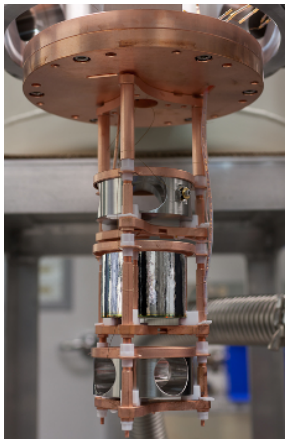
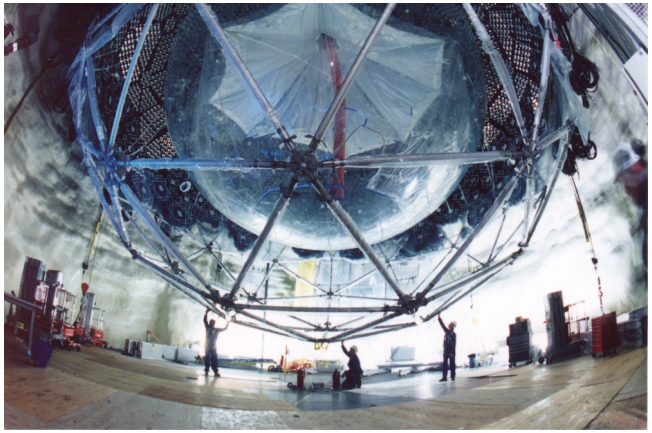


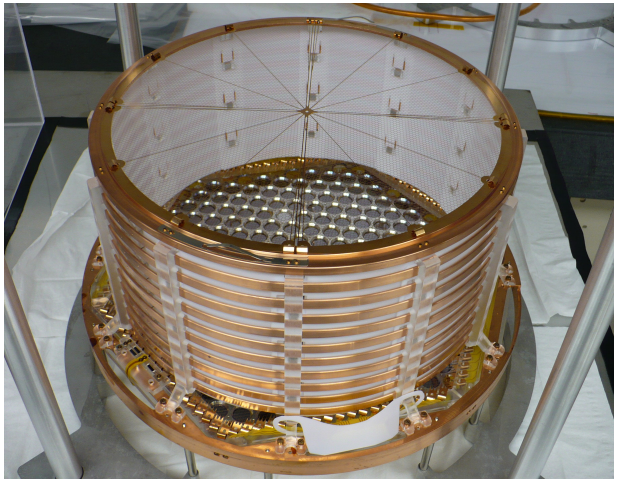


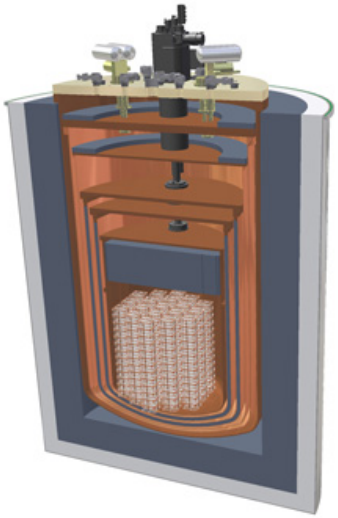
Experimental Overview of ββ0ν

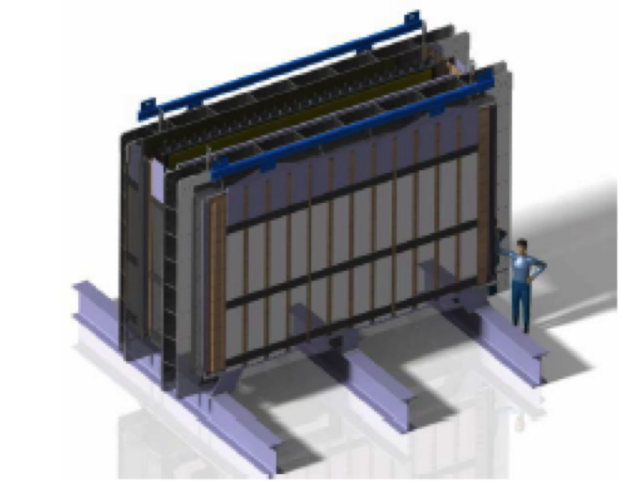
Carter Hall, Univ. of Maryland

Snowmass neutrino meeting

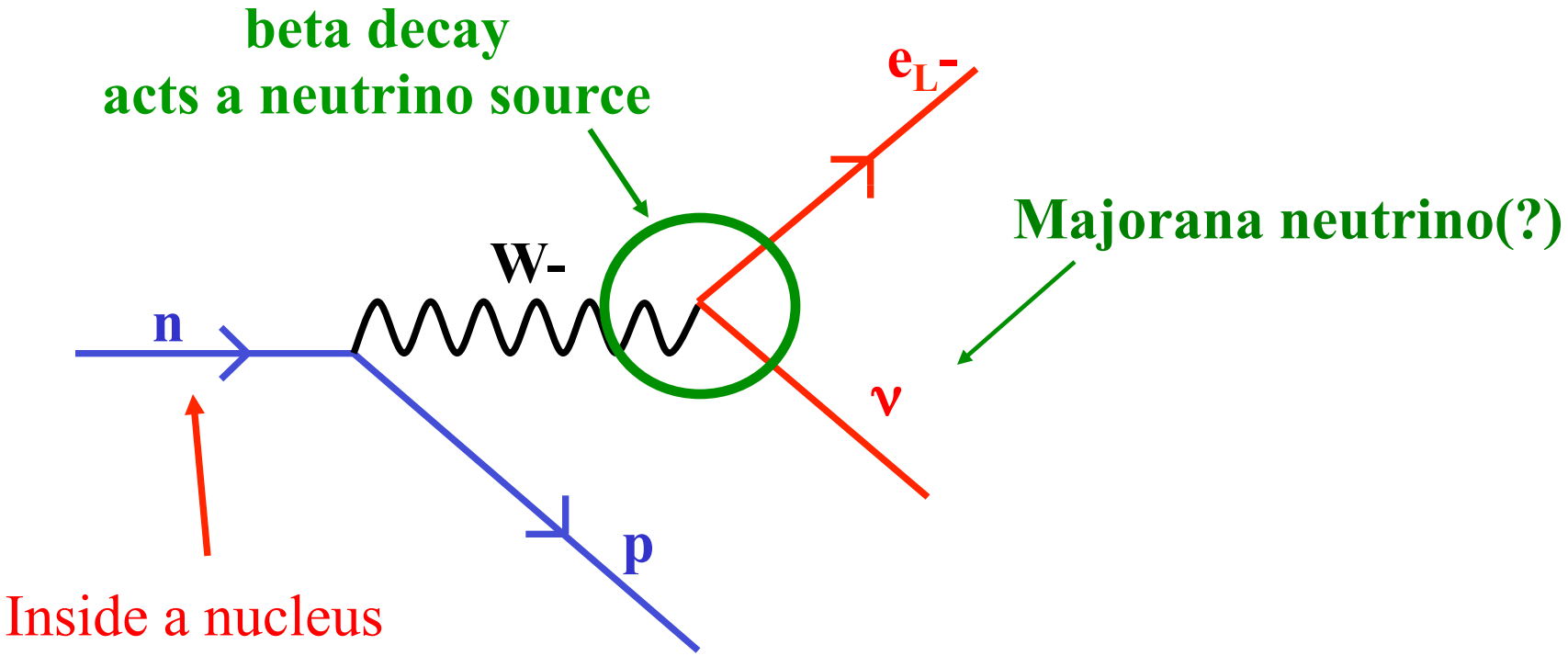
March 6, 2013



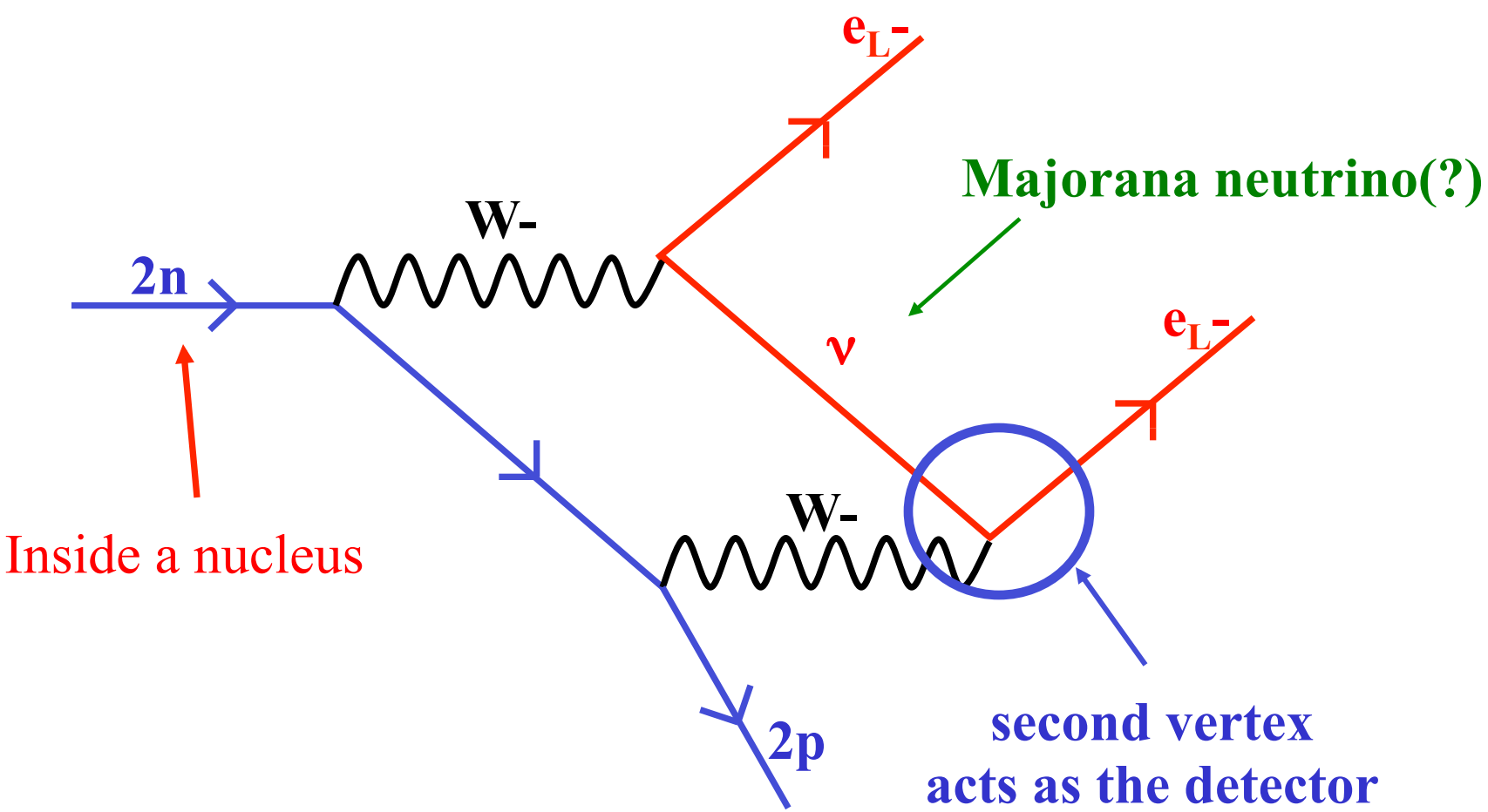




The nucleus as a neutrino source :

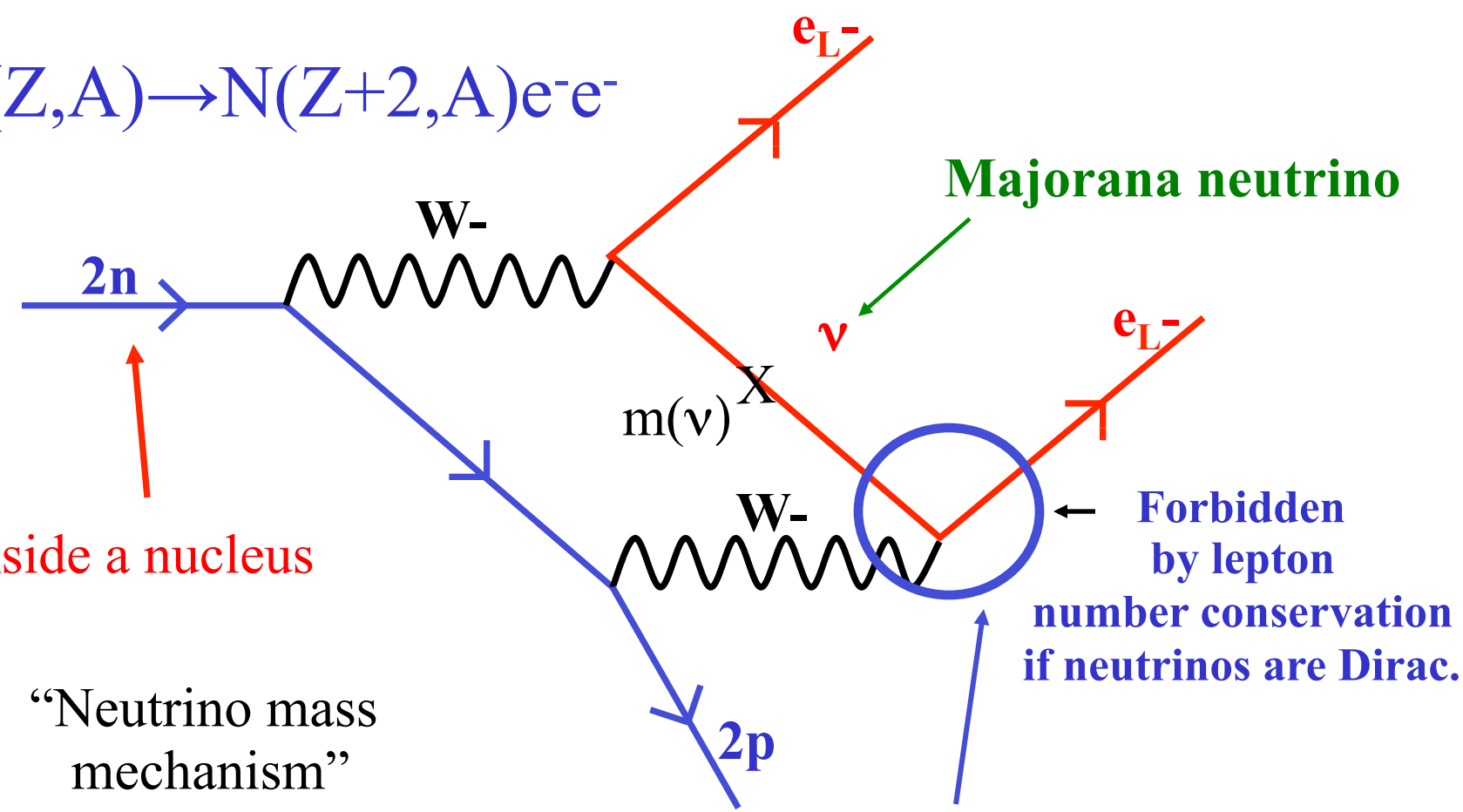


Use nuclear physics to test neutrino charge properties:



Neutrinoless Double Beta Decay ($\beta\beta0\nu$)

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



"Neutrino mass mechanism" for double beta decay

The ββ0ν half-life depends directly on the absolute neutrino masses:

Decay rate

$$\left(T_{1/2}^{0\nu\beta\beta}\right)^{-1} = G^{0\nu\beta\beta} \cdot \left|NME\right|^2 \cdot \left|\langle m_\nu \rangle\right|^2,$$

phase space

Nuclear Matrix Element

effective mass

$$\langle m_\nu \rangle = \sum_i U_{ei}^2 m_i e^{i\alpha_i}$$

mixing matrix (with phases)

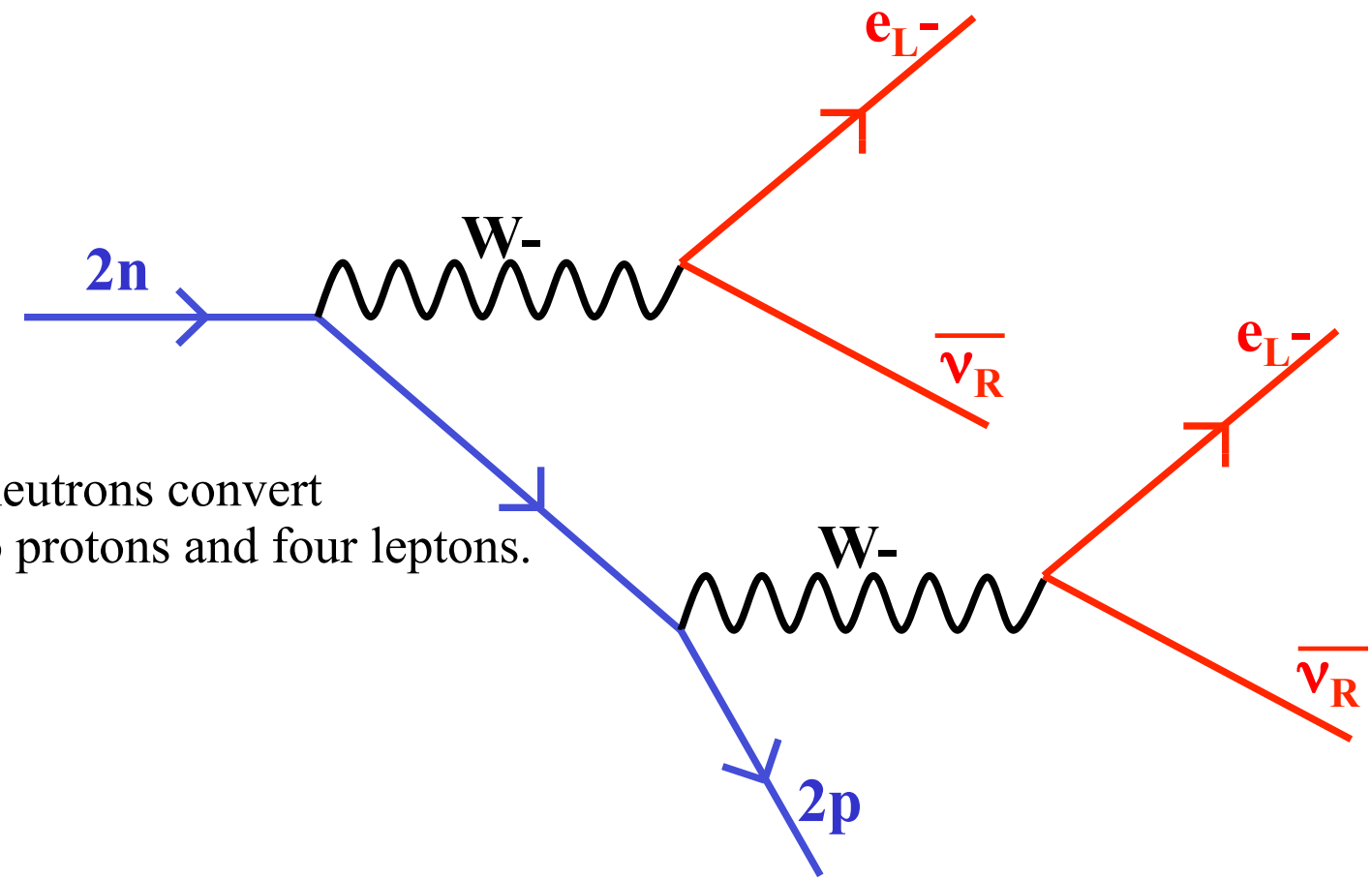
mass eigenvalues

Majorana phases

We can use the ββ0ν decay rate to measure the absolute neutrino mass if:

1) neutrinos are Majorana
2) we have a reliable calculation of the nuclear matrix element
3) the neutrino mass mechanism dominates the decay

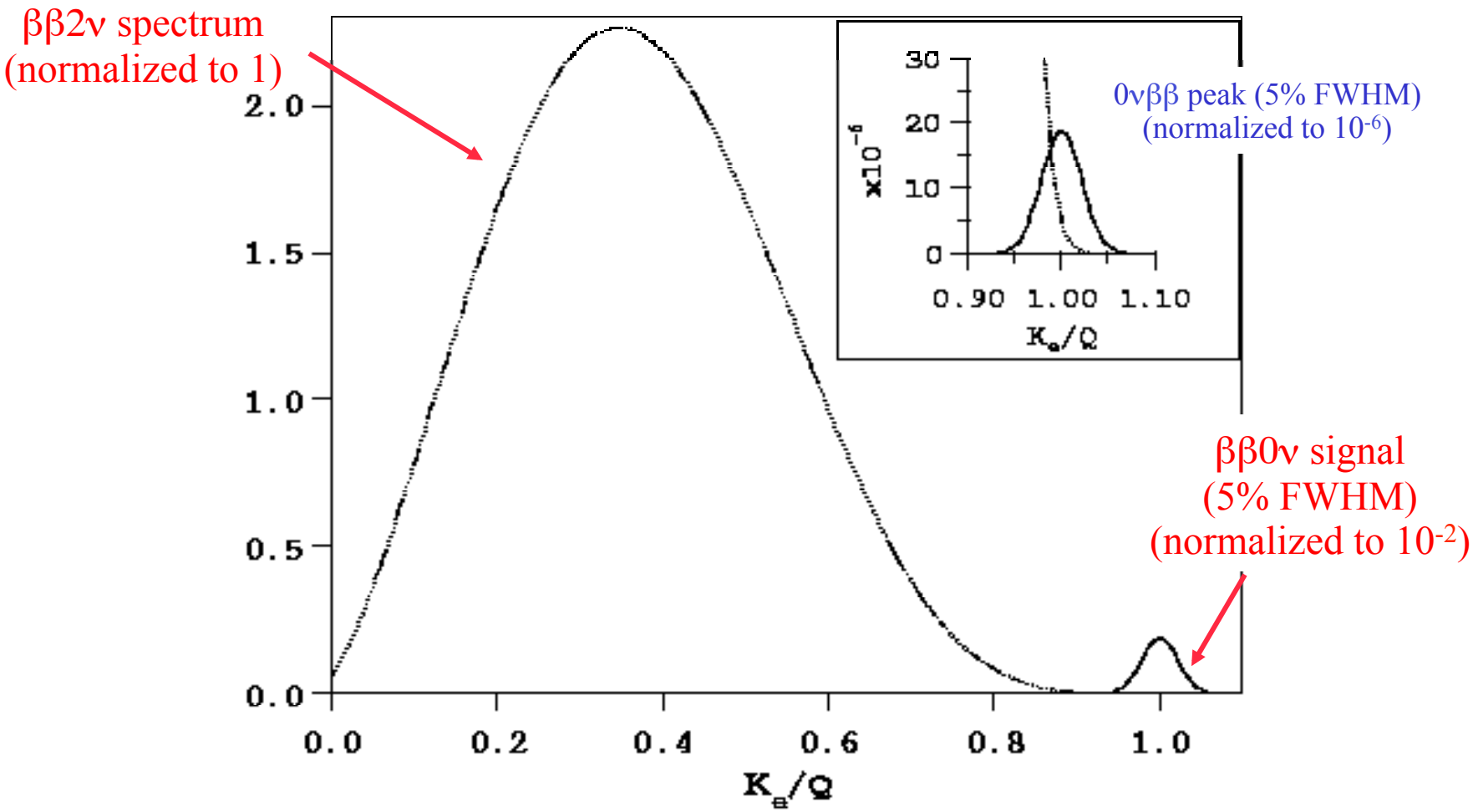
Two-Neutrino Double Beta Decay:



Two neutrons convert
to two protons and four leptons.

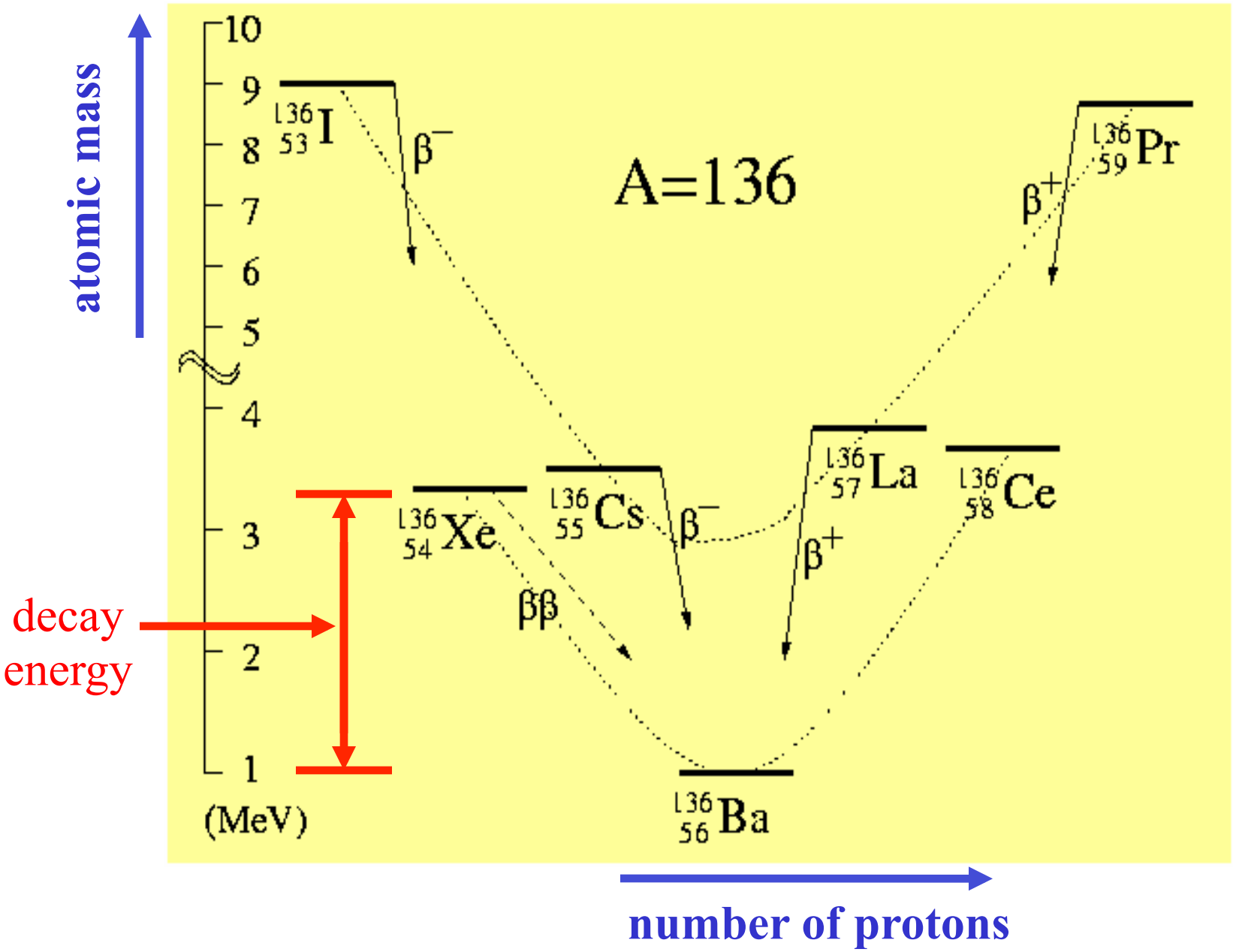
No direct implications for neutrino mass, but useful for constraining and testing the nuclear matrix element calculations

ββ0ν signature: a peak in the ββ energy spectrum



Summed electron energy in units of the kinematic endpoint (Q)

