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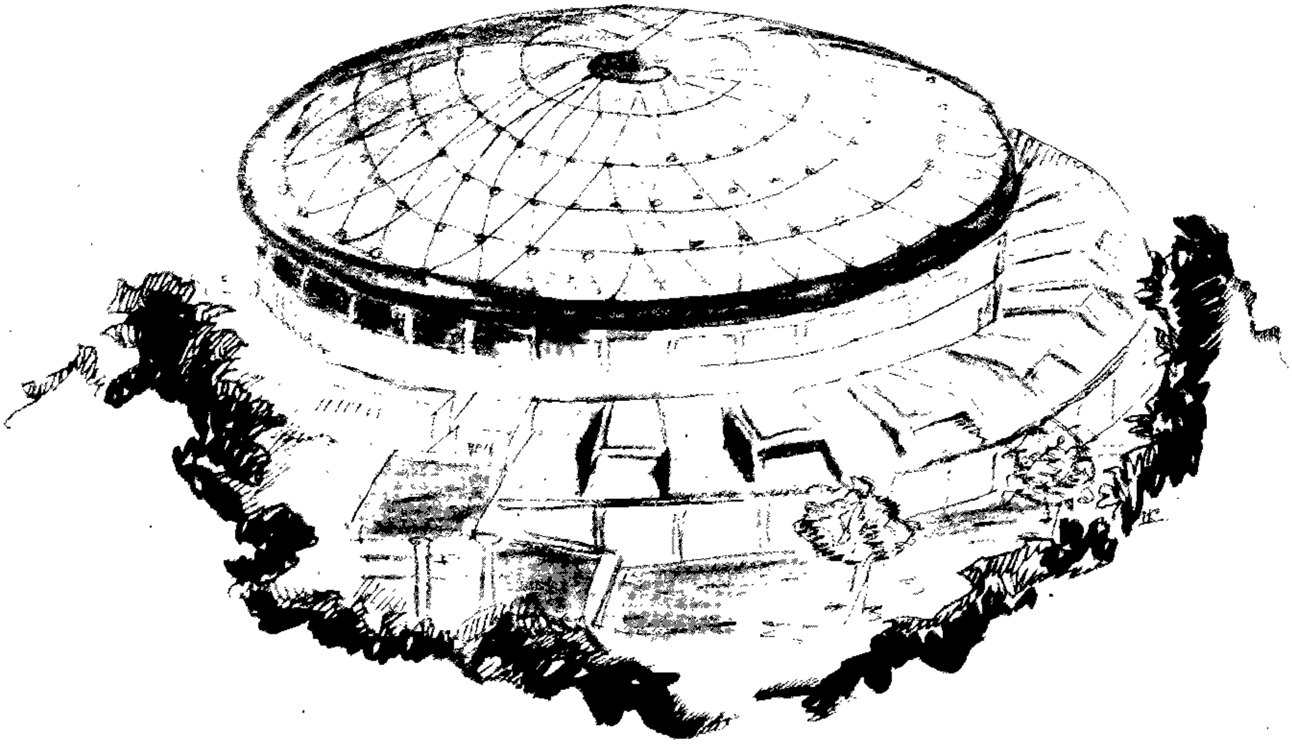

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Cosmic Ray Muon Spectrum in the Atmosphere

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ABSTRACT

A measurement of the negative muon flux in the atmosphere has been carried out using the data collected by the Matter-Antimatter Superconducting Spectrometer (MASS) apparatus during the ascent of the 1989 flight. This experiment was flown on September 5, 1989 from Prince Albert, Saskatchewan (Canada). The muon spectrum has been determined in the momentum interval 0.3-100 GeV/c and its dependence on altitude studied between 0.6 and 36 km a.s.l. We discuss here some preliminary results and their importance. A positive muon analysis is in progress and the results will hopefully be available at the Conference.

