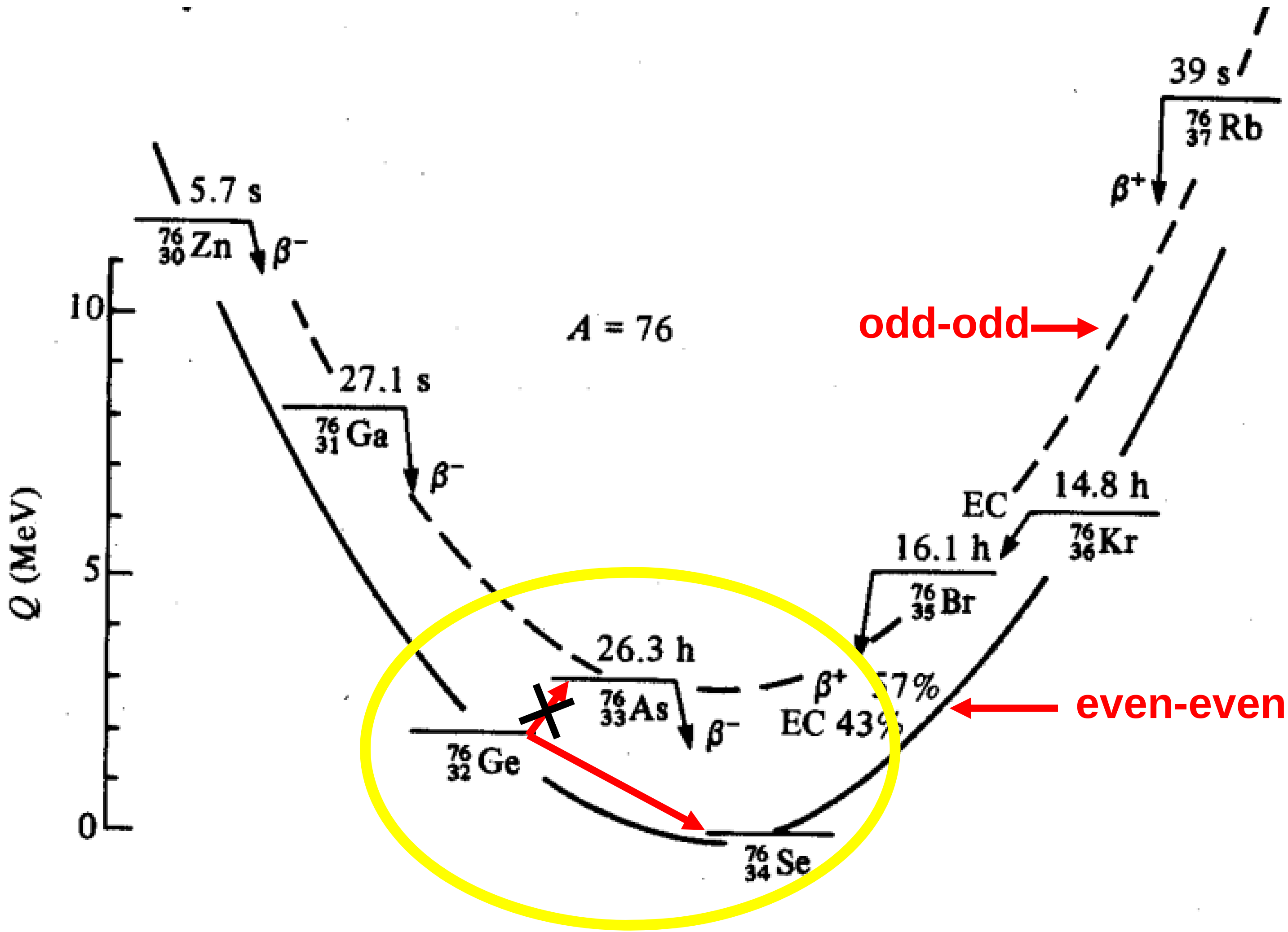
Neutrinoless double beta decay search

GDR Neutrino Caen 2012, 30-31 October 2012

Stefan Schönert, Physik Department, TU München

Mass parabolas

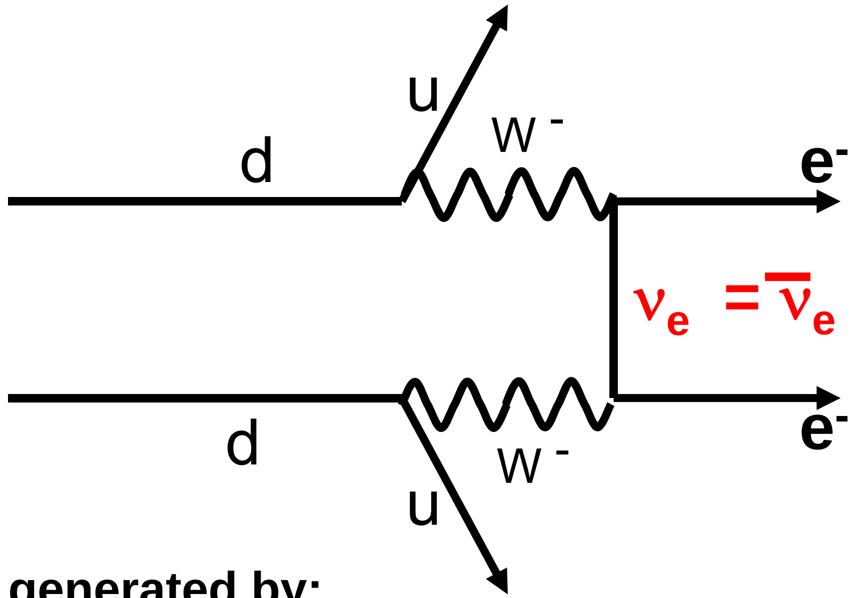


Ground states of even-even nuclei: 0^+

0ν-ββ Decay

$$(A,Z) \rightarrow (A,Z+2) + e_1^- + e_2^-$$

ΔL=2



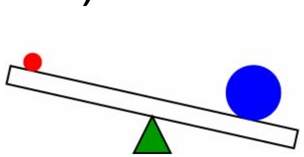
0νββ can be generated by:
- exchange of light Majorana neutrinos (active/sterile)
- SUSY
- LR
- …..

Schechter & Valle:
if 0νββ observed ⇒ ν is Majorana particle!

Why is it interesting?

1) Violation of lepton number conservation ($\Delta L=2$)
   Dirac vs. Majorana particle: (i.e. its own anti-particle)?
   $0\nu\beta\beta \Rightarrow$ Majorana nature
   Majorana $\Rightarrow$ See-Saw mechanism

$$m_\nu = \frac{m_D^2}{M_R} << m_D$$

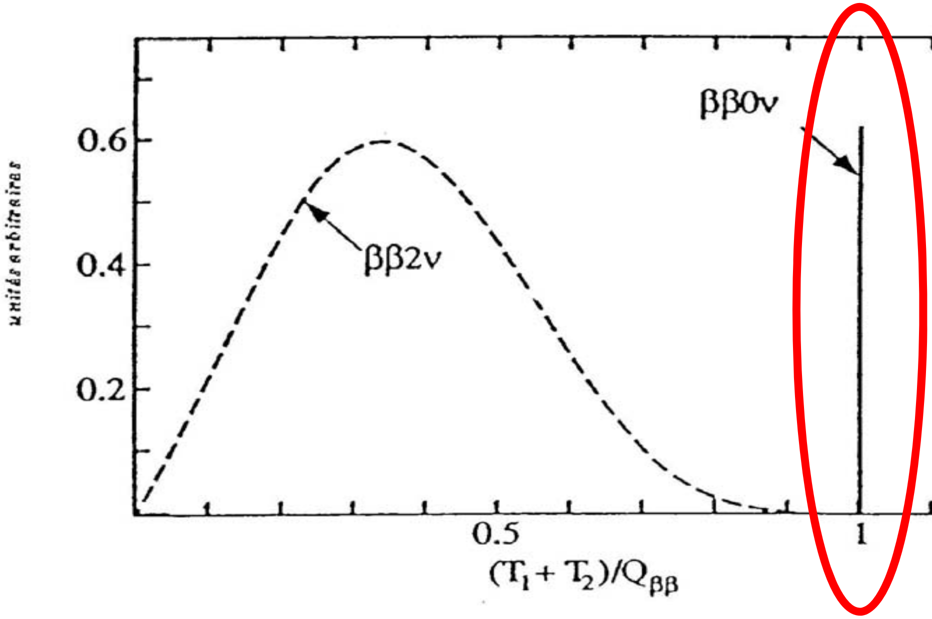


For $m_3 \sim (\Delta m^2_{atm})^{1/2}$, $m_D \sim m_t$ ➔ $M_R \sim 10^{15}$GeV

2) Absolute mass scale:
   (effective) neutrino mass
   Hierarchy: degenerate, inverted or normal
   sensitive to Majorana CP phases

Main 0νββ experimental observables:

- Sum energy of 2 electrons equal to Q-value



- 2 electrons from one vertex
  - ➔ point-like in high density detectors
  - ➔ Two tracks from single vertex in tracking detector

Life time and effective Majorana mass

$$1 / t_{1/2}(0\nu) = G\, M^2\, m^2_{ee}$$

G: Phase space

M: Nuclear matrix element

m_{ee}: Effective neutrino mass

$$m_{ee} = |\sum_i U_{ei}{}^2\, m_i\,|$$

U_{ei} complex:

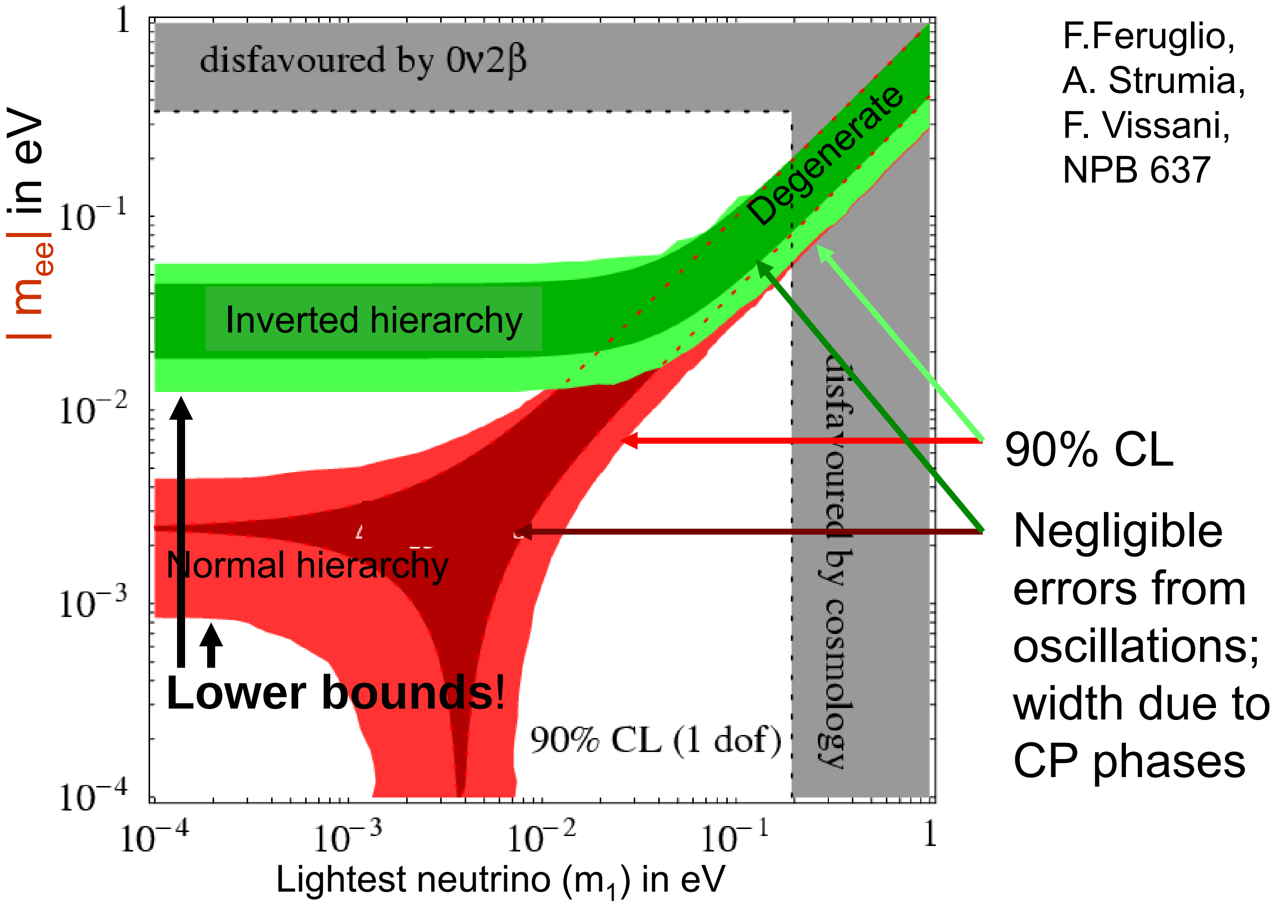
⇒ sensitive to CP violating phases (optimist☺)

⇒ cancellation possible (pessimist)

$0\nu\beta\beta$: Range of m_{ee} derived from solar and atmospheric oscillation experiments

$$m_{ee} = f(m_1, \underbrace{\Delta m^2_{sol}, \Delta m^2_{atm}, \theta_{12}, \theta_{13}}_{\text{from oscillation experiments}}, \alpha\text{-}\beta)$$

$$\langle m_{ee} \rangle = \left| \sum_i U_{ei}^2 m_i \right|$$



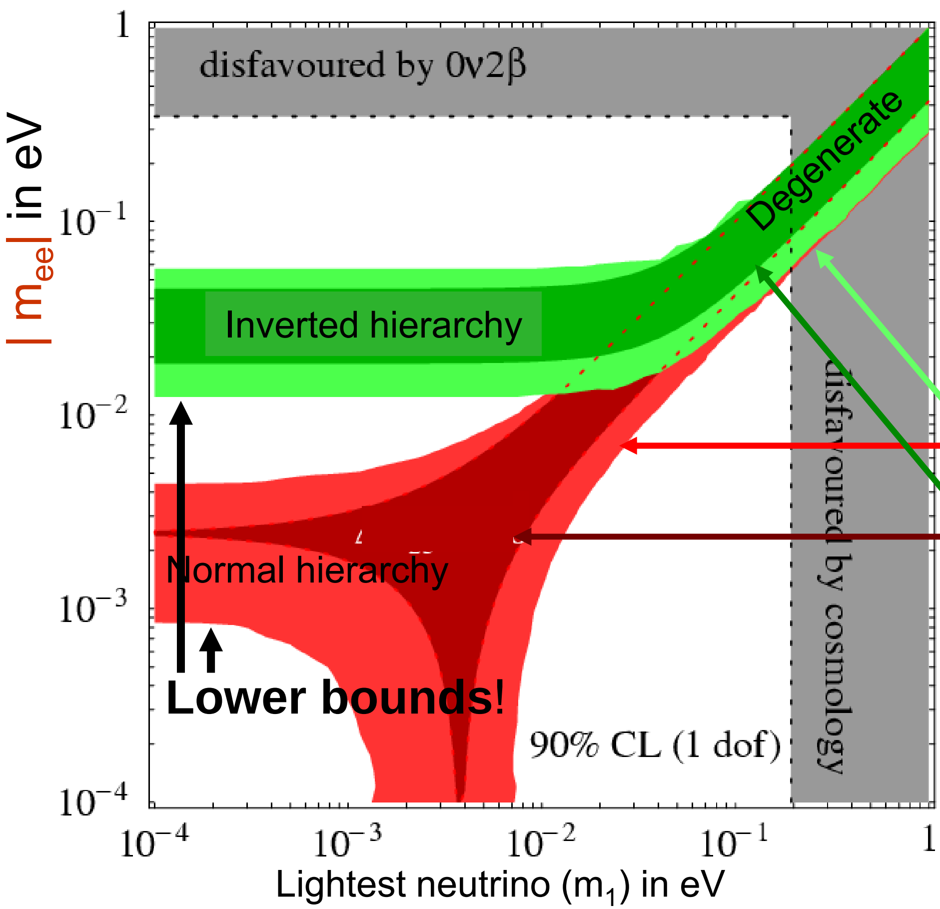
F.Feruglio, A. Strumia, F. Vissani, NPB 637

$0\nu\beta\beta$: Range of m_{ee} derived from solar and atmospheric oscillation experiments

$$m_{ee} = f(m_1, \underbrace{\Delta m^2_{sol}, \Delta m^2_{atm}, \theta_{12}, \theta_{13}}_{\text{from oscillation experiments}}, \alpha-\beta)$$

KDKC claim: 0.44 eV

Goal of next generation experiments: ~10 meV

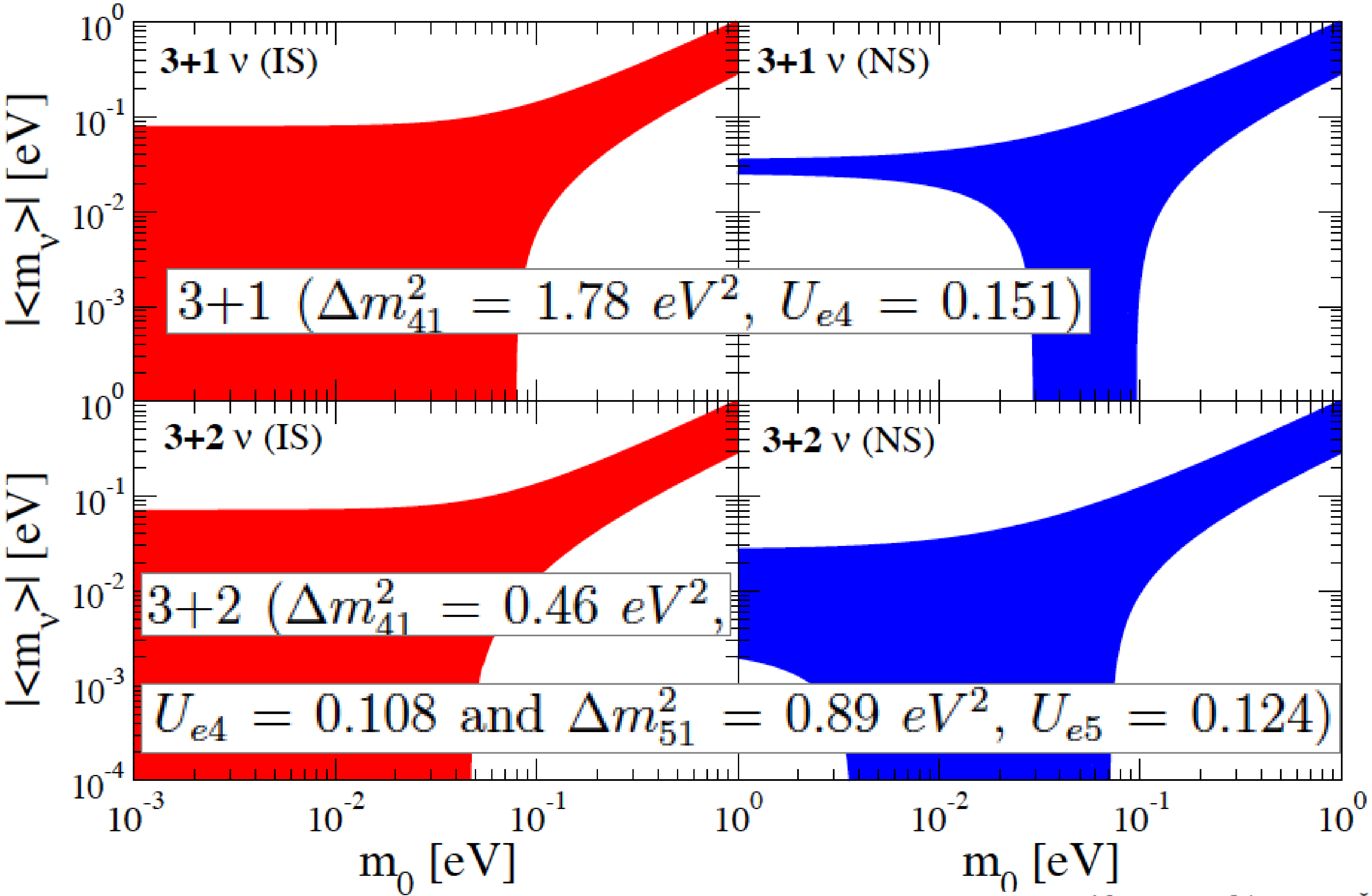


F.Feruglio, A. Strumia, F. Vissani, NPB 637

90% CL

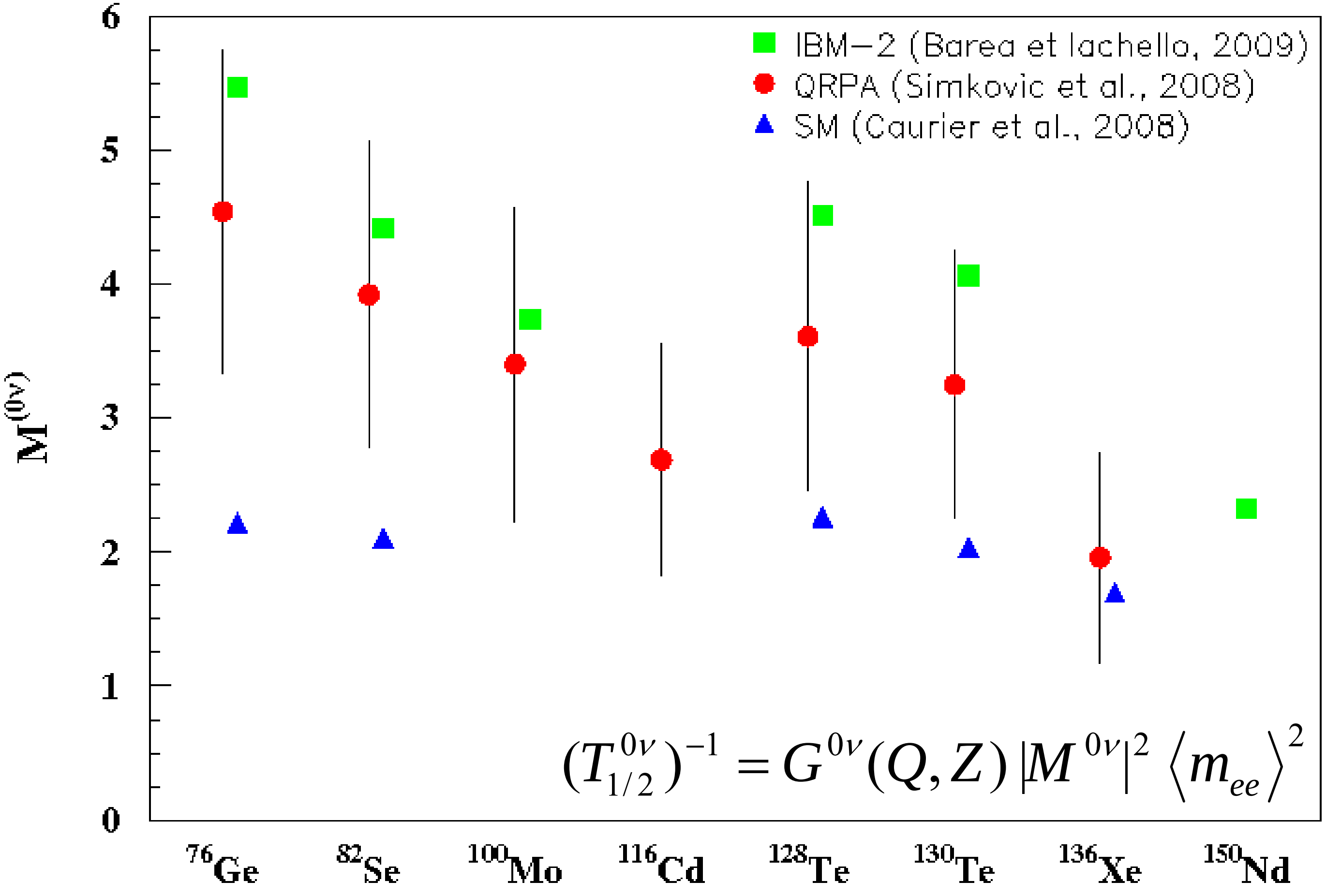
Negligible errors from oscillations; width due to CP phases

