SuperNEMO 0νββ Sensitivity Studies

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The SuperNEMO Search for Neutrinoless Double-Beta Decay

SuperNEMO searches for the proposed neutrinoless double-beta decay process (0νββ), an interaction that would:

- Violate lepton number conservation, **creating matter.**
- Only be possible if neutrinos were **Majorana particles** ($\nu = \bar{\nu}$).
- Have a half-life > 10^{24}-10^{26} years (**eliminating backgrounds is key).**
- Occur in isotopes that undergo Standard Model double-beta decay (2νββ)

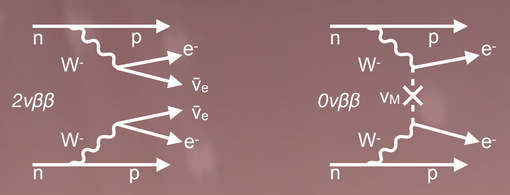


Fig 1: The SuperNEMO Demonstrator Module at LSM in France, which will be closed in the coming weeks.

The SuperNEMO Demonstrator Module uses a unique tracker-calorimeter architecture to characterise event topology, making it sensitive to the underlying 0νββ mechanism.

The SuperNEMO Demonstrator Module consists of:

- A **source foil** containing 7kg of ββ-decaying ^{82}Se,
- 2034 **drift cells** to track particle trajectories,
- 712 **optical modules** to measure particle energies.

A proposed full SuperNEMO, consisting of 20 Demonstrator-like modules, would be sensitive to a 0νββ half-life > 10^{26} years.

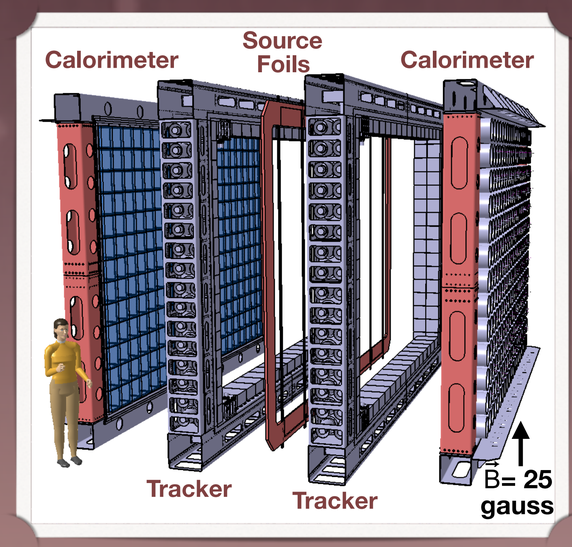


Fig 2: The SuperNEMO Demonstrator Module

Signal & Background

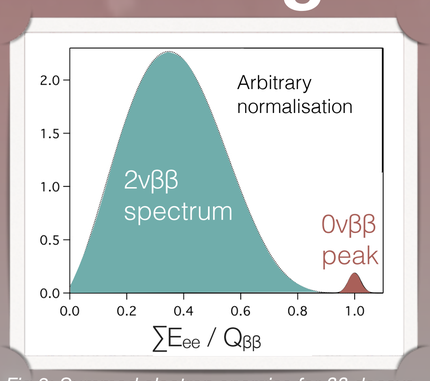


Fig 3: Summed electron energies for ββ decays

The 0νββ signature is 2 electrons whose energies add up to the total decay energy $Q_{\beta\beta}$.

There is an irreducible background from the high-energy tail of the 2νββ spectrum

β-decaying isotopes can mimic ^{82}Se 0νββ decay if:

- The total energy released in the β decay > $Q_{\beta\beta}$ for ^{82}Se (3 MeV).
- A second electron is produced near the decay vertex (Møller/ Compton scattering or internal conversion).

We minimise contamination with:

- Radio-pure components.
- Topological cuts to discriminate signal from background.

