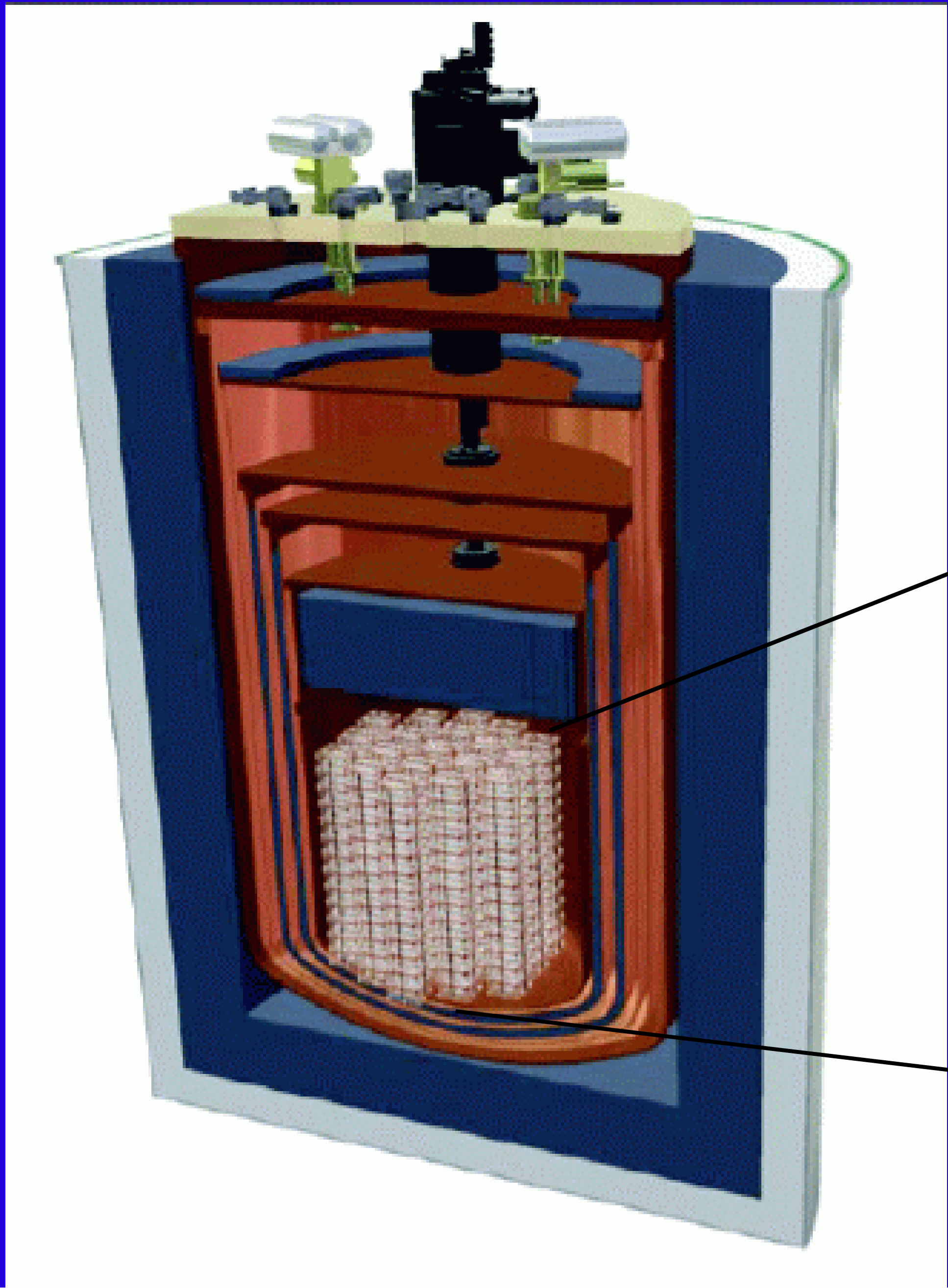
Evaluated contributions to the DBD0ν region bkg (0.18 +/- 0.01 cnts/keV/kg/y):

- 30 ± 5% from ^{208}Tl (2614.5 keV line) Compton events (^{232}Th in cryostat shields)
  (easily avoided by proper material selection)
- 20 ± 5% from crystals surface ^{238}U, ^{232}Th, ^{210}Pb contamination
- 50 ± 10% from degraded alpha produced by ^{238}U, ^{232}Th, ^{210}Pb contaminations of mounting structure (main candidate the copper surface)





