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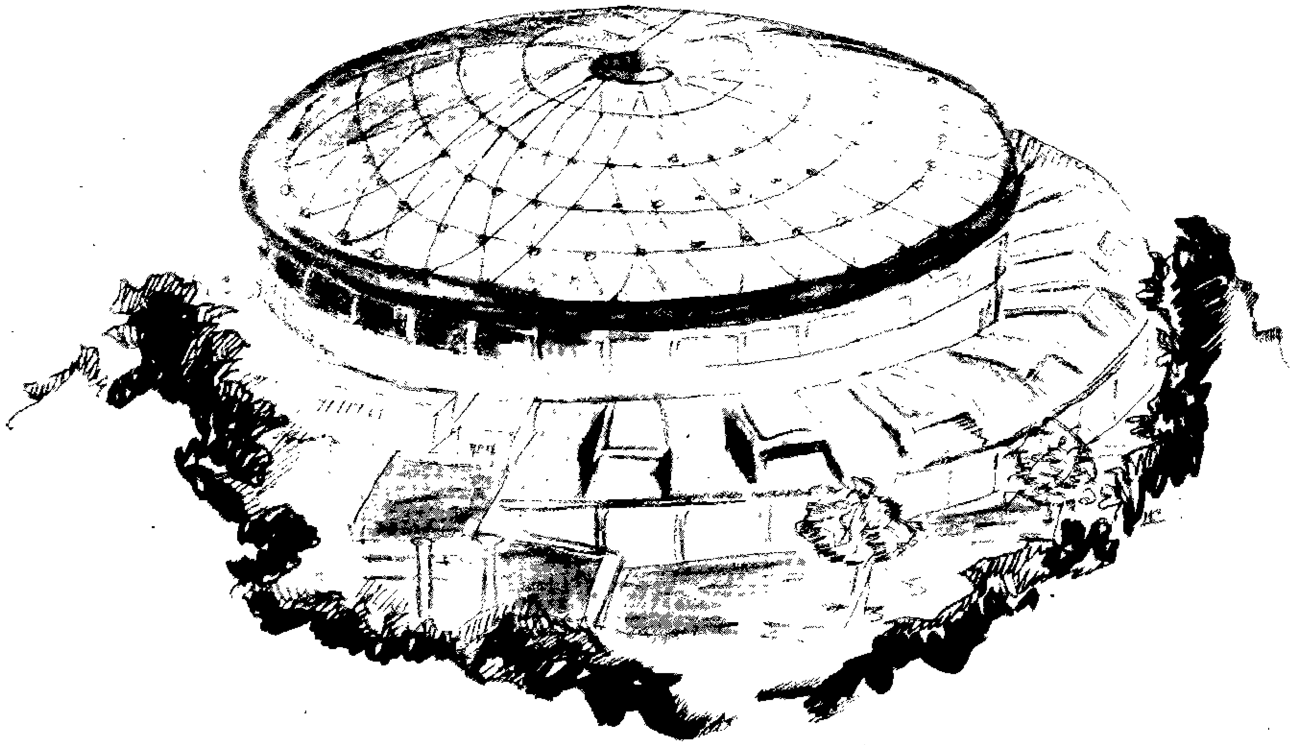

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Negative Muon Spectrum at 5 g/cm^2

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ABSTRACT

The negative muon spectrum at 5 g/cm^2 (atmospheric depth)has been measured in the momentum range 300 MeV/c - 15 GeV/c with the MASS experiment. This experiment was flown on September 5th 1989. The flight was launched from Prince Albert , Canada and spent about 5.5 hours at float. We present our preliminary results and compare them to theoretical calculations.

1. INTRODUCTION

The study of the muon flux at different atmospheric depths, provides information about how primary cosmic rays interact with and propagated through the atmosphere. At 5 g/cm^2, a typical atmospheric depth for balloon-borne experiments, muons in the energy range of the experiment are mainly generated by the decay of pions which are produced in hadronic interactions of primary cosmic rays with the atmosphere above the instrument. Kaon decay becomes an important source of muons above 100 GeV. Theoretical calculations have been carried out by several authors (Badhwar et al. (1977), Stephens (1981)). Negative muon measurements at balloon altitudes are made difficult by poor statistics and electron background. To our knowledge, this is the first negative muon measurement ever carried-out at 5 g/cm^2. We believe that this measurement is of great interest since these muons can give rise to neutrinos which can act as background for underground neutrino experiments.