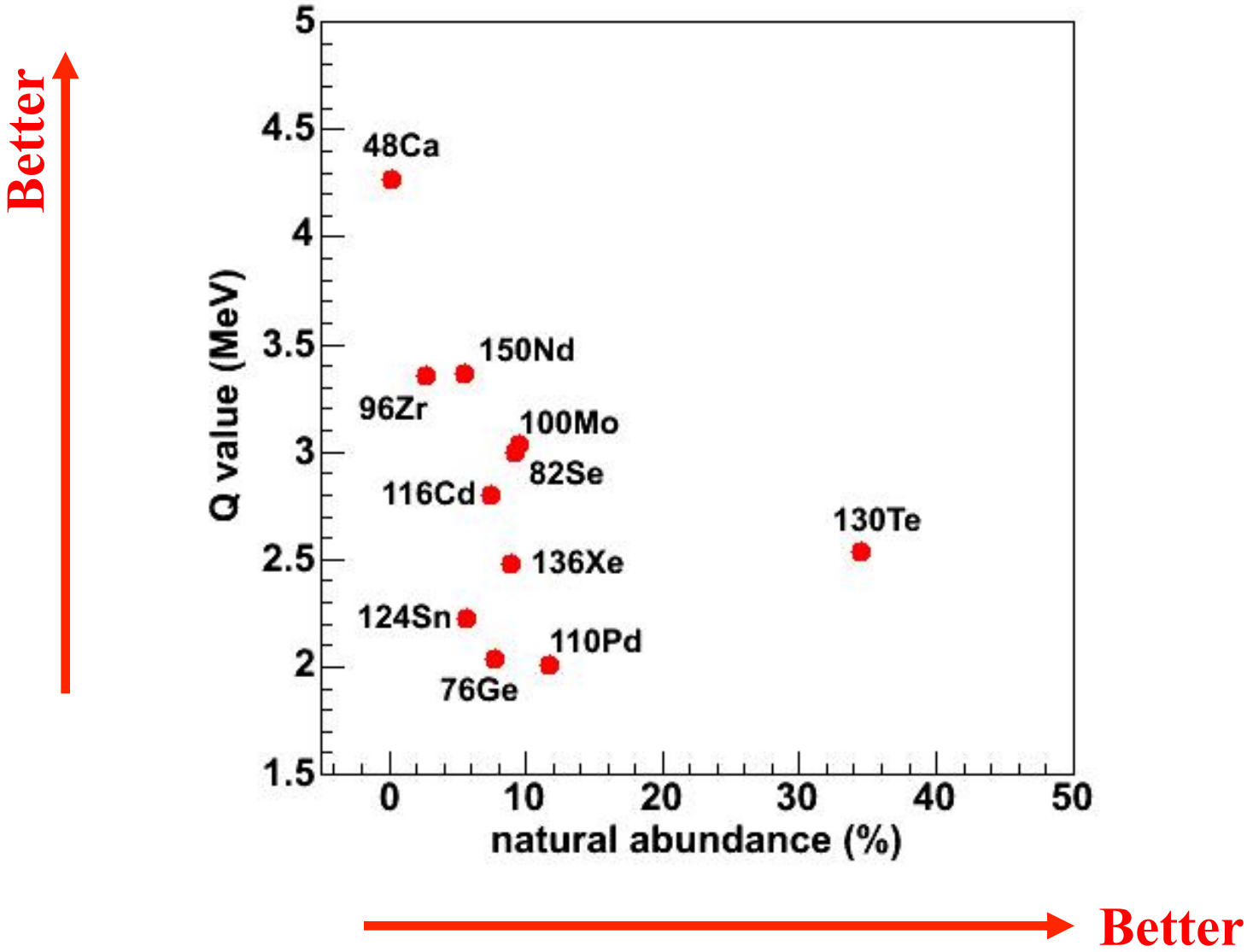
Choice of ββ source isotope



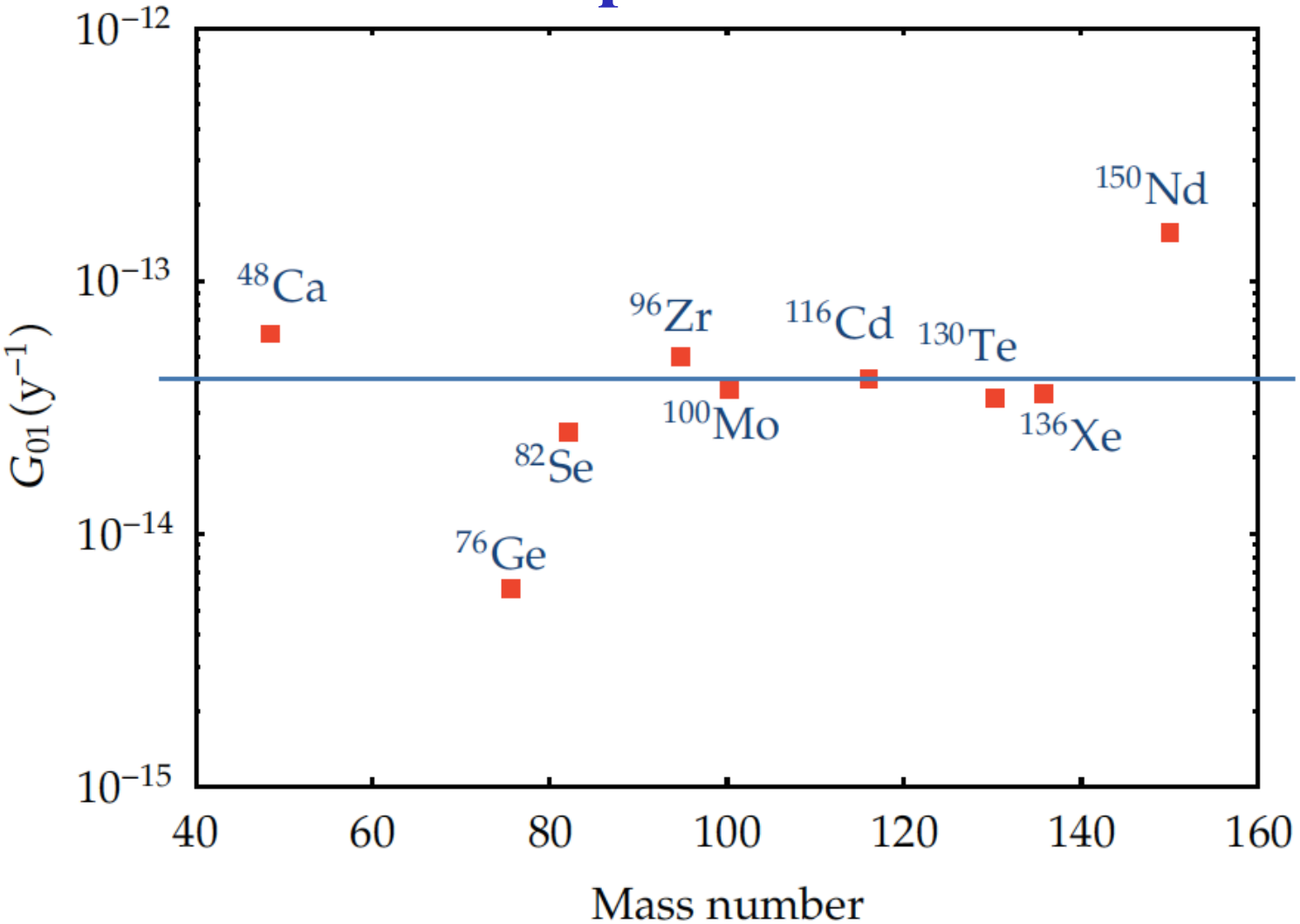
Choice of ββ source isotope

Isotope	Q value (MeV)	Abundance (%)	centrifuge enrichment?
^{48}Ca	4.271	0.187	No
^{76}Ge	2.039	7.8	Yes
^{82}Se	2.995	9.2	Yes
^{96}Zr	3.350	2.8	No
^{100}Mo	3.034	9.6	Yes
^{110}Pd	2.013	11.8	
^{116}Cd	2.802	7.5	Yes
^{124}Sn	2.228	5.64	
^{130}Te	2.533	34.5	Yes
^{136}Xe	2.457	8.9	Yes
^{150}Nd	3.367	5.6	No

Q values and natural abundance



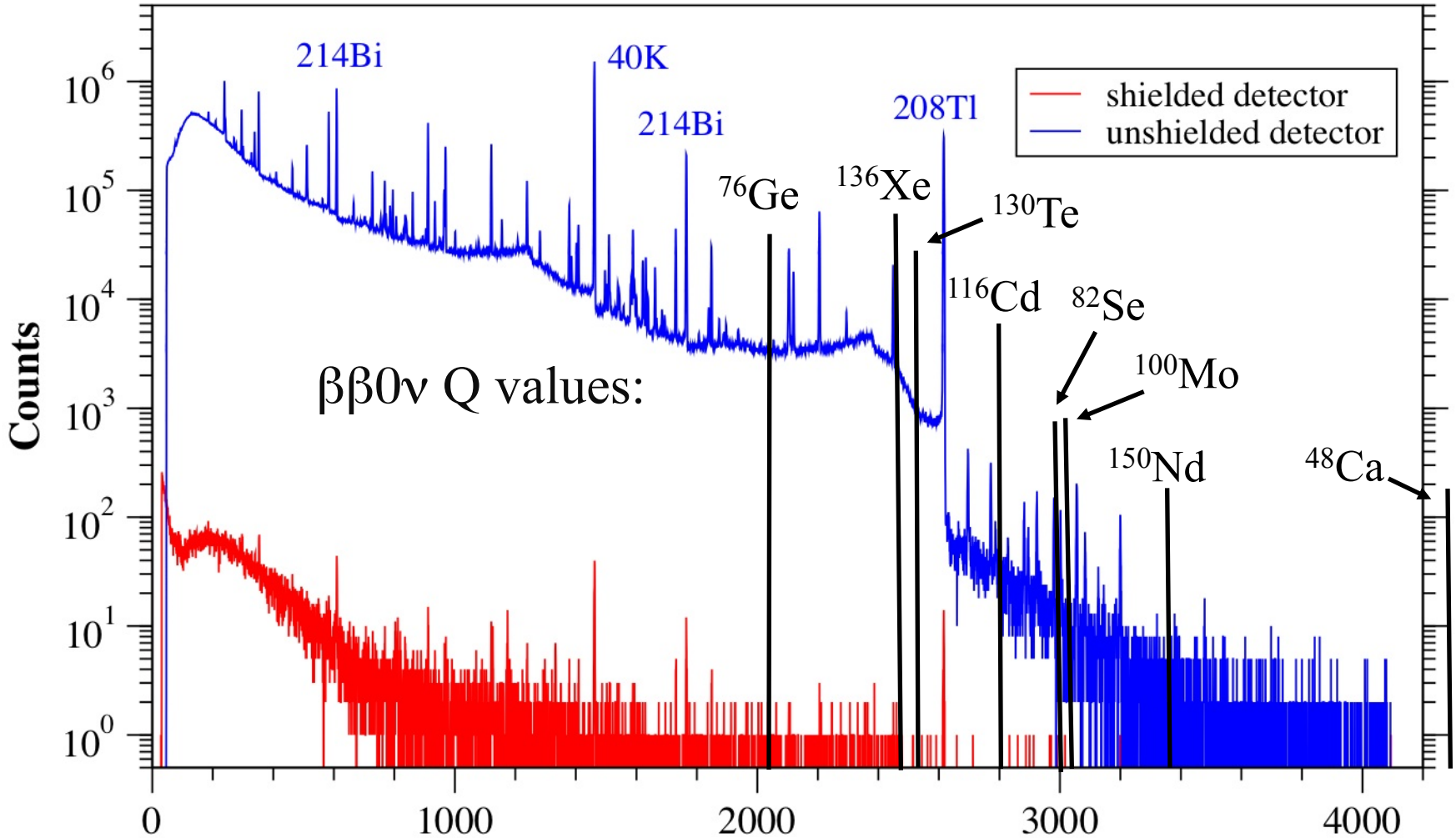
Phase space factors



From A. Giuliani and A. Poves, Advances in High Energy Physics, 2012 (2012) 857016.

