University of Texas at Austin Technical Progress Report, SNO Group

1 Overview

Over the past year, our group here at the University of Texas has continued to focus primarily on analysis of data from the Sudbury Neutrino Observatory (SNO), in particular on a push to lower the energy threshold used in solar neutrino analyses and on a search for short time-scale astrophysical phenomena in the neutrino data set. We have in addition begun R&D and simulation work on a new direct search for dark matter as part of the DEAP/CLEAN collaboration, as well as an effort associated with work on a new experiment using the existing SNO detector (SNO+). Lastly, we have also been doing some very early studies of an experiment to measure the neutrino mass using the beta decay of cold tritium atoms.

2 Work on SNO

Our work on SNO has focused primarily on making a low-threshold spectral measurement of the flux of ^{8}B solar neutrinos. The work forms the bulk of graduate student Stan Seibert's PhD thesis. Nearly all systematic uncertainties associated with the analysis have now been measured, in particular the dominant uncertainties such as energy scale and resolution, and the uncertainty on SNO's 'isotropy' parameter used to distinguish electrons, neutrons, and radioactive backgrounds. It is now clear that we will be able to fit the ^{8}B energy spectrum to a threshold of 4 MeV or below, with uncertainties in the 4 MeV bin somewhere between 15-20%. This will be the lowest threshold measurement ever made using the water Cherenkov technique, and will provide a test of the MSW-predicted distortion of the ^{8}B energy spectrum. As an additional benefit of the low threshold analysis, we expect to get total uncertainties on the NC flux in the neighborhood of 4%, nearly a factor of 2 better than any of SNO's previous measurements of the total ^{8}B flux.

To work at such a low energy threshold, we have had to fit for over 17 different signals and backgrounds, in multiple dimensions, and allow several systematic parameters to 'float' in the fit. To be able to test for biases, and develop the code, the fit needs to be fast despite the large number of free parameters and the complexity of the likelihood space. Seibert has solved this problem by coding his fit to run on a high-end graphics card (a 'GPU') which provides us with roughly 128 processors all running in parallel. We do not know of any other such application of a GPU in the nuclear or particle physics community, although it is likely others have been looking into this approach as analyses become more complex and slower.

The low energy threshold analysis (LETA) is now under review by the SNO Collaboration. Figure 1 shows Seibert's fit of the charged current energy spectrum down to an effective electron kinetic energy $T_{\rm eff} = 3.5$ MeV, for 1/3 of SNO's full data set (the other 2/3 remaining effetively blind at this point). Figure 2 shows an entirely new way of presenting the data: a direct fit to the ν_e survival probability, parameterizing the survival probability as a second-order polynomial. Such

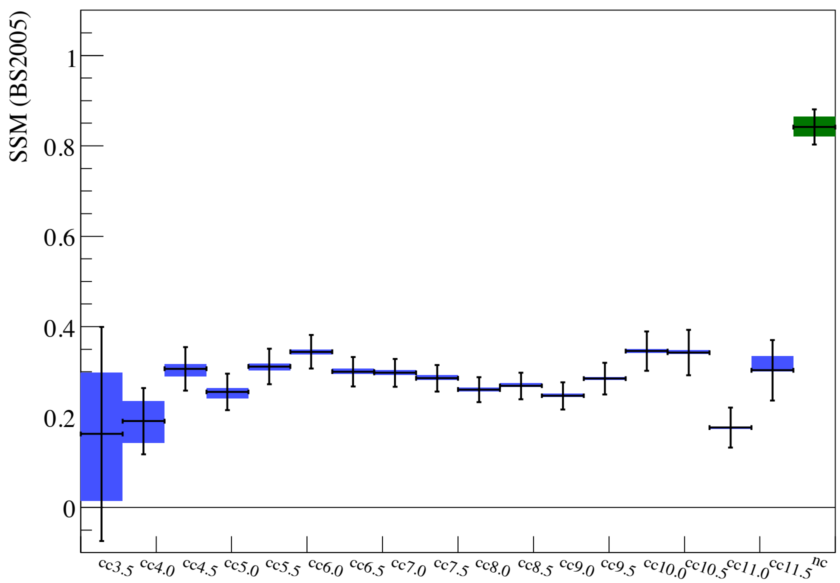

Figure 1: The SNO charged-current spectrum down to an effective electron kinetic energy threshold of $T_{\rm eff} = 3.5MeV$, the lowest threshold ever used in a water Cherenkov detector. What is shown is the ratio of the measured SNO CC spectrum to the Monte Carlo prediction for an undistorted spectrum, for a combination of 1/3 of the data sets from SNO Phase I and SNO Phase II. The rightmost point is the measured NC flux

a fit has never been done before for any solar neutrino experiment, but it makes the possibility of testing various new physics hypotheses a simple matter of comparing a prediction to the parameters in the fit. Seibert has now graduated, completing his PhD thesis in July, and has gone on to Los Alamos National Laboratory on a Director's Fellowship.

