Scattering length monitoring at the SNO+ detector

S. Langrock[1], J. Lidgard[2], E. Turner[2], L. Segui[2], A. Reichold[2], J. R. Wilson[1] on behalf of SNO+ collaboration

[1]Queen Mary University of London, UK, [2]University of Oxford, UK

E-mail: `s.langrock@qmul.ac.uk, jeffrey.lidgard@physics.ox.ac.uk`

Abstract.
SNO+ is a neutrinoless double beta decay and low energy neutrino detector located in Sudbury, Canada. To improve our understanding of the detector energy resolution and systematics, calibration systems have been developed to continuously monitor the optical processes in the detector, such as absorption, reemission and scattering. This poster provides an overview of the scattering calibration system: the Scattering Module of the Embedded LED/Laser Light Injection Entity (SMELLIE), designed to measure the Rayleigh scattering length *in situ*, over a wavelength range of 375nm – 700nm. The analysis procedure is presented for two detector scenarios: during water running and in scintillator.

1. Introduction

The primary goal for the SNO+ experiment is to search for neutrinoless double-beta decay ($0\nu\beta\beta$) in ^{130}Te, however, the detector will also be sensitive to: low energy solar neutrinos, geo-neutrinos, reactor neutrinos, supernova neutrinos and other exotic physics searches [1], making it a truly multi-purpose detector. The detector will use 780 tonnes of liquid linear alkyl-benzene (LAB) scintillator (doped with diphenyloxazole, PPO) in which the Tellurium will be dissolved [2]. The infrastructure of the SNO experiment [3] is used, the 12m diameter acrylic vessel holds the scintillator mixture, while the 9300+ 8-inch photomultiplier tubes detect the scintillation light. Some changes of the SNO infrastructure were required in order to use scintillator [4]. The low energy threshold of the scintillator, which enables the new physics goals also requires new, upgraded data acquisition electronics [5] and calibration systems [6][7]. This poster discusses one of these calibration systems, designed to measure scattering effects in the detector, named SMELLIE (Scattering Module of the Embedded LED/Laser Light Injection Entity). The calibration of scattering effects will aid event reconstruction and Monte Carlo models of the detector, as both depend on the optical properties of the scintillator. Initially, the detector will be temporarily filled with water (currently underway). The scattering processes in water are well known, so during this phase the measurements made by SMELLIE can be checked. Shortly after, the next phase will begin with the water being displaced by scintillator and SMELLIE will begin monitoring the scattering in scintillator, precisely.

2. Hardware

The SMELLIE system uses an arrangement of lasers coupled to fibres to deliver collimated light into the detector. The scattering at all wavelengths of interest (i.e. wavelengths measurable by the PMTs) is produced by: four lasers, with wavelengths of 375nm, 405nm, 450nm, 550nm, and a broadband 'supercontinuum' laser which has a wavelength range spanning 400nm – 700nm from which pulses can be produced with bandwidth of 10nm up to 100nm.

Laser light is delivered to the detector via 12 collimated optical fibres instrumented within the PMT Support Structure surrounding the acrylic vessel, at 4 different locations. At each of these locations, the fibres are angled at 3 different angles, thereby achieving beams covering much of the detector, with different path lengths through the detector media. This allows a detailed *in situ* measurement of both the angular and wavelength dependence of the Rayleigh scattering. The system has been optimised to produce light pulses with a short duration to enable the reconstruction of scattering events using timing techniques. Diagnostic hardware monitors the intensity and spectrum of the laser light for later use in analysis. A trigger system is used to initiate the detector acquisition systems based on the timing of the produced laser pulses. All hardware is remotely controllable via software.

3. Analysis Strategy

In order to maximise the performance of event reconstruction algorithms and keep systematic uncertainties low, the optical properties of the detection materials need to be determined. The first physics runs will be carried out in a water-filled detector. An analysis strategy was developed to measure the Rayleigh scattering length of a water-filled detector. For each SMELLIE fibre, a set of timing and spatial constraints were defined, separating direct beam photons and scattered photons from photons originating from other optical interactions within the detector, see figure 1. These cuts were verified using the Monte Carlo truth information on the history of the photon tracks and by varying the detector geometry to study the reflection effects of geometry aspects. The analysis procedure used to determine the scattering length given data is as follows. Firstly, the same set of cuts are applied to both the simulated data of various scattering lengths (control samples) and to the measured data. The scattering lengths in the simulation are altered using a scaling factor, which is applied to the nominal scattering length of water. The photons selected in the direct beam region and by the scattering region cut are scaled by the total number of photons detected over the entire run. These ratios are plotted against the scaling factor used for each simulation. Applying a linear fit to these distributions and comparing the ratios extracted from the data runs to these fits yields the equivalent Rayleigh scattering length of the data.

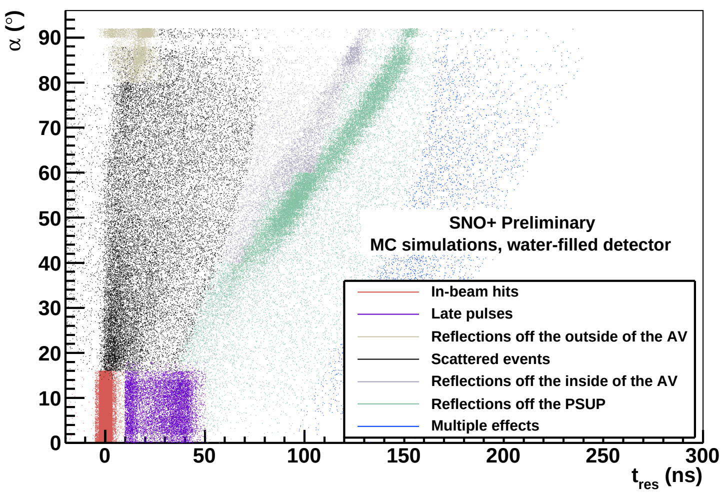

Figure 1. Timing and spacial profile of categorised PMT events, in simulation.

4. Adapting for Scintillator

The solar neutrino measurements, as well as $0\nu\beta\beta$ studies, are carried out with the acrylic vessel filled with the scintillator cocktail. In scintillator, photons can be isotropically re-emitted at lower energy after being absorbed: a process which can look similar to scattering. The scattering analysis strategy for a water-filled detector can be adapted for a scintillator phase by re-defining the timing and spatial cuts to accommodate for this additional process. This will allow for characterisation of the scattering process. Analyses are improving to include the angular distribution of scattering, which will allow further discrimination between scattered and re-emitted photons.

5. Water Quality Scans

SMELLIE could also be used to provide an *in situ* measurement of the quality of the detection medium as well as the scattering properties, by using the supercontinuum laser to detect wavelength dependent effects such as scattering or absorption of any possible contaminants in the medium. SMELLIE causes multiple beamspots in the detector, each associated with a different path length through the detector medium, making different beamspots more or less sensitive to any possible contaminants. This analysis would therefore be conducted by taking the ratio of hits in a beamspot with the number expected from simulation and dividing this by the same ratio for a different beamspot. This double ratio should account for the expected attenuation of the detector medium and, as a function of wavelength, should be sensitive to any wavelength dependent attenuation from a contaminant. This analysis was attempted during the water fill of the detector, using the beamspots caused by total internal reflection from the water surface and reflections from the nearside of the acrylic vessel. However, a number of wavelength and angular dependent effects specific to the partially air-filled detector makes this a particularly challenging analysis.

In this poster, the Scattering Module for the Embedded LED/Laser Light Injection Entity has been presented. This calibration system aims to measure and characterise the scattering properties of the detector media of the SNO+ detector. The hardware and analysis strategy for water-fill has been outlined, along with the method for extending the analysis to a scintillator-filled detector and measuring wavelength dependent effects from any possible contaminants in the detector medium.

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