Identification of Muons and Spallation Events in the Sudbury Neutrino Observatory

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SNO detects a small flux of high energy muons produced by cosmic ray interactions in the atmosphere. When cosmic rays interact with the Earth's upper atmosphere, they produce large quantities of pions and kaons. It is the decay of these pions and kaons into muons that is the main contributor to the muon signal at SNO. On average, the measured muon rate at SNO is ~ 24000 muons per year, which is low in comparison to other existing neutrino experiments. The following is the predominant mechanism for producing high energy muons.

$$p +^{14} N \rightarrow \pi(K) + X \tag{1}$$

$$\pi(K) \rightarrow \mu\nu_\mu \tag{2}$$

When a muon reaches SNO it can interact with nuclei through inelastic scattering (spallation) or photoexcitation, producing neutrons and various other radioactive nuclei. Because SNO primarily detects neutrinos through NC, CC and ES reactions, muon induced neutrons, beta and gammas are a source of background. These can be reduced with algorithms that identify muons and remove associated spallation events. A study of muons and the events following muons has been performed [1]. The efficiency of the muon identification was verified with extensive inspection. The muon and spallation event algorithms were applied to pure D_2O data, as well as data produced after the addition of NaCl to the detector and compared.

Figure 1 presents a time distribution of events that followed muons. A peak is seen at times earlier than 0.2 seconds. After a comprehensive analysis we determined that 18077 events were candidate muons, from the pure D_2O data. These muons were associated with a total of 2209 spallation events.

Although muon spallation on oxygen is predicted to generate neutrons, betas and gammas, the data behaved as a neutron signal, which has an expected capture time of roughly 45 msec. The extracted spallation candidate signal reconstructed mainly within the Acrylic Vessel, suggesting that the spallation events originated in the heavy water. The candidate spallation events occurred within 0.2 sec after the muon events, which accounts for a substantial percentage of decay products. Another feature of the candidate events was their clustered energy distribution, between 40 - 70 Nhit ($\sim$6.25 MeV). This suggests that the events were generated by mechanisms that produce free neutrons. The addition of NaCl to the D_2O increased in the NC energy, decreased neutron capture time and increased signal isotropy.

Signs of longer-lived spallation products were not readily observable above random background in this study. We anticipate developing further improvements the muon and spallation algorithms and the use of larger amounts of data to extract the long-lived muon induced spallation events in SNO. This study provides valuable limits to external neutron sources in the D_2O and NaCl runs.

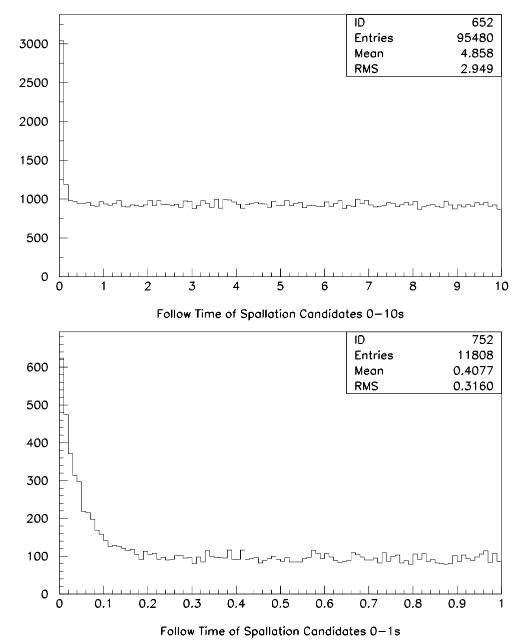

FIG. 1: **Time distribution for spallation candidates, as measured from the preceding muon.**
In the upper distribution, the spallation candidates mostly form a uniform background. A peak is seen at times earlier than a second. In the lower plot it is shown that there is a peak earlier than 0.2 sec.

[1] Y.P. Opachich and C.E. Okada, "Identification of Muons and Spallation Events in the Sudbury Neutrino Observatory", SNO Analysis Note, October 2002