

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

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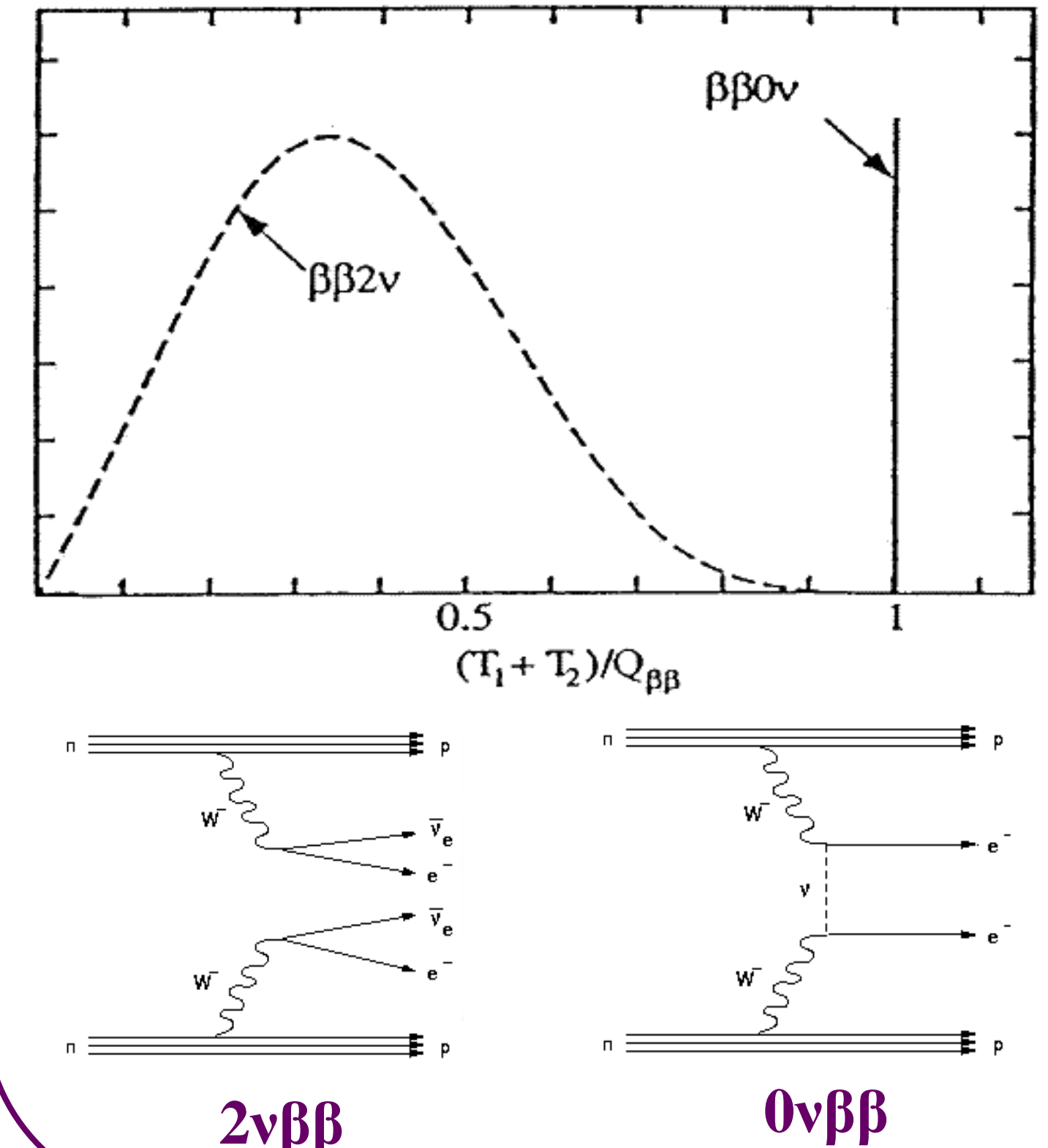
INTRODUCTION

