CUORICINO 2005 results and the evolution of the CUORE project.

Maura Pavan

on behalf of the CUORE collaboration:

Dipartimento di Fisica dell' Università and Sez. INFN di Milano - Italy

Lawrence Berkeley Laboratory, Berkeley – California – USA

University of California - Berkeley - USA

Università dell' Insubria e Sezione di Milano dell'INFN, Como, Italy

Università and Sez. INFN di Firenze - Firenze- Italy

Kamerling Onnes Laboratory, Leiden University- Leiden -The Netherlands

Laboratori Nazionali del Gran Sasso, INFN - L'Aquila - Italy

University South Carolina - Columbia S. C. - USA

Laboratori Nazionali di Legnaro, INFN - Padova - Italy

Lab. of Nucl. and High En. Physics, University of Zaragoza – Zaragoza – Spain

Università e sez. INFN di Roma – Roma – Italy

Università e sez. INFN di Genova – Genova -Italy

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Outline

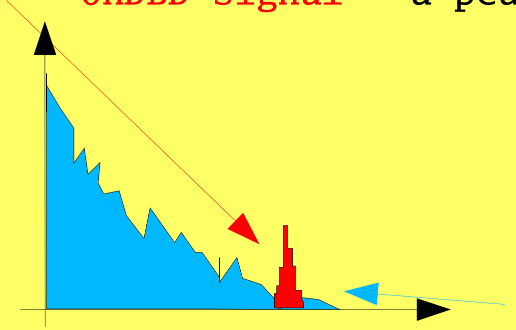
1. TeO_2 bolometers to search for Double Beta Decay
2. The CUORE project
3. CUORICINO statistics and data
4. CUORICINO On DBD results
5. Comments on CUORICINO bkg and CUORE
6. Conclusions

TeO_2 bolometers to search for Double Beta Decay

the source = detector approach

the source = detector approach it is a widely and successfully used technique to search for DBD that allows the realization of high mass experiment. When the detector is a high resolution device this technique <u>is probably the most powerful one</u> for OnDBD searches (as proved by the Ge diodes experiments)

OnDBD signal = a peak at the transition energy of the nucleus

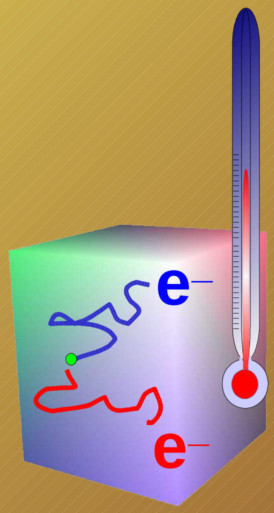


$$S^{0\nu}_{1/2} = \ln 2 \times N_{\beta\beta} \times \left(\frac{T}{B\ \Gamma} \right)^{1/2} \times \varepsilon$$

the signal is searched for in the background spectrum of the detector, generally dominated by radioactivity induced events

bolometers = low temperature calorimeters the energy released by the particle interaction in the absorber (calorimetric mass) is read-out after thermalization by a temperature trasductor (thermometer)

- **wide choice of materials**
- **detectors with an energy resolution comparable with that of Ge diodes**



TeO_2 bolometers to search for Double Beta Decay

study new DBD candidates

^{130}Te presents several nice features

excellent feature for future reasonable-cost expansion of Double Beta Decay experiments

- high natural isotopic abundance (i.a. = 33.87 %)
- high transition energy (Q = (2528.8 ± 1.3) keV)
- encouraging theoretical calculations for 0n-DBD lifetime
- already observed with geo-chemical techniques ($\tau_{1/2\ incl}$ = (0.7 - 2.7) 10^{21} y)

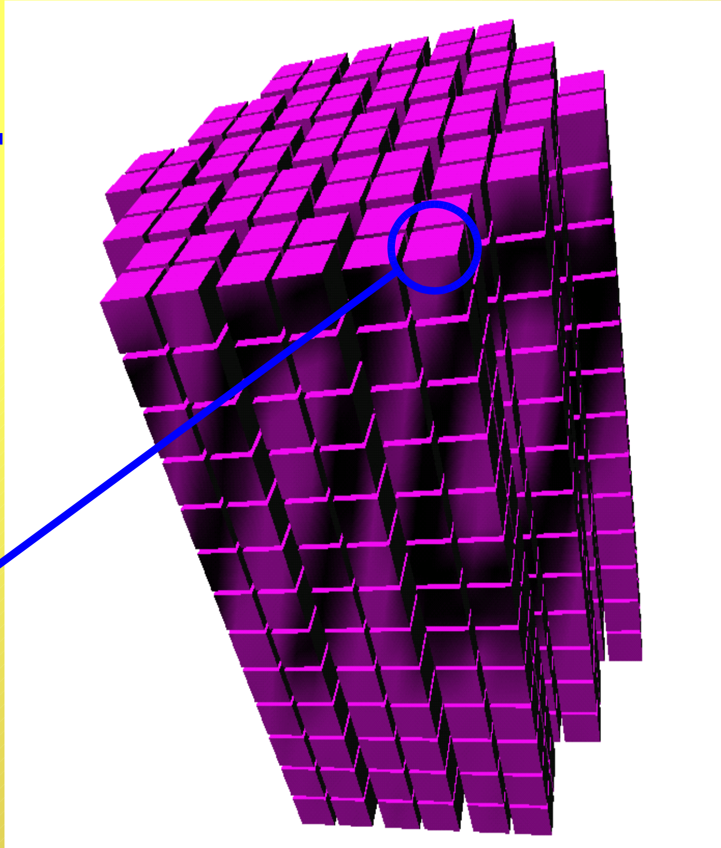
large phase space, lower background (clean window between full energy and Compton edge of ^{208}Tl photons)

TeO_2 has good thermal, mechanical, radioactive properties

extensively tested by the Milano group during the last 10 years

- easy to grow large size crystals (up to 6x6x6 cm^3)
- good intrinsic radiopurity (~ 10^{-13} g/g in U and Th)
- extremely good bolometric performances (FWHM at the ^{130}Te DBD transition energy ~ 7 keV)

CUORE

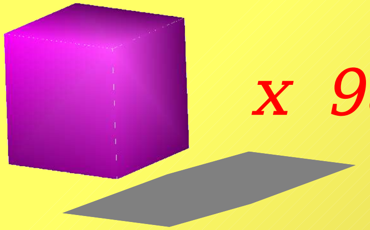


reach a sensitivity on $<m_\nu>$ ~ 50 meV

(bkg requirements is < 0.01 c/keV/kg/y)

low cost – ready soon experiment

750 g TeO_2



x 988

0.75 kg x 988 = **741 kg TeO_2**

~ 600 kg Te = **200 kg ^{130}Te**

- crystals are grouped in 19 towers with 13 module/tower and 4 crystals/module
- the array will be placed in a single dilution refrigerator at ~ 10 mK

the elementary module:

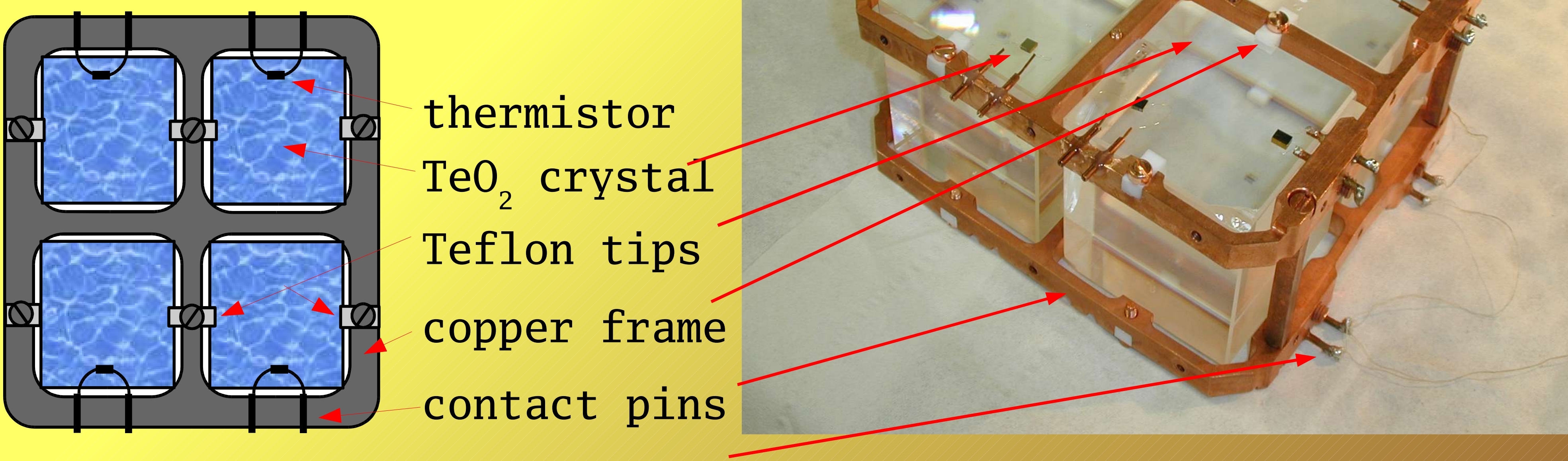
a 4-crystal plane is a mechanically independent module made of 4 crystals, various 4-crystal planes have been tested with good results on both reproducibility and reliability

