SuperNEMO and Low Radioactivity Measurements with the BiPo3 Detector

Understanding Neutrinos 2012, Prague

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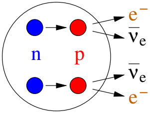
Introduction to double beta decay

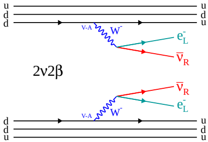
Experimental principle of NEMO experiments

From NEMO3 to SuperNEMO

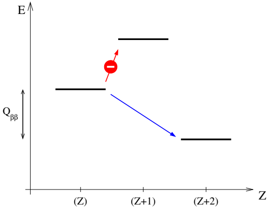
Two Neutrinos Double Beta Decay ($2\nu2\beta$)

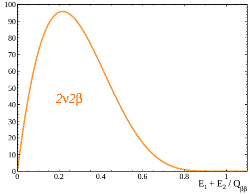
- The $2\nu2\beta$ is similar to 2 simultaneous beta decays:



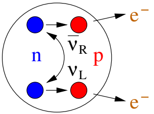


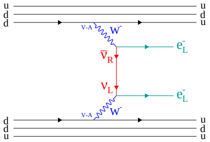
- Naturally occurs in few nuclei if β-decay is impossible
- 2^{nd} order of the weak interaction with $\Delta L = 0$
- 2 e^- energy spectra continuous from 0 to $Q_{\beta\beta}$ (e.g. 3 MeV)
- Measured for many isotopes: $\mathcal{T}_{1/2} \sim 10^{18} - 10^{21}$y



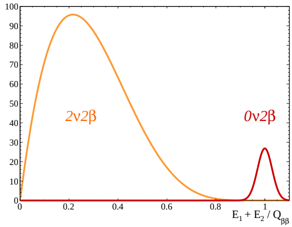


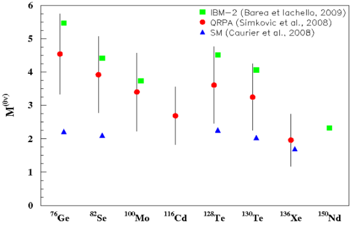
Neutrinoless Double Beta Decay ($0\nu2\beta$)





- Violates lepton number conservation $\Delta L = 2$
- Energy spectra of the 2 electrons is a line at $Q_{\beta\beta}$
- Best experimental way of studying the Majorana nature of ν
- Never been observed yet: $\mathcal{T}_{1/2} > 10^{24} - 10^{25}$ y (one claim)
- Half-life or the process: $(\mathcal{T}^{0\nu}_{1/2})^{-1} = G_{0\nu}|\mathcal{M}_{0\nu}|^2|m_{\beta\beta}|^2$



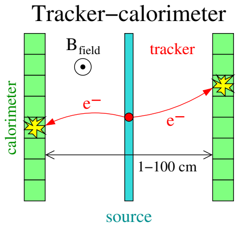


Experimental principle

- 2β decays half-life compensated by: $N_A = 6.022\ 10^{23}\text{mol}^{-1}$

$$\mathcal{T}^{0\nu}_{1/2} > \frac{ln\ 2\ N_A\ \mathcal{E}_{0\nu}}{1.64\ A}\sqrt{\frac{m\ t}{N_{bdf}\ r}}$$

- 2β isotopes decay through the 2 processes:
  - distinguished by the energy of the 2 electrons emitted
  - $2\nu2\beta$: irreducible background for $0\nu2\beta$
- NEMO experiments based on tracker-calorimeter principle:



– tracking & particles identification
– individual electron parameters
– precise backgrounds measurements
– almost any isotope

Choice of double beta decay isotopes

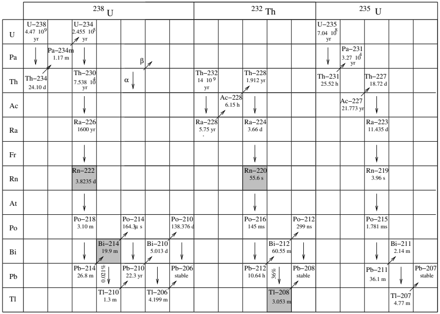
The best 2β isotope for an experiment should have:

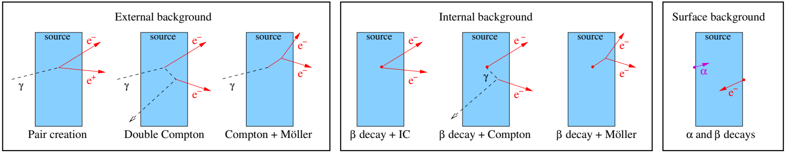
- suit with the experimental technique
- high $Q_{\beta\beta} > Q_{\beta}(^{214}Bi) = 3.2$ MeV $> E_{\gamma}(^{208}Tl) = 2.6$ MeV
- low $\mathcal{T}^{0\nu}_{1/2}$ by high $G_{0\nu}$ and high $\mathcal{M}_{0\nu}$
- high $\mathcal{T}^{2\nu}_{1/2}$ (less $2\nu2\beta$ events)
- high mass: natural abundance enrichment and purification

2β	$Q_{\beta\beta}$ MeV	$G_{0\nu}$ 10^{-25}y^{-1}	$\mathcal{T}^{2\nu}_{1/2}$ y	NA %
^{48}Ca	**4.272**	2.44	4.3 10^{19}	**0.19**
^{76}Ge	**2.039**	**0.24**	**1.3 10^{21}**	7.61
^{82}Se	2.995	1.08	9.2 10^{19}	8.73
^{96}Zr	**3.350**	2.24	2.0 10^{19}	2.8
^{100}Mo	3.034	1.75	7.0 10^{18}	9.63
^{116}Cd	2.805	1.89	3.0 10^{19}	7.49
^{130}Te	2.529	1.70	**6.1 10^{20}**	**33.8**
^{136}Xe	2.479	1.81	**2.1 10^{21}**	8.9
^{150}Nd	**3.368**	**8.00**	7.9 10^{18}	5.6

Natural radioactivity background

- Decay chains of very long half-life isotopes: ^{238}U ($4.5\ 10^9$y), ^{232}Th ($1.4\ 10^{10}$y), ^{235}U ($7.0\ 10^8$y) and ^{40}K ($1.3\ 10^9$y)

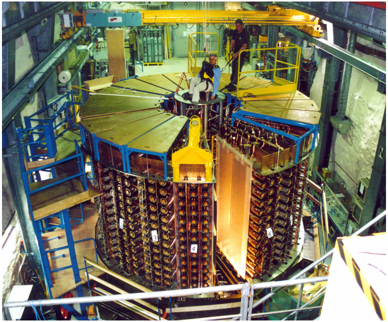




- Use of ultra-low radioactivity materials and huge shielding

NEMO3: the Neutrino Ettore Majorana Observatory

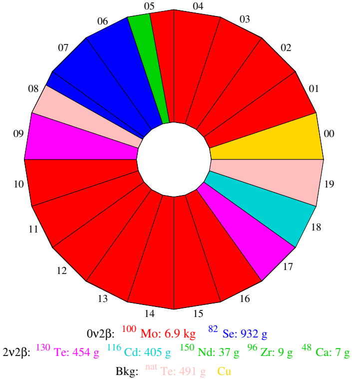
- NEMO3 ran from 2003 to 2010
- Only 2β experiment with the direct reconstruction of the $2e^-$
- Modest energy resolution but a high background rejection
- Direct measurement of the various backgrounds ($1e^-$, $1e^- n\gamma$...)
- Background in the $0\nu2\beta$ region equivalent to calorimeter exp