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

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

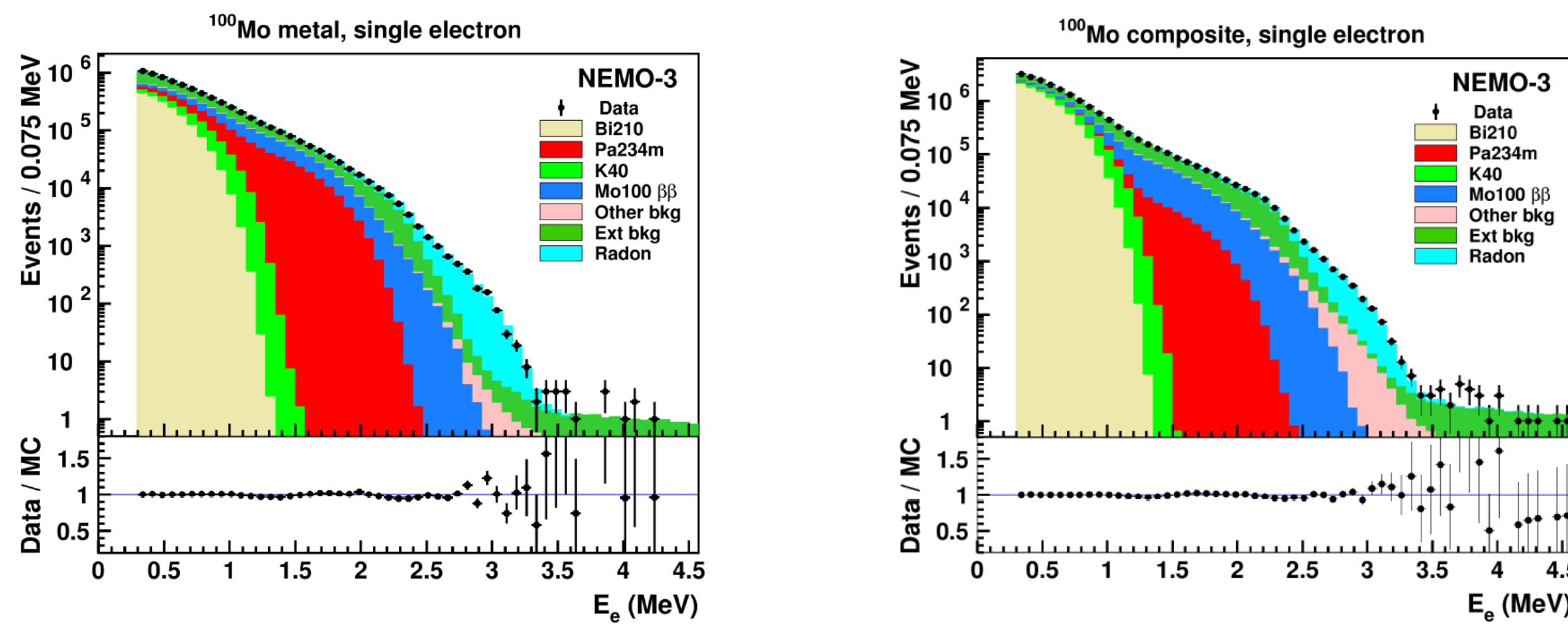
where $G^{0\nu}$ and $M^{0\nu}$ are the theoretically calculated phase space and nuclear matrix elements, respectively. Observation of $0\nu\beta\beta$ decay would be direct evidence that neutrinos are Majorana particles and lepton number conservation is violated. Therefore, $0\nu\beta\beta$ decay is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

