Measurement of $2b2\nu$ Half-Life of Zr96

and

Lightguide Studies for SuperNEMO Calorimeter

Matthew Kauer
UCL London
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2b0ν - Motivation

Neutrinos oscillate and have mass
- Dirac or Majorana Neutrino?
- Absolute mass scale?

2b0ν decay answers both questions
- Observation of 2b0ν is direct evidence that neutrinos are Majorana
- Effective Majorana mass is inversely proportional to 2b0ν half-life

\[ [T_{1/2}^{0ν}]^{-1} = G^{0ν} |M_{0ν}|^2 <m_{ββ}>^2 \]
NEMO-3 Detector
- Tracker + Calorimeter
- 10 kg of source
- Magnetic Field
- passive shielding
- 4800 MWE
- 0.3 eV sensitivity
**External Backgrounds**

Success of NEMO-3 depends on how well we understand our backgrounds.

External backgrounds are characterized as radioactive impurities NOT within the source foils:
- support structure
- PMTs
- drift cell wires
- radon

Measure the external background using the Cu sector.
Look in the $\gamma\gamma$ channel for more statistics.

<table>
<thead>
<tr>
<th>Background</th>
<th>Phase-1 Bq</th>
<th>Phase-2 Bq</th>
</tr>
</thead>
<tbody>
<tr>
<td>air_b1214</td>
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<td>0.0</td>
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<tr>
<td>iron_co60</td>
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<td>50.7</td>
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<tr>
<td>pm_ac228</td>
<td>515.0</td>
<td>515.0</td>
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<tr>
<td>pm_b1212</td>
<td>515.0</td>
<td>515.0</td>
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<tr>
<td>pm_b1214</td>
<td>374.0</td>
<td>374.0</td>
</tr>
<tr>
<td>pm_k40</td>
<td>954.0</td>
<td>954.0</td>
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<tr>
<td>pm_tl208</td>
<td>41.6</td>
<td>41.6</td>
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<tr>
<td>sf_b1214</td>
<td>0.0200</td>
<td>0.0085</td>
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<tr>
<td>sw_b1214</td>
<td>0.6000</td>
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<tr>
<td>sw_tl208</td>
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<td>sf_b1210</td>
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<tr>
<td>sf_nb214</td>
<td>0.0200</td>
<td>0.0085</td>
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</tbody>
</table>
Internal Backgrounds

Internal backgrounds are characterized as radio-impurities within the source foil.

Keep the external background activities fixed and measure the internal backgrounds using different channels.

1 electron channel

<table>
<thead>
<tr>
<th>Background</th>
<th>Bq</th>
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<tbody>
<tr>
<td>foils_ac228</td>
<td>1.63E-4</td>
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<tr>
<td>foils_bi212</td>
<td>1.63E-4</td>
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<tr>
<td>foils_bi214</td>
<td>1.35E-4</td>
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<tr>
<td>foils_pb214</td>
<td>1.35E-4</td>
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<tr>
<td>foils_k40</td>
<td>1.90E-2</td>
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<td>foils_pa234m</td>
<td>6.55E-4</td>
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<tr>
<td>foils_tl208</td>
<td>5.88E-5</td>
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</tbody>
</table>

Bi214 → e + alpha
Pb214=Bi214
Tl208 → egg, eggg
Ac228=Bi212~Tl208
Bi210,K40,Pa234m → e, eg
Selection Cuts

- 2 tracks with negative curvature
- each track has associated scint hit with $E > 200$keV
- scint hits are isolated
- track hits face of scintillator
- no other energy deposit in calorimeter
- reconstructed vertex
- distance between track origins, $XY < 2$cm and $Z < 4$cm
- event vertex in Zr96 sector
- has GG hit in one of the 2 closest layers
- sum of track lengths > 60cm
- TOF prob internal > 4% and TOF prob external < 1%
- less then 3, non associated, fast GG hits with distance to event vertex < 15cm (checks track reconstruction quality)
- if both tracks in one part of detector, no fast GG hits in other part with distance to event vertex < 15cm (checks that the event didn’t start on the opposite side of foil)
- 700 microSec time delay to cut out alpha events from Po214

- 2 electron tracks
- 2 scint hits where tracks end
- event vertex is in the foil
- check reconstruction quality
**First Year Report**

**2b2n Measurement**

**Phase-1**

Runtime = 404 days

Data = 303.0 +/- 17.4

Bgr = 129.3 +/- 5.7

Signal = 173.7 +/- 18.3

Half-life = \(1.85 +/- 0.12\ \text{e}^{19}\) years

\(\varepsilon = 7.1\%\)

**Phase-2**

Runtime = 534 days

Data = 308.0 +/- 17.5

Bgr = 153.8 +/- 10.3

Signal = 154.3 +/- 20.3

Half-life = \(2.63 +/- 0.35\ \text{e}^{19}\) years

\(\varepsilon = 6.8\%\)
Compare Angular Distribution and Min Energy Electron

**Phase-1**

Angular distribution reveals crossing electrons and Moller scattering from backgrounds.

