Calibration Hardware for SNO+

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Abstract. The SNO+ experiment has a varied neutrino physics program that includes a neutrino-less double beta decay experiment in addition to reactor, solar, and geoneutrino measurements. SNO+ uses the architecture of SNO, using an acrylic vessel filled with scintillator as its neutrino target suspended in a water volume. At this time data is being collected with the acrylic vessel filled with water in preparation for the scintillator phase. An essential component to the successful execution of this physics program is a calibration of the optical and energetic response of the detector. Calibrations are underway using a laser-driven light source and radioactive gas sources, such as Nitrogen-16, that are to be lowered into the detector vessel on an umbilical. The position can be manipulated in 1-D using the umbilical retrieval mechanisms (URM) or in 2-D using ropes to guide the source off-axis. The sources and drive systems will be presented here with the goals of the calibration in the context of its impact on the SNO+ physics program.

1. Introduction

SNO+ is a multi-purpose neutrino experiment that uses the infrastructure developed by the Sudbury Neutrino Observatory and improves upon the range of sensitive energies available to SNO while increasing the background suppression. Its premier measurement is of neutrino-less double beta decay from a tellurium isotope suspended in liquid scintillator[1]. Other important measurements of reactor, solar, and geo-neutrinos are also accessible. Physics data have been collected in the water phase since May 2017. Liquid scintillator will be introduced to the detector volume in early 2018. In either detection mode, a comprehensive calibration program is required to understand the signals observed by the detector. The calibrations are loosely grouped into measurements of the detector's optical properties and energy response. This proceedings paper will begin by discussing the SNO+ detector, and continue by describing the deployment systems and the calibration sources that are used in the experiment.

2. The SNO+ Detector

SNO+ is located at Snolab in the Creighton Mine under 6 km water equivalent rock overburden. The detector consists of a spherical acrylic volume (AV), 6 m in radius, surrounded by a PMT support structure (PSUP), 8.4 m in radius, suspended in a cavern 30.5 m in depth. The PSUP is a geodesic structure that holds ≈9500 photomultiplier tubes providing 54% coverage of the detector volume. A three dimensional rendering of the SNO+ detector is shown in Fig.1a. The target volume of the experiment is contained within the AV so special procedures are assumed to maintain cleanliness, and therefore reduce the backgrounds, of the volume. At the time of this writing the AV is filled with ultra pure water and will be filled with liquid scintillator in the

(a) Rendering of SNO+   (b) Schematic of SNO+ detector in XZ plane with calibration mechanisms
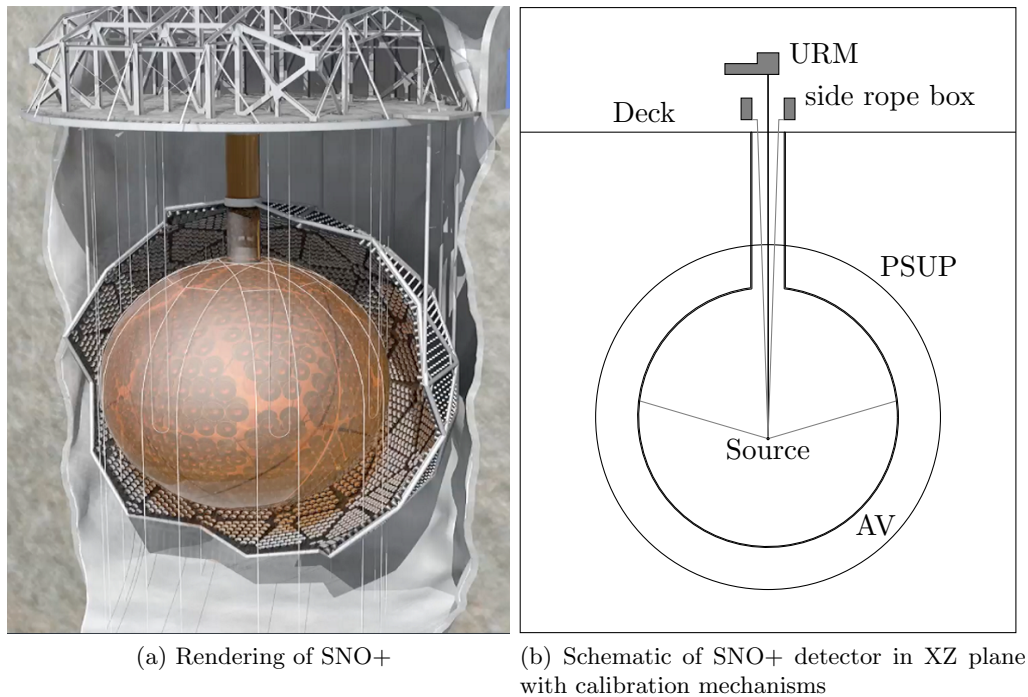
Figure 1: Representations of the SNO+ detector

