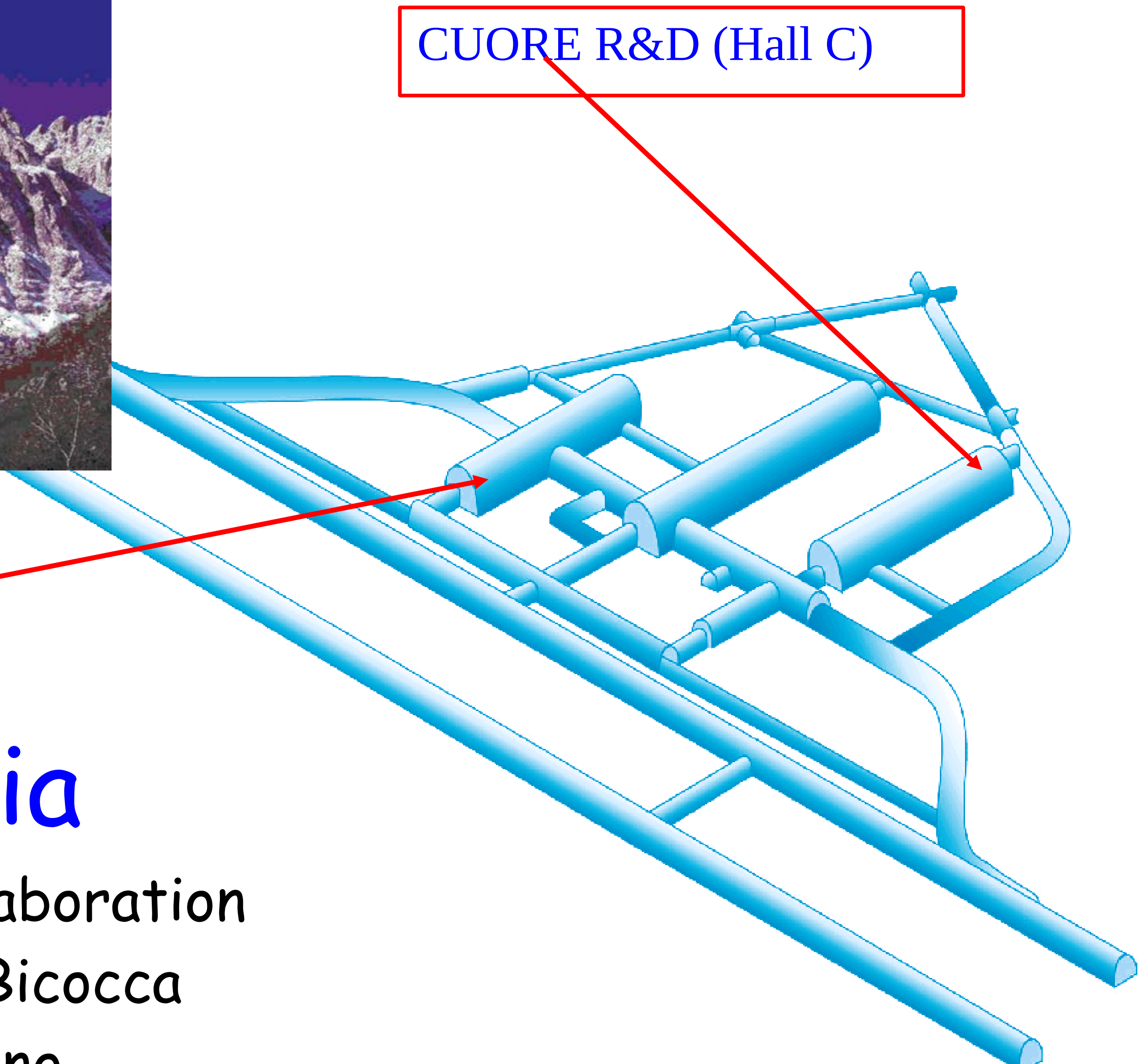
CUORicino @ LNGS



Capelli Silvia

on behalf of CUORE Collaboration

Universita` di Milano Bicocca

Sez. INFN di Milano

Outline

- Double Beta Decay
- Thermal Detectors
- The first TeO_2 experiment: MiDBD
- The running TeO_2 experiment: CUORICINO
- The future TeO_2 experiment: CUORE

Double Beta Decay

Neutrino oscillation experiments have given convincent evidences that

neutrinos are massive and mixed

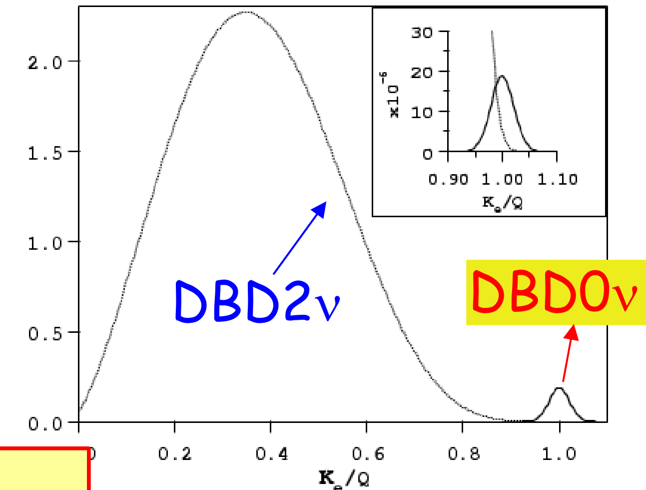
Missing informations:

- neutrino absolute mass scale
- Mass hierarchy
- nature (Dirac/Majorana)
- CP (Majorana) phases

β-endpoint (neutrino absolute mass scale)

DBD0ν (all of the above)

2 electrons sum energy spectra



DBD

SM allowed
$T_{1/2} = 10^{18} \div 10^{25}$ y

a) DBD2ν: $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\nu_e$

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

c) DBDχ: $(A,Z) \rightarrow (A,Z+2) + 2e^- + n\chi$

$m_\nu > 0$
ν Majorana
L violation
$T_{1/2} \geq 10^{25}$ y

Phase space factor — Nuclear matrix elements

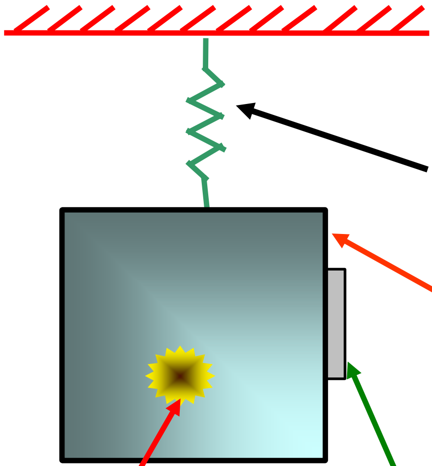
$$\left(T^{0\nu}_{1/2}\right)^{-1} = \sum_k G_k(Q, Z) M_k^2 \, |\langle m_\nu \rangle|^2$$

Mixing matrix — ±1 if CP conserved

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

Thermal Detectors for DBD0ν research

TeO_2 crystals work as source (^{130}Te) and detector (bolometers)



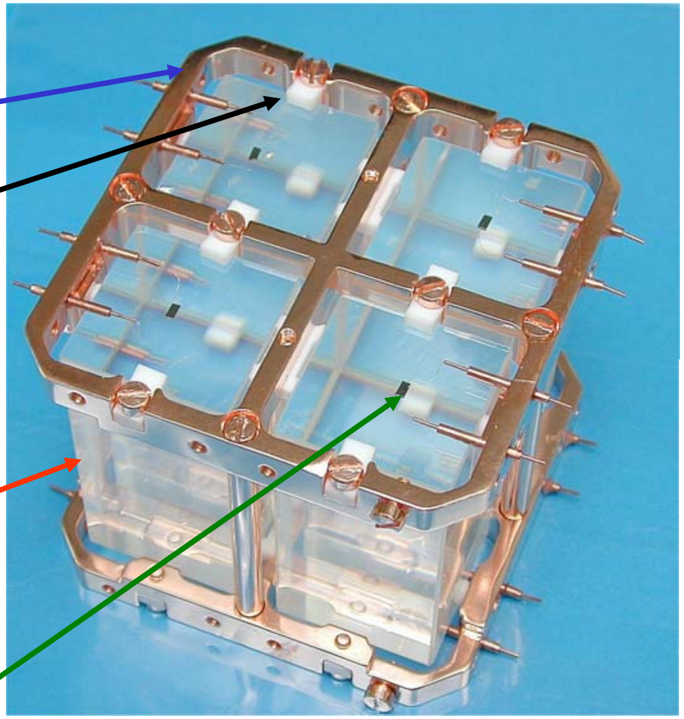
heat sink (~ 10 mK)

weak thermal coupling

incident particle
or internal DBD0n decay

Crystal absorber
(TeO_2)
$\Delta T = E/C \div T^{-3}$

thermometer
(Ge thermistor)
$\Delta T \Rightarrow \Delta R$



Phases of the exp. on TeO_2 at LNGS

Past, present and future:

1997 The first large mass array of bolometers was operated

20 crystals × 340 g = 6.8 kg (Mi DBD - I)

1998-2001 Tests on larger crystals (~750 g) were successfully carried out aiming at more powerful experiments

2001 The 20 crystal array was rebuilt with improved BKG features (Mi DBD - II)

2002 A new, larger mass array is assembled

44 crystals × 790 g
18 crystals × 330 g $\approx$ 41 kg (CUORICINO)

2003-... Full data taking of CUORICINO (1st run: March 2003 – November 2003
2nd run: May 2004 - ...)

2004-2009 Construction of a second generation array

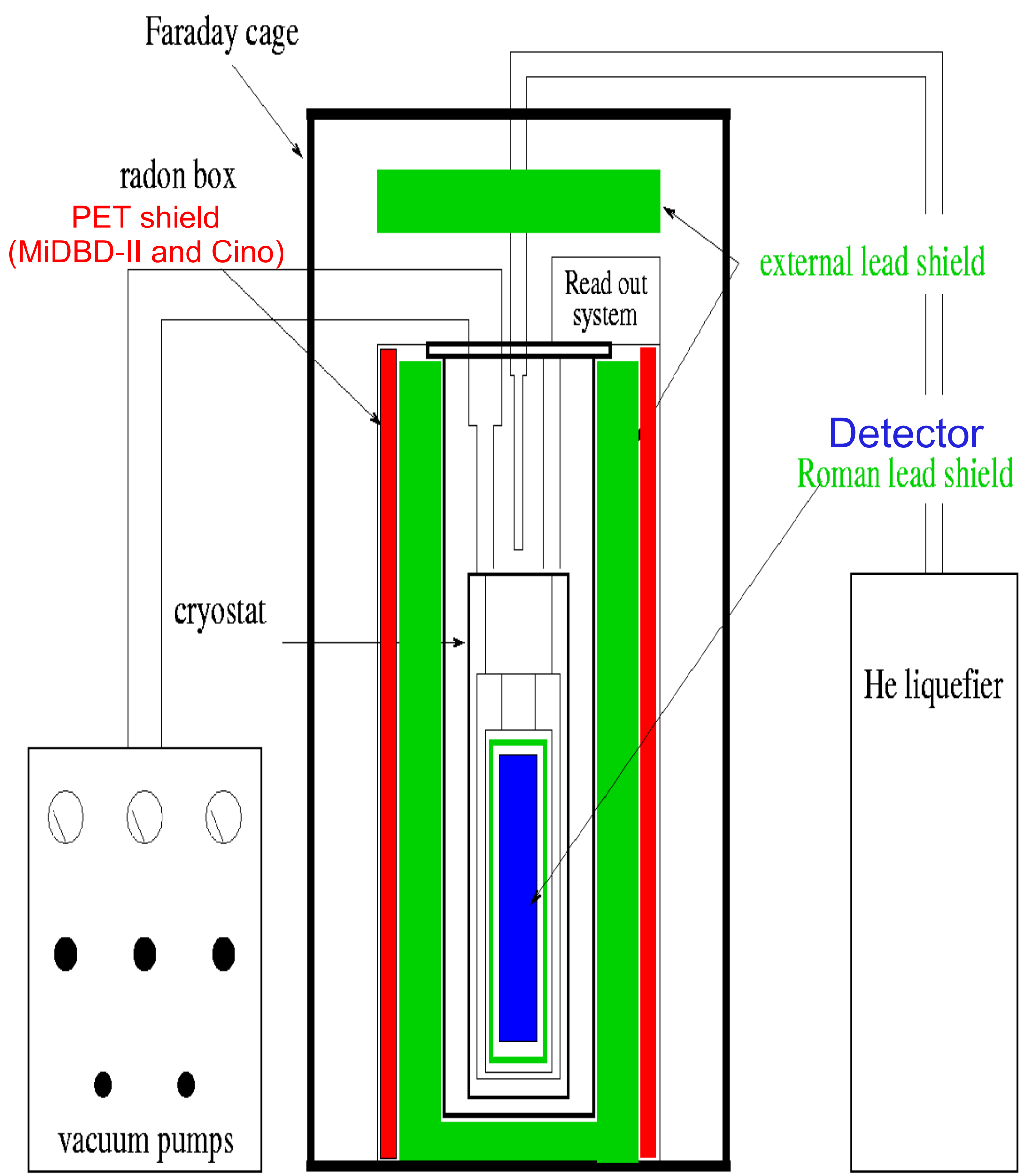
988 crystals × 760 g $\approx$ 741 kg (CUORE experiment)