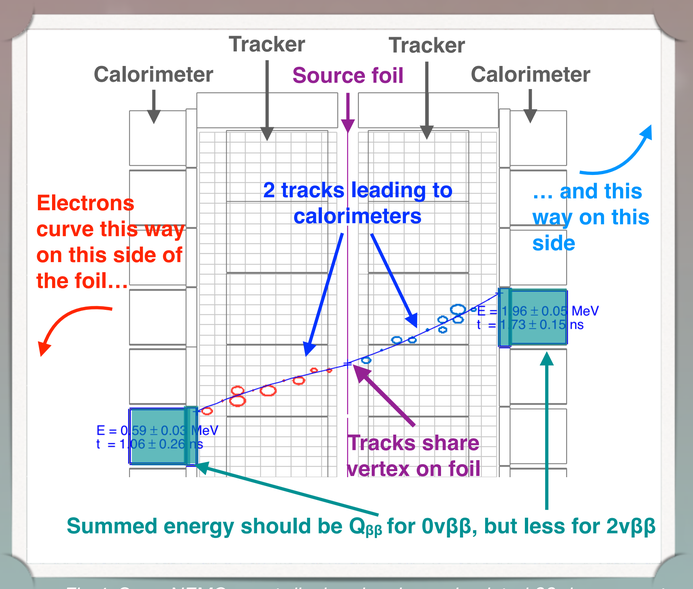


Fig 4: SuperNEMO event display showing a simulated ββ decay event. Overhead view of a subsection of the detector (trimmed for clarity).

Estimating Sensitivity

We preselect events with:

- Two electron-like tracks associated to calorimeter hits,
- A common vertex in the foil,
- No additional calorimeter hits (signature of γ's in the event).

The primary signal/background discriminator is the 2-electron energy sum.

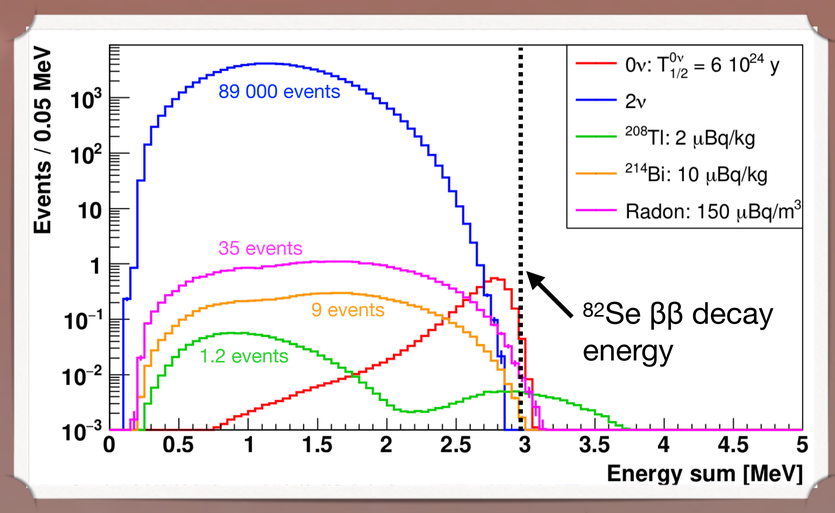
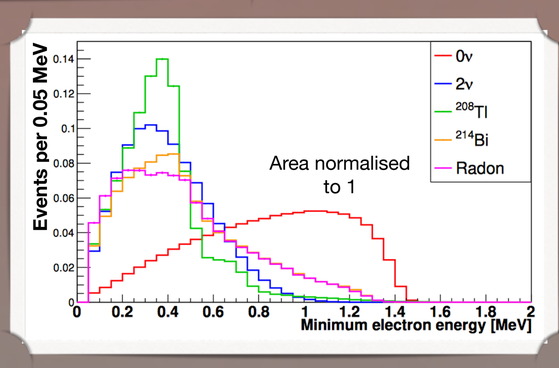
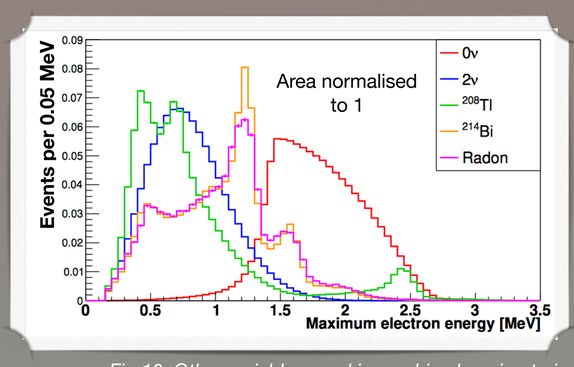


