Optical Calibration of SNO+.

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Abstract. SNO is being upgraded to SNO+, which has as its main goal the search for neutrinoless double-beta decay. The upgrade is defined by filling with a novel scintillator mixture containing \textsuperscript{130}Te. With a lower energy threshold than SNO, SNO+ will be sensitive to other exciting new physics. Here we are describing new optical calibration system that meets new, more stringent radiopurity requirements has been developed.

1. Introduction

SNO+ is using the infrastructure from the Sudbury Neutrino Observatory (SNO) \cite{1}. The upgrade to SNO+ is characterised by the change in target mass: from the heavy water of SNO to a novel scintillator mixture. Situated in the SNOLAB facility, 2092 m underground in Sudbury, Northern Ontario, the depth provides SNO+ with effective shielding from cosmic muons, receiving only 3 per hour \cite{2}. The detector consists of a 5 cm thick spherical acrylic vessel (AV) 12 m in diameter containing the target mass. The AV is mounted within a stainless steel geodesic sphere, 17.8 m in diameter. The geodesic sphere, known as the PMT support structure (PSUP), holds approximately 9500 PMTs. The PSUP and AV are suspended inside a 34 m deep cylindrical cavity, lined with Urylon as a Rn barrier. The cavity is filled with a little over 7000 tonnes of ultra pure water, providing further shielding to the inner detector from the intrinsic radioactivity of the PMTs and surrounding rocks.

Using liquid scintillator lowers the energy threshold to approximately 200 keV, making SNO+ a multifaceted experiment. SNO+’s main physics goal is addressing the question of whether neutrinos are Dirac or Majorana particles, through the search for neutrinoless double-beta decay of \textsuperscript{130}Te. SNO+ will also be studying reactor, geo, supernovae and solar neutrinos, the experiment will be sensitive to \textsuperscript{7}Be neutrinos during the initial commissioning phase.

The increased sensitivity to backgrounds, in particular the daughters of \textsuperscript{222}Rn, imposes tight constraints on the calibration system. A number of self contained radioactive sources will be used to calibrate absolute light yield, energy linearity, geometric uniformity and alpha-beta discrimination\cite{3}. Two complimentary systems, a deployed diffuse light source, the laserball, and the External LED/Laser Light Injection Entity (ELLIE) will be used to calibrate the
PMT timing and gain, scintillator properties and PMT response as function of event position. Source deployment must be kept to a minimum and eliminated if possible to meet radio purity requirements. This paper will provide an overview of the timing component of ELLIE, and the new laserball hardware.

2. Laserball
The laserball is a light diffusing sphere, consisting of a quartz flask filled with silicone gel, in which hollow glass spheres are suspended [4]. This diffuser is connected via optical fibres to a pulsed N₂-dye laser, which can be operated at a number of different wavelengths, allowing the scintillator to be monitored in high absorption/reemission and low absorption/scattering regimes. It was successfully used in the PMT calibration of SNO [5]. A radioactively pure laserball has been developed for SNO+, using a fully synthetic fused quartz flask which has less than 13 counts of ²²²Rn per day and a neck diameter 19 mm narrower than the SNO flask, reducing shadowing to the upper PSUP. The laserball will be deployed no more than twice a year.

3. TELLIE hardware
ELLIE uses electronics mounted on a deck above the cavity, to generate light which is injected into the detector via 47.75 m long optical fibres terminating at the nodes of the PSUP. ELLIE has three sub systems: one motoring the attenuation of the scintillator, another measuring the scintillator’s scattering length and the largest subsystem which provides continually calibration of PMT timing and gain (TELLIE).

Figure 1. A TELLIE event during the commissioning phase, the silhouette of a cleaning ladder with the AV is visible, the smaller spot is the reflection from the first surface of the AV.

TELLIE uses 92 PMMA fibres with large opening angles ensuring overlapping PMT coverage, Figure 1 shows the coverage of a single injection point. Enough redundancy is present to bootstrap the timing calibration using overlapping regions. The fibres are connected to 12 driver boxes, each containing 8 LED drivers and PIN-diodes monitoring LED output. The drivers use transistors to flip the voltage across the LED from a reverse bias into a forward bias and then back. Low resistance LEDs improve the time profile of the pulse [6]. TELLIE has an operating range of 10³ to 10⁶ photons per pulse with widths of 4.2 ns and 7.0 ns respectively, after the full length of fibre. Figure 2 shows the a pulse of 10³ photons, measured with a single photon counting technique.
Figure 2. A TELLIE pulse of $10^3$ photons before and after the 47.75 m PMMA fibre, measured using a single photon counting technique.

4. Conclusions
SNO has been upgraded to SNO+, a multipurpose neutrino detector with the primary goal of observing neutrinoless double-beta decay. Radiopurity concerns have led to the development of an external optical calibration system, which has been shown to work during air-fill, providing useful demonstration of DAQ and data flow readiness. For situations where deployment of an optical source is necessary, a much improved laserball is being developed.

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