Measurement of the Cosmic Ray Induced Muon Flux through the Atmosphere using IMAX

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Abstract

Measurements of both the positive and negative components of the atmospheric muon flux have been performed using the Isotope Matter Antimatter eXperiment (IMAX). The experiment was flown from Lynn Lake, Manitoba, Canada (56° latitude, geomagnetic cutoff $\approx$ 100 MV) on July 16-17, 1992 and experienced a 7+ hour ascent from approximately 0.3 km to 36 km above sea level. Preliminary measurements of the muon flux and charge ratio in the momentum interval $0.42 \rightarrow 0.47$ GeV/c at the top of instrument (TOI) as a function of atmospheric depth are presented. The relevance of these results in the context of the atmospheric neutrino anomaly is discussed.

1 Introduction

Balloon-borne astroparticle physics experiments offer a unique resource in their ability to measure particle fluxes through the atmosphere. In particular, the measurement of the secondary muon flux as a function of atmospheric depth can be employed to indirectly measure the atmospheric neutrino flux [1] which is used to predict neutrino interaction rates in deep underground experiments. These experiments such as Kamiokanda [2], IMB [3], and Soudan [4] have determined that a statistically significant discrepancy exists between the values of the calculated versus measured atmospheric neutrino interaction flavor ratios. This effect is known as the atmospheric neutrino anomaly. Furthermore, an analysis of higher energy neutrino interactions in the Kamiokanda experiment has indicated that the anomaly has a possible zenith angle (hence possible neutrino path length) dependence [5]. A comparison [6] of the calculated [7, 8] muon neutrino flux to that measured by Kamiokanda favors the source of the atmospheric neutrino anomaly as being a ν_μ *deficit* as opposed to a ν_e excess. As neutrinos in the energy range of interest predominantly come from pion decay [1], accurate measurements of the secondary muon and pion fluxes through the atmosphere can help better quantify the source of the atmospheric neutrino anomaly [7, 9]. This motivates a program we have begun using the IMAX instrument to measure the individual fluxes of positive and negative muons and pions as a function of atmospheric depth. This paper reports on the preliminary results of the muon analysis.

2 The IMAX Apparatus

The IMAX apparatus [11] consisted of a magnetic spectrometer (MDR $\approx$ 200 GV for $Z = 1$), a time-of-flight (TOF) system, two aerogel Cherenkov counters, a Teflon Cherenkov counter, and two dE/dx scintillator counters. A single coil superconducting magnet provided a $0.1 \rightarrow 2.1$ Tesla magnetic field in the tracking volume. Charged particle tracking was performed via two drift chambers and three sets of MWPC's which were located above, below, and in between the drift chambers. This combination yielded 20 planes of measurements in the bending plane (x) and 12 in the non-bending plane (y). The two aerogel Cherenkov counters ($n = 1.043$) yielded threshold momenta of 0.35 GeV/c for muons, 0.47 GeV/c for pions, and 3.2 GeV/c for protons. The TOF system ($\sigma_t = 122$ psec for β, $Z = 1$) was formed by two planes of scintillators separated by 2.5 meters. Each plane of TOF scintillator was comprised of three individual paddles. The event trigger was formed by a four-fold coincidence between the PMT's on the upper and lower TOF paddles. The nominal geometry factor of IMAX was 143 cm^2-ster at rigidities larger than 1 GeV/c and 115 cm^2-ster for a rigidity of 0.4 GV/c.

3 Event Selection Criteria and Analysis

The strategy of the data reduction was first to accurately identify singly charged tracks in the instrument. This was then followed by criteria which rejected any non-muonic backgrounds. The selection requirements are similar to those reported in [12] with less restrictive requirements on the deflection error (< 0.03), χ^2_x (< 6), and χ^2_y (< 8) as determined by the track fitting procedure. The selection criteria required a well measured, $Z = 1$ track within the active elements of the apparatus. In the momentum range $0.42 \rightarrow 0.47$ GeV/c (TOI), only muons and electrons are above the aerogel Cherenkov threshold while pions, kaons, protons, and heavier nuclei are below threshold. Electrons and any sub-threshold particles producing δ-rays are rejected by restricting the accepted aerogel light yield (Figure 1).