$0\nu\beta\beta$ including sterile neutrinos: range of m_{ee} derived from solar/atm experiments & reactor/Ga anomalies



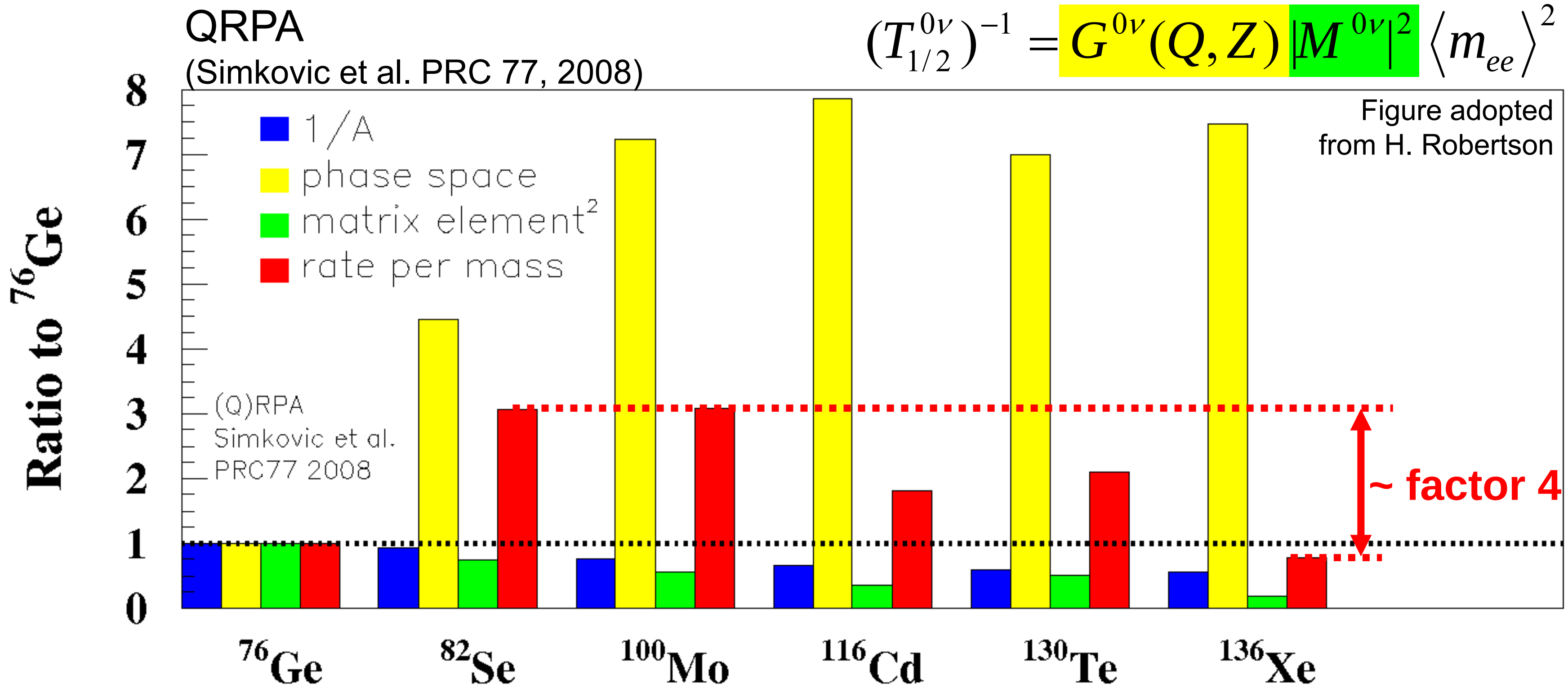
J D Vergados[1,2], H Ejiri[3,4] and F Šimkovic[5,6]

Comparison of DBD isotopes: NME's



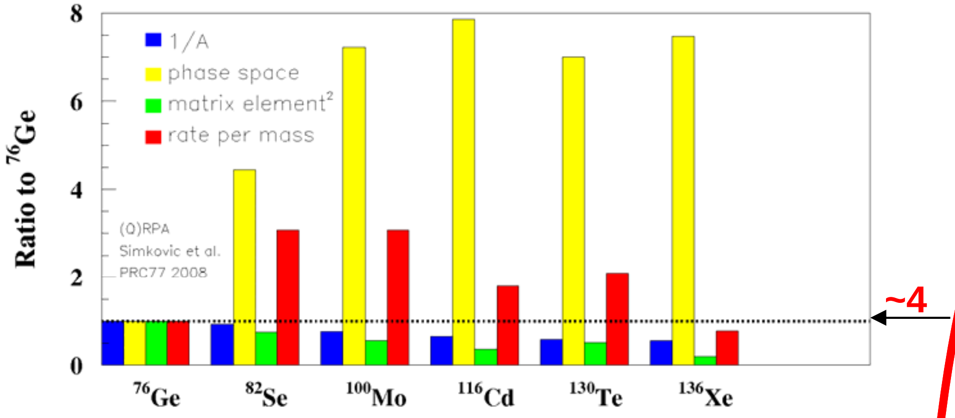
Comparison of isotopes:
Is there a *super-DBD-isotope* ?

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



Expected 0νββ **rates per mass** vary within a factor ~ 4 !

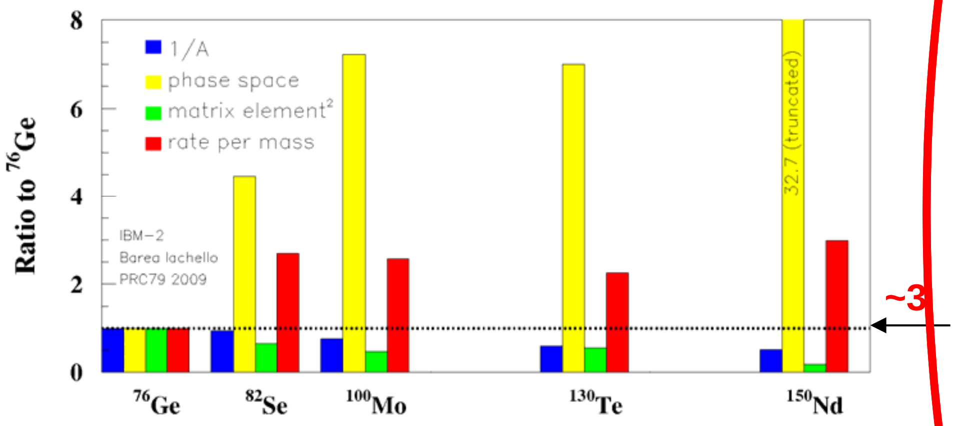
QRPA
(Simkovic et al. PRC 77, 2008)



for $\langle m \rangle = 50\,\mathrm{meV}$:

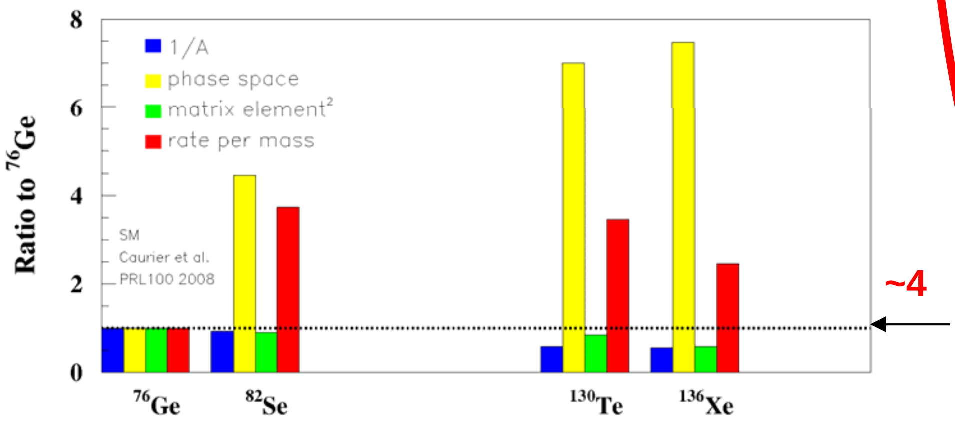
9.1 cts/(ton year)

IBM2
(Barea and Iachello, PRC 79, 2009)



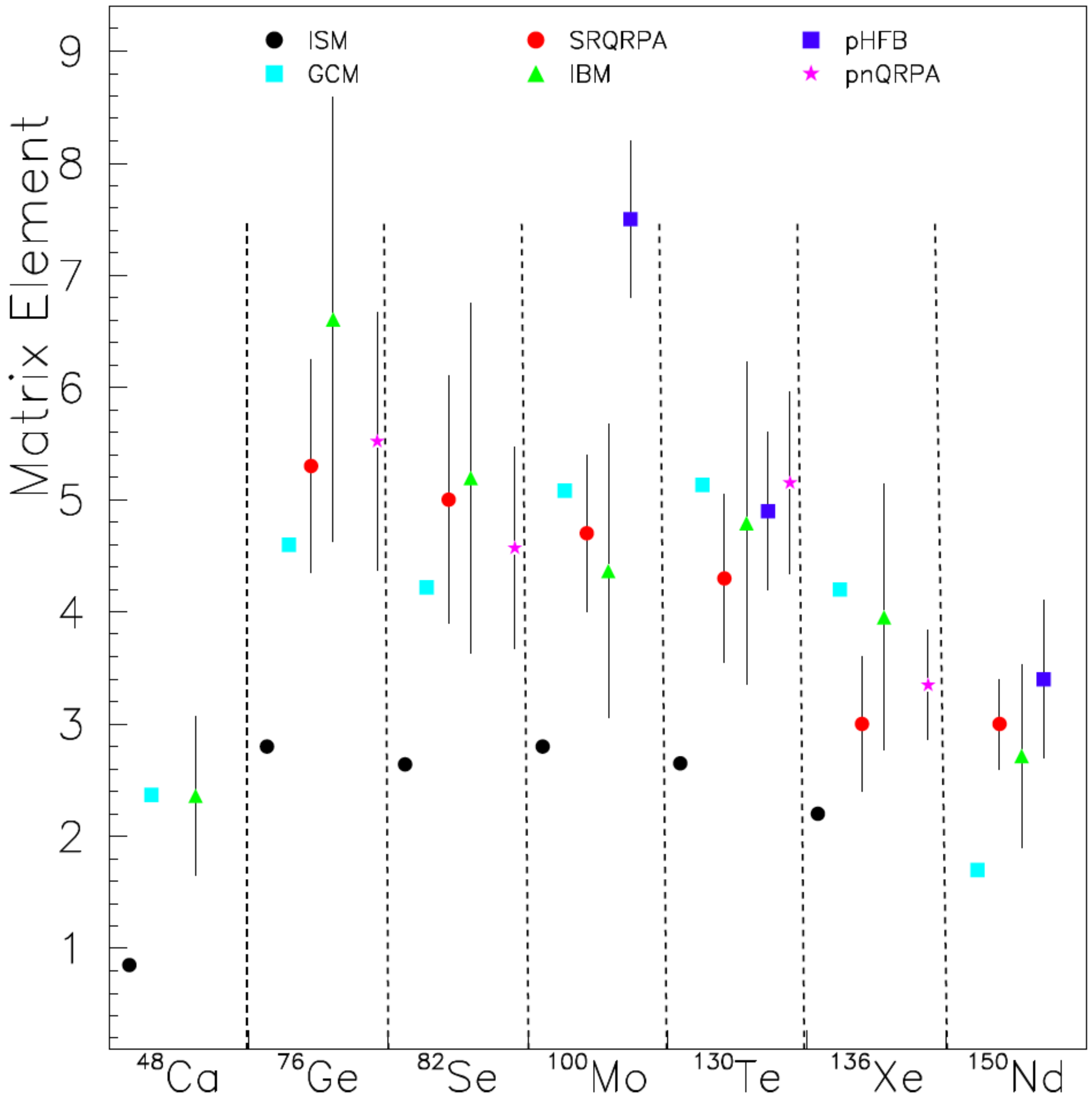
13.2 cts/(ton year)

SM
(Caurier et al., PRL 100, 2008)



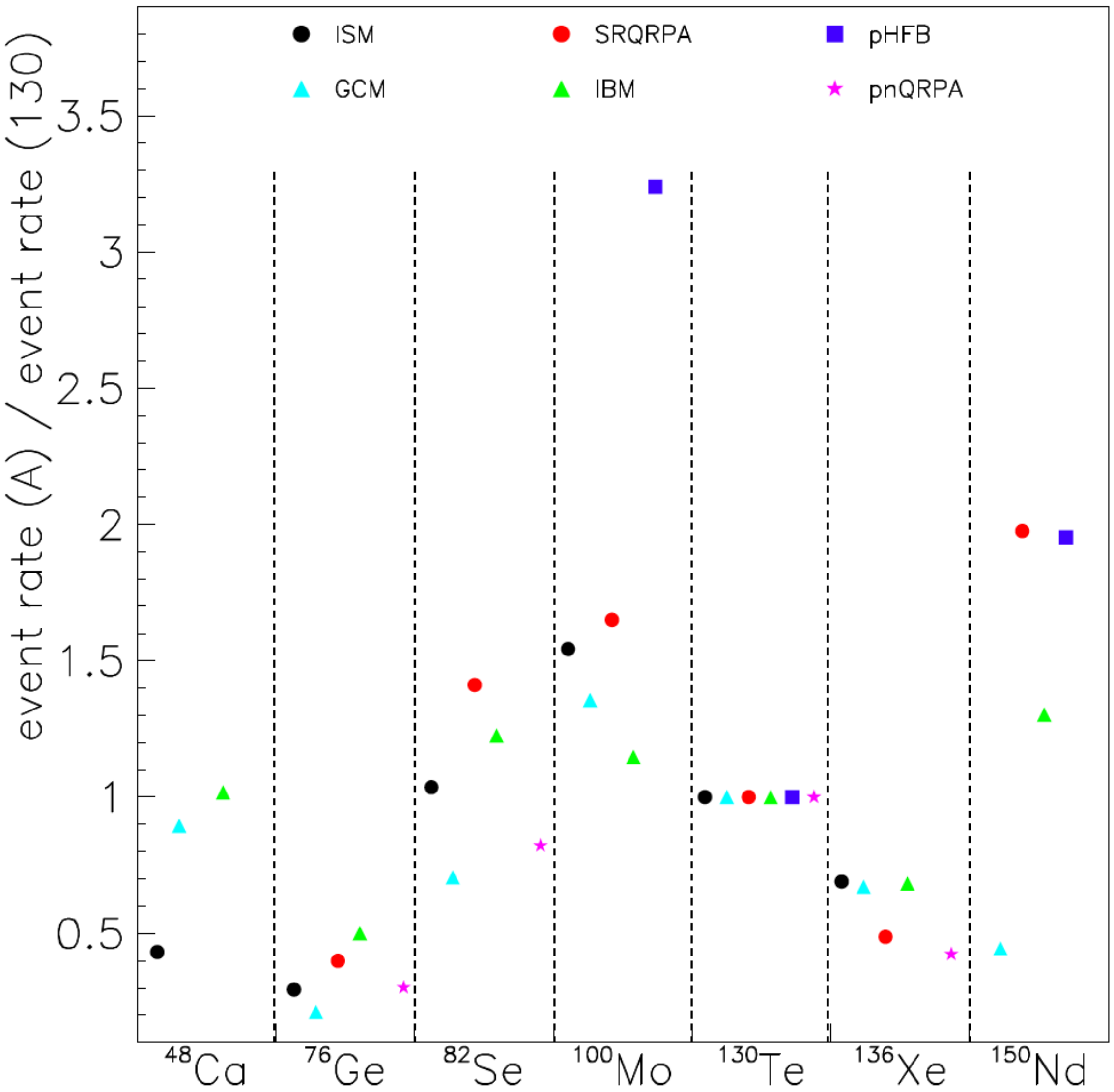
2.2 cts/(ton year)

Recent up date: NME's



B. Schwingenheuer, Annalen der Physik, August 22, 2012

Recent up date: relative event rate per kg of isotopes



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Experimental sensitivity: w/o background

Experimental life time

number of nuclides under control $\propto$ M

Time of measurement

number of detected decays

$$\tau = \frac{N_N \; T}{N_S}$$

Background free limit:
0 cnts in the analysis energy window $\Rightarrow$ Poisson upper limit: N_P

Remember: $1/t_{1/2}(0\nu) = G\,M^2\,m^2_{ee}$

$$\tau \geq \frac{N_N \; T}{N_P} \propto \mathbf{M \cdot T} \quad \Rightarrow \quad \langle m \rangle < \frac{\text{const}}{(M\,T)^{1/2}}$$

Sensitivity: with background

If no decay is observed in presence of N_B background events in an energy window ΔE:

detector energy resolution

$$N_S < (N_B)^{1/2} \quad \Longrightarrow \quad \tau > \frac{N_N\ T}{(N_B)^{1/2}}$$

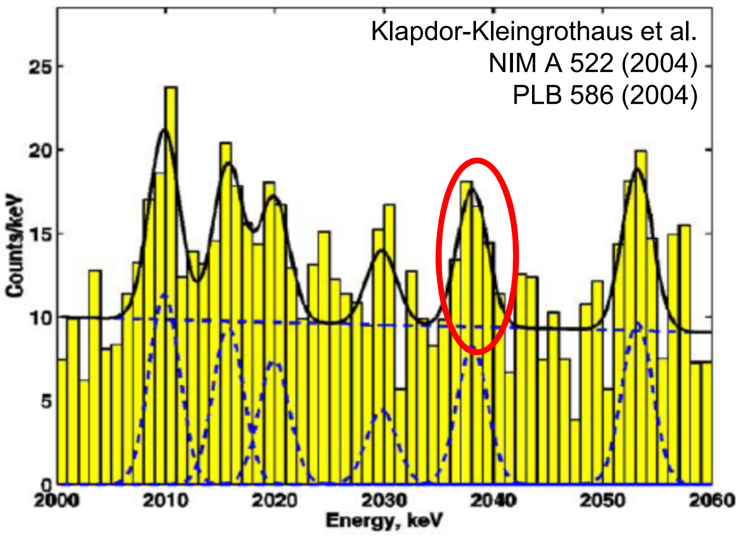
$$N_B = b\ M\ T\ \Delta E$$

b: background index [1/(kg · year · keV)]

$$\Rightarrow \quad \tau > \frac{N_N\ T}{(b\ M\ T\ \Delta E)^{1/2}} \propto \left(\frac{M\ T}{b\ \Delta E} \right)^{1/2}$$

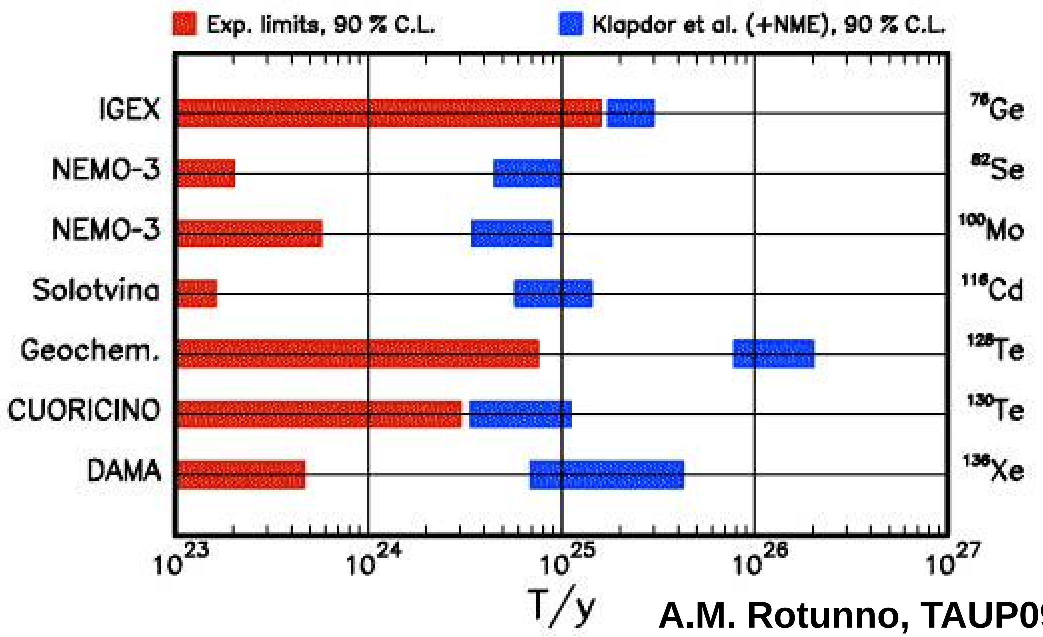
$$\Rightarrow \quad \langle m \rangle < \text{const.} \cdot \left(\frac{b\ \Delta E}{M\ T} \right)^{1/4}$$

As of early 2012: limits & claim



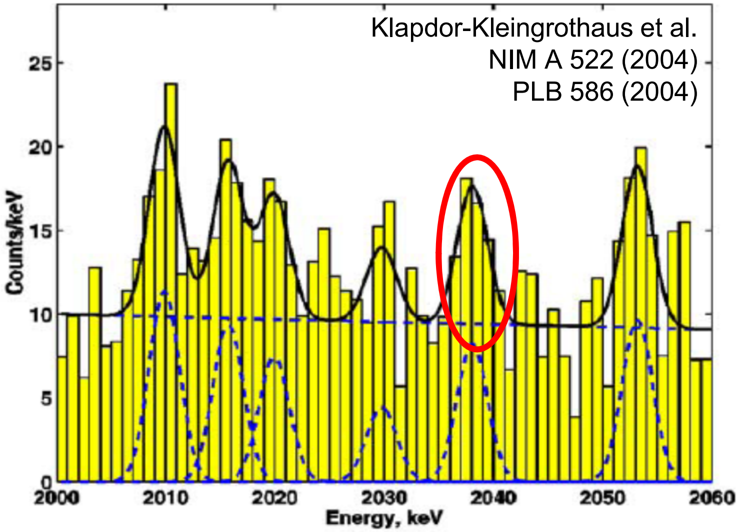
- 71.7 kg year - Bgd 0.11 / (kg y keV)
- 28.75 ± 6.87 events (bgd:~60)
- Claim:4.2σ evidence for $0\nu\beta\beta$
- (0.69–4.18) x10^{25} y (3σ)
- Best fit: 1.19 x10^{25} y (NIMA 522/PLB 586)
- PSA analysis (Mod. Phys. Lett. A21): (2.23 + 0.44 – 0.31)x10^{25} y (6σ) (but analysis & results flawed….)
- Tuebingen/Bari group (PRD79): m_{ee} /eV = 0.28 [0.17-0.45] 90%CL

Significance and $T_{1/2}$ depend on bgd discription:
- Strumia & Vissani Nucl.Phys. B726 (2005)
- Chkvorets, PhD dissertation Univ. HD, (2008): using realistic background model
  $\Rightarrow$ peak significance: 1.3σ,
  $\Rightarrow T_{1/2} = 2.2 \times 10^{25}$ y



A.M. Rotunno, TAUP09 (PRD 79)

