Atmospheric proton and helium fluxes compared to AIRES simulation results

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Abstract

Air shower simulation programs are important tools for estimating distributions of particles of different kinds, and that can be measured experimentally. The region of interest spans many orders of magnitude in primary energy, from atmospheric fluxes measured in balloon–borne experiments up to the highest energy cosmic rays detected at the Auger Observatory, for example. The comparison of observed rates of atmospheric neutrino interactions with calculated ones also requires accurate air shower simulations. In this paper we compare the CAPRICE98 results on atmospheric fluxes of protons and alpha particles with results from the AIRES simulation program. The energy range depends on the residual atmosphere and on the kind of particle. Detailed measurements of atmospheric fluxes allow fine–tuning of the models used in the air shower simulations.

1. Introduction

Comparing measurements of fluxes of muons and other particles at different altitudes with simulated data is a powerful tool to check and calibrate air shower simulation programs.

Such programs are not only essential to predict the atmospheric neutrino flux, but also play an important role in the analysis of data taken at highest energy air shower experiments like Auger [9], AGASA [6] or HiRes [5]. They are also used in Cherenkov light detector experiments like AMANDA [2] or ANTARES [3] to estimate backgrounds from atmospheric neutrinos.

In this work we make a comparison between the direct measurement of the flux of protons and helium nuclei in the atmosphere by the CAPRICE98 experiment [10] and the corresponding simulated values obtained from the air shower simulation program AIRES [11].

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2. The AIRES simulator

The AIRES program is a 3D Monte Carlo simulator where the majority of the processes that may undergo the shower particles are taken into account. AIRES has also the advantage of including effects of the curvature of the Earth and of the geomagnetic field. The AIRES program has the possibility to swap between different hadronic models and it includes links to two well–known external hadronic interaction packages, namely SIBYLL [7] and QGSJET [8].

The AIRES simulation engine provides full space–time particle propagation in a realistic environment, taking into account the characteristic of the atmospheric density profile, the curvature of Earth, and the geomagnetic field (calculated in this work for the location and date of the CAPRICE98 flight).

3. The CAPRICE98 experiment

The balloon–borne CAPRICE98 detector was flown from Ft. Sumner, New Mexico, USA on May 28–29, 1998 at an average 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]).

The CAPRICE98 spectrometer accepted particles arriving with an inclination with respect to the vertical axis of less than 20°. This characteristic was taken into account in the simulation in order to reproduce correctly the experimental results.

4. Results and discussion

In the present work, AIRES (linked to SIBYLL) has ben used to simulate showers with primary energies from 2 GeV up to 50 TeV. An interpolation of the flux of protons and helium nuclei as measured by the CAPRICE98 experiment [4] was used as input flux.

The flux at very high energies was obtained extrapolating the experimental data while the flux at low energy was the flux at the top of the atmosphere modulated with the geomagnetic cutoff function as measured by the CAPRICE98 experiment. In fact, it was noticed that by propagating the flux at the top of the atmosphere back to ground from an altitude of 100/200 km a.s.l. it was not possible to reproduce the experimental geomagnetic cutoff even if the simulated