winter of 2018. The detector is calibrated using sources that are external to the AV, embedded on the PSUP, and deployed inside the AV.

3. Source Deployment Systems

Calibration sources are deployed inside the AV suspended by a rope system deployed from the deck above the detector. Services to the calibration source are carried through an umbilical composed of polyurethane tubing which is wound onto an umbilical retrieval mechanism. A rope runs parallel to the umbilical, taking approximately half the weight of the suspended source during standard operation so that the combination of the two adjusts the vertical position of the source. When combined with two ropes attached to the sides of the detector, controlled by two independent side rope motor systems, positions throughout the plane defined by the three degrees of freedom are accessible. The side rope boxes and the URMs are mounted on the Universal Interface (UI) on top of the AV neck so that the calibration system moves with the AV. Fig. 1b shows the location of the elements of this deployment system.

4. Deployed Optical Sources

A deployed optical source acts as the primary method for calibrating PMT timing and optical properties. The source, called the laserball, consists of a spherical diffuser bulb attached to a stainless steel carriage. Pulsed laser light is injected into the diffuser by way of an optical fibre that runs from a dye laser through the umbilical to the optical source[2]. The laser pulse is fed into the detector trigger system. PMTs triggered in coincidence with the trigger pulse and can then be used to measure per channel and global PMT efficiencies, measure PMT time offsets, and validate position fits. The laserball has been successfully deployed several times in the current water phase. On one occasion lights in the PSUP were turned on to allow the source

(a) The deployed laserball source

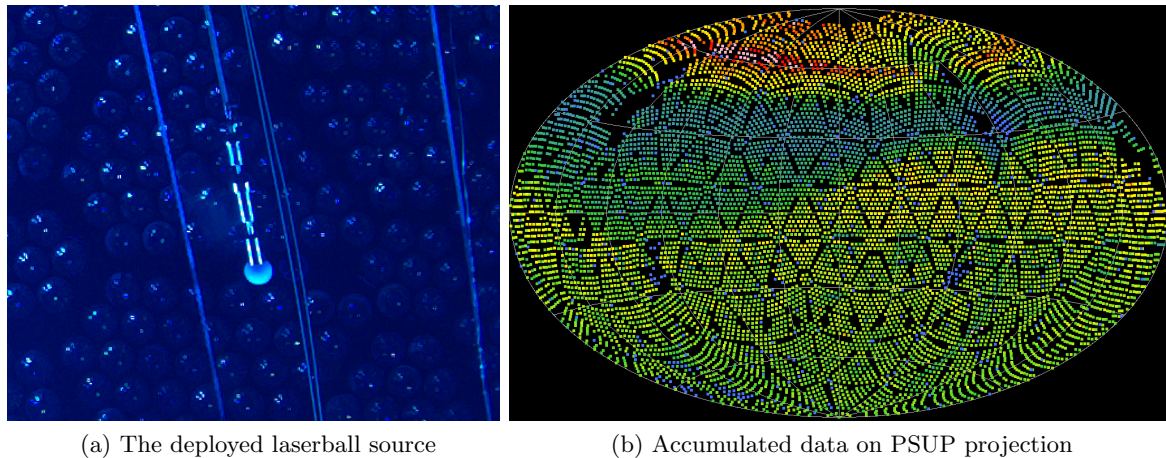(b) Accumulated data on PSUP projection

Figure 2: Images of the laserball source when deployed as viewed (a) with optical cameras on the PSUP, and (b) from the accumulated hits during data collection when the laserball is near the top of the AV.

to be viewed using PSUP mounted cameras, as shown in Fig. 2a. Otherwise, the position was determined from the analysis of the accumulated data represented in Fig. 2b.

