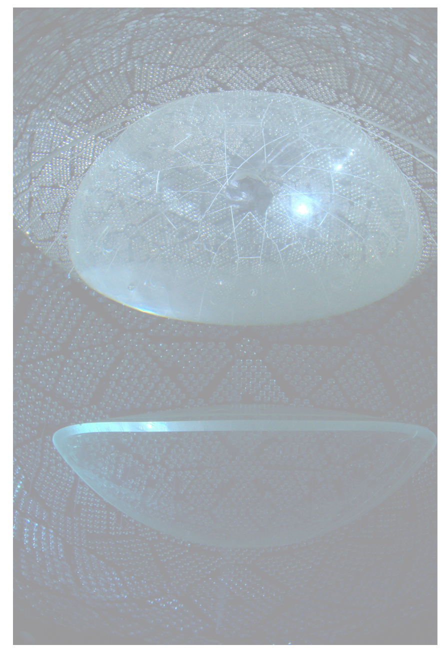
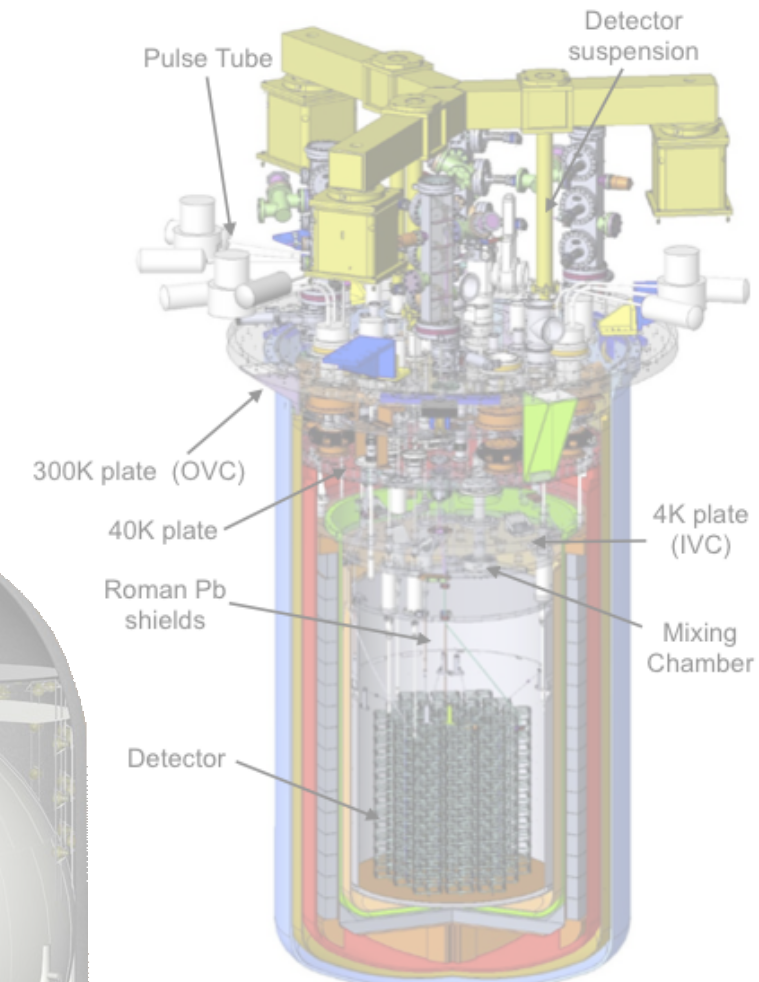
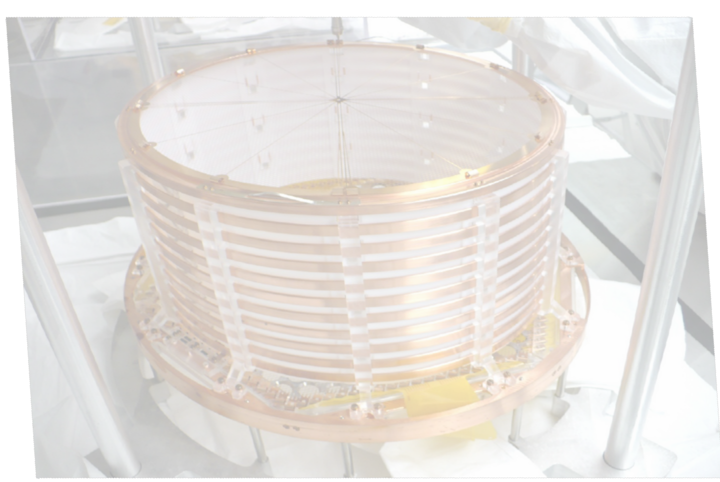
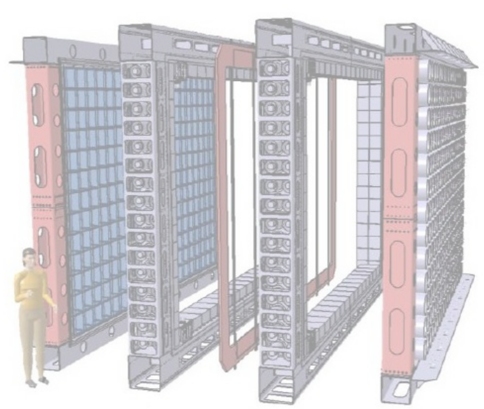
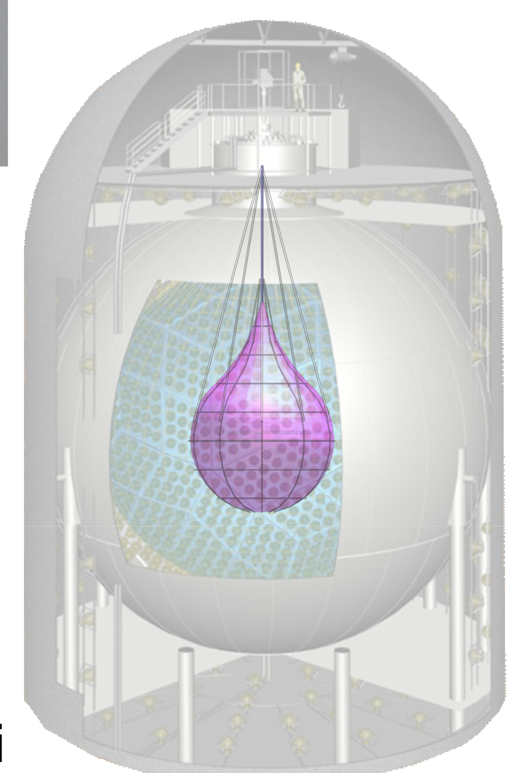
Detecting 0ν-ββ decay: current status and future challenges











Carlo Bucci

INFN - Laboratori Nazionali del Gran Sasso

Present knowledge about neutrinos

- neutrinos are massive fermions
- there are 3 active neutrino flavors (ν_α)
- neutrino flavor states are mixtures of mass states (ν_k)

$$|\nu_\alpha\rangle = \sum_k U_{\alpha k} |\nu_k\rangle$$

Pontecorvo–Maki–Nakagawa–Sakata matrix

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Atmospheric / Accelerator — Reactor / Accelerator — Solar / Reactor

Measurements of neutrino parameters from:
- neutrino oscillations
- single beta decay
- cosmology
- neutrinoless double beta decay

Open questions

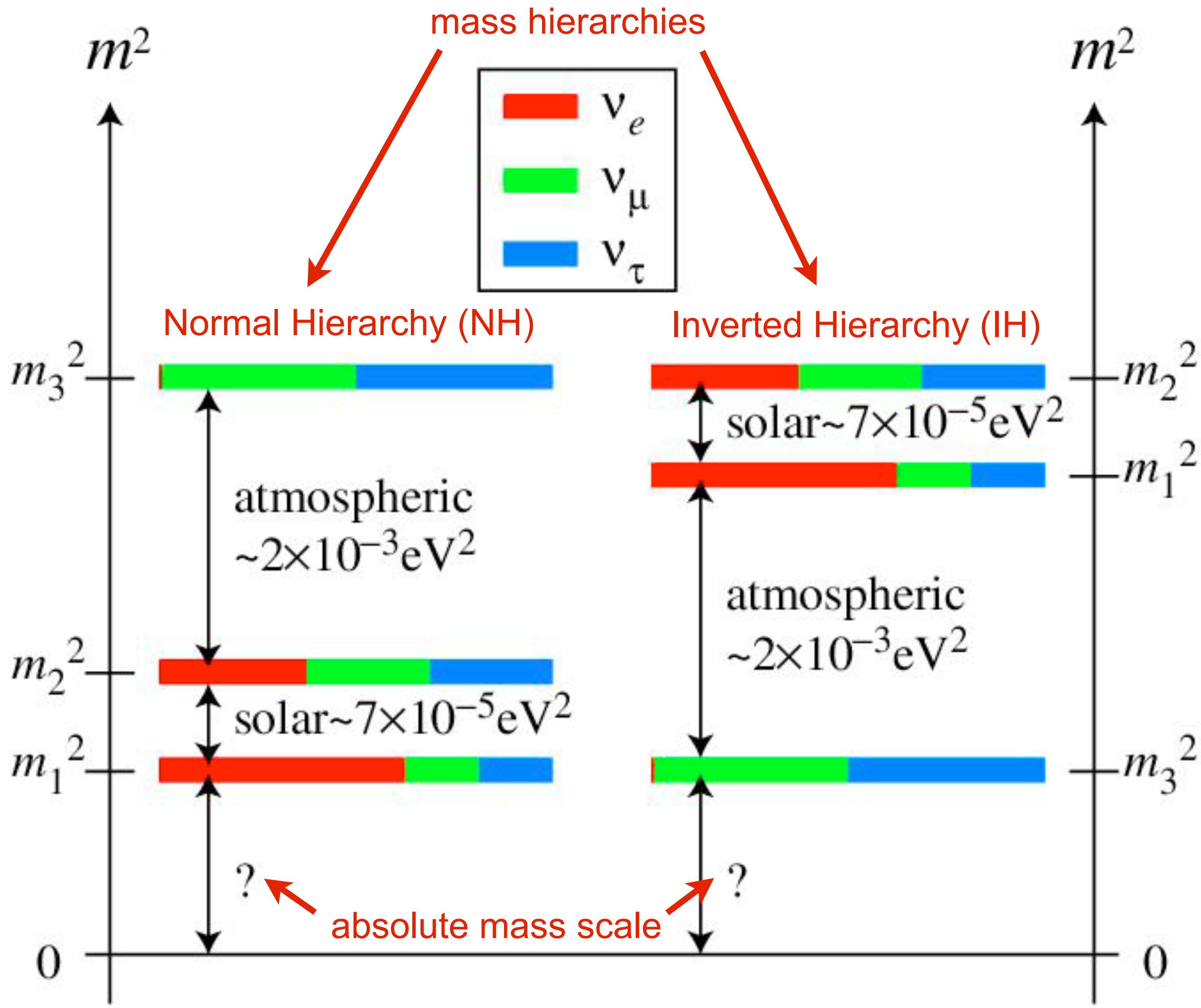
- What is the absolute neutrino mass scale?
- What is the neutrino mass hierarchy?
  Normal ($m1 < m2 \ll m3$) or Inverted ($m3 \ll m1 < m2$)?
- Are neutrinos Dirac or Majorana particles?
- What is the origin of neutrino masses and flavor mixing?
- Is there CP violation in the lepton sector?

  - Neutrinos are important probes of the Standard Model limits
  - Neutrino masses are linked (directly or indirectly) to all the above questions

Open questions

0ν-ββ can give an answer to three of those questions:

- Dirac or Majorana nature
- absolute mass scale:
  mass of the lightest ν
- hierarchy of masses
  (m1 < m2 ≪ m3 or m3 ≪ m1 <m2)

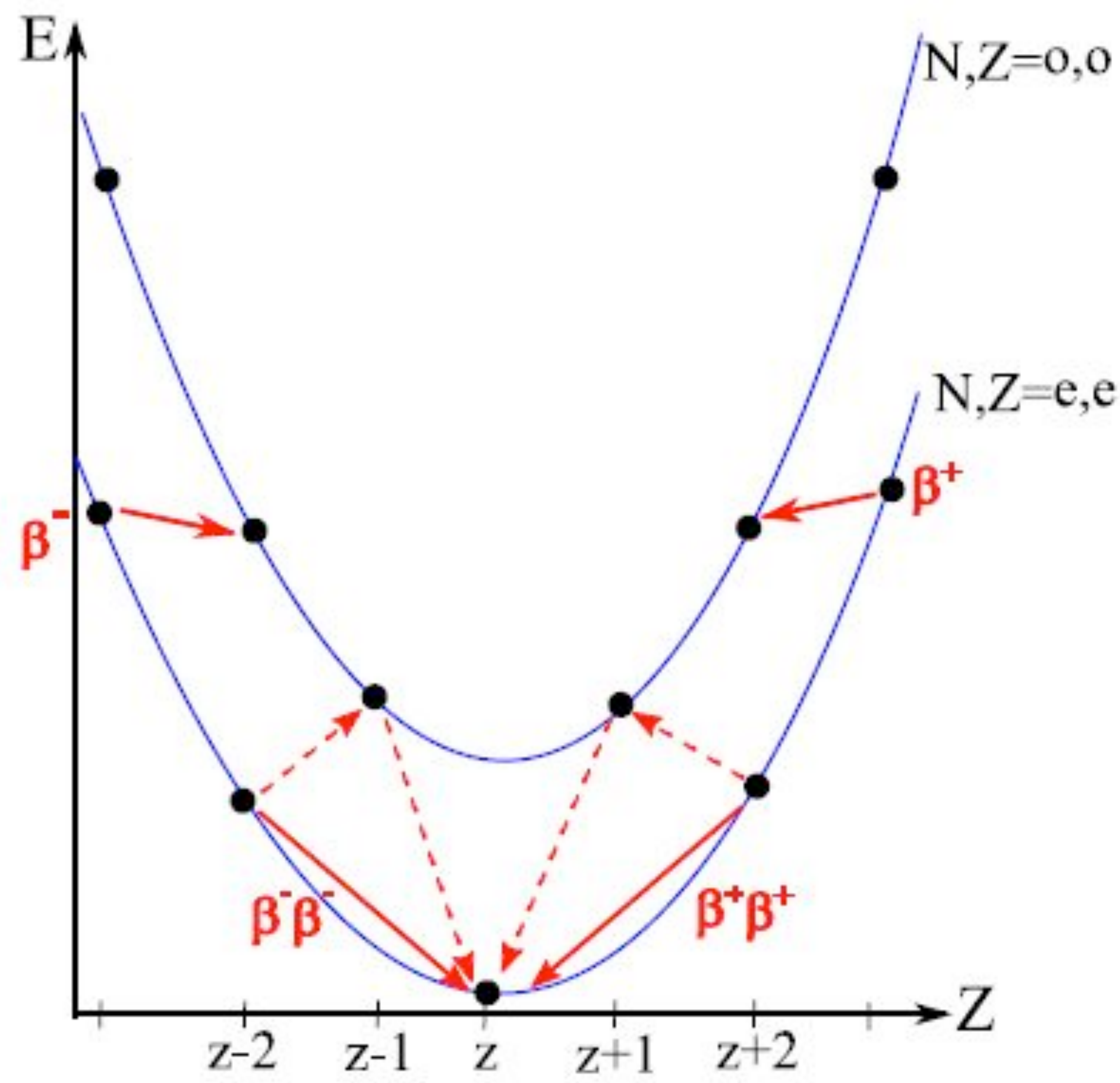


Oscillation experiments can determine the hierarchy but are blind to the other two questions

Double beta decay

Very rare nuclear decay (A,Z) → (A,Z+2) + 2e⁻ (+?)

