Cuoricino latest results and the way to CUORE

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Outline

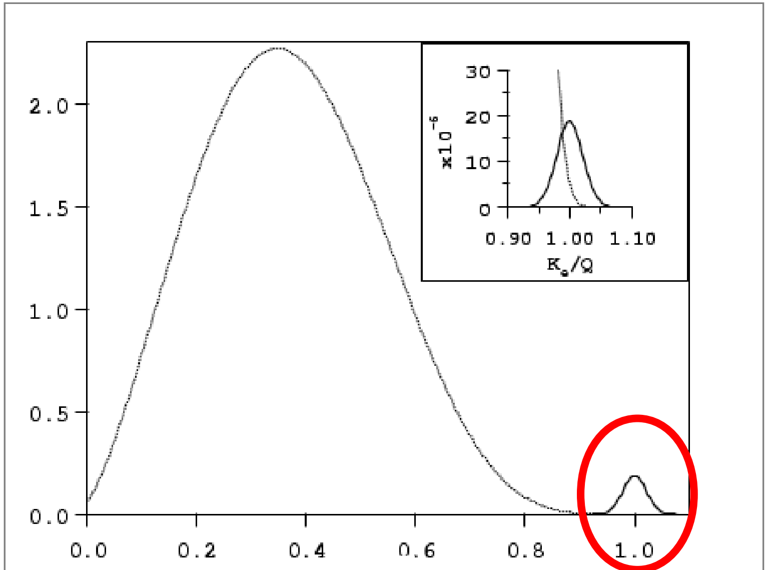
- Neutrinoless Double Beta Decay search with calorimetric technique
- Low temperature calorimeters
- Why TeO_2 ?
- CUORICINO detector and latest results
- From CUORICINO to CUORE: R&D for bkg reduction
- CUORE status

DBD0ν search

DBD is a second order nuclear weak decay of A even-even nuclei:
^{48}Ca, ^{76}Ge, ^{100}Mo, ^{113}Cd, ^{130}Te, ^{136}Xe,...

DBD2ν decay: (A,Z) $\rightarrow$ (A,Z+2) + 2e$^-$ + 2ν SM allowed (observed with $\tau > 10^{19}$ y)

DBD0ν decay: (A,Z) $\rightarrow$ (A,Z+2) + 2e$^-$ Beyond SM (^{76}Ge claim $\tau > 10^{25}$ y [1])



sum electron energy / Q

Experimental signature for DBD0ν in direct counting experiments:

peak at Q-value
in the electron sum energy spectrum

DBD0ν: experimental needs

Sensitivity $S_{0\nu}$: lifetime corresponding to the minimum detectable number of events over background at a given confidence level

$$S_{0\nu} \propto \varepsilon \frac{i.a.}{A} \sqrt{\frac{M \cdot T}{\Delta E \cdot b}}$$

- ε = Detection efficiency
- i.a. = Isotopic abundance of the DBD candidate
- A = Compound atomic mass
- M = Source mass
- T = Measure live time
- ΔE = Energy Resolution in the ROI
- b = Background in the ROI

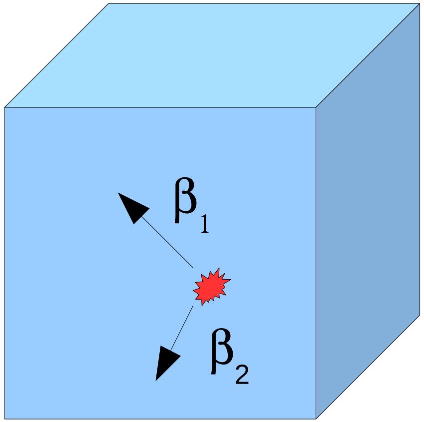
Experimental needs for high sensitivity:

- High detection efficiency
- High isotopic abundance
- Large source mass
- Long time measurement
- High energy resolution in the ROI
- Low Background in the ROI

The calorimetric technique

In the calorimetric approach source $\subseteq$ detector:

scintillation, phonon-mediated, solid-state, gaseous detectors

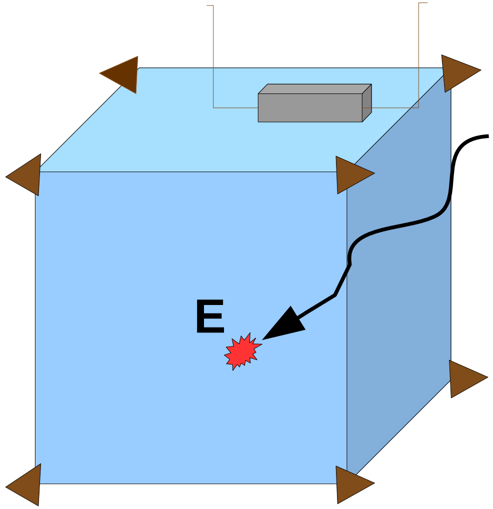


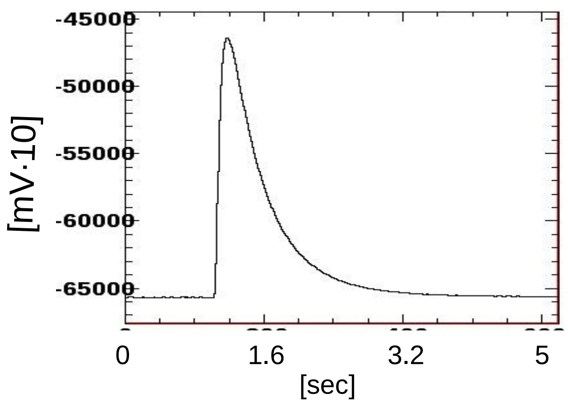
- High efficiency (~ 100%)
- High energy resolution (solid-state and phonon detectors)
- Large masses (detector mass up to 1 t are feasible)
- Topology (Xe TPC)

Non calorimetric detectors can perform event reconstruction by tracking but are limited by low efficiency and low energy resolution, and thus by a high contribution from DBD2ν

Low temperature calorimeters

The bolometric technique was proposed by E. Fiorini and T.O. Niinikoski in 1983 as an alternative to the more standard enriched -^{76}Ge diodes. It allows a wider choice of materials (more DBD candidate are therefore exploitable).





A bolometer is composed by:

- **Absorber :**
  a particle energy deposition originates a temperature rise:

$$\Delta T = \frac{E}{C(T)}$$

- **Temperature sensor:**
  It converts the temperature rise in electric signal:

$$R = R_0 \exp(T_0 / T)^{\gamma}$$

- **Termal link:**
  Signal wires and absorber supports

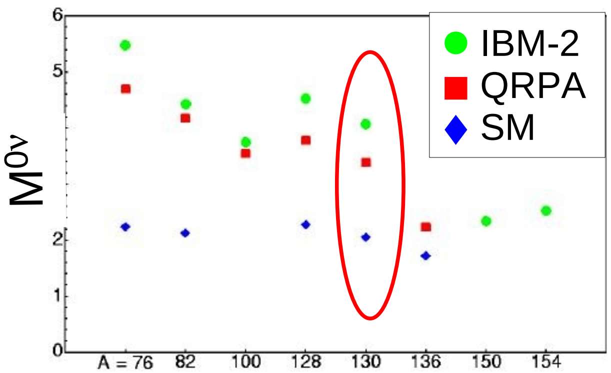
Working at very low temperature (~10 mK) and using dielectric and diamagnetic absorbers ΔT becomes measurable (~100 μK @ 1 MeV)

Why TeO_2 ?