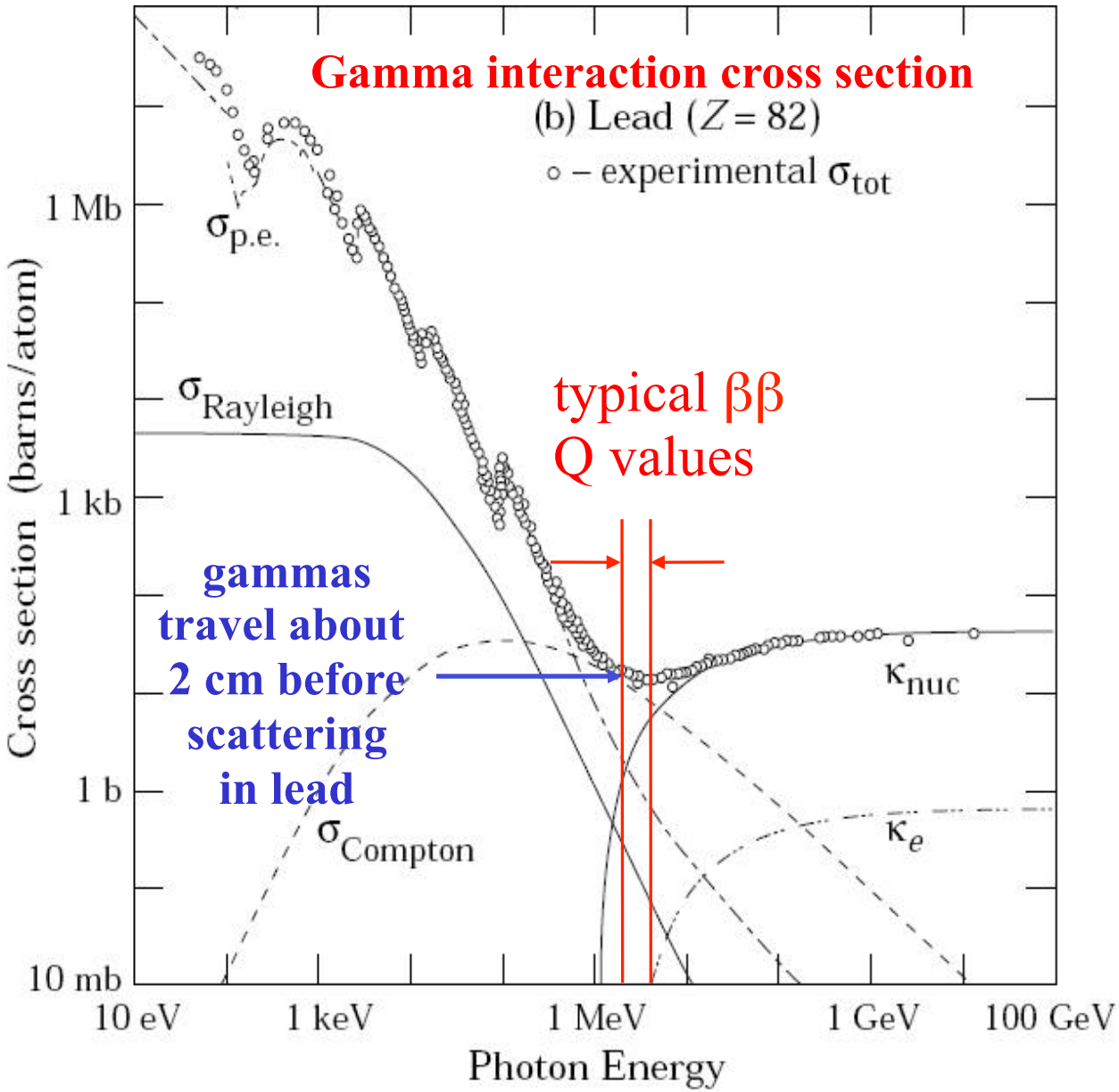
doi: 10.1155/2012/857016

Radioactive decay here on earth

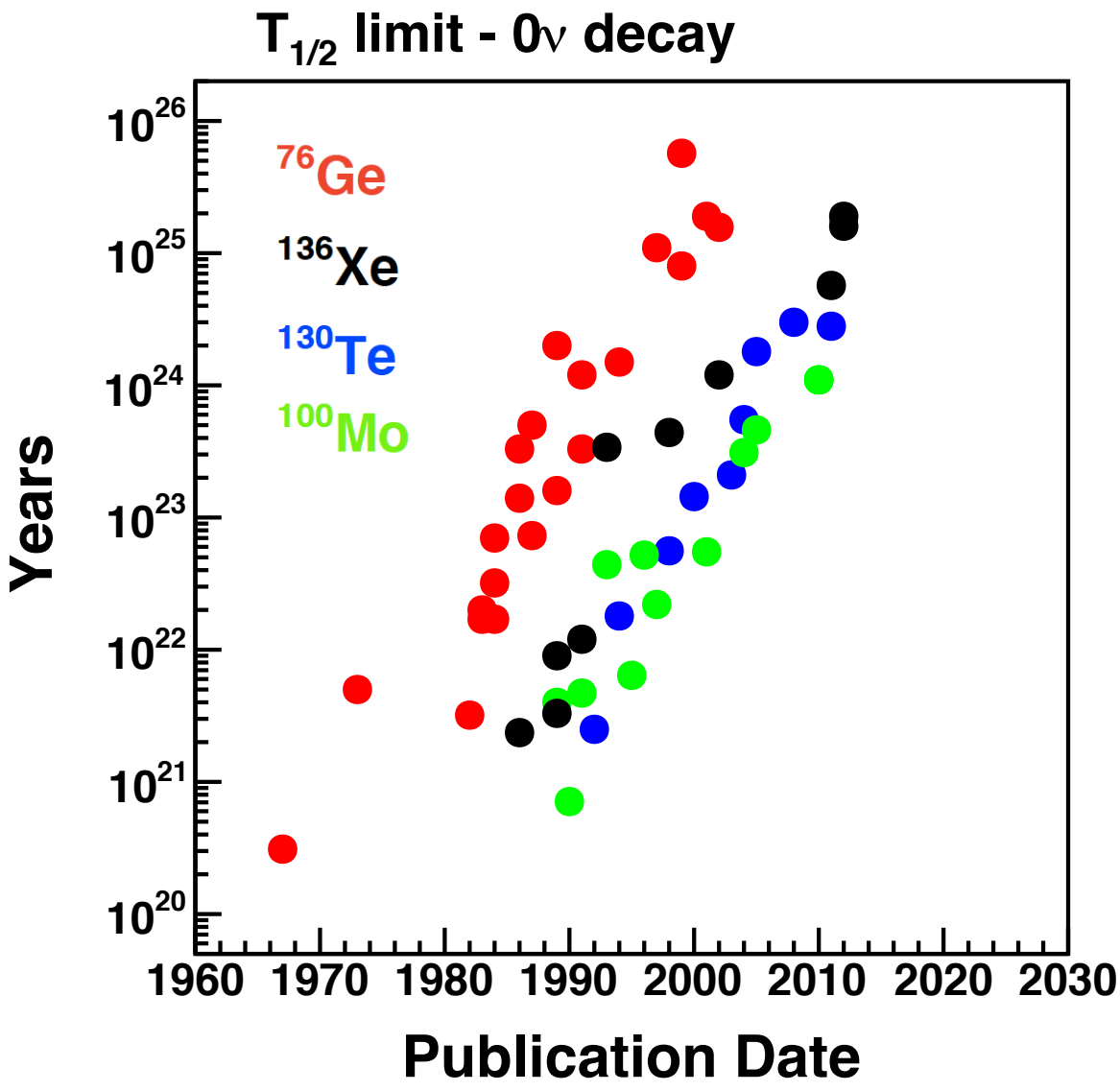


Source: http://npgroup.pd.infn.it/luna/images/background.jpg

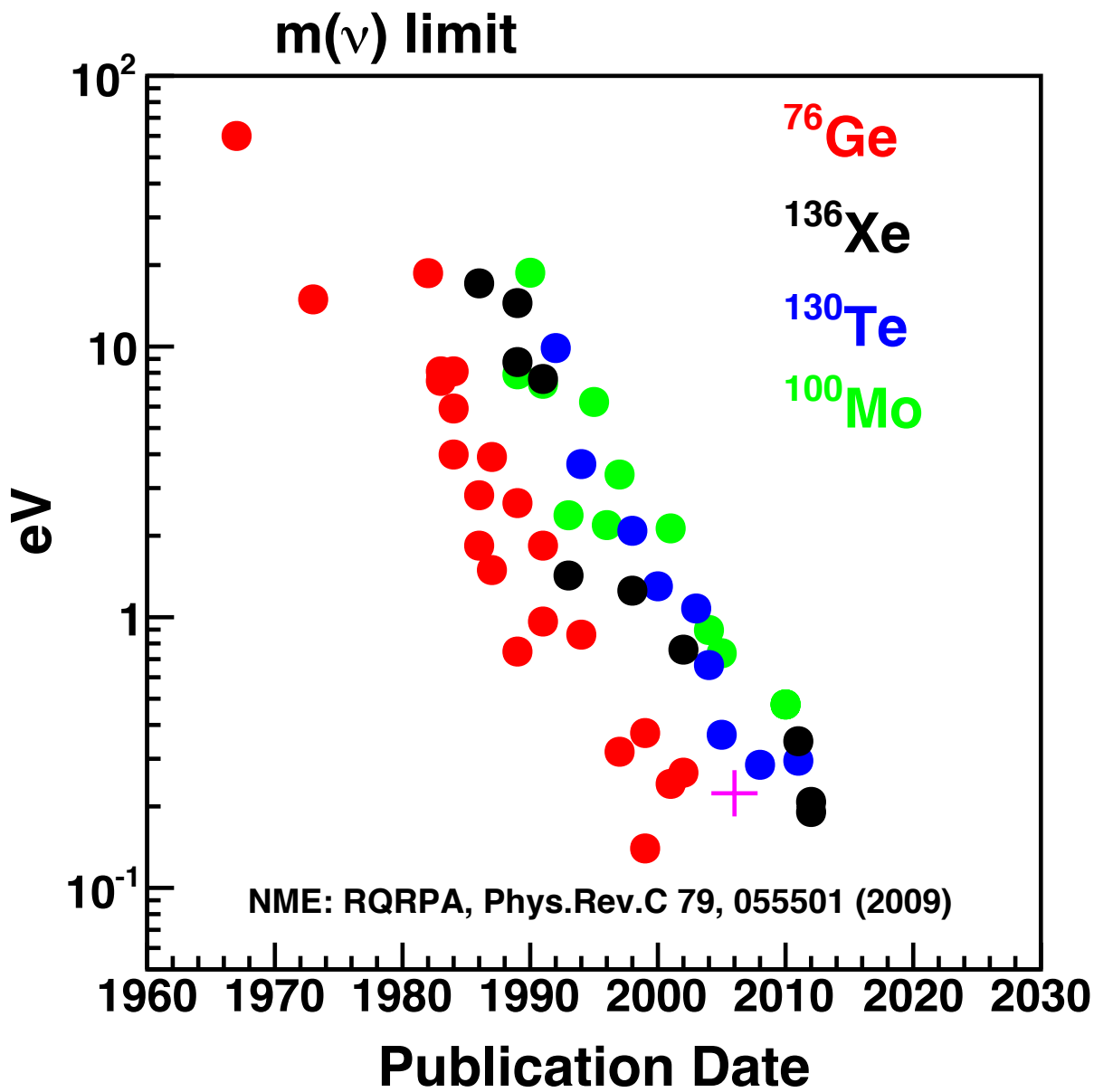
Double beta decay frustration theorem



Historical progress

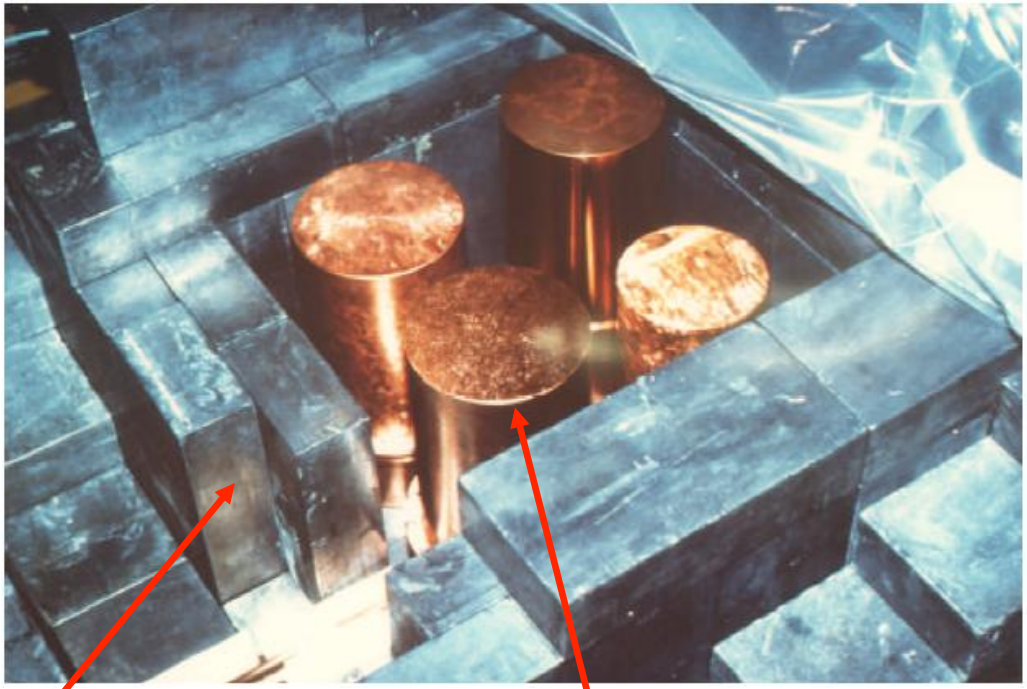


Historical progress



Germanium Diodes

Heidelberg-Moscow and IGEX experiments



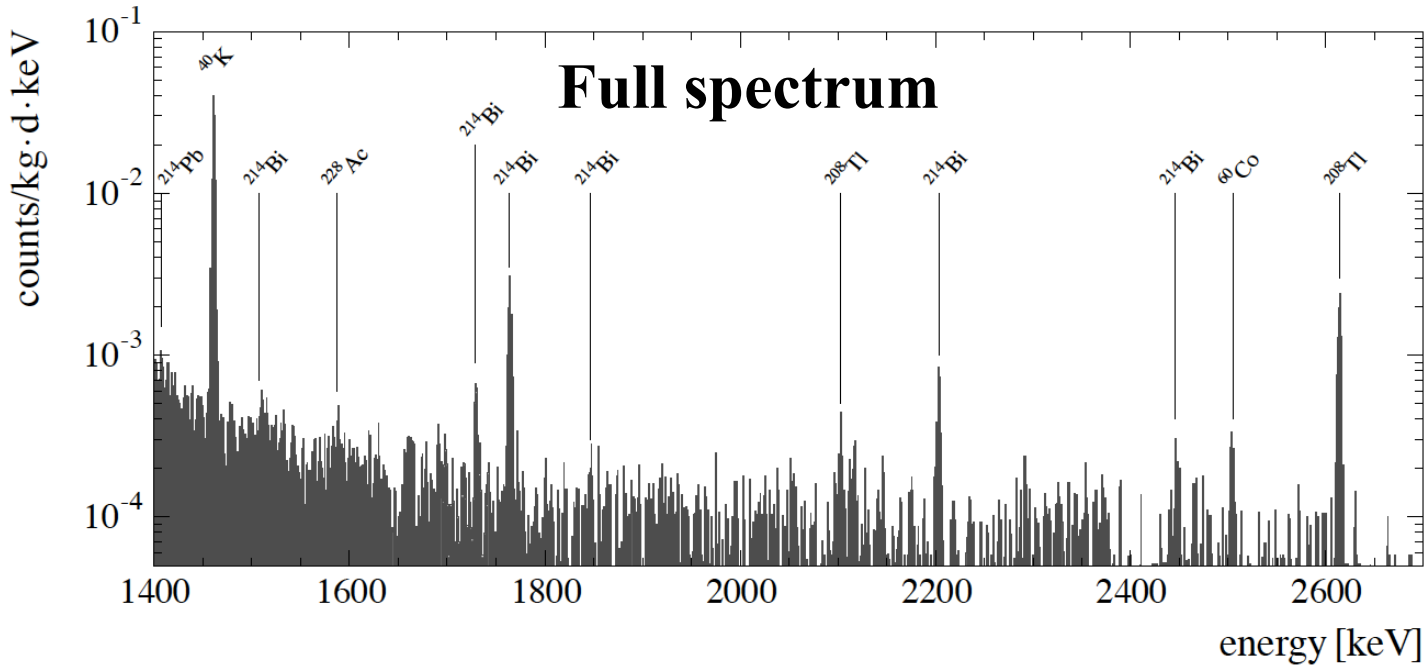
2-3 kg Ge diodes,

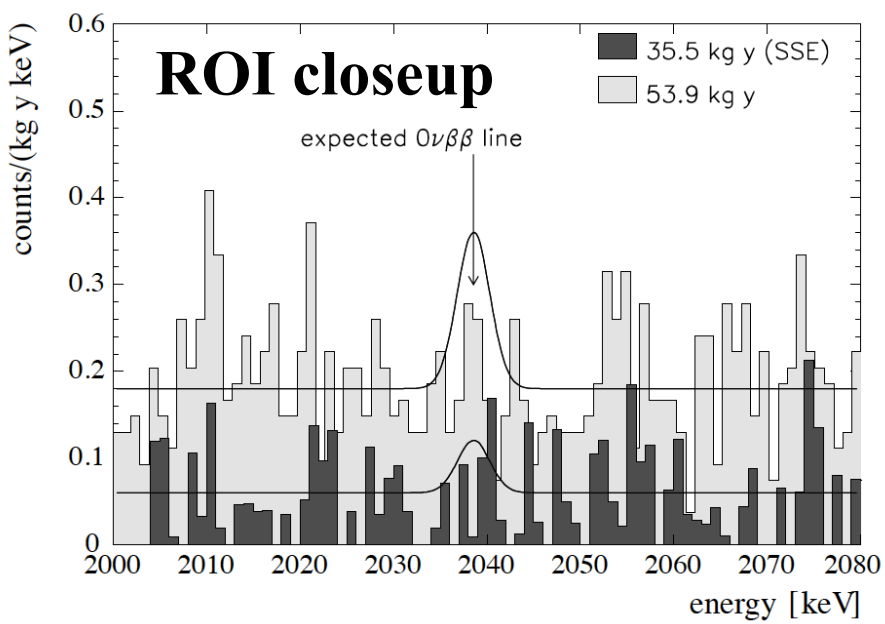
80% ^{76}Ge

Lead shielding **Cu cryostats**

- Precise energy resolution (4 keV FWHM).
- Pulse shape analysis rejects multiple site events within a single crystal.
- Modest Q value (2039 keV)

^{76}Ge: Heidelberg-Moscow





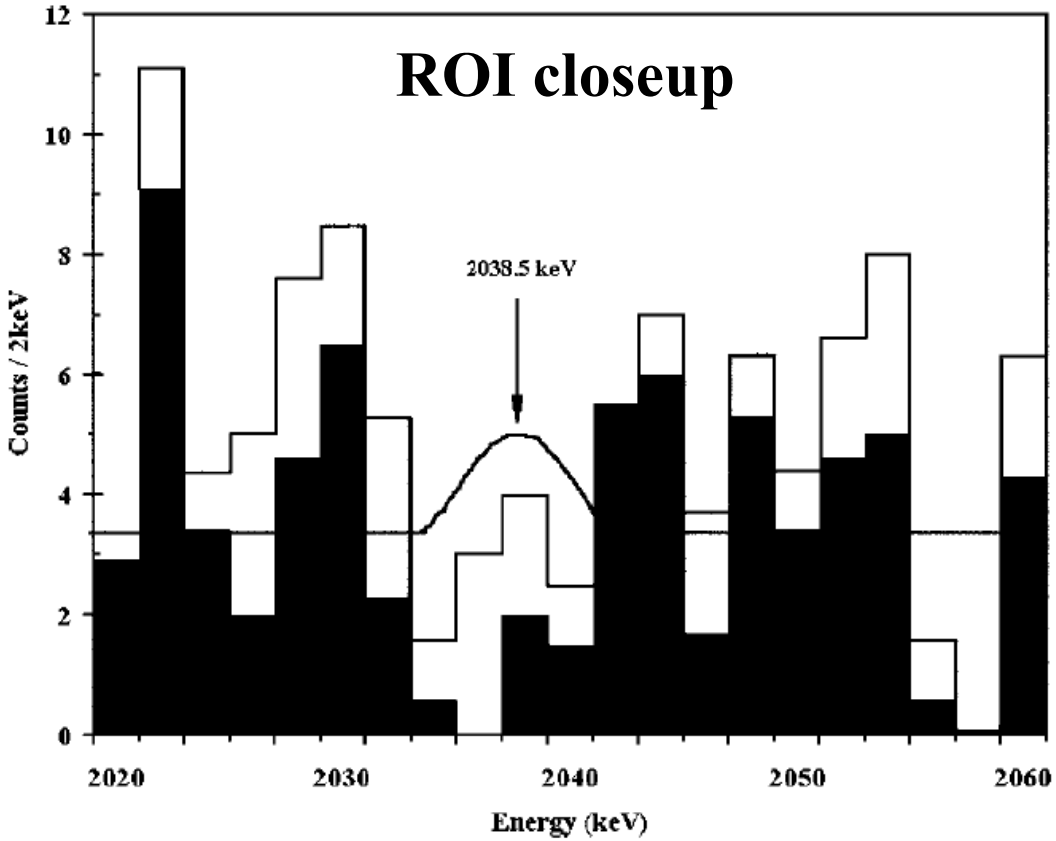
$T_{1/2}(\beta\beta0\nu) > 1.9 \times 10^{25}$ yrs (90%C.L.)