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



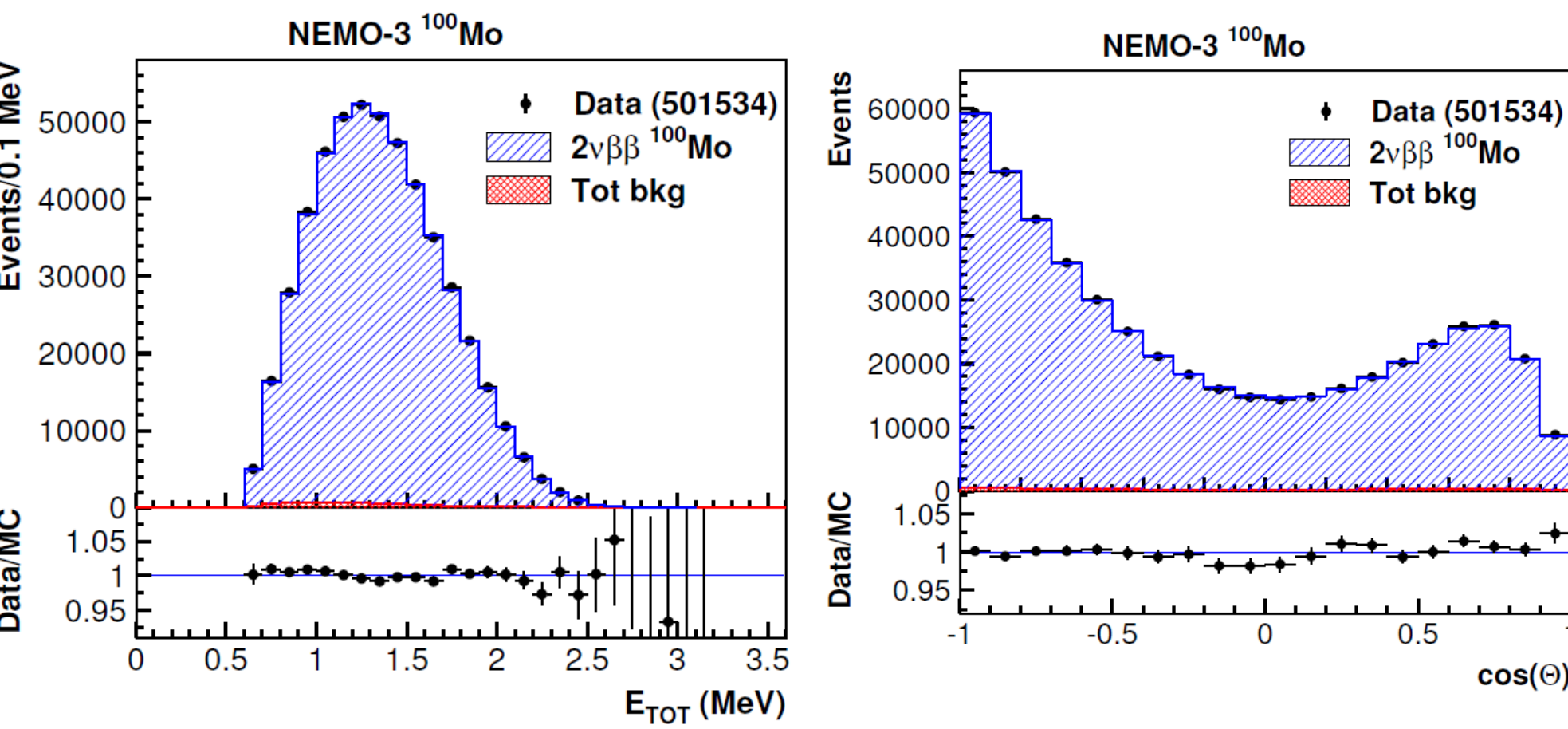
MEASURING BACKGROUNDS WITH NEMO-3

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 $2\nu\beta\beta$ and $0\nu\beta\beta$ signal regions.



The most significant background to the ^{100}Mo $0\nu\beta\beta$ decay is the irreducible $2\nu\beta\beta$ decay spectrum.