As of early 2012: limits & claim



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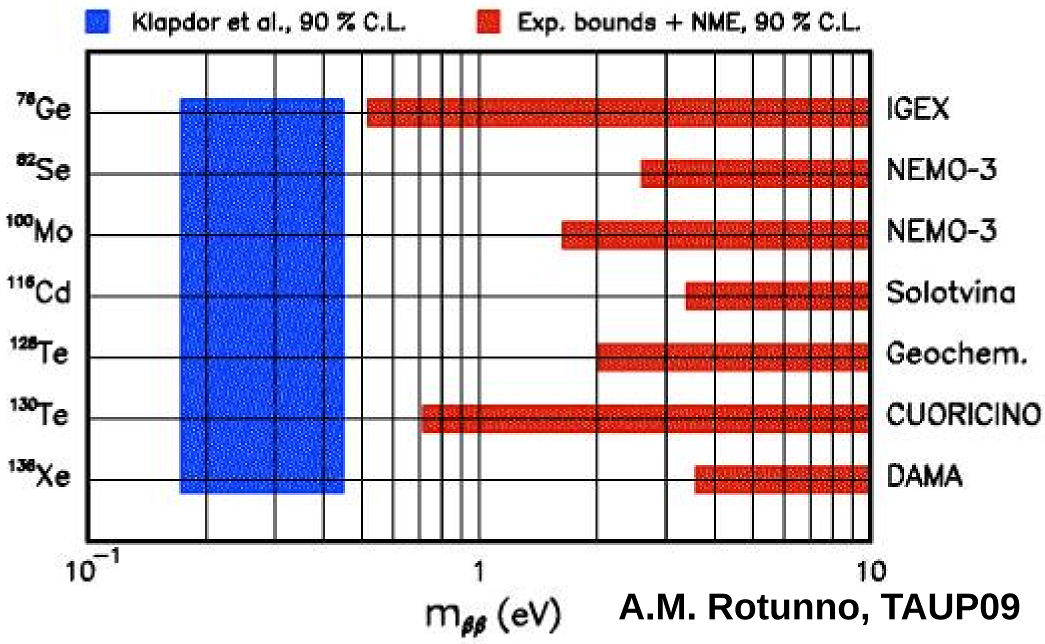
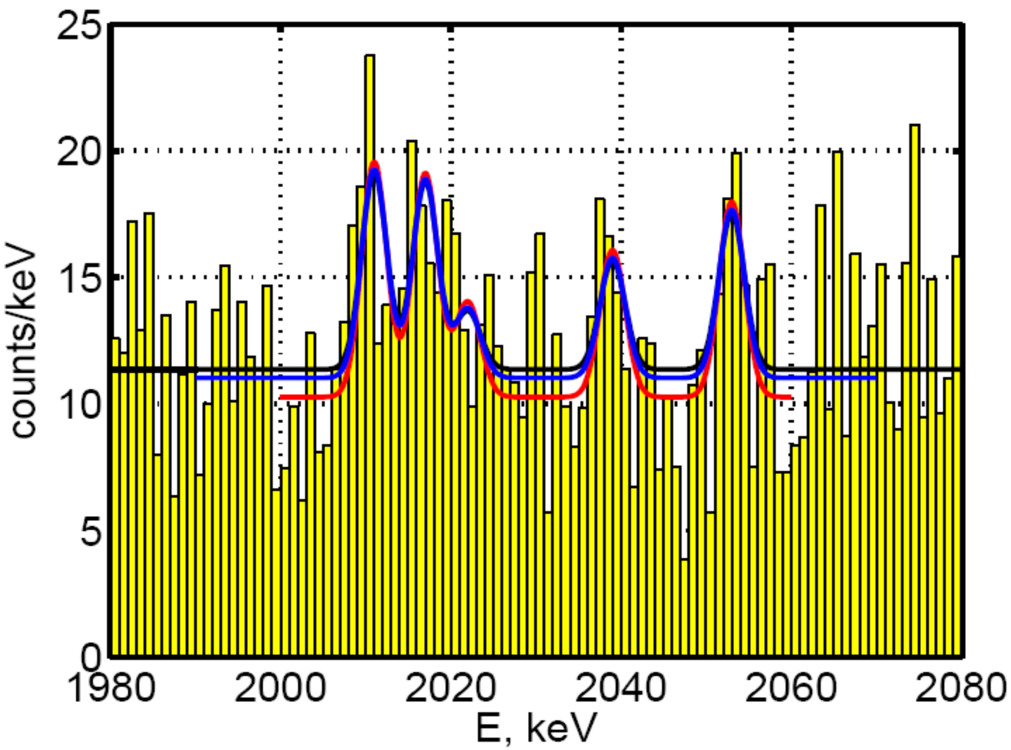
- Strumia & Vissani Nucl.Phys. B726 (2005)
- Chkvorets, PhD dissertation Univ. HD, (2008): using realistic background model
  $\Rightarrow$ peak significance reduced to 1.3σ,
  $\Rightarrow T_{1/2}$ = 2.2x10^{25} y



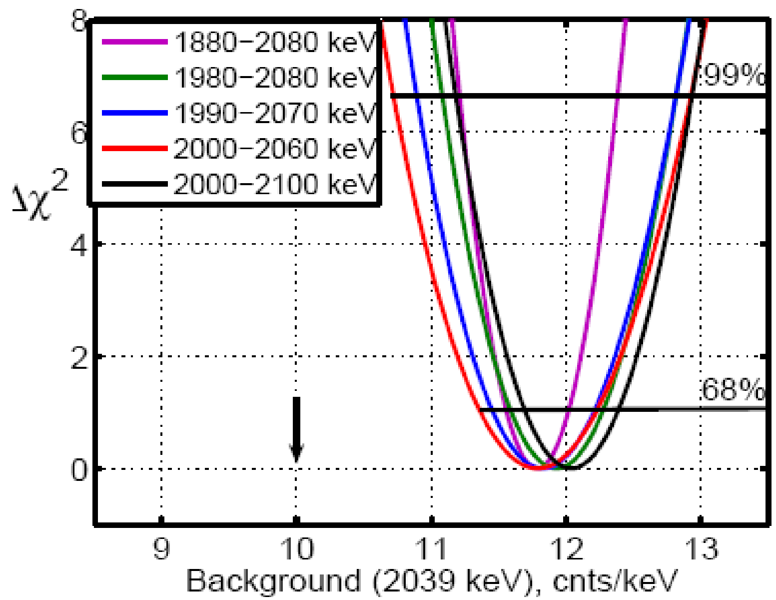
A.M. Rotunno, TAUP09

$\Rightarrow$ Claim must be scrutinized with ^{76}Ge AND other isotopes

Significance of claim weaker if background uncertainties included



O.Chkvorets, Dissertation
Univ. Heidelberg 2008;
see also Vissani Feruglio, Strumia)



Method	E_{peak} [keV]	Peak area [counts]
$S_{Feldman-Cousins}$	2039.0	15±12
S_{Fit}	2038.1±1.3	13.0±8.5

Table 4.7: The 2039 keV peak intensity determined with Feldman-Cousins and LSQ methods using background 11.9±0.5 counts/keV.

Significance: ~1.3-1.5 σ !

Table 3 Selection of $0\nu\beta\beta$ experiments.

experiment	isotope	mass [kg]	method	start / end	ref.
		past experiments			
Heidelberg-Moscow	^{76}Ge	11	ionization	-2003	[6]
Cuoricino	^{130}Te	11	bolometer	-2008	[40]
NEMO-3	^{100}Mo, ^{82}Se	7,1	track. +calorim.	-2011	[41]
		current experiments			
EXO-200	^{136}Xe	175	liquid TPC	2011-	[2]
Kamland-Zen	^{136}Xe	330	liquid scintil.	2011-	[3]
GERDA-I/ GERDA-II	^{76}Ge	15/35	ionization	2011-/ 2013-	[45]
CANDLES	^{48}Ca	0.35	scint. crystal	2011-	[46]
		funded experiments			
NEXT	^{136}Xe	100	gas TPC	2015	[47]
Cuore0/ Cuore	^{130}Te	10/200	bolometer	2012- 2015-	[48]
Majorana Demo.	^{76}Ge	30	ionization	2013	[49]
SuperNEMO demo./total	^{82}Se	7/100	track.+calorin	2014- /??	[50]
SNO+	^{150}Nd	44	liquid scint.	2013	[51]
		proposal, proto-typing			
Cobra	^{116}Cd		solid TPC		[52]
Lucifer	^{82}Se		bolom. +scint.		[53]
DCBA/MTD	^{150}Nd	32	tracking		[54]
MOON	^{82}Se, ^{100}Mo	30-480	track. +scint.		[55]
AMoRE	^{100}Mo	100	bolom. +scint.		[56]
Cd exp.	^{116}Cd		scint.		[57]

B. Schwingenheuer, Annalen der Physik, August 22, 2012

Next generation experiments

Calorimeters

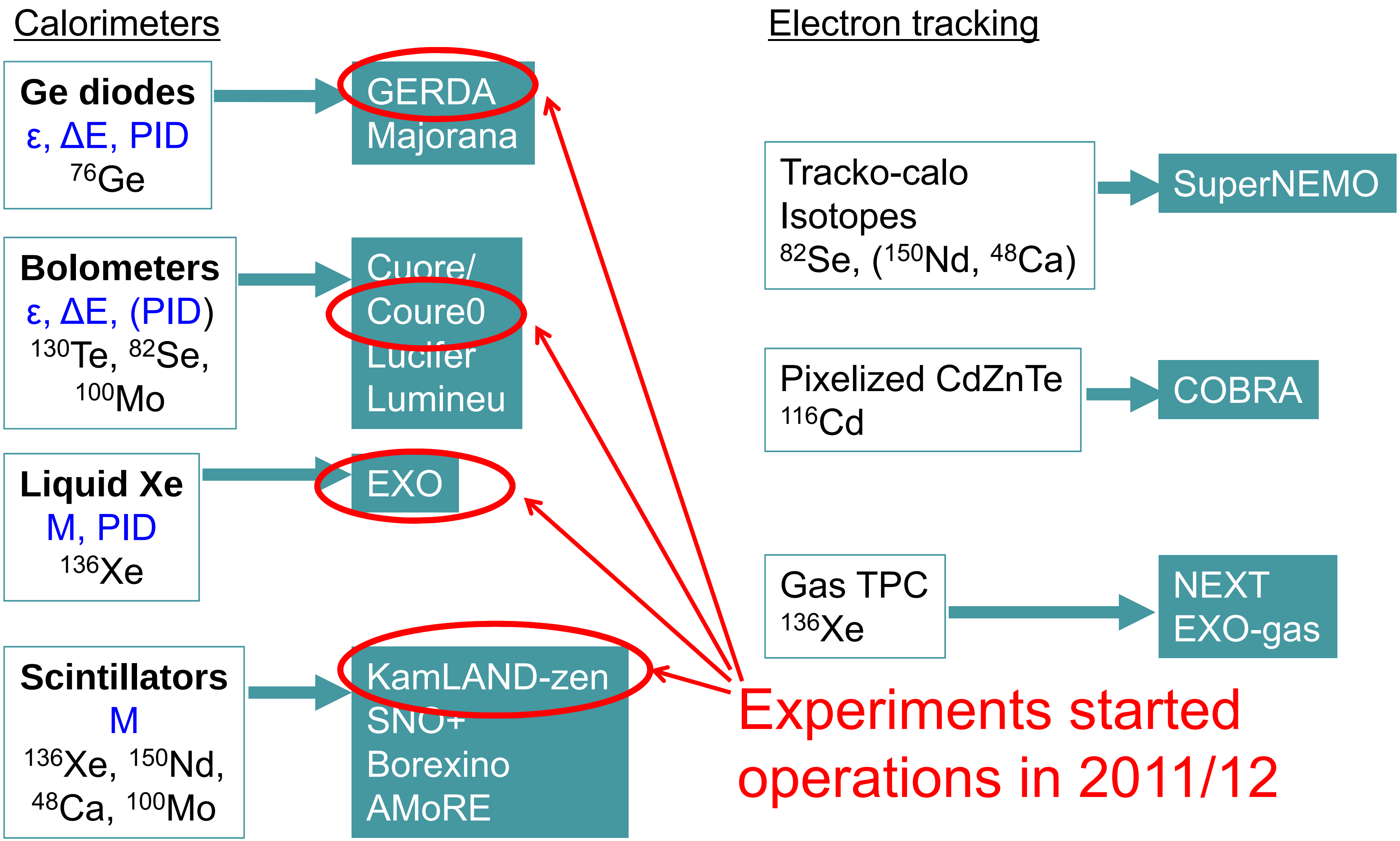
- **Ge diodes** — ε, ΔE, PID — ^{76}Ge → GERDA, Majorana
- **Bolometers** — ε, ΔE, (PID) — ^{130}Te, ^{82}Se, ^{100}Mo → Cuore, Lucifer, Lumineu
- **Liquid Xe** — M, PID — ^{136}Xe → EXO
- **Scintillators** — M — ^{136}Xe, ^{150}Nd, ^{48}Ca, ^{100}Mo → KamLAND-zen, SNO+, Borexino, AMoRE

Electron tracking

- Tracko-calo, Isotopes — ^{82}Se, (^{150}Nd, ^{48}Ca) → SuperNEMO
- Pixelized CdZnTe — ^{116}Cd → COBRA
- Gas TPC — ^{136}Xe → NEXT, EXO-gas

Adopted from F. Piquemal

Next generation experiments



Adopted from F. Piquemal

NEMO 3

Tracking detector: drift chambers (6180 Geiger cells)
$\sigma_t = 5$ mm, $\sigma_z = 1$ cm (vertex)

Calorimeter (1940 plastic scintillators and PMTs)
Energy Resolution FWHM=8 % (3 MeV)

Identification e^-, e^+, γ, α
Very high efficiency for background rejection

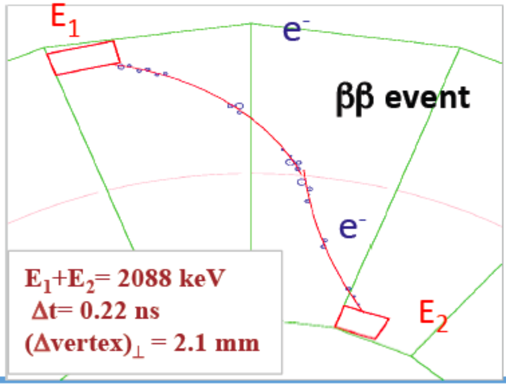
Background level @ $Q_{\beta\beta}$ [2.8 – 3.2 MeV] : 1.2 10^{-3} cts/keV/kg/y

Multi-isotope (7 measured at the same time)

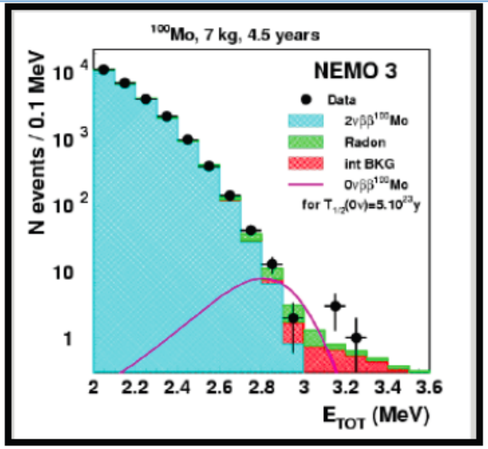
Running at Modane underground laboratory (2003 - 2011)

Unique feature

Measurement of all kinematic parameters: individual energies and angular distribution



Measurement of 7 isotopes $\beta\beta(2\nu)$ half-lifes
Excited states, Majoron limits for $\beta\beta(0\nu)$



[2.8 – 3.2] MeV 18 observed events, 16.4 ± 1.3 expected

^{100}Mo $T_{1/2}$ ($\beta\beta0\nu$) > 1.0 10^{24} y (90% C.L.)
$\langle m_\nu \rangle$ < 0.31– 0.79 eV

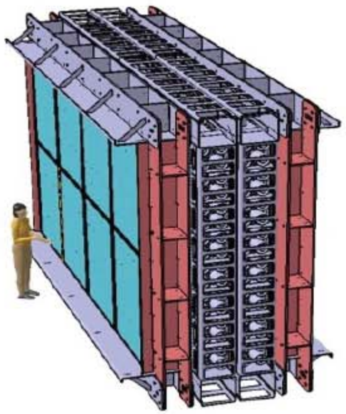
From F. Piquemal, Neutrino 2012

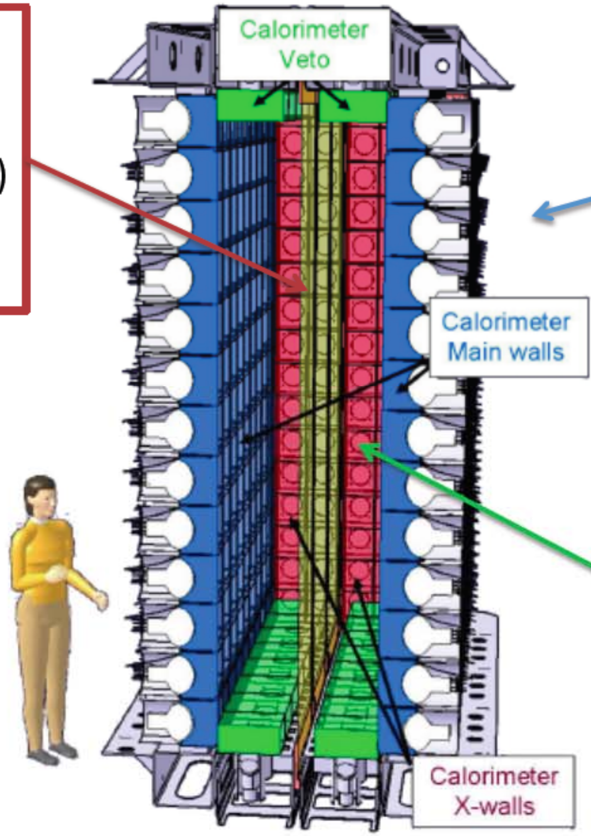
SuperNEMO Demonstrator

Objective: to reach the background level for 100 kg
to perform a no background experiment with 7 kg isotope of ^{82}Se in 2 yr

Source

^{214}Bi < 10 μBq/kg
(NEMO3 100 μBq/kg)
208Tl < 2 μBq/kg
(NEMO3 100 μBq/k)





Calorimeter

ΔE/E < 4% @ 3 MeV
(NEMO3 8.6% at 3MeV)

Tracker

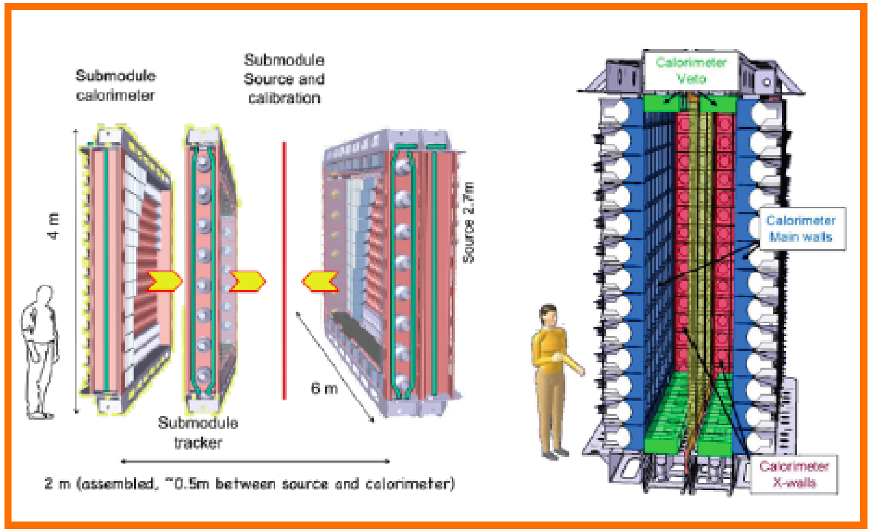
3.7 m long **(NEMO3 2.7 m)**
σ_t = 5 mm, σ_z = 1 cm
Radon < 0.15 mBq/m^3
(NEMO3 5 mBq/m^3)
Wiring robot

Global efficiency : 30 % (NEMO3 8%)

From F. Piquemal, Neutrino 2012

SuperNEMO

A module



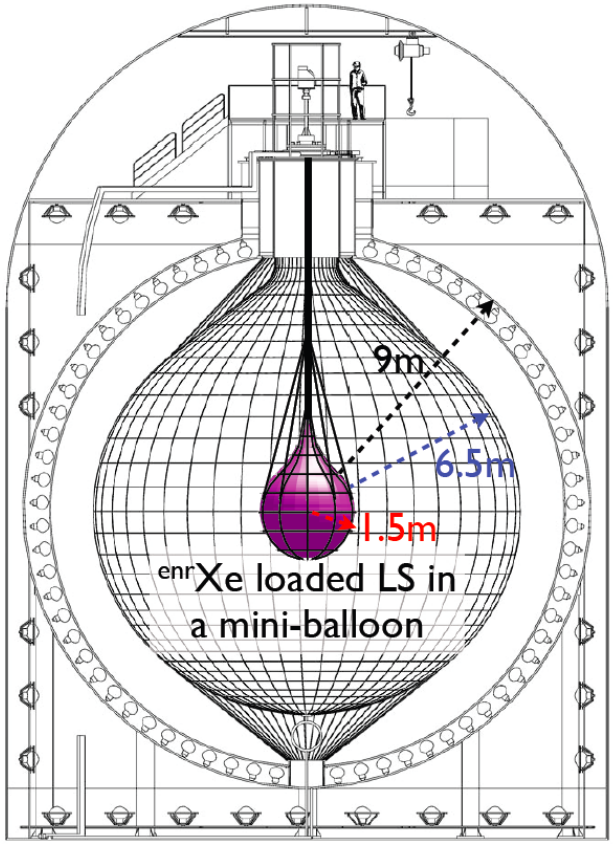
20 modules

	Demonstrator module	20 Modules
Source : ^{82}Se	7 kg	100 kg
Drift chambers for tracking	2 0000	40 000
Electron calorimeter	500	10 000
γ veto (up and down)	100	2 000
$T_{1/2}$ sensitivity	6.6 10^{24} y (No background)	1. 10^{26} y
<m_ν> sensitivity	200 – 400 meV	40 – 100 meV

From F. Piquemal, Neutrino 2012

KamLAND-Zen

Zero Neutrino
double beta decay search



idea to load Xe into LS is from Raju PRL72,1411(1994)

~320kg 90% enriched ^{136}Xe installed so far
total 600+ kg in the mine
production reaches 700kg in this year