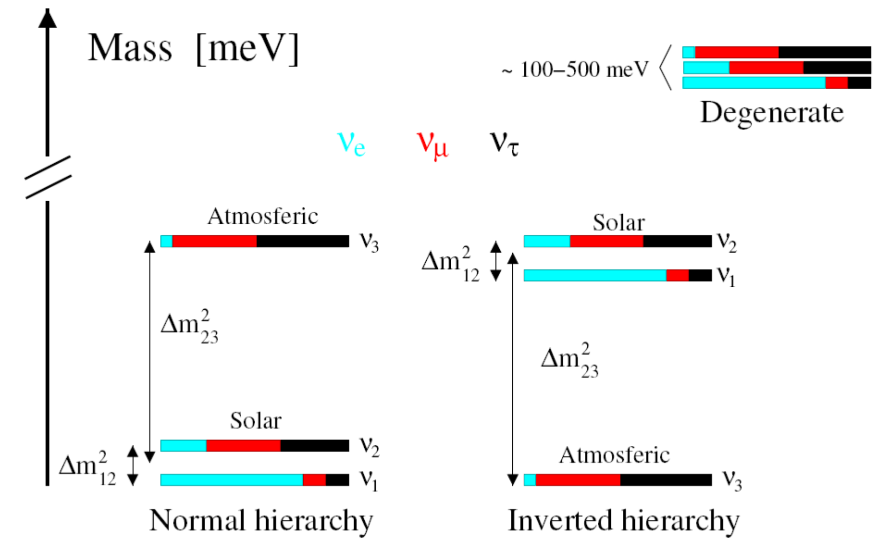
Isotope	Q-value [keV]	Isotopic abundance
^{48}Ca	4272	0,19
^{76}Ge	2039	7,8
^{82}Se	2996	9,2
^{96}Zr	3350	2,8
^{100}Mo	3034	9,6
^{116}Cd	2814	7,6
^{130}Te	2527	33,4
^{136}Xe	2459	8,9
^{150}Nd	3371	5,6

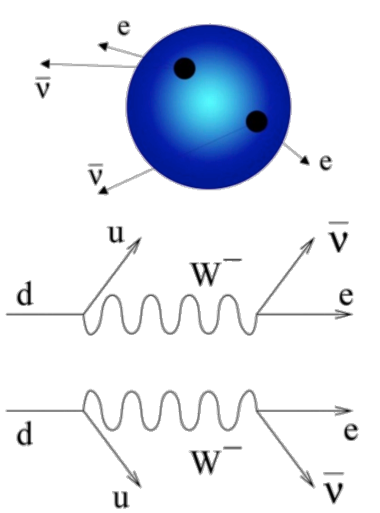


Double beta decay

0ν-DBD is a fundamental tool to determine neutrino properties

- Dirac or Majorana nature
- Absolute mass scale
- Mass hierarchy



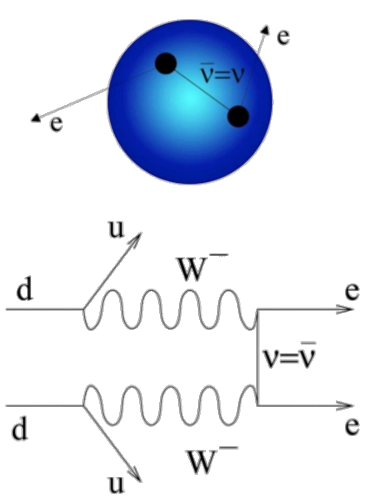


$$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\overline{\nu}$$

2ν-DBD

2nd order process allowed in the SM

observed in several nuclei with $\tau^{2\nu} \sim 10^{19}$-10^{21} y



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

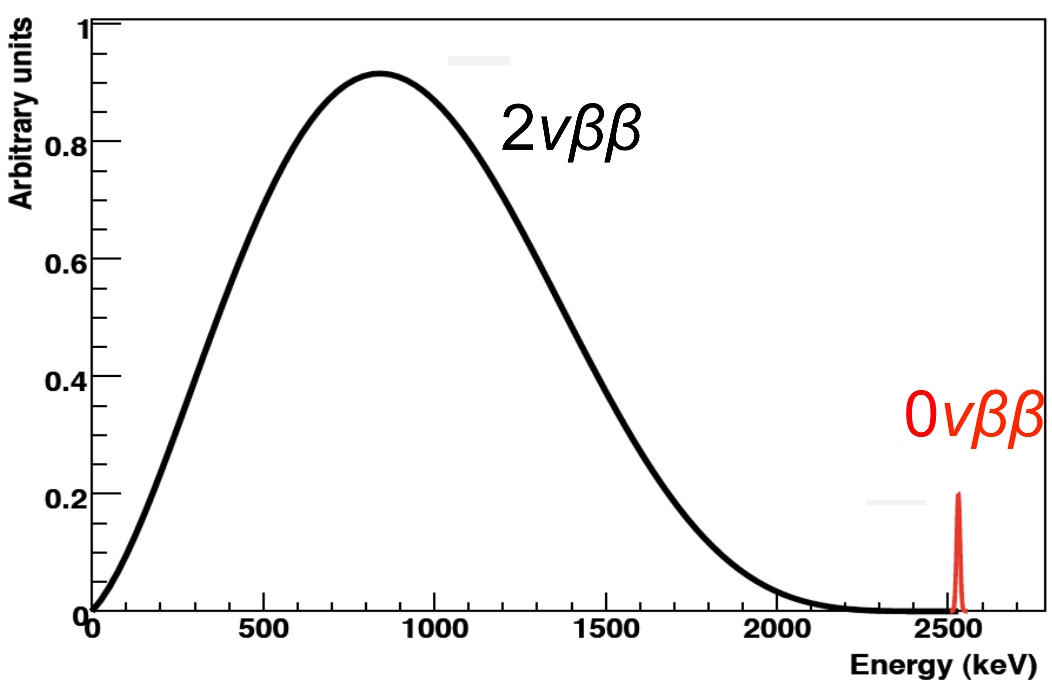
0ν-DBD (implies physics beyond SM)

lepton number violating process

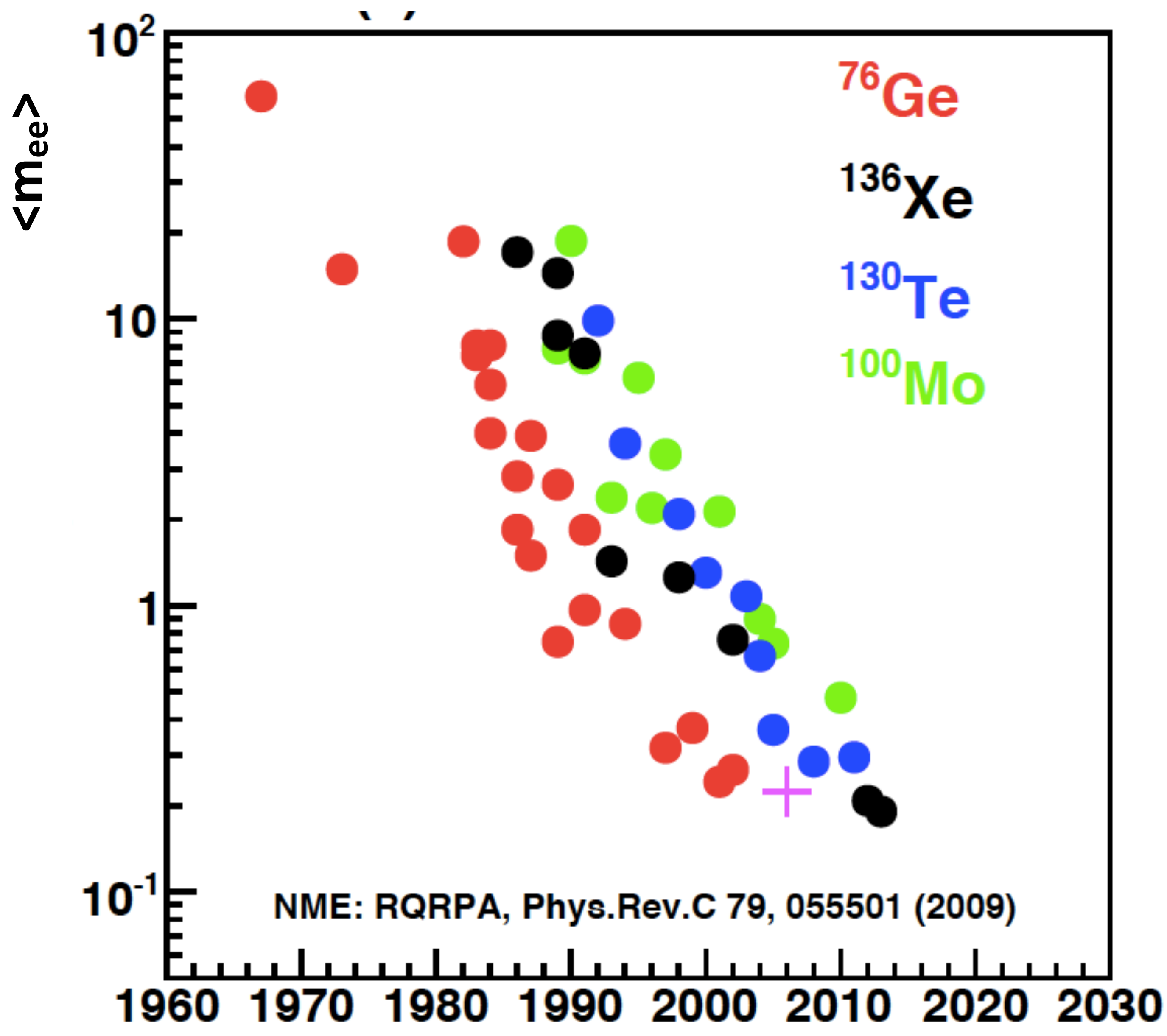
$\tau^{0\nu} > 10^{24}$-10^{25} y

exists if neutrino is a Majorana particle and $m_\nu \neq 0$

ββ summed e^- energy spectrum



A long history of 0ν-ββ experiments



An order of magnitude on the effective Majorana mass every 15 years?

0ν-ββ and Majorana mass

$$[T^{0\nu}_{1/2}]^{-1} = G_{0\nu}\, g_A^4\, |M_{0\nu}|^2 \langle m_{\beta\beta}\rangle^2$$

- 0νββ decay rate
- Phase space factor
- Axial vector coupling
- Nuclear matrix element
- Effective Majorana mass

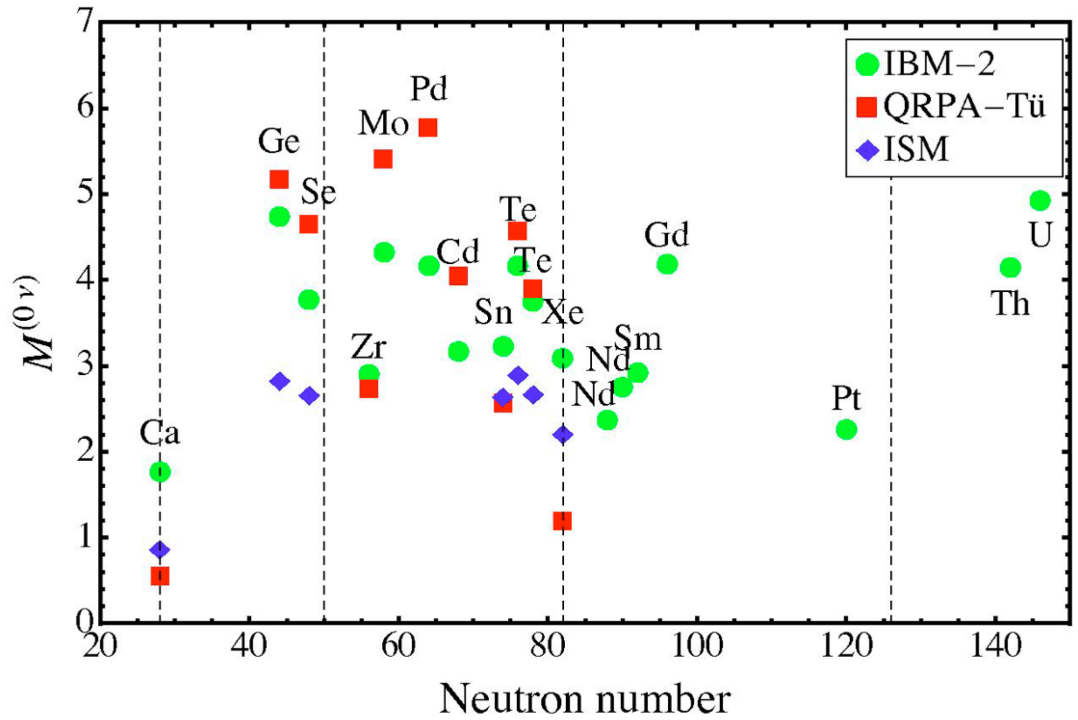
NEUTRINO MASS EIGENVALUES

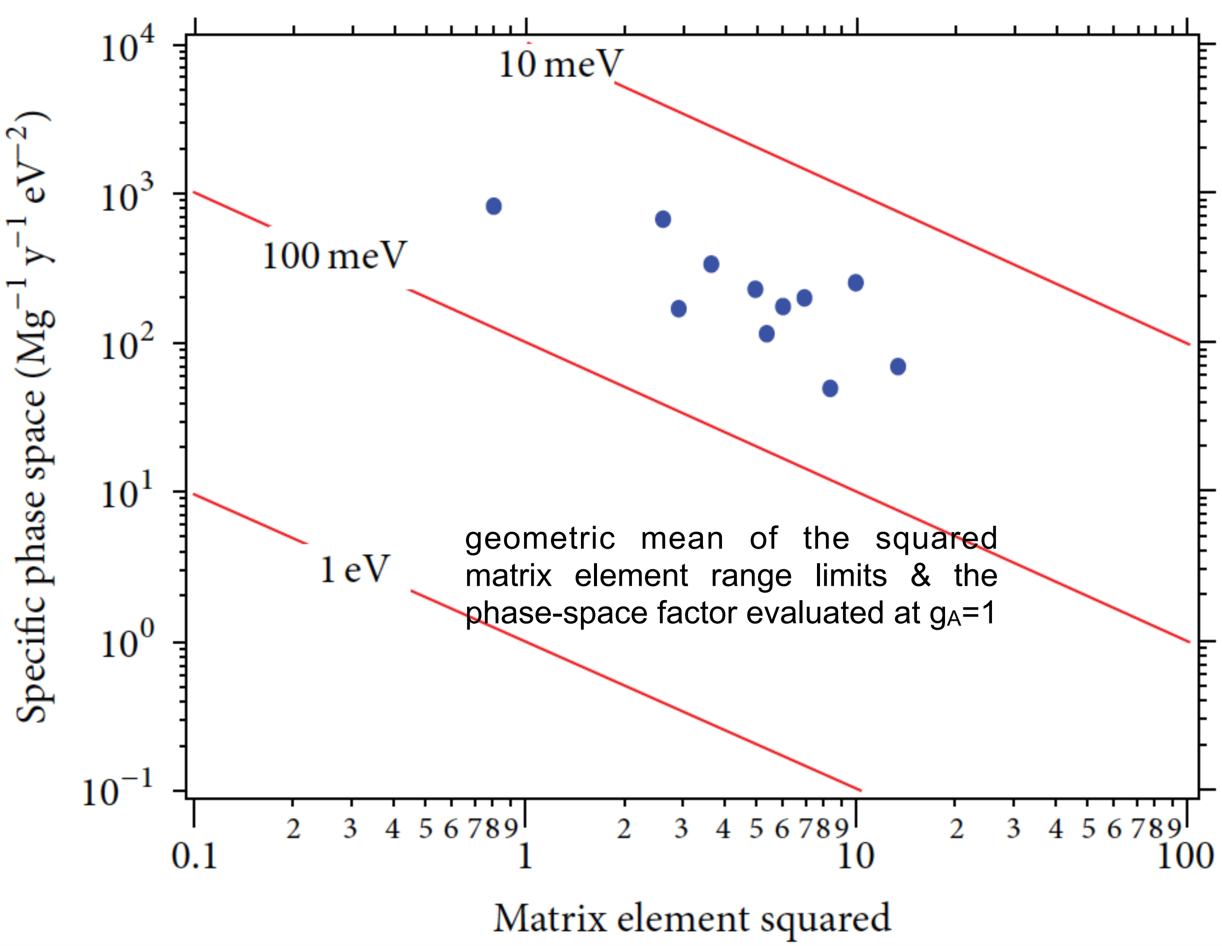
$$\langle m_{\beta\beta}\rangle = \sum_k U_{ek}^2 m_k = c_{12}^2 c_{13}^2 m_1 + s_{12}^2 c_{13}^2 e^{i\alpha} m_2 + s_{13}^2 e^{i\beta} m_3$$