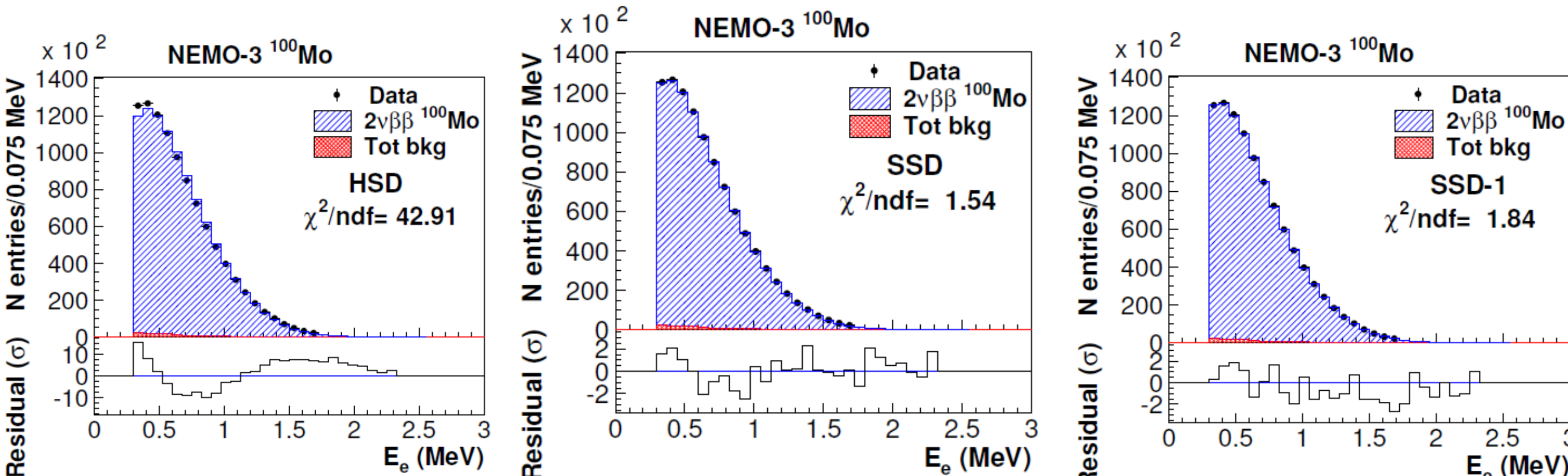
$2\nu\beta\beta$ RESULTS FOR ^{100}Mo



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 $2\nu\beta\beta$ 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 :

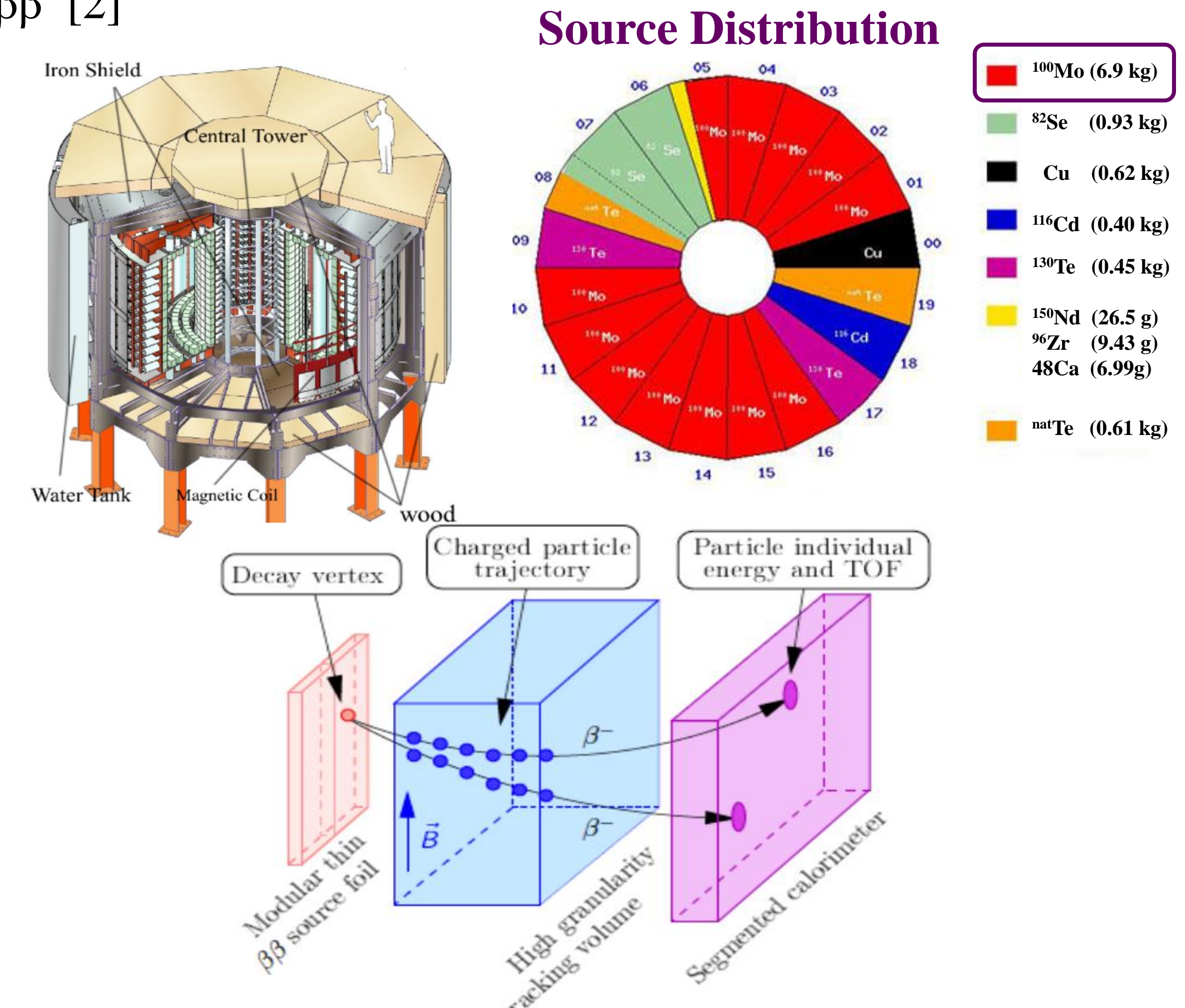
$$T_{1/2}(2\nu\beta\beta) = (6.81 \pm 0.01 \pm 0.46) \times 10^{18} \text{ years.}$$



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.

