Geant4 Simulation of the Propagation of Cosmic Rays through the Earth's Atmosphere

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Abstract

We have developed a Monte Carlo code based on Geant4 to simulate the interaction of cosmic rays (E<100GeV) with the Earth's atmosphere. The code allows to compute the flux of secondaries at user-defined altitudes. Possible applications include e.g. neutron albedo estimations, solar particle flux studies, and cosmogenic nuclide production. The paper describes the code and presents the results of first simulations.

1. Introduction

The precise knowledge of the flux of atmospheric cascade particles induced by galactic and solar cosmic rays is of utmost importance for a large field of applications. Complex Monte Carlo codes that can simulate the transport of cosmic rays through the atmosphere allow to better quantify these fluxes. The Geant4 Monte Carlo toolkit offers all the libraries needed to build such codes [2]. It allows to simulate the propagation of primary and secondary particles through matter in the energy range ∼250 eV–10 TeV. First developed for the accelerator community, it has been sponsored by ESA for extending its capabilities for the space and astrophysics community. We have developed a Monte Carlo code based on Geant4 that simulates the interaction of cosmic rays (E<100GeV) with the Earth's atmosphere. The paper describes the code and presents the results of first simulations.

2. Description of the Code

In our Monte Carlo code the atmosphere is represented by the superposition of several homogeneous horizontal layers with the same atmospheric depth. The density, pressure and temperature are taken as a function of altitude according to the 1976 U.S. standard atmospheric model [5]. The atmosphere is considered as composed by 78.1 % of N_2 and 21.9 % of O_2.

The electromagnetic shower is simulated by the standard electromagnetic package available in Geant4. For the simulation of hadronic interactions, different models of Geant4 are used, depending on the energy range [3]. For high energies

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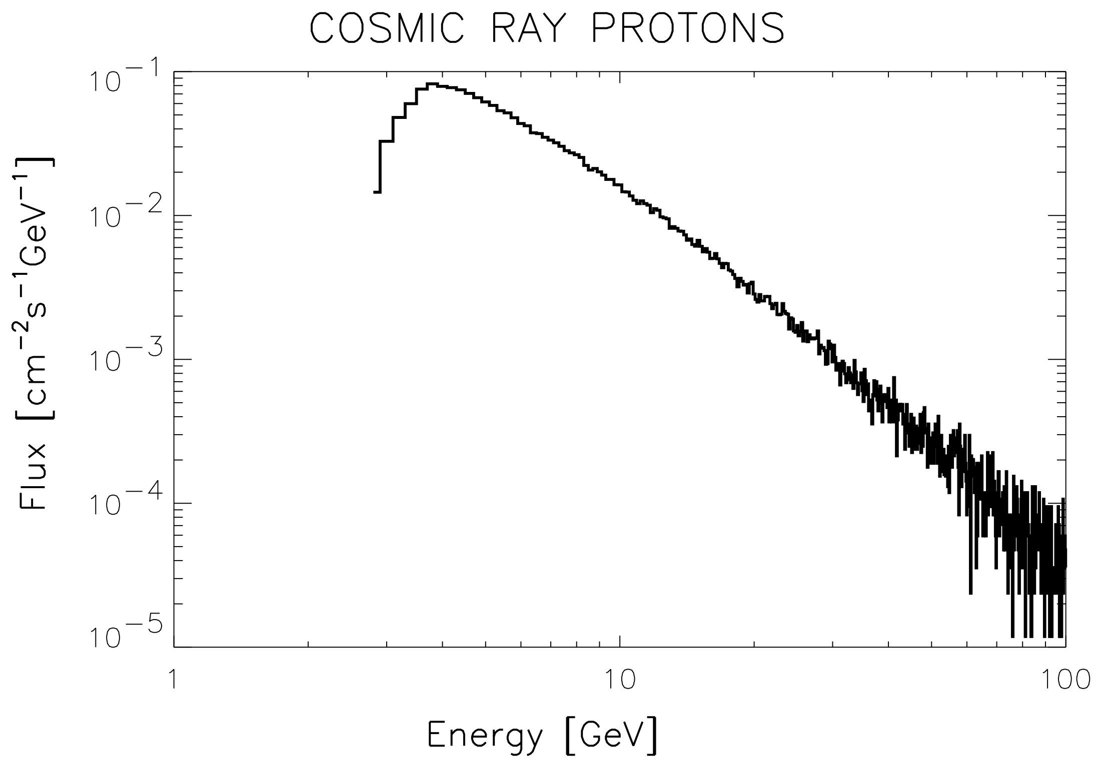

Fig. 1. Primary cosmic ray proton flux used in the simulations.

