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Pinning down the uncertainties in the high energy atmospheric neutrino flux.

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Several new calculations of the production spectrum of atmospheric neutrinos (before oscillations) give results which differ in normalization by as much as 15-20%. The calculations involve input of many experimentally determined properties, the most important of which are primary cosmic ray fluxes and information on hadron production. The assessment of the errors on these quantities is not easy to obtain, particularly in the hadron production information which is sparse and requires interpolation and extrapolation. We have taken three approaches to this problem which are outlined in this talk: (a) Comparing neutrino and muon fluxes with calculations (b) Using high energy accelerator data to tune the K/π production ratio in Monte-Carlo and (c) Using estimates of hadron production and primary flux errors to investigate the errors on the neutrino fluxes and the degree to which cancellation occurs when taking ratios of fluxes.

Cosmic ray produced neutrinos have been interesting for a long time now, initially as a background to nucleon decay experiments, then in their own right when neutrino oscillations were discovered at SuperKamiokande [1]. Although the oscillation signal was initially observed in the contained events produced by low energy neutrinos, higher energy neutrinos may also be used to study oscillations through the upward-moving muons they produce. The high end of the atmospheric neutrino flux spectrum is also relevant to neutrino telescopes.

The sources of uncertainty in neutrino fluxes depend on energy, generally leading to larger uncertainty at higher energy. Neutrinos in the region 30 GeV-30 TeV, which comprise most of the through going upward muons, are produced in interactions of primary cosmic rays about an order of magnitude higher in energy. Above 300 GeV measurements of the primary spectrum are made with calorimeters, which are generally subject to larger uncertainties that the spectrometer measurements at lower energy. Accelerator data on hadron production in this energy range is limited in its coverage of the relevant phase space. Additionally, at high neutrino energies, the importance of kaon production (which is not as well measured as pion production) increases because the competition between decay and interaction in the atmosphere is different for charged kaons and pions — kaons are shorter-lived. Also, because the difference in mass between pions and muons is small, the decay $\pi \to \mu\nu$ produces relatively low energy neutrinos in the centre of mass system whereas $K \to \mu\nu$ generates the higher energy neutrinos.

References

[1] Y. Fukuda et al., Phys. Rev. Lett. **81**, 1562 (1998); Y. Ashie et al. [Super-Kamiokande Collaboration], arXiv:hep-ex/0501064.