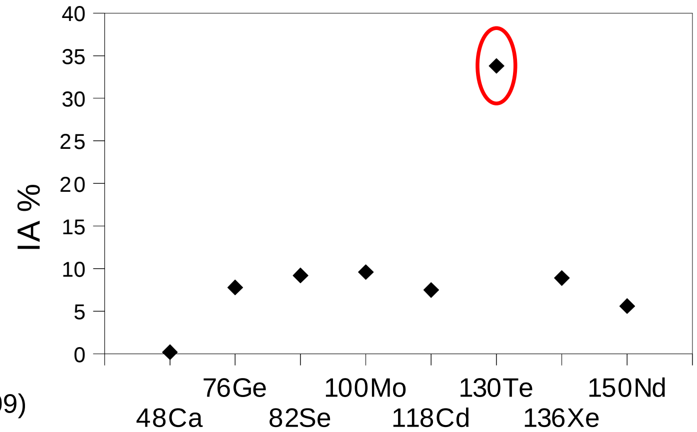
DBD0ν half-life:

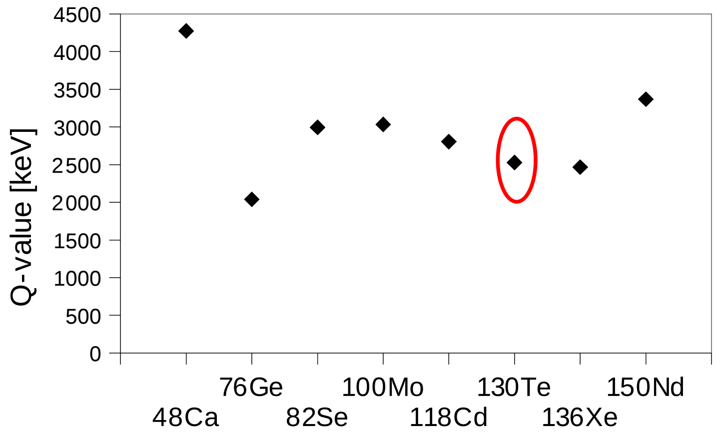
$$\frac{1}{T_{1/2}^{0\nu}} = G^{0\nu}(Q,Z)\cdot|M^{0\nu}|^2 \frac{\langle m_\nu \rangle^2}{m_e^2}$$

$G^{0\nu}(Q,Z)$ = Phase Space Factor ($\div Q^5$)
$|M^{0\nu}|$ = Nuclear Matrix Element
$\langle m_\nu \rangle$ = Electron Neutrino Majorana mass



Barea and Iachello, Phys. Rev. C79, 044301 (2009)



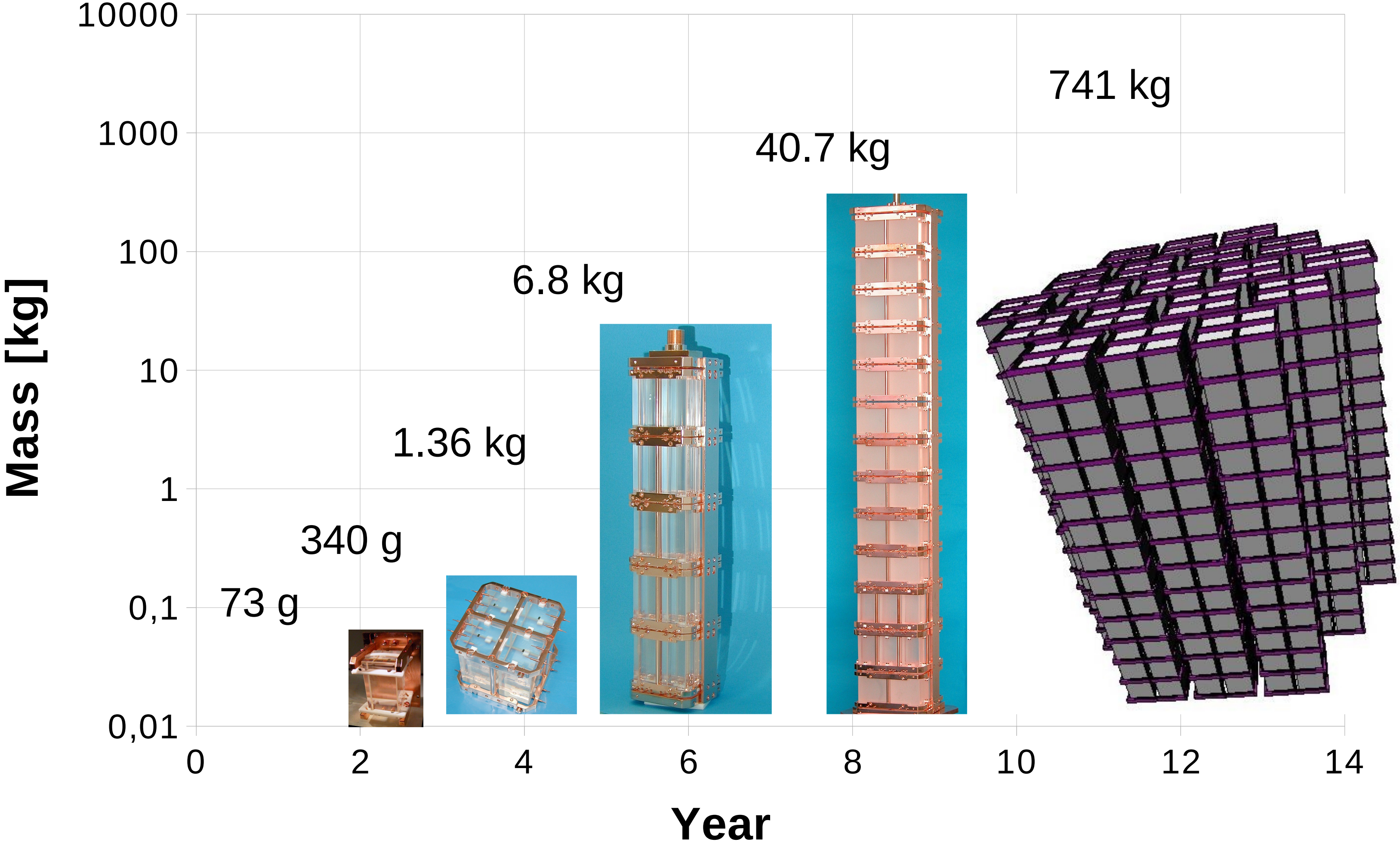


⇒ TeO_2 is a compound with good mechanical and thermal properties containing ^{130}Te.

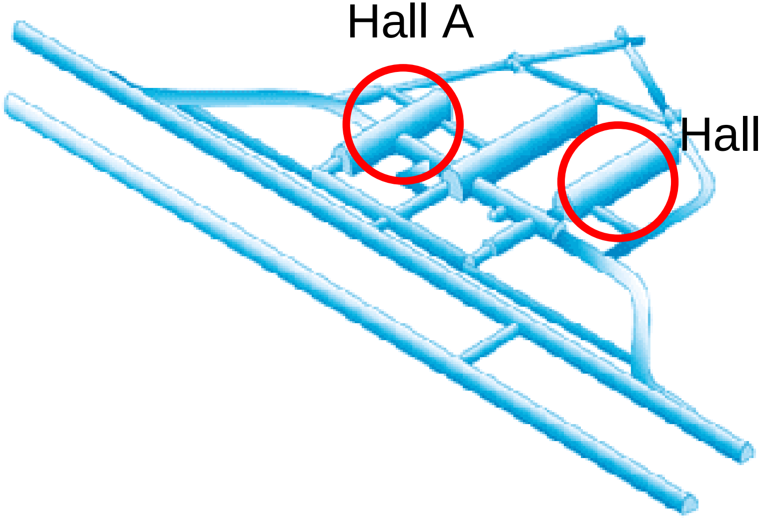
⇒ ^{130}Te is a good DBD candidate:

- reasonably favorable theoretical calculation of NME
- high natural Isotopic Abundance (33.8%)
- high DBD transition energy (2527.52±0.013 keV) [2] [3]

TeO_2 experiments through time



Location: LNGS



LNGS

Natural shield for cosmic rays: 3600 mwe

Muon flux: $(3.2 \pm 0.2)\cdot 10^{-8}$ μ/s/cm^2 [4]

Neutron flux: $10^{-7} \div 10^{-6}$ n/s/cm^2 [5,6]

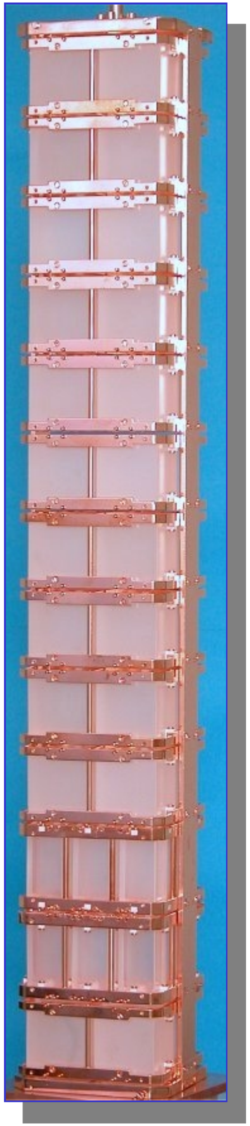
Gamma flux below 3 MeV: 0.73 γ/s/cm^2 [7,8]

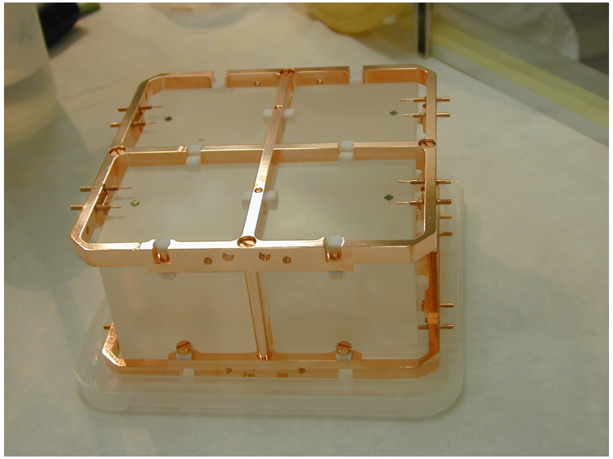
Two locations:

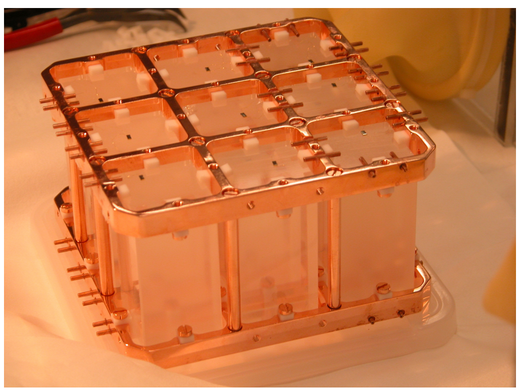
Hall A: Cuoricino -> CUORE

Hall C: R&D and final tests for CUORE

CUORICINO

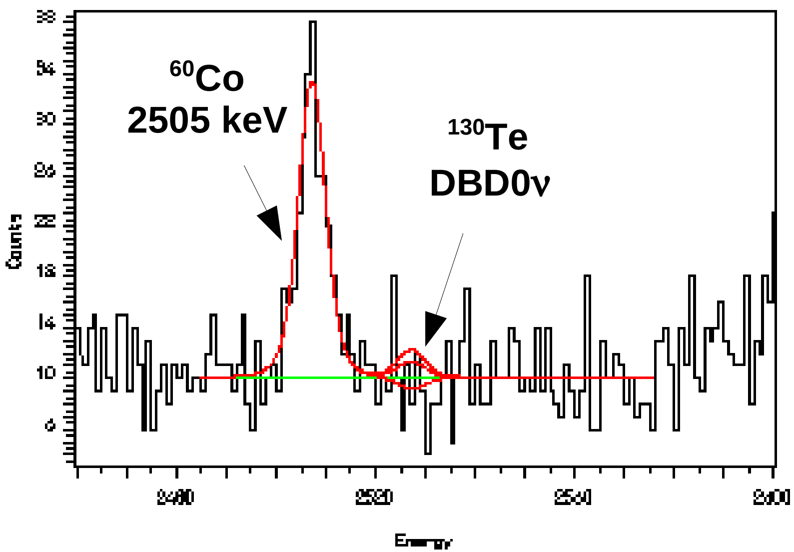






- Operated **2003-2008** at LNGS HallA
- Placed in a dilution refrigerator at ~ 10 mK
- Provided with Cu and Pb shields
- **62 TeO_2 crystals**
- 11 planes 4 “big” crystals each (790 g /crystal)
- 2 planes 9 “small” crystals each (340 g/crystal)
- 2 small crystals enriched to 75% in ^{130}Te
- 2 small crystals enriched to 82.3% in ^{128}Te
- 40.7 kg of TeO_2
- **11.6 kg of ^{130}Te**
- ~ 5×10^{25} ^{130}Te nuclei

CUORICINO latest result



- No peak appears at the Q-value (2527.5 keV) and with a ML procedure the 90% C.L. limit for the $T_{1/2}^{0\nu}$ of ^{130}Te is set
- The ^{60}Co peak is included in the fit energy window
- The bkg underlying the peak is fit with a flat function
- The limit is evaluated using anticoincidence sum spectra and considering separately big, small and enriched crystals
- For each spectrum is used as the response function a sum of N Gaussians, one for each crystal. The FWHM of each Gaussian is fixed to the characteristic one of each corresponding detector (2615 keV calibration peak).

