Latest Results of NEMO-3:
^{100}Mo 2νββ decay measurement and search for Majoron and exotic processes

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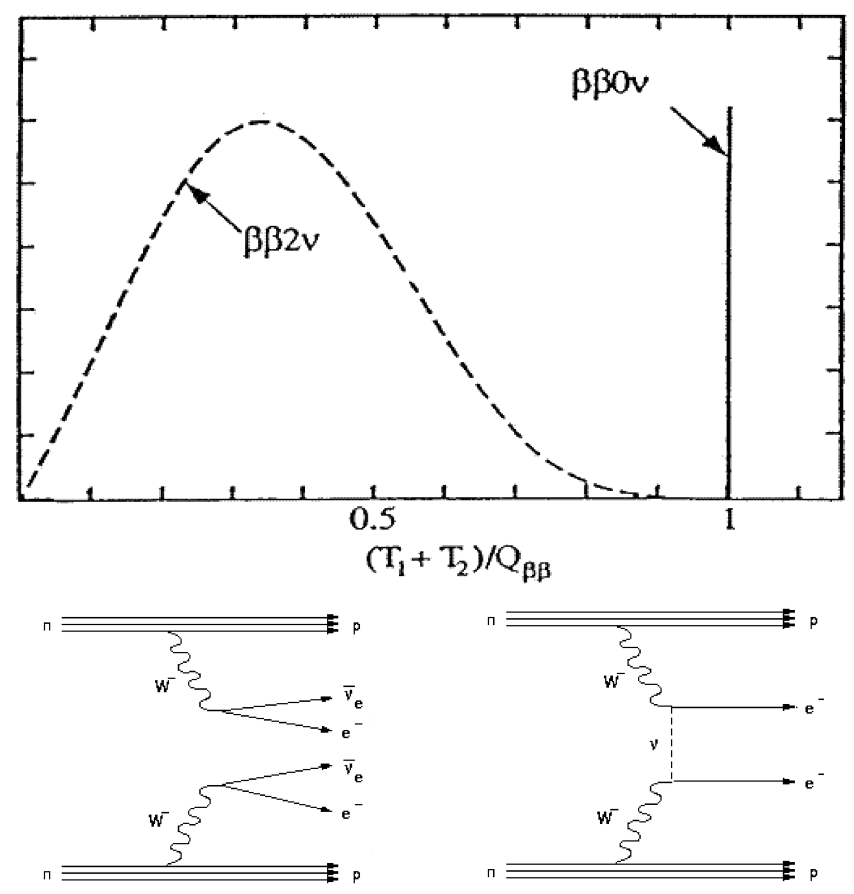
INTRODUCTION

The NEMO-3 experiment searches for neutrino-less double beta decay (0νββ). This is a hypothesized nuclear decay. Its rate is proportional to the effective neutrino mass squared:

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}|M^{0\nu}|^2|\langle m_\nu\rangle|^2, \qquad (1)$$

where $G^{0\nu}$ and $M^{0\nu}$ are the theoretically calculated phase space and nuclear matrix elements, respectively. Observation of 0νββ decay would be direct evidence that neutrinos are Majorana particles and lepton number conservation is violated. Therefore, 0νββ decay is a process which is beyond the current standard model of particle physics [1].

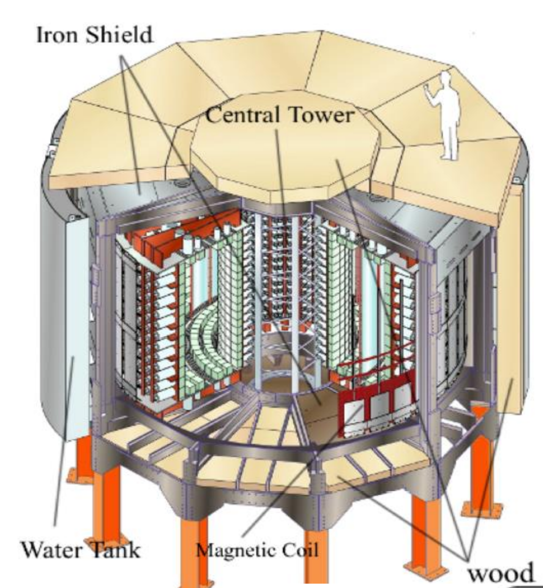
Examples of 2νββ and 0νββ energy spectra. Note that in reality the 0νββ line would be smeared by detector resolution.