Hall A experimental set-up

MiDBD-I, MiDBD-II and CUORICINO are installed in a dilution refrigerator (T~10 mK) and surrounded by:

- Cu shields,
- **Roman Lead Inner shield**,
- nitrogen overpressure,
- **20 cm commercial Lead** external shield,
- a Faraday Cage.

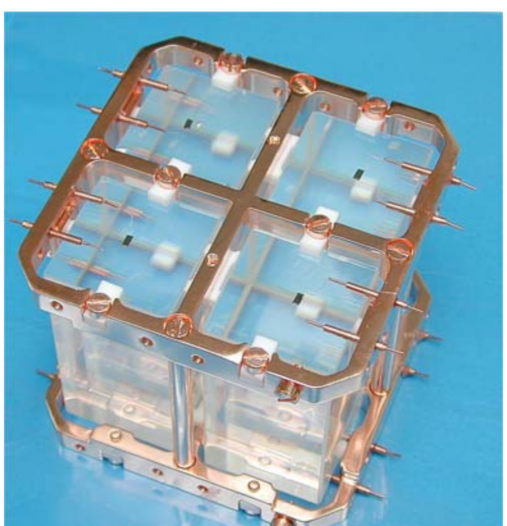
MiDBD-II and CUORICINO have an additional 10 cm **Borated PET external shield**.



MiDBD-I and MiDBD-II

MiDBD-I

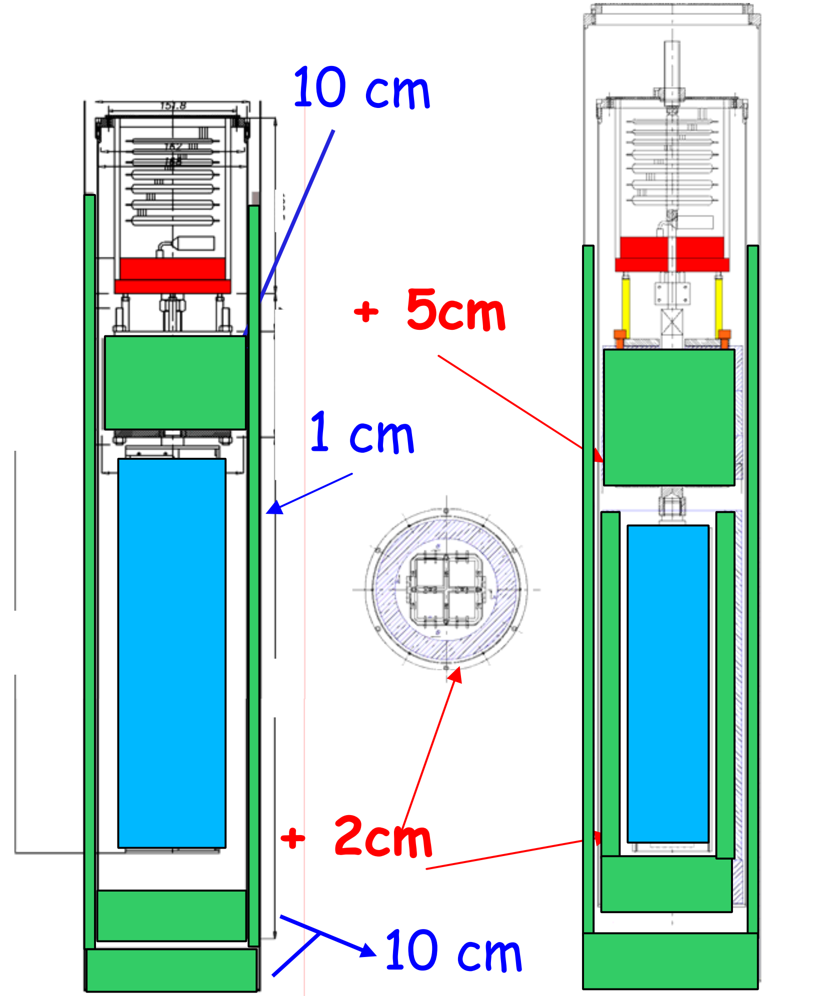
MiDBD-II



- Single detector module
- Large amount of PTFE
- Crystal surfaces treated in China with **not radiopure powders**

- 4 detectors module
- Less PTFE amount
- Crystals **surface treatment**
- Cu surface treatment in Legnaro
- Inner **Roman lead** shield addition
- External 10 cm Borated PET Shield

MiDBD-I MiDBD-II



20 3x3x6 cm^3 (340 g) TeO_2 crystals
♦(16 natural + 4 enriched)

Total mass ~ 6.8 kg

MiDBD-I and MiDBD-II: <m$_\nu$> results

Statistics:

MiDBD-I: 31.508 kgxh

MiDBD-II: 5.690 kgxh

Background (@DBD0ν):

MiDBD-I: 0.59 ± 0.06 c/keV/kg/y

MiDBD-II: 0.33 ± 0.11 c/keV/kg/y

FWHM(@2615keV)

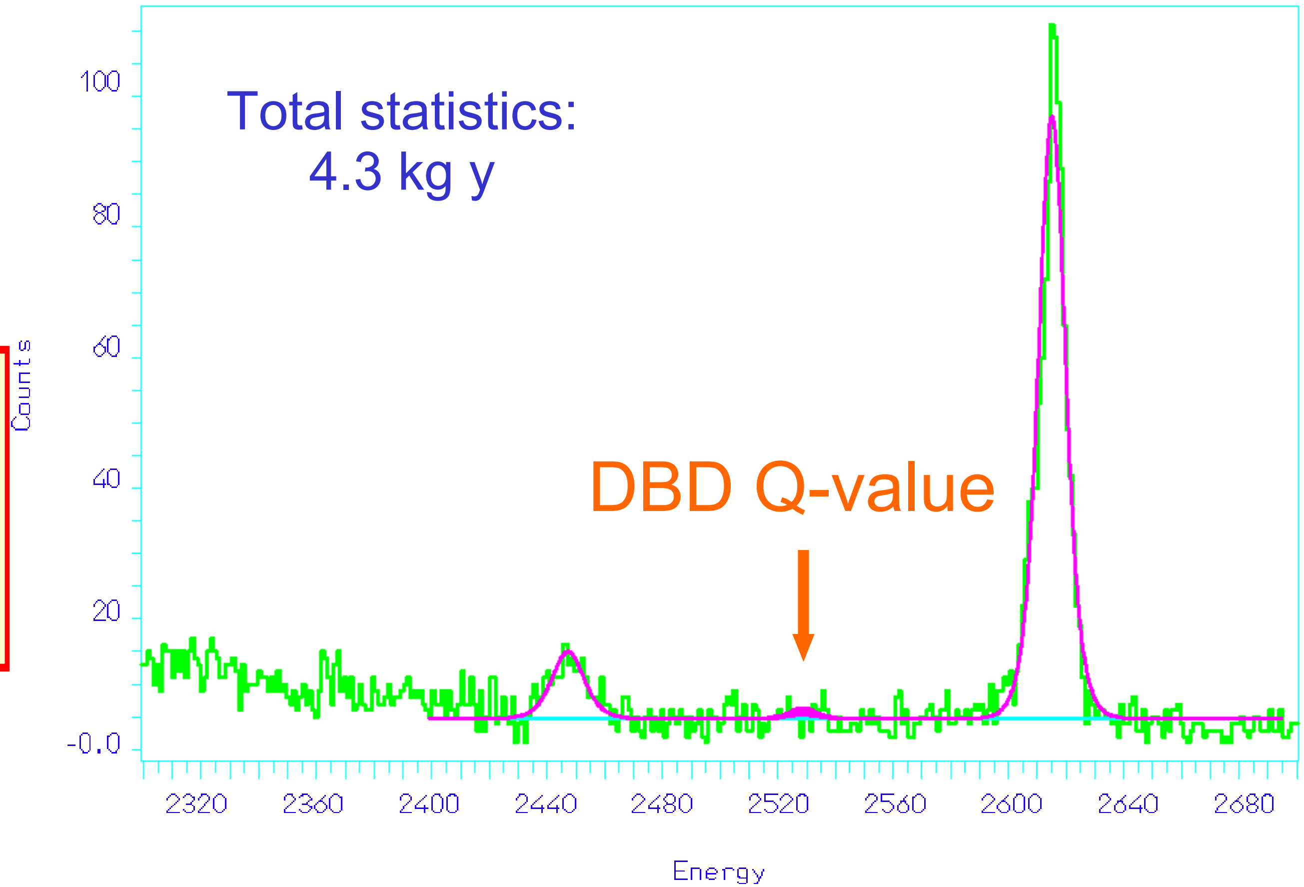
MiDBD-I: 9.3 keV

MiDBD-II: 15 keV

DBD0ν results:

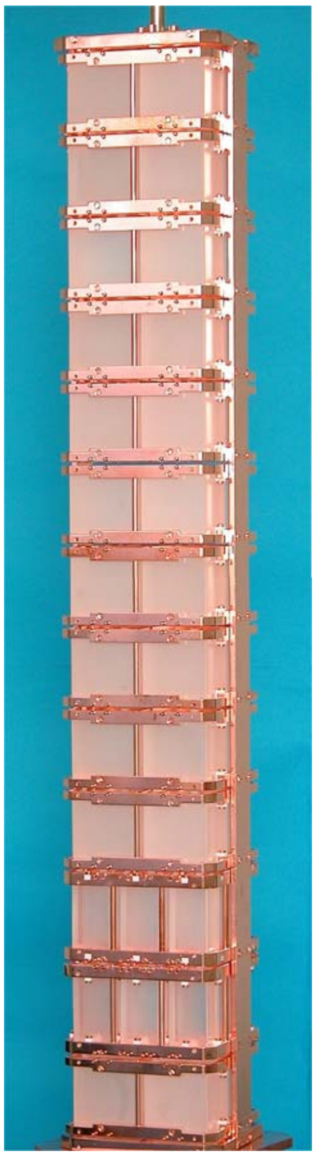
$T_{1/2}^{130Te}$ > **2.1x10^{23} y**

$\langle m_\nu \rangle$ < [1.1÷2.6] eV

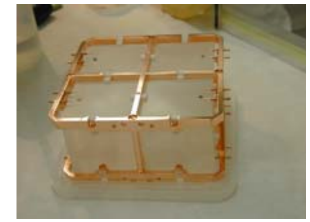


CUORICINO set-up

Total mass
~41 kg

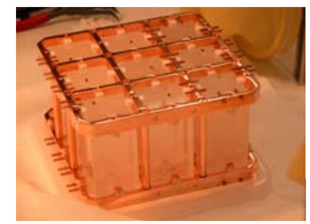


11 modules 4 detector each,
5x5x5 cm^3 **790 g** TeO_2 crystals



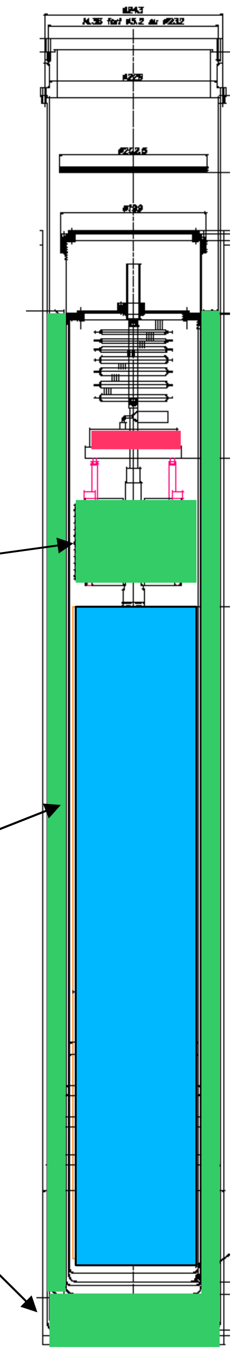
+

2 modules 9 detector each,
3x3x6 cm^3 **330 g** TeO_2 crystals



Particular care devoted to **selection** and **cleaning** of materials:

- -cystals grown from pre-tested low activity powders
- -crystals surface treatment with low activity materials
- -low activity selected copper faced to the detector
- - Copper and PTFE surface cleaning
- - Mounting operations in clean environment



10 cm

1 cm

7.5 cm

Collected statystics 1st run

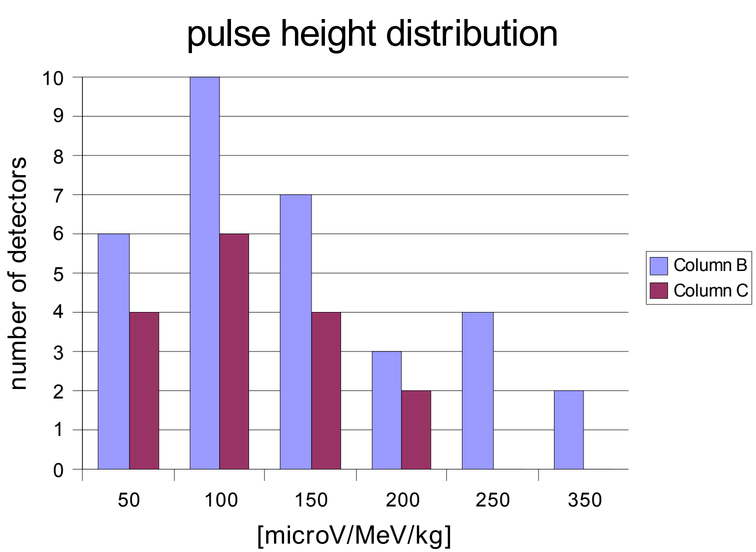
- march 2003-november 2003

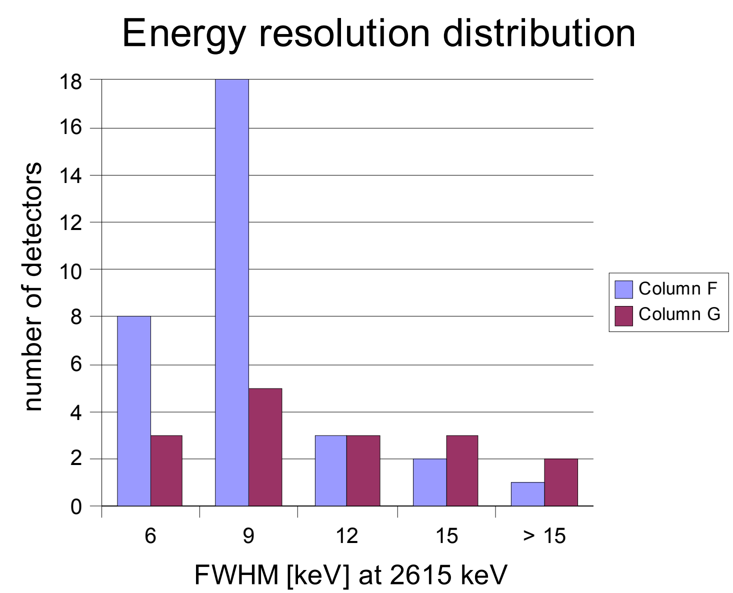
some detector connections were broken ; cryogenic problems limiting live time

32 working detectors => 29 used

3.75 kg * y of TeO_2

17 working detectors => 15 used (11 natural + 4 enriched)





120 ± 75 μV/MeV*kg

104 ± 35 μV/MeV*kg

7.8 ± 2.5 keV

9.1 ± 3.1 keV

Collected statystics 2nd run

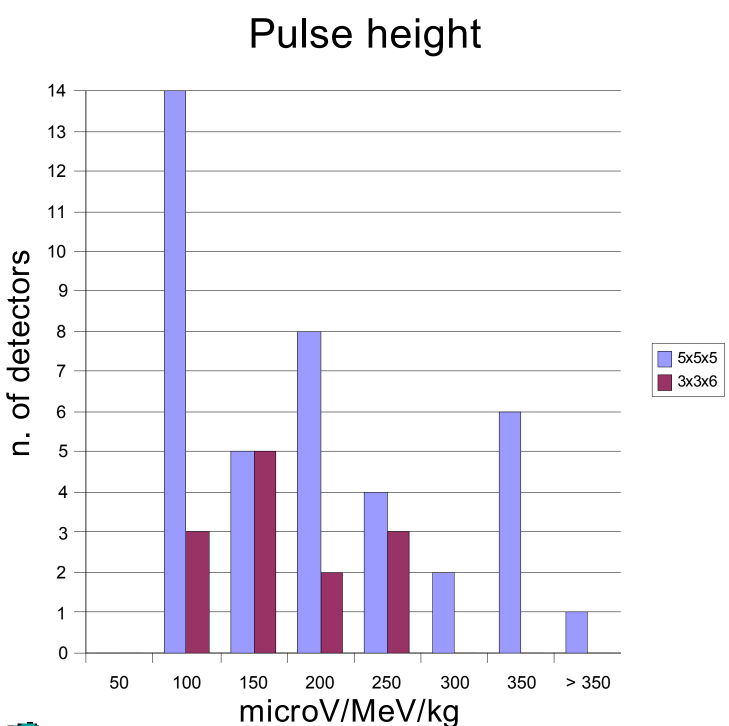
- may 2004 – december 2004

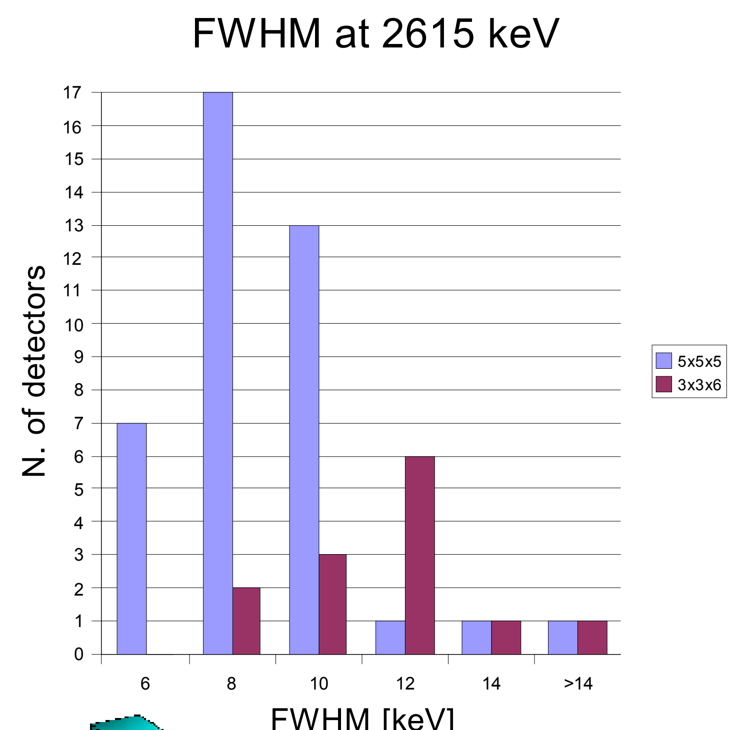
disconnected detectors recovered ; He liquifier disconnected

42 working detectors => 40 used

7.1 kg * y of TeO_2

18 working detectors => 17 used (13 natural + 4 enriched)