From K. Inoue, Neutrino 2012

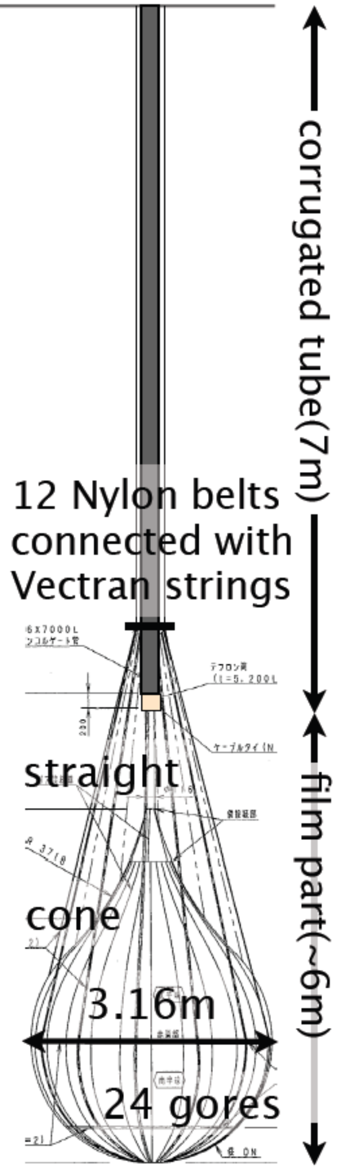
mini balloon fabrication

- produced in a class 1 super-clean-room
  (class 1 = less than 1 0.5-micron-particle in cubic feet)

less material → 25 μm Nylon6
- transparency 99.4% @400nm
- strength 19.4 N/cm
- Xe barrier < 220 g/year

low radioactivity
→ specially made no filler film

U	:	150 →	2×10^{-12}g/g
Th	:	59 →	3×10^{-12}g/g
^{40}K	:	140 →	2×10^{-12}g/g

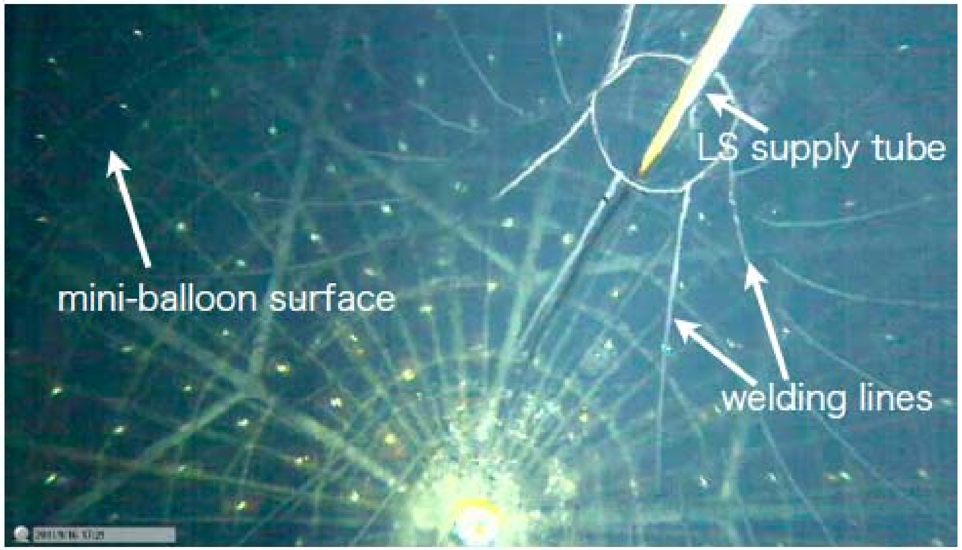


From K. Inoue, Neutrino 2012

balloon and corrugated tube deployment

balloon went through the black sheet

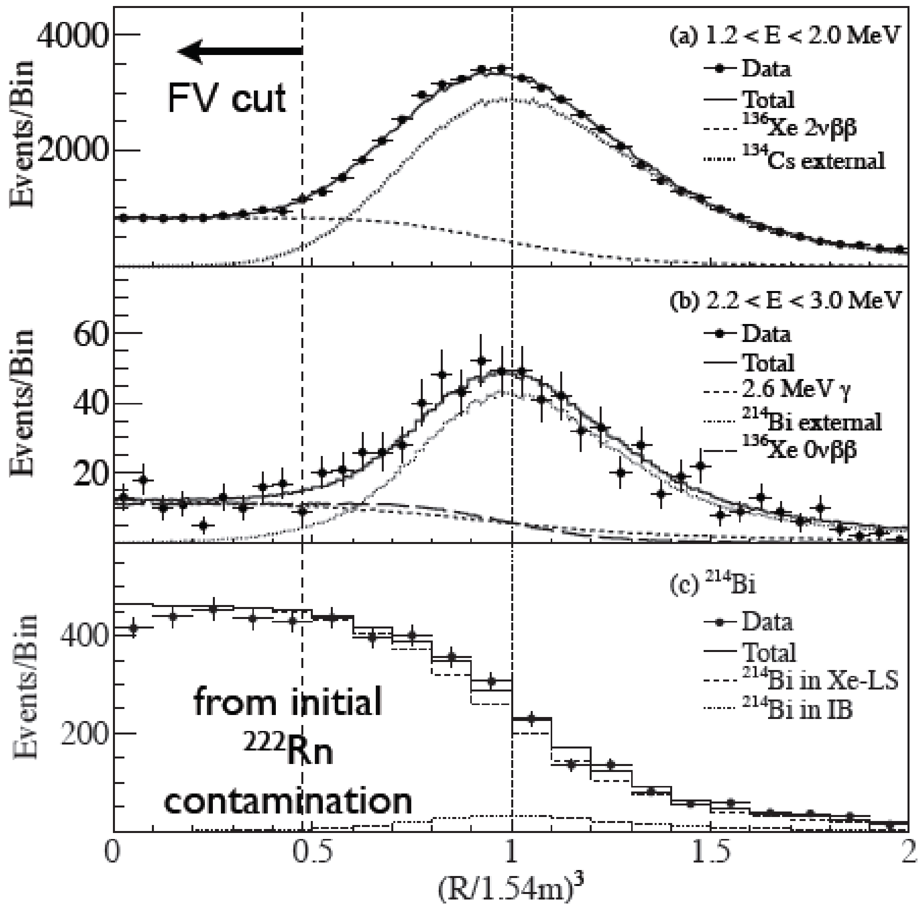
installation completed



mini-balloon inflated with dummy LS and then replaced with Xe-loaded LS
density tuning finished and tubes to be extracted

R^3 vertex distribution

R = 1.2 m R = 1.54 m



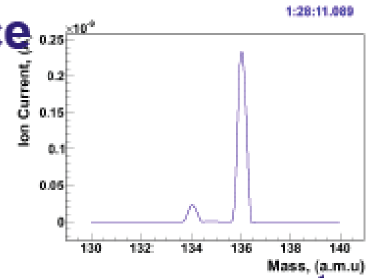
vertex resolution from balloon events
$\sim 15\text{cm}/\sqrt{E}$

Fiducial volume of Xe-LS

$R < 1.2$ m $V = 7.24$ m^3

Xe isotopic abundance

^{136}Xe : 90.93%,
^{134}Xe : 8.89%



Xe amount by weight measurement

(supplied)-(returned)

- Xe concentration = (2.44 ± 0.01) wt%

consistent direct gas chromatography analysis

- Xe concentration = (2.52 ± 0.07) wt%

Uncertainty of the fiducial volume

^{214}Bi vertex uniformity check

$V_{1.2m} / V_{total} = 0.438 \pm 0.005$
$N_{1.2m} / N_{total} = 0.423 \pm 0.007(stat) \pm 0.004(syst)$

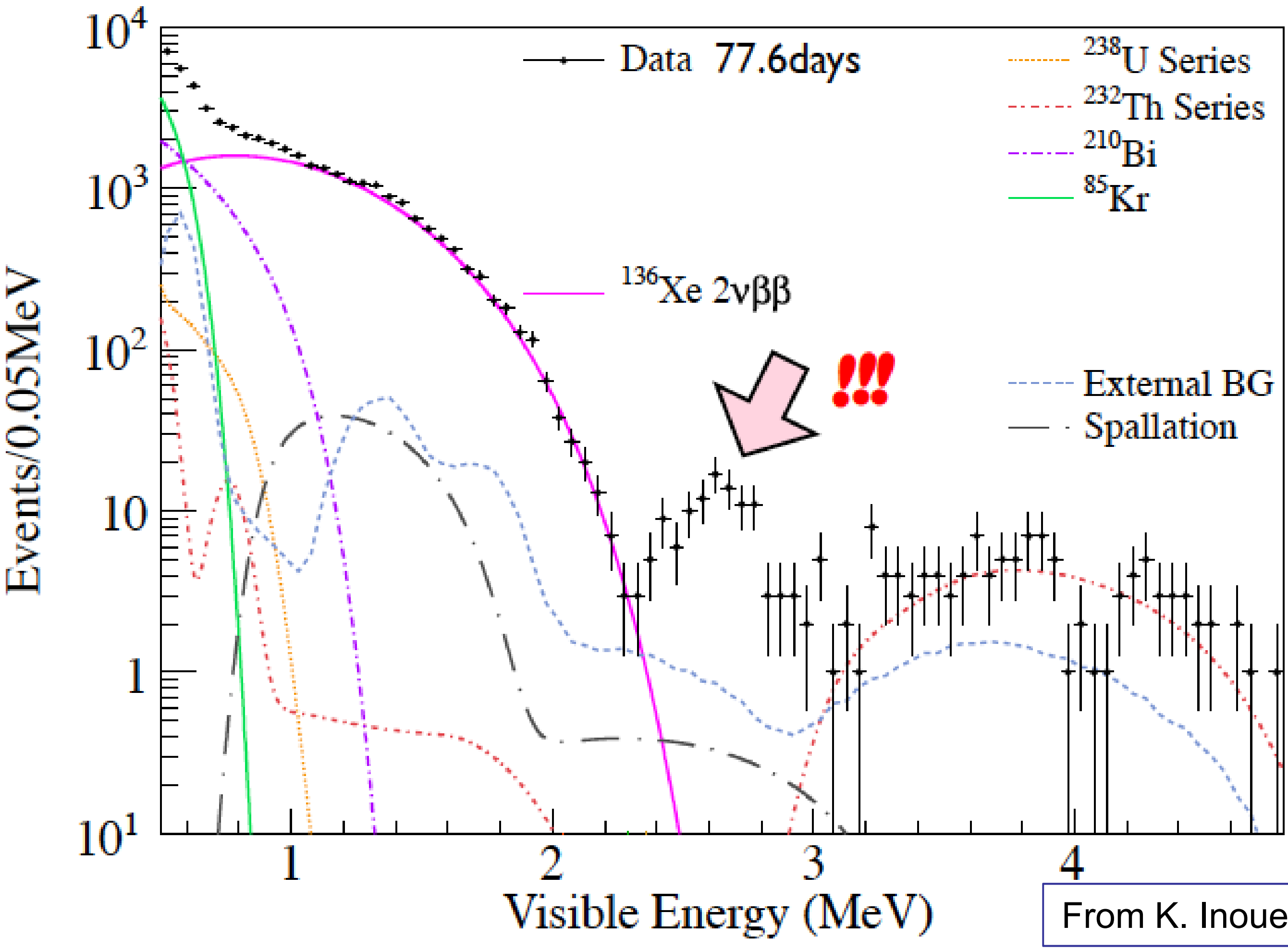
FV uncertainty ⟶ 5.2% dominant error

Xe amount in the fiducial volume

125±7 kg of ^{136}Xe in the FV

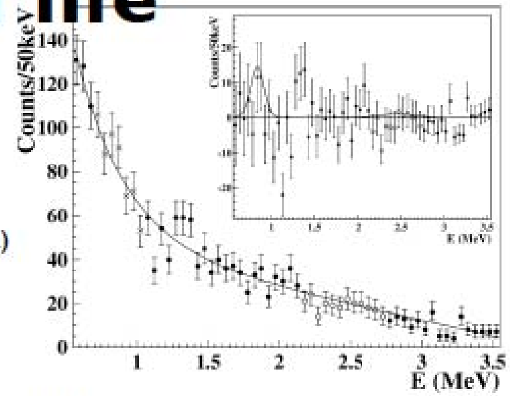
KamLAND-Zen: energy spectrum

update 2011 10/12~2012 2/9 112.3 days 38.6kg-yr



From K. Inoue, Neutrino 2012

Measurement of the 2ν2β half life

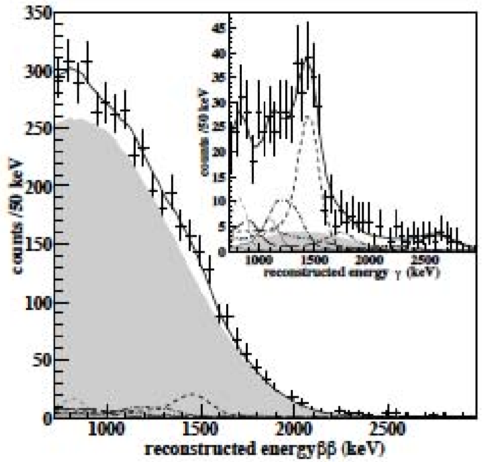


DAMA (2002) Liquid Xe scintillator

$T^{2\nu}_{1/2} > 1.0 \times 10^{22}$ years at 90% CL Phys.Lett.B546,23(2002)

factor 5 contradiction

EXO-200 (2011) Liquid Xe TPC + scintillator



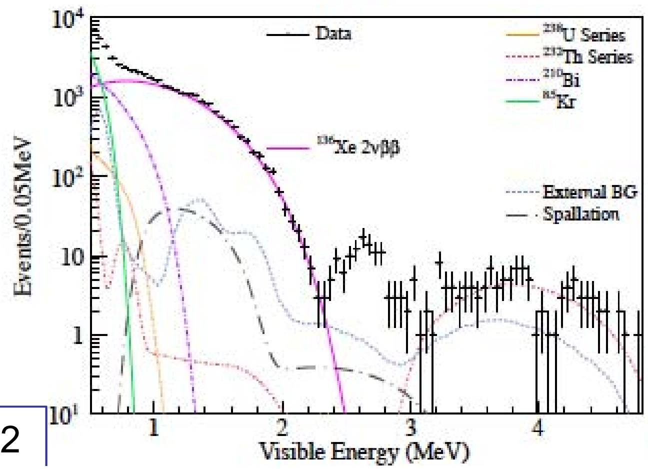
$T^{2\nu}_{1/2} = 2.11 \pm 0.04(\text{stat}) \pm 0.21(\text{syst}) \times 10^{21}$ years

Phys.Rev.Lett.107,212501(2011)

update $T^{2\nu}_{1/2} = 2.23 \pm 0.017(\text{stat}) \pm 0.22(\text{syst}) \times 10^{21}$ years

arXiv:1205.5608

KamLAND-Zen (2012) Xe loaded liquid scintillator



$T^{2\nu}_{1/2} = 2.38 \pm 0.02(\text{stat}) \pm 0.14(\text{syst}) \times 10^{21}$ years

Phys.Rev.C85,045504(2012)

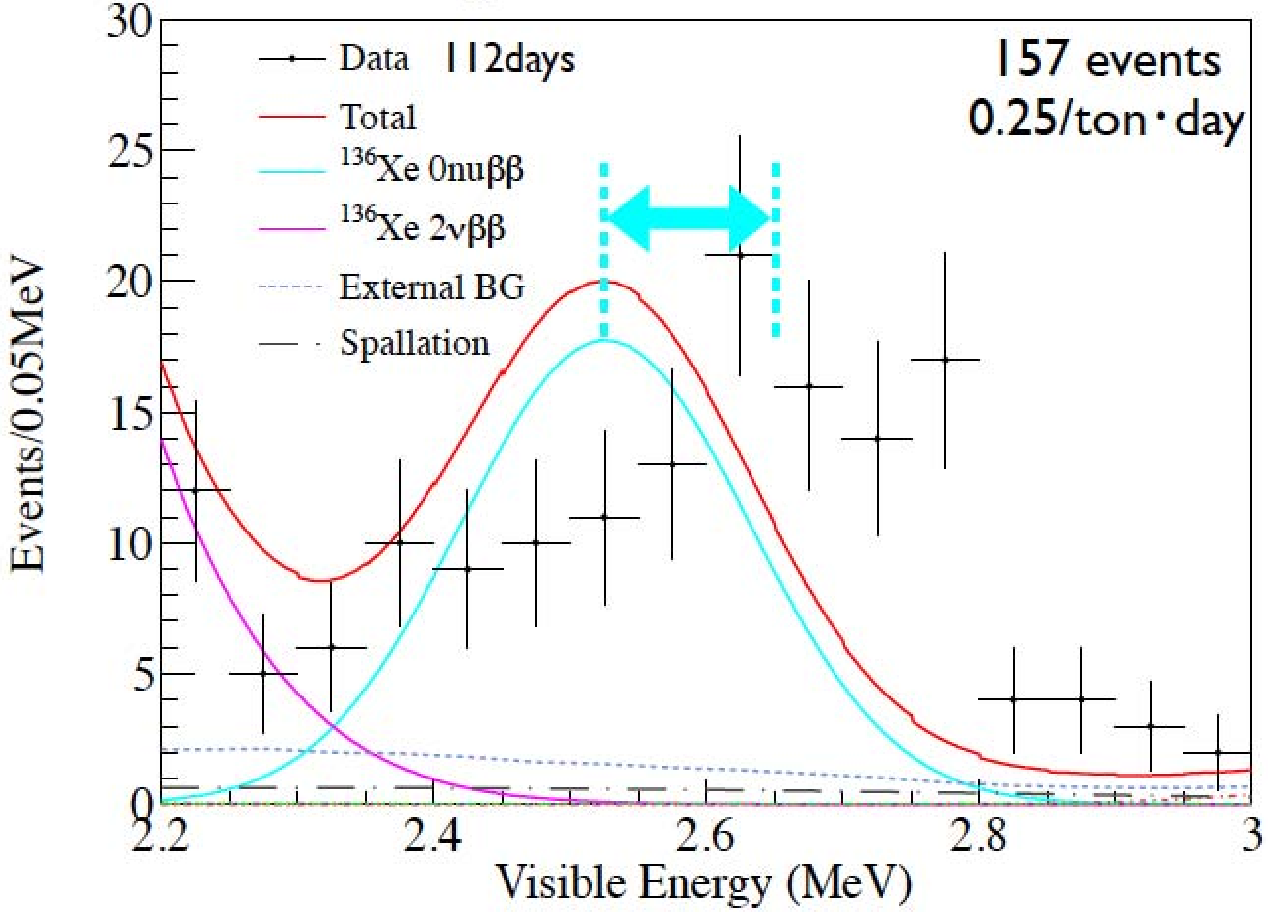
update $T^{2\nu}_{1/2} = 2.30 \pm 0.02(\text{stat}) \pm 0.12(\text{syst}) \times 10^{21}$ years

arXiv:1205.6372

From K. Inoue, Neutrino 2012

Background situation

Peak fit with 0ν signal

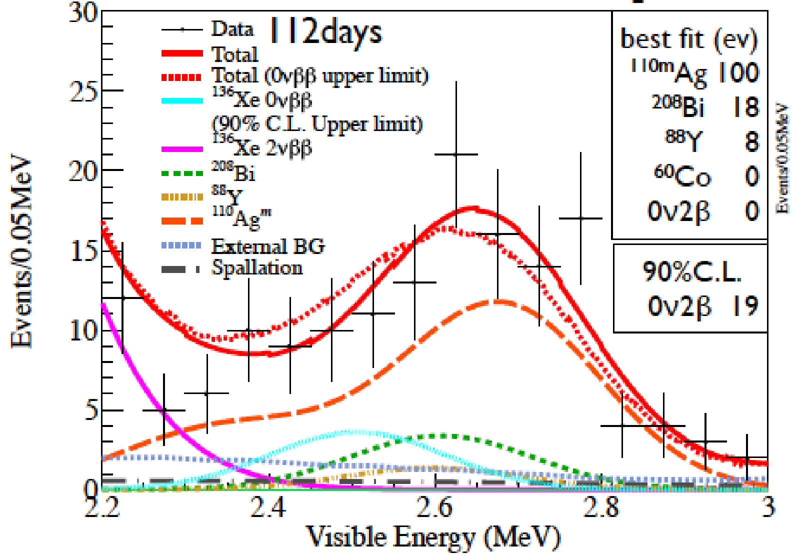


Peak position is different from that of expected 0ν.

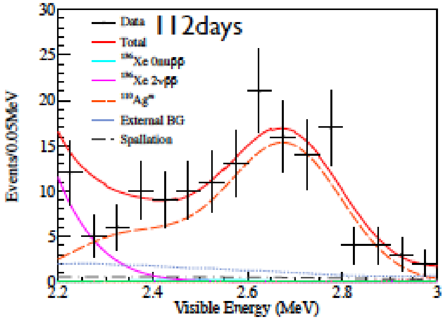
0ν only is rejected at more than 8σ level.

From K. Inoue, Neutrino 2012

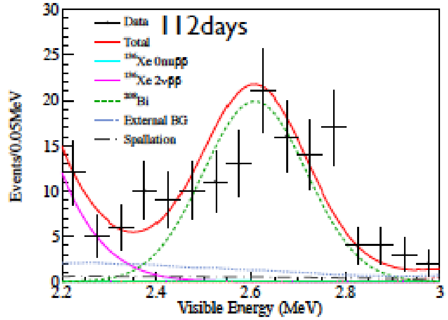
Limit on the 0ν2β half life



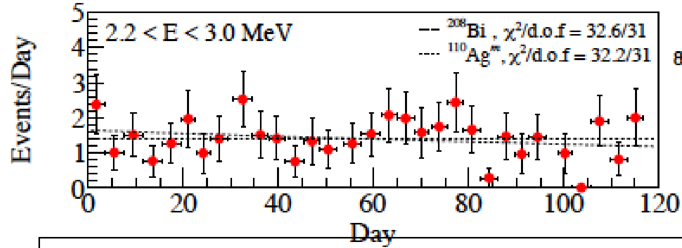
simultaneous fit and 90% CL upper limit for 0ν2β



110mAg fits well



208Bi doesn't fit well



88Y 36.0

stable in time, but no strong discrimination yet

(χ^2 at 2.2~3.0MeV)

	χ^2 112days	
simul. fit	11.6	
0ν+^{110m}Ag	13.1	
0ν+^{208}Bi	22.7	△
0ν+^{88}Y	22.2	△
0ν+^{60}Co	82.9	✕
0ν only	85.0	✕

BG is likely to be ^{110m}Ag

$T^{0\nu}_{1/2} > 5.7\times10^{24}$ years at 90% C.L. (78days)

factor 5 improvement from DAMA

$T^{0\nu}_{1/2} > 6.2\times10^{24}$ years (KL-Zen 112days)

(ref. current best is 16×10^{24} years from EXO-200)

(R)QRPA (CCM SRC)
Phys.Rev.C79,055501(2009)

$\langle m_{\beta\beta}\rangle$ <0.26~0.54 eV @90% C.L.

