Measurements of the Absolute Flux of Atmospheric Muons with BESS

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Abstract

We measured atmospheric muon fluxes during ascending (800 – 4 g/cm^2) and floating (about 5 g/cm^2) periods of the BESS balloon flight experiments. The observations were carried out at Lynn Lake, Manitoba, Canada in 1999 and 2000 and at Ft. Sumner, New Mexico, USA in 2001. The atmospheric depth dependence on the muon fluxes was clearly observed.

1. Introduction

A measurement of muon fluxes enables us to understand hadronic interactions of primary cosmic rays with atmospheric nuclei. It is crucially important to measure muon fluxes at various altitudes and locations for a check of calculations of the atmospheric neutrino fluxes. Some measurements were carried out by balloon-borne experiments [4,5,6,7,8,9]. We report here muon spectra as a function of the atmospheric depth, and we discuss the effects of solar modulation on the muon fluxes.

2. BESS Detector

The BESS (Balloon-borne Experiment with a Superconducting Spectrometer) detector is designed as a high-resolution spectrometer with a large acceptance
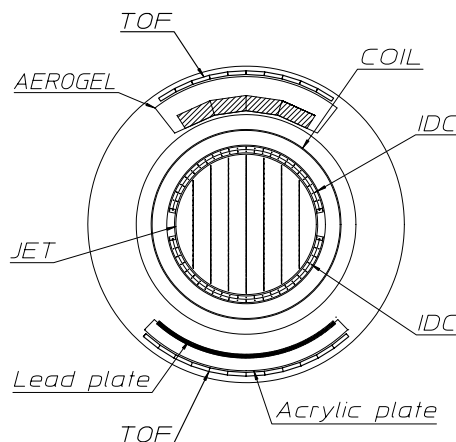
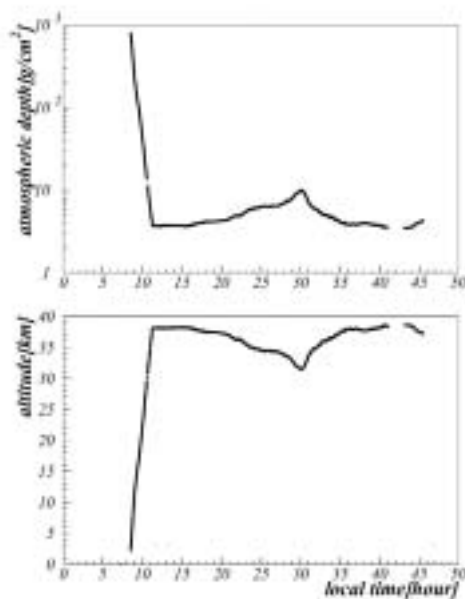**Fig. 1.** Cross-sectional view of the BESS detector.

Fig. 2. Atmospheric depth (above) and altitude (below) v.s local time.

to perform precise measurements of primary and secondary cosmic rays as well as rare cosmic-ray components [3,11,12].

As shown in Fig. 1, all detector components are arranged cylindrically in a simple configuration with a thin superconducting solenoidal magnet. The super-conduting solenoid produces a uniform magnetic field of 1 Tesla in the central region [2,15]. A jet-type drift chamber (JET) and two inner-drift chambers (IDC's) are located inside the magnetic field, and these chambers measure the magnetic-rigidity ($R \equiv pc/Ze$) of an incoming charged particle. Time-of-flight (TOF) scintillator hodoscopes measure particle velocity (β) and energy loss (dE/dx) [14]. The time resolution for muons in each counter is about 80 ps, resulting in a β^{-1} resolution of 1.7% in this analysis.

3. Experiment

The BESS detector was launched by using a balloon from Lynn Lake, Manitoba, Canada, each in 1999 and 2000. The geomagnetic cut-off rigidity is about 0.4 GV. We observed cosmic rays for an ascending period of about 3 hours, and a floating period of about 26 hours, in each experiment. In 2001, we carried out the experiment at Ft. Sumner, New Mexico, USA, where the geomagnetic cut-off rigidity is 4.2 GV. We precisely measured the residual pressure and the altitude during these measurements to obtain the altitude dependence on the molecular

density. It will be indispensable information to study hadronic interaction inside the atmosphere. Fig. 2 shows monitor data of the residual atmospheric depth and the altitude in the 2000 flight.

