Water Phase Results and $0\nu\beta\beta$ Prospects of the SNO+ Experiment

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Tereza Kroupa (SNO+ Collaboration)
SNO+

Multipurpose neutrino detector in Sudbury, Canada

~9300 PMTs

Acrylic vessel 12 m diameter

2070 m of rock overburden

PMT support structure 18 m diameter

Hold up and hold down rope systems

7 kt ultra pure water shielding

Timeline

Water phase (905 t UPW): Finished
Pure scintillator phase (780 t scintillator): Filling ongoing
Tellurium phase (4 t of Te): Loading starts 2020

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SNO+ Physics

Low energy solar neutrinos

Reactor antineutrinos

Invisible nucleon decay + other exotic physics

Geoneutrinos

Neutrinoless double beta decay

Supernova

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Water results

Observed solar $^8$B neutrino flux with very low backgrounds

$$2.53^{+0.31}_{-0.28} \text{(stat.)}^{+0.13}_{-0.10} \text{(syst.)} \times 10^6 \text{ cm}^{-2} \text{ s}^{-1}$$

consistent with previous measurements

Phys. Rev. D 99, 012012

Invisible nucleon decay

Proton decay

$$^{16}\text{O} \rightarrow ^{15}\text{N}^* + inv$$

$$^{15}\text{N}^* \rightarrow ^{15}\text{N} + \gamma$$

Neutron decay

$$^{16}\text{O} \rightarrow ^{15}\text{O}^* + inv$$

$$^{15}\text{O}^* \rightarrow ^{15}\text{O} + \gamma$$

Measured lifetime limits

<table>
<thead>
<tr>
<th>Spectral analysis</th>
<th>Counting analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n$</td>
<td>$2.5 \times 10^{29}$ y</td>
</tr>
<tr>
<td>$p$</td>
<td>$3.6 \times 10^{29}$ y</td>
</tr>
<tr>
<td>$pp$</td>
<td>$4.7 \times 10^{28}$ y</td>
</tr>
<tr>
<td>$pn$</td>
<td>$2.6 \times 10^{28}$ y</td>
</tr>
<tr>
<td>$nn$</td>
<td>$1.3 \times 10^{28}$ y</td>
</tr>
</tbody>
</table>

Phys. Rev. D 99, 032008
Scintillator fill ongoing...
Tellurium loaded scintillator

Requirements: High light yield, radiopurity, long term stability, material compatibility, safety...

Linear alkylbenzene (LAB)

\[ + \]

2g/L 2,5-diphenyloxazole (PPO)

\[ + \]

Tellurium-butane diol (TeBD)

\[ + \]

N,N-dimethyldodecylamine (DDA, 0.5 molar DDA:Te)
Amine addition

**Advantages:**
- Helps stabilise TeBD in LAB
- Safe for underground handling
- Increases light yield by ~15%
- Improves resistance against water

DDA neutralises TeBD mixture and forms an ionic association with the complex to solubilise in LAB

Relative light yield comparison measured with $^{90}$Sr

Flake formation in samples without DDA upon extreme humidity exposure

No flake formation observed in any samples with DDA:Te > 0.25 molar

DDA offsets Te quenching to some extent

0.5 molar ratio chosen to optimise light output

2 yrs after humidity exposure
0νββ in Phase I

Tellurium 130

- High Q value (2.5 MeV)
- High natural abundance (34 %)
- Long 2νββ half-life (7.9x10^{20} yrs)
- Light yield of 460 PMT hits/MeV with loading technique

Counting analysis
9.47 counts/yr → T_{1/2} > 2.1x10^{26} yrs after 5 yrs with 0.5 % Te (Phase I)
Multi-site discrimination

0νββ events have more point-like energy deposition compared to background events involving γ-rays with more spread-out deposition.

Possible to break degeneracies of signal with backgrounds (cosmogenics, internal and external) using timing information.


Likelihood analysis development

~30 background normalisations floated in the fit
Currently a 2D fit in energy and R³
Planned extension to more dimensions using timing and topological background discrimination
Future prospects

Improve sensitivity by simply increasing loading 4% Te or higher possible with improved technique!

R&D ongoing...
Summary

SNO+ is online and published results from water data
Scintillator fill ongoing, will deploy a novel technique for tellurium loading
DDA improves properties of loaded scintillator mixture (light yield and water attack resistance) and can be used in synthesis to enable higher loading in the future
SNO+ will have world leading sensitivity to 0νββ in $^{130}\text{Te}$
Back up

$^{16}\text{N}$ deployed source energy and position calibration
U and Th contamination during water phase data taking period presented here

<table>
<thead>
<tr>
<th>Period</th>
<th>U (x10^-14 gU/gH2O)</th>
<th>Th (x10^-13 gTh/gH2O)</th>
<th>Water shielding U (x10^-14 gU/gH2O)</th>
<th>Th (x10^-13 gTh/gH2O)</th>
<th>Ropes Th gTh/grope</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19.0 ± 1.8</td>
<td>5.9 ± 5.2</td>
<td>2.2 ± 0.3</td>
<td>9.9 ± 1.6</td>
<td>5.5 ± 1.5</td>
</tr>
<tr>
<td>2 (z&gt;0)</td>
<td>48.5 ± 3.1</td>
<td>34.5 ± 13.7</td>
<td>86.9 ± 1.1</td>
<td>207.7 ± 6.4</td>
<td>33.0 ± 16.4</td>
</tr>
<tr>
<td>2 (z&lt;0)</td>
<td>3.6 ± 0.9</td>
<td>2.7 ± 2.7</td>
<td>16.3 ± 0.4</td>
<td>39.8 ± 2.8</td>
<td>7.7 ± 5.5</td>
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<tr>
<td>3</td>
<td>8.7 ± 0.7</td>
<td>8.3 ± 3.1</td>
<td>1.7 ± 0.1</td>
<td>9.3 ± 0.5</td>
<td>1.2 ± 0.9</td>
</tr>
<tr>
<td>4</td>
<td>19.4 ± 1.0</td>
<td>9.4 ± 4.1</td>
<td>0.6 ± 0.1</td>
<td>10.6 ± 0.6</td>
<td>0.3 ± 0.5</td>
</tr>
<tr>
<td>5</td>
<td>53.5 ± 3.7</td>
<td>29.0 ± 17.1</td>
<td>2.3 ± 0.2</td>
<td>8.6 ± 1.3</td>
<td>5.2 ± 0.9</td>
</tr>
<tr>
<td>6</td>
<td>67.5 ± 2.1</td>
<td>67.1 ± 10.0</td>
<td>1.2 ± 0.1</td>
<td>10.0 ± 0.7</td>
<td>1.7 ± 0.9</td>
</tr>
</tbody>
</table>

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Deexcitation spectra of $^{16}$O invisible nucleon decay

22 events in ROI (17.3 expected) consistent with no signal
Back up

Water association can cause phase separation in samples without DDA - Te effectively falling out of solution decreases quenching and hence LY increases over time.

Light yield remains stable over time with DDA.
Back up

**Time residuals** = $t_{\text{hit}} - t_{\text{ref}} - t_{\text{ch}}$

$\theta$ = angle between reconstructed position and hit PMT