energy resolution

~ 1 keV at threshold

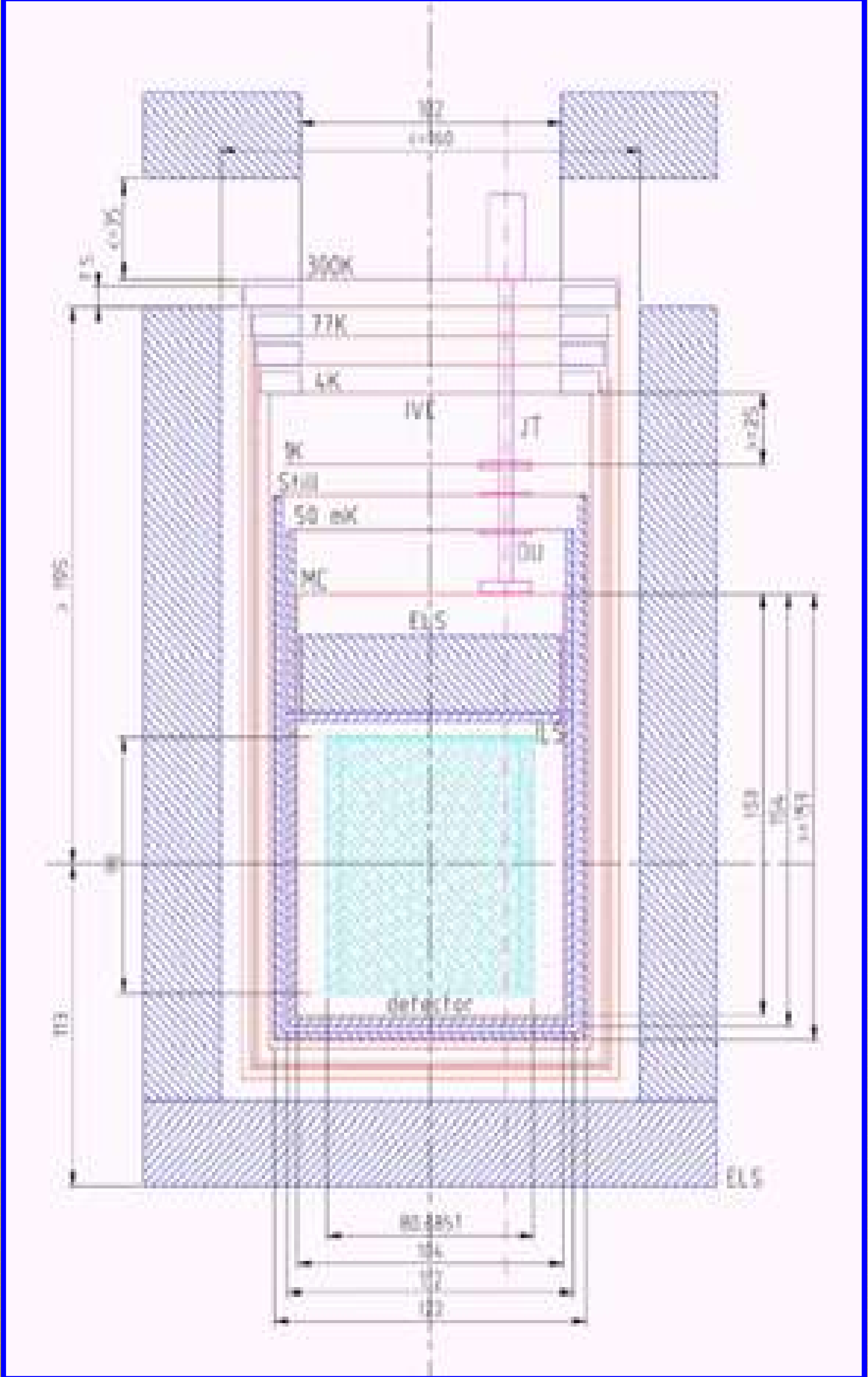
5 - 10 keV at 3 MeV

nuclear recoil quenching factor
~ 1



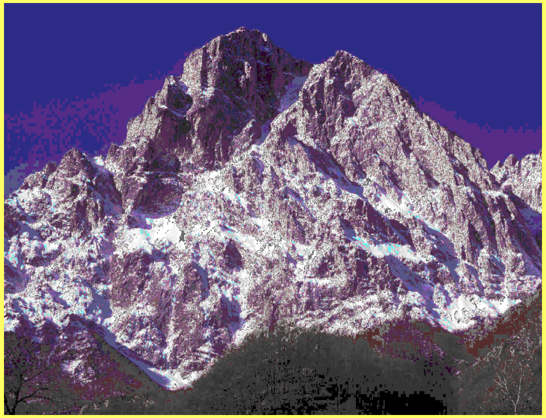
the experimental set-up

- closed inside a cylindrical 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



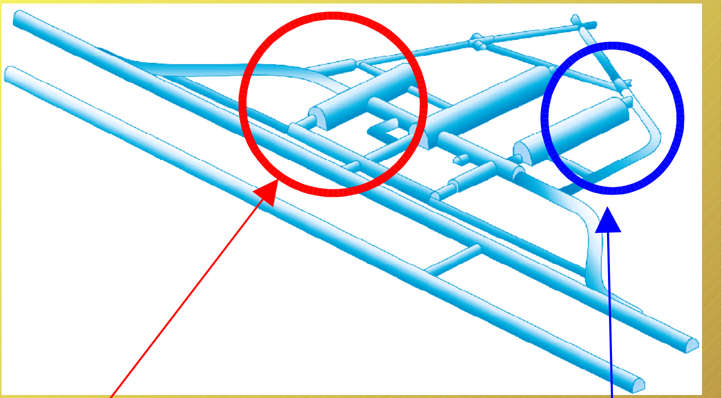
CUORE status of the art

- work is in progress for detector optimization
(particularly to uniform the reproducibility and optimize the mounting process)
- cryostat requirements are fixed, money assigned
- location is fixed



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 and then CUORE)
Hall C (R&D final tests for CUORE)

a general test of CUORE technical feasibility was the realization of the CUORICINO detector now working as a DBD experiment

CUORE do not appears to be technically challenging

The real challenge of CUORE will be control and reduction of background

- a completely new set-up will allow the optimization of shielding
- CUORE is specifically designed to reduce as far as possible the amount of materials interposed between the crystals.
- the high granularity of the CUORE detector will allow to use with high efficiency the coincidence/anticoincidence technique to identify and reject background events
- only low radioactivity materials will be employed to build the refrigerator and the entire mechanical set up for CUORE
  - ***construction material selection is started***
- a MonteCarlo simulation was used to study the various components of CUORE background

MC model and inputs

- detailed description of everything is inside the Roman lead internal shield that surrounds the detector
- measured surface and bulk contamination levels of materials
- results and informations obtained from MiDBD and Cuoricino concerning bkg sources composition
- results of bolometric dedicate measurements in progress in Hall C identification/reduction and control of the source responsible of the Cuoricino DBD bkg

A complete MonteCarlo simulation of CUORE set up shows:

- Environmental radioactivity and neutrons will be reduced to a minimum thanks to the lead and neutron shields – **NO PROBLEM**

- Cosmogenic activation of Cu and Te (^{60}Co) will be reduced to a minimum by the underground storage of materials – **NO PROBLEM**

- Bulk contamination of construction materials are not a problem < 0.002 c/keV/kg/y
MC simulation with **MEASURED** 90% upper limits on contaminations

TeO_2	– U and Th < 10^{-14} g/g	– bolometric measurement
Cu	– U < 2 10^{-12} g/g & Th < 6 10^{-12} g/g	– HPGe measurement
Roman Pb	– U < 30 10^{-12} g/g & Th < 50 10^{-12} g/g	– HPGe measurement
	– ^{210}Pb < 4 mBq/kg	– bolometric measurement

- Two neutrino double beta decay contribution < 0.0001 c/keV/kg/y – **NO PROBLEM**

- Surface contaminations – **THEY COULD GIVE PROBLEMS** (see Cuoricino bkg discussion)

assuming the same surface contamination levels deduced from CUORICINO

- crystal surface contamination = 0.016 c/keV/kg/y
- ?Cu surface contamination = 0.057 c/keV/kg/y

There is apparently just one source we have to work on !!