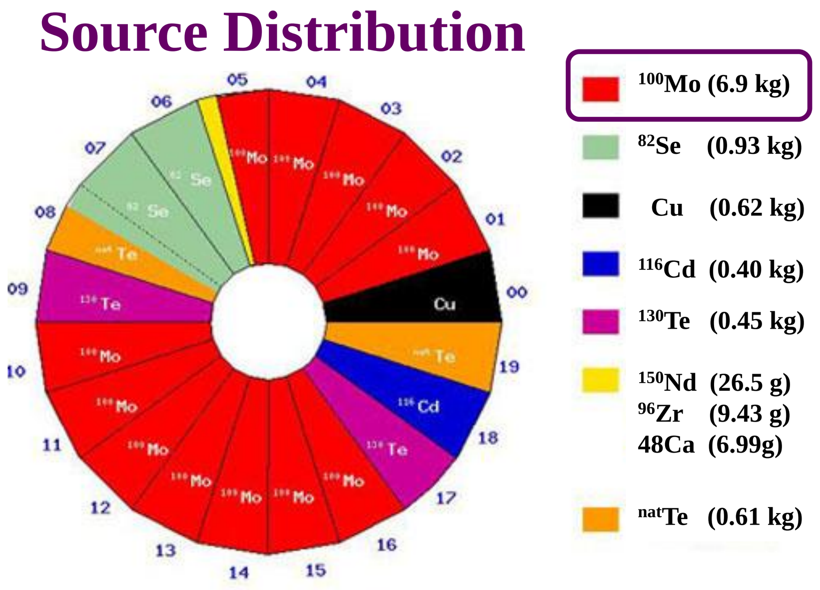
2νββ 0νββ

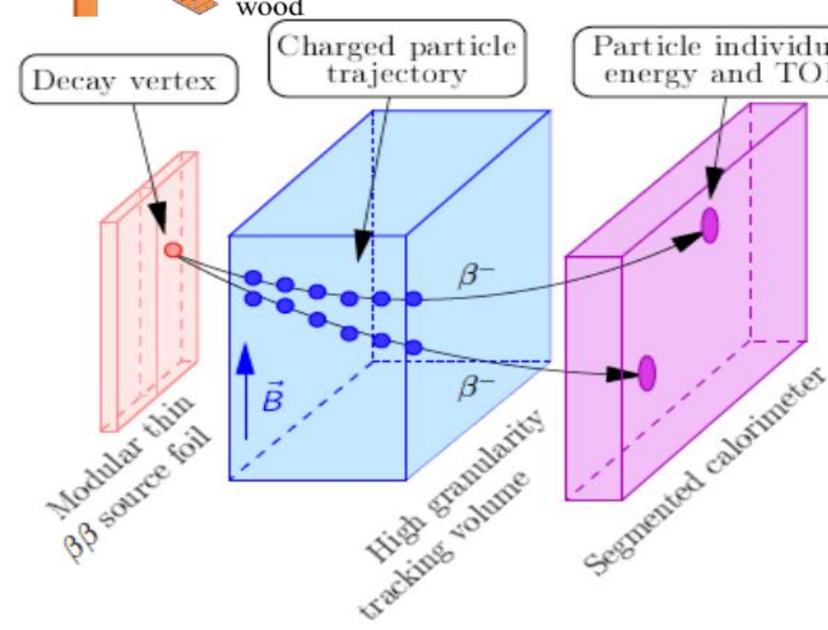
THE NEMO-3 EXPERIMENT

- Located in the Modane Underground Laboratory (LSM)
- Operated from February 2003 to January 2011
- Unique detector among 0νββ decay experiments due to the separation of the isotopes from the active detector system
- Allows for direct measurements of internal and external background rates and final state kinematic variables
- 7 different isotopes investigated *simultaneously* for 2νββ and 0νββ [2]



