A Measurement of the Proton and Helium Components in the Atmosphere

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Abstract

We report on the measurements of the proton and helium components in the atmosphere from the data collected by the MASS apparatus during the ascent of the balloon-borne experiment of 1991. The detector configuration was such that proton identification was possible both below 1 GeV/c and in a higher momentum range, 5–15 GeV/c. The helium component was studied above the vertical geomagnetic cutoff rigidity of 4.5 GV. We point out the different dependences on atmospheric depth for low energy secondary protons with respect to primary particles. In addition, we have measured sigificantly different attenuation lengths for protons and helium nuclei, consistently with the expectations.

1 Introduction

Balloon-borne detectors deployed for cosmic ray measurements at stratospheric altitudes collect data over a large range of atmospheric depth during the ascent phases of the experiments. This occurrence make it possible to perform investigations of the dependence of the different components of cosmic rays on energy and altitude. Based on this approach, several muon measurements from balloon experiments have been reported in the last few years (see Circella et al. 1999 and references therein). The importance of such measurements has been increasing together with the increasing evidence of the atmospheric neutrino anomaly. This is due to the possibility of cross-checking the atmospheric neutrino calculations with comparisons of the expected fluxes of muons to muon measurements.

In this work, we propose a study of the dependence of the nucleon component (namely, protons ans helium nuclei) on atmospheric depth. These measurements may also serve for a cross-check of the codes for atmospheric shower simulations. In fact, nuclear measurements in the atmosphere can provide more direct constrains on the hadronic part of the simulations than muon measurements, since muons are not among the direct products of the interactions and in addition can propagate for long distances in the atmosphere before being detected.

On the other hand, protons represent a significant background source for secondary particle measurements in the atmosphere. In fact, this is the main reason why positive muon investigations from this and other experiments were typically limited to momenta lower than 2 GeV/c. Measurements of the proton flux as a function of atmospheric depth may therefore help in the design of experiments devoted to the measurements of high altitude particle fluxes (see, for instance, G. Fiorentini et al. 1999).

2 The Experiment

The Matter Antimatter Spectrometer System (MASS) apparatus was flown from Ft. Sumner, NM on September 23, 1991. This location is at a vertical geomagnetic rigidity cutoff of about 4.5 GV. The apparatus consisted of the WiZard/NMSU superconducting magnet spectrometer equipped with a hybrid tracking device consisting of multiwire proportional chambers and drift chambers, and complemented by a scintillator time-of-flight (ToF) device, a gas Cherenkov detector and an imaging brass streamer tube calorimeter. The detector is described in some more details elsewhere at this Conference (Basini et al. 1999).

The data file analyzed in this work, taken during the ascent of the flight, contained information on more than $240\,000$ triggers collected in $9\,820$ s.

In Figures 1 and 2 we show how the different components of cosmic rays may be separated by means of the scintillator measurements at low energy in this experiment. In particular, the effects of the geomagnetic suppression can be seen in the dramatic suppression of the helium component below the geomagnetic cutoff (i.e., deflection larger than about 0.22 GV^{-1}). It is clear from this plot, then, that the low-energy component of protons has to be of a secondary nature.

