Geant4 Simulation for Hadronic Interactions in Space Radiation Environment

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1. Introduction

The space radiation environment is a significant challenge to future space travel. Future space missions will rely more on accurate simulations of radiation transport in space through spacecraft to predict astronaut dose and energy deposition within spacecraft electronics. The existing radiation models are not been able to explain the experimental data for an intense space radiation environment, which mainly consists of high energy particles, for example hadrons and heavy ions originating from Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE's). Therefore there is an urgent need to develop a precise radiation model for deep space missions through fast simulations. In this work, Geant4 (Geometry and Tracking Software) [1] Monte Carlo simulation tool is used to simulate and model the hadronic interactions of high energy particles (0.1~10 GeV/nucleon) in the GCR spectrum. We have incorporated the physics model FTFP_BERT_HP to understand the interaction of proton and heavy ions with water phantom for two different detector shapes: a) Slab b) Sphere. Energy loss by proton and heavy ions is measured and compared for both shapes for beam kinetic energy in the range of eV to the order of TeV. This study is useful to determine radiation dose in the space radiation environment.

2. Simulation of Hadronic Interactions in Space

In this section, complete process steps, which are used to simulate and model the hadronic interactions in the space radiation environment are discussed. The G4Material class is used to describe the macroscopic properties of matter and geometry is created using the detector construction class in Geant4. Further, the hadronic interactions are simulated and modeled through FTFP_BERT_HP (Fritiof + Pre-compound Bertini Cascade) [2,3,4]. This model explains the interactions of charged particles (hadrons) and heavy ions with detector material. These high energy particles are the main components of the space radiation environment. This radiation model works for kinetic energy of protons and heavy ions ranging from eV to order of few TeV. The pencil beam of protons of various kinetic energies is generated and simulated using G4PrimaryEventGeneration Class in GEANT4. This class generates primary particle(s) with a given momentum and position. These particle beams are transported to interact with detector geometry. Due to various interactions, such as hadronic and electromagnetic interactions, the incoming particle beam loses its energy and is deposited inside the target/phantom. Energy loss is calculated and analyzed through ROOT software [5], developed by CERN.

3. Detector Geometry in Geant4

The spacecraft and human body are strongly affected by intense high energy radiation during deep space missions. The radiation usually comes from the GCR and SPE environment, mainly composed of protons, helium nuclei and heavy ions. These particles deposit energy as they transverse through the spacecraft and its electronics. To simulate and model the hadronic interactions, the detector geometry is constructed using the detector construction class in GEANT4. It consists of a slab with thickness of 350 μm filled with water. A pencil beam of proton with kinetic energy ranging from few MeV to 1 TeV is simulated using Primary Action Generation Class. This can be visualised on a slab by blue colour as shown in Fig 1 (left). Since the energy deposited depends on detector geometry and detector material, therefore the effect of shape is examined in addition with spherical detector geometry composed of water with radius r = 414 μm as visualised in Fig 1 (right).

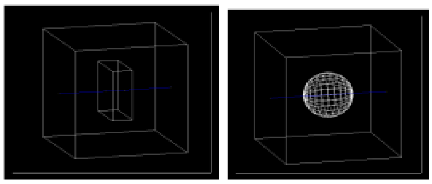

Fig. 1: Visualisation of detector geometry: Slab (left), Sphere (right) in Geant4 simulation.

4. Results

The understanding of how radiation interacts with a specific detector is to determine the average deposited energy as a function of particle kinetic energy. When a beam of charged particles enters the detector material, it loses energy via Coulombic interactions with electrons and nucleus of the atom. The energy loss is measured in terms of deposited energy. The effect of shape on deposited energy as a function of kinetic energy is studied and shown in Fig 2 (left). As can be seen from the figure, at low energies the behaviour is linear, because of higher interactions of the proton beam with water phantom and hence large energy is deposited inside the detector geometry. As the incoming energy increases, the energy deposited inside the geometry decreases rapidly, due to less interactions of the proton beam with detector material.

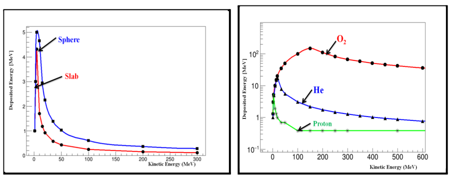

Fig. 2: Energy loss spectrum: effect of different geometrical shapes (left), effect of charge of protons and heavy ions (right).

At higher energies (of order of GeV and TeV) the deposited energy is almost constant as the beam passes the geometry without undergoing much interactions. Further, the energy deposited curve lies higher for spherical shape. The origin is boundary effects due to the fact that at the corners of the slab detector, the probability of the particle to exit on the sides, is higher than for the spherical detector. Moreover, the effect of charge is also studied by simulating beams of heavy ions, Helium and Oxygen. As seen from fig 2 (right), heavy ions passing through detector material cause much more damage due to high energy deposited as compared to protons, because energy deposited by charged radiation depends on the square of charge in accordance with the Bethe- Bloch formula.

5. Summary

The hadronic interaction in the Space radiation environment is modelled using the FTFP_BERT_HP model in Geant4. The detector geometries: slab and sphere are simulated and energy loss is measured by proton and heavy ions. Further, the effect of shapes and charge on the energy loss spectrum are studied. This study is useful to measure the radiation dose in future space missions.

6. References

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