Energy Spectra and Charge Ratios of Atmospheric Muons

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Abstract

We present a new measurement of atmospheric muons made during an ascent of the High Energy Antimatter Telescope balloon experiment. The muon charge ratio μ^+/μ^- as a function of atmospheric depth in the momentum interval 0.3–0.9 GeV/c is presented. The differential μ^- fluxes in the 0.3–50 GeV/c range and for atmospheric depths between 4–960 g/cm^2 are also presented. We compare these results with other measurements and model predictions.

1. Introduction

Measurements and theoretical calculations of atmospheric neutrino fluxes have consistently disagreed, resulting in the possibility of neutrino oscillations. However, this interpretation requires an accurate understanding of neutrino fluxes in the atmosphere. Simulations of the absolute fluxes have been conducted (Barr et al. 1989, Wentz et al. 2001, Gaisser & Honda 2002 and references therein) but suffer from systematic uncertainty in the normalization of the atmospheric neutrino spectrum. Fortunately, these simulations also predict the spectrum of other atmospheric secondaries, specifically muons. Therefore, measurements of atmospheric muons by ascending high altitude balloon borne instruments can be used to reduce the model uncertainties. An earlier version of the High Energy Antimatter Telescope (HEAT) instrument had been used to measure air-shower muons during atmospheric ascent (Coutu et al. 2000). The HEAT instrument is described in detail elsewhere (Barwick et al. 1997, Nutter et al. 2003). It combines a superconducting magnet spectrometer (using a drift-tube hodoscope), a time-of-flight system, and two stacks of multiwire proportional chambers, in its present configuration optimized to study antiprotons. We report here a new

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measurement of the muon charge ratio μ^+/μ^- as a function of atmospheric depth in the momentum interval 0.3–0.9 GeV/c and differential μ^- fluxes in the 0.3–50 GeV/c range, and for atmospheric depths between 4–960 g/cm^2 for a balloon flight from Fort Sumner, NM on June 3, 2000.

2. Results and Discussion

2.1. Muon Charge Ratio

The μ^+/μ^- ratio is shown as a function of atmospheric depth in Figure 1. (labeled HEAT 00) together with the measured ratios for two previous HEAT flights and other recent measurements (Coutu et al. 2000, and references therein). The various measurements were made at different geomagnetic rigidity cutoffs and solar epochs, so direct comparison is problematic. There appears to be good agreement between the MASS 91 and HEAT 00 ratios, both of which were measured at the same rigidity cutoff ($\sim$ 4.5 GV) and the same solar epoch (solar maximum). The ratio for HEAT 00 appears essentially flat at about 1.1–1.2 for increasing atmospheric depth, but a slight decrease around 200 g/cm^2 cannot be ruled out. Also shown on Figure 1. are 3-dimensional calculations of the air shower development with the TARGET algorithm (Agrawal et al. 1996), widely used for neutrino flux calculations. Curves are shown for both solar maximum (HEAT 00) and solar minimum (HEAT 95) conditions at a location with a 4.5 GV geomagnetic cutoff and for average primary fluxes for each solar epoch (which may not represent the actual spectrum at the time of the flight). The agreement between the calculation and the measurements appears reasonably good, with the caveat that statistical uncertainties at high altitudes for the HEAT 95 measurements are large.

2.2. μ^- Differential Flux

Our measurement of the μ^- differential fluxes was made using similar corrections as for previous HEAT flights (Coutu et al. 2000), with only minor modifications for differing instrument configuration. The results are shown in Figure 2. The differential fluxes as a function of rigidity and atmospheric depth are shown multiplied by R^2 for better comparison. Also shown are the results of other measurements. The level of agreement is quite good despite the differing solar epochs and rigidity cutoffs. The curves shown are for calculations with the TARGET algorithm with the same parameters as for the previous ratio plot. The agreement between the HEAT measurements and model predictions is excellent, except for the very highest altitudes where the predictions are below the measured fluxes.

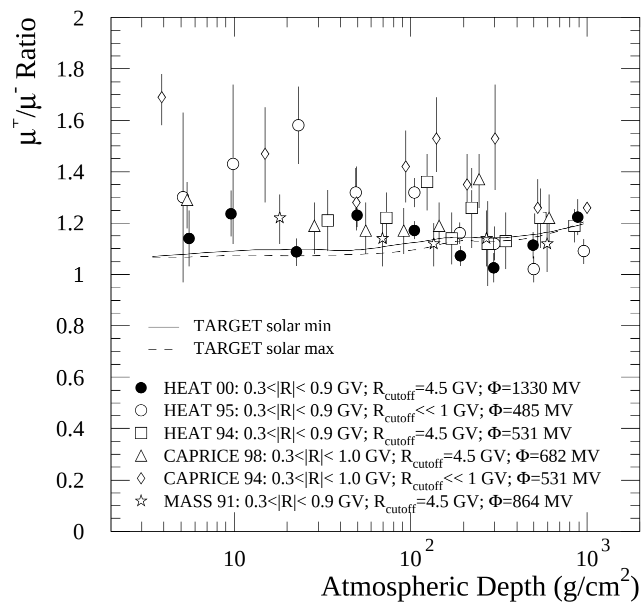

Fig. 1. Atmospheric muon charge ratio as a function of atmospheric depth. Also shown are the ratios for HEAT 1994 and 1995 flights as well as other measurements. The curves are calculations with the 3-dimensional TARGET algorithm for the conditions of the HEAT 2000 flight.

