Neutrinoless Double Beta Decay

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The New, the Rare and the Beautiful
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GERDA

Overview

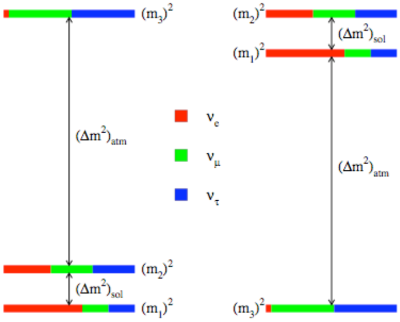
Status

We know

- Neutrinos have a mass
- Mass difference between eigenstates

The 3 big questions

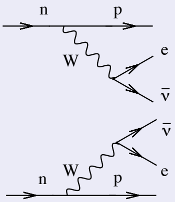
- Absolute mass scale
- Mass hierarchy
- Majorana vs. Dirac



Double Beta Decay

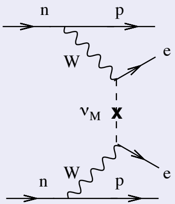
$2\nu\beta\beta$

- $(Z, A) \rightarrow (Z+2, A) + 2e^- + 2\bar{\nu}_e$
- $\Delta L = 0$
- $\left|T_{1/2}^{2\nu}\right|^{-1} = G^{2\nu}(Q_{\beta\beta}, Z)\,|M_{2\nu}|^2 \sim \left|10^{20}\ \mathrm{y}\right|^{-1}$



$0\nu\beta\beta$

- $(Z, A) \rightarrow (Z+2, A) + 2e^-$
- $\Delta L = 2$
- $\left|T_{1/2}^{0\nu}\right|^{-1} = G^{0\nu}(Q_{\beta\beta}, Z)\,|M_{0\nu}|^2\,\langle m_{\beta\beta}^2\rangle \sim \left|10^{25}\ \mathrm{y}\right|^{-1}$
- $\langle m_{\beta\beta}\rangle = \left|\sum_i U_{ei}^2\ m_i\right|$



Nuclear Matrix Elements

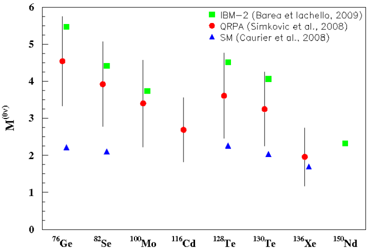
Three different methods for calculation:

Nuclear Shell Model (SM) Uses Pauli exclusion principle to describe the structure of the nucleus in terms of energy levels

Quasi-Particle Random Phase Approximation (QRPA) Uses 3 parameters accounting for pairing, particle-particle and particle-hole interactions.

Interacting Boson Model (IBM) Bosons can interact through 1- and 2-body interactions giving rise to bosonic wave functions.

- QRPA and IBM (coincidentally?) in agreement
- SM a factor of 2 lower



What do we measure?

Requirements

We measure

$$T_{1/2}^{0\nu} \propto \langle m_{\beta\beta} \rangle^{-2} \propto const \sqrt{\frac{M \times t}{\Delta E \times B}}$$

To get the best possible measurements we need

- High mass M and/or long time t (exposure)
- Excellent energy resolution ΔE
- Minimal background B

What would it look like?

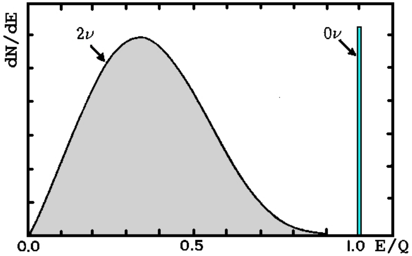
Signature

Measuring the energy of both electrons

- $2\nu\beta\beta$: Continuous energy spectrum
- $0\nu\beta\beta$: Sharp peak at Q value of decay

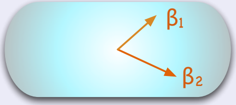
$$Q = E_{\text{mother}} - E_{\text{daugther}} - 2m_e$$

- Schechter & Valle (1982): Measuring $0\nu\beta\beta \Rightarrow \nu$ Majorana particle



How do we measure?
General Principal

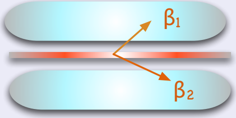
Source = Detector



- ☺ High masses possible
- ☺ High efficiency for the detection of both electrons
- ☺ Good energy resolution