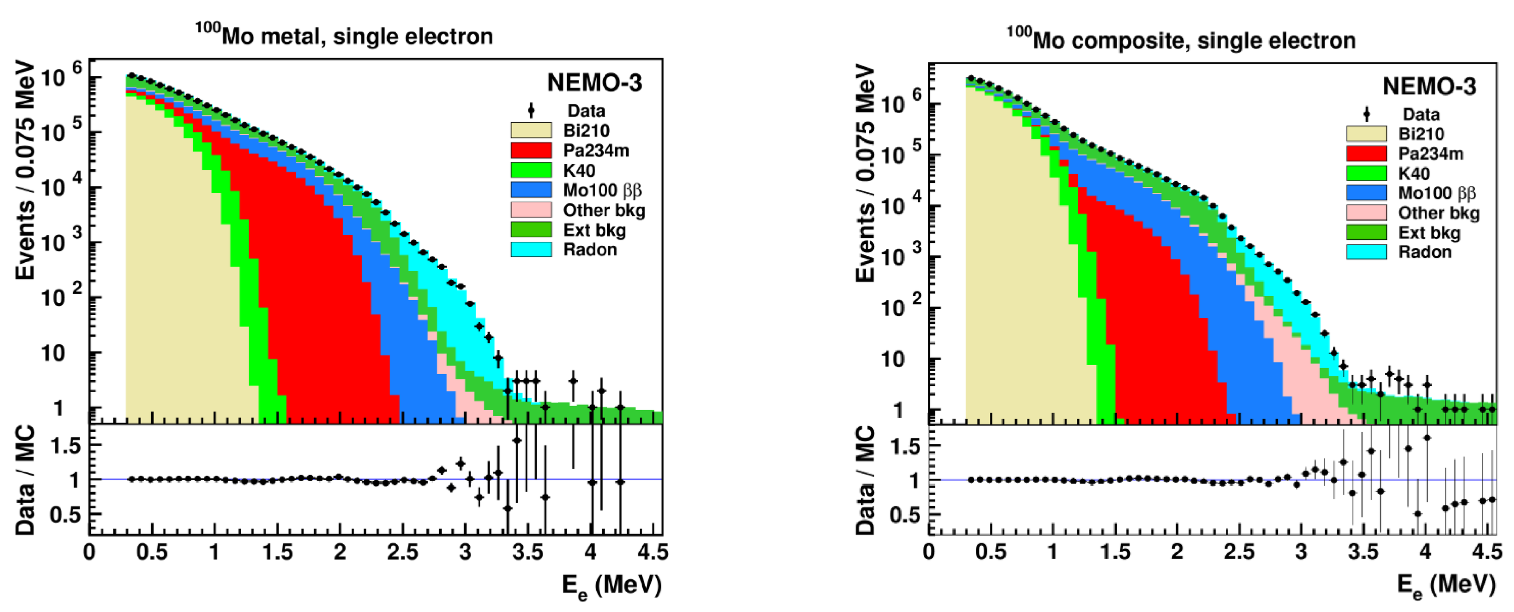
Source Distribution





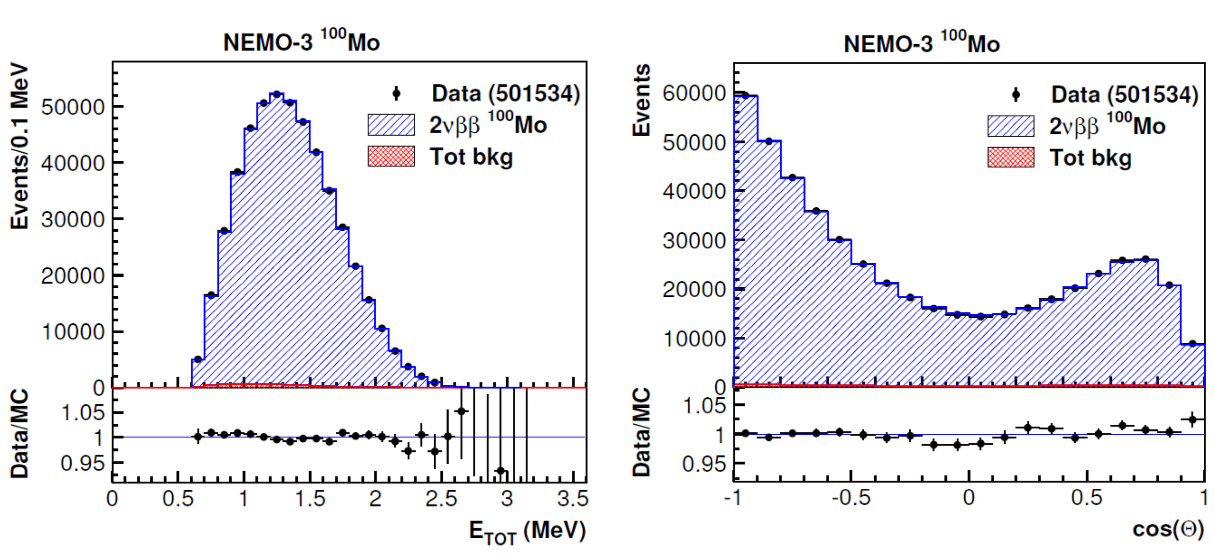
MEASURING BACKGROUNDS WITH NEMO-3

The source foils contain small amounts of background radioactive isotopes which were detected with a high-purity Germanium detector. Using a number of control regions defined by different final state event topologies, the activity of these background isotopes can be directly measured with the NEMO-3 detector, and used to estimate the number of expected events in the 2νββ and 0νββ signal regions.



