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A New Measurement of the Muon Component in the Atmosphere

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Abstract

We report new measurements of the muon charge ratio in the atmosphere from the data collected by the CAPRICE98 balloon-borne magnet spectrometer during the ascent of the payload. The measurement was performed starting from Ft. Sumner, NM at a vertical rigidity cutoff of about 4.5 GV on May 28, 1998. The results are reported separately in three momentum bins, in none of which significant dependences on altitude have been found. The charge ratio below 1 GeV/c measured in this experiment is in agreement with previous results from experiments at comparable latitudes, and lower than measurements at low geomagnetic cutoff, which may point out latitude-dependent effects. This is the first time that the muon charge ratio has been investigated from ground level down to residual atmospheric depths of 5 g/cm^2 at particle momenta larger than 2 GeV/c.

1 Introduction

Muon measurements in the atmosphere may provide useful constraints to the atmospheric shower calculations used to interpret the atmospheric neutrino observations (Circella et al. 1999a and references therein). Several measurements of the muon flux have been proposed recently, subsequently to the pioneering work of the WiZard Collaboration (Circella et al. 1993).

Most of these investigations have explored the negative muon spectra in a wide momentum range (Bellotti et al. 1996, Bellotti et al. 1999, Boezio et al. 1999, Coutu et al. 1998), while measurements of the muon charge ratio were typically limited to narrower momentum bins, up to 2 GeV/c (Boezio et al. 1999) or less (Bellotti et al. 1999, Krizmanic et al. 1995, Schneider et al. 1995, Coutu et al. 1998). This is due to the high background of protons, which imposes severe requirements on the particle discrimination capabilities of the detectors. Primary protons attenuate almost exponentially with atmospheric depth (see, for instance, Circella et al. 1999b, Francke et al. 1999). Consequently, they overcome muons at atmospheric depths less than a few hundreds g/cm^2.

In this paper, we present new measurements of the muon charge ratio in the atmosphere in a large momentum interval. In particular, these are the first measurements ever performed at particle momenta larger than 2 GeV/c, further to our earlier investigation with the MASS experiment of 1991, which was limited to depths larger than 100 g/cm^2 (Circella 1997). This was possible thanks to the excellent particle classification capabilities of our apparatus, the CAPRICE98 balloon-borne magnet spectrometer.

2 The Detector

The CAPRICE98 detector was launched from Ft. Sumner, NM on May 28, 1998. This location is at a vertical rigidity cutoff of about 4.5 GV. The data analyzed in this work were collected during the ascent of the flight (11 700 s) and cover the depth range from 5 to 886 g/cm^2. Measurements of the muon charge ratio performed with this experiment at float are reported separately at this conference (Carlson et al. 1999).

The CAPRICE98 apparatus consisted of the WiZard/NMSU superconducting magnet spectrometer equipped with a drift-chamber tracking device, a time of flight (ToF) scintillator system, a gas Ring Imaging Cherenkov (RICH) detector and a silicon-tungsten imaging calorimeter. In Fig. 1 we show the particle discrimination possible by means of the ToF measurement at low energy. More details on the detector capabilities and performances during the flight are reported elsewhere at this conference (Ambriola et al. 1999, Ricci et al. 1999, Bergström et al. 1999, Carlson et al. 1999).

