Study of secondary cosmic ray through Extensive Air Shower (EAS) simulation

Abhijit Roy[1],* Ritabrata Sarkar[1], and Sandip K. Chakrabarti[1,2]
[1]*Indian Centre for Space Physics, 43 Chalantika, Garia Station Rd., Kolkata 700084, W. B., India and*
[2]*S.N. Bose National Centre for Basic Sciences, JD Block, Salt Lake, Kolkata 700097, W. B., India*

Introduction

Galactic Cosmic Rays (GCR), which are mostly composed of H and He nuclei, mainly originated outside the solar system. They propagate through the galactic medium with relatively weak magnetic field and interact with the medium and magnetic field. While in the heliosphere they interact with the electromagnetic field carried by the solar wind, which effectively modify their flux intensity up to the energy of several GeVs. The Cosmic Rays (CRs) has a wide energy range from sub-GeV to about 10^{21} eV and the intensity decrease rapidly for higher energies.

The earth's magnetic field provides a shielding from these cosmic ray particles. Depending on their rigidity, cosmic rays penetrate the magnetic field of the earth and reach the top of the atmosphere. The CR flux at this point depends on the earth's magnetic field distribution and as well as on the solar activity which in turn modulates the magnetic field distribution surrounding earth.

When CRs interact with the atmospheric nuclei they produce cascade of secondary particles which decay or interacts further to produce other particles and radiation. These secondary cosmic rays are observed by ground-based [7] and balloon born detectors [3, 6].

Here in this current work we study the secondary CRs generated in the earth's atmosphere due to the interactions of the GCRs by means of Monte Carlo simulation.

*Electronic address: aviatphysics@gmail.com

Procedure of EAS simulation

To study the interaction of the GCR particles in the earth's atmosphere we consider a full 3D model of the atmosphere and magnetosphere using Geant4 [1] simulation toolkit. The atmosphere surrounding the earth is defined by considering the NRLMSISE-00 [5] standard atmospheric model parameters up to 100 km from the earth surface. For earth's magnetic field we consider 12^{th} generation IGRF model (for internal magnetic field) [9] and Tsyganenko Model (for external magnetic field) [8]. Some sample of the magnetic field line distribution are shown in Fig. 1.

FIG. 1: Earth's magnetic field line distribution used in the simulation.

The primary CR spectra modified by the solar activity can be represented by the modified power law [4]. For the simulation we use H and He as the primary CR because they are the most abundant particles in primary CR. The solar modulation parameter ϕ is fixed at 650 MV considering the time of the simulation. We considered the energy of the primary CRs in 100 MeV to 800 GeV.

Results and discussions

A prominent modulation of the primary flux comes from the low-energy cutoff due to geomagnetic field. This modulation is inherently achieved in the simulation by the incorporation of geomagnetic field. The generated primary flux of the H and He and the corresponding modulated flux due to the geomagnetic cutoff is shown in Fig. 2.

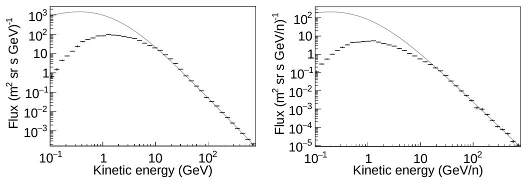

FIG. 2: Primary CR flux considered in the simulation: (left) H flux; (right) He flux. The gray curve represented original primary flux, while the points below the curve presents the same fluxes after geomagnetic cutoff.

The upward and downward proton flux at the satellite height (400 km) due to H and He particle interactions in the Field Of View (FOV) of 35° around zenith and nadir directions and in 0.7 to 0.8 geomagnetic latitude range are shown in the Fig. 3.

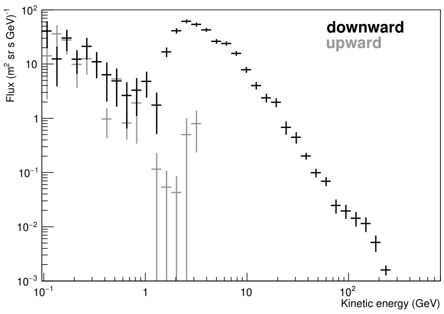

FIG. 3: Secondary proton flux at satellite height (400 km) in 35° Fov.

The simulated result of proton distribution over the whole latitude-longitude range is shown in the Fig. 4.

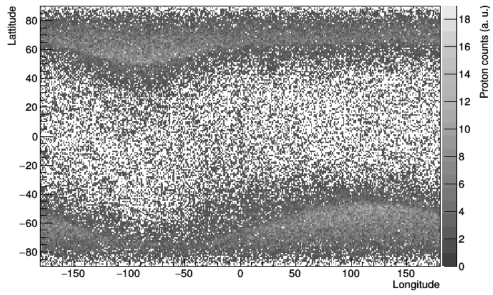

FIG. 4: Proton distribution in latitude and longitude at 400 km height.

Conclusion

We simulated the primary GCR interactions in the earth's atmosphere to produce the secondary particles. Though here we have presented the results for the secondary protons at the satellite height which have been verified with the observed proton flux from the satellite based measurements such as by AMS02 [2], we can study the distribution of other secondary products of the CR shower and their flux variation at different height through the atmosphere.

Acknowledgments

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