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Nuclear Physics B Proceedings Supplement 00 (2014) 1–3

Nuclear Physics B Proceedings Supplement

The SNO+ Project

Laura Segui[1], for the SNO+ Collaboration

Denys Wilkinson Building, University of Oxford, Oxford OX1 3RH (United Kingdom)

Abstract

The SNO+ project will make use of the basic SNO detector infrastructure to create a large liquid scintillator experiment to explore a variety of fundamental physics, with a strong focus on neutrinoless double beta decay using ^{130}Te. Substantial modifications to the original SNO detector are being effected in order to achieve this. The initial water fill is currently under-way, with the transition to liquid scintillator scheduled for next year. Details of the detector preparation, commissioning and design goals will be presented.

Keywords: double-beta, SNO+, neutrino

1. Introduction

The SNO+ detector [1] is a multi-purpose large scale liquid scintillator detector based on the SNO experiment infrastructure. Located in the SNOLAB underground laboratory with an overburden of 2070 m (6000 m.w.e), SNO+ will contain approximately 780 tonnes of liquid scintillator inside an acrylic vessel (AV). An internal and external shielding of ultra-pure water (1700 tonnes and 5300 tonnes, respectively) will stop most of the external backgrounds. The AV is surrounded by about 9500 photomultipliers tubes (PMTs). The primary goal of SNO+ is the search for and detection of the neutrinoless double beta decay mode ($0\nu\beta\beta$) of ^{130}Te with Te-loaded liquid scintillator (TeLS). The detection of the $0\nu\beta\beta$ would provide fundamental information about the nature and mass of the neutrinos, explaining some of the open questions in particle physics. The first phase of the experiment will involve the loading of 0.3% natural tellurium (~790 kg of ^{130}Te) as a demonstrator of the technique, with the intention to extend to further loadings in order to cover the full inverted hierarchy region of neutrino masses. Additional physics goals in SNO+ include measurements of low energy solar neutrinos, supernova neutrinos, geo-neutrinos, reactor neutrinos and "invisible" modes of nucleon decay (during the initial phase of the experiment, with water inside the AV, taking place before the transition to scintillator).

SNO+ was originally conceived to deploy ^{150}Nd into the liquid scintillator, however in 2012 the option to use ^{130}Te was re-evaluated. A new metal loading technique was developed at BNL to obtain a clear and stable loaded scintillator: first Telluric acid is dissolved in water, in which it is highly soluble. A portion of this mixture is then combined with the base scintillator, LAB, using an amine-based surfactant. The re-evaluation of using Te conclusions showed a higher potential and emphasized several advantages as described in [2]. These include:

- The obtained TeLS has a longer attenuation length and does not present inherent optical absorption lines in the optical range.
- Tellurium has the highest natural abundance of $\beta\beta$ isotope (34% of ^{130}Te).
- It also has a relatively long $2\nu\beta\beta$ lifetime (measured by [3]).
- In addition, several strategies can be applied to

Email address: laura.segui@physics.ox.ac.uk (Laura Segui)

effectively mitigate the backgrounds.

2. Purification and backgrounds

Particularly relevant in a very-low rate experiment such as one measuring $0\nu\beta\beta$ is to control and understand all sources of background as well as to develop appropriate rejection techniques. As mentioned in the previous section, the experiment is underground and surrounded by ultra-pure water to reduce the external backgrounds. In addition, the scintillator will be purified with target levels: $6.8 \cdot 10^{-18}$ g/g in ^{232}Th (implies 1.2 c/day in ^{208}Tl and 1.8 c/day ^{208}Ac), $1.6 \cdot 10^{-17}$ g/g in ^{238}U (implies 13.4 c/day in ^{214}Bi and ^{222}Rn, which is two orders of magnitude more stringent than in SNO), 10^{-18} g/g in ^{40}K, 10^{-25} g/g in ^{85}Kr and 10^{-24} g/g in ^{39}Ar. The purification plant is described in [4]. Briefly, this involves:

- Multi-stage distillation: to remove heavy metals. An ancillary consequence is to improve the UV transparency of the scintillator.
- N_2/steam stripping to remove Rn, Kr, Ar and O_2.
- Water extraction to remove Ra, K and Bi.
- Micro-filtration to remove dust

While the detector is full with pure scintillator it can be recirculated at 150 LPM (whole volume in 4 days) to provide re-purification if required.

We have developed an strategy to purify the tellurium previous to loading it in the LAB to reduce its cosmogenic activation. A complete study of the possible backgrounds from cosmogenic isotopes created by such activation of the Tellurim has been carried out in [5], concluding that rejection factors of $\sim 10^4$ are required. This is the same reduction factor required for the raw material to reduce the content of the U/Th chains of $2-3 \cdot 10^{-11}$g/g (initially measured using ICP-MS) to the target levels (for the full cocktail (TeLS), we require $2.5 \cdot 10^{-15}$ g/g in ^{238}U and $3.0 \cdot 10^{-16}$ g/g for ^{232}Th). A 2-stage procedure has been defined [6]. The first step is done on surface. The method consists in dissolving $Te(OH)_6$ in water, further recrystallizing it with nitric acid and rinsing with ethanol. A reduction factor of $\sim 10^5$ was obtained after two passes. The second step will take place underground to reduce the possible reactivation of the tellurium while being transported underground. Due to safety constraints of the mine environment, a different method has been developed. It consists in the dissolution of the telluric acid in warm water followed by a cool down to recrystallize it thermally. With this technique an extra reduction factor of about 10^2 is obtained. Moreover, the Te will be stored underground before loading it in the scintillator to allow it to cool down.

