A New Measurement of the μ^+/μ^- Ratio at Small Atmospheric Depth

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Abstract

We report on a new measurement of the μ^+/μ^- ratio at small atmospheric depth in the momentum range 0.3-20 GeV/c using the NMSU-WIZARD/CAPRICE98 balloon-borne magnetic spectrometer. The flight took place on 28-29 May 1998 from Ft. Sumner, New Mexico. In the momentum range 0.3-1 GeV/c the ratio is 1.29 ± 0.08, lower than the corresponding ratio measured in 1994 at Lynn Lake, Canada, which was 1.59 ± 0.06. The difference is attributed to the difference in latitude of the two experiments. For the range 2-20 GeV/c we report a value of the ratio of 1.4 ± 0.1.

1 Introduction

Evidence for neutrino oscillations has been reported from the study of atmospheric neutrino interactions in the Super-Kamiokande experiment (Fukuda et al. 1998). The observed neutrino interactions are mainly of low energy, typically in the range 0.3-3 GeV and show the now well-known anomaly of either too many ν_e or too few ν_μ as compared to calculations. The calculations (Honda et al. 1995, Gaisser and Stanev 1995, Barr et al. 1989, Bugaev and Naumov 1989) are based on one dimensional simulations of atmospheric showers and give flux values that differ by as much as 30% but with an electron to muon ratio that is stable to within 5%. Because of the direct relation between atmospherically produced neutrinos and muons, a measurement of the flux of the latter will make it possible to carefully check the calculated neutrino flux from the measured muon flux.

In this paper we report on a new measurement of the μ^+/μ^- ratio at 5.5 g/cm^2 residual atmosphere above the payload. Results are presented for the momentum range 0.3-20 GeV/c. The data represent mainly the results of the first interaction of the cosmic rays in the atmosphere. Of particular interest is to compare data taken at different latitudes with different geomagnetic cut-offs among themselves and to the results of simulations.

2 The NMSU-WIZARD/CAPRICE98 Experiment

The CAPRICE98 experiment used the NMSU-WIZARD/CAPRICE98 balloon-borne magnet spectrometer. It was designed to give excellent particle identification properties and the experiment was equipped with a gas radiator Ring Imaging Cherenkov (RICH) detector, a time-of-flight (ToF) system, a tracking magnetic spectrometer and a silicon-tungsten calorimeter. Detailed performance of the spectrometer is described elsewhere (Cafagna et al. 1999). The flight took place on 28-29 May 1998 from Ft. Sumner, New Mexico, USA (34.3° N, 104.13° W) to Heber, Arizona, USA. During the 21 h long flight at an atmospheric overburden of about 5.5 g/cm^2 data from about 4 million triggers were collected. The muon charge ratio measured during the ascent of the flight is presented separately at this conference (Circella et al. 1999).

Muons constitute a small part of the flux of particles at small atmospheric depths and particle identification is therefore very important. In particular for positive muons the much larger flux of protons necessitates two