Updated statistics: ~18.14 kg ^{130}Te × y
Average FWHM@ROI : 7 keV

Bkg@ROI = 0.18 ± 0.02 c/keV/kg/y

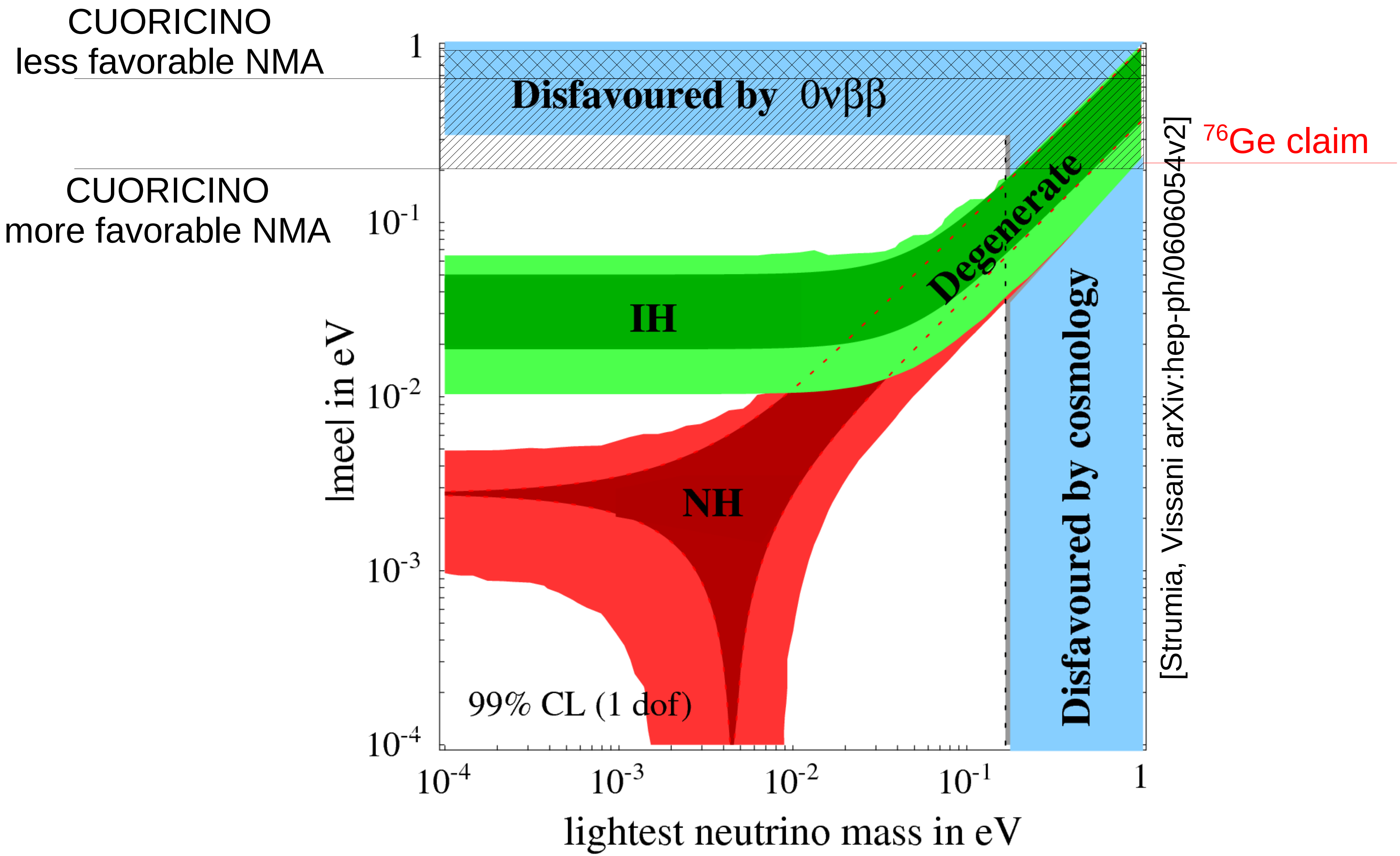
$T_{1/2}^{0\nu}$ (^{130}Te) > 2.94 × 10^{24} y (90% CL)

$\langle m_\nu \rangle \leq$ 0.21 ÷ 0.72 eV (NME from [9,10] -QRPA)

Analysis of complete CUORICINO data set is being performed with new software developed for CUORE.

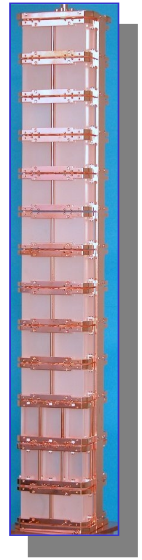
Potential improvements are being tested.

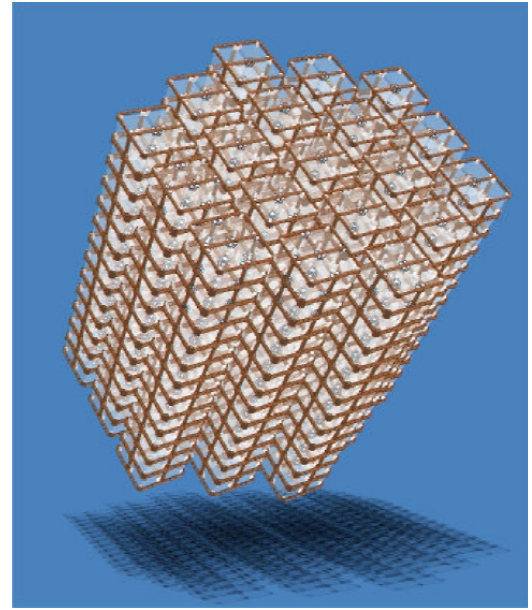
CUORICINO latest result & <m$_\nu$>



Future: how to improve the sensitivity?

$$S_{0\nu} \propto \varepsilon \frac{i.a.}{A} \sqrt{\frac{M \cdot T}{\Delta E \cdot b}}$$





From CUORICINO to CUORE:

- Increase the mass: a factor ~ 20
- Improve the resolution: reduce ΔE by 40%
- Improve the live-time: improving sistem reliabiliy and duty cicle
- Reduce the bkg in the ROI: target 0.01 c/keV/kg/y (a factor 18)

⇒ **Bkg reduction is the most crucial issue**

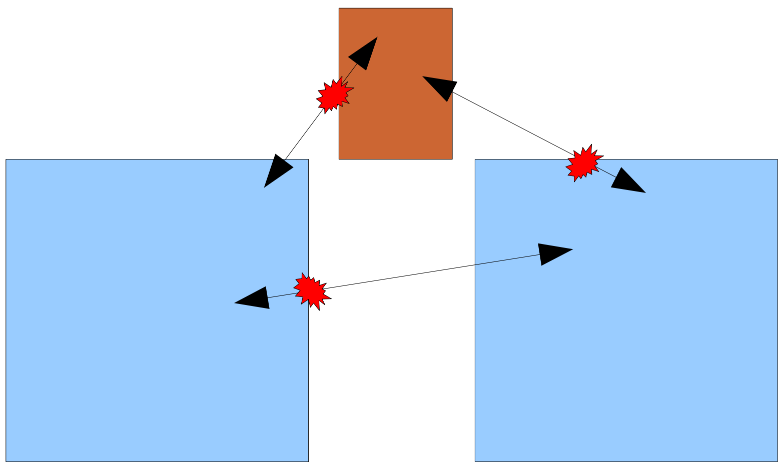
988 TeO_2 crystals
~741 kg TeO_2
~204 kg of ^{130}Te

19 towers
13 planes each
4 crystals each

CUORICINO bkg model

The modelization of the CUORICINO background by means of MC simulations has shown that the most probable contribution to the ROI are:

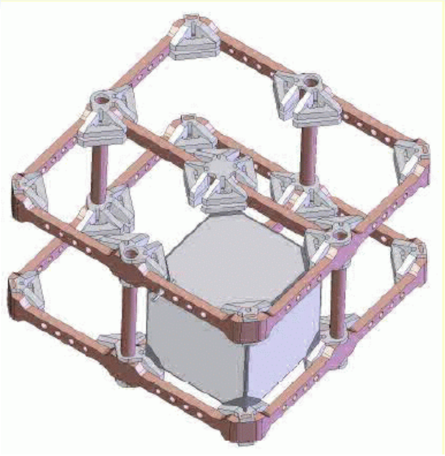
- Multi-Compton events from ^{208}Tl events (^{232}Th contamination in the cryostat): $(40 \pm 10)\%$
- Degraded α and β from surface contamination of inert materials facing the crystals: $(50 \pm 10)\%$
- Degraded α and β from surface contamination of the crystals: $(10 \pm 5)\%$

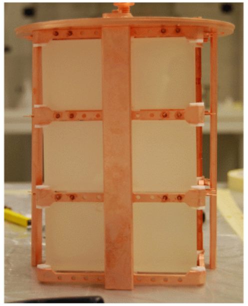


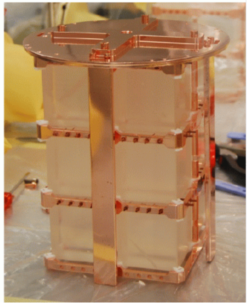
Background reduction achievements

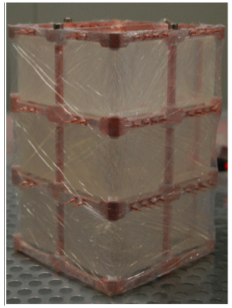
- **New holder design** to reduce the amount of copper facing the crystals: bkg contribution reduced by a factor ~ 2.
- **Shields design and materials selection** have been performed in order to keep the overall bulk contribution in the ROI down to 10^{-3} c/keV/kg/y
- **TeO_2 crystals bulk contamination**: strict protocol for crystal production and quality checks at every production step has been signed.
- **Crystals surface contamination**: new mechanical treatment developed at LNGS and implemented at crystal factory. Reduction by a factor 4 measured in hall C test facility.
- **Surface contamination of the copper facing the crystals**: an ultimate test is just finished in the Hall A test facility to compare three different surface treatements: chemical etching, plasma cleaning, polyethilene wrapping.