(>10 GeV), a quark gluon string model has been selected. For nucleons at energies lower than 10 GeV the binary intranuclear cascade model has been chosen. In this model the cascade phase is followed by a preequilibrium phase at intermediate energy, and then by an evaporation regime at lower energy. For neutrons with energy lower than 20 MeV the G4NeutronHP model based on the ENDF database is used. The decay of particles is included in the code. If needed, the decay of radioactive ions produced by spallation reactions can be simulated. At this moment a model for hadronic ion interactions is not available in the Geant4 toolkit. Such a model is under development and a first release should be available at the end of 2003. When released this model will be incorporated in our code.

Our code registers the fluxes of secondaries at user defined altitudes, the energy deposited by particles in function of altitude, as well as the production of cosmogenic nuclides over the entire atmosphere.

3. First Simulation Results

In a first application, we have simulated the interaction of a cosmic ray proton population with the atmosphere by using the primary spectrum shown in Fig. 1. This spectrum is based on Belotti et al. [1,4]. We have chosen a 2.7 GeV

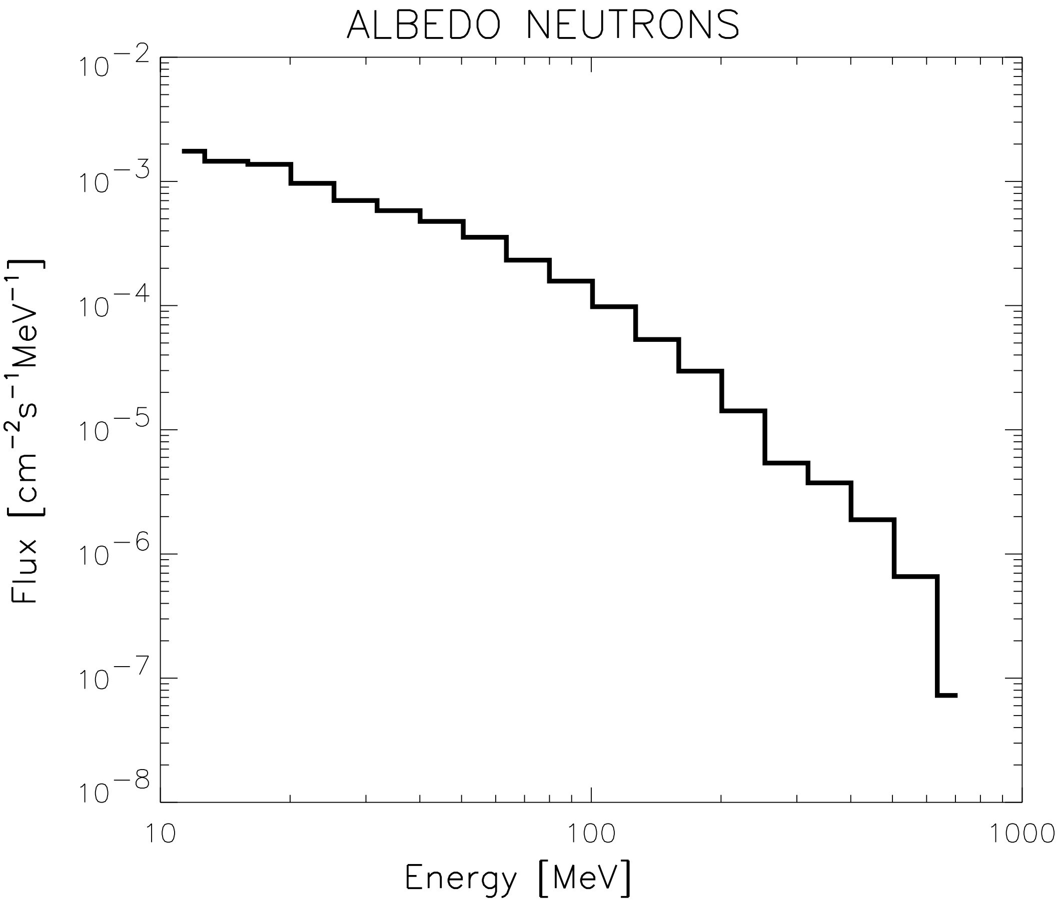