CUORE sensitivity

Bkg summary:

Bulk contamination < 0.002 c/keV/kg/y (but could be much better)
External bkg will be properly shielded ~ 0 c/keV/kg/y
Cosmogenic activation - 2n decay ... are not a problem ~ 0 c/keV/kg/y
Surface contamination - potentially dangerous - require improvements by a factor ~ 10 or ~ 100

bkg=0.01 c/keV/kg/y
FWHM =5 keV

$F^{0n} = 9.2\text{x}10^{25}\ t^{1/2}\ y$
$\langle m_n \rangle = 0.03 \div 0.13\ t^{1/4}\ eV$

3 years $\langle m_n \rangle$= 20-100 meV

bkg=0.001 c/keV/kg/y
FWHM =5 keV

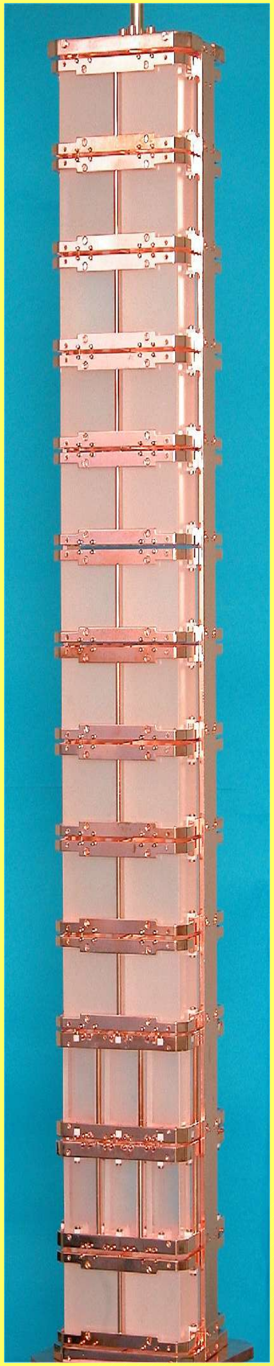
$F^{0n} = 2.9\text{x}10^{26}\ t^{1/2}\ y$
$\langle m_n \rangle = 0.02 \div 0.07\ t^{1/4}\ eV$

3 years $\langle m_n \rangle$= 15-55 meV

+ the enrichment option

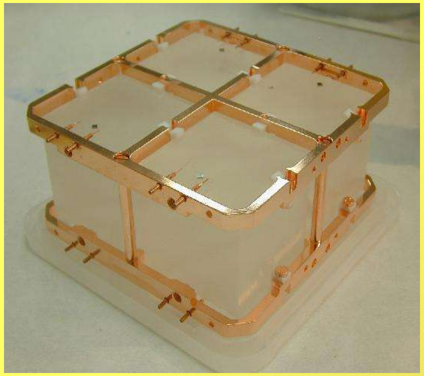
CUORICINO = 40.7 kg of TeO_2

Test facility for CUORE
a self consistent DBD experiment
first test of the Ge DBD signal



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

array with a CUORE tower-like structure

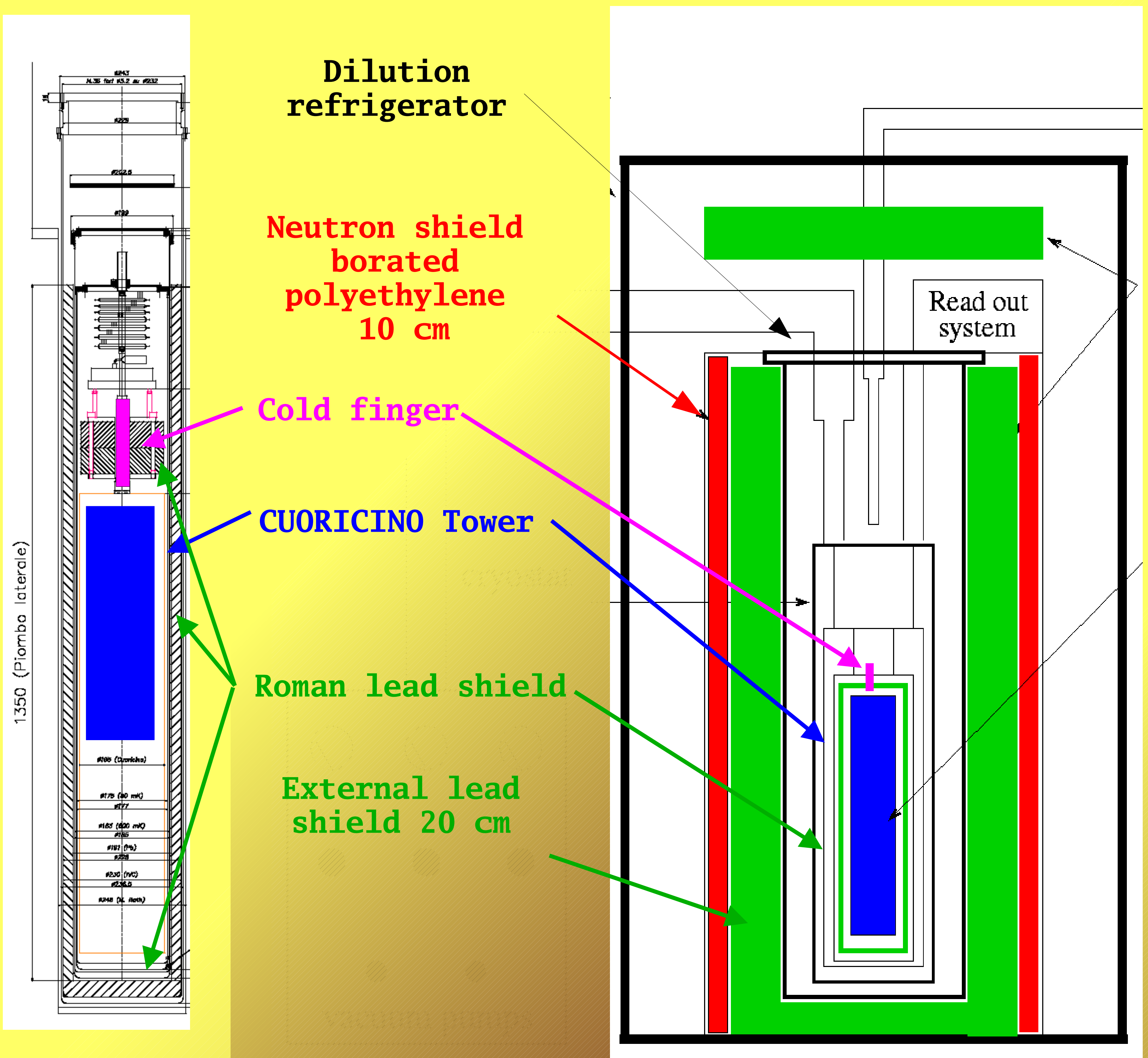


11 modules, 4 detector each,
crystal dimension 5x5x5 cm^3
crystal mass 790 g

4 x 11 x 0.79 = 34.76 kg of TeO_2

2 modules, 9 detector each,
crystal dimension 3x3x6 cm^3
crystal mass 330 g

9 x 2 x 0.33 = 5.94 kg of TeO_2


Dilution refrigerator
Neutron shield borated polyethylene 10 cm
Cold finger
CUORICINO Tower
Roman lead shield
External lead shield 20 cm
Read out system
1350 (Piombo laterale)

First results of CUORICINO

February 2003 - April 2005

RUN I

Cool down: February 2003
Detectors: some electrical connection were lost during the cooling of the tower

4x11 = 44 big size crystals (~5x5x5 cm^3 av. mass = 790 g)
9x2 = 18 small size crystals (~3x3x6 cm^3 av. mass = 330 g)

32 working
16 working

RUN II

Cool down: May 2004
Detectors: two detectors were not recovered (it would have be necessary to open the tower) and two show an excess noise

4x11 = 44 large size crystals (~5x5x5 cm^3 av. mass = 790 g)
9x2 = 18 small size crystals (~3x3x6 cm^3 av. mass = 330 g)