167 ± 99 μV/MeV*kg

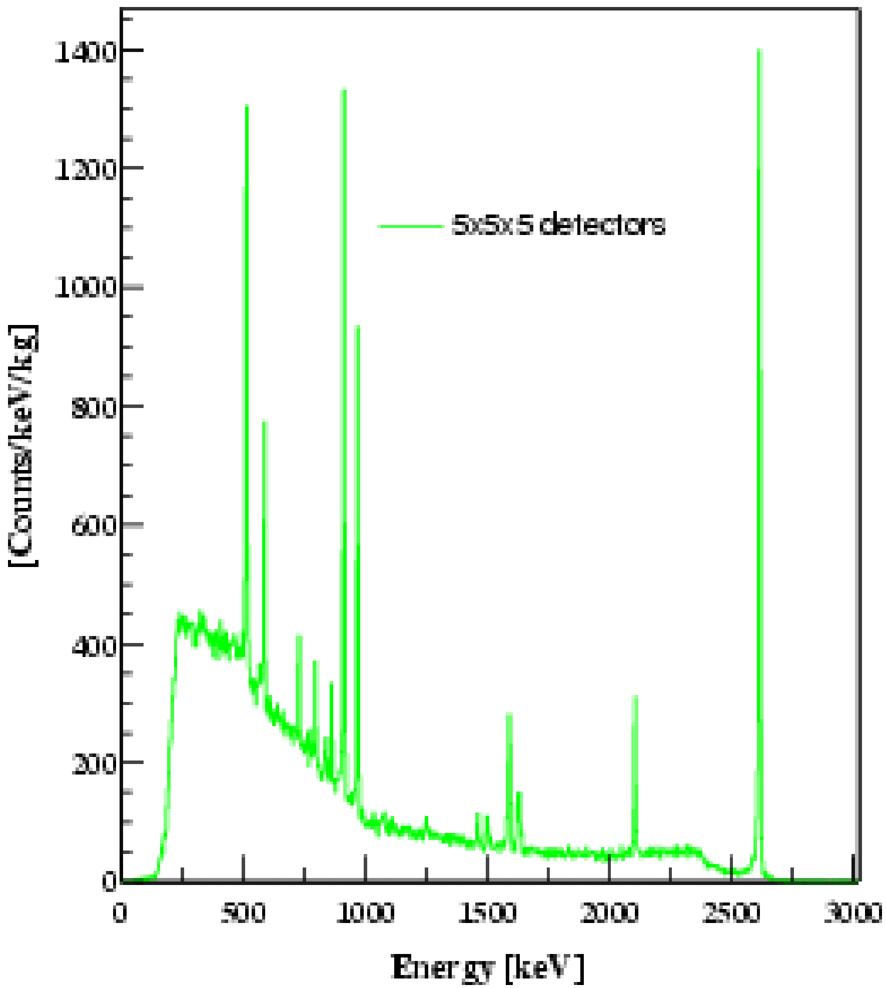
147 ± 60 μV/MeV*kg

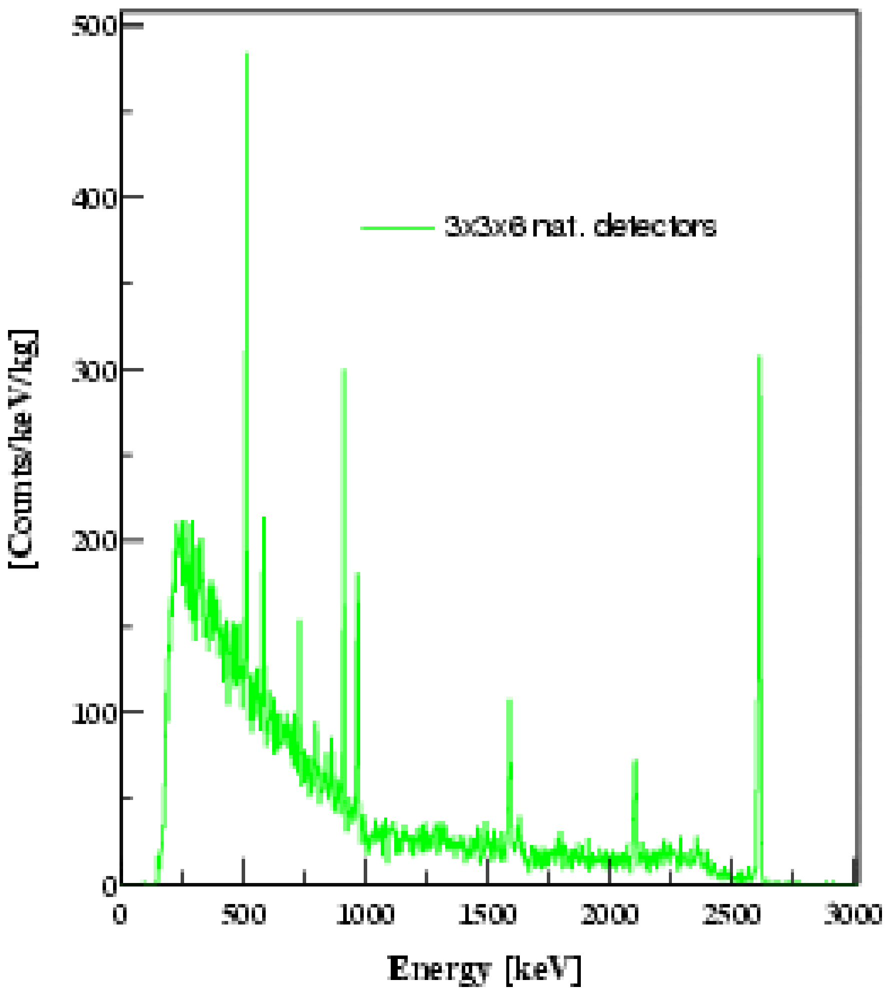
7.5 ± 2.9 keV

9.6 ± 3.5 keV

Calibration spectra

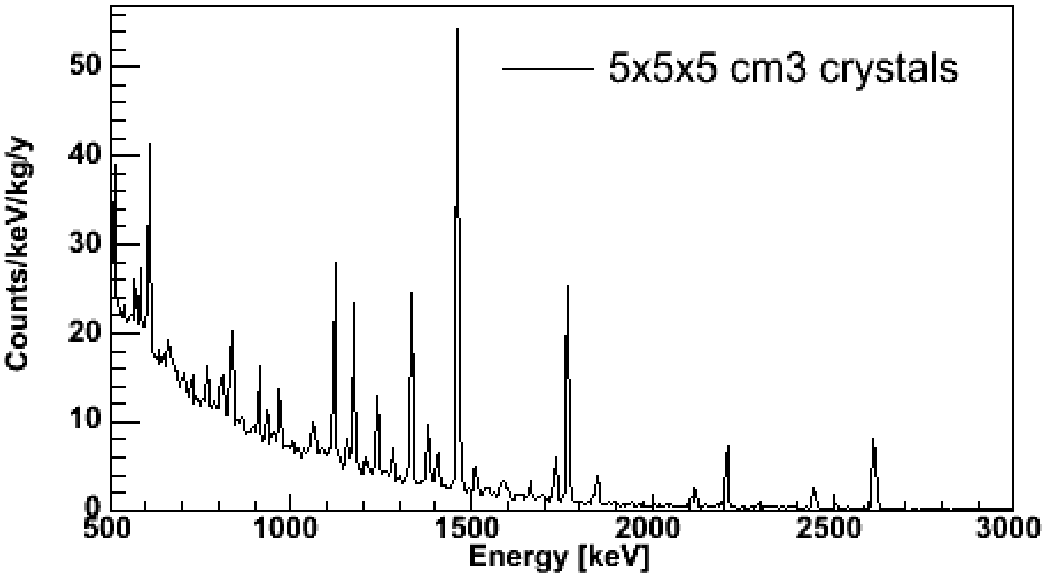
^{232}Th wire source

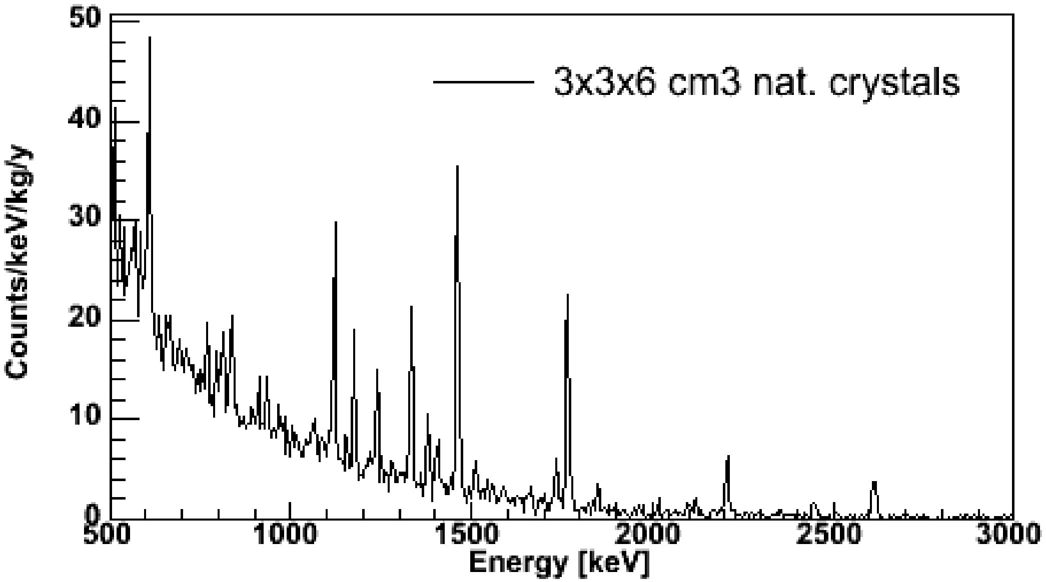




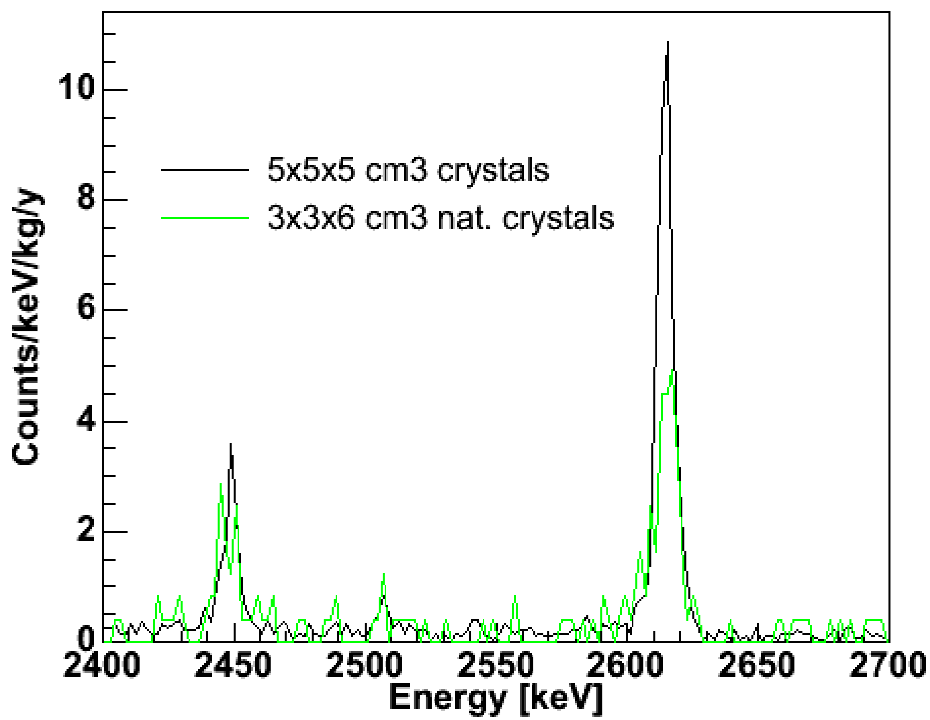
Background spectra

gamma region





DBD0ν region



CUORICINO results

Total Statistics: 10.85 kgxy

Background (@DBD0ν):