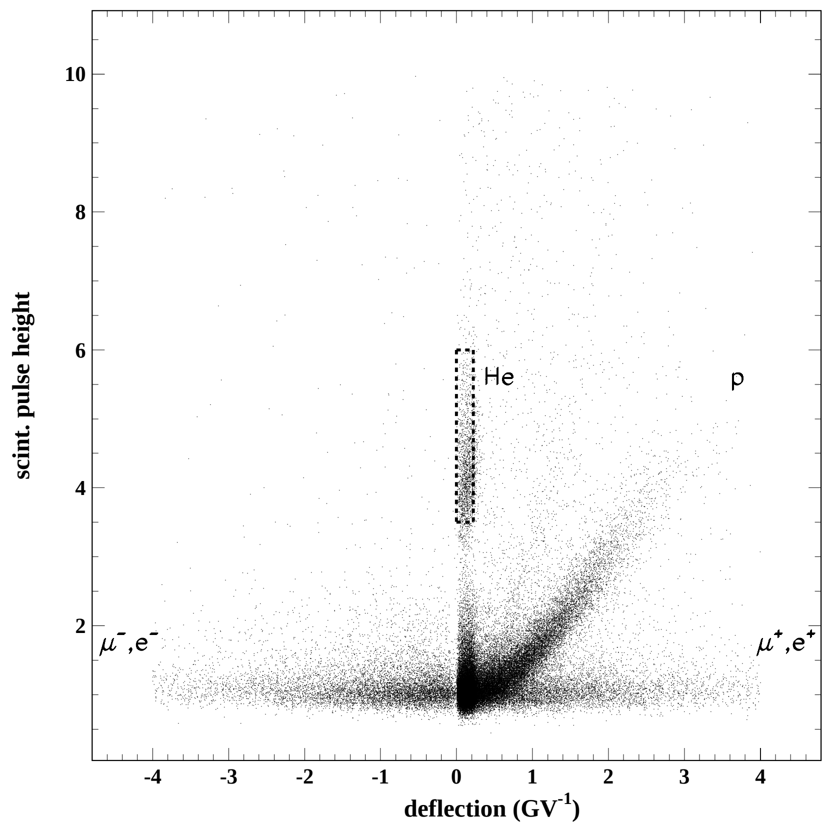

Figure 1: Scintillator pulse height as a function of magnetic deflection for particles collected during the ascent of the flight. The scintillator signals have been normalized with respect to the average signals from minimum ionizing singly charged particles. The helium selection is shown by a dashed line. The number of events in this plot, as well as in Fig. 2, is $56\,944$.

Low energy protons can be discriminated from lighter particles either by means of the pulse height information, as from Fig. 1, or more efficiently by means of the ToF measurement, as from Fig. 2. Protons below 1 GeV/c were indeed identified in this work by means of a selection on the mass value estimated for the events by means of the combined measurements of velocity $\beta = v/c$ and deflection η:

$$\frac{\frac{1}{\beta^2} - 1}{\eta^2} \times Z^2 e^2. \qquad (1)$$

High energy protons were selected by means of the Cherenkov detector information. In fact, the threshold for Cherenkov emission in the freon radiator was $\gamma_{th} \approx 25$, corresponding to about 25 GV for a proton, 3.5 GV for a pion and 2.6 GV for a muon.

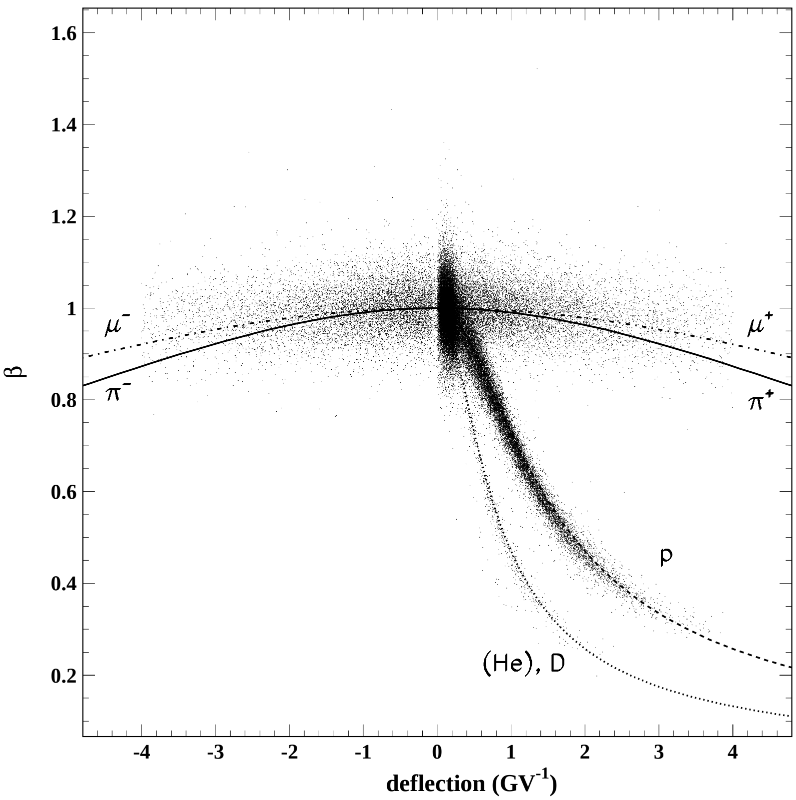

Figure 2: Velocity measurement from the ToF system as a function of magnetic deflection for particles collected during the ascent of the flight.

Therefore 5–15 GV protons may be identified by requiring that the particles do not show any Cherenkov signal. This selection will leave negligible residual background from lighter particles because of the low inefficiency of the detector for particles above threshold and of the relative ratios of the proton flux to those of the other components.

