Continuing Prospects of the SNO+ Calibration Program

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The SNO+ Experiment

- Detector situated in Vale Creighton Mine
  - 6 km water equivalent rock overburden
  - Contained in a cavity 30 m tall and 10 m in radius
- Composed of a 6 m radius spherical acrylic vessel
  - To be filled with a liquid scintillator
  - Now filled with 900 Ton ultra pure water.
- Surrounded by $\approx 9400$ PMTs mounted on a 8.4 m radius geodesic sphere.
- See talk by Aleksandra Bialek (Session M1-8)
SNO+ Calibration Strategy

- Validate response at energies for
  - $0\nu\beta\beta$
  - Low energy solar neutrinos
  - Reactor anti-neutrinos
  - Geo anti-neutrinos
- Optical and radioactive sources
- Internal and external deployments
- Optics to be evaluated
  - PMT response and timing
  - Rayleigh scattering
  - Absorption of materials
- Radioactive sources validate
  - PMT response
  - Energy reconstruction
  - Position reconstruction
  - Event tagging / efficiency
SNO+ Calibration Hardware

- Sources deployed via system of ropes
  - Central rope
  - Side ropes
  - Source steered in two dimensions
- Services carried via polyurethane (tygothane) "umbilical"

- Umbilical/central rope stored in URM
- Four rope boxes control side ropes
- URM and rope boxes connected to AV through Universal Interface (UI)

External Deployment

- Guide tubes pass outside AV
- Complementary source deployment
Optical Calibration

- Provides (nearly) isotropic light occupancy
- Provides strong measurement of PMT calibrations

- Diffuser coupled to optical fibre (Laserball)
- Light produced from N2 laser
- Laser dye system used for other wavelengths

PMT flat map for the central laserball run 102552, taken on June 2017 at 337nm. The colour scale represents the amount of hits in each PMT.

R. Bayes (LU)  SNO+ Calibrations  2019 CAPC 5 / 14
Embedded Laser Light Injection System

- PSUP embedded optical fibres
  - 106 laser injection sites
  - 96 dedicated to timing studies
  - 10 sites dedicated to scattering modules
- Calibrations conducted without deploying source
  - Plan to run as a constant PMT timing monitor
Leading Optical Results

Absorption Coefficient in Water

- Produced from internal and external laserball measurements
- Significant check for water phase reconstruction and simulation

Water measurements are a useful input to scintillator phase

Group Velocity

- Water measurements are a useful input to scintillator phase
Reconstruction Response

- Measured from $^{16}$N in water
  - $^{16}$N$\rightarrow^{16}$O$\beta\gamma$ (6.13 MeV)
- Compton scatters produces signal spectrum
- $\beta$ used to tag signal
- Signal spectra from data and MC to be compared

Energy Validation

Position Validation
Neutron Capture Measurements

**Event Selection**

- Completed using $^{241}$Am$^9$Be source
  - Produces a neutron and a 4.4 MeV $\gamma$
  - neutron capture produces a 2.2 MeV $\gamma$
- Significant for $\bar{\nu}$ detection
- Neutron detection efficiency $\approx 46\%$

**Capture Time**

- See poster by Jamie Grove: "AmBe Source Calibrations in Measuring Reactor Antineutrinos in SNO+ Water Phase"
Scintillator Requirements

Backgrounds in Water

- SNO+ requires contamination below $10^{-17}$ g U/g
  - Calibration hardware maintains purity requirements
  - Materials chosen for LAB compatibility

- Static N$_2$ volume prevents Rn ingress
  - Systems connected to detector must maintain cover gas

- Dedicated radon monitor tests cover gas purity
Hardware Upgrades

- Complete UI installed
  - Constructed for use with scintillator
  - Systems maintain cover gas through calibrations

- New URMs have been developed
  - First has been assembled and tested in Sudbury
  - Second is on its way from Portugal
Updated Calibration Sources

- Updated Laserball (Sussex) and AmBe (Snolab) sources in preparation
- Introducing tagged (UofA) and untagged (LIP) encapsulations to contain arbitrary sources
Available Energies

- Several radioactive isotopes under consideration
- First source to be deployed is $^{241}\text{Am}^{9}\text{Be}$

<table>
<thead>
<tr>
<th>Source</th>
<th>Method</th>
<th>Deposited Energy Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{48}\text{Sc}$</td>
<td>Beta Tagged</td>
<td>2 - 3.5 MeV</td>
</tr>
<tr>
<td>$^{137}\text{Cs}$</td>
<td>Unagged</td>
<td>0.1 - 0.68 MeV</td>
</tr>
<tr>
<td>$^{241}\text{Am}^{9}\text{Be}$</td>
<td>Time Coincidence</td>
<td>0.1 - 4.4 MeV</td>
</tr>
</tbody>
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- Energy range of deposited energy covers that of physics
- Will also deploy $^{16}\text{N}$ source external to AV
  - Expect to relate measurements to internal water deployments
Conclusion

- Calibration of SNO+ water phase is complete
  - Results have been used in published papers
  - Data is still being used to refine analysis for scintillator phase
- SNO+ is progressing towards scintillator phase
- Calibration systems are similarly being upgraded
  - Embedded injection system commissioned
  - Deployment systems and sources are in development
- Goal is to begin deployments soon after complete scintillator fill