1. INTRODUCTION

In the past, the muon flux has been studied in order to examine cosmic ray interactions in the atmosphere. The main source of muons in the momentum range investigated in this work is the decay of pions produced in hadronic interactions of cosmic rays. The contribution from kaon decay increases above a few hundred GeV/c. While sea-level measurements are widely reported in the literature, there are only a few measurements of the muon flux as a function of altitude (Conversi, 1950, Blokh *et al.*, 1977). This measurement can serve two purposes: a check for cosmic ray cascade calculations and for atmospheric neutrino calculations (Gaisser *et al.*, 1988, Lipari, 1993). The main difficulty in performing a muon measurement at or above stratospheric altitudes is to properly compensate for the contamination of the muon sample by other particles. This problem becomes even more complex for positive muon measurements, since the proton flux strongly increases with altitude.

2. EXPERIMENTAL SETUP

The MASS apparatus consists of [1] a superconducting magnet spectrometer with 8 multiwire proportional chambers (MWPC), [2] a time of flight (TOF) system with 2 planes of 2 scintillator layers each, [3] a high resolution scintillator-the TOF system and the scintillator providing 5 independent dE/dx measurements-, [4] a gas Cherenkov detector and [5] a streamer tube imaging calorimeter. A coincidence between the TOF scintillators gives the trigger for data acquisition. Before transmitting the data to the ground an on-board computer checks that the pulse height in the high resolution scintillator is greater than 0.25 times that corresponding to a minimum ionizing particle. The Cherenkov detector is filled with a 50-50 mixture of Freon 12 and Freon 22 with a Lorentz threshold factor of 23. The calorimeter consists of 40 layers of 64 streamer tubes each and it is 7.3 radiation lengths and 0.7 nuclear interaction lengths long. More details on the apparatus characteristics and performance are given elsewhere (Golden *et al.*, 1991, Golden *et al.*, 1991b, De Pascale *et al.* ,1993).

3. DATA ANALYSIS

The dE/dx measurements from the scintillators and the hit pattern in the calorimeter were used to identify muons. The Cherenkov signal was used to estimate the fraction of contaminating electrons in the muon candidate sample. The TOF measurement was used to reject upward moving particles. Muons were required to have a signal between 0.5 and 2.0 I_0 in the high resolution scintillator and in the two uppermost scintillator layers of the TOF system, I_0 being the pulse height for a minimum ionizing singly charged particle. Muon candidates were also required not to have a shower in the calorimeter. The latter condition was imposed by considering the calorimeter divided into two parts and by selecting events with a number of hits n, $2 \leq n \leq 9$ for the upper part along the x- and y-views and $3 \leq n \leq 12$ for the lower part along the x-view (the lower part y-view was not operated during the flight). For a reliable determination of the particle curvature the muon events were also requested to satisfy MWPC data cuts as discussed in De Pascale *et al.*, 1993.

4. RESULTS AND DISCUSSION

The negative muon momentum spectrum has been measured at several altitudes, and the results are shown in Figure 1 through Figure 7. The exposure time as well as the altitude-dependent deadtime fraction were considered in evaluating the absolute fluxes. The tracking efficiency of the spectrometer and the geometric factor of the apparatus are energy dependent and are discussed in De Pascale *et al.*, 1991. The average values of the geometric factor and the spectrometer efficiency for negatively charged particles are reported in Table 1 for different momentum intervals. The calorimeter efficiency for muon tracks satisfying the above criteria was found to be 0.82 and a scintillator efficiency of 0.82 was assumed. An additional correction of 0.77 was considered in order to take into account the inefficiency due to the trigger system, the TOF measurement and the ground computer data transfer. At this point of the analysis, there could be an overall uncertainty of about 20% in the estimate of the total efficiency.

Momentum Interval (GeV/c)	0.3 0.46	0.46 0.63	0.63 0.89	0.89 1.18	1.18 1.58	1.58 2.22	2.22 3.55	3.55 8.	8. 100.
Geom. Factor (cm^2 sr)	81.5	107.4	117.2	122.4	125.0	126.5	127.5	128.0	128.1
Spectrometer Efficiency	0.52	0.58	0.63	0.67	0.69	0.69	0.69	0.69	0.69

TABLE 1: Momentum-dependent spectrometer efficiency and geometric factor of the apparatus for negative particles.