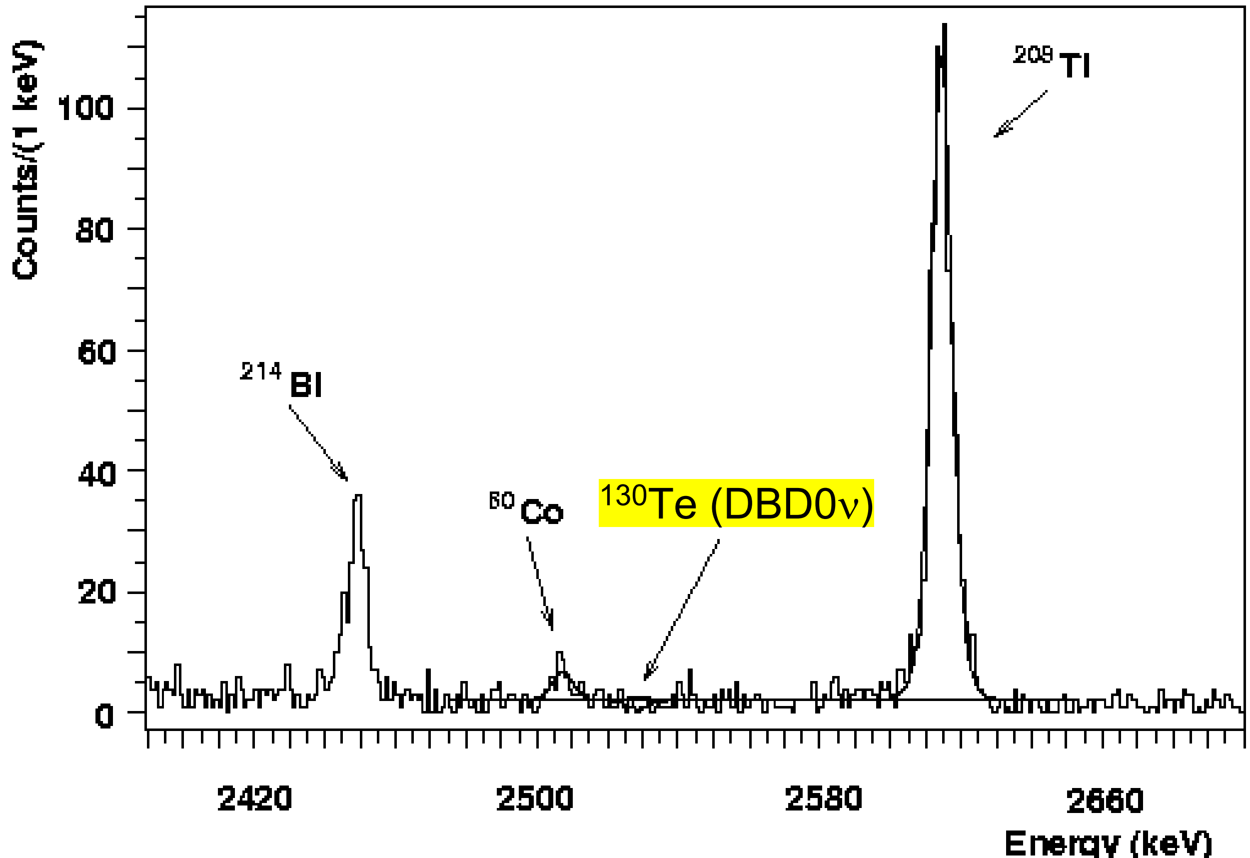
0.18 ± 0.01 c/keV/kg/y => reduction of ~ 2 (4) with respect to MiDBD-II (I)

arXiv:hep-ex/0501034 v1

DBD0ν result:

$T_{1/2}^{130Te}$ > 1.8×10^{24} y

$\langle m_\nu \rangle$ < [0.2÷1.1] eV



CUORICINO sensitivity

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

Detector mass (kg)

Running time (y)

Isotopic abundance

Detector efficiency

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

Molecular weight

BKG (counts/keV/kg/y)

Energy resolution (keV)

For: $b = 0.2$ and $\Gamma = 8$ keV

$F^{0\nu} = 4.2 \times 10^{24}\ T^{1/2}$ (68% CL)

$\langle m_\nu \rangle <$ 0.07 - 0.5 eV

5 years

CUORE experimental setup

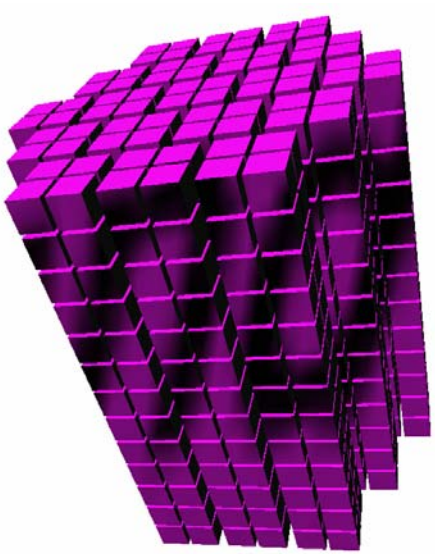
Closely packed array of 988 detectors (750 g each)

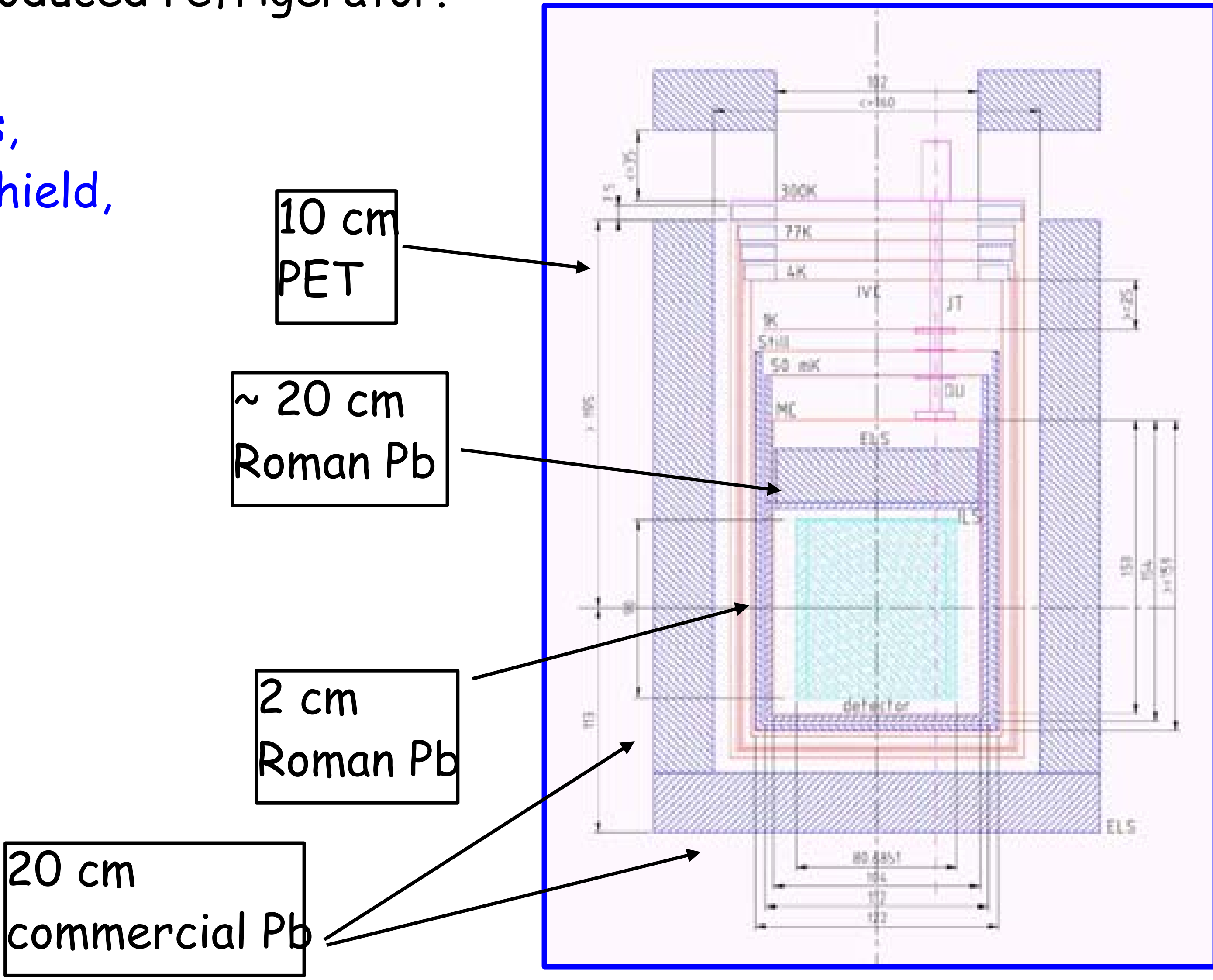
19 towers - 13 modules/tower - 4 detector/module

placed inside a specially produced refrigerator.

M ~ 741 kg

- Cu shields,
- **Roman Lead** Inner shields,
- 20 cm commercial Lead shield,
- Borated PET,
- nitrogen overpressure,
- a Faraday Cage.





From CUORICINO to CUORE

CUORICINO proves:

- the feasibility of a large bolometric array with the tower-like structure
- that detector performances (signal rise and decay time, pulse height, energy resolution) are not affected by the increase in crystal size (from 330 g to 790 g)

Cuoricino can't be a direct test of Cuore feasibility for what concerns bkg but:

- The tightly closed structure of CUORE should give a strong reduction of the bkg operating with the detector in anticoincidence
- The lead shield designed for CUORE will be optimized in order to practically cancel the outside bkg
- R&D activities as respect to surface cleaning and material selection will give an additional reduction in the bkg contribution in the DBD region

CUORICINO bkg model PRELIMINARY !

Sources identified as possible responsible for the bkg in the DBD0ν :

- β and α from TeO_2 surface
- β and α from surface of materials facing the crystals (the biggest surface is Cu)
- ^{208}Tl multi-compton events (^{232}Th contaminations of distant parts)

Evaluated surface contamination level: ~ 10^{-9} g/g in U and Th (of both TeO2 and Cu)

Estimated contributions to the DBD0n region:

TeO_2 surface	~ 10 ± 10 %
Cu surface	~ 50 ± 20 %
Th cont. of the set-up	~ 30 ± 10 %

CUORE bkg evaluation

An evaluation of the background reachable in CUORE with the contamination levels measured so far (MiDBD, CUORICINO and Ge measurements) for the materials commercially at our disposal was made by means of MonteCarlo simulations:

Bulk contaminations

$TeO_2 \sim 10^{-13}$ g/g

=> < 2×10^{-3} counts/kev/kg/y

Cu ~ 10^{-12} g/g

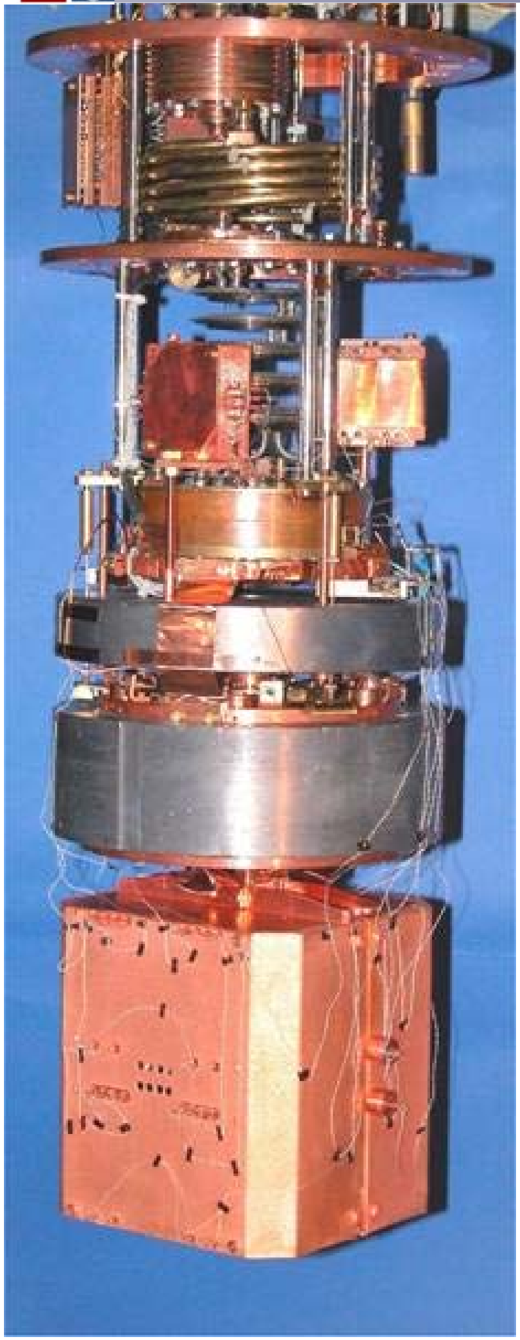
Surface contamination

~ 10^{-9} g/g for TeO_2 and Cu => < 7×10^{-2} counts/kev/kg/y

We aim at reaching AT LEAST a reduction by a factor 10 in Cu surface contamination and by a factor 4 in TeO_2 surface contamination