- ☹ No angular correlation of electrons measurable

Source ≠ Detector



- ☺ Topology of events can be used for background suppression
- ☺ Angular correlation and energy of single electrons measurable
- ☺ Many isotopes as possible sources

- ☹ Small masses
- ☹ Low efficiency
- ☹ Worse energy resolution

Heidelberg-Moscow Experiment

The Claim

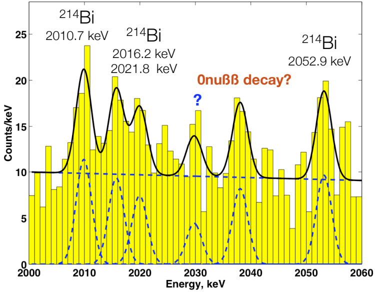
- 5 HPGe crystals with 71.7 kg y
- Peak at Q value:

$$T_{1/2}^{0\nu} = 1.2 \times 10^{25} y \qquad (4\sigma)$$
$$\langle m_{\beta\beta} \rangle = 0.44\,\text{eV}$$

- Problem: Confidence depends on background model and energy region selected for analysis

$\Rightarrow$ New experiments with higher sensitivity needed

H.V.Klapdor-Kleingrothaus et al., Phys. Lett. B 586 (2004) 198



Isotopes

Isotope	Q-Value [keV]	Half-life [y]	$\langle m_\nu \rangle$ [eV]
^{48}Ca	4271	$> 9.5 \times 10^{21}$	< 8.3
^{76}Ge	2039	$> 1.9 \times 10^{25}$	< 0.35
^{82}Se	2995	$> 3.6 \times 10^{23}$	$< 0.9 - 1.61$
^{100}Mo	3034	$> 1.1 \times 10^{24}$	$< 0.45 - 0.9$
^{116}Cd	2805	$> 7.0 \times 10^{22}$	< 2.6
^{130}Te	2528	$> 3.0 \times 10^{24}$	$< 0.2 - 0.7$
^{136}Xe	2476	$> 4.4 \times 10^{23}$	$< 1.8 - 5.2$
^{150}Nd	3367	$> 1.2 \times 10^{21}$	< 3.0

Experiments

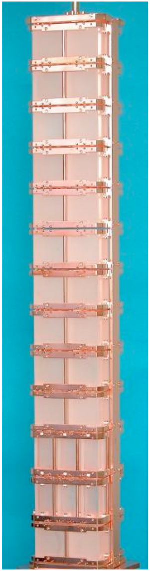
Past, Present and Future

Name	Isotope	Mass	Method	Location	Time Line
		Operational & Recently completed experiments			
CUORICINO	^{130}Te	12 kg	bolometric	LNGS	2003-2008
NEMO-3	^{100}Mo/^{82}Se	6.9/0.9 kg	tracko-calo	LSM	until 2010
		Construction funding			
CUORE	^{130}Te	200 kg	bolometric	LNGS	2012
EXO-200	^{136}Xe	160 kg	liquid TPC	WIPP	2009 (comiss.)
GERDA I&II	^{76}Ge	35kg	ionization	LNGS	2009 (comiss.)
SNO+	^{150}Nd	56 kg	scintillation	SNOlab	2011
		Substantial R&D funding / prototyping			
CANDLES	^{48}Ca	0.35 kg	scintillation	Kamioka	2009
Majorana	^{76}Ge	26 kg	ionization	SUSL	2012
NEXT	^{136}Xe	80 kg	gas TPC	Canfranc	2013
SuperNEMO	^{82}Se or ^{150}Nd	100 kg	tracko-calo	LSM	2012 (first mod.)

CUORICINO

Source = Detector

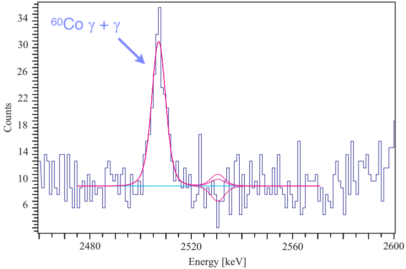
Location	LNGS
Isotope	40.7 kg of TeO_2
Bolometer	Cystals cooled down to ~8 mK to measure temperature increase proportional to energy deposition of the event
Energy resolution	FWHM ~8-10 keV
Status	Data from 2003–2008