40 working
18 working

CUORICINO DUTY CYCLE

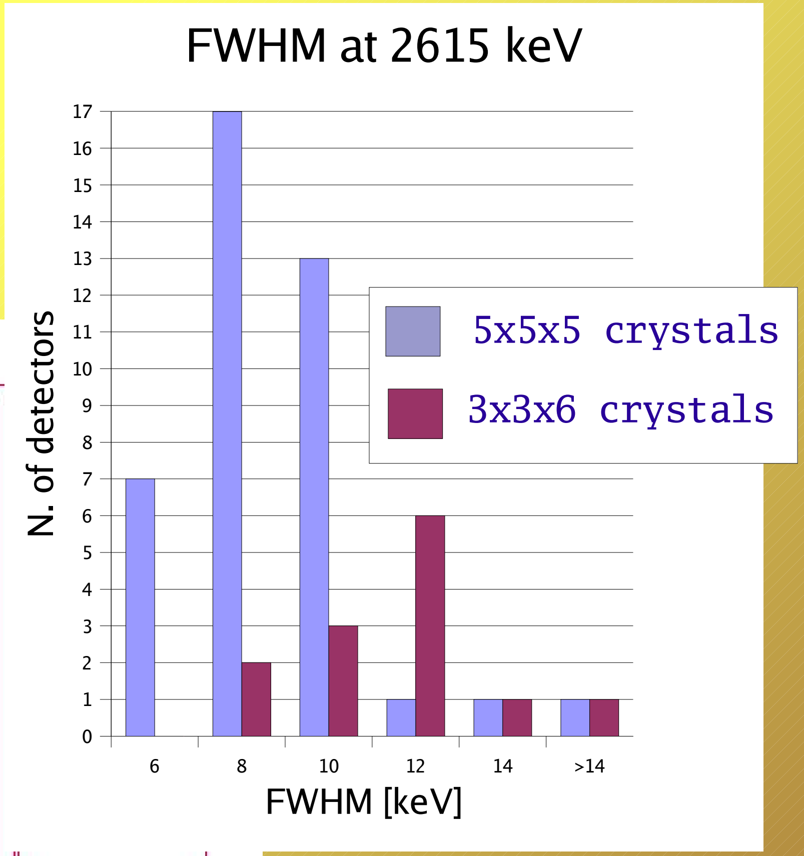
Source calibration: Th wire ~ 3 days
Background measurement: 3-4 weeks
Source calibration: Th wire ~ 3 days

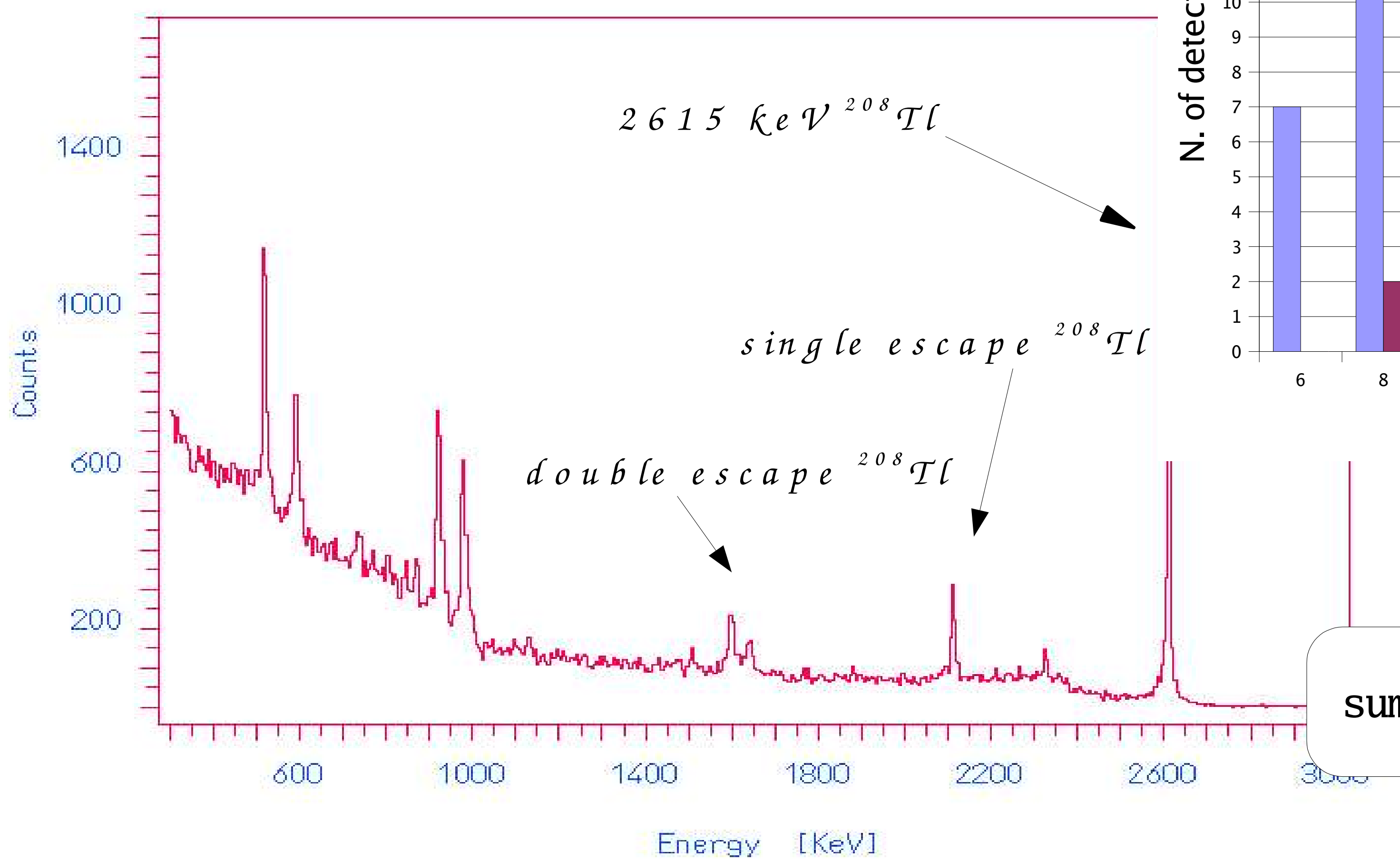
presently live time (background measurement) ~ 64%

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 ~ 7.5+/-2.9 keV
average 3x3x6 cm^3 crystals ~ 9.6+/-2.5 keV