In addition to the low threshold analysis, graduate student Aubra Anthony has been working on a high-frequency (periods of minutes to hours) periodicity analysis of SNO data from the first two phases of the experiment. Such high-frequency variations could be the result of g-mode oscillations in the Sun's core, to which optical measurements are not very sensitive. SNO is unique in being able to make this search, because of our low backgrounds. Figure 3 shows the results of her periodicity analysis, both the power spectrum of the data (black) and the 90% confidence-level detection threshold used in the analysis, for periods ranging from 1/day to 1/10 minutes. No evidence of significant high frequency variations were found. Ms. Anthony has also done a directed search looking for frequencies claimed to have been seen in the GOLF satellite data, and the results of this search are shown in Figure 4. The sensitivity to a high-frequency oscillation in the 'open' search is

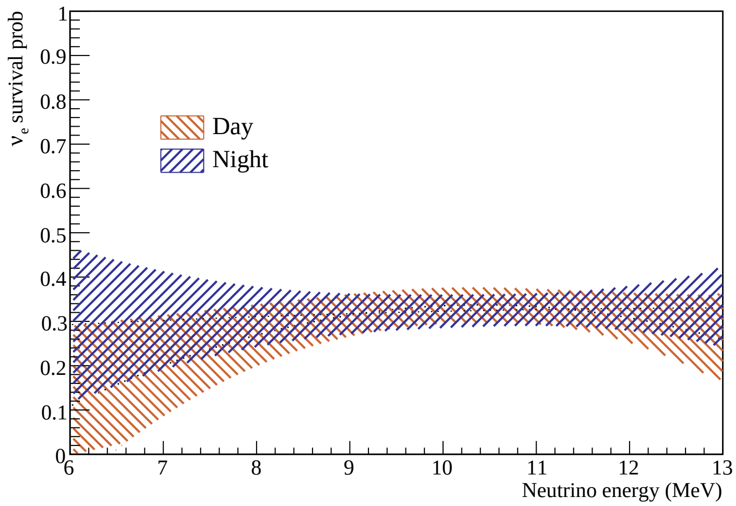

Figure 2: The ν_e survival probility, extracted from the SNO Phase I and Phase II data sets, with an effective electron kinetic energy threshold of 3.5 MeV. This is the first direct measurement of a survival probability with solar neutrinos.

roughly to a 12% amplitude signal, while in the directed search it is roughly a 10% signal. These results are now under review by the SNO Collaboration, and a paper is being prepared.

Ms. Anthony is now turning to a search for bursts in the data set (perhaps the result of optically un-observed supernovae). She has found that she can search for bursts with multiplicities as low as two events, again because of the low rate of backgrounds in the detector.

3 SNO+ and DEAP/CLEAN

Our work on both DEAP/CLEAN and SNO+ has focused on simulation. The DEAP/CLEAN experiment is a single-phase liquid argon detector, which is intended to detect WIMPs through the scintillation light produced by nuclear recoils. The DEAP/CLEAN collaboration has now adopted a simulation and analysis package written by Seibert (called 'RAT') and development is proceeding quickly throughout the collaboration. The simulation includes not just the usual GEANT4 particle propagation, but details of the optics, PMTs, and data acquisition system. The SNO+ collaboration is also looking carefully at the RAT code as the basis of its simulation, to replace the long-standing but FORTRAN-based SNOMAN code used by the SNO collaboration. We have also worked on measurements of some of the optical and PMT-related parameters for DEAP/CLEAN, through the efforts of an undergraduate students, Julia Majors and Anthony Latorre.