$m_{\beta\beta} < 350$ meV

Exposure: 709 mol*years

Eur. Phys. J. A 12, 147–154 (2001)

^{76}Ge: IGEX



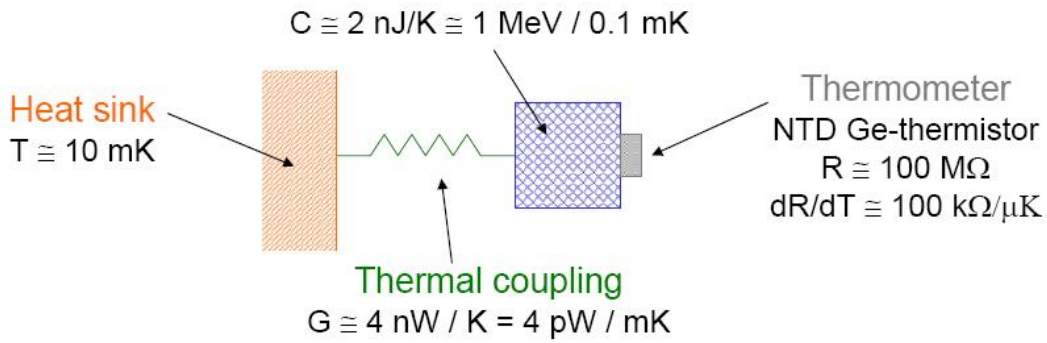
$T_{1/2}(\beta\beta0\nu) > 1.57 \times 10^{25}$ yrs (90%C.L.)

$m_{\beta\beta} < 330 - 1350$ meV

Exposure: 117 mol*years

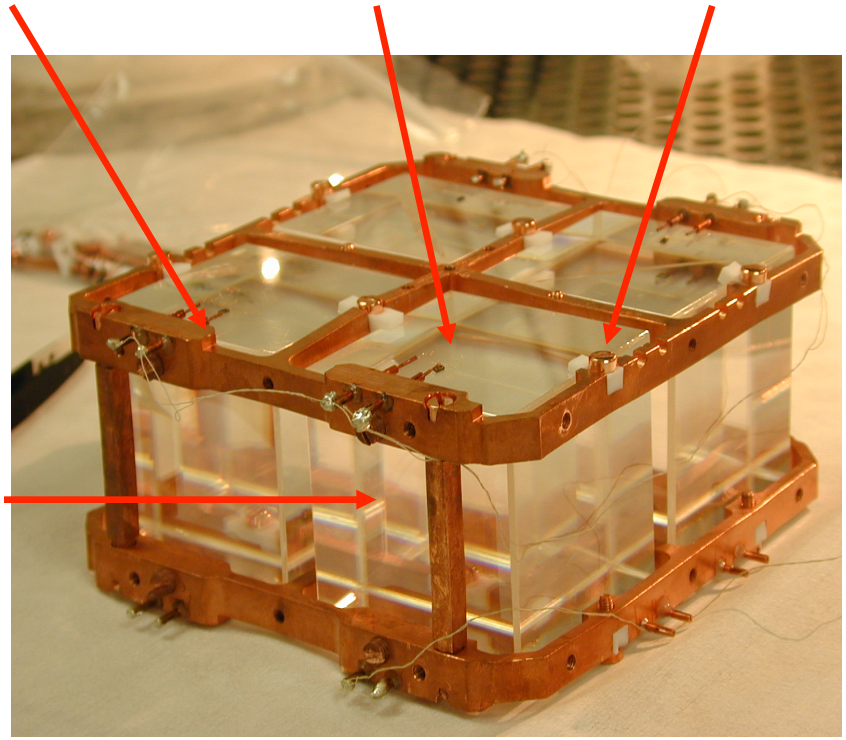
Phys. Rev. 65 (2002) 092007

130Te : Cryogenic bolometer



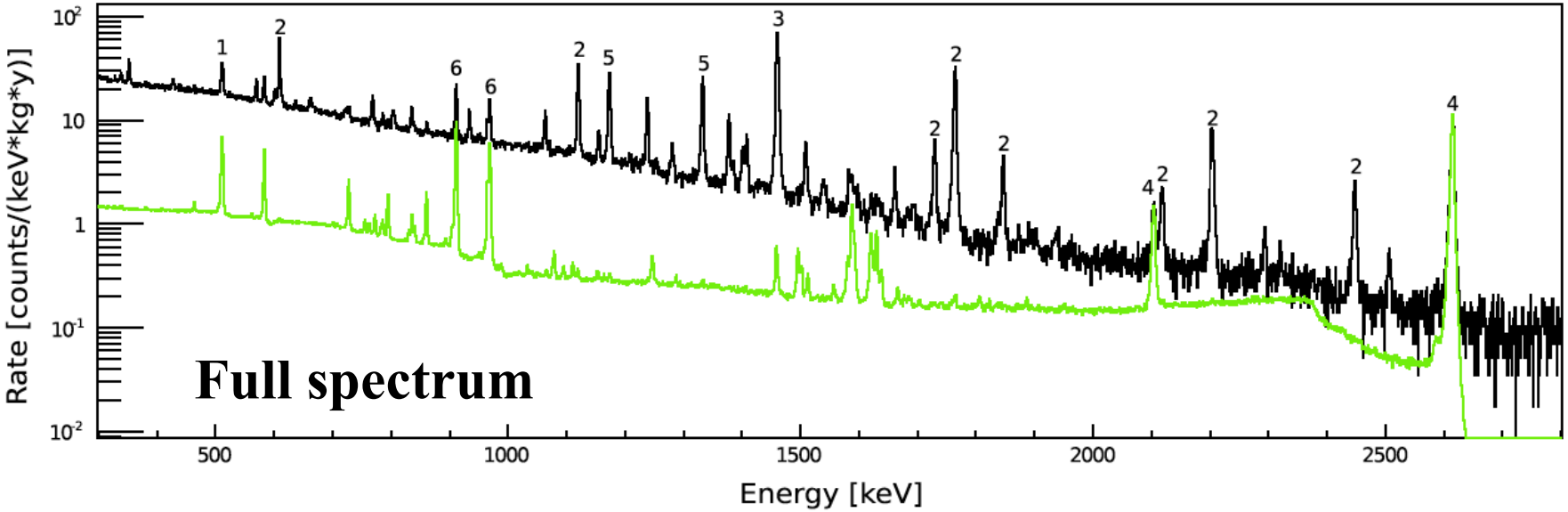
heat sink **thermometer** **thermal link**

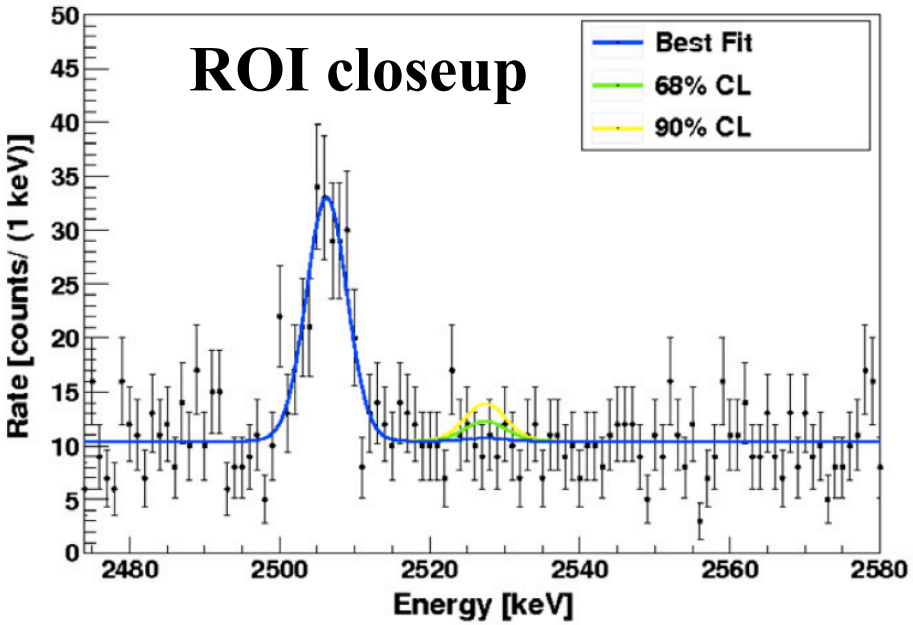
TeO2 crystal



Cuoricino tower under construction

^{130}Te: Cuoricino





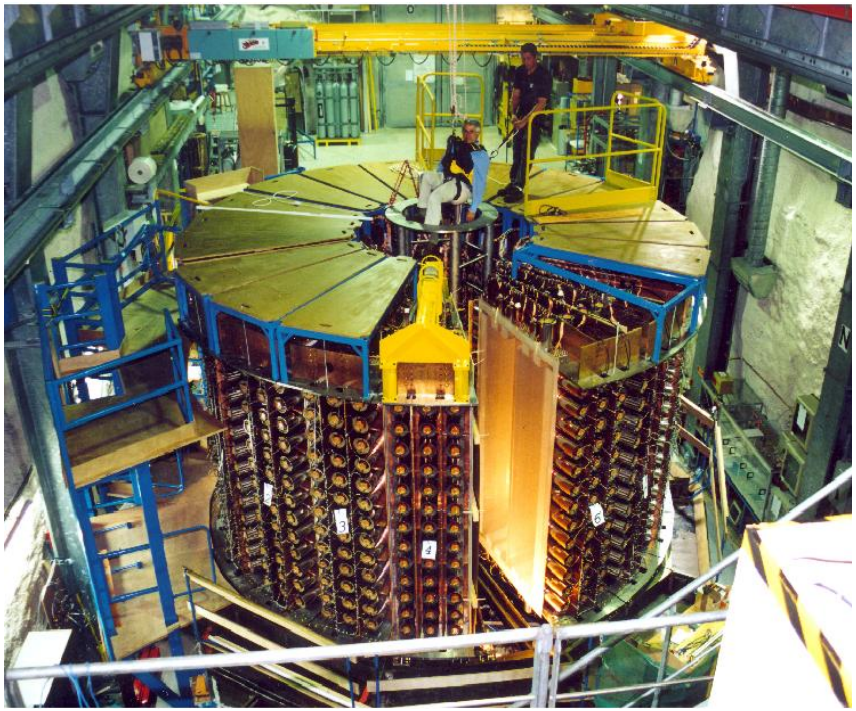
$T_{1/2}(\beta\beta0\nu) > 2.8 \times 10^{24}$ yrs (90%C.L.)

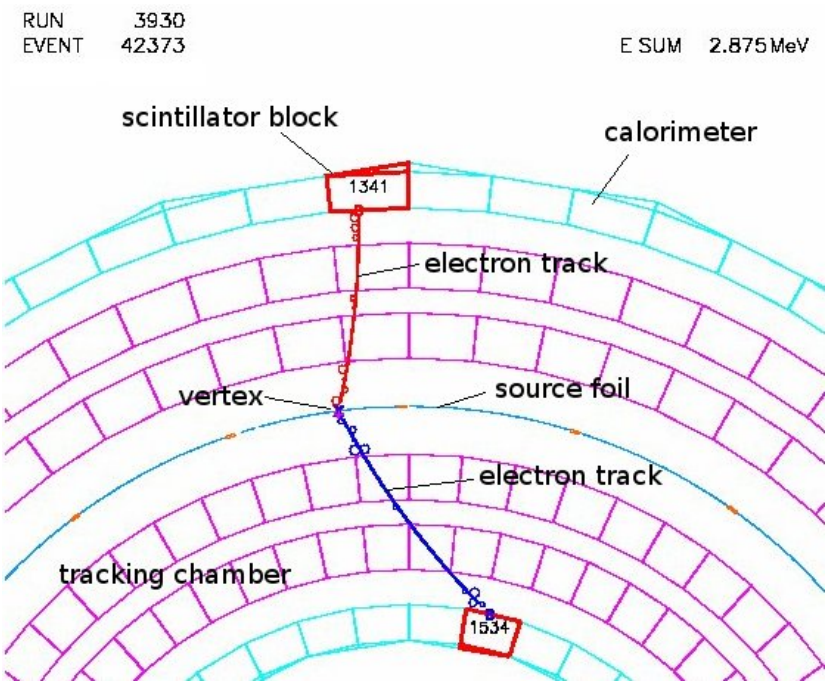
$m_{\beta\beta} < 300 - 710$ meV

Exposure: 152 mol*years

Astropart. Phys. 34 (2011) 832

100Mo: β tracking with thin foils (NEMO-3)

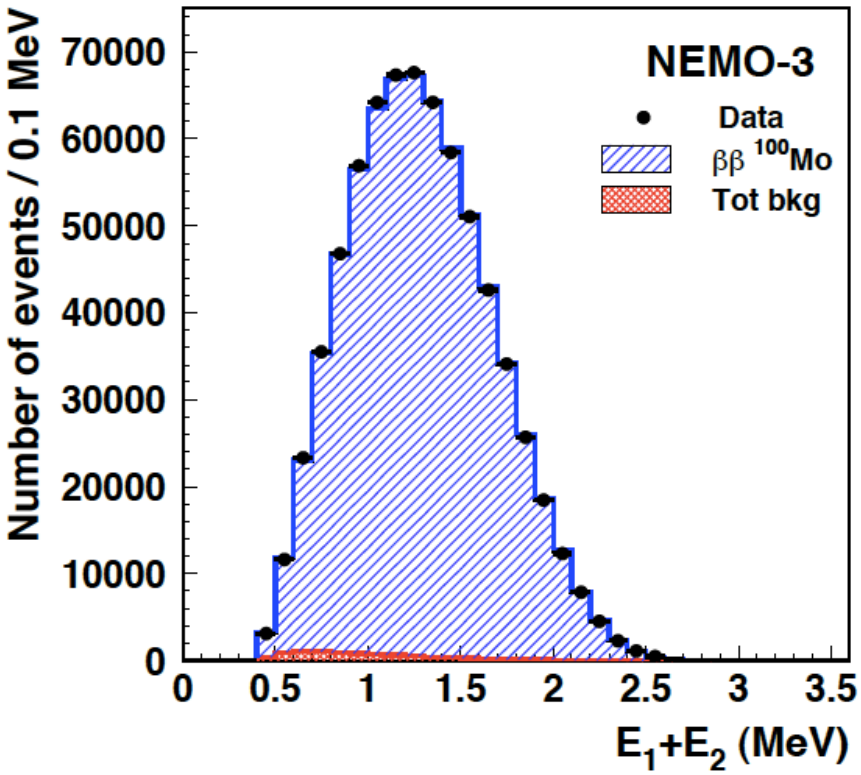




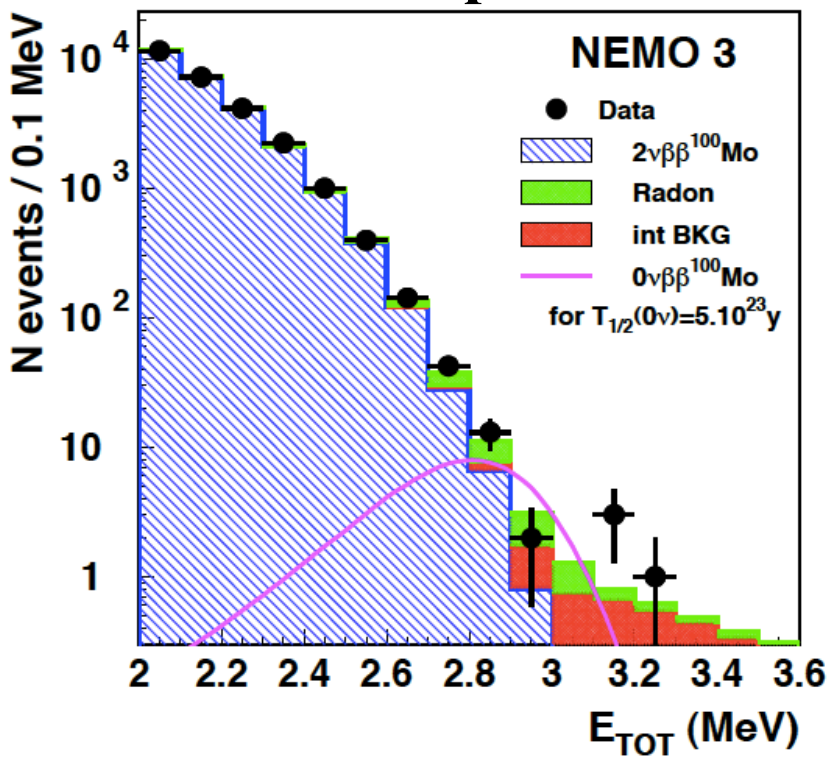
- Passive isotope on thin foils surrounded by Geiger mode drift cells.
- Plastic scintillator for energy measurement.
- Electron angular distribution and single electron spectra.
- Modest energy resolution.