Fig 9: The summed energy of the two reconstructed electrons is the best way to discriminate between 0νββ signal (red), 2νββ background (blue) and backgrounds due to β - decaying natural isotopes (green, pink, yellow). This plot shows target ^{214}Bi, ^{208}Tl and tracker radon contamination levels, after preselection cuts, but with no electron energy cut.

SuperNEMO's tracker/ calorimeter design lets us look at other variables: individual energies, angle between tracks, vertex separation, relative timing…





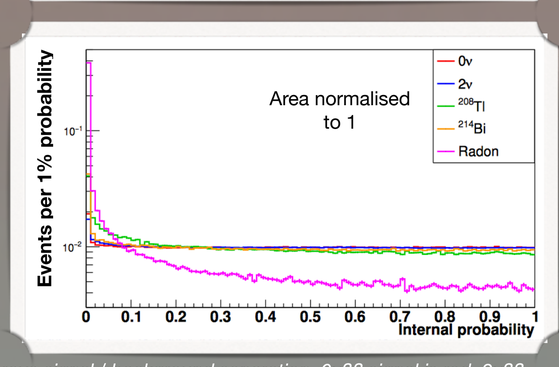


Fig 10: Other variables used in machine learning to improve signal / background separation. 0νββ signal is red, 2νββ background is blue, and backgrounds due to β-decaying natural isotopes are green, pink, and yellow.

With target background activities, 2.5 years of running, 7kg of ^{82}Se, and cuts on these variables, the SuperNEMO Demonstrator Module is sensitive to $T^{0\nu\beta\beta}_{1/2}$ > 5.4 x 10^{24} years. For this exposure, we expect 1 background event or less.

A boosted decision tree (BDT) helps us exploit the full event information, increasing sensitivity to:

$T^{0\nu\beta\beta}_{1/2}$ > 5.9 x 10^{24} years (90% C.L.)

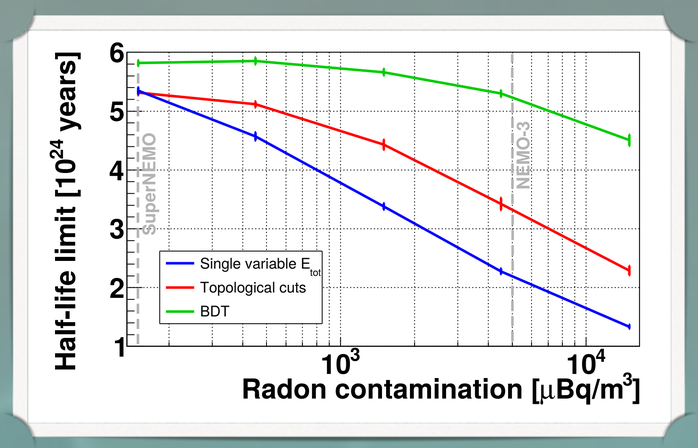


Fig 11: Variation in 0νββ half-life sensitivity with radon level in the detector. The blue line shows sensitivity with only a summed electron energy cut; red uses additional topological cuts, and green uses the BDT. SuperNEMO's 150 μBq target is shown, as is the level in our predecessor, NEMO-3.

The BDT helps us maintain sensitivity even if backgrounds exceed our targets.

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Backgrounds: Radon & Bismuth

^{214}Bi (Q_β = 3.2 MeV) contaminates the **source foil** (^{238}U decay chain). A decay product of ^{222}Rn in tracker gas, it is deposited on foil **surfaces** and **tracker wires**.

