Atmospheric Protons and Antiprotons from sea level to satellite altitudes

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Abstract

The cosmic $\overline{p}$ flux have recently been measured by several balloon experiment but although the measurement was made at hight altitude, the atmospheric $\overline{p}$ contribution is significant and have to be subtracted. This requires a precise description of the particle interaction and propagation in the atmosphere for p, n and $\overline{p}$. Here the secondary atmospheric p and $\overline{p}$ flux are studied by means of a Monte-Carlo simulation procedure. The calculated flux are compared with the available experimental measurements from sea level up to the top of atmosphere (TOA). The agreement with data are very good at all altitudes, and a new estimation of $\overline{p}$ flux at balloon altitude is shown. The calculation are extended at higher altitudes up to 10 Earth radii, to study the extension of the quasi-trapped particle belt beyond the atmosphere.

1. Introduction

Cosmic $\overline{p}$ have been experimentally studied for several decades by satellite or balloon borne experiments (see references in [3]). Recent balloon experiments (BESS [11][10], CAPRICE [3]) have collected new data samples whose analysis have provided determinations of the galactic $\overline{p}$ flux. In these works, the values of the galactic $\overline{p}$ flux were obtained by subtracting the calculated atmospheric $\overline{p}$ flux from the values of the measured total flux. A precise description of both the p, n and $\overline{p}$ atmospheric production and propagation is needed to get a accurate estimation of the $\overline{p}$ atmospheric contribution

2. Simulation

The flux of secondary atmospheric protons and antiprotons has been investigated using the same simulation approach which allowed to successfully account for the p, d, He, and $e^{\pm}$ experimental flux below the Geomagnetic Cutoff measured by the AMS experiment.

The calculation proceeds by means of a full 3D-simulation program. Incident Cosmic Rays are generated on a virtual sphere chosen at a 2000 km altitude. The geomagnetic cut-off is applied by back-tracing the particle trajectory

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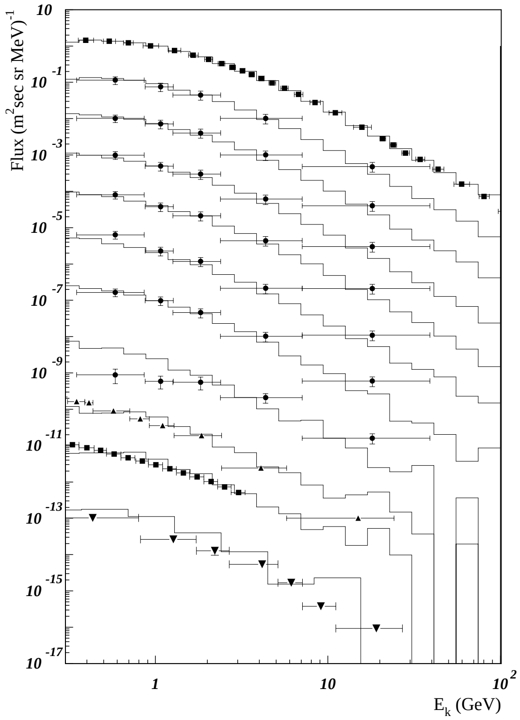

Fig. 1. Simulated p flux in the atmosphere (histograms) compared to experimental results (symbols) between TOA and sea level. From top to bottom: CAPRICE TOA [2] (full squares), CAPRICE 94 [8] (7 altitudes: 29.9, 22.1, 17.5, 16, 12.6, 9.9, 5.75, in km), Kocharian et al., [9] (3.2 km, full triangles), BESS [7] (2.77km, full squares), Diggory et al., [6] (sea level, inverted full triangles).

in the geomagnetic field, and keeping in the sample only those particles reaching a backtracing distance of 10 Earth radii. For the incident proton and helium flux, the 1998 AMS measurements were used [1] and are corrected for different solar modulation strength using a simple force law approximation. Each particle is propagated in the geomagnetic field and interacts with nuclei of the local atmospheric density according to their total reaction cross section and producing secondary nucleons p, n, and antinucleons $\overline{p}$, with cross sections and multiplicities. The specific ionization energy loss is computed for each step along the trajectory. In the following step, each secondary particle produced in a primary collision is propagated in the same conditions as incident cosmic rays in the previous step, resulting in a more or less extended cascade of collisions through the atmosphere. The inclusive p, n production cross sections used here are described in [5]. The inclusive $\overline{p}$ production cross section has been obtained by fitting a set of experimental data (see [4] for a detailed description).

3. Proton and antiproton in the atmosphere

To probe the p, n production in the atmosphere, the simulated flux are compared with recent p flux measurements by the CAPRICE experiment between 5 and 29.9 km [8] and at TOA [2], and by BESS at lower altitude (2.77 km) [7] and with previous measurements from [9] at 3.2 km, and from [6] at sea level. The comparison shown in figure 1. is remarkably good through the whole range of altitudes.

