Extensive simulation of muons at SNO

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The simulation of cosmic muons over a wide range of energy is of prime importance in the studies of atmospheric neutrinos. To date over 800 days of data is available to perform a measurement of θ_{23} in SNO.

The energy spectrum of cosmics spans over 5 decades [1], from O(100 MeV) to O(10 TeV). The typical energy of the processes originally intended to be simulated by the SNO collaboration software `Snoman` goes from 5 MeV (DAQ threshold) to around 20 MeV (so called *hep* events).

Muons produced in the atmosphere are propagated from surface down to the SNO detector 6800 ft underground using the `MUSIC` package [2]. This code has been interfaced with `Snoman` to obtain the energy distribution and angular and lateral deviations of single muons. The description of the rock reflects the different structures that we know next to the SNO cavity. All processes of muon interaction with matter with high energy loss (including the knock-on electron production) are treated as stochastic processes. The angular deviation and lateral displacement of muons due to multiple scattering, as well as bremsstrahlung, pair production and inelastic scattering are taken into account. Figure 1 shows very good agreement between the stand alone `MUSIC` code (black) and the SNOMAN output (red).

The simulation of the muons created by neutrino interations in the rock surrounding the detector is handled by the package `Nuance` [3]. This code describes the propagation and interactions of neutrinos through rock based on various models of atmospheric neutrino fluxes as a starting point. Neutrino-induced muons are in turn propagated up to the edge of the SNO detector. At this point the detailed simulation of the dectector response is handed over to `Snoman`.

The description of the muon interactions in the SNO detector (light and heavy water) includes the processes illustrated in Figure 2, ordered in increasing energy where they become prevalent.

All the products of the reactions are tracked down until they reach rest energy or thermal energy for neutrons (1/40 eV). In other words, the same data structure successfully unifies the simulation of physics processes over 15 orders of magnitude in energy in a single software.

Different track fitter algorithms have been developed that reconstruct the incident muon track. One of them is based on phototubes (PMT) charge and timing information used to backtrack the Cherenkov light to the point it was emitted along the trajectory. An independent fitter uses a pattern recognition technique in order to identify the direction and impact parameter of the track. Both algorithms suppose the muons traverse the detector. The efficiency of the latter fitter is virtually 100% for impact parameters up to $0.95 \times R_{\rm PSUP}$, where $R_{\rm PSUP}$ is the radius of the PMTs supporting structure (corresponding to path lengths of 4 m or more). A separate algorithm is currently in development that identifies and reconstruct low energy muons that stop inside the detector.

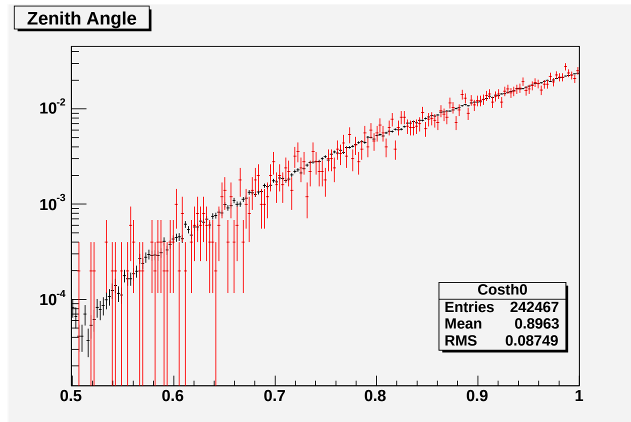

FIG. 1: Zenith angle distribution of muons after propagation through rock down to the SNO cavity. Results from a standalone simulation using `MUSIC` (black) are compared to the output of the SNO collaboration software `Snoman` (red).

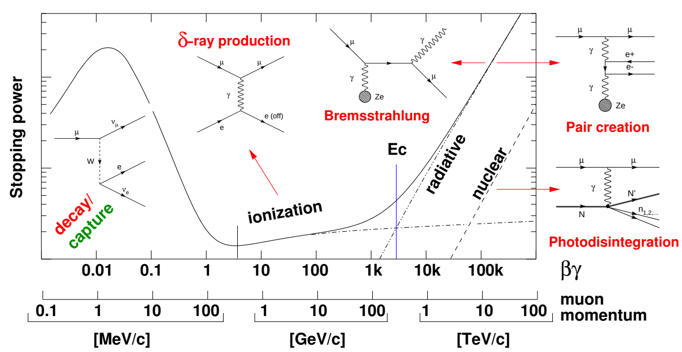

FIG. 2: Processes involved in the description of the energy loss of muons in the detailed simulation of the response of the SNO detector.

[1] K. Hagiwara et al., Phys. Rev. D **66**, 010001 (2002).
[2] P. Antonioli et al., Astropart. Phys. **7**, 357 (1997).
[3] D. Casper, Nucl. Phys. Proc. Suppl. **112**, 161 (2002).