The efficiency for accepting muons was determined by comparing the I-MAX positive and negative muon spectra at 0.3 km above sea level in the

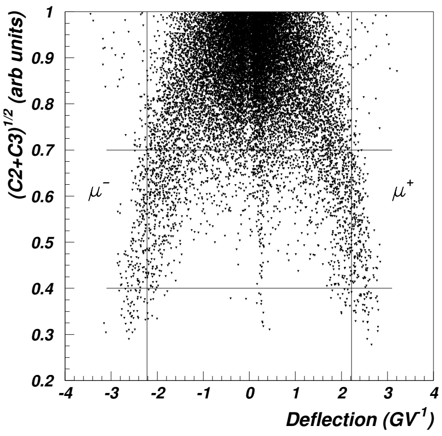

Figure 1: *The aerogel selection criteria used to define IMAX muons using the 0.3 km above sea level data set.*

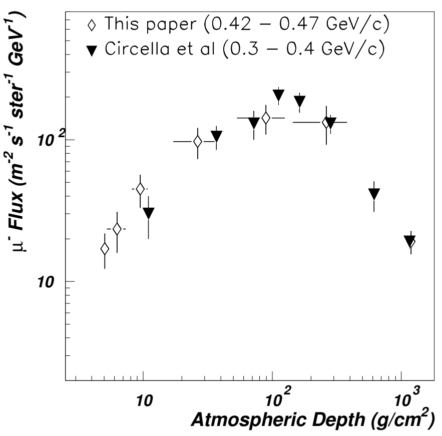

Figure 2: *The differential μ^- flux as a function atmospheric depth as measured my IMAX and MASS experiments.*

momentum range of interest to that of De Pascale et al [13] which was measured at a similar atmospheric depth. This methodology yields an IMAX μ^+ acceptance of 0.248 ± 0.041 (statistical) and 0.212 ± 0.036 (statistical) for μ^- in the momentum range 0.37 GV/c $\leq R \leq$ 0.47 GV/c (TOI).

Using the flight times, livetimes (nominally 75%), muon acceptances, and the IMAX geometry factor, the measured positive and negative muon event rates were each converted to a flux as a function of atmospheric depth. The μ^- flux is presented in Figure 2 along with that from the MASS experiment [10] for comparison. The charge ratio of μ^+/μ^- as measured by IMAX as a function of atmospheric depth is shown in Figure 3.

4 Discussion

As previously stated, the IMAX results presented in this paper are preliminary. At the time of writing, the effects and magnitude of systematic errors were still being determined. Alternate methods for ascertaining the muon acceptances were also under investigation. However, the initial results indicate that IMAX should be able to accurately measure particle fluxes in several momenta ranges through the atmosphere and at low atmospheric depths.

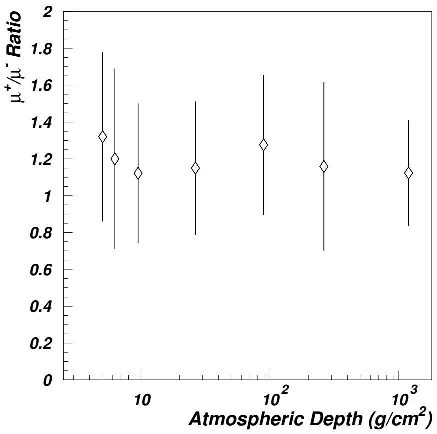

Figure 3: *The μ^+/μ^- ($0.42 \leq p < 0.47$ GeV/c (TOI)) ratio measured by IMAX as a function of atmospheric depth.*

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