The NEMO experiment. Present and Future.

Ruben Saakyan
UCL
28 January 2004
IOP meeting on double beta decay
Sussex
Neutrino Ettore Majorana Observatory

50 physicists and engineers

13 Laboratories/Universities

7 Countries
NEMO-III in Frejus

Frejus

NEMO-III and CUORICINO to determine $\beta\beta$ sensitivity until 2008-10
From scintillator detector:
\[ \sigma_\tau = 250 \text{ ps} \]

From tracker:
\[ \sigma_\parallel = 1\text{cm} \quad \sigma_\perp = 0.45\text{mm} \]
(using timing information on plasma propagation)

Calibration:
- Laser survey
- Neutron Am/Be for \( \sigma_\parallel, \sigma_\perp, e^+ \) signature
- \( e^- \ 207\text{Bi}, \ 90\text{Sr} \) for energy calibration
- \( \gamma^{60}\text{Co} \) for time alignment

Trigger:
1 scintillator hit > 150 keV
+ 1 track: few Geiger planes
(flexible \( \rightarrow \) 3 - 7 Hz)
NEMO $\beta\beta$ events
NEMO background events

\[ \gamma \rightarrow e^+e^- \quad e^- (\sim 7 \text{ MeV}) \text{ from } n\gamma \]
SOURCE DISTRIBUTION in NEMO 3

- $^{100}$Mo (6.9 kg)
- $^{82}$Se (0.93 kg)
- Cu (0.62 kg)
- $^{116}$Cd (0.40 kg)
- $^{138}$Te (0.45 kg)
- $^{150}$Nd (36.5 g)
- Zr (9.43 g)
- Ca (6.99 g)
- Te (0.61 kg)
Pure materials:

Source foils measured with the NEMO-3 detector

- $^{208}\text{Tl} < 2 \mu\text{Bq/kg}$
- $^{214}\text{Bi} < 2 \mu\text{Bq/kg}$
- neutrons $< 10^{-9} \text{ n cm}^{-2}\text{s}^{-1}$

Radon in the detector
- $^{222}\text{Rn} \sim 20 \text{ mBq/m}^3$
- $^{220}\text{Rn} \sim 1.6 \text{ mBq/m}^3$

...to be improved with new anti-radon shielding
Data taking

- June 2002: start with all 20 sectors, iron shielding, neutron shielding but...
- ...still a lot of debugging (both tracking detector and calorimeter)
- 14 February 2003: start of routine data taking
NEMO-3 First Results

$^{100}$Mo

2ν 1200 h:
$T_{1/2} = [7.4 \pm 0.05 \text{(stat)} \pm 0.8 \text{(sys)}] \times 10^{18} \text{yr}$
(19000 events; S/B $\approx$ 50)

0ν:
Preliminary from 3800 h:

$T_{1/2} > 2.3 \times 10^{23} \text{ yr (90\% CL)}$
$<m_\nu> < 0.6 \text{ eV} - 1.3 \text{ eV}$

World’s best result for $^{100}$Mo

2.8-3.2 MeV is used for 0ν analysis
Single State Dominance (SSD) VS Higher order State Dominance (HSD)

Simkovic, Domin, Semenov nucl-th/0006084, Phys. Rev. C

$^{100}\text{Mo} + \text{NEMO-like detector can test it experimentally!}$
NEMO-3 First Results
$^{100}$Mo 1200 h

single $e^-$ spectrum

Angular distribution between two $e^-$

Preliminary: SSD is preferred
NEMO-3 First Results
Other Isotopes

$^{82}\text{Se}$

$T_{1/2} = [8.2 \pm 0.4 \text{(stat)} \pm 0.8 \text{(sys)}] \times 10^{19}$

$T_{1/2} > 4 \times 10^{22} \text{ y} \quad 90\% \text{ CL}$

$T_{1/2} > 7.7 \times 10^{20} \text{ y} \quad 90\% \text{ CL}$

$^{150}\text{Nd}$

$T_{1/2} = [7.0 \pm 0.7 \text{(stat)} \pm 0.7 \text{(sys)}] \times 10^{18}$

$T_{1/2} > 7.7 \times 10^{20} \text{ y} \quad 90\% \text{ CL}$

$^{116}\text{Cd}$

$T_{1/2} = [3.9 \pm 0.3 \text{(stat)} \pm 0.4 \text{(sys)}] \times 10^{19}$

$T_{1/2} > 1.0 \times 10^{22} \text{ y} \quad 90\% \text{ CL}$

28/01/04

Ruben Saakyan, UCL
IOP meeting, Sussex
NEMO-3 $0\nu\beta\beta$ sensitivity
5 years