Crystals and Copper cleaning procedure under development

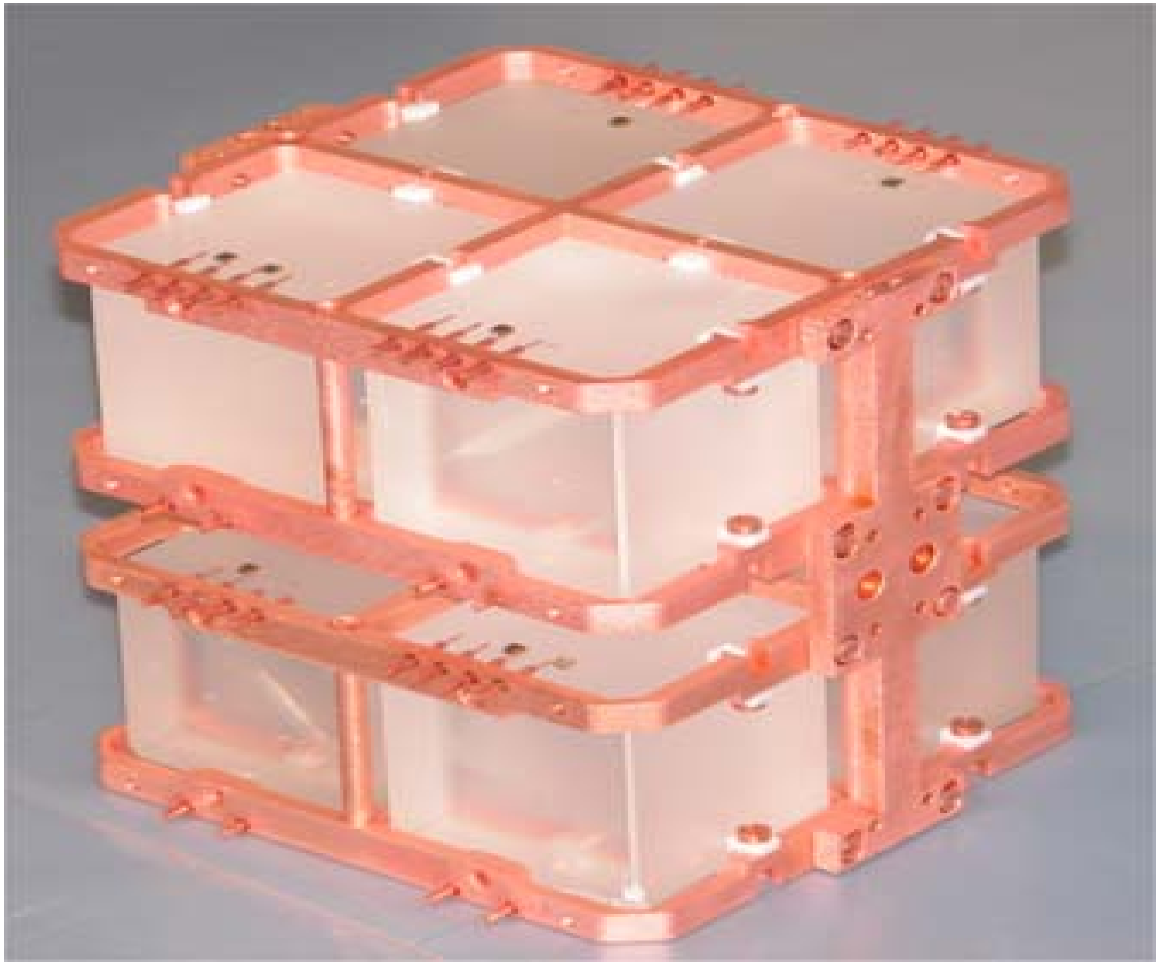
R&D: Cleaning test (September-November 2004)



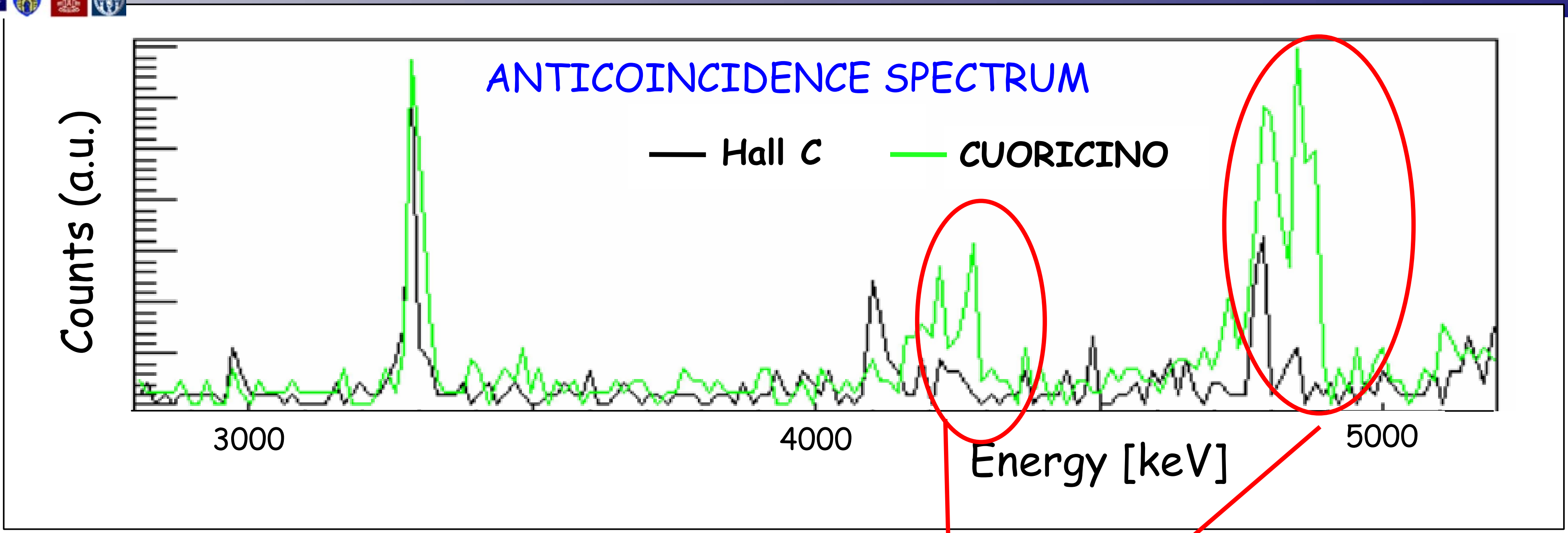
Cu: etching, electropolishing and passivation

TeO_2: etching and lapping with clean powders

Assembling with clean materials



R&D: Cleaning test results



Reduction of a factor ~ 4 on crystal surface contaminations: milestone of CUORE for this task reached.

Crystal Bulk contamination ~ 10^{-14} g/g in U and Th

CUORE sensitivity

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

- Montecarlo simulations indicate that the present bulk contaminations of the experimental materials commercially available are compatible with a bkg in the DBD0n region ~ 0.001 counts / (keV kg y)
- The reduction obtained for the crystal surface contaminations reaches CUORE milestone
- A dedicated R&D with respect to material surface cleaning and measurements is under progress in order to reduce their contribution

Sensitivity (1σ):

b=0.01 c/keV/kg/y		b=0.001 c/keV/kg/y
Γ=5 keV		Γ=5 keV
$F^{0\nu}=9.2\times10^{25}\sqrt{t}$ y		$F^{0\nu}=2.9\times10^{26}\sqrt{t}$ y
$\langle m_\nu \rangle$=0.02÷0.1 eV	← 5 years →	$\langle m_\nu \rangle$=0.01÷0.06 eV

Conclusions

- 1997÷ 2001: MiDBD-I and MiDBD-II (m = 6.8 kg)

bkg level in the DBD0ν region: 0.59 => 0.33 c/keV/kg/y

limit: $T_{1/2}^{130Te} > 2.1 \times 10^{23}$ y

- 2002 ÷ now : CUORICINO (m = 41 kg)

bkg level in the DBD0ν region: ~ 0.18 c/keV/kg/y

limit: $T_{1/2}^{130Te} > 1.8 \times 10^{24}$ y

-2010 ÷ ... : CUORE (m = 741 kg)

bkg level goal in the DBD0ν region: ~ 0.01 ÷ 0.001 c/keV/kg/y

sensitivity: $T_{1/2}^{130Te} > 9.2 \times 10^{25} \sqrt{t}$ y (worst case)

$T_{1/2}^{130Te} > 2.9 \times 10^{26} \sqrt{t}$ y (best case)

Nuclear matrix and $\langle m_\nu \rangle$

Phase space factor — Nuclear matrix elements

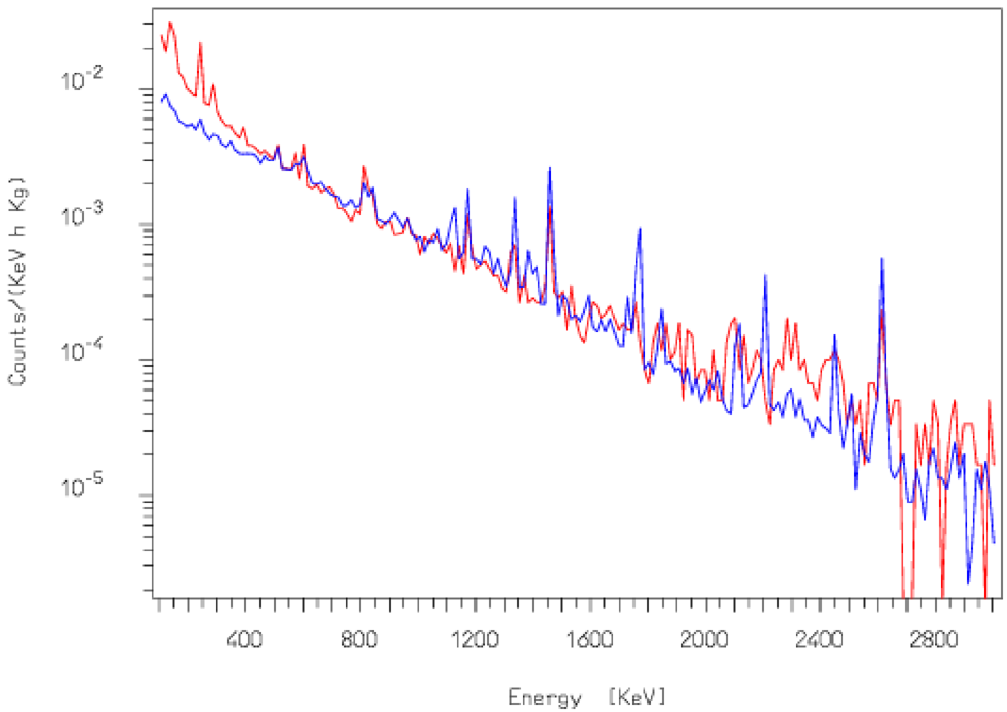
$$\left(T_{1/2}^{0\nu}\right)^{-1} = \sum_k G_k(Q, Z) M_k^2 \, |\langle m_\nu \rangle|^2 = F^{0\nu} \, |\langle m_\nu \rangle|^2$$