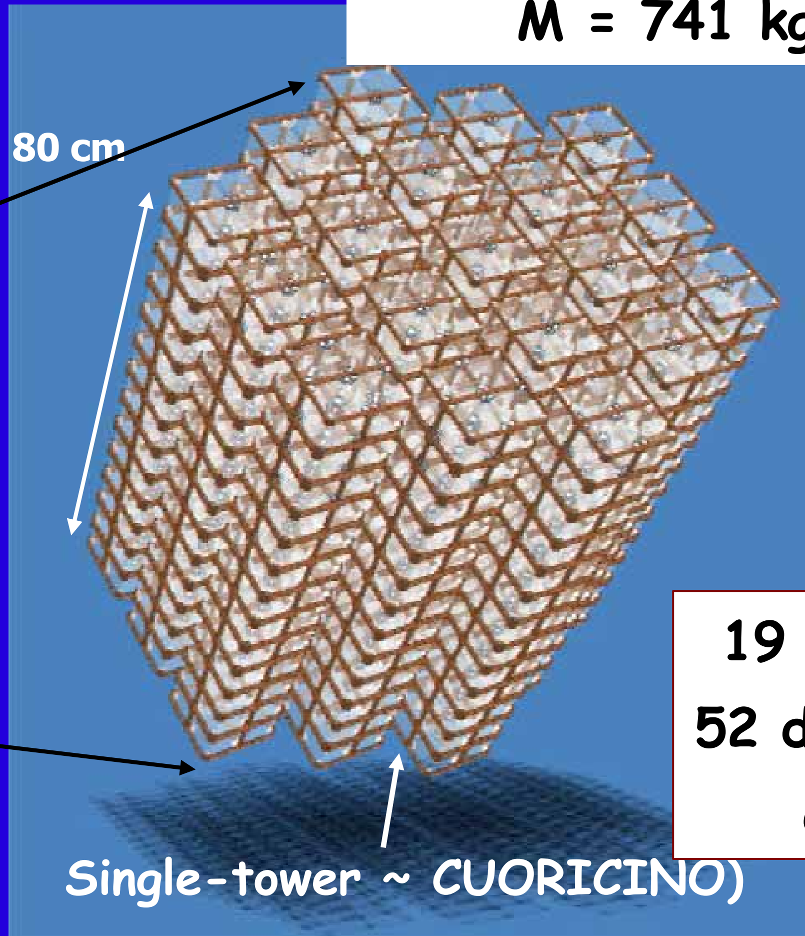
CUORE set-up



988 detectors

(cilindrically arranged)

M = 741 kg



19 towers

52 detectors

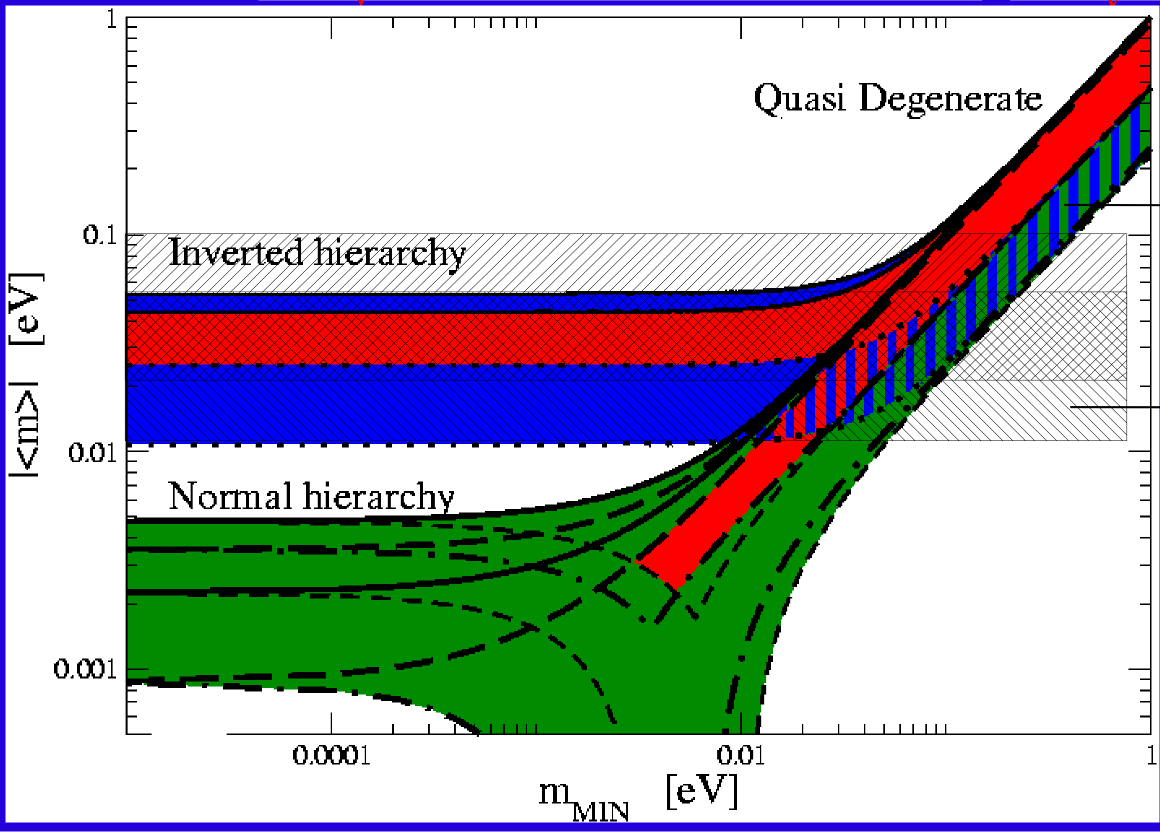
each

CUORE sensitivity

CUORE bkg goal: 0.001 ÷ 0.01 c/keV/kg/y

SENSITIVITY:

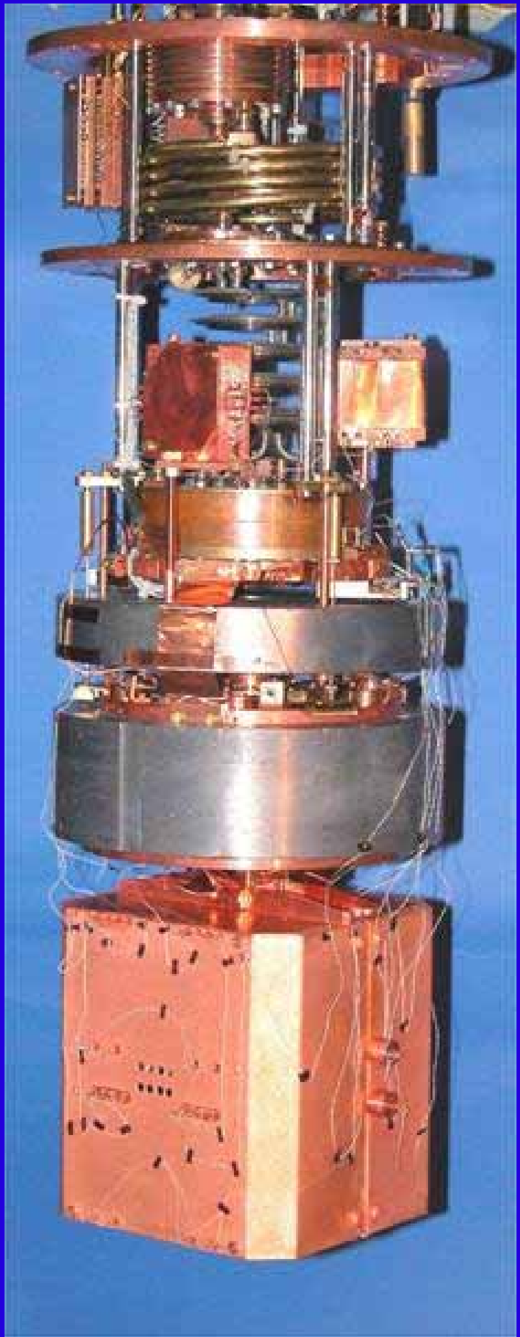
b=0.01 c/keV/kg/y	b=0.001 c/keV/kg/y
Γ=5 keV	Γ=5 keV
$F^{0\nu}=9.25\times10^{25}\sqrt{t}$ y	$F^{0\nu}=2.9\times10^{26}\sqrt{t}$ y
$\langle m_\nu \rangle$=29÷150 $t^{-1/4}$ meV	$\langle m_\nu \rangle$=16÷85 $t^{-1/4}$ meV