- Further improvement thanks to detector granularity









CUORE bkg projection

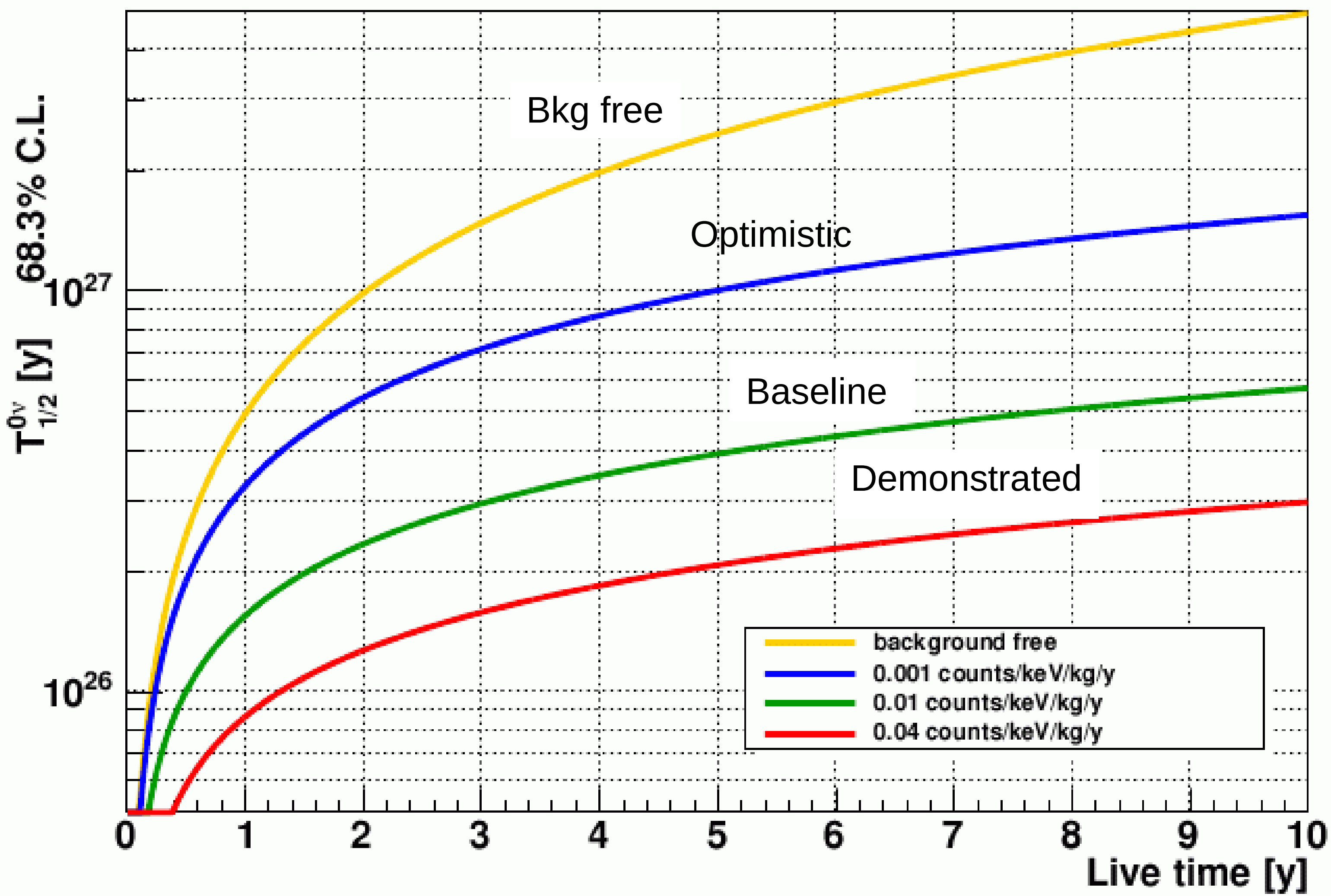
On the basis of the actual achievements the projection to the CUORE bkg has been evaluated (MC simulations):

Element	**DBD rate [10^{-3} c/keV/kg/y]**
Crystal bulk	< 1
Crystal surface	< 3
Cu mounting bulk	< 0,6
Cu mounting surface	**20 ÷ 40**
Experimental set-up	< 10
Environmental gammas [8]	< 0.4
Environmental neutrons [8]	(8,6 +/- 6,06) x 10^{-3}
Environmental muons (no VETO) [8]	0,104 +/- 0,022

Target bkg:
< 0.01 c/keV/kg/y

We are amost there..