4 Neutrino Measurements using Cold Atoms

We have recently begun work with Mark Raizen's group here at Texas on a new idea for a tritium β-decay experiment aimed at measuring the neutrino mass. Although oscillations have shown us

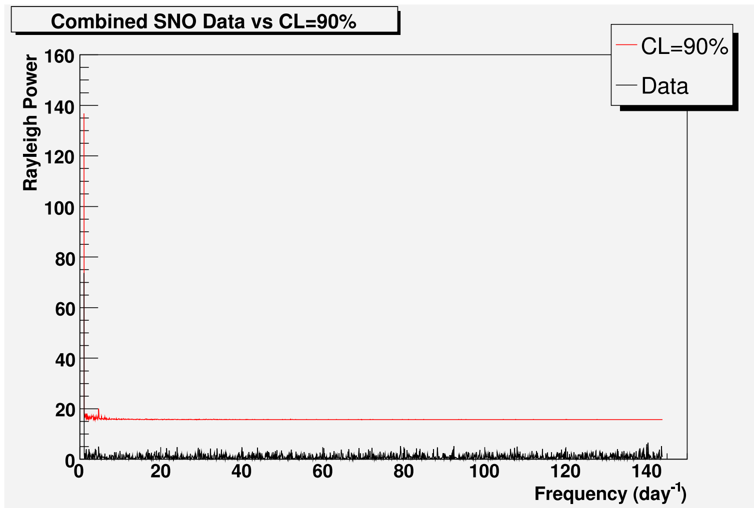

Figure 3: High-frequency Rayleigh Power spectrum for combined SNO salt and D_2O phase data sets, with the 90% CL detection threshold indicated, for periods ranging from 1/day to 1/10 minutes.

that neutrinos are massive and are mixed, what they do not tell us is what the mass scale is—only the mass differences.

The only practical direct way of determining the neutrino mass to date has been by looking at the endpoint energies of electrons released in β-decay. The maximum energy the electrons can have will be limited by the energy removed from the decay by the neutrino mass. The best limit to date, from both the MAINZ and Troitsk experiments, is around $m_\nu < 2.2$ eV. There is now a much larger version of these types of experiments being built, the KATRIN experiment, which aims to do an order of magnitude lower.

These experiments are inherently difficult, and in particular they have been limited by energy losses in the tritium target, backgrounds from ions entering the spectrometer, from the very poor statistics near the endpoint, and from knowledge of the final state energies of the final diatomic state.

Mark Raizen's group here at Texas has developed a paramagnetic method of slowing atoms of almost any atomic weight, and they have thus suggested that slowing tritium atoms could provide a very clean way of doing a tritium beta decay measurement. The advantages of using cold atoms are that the source would be extremely thin (roughly 10^{11} atoms in total) and so both the electron and the beta decay ion can be detected and measured, thus allowing the neutrino mass to be kinematically reconstructed. The source would also be monatomic, removing final state uncertainties. Backgrounds would be eliminated by requiring a coincidence between the electron and the ion.

We have created a simple simulation of this experiment, which is being worked on by graduate student Melissa Jerkins. The simulation is allowing us to study both a three-body decay scheme, in

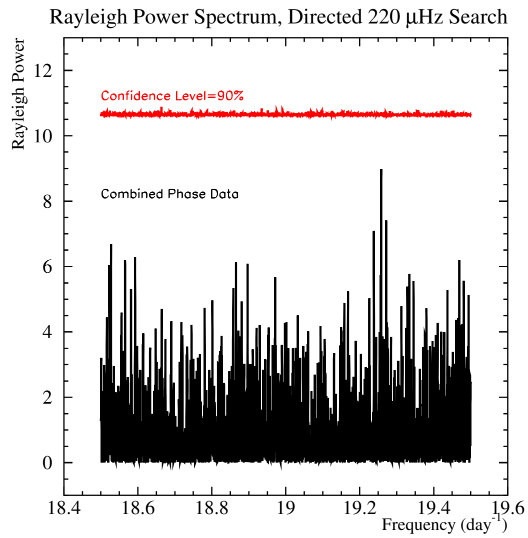

Figure 4: High-frequency Rayleigh Power spectrum for combined SNO salt and D_2O phase data sets, with the 90% CL detection threshold indicated, for a directed search in the region where *g*-mode oscillations have been claimed in the GOLF satellite data.

which the neutrino mass is directly reconstructed, as well as the tritium decay to the bound state of ^{3}He, which has the advantage of a simpler reconstruction scenario but ultimately less precision. We hope to have a publication out in the near future describing this approach, and work is beginning in the Raizen group to cool deuterium as a test case for tritium.

As an additional related effort, we are looking at the possibility of searching for the neutrino Mossbauer effect, which would make use of the cold atom approach by being able to count tiny numbers of tritium atoms created in a block of solid ^{3}He when neutrinos are resonantly captured by the helium.

5 Future of the Texas Group

Klein is leaving Texas this summer for a position at the University of Pennsylvania, and thus this is the last technical progress report for the Texas group. Graduate student Aubra Anthony will be completing her thesis very soon, and will remain at Texas for that short time before beginning her post-doctoral work. Melissa Jerkins will remain at Texas as part of the Raizen group.