B=0.01 c/keV/kg/y
T=5 y

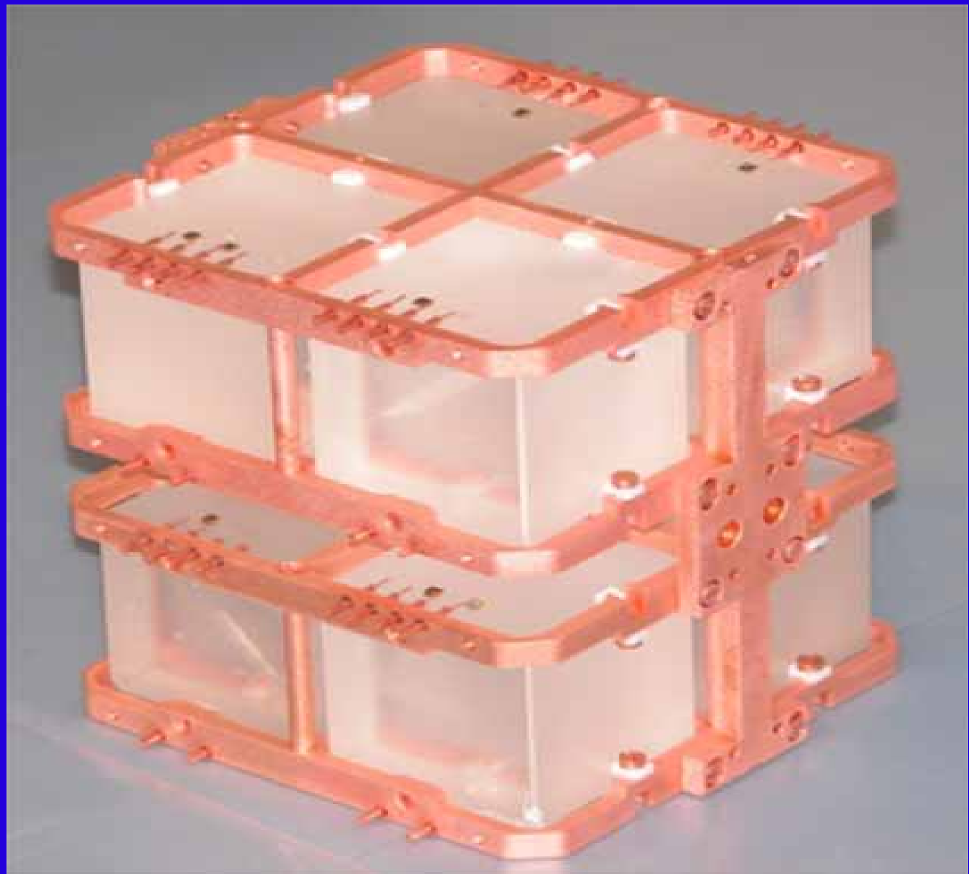
B=0.001 c/keV/kg/y
T = 5 y

R&D: 1st test run



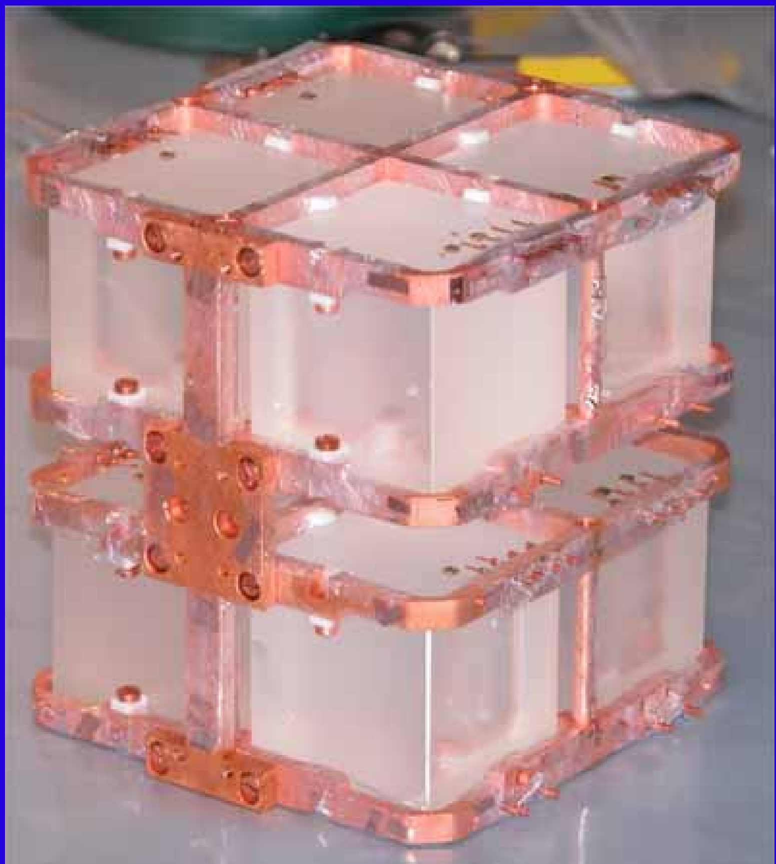
Cu: etching, electropolishing and passivation
TeO2: etching and lapping with clean powders