4. Results and Discussions

We measured the muon fluxes at atmospheric depths of 800 g/cm^2 to 4 g/cm^2, in 1999, 2000 and 2001. Fig. 3 shows the atmospheric depth dependence on the muon fluxes. Below about 100 g/cm^2 the muon fluxes increase nearly linearly as the atmospheric depth increases. The fluxes reach maximum around at 200 g/cm^2 and then decrease as the atmospheric depth further increases.

The primary proton flux is affected below 10 GeV by the solar modulation [3]. On the other hand, the muon fluxes observed in 1999, 2000, and 2001 had only a little variation within about 10 %, thus they were not much influenced by the solar modulation. It shows that parent particles of the observed muons are so energetic that the muon fluxes are not affected by the solar modulation.

We had reported, previously, precise muon fluxes at various altitudes, at sea level (about 1000 g/cm^2) [10], at mountain altitude (743 g/cm^2) [13] and at balloon altitudes (5–20 g/cm^2) [1]. Combining all the BESS data, our measured muon spectra can cover atmospheric depth from sea level to balloon floating altitude. The precise and systematic experimental results contribute to check and tune the atmospheric neutrino calculations.

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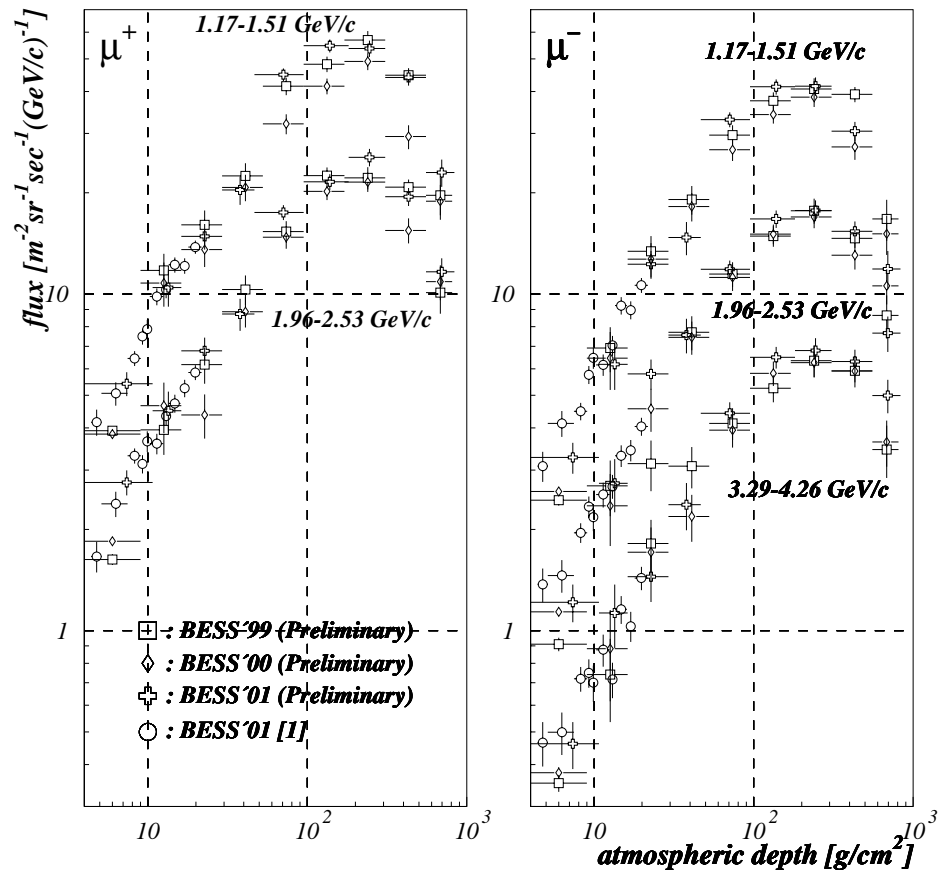3. Asaoka Y. 2002, Phys. Rev. Lett 88(5), 051101

Fig. 3. Growth curves of positive atmospheric muons (left) and negative ones (right).

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