To measure contamination, select a characteristic "BiPo" topology:

$$^{214}_{83}\mathrm{Bi} \xrightarrow{\beta} {}^{214}_{84}\mathrm{Po} \xrightarrow{\alpha} {}^{210}_{82}\mathrm{Pb}$$

$T_{1/2}$=164μs

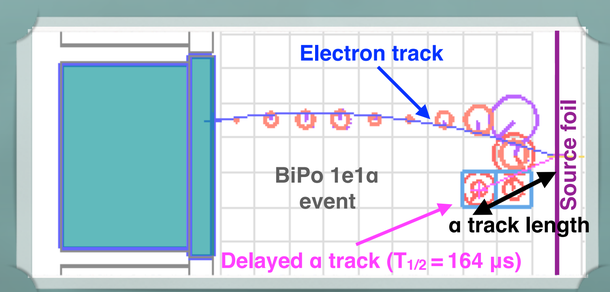

Fig 5: SuperNEMO event display showing a characteristic BiPo decay

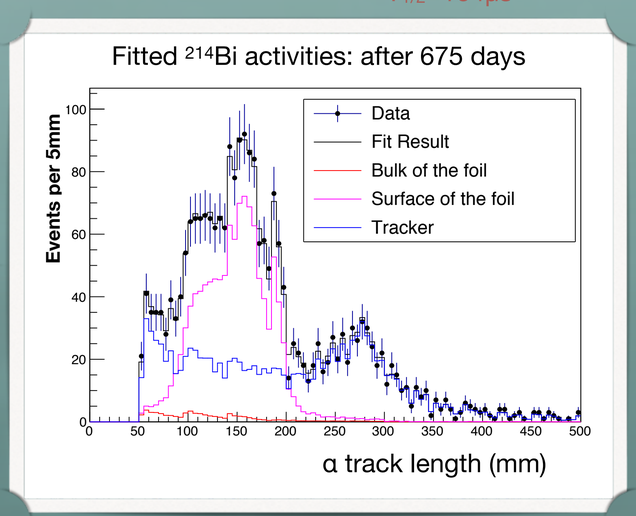

Fig 6: A fractional fit in α track length distinguishes the components of the reconstructed 1e1α sample to extract activities

Extract the activity of each detector component using α-track length as discriminating variable.

Target is 10 μBq / kg in the foil and 150 μBq / m^3 in the tracker

Backgrounds: Thallium

^{208}Tl (Q_β = 5.0 MeV) contaminates the source foil (^{232}Th decay chain). Target activity: 2 μBq / kg

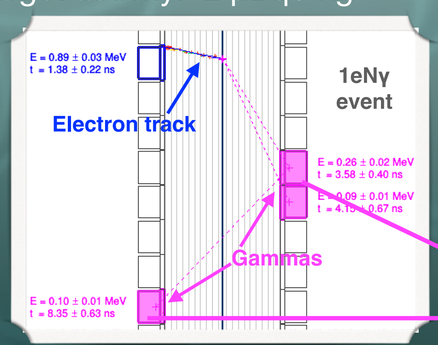

Fig 7: ^{208}Tl events typically have 1 electron and 1 or more γ's

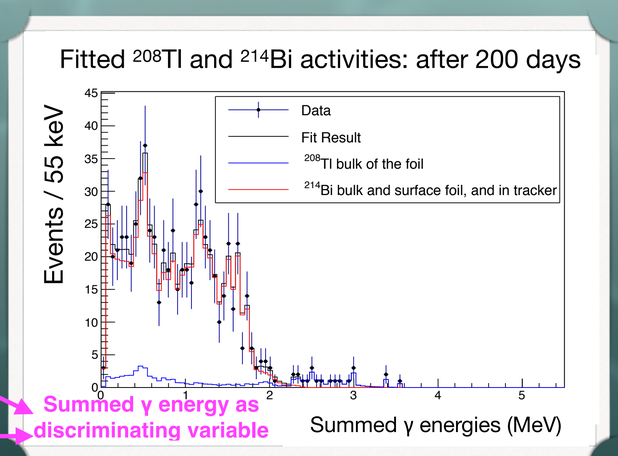

Fig 8: ^{208}Tl and ^{214}Bi can be separated by looking at the total energy of reconstructed γ's, so we can extract an activity