SuperNEMO searches for the proposed neutrinoless double-beta decay process ($0\nu\beta\beta$), 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 $> \text{10^{25}-10^{26}}$ years (eliminating backgrounds is key).
- Occur in isotopes that undergo Standard Model double-beta decay ($2\nu\beta\beta$).

We minimise contamination with:

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

The 0$\nu\beta\beta$ signature is 2 electrons whose energies add up to the total decay energy $Q_\beta$. There is an irreducible background from the high-energy tail of the 2$\nu\beta\beta$ spectrum.

**Backgrounds: Radon & Bismuth**

$^{214}$Bi ($Q_\beta = 3.2$ MEV) contaminates the source foil ($^{208}$Tl decay chain). A decay product of $^{214}$Pb in tracker gas, it is deposited on foil surfaces and tracker wires.

Extract the activity of each detector component using $\alpha$-track length as discriminating variable.

Target is 10 mBq / kg in the foil and 150 mBq / m$^2$ in the tracker.

**Backgrounds: Thallium**

$^{208}$Tl ($Q_\beta = 5.0$ MEV) contaminates the source foil ($^{208}$Pb decay chain). Target activity: 2 mBq / kg.

We preselect events with:

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

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

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

The SuperNEMO Demonstrator Module consists of:

- A source foil containing 7kg of $\beta$-decaying $^{76}$Ge.
- 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 0$\nu\beta\beta$ half-life $> 10^{24}$ years.

With target background activities, 2.5 years of running, 7kg of $^{76}$Ge, and cuts on these variables, the SuperNEMO Demonstrator Module is sensitive to $\text{T}_{1/2} > 5.4 \times 10^{26}$ 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:

$$\text{T}_{1/2} > 5.9 \times 10^{26} \text{ years} \quad (90\% \text{ C.L.})$$

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

**Estimating Sensitivity**

We estimate the sensitivity of the detector to $0\nu\beta\beta$ with a Monte Carlo simulation. The primary background comes from radon and its decay products. We use the BDT to discriminate between $0\nu\beta\beta$ signal and background.

With target background activities, 2.5 years of running, 7kg of $^{76}$Ge, and cuts on these variables, the SuperNEMO Demonstrator Module is sensitive to $\text{T}_{1/2} > 5.4 \times 10^{26}$ years. For this exposure, we expect 1 background event or less.

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

**Signal & Background**

The 0$\nu\beta\beta$ signature is 2 electrons whose energies add up to the total decay energy $Q_\beta$. There is an irreducible background from the high-energy tail of the 2$\nu\beta\beta$ spectrum.

Electrons curve this way in the foil. $^{214}$Bi activities: after 200 days $^{214}$Bi, $^{214}$Po, $^{214}$Pb.

**Fig 1**

- The SuperNEMO Demonstrator Module at LSM in France, which will be closed in the coming weeks.
- The primary signal/background discriminator is the 2-electron energy sum.
- To measure contamination, select a characteristic $^{214}$Bi$^0$ topology.
- Extract the activity of each detector component using $\alpha$-track length as discriminating variable.
- Target is 10 mBq / kg in the foil and 150 mBq / m$^2$ in the tracker.
- With target background activities, 2.5 years of running, 7kg of $^{76}$Ge, and cuts on these variables, the SuperNEMO Demonstrator Module is sensitive to $\text{T}_{1/2} > 5.4 \times 10^{26}$ 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:

$$\text{T}_{1/2} > 5.9 \times 10^{26} \text{ years} \quad (90\% \text{ C.L.})$$

**Fig 2**

- The 0$\nu\beta\beta$ electron energy spectrum, showing a simulated $0\nu\beta\beta$ decay event.
- Fig 6: A fractional fit in track length distinguishes the components of $\alpha$ events.

**Fig 3**

- The fractional fit in track length distinguishes the components of $\alpha$ events.

**Fig 4**

- Overhead view of a subsection of the detector (trimmed for clarity).
- SuperNEMO's tracker/calorimeter design lets us look at other variables: individual energies, angle between tracks, vertex separation, relative timing...

**Fig 5**

- Other variables used in machine learning to improve signal/background separation. 0$\nu\beta\beta$ signal in red, 2$\nu\beta\beta$ background in blue, and background due to $\beta$-decaying natural samples in green, pink, and yellow.

**Fig 6**

- The discriminant variable $S_{\nu\beta\beta}$ and this way on this side of the foil...
- Summed energy should be $Q_\beta$ for $0\nu\beta\beta$, but less for $2\nu\beta\beta$.

**Fig 7**

- The 0$\nu\beta\beta$ electron energy spectrum, showing a simulated $0\nu\beta\beta$ decay event.
- The primary signal/background discriminator is the 2-electron energy sum.

**Fig 8**

- The 0$\nu\beta\beta$ electron energy spectrum, showing a simulated $0\nu\beta\beta$ decay event.