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Scattering length monitoring with the Scattering Module at the SNO+ detector

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Abstract. SNO+ is a multipurpose detector built to investigate neutrinoless double-beta decay and neutrino oscillations. The Scattering Module is part of the SNO+ calibration program, and is designed to measure its scattering properties using laser pulses sent into the detector at different wavelengths. We describe the modules hardware and outline the general strategy for measuring the scattering length using a cut based analysis selecting direct in-beam photons and Rayleigh scattered photons. The cut verification process for a water-filled detector is presented. The efficiency of selecting scattered photons is found to be $> 60\,\%$ with a purity in excess of $95\,\%$.

1. Introduction

The SNO+ detector is located about 2 km underground in the Creighton Mine in Sudbury, ON, Canada. Due to its location, the experiment is overburdened by a 6000 m.w.e. layer of rock [1]. Thus, background contributions from the cosmic muon flux are significantly reduced to an average of 3 muons per hour. Being the successor experiment of SNO (Sudbury Neutrino Observatory), the main structures of the detector, which are described in detail in [2], are being reused. The Acrylic Vessel (AV) with a diameter of 12 m will be filled with 780 tonnes of scintillator (Linear Alkyl Benzene or LAB). To reduce the effect of background radiation emitted from the neighbouring rock, the AV will be surrounded by 7000 tonnes of ultra pure water. Scintillation events will be registered by more than 9000 Photomultiplier Tubes (PMT). For the neutrinoless double-beta decay program, the scintillator material will be loaded with ^{130}Te.

To achieve a detailed detector profile, a sophisticated calibration program is being developed. One of its main components is the Embedded LED Light Injection Entity system, which was designed for frequent optical calibration [3]. Its optical fibres are mounted on the PMT Support structure (PSUP), enabling the measurement of different optical properties by injecting light pulses to the inner detector region without contaminating the LAB inside the AV. The Entities main calibration tasks are performed by three subsystems and consist of: timing calibration of the PMTs (Timing Module), the measurement of the Rayleigh scattering lengths in the detector (Scattering Module) and the measurement of the attenuation lengths in the detector (Attenuation Module). This paper focuses on the description of the hardware of the Scattering Module and describes the analysis strategy that will be used to measure the scattering length.

2. The Hardware of the Scattering Module

The Scattering Module is centered around four milliwatt lasers. These lasers, operating at a peak wavelength of 375, 407, 446 and 495 nm with very narrow wavelength profiles, allow the investigation of the λ^{-4} dependence of Rayleigh scattering within the detector.

Controlled via the SEPIA II Laser Driver, the lasers are connected using a bespoke Laser Switching Unit which allows fast (< 30 s) and automated changing between lasers via computer control. Slight changes in the laser output between pulses can result in a large change in the light yield and timing of the scintillator. Thus, the Module is equipped with an internal monitoring system using a high-efficiency, high-speed PMT, which records on a pulse by pulse basis. A fraction of the laser light is fed into the PMT, the output of which gives a measure of the per-pulse power and stability of the laser. Measuring the laser power will also help determining the number of photons entering the detector, which is vital for calibrating the Module internally.

Using a 5x14 mechanical-relay optical Fibre Switch, the other fraction of the laser light can be directed from any one of the four lasers to enter the detector through any one of the twelve optical fibres, leaving 2 spare fibre ports on the switch. The twelve fibres of the Scattering Module are installed in four different mounting points in the PSUP. Each of the four points houses three fibres pointing in a different direction relative to the centre of the detector: 0°, 10° and 20° (0° being directly through the centre).

3. Analysis Strategy

Only a few PMTs will be illuminated directly by the beams from the Scattering Module. Hits in the remaining PMTs will originate from scattered, absorbed and re-emitted, and reflected photons. Using timing and spatial constraints, a cut selection is applied to all photons in the Module beams in order to classify different analysis regions according to optical deflections. Figure 1 shows the time residual of all selected analysis regions. The time residual t_{res} is the time at which the PMTs have been hit, corrected by the time of flight of the photons from the fibre to the hit PMT. Hence, the earliest registered hits are direct in-beam photons which have not been obstructed in the detector, resulting in a sharp peak around $t_{\text{res}} = 0$ ns. Very short time differences are observed between scattered and AV reflected light, resulting in close distributions. The observed peaks in the PSUP reflections are due to distinct PMT reflections at different angles [4].

For the measurement of the scattering properties in the detector, only the in-beam and scattered events are relevant. To determine the scattering length, the ratios of the events in these analysis regions with respect to the total number of events are calculated. These ratios will be compared between data samples taken with the Scattering Module and Monte Carlo samples simulated with different scattering lengths. Thus, the purity and efficiency of the cut selections

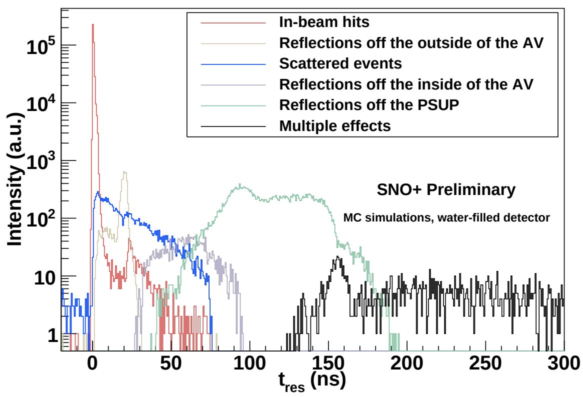

Figure 1. Time residual of events from the Scattering Module simulated with a 0° fibre and 495 nm in a water-filled detector. The time residual has been split into different analysis regions.

Table 1. Scattering cut purity and efficiency, and in-beam cut contamination with their statistic uncertainties for all wavelengths for a 0° and a 20° fibre.

	Scattering Cut Purity [%]	Scattering Cut Efficiency [%]	In-beam Cut Contamination with scattered events [%]
0° - 495 nm	96.8 ± 1.8	65.4 ± 0.7	0.6 ± 0.1
0° - 446 nm	98.2 ± 1.2	64.2 ± 0.5	0.9 ± 0.1
0° - 407 nm	98.9 ± 1.0	63.9 ± 0.4	1.3 ± 0.1
0° - 375 nm	99.2 ± 0.9	65.4 ± 0.7	1.8 ± 0.1
20° - 495 nm	96.4 ± 1.9	63.5 ± 0.7	0.5 ± 0.1
20° - 446 nm	97.8 ± 1.3	61.7 ± 0.5	0.7 ± 0.1
20° - 407 nm	98.6 ± 1.0	61.3 ± 0.4	1.0 ± 0.1
20° - 375 nm	99.0 ± 0.9	62.2 ± 0.3	1.4 ± 0.1

need to be ensured.

The tracking information for each photon from the Scattering Module was extracted from Monte Carlo samples simulating the SNO+ detector filled with H_2O. These tracks contain a history of the photons path in the detector, enabling us to know if the photon was Rayleigh scattered. The number of scattered photons in the scattering and in-beam cut was determined. To achieve the purity of the scattering cut and the contamination of the in-beam cut, these photons are compared to the total number of events selected by each cut. The efficiency of the scattering cut was calculated by comparing all scattered events to the number which has been selected by the scattering cut. Table 1 shows these values for both cuts for a selection of fibres and wavelengths.

A wavelength dependence of the Rayleigh scattering in the purity and contamination levels can be observed, resulting in higher amounts of scattering for smaller wavelengths. Over 95 % of all events selected by the scattering cut are Rayleigh scattered photons, whilst the contamination of in-beam light does not exceed 2 %. An efficiency of $(60 - 65)$ % can be achieved for the scattering cut. The efficiency values for the 20° fibre are marginally smaller due to its angled position in the detector making the applied spatial constraints less efficient.

4. Conclusion

The cut selection performs to a very high standard with very good efficiency and purity. Thus, the scattering length in the simulation can be tuned using these in-beam and scattered analysis regions to compare data events to Monte Carlo simulations.

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References

[1] Lozza V 2012 *J. Phys.: Conf. Series* **375** 042050
[2] SNO Collaboration 2000 *Nucl. Instrum. Methods* A **449** 172–207
[3] Lefeuvre G 2013 *Nucl. Instrum. Methods* A **718** 506–8
[4] Cameron J 2001 Ph.D. thesis Oxford University