2. EXPERIMENT

The MASS apparatus consisted of a magnetic spectrometer, a scintillator TOF system, a high resolution scintillator, a gas-Cherenkov detector and a streamer-tube calorimeter. The magnetic spectrometer and its performance, are described in Golden et al. (1991). A coincidence between the scintillator paddles of the TOF system generated the trigger for the experiment. The high resolution scintillator was located directly above the spectrometer and served as an entrance plane for the tracking system. In order to limit the number of events that miss the active volume of the tracking system, the on-board computer checked that the pulse-height in the high resolution scintillator is greater than 0.25 times the signal for a minimum ionizing particle before transmitting the events to the ground. The Cherenkov detector was filled with a 50 - 50 mixture of Freon 12 and Freon 22. This corresponds to a threshold Lorentz factor of 23. The Cherenkov counter consisted of a segmented mirror which focused the Cherenkov light on four phototubes. The calorimeter was comprised of 40 layers of brass streamer tubes. Each layer was divided into 64 cells. The 40 layers represent a total of 7.3 radiation lengths and 0.7 nuclear interaction lengths. The calorimeter data allows the topological structure of the particle's interaction to be reconstructed. (More details of the apparatus performance and characteristics are given in Basini et al., 1991 and references therein).

3. DATA ANALYSIS

In order to obtain the negative muon flux, the muon events must be separated from all other negative curvature events. Electron, antiprotons and upward moving albedo protons comprise the majority of the background events. The data analysis has been carried out using different criteria below and above the Cherenkov threshold for muons (2.4 GeV).

In the momentum range up to 2 GeV/c, where electrons are above the Cherenkov threshold, muon candidates were selected as particles that did not generate a Cherenkov signal (Cherenkov pulse-height <1 photo-electron). The chance rate for accidental Cherenkov signals has been found to be 5×10^{-4}. The low energy albedo protons were removed by using the TOF measurement. With a resolution of 256 ps, upward moving particle are separated form downward moving particles by more that 25 sigma.

Above 2.5 GeV/c muon candidates were selected as singly charge ionizing particles showing a Cherenkov signal. This cut removed the possible antiproton contamination since the antiproton Cherenkov threshold corresponds to 21.4 GeV. In order to remove electrons from the events above 2.5 GV/c, we required the muon candidates to have a single straight track in the calorimeter (i.e. no more than 2 calorimeter planes can show a shower cluster, Basini et al., 1991). This constraint was not applied at lower energies because the low energy electrons do not reliably show a clear shower in the calorimeter. Near the muon Cherenkov threshold (in the momentum range 2.0 - 2.5 GeV/c), the Cherenkov counter has a high inefficiency for muon detection. In this same range, the calorimeter also does not provide good discrimination of electrons and muons. Thus we do not report muon fluxes in the 2.0 - 2.5 GeV/c.

4. RESULTS

The muon flux obtained with our measurement is shown in Fig. 1 along with theoretical calculations (Stephens, 1981). In order to estimate the absolute flux, corrections were made for the geometric factor, the exposure time and the selection efficiencies. In the energy range up to 2 GeV the geometrical factor and the chamber efficiency are energy-dependent. This dependence has been discussed in De Pascale et. al., 1993. In this energy range the total elapsed time was of 12600 s. The dead-time associated with on board data processing was measured with an on-board timer. It was found to be 33% of the total elapsed time. Efficiencies for the Z=1 selection in the TOF system was found to be 0.97. The correction to the trigger geometry was found to be 0.82. Finally the live-time efficiency of the taper recording process was found to be 0.94. Above 2 GeV, we included data for the total elapsed time (19812 s) estimating the loss of particles for the events hitting the mirror while the phototube was not working. This loss of particles results in an additional Cherenkov inefficiency. Total efficiencies and data for flux calculation are given in Table 1. Also, in the energy range above 2.0 GeV/c, we used a restricted geometry, in order to assure that electron showers were completely contained in the calorimeter (Basini et al., 1991). This restricted geometrical factor is constant and equal to 80 cm^2 sr, and the trigger geometry correction was 0.90. Electron contamination in the low energy sample, due to the Cherenkov inefficiency for electrons (efficiency is 0.98) has been estimated considering the electron flux at the time of the flight (Basini et al. 1991). Below 1 GeV the contamination is about 1% and between 1 and 2 GeV about 3%. The possible contamination of negative pions and kaons in the muon sample has been studied (Stephens, 1981). The kaon flux at 5 g/cm^2 is of several order of magnitude smaller than the muon flux. We estimated a pion contamination at energies greater than 3 GeV to be a few percent and less than 1% at smaller energies.