The most significant background to the ^{100}Mo 0νββ decay is the irreducible 2νββ decay spectrum.

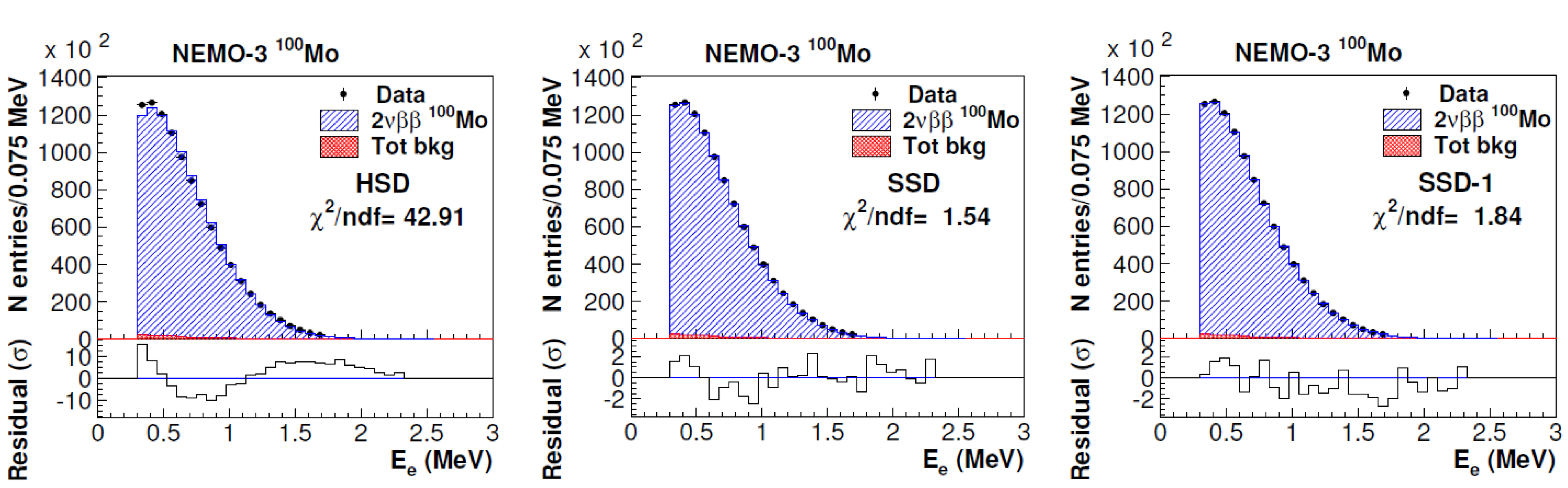
2νββ RESULTS FOR ^{100}Mo



Source of uncertainty	Effect on $T_{1/2}^{2\nu}$ (%)
Absolute normalization of ε_{2n}	± 5
Thin source foil modelling	± 4
^{100}Mo decay model	± 1.8
Energy calibration	± 0.6
^{100}Mo mass	± 0.3
Background uncertainty	± 0.2
Total	± 6.7