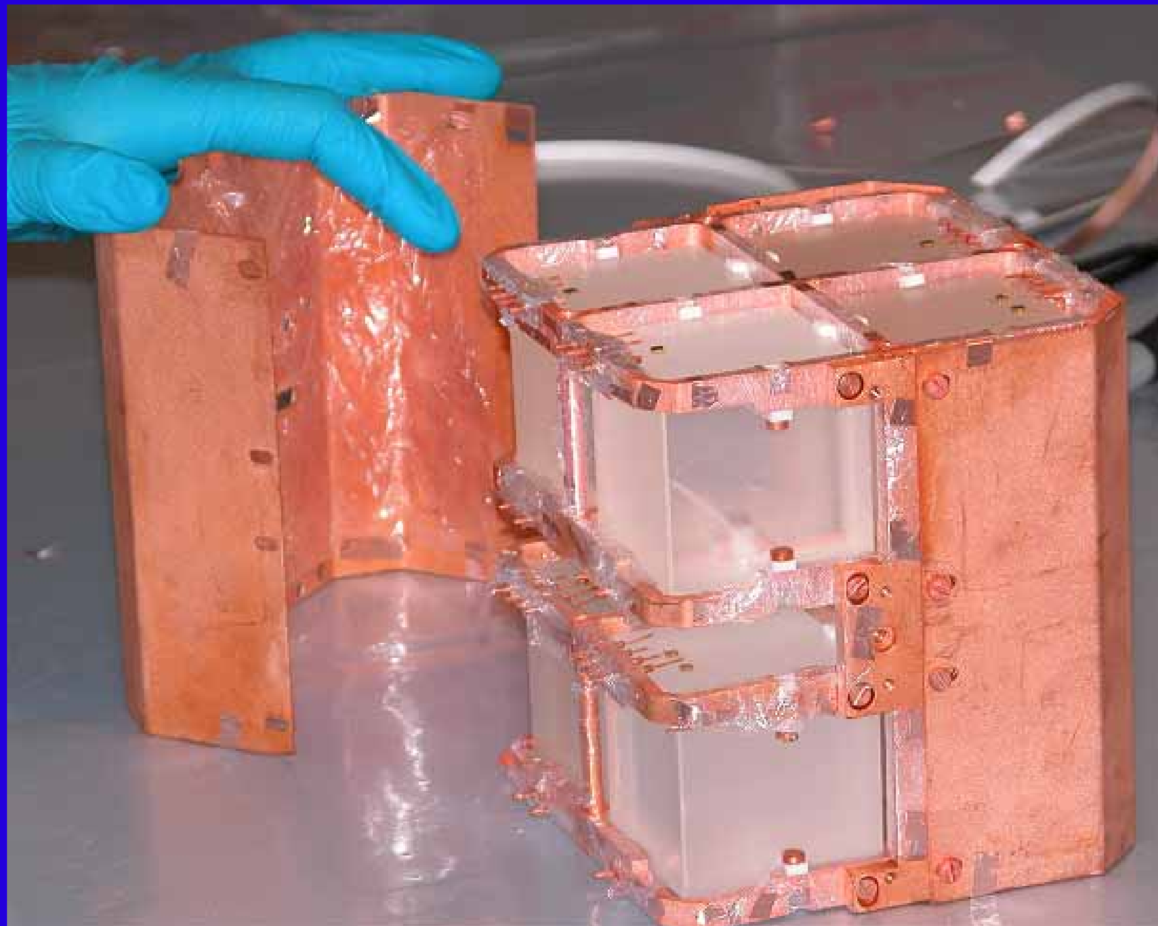
Assembling with clean materials



R&D: 2nd test run

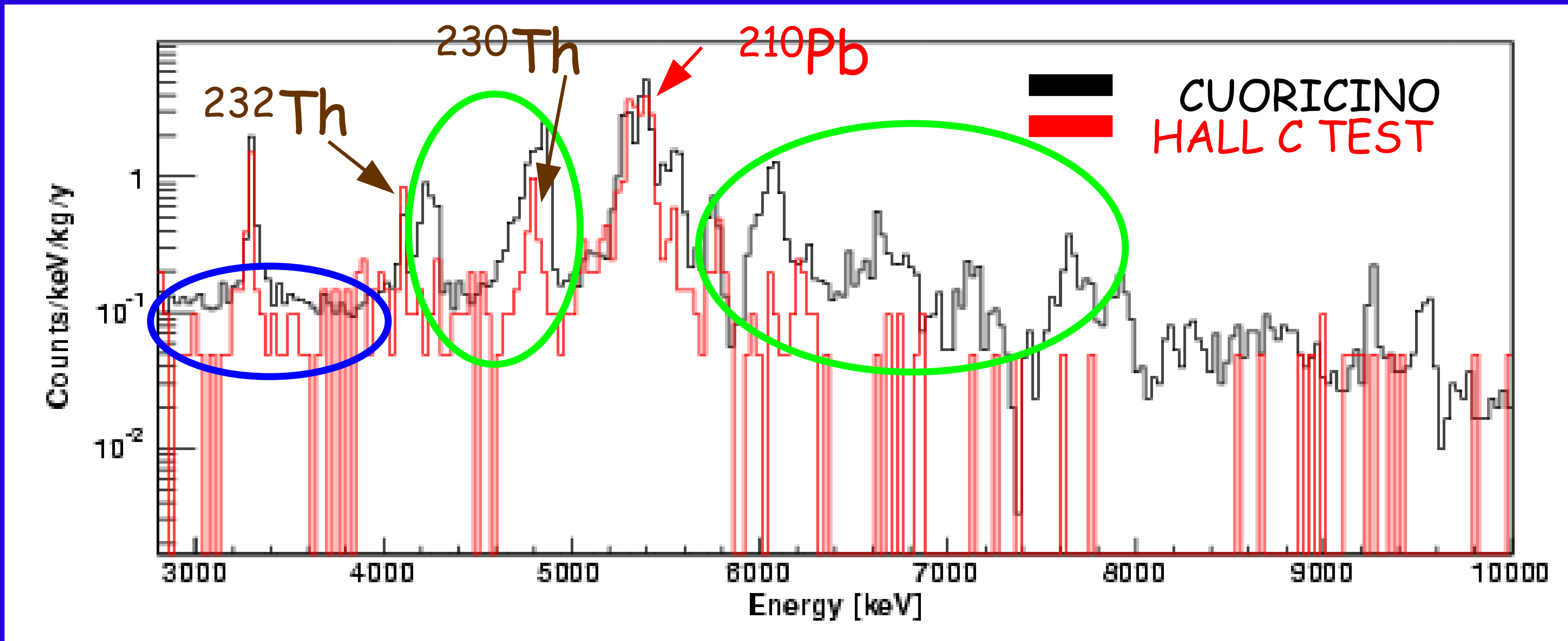
Used 12 μm polyethylene sheet to cover Cu surfaces facing the crystals => enough to stop α's coming from Cu surface





RAD results

=> reduction of ~5 of α peaks (crystal surface contamination)
=> reduction of ~ 1.8 of the continuum in the 3-4 MeV α peak free region (Cu surf.)
=> appearance of sharp and gaussian α peaks (crystals bulk contaminations)
=> 5.3MeV peak with rate ~ CUORICINO (^{210}Pb on both TeO_2 and Cu surface)



We were able to disentangle bulk vs. surface crystal contamination (Apparently crystals bulk has Th isotope contaminations, no evidence of U contamination in secular equilibrium)

CUORE bkg at the state of the art

TeO2 Bulk contamination:

from the visible peaks and assuming secular equilibrium crystal bulk contaminations have been evaluated:

^{232}Th => (2 +/- 0.4) x 10^{-13} g/g

^{238}U => (1.0 +/- 0.2) x 10^{-13} g/g

^{210}Pb => (8 +/- 1) x 10^{-6} Bq/kg

Contribution to CUORE DBD bkg (Montecarlo simulation)
~ 10^{-4} c/keV/kg/y

Surface contaminations:

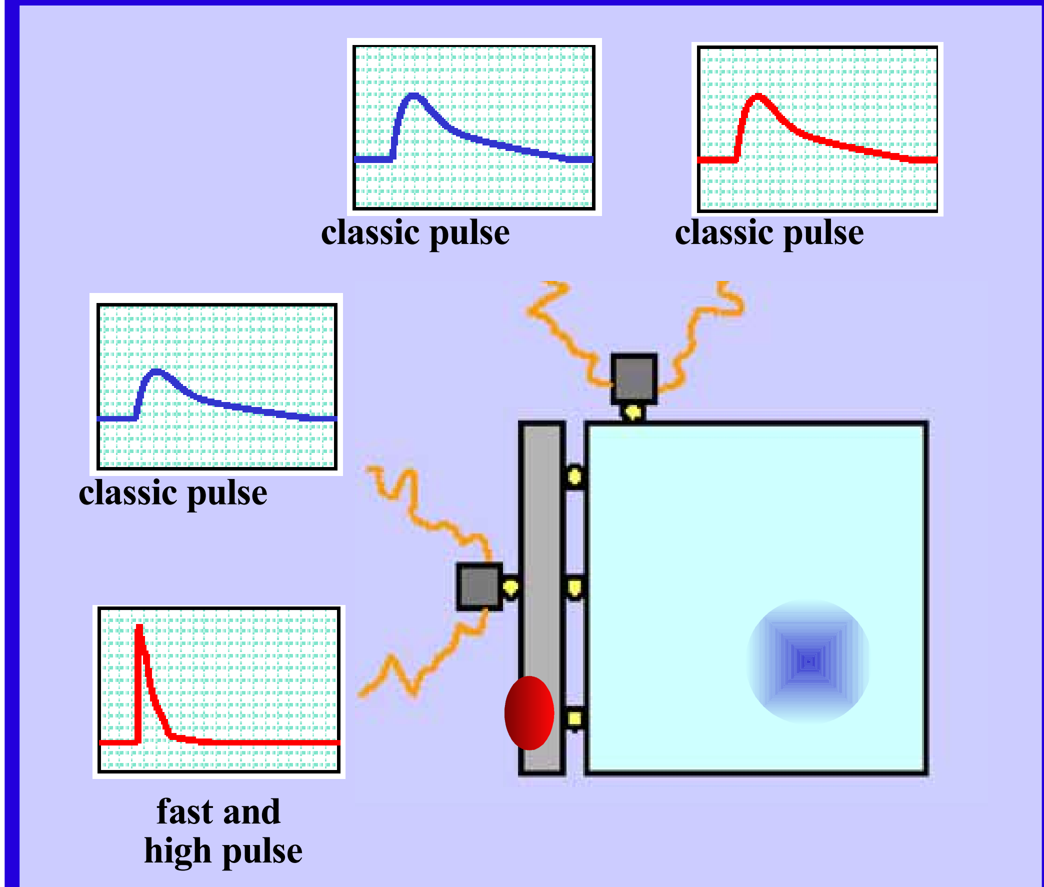
CUORICINO DBD bkg: 0.18 ± 0.01 c/keV/kg/y =
- 30 ± 5 % ^{232}Th in cryostat
- 20 ± 5 % TeO_2 Surface
- 50 ± 10 % Cu Surface

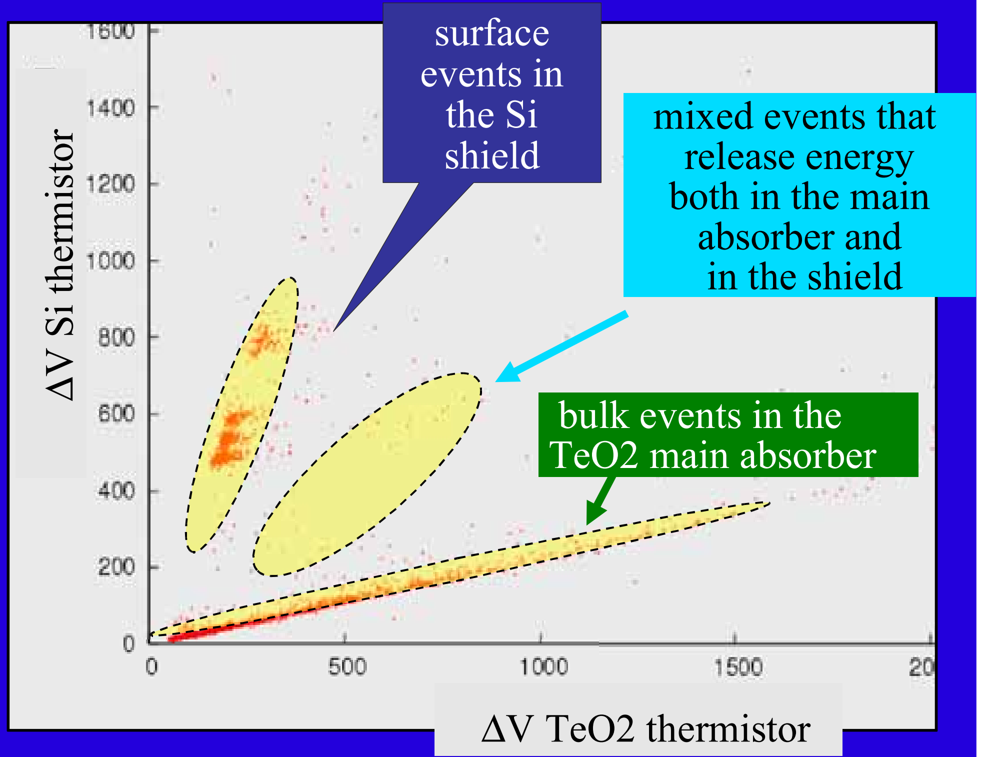
1. Selected and optimized shields
2. Factor ~ 5 reduction in TeO_2 cont.
3. Factor ~ 1.8 reduction in Cu cont.
   New structure geometry
   (~ 1/2 Cu facing crystals)