15

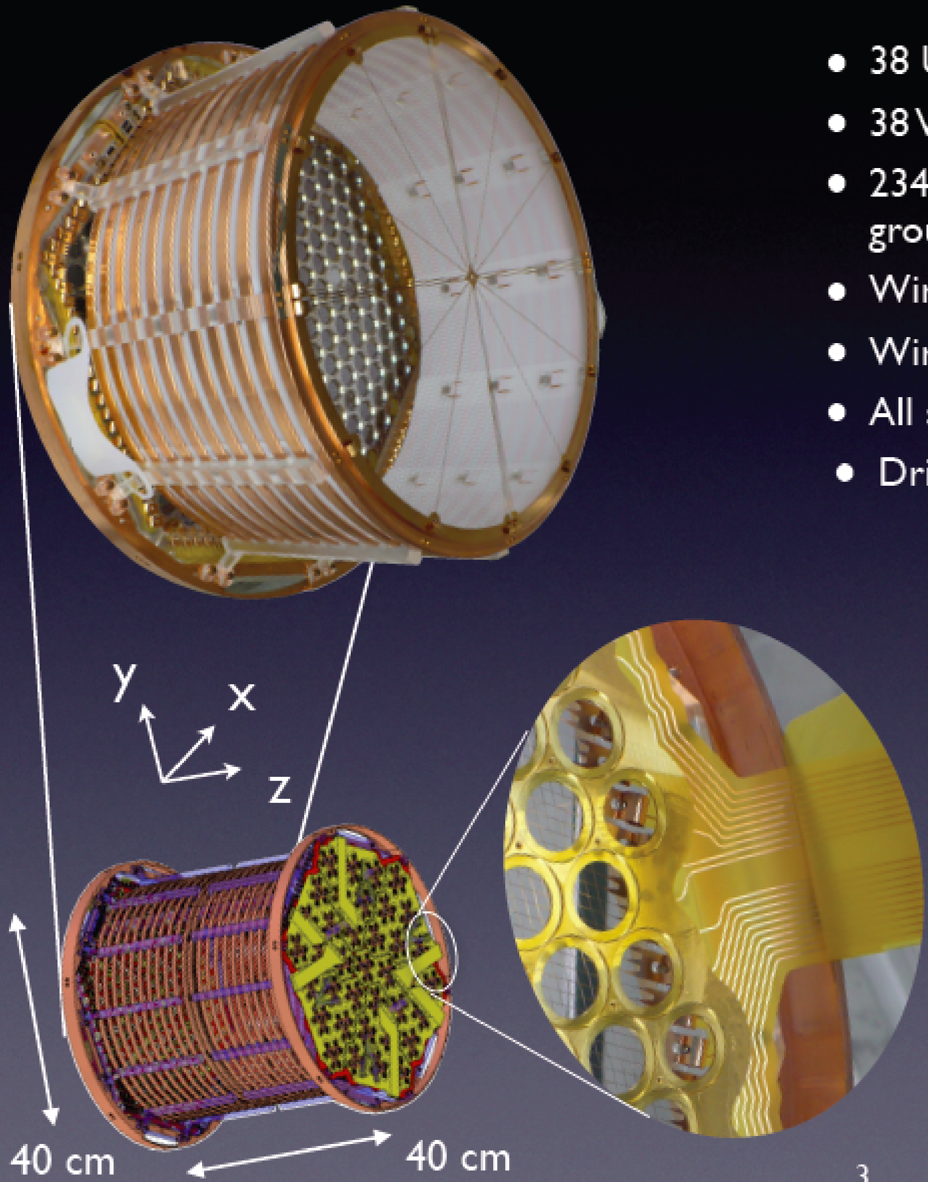
From K. Inoue, Neutrino 2012

N.B.: limit depends on correctness of background model

The EXO-200 TPC

Two almost identical halves reading ionization and 178 nm scintillation, each with:

- 38 U triplet wire channels (charge)
- 38 V triplet wire channels, crossed at 60° (induction)
- 234 large area avalanche photodiodes (APDs, light in groups of 7)
- Wire pitch 3 mm (9 mm per channel)
- Wire planes 6 mm apart and 6 mm from APD plane
- All signals digitized at 1 MS/s, ±1024S around trigger
- Drift field 376 V/cm



- Field shaping rings: copper
- Supports: acrylic
- Light reflectors/diffusers: Teflon
- APD support plane: copper; Au (Al) coated for contact (light reflection)
- Central cathode, U+V wires: photo-etched phosphor bronze
- Flex cables for bias/readout: copper on kapton, no glue

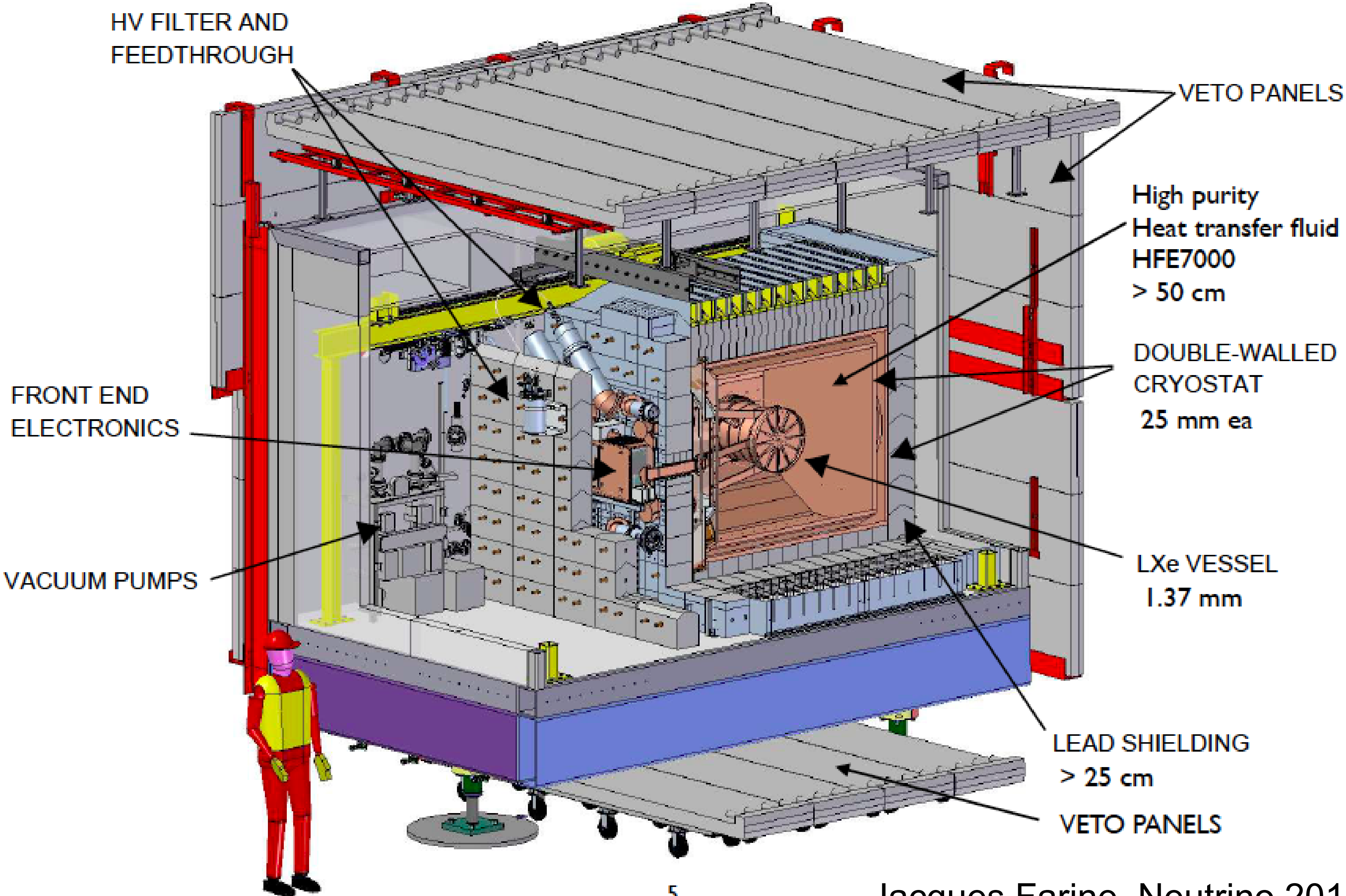
Comprehensive material screening program

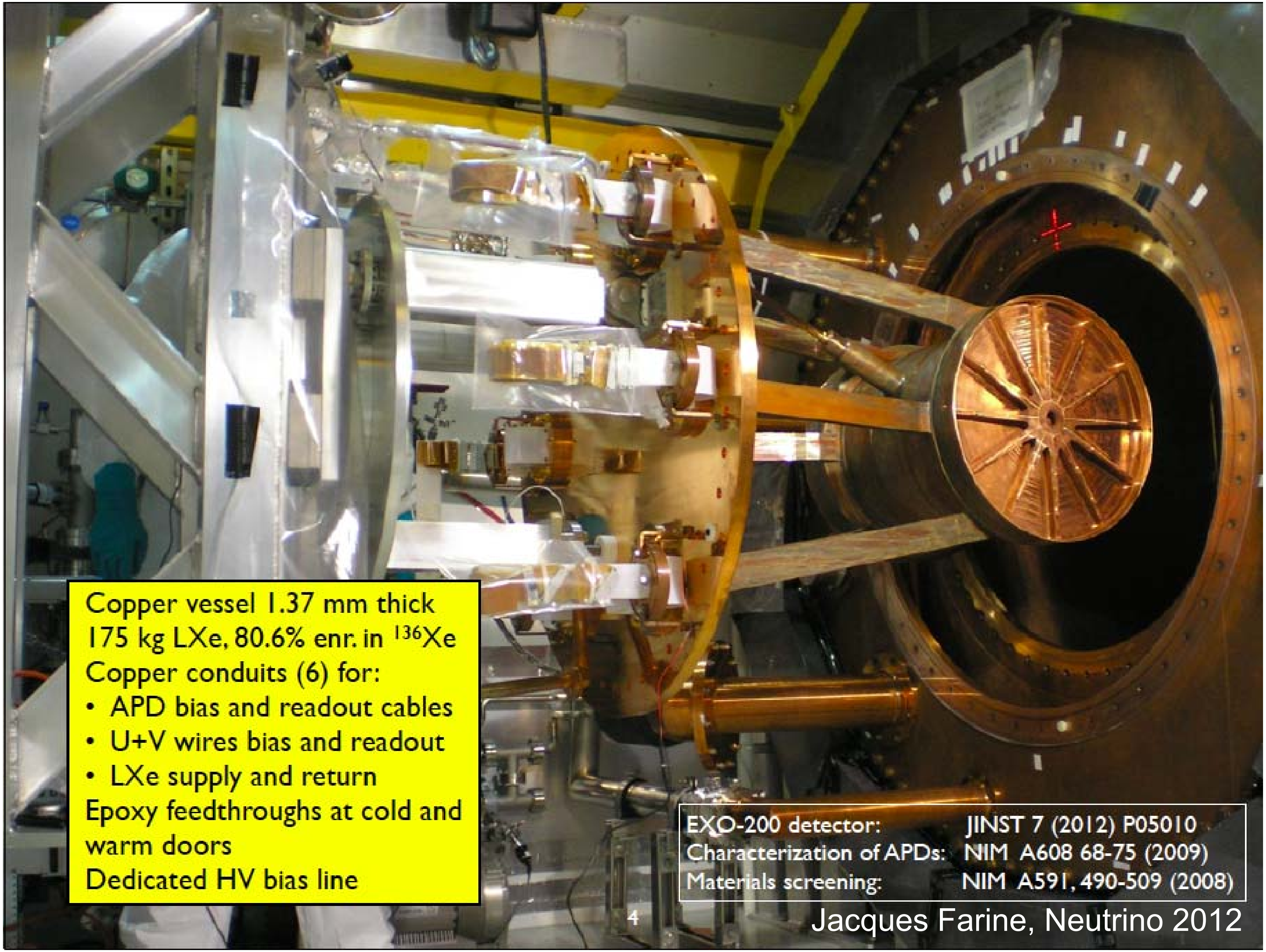
Goal: 40 cnts/2y in $0\nu\beta\beta$ ±2σ ROI, 140 kg LXe

3

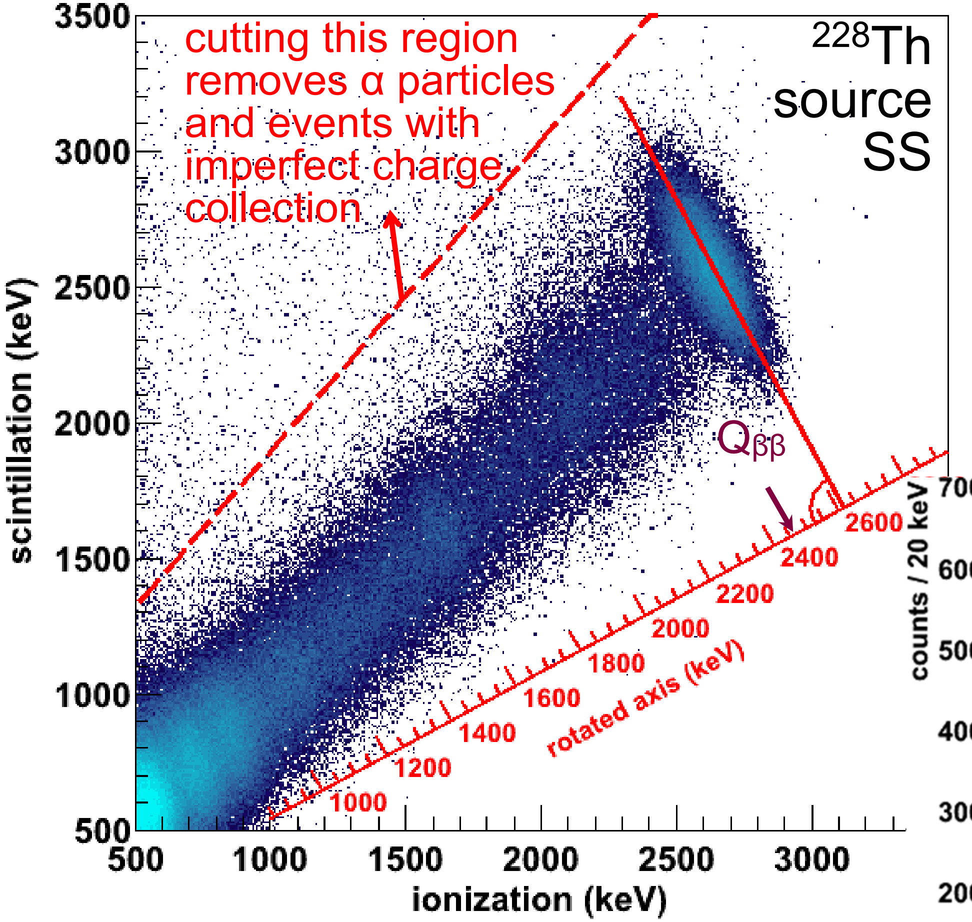
Jacques Farine, Neutrino 2012

The EXO-200 Detector




Copper vessel 1.37 mm thick
175 kg LXe, 80.6% enr. in ^{136}Xe
Copper conduits (6) for:
• APD bias and readout cables
• U+V wires bias and readout
• LXe supply and return
Epoxy feedthroughs at cold and warm doors
Dedicated HV bias line
EXO-200 detector: JINST 7 (2012) P05010
Characterization of APDs: NIM A608 68-75 (2009)
Materials screening: NIM A591, 490-509 (2008)
4
Jacques Farine, Neutrino 2012

Combining Ionization and Scintillation

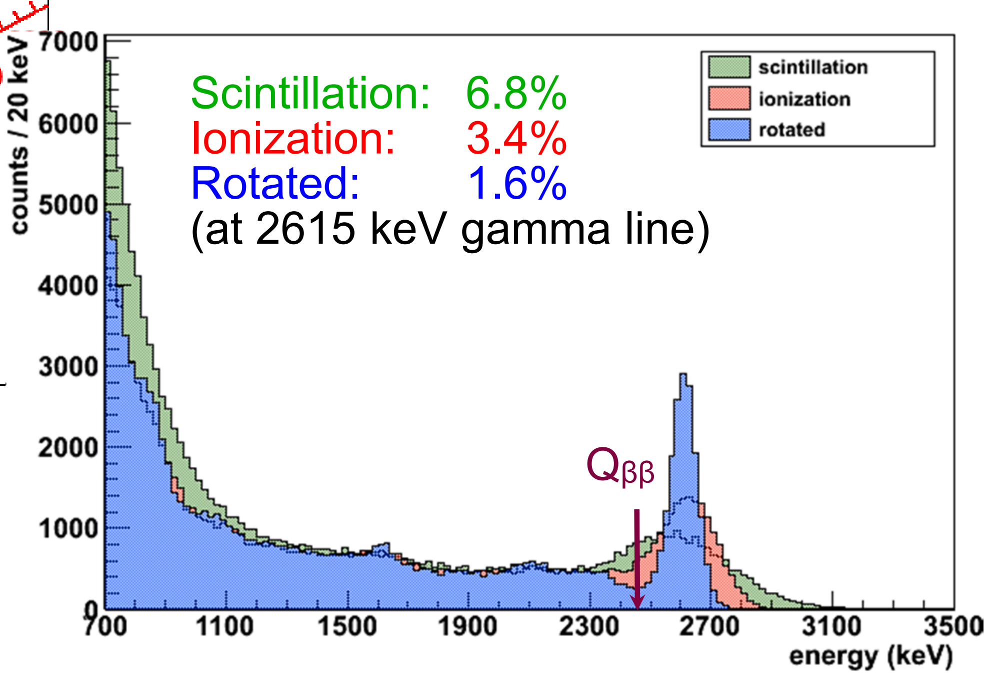


Rotation angle chosen to optimize energy resolution at 2615 keV

Properties of xenon cause increased scintillation to be associated with decreased ionization (and vice-versa)

E. Conti et al. Phys. Rev. B 68 (2003) 054201

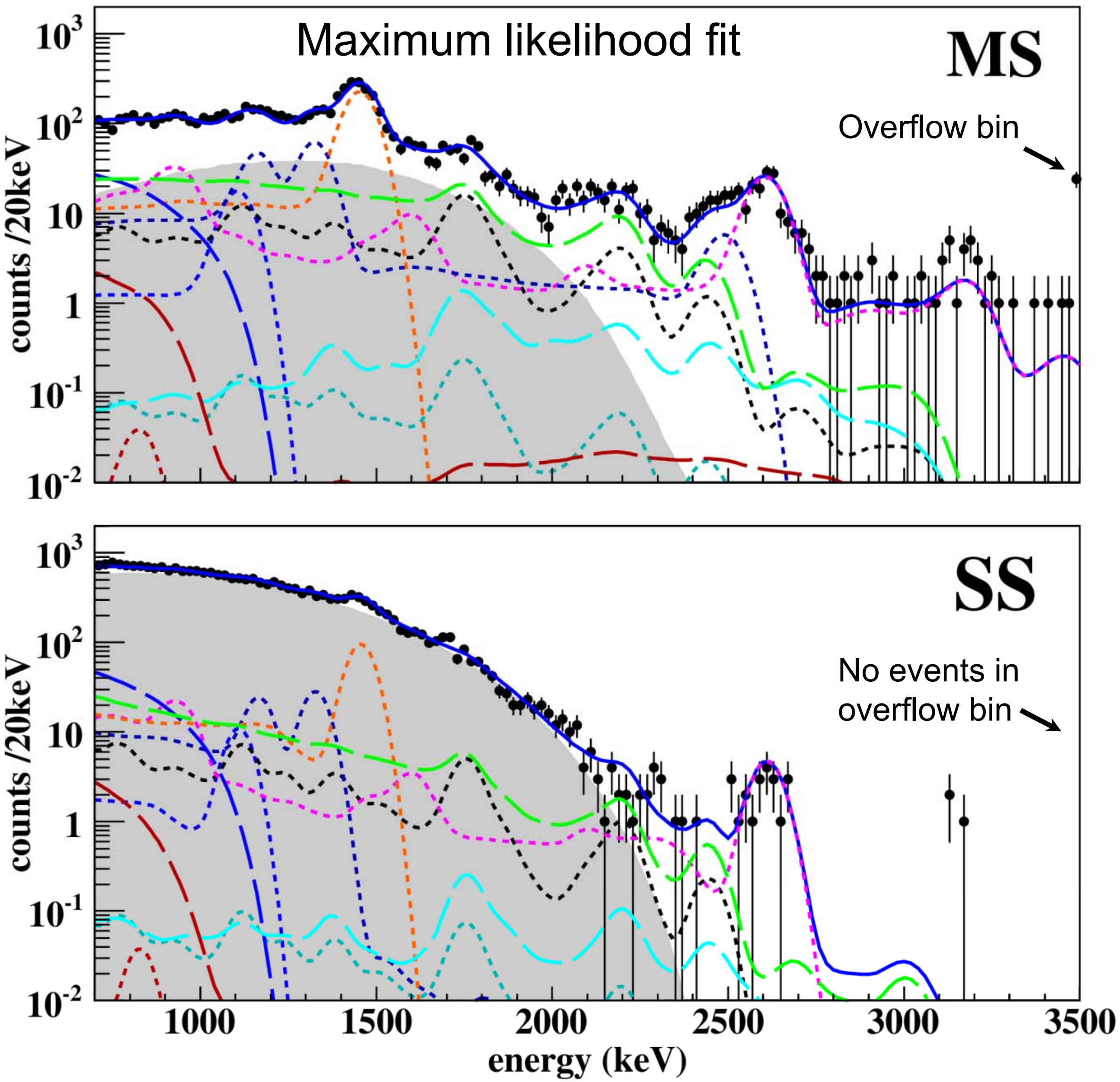
Use projection onto a rotated axis to determine event energy



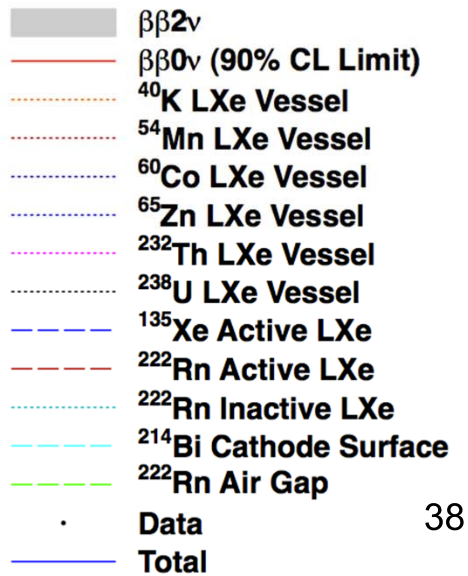
Jacques Farine, Neutrino 2012 37

From J. Farine, Neutrino 2012

Low Background Spectrum



- Trigger fully efficient above 700 keV
- Low background run livetime: **120.7 days**
- Active mass: **98.5 kg LXe (79.4 kg ^{136}LXe)**
- Exposure: **32.5 kg·yr**
- Total dead time (vetos): 8.6%
- Various background PDFs fitted along with 2νββ and 0νββ PDFs

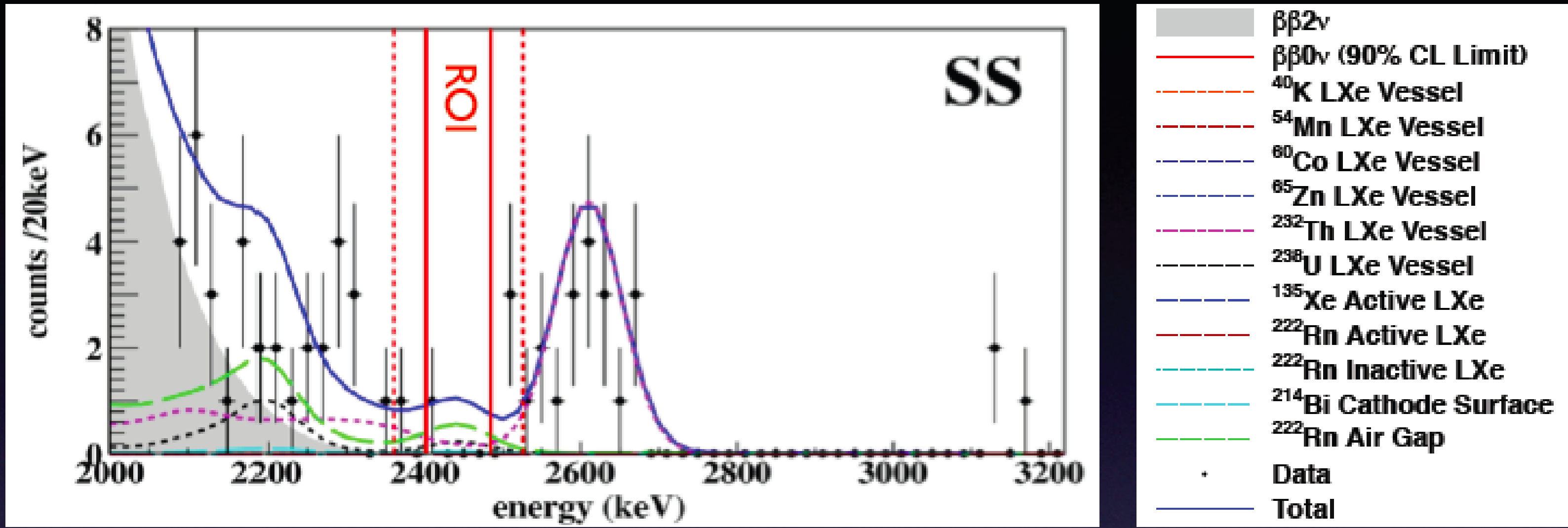


$T_{1/2}^{2\nu\beta\beta}$ (^{136}Xe) = (2.23 ± 0.017 stat ± 0.22 sys)·10^{21} yr

