Status of the SuperNEMO $\beta\beta$-decay experiment

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SuperNEMO in one slide
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- neutrinoless double-beta decay experiment
SuperNEMO in one slide

- neutrinoless double-beta decay experiment
- unique tracker-calorimeter architecture
- ultra-low backgrounds
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- under construction at LSM, France
SuperNEMO in one slide

- neutrinoless double-beta decay experiment
- unique tracker-calorimeter architecture
- ultra-low backgrounds
- under construction at LSM, France
- first data this year
beta decay

\[ \beta \text{ decay} \]

\[ n \rightarrow p + e^- + \bar{\nu}_e \]
double-beta decay

\[ \text{2νββ} \]

Neutrinoless double-beta decay

Neutrino must be Majorana ($\nu = \bar{\nu}$)
So how does this look?

Summed 2-electron energy as fraction of $\beta\beta$ decay energy

Some fraction of energy goes to neutrinos

$\sum E_{ee} / Q_{\beta\beta}$

Arbitrary units

2v$\beta\beta$ spectrum

Summed 2-electron energy as fraction of $\beta\beta$ decay energy
So how does this look?

Summed 2-electron energy as fraction of $\beta\beta$ decay energy

No neutrinos means all energy goes to electrons (smeared in reconstruction)
NEMO-3 - the slightly-less-super NEMO

- 2νββ measurements and 0νββ limits for several isotopes
  - $^{100}$Mo (Phys. Rev. Let. 95, 182302)
  - $^{150}$Nd (Phys. Rev. D 94, 072003)
  - $^{48}$Ca (Phys. Rev. D 93, 112008)
  - $^{116}$Cd (Phys. Rev. D 95, 012007)
  - $^{130}$Te (Phys. Rev. Lett. 107, 062504)
  - $^{96}$Zr (Nucl. Phys. A847:168-179)
  - $^{82}$Se (coming soon)
- Quadruple beta decay limit (Phys. Rev. Lett. 119, 041801)
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$2\nu\beta\beta$: $T_{1/2} = 7.1 \pm 0.02 \text{ (stat)} \pm 0.54 \text{ (sys)} \times 10^{18} \text{ yr}$

$0\nu\beta\beta$: $T_{1/2} > 1.1 \times 10^{24} \text{ years}$

$\left\langle m_\nu \right\rangle < 0.33 - 0.62 \text{ eV}$

Phys. Rev. Let. 95, 182302
Backgrounds to $0\nu\beta\beta$: $2\nu\beta\beta$

Need good energy resolution
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$2\nu\beta\beta$

Optical module = polystyrene scintillator block + 8” radiopure PMT

Energy Resolution: 8% FWHM (1MeV) twice as good as NEMO-3

Time resolution: 400ps (1MeV)

Nucl. Inst. Meth. A 868 98-108
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Need good energy resolution

Main calorimeter walls: 520 optical modules

With side, top and bottoms: 712 modules total
• Radon is a gaseous decay product of natural uranium/thorium
• $\beta$-emitting daughters in detector and $\beta\beta$ source can mimic $\beta\beta$
• 4-pronged attack…
Radon is a gaseous decay product of natural uranium/thorium. β-emitting daughters in detector and ββ source can mimic ββ. 4-pronged attack...

1) Use radio-pure components

See Fang Xie’s talk
Radon is a gaseous decay product of natural uranium/thorium.

β-emitting daughters in detector and ββ source can mimic ββ

4-pronged attack…

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2) Flow gas through detector

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1) Use radio-pure components
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2) Flow gas through detector
   See Lauren Dawson’s talk

3) Measure background activities
Radon is a gaseous decay product of natural uranium/thorium. β-emitting daughters in detector and ββ source can mimic ββ. 4-pronged attack...

1) Use radio-pure components
2) Flow gas through detector
3) Measure background activities
4) Clever topological cuts

- Tracker reconstructs particles’ paths
- Magnetic field for charge information
- Calorimeter timing identifies their origin

See Fang Xie’s talk
See Lauren Dawson’s talk
Figure 3: Expanded diagram of the Demonstrator Module showing the a) source foil frame, b) the tracker and c) the calorimeter wall.
The SuperNEMO demonstrator

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Wire trackers
The SuperNEMO demonstrator

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**ββ Sources**

- 7kg of ββ emitter (\(^{82}\)Se)
- Enriched selenium mixed with PVA in Mylar wrapper
- Purified with distillation / chromatography / chemical precipitation
- BiPo detector confirmed \(^{208}\)Tl and \(^{214}\)Bi contamination at few µBq/kg levels
- Ready to hang at LSM