^{100}Mo: NEMO-3

Full spectrum



ROI closeup



$T_{1/2}(\beta\beta0\nu) > 1.1 \times 10^{24}$ yrs (90%C.L.)

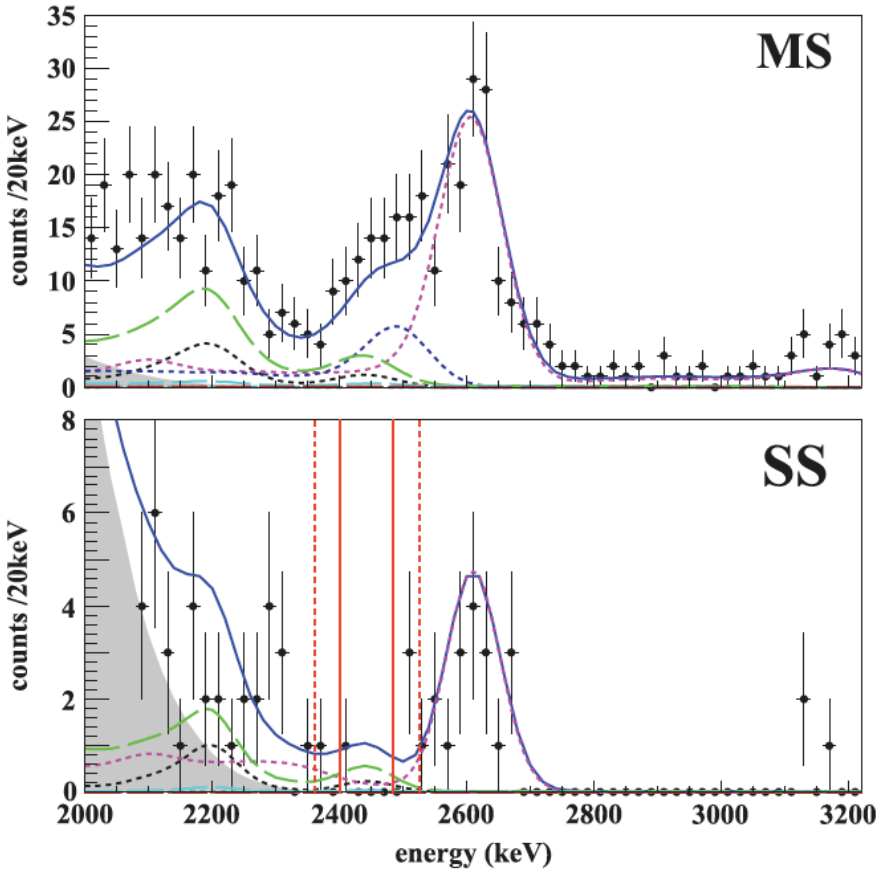
$m_{\beta\beta} < 450 – 930$ meV

Exposure: 266 mol*years

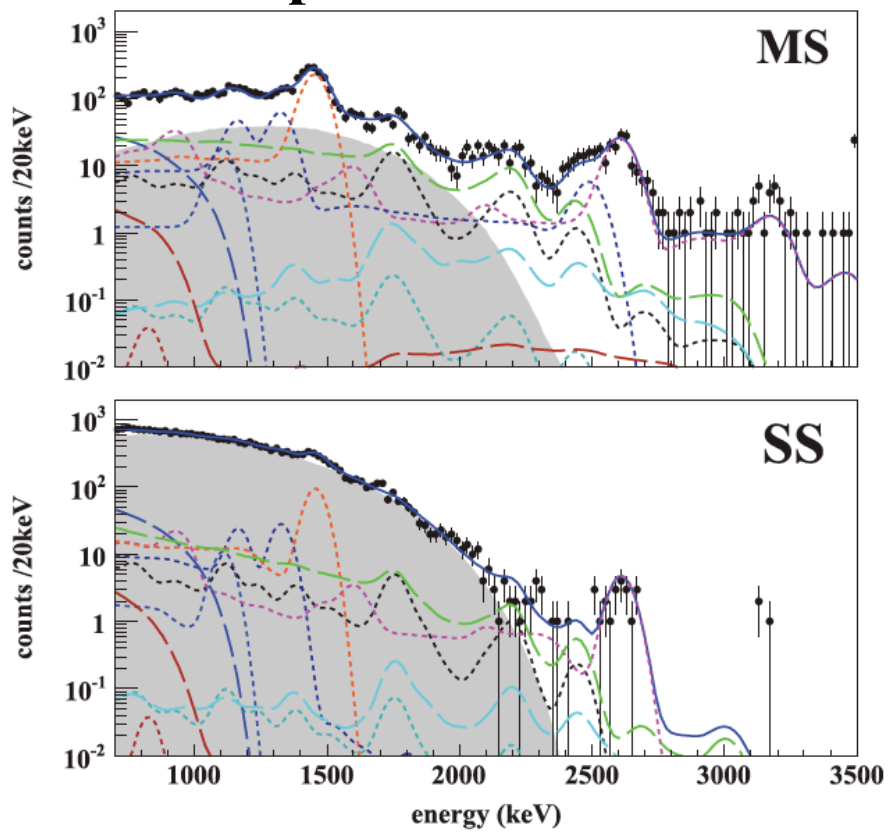
Phys. Atom. Nucl. (2011) 74 312.

^{136}Xe: EXO-200

ROI closeup



Full spectrum



$T_{1/2}(\beta\beta0\nu) > 1.6 \times 10^{25}$ years (90% C.L.)

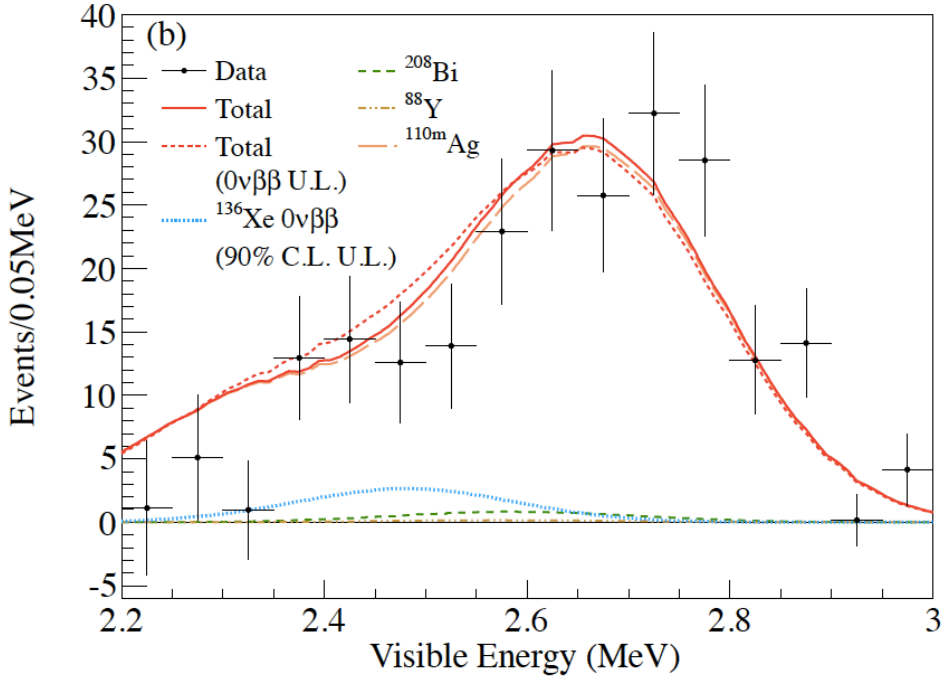
$m_{\beta\beta} < 140 - 380$ meV

Exposure: 193 mol*years

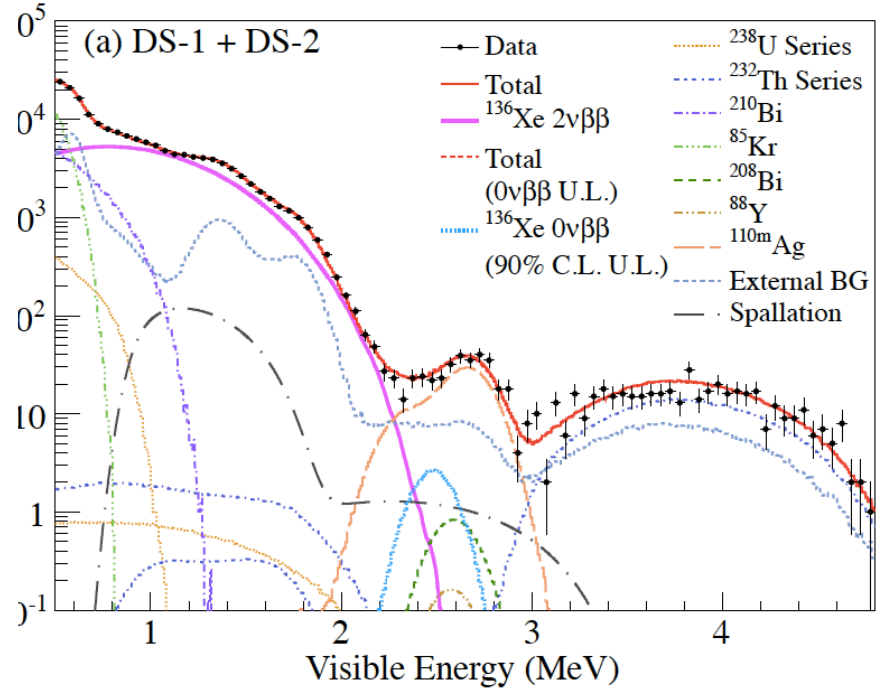
Phys. Rev. Lett. 109 032505 (2012)

^{136}Xe: KamLAND-Zen

ROI closeup



Full spectrum



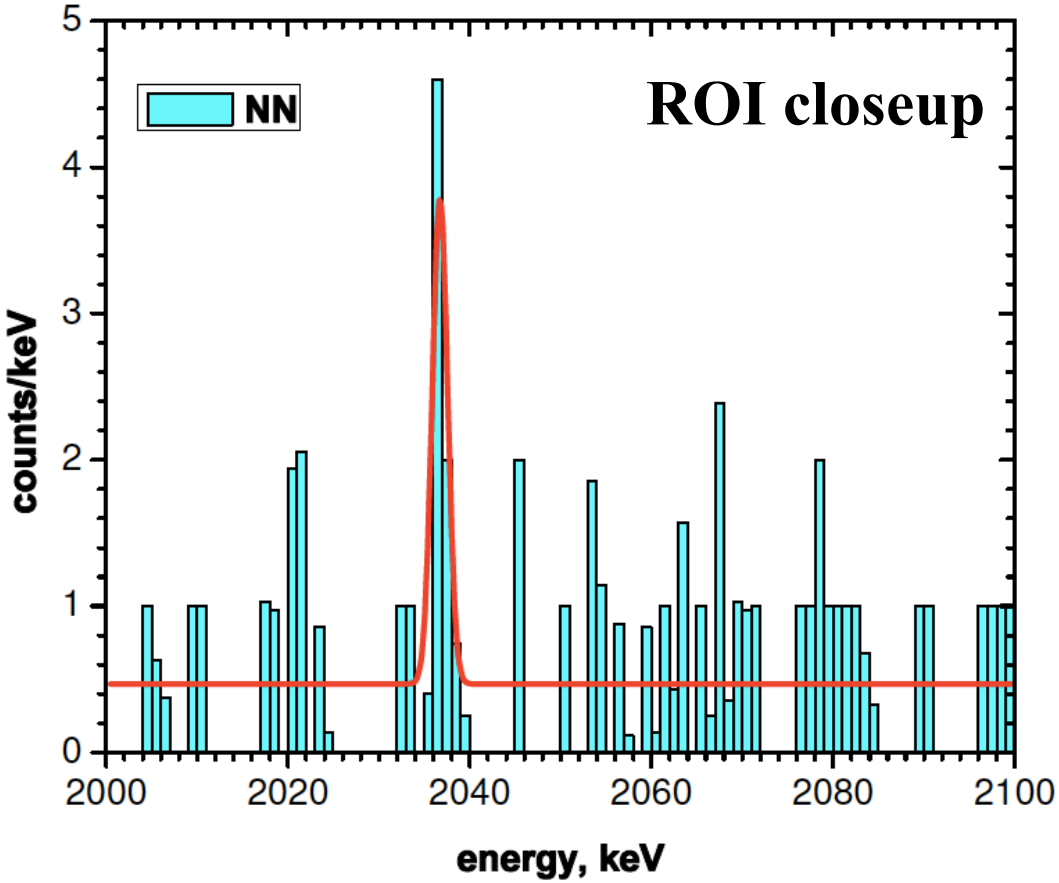
$T_{1/2}(\beta\beta0\nu) > 1.9 \times 10^{25}$ years (90% C.L.)

$m_{\beta\beta} < 140 - 380$ meV

Exposure: 658 mol*years

Phys. Rev. Lett 110 062502 (2013)

^{76}Ge: K-K & K

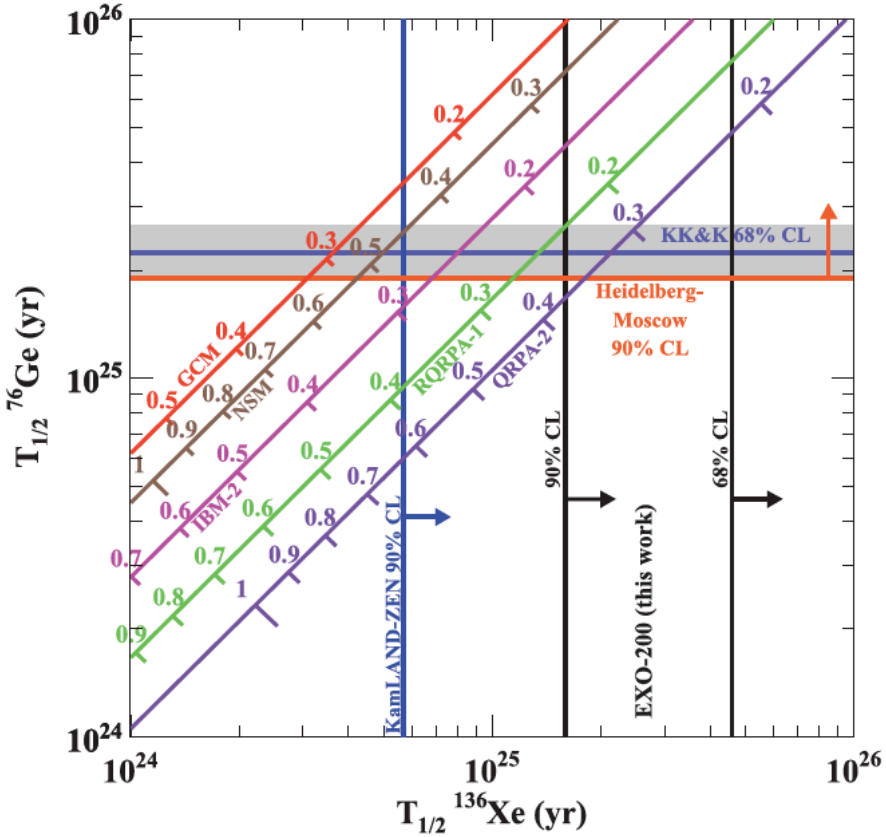


$T_{1/2}(\beta\beta0\nu) = 2.23 + 0.44 - 0.34 \times 10^{25}$ yrs (90%C.L.)

