Investigating SNO+ sensitivity to Majoron-emitting neutrinoless double beta decay modes

Ashley Back for the SNO+ collaboration
IOP Particle, Astroparticle, and Nuclear physics group meeting
Tuesday, 31 March 2015
Overview

• Introduction to SNO+
• Theory - neutrinoless double beta decay and Majoron-emitting modes
• Developing the limit-setting software
• Verifying the technique
• Future work
• Conclusions
• Multi-purpose underground neutrino detector
• Located in SNOLAB
• Search for neutrinoless double beta decay (0ν2β) in $^{130}\text{Te}$
  + other physics goals
• Full water phase – late 2015, double beta phase – 2017

Other talks on SNO+
This session: E. Arushanova, L. Segui
Other sessions: S. Langrock, K. Majumdar, R. Stainforth,
J. Walker, J. Waterfield
Neutrinoless double beta decay

Light-majorana neutrino exchange

\[(A, Z) \rightarrow (A, Z + 2) + 2e^-\]

- Lepton number violation
- Can only occur if neutrinos are Majorana particles

Majoron-emitting modes

- Variety of models:
  - Number (1 or 2)
  - Goldstone boson(s)
  - Charged (Lepton number)
  - Massive
- Charged Majoron modes can conserve Lepton number
Majoron-emitting mode spectrum

- Spectra described by a few key parameters
  - Spectral index $n$
  - Q-value $Q$
  - Electron energies $\varepsilon_1$ and $\varepsilon_2$

\[
\frac{d\Gamma}{d\varepsilon_1 d\varepsilon_2} = C(Q - \varepsilon_1 - \varepsilon_2)^n[p_1\varepsilon_1 F(\varepsilon_1)][p_2\varepsilon_2 F(\varepsilon_2)]
\]

- Spectral index $\rightarrow$ shift in visible energy spectrum
  - Main parameter used to distinguish modes
- Plot: compares spectral shapes
  - All normalised to 10000 events
  - Except $0\nu2\beta$ $\rightarrow$ normalised to 33% of $2\nu2\beta$
KamLAND-Zen results

- KamLAND-Zen have already looked at Majoron-emitting modes
  - 125 kg $^{136}$Xe
  - Livetime: 112.3 days
- New limit-setting software – echidna
  - SNO+ UK lead project
  - Multiple applications
- Work in progress comparing KamLAND-Zen results

Limit setting technique

- $\chi^2$ grid search technique
  - Future optimisation
- Float any systematic, including background rates
  - Each systematic $\rightarrow$ axis in $\chi^2$-space
- At each grid position, calculate Poisson Likelihood $\chi^2$
  $$\chi^2_{\lambda,p} = 2 \sum_i y_i - n_i + n_i \ln \left( \frac{n_i}{y_i} \right)$$
- Add penalty term
  $$\left( \frac{s_i - s()}{\sigma_s} \right)^2$$
- Find minimum $\chi^2$ along each dimension
- Signal contribution corresponding to given confidence limit
Understanding the penalty term

- Testing using random gaussian mock data-set
  - Background → 100 counts → \( \sigma_{\text{stat}} = 10 \)
  - Signal → same gaussian
- Assume uncertainty in background rate of 20 counts
  - \( \sigma_{\text{syst}} = 20 \) (20%)
- Applied limit setting technique...
  - ...with \( 100 - \sigma_{\text{syst}} \leq b \leq 100 + \sigma_{\text{syst}} \)
- Expected total error:

\[
\sigma = \sqrt{(\sigma_{\text{stat}}^2 + \sigma_{\text{syst}}^2)} = 22.36
\]
Limit-setting verification

- Tested using recent production MC (two dominant backgrounds ONLY)
- Scenario based on these assumptions:
  - Energy resolution $\rightarrow$ 200 NHit/MeV
  - 3.5 m fiducial volume
  - 5 year livetime
  - KamLAND-Zen lifetime for $2\nu2\beta$
  - SNO levels for $^8$B solar neutrinos
  - $M = 4.03$, $G = 3.69 \times 10^{14} y^{-1}$ [1]
- $\sigma_{syst,2\nu2\beta} = 5.3\%$, $\sigma_{syst,8B} = 4\%$

Example 90% CLs ($0\nu2\beta$):

<table>
<thead>
<tr>
<th>Method</th>
<th>ROI signal counts</th>
<th>lifetime</th>
<th>$m_{\beta\beta}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>echidna technique</td>
<td>12.06</td>
<td>$1.342 \times 10^{26}$</td>
<td>56.98 meV</td>
</tr>
<tr>
<td>Poisson likelihood</td>
<td>12.12</td>
<td>$1.336 \times 10^{26}$</td>
<td>57.12 meV</td>
</tr>
<tr>
<td>(counting experiment)</td>
<td></td>
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</tbody>
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Future work

• Work ongoing to compare against standard SNO+ bounds and KamLAND-Zen results using echidna
  → Verify echidna for Majoron mode analyses
• Once complete → comprehensive study of SNO+ sensitivity to Majoron-emitting modes
Conclusions

- Majoron-emitting modes → alternative channel for probing neutrinoless double beta decay
- Introduced UK-lead SNO+ limit setting software – echidna
  – Being rigorously verified
  – Limit-setting technique → expected results
- Goal → comprehensive study of SNO+ sensitivity to Majoron-emitting modes
Backup
Spectral plot for verification scenario
SNO+ spectral plot