negligible cryostat contribution
~ $7\cdot10^{-3}$ c/keV/kg/y

~ $2.5\cdot10^{-2}$ c/keV/kg/y

Bkg R&D: surface sensitive bolometers

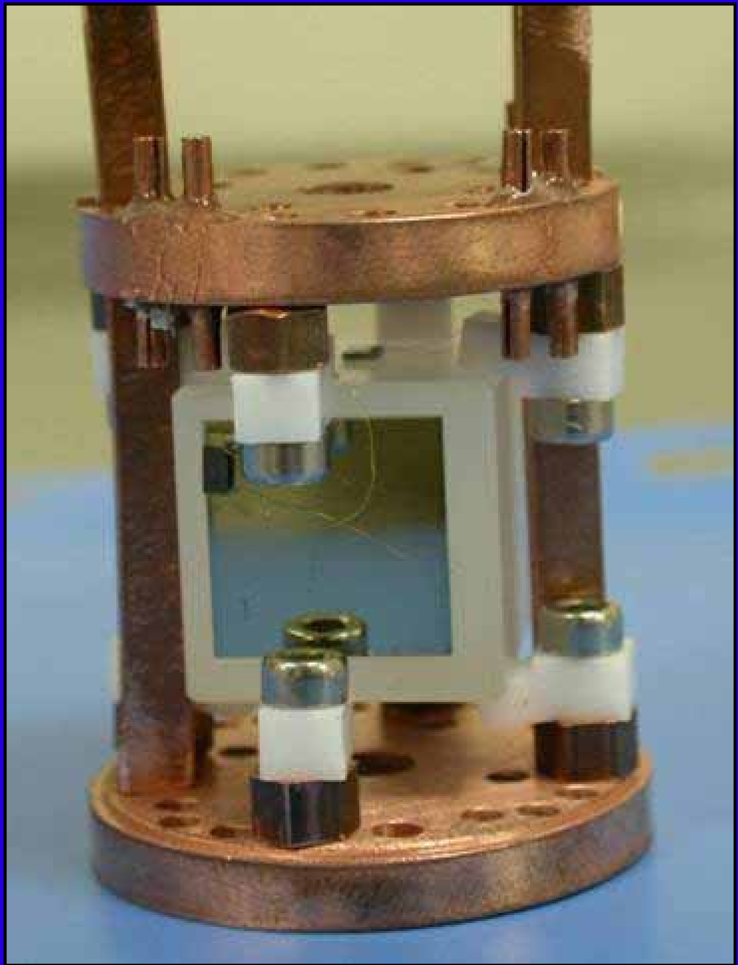


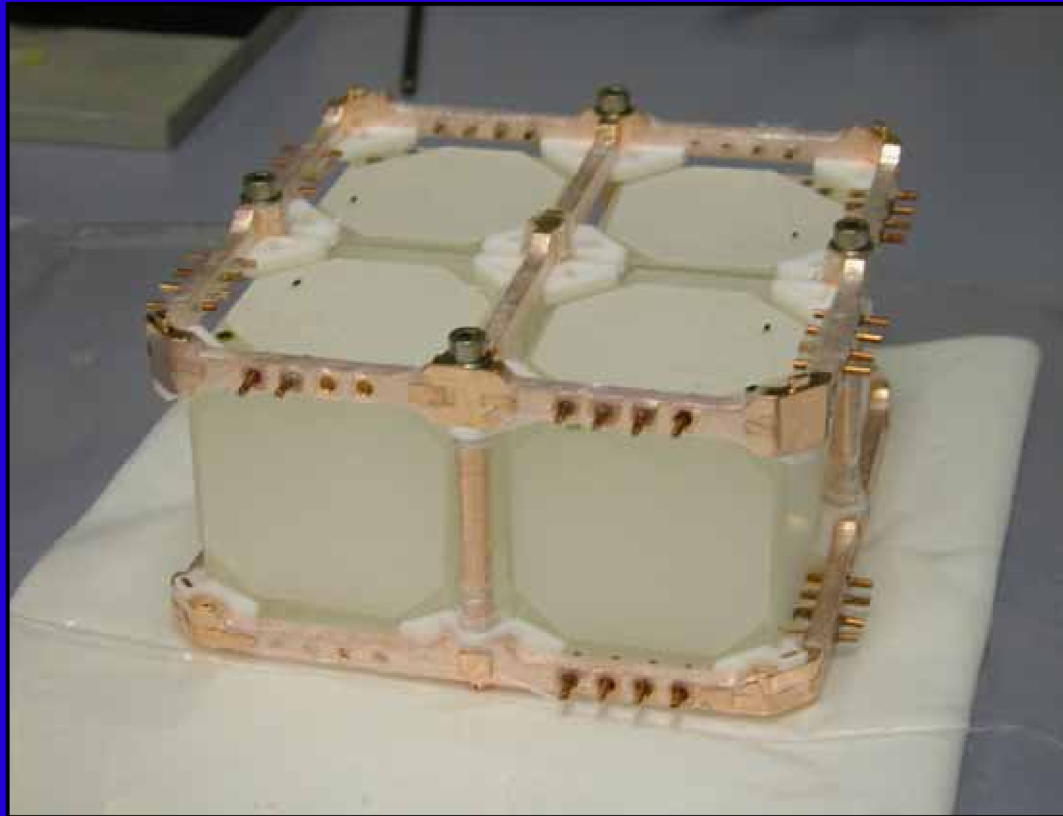


L. Foggetta et al., Appl. Phys. Lett. 86, p.134106 2005

Very useful technique able to discriminate Bulk vs. External events

R&D: surface sensitive bolometers

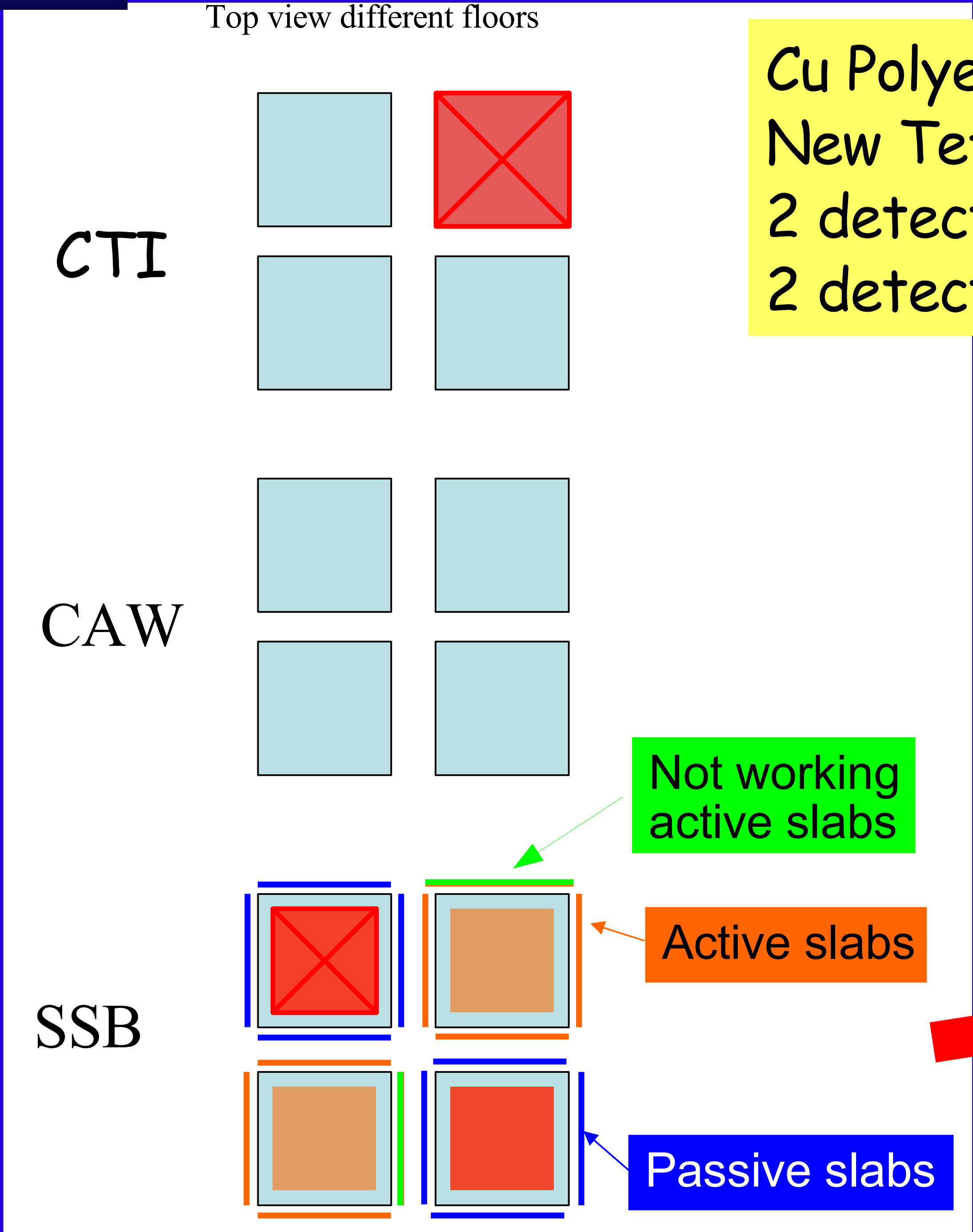




New test performed with TeO_2

Germanium and Silicon slabs tested

Test with TeO_2 SLABS (1)



Cu Polyethylene coverage
New Teflon spacers
2 detectors with passive slabs
2 detectors with 5 working active slabs

Test with TeO_2 SLABS (2)

Reduction of a factor ~2 with respect to RAD test of the flat continuum between 3-4 MeV => 0.04 ± 0.02 c/keV/kg/y

Why haven't SSB removed all the residual surface radioactivity?

1. Only partial coverage
2. 1 slab out of 6 was not active in both detectors
3. Slabs contaminated in Th and U – passive slabs not fully efficient
4. We have reached a hard pedestal which is not Cu surface radioactivity

Future tests:

- run without TEFLON spacers (teflon relaxations could be the pedestal source ??)
- run with 4 full covered detectors with cleaned and active slabs
- other??

Conclusions

- CUORICINO is a DBD0ν experiment running since 2003 with good performances
- With a statistics updated to June 2006 of 8.38 kg y of ^{130}Te the limit on $\langle m_\nu \rangle < (0.18 \div 0.94)$ eV
- New statistics (reaching 11.8 kg y of ^{130}Te) is being analysed in these days.

- Large masses, high energy resolutions and low background are mandatory in order to have high sensitivity to DBD0ν.

- The study of the CUORICINO measured background gave important hints with respect to background sources identification.
-An intense R&D with promising results is going on with respect to bkg reduction in view of the 2nd generation experiment CUORE (~1ton), expected to reach the inverse hierarchy region of the ν mass spectrum