(In agreement with previously reported measurements)

From J. Farine, Neutrino 2012

Background counts in ±1,2 σ ROI



	Expected events from fit			
	±1 σ		±2 σ	
^{222}Rn in cryostat air-gap	1.9	±0.2	2.9	±0.3
^{238}U in LXe Vessel	0.9	±0.2	1.3	±0.3
^{232}Th in LXe Vessel	0.9	±0.1	2.9	±0.3
^{214}Bi on Cathode	0.2	±0.01	0.3	±0.02
All Others	~0.2		~0.2	
Total	4.1	±0.3	7.5	±0.5
Observed	1		5	
Background index b ($kg^{-1}yr^{-1}keV^{-1}$)	$1.5 \cdot 10^{-3} \pm 0.1$		$1.4 \cdot 10^{-3} \pm 0.1$	

EXO-200 goal (slide 3):

40 cnts/2y in ±2σ ROI, 140 kg LXe

In this data 120 days, 98.5 kg, this would be: 4.6

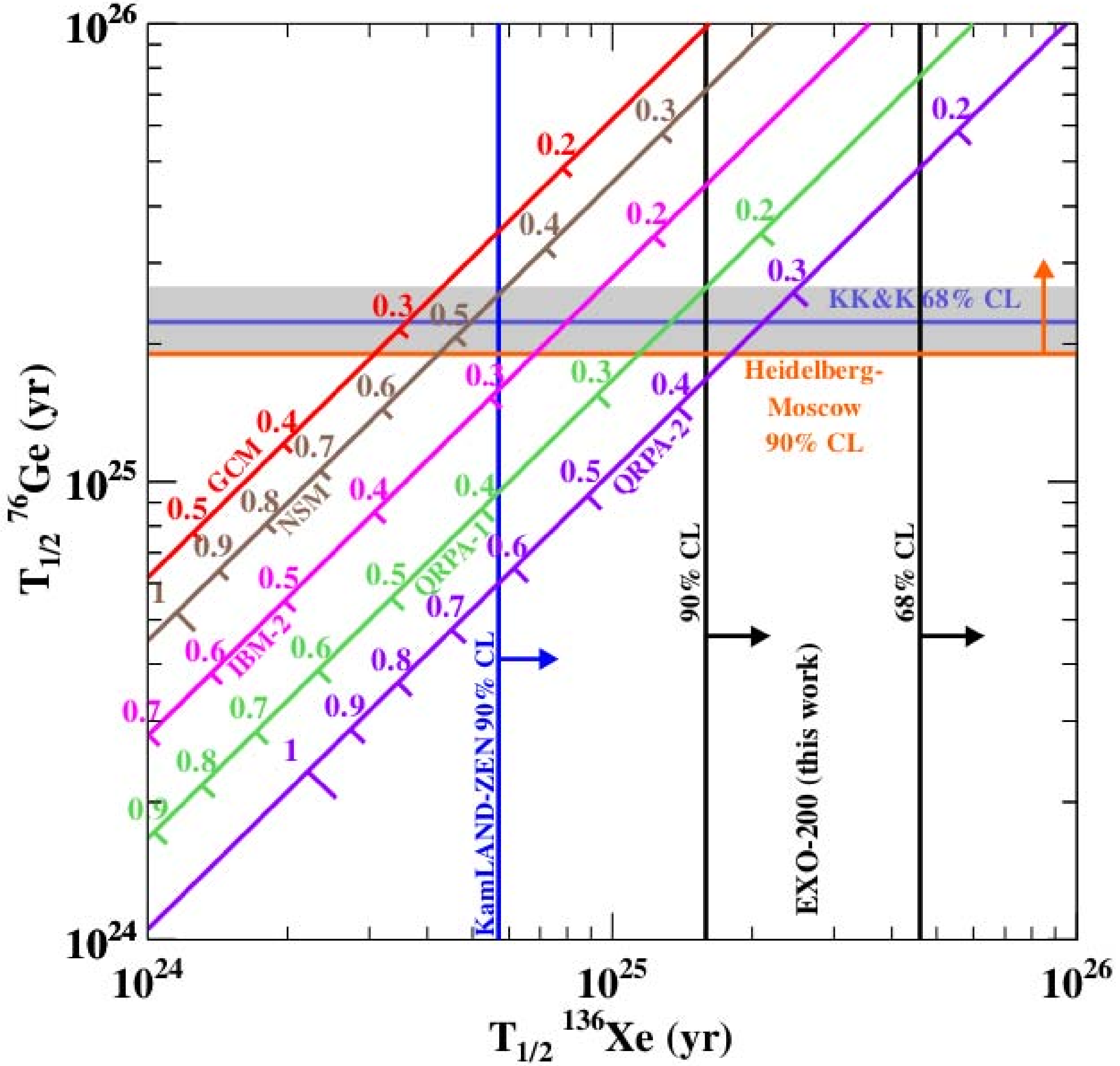
Expected from the fit: 7.5

Observed: 5

Background within expectation

From J. Farine, Neutrino 2012

Limits on $T_{1/2}^{0\nu\beta\beta}$ and $<m_{\beta\beta}>$



90% C.L. limit compared with Recent ^{136}Xe constraints (KamLAND-ZEN) >2.5 factor improvement.

$T_{1/2}^{0\nu\beta\beta} > 1.6 \cdot 10^{25}$ yr

$<m_{\beta\beta}> < 140 - 380$ mV

(90% C.L.)

[arXiv:1205.5608]

Tension with discovery claim in Ge.

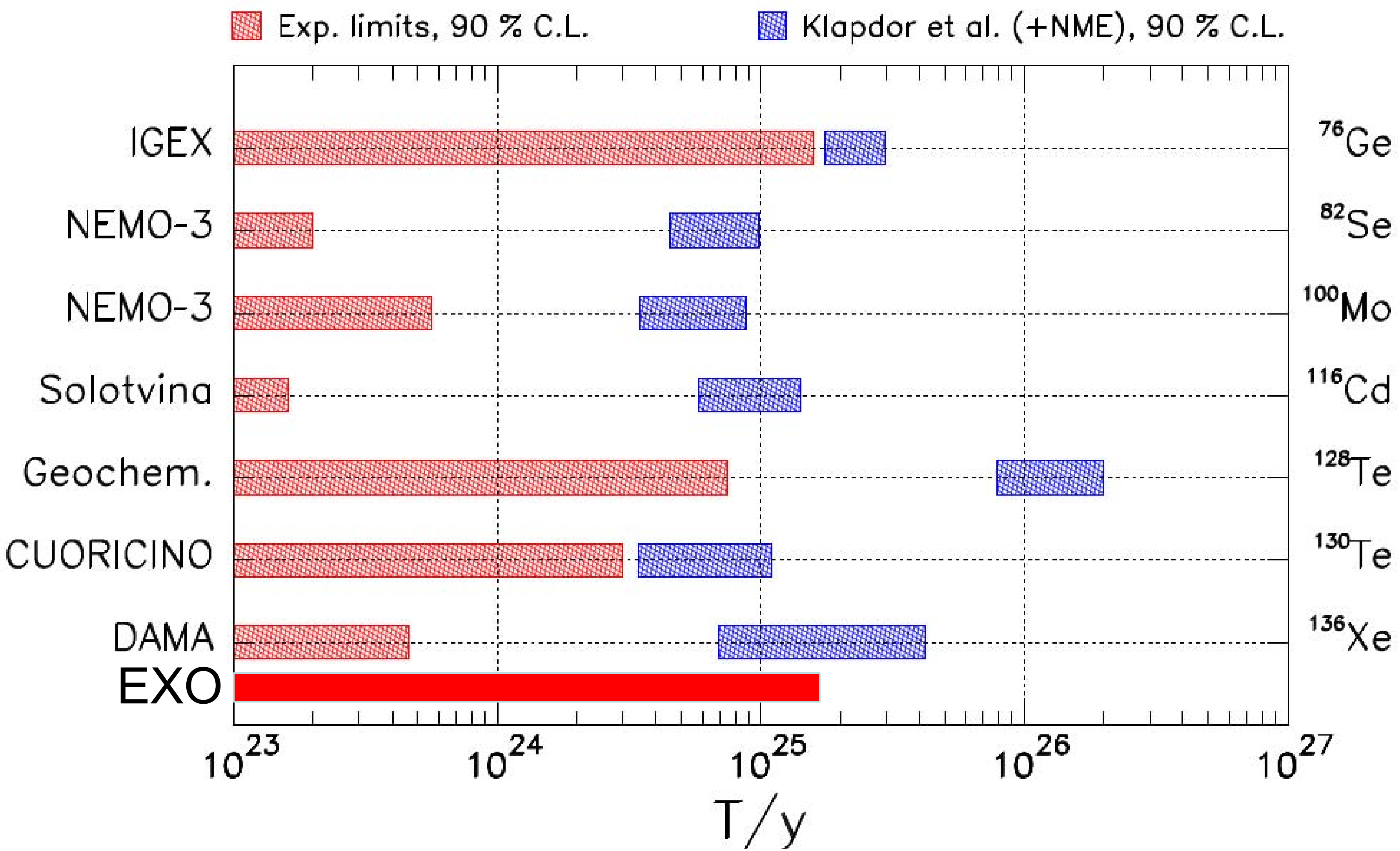
KamLAND-Zen Collaboration
Phys. Rev. C 85 (2012) 045504]
[H.V. Klapdor-Kleingrothaus et al.
Eur. Phys. J. A12 (2001) 147]
[H.V. Klapdor-Kleingrothaus and I.V. Krivosheina
Mod. Phys. Lett., A21 (2006) 1547]

From J. Farine, Neutrino 2012

Comparison of upper limits (90 % C.L.) with claim [16] for QRPA NME

A.Faessler, G.L. Fogli, E. Lisi, V. Rodin, A.M. Rotunno, F. Simkovic, PhysRevD.79.053001

arXiv:0810.5733v2 (EXO result included by 'hand')



[16] H. V. Klapdor-Kleingrothaus and I. V. Krivosheina, "The Evidence For The Observation Of $0\nu\beta\beta$ Decay: The Identification Of $0\nu\beta\beta$ Events From The Full Spectra," Mod. Phys. Lett. A **21**, 1547 (2006).

Table 2 Bayesian posterior probabilities $p(\bar{H})$ using EXO-200 data for the hypothesis that the $0\nu\beta\beta$ signal of Heidelberg-Moscow is correct. Probabilities are given for different matrix element calculations and for the $\pm 1\sigma$ and $\pm 2\sigma$ energy windows.

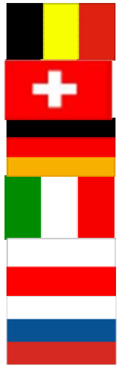
method	**expected signal events**	$p(\bar{H})$ **in %**	**expected signal events**	$p(\bar{H})$ **in %**
	in $\pm 1\sigma$ window		in $\pm 2\sigma$ window	
QRPA max	4.4 ± 1.1	4	6.1 ± 1.5	6
QRPA min	2.8 ± 0.7	11	3.9 ± 0.9	16
ISM	10.6 ± 2.5	0.1	14.8 ± 3.5	0.2
GCM	14.3 ± 3.4	0.03	19.9 ± 4.8	0.05
pnQRPA	6.3 ± 1.5	1	8.8 ± 2.1	2
IBM	6.1 ± 1.5	1	8.6 ± 2.1	2

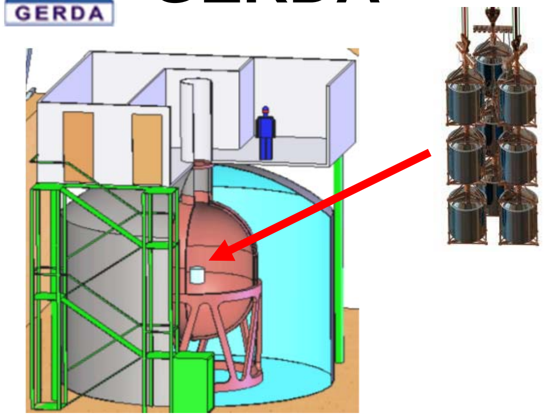
N.B. comparison with HdM claim (28±6.86) cts in 71.7 kg yr

B. Schwingenheuer, Annalen der Physik, August 22, 2012

Two ^{76}Ge projects:

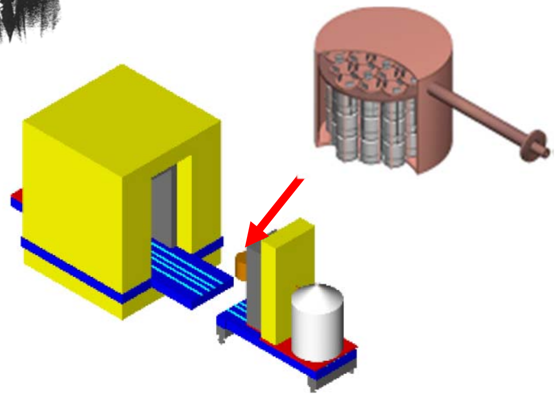
GERDA

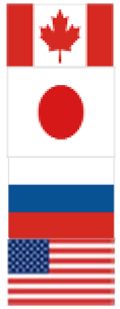




- 'Bare' ^{enr}Ge array in liquid argon
- Shield: high-purity liquid Argon / H_2O
- Phase I: 18 kg (HdM/IGEX) / 15 kg nat.
- Phase II: add ~20 kg new enr. detectors; total ~40 kg

Majorana





- Array(s) of ^{enr}Ge housed in high-purity electroformed copper cryostat
- Shield: electroformed copper / lead
- Initial phase: R&D demonstrator module: Total ~60 kg (30 kg enr.)

Physics goals: degenerate mass range
Technology: study of bgds. and exp. techniques

LoI
- open exchange of knowledge & technologies (e.g. MaGe MC)
- intention to merge for O(1 ton) exp. (inv. Hierarchy) selecting the best technologies tested in GERDA and Majorana

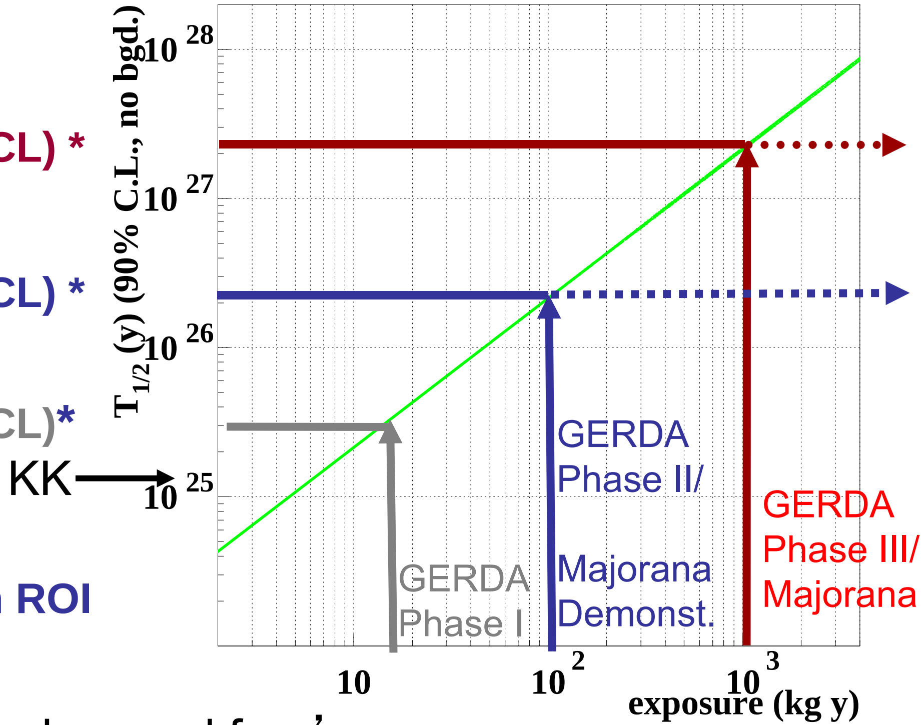
Phases and physics reach

2·10^27 (90 % CL) *

2·10^26 (90 % CL) *

2·10^25 (90 % CL)*

*: no event in ROI



<24 - 41 meV

<75 - 129 meV

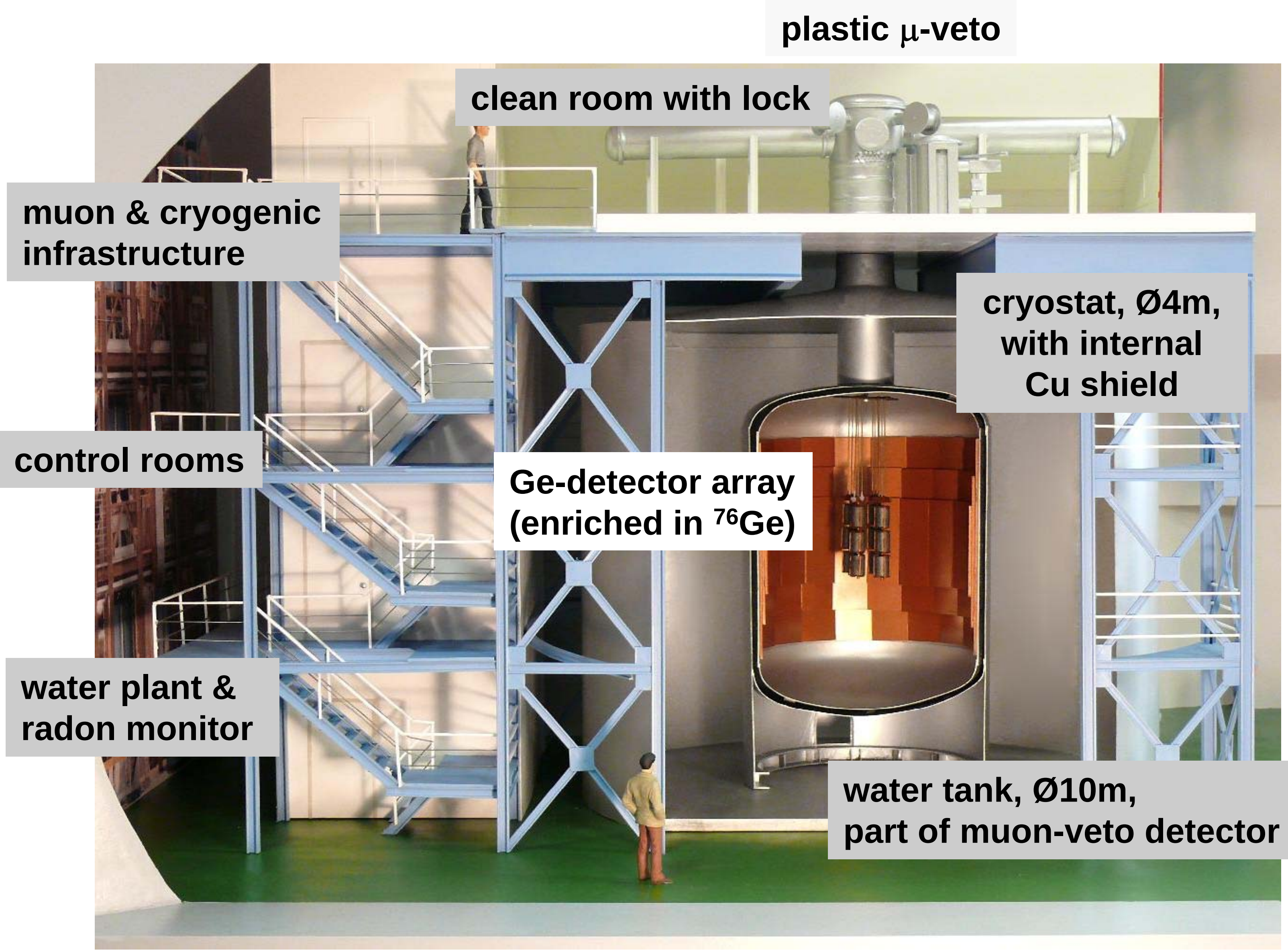
assuming
$|M^{0\nu}|$=2.99-8.99
[Smol&Grab PRC' 10]
and 86% enrichment

required for 'background free'
exp. with ΔE~3.3 keV (FWHM): **O(10^-3)** **O(10^-4)** counts/(kg·y·keV)

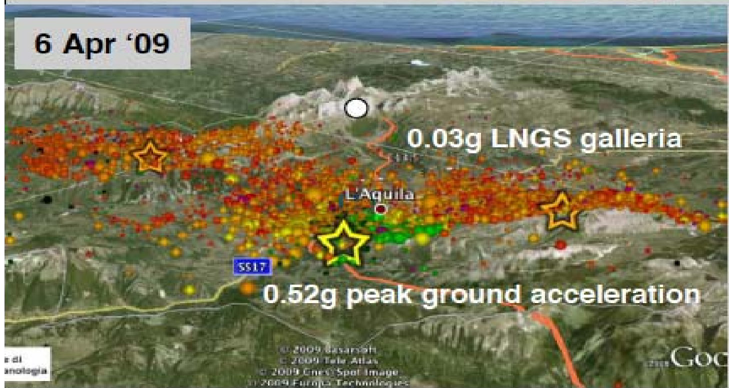
Background requirement for GERDA/Majorana:

⇒Background reduction by factor **10^2 - 10^3** required w.r.t. to precursor exps.

