ID de Contribution: **73** Type: **Oral**

Atmospheric muons and neutrinos

jeudi 19 avril 2012 09:20 (30 minutes)

Primary cosmic-protons and nuclei interact in the atmosphere and produce cascades of secondary hadrons, some of which decay to produce muons and neutrinos. Production of pions, kaons and other hadrons occurs at the level of nucleon-nucleon interactions. For example, the excess of positive muons is a consequence of the excess of protons over neutrons in the primary spectrum of cosmic-ray nucleons. On average, the most energetic pion from interaction of a high-energy proton is positively charged, while the opposite is the case for a neutron. Thus the charge asymmetry in the primary cosmic radiation persists in the muons observed at the surface and deep underground.

In this talk I will start with a review of the primary spectrum and then discuss the consequences for the muon charge ratio and the ratio of neutrinos to antineutrinos. These ratios are sensitive to the relative contribution of pions and kaons. The response of the muon and neutrino fluxes to changes in the stratosphere can also be used as a probe of flavor content, including the contribution from decay of charmed hadrons at very high energy. I will discuss seasonal variations in rates as a probe of kaon and charm contributions to the flux of muons and neutrinos. Finally, I will comment on the shape of the spectrum of atmospheric neutrinos around 100 TeV and above where the influence of the "knee"in the primary cosmic ray spectrum appears. Understanding the atmospheric neutrino spectrum in this energy region is important because it is the background in the search for neutrinos of astrophysical origin as well as a probe of density structure of the Earth.

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Classification de Session: Atmospheric Muons and Neutrinos

Classification de thématique: Earth and Planetary Science with muons and neutrinos