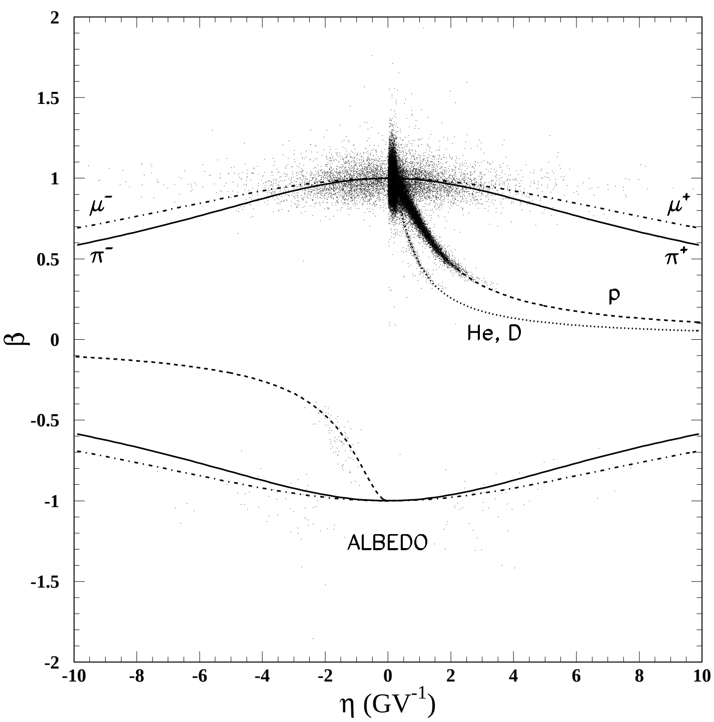

Figure 1: Velocity ($\beta = v/c$) from the ToF measurement as a function of deflection for a sample of particles collected during the ascent of the flight. The code for the albedo components is as follows: solid line for pions, dash-dotted line for muons, dashed line for protons. The large number of particles at small deflection is due to the large number of primaries which can reach the detector above the geomagnetic cutoff. The number of events in this plot is 39 092.

Muons were selected by means of the following criteria: i) a good-fit track is reconstructed in the spectrometer. This allows the rigidity of particles to be determined; ii) albedo events, i.e. particles propagating upward through the apparatus, are removed by means of a ToF selection; iii) the calorimeter information is checked in order to select clean tracks of non interacting, singly charged particles; iv) the scintillator pulse height is checked in order to reject higher charge particles. In addition, depending on the momentum of the particles: v) 0.3–1 GeV/c muons were required to satisfy a ToF selection (in order to reject protons) and not to show a signal in the RICH detector (in order to remove any residual electron/positron contamination); vi) 2-15 GeV/c muons were required to show a Cherenkov ring in the RICH detector compatible with that expected according to the momentum of the particle.

This redundant classification allows a good quality sample of muons to be selected. In fact, electrons and positrons are removed by the calorimeter selection, with a rejection factor of the order of 10^{-4}, at high energy and by the combination of the calorimeter and RICH selection at low energy. Protons are removed by means of the calorimeter and RICH selection at high energy and by the calorimeter and ToF selection at low energy. Pions, finally, can also be classified and removed by means of the RICH measurement in the 2–6 GeV/c momentum range (Bergström et al. 1999).

We would like to point out that we have imposed very severe criteria for particle selection. More work is in progress in order to accurately determine the level of background. Once this study is complete, we hope to be able to apply a looser selection in order to increase the statistics of the selected events. For instance, primary protons below 4.5 GV can not reach the detector due to the geomagnetic suppression. Low energy protons will be therefore of a secondary nature, and the extent of this background will be smaller than at higher rigidity (see, for instance, Bellotti et al. 1999).

3 Results and Discussion

The measurements of the muon charge ratio from this work are shown in Fig. 2, separately for three momentum intervals. In none of them, a definite dependence on the atmospheric depth may be noticed. Instead, we note an increase of the value of the ratio averaged over the depth range with increasing particle momentum, in a trend similar to that reported in our earlier experiment over a narrower momentum interval (Bellotti et al. 1999).

A comparison of the current measurements to results from previous experiments is possible at low energy: Boezio et al. 1999 (0.3–1 GeV/c), Bellotti et al. 1999 (0.3–0.9 GeV/c), Conversi 1950 (0.315–0.348 GeV/c), Quercia et al. 1950 ($\geq$460 MeV), Krizmanic et al. 1995 (0.42–0.47 GeV/c), Schneider et al. 1995 and Coutu et al. 1998 (0.3–0.9 GeV/c).

In particular, we note a good agreement of the current results with other measurements performed at comparable values of