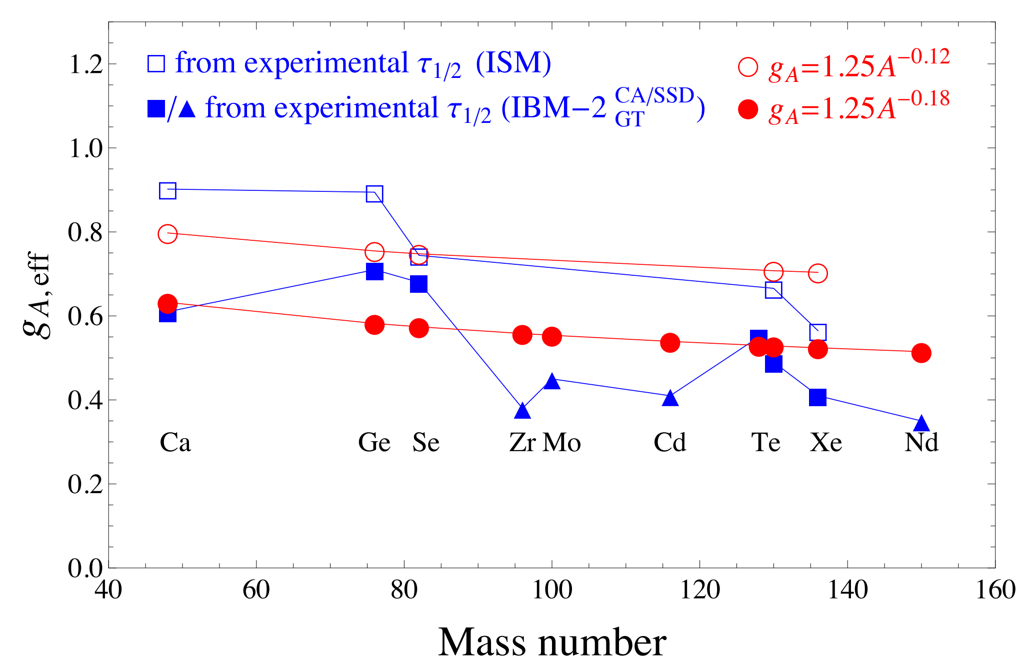
NEUTRINO MIXING MATRIX

Is there a preferred isotope?

- Nuclear matrix elements calculations are rapidly improving and today the differences between different methods (IBM, QRPA, ISM) are much smaller than in the past
- Uncertainty on g_A plays a relevant role
  factor 2 in g_A is a factor 16 in decay rate
- inverse correlation observed between phase space and square of the nuclear matrix element





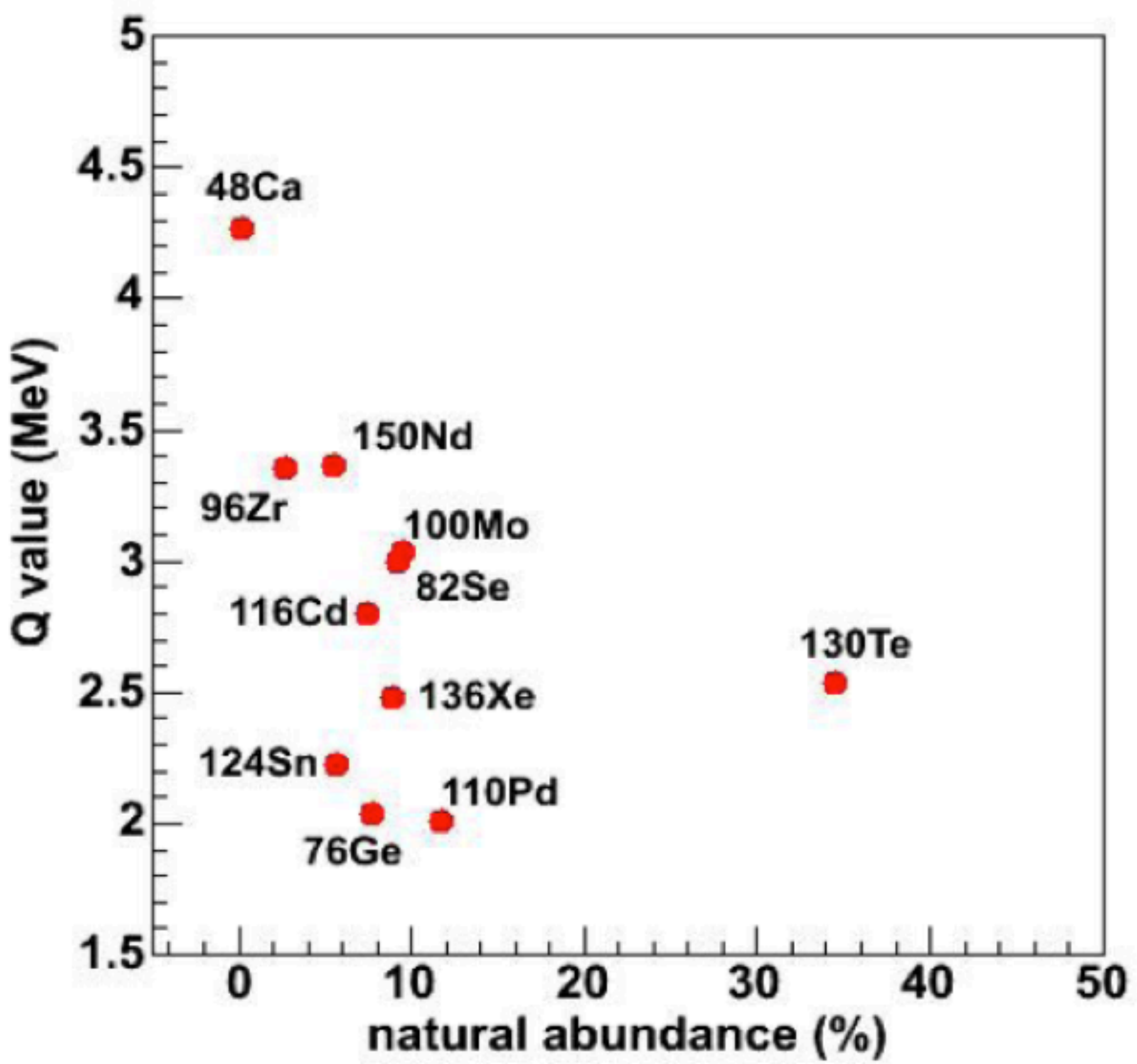


Isotope choice

In many cases driven by the detector characteristics.

- ^{76}Ge with Germanium diodes
- ^{136}Xe with Xenon TPCs
- bolometers and scintillators have multiple choices

- Isotopic abundance as high as possible
  - money issue
- Q-value as high as possible
  - background
- 2v-DBD half-life as high as possible
  - energy resolution



Sensitivity

Half-life corresponding to the minimum detectable number of events over background at a given confidence level

$$S_{0\nu} = ln(2) N_A \frac{\eta \cdot \epsilon}{W} \sqrt{\frac{M \cdot T}{\Delta E \cdot B}}$$

finite background: M·T·B·ΔE >1

$$S_{0\nu} = ln(2) N_A \frac{\eta \cdot \epsilon}{W} M \cdot T$$

zero background: M·T·B·ΔE ≲1

M: active detector mass [kg]
T: measurement life time [anni]
B: background in the ROI [counts keV^{-1} kg^{-1} y^{-1}]
W: molecular weight

N_A: Avogadro number
η: isotopic abundance
ε: detector efficiency
ΔE: FWHM energy resolution @ Q-value

How to improve sensitivity?

- Increase measurement time
- Increase mass
- Increase isotopic abundance (enrichment)
- Improve energy resolution
- Reduce background

Mass and isotopic abundance

- Is obviously mandatory to increase mass and isotopic abundance
- We can even imagine to reach zero background but if we do not have a large enough number of active ββ atoms is useless

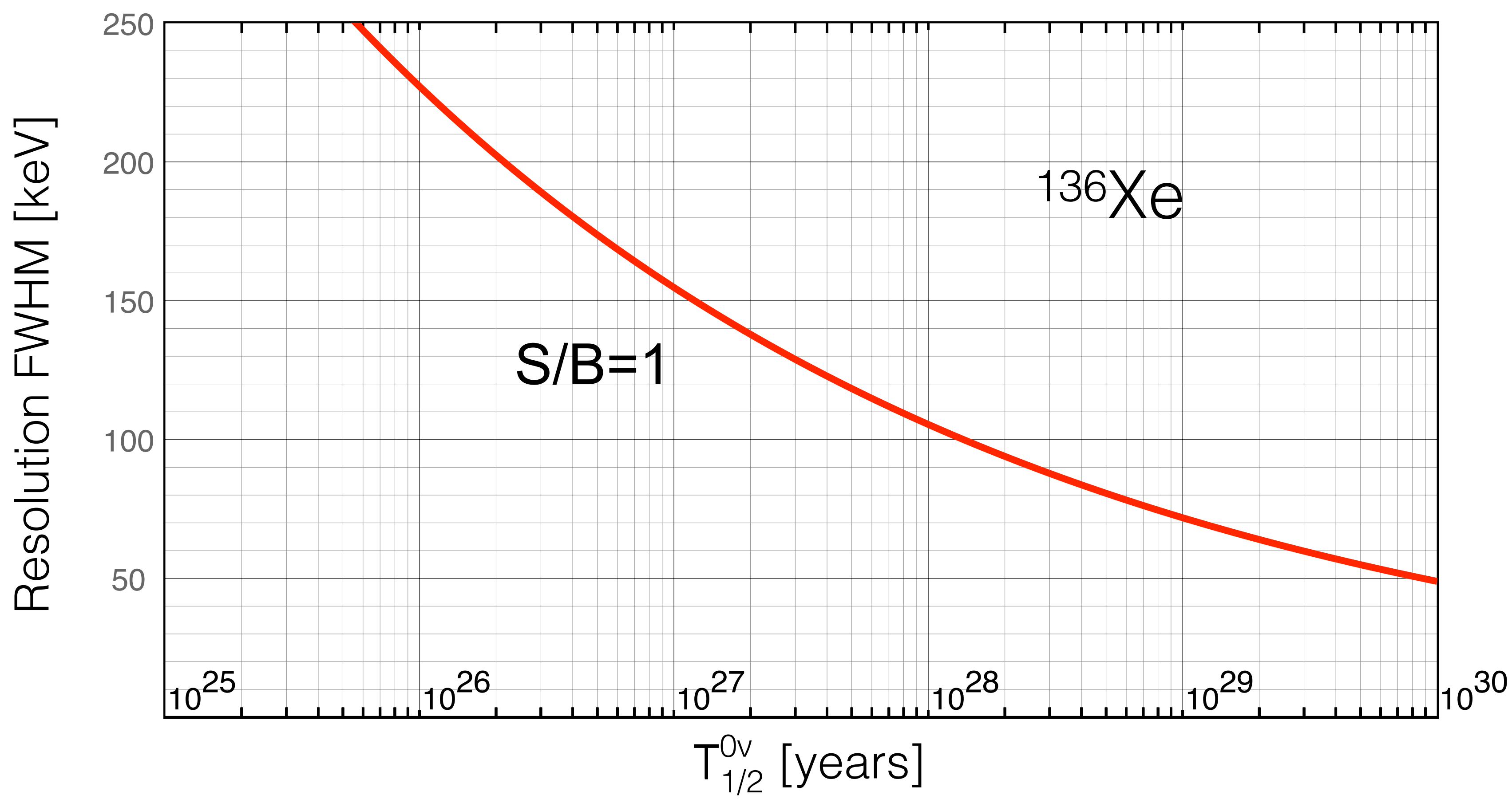
$$T_{1/2}^{0\nu} = ln(2) \cdot N_A \cdot \frac{M}{W} \cdot \eta \cdot \epsilon \cdot T$$

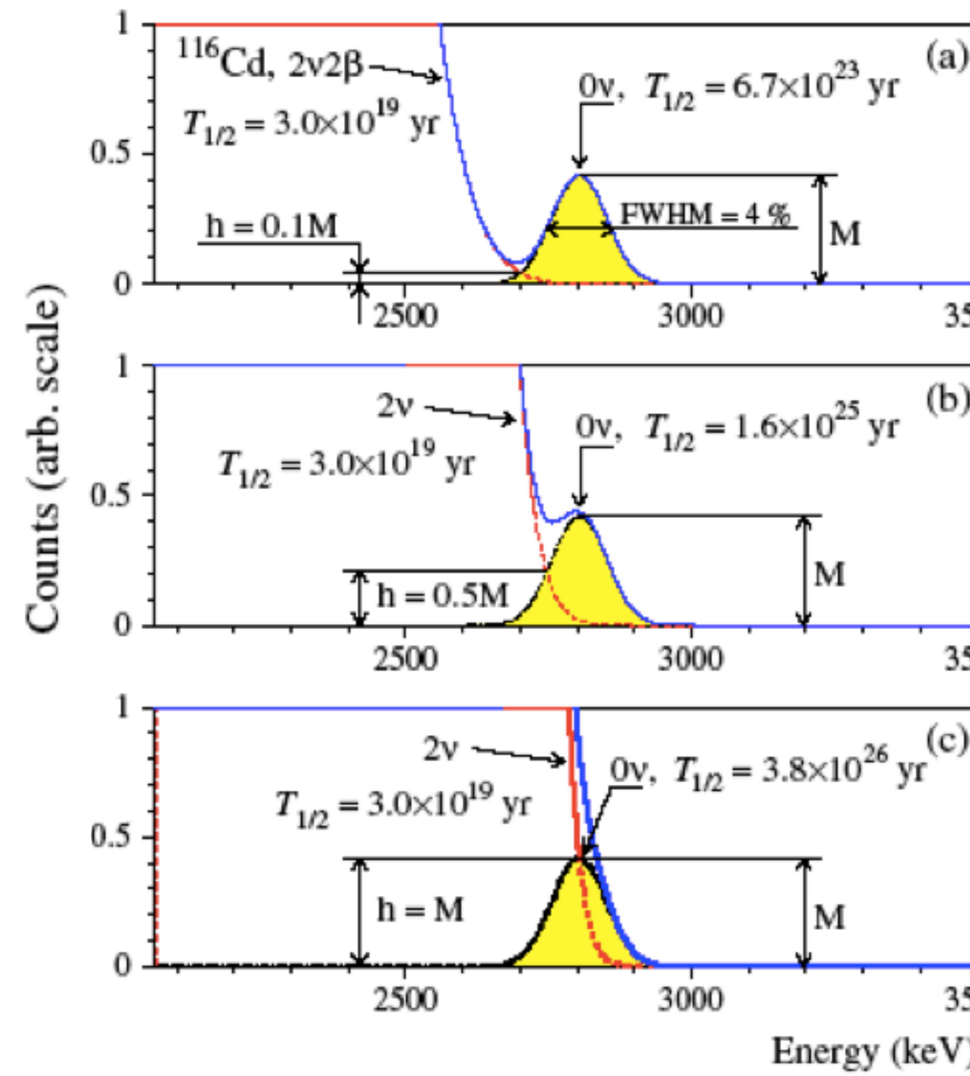
Energy resolution

- A good energy resolution is important for several reasons:
  - a smaller ROI means a better sensitivity
  - it's easier to identify background contributions
  - less probability of superposition of with natural radioactivity peaks (e.g. 2448 keV ^{214}Bi peak is only 10 keV away from ^{136}Xe 0ν-ββ Q-value)
  - minimize the impact of the background induced by the 2ν-ββ

Irreducible background from 2ν-ββ

- The irreducible background induced by the 2ν-ββ could be mitigated just by the energy resolution
- The effect can be partially attenuated with an asymmetric ROI (but losing efficiency)





Zdesenko, Danevich, Tretyak, J. Phys. G 30 (2004) 971

$$\frac{S}{B} = \frac{m_e}{7Q\delta^6}\frac{\Gamma_{0\nu}}{\Gamma_{2\nu}} = \frac{m_e}{7Q\delta^6}\frac{T^{2\nu}_{1/2}}{T^{0\nu}_{1/2}}$$

Energy resolution

- Germanium diodes and bolometers have already an energy resolution good enough to neglect the background induced by the 2ν-ββ.
- Bolometers (in theory) can still improve; every improvement on energy resolution is equivalent to background reduction. But we cannot expect orders of magnitude
- Xenon TPCs (gas or liquid) have decent energy resolution
- Scintillation detectors (e.g. SNO+ or KamLAND-Zen) are limited by light yield and light collection

Background

- Many R&Ds aiming to strong background reduction
  - materials selection
  - active vetoes
  - Ge diodes: copper electroforming
  - Ge diodes: Pulse shape discrimination SSE/MSE
  - TPC Xe: Barium tagging
  - TPC Xe gas: topological discrimination
  - Bolometers: scintillation or Cherenkov light detection to discrimineta α/β or surface/bulk
  - ....

