ATMOSPHERIC MUONS AT VARIOUS ALTITUDES

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For a more detailed study of neutrino oscillation phenomena observed by Super-Kamiokande, it is essential to minimize the systematic errors in the predicted energy spectra of neutrinos. In order to improve the accuracy of the predictions, a detailed understanding of (i)primary cosmic ray intensities, (ii)hadronic interactions, and (iii)geomagnetic effect are indispensable.
Since production and decay process of muons are accompanied by neutrino productions, the intensities of muons correlate directly to the hadronic interactions. The geomagnetic effect is observed in the charge ratio of muons.
The atmospheric muon spectrum has been measured by many groups with solid iron magnet spectrometers, in which multiple scattering made it difficult to measure the absolute rigidity reliably. Most of the previous experiments did not obtain an absolute flux but normalized their observed spectrum to the "standard" value such as "Rossi point." In these kinds of measurements, small error in the momentum measurement leads to a large systematic error in the absolute flux, because atmospheric muons have very steep spectral shapes.
We have carried out a series of atmospheric muon measurements with the BESS spectrometer at various altitudes. At the top of Mt. Norikura, Japan (2,770 m above sea level, cutoff rigidity is 11.5 GV), the muon spectra was measured very precisely. The observed intensity of atmospheric muons is about 70 % higher than at sea level. The charge ratio of muons was consistent with our result measured at Tsukuba, Japan (30 m above sea level, cutoff rigidity is 11.4 GV). During the ascending and floating periods of the balloon experiments, the intensity of atmospheric muons was also continuously measured. The muon energy spectra at float altitude (5 g/cm^2) can provide much useful information about the hadronic interaction models. The measurement of muon growth curve in the atmosphere has been crucially important to calibrate the atmospheric neutrino calculations.