Atmospheric neutrinos in SNO

C.A. Currat, Y.D. Chan, K.T. Lesko, A.D. Marino, E.B. Norman, A.W. Poon, and R.G. Stokstad for the SNO Collaboration

High energy muons and neutrinos are produced constantly by the interaction of primary cosmic rays in the Earth's upper atmosphere. These primary interactions produce mesons which decay into muons and neutrinos in a typical sequence:

$$\begin{aligned} p + {}^{14}N &\rightarrow \pi^+(K^+) + X \\ &\hookrightarrow \pi^+(K^+, D^+) \rightarrow \mu^+ \nu_\mu \\ &\hookrightarrow \mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu \end{aligned}$$

At the depth of over 6 km water equivalent, SNO is the deepest underground laboratory currently in operation.

The only particles that can penetrate down to the SNO detector are neutrinos and muons. The atmospheric neutrinos can interact with the rock and in turn produce muons that can be detected by SNO. The rate of detection of such events is tiny compared with the downward muon rate but SNO's angular resolution is sufficient to make a clean separation up to an angle $\cos\theta < 0.4$ above the horizon. This feature puts SNO in a unique position amongst world experiments located underground but at shallower depths.

SNO can make a number of important measurements in the muon sector:

- the detector is sensitive to the downward muon rate coming from primary cosmic ray interactions.
- SNO's depth allows for an unprecedented measurement of atmospheric neutrinos (via the detection of neutrino induced muons) at inclinations as large as $\cos(\theta_{\mathrm{Zenith}}) \simeq 0.4$.

SNO's unique niche allows it to make important model independent checks of atmospheric neutrino oscillations. Assuming $\nu_\mu \rightarrow \nu_\tau$ oscillation parameters $(\Delta m^2, \sin^2 2\theta) = (2.5 \times 10^{-3}, 1)$ which existing atmospheric neutrino data point to [1], the geometry of the Earth makes it that such neutrinos coming from above the horizon do not oscillate whereas the lower energy half of those coming below the horizon do ($E \lesssim 100$ GeV). SNO's contribution is to detect both oscillated and unoscillated neutrino-induced through going muons at the same time. Those coming from abve the horizontal are unhampered by oscillation effects and provide a good test of flux models. These muons thus set a model-independent normalization for the analysis of a possible oscillation signal of events from below the horizon as illustrated on Figure 1.

Previous work by Tagg [2] investigated the SNO capability of making a measurement of θ_{23} based on 149 live days that showed encouraging results. To date about 700 days of data is available. The projected sensitivity [3] to the atmospheric neutrino parameters in SNO is shown in Figure 2. This extraction is strictly statistical and does not take into account instrumental effects.

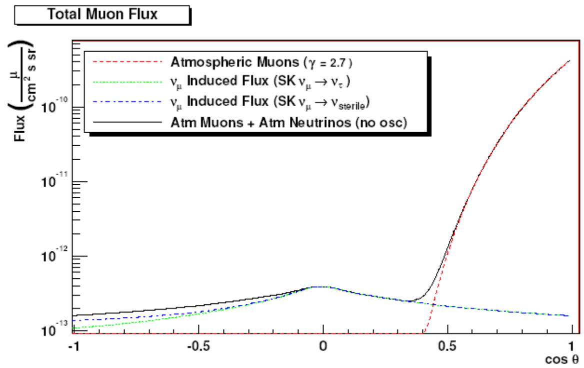

FIG. 1: Simulated zenith dependence of the flux for both down-going cosmic muons and neutrino induced muons as expected at SNO. The effect that various oscillation scenarios would have on the flux is also displayed.

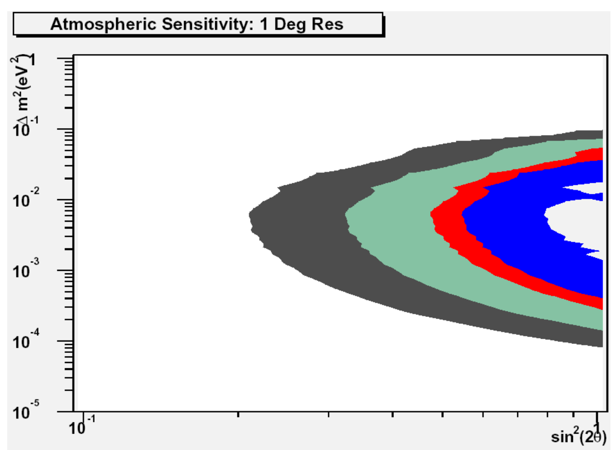

FIG. 2: *Preliminary* projected sensitivity contours for a $\nu_\mu \rightarrow \nu_\tau$ oscillation at SNO with $(\Delta m^2, \sin^2 2\theta) = (2.5 \times 10^{-3}, 1)$ with 700 live days of data. The curves represent confidence levels of 68%,90%,95%,99% and 99.73%.The curves assume a 3 degree smearing of the reconstructed direction of the muon track. No systematics effects are taken into account.

Even though SNO does not compete with other experiments featuring a much larger fiducial volume, our potential to perform a measurement in the atmospheric neutrino sector is particularly attractive in that it can be performed for the first time in a virtually model-independent way.

[1] Y. F. *et al.*, Phys. Rev. Lett. **82**, 2644 (2002).
[2] N. Tagg, Thesis, University of Guelph (2001).
[3] J. Formaggio, SNO internal note 4/16, UW (2004).