Current status of the SNO+ detector: preparations for first physics data

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Abstract. SNO+ is a multi-purpose neutrino detector, which will primarily study neutrinoless double beta decay. Preparations are underway for the first phase of physics data-taking, with a water-filled detector. In terms of hardware, recent electronics repairs are described, as well as the programme which has shown to be ∼90% effective in repairing failed photomultiplier tubes. Testing of Data Quality has revealed some areas in the software that could be developed further and has provided useful cross-checks of trigger behaviour.

1. Introduction
The SNO+ detector [1] is located at SNOLAB, a Canadian laboratory two kilometres underground (6000 mwe), in Creighton mine, near Sudbury, ON. Its key physics goal is to probe neutrinoless double beta decay with the isotope $^{130}$Te. The varied physics program also hopes to build on the success of predecessor the Sudbury Neutrino Observatory (SNO) [2], in solar and supernova neutrinos, among others. To achieve these goals the detector has been upgraded, so that it can be filled with nearly one kilotonne of liquid scintillator; first scintillator data is expected in autumn 2015. Considerable upgrades are required to transform a D$_2$O detector, sensitive to Čerenkov light, into a liquid scintillator detector, with 50 times higher light yield. For example a hold-down rope-net has been installed [3] to combat the buoyancy of a scintillator-filled acrylic vessel (AV).

In these proceedings, Section 2 provides details on some of the more recent detector work. The cavity outside the AV is currently being filled with ultrapure water. In February and March 2014 commissioning detector running took place, with ∼100 photomultiplier tubes (PMTs) submerged. Section 3 focusses on recent developments in software, namely SNO+ Data Quality, which have used these commissioning runs for testing, in preparation for first physics data-taking.

2. Hardware preparations
The electronics that handle triggering and data acquisition (DAQ), were inherited from SNO, but have been upgraded, in places, to cope with the higher data rate expected for SNO+. Testing during two short periods of (air-filled) detector running, in February and October 2012, revealed over 200 (of about 9600) electronics channels not functioning as expected. In the majority of cases the problem was with the board that prepares the raw PMT signal before it enters the trigger electronics—the PMT Interface Card (PMTIC). Simple tests of the resistance and capacitance at strategic points on the PMTIC, usually identified a blown resistor or capacitor as...
the problem, which was then promptly replaced. The electronics repairs performed in autumn 2013, saw around 90% of these bad channels inspected and successfully repaired, as confirmed by the recent commissioning runs.

Like the AV and triggering/DAQ electronics, SNO+ has inherited its PMTs from SNO. SNO was designed to have close to 10,000 Hamamatsu R1408 PMTs (see [2] for a detailed schematic), but about 800 PMTs failed during its lifetime. Some were removed to accommodate the hold-up rope-net, yet SNO+ is still designed to have nearly 9600 PMTs. Since increasing the PMT coverage of the AV directly improves energy resolution, some of the failed ones are being repaired. So far about 300 PMTs have been repaired at Laurentian University (and previously at Queens University). The remaining failed PMTs will be accessed by boat during the water-fill, so a quick turnaround on removing, repairing and replacing them is required.

The remainder of this section aims to provide a brief overview of the PMT repair process. Work begins with some basic tests using the dark box set-up pictured in Figure 1(a), predominantly to confirm that the PMT actually needs to be repaired and to begin isolating the problem. The resistance and capacitance are measured and the potential across the PMT is gradually ramped up to its operating voltage; to check for breakdowns. In most cases signs of failure will be visible by this point, but if not the trigger rate at different thresholds is also tested. Repair work so far has found that in around 90% of cases the PMT works as expected after replacing the base.

![Figure 1.](a) – The full set-up used for dark box testing. (b) – The lower part of a PMT being cleaned in mineral solution. (c) – The hub being potted with the two-part SilGel mix.

In order to replace the base, the PMT must be disassembled and cleaned. It is dismantled by meticulously slicing through the heat shrink wrap, being careful not to damage the hub, which is re-used, or PMT. Once the heat shrink wrap is peeled off, the hub must be carefully prised away from the silicone gel—used to create a watertight seal and protect the base and pins. The base is de-soldered and discarded and the majority of the gel is removed, before soaking in mineral spirits (Figure 1(b)) to break down any remaining gel. Once cleaned thoroughly, a new base is soldered on and the dark box testing is repeated to verify that it is operating as normal.

In the final stage the original hub is affixed using a new heat shrink wrap and glue tape, which are both heated steadily and evenly for a good seal. The seal is further improved by applying a conformal coating to the inside of the hub and electronics. The potting process sees the hubs refilled with SilGel, a two-part silicon mix, using a nozzle that ensures the two components are correctly mixed (Figure 1(c)). The SilGel shrinks as it sets so the hubs are topped up before being capped. The PMT is ready to be installed back in the detector once the cap has been sealed in place.
3. Data Quality software
As well as hardware, the recent commissioning runs have seen equally significant developments in software areas. One such area concerns the quality control and selection of runs for physics analyses, which is critical for SNO+ to achieve its physics goals [1, 3]. Although, a varied and comprehensive set of online monitoring tools will be available, the offline SNO+ Data Quality software has the opportunity to consider entire runs, as well as the behaviour of the detector as a whole. The software was developed by first considering the run selection checks used in SNO [4], and forming groups of similar checks. Two of these groups—including the most recently developed group of timing checks, which examines the time interval between consecutive events ($\Delta t$)—were tested on recent commissioning data. The performance of all the checks was measured across 42 runs in the February stable running period. Whilst some checks performed as expected, others failed on almost all runs, highlighting that further development is required. These issues are being addressed and recent reprocessing of the data revealed a significant improvement in performance in one of the checks.

![Figure 2](image)

**Figure 2.** $\Delta t$ distribution from one particular run during the February 2014 stable running period. Note the large peak at $\sim 400$ ns.

SNO+ uses a 400 ns trigger window in which information is collected from every PMT that fired. The master trigger card has the functionality to initiate a new 400 ns trigger window, directly following the current window, with 30–50 ns down time separating the two. This is referred to as an automatic re-trigger. Figure 2 provides an example $\Delta t$ distribution, where a peak at around 400 ns is evident. Further analysis found it to be at 440 ns, which corresponds well with the signature of an automatic re-trigger. Detector operators confirmed that automatic re-triggers were enabled for every event, in a particular trigger channel, so this analysis has proved a valuable cross-check.

4. Conclusion
The PMT repair programme has already proved successful in repairing $\sim 90\%$ of failed PMTs, and will improve the energy resolution of the detector. Software frameworks, such as SNO+ Data Quality have effectively used the recent commissioning data as a platform for testing, whilst it has also been used to validate recent electronics repairs. These are important steps towards readiness for physics data taking and our first physics results.

References
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