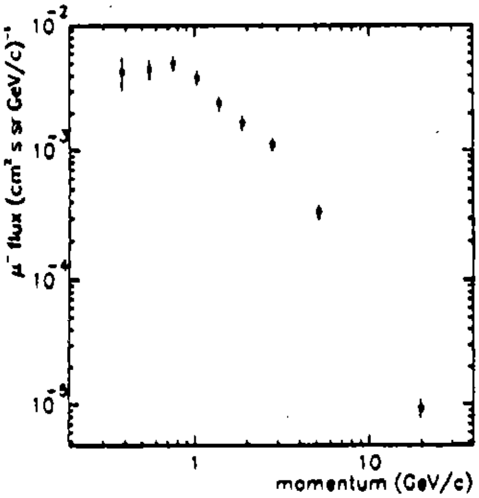

Fig. 1: Negative muon spectrum at 615 g/cm^2 average payload depth.

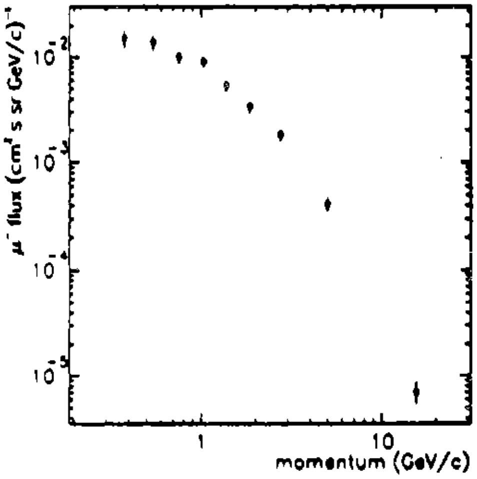

Fig 2: Negative muon spectrum at 283 g/cm^2 average payload depth.

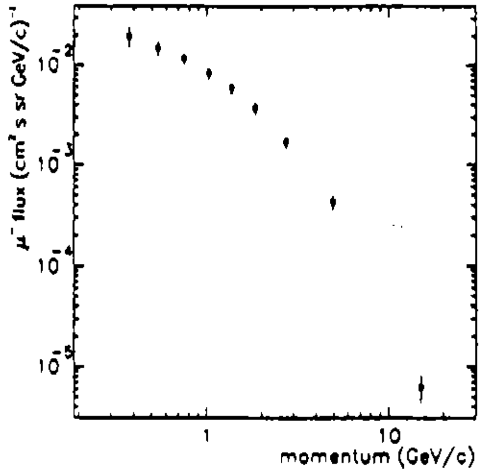

Fig. 3: Negative muon spectrum at 163 g/cm^2 average payload depth.

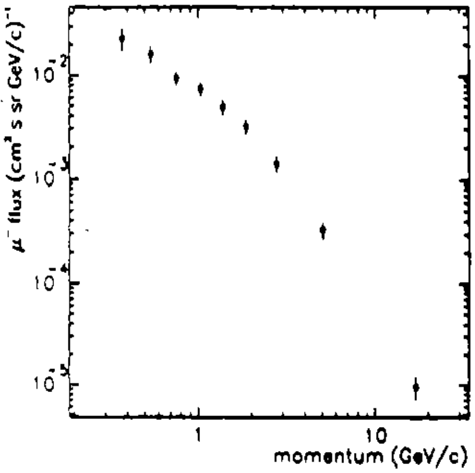

Fig. 4: Negative muon spectrum at 112 g/cm^2 average payload depth.

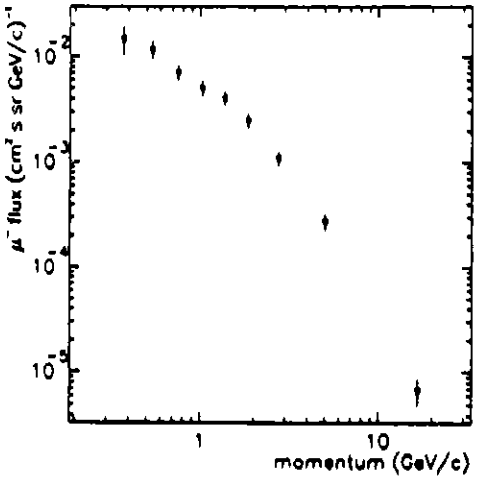

Fig. 5: Negative muon spectrum at 72 g/cm^2 average payload depth.

