Atmospheric Muon Measurements at Sea Level IV: Muon Charge Ratio

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Abstract

The acceptance and the momentum resolution of the OKAYAMA telescope were improved to measure up to the momentum around 100 GeV/c for any directions. We got sufficient muon data in higher momentum than previous presented ones. We report the results of the muon measurements, the muon charge ratio in vertical, 20° and 40° zenith angles. We discuss charge ratio values in the high momentum region (near 100 GeV/c).

1. Introduction

One of the significant aims to measure the atmospheric muon charge ratio is to investigate the contribution of kaon for atmospheric muon productions. In case of a atmospheric muon with a energy 100 GeV and 1 TeV, a contribution of kaons for the production is 8% and 19% respectively, and K^+/K^- is larger than π^+/π^-. Thus the atmospheric muon charge ratio (μ^+/μ^-) is predicted to be growing slowly up to high energy region ($\sim$ TeV)[2]. A lot of atmospheric muon charge ratio at sea level have been reported. However these experimental results show large fluctuations in high momentum region.

CAPRICE 94 experiment [4] shows the growing charge ratio value around 30 GeV/c. Hebbeker & Timmermans [3] also reports to have a peak of the charge ratio around 30 GeV/c using Baxendale et al. results [1]. These results shows the kaon contribution in lower momentum regions than predicted ones. The kaon contribution for the atmospheric muon production leaves ambiguities by fluctuations from the experimental results.

We measured the atmospheric muon charge ratio at sea level to investigate the kaon contributions for muon productions under the muon momentum 100 GeV/c. We also checked the charge ratios depending on atmospheric depth to relate the contributions between pions and kaons going through the air. We report

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the atmospheric muon charge ratios in momentum range from 2 to 100 GeV/c, in 0°, 20° and 40° zenith angles.

2. Simulation

The limited resolutions of the position chambers and the multiple Coulomb scattering are contain in the the systematical errors. Generally, a charge ratio come to 1.0 near the Maximum Detectable Momentum which shows the limit of the detector resolutions. We simulated the muon charge ratio behaviors in case of using the OKAYAMA telescope [8] to check the systematic errors. The total

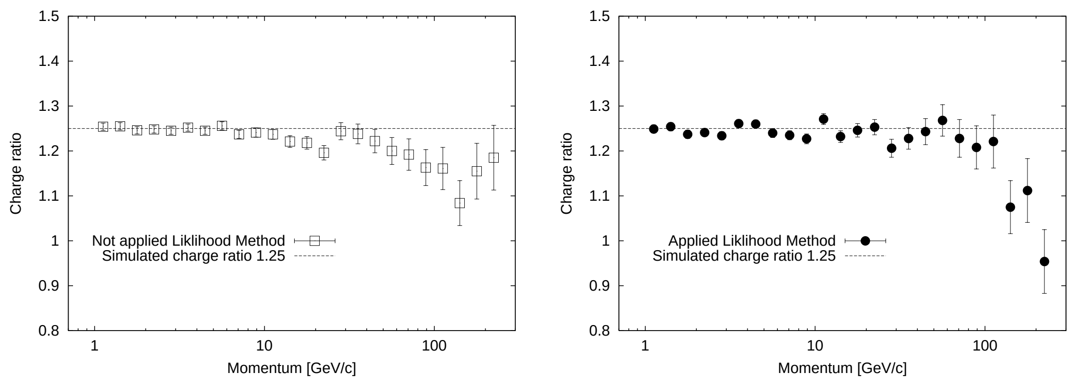

Fig. 1. The simulation of charged particle in the telescope.

number of simulated test particle is about 3.1×10^6. Defined charge ratio keep the constant value($= 1.25$) not depending on momentum. Simulated intensities in each momentum is weighted by the fluxes of BESS experiment [5] and Hebbeker & Timmermans equation [3]. Fig. 1 shows the improvement of muon charge ratios applying the maximum likelihood technique [6]. The simulation of the muon charge ratio using our telescope are tendency to decline from 40 GeV/c (Fig. 1 left). Another simulation applying the maximum likelihood technique show keeping constant value(=1.25) up to 100 GeV/c (Fig. 1 right). In this paper, we analyzed all data applied the maximum likelihood technique.

3. Observation time and events

We have accumulated muon data using new OKAYAMA telescope [8], and analyzed data is used since January in 2002. The observation time and analyzed events are following, 0° zenith angle 8187.5 hours (341.1 days) 4093278 events, 20° zenith angle 1140.3 hours (47.5 days) 512691 events, 40° zenith angle 962.7 hours (40.1 days) 300796 events.

4. Results

The atmospheric muon charge ratios are shown in the momentum range 2 to 100 GeV/c.