CUORE projected sensitivity



FWHM resolution assumed at ROI: 5 keV

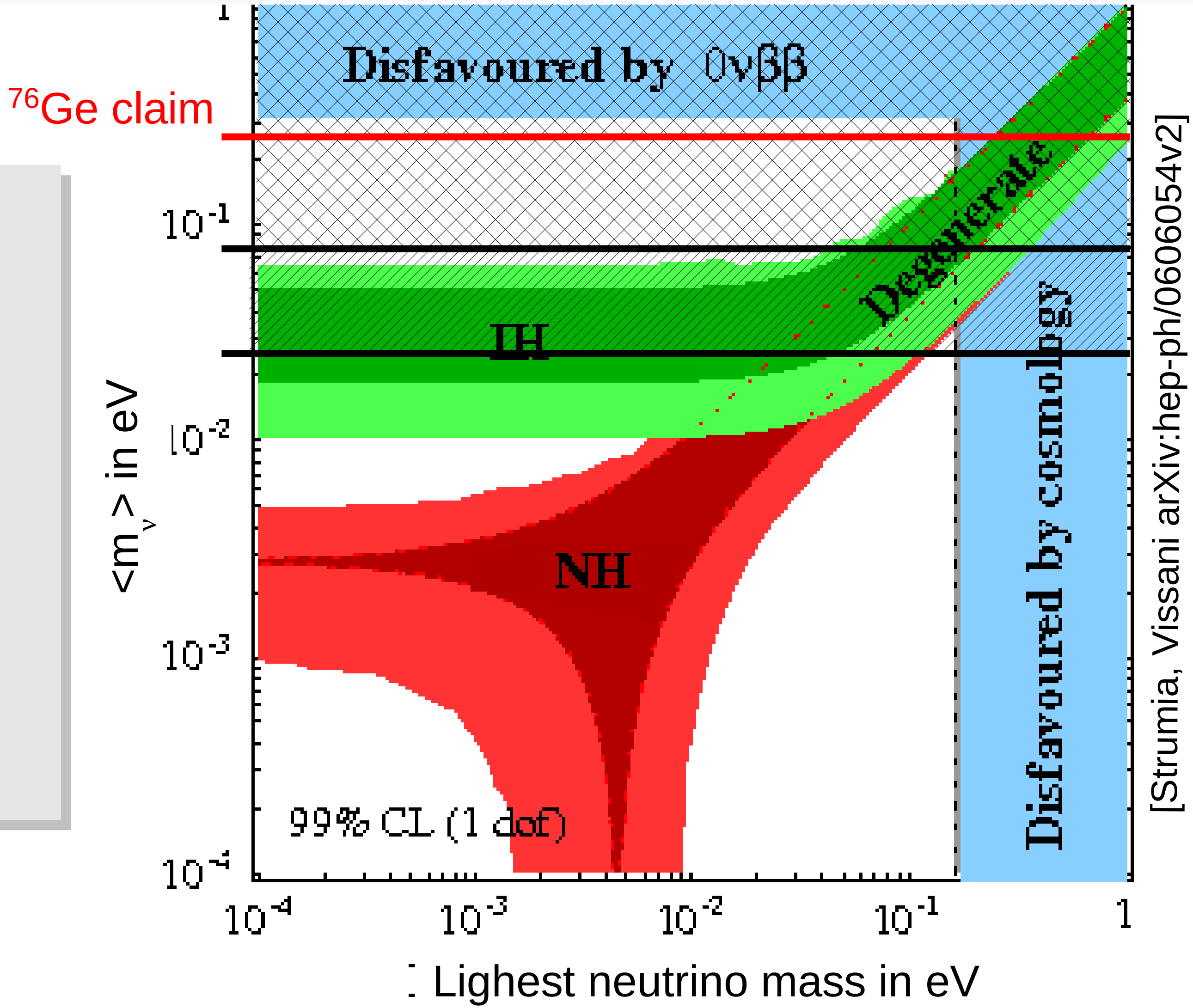
CUORE projected sensitivity in 5 years

1σ sensitivity with a realistic scenario:

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

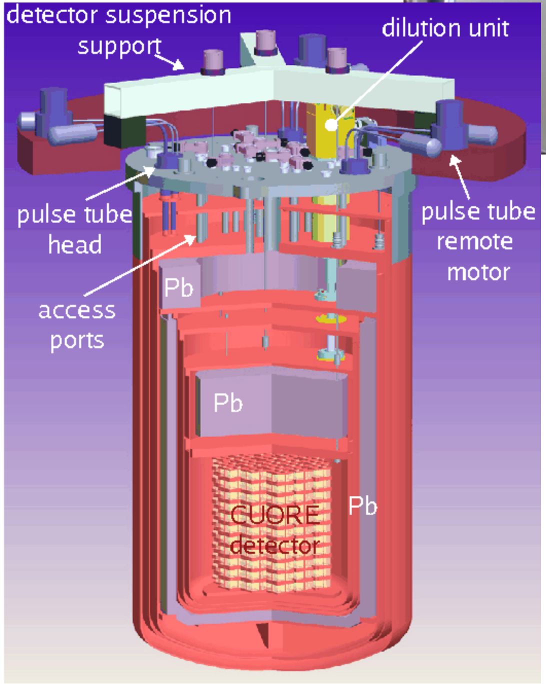
$T_{1/2}^{0\nu} > 2.1 \times 10^{26}$ y

$\langle m_\nu \rangle < 23 \div 82$ meV
[NME from [9,10] - QRPA]

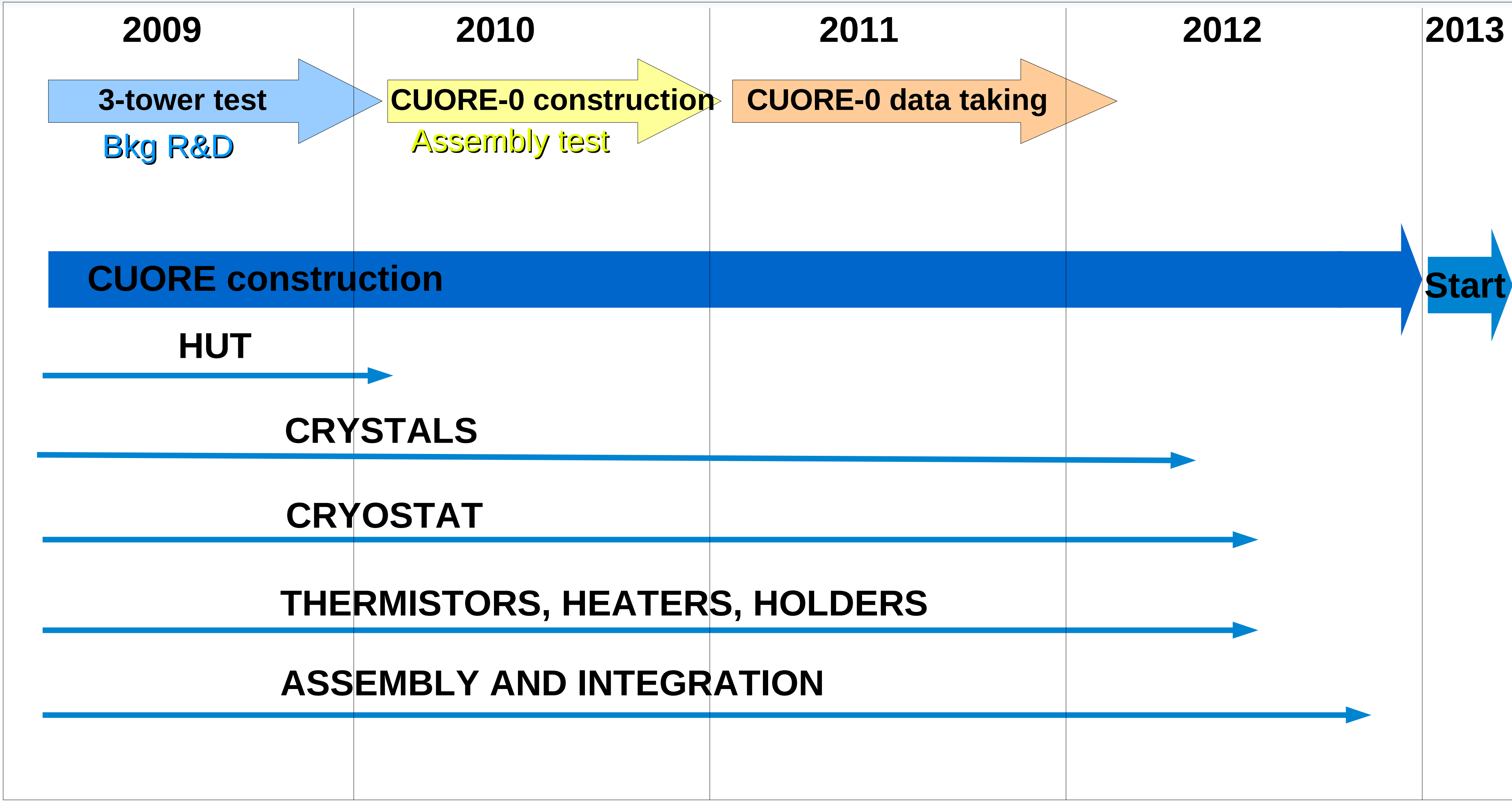


CUORE status

- CUORE building and cryostat support structure are completed
- The cryostat has been purchased. Delivery of dilution unit and flanges in 2010
- Production of 988 TeO2 crystals started in 2008: 241 already delivered to LNGS
- Electronics designed and is being procured
- Test of first CUORE tower (CUORE-0) under preparation: to be operated in 2011



CUORE schedule



Beyond CUORE

$$S_{0\nu} \propto \varepsilon \frac{i.a.}{A} \sqrt{\frac{M \cdot T}{\Delta E \cdot b}}$$

- Relatively inexpensive isotopic enrichment of ^{130}Te
- No change needed to the experimental infrastructure
- > 500 kg of ^{130}Te
- A factor 3 increase in i.a.

