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DEASA studies and applications to space physics and muon tomography

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Abstract

The high energy cosmic rays entering the Earth's atmosphere throw light upon many aspects of Astroparticle and Particle Physics. This work outlines investigative learning about these high energy primaries based on a mini array DEASA [1] in Agra,India. DEASA (Dayalbagh Educational Air Shower Array) consists of eight plastic scintillators each with an area of 1 square meter. This array covers an area of 260 square meters and is the first array in the northern part of our country. A real-life application of these highly energetic particles has been to find the best material to protect the astronaut from them in form of galactic cosmic rays (GCR) [2]. Geant4 based hadronic binary model was used in simulation of phantom, vehicle, SEP (Solar Energetic Particles) and GCR shield. The SEP shielding material was fixed as water and GCR shield was varied among aluminum, Polystyrene and Polyethylene. The poly materials were found to be the best due to large amount of hydrogen (H) and low atomic number (Z). In this work the equivalent dose deposited in the phantom with Polystyrene material for GCR shield was calculated to be minimum (107 sievert) as compared to the other materials.In the second application, the high energy muons have been studied to image nuclear caskets through muon tomography [3].In this Monte Carlo based simulation, a dry cask container containing different number of the UO2 rods have been bombarded with definite energy muons to measure the muon scattering .The parameters computed in this work are energy loss,radiation length and scattering angle which can calibrate these containers for correct identification of nuclear wastage.

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Contents

1 Introduction

The cosmic rays mainly come from radioactive decay inside the stars, supernovae, the Sun, active galactic nuclei,and pulsars. The higher energy ones seem to be coming from super massive black holes at the heart of galaxies. On reaching the Earth's atmosphere, they produce showers of particles that pass through us almost 500 times a minute. The cosmic flux is a crucial tool for calibrating particle detectors and this study is also being done for DEASA detectors. The muons entering our detectors do not have a constant flux but slightly more in summer and lower in winter. This is connected to pions which have decayed into muons in the shower. In summer, the air warms and expands, leading to more gap between air molecules allowing pions to further decay into muons. In winter, the air is cold and dense resulting in higher collisions of pions leading to fewer decays into muons.
The cosmic rays before entering the atmosphere are primarily energetic galactic particles coming from inside the galaxy and more energetic extragalactic particles from the active galactic nuclei, quasars or gamma ray bursts. These energetic particles affect the human body in many different ways as shown in the study of the twins physiology, memory abilities and genes where one of the twin is on Earth and other on International Space Station(ISS) for 340 days [1].The study confirms that space time manipulates genes and affects the human immune system. The exposed person suffers from mental reasoning and memory loss and studies are going on for long term ailments. One of the stickiest problems for NASA is how to shield astronaut from energetic cosmic rays and solar flares.
The air shower developed by an energetic particle entering the atmosphere grows with depth into hadronic and electromagnetic particles at sea level. These muons can look into the interiors of impenetrable structures in parallel to the x-ray imaging of our body. The difference is that X-rays have to be produced in the laboratory and muons are always available. This feature defines them as a good tool for impenetrable imaging structures like pyramids and volcano to nuclear reactor containers .Muons travelling through a structure will be stopped along the path or scattered depending on the thickness and density of the material. The plastic scintillator lights up when a charged particle passes through so we design the simulation with a nuclear casket surrounded by two plastic scintillators. Finally, this muon imaging technique has been used to image the interiors of the nuclear reactors at Fukushima Daiichi plant [2].

2 DEASA

The cosmic ray flux decreases rapidly with energy as $E^{-2.7}$ around 10^{14} eV. Hence is impossible to have direct measurements. The secondaries produced at sea level increase with primary particle energy at these energies. The change in transverse momentum and scattering of the secondary particles with the atmospheric particles leads to their lateral spread on ground. This

process of almost parallel arrival of the secondary particles reaching ground is called extensive air shower in which the spread is between $10^4 m^2$ to $10 km^2$.
This phenomenon gave insight into:

1. Particle Physics from air shower spread.
2. The direction of secondaries arriving on ground tells about high-energy particles.
3. The cosmic ray energy spectrum.
4. Mass of primary cosmic rays.

DEASA is a mini array of eight plastic scintillators each with an area of 1 square meter, has been set up as shown in Figure 1. This array covers an area of 260 square meters and is the first array in the northern part of our country. The pulses from the eight detectors are manually studied.The pulse amplitudes, time over threshold, rise time,fall time and Full width half maximum are being observed to study correlations between them. The calibration of the 12 dynode photomultiplier tubes attached to each of the eight detectors has been completed and the flux measured is around 13500 counts per minute. Daily monitoring of the detectors is maintained in log book.

Figure 1: The mini array

3 Space studies

In space, astronauts are exposed to cosmic ray particles in the form of solar energetic particles(SEP) and galactic cosmic rays(GCR) [3].To design shields from these energetic particles different materials were studied in Geant4.The water phantom analogue to human being, was irradiated with primary proton following a galactic cosmic ray energy spectrum with different shielding materials. The secondary particles are created with interactions between protons and the shield material.
We found poly materials are the best material due to large content hydrogen (H) and low atomic number (Z). High H leads to fragmentation of the heavy GCR particles into small fragments and low Z produces a maximum number of secondaries. Poly materials are 16 percent more effective than aluminum in reducing the dose equivalent with only 1.5148 g/cm2. Polymeric materials are expected to play an important role in protecting astronauts in future missions. The calculated equivalent dose for poly-materials is minimum (107 sievert) as compared to the other materials.

4 Muon tomography

The second study defines the application of muons to identify nuclear wastage using plastic scintillation detectors [4] in muon