Table 1

Kin. En. Interval (GeV)	Number of Events	Geom. Factor (cm^2 sr)	Total Efficiency	Flux (part/(m^2 sr s GeV))
0.213-0.318	94	74.6	0.257	40.96±4.22
0.308-0.406	119	94.0	0.282	36.36±3.33
0.406-0.504	126	104.6	0.299	32.63±2.90
0.504-0.603	95	113.3	0.316	21.27±2.18
0.603-0.702	83	117.0	0.325	17.50±1.92
0.702-0.801	77	119.2	0.332	15.60±1.78
0.801-0.900	61	120.8	0.338	11.98±1.53
0.900-1.10	98	121.9	0.338	9.44±0.95
1.10-1.30	84	123.7	0.342	7.88±0.86
1.30-1.50	64	125.0	0.343	5.92±0.74
1.50-1.90	73	126.2	0.343	3.35±0.39
2.42-3.91	62	80.0	0.148	1.77±0.22
3.91-5.90	36	80.0	0.284	0.40±0.07
5.90-8.90	22	80.0	0.306	0.15±0.03
8.90-14.90	8	80.0	0.306	0.027±0.01

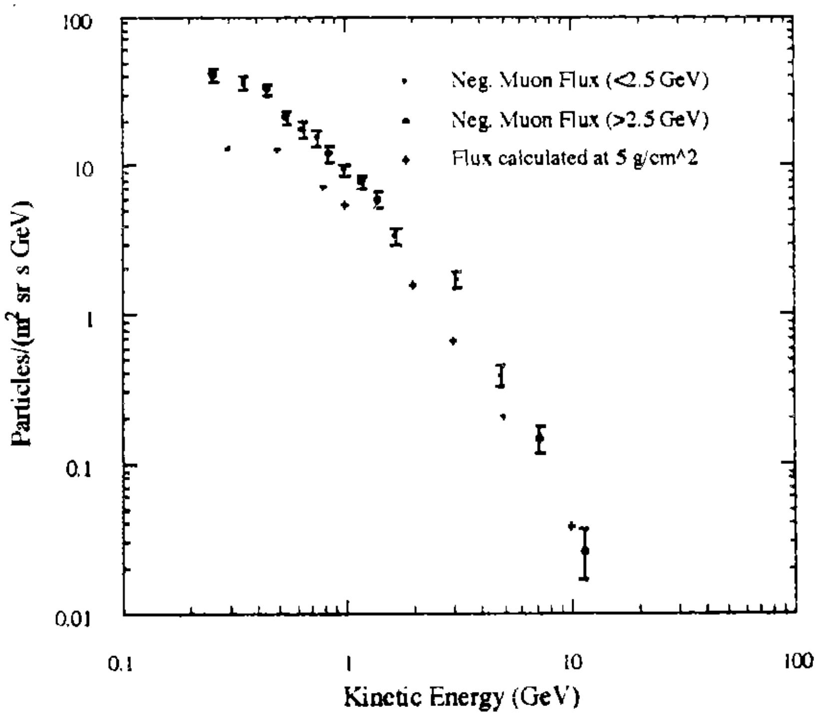

Fig 1 : Measured and calculated negative muon flux as a function of kinetic energy

5. DISCUSSION

Figure 1 shows that at lower energies (0.4 - 1.0 GeV), the observed muon flux is about two times greater than predicted. At 3 GeV the fluxes again differ by about a factor of 2 but above that energy the observed spectrum falls more rapidly than predicted. We are currently investigating the possibilities of errors in event selection, efficiency determination and in the prediction to try to resolve the differences. The reader is reminded that the muons are difficult to identify and that absolute fluxes require painstaking care in the efficiency measurements.

Muon fluxes lower in the atmosphere are reported in a separate paper at the conference (Circella et al.,1993)

6. ACKNOWLEDGMENTS

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REFERENCES

Badhwar G. D., Stephens S. A., Golden R. L.:1973, Phys. Rev., **D 15**, 820.
Basini G.et al.:1991, Proc., 22th Internat. Cosmic Ray Conf., Dublin (Ireland),**2**, 137, also submitted to Ap. J.
Circella, M., et al.:1993 presented at this conference
De Pascale, et al.:1993, Journal of Geophysical Research, **9 8** 3501.
Golden R. L. et al.:1991, Nucl. Instr. Meth., **A 306**, 366.
Golden R. L. et al.:1979, Phys. Rev. Lett. ., **4 3**, 1264.
Stephens S. A.: 1981, Proc. 17th Internat. Cosmic Ray Conf., Paris (France),**4**, 282. .