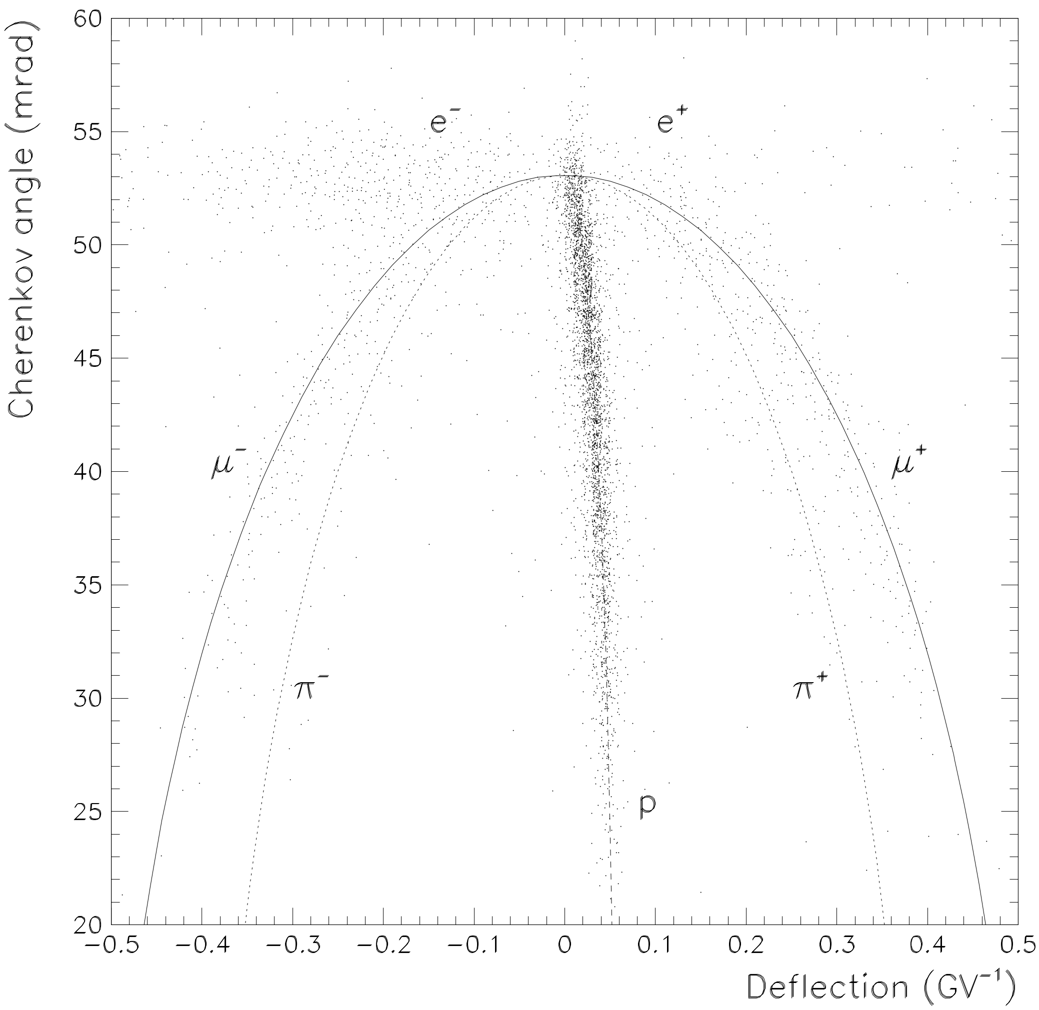

Figure 1: Cherenkov angle as function of deflection in the spectrometer for the data observed in this experiment. The rigidity is 1/deflection. The total number of events included in the plot is 8147.

independent rejection methods. The ToF system rejected protons against lighter particles for momenta below 1.3 GeV/c. It also rejected higher charged particles, mainly alphas, by means of pulse heights measurements. Finally, the ToF system rejected albedo particles.

The 1 m RICH detector used C_4F_{10} as radiator giving a threshold proton (muon) momentum of 17.7 (2.0) GeV/c. It was used to discriminate between protons and lighter particles below 20 GeV/c. It was also used to discriminate between pions, mostly produced locally in the payload, and muons in the momentum range 2-6 GeV/c. The performance of the RICH is illustrated in figure 1 where the Cherenkov angle is shown as a function of deflection. It is clear that this gas RICH detector, the first ever flown of its type sensitive to charge one particles, is a very powerful tool for particle identification, including its unique feature to discriminate between pions and muons over a large range in momentum.

The 7 radiation length thick silicon-tungsten calorimeter is used in several ways. Electrons and positrons are rejected against minimum ionizing particles, mostly muons and some pions, with a rejection factor of 10^4 above 0.5 GeV/c keeping the efficiency for muon detection close to 100%. Protons below 0.8 GeV/c do not cross the full calorimeter. For strongly interacting particles the calorimeter thickness corresponds to only about 0.3 interaction lengths.

In summary muons are identified using the calorimeter and the ToF system in the range 0.3-1.0 GeV/c and using the calorimeter and the RICH in the range 2-20 GeV/c. In addition, a pulse height selection is performed at all momenta.

3 Results and Discussion

The measured μ^+/μ^- ratio is shown in figure 2 as function of momentum. In the range 0.3-1.0 GeV/c (2-20 GeV/c) there are 2815 (749) muons. Also shown are our previous results from CAPRICE94 (Boezio et al. 1999b) and also the MASS91 results (Codino et al. 1997). The average value of the CAPRICE98 measured ratio is 1.31 ± 0.05 to be compared with the CAPRICE94 result of 1.59 ± 0.06. Notice that the momentum ranges for these two experiments are different because of different radiators in the Cherenkov detectors used. Up to 1 GeV/c a good agreement is found between CAPRICE98 and MASS91 results, obtained at the same location.

