Composition of cosmic ray particles in the atmosphere as measured by the CAPRICE98 balloon borne apparatus

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Abstract

We report a measurement of the composition and spectra of both the primary and secondary cosmic ray particles at different depths in the atmosphere. The data were collected by the balloon–borne experiment CAPRICE98 during the ascent of the payload on 28 May 1998 from Fort Sumner, New Mexico. The identification of various kinds of particles, such as, protons, deuterons, helium nuclei, electrons and positrons was possible in various energy ranges depending on the kind of particle and the particle background at different residual atmosphere. These measurements, together with the atmospheric muon spectra, will allow fine–tuning of models used in air shower simulations.

1. Introduction

Recently, the importance of the programs for simulation of atmospheric showers has been emphasized in connection to the atmospheric neutrino observations performed by underground experiments, e.g. Super–Kamiokande [6]. In

fact a correct interpretation of these measurements depends on the accuracy of the predictions to which they are compared.

One of the main sources of inaccuracies is the model used in the simulations to reproduce interactions in the atmosphere. Usually air shower simulations are compared with the experimental muon spectra in the atmosphere [3]. Accurate measurements of the spectra of different kinds of particles in the atmosphere and of the attenuation of the spectra of the primary cosmic rays components provide an additional tool for the fine–tuning of models used in air shower simulations.

2.   The CAPRICE98 experiment

The balloon–borne CAPRICE98 detector was flown from Ft. Sumner, New Mexico, USA on May 28–29, 1998 at a vertical rigidity cutoff of about 4.3 GV. The data analyzed for this work were collected during the ascent of the payload with an exposure time of about 3 hours. Data at float were collected at an average atmospheric depth of about 5.5 g/cm^2 in almost 21 hours. Ground data (885 g/cm^2) were collected before the flight with a 15 hours long run.

The apparatus consisted of a superconducting magnet spectrometer, a time–of–flight device, a gas ring imaging Cherenkov detector (RICH) and a silicon–tungsten imaging calorimeter. More details on the instrumental setup and capabilities of this experiment can be found in previous publications (i.e. [1]).

3.   Data analysis

The selection of particles was different depending on the kind of particle, on the atmospheric depth and on the energy range. Atmospheric binning was the result of a compromise between the need of having a good statistics and a significant number of atmospheric bins.

The efficiencies of each detector were determined by selecting independent samples of different particle types during the ascent of the payload. The number of detected particles was corrected in order to compensate for the fraction of events lost due to interactions in the payload. Systematic uncertainties are discussed in detail in [4].

Proton spectra. Protons in the atmosphere can be reliably identified using the time–of–flight information below 1.2 GV.

Above this energy the RICH was used to identify protons. While deuteron, pions and positrons contamination was negligible in the whole energy range, muon contamination had to be subtracted in the energy range from 1.2 to 3 GV and above 50 GV in the atmospheric bin from 65 to 90 g/cm^2 (open circles in Fig. 1 upper left). The subtraction was made using a parametrization of the muon spectra in the atmosphere as measured by the CAPRICE98 experiment [3].

Figure 1 upper left shows the resulting proton spectra in the atmosphere

and at float (spectrum scaled by a factor 10^{22}). The atmospheric bin was from 15 to 33 (scaled by 10^{20}), 33 to 65 (10^{18}), 65 to 90 (10^{16}), 90 to 120 (10^{14}), 120 to 150 (10^{12}), 150 to 190 (10^{10}), 190 to 250 (10^8), 250 to 380 (10^6), 380 to 581 (10^4), 581 to 885 (10^2) g/cm^2. The primary and secondary components can be distinguished: the primary component dominates at high energy and is attenuated by the atmosphere while the secondary component dominates at low energy and in all the energy range deep in the atmosphere. Note that the secondary component includes both protons resulting directly from interaction of primary particles and reentrant albedo protons. Also shown are ground data from both the CAPRICE98 and the CAPRICE97 [7] experiments (scaled by a factor 1). The spectrum at the top of the atmosphere (TOA, scaled by a factor 10^{24}) is published in [4]. An exponential attenuation length for protons of $\Lambda_p = 121 \pm 4$ g/cm^2 can be estimated from the results in the energy bin from 9.1 to 49 GeV, Fig. 1 lower right open circles scaled by a factor 10. This value is consistent with the expectation value of $\Lambda_p = 120$ g/cm^2 [9] and with the MASS results [5] not shown in figure.

Helium nuclei spectra. Helium nuclei in the atmosphere can be reliably identified using the dE/dx measurement of the scintillators in the whole rigidity range and with a negligible contamination of particles with different charge. Essentially no helium nuclei were detected below 0.8 GeV/n nor above 160 g/cm^2 of residual atmosphere.

Figure 1 upper right shows helium nuclei spectra at float (spectrum scaled by a factor 10^3) and in the atmospheric bins from 7 to 30 (10^2), 30 to 80 (10), 80 to 160 (1) g/cm^2. Data at the top of the atmosphere are published in [4] (scaled by 10^4). As can be seen from Fig. 1 lower right the helium nuclei attenuation length, in the energy bin from 1.7 to 9.1 GeV/n, is smaller than in the case of protons, being $\Lambda_{He} = 49 \pm 3$ g/cm^2. This value is in a very good agreement with the expected value of 50 g/cm^2 [8] and with MASS experimental results [5].