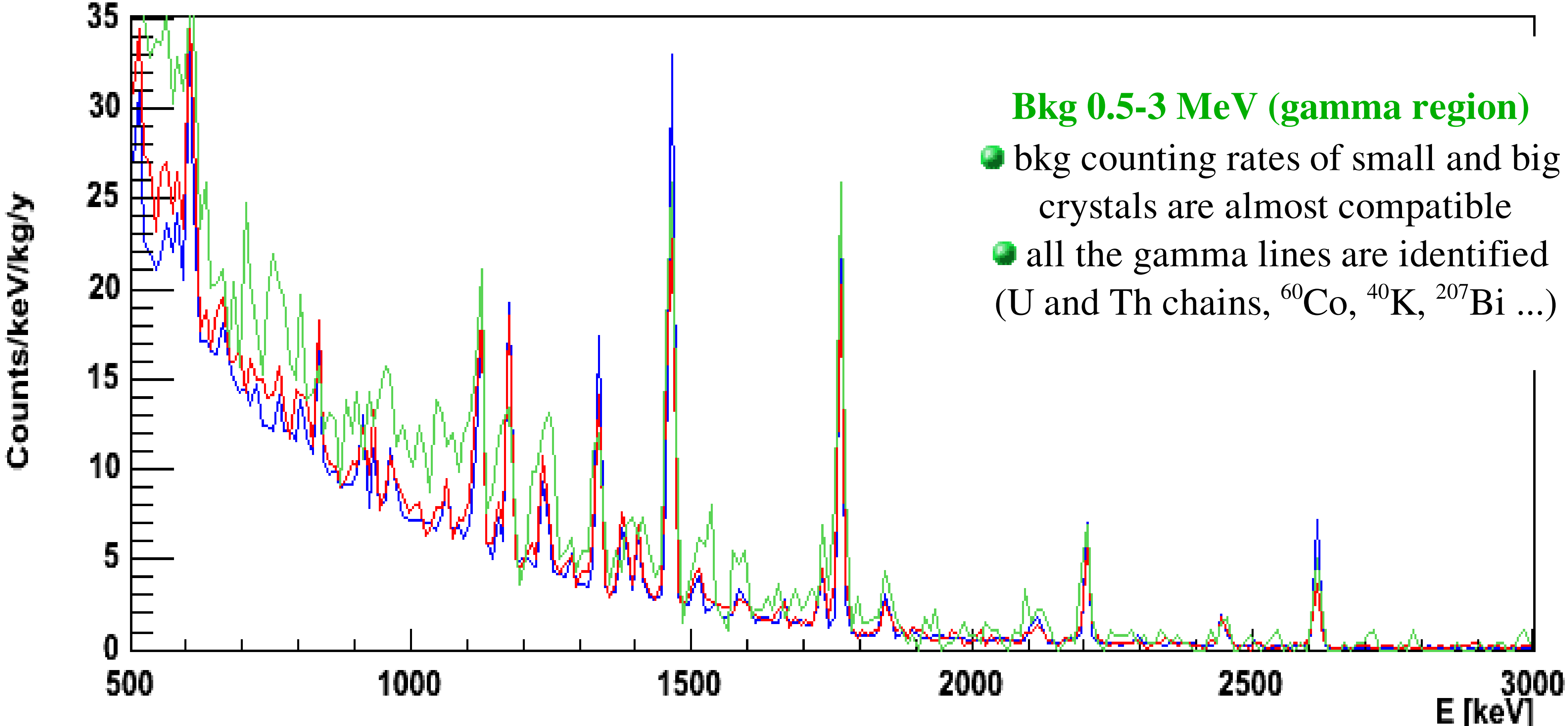




Detector performances: background

Statistics and resolution measured at the 2615 keV gamma line of ^{208}Tl in the sum bkg spectra of:

—	$5x5x5\ cm^3$ cryst.	4.3 kg ^{130}Te * y – FWHM ~ 7.5 keV
—	$3x3x6\ cm^3$ nat. cryst.	0.5 kg ^{130}Te * y – FWHM ~ 12 keV
—	$3x3x6\ cm^3$ enrich. cryst.	0.2 kg ^{130}Te * y – peak not visible



Bkg 0.5-3 MeV (gamma region)

- bkg counting rates of small and big crystals are almost compatible
- all the gamma lines are identified (U and Th chains, ^{60}Co, ^{40}K, ^{207}Bi ...)

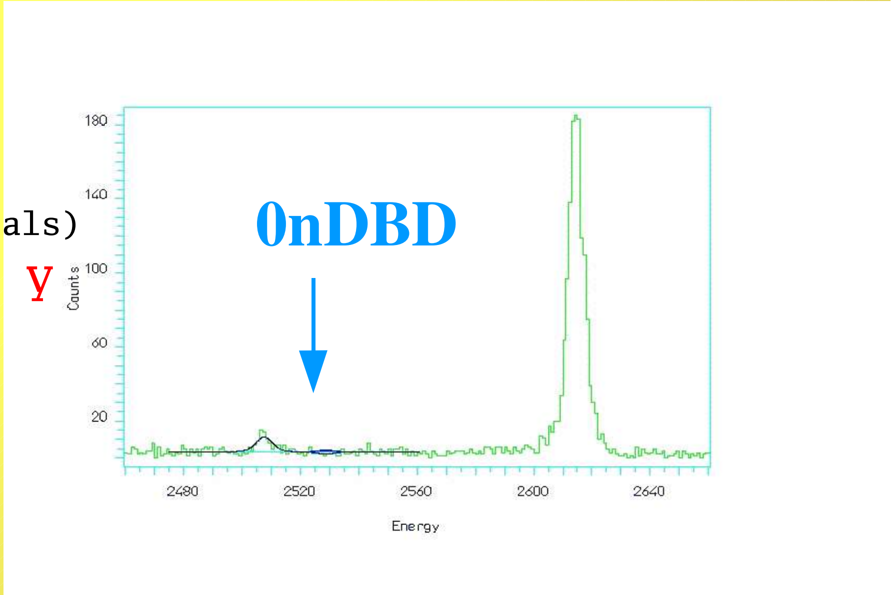
CUORICINO 0νDBD RESULT

statistics:

- anticoincidence spectrum

(=> det. eff. 86.4% and 84.5% for big/small size crystals)

- updated at 3 April 2005 = 5 kg ^{130}Te x y
- No peak at 0nDBD Q-value (2528.8 keV)
- Bkg = 0.18+/-0.02 c/keV/kg/y



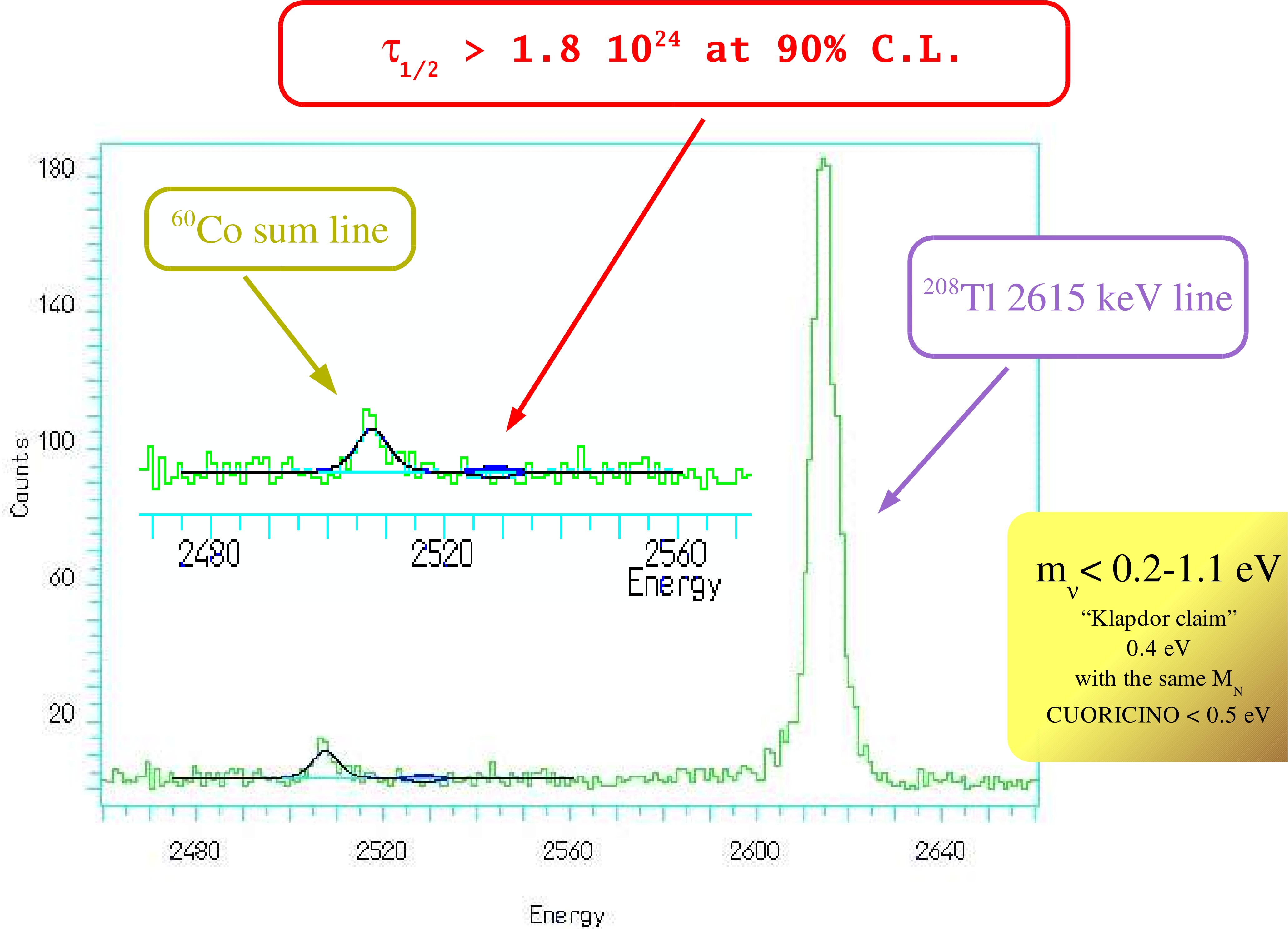
procedure:

- Maximum Likelihood + flat background + fit of the 2505 keV peak
- energy region = 2470 - 2560 keV
- response function = sum of N gaussian each with the characteristic FWHM resolution at 2615 keV of the nth detector

result:

$$\tau_{1/2} > 1.8 \; 10^{24} \text{ at } 90\% \text{ C.L.}$$

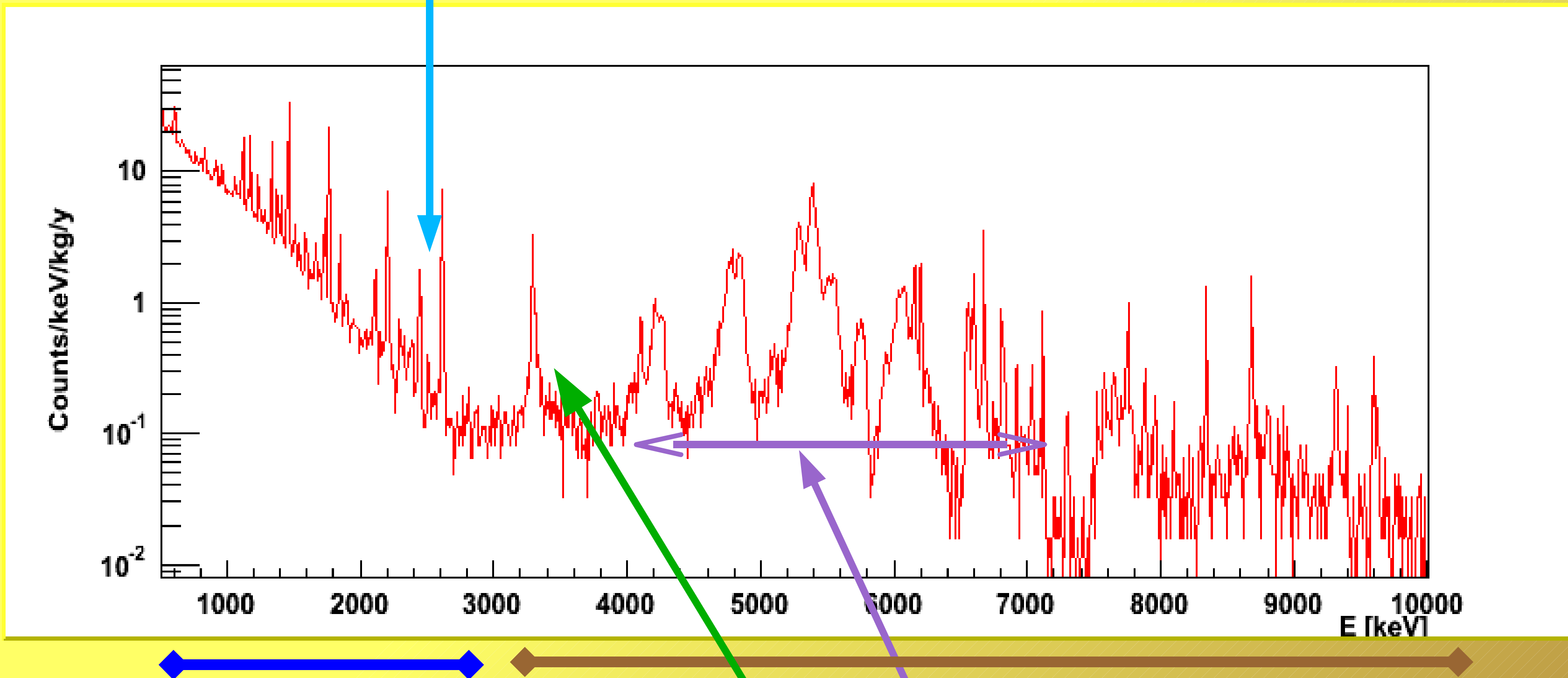
- best fit yields a negative effect ...
- ~5% variation of the limit when changing the energy region, the bkg shape (linear or flat) and when including/excluding the 2615 keV peak
- Feldman and Cousin yields a similar value



$\tau_{1/2} > 1.8\ 10^{24}$ at 90% C.L.
^{60}Co sum line
^{208}Tl 2615 keV line
$m_\nu < 0.2\text{-}1.1$ eV
"Klapdor claim"
0.4 eV
with the same M_N
CUORICINO < 0.5 eV
Counts
Energy
180
140
100
60
20
2480
2520
2560
2600
2640

CUORICINO 0νDBD BACKGROUND

0nDBD



Gamma region, dominated by gamma and beta events, highest gamma line = 2615 keV ^{208}Tl line (from ^{232}Th chain)

Alpha region, dominated by alpha peaks (internal or surface contaminations)

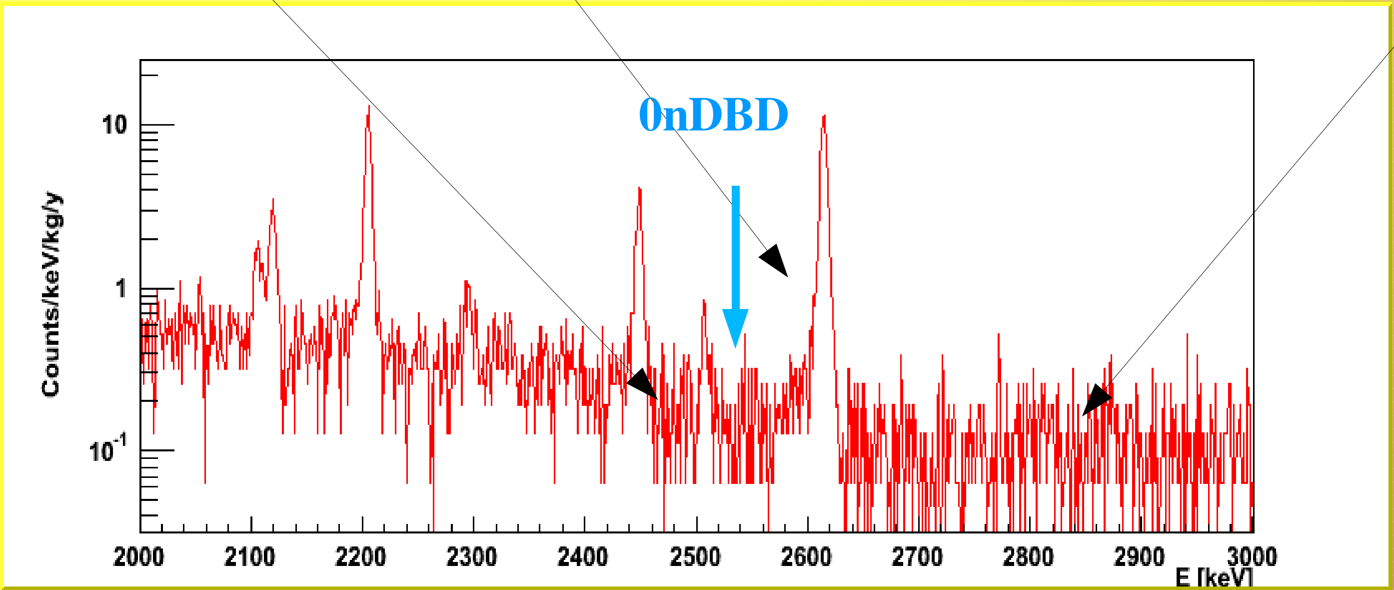
CUORICINO 0νDBD BACKGROUND

Identified contributions:

- **2615 keV Tl line** proves that there is a contribution to the DBD bkg due to Th, via multiCompton events. The most probable location of the Th source is in between the inner Roman lead shield and the external lead shield (clear indications in this direction come from the intensity ratios of Th gamma lines at different energies). MonteCarlo simulations and source calibration measurement (the source is a Th wire inserted between the external lead shield and the cryostat) appear to reproduce well the measured bkg and allow to evaluate the Tl contribution to the DBD bkg:

  ~ 40% ***(preliminar result)***

- **2505 keV line ^{60}Co line** (1173 + 1332 keV), it is probably due to neutron activation of the Copper detector mounting structure – a negligible contribution to the DBD region comes from the beta tail the accompanies the 2505 peak (MonteCarlo evaluation)



- No other gamma peaks is identified near or above the OnDBD transition energy (therefore contributions from other gamma sources seem to be excluded)