		^{130}Te		^{76}Ge		
		F^N(1e-13 y^{-1})	<m >($T_{1/2}$=1.8E+024)	F^N(1e-13 y^{-1})	<m >($T_{1/2}$=1.2E+025)	F^N(Te)/F^N(Ge)
QRPA	Staudt et al., 1992 [28]	34	0.207	10	0.148	3.4
		29	0.224	8.9	0.156	3.3
	Staudt, Muto, Klapdor, 1990	**5.22**	0.527	**1.12**	**0.441**	4.7
	Pantis et al., 1996 [29]	3	0.695	0.73	0.546	4.1
		1.24	1.082	0.14	1.247	8.9
	Vogel, 1986 [30]	3.96	0.605	0.19	1.070	20.8
	Civitarese, 1987 [31]	5	0.539	1.2	0.426	4.2
	Tomoda, 1991 [32]	5.03	0.537	1.2	0.426	4.2
	Barbero et al., 1999 [33]	7.77	0.432	0.84	0.509	9.3
	Simkovic, 1999 [34]	1.79	0.900	0.62	0.592	2.9
	Suhonen et al., 1992 [35]	3.13	0.681	0.72	0.550	4.3
	Muto et al., 1989 [36]	5.34	0.521	1.1	0.445	4.9
	Stoica et al., 2001 [37]	2.44	0.771	0.65	0.579	3.8
		2.66	0.738	0.9	0.492	3.0
	Faessler et al., 1998 [38]	2.78	0.722	0.83	0.512	3.3
	Engel et al., 1989 [39]	10.9	0.365	1.14	0.437	9.6
	Aunola et al., 1998 [40]	5.72	0.504	0.9	0.492	6.4
		5.06	0.535	1.33	0.404	3.8
SM	Rodin et al., 2003 [41]	0.95	1.236	0.45	0.695	2.1
	Haxton et al., 1984 [42]	16.3	0.298	1.54	0.376	10.6
	Caurier et al., 1996 [43]	0.45	1.795	0.15	1.204	3.0
OEM	Hirsh et al., 1995 [44]	3.6	0.635	0.95	0.479	3.8

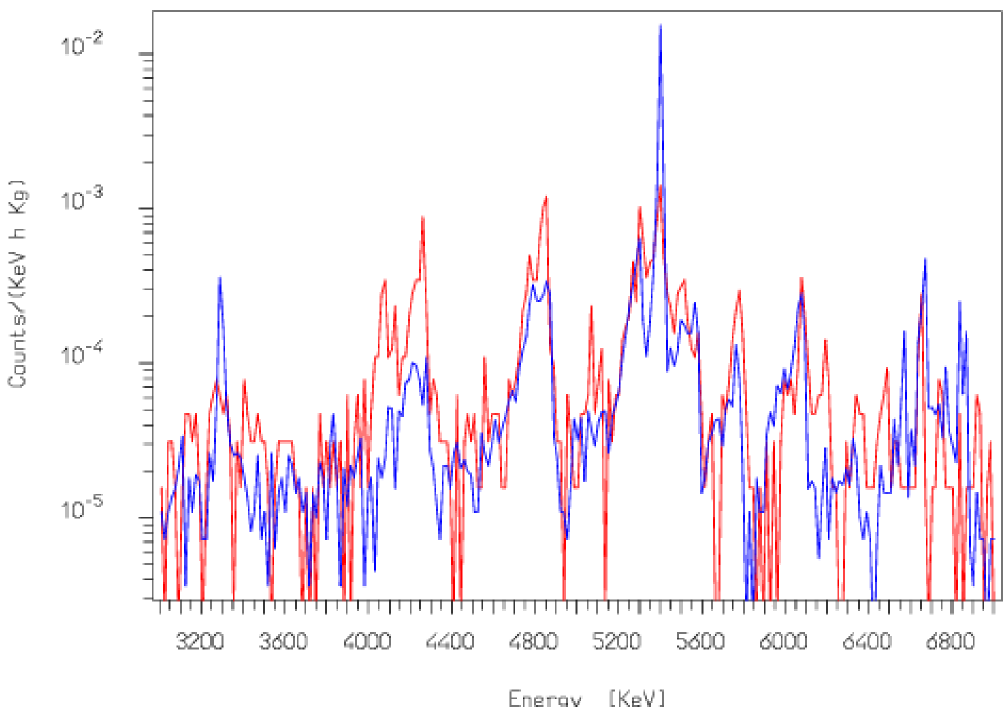
With the same model of HM claim: $T_{1/2}^{130Te}$=2.4x10^{24} y (~2 y of CUORICINO live time meas.)

CUORICINO: vs. MidBD-II bkg spectra

Gamma region



Alpha region



MiDBD-II

CUORICINO

CUORICINO: bkg analysis

γ region: - gamma peaks due to ^{232}Th, ^{238}U, ^{40}K, ^{60}Co (also the sum peak at 2505 keV), ^{57}Co, ^{54}Mn and tellurium activation lines are visible in the bkg spectru

α region: - peaks at $E=E_\alpha+E_R$ due to ^{232}Th, ^{238}U, ^{210}Po (rate decreasing in time) are visible in the bkg spectrum

- peak at $E=E_\alpha$ of ^{210}Pb visible in the spectrum
- peak at 3250 keV

Comparison with MiDBD:

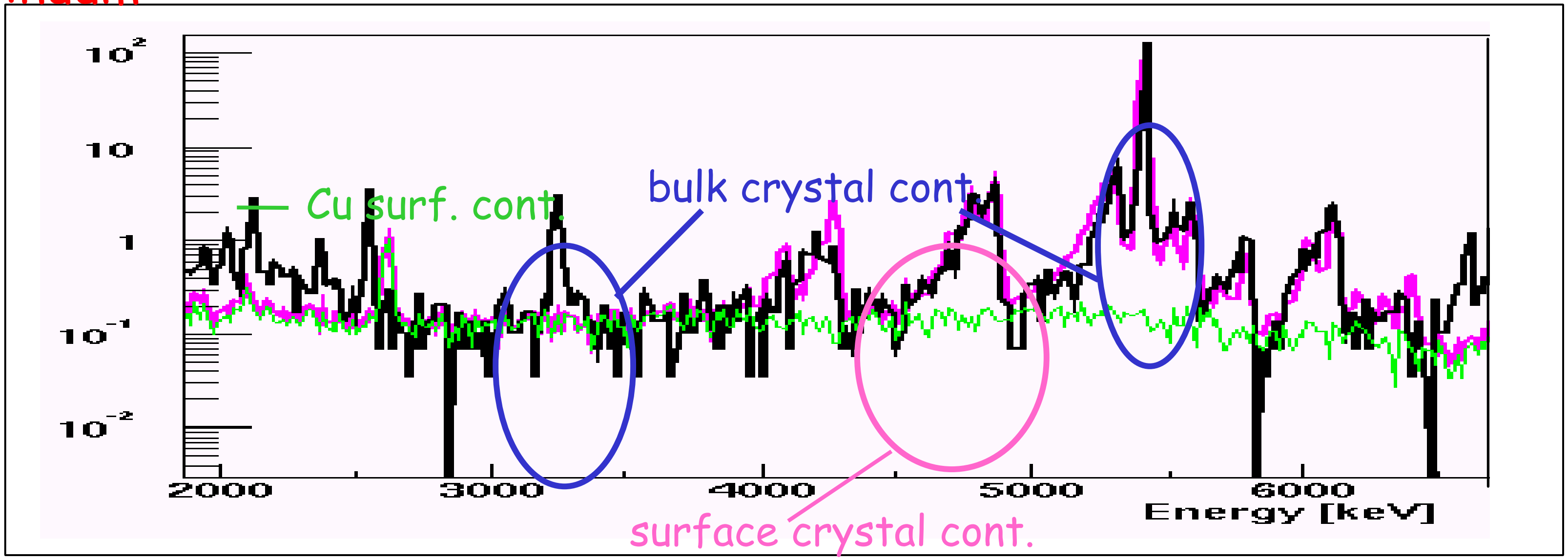
Ratios MiDBD-II / CUORICINO

peaks	U and Th gammas	^{60}Co	^{40}K	U and Th alphas
	~0.5	~0.3	~0.5	~3
continuum	[1-2] MeV	[2-3] MeV	DBD region	[3-4] MeV
	~1	~1.5	~2	~2

CUORICINO bkg model PRELIMINARY !

ANTICOINCIDENCE bkg spectrum

- Crystal bulk contaminations: gaussian peaks at the Q-value of the decay
- Crystal surface contaminations: peaks at the α energy with low energy tails
- Surface contaminations at a depth ~ 5 μm of the materials facing the crystals: flat continuum



COINCIDENCE spectrum

only CRYSTAL SURFACE contam. Contribute => check

Evaluated contamination levels:

surface : ~ 1 ng/g
bulk < 1 (0.1) pg/g for Cu (TeO_2)

CUORE: bkg sources

In the computation of the CUORE bkg we have considered the contribution of:

- neutrons and muons => small contribution (possibility of a μ veto)
- gamma environmental bkg => small contribution thanks to a 4π 20 cm lead shield
- DBD2ν in the TeO_2 crystals => evaluated from the present upper limits of $T_{1/2}^{2\nu}$
- **bulk and surface** contaminations of the experimental materials
- **cosmogenic** activation of Te and Cu

COSMO
4 months C.R. exposition
2 years underground

Assumed contamination levels:

Bulk	^{232}Th	^{238}U	^{40}K	^{210}Pb	^{60}Co
(Bolometric →) TeO_2	0.5 pg/g	0.1 pg/g	1 pg/g	10 μBq/kg	0.02 μBq/kg
(Ge measure →) Cu	4 pg/g	2 pg/g	1 pg/g	0	10 μBq/kg
Roman Lead	2 pg/g	1 pg/g	1 pg/g	4 mBq/kg	0

Bolometric (→ Roman Lead ^{210}Pb)

Bolometric: CUORICINO

Direct meas. under study : ICMPS, laser ablation...

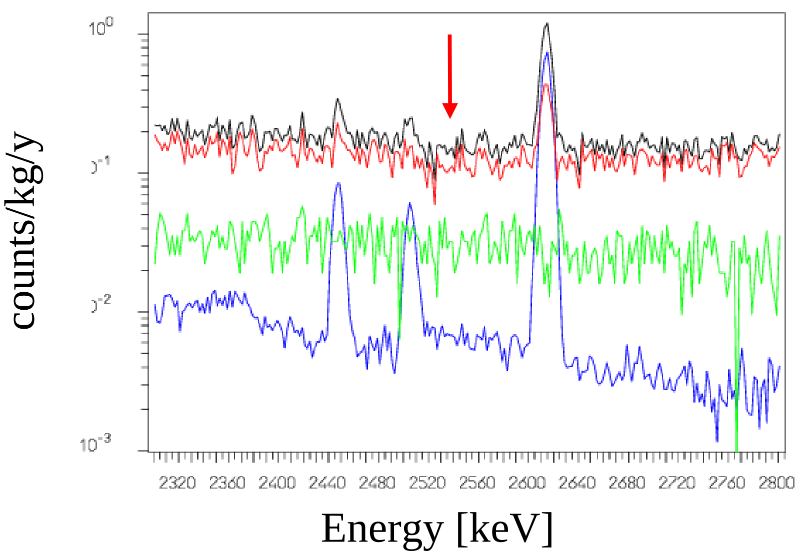
Surface	^{238}U Bq/cm^2 ($\times10^{-8}$)	^{232}Th Bq/cm^2 ($\times10^{-8}$)
TeO2-^{238}U	2 ± 1	-
Cu-^{238}U	5 ± 2	3.4 ± 1.3

CUORE: bkg contributions

Bulk: The contribution from C.R. activation of Te and Cu can be lowered by means of **an optimization** of the production and storage procedure...

Surface	^{238}U c/keV/kg/y
TeO2	1.6e-2 +/- 8.4e-3
Cu	5.8e-2 +/- 6.6e-3
Sum	7.4e-2 +/- 1.1e-2

Surface: we need a reduction of **an order of magnitude** with respect to CUORICINO surface contamination levels !!



Sum
TeO_2 surface contam.
Cu structure surface contam.
Bulk total contam.

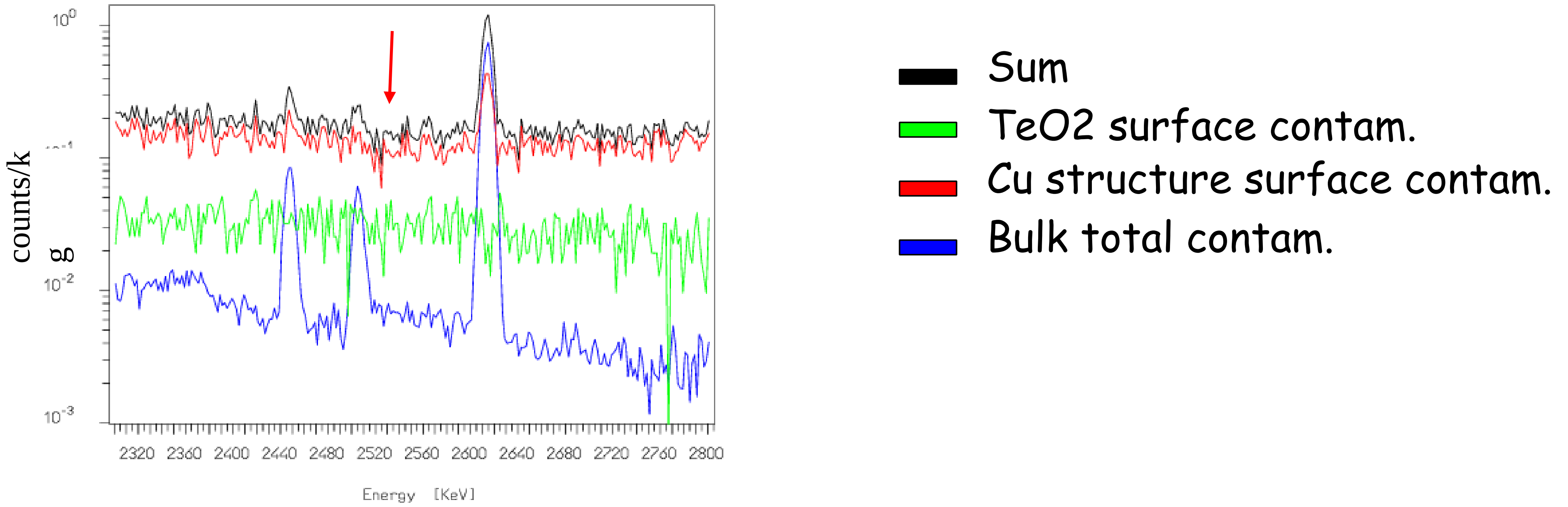
Recent measurements performed in hall C with new cleaning procedures have shown a **reduction of ~ 5** in the crystal surface contaminations .

New cleaning procedures (plasma cleaning...) for Cu surfaces are under study

CUORE: bkg contributions

Surface	^{238}U c/keV/kg/y
TeO2	1.6e-2 +/- 8.4e-3
Cu	5.8e-2 +/- 6.6e-3
Sum	7.4e-2 +/- 1.1e-2

➡ we need a reduction of a factor ~ 20 with respect to CUORICINO surface contamination levels!!



Recent measurements performed in hall C with new cleaning procedures have shown a reduction of ~ 5 in the crystal surface contaminations

New cleaning procedures (plasma cleaning...) for Cu surfaces are under study

Double Beta Decay - 0 ν

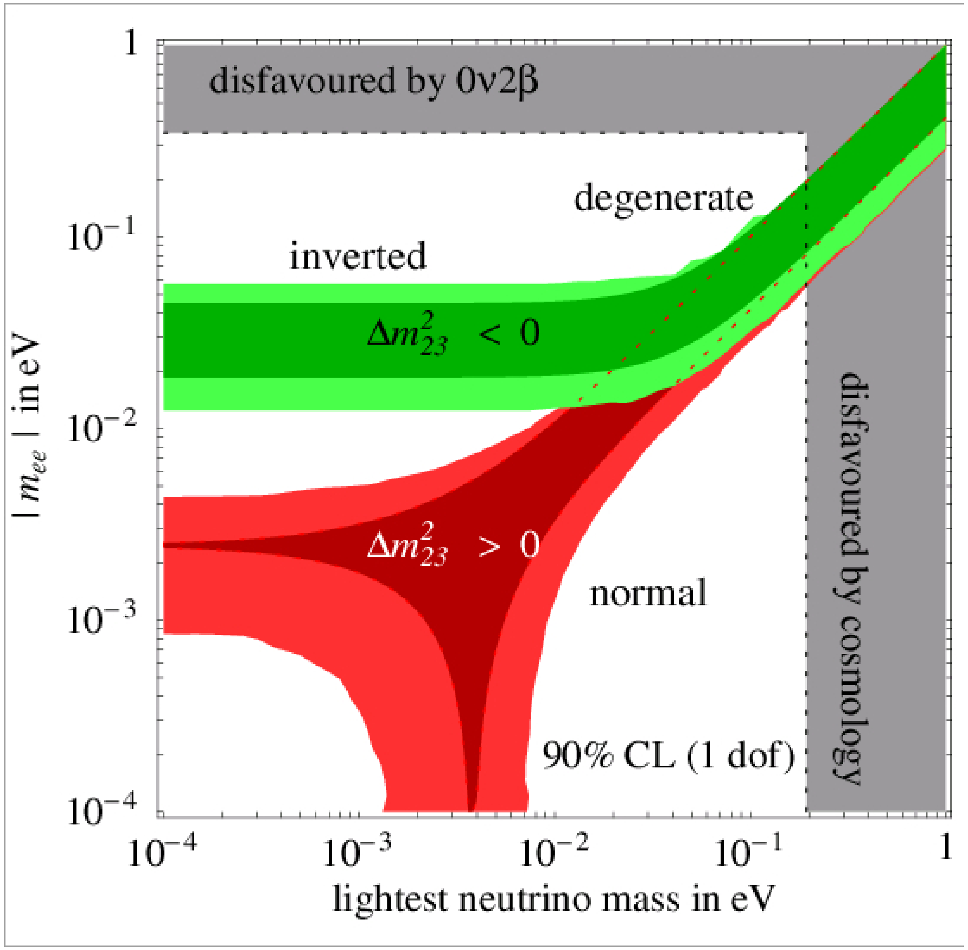
±1 if CP conserved

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

Mixing matrix

From DBD experiments we can have information about:

- L violation
- neutrino nature
- neutrino absolute scale
- mass hierarchy
- CP phases



Neutrino physics situation

ν_{atm}(SK): $1.3\times10^{-3} \le |\Delta m^2_{23}| \le 3.0\times10^{-3}$ eV ^{2} $\sin^2 2\theta_{23} > 0.9$

ν_{sol}(SNO) + ν_{react}(kamland, CHOOZ, Palo Verde):

$5.6\times10^{-5} \le |\Delta m^2_{21}| \le 9.2\times10^{-5}$ eV ^{2} $0.23 \le \sin^2 2\theta_{12} \le 0.38$ $\sin^2\theta_{13} = 0$

$6.1\times10^{-5} \le |\Delta m^2_{21}| \le 8.5\times10^{-5}$ eV ^{2} $0.25 \le \sin^2 2\theta_{12} \le 0.36$ $\sin^2\theta_{13} = 0.04$

Beta Decay (H3) (Mainz and Troitsk): $m_1 \le 2.2$ eV

Astrophysical data (WMAP): $\Sigma m_i \le 0.7$ eV

DBD0ν (IGEX, H-M): $\langle m_\nu \rangle < 0.1 \div 0.9$ eV H-M claim: $\langle m_\nu \rangle = 0.39$ eV

$\langle m_\nu \rangle$ possible ranges:

NH) $\langle m_\nu \rangle \lesssim 5.5 \times 10^{-3}$ eV

IH) $10^{-2} \lesssim \langle m_\nu \rangle \lesssim 5.5\times10^{-2}$ eV

QDH) $0.42\, m_1 \lesssim \langle m_\nu \rangle \lesssim m_1$ with $m_1 \gg 4.5\times10^{-2}$ eV

Why ^{130}Te

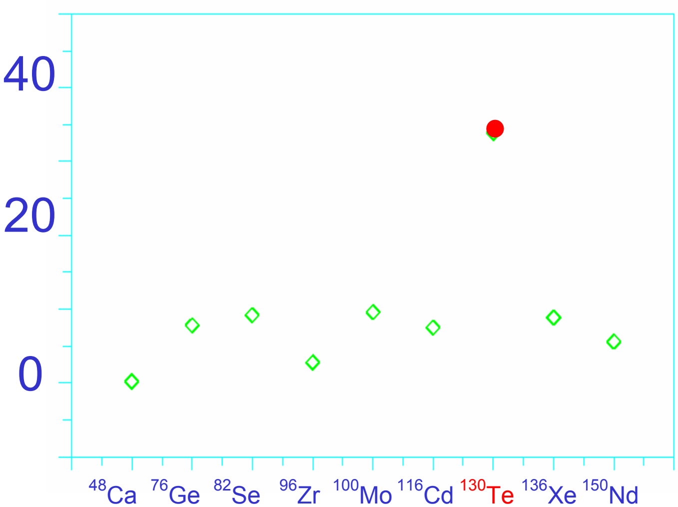
^{130}Te features as a DBD candidate:

- - high natural isotopic abundance (I.A. = 33.87 %)
- - high transition energy (Q = 2528.8 ± 1.3 keV) < large phase space ($G^{0\nu} \div Q^5$), lower background
- - encouraging theoretical calculations for DBD0ν lifetime $m_{ee} \approx 0.1$ eV $\Leftrightarrow \tau \approx 10^{26}$ y

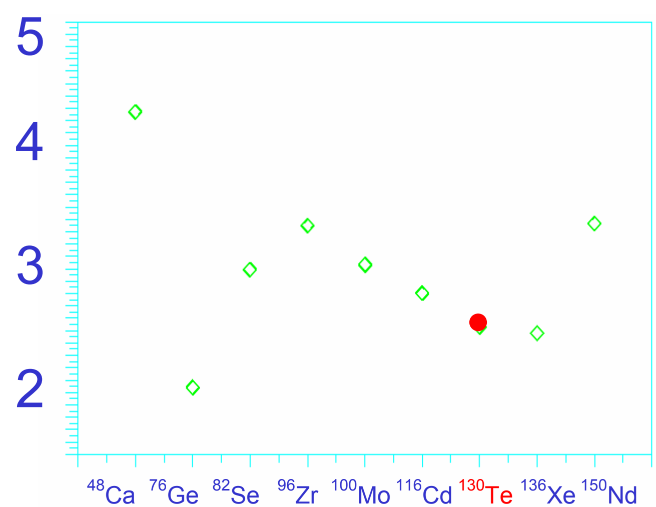
- already observed with geo-chemical techniques ($\tau_{1/2\ incl} = (0.7 - 2.7) \times 10^{21}$ y)

Comparison with other candidates:

Isotopic abundance (%)



Transition energy (MeV)



0ν–DBD half-life (y) for m_{ee} = 0.1 eV (different calculations)