\[ E = 2.8 - 3.2 \text{ MeV} \]

\[ \begin{array}{ll}
\text{\textsuperscript{100}Mo} & \text{\textsuperscript{82}Se} \\
7 \text{ kg} & 1 \text{ kg} \\
Q_{\beta\beta} = 3.034 \text{ MeV} & Q_{\beta\beta} = 2.995 \text{ MeV} \\
2\nu\beta\beta = 0.11 \text{ event/y/kg} & 2\nu\beta\beta = 0.01 \text{ event/y/kg} \\
\end{array} \]

\[ \begin{align*}
\text{External BG: } & 0 \\
\text{Internal BG: } & \\
\text{radioactivity } & < 0.04 \text{ event/y/kg} \\
\text{radioactivity } & < 0.01 \text{ event/y/kg} \\
\text{T}_{1/2} & > 3 \times 10^{24} \text{ yr} \\
\langle m_\nu \rangle & < 0.2 - 0.5 \text{ eV} \end{align*} \]

\[ \begin{align*}
\text{T}_{1/2} & > 1 \times 10^{24} \text{ yr} \\
\langle m_\nu \rangle & < 0.6 - 1.2 \text{ eV} \\
\end{align*} \]

In case of full load of $^{82}\text{Se}$ (~14 kg) $\langle m_\nu \rangle < 0.15 - 0.3 \text{ eV}$
From NEMO-III to SuperNEMO

- Very well known and working technology (15 yr of R&D experience)
- Successful detector operation and physics results with NEMO-II and NEMO-III
- Modest amount of isotope needed (100kg of $^{82}\text{Se}$)
  - Current enrichment capabilities – 30 kg/yr max
- Short time scale and modest price
  - 40-50 meV by 2014
  - 20-25 MEuros
- 3-5 December 1st SuperNEMO meeting in Orsay. EOI to national funding agencies in preparation
**Which Isotope?**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Q, MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{100}$Mo</td>
<td>3.033</td>
</tr>
<tr>
<td>$^{82}$Se</td>
<td>2.995</td>
</tr>
<tr>
<td>$^{116}$Cd</td>
<td>2.802</td>
</tr>
<tr>
<td>$^{130}$Te</td>
<td>2.529</td>
</tr>
</tbody>
</table>

Factor of 10 lower BG for $^{82}$Se

Can be produced in centrifuge - $30K$-$50K/kg

\[
\frac{T_{1/2}^{2\nu}(^{82}\text{Se})}{T_{1/2}^{2\nu}(^{100}\text{Mo})} \sim 10
\]
Energy Resolution and Sensitivity

Discovery potential for 
\( <m_{\nu}> = 0.05 \text{ eV} \) (mass scale from \( \Delta m^2_{\text{atm}} \))

In 5 yr:

\( \Delta E / E = 14% / \sqrt{E} \) (NEMO-III)
SIGNAL = 5 events
BG = 15 events

\( \Delta E / E = 8% / \sqrt{E} \) (R&D goal)
SIGNAL = 5 events
BG = 0.6 events

\[ F \sim (\sigma_E/E)^6 \]
SuperNEMO

4 supermodules, planar geometry
100 kg $^{82}\text{Se}$ ($Q_{\beta\beta} \sim 3$ MeV, long $T_{1/2}^{2\nu}$)

Boulby mine is the most attractive experimental site

Sensitivity ~0.04 eV in 5 yr
Feasible if Zero BG experiment:

1) No BG from radioactivity
   the only possible BG from $2\nu$ tail (NEMO-III)
2) Improve $\Delta E/E$ from existing $(14\%-16\%)/\sqrt{E}$ to
   $(8\%-10\%)/\sqrt{E}$

R&D in UK and Dubna
SuperNEMO. Time Scale.

- 2004 – 2005: scintillator R&D
- 2006-2007: Development and characterization of 1st submodule
- 2007-2008: Start SuperNEMO installation (Boulby..?)
- 2009-2010: Start taking data
- 2014: planned sensitivity ~0.04 eV
- Excellent chance to be the first to reach 40-50 meV
Summary

- First anniversary of NEMO-III data taking approaching.
- So far: $<m_\nu> < 0.6$ eV, precise 2ν measurements for several isotopes
- $<m_\nu> < 0.2$ eV by 2009
- Experimental proof that BG(radioact)=0 reachable
- SuperNEMO is well positioned to reach 40-50 meV on a very competitive time scale