A calculation of the radiation environment for satellite experiments operating below the Van Allen belts

P. Zuccon[1], B. Bertucci[1], B. Alpat[1], G. Ambrosi[1], R. Battiston[1], W. J. Burger[1], D. Caraffini[1], C. Cecchi[1], L. Di Masso[1], N. Dinu[1], G. Esposito[1], E. Fiandrini[1], M. Ionica[1], R. Ionica[1], G. Lamanna[2], M. Menichelli[1], M. Pauluzzi[1]
(1) Università and Sezione INFN of Perugia, I-06123 Perugia, Italy
(2) CERN, CH-1211 Geneva, Switzerland

Abstract

A Monte Carlo simulation of the cosmic rays interaction with the Earth's atmosphere and magnetosphere has been developed. This simulation has been validated by a thoughtful comparison with the cosmic and undercutoff particle fluxes measured by the AMS experiment in 1998 at an altitude of $\sim 400\,km$. The results of our simulation are used to calculate the flux of secondary particles in the region above the AMS orbit and below the Van Allen belts (1000 km), where several experiments are scheduled to take data in the next years.

1. Introduction

Cosmic rays approaching the Earth interact with the atmosphere and produce a flux of secondary particles which significantly contributes to the near Earth radiation environment. The knowledge of the composition, the intensity and the energy spectra of these particles is relevant for the evaluation of background radiation for satellites experiments and manned spacecrafts.

The AMS measurements in near Earth orbit [1] provided the first accurate information on the intensity, energy spectra and geographical origin of charged particle fluxes at energies below the geomagnetic cutoff over a wide range of latitudes and longitudes. A robust interpretation of the characteristics of the under cutoff fluxes in terms of secondary particles produced in the atmosphere has been developed with a Monte Carlo simulation and validated against the AMS measurements [6,7].

In this work, we extend the results of our simulation to estimate the flux of particles of atmospheric origin at altitudes well above the AMS orbit.

2. Method

In our Monte Carlo simulation, cosmic H and He fluxes are generated isotropically on a geocentric spherical surface with a radius of 1.07 Earth radii

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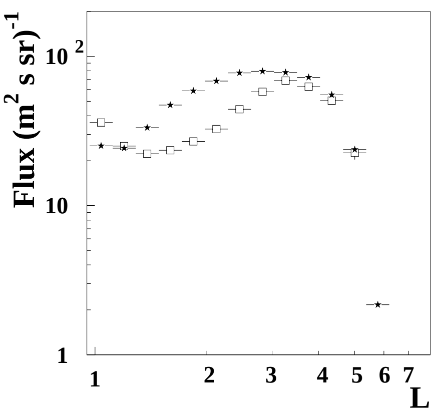

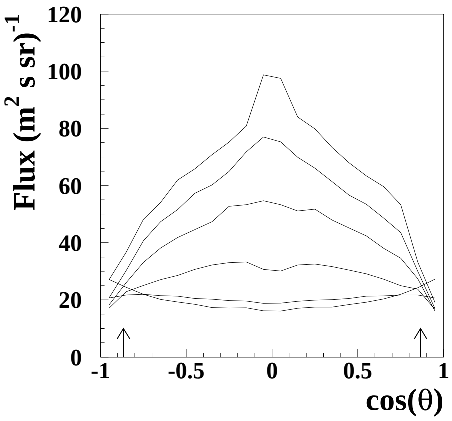

Fig. 1. Left: Secondary proton flux as a function of L, see text for details. Right: Secondary proton flux as function of the zenith angle(θ), the curves correspond to fixed L values, from the bottom to the top $L = 1.02, 1.18, 1.36, 1.57, 1.81, 2.09$.

($\sim$ 500 km a.s.l.). By means of a backtracing technique only particles allowed by the geomagnetic cutoff are propagated to the atmosphere, where their interactions are described by the FLUKA package [4]. The atmospheric secondaries are then propagated in the geomagnetic field and revealed on a geocentric spherical detector matching the altitude of the AMS orbit. With this simulation, the intensity, the energy spectra and the dynamical properties of the under cutoff fluxes observed by the AMS experiment have been correctly reproduced, pointing out the atmospheric origin of their Quasi Trapped components [2].

In particular, what has been observed is that only a small fraction ($\sim 8\%$) of the secondary particles generated by the interaction of cosmic rays with the atmosphere contributes to the flux observed at 400 km. The structure of the geomagnetic field plays a key role in fixing the kinematical conditions for the extraction of atmospheric secondaries and, at energies below the geomagnetic cutoff, induces their trapping in the Earth proximity. The dynamical features of the trapped secondaries are naturally understood in terms of their motion along the geomagnetic shells defined by the canonical invariant coordinates L, α_o [3]. In this context, the flux intensity is constant within each shell: the same fluxes are detected at different locations laying on the same shell.