- Active background rejection (mainly alpha rejection) could be achieved by means of surface sensitive detectors [11] or scintillating bolometers (different compounds and DBD candidates are being tested: ZnSe, $CdWO_4$, $CdMoO_4$...) [see A.Giulianii talk]

Conclusions

- Low temperature bolometers are a well established and competitive technique for DBD0ν search
- Cuoricino has demostrated the potential of this technique and has provided one of the most stringent limits on $\langle m_\nu \rangle$
- Intense R&D and careful material selection and shielding design has been performed to lower background sources limiting the sensitivity for CUORE. We are almost there!
- CUORE, presently under contruction at LNGS, will have the capability of exploring the IH of neutrino mass spectrum
- CUORE data taking is forseen in 2013

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[7] C. Bucci et al. Eur. Phys. J. A 41:155-168, 2009

[8] F.Bellini et al. Astrop. Phys, In press

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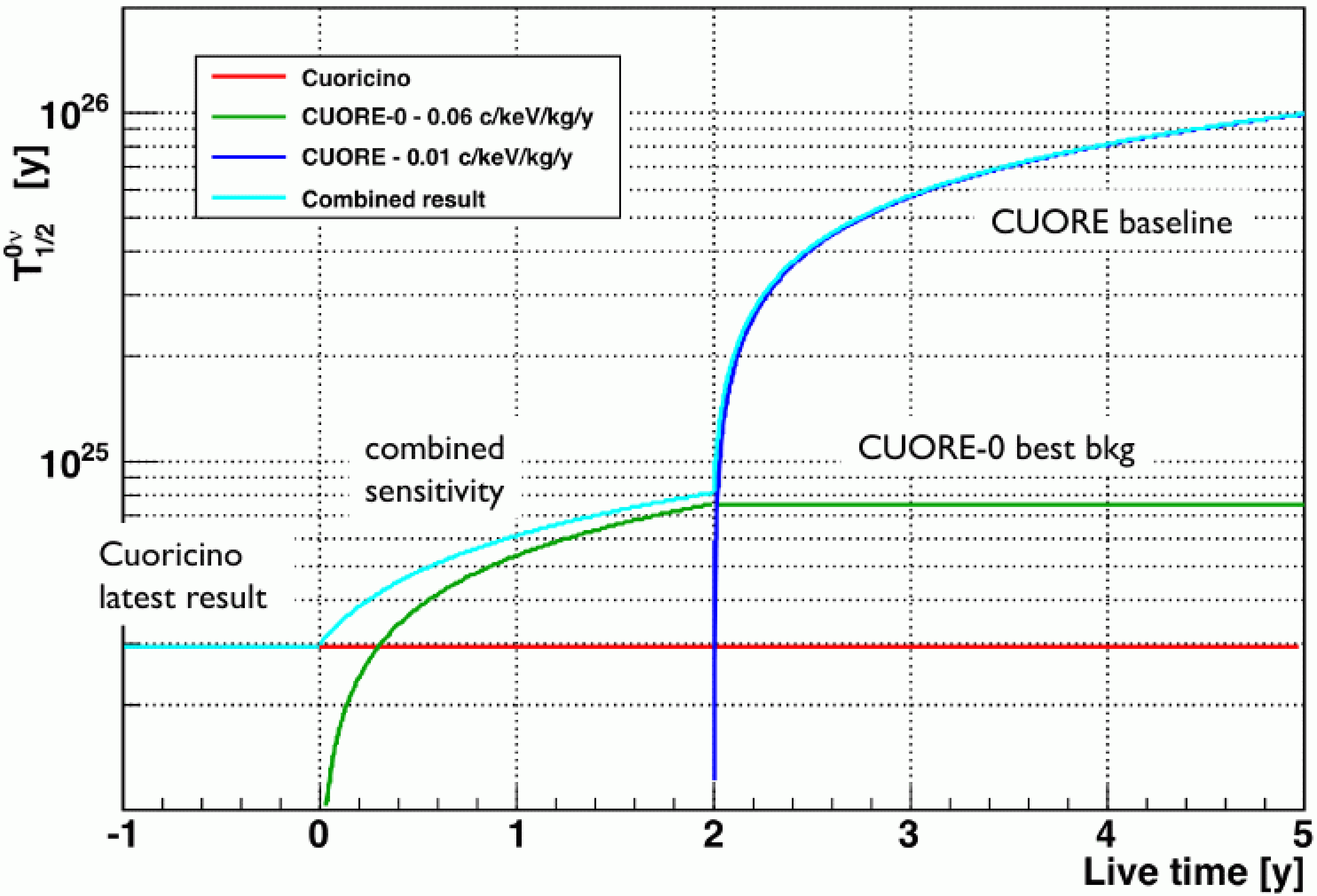
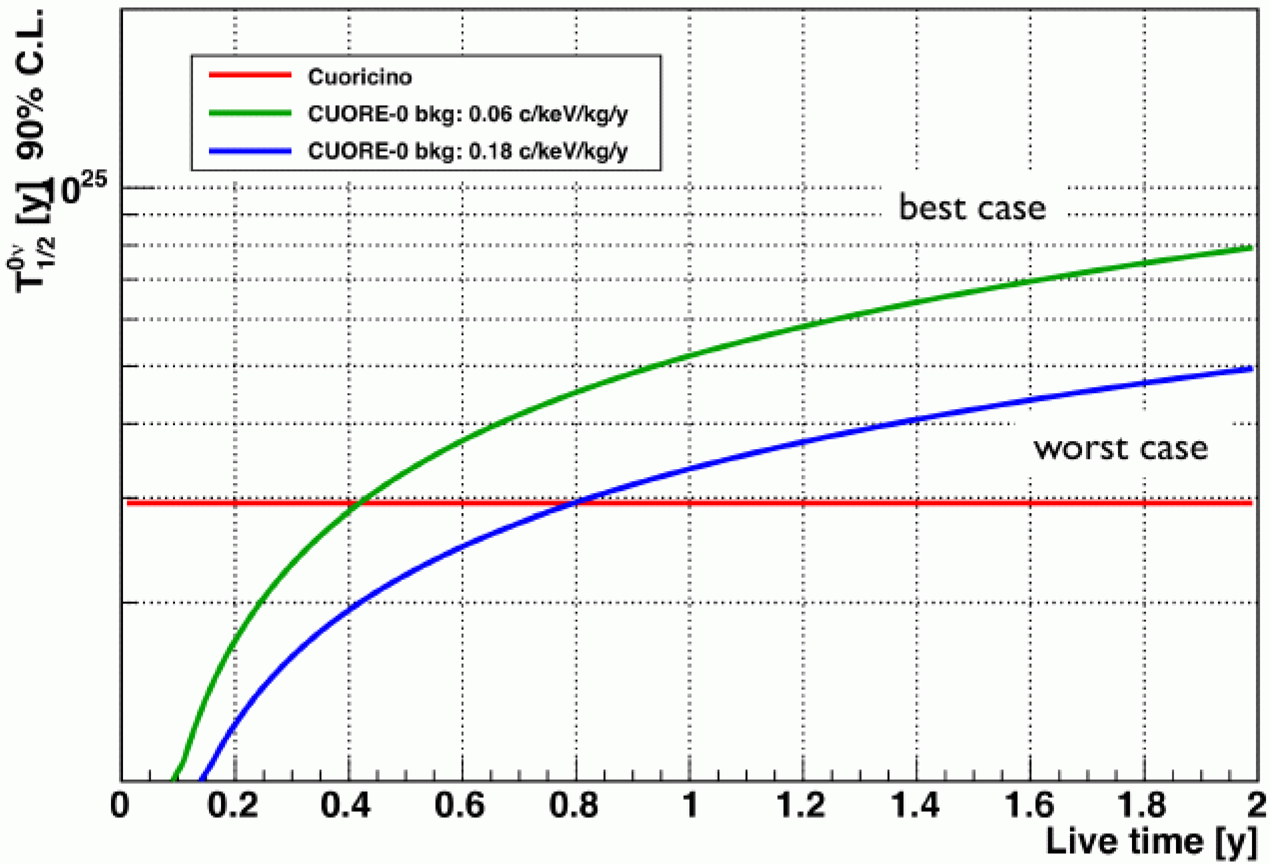
Backup: Combined sensitivities