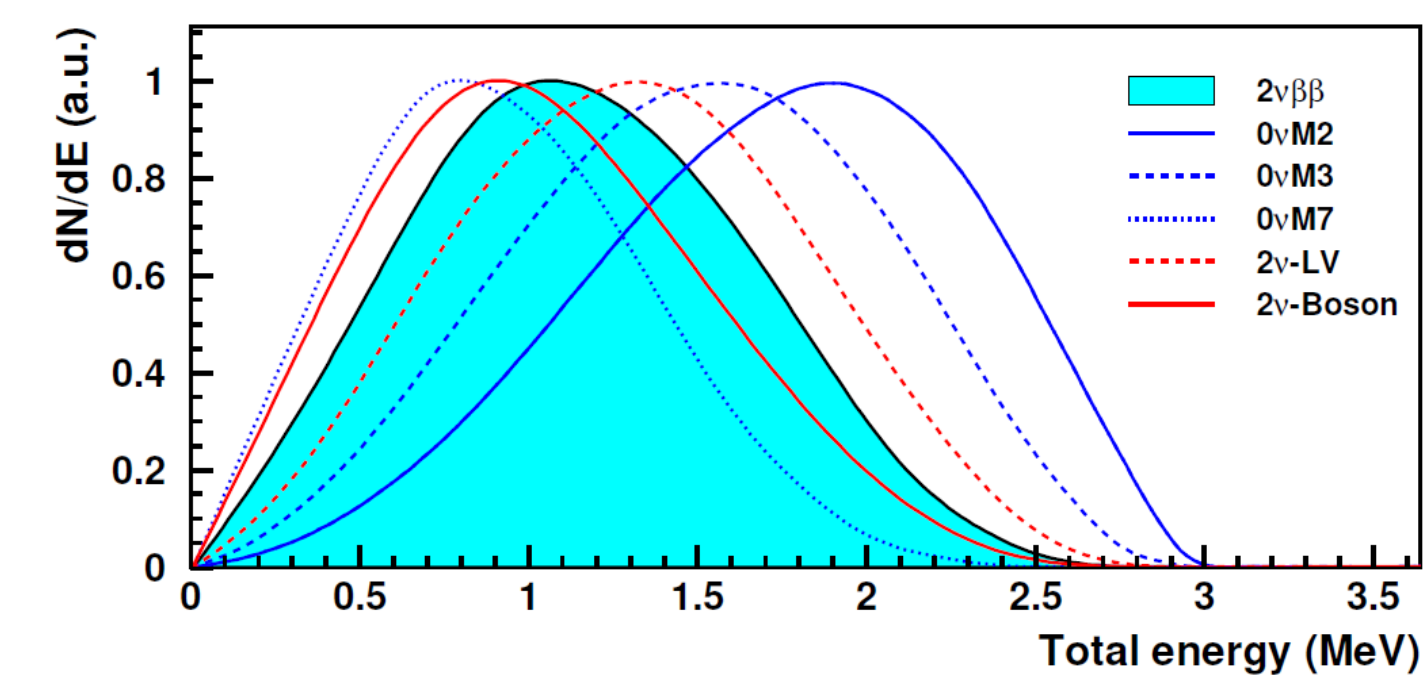
THE NEMO-3 EXPERIMENT

- Located in the Modane Underground Laboratory (LSM)
- Operated from February 2003 to January 2011
- Unique detector among $0\nu\beta\beta$ 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 $2\nu\beta\beta$ and $0\nu\beta\beta$ [2]



MAJORON AND EXOTIC SEARCHES

NEMO-3 also investigated the majoron and exotic $\beta\beta$ 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 :

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

The search for the bosonic neutrino is more promising when searching the $2\nu\beta\beta$ 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 $2\nu\beta\beta$ process. NEMO-3 sets constrain on the Lorentz violation which can produce a positive or negative distortion of the spectrum :

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

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] J.J. 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.