Recent results

GERDA phase I

Advantages:

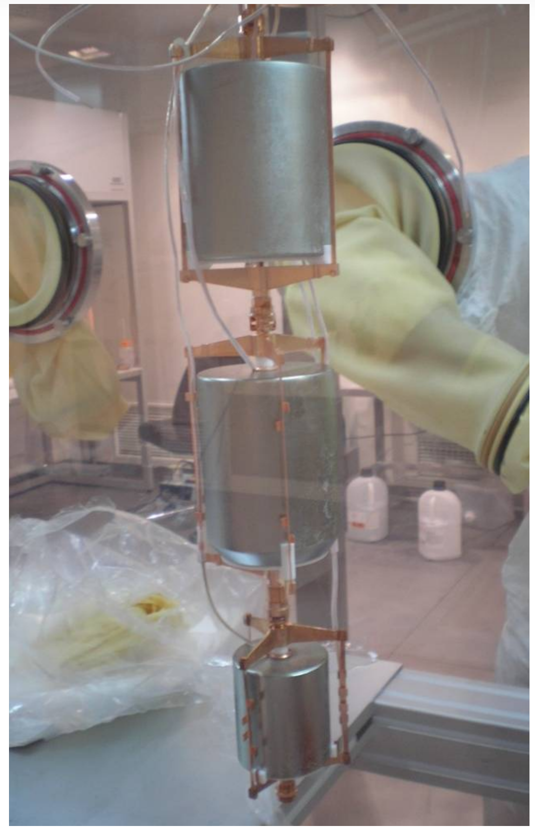
- known technology (enrichment + diode production)

- best energy resolution

- handles to reduce background PSD

- Ge diodes enriched to 86% with ^{76}Ge
- Q-value: 2039 keV
- $\Delta E \sim 3$ keV in ROI

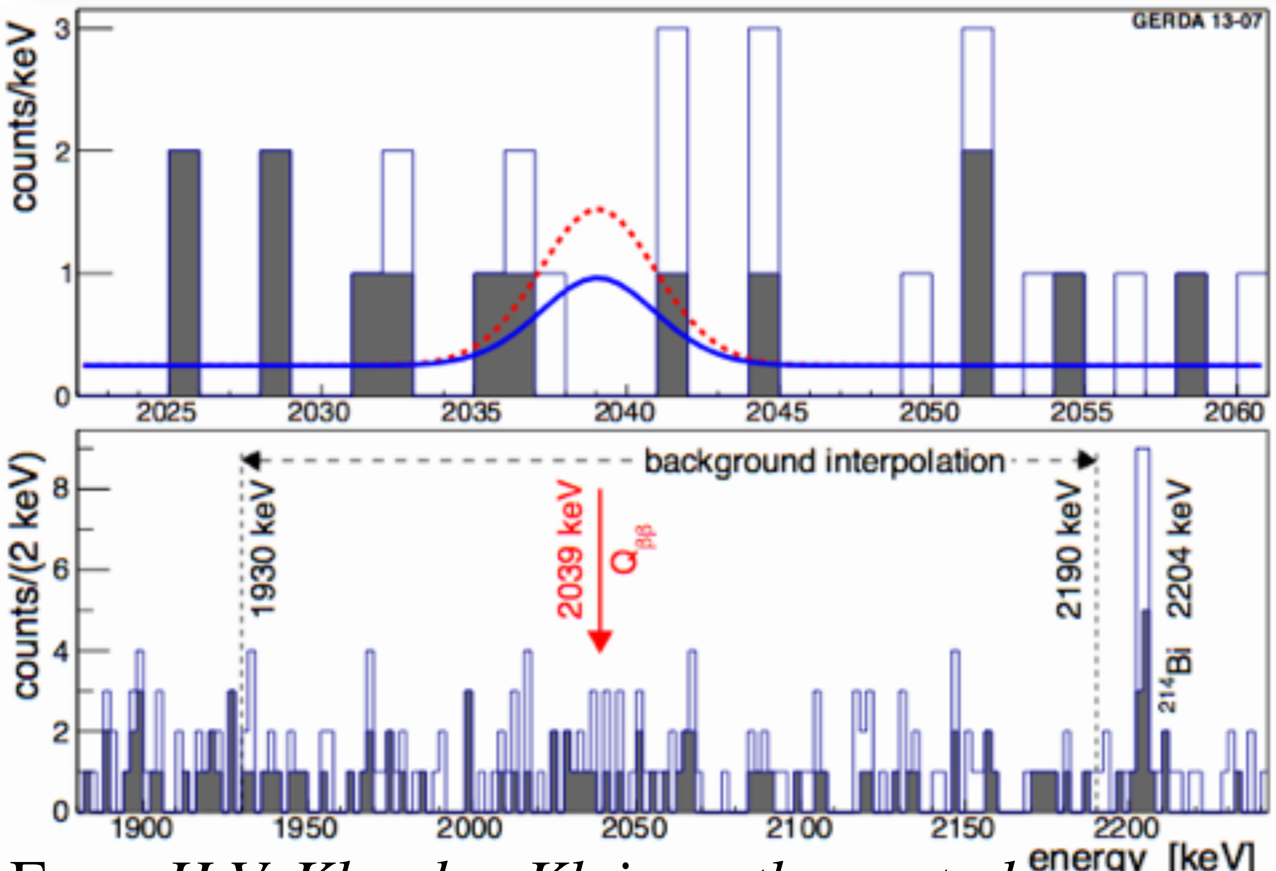
GERDA Phase I

- HdM and IGEX detectors refurbished
- operated bare in LAr
- 8 coax detectors with 18 kg mass
- 5 BEGe detectors (3 kg) added in June 2012
- Total exposure of 21.6 kg yr between Nov. 2011 and May 2013

Technische Universität München

GERDA results

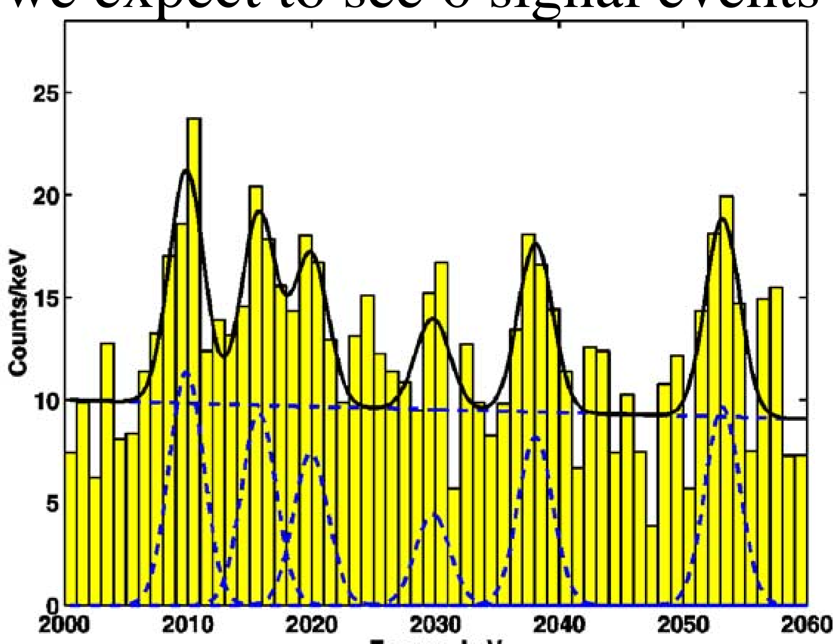


In 2039 ±5 keV we see 7 counts, after PSD only 3 remain:

$T^{0\nu}_{1/2} > 2.1 \times 10^{25}$ yr (90% C.L.)

Phys. Rev. Lett. 111, 122503 (2013)

From *H.V. Klapdor-Kleingrothaus et al. / Physics Letters B 586 (2004)* we expect to see 6 signal events

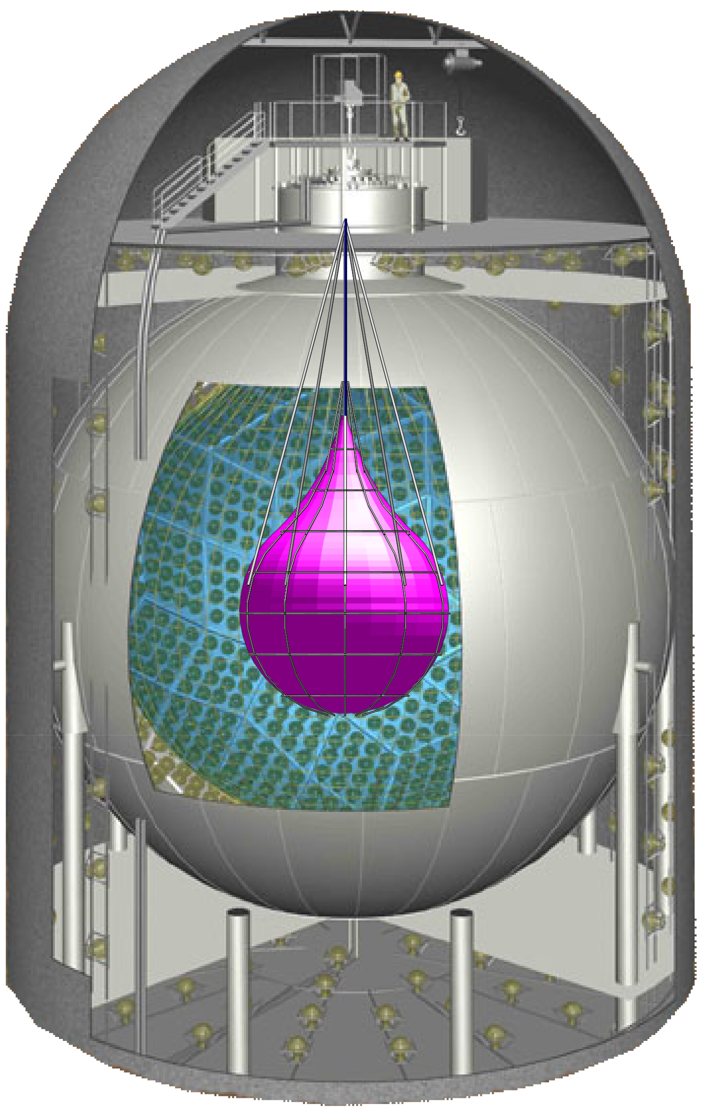


data set	$\mathcal{E}$[kg·yr]	$\langle\epsilon\rangle$	bkg	BI †)	cts
without PSD					
golden	17.9	0.688 ± 0.031	76	18 ± 2	5
silver	1.3	0.688 ± 0.031	19	63^{+16}_{-14}	1
BEGe	2.4	0.720 ± 0.018	23	42^{+10}_{-8}	1
with PSD					
golden	17.9	$0.619^{+0.044}_{-0.070}$	45	11 ± 2	2
silver	1.3	$0.619^{+0.044}_{-0.070}$	9	30^{+11}_{-9}	1
BEGe	2.4	0.663 ± 0.022	3	5^{+4}_{-3}	0

†) in units of 10^{-3} cts/(keV·kg·yr).

Technische Universität München

KamLAND-Zen

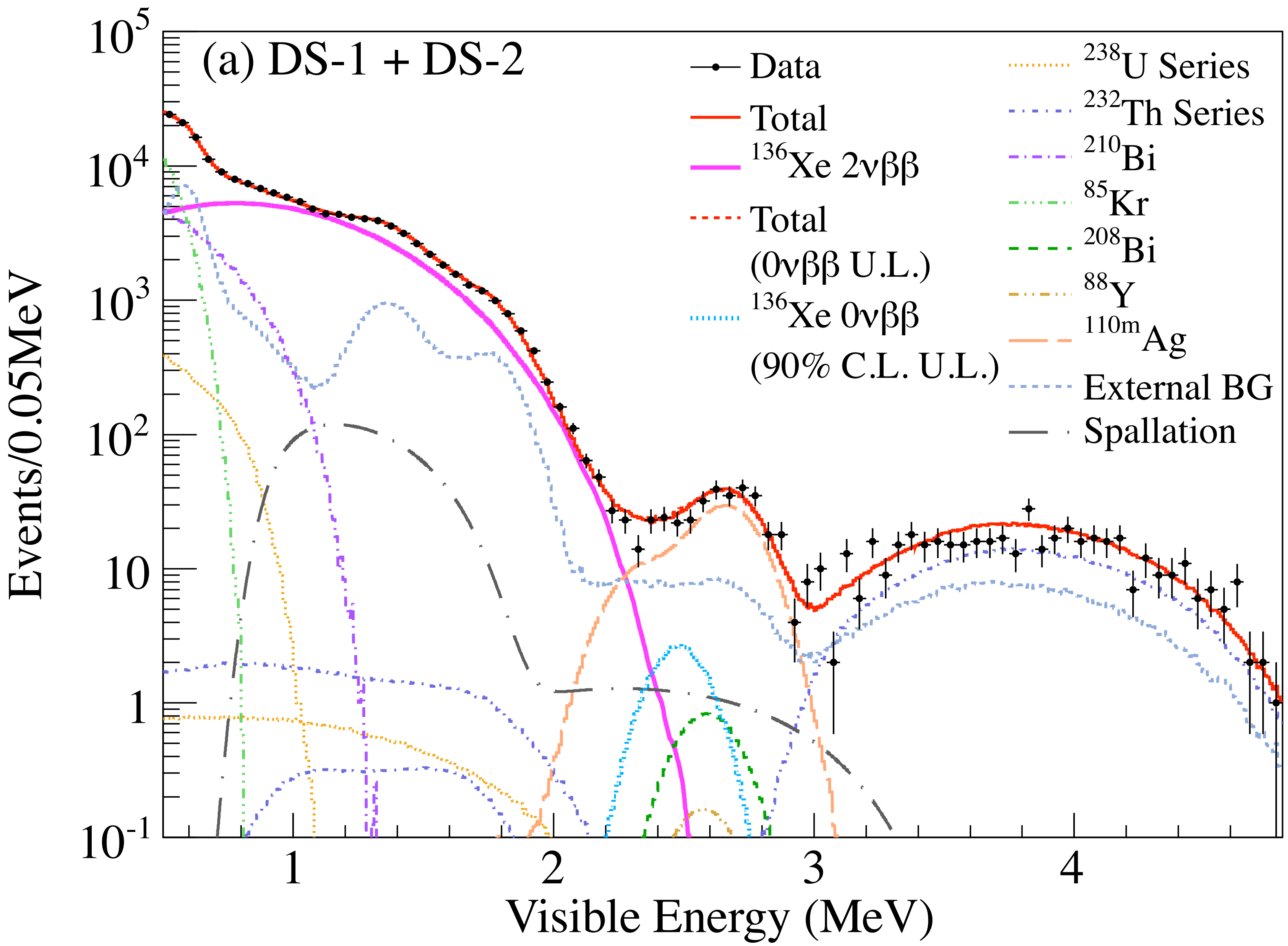


- Hosted in the KamLAND detector
- 3 m diameter mini-balloon at the center
- Loaded with 13 tons of Xe-loaded LS
  - ➡ ~2.5% by weight Xe
  - ➡ 90% ^{136}Xe (300 kg)
  - ➡ Q-value = 2458 keV
- KamLAND LS, 5m thick ultra-pure active shield
- KamLAND mineral oil buffer (2m thick)
- 3.2 kt water Cherenkov muon veto