In the present study, we exploit this feature to extrapolate at higher altitudes the fluxes predicted with the Monte Carlo simulation at 400 km. The basic assumption is that all particles produced in atmosphere have mirror points below our detection sphere, therefore all atmospheric secondaries reaching altitudes greater than 400 km are accounted in our simulation. This allows to integrate any flux dependence over α_o and consider only the flux intensity as a function of L. It follows that, for any given L, the atmospheric flux at 400 Km is equivalent

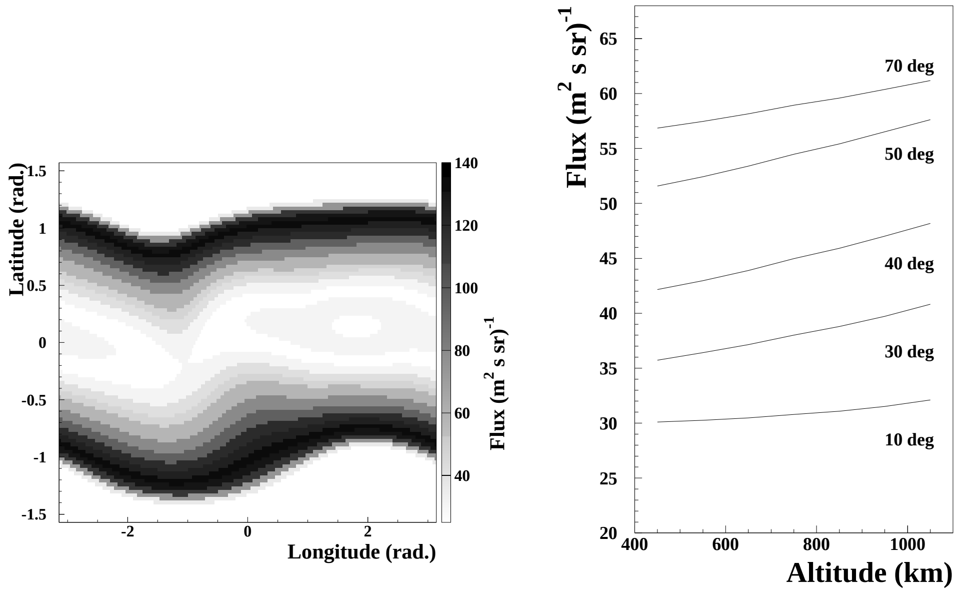

Fig. 2. Left: geographic map of the secondary proton flux at 600 km of altitude. Right: Average secondary proton flux as a function of orbital altitude, the curves correspond to different orbit inclinations.

to the flux present at higher altitudes at the same L.

In Fig. 1 (left) the Monte Carlo estimate of the atmospheric proton fluxes at 400 Km is shown as a function of L, where L and α_o are evaluated using the UNILIB package [5]. The two distributions are relative to the omnidirectional flux over whole detection sphere (stars) and to an AMS-like flux at zenith (empty squares), i.e. the flux revealed within $\pm 30°$ around the zenith direction in the latitude interval $|\lambda| < \pm 51.7°$. At low values of L, a striking difference among the omnidirectional fluxes and the AMS-like flux is observed. This difference arises from the anisotropy of the flux shown in Fig. 1 (right). There we report the flux intensity as a function of the direction with respect to the local zenith. The different curves refer to the lowest six L intervals of Fig. 1 (left). The arrows in the figure delimit the field of view of AMS when pointing to zenith and nadir.

As a consequence of the large asymmetries, a reliable estimate of trapped fluxes near Earth cannot be based simply on the extrapolation of the published AMS data, which do not have a complete angular coverage, but needs as input the result of the a complete simulation.

3. Results

The omnidirectional flux as a function of L is mapped in geographical coordinates finding the regions of constant L at a given altitude. The result is shown at an altitude of 600 km in Fig. 2 (left) for protons in the kinetic energy range from 1 MeV up to the local cutoff. The bands of constant flux intensity reproduce the pattern of the intersections of different shells with the selected spherical surface. Low L shells are encountered in the most equatorial region, where the flux intensity is lower.

Fig. 2 (right) shows, as a function of altitude, the average proton flux over the area spanned by circular orbits with different inclinations. A steady increase of the flux intensity is observed going towards higher altitudes and larger inclinations. Both effects are related to the different L intervals observed changing the inclination and the altitude of the orbit. The minimum observable L increases as moving towards higher orbits, on the other hand, at a given altitude, the maximum observable L increases with the orbit inclination. Considering higher altitudes of larger inclination, corresponds to a L range shifted towards higher L values. Since the flux intensity is rapidly varying with L, this results in a not negligible increase of the overall flux.

Similar results have also been found for secondary e^+ and e^- fluxes.

4. Conclusions

We have presented a new tool to evaluate the atmospheric component of the charged particle fluxes trapped near Earth. This tool can be used to study the environment on which most of the future satellites experiments will operate. The results shown for trapped protons evidence a significant anisotropy of the fluxes and a steady increase of their intensity with altitude and latitude. A full Monte Carlo simulation is under way to extend our estimates to lower altitudes and verify the contribution given by not trapped secondaries.

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5. References

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