4.1. In 0° zenith angle

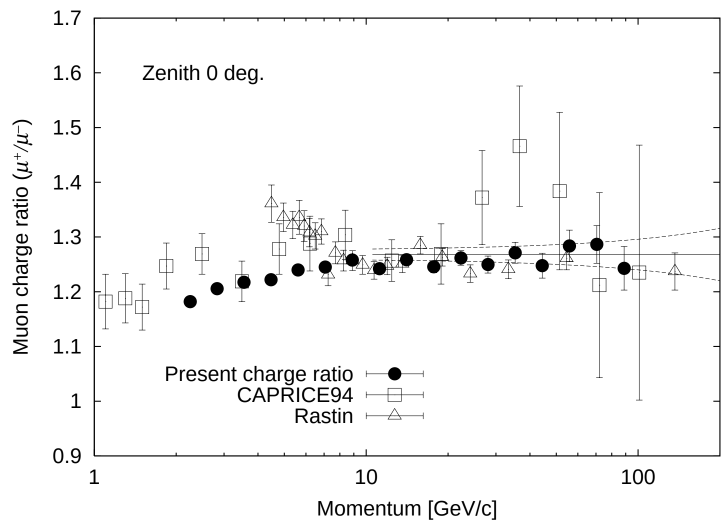

Fig. 2. Muon charge ratios in $0° \pm 5°$. Black circles: Present muon charge ratios. White squares: CAPRICE 94 results [4]. White triangles: Rastin results [7]. Lines: Summarized value of mean charge ratio more than 10 GeV/c by Hebbeker & Timmermans [3].

The muon charge ratio in $0° \pm 5°$ zenith angle is shown in Fig. 2 as black circle plots. The error bars show one standard deviation. White square plots show CAPRICE 94 results [4] and white triangle plots show Rastin results [7]. A solid line shows the summarized almost all charge ratio measurements in 0° zenith angle by Hebbeker & Timmermans in momentum more than 10 GeV/c[3]. Broken lines show one standard deviations from the solid line. CAPRICE 94 results have a large peak around about 30 GeV/c. Our results show small error bars and very near an averaged charge ratio value summarized by Hebbeker & Timmermans more than 10 GeV/c[3]. These results do not show a remarkable peak around about 30 GeV/c.

4.2. In 20° and 40° zenith angles

The muon charge ratios in $20° \pm 5°$ and $40° \pm 5°$ zenith angles are shown in Fig. 3 as black circle plots. The lines also show the summarized almost all charge ratio in 0° zenith angle as shown in Fig. 2[3]. The muon charge ratio in 40° (Fig. 3

right) shows large value in the momentum less than 10 GeV/c. This is caused by a geomagnetic field effect since we observed muons to the west direction. The results are not more reliable than ones in 0° zenith angle since statistical errors in the momentum more than 20 GeV/c are large as shown in Fig. 3. It is not sufficient to discuss kaon contributions for muon productions.

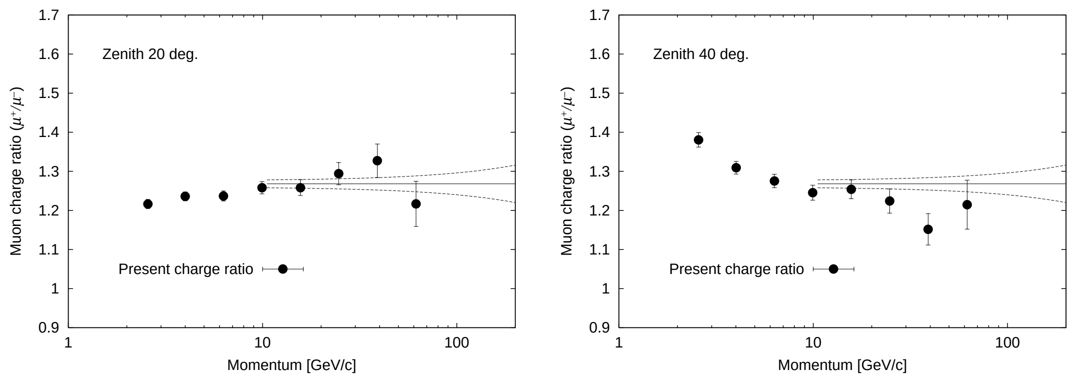

Fig. 3. Muon charge ratios in $20° \pm 5°$ (left) and $40° \pm 5°$ (right). Black circles: Present muon charge ratios. Lines: Summarized value of mean charge ratio more than 10 GeV/c in vertical by Hebbeker & Timmermans.

5. Conclusion

We presented atmospheric muon charge ratios in $0° \pm 5°$, $20° \pm 5°$ and $40° \pm 5°$ zenith angles. In $0° \pm 5$ zenith angle, we do not make sure remarkable peaks in the momentum range 2 to 100 GeV/c. It is found that kaon contributions for muon productions have little effects in the muon momentum range 2 to 100 GeV/c as the prediction.

Reference

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