- Scintillation light detected by array of ~2000 PMTs
- Energy resolution: $\sigma_E/E = 6.6\ \%/\sqrt{E}$ or 100 keV @ Q-value

KamLAND-Zen phase I

Phase 1: Sept 2011-June 2012, 89.5 kg×yr exposure of ^{136}Xe

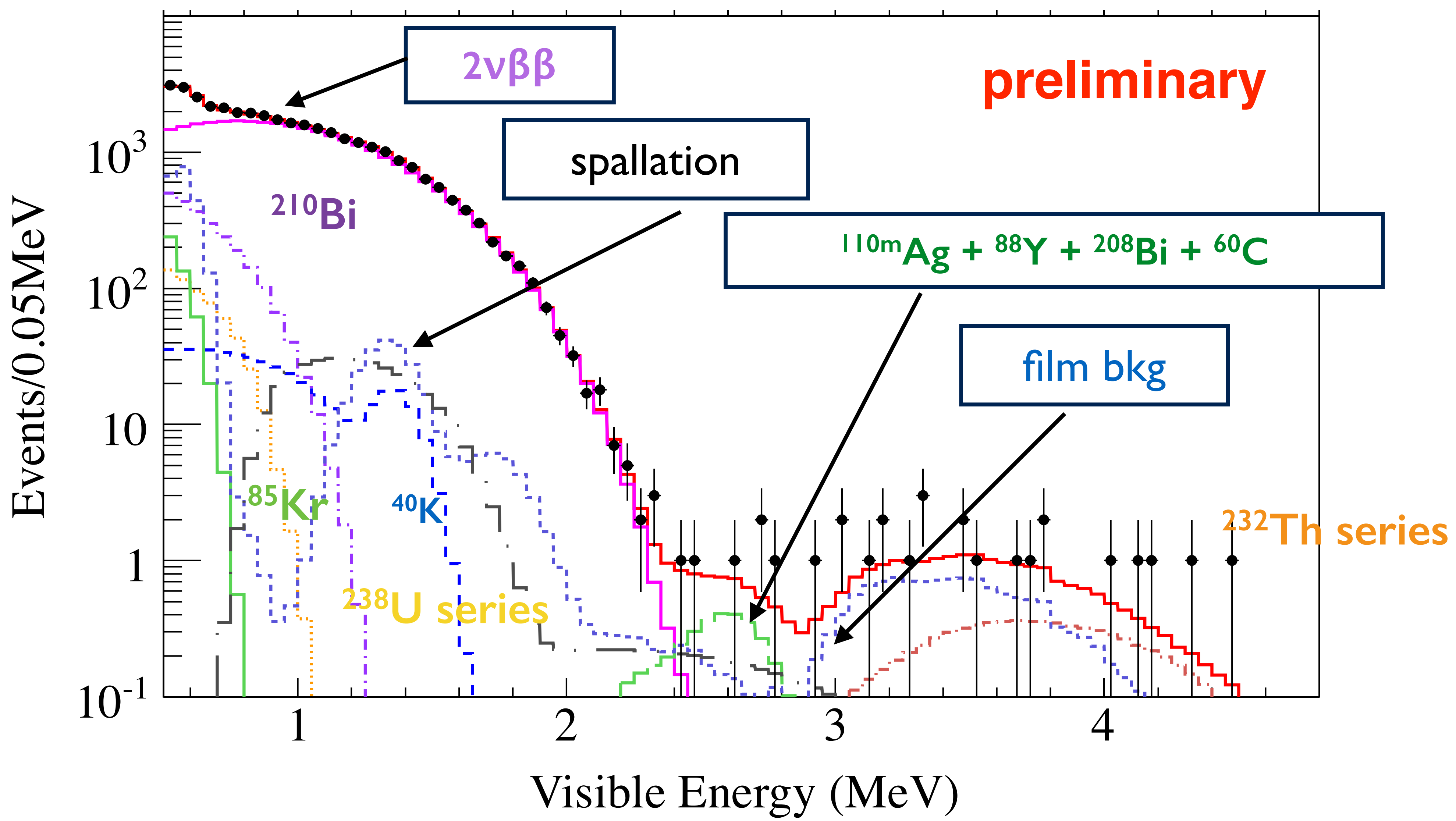


$$T^{0\nu}_{1/2} > 1.9 \times 10^{25}\ \text{yr} \quad (90\%\ \text{C.L})$$

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

KamLAND-Zen phase II

At the end of Phase 1, the Xe and Xe-LS were purified to try to reduce the background



$$T_{1/2}^{2\nu} = 2.32 \pm 0.05(\mathrm{stat}) \pm 0.08(\mathrm{syst}) \times 10^{21}\mathrm{yr}$$

$T_{1/2}^{0\nu} > 1.3 \times 10^{25}$ yr 90% C.L.

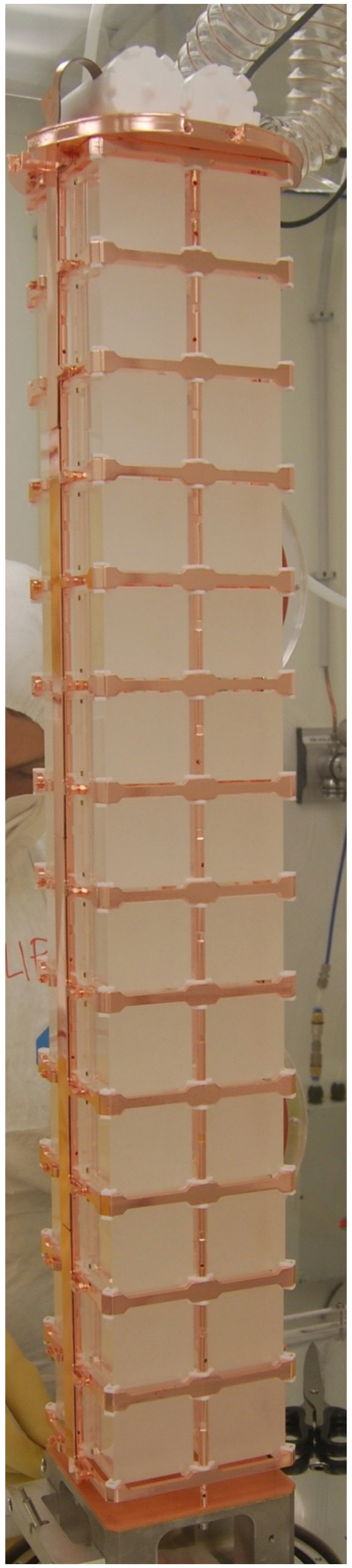
CUORE-0

CUORE-0 is the first tower produced out of the CUORE assembly line.

- 52 TeO_2 5x5x5 cm^3 crystals (~750 g each)
- 13 floors of 4 crystals each
- total detector mass: 39 kg TeO_2 (10.9 kg of ^{130}Te)

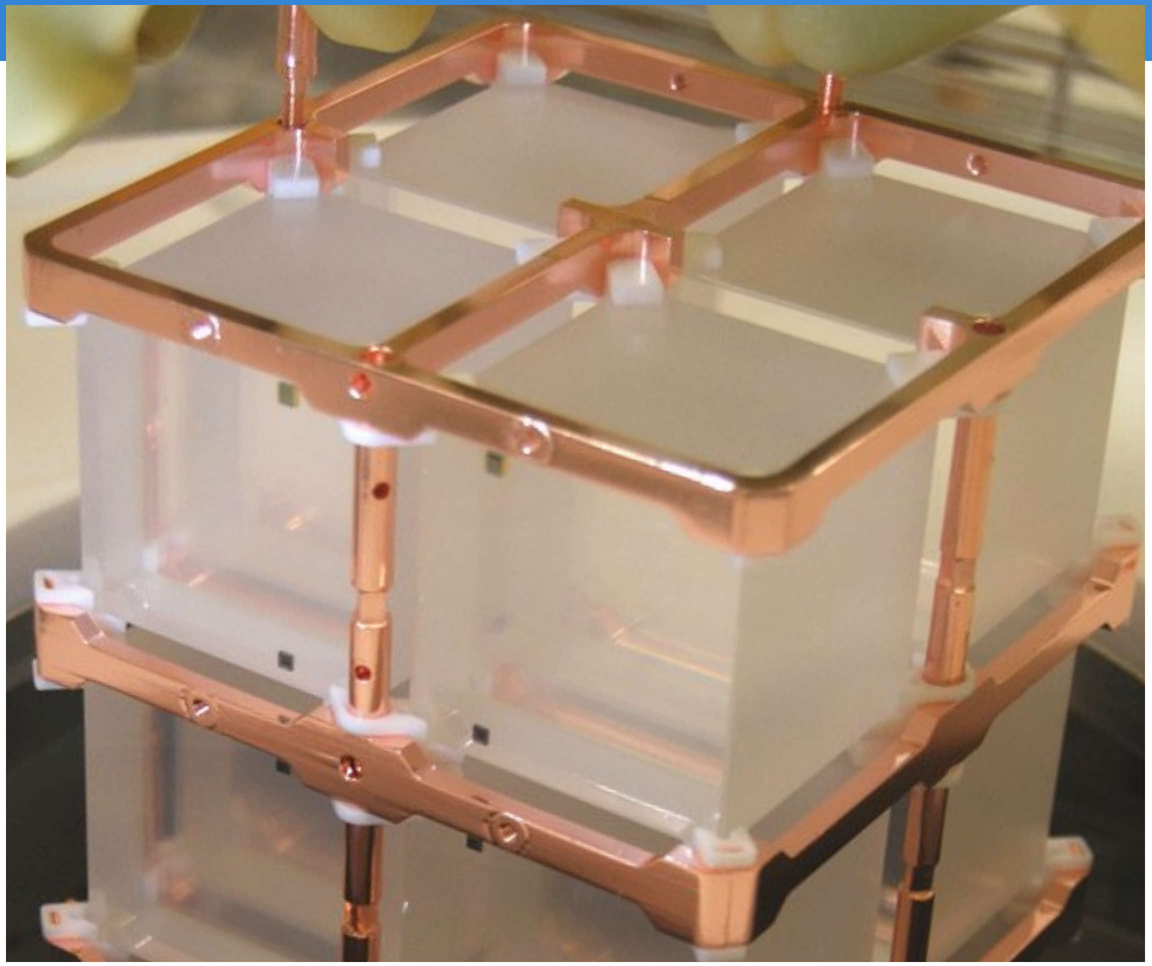
CUORE-0 has been taking data since March 2013 in the 25 year old Cuoricino cryostat.

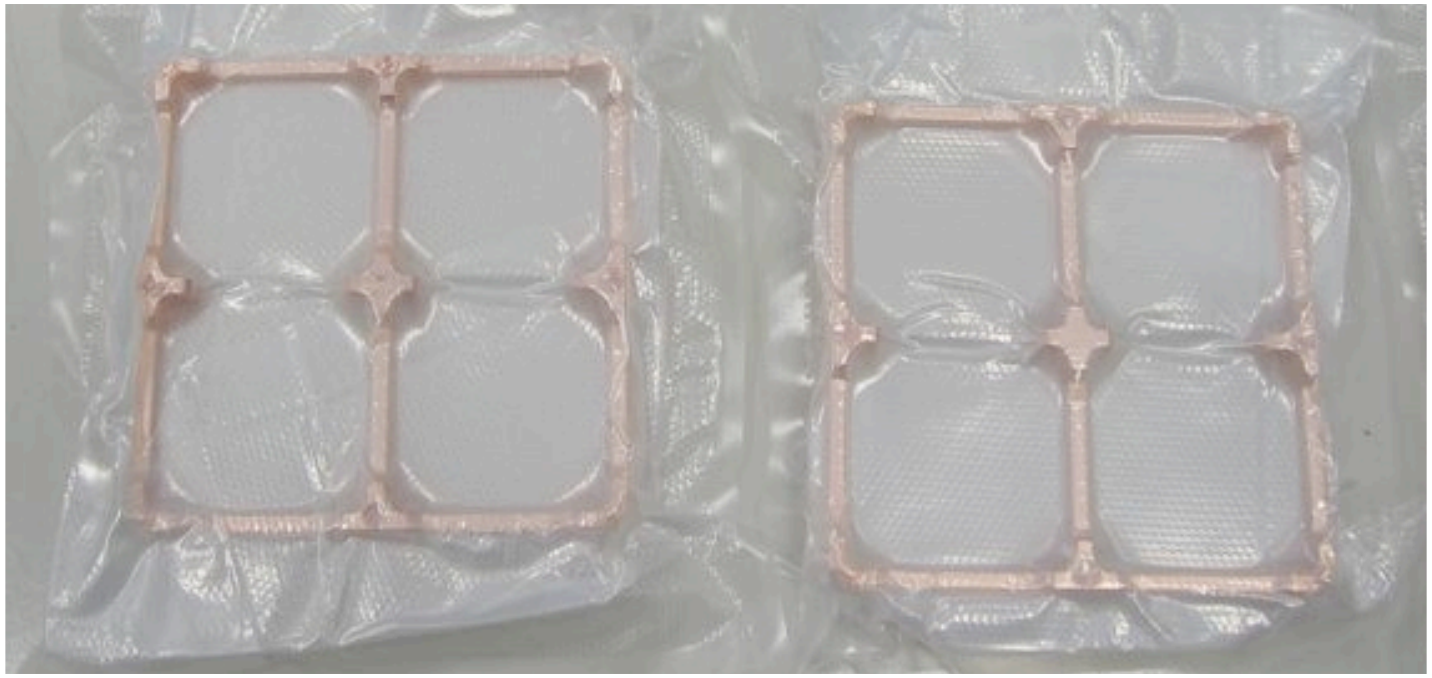
- Proof of concept of CUORE detector in all stages
- Test and debug of the CUORE tower assembly line
- Test of the CUORE DAQ and analysis framework
- Check of the radioactive background reduction
- Extend the physics reach beyond Cuoricino while CUORE is being assembled
- Sensitive 0vDBD experiment