This system is complemented by an array of 120 optical fibres strategically embedded around the PSUP, providing a number of external sources with which to measure timing and optical scattering properties without opening the acrylic vessel. In the scintillator phase of the experiment, a new laser ball with slightly different geometry will be provided.

5. Radioactive Sources

Measurements of the energy scale of the detector will be achieved through the use of known radiological sources deployed inside the detector. During SNO and now in the SNO+ water phase the primary source used for this purpose is the de-excitation of ^{16}O resulting from decays of ^{16}N. A DT generator is used to produce ^{16}N by bombarding CO_2 with neutrons. The gas is transported to the detector and injected into a suspended decay chamber via the umbilical[3]. The decay chamber is lined with scintillating plastic, encapsulated by a steel jacket so that electrons generated by the decay $^{16}N \rightarrow {}^{16}O^* + e^-$ produce scintillation light that is collected by a PMT, providing a signal which tags the decay event. In 72% of decays, the de-excitation of the $^{16}O^*$ produces a 6.1 MeV (66.2%) or 7.12 MeV (5%) gamma ray which Compton scatters in the detector volume. The energy of the electrons released by the Compton scattering process are reconstructed in water from the Cerenkov light. The remaining ^{16}N decays produce a ground state ^{16}O with no gamma ray emitted. The number of PMTs hit in the decay event can be compared to simulation to evaluate relative energy offsets and smearing as shown in Fig. 3.

Other tagged and untagged sources are planned for the future in both the water and scintillator phases. A source using ^8Li is under preparation for deployment to verify PMT efficiency as is an AmBe source to validate the neutron response. Further sources are being planned for the scintillator phase in a multi faceted approach to understand the detector behaviour and assess systematic uncertainties.

6. Outlook and Conclusions

The calibration program for SNO+ is well underway. Scans of the central axis of the detector were conducted in the spring of 2017 with further scans conducted in the fall of 2017. At the time
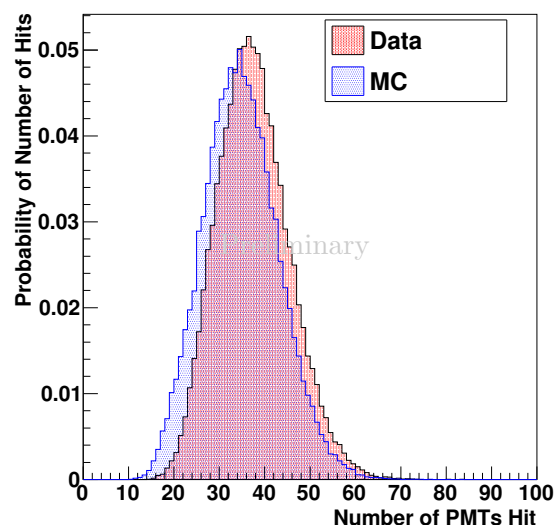
Figure 3: Number of PMTs hit in tagged events for simulation and data.

of this writing new deployment systems and sources are being assembled for the liquid scintillator phase of the experiment which is planned to begin in the winter of 2018. All of the deployment systems are constructed and run with an eye on maintaining a high degree of cleanliness to keep the backgrounds low. In SNO, water contamination was measured as 3.5×10^{-14} ^{238}U g/g and 3.5×10^{-15} ^{232}Th g/g. The requirements for SNO+ are that the contamination is an order of magnitude smaller. This is to be achieved using a completely sealed system with materials chosen specifically to ensure compatibility with the liquid scintillator. The development and deployment of these new systems will follow the progression of SNO+ from water to scintillator phase.

References
[1] Collaboration S 2014 *DOE Long Range Plan Town Hall*
[2] Moffat B *et al.* 2005 *Nucl. Instr. Meth. Phys. Res* **A554** 255–265
[3] Dragowsky M *et al.* 2002 *Nucl. Instr. Meth. Phys. Res* **A481** 284–296