Deuteron spectra. Secondary deuteron with energy below 2 GV were identified using the time–of–flight information. Between 25 and 40 GV the RICH is able to separate deuteron from protons but the statistic in the atmosphere was too low (for the cosmic spectrum of deuteron see [2]).

Figure 1 lower left shows results at ground (spectrum scaled by a factor 1), at float (10^5) and in the atmospheric bins from 9 to 17 (10^4), 17 to 41 (10^3), 41 to 94 (10^2), 94 to 226 (10), 226 to 582 (1) g/cm^2. Being a measurement of a pure secondary spectrum no attenuation length can be determined.

The analysis of the electrons and positrons spectra is in progress and results will be presented at the Conference.

4. References

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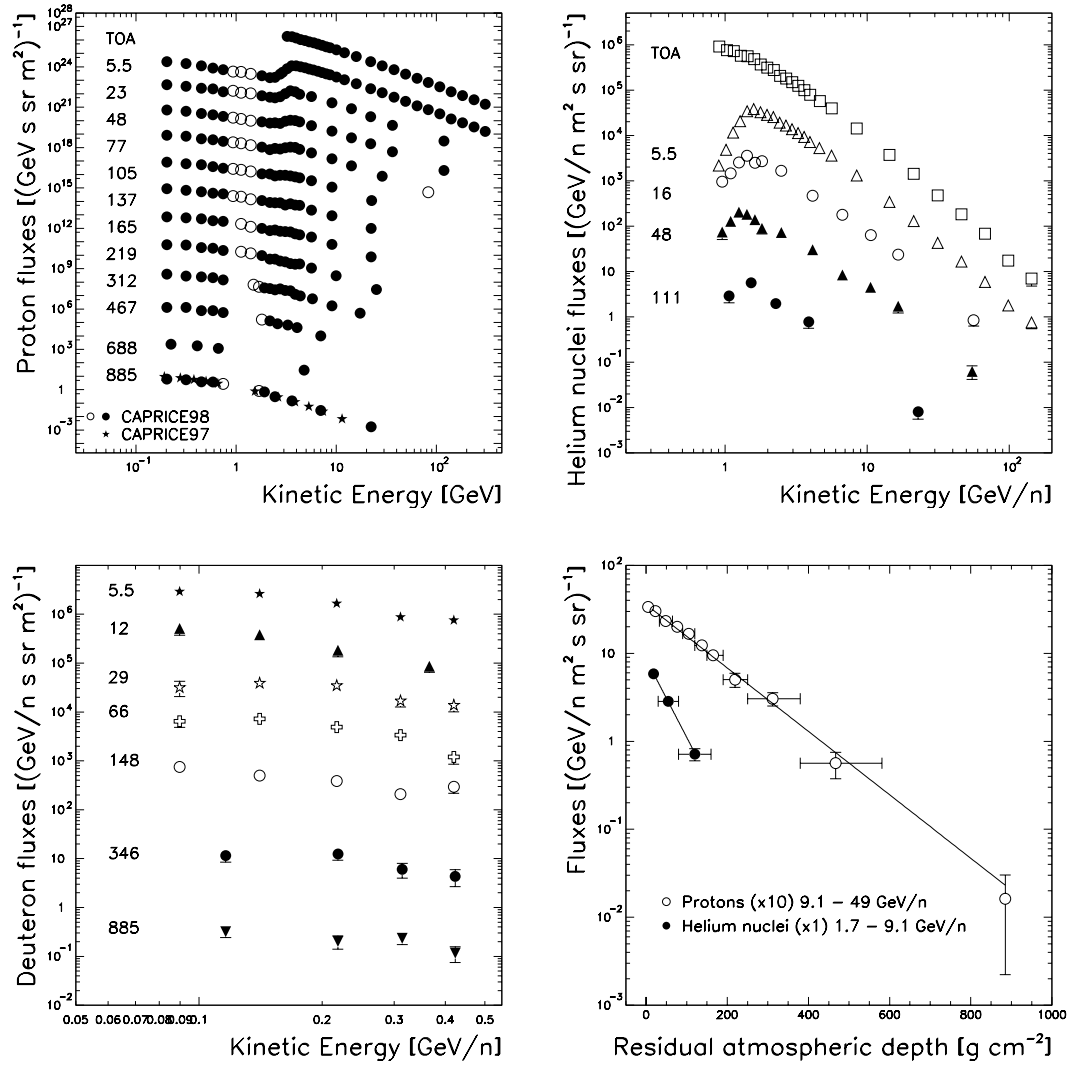
Fig. 1. From the upper left clockwise: the proton spectra, the helium nuclei spectra, the proton and helium nuclei fluxes as function of the atmospheric depth and the deuteron spectra. Spectra are scaled as described in the text, the average residual atmospheric depth is reported and expressed in g/cm^2.

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