CUORICINO

Results

Exposure	11.83 kg y of ^{130}Te
Background level	0.18 ± 0.02 cts/(keV kg y)
Half-life	$T_{1/2} > 2.94 \times 10^{24}$ y
Majorana mass	$m_{ee} < 0.19 - 0.68$ eV
Follow-up experiment	CUORE with 200 kg of ^{130}Te

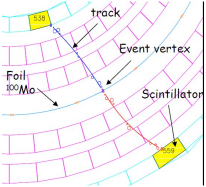


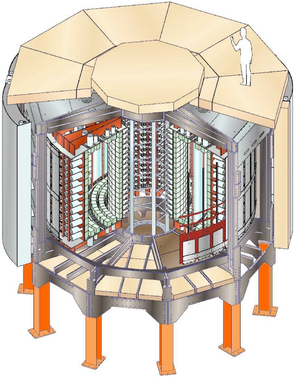
Arnaboldi et al. 2008

NEMO-3

Source $\neq$ Detector

Location	Frejus Underground Laboratory
Isotope	10 kg of different isotopes, mainly ^{100}Mo
Tracking	Drift wire chamber operating in Geiger mode (6180 cells)
Calorimeter	1940 plastic scintillators coupled to low radioactivity PMTs
Energy resolution	8% FWHM @ 3 MeV
Status	Data collection started 2003





NEMO-3

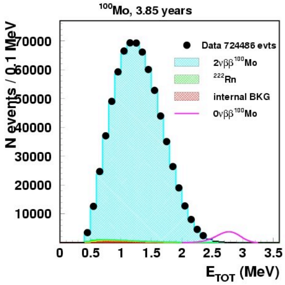
Results until end of 2008

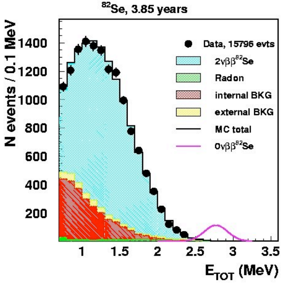
^{100}Mo

Exposure	26.6 kg y
Half-life	$T_{1/2} > 1.1 \times 10^{24}$ y
Majorana mass	$m_{ee} < 0.45 - 0.93$ eV

^{82}Se

Exposure	3.6 kg y
Half-life	$T_{1/2} > 3.6 \times 10^{23}$ y
Majorana mass	$m_{ee} < 0.89 - 1.61$ eV





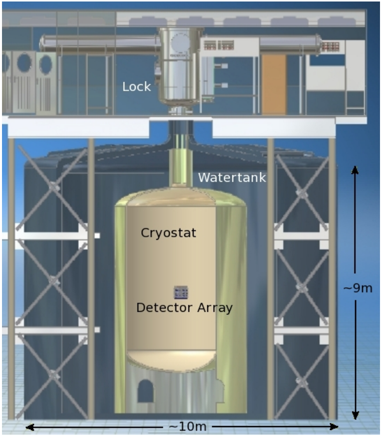
Follow-up experiment SuperNEMO with 100 kg of ^{82}Se or ^{150}Nd

Mauger, Taup 2009

The GERmanium Detector Array (GERDA)

Overview

Location	LNGS
Isotope	17.8 kg (Phase I) and $\sim$40 kg (Phase II) of ^{76}Ge
Ionization	Naked high purity semiconductor diodes placed in liquid argon
Status	Commissioning



GERDA
Goals & Status

Phase I goals

Exposure	15 kg y
Background	10^{-2} cts/(keV kg y)
Half-life	$T_{1/2} > 2.2 \times 10^{25}$
Majorana mass	$m_{ee} < 0.27$ eV

Phase II goals

Exposure	100 kg y
Background	10^{-3} cts/(keV kg y)
Half-life	$T_{1/2} > 15 \times 10^{25}$
Majorana mass	$m_{ee} < 0.11$ eV

Status

- Most parts installed
- Liquid argon filled
- Operating first detector in a couple of weeks

Summary

- Observing $0\nu\beta\beta$ would answer the questions about the absolute mass scale, the hierarchy and the nature of neutrinos
- $2\nu\beta\beta$ measured in more than 10 isotopes
- Experiments uses different isotopes and techniques
- So far just upper limits on m_{ee} and a claim but no evidence for $0\nu\beta\beta$
- Promising experiments start data taking this year!