The remaining internal U/Th backgrounds can be further reduced by tagging decays using the associated alpha particles. The analysis techniques developed using a complete MC simulation of the detector and the interaction of the particles indicates the following results (more details can be found in [7] in this same proceedings). A rejection of $\sim 100\%$ is expected for the Bi-Po events (a beta followed by and alpha decay after a short period of time) when following in separated trigger windows. For the pile-up of each isotope, a reduction factor of ~ 50 is obtained based on the time differences measured between the α's and β's in the scintillator. The total rejection factor for the ^{214}BiPo is >25000 in the region of interest (RoI) and for the ^{212}BiPo it is >70 in the RoI.

For the external backgrounds, besides the use of passive shielding, a fiducial cut will be applied as well as event selection based also on timing differences.

Finally, solar ^{8}B neutrinos and the $2\nu\beta\beta$ backgrounds can be mitigated by improving the energy resolution, either with better PMTs or with a higher light yield cocktail. The expected total number of events per year for the demonstrator is expected to be 18.6 corresponding to a sensitivity of $T^{0\nu}_{1/2} = 9.8 \cdot 10^{25}$ y at a 90% CL after 5 years of exposure.

3. Calibration systems

Different calibration systems will allow us to characterize and understand the detector response. The calibration of SNO+ will be done by a combination of radioactive and optical sources, trying to keep the deployment of any radioactive substance to a minimum to avoid any possible contamination. Several isotopes have been considered to cover a range of energies up to several MeV's. In addition, the possibility of using internal backgrounds is under study.

For the optical calibration system, different methods have been inherited from SNO and have been improved. This includes a Cerenkov source and a laserball. The first one is very useful to determine the PMT timing and to perform direction distribution studies. Also, the produced light level is well understand and can thus help to calibrate the optimal model of the detector. The laserball consists of a light diffusing sphere coupled to a N_2 laser. The wavelengths can be altered by inserting special dyes in the beam. It will allow us to calibrate the

PMT angular response and to measure the scintillator extinction length.

A complete new system has been installed for SNO+, the ELLIE system (Embedded LED/Laser Light Injection Entity). It injects light from the PMT support structure to the detector using optical fibres. ELLIE consists of three subsystems: TELLIE, SMELLIE and AMELLIE. TELLIE produces 510 nm LED light, which can be injected at 92 different positions around the PMT support structure. Its main task is to perform timing calibration of the PMTs. It will also permit us to perform gain calibrations and to study the optical transparency of the scintillator. SMELLIE will focus in the measurement of the scattering properties of the detector medium. It injects laser light at 4 different wavelengths (375, 405, 440, 500 nm). There are 4 injection positions in the PMTs where the light is directed at three different angles. The advantage of using laser light is they have narrow emission angles to perform accurate measurements as required to measure the scattering. Finally, AMELLIE will measure the stability of optical attenuation of light in the medium. It uses LED light of 400 and 520 nm. It will be injected in 4 different positions with two angles per position. Some runs in air have been done in February, March and August of this year. During these runs different systems were checked, such as the monitoring and slow controls, the data flow, the DAQ and the ELLIE systems. In Figure 1 we can see the hit map of the PMT array for a TELLIE run in air. The different colours indicate the number of hits detected by each PMT in the run. We can see the good performance of the PMTS and also identify the ones covered by water due to the higher production of light on this region.

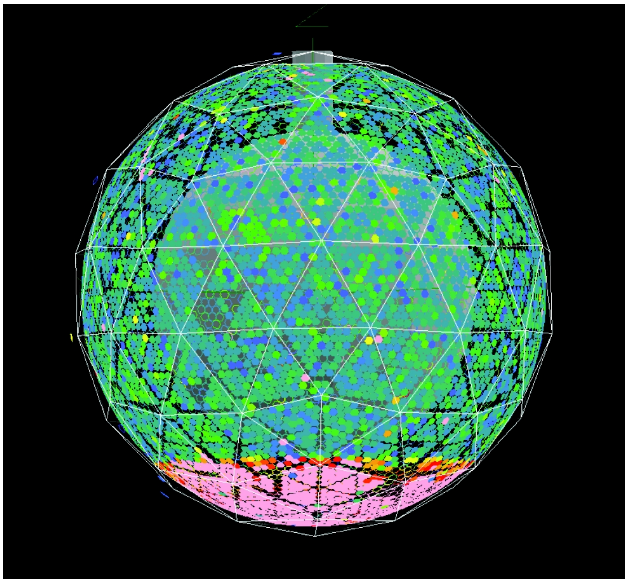

Figure 1: *Hit map of the PMT array of a TELLIE commissioning run in air. The colour scale indicates the occupancy of each PMT (represented as a circle). Some of the PMTs were already covered by water. We can identify them because, due to the higher production of light in water, they have a higher occupancy.*

4. Conclusions and SNO+ Future

SNO+ is a liquid scintillator detector with a main goal of detecting the $0\nu\beta\beta$ of ^{130}Te. It is now in its commissioning phase; some runs done in air have shown good performance of electronics and calibration systems. The first phase of the experiment, with water, is expected to start in spring 2015, and the transition to scintillator will take place in fall 2015. The introduction of the isotope will take place as soon as possible, likely at the beginning of 2016. The telluric acid production is now complete and the first delivery to SNOLAB is expected in fall 2014. In addition, a good understanding of the backgrounds and possible rejection techniques have been done with a complete framework of simulations, while results will be checked with real data, this should enable us to achieve a highly sensitive $0\nu\beta\beta$ experiment.

Furthermore, possible upgrades to increase the sensitivity are being considered. The currently planned Phase I is to load 0.3% of Te as a proof of the technique. In future phases, possible options are to go to higher loading to increase the light yield (loading has been proven now up to 5%) and/or to use a low background bag to improve the sensitivity further.

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