The 2νββ efficiency is 2.47% for metallic and 2.29% for composite foils. S/B is 63 for metallic, 94 for composite. Using an exposure of 34.7 kg y of ^{100}Mo :

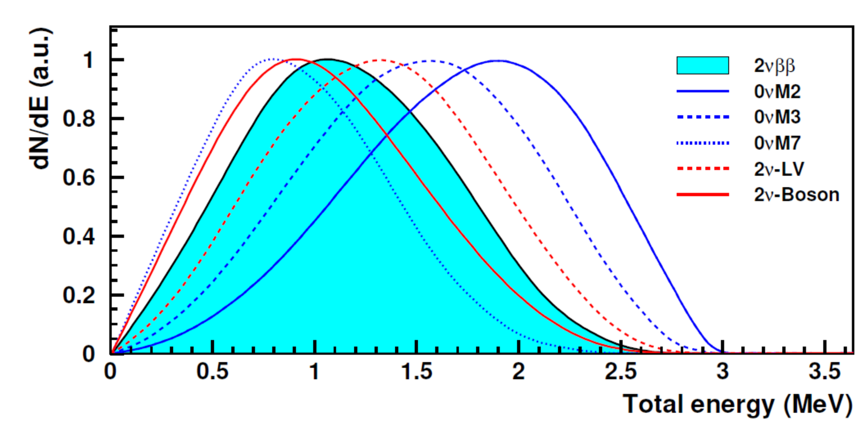
$$T_{1/2}(2\nu\beta\beta) = (6.81 \pm 0.01 \pm 0.46) \times 10^{18} \text{ years.}$$



The HSD (high intermediate state) model is excluded. The SSD (single state dominant) and SSD-1 (where the contribution of the first 1+ excited state is taken into account) are favoured.

MAJORON AND EXOTIC SEARCHES

NEMO-3 also investigated the majoron and exotic ββ decays for ^{100}Mo.



In various theoretical models the neutrinoless double beta decay can occur with the emission of a single or double majoron (massless or light boson with a coupling to neutrinos). Using ^{100}Mo, NEMO-3 provided one of the most sensitive constrain on the majoron coupling constant.

Spectral index	Mode	^{100}Mo	^{136}Xe[3]	^{76}Ge[4]
n=3	χ^0	0.013-0.035	0.06	0.047
n=3	$\chi^0\chi^0$	0.59-5.9	0.6-5.5	0.7-6.6
n=7	$\chi^0\chi^0$	0.48-4.8	0.4-4.7	0.8-7.1

Upper limits on the majoron coupling constant g_{ee}

The violation of the Pauli principle in the neutrino sector could be much stronger (neutral and very low mass particles). The double beta decay allows a sensitive test of the Pauli exclusion principle and statistics of neutrinos. NEMO-3 set limit on the bosonic component of the neutrino state :

$$\sin^2\chi < 0.27 \qquad (T_{1/2}^{b}(0^+ \text{ g.s.}) > 1.2 \times 10^{21} \text{ y})$$

The search for the bosonic neutrino is more promising when searching the 2νββ to the first 2^+_1 excited state.

The Lorentz invariance can be tested with double beta decay as its violation leads to energy spectra of emitted particles different from those in usual 2νββ process. NEMO-3 sets constrain on the Lorentz violation which can produce a positive or negative distortion of the spectrum :

$$-4.2\ 10^{-7} \text{ GeV} < \mathring{a}_{of}^{(3)} < 3.5\ 10^{-7} \text{ GeV}$$

References

[1] W. Rodejohann. *Neutrino-less Double Beta Decay and Particle Physics*. Int. J. Mod. Phys. E20, 1833-1930, 2011.

[2] R. Arnold, et al [NEMO Collaboration]. *Technical design and performance of the NEMO-3 detector*. Nucl. Instr. Meth., A536, 2005.

[3] JJ. B. Albert et al. "Search for Majoron-emitting modes of double-beta decay of ^{136}Xe with EXO-200", Phys. Rev.D 90 (2014) 092004.

[4] GERDA Collaboration, Agostini, M., Allardt, M. et al. "Results on decay with emission of two neutrinos or Majorons in ^{76}Ge from GERDA Phase I", Eur. Phys. J. C (2015) 75: 416.