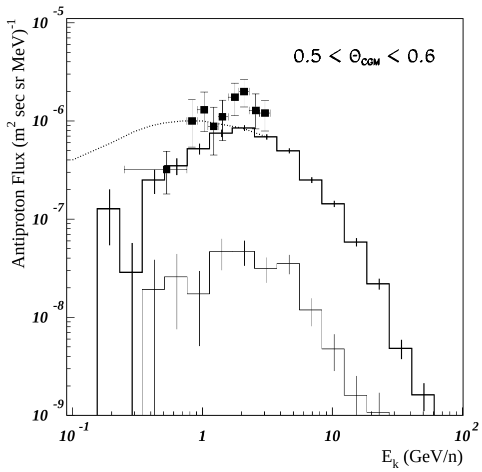

Fig. 2. $\overline{p}$ flux data at 2770 m measured by BESS [7] (symbols) compared with simulation results (histograms). Thick histogram: full calculation; Thin histogram: ^{4}He contribution; dotted line: transport equation calculation from [12].

To probe the $\overline{p}$ production simulation, we use the recent measurement at 2770 m of altitude by the BESS collaboration [7] since at this altitude the $\overline{p}$ flux is dominated by the atmospheric contribution. Figure 2. shows the $\overline{p}$ spectrum at 2770 m of altitude measured by BESS, compared to the simulation results.

Regarding the remarkably good ability of the simulation for reproducing both p and $\overline{p}$ flux in the atmosphere, the simulation can be used to estimate the atmospheric $\overline{p}$ contribution to the BESS and CAPRICE measurements respectively (figure 3.). These values have been obtained from the measured raw flux by subtraction of the atmospheric $\overline{p}$ flux evaluated using an average of theoretical calculations for the BESS experiment [10], and using the calculations of ref [12] for CAPRICE. On the figure, the atmospheric flux calculated in [12] is compared with the results from the present work.

4. Proton and Antiproton beyond the atmosphere

The same simulation program was used to study the quasi-trapped p and $\overline{p}$ population. It was found that the corresponding flux are significant up to a altitude of 10^4 km, of the order of 3 $10^{-3}(\mathrm{m^2 sec\ \ sr})^{-1})$ for $\overline{p}$ and 2 $10^1(\mathrm{m^2 sec\ \ sr})^{-1})$ for p for particle with kinetic energy above 100 MeV.

5. Conclusion

In summary, the secondary $\overline{p}$ flux produced by the Cosmic Ray proton and Helium flux on the atmosphere has been calculated by Monte-Carlo simulation. The ability of the simulation to reproduce both the p and $\overline{p}$ flux in the atmosphere provides reliable basis for a new estimation of the atmospheric $\overline{p}$ contribution for balloon experiments. The latter is in fair agreement with previous estimate.

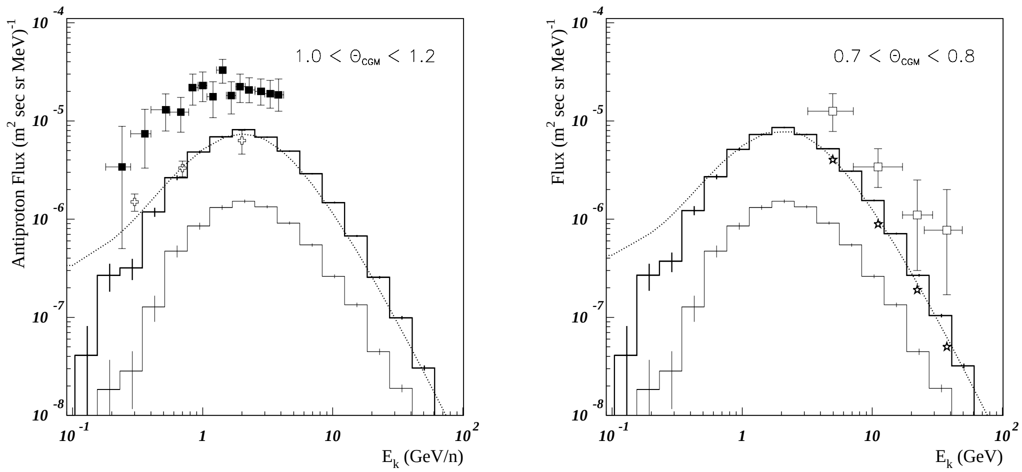

Fig. 3. Left : BESS results: Galactic $\overline{p}$ distributions deduced from the data (full squares), atmospheric $\overline{p}$ flux from ref [12] (curve), and corrections applied by the authors of [10] to correct the raw flux values for the atmospheric contribution in the original work (open crosses), compared with the atmospheric flux obtained in the present work: all (p + ^{4}He) contributions (thick histogram); ^{4}He contribution (thin histogram). Right : Same for the CAPRICE experiment data [3] (data: open squares; corrections applied in [3]: star symbols). In both panels Θ_{CGM} stands for the geomagnetic latitude of the measurements.

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