JINST 12 (2017) P06002
Wire trackers

2034 drift cells wired in Manchester
To run in Geiger mode

Installed into 4 C-shaped tracker sections at MSSL (UCL);
C-sections commissioned and tested for radon
Wire trackers

Completed C-section ready for shipping

Pairs of C-sections joined and attached to a calorimeter wall

In the Fréjus tunnel, approaching LSM
2017: half-detector commissioning with cobalt-60 source

Half-detector opened and awaiting source frame attachment
Falaise reconstruction software can identify:

- Electrons
  - Track with negative curvature, intercepting a calorimeter

- Gammas

\[
E = 0.77 \pm 0.03 \text{ MeV} \\
t = 3.31 \pm 0.23 \text{ ns}
\]

\[
E = 0.43 \pm 0.02 \text{ MeV} \\
t = 5.37 \pm 0.31 \text{ ns}
\]

Isolated calorimeter hits
Timing information can group isolated calorimeter hits that could come from the same gamma.

- $E = 0.46 \pm 0.02$ MeV, $t = 3.34 \pm 0.30$ ns
- $E = 0.91 \pm 0.03$ MeV, $t = 1.66 \pm 0.21$ ns
- $E = 0.16 \pm 0.01$ MeV, $t = 6.93 \pm 0.50$ ns
- $E = 0.05 \pm 0.01$ MeV, $t = 11.02 \pm 0.87$ ns
Short, straight tracks a few µs after an electron are characteristic of alpha particles from $^{214}\text{Bi}-^{214}\text{Po}$ decays.
ββ events are characterised by

- Two electron-like tracks (negative curvature, associated calorimeter)
Demonstrator sensitivity

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$\beta\beta$ events are characterised by

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- Vertex separation < 7cm parallel and 6 cm perpendicular to wires
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- Two electron-like tracks (negative curvature, associated calorimeter)
- A combined vertex on the source foil
- Vertex separation < 7cm parallel and 6 cm perpendicular to wires
- Internal probability > 4%
- No unassociated (gamma-like) hits
Summed 2-electron energy is best distribution to separate signal from background.

Using a boosted decision tree, we can improve sensitivity by including other variables (angle between tracks, individual electron energies, internal/external probability, vertex separation…)

$T_{1/2} > 5.85 \times 10^{24}$ years (90% C.L)

For 7kg of $^{82}$Se (demonstrator) and 2.5 years’ exposure
Other analyses

Background measurements
- Radon
- Foil contamination
- External background rates

Alternative 0νββ mechanisms
- Majorons
- L-R symmetry
- SUSY
- Leptoquarks

2νββ measurements
- SSD
- HSD

Improved simulation and techniques
- Machine learning techniques
- Optical simulations
- Magnetic field mapping
- Statistical techniques

Radon

F. Deppisch, NuPhys 2016
Next steps

Validate calibration system

Install source foils (April/May)

Close the detector

Commissioning Calibration
Monte Carlo challenge

FIRST DATA!
Long-term plans

• Other isotopes

NEMO-3 "camembert" (source top view)

NEMO-3 studied 7 of the 13 observed ββ isotopes

SuperNEMO’s design allows us to exchange the $^{82}$Se source foils for foils of other materials
**Long-term plans**

- Other isotopes
- Full SuperNEMO

A proposed 20-module full SuperNEMO detector improves our sensitivity to

\[ T_{1/2} > 10^{26} \text{ years}; \langle m_\nu \rangle < 50-100 \text{ meV} \]

For 100kg of \(^{82}\text{Se}\) and 5 years’ exposure
Long-term plans

- Other isotopes
- Full SuperNEMO
- Detector R&D:
  - scintillator bars
Long-term plans

- Other isotopes
- Full SuperNEMO
- Detector R&D
  - scintillator bars

- Walls of 2m scintillator bars sandwiched between tracker layers = good background rejection?
- Fewer PMTs - save ££ and radioactivity
- Easier to build
- But can we maintain our energy & time resolution?
Long-term plans

• Other isotopes
• Full SuperNEMO
• Detector R&D:
  • scintillator bars
  • tracker improvements

- SuperNEMO’s tracker cells operate in the Geiger regime (electron avalanche saturated, independent of ionisation)
- Could we use proportional mode and measure the ionisation energy?
Long-term plans

• Other isotopes
• Full SuperNEMO
• Detector R&D:
  • scintillator bars
  • tracker improvements

Goal: an improved SuperNEMO that is

• extensible,
• compact and
• inexpensive,
• and retains the performance of the demonstrator

WE CAN DO IT!