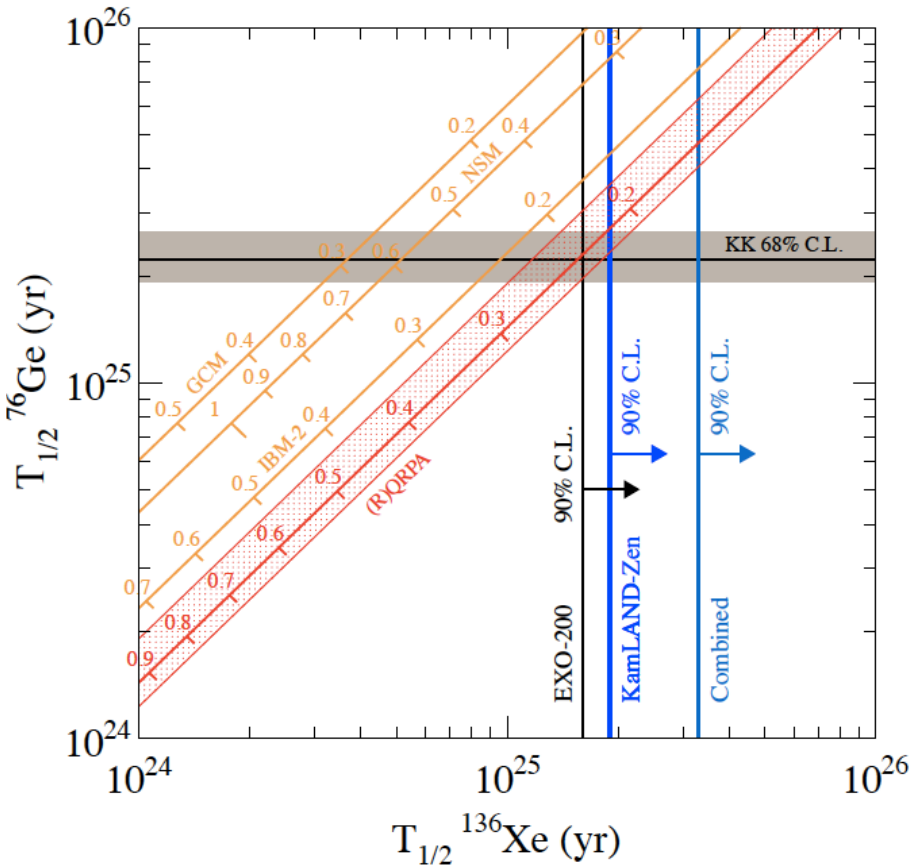
$M_{\beta\beta} = 320 \pm 0.03$ meV

Mod. Phys. Lett. A Vol. 21, No. 20 (2006) 1547

Comparison of ^{76}Ge claim with recent ^{136}Xe results



EXO-200: Phys. Rev. Lett. 109 032505 (2012)

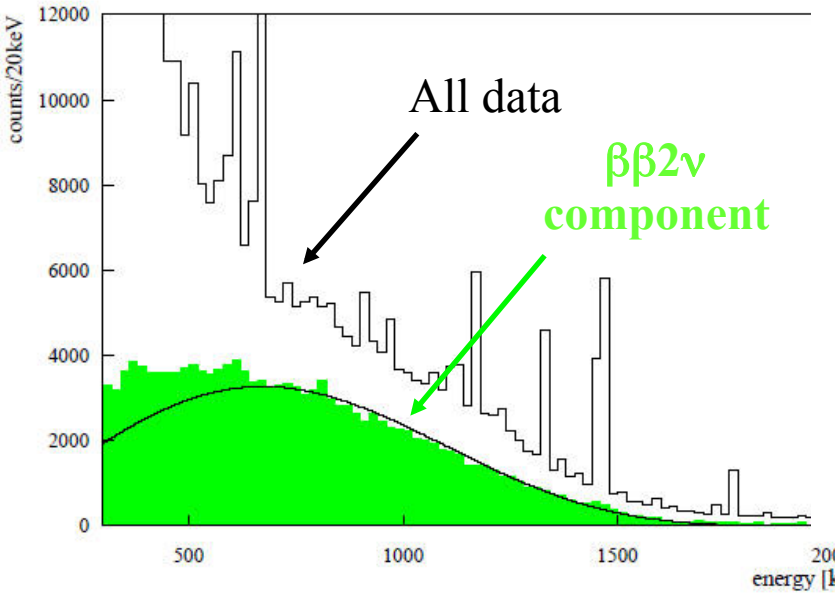


KamLAND-Zen: Phys. Rev. Lett. 110 062502 (2013)

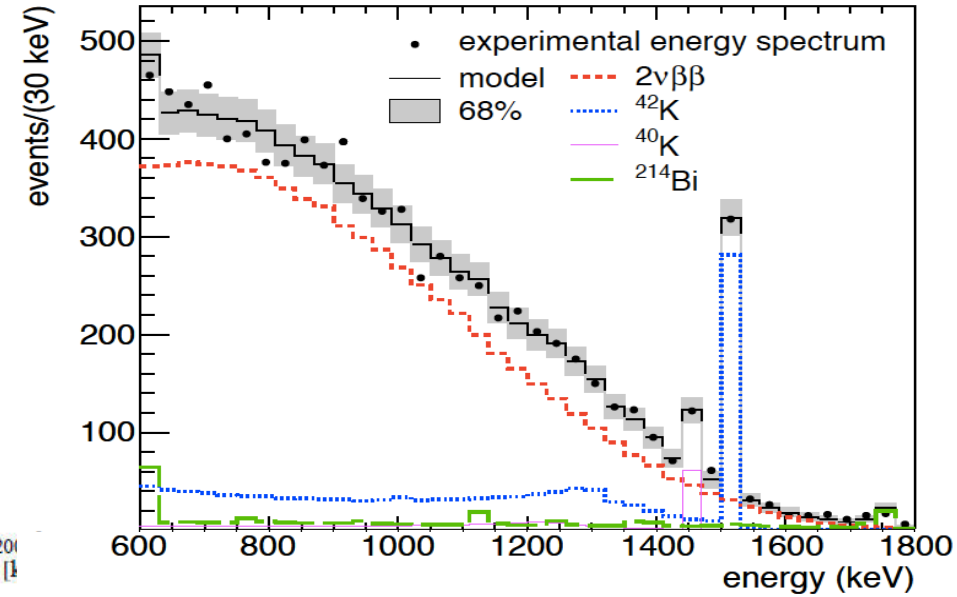
KL-Z: "We find that the combined result for ^{136}Xe refutes the detection claim in ^{76}Ge at > 97.5% C.L. for all NME considered assuming that $0\nu\beta\beta$ decay proceeds via light Majorana neutrino exchange."

Experimental progress: ββ2ν in ^{76}Ge

HdM experiment - 2001



Gerda - 2013



$T_{1/2}(\beta\beta2\nu)=(1.55 \pm 0.19)\times10^{21}$ **years**

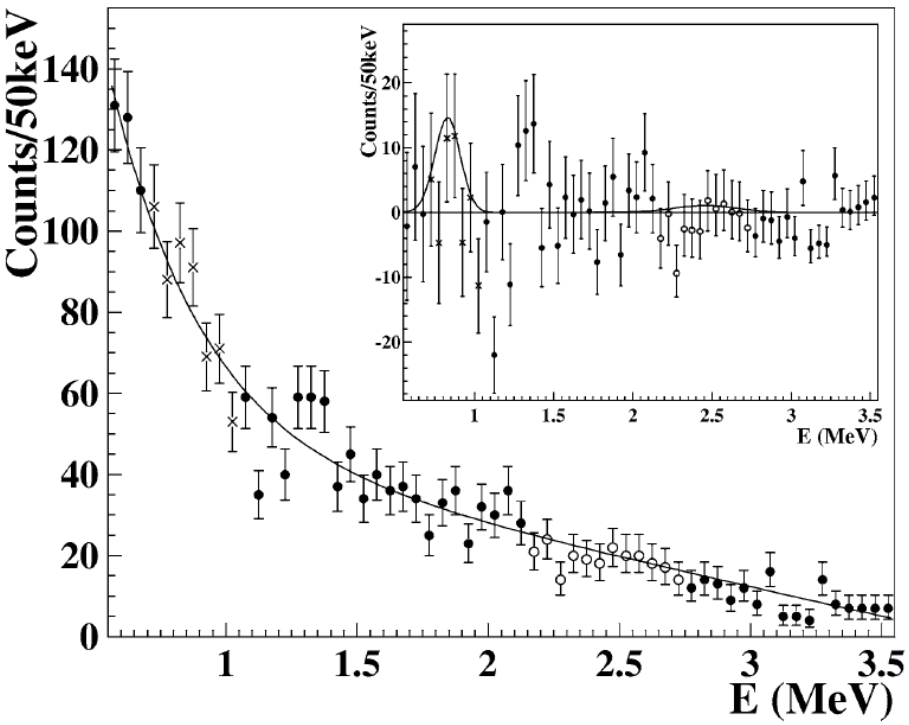
Eur. Phys. J. A 12, 147–154 (2001)

$T_{1/2}(\beta\beta2\nu)=(1.84 + 0.14 - 0.1)\times10^{21}$ **years**

J.Phys.G 40 (2013) 035110

Experimental progress: ββ2ν in ^{136}Xe

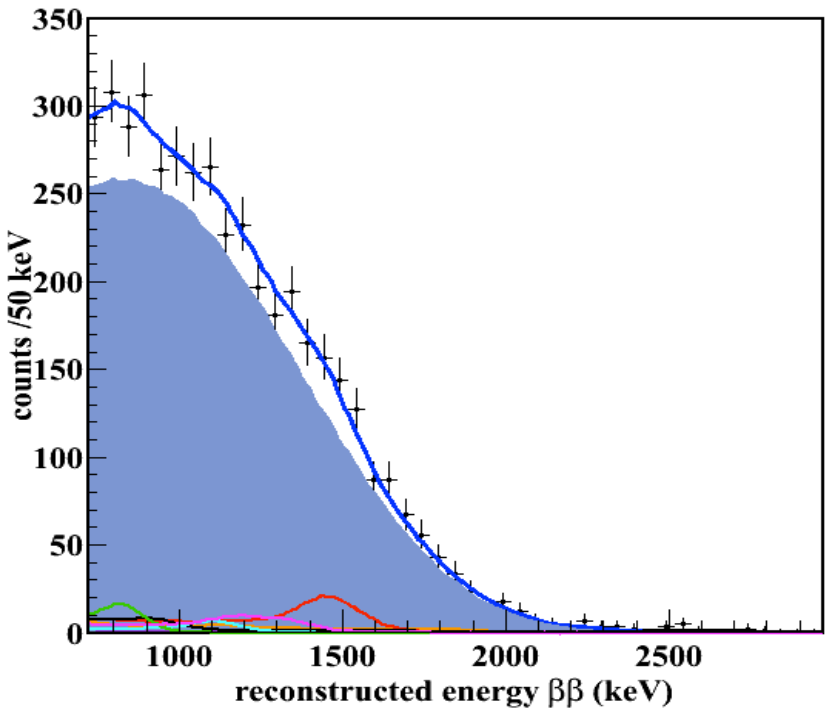
LXe DAMA (2002)



$T_{1/2}(\beta\beta2\nu) > 2.0\times10^{22}$ yrs

Phys.Lett.B 546 (2002) 23

EXO-200 (2011)

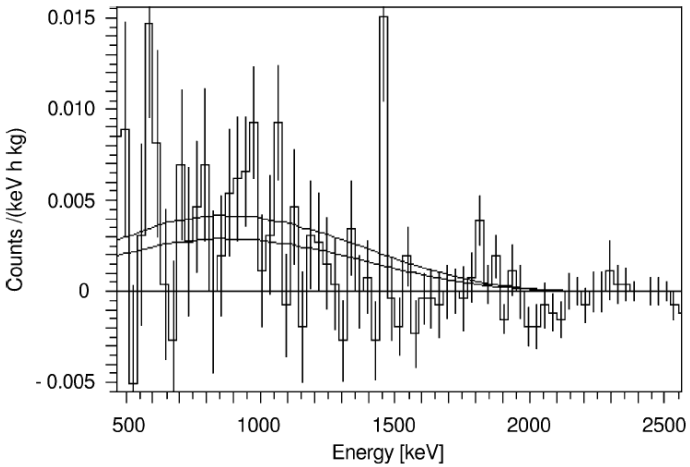


$T_{1/2}(\beta\beta2\nu) = 2.11\pm0.04\pm0.21\times10^{21}$ yrs

Phys.Rev.Lett. 107 212501 (2011)

Experimental progress: ββ2ν in ^{130}Te

MIBETA (2003)



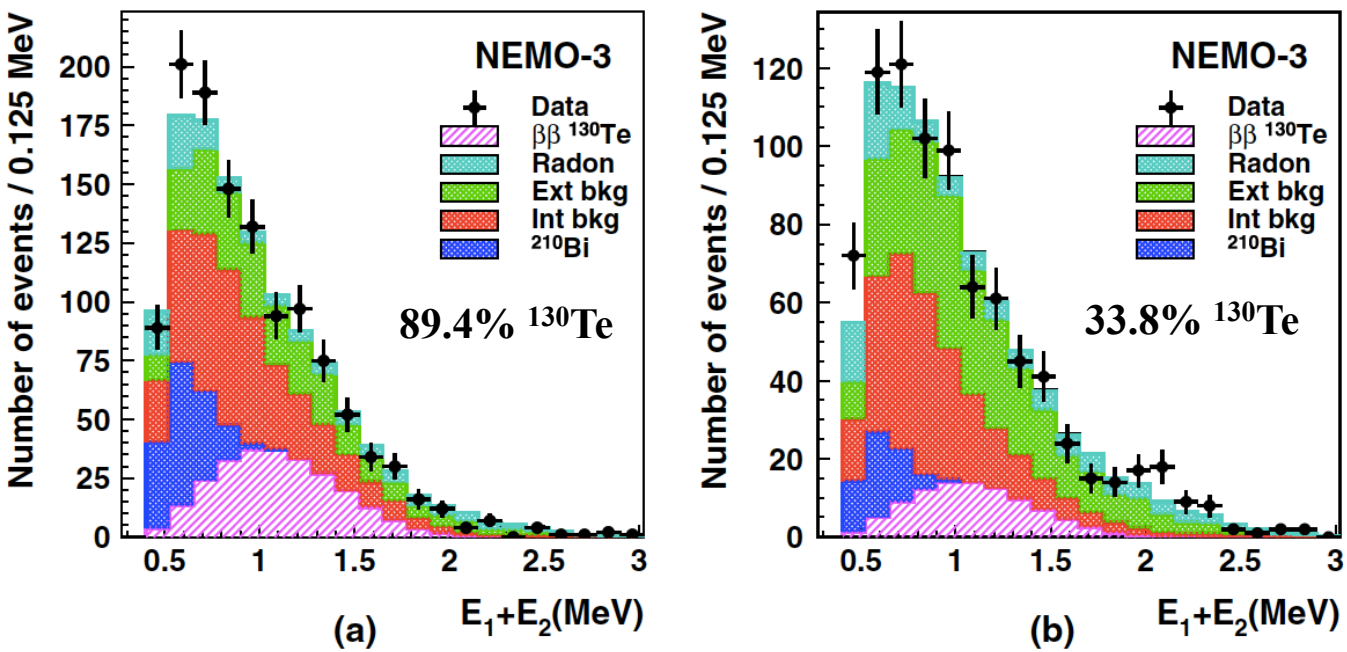
$T_{1/2}(\beta\beta2\nu) = 6.1\pm1.4(+2.9-3.5)\times10^{20}$ yrs