⇒Degenerate mass scale **O(10^2 kg·y)** ⇒ Inverted mass scale **O(10^3 kg·y)**


plastic μ-veto
clean room with lock
muon & cryogenic infrastructure
cryostat, Ø4m, with internal Cu shield
control rooms
Ge-detector array (enriched in 76Ge)
water plant & radon monitor
water tank, Ø10m, part of muon-veto detector

GERDA construction phase 2008-2010



Cryostat filled since December 2009

GERDA phase I detectors

- All diodes reprocessed and optimized for LAr
- Well tested procedure for detector handling
- Long term stability in LAr established
- Energy resolution in LAr: ~2.5 keV (FWHM) @1.3 MeV

8 diodes (from HdM, IGEX):
- Enriched 86% in ^{76}Ge
- Total mass 17.66 kg

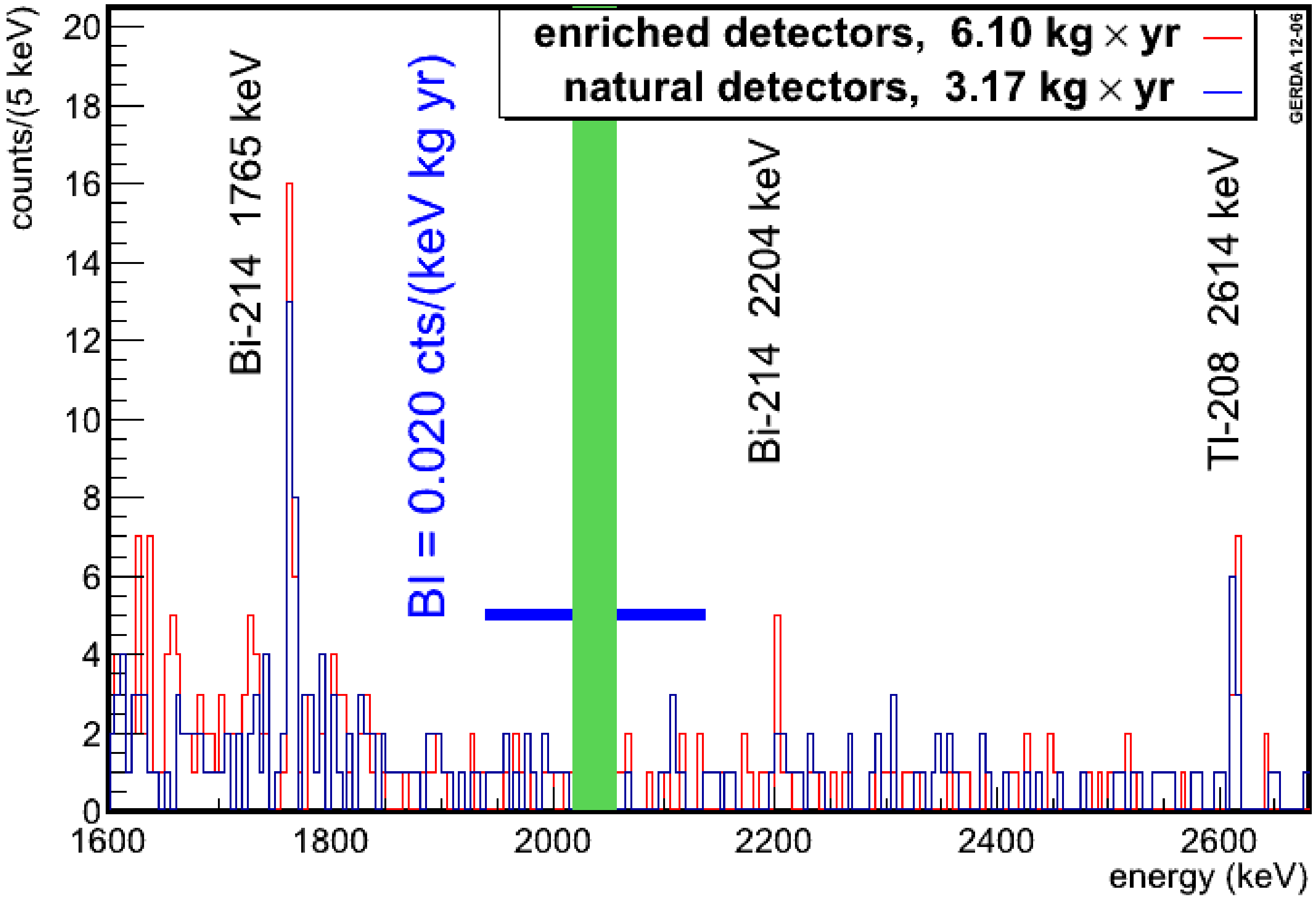
6 diodes from Genius-TF:
- ^{nat}Ge
- Total mass: 15.60 kg

3-string assembly for phase I run

started Nov 2011

8 refurbished enriched diodes from HdM & IGEX
- 86% isotopically enriched in Ge-76
- 17.66 kg total mass
- plus 1 natural Ge diode from GTF

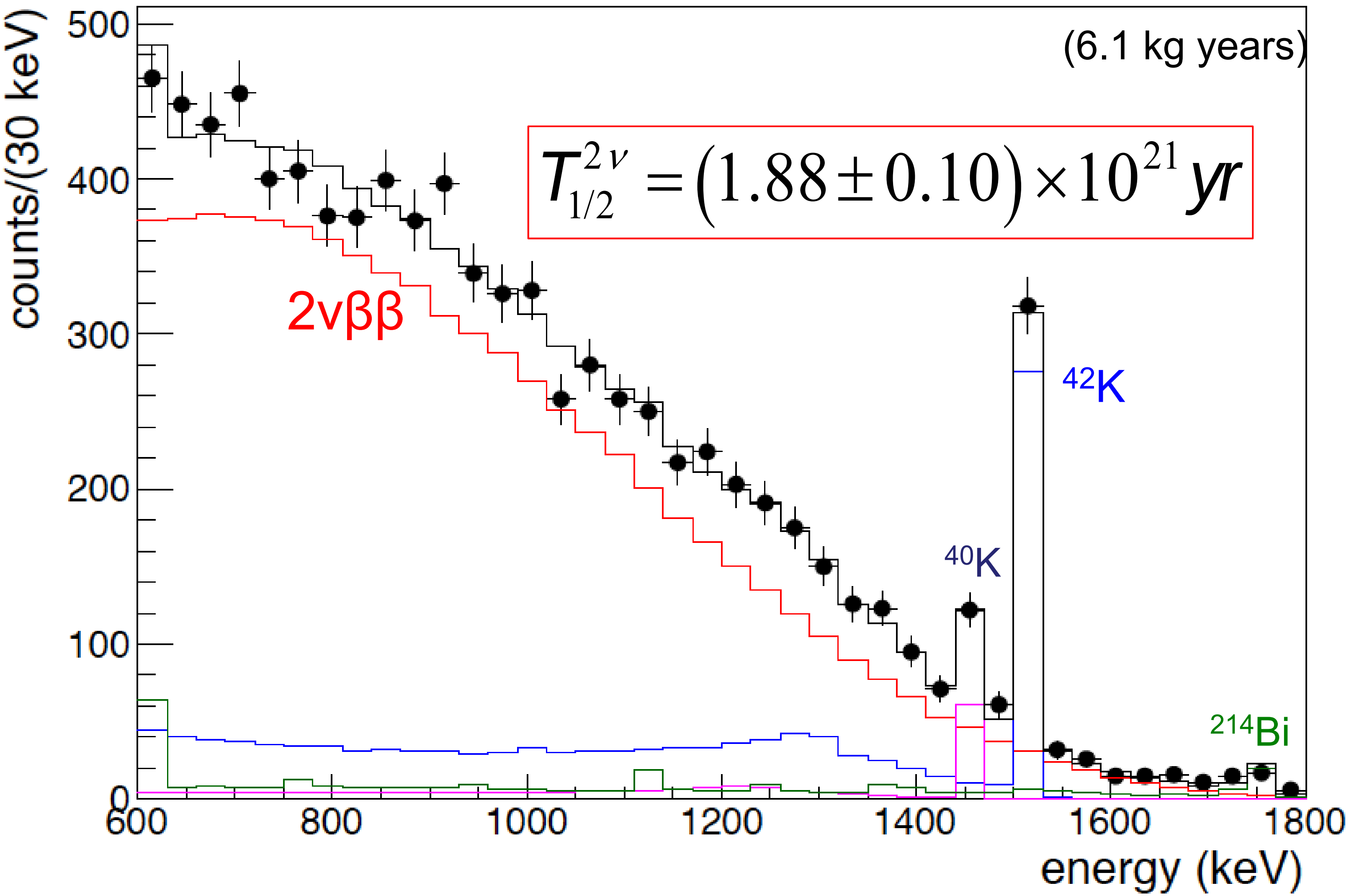
2 diodes shut off because leakage current high:
- total enriched enriched detector mass 14.6 kg



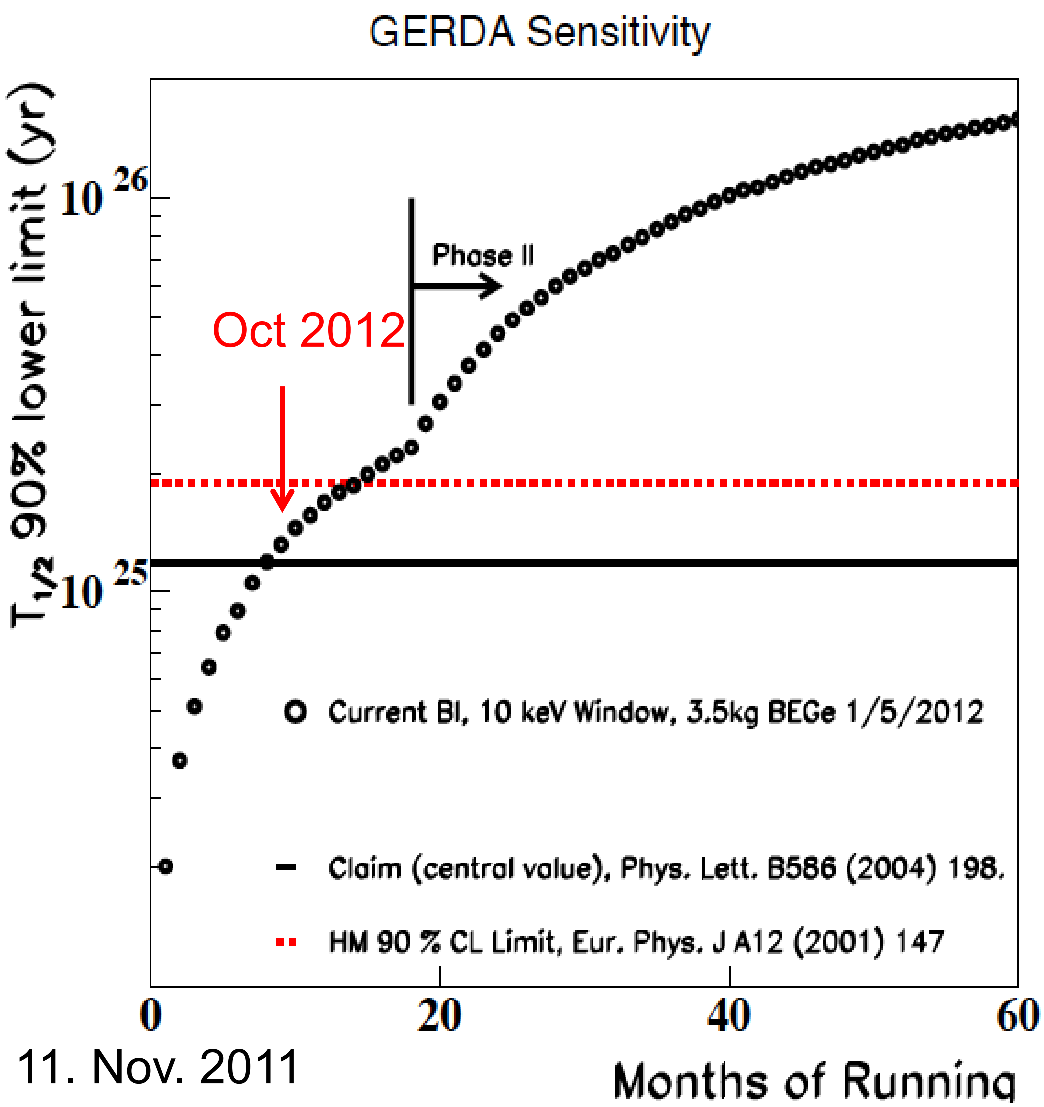
Background index usually evaluated in ($Q_{\beta\beta} \pm$ 100) keV
(excluding blinded region of ($Q_{\beta\beta} \pm 20$) keV)

preliminary results

2νββ-spectrum

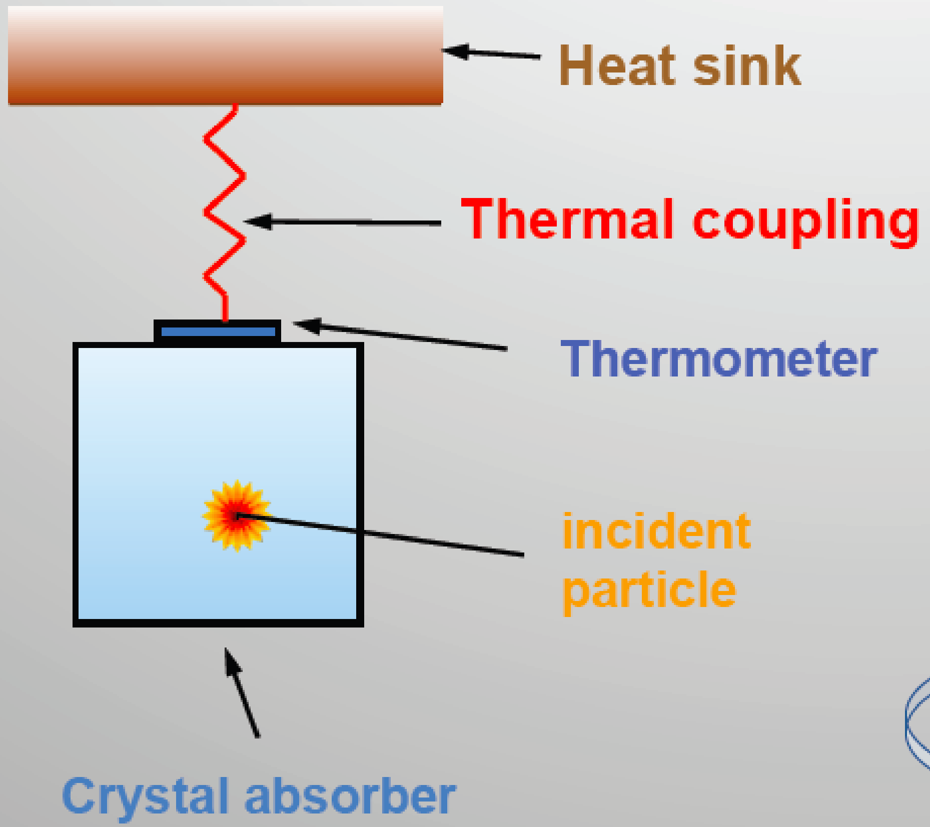


GERDA sensitivity



Bolometric technique

The working principle is very simple:



This technique measures **all** the energy deposited by a particle in form of increase of temperature in the absorber

↓

Absorber ≡ DBD source

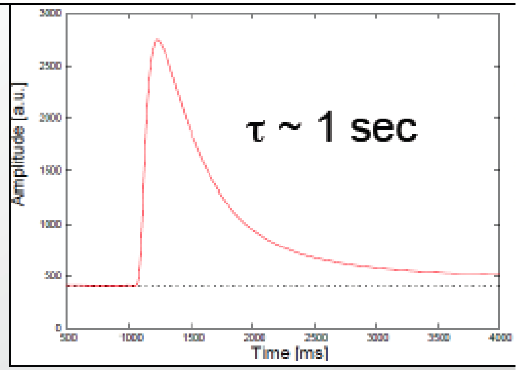
Signal: $\Delta T = E/C$

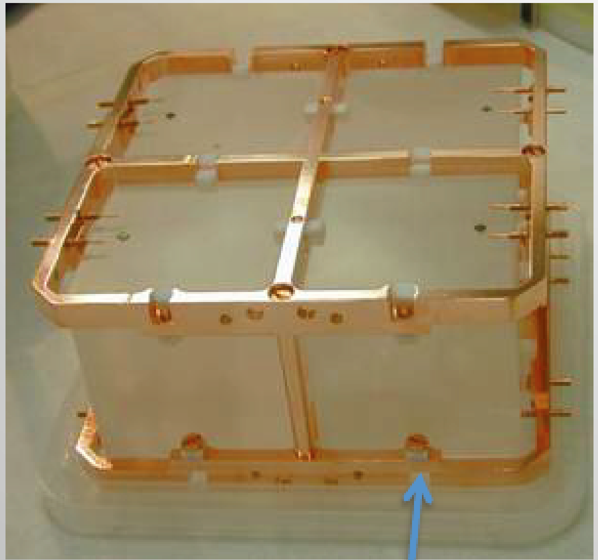
Time constant $= C/G$

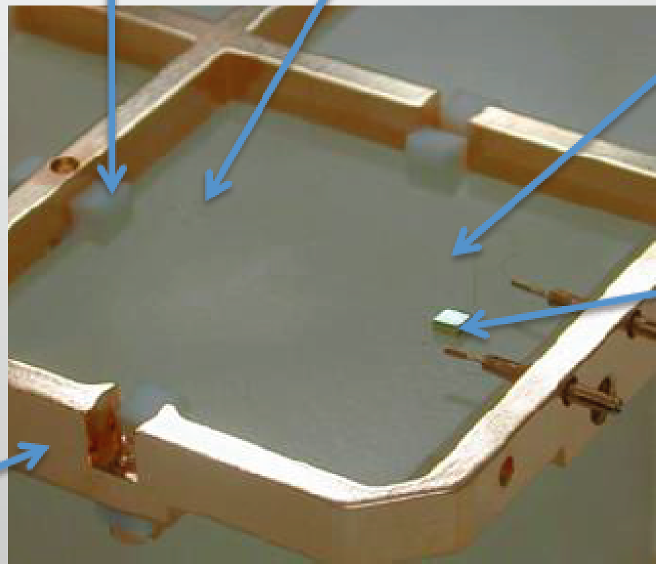
Low heat capacity
- Low temperatures (~10mK)
- Dielectric diamagnetic materials

From M. Pedretti, Neutrino 2012

TeO_2 Bolometers







PTFE pieces

TeO_2 crystal

25 μm gold wire connection

Neutron Transmutation Doped Ge sensor

Copper holder

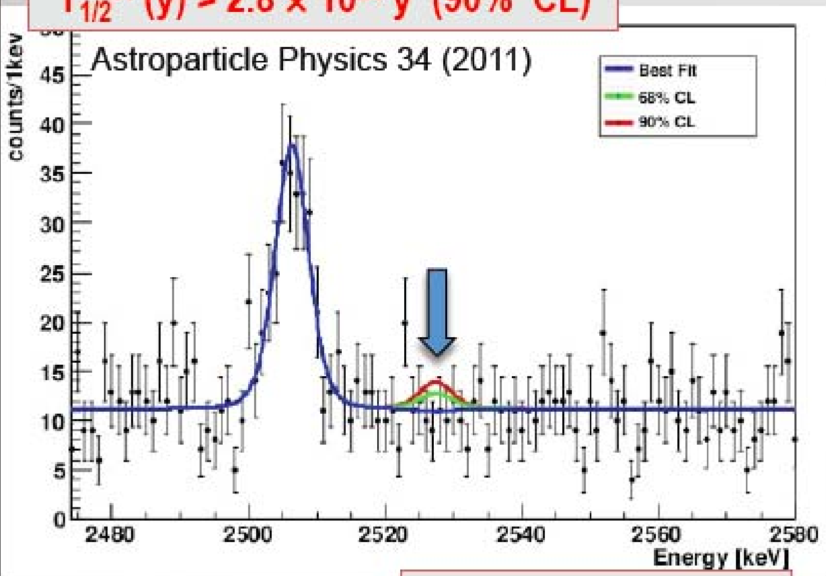
From M. Pedretti, Neutrino 2012

Bolometric 0νDBD experiment evolution

$\Delta E = 6.2 \pm 2.5$ keV (~0.3% FWHM)

Bkg = 0.169 ± 0.006 c/keV/kg/y

$T_{1/2}^{0\nu}$ (y) > 2.8×10^{24} y (90% CL)

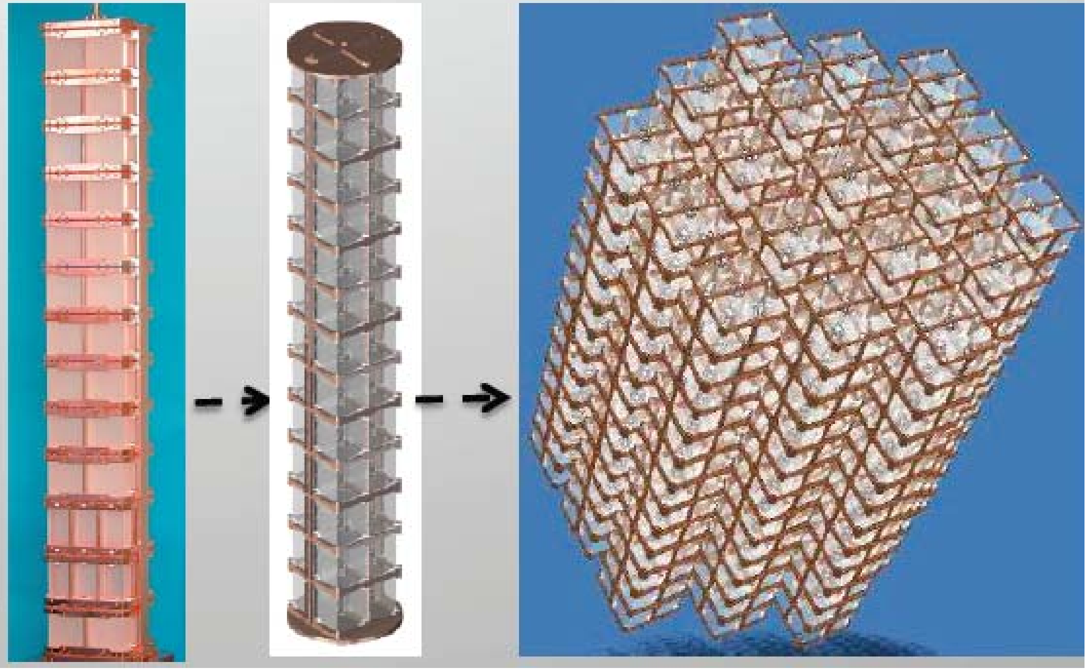


$\langle M_{bb} \rangle < 0.3 - 0.7$ eV

CUORICINO
40 kg
(2003-2008)

CUORE-0
(2012)

CUORE
1 ton
(~2014)

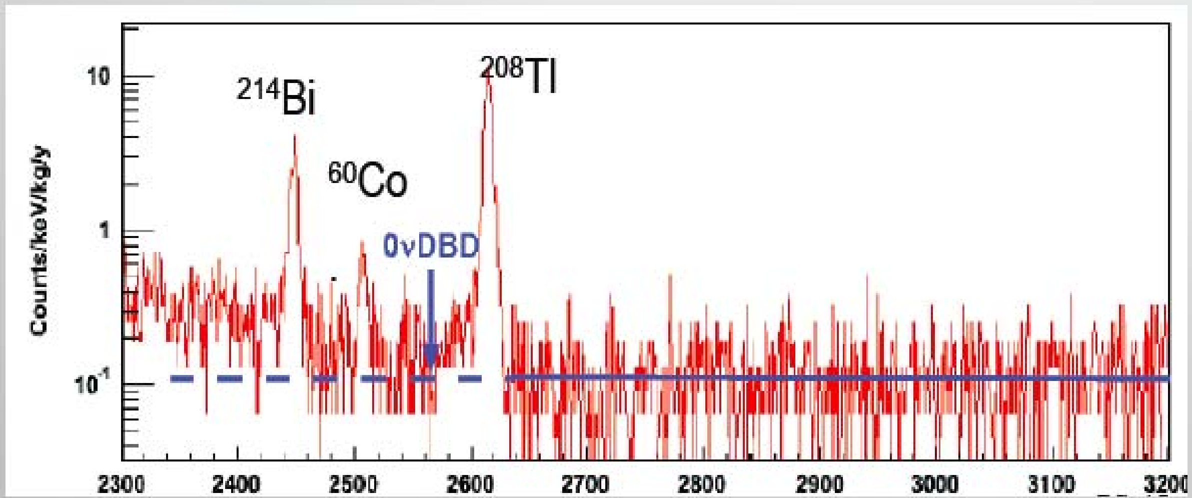


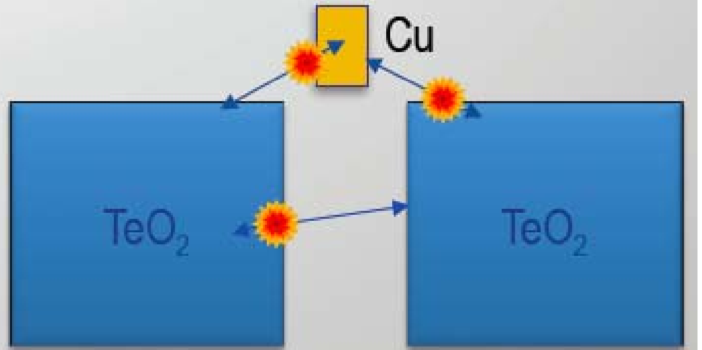
From M. Pedretti, Neutrino 2012

CUORICINO lesson: background

Sensitivity of current generation bolometric DBD experiment is limited by bkg.