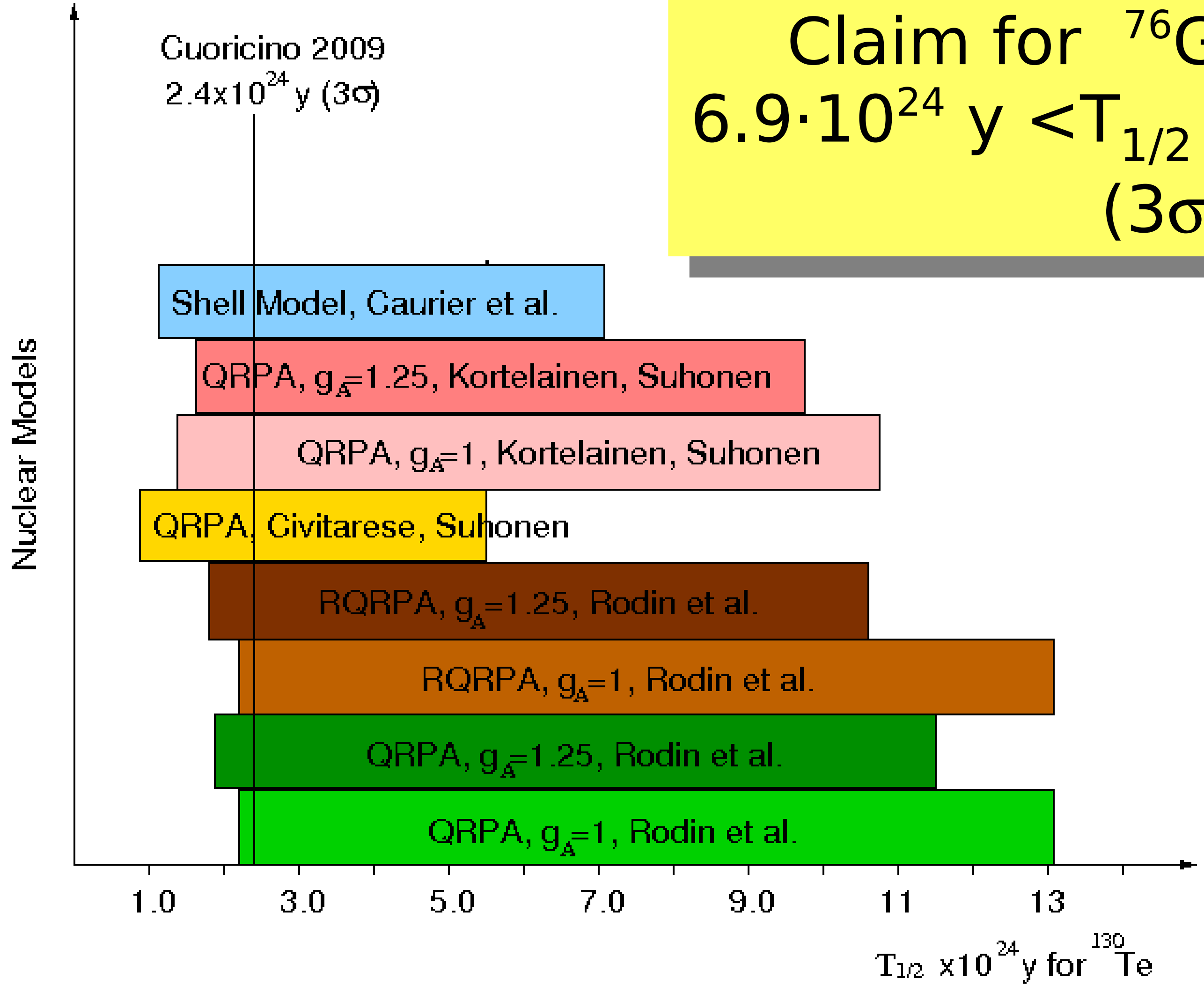
Backup: CUORE-0 sensitivity



Worst case: Cuoricino bkg = 0.18 c/keV/kg/y

Best case: limited by cryostat contamination = 0.06 c/keV/kg/y

Backup:CUORICINO vs. KK et al. claim



Claim for ^{76}Ge DBD0ν:
$6.9 \cdot 10^{24}$ y $< T_{1/2} < 4.18 \cdot 10^{25}$ y (3σ)

Backup:DBD0ν present situation

Nucleus	Experiment	%	$Q_{\beta\beta}$	Enr	Technique	$T_{0\nu}$ (y)	<m_ν>
^{48}Ca	Elegant IV	0.19	4271		scintillator	>1.4x10^{22}	7-45
^{76}Ge	Heidelberg-Moscow	7.8	2039	87	ionization	>1.9x10^{25}	.12 - 1
^{76}Ge	IGEX	7.8	2039	87	Ionization	>1.6x10^{25}	.14 – 1.2
^{76}Ge	Klapdor et al	7.8	2039	87	ionization	1.5x10^{25}	.39
^{82}Se	NEMO 3	9.2	2995	97	tracking	>2.1x10^{23}	1.2-3.2
^{100}Mo	NEMO 3	9.6	3034	95-99	tracking	>5.8x10^{23}	.6-2.7
^{116}Cd	Solotvina	7.5	3034	83	scintillator	>1.7x10^{23}	1.7 - ?
^{128}Te	Bernatovitz	34	2529		geochem	>7.7 × 10^{24}	.1-4
^{130}Te	Cuoricino	33.8	2529		bolometric	>2.4x10^{24}	.2-1.
^{136}Xe	DAMA	8.9	2476	69	scintillator	>1.2x10^{24}	1.1 -2.9
^{150}Nd	Irvine	5.6	3367	91	tracking	>1.2x10^{21}	3 - ?

Experiment	Author	Isotope	Detector description	$T^{5y}_{1/2}$(y)	$<m_\nu>$*
CUORE	Bolometric	^{130}Te	760 kg of TeO_2 bolometers	2.1×10^{26}	0.023
COBRA	Ionization	^{130}Te	10 kg CdTe semiconductors	1×10^{24}	0.71
GERDA	Ionization	^{76}Ge	1 t enriched Ge diodes in liquid nitrogen	2×10^{27}	0.034
MAJORANA	Ionization	^{76}Ge	0.5 t enriched Ge segmented diodes	4×10^{27}	0.025
SUPERNEMO	Tracking	^{82}Se	100- 200 kg enriched Nd or Se foils between TPCs	2×10^{25}	
DCBA	Tracking	^{150}Nd	20 kg enriched Nd layers with tracking	2×10^{25}	0.035
MOON	Tracking	^{100}Mo	34 t natural Mo sheets between plastic scintillator	1×10^{27}	0.036
EXO	Tracking	^{136}Xe	1 t enriched Xe TPC	1.3×10^{28}	0.013
Xe	Scintillation	^{136}Xe	1.56 t of enriched Xe in liquid scintillator	5×10^{26}	0.066
XMASS		^{136}Xe	10 t of liquid Xe	3×10^{26}	0.086
CAMEO	Scintillation	^{116}Cd	1 t $CdWO_4$ crystals in liquid scintillator	$> 10^{26}$	0.069
CANDLES	Scintillation	^{48}Ca	tons of CaF_2 crystal in liquid scintillator	1×10^{26}	
GSO	Scintillation	^{160}Gd	2 t Gd_2SiO_5:Ce cristal scintillator in liquid scintillator	2×10^{26}	0.065

** using nuclear calculations of Staudt et al. Europhys. Lett 13 (1990) 31*