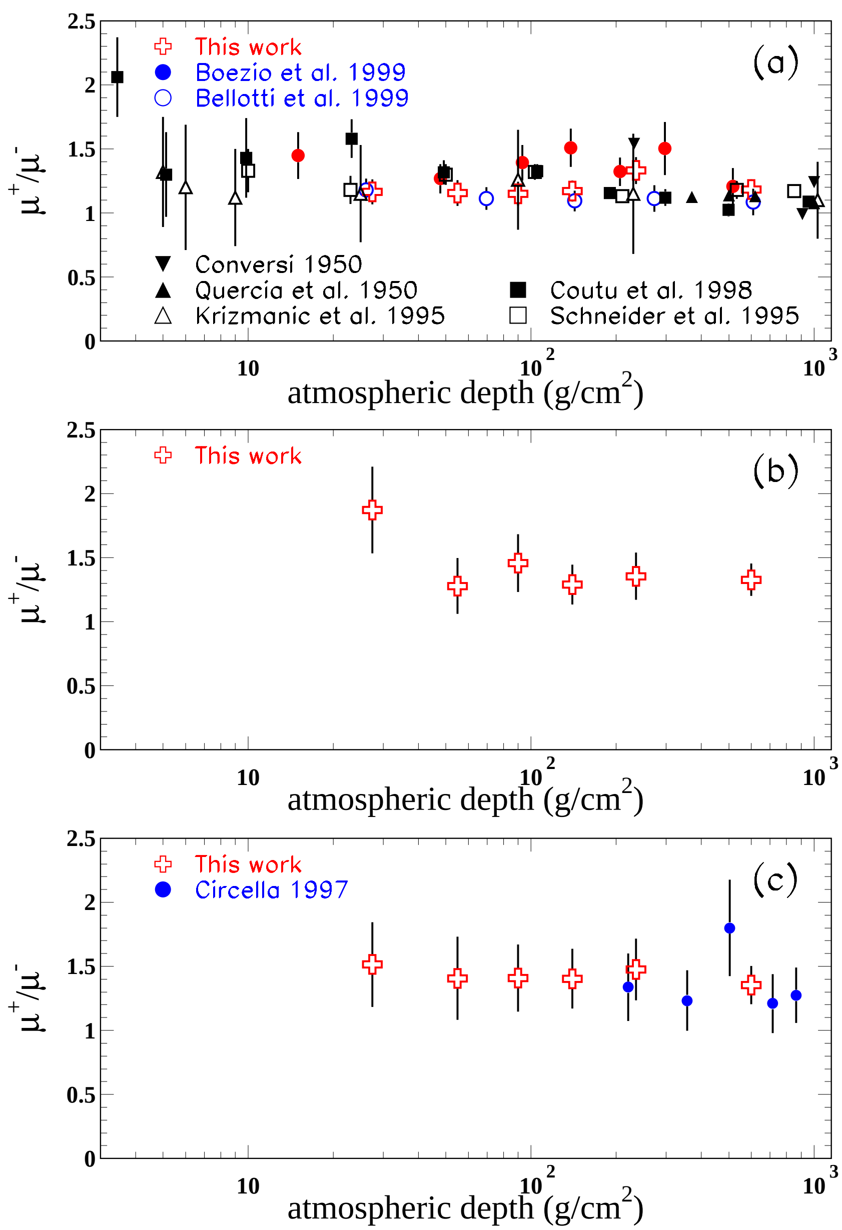

Figure 2: Muon charge ratio measured in different energy intervals: (a) 0.3–1 GeV/c; (b) 2–4.5 GeV/c; (c) 4.5–15 GeV/c, along with results from previous experiments.

geomagnetic cutoffs (Bellotti et al. 1999, Schneider et al. 1995), while experiments at higher latitudes have reported higher values of the charge ratio (Boezio et al. 1999, Coutu et al. 1998). The results by Krizmanic et al. (1995) are consistent with any of these experiments within the errors. The data in Fig. 2a therefore seem to point out latitude dependent effects. These are mainly due to the different role played by bound nucleons with respect to free protons due to the geomagnetic suppression. A nucleon bound in a helium nucleus, in fact, has a different (namely, lower) kinetic energy per nucleon, at the same magnetic rigidity, than for a free proton. Depending on the different geomagnetic and solar modulation conditions, therefore, the role of bound nucleons, which include neutrons as well as protons, will change with respect to the free protons. In addition, the East-West effect may play a major role. Positive muons come in fact predominantly from cosmic rays arriving from the East, while it is the opposite case for negative muons. Both of these effects eventually lead to a depression of the muon charge ratio for low geomagnetic latitudes (Stanev 1999).

The results in Fig. 2b-c represent the first measurement of the muon charge ratio at momenta larger than 2 GeV/c performed over such a large depth range from 5 to 886 g/cm^2. The results in Fig. 2c agree well with our previous observations from the MASS experiment of 1991, also in the 5–15 GeV/c momentum range, which were limited to depths larger than 100 g/cm^2 (Circella 1997).

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