MC: the background in CUORICINO is due to degraded alpha particles which release only part of their energy in the detector (surface contamination)





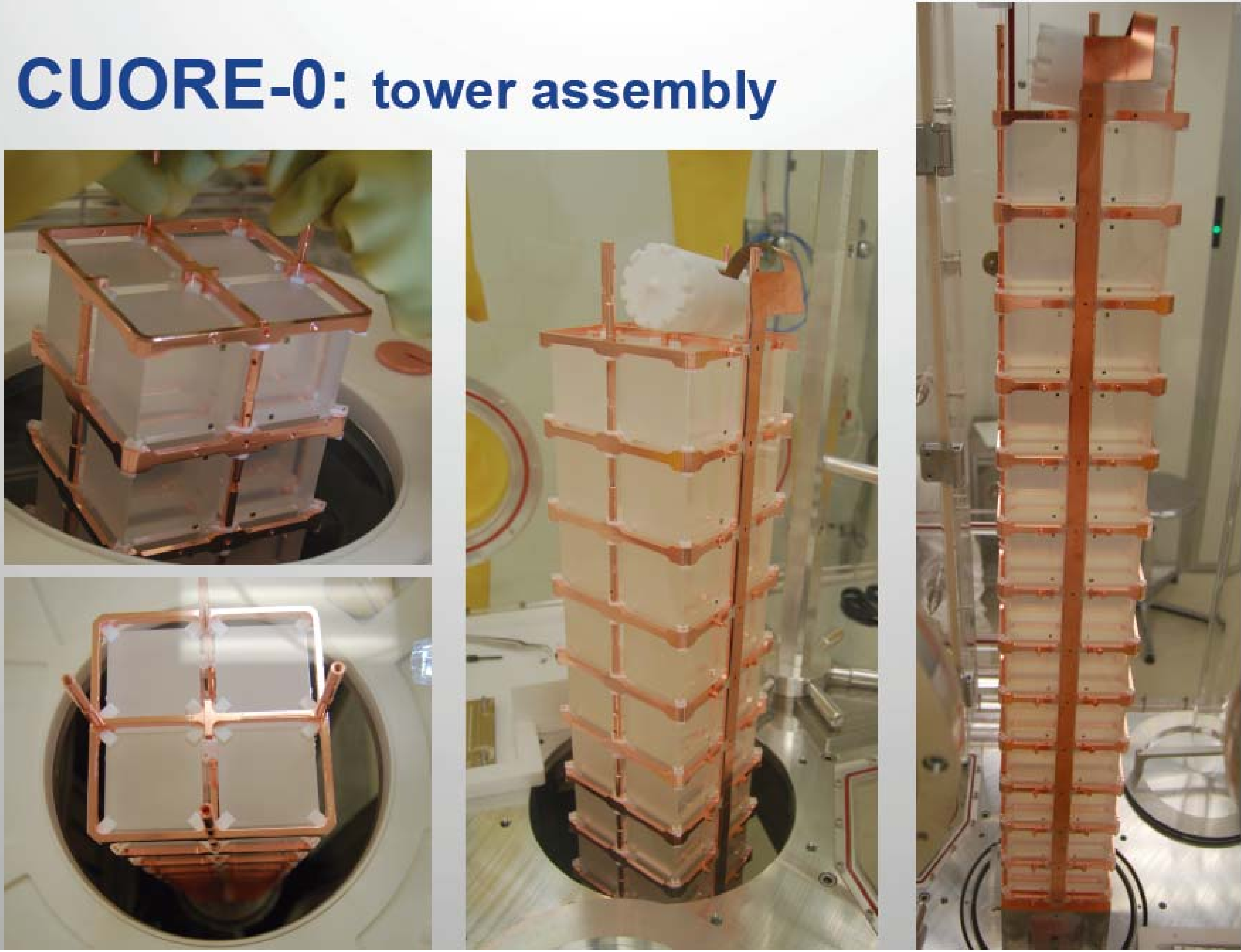
$b_{CUORICINO}$ = 0.169 c/keV/kg/y due to:

- ^{232}Th in cryostat (30 ± 10%) → γ
- TeO_2 surfaces (10 ± 5%)
- Surfaces facing detectors (50 ± 20%)

} degraded α particles

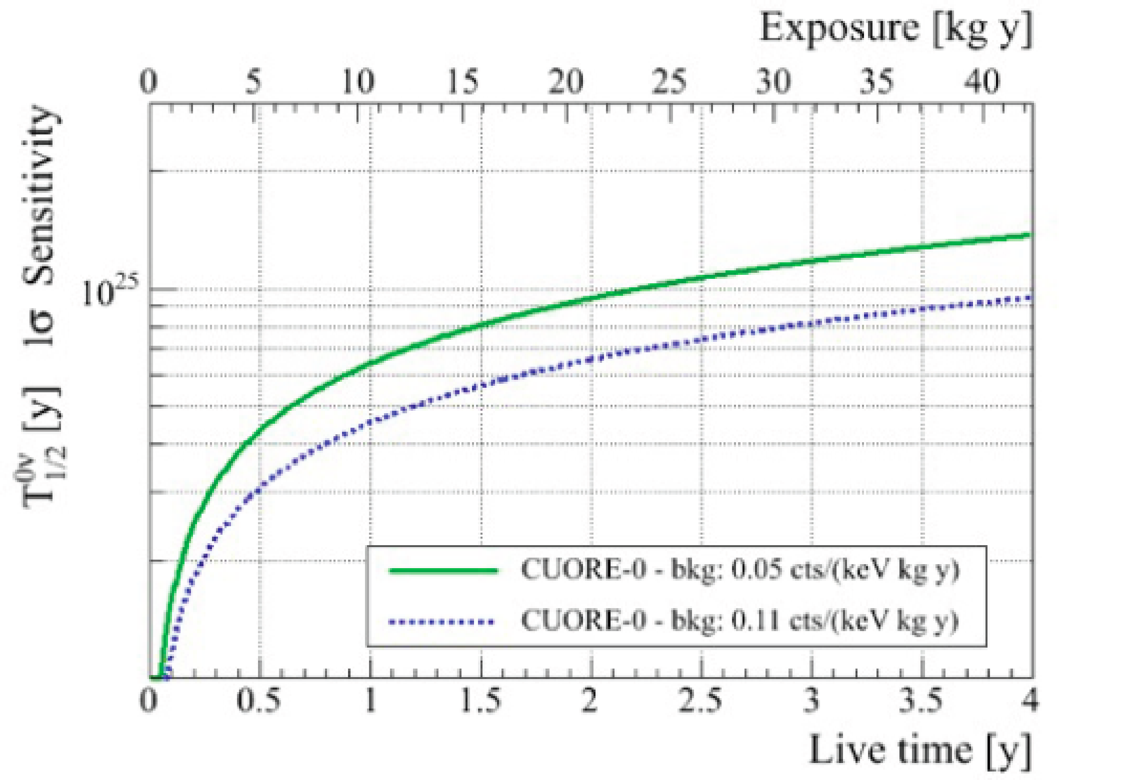
From M. Pedretti, Neutrino 2012

CUORE-0: tower assembly



From M. Pedretti, Neutrino 2012

CUORE-0: sensitivity



Limited by the cryostat contamination bkg

Background: 0.05-0.11 c/keV/kg/y range

If 0.05 c/(keV kg y), expected 2-year sensitivity is

$T_{1/2} = 5.9 \times 10^{24}$ y @ 90% CL

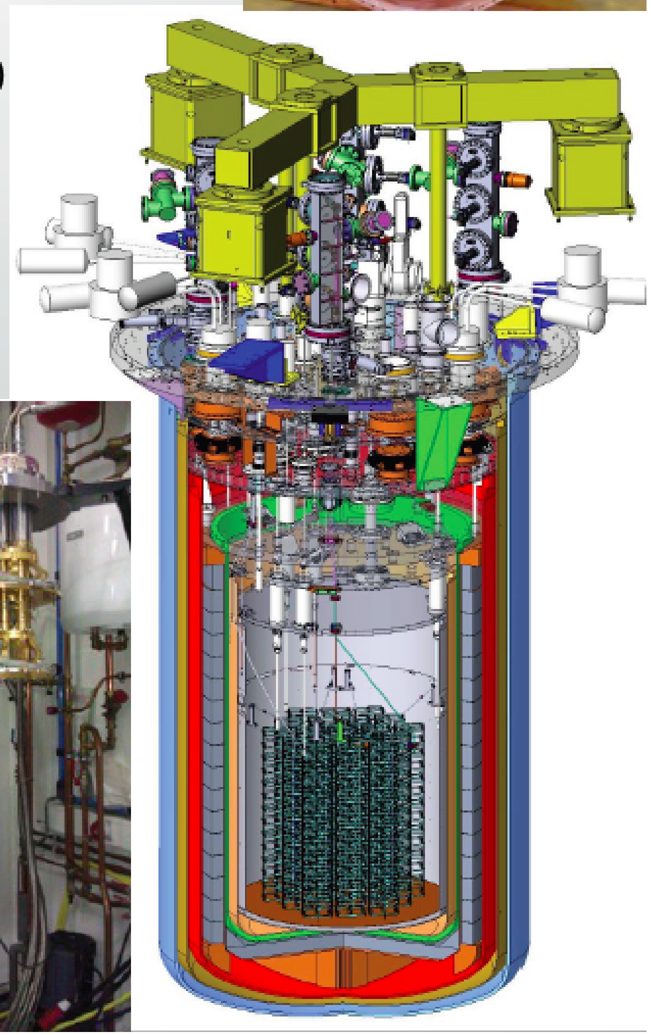
(CUORICINO: $T_{0\nu} > 2.8 \times 10^{24}$ y)

$m_{\beta\beta}$ = 170 - 390 meV

From M. Pedretti, Neutrino 2012

CUORE status

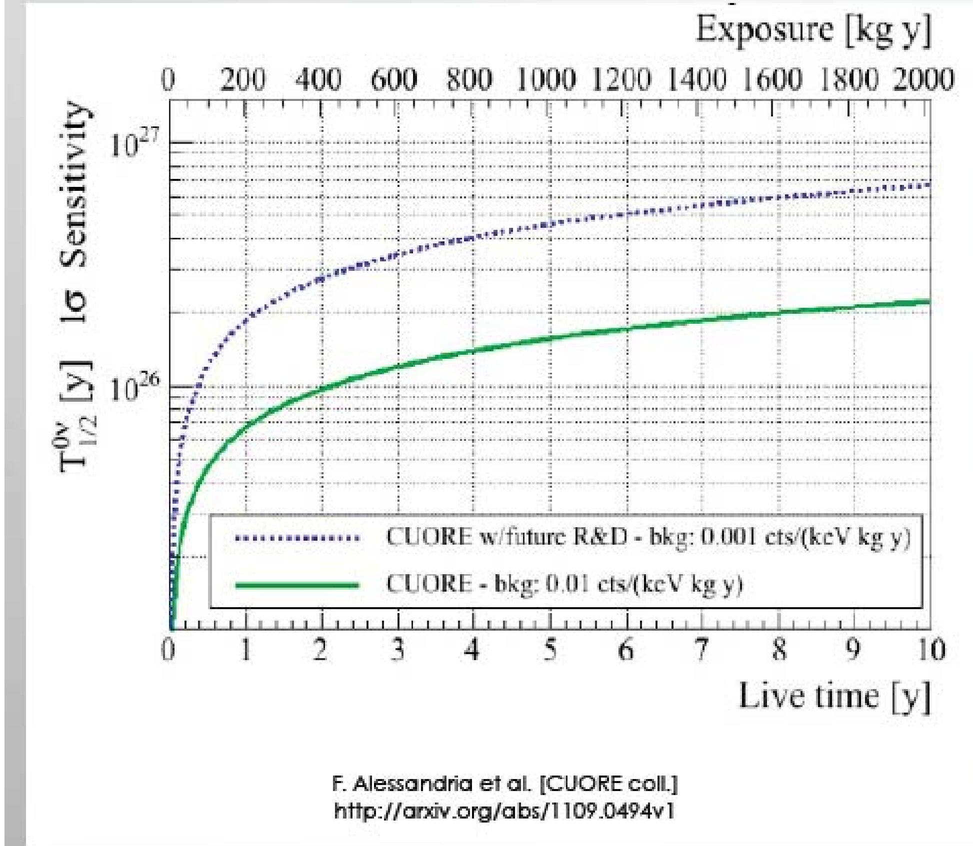
- Crystals, almost all arrived (all at LNGS by the end of 2012)
- Copper parts are being machined and cleaned
- Dilution unit delivered to LNGS (though some repairs needed)
- CUORE Hut, and most of all the infrastructures, ready
- Detector assembly line, ready (small modifications)
- Radon abatement system installed
- 3 (of 6) cryostat vessels delivered soon at LNGS
- Commissioning of the cryostat second half of 2012

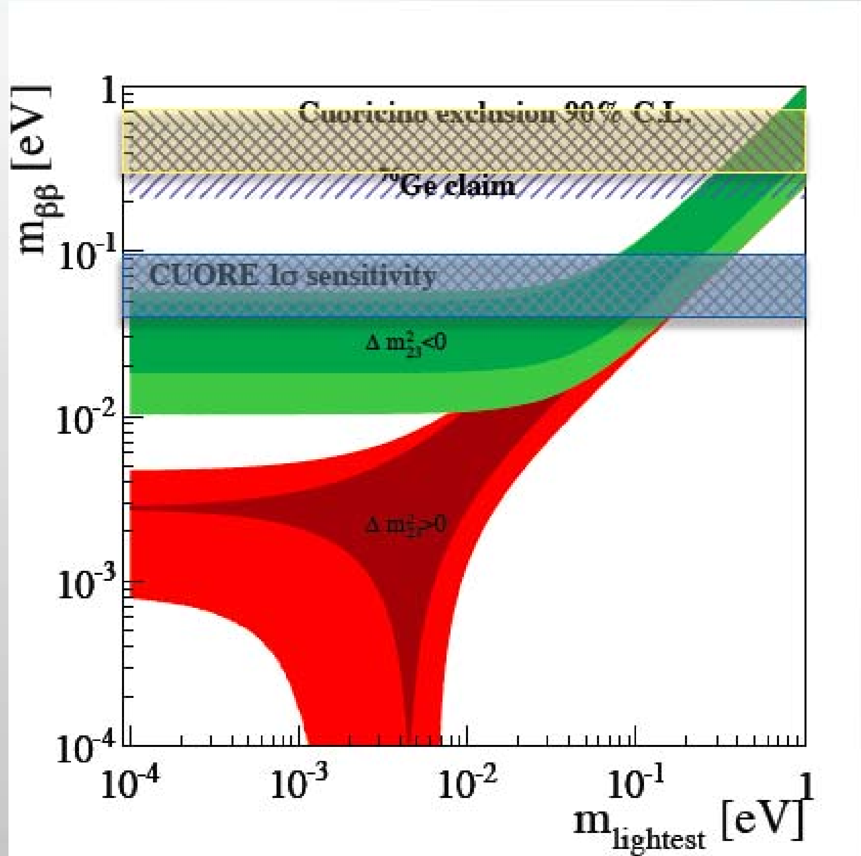


Crystals	12/12
Thermistors	13/03
Cleaned Cu parts	13/12
Cryogenic	13/12
Tower Assembly	14/04
Detector insertion	14/07
Cool Down	14/11

From M. Pedretti, Neutrino 2012

CUORE sensitivity





$T_{1/2}^{0\nu}$ (^{130}Te) > 1.6 x 10^{26} y (1σ)
$m_{\beta\beta}$ < 40 - 90 meV

From M. Pedretti, Neutrino 2012

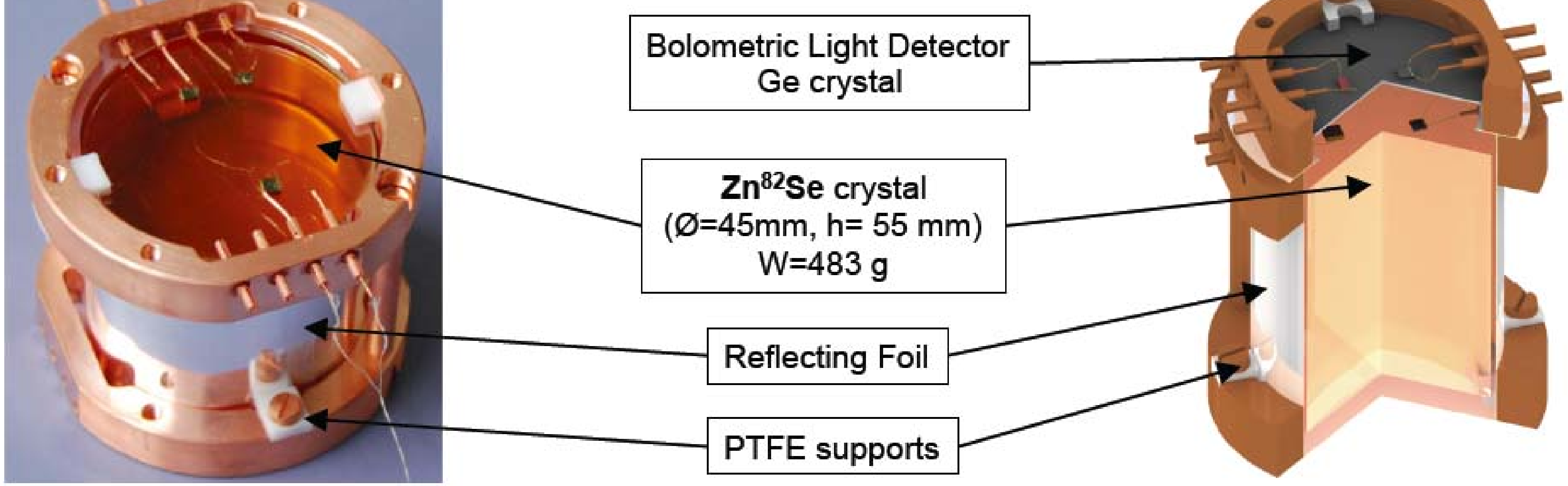
Scintillating bolometers: Lucifer/Lumineu

Lucifer (Italy): ZnSe

Lumineu (France): $ZnMoO_4$

Scintillating bolometers to recognize the α-induced background thanks to the readout of the scintillation light

Example: Lucifer



Array of 36÷44 enriched (95%) $Zn^{82}Se$ crystals.

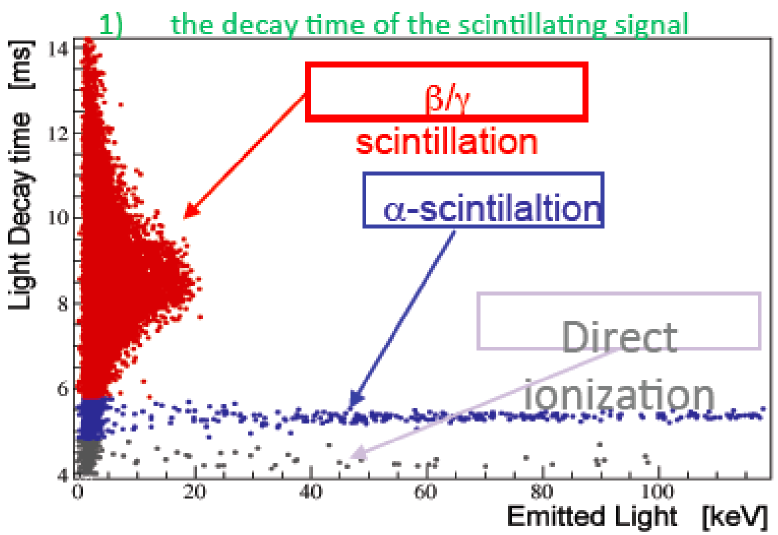
Expected background in the ROI (2995 keV) is ~ 3÷6 10^{-3} c/keV/kg/y

Energy resolution ~10 keV FWHM

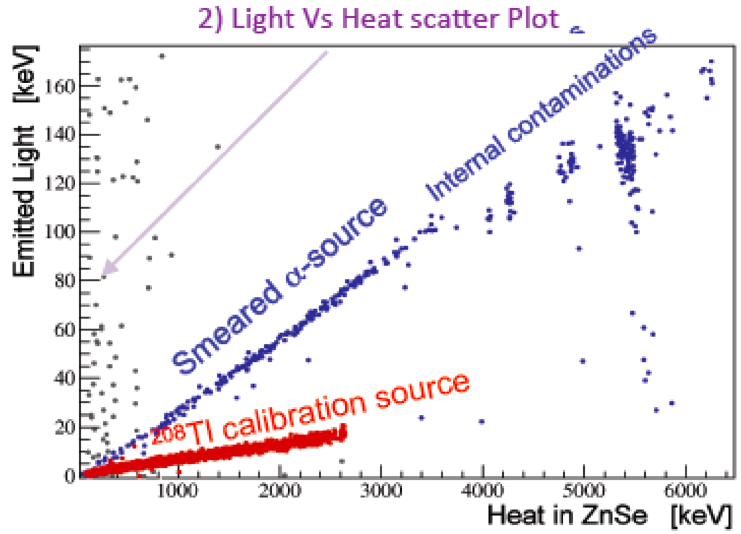
The α-induced background is recognized:

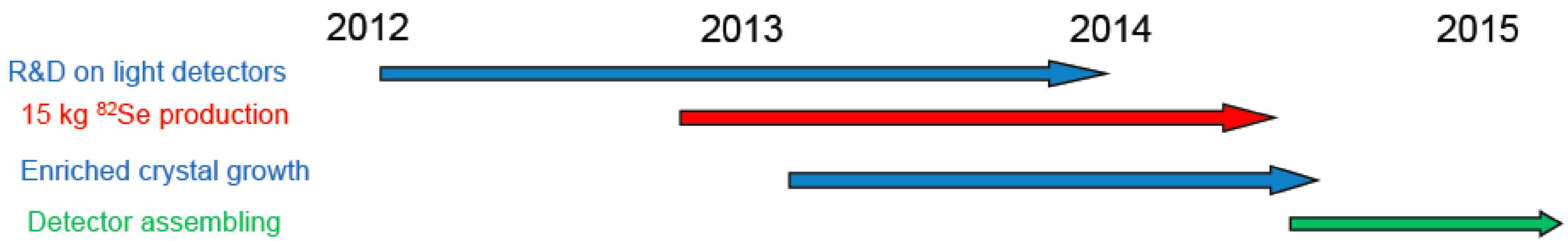
1) the decay time of the scintillating signal

2) the different scintillation yield between α and γ/β particles (the "usual" light Vs Heat scatter plot)



12.5 days measurement





LUCIFER will be located in CUORICINO (now CUORE-0) cryostat, once CUORE-0 will finish his data taking (2015)

Next generation experiments

Calorimeters

- **Ge diodes** — ε, ΔE, PID — ^{76}Ge → GERDA, Majorana
- **Bolometers** — ε, ΔE, (PID) — ^{130}Te, ^{82}Se, ^{100}Mo → Cuore, Lucifer, Lumineu
- **Liquid Xe** — M, PID — ^{136}Xe → EXO
- **Scintillators** — M — ^{136}Xe, ^{150}Nd, ^{48}Ca, ^{100}Mo → KamLAND-zen, SNO+, Borexino, AMoRE

Electron tracking

- Tracko-calo, Isotopes — ^{82}Se, (^{150}Nd, ^{48}Ca) → SuperNEMO
- Pixelized CdZnTe — ^{116}Cd → COBRA
- Gas TPC — ^{136}Xe → NEXT, EXO-gas

Adopted from F. Piquemal