Helium events were selected in the 5-20 GV rigidity range (1.7–9.1 GeV/n kinetic energy) at the spectrometer by means of the selection requirement shown in Fig. 1 plus a consistency check between the signals collected from the different phototubes (for more details, see Bellotti et al. 1999). This selection may not completely remove the proton contamination due to energy-loss fluctuations. An altitude-dependent fraction of residual proton contamination (of the order of a few percent at maximum) was therefore estimated and subtracted from the helium sample.

Finally, we note from a comparison of Fig. 2 to Fig. 1, that a low-energy component of deuterium is also present in the data sample. These events have not been explicitly considered in this analysis: the low-energy events were removed by means of a ToF selection, and will be investigated separately. No proton/deuterium discrimination is available at higher energies.

3 Results and Discussion

We have performed separate analyses for particles below and above the vertical geomagnetic cutoff. At low energy it turns out that protons are of a secondary origin. The depth dependence of sub-GeV/c protons will be illustrated at the Conference.

On the contrary, primary particles can also be measured above the geomagnetic cutoff. In this case the proton flux is expected to attenuate almost exponentially with atmospheric depth. However, under the hypotheses of scaling of the interaction cross-sections and of power-law spectra of the particles, the attenuation length for this exponential attenuation is expected to be significantly larger than the particle interaction length on the atmospheric nuclei.

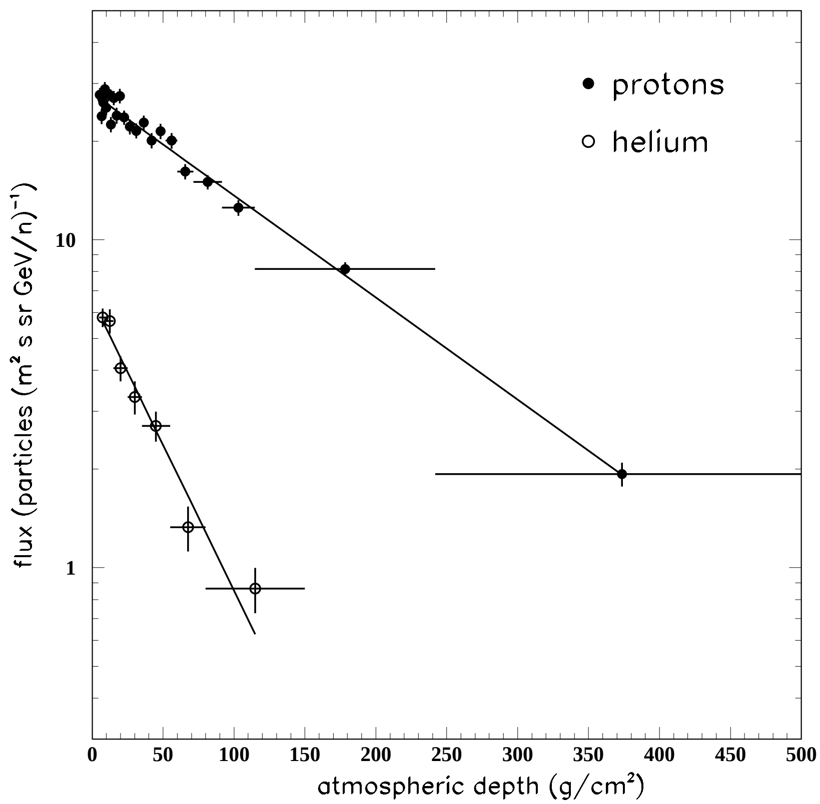

Figure 3: Helium and proton fluxes as a function of atmospheric depth. The helium events were selected in the 1.7–9.1 GeV/n kinetic energy range. The proton events were selected in the 4.1–14.1 GeV kinetic energy range.

This occurrence is confirmed from the results in Fig. 3, where we show the flux measurements of protons and helium nuclei collected respectively in the 5–15 GV and 5-20 GV rigidity ranges at the spectrometer. The data in the figure have been corrected for the fraction of events lost due to interactions in the payload. Efficiency factors have also been introduced in order to calculate absolute fluxes.

An exponential attenuation length for protons of about $\Lambda_p \approx 126 \pm 5$ g/cm^2 can be estimated from the results in this figure. The helium data show a significantly smaller attenuation length, being $\Lambda_{He} \approx 49 \pm 4$ g/cm^2. Both these values are consistent with the expectations. For instance, Hatano et al. (1995) assume $\Lambda_{He} = \lambda_{He}/(1-p)$, λ_{He} being the helium interaction length in the atmosphere with $p = 0.92$–0.98 representing the contribution to the helium flux due to nuclear spallation of heavier nuclei, and $\lambda_{He} = 50$ g/cm^2 according to Papini, Grimani & Stephens (1996).

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