3. Conclusions

We have measured with good statistics the muon charge ratio μ^+/μ^- as a function of atmospheric depth in the momentum interval 0.3–0.9 GeV/c and the differential μ^- fluxes in the 0.3–50 GeV/c range and for atmospheric depths between 4–960 g/cm^2. We have found the ratio to be ~ 1.1 for all atmospheric depths, with a possible slight decrease at depths greater than 200 g/cm^2. Comparison of our results with other measurements yields general agreement despite varying solar epochs and geomagnetic rigidity cutoffs.

4. References

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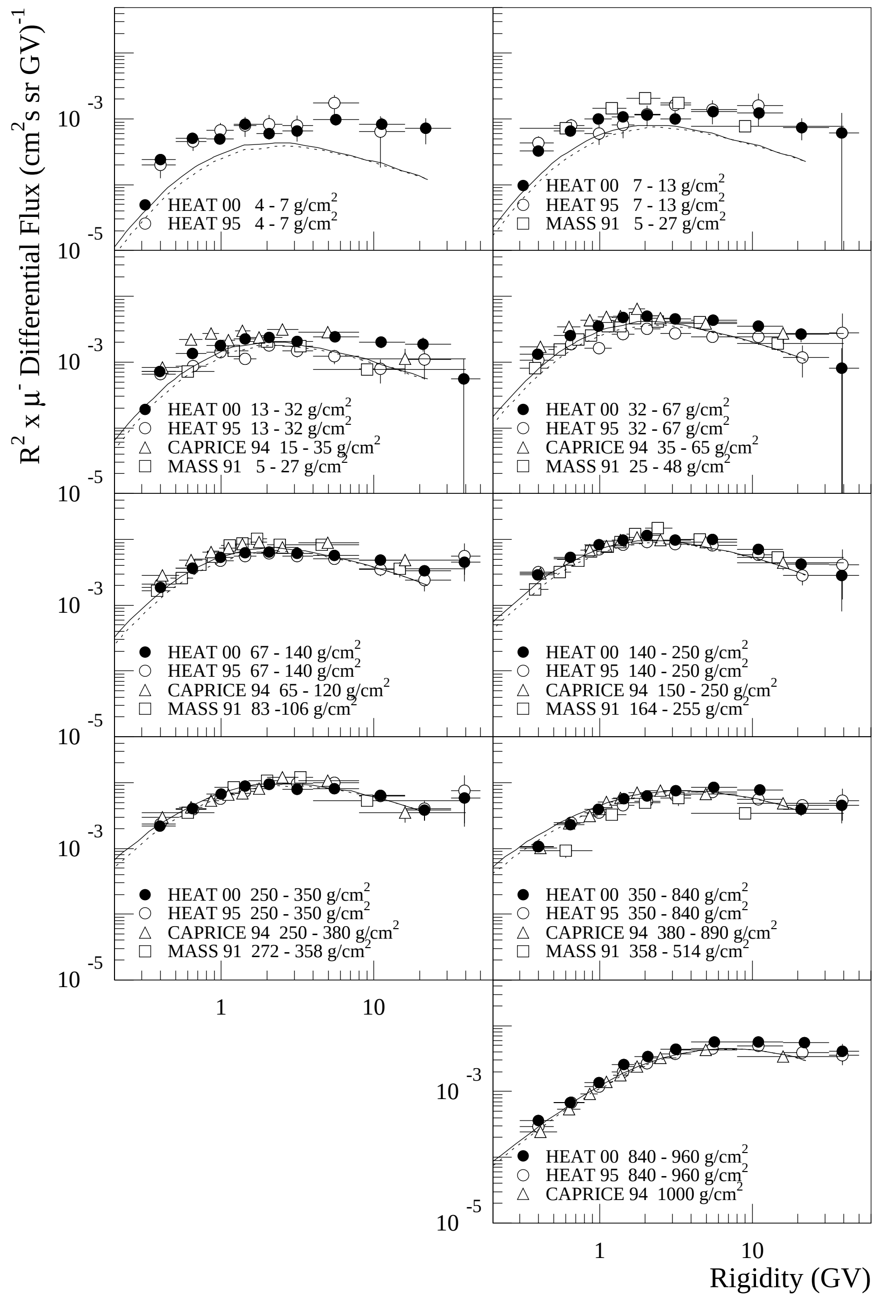

Fig. 2. Differential μ^- fluxes as a function of rigidity for various atmospheric depth ranges. Also shown are results from various other instruments. The plots have been scaled by a factor of R^2. The curves are calculations with the 3-dimensional TARGET algorithm for solar minimum (*solid*) and solar maximum (*dashed*). See Figure 1. for each measurement's solar and geomagnetic conditions.