**Phase-2**

Minimum energy electron reveals conversion electrons from backgrounds.
**Dependence on Energy Cut**

Half-life measurement should not depend on energy cut

<table>
<thead>
<tr>
<th>Energy Cut (MeV)</th>
<th>Phase-1 Half-Life</th>
<th>error</th>
<th>Phase-2 Half-Life</th>
<th>error</th>
<th>significance</th>
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<tbody>
<tr>
<td>0.4</td>
<td>1.85 x10e19 Yrs</td>
<td>0.20</td>
<td>2.63 x10e19 Yrs</td>
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<td>1.93</td>
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<td>0.8</td>
<td>2.02 x10e19</td>
<td>0.21</td>
<td>2.53 x10e19</td>
<td>0.27</td>
<td>1.49</td>
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<td>0.9</td>
<td>2.06 x10e19</td>
<td>0.21</td>
<td>2.44 x10e19</td>
<td>0.23</td>
<td>1.22</td>
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<tr>
<td>1.0</td>
<td>2.06 x10e19</td>
<td>0.20</td>
<td>2.58 x10e19</td>
<td>0.25</td>
<td>1.62</td>
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<tr>
<td>1.1</td>
<td>2.05 x10e19</td>
<td>0.20</td>
<td>2.71 x10e19</td>
<td>0.28</td>
<td>1.92</td>
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<td>1.2</td>
<td>1.94 x10e19</td>
<td>0.19</td>
<td>3.13 x10e19</td>
<td>0.36</td>
<td>2.92</td>
</tr>
<tr>
<td>1.5</td>
<td>2.17 x10e19</td>
<td>0.29</td>
<td>3.20 x10e19</td>
<td>0.46</td>
<td>1.89</td>
</tr>
</tbody>
</table>

Consistency check to show how well we understand our backgrounds

**Phase-2 has strong dependence on energy cut**

- < 2σ difference so this is statistical fluctuation
- missing low energy background, Pb211 and Tl207
- no measurement of the U235 chain with HPGe

Now having another 6 months of data, I need to re-run the analysis.

Fit the data above the energy threshold.
Future Plans:

- determine independent internal background model
- study the systematic errors of the analysis
- do analysis of the 2b0n channel
- finalize a 2b2n half-life result
- find limit for 2b0n half-life
- submit a report of my analysis to NEMO-3 collaboration to be published in joint paper.
Lightguide Studies for SuperNEMO Calorimeter
**SuperNEMO**

- continuation of NEMO-3
- 100 kg of source
- tracker + calorimeter
- modular (20 modules)
- better performance than NEMO-3
- 50-80 meV sensitivity
- energy resolution < 7% at 1 MeV where NEMO-3 has ~14%

**Lightguide Studies - Motivation**

- With small 5x5 cm scint. we get nice resolution
- 7-7.5% at 1 MeV even ~6.8% for high QE PMT
- Baseline SuperNEMO design calls for 20x20cm scintillator blocks
- The biggest PMT with flat window is 5”
- It is likely we will need a concave light guide to couple to the hemispherical PMT window
**Lightguide Problems**

- PMTs not ideally hemispherical
- Not repeatable
- Standard optical gel (BC-630) not ideal due to its high viscosity
- Preliminary results from DETECT2000 simulations show configuration with light guide should not worsen resolution as long as the **optical contact is good!**

**Suggested solution:**
Fluid: Cargille Laboratories fused silica matching fluid type 06350
Viscosity ~ water and an index of refraction = 1.48
Test Setup

- use conversion electron from Bi207 source
- do a run with the full Bi207 spectrum
- do a run filtering out conversion electrons
- subtract the filtered run from the full spectrum

Fit the K, L, M conversion electron peak with 3 Gaussians
BC-630 Optical Gel Results

9.7% dE/E at FWHM at 976 keV
Optical Fluid 06350 Results

Mylar $dE/E = 9.8\%$ at 976 keV

Teflon = 9.5\%
Polish the surface of the lightguide to reduce diffusive reflections. And see how strongly the resolution depends on this factor.

- Brian Anderson polished by hand for days and days....
Polished Lightguide with 06350

Mylar = 8.4%

Teflon = 8.0%

Looking better…
Future Plans:

• use LED and LASER to test transmittance of light guide as function of wavelength

• test new high QE PMs (~35-40%) from ETL and Hamamatsu

• do light simulations for PMT / lightguide coupling

• testing PMs and scintillator for SuperNEMO prototype

• “physics rich” SuperNEMO simulations