Phys.Lett.B 557 (2003) 167

Enriched/Natural difference spectrum

$T_{1/2}(\beta\beta2\nu) = 7.0\pm0.9\pm1.1\times10^{20}$ yrs

PRL 107 062504 (2011)



ββ2ν matrix elements from $T_{1/2}$ measurements

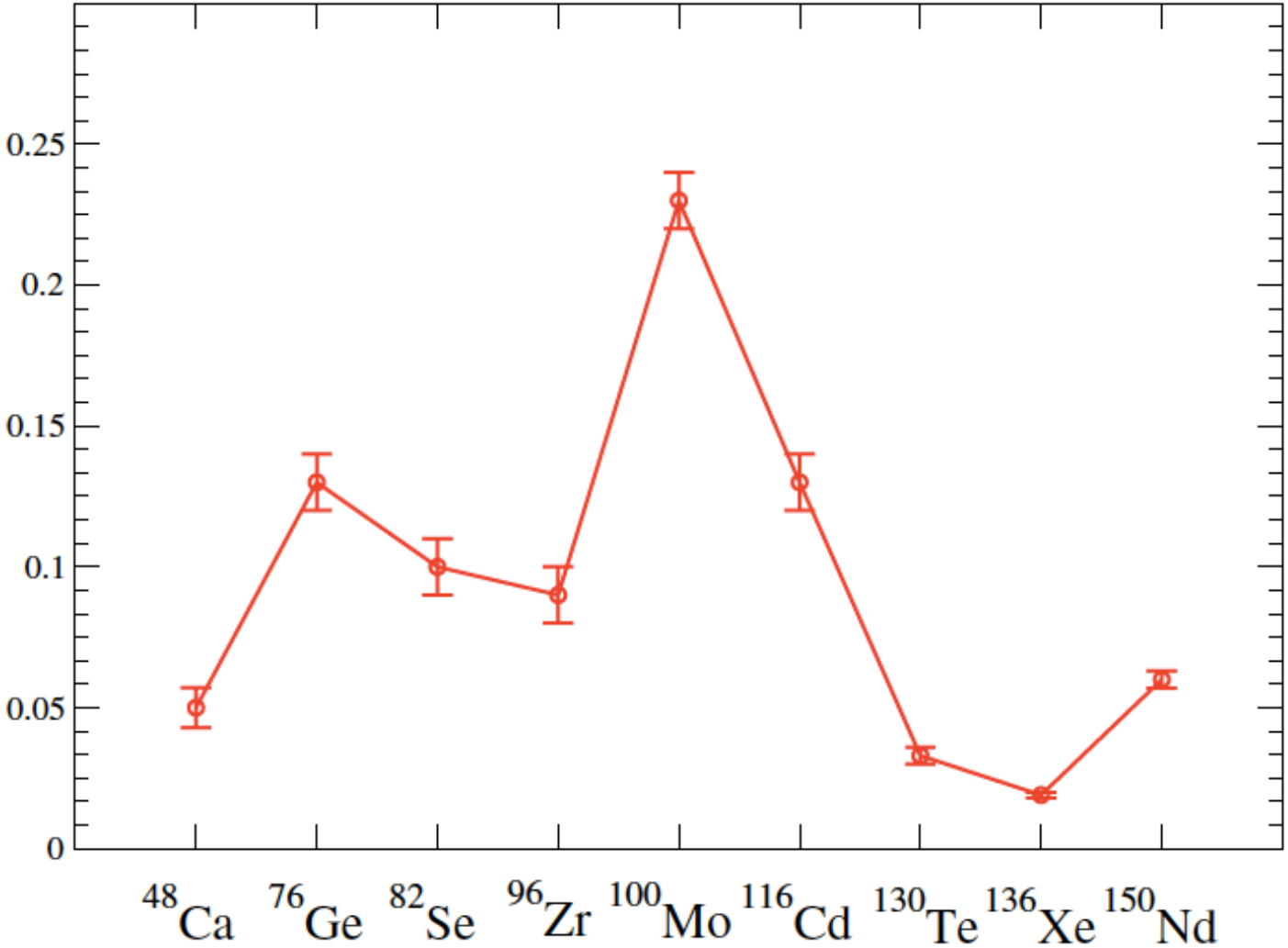
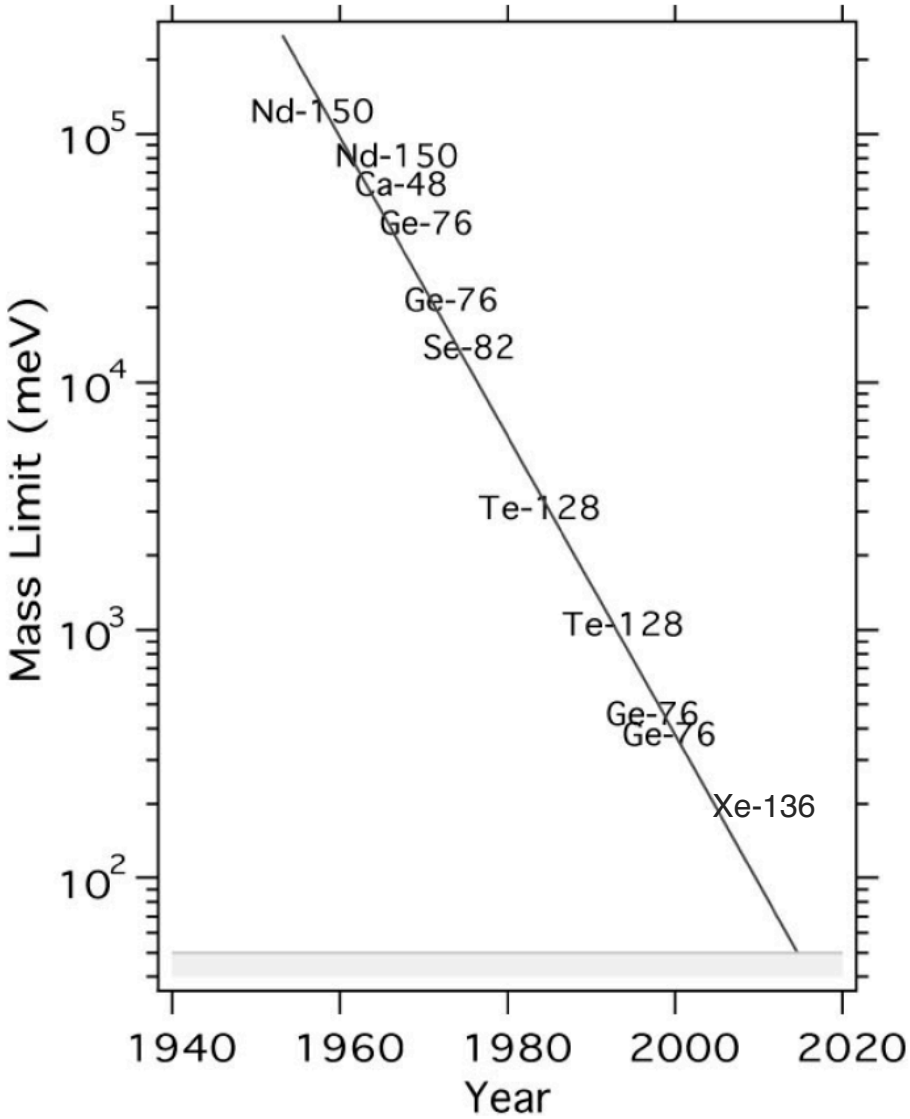


Figure 2. Matrix elements $M^{2\nu}$ in MeV^{-1} based on the experimental half-life measurements.

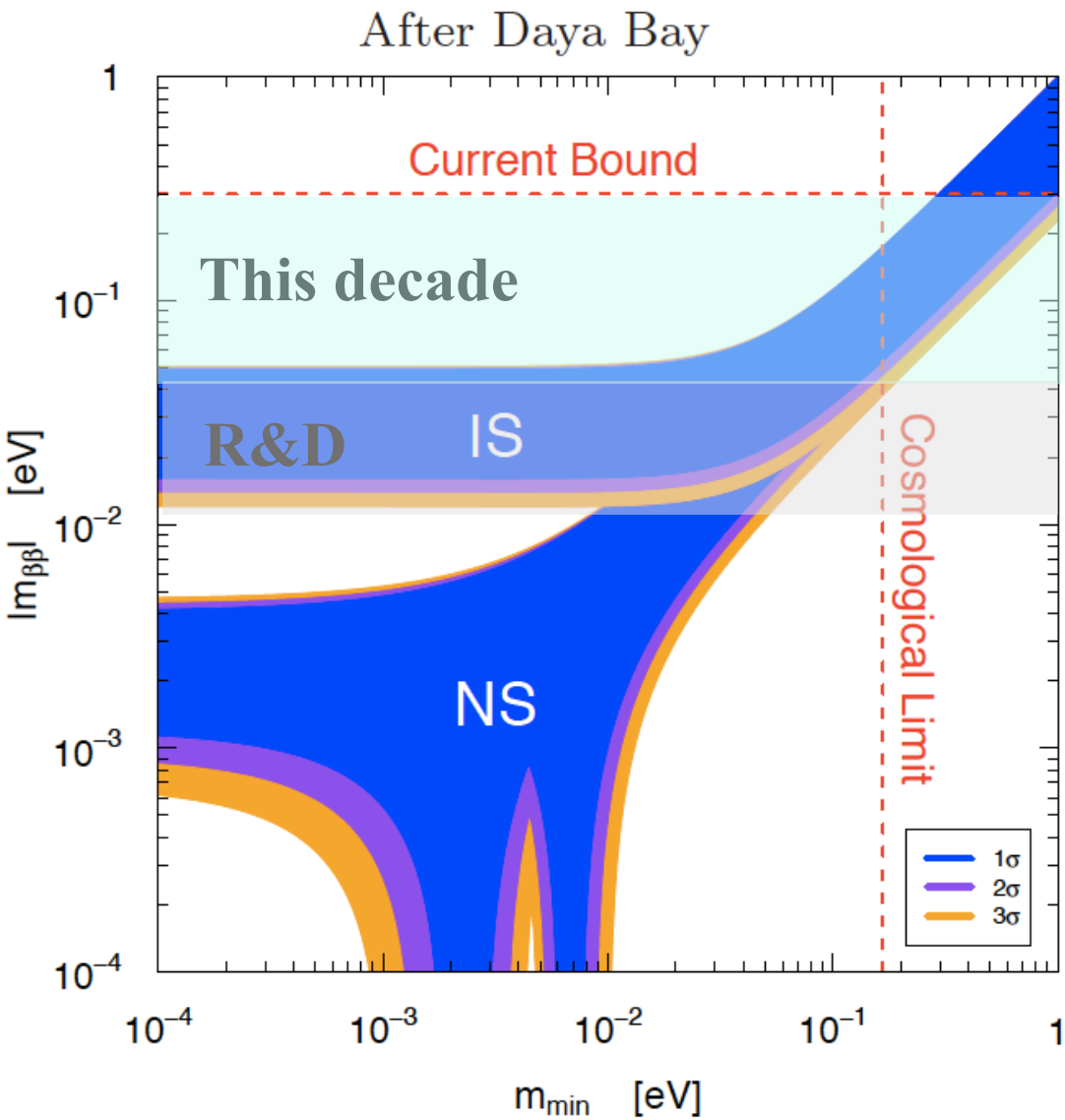
From Petr Vogel, J. Phys. G: Nucl. Part. Phys. 39 (2012) 124002

Moore's Law for Double Beta Decay

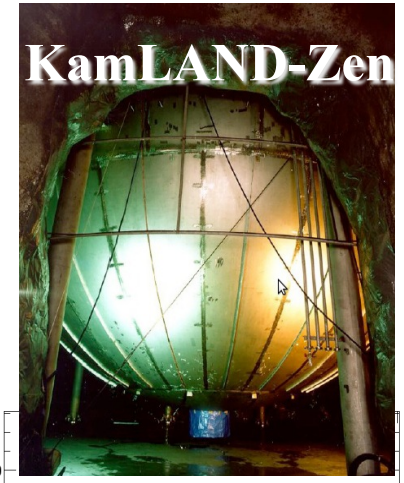
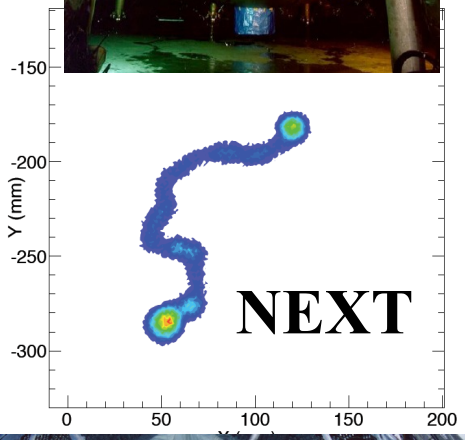
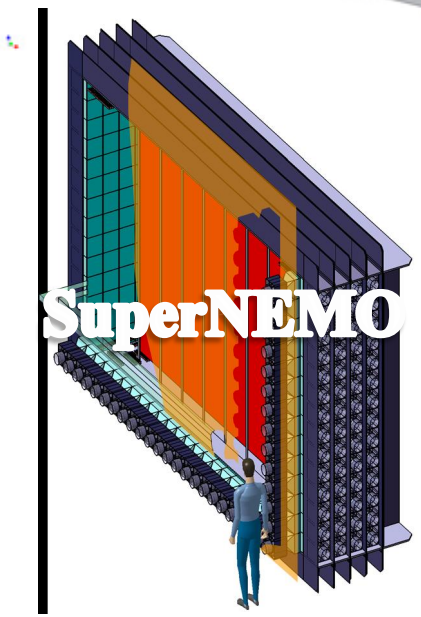


Elliott and Vogel: Annu. Rev. Nucl. Part. Sci. 2002. 52:115–51

Where we're going



- Watch for Planck results on Σm(ν) on March 21st.
- Hierarchy can be determined by LBL ν's and atmospheric ν's.

From S. M. Bilenky and C. Giunti, Mod. Phys. Lett. A Vol. 27, No. 13 (2012) 1230015

How we'll get there