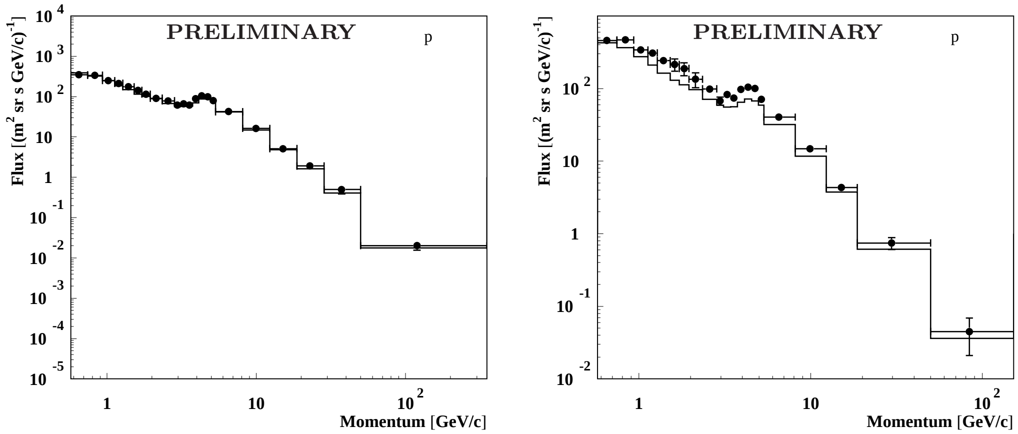

Fig. 1. Proton spectrum at 48 (on the left) and 77 g/cm^2 (right); circles CAPRICE98 data (preliminary), full lines AIRES simulation.

geomagnetic field was correct. This is due to the fact that low energy particles will never reach the injection point due to the geomagnetic field of the Earth and to the fact that the experimental data extrapolated at the top of the atmosphere refer to 0 g/cm^2 residual atmospheric depth, i.e. an altitude of the order of $10^3/10^4$ km a.s.l.. At present AIRES cannot accept injection altitudes of more than 400 km.a.s.l. and accurate models of the geomagnetic field are needed to follow particles injected from the outer space; for this reason AIRES is used in this work only to simulate the fluxes within the atmosphere, below 100 km.a.s.l.

The simulation was performed in the same atmospheric and energy binning as the experimental data presented in [10].

Figure 1 shows a comparison of simulated and experimental proton data at 48 and 77 g/cm^2 of residual atmospheric depth (preliminary data). The simulation is in a good agreement with experimental data. 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. Note that the experimental secondary component includes both protons resulting directly from interaction of primary particles and reentrant albedo protons. The difference between simulation and experimental data at low energy can be explained with the later one.

Figure 2 shows the comparison between simulated and experimental helium nuclei data at 5.5 and 15 g/cm^2 (preliminary data). Again a good agreement between simulated and experimental data can be noticed. In the helium nuclei case only the attenuating primary component was measured by the CAPRICE98 experiment [10].

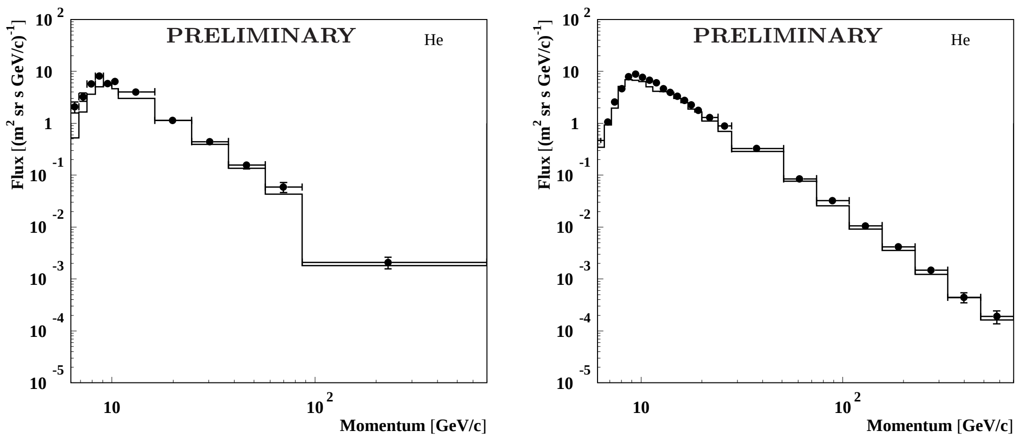

Fig. 2. Helium nuclei spectrum at 15 (on the left) and 5.5 g/cm^2 (right); circles CAPRICE98 data (preliminary), full lines AIRES simulation.

5. References

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