Status of SuperNEMO Demonstrator

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On behalf of the SuperNEMO collaboration
The SuperNEMO experiment with the Tracker-Calorimeter technique

Radiopurity strategies to achieve a « 0-background » Demonstrator module

Status of the SuperNEMO Demonstrator construction & integration

Conclusion
The SuperNEMO experiment with the Tracker-Calorimeter technique
The Tracker-Calorimeter technique

- Choice of the $\beta\beta$ isotopes (source ≠ detector)
- Full topological event reconstruction (vertex, energy, TOF) including $\alpha$-particle, $e^\pm$ and $\gamma$-ray identification
  - Strong background suppression
  - Ability to disentangle different mechanisms for $\beta\beta0\nu$ by looking at several observables ($E_1$, $E_2$, $E_1+E_2$, $\cos(\theta)$, $\gamma$'s for decay to excited states)
- Poorer efficiency and energy resolution compared to pure calorimeter techniques
From NEMO-3 to SuperNEMO

<table>
<thead>
<tr>
<th></th>
<th>NEMO-3</th>
<th>SuperNEMO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass</strong></td>
<td>6.9 kg</td>
<td>100 kg</td>
</tr>
<tr>
<td><strong>Main ββ isotope</strong></td>
<td>$^{100}$Mo</td>
<td>$^{82}$Se</td>
</tr>
<tr>
<td><strong>Other ββ isotopes</strong></td>
<td>$^{82}$Se, $^{130}$Te, $^{116}$Cd, $^{150}$Nd, $^{96}$Zr, $^{48}$Ca</td>
<td>$^{150}$Nd or $^{48}$Ca ?</td>
</tr>
<tr>
<td><strong>Energy resolution FWHM @ 3 MeV</strong></td>
<td>8%</td>
<td>4%</td>
</tr>
<tr>
<td><strong>ββ sources radiopurity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A(^{208}$Tl)</td>
<td>~100 μBq/kg</td>
<td>&lt;2 μBq/kg</td>
</tr>
<tr>
<td>$A(^{214}$Bi)</td>
<td>60 - 300 μBq/kg</td>
<td>&lt;10 μBq/kg</td>
</tr>
<tr>
<td><strong>Radon in Tracker</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A(^{222}$Rn)</td>
<td>5.0 mBq/m³</td>
<td>&lt; 0.15 mBq/m³</td>
</tr>
<tr>
<td><strong>Total background</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cts.keV⁻¹.kg⁻¹.y⁻¹</td>
<td>1.3 ×10⁻³</td>
<td>5.0 × 10⁻⁵</td>
</tr>
<tr>
<td><strong>Sensitivity (90% C.L.)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_{1/2}^{0ν}$</td>
<td>&gt; 1.1×10²⁴ y</td>
<td>&gt; 1.0×10²⁶ y</td>
</tr>
<tr>
<td>$&lt;m_ν&gt;$</td>
<td>&lt; 0.3 - 0.6 eV</td>
<td>&lt; 0.05 – 0.10 eV</td>
</tr>
</tbody>
</table>
$^{82}\text{Se}$ baseline and other possible isotopes

- $^{82}\text{Se}$ has $Q_{\beta\beta} = 3.0$ MeV (above the 2.6 MeV $\gamma$-ray)
- Enrichment up to 98% of $^{82}\text{Se}$
- High $T_{1/2}^{2\nu} \approx 10^{20}$ y (14 times higher than for $^{100}\text{Mo}$)
  → contribution of $2\beta2\nu$ events in $2\beta0\nu$ energy window strongly reduced
  → baseline isotope for SuperNEMO

- Other promising isotopes:
  - $^{150}\text{Nd}$ ($Q_{\beta\beta}=3.37$ MeV) with a high phase space factor, even in $2\beta0\nu$ decay to excited states
  - $^{48}\text{Ca}$ ($Q_{\beta\beta}=4.28$ MeV)

