Studies of Low Energy Solar Neutrinos Using Slow-Fluor Liquid Scintillators

(paper in progress)

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The potential for using slow-fluor liquid scintillators to study low energy solar neutrinos has been explored through a series of simulations involving LAB and acenaphthene (see [1] and LoI for "Slow Fluors…") for various detector configurations. These studies suggest that a detector with ~50% coverage by standard HQE PMTs could be able to make a measurement of the CNO solar neutrino flux to a precision of 10% (enough to distinguish metallicity models) with a few kiloton-years of exposure, making use of directional Cherenkov information to distinguish the signal from other backgrounds, including ^{210}Bi. Acenaphthene seems to be a particularly good fluor for this due to its long fluorescence decay time (~45ns) and reduced absorption at lower wavelengths compared to PPO, which is favourable for Cherenkov light.

Simulations were performed using the SNO+ version of the GEANT4-based RAT software package. The model assumes a spherical liquid scintillator detector, with the target liquid scintillator housed in a spherical acrylic vessel (AV) with 8.8m radius and 5cm thickness. Photons produced in the scintillator propagate outwards towards 21873 inward-pointing photomultiplier tubes (PMTs). Each PMTs is modelled after the 8" Hamamatsu R5912 with an HQE photocathode, equipped with a reflective conical concentrator of diameter 28cm, thus providing an effective photocathode coverage of 77%. For the purposes of this study, as a further simplification to geometric corrections, events are only simulated in the central 1m of the detector, although fully reconstructed vertex positions are still used. Here we explore the impact of timing by considering both relatively slow vs fast PMTs (TTS=3.7ns and 1ns FWHM, respectively). By changing the PMT efficiency, lower effective HQE coverages as well as 77% are also examined. Another important consideration is whether or not to add a secondary shifter, such as bis-MSB. As shown in Fig 1, adding even a small amount would significantly increase light levels, improving both energy and position reconstruction, but at the cost of reducing direct Cherenkov light and increasing "contamination" of this from scintillation light. We therefore explore both zero and 1mg/L bis-MSB cases.

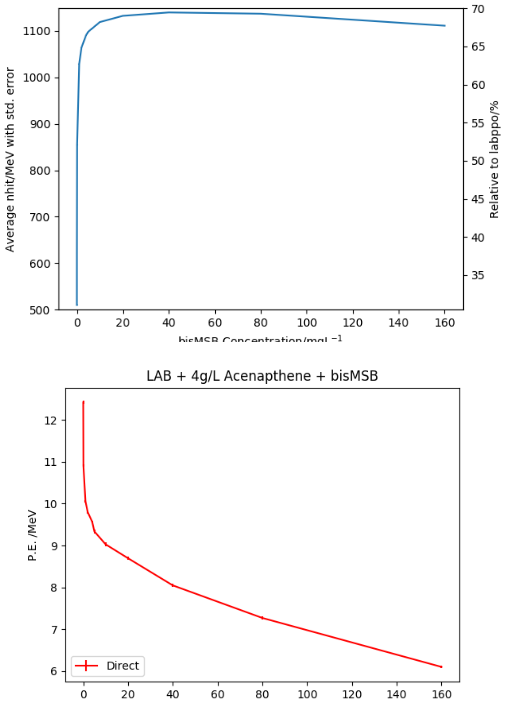

Fig 1: Impact of bis-MSB on light levels (top) and direct Cherenkov light (bottom).

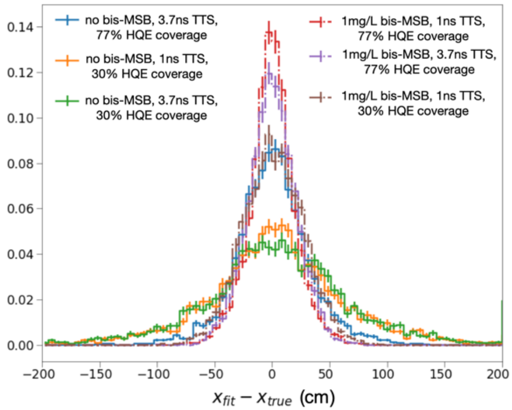

Fig 2: Vertex resolution for 1.25 MeV electrons under different scenarios.

We will concentrate on lower energies of most relevance for CNO neutrinos. Resulting vertex and directional reconstruction abilities are shown in the left and right figures, respectively, for 1.25 MeV electrons under different scenarios.

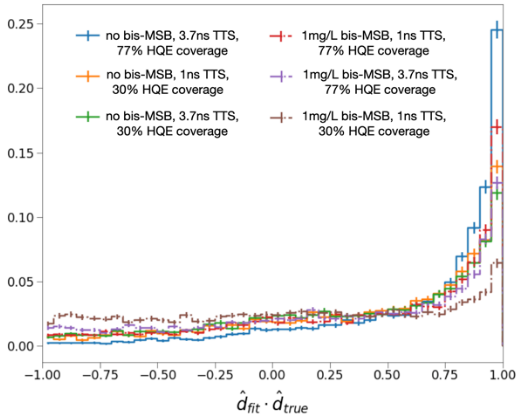

Fig 3: Cosine of the angle between true and reconstructed directions for 1.25 MeV electrons.