Fig. 2. Albedo neutron flux at the top of the atmosphere computed by using a vertically incident flux of cosmic ray protons as given in Fig. 1.

cutoff energy and have only considered primary protons of vertical incidence. The resulting albedo neutron flux at the top of the atmosphere and the resulting flux of secondaries at sea level are plotted in Fig. 2 and Fig. 3, respectively. These fluxes were obtained by simulating $3 \cdot 10^5$ cascades, and by scaling the results to the primary flux level given in Fig. 1.

A rapid comparison with former Monte Carlo simulation results and measurements shows that these results are realistic [4]. However to validate the code, more simulations with varying input parameters are needed.

4. Summary and Conclusions

We have developed a Geant4 application to simulate the interaction of cosmic rays with the Earth's atmosphere. First simulation results are encouraging and demonstrate that the Geant4 toolkit combined with analyzing libraries, is a

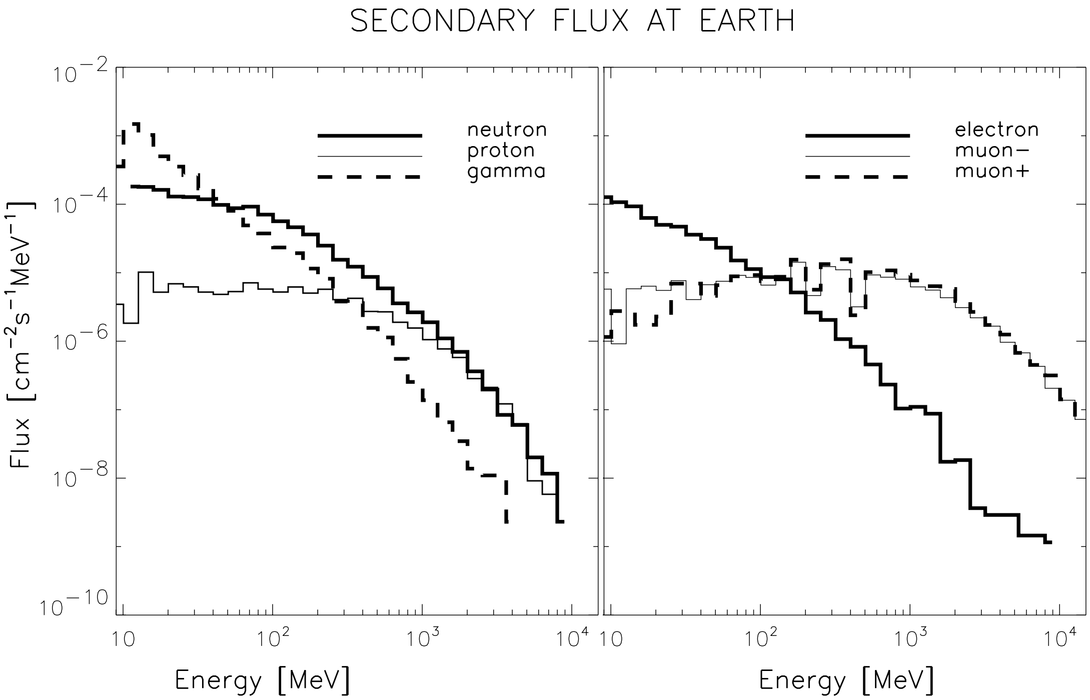

Fig. 3. Computed secondary flux at the Earth surface obtained when considering a normal incident flux of cosmic ray proton at top of the atmosphere as given in Fig.1.

powerfull tool for cosmic ray physics.

5. Acknowledgments

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6. References

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