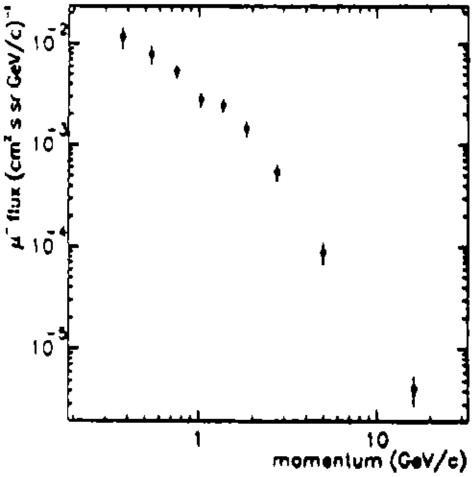

Fig. 6: Negative muon spectrum at 37 g/cm^2 average payload depth.

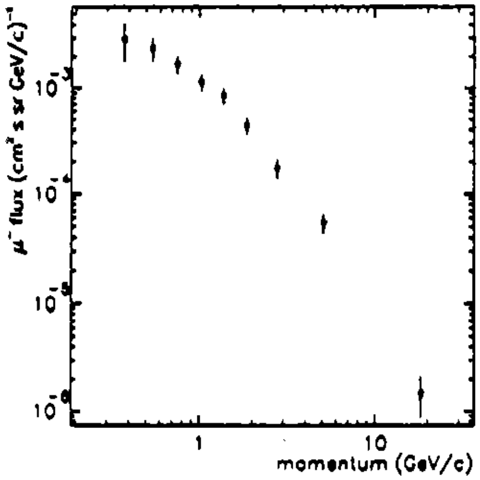

Fig. 7: Negative muon spectrum at 11 g/cm^2 average payload depth.

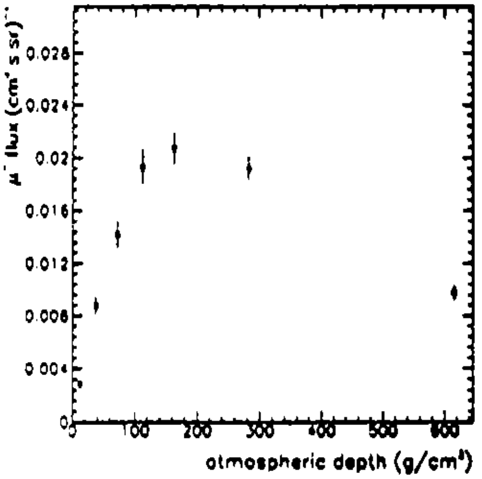

Fig. 8: Total negative muon flux in the 0.3-100 GeV/c momentum interval. Data are plotted at the average payload working depths.

At momenta less than 2 GeV/c, where the electron showers in the calorimeter become difficult to detect, the Cherenkov detector was used to get an estimate of the fraction of electrons in the muon sample and the flux values were corrected accordingly. The fraction of contaminating electrons at low energy is a function of energy and altitude. We are rather confident that no electron contamination should affect the measured flux at momenta above a few GeV/c. In order to account for the poorer resolution of the spectrometer at high energies, the number of spill-over particles, estimated by convolving the spectrum of the positive particles that survive the negative muon selection criteria with the resolution function of the spectrometer, was subtracted from muons in the highest energy bin. The possible contamination by pions and kaons was also studied, by comparing the present results with theoretical calculations at several altitudes in the atmosphere (Badhwar *et al.*, 1977). There could be an altitude-dependent pion contamination of the order of a few percent in the muon sample. The kaon contamination should be much smaller.

The negative muon flux has also been measured at the float altitude of 5 g/cm^2. The float altitude observations are reported in a separate paper at this Conference (Grimani *et al.*, 1993).

5. CONCLUSION

Data in Figure 8 can be used in order to evaluate the vertical profile of the negative muon flux in the atmosphere. This curve will serve both as a check on cosmic ray flux calculations in the atmosphere and as a boundary condition for atmospheric neutrino calculation. This is the first measurement of the muon flux as a function of altitude made over such a large altitude range with a single instrument. The room here is not enough to show all our results. They will be available at the Conference. The current evidence is that the flux profile is momentum dependent, the low energy muon flux peaking around 120 g/cm^2 and the higher energy muons penetrating to larger depths in the atmosphere. The spectral distribution of muons is affected accordingly.

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