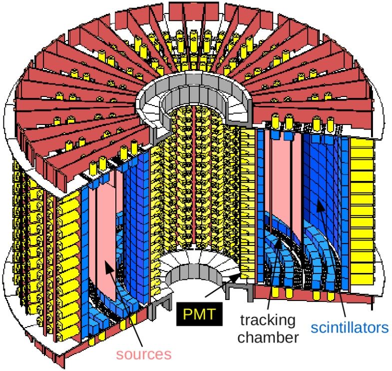


The NEMO3 Experiment

NEMO3 tracker-calorimeter experiment with passive sources

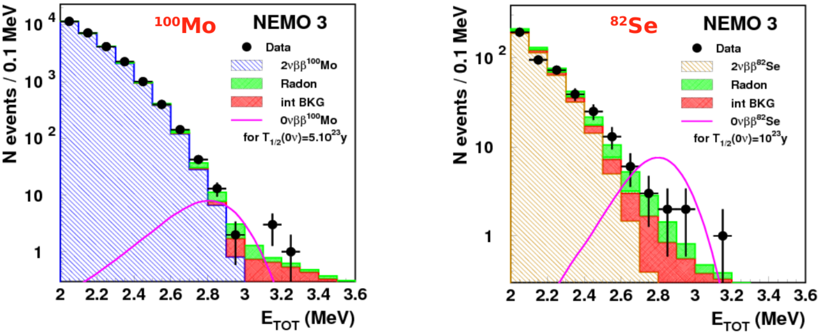
- 10 kg of 2β enriched isotopes in thin vertical foils (60 mg/cm^2):
  $0\nu2\beta$**: ^{100}Mo (6914 g) & ^{82}Se (932 g)**
- Shielding: LSM (4800 m.w.e.), borated water or wood & pure iron





NEMO3 $0\nu2\beta$ Results

Phase1 + Phase2, 4.5years



[2.8 – 3.2] MeV
Phase 1: 6 obs., 5.3±0.6 expect.
Phase 2: 12 obs., 11.1±0.9 expect.

$\mathcal{T}_{1/2}^{0\nu}(^{100}\text{Mo}) > 1.0\ 10^{24}$ yr

$|m_{\beta\beta}| < 0.31 - 0.79$ eV

[2.6 – 3.2] MeV
Phase 1: 4 obs., 3.6 expect.
Phase 2: 10 obs., 7.3 expect.

$\mathcal{T}_{1/2}^{0\nu}(^{82}\text{Se}) > 3.2\ 10^{23}$ yr

$|m_{\beta\beta}| < 0.85 - 2.08$ eV

From NEMO3 to SuperNEMO

	NEMO3	SuperNEMO
Mass	7 kg	100 kg
Isotopes	^{100}Mo	^{82}Se
	8 isotopes	^{150}Nd, ^{48}Ca
Foil density	60 mg/cm^2	40 mg/cm^2
Energy resolution (FWHM)		
@ 1 MeV	15 %	7 %
@ 3 MeV	8 %	4 %
Sources contaminations		
$\mathcal{A}(^{208}\text{Tl})$	$< 20\ \mu$Bq/kg	$< 2\ \mu$Bq/kg
$\mathcal{A}(^{214}\text{Bi})$	$< 300\ \mu$Bq/kg	$< 10\ \mu$Bq/kg
Radon		
$\mathcal{A}(^{222}\text{Rn})$	~ 5.0 mBq/m^3	~ 0.1 mBq/m^3
Detector		
tracking cells	6180	20$\times$2034
calo blocks	1940	20$\times$712
Sensitivity		
$\mathcal{T}^{0\nu}_{1/2}$	$> 1\ 10^{24}$ yr	$> 1\ 10^{26}$ yr
$\|m_{\beta\beta}\|$	$<$ 470 - 960 meV	$<$ 50 - 140 meV

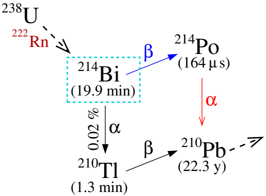
Improvements

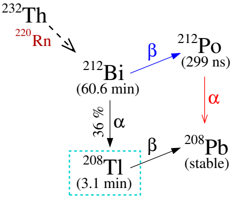
Several major improvements realised after R&D:

- Energy Resolution:
  - Improvement of the quantum efficiency of PMTs
  - Change the scintillators material:
    Polyethylene (8,000 γ/MeV) $\rightarrow$ PVT (1200 γ/MeV)
  - Change in the design of calorimeter blocks:
    5" PMTs coupled to light guides $\rightarrow$ 8" PMTs with thicker scintillators
- Sources:
  - 500 g purified and 5 kg enriched of ^{82}Se
  - Issue: purification below the sensitivity of HPGe detectors
    $\Rightarrow$ need of a new detector: BiPo
- Reduction of the radon background:
  - Use of radon tight joints
  - Isolation of the calorimeter with tight plastic film
  - Selection of materials

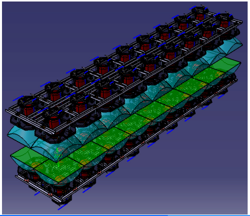
The BiPo3 Detector Principle

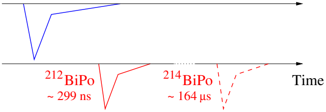
- Measure the radiopurity of the SuperNEMO sources at the level of few μBq/kg (50 times better than HPGe γ spectroscopy)
- ^{214}Bi and ^{208}Tl contaminations measured by BiPo processes:





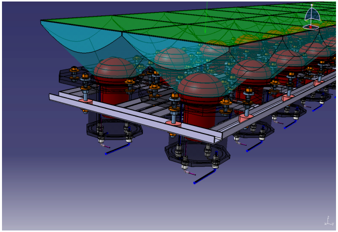
- β & α particles detected by thin radiopure plastic scintillators coupled to light-guides and low radioactivity PMTs:

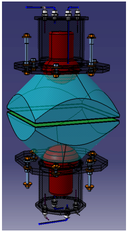


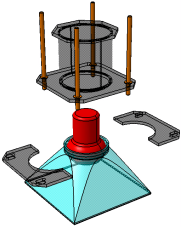


The BiPo3 Detector

- Total surface of 3.6 m^2 measures 1.4 kg of ^{82}Se (40 mg/cm^2)
- Each high radiopurity module consists of 40 light lines
- Start the SuperNEMO sources measurements end of 2012
- Goal: $\mathcal{A}(^{208}\text{Tl})_{sce} < 2\ \mu$Bq/kg & $\mathcal{A}(^{214}\text{Bi})_{sce} < 10\ \mu$Bq/kg

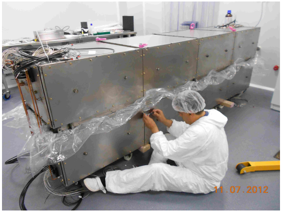






Assembly of the BiPo3 detector

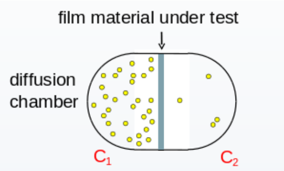
- First module assembled in the *Laboratorio Subterráneo de Canfranc* in Spain



Another improvement: radon background reduction

- Radon: one of the most dangerous backgrounds for $0\nu2\beta$
- Principle: isolate the tracker (outside and calorimeter) and build a tracker emanating less than 0.1 $\mathrm{mBq/m^3}$
- Tests on detector and tracker isolation and radon diffusion here in Prague at the IEAP CTU

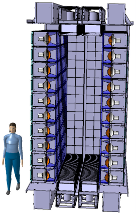
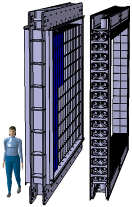
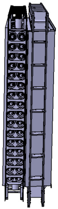
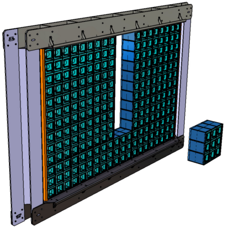
- Use of a high activity radon source $\sim$30 $\mathrm{kBq/m^3}$
- Tests on radon tight films



SuperNEMO Timeline

- 2005-2010: Successful SuperNEMO R&D
  - Calorimeter blocks better than 7 % FWHM @ 1 MeV
  - 2 BiPo prototypes demonstrating the sources qualification
  - Tracker improvement (larger and longer cells) + wiring robot

- SuperNEMO Demonstrator commissioning in the LSM in 2014
  - NEMO3 sensitivity in 5 months
  - no background in 3 years for 7 kg (53 mg/cm^2)
    $\Rightarrow \mathcal{T}_{1/2}^{0\nu} > 6.5\ 10^{24}$ yr & $|m_{\beta\beta}| < 200 - 550$ meV
    (To be compared to NEMO3 results on ^{82}Se:
    $\mathcal{T}_{1/2}^{0\nu} > 3.2\ 10^{23}$ yr & $|m_{\beta\beta}| < 0.85 - 2.08$ eV)

Conclusion

- NEMO3 data taking successfully ended in 2011 after 7 years
  - No evidence of $0\nu2\beta$ event recorded
  - Important results on several isotopes $2\nu2\beta$ observed

$$\mathcal{T}^{0\nu}_{1/2}(^{100}\text{Mo}) > 1.0\ 10^{24}\ \text{yr}$$
$$|m_{\beta\beta}| < 0.31 - 0.79\ \text{eV}$$

  - One more year necessary as data analysis is still ongoing
- The SuperNEMO demonstrator is under construction
  - Tracker construction is ongoing in UK
  - First calorimeter modules are assembled in CENBG, France.
- The BiPo3 detector is half constructed
  - Last prototype validated the technique
  - First module installed and running since July 2012
  - Second module will be assembled by the end of the year