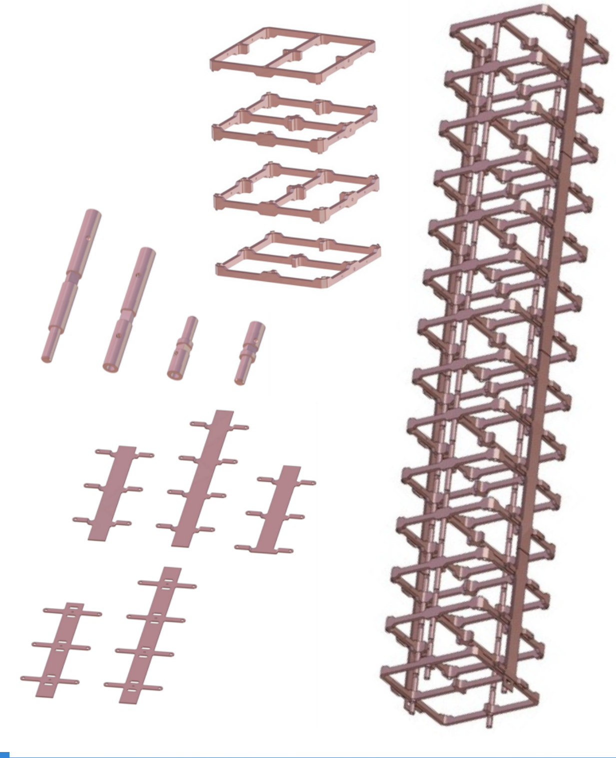


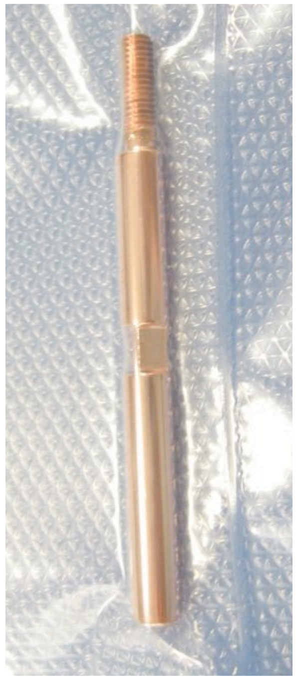
From Cuoricino to CUORE

- New lighter detector design structure
- Reduced overall copper surfaces by a factor ~2
- New surface cleaning technique
- Strict production protocols for TeO_2 surface contamination
- Minimization of Rn exposure (Glove Box assembly)
- Strict material selection