$T_{1/2}^{0\nu} > 2.5 \times 10^{23}$ y (90% C.L.)
$\langle m_\nu \rangle < (1.2 - 3.0)$ eV

with 7 times less mass and dirtier foils, only a factor 3 less sensitive than $^{100}\text{Mo}$

Poster #721
SuperNEMO Demonstrator Module

- 7 kg of $^{82}\text{Se}$ in thin foils with e~250 µm ($\sim$50 mg/cm$^2$)
- 2034 Tracker Cells operating in Geiger mode
- 712 Calorimeter Modules with Polystyrene Scintillators + 8”(5”) PMTs
- Magnetic field for particle identification
- Passive shieldings (iron, water)

Full SuperNEMO: 20 modules
First step: Demonstrator Module

Expected sensitivity for a 17.5 kg·y exposure (90 % CL)

\[ T_{1/2} > 6.0 \times 10^{24} \text{ y} \]
\[ \langle m_\nu \rangle < 0.2 - 0.4 \text{ eV} \]
The SuperNEMO Collaboration
Radiopurity strategies
Radiopurity strategies

- Goal: to reach a « 0-background » level for the Demonstrator module

- Strategies:

  ✓ Purification and measurement of the $^{82}\text{Se}$ $\beta\beta$ foil internal radiopurity at the level of 2–10 $\mu$Bq/kg → development of the BiPo3 detector

  ✓ Selection of radiopure internal materials to reach a Radon level of 150 $\mu$Bq/m$^3$ in the Tracker → development of several Radon facilities

  ✓ Selection of radiopure surrounding materials → large screening process using low-background $\gamma$ spectrometry with HPGe detectors
BiPo-3 detector

Goal: to measure $^{82}\text{Se} \beta\beta$ foils at 2 $\mu$Bq/kg (10 $\mu$Bq/kg) level for $^{208}\text{Tl}$ ($^{214}\text{Bi}$)

Principle: $^{82}\text{Se}$ foil placed between two PS scintillators + 5” PMTs

$^{232}\text{Th}$ → $^{212}\text{Bi}$ (60.5 min) → $^{212}\text{Po}$ (300 ns) → $^{208}\text{Tl}$ (3.1 min)

$^{208}\text{Tl}$ measured by electron-alpha coincidence from $^{212}\text{Bi}$-$^{212}\text{Po}$ cascade with $\Delta T \sim 300$ ns

In operation in Canfranc lab. since 2013

$^{208}\text{Tl}$ sensitivity is achieved in 6-8 months for a 3.6 m$^2$ $\beta\beta$ foil

→ first $^{82}\text{Se}$ foils are under qualification with BiPo-3 detector

PRELIMINARY

$^{82}\text{Se}$ foils: 40 mg/cm$^2$

$^{208}\text{Tl}$ bkg: $0.9 \pm 0.2$ $\mu$Bq/m$^2$ scint

SuperNEMO requirement
Radon Challenges

Goal: to reach 150 µBq/m³ in the tracker gas (i.e. 70 atoms of Rn/m³!)

- **222Rn** is a noble gas coming from **238U** chain with $T_{1/2} = 3.8$ d
- If **222Rn** is present in the tracker gas, its daughter nuclei can stick to the ββ foil leading to **214Bi**-like internal contamination

$\rightarrow 214$Bi decay: emission of 2 electrons via several mechanisms

**Sensitivity vs exposure** depending on **222Rn** contamination

**Sources of 222Rn contamination** in the Tracker gas

**Poster #644**
Strategies against Radon

Radon emanation of critical materials

Large emanation facility with V~700L well-adapted to large volume or surface samples (films, PMTs…)

Small emanation facilities with V~3L well-adapted to smaller samples with a higher sensitivity

Radon diffusion in the Tracker

Rn diffusion facility to select ultra tight barriers (nylon film, sealing) to prevent Radon diffusion in the Tracker

Rn tent and ‘Rn-free’ air to prevent diffusion into the Demonstrator module from normal air in the lab.