The observed difference is attributed to the difference in latitude of the two launch sites, CAPRICE98 and MASS91 at 34.3° N and CAPRICE94 at 56.5° N, with corresponding differences in the geomagnetic cut-offs, 4.5 GeV/c for CAPRICE98 and MASS91 and 0.4 GeV/c for CAPRICE94. Interacting protons give on average more positive pions and less negative than interacting neutrons. For a given energy per nucleon, incident alphas, containing equal numbers of protons and neutrons, will therefore give a lower value of the μ^+/μ^- ratio than protons. For a given rigidity, the alpha particle has about half energy per nucleon of a proton. Below the cut-off rigidity alpha particles will therefore contribute more to the pion flux. The higher cut-off rigidity for the CAPRICE98 experiment will therefore result in a lower μ^+/μ^- ratio in the momentum range below 1 GeV/c. We note, however, that the calculation of the ratio for the CAPRICE94 experiment, that takes into account the low rigidity, gives a result lower than that observed (Boezio et al. 1999). We also point out the latitude effect for the ground muon data reported in the CAPRICE94 and CAPRICE97 experiments (Kremer et al. 1999).

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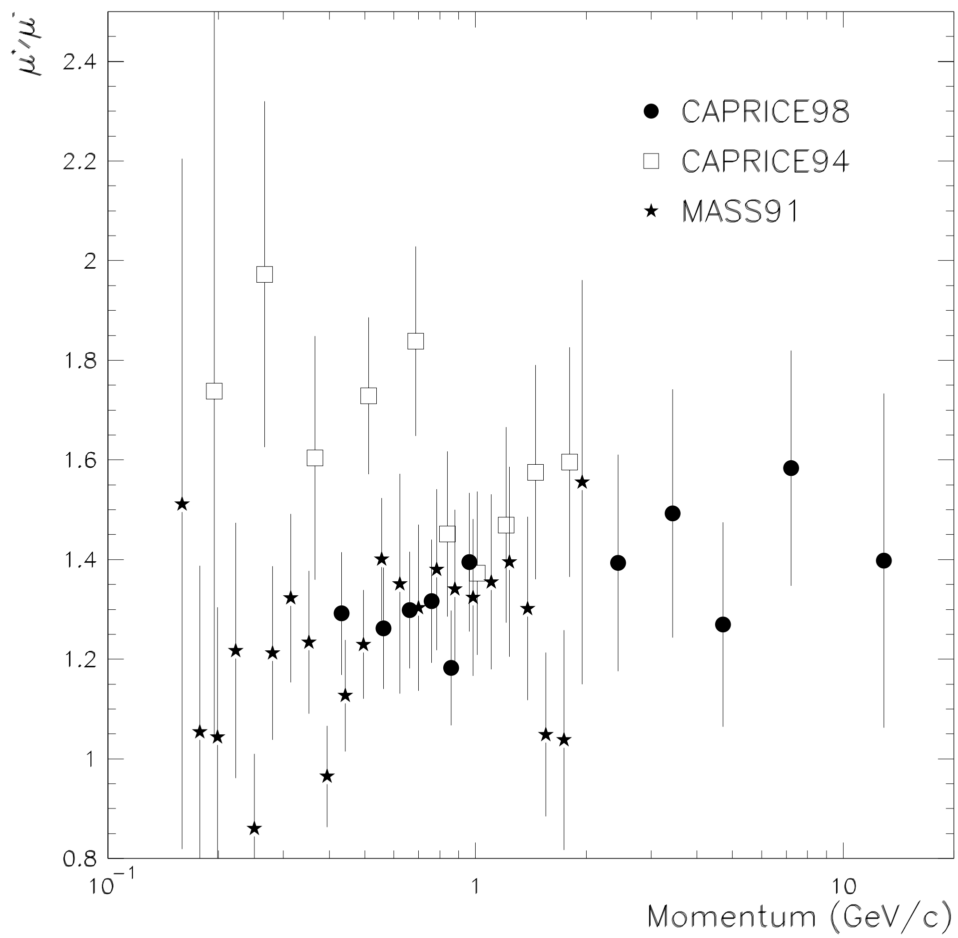

Figure 2: The measured μ^+/μ^- ratio in the CAPRICE98 experiment compared to the results of the CAPRICE94 and MASS91 experiments.

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