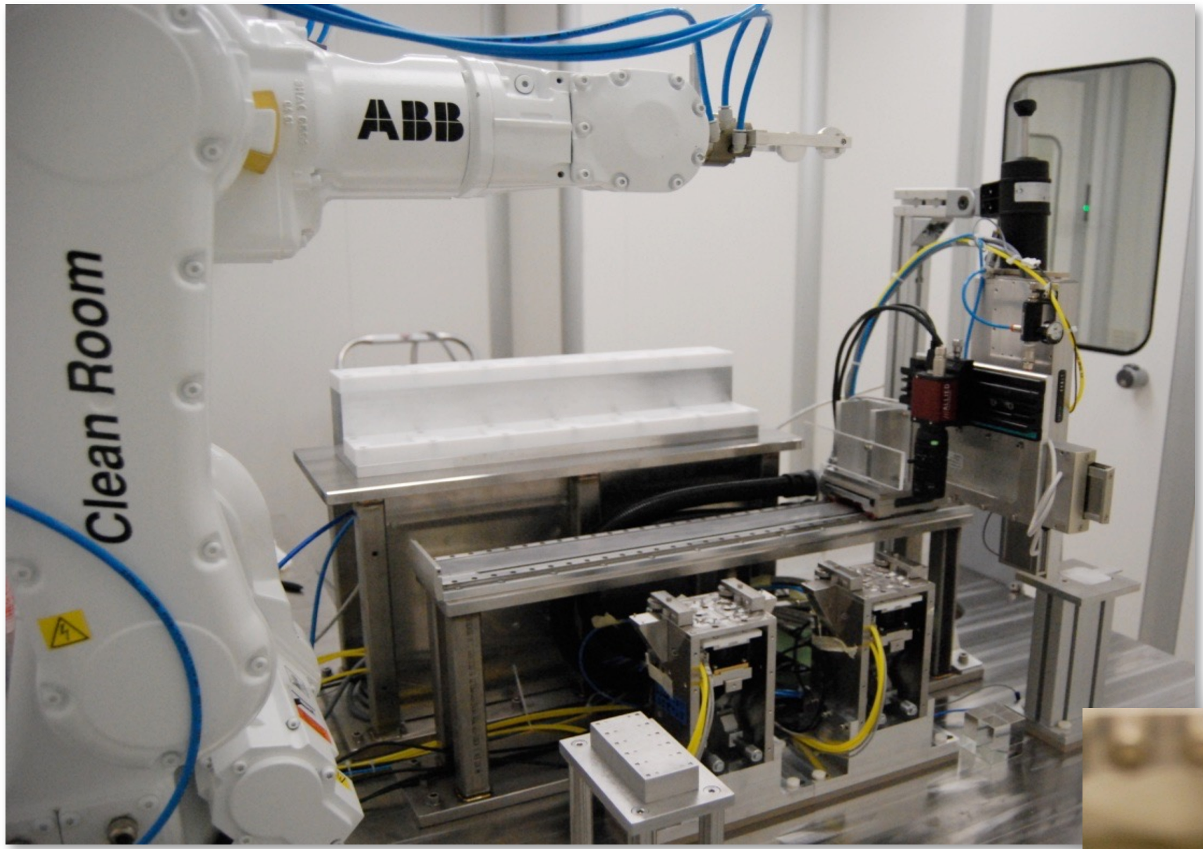


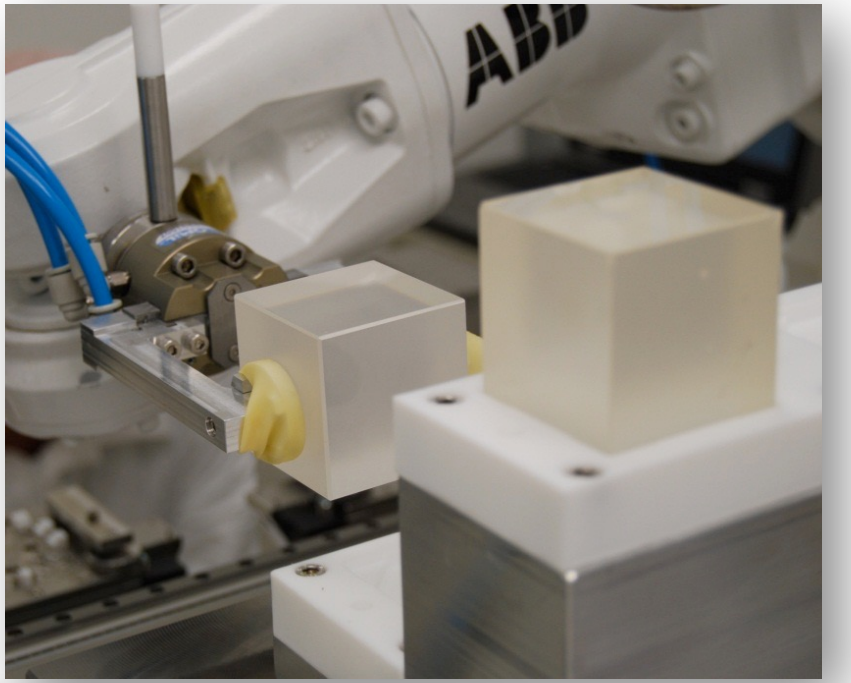


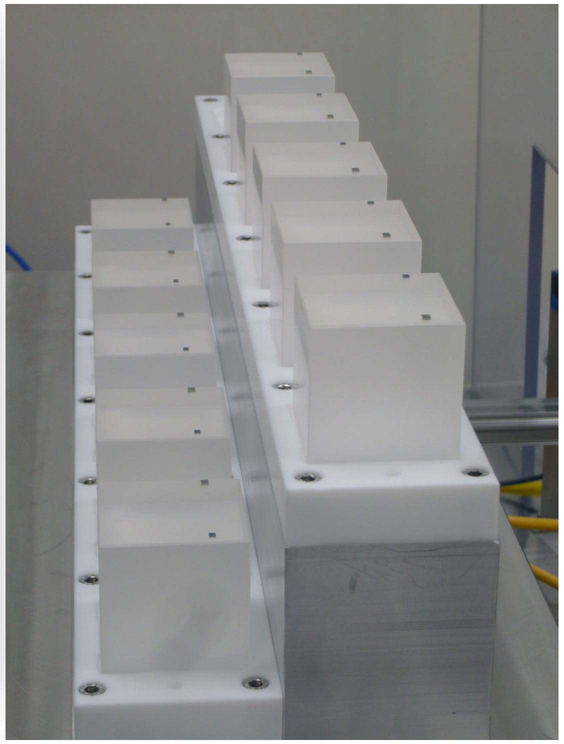


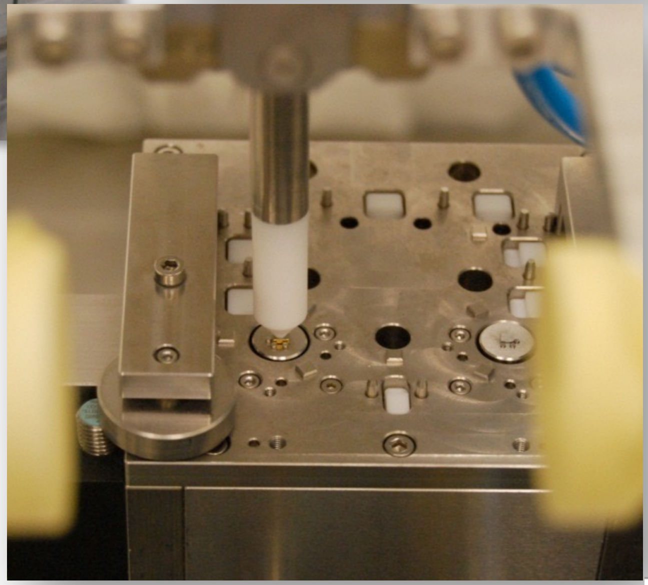


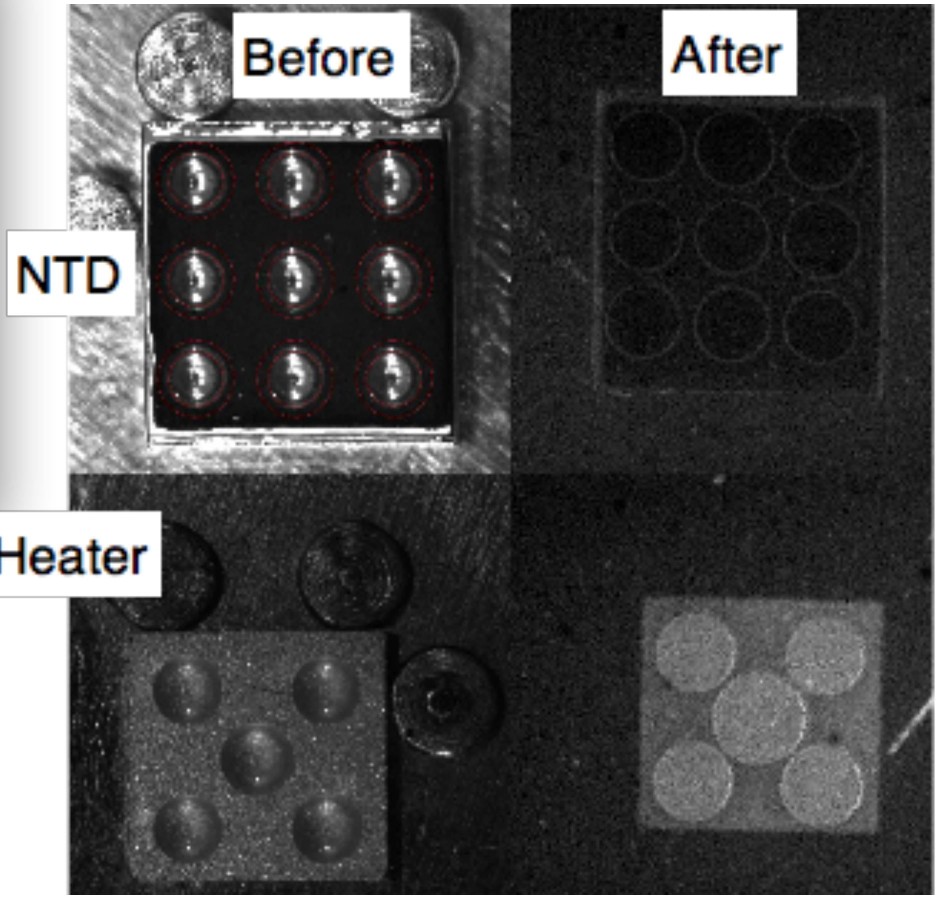
Thermistors & Heaters coupling







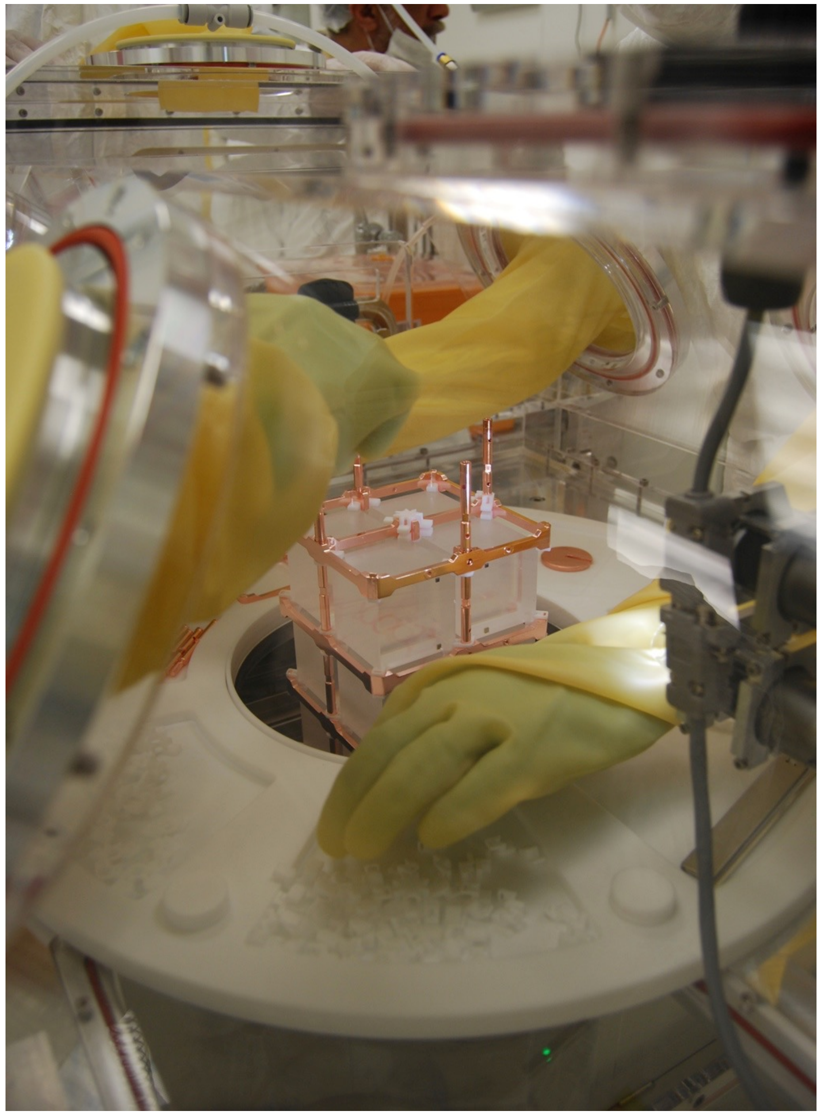


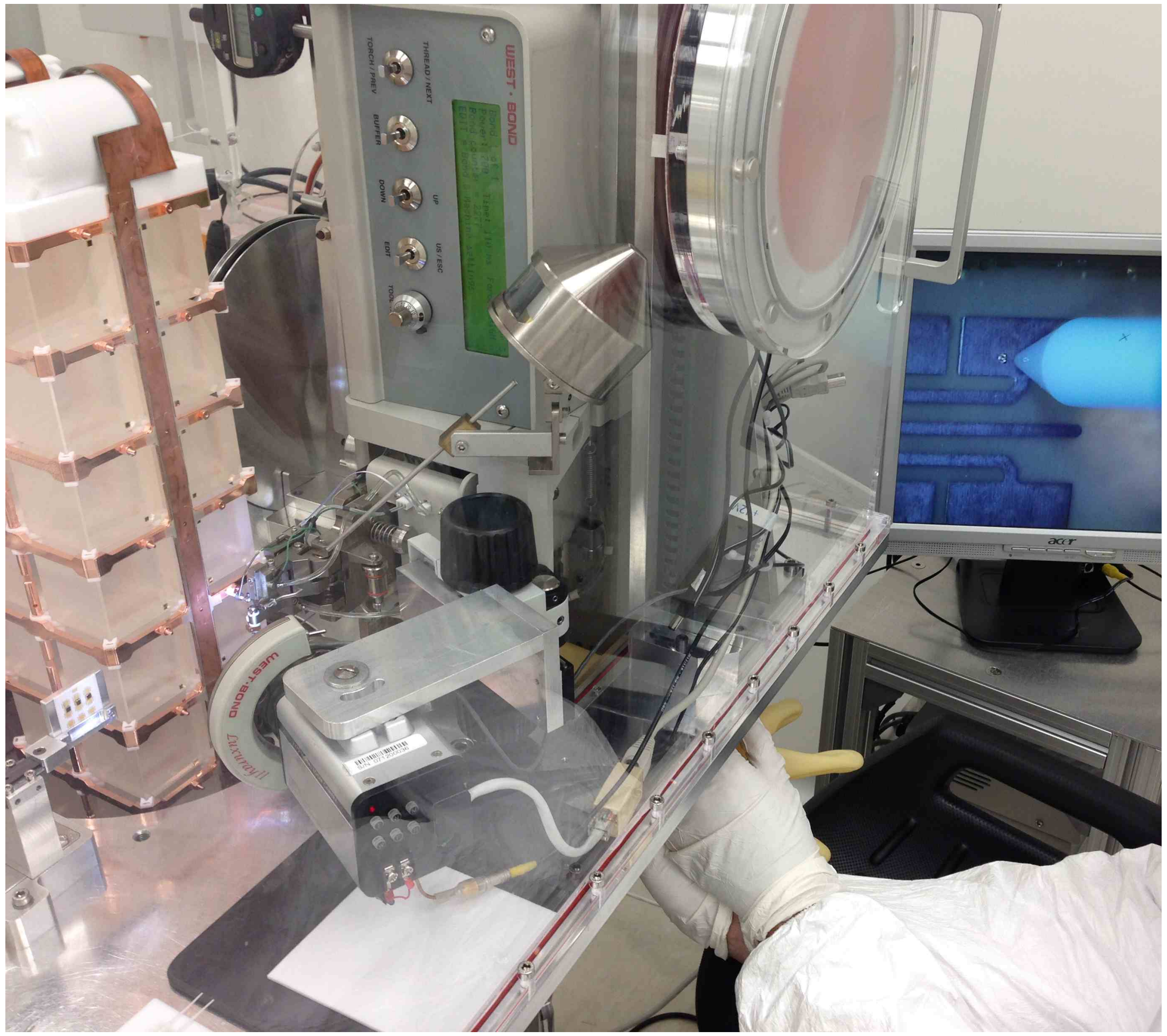


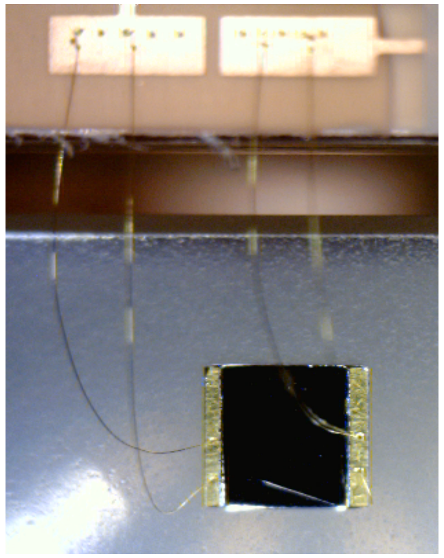
Features:

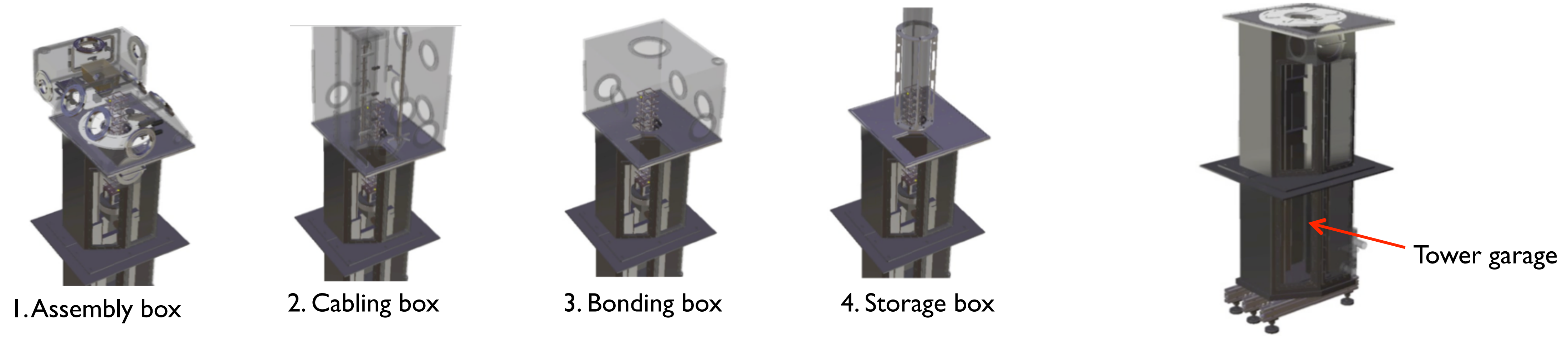
- new semi-automatic system
- highly-reproducible
- fully performed under N_2 atmosphere to minimize radioactive recontamination.

CUORE-0 Assembly & Bonding

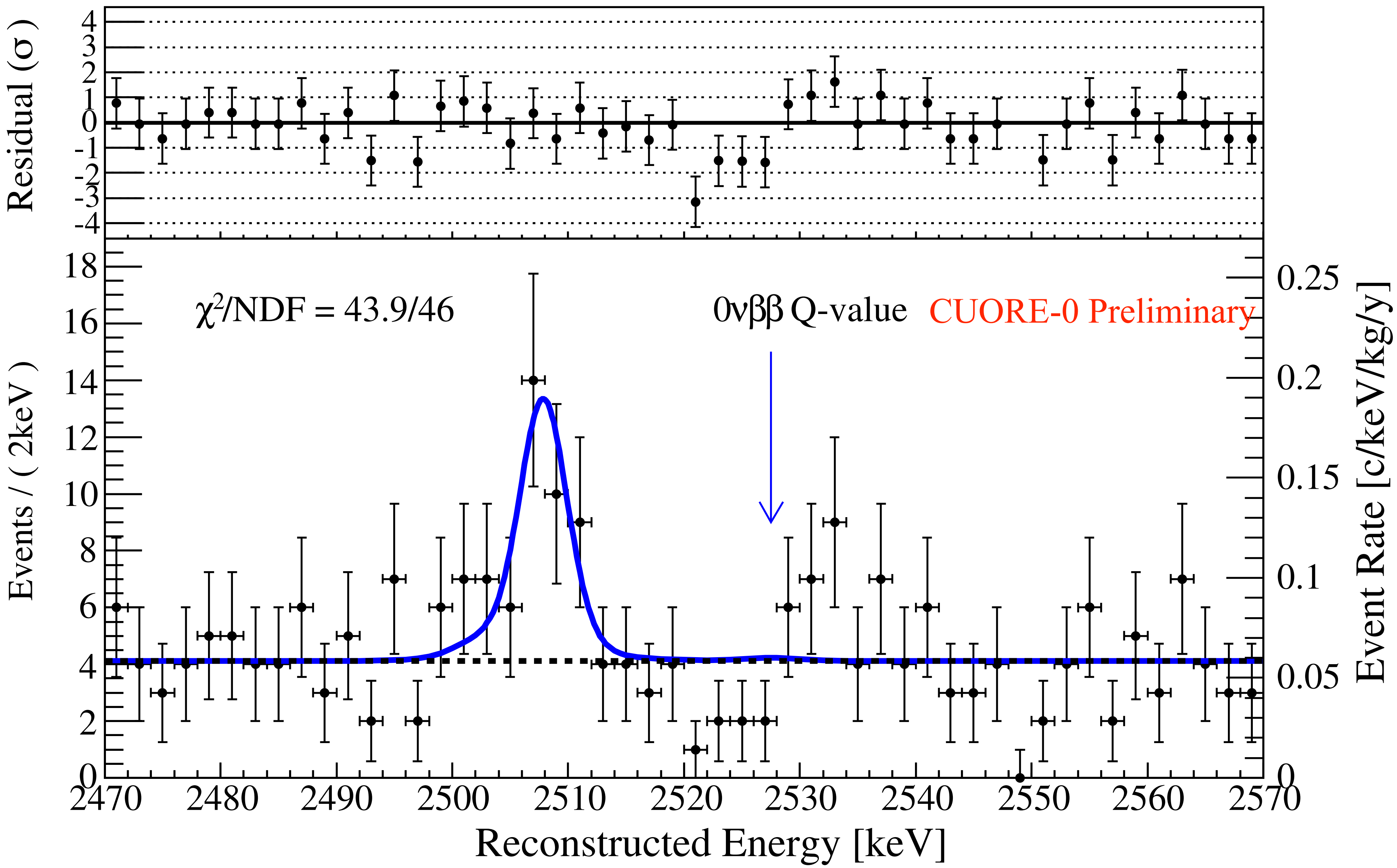








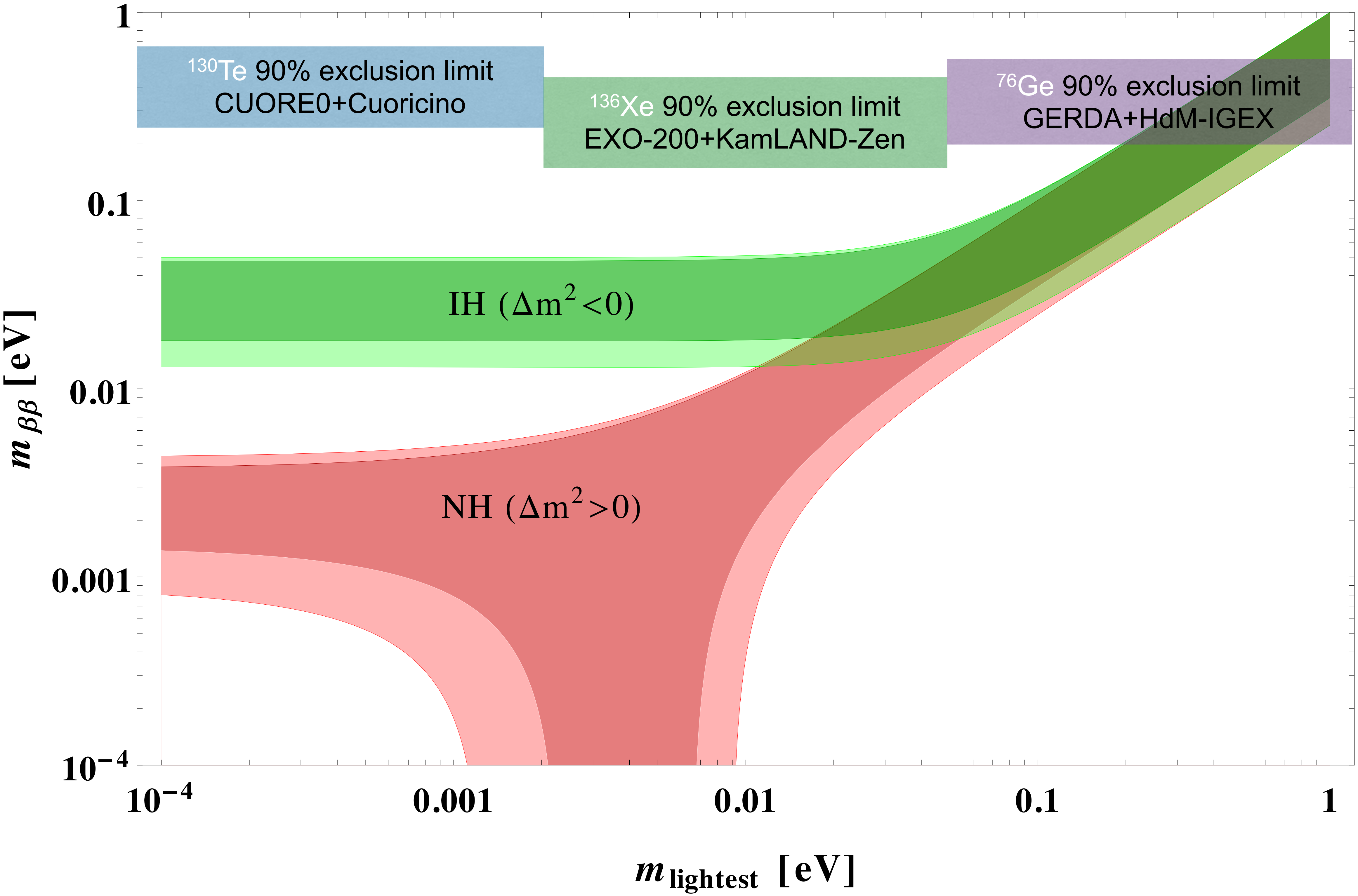
CUORE-0 results



Background index: 0.058 ± 0.004 (stat.) ± 0.002 (syst.) c keV^{-1} kg^{-1} yr^{-1}

0vDBD ^{130}Te Bayesian 90% C.L. limit: $T_{1/2} > 2.7 \times 10^{24}$ yr

Present limits



Near Future

Several experiments in the next 2-3 years

- Gerda phase II
  - 30 BeGe detectors with improved background; ~20 kg enriched at 86%
- Majorana demonstrator
  - 30 kg of Ge diodes enriched at 87%; very low level background setup
- CUORE
  - ~ 1000 TeO2 bolometers; ~200 kg of 130Te
- Lucifer/Lumineu
  - Enriched Se and Mo bolometers with alpha background discrimination;
- SuperNEMO demonstrator
  - 7 kg of 82Se; reconstruction of electron kinematics, good background rejection
- Improved EXO-200
  - improved energy resolution and possibly background
- KamLAND-Zen fase 3
  - 600 kg of 90% enriched Xe; improved background
- SNO+ 0.3%
  - liquid scintillator loaded with natural Te; 800 kg of 130Te
- NEXT-NEW
  - gaseous Xe TPC; ~ 10 kg of 136Xe