Radon Concentration Line to measure the final volumic activity in the Tracker

Rn purification of the entrance gas

Gas flow in 1/4 tracker

→ for 2 m³/h flow rate, the 150 µBq/m³ level is achievable!
Status of the SuperNEMO Demonstrator construction & integration
SuperNEMO $^{82}$Se foils production

- 7 kg of $^{82}$Se $\beta \beta$ source divided into 36 foils of 270 x 13.5(12.5) cm$^2$ with a 250 µm thickness
- 3 different $^{82}$Se powder purification techniques have been used
- 11 foils among 36 (30% complete) already produced and under qualification with BiPo-3
- Other foils prepared in an ISO 6 clean room (1000 class room)

Calibrations will be performed with radioactive sources at controlled positions thanks to an automatic deployment system

→ End of production and installation of the $^{82}$Se foils planned for the end of 2016
SuperNEMO Tracker Construction

- Geiger-mode multi-wires drift chamber
- Robotic construction of 2034 drift cells containing approx. 15,000 wires
- Restricted set of materials: copper, steel, duracon
- Ultra-clean construction, assembly and testing conditions

→ 93% of the Tracker Cells is completed with only 1% rate of dead channels

→ full Tracker completed in autumn 2016
SuperNEMO Calorimeter Construction

- 520 Calorimeter Modules
  - PS Scint. + 8” High QE Radiopure PMTs
  - $<\text{FWHM}> = 8.0-8.3\% @ 1\text{ MeV}$
  - Time resolution of 400 ps @ 1 MeV
  - Calibration systems to maintain energy stability better than 1%
  - Validation with detailed optical simulations

→ Calorimeter completed and delivered in July!
More than ½ detector installed at Modane Underground Lab. (LSM, Fréjus, 4800 m.w.e.)

Remaining sub-detectors delivered in 2016

Commissionning of ½ Demonstrator Module starts in autumn 2016!
SuperNEMO is an experiment using the tracking calorimeter technique, very powerful to identify and reject the backgrounds for $\beta\beta$ studies.

A first Demonstrator Module is in construction with 7 kg of $^{82}\text{Se}$ with an expected sensitivity of $<m_\nu> < 0.2 – 0.4 \text{ eV}$ with a 17.5 kg·y exposure.

Several strategies have been successfully initiated to reach a « zero-background » level:

- BiPo-3 Detector able to measure the $^{208}\text{Tl}$ at the level of 2 µBq/kg
- Radon facilities developed to reduce the Radon contamination in the Tracker and to measure it at the level of 150 µBq/m$^3$

Status of SuperNEMO Demonstrator:

- All production will be completed in 2016
- Integration under progress
- Early commissioning of $\frac{1}{2}$ detector by the end of 2016
- First $\beta\beta$ events expected in 2017
Saturday 6th August at 6:00 PM
- Poster #479 : Radioactive source deployment system for the calibration of the SuperNEMO detector – R. Salazar, J. Bryant

Monday 8th August at 6:30 PM
- Poster #442 : The SuperNEMO $\beta\beta$ source production – A. Jérémie, A. Remoto
- Poster #472 : Gamma-tracking and sensitivity to gamma-emitting backgrounds in SuperNEMO – S. Calvez
- Poster #644 : Sensitivity to Radon induced background in SuperNEMO – Th. Le Noblet, A. Remoto
- Poster #664 : The SuperNEMO Calorimeter – Ch. Marquet, C. Cerna

Thank you for your attention
Backup slides
Simulations of $\beta\beta$ decays and main backgrounds: Rn, $^{208}$Tl and $^{214}$Bi internal

$\beta\beta$0v efficiency $\sim 25\%$
Demonstrator sensitivity and Rn studies

For $2.8 \text{ MeV} \leq E \leq 3.2 \text{ MeV}$:

- $2\beta 2\nu$: 0.175 count
- $^{222}\text{Rn}$: 0.070 count
- $^{208}\text{Tl}$: 0.040 count
- $^{214}\text{Bi}$: 0.040 count
- Total: 0.325 count

$4.6 \times 10^{-5}$ cts/kev/kg/y

$\sim 50\%$ from $2\beta 2\nu$

$\sim 50\%$ from $^{222}\text{Rn} + \text{internal contaminations}$
Ability to measure its own background

With combined $1e1g$ and $1e2g$ channels and gamma-tracking:
- $^{208}\text{Tl}$: activity measured with 10% of uncertainty in 8 months
- $^{214}\text{Bi}$: activity measured with 10% of uncertainty in 2 months
Ability to measure its own background

With $1 \times 10^3 \alpha$ channel + alpha track length, the Demonstrator is able to distinguish the different Radon contributions from:

- The bulk of the source foil
- The surface of the source foil
- The surface of the Tracker wires

- Radon level known at 4% in 1 week (not hoped!)
Ability to measure its own background

With 1e channel, the Demonstrator will be able to detect and remove « hot spots »

Exemple of « hot spots » in the $^{82}$Se foils in NEMO3

(a) Before Removal

(b) After Removal
How To Build a $\beta\beta$-Experiment

- Maximise efficiency ($\varepsilon$) & isotope abundance ($a$)
- Maximise exposure = mass ($M$) $\times$ time ($t$)

$$T_{1/2}^{0\nu} (90\% \text{ C.L.}) = 2.54 \times 10^{26} \text{ y} \left( \frac{\varepsilon \times a}{W} \right) \sqrt{\frac{M \times t}{b \times \Delta E}}$$

$W$ = atomic weight

- Minimise background ($b$) & energy resolution ($\Delta E$)

Graph showing half-life limit vs. exposure (kg years) with
- Background free
- Background limited

Half Life Limit (a.u.)

Exposure (kg years)
Other observables with the Demonstrator

Decays to Excited States

For example: 2e2γ channel

Majoron Emission

Right-handed current…
BiPo3 sensitivity

$^{208}\text{Tl}$

$^{82}\text{Se}$ foils: 40 mg/cm$^2$

$^{208}\text{Tl}$ bkg: 0.9 ± 0.2 μBq/m$^2$ scint

$^{214}\text{Bi}$

$^{82}\text{Se}$ foils: 40 mg/cm$^2$

$^{214}\text{Bi}$ surf. bkg: 1.0 ± 0.3 μBq/m$^2$ scint

$^{214}\text{Bi}$ rand. coinc. bkg: 0.063 ± 0.006 cts/day/m$^2$ scint
The Radon Concentration Line

Sensitivity extrapolated depending on the volume of Helium trapped
Radon emanation results for Tracker

Tracker was divided in 4 sections labelled C0, C1, C2 and C3.

Extrapolation of Radon activity in the Tracker by using the average emanation value of C0, C1 and C2

<table>
<thead>
<tr>
<th>Input Flow (m³/hr)</th>
<th>Suppression Factor</th>
<th>Activity in the Tracker with tent (mBq/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>5.4</td>
<td>0.51 ± 0.06</td>
</tr>
<tr>
<td>1.0</td>
<td>9.7</td>
<td>0.28 ± 0.03</td>
</tr>
<tr>
<td>2.0</td>
<td>18.4</td>
<td>0.15 ± 0.02</td>
</tr>
</tbody>
</table>
Large Rn emanation chamber: principle

Large emanation chamber

Rn detector

Sample

Rn decay in the detector

T_{1/2}(Rn)~3.8d

Det. Background (~3 cts/d)

Background (~20 cts/d)

Alpha spectrum

^214\text{Po} (7.7 \text{ MeV})

Determination of the Radon emanation rate from the sample
Sensitivity of the Rn emanation setup

For 1 m² surface sample → emanation rate < 400 Rn atoms/day (95% C.L.)
For 30 m² surface sample → emanation rate < 12 Rn atoms/day (95% C.L.)