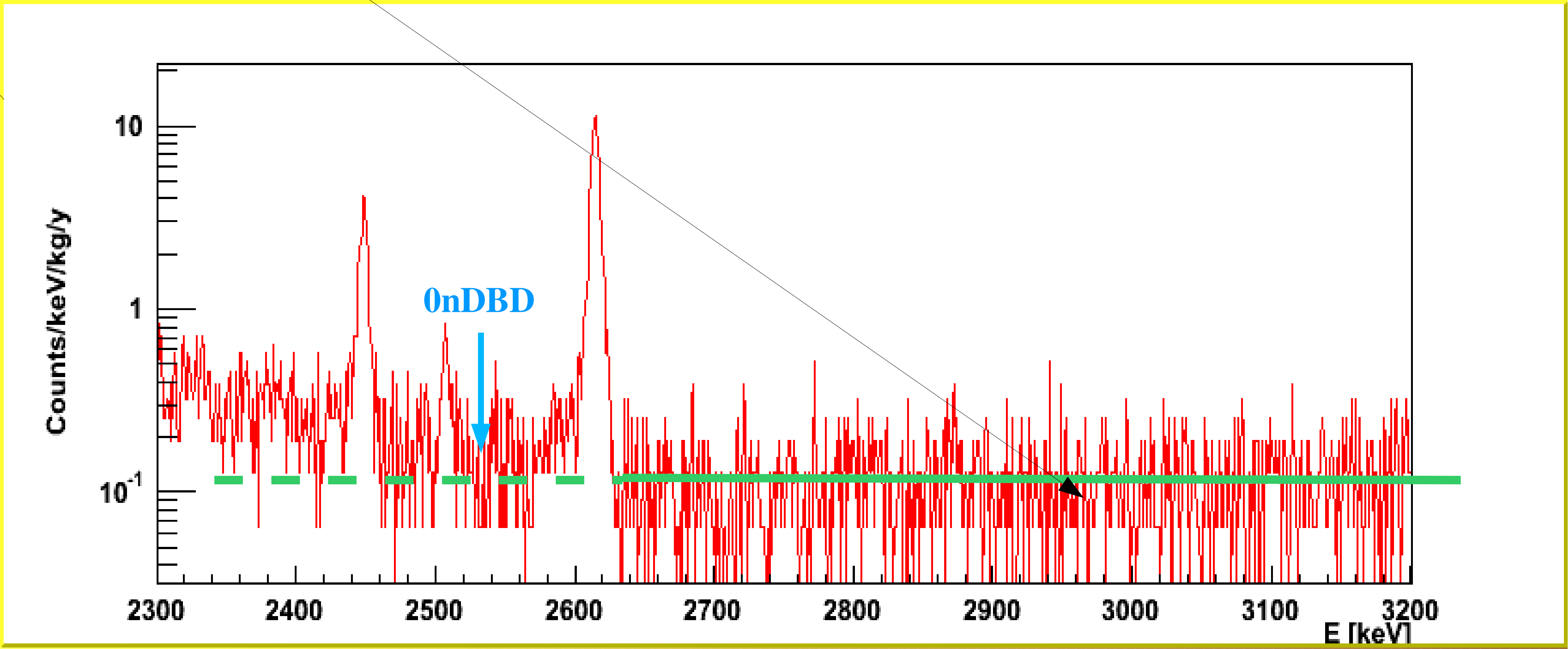
CUORICINO 0νDBD BACKGROUND

Identified contributions: ...

- a flat bkg is present in the energy region above the Tl 2615 peak, it is natural to assume that this same bkg extends below the 2615 keV peak thus contributing to the counting rate in the OnDBD region with a percentage of about

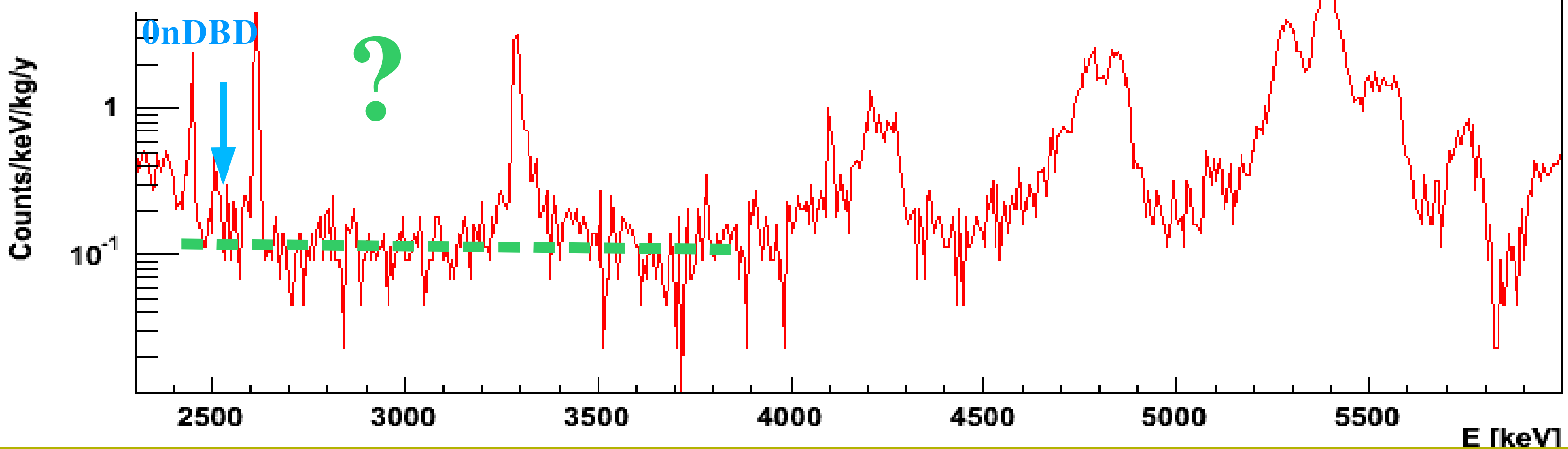
~ 60% *(preliminar result)*

that is exacltly what is missing when assuming a 40% contribution form Tl



flat bkg extending toward

the 0nDBD region (~ 60% contribution)



possible sources for this **60%**:

- **neutrons** - but Cuoricino is provided with a n shield (borated polyethylene 10 cm) and when the shield was mounted around the MiDBD experiment no variation in the 3-4 MeV bkg counting rate was observed

- **degraded alpha particles** from crystal surface contaminations, various alpha peaks appear in the bkg spectrum, their central energy, their low energy tail and the scatter plots of coincident events prove that these peaks are due to a surface contamination of the crystals mainly in ^{238}U - from the spectra of coincident event on facing crystals and from MonteCarlo simulation we evaluated a contribution of this contamination to the DBD region of

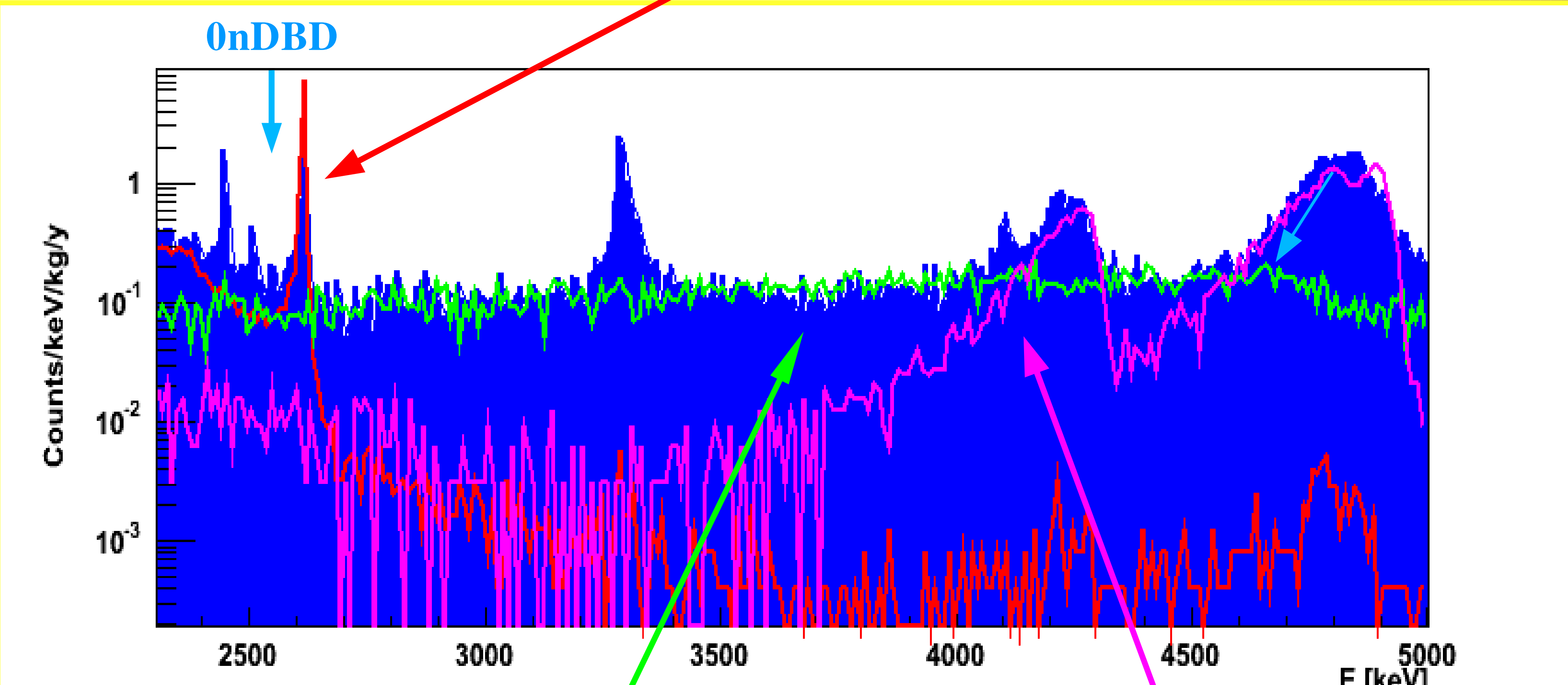
  ~ 10%

- **degraded alpha particles** contaminations of the inert materials facing the crystals (e.g. the Cu mounting structure), there is no direct evidence of the existence of this contamination that according to our MonteCarlo simulation (for depth of the order of microns) gives simply a continuum bkg and no clear signature.

  ~ 50%

Cuoricino bkg sum spectrum

Th calibration normalized to the 2615 keV line
of the Cuoricino bkg sum spectrum



MonteCarlo simulation
Bkg contribution due to Cu mounting structure
surface contamination (232Th, 5 micron depth)

MonteCarlo simulation
Bkg contribution due to
crystal surface contaminations

CUORICINO 0νDBD BACKGROUND vs. CUORE: how can the bkg be reduced ?

Tl 2615 keV line -> just a problem of shieldings

- *Tl 2615 keV line is ascribed to a cryostat ^{232}Th contamination (Cuoricino is housed inside an old crystat where space is much reduced and only a thin internal lead shield could be mounted) CUORE cryostat is specifically designed to maximize the shield efficiency + severe selection of construction materials should guarantee a relevant reduction of Tl bkg (proved by MC simulation of the CUORE apparatus based on measured contaminant levels of the contruction materials)*

3-4 MeV continous background -> work in progress

- Crystal surface: the contamination can be controlled with proper surface treatments (including chemical etching and polishing with "clean" powders). A recent test on 8 crystals (CUORE-like) proved that the new surface treatment studied in LNGS reduces the contamination by a factor ~ 4

  CUORICINO contam. projected on CUORE = 0.016 c/keV/kg/y
  new level of contamination = 0.004 c/keV/kg/y

- the second source of contamination – that is more likely a surface contamination of the detector mounting structure – is being under investigation:

  CUORICINO contam. projected on CUORE = 0.06 c/keV/kg/y

  - a dedicated array of 8 5x5x5 cm^3 crystals operated in Hall C
  - ICMPS bulk and surface measurement
  - low bkg Ge spectroscopy
  - some more investigation on neutrons contribution

Conclusions: CUORICINO and CUORE

CUORICINO

- is working continuosly with a good efficiency
- 0nDBD limit is now 1.8 10^{24} y corresponding to a mass range of 0.2 – 1.1 eV

  (for Nuclear Matrix Elements evaluation see arXiv:hep-ex/0501034)
- 2nDBD analysis (enriched crystals) – in progress
- information on low energy (Dark Matter) will come
- has proved the feasibility of CUORE !!

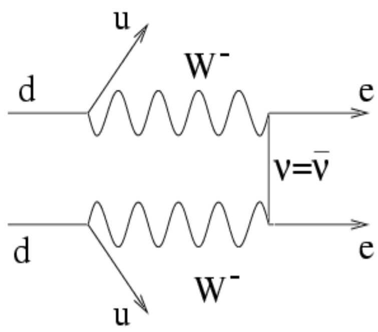
CUORE

- **It is (partially) funded + space is allocated !!!**
- Cryostat and hut will be soon realized
- Work in progress to optimize detector construction and assembly
- DAQ and electronics are designed and will be soon tested
- **The real challenge of CUORE is background reduction !!**
  - CUORICINO results and the test measurements done with a dedicated array in Hall C prove that we are walking in the right direction !!!
  - We are studing innovative solution that could solve the problem of surfaces contamination (surface sensitive detectors)

We plan to switch on CUORE at the beginning of 2008 with a < 0.01 c/keV/kg/y

Neutrinoless Double Beta Decay

a way to measure the absolute scale of mass



a RH antineutrino emitted at one vertex is absorbed at the other vertex as a LH neutrino => the change in helicity is possible if n are massive particles, the violation of the lepton number is possible if n are Majorana particles

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

$$\tau = \frac{1}{G(Q,Z)\,|M_{nucl}|^2 \langle m_\nu \rangle^2}$$

- **G(Q,Z) =** phase space
- $\langle m_\nu \rangle^2$ **=** effective Majorana mass given by

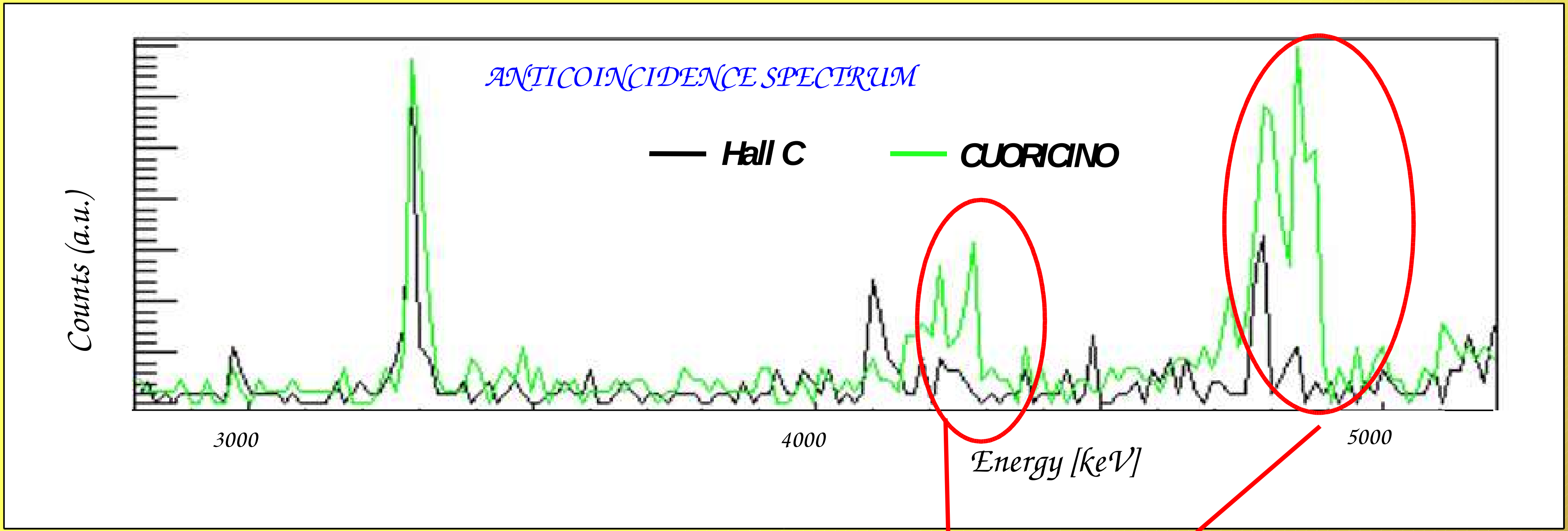
$$\langle m_\nu \rangle^2 = |\,|U_{e1}|^2 m_1 + e^{i\beta} |U_{e2}|^2 m_2 + e^{i\alpha} |U_{e3}|^2 m_3\,|$$

the $\langle m_\nu \rangle$ range should be of the order of 10-100 meV in the case of inverted hierarchy, while it is lower in the case of normal hierarchy

- $|M_{nucl}|^2$ nuclear matrix element

theoretically evaluated (shell model, QRPA models ...)
different results according to the nuclear model used
to extract from the measured (limit) lifetime the value (limit) of $\langle m_\nu \rangle$

		^{130}Te		^{76}Ge		
		F^N(1e-13 y^{-1})	<m > (T1/2=1.8E+024)	F^N(1e-13 y^{-1})	<m > (T1/2=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



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

Crystal Surface contamination
reduced by ~ 4