And others planned later on

- Gerda+Majorana
  - ton scale Ge experiment with the best technology
- CUPID
  - ~1 ton of enriched Te, Mo or Se bolometers in the CUORE setup, with background discrimination
- AMORE
  - ~100 kg CaMoO4 scintillating bolometers with enriched 100Mo
- SuperNEMO
  - 100 kg of 82Se (150Nd, 48Ca)
- nEXO
  - 5 tons of 90% enriched Xe; possible barium tagging
- KamLAND2-Zen
  - ~1 ton of 90% enriched Xe
- SNO+ 3.0%
  - 8 tons of 130Te
- NEXT-100, BEXT
  - 100-1000 kg of 136Xe

Different technologies

Different detector technologies are planned

- different challenges
- different capabilities

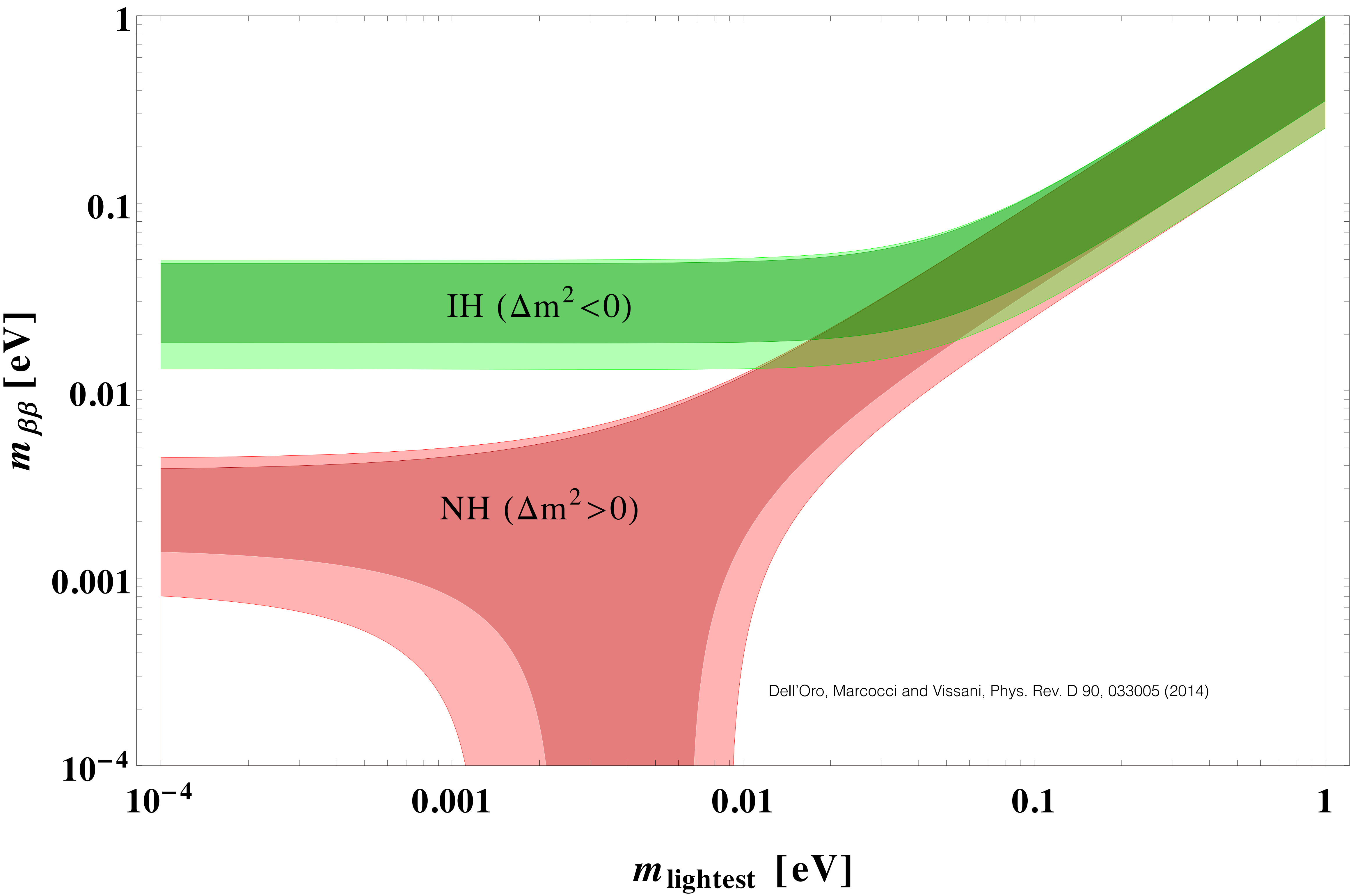
Liquid/Gaseous vs Solid detectors

- Liquid detectors have (generally)
  - worser energy resolution
  - better background (purification)
  - better for reach lower limits

- Solid detectors have (generally)
  - excellent energy resolution
  - worser background
  - better for discovery

Far Far Away…

Which is the level that we can reach?



Assumptions

- Nuclear matrix elements from IBM-2
- 1 sigma sensitivity
- Zero background (i.e. $M \cdot T \cdot B \cdot \Delta E \lesssim 1$)
- 90% isotopic enrichment
- Present isotope cost
- Present detector technologies
- Present efficiencies (fiducial volume)
- Present (or anticipated) energy resolution
- Measurement time: 5 years
- Goal: $\langle m_{\beta\beta} \rangle = 12$ meV

$<m_{\beta\beta}>$=12 meV g_A=1,269

	T1/2 0v [years]	Isotope mass [ton]	Efficiency (fiducial volume)	Total detector mass [ton]	a.i. [%]	Isotope cost/kg [k€]	Isotope cost [M€]	B*ΔE [c/kg/y]	ΔE FWHM [keV]	Background [c/keV/kg/y]	Q value [keV]	T1/2 2v [years]	Ratio 0v/2v
^{76}Ge GERDA	1,0E+28	0,365	0,82	0,49	7,8	70,00	34,64	5,5E-04	3	**1,8E-04**	2039	1,8E+21	**6,3E+08**
^{82}Se Lucifer	3,7E+27	0,145	0,80	0,36	9,2	70,00	14,11	1,4E-03	10	**1,4E-04**	2996	9,2E+19	**4,4E+05**
^{100}Mo ($ZnMO_4$)	3,2E+27	0,151	0,80	0,48	7,6	100,00	20,97	1,3E-03	9	**1,5E-04**	3034	7,1E+18	**8,0E+04**
^{116}Cd ($CdWO_4$)	5,4E+27	0,301	0,80	1,31	9,6	150,00	62,64	6,7E-04	6	**1,1E-04**	2814	2,8E+19	**1,4E+06**
^{130}Te CUORE	3,0E+27	0,189	0,87	0,30	34,2	13,00	3,14	1,1E-03	5	**2,1E-04**	2527	6,8E+20	**1,1E+08**
^{130}Te SNO+	3,0E+27	0,189	0,20	350,61	34,2	13,00	13,67	1,1E-03	270	**3,9E-06**	2527	6,8E+20	**4,3E-03**
^{136}Xe EXO	4,3E+27	0,281	0,50	0,63	8,9	8,00	5,00	7,1E-04	58	**1,2E-05**	2458	2,1E+21	**8,4E+01**
^{136}Xe Kam-Zen	4,3E+27	0,281	0,30	42,72	8,9	8,00	8,34	7,1E-04	250	**2,8E-06**	2458	2,1E+21	**1,3E-02**
^{136}Xe NEXT	4,3E+27	0,281	0,30	1,04	8,9	8,00	8,34	7,1E-04	15	**4,7E-05**	2458	2,1E+21	**2,8E+05**

$<m_{\beta\beta}>=12$ meV $\quad g_A=1,269 \cdot A^{-0.18}$

	T1/2 0v [years]	Isotope mass [ton]	Efficiency (fiducial volume)	Total detector mass [ton]	a.i. [%]	Isotope cost/kg [k€]	Isotope cost [M€]	B*ΔE [c/kg/y]	ΔE FWHM [keV]	Background [c/keV/kg/y]	Q value [keV]	T1/2 2v [years]	Ratio 0v/2v
^{76}Ge GERDA	2,3E+29	8,26	0,82	11,19	7,8	70,00	783,0	2,4E-05	3	**8,1E-06**	2039	1,8E+21	**6,3E+08**
^{82}Se Lucifer	8,8E+28	3,46	0,80	8,65	9,2	70,00	336,9	5,8E-05	10	**5,8E-06**	2996	9,2E+19	**4,4E+05**
^{100}Mo ($ZnMO_4$)	8,7E+28	4,16	0,80	13,25	7,6	100,00	577,4	4,8E-05	9	**5,3E-06**	3034	7,1E+18	**8,0E+04**
^{116}Cd ($CdWO_4$)	1,7E+29	9,22	0,80	40,14	9,6	150,00	1919,9	2,2E-05	6	**3,6E-06**	2814	2,8E+19	**1,4E+06**
^{130}Te CUORE	1,0E+29	6,30	0,87	10,02	34,2	13,00	104,6	3,2E-05	5	**6,4E-06**	2527	6,8E+20	**1,1E+08**
^{130}Te SNO+	1,0E+29	6,30	0,20	11664,54	34,2	13,00	454,9	3,2E-05	270	**1,2E-07**	2527	6,8E+20	**4,3E-03**
^{136}Xe EXO	1,5E+29	9,67	0,50	21,50	8,9	8,00	172,0	2,1E-05	58	**3,6E-07**	2458	2,1E+21	**8,4E+01**
^{136}Xe Kam-Zen	1,5E+29	9,67	0,30	1468,24	8,9	8,00	286,6	2,1E-05	250	**8,3E-08**	2458	2,1E+21	**1,3E-02**
^{136}Xe NEXT	1,5E+29	9,67	0,30	35,83	8,9	8,00	286,6	2,1E-05	15	**1,4E-06**	2458	2,1E+21	**2,8E+05**

What can we afford?

- Assume to build an experiment with a budget of ~100 M€
- More we increase the mass and more the isotope cost will dominate the other expenses
- Suppose that the isotope cost will be 50% of the total budget
- What we can build with that money?

Isotope cost = 50 M€ g_A=1,269

	T1/2 0v [years]	Isotope mass [ton]	Efficiency (fiducial volume)	Total detector mass [ton]	a.i. [%]	Isotope cost/kg [k€]	<mββ> [meV]	B*ΔE [c/kg/y]	ΔE FWHM [keV]	Background [c/keV/kg/y]	Q value [keV]	T1/2 2v [years]	Ratio 0v/2v
^{76}Ge GERDA	1,4E+28	0,53	0,82	0,71	7,8	70,00	**9,8**	3,8E-04	3	**1,3E-04**	2039	1,8E+21	**4,4E+08**
^{82}Se Lucifer	1,3E+28	0,51	0,80	1,28	9,2	70,00	**6,4**	3,9E-04	10	**3,9E-05**	2996	9,2E+19	**1,2E+05**
^{100}Mo ($ZnMO_4$)	7,5E+27	0,36	0,80	1,15	7,6	100,00	**7,8**	5,6E-04	9	**6,2E-05**	3034	7,1E+18	**3,3E+04**
^{116}Cd ($CdWO_4$)	4,3E+27	0,24	0,80	1,05	9,6	150,00	**13,4**	8,3E-04	6	**1,4E-04**	2814	2,8E+19	**1,8E+06**
^{130}Te CUORE	4,8E+28	3,01	0,87	4,79	34,2	13,00	**3,0**	6,6E-05	5	**1,3E-05**	2527	6,8E+20	**6,8E+06**
^{130}Te SNO+	1,1E+28	0,69	0,20	1280,37	34,2	13,00	**6,3**	2,9E-04	270	**1,1E-06**	2527	6,8E+20	**1,2E-03**
^{136}Xe EXO	4,3E+28	2,81	0,50	6,24	8,9	8,00	**3,8**	7,1E-05	58	**1,2E-06**	2458	2,1E+21	**8,4E+00**
^{136}Xe Kam-Zen	2,6E+28	1,69	0,30	256,18	8,9	8,00	**4,9**	1,2E-04	250	**4,7E-07**	2458	2,1E+21	**2,2E-03**
^{136}Xe NEXT	2,6E+28	1,69	0,30	6,25	8,9	8,00	**4,9**	1,2E-04	15	**7,9E-06**	2458	2,1E+21	**4,7E+04**

Isotope cost=50 M€ $g_A = 1,269 \cdot A^{-0.18}$

	T1/2 0v [years]	Isotope mass [ton]	Efficiency (fiducial volume)	Total detector mass [ton]	a.i. [%]	Isotope cost/kg [k€]	<mββ> [meV]	B*ΔE [c/kg/y]	ΔE FWHM [keV]	Background [c/keV/kg/y]	Q value [keV]	T1/2 2v [years]	Ratio 0v/2v
^{76}Ge GERDA	1,4E+28	0,53	0,82	0,71	7,8	70,00	**47,5**	3,8E-04	3	**1,3E-04**	2039	1,8E+21	**6,3E+08**
^{82}Se Lucifer	1,3E+28	0,51	0,80	1,28	9,2	70,00	**31,2**	3,9E-04	10	**3,9E-05**	2996	9,2E+19	**4,4E+05**
^{100}Mo ($ZnMO_4$)	7,5E+27	0,36	0,80	1,15	7,6	100,00	**40,8**	5,6E-04	9	**6,2E-05**	3034	7,1E+18	**8,0E+04**
^{116}Cd ($CdWO_4$)	4,3E+27	0,24	0,80	1,05	9,6	150,00	**74,4**	8,3E-04	6	**1,4E-04**	2814	2,8E+19	**1,4E+06**
^{130}Te CUORE	4,8E+28	3,01	0,87	4,79	34,2	13,00	**17,4**	6,6E-05	5	**1,3E-05**	2527	6,8E+20	**1,1E+08**
^{130}Te SNO+	1,1E+28	0,69	0,20	1280,37	34,2	13,00	**36,2**	2,9E-04	270	**1,1E-06**	2527	6,8E+20	**4,3E-03**
^{136}Xe EXO	4,3E+28	2,81	0,50	6,24	8,9	8,00	**22,3**	7,1E-05	58	**1,2E-06**	2458	2,1E+21	**8,4E+01**
^{136}Xe Kam-Zen	2,6E+28	1,69	0,30	256,18	8,9	8,00	**28,7**	1,2E-04	250	**4,7E-07**	2458	2,1E+21	**1,3E-02**
^{136}Xe NEXT	2,6E+28	1,69	0,30	6,25	8,9	8,00	**28,7**	1,2E-04	15	**7,9E-06**	2458	2,1E+21	**2,8E+05**

Few thoughts

- All those numbers get worse if we are not in zero background conditions (e.g. if $M \cdot T \cdot B \cdot \Delta E = 10$, the needed mass to reach the same result is Mx10)
  - an example: CUORE with 90% enriched ^{130}Te with background of 10^{-2} conteggi keV^{-1} kg^{-1} y^{-1} and with $g_A = 1{,}269$, in order to reach $\langle m_{\beta\beta} \rangle = 12$ meV should have a mass of ~15 ton.
- On the other hand an experiment with a good background rejection but with not feasible/affordable large masse is not useful
- If g_A is quenched the road is very hard
- Likely is needed to start thinking at isotopic enrichment with reasonable cost
  - If the best future technique will be based on a isotope different from ^{136}Xe and ^{130}Te, it is mandatory
  - For ^{130}Te (bolometers) and ^{136}Xe (NEXO, NEXT) even with the present cost and g_A quenched looks feasible to cover inverted hierarchy; but background reduction is still far from the needs

M. Biassoni, O. Cremonesi, P. Gorla, http://arxiv.org/abs/1310.3870