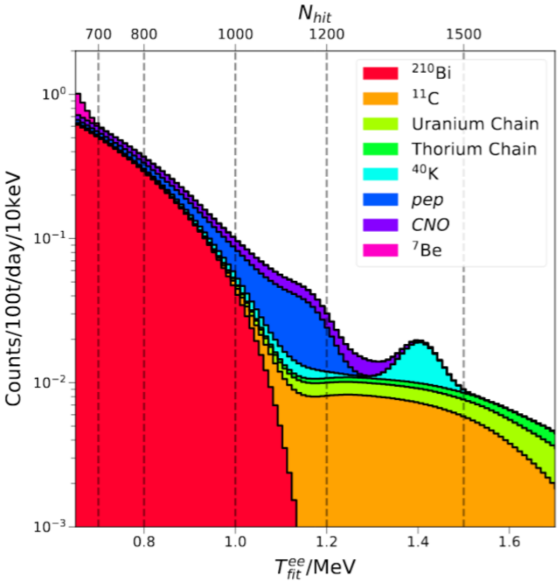

Fig 4: Background model used for CNO analysis [2].

For this application, the use of acenaphthene without bis-MSB seems to offer notable advantages, as the energy and position resolution are sufficient and backgrounds can be better suppressed by the improved directional information. The use of faster PMTs appear to offer relatively modest improvement under this scenario, suggesting that currently available PMTs are more than sufficient. To explore the detection of CNO neutrinos more specifically, the background model shown on the left is used, based on Borexino Phase I levels [2]. The pep flux is taken as 1.44x10^8 cm^{-2} s^{-1} [3]. All other normalisations, including ^{210}Bi, were treated as free parameters in a likelihood fit.

Examples of sensitivity curves, showing the expected measurement precision in the CNO flux as a function of exposure, are given in figures 5 and 6 below. Approximately equivalent ways of obtaining such sensitivities are indicated on the figures. The exposure at which a 10% constraint is obtained at 1σ is also shown.

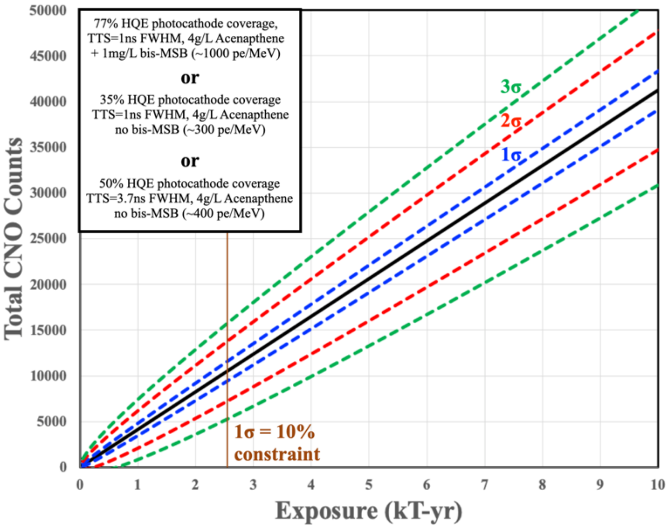

Fig 5: Expected measurement precision in the CNO flux as a function of exposure for indicated scenarios.

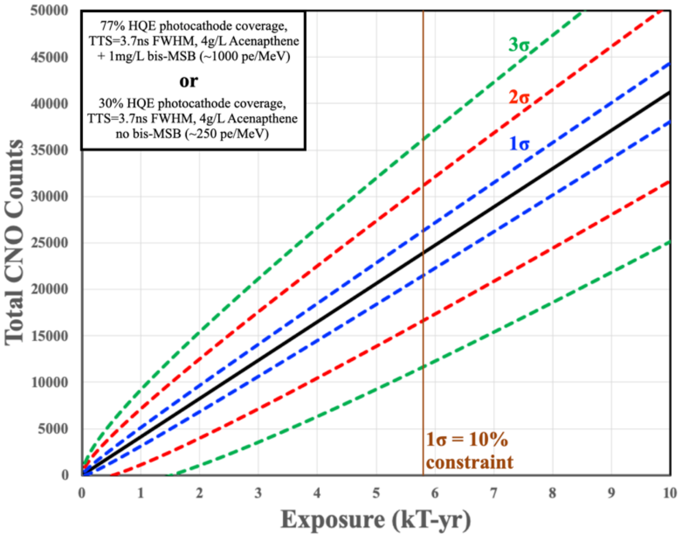

Fig 6: Expected measurement precision in the CNO flux as a function of exposure for indicated scenarios.

Liquid scintillators using slow fluors, such as acenaphthene, therefore provide a means to improve the precision of low energy solar neutrino measurements through the use of directional Cherenkov information. This can be done using currently available phototube technology with detector volumes and photocathode coverage comparable to existing instruments. Indeed, both SNO+ and KamLAND detectors are good targets for this approach if they can achieve backgrounds levels in the vicinity of those obtained by Borexino, potentially with the use of inner containment bags. It is also an approach that is useful to consider for future ~kT-scale detectors, such as Jinping or WATCHMAN, to improved sensitivity to low energy solar neutrinos and other physics.

[1] Biller, Leming and Paton, NIM A 972, 2020
[2] Bellini *et al.*, Phys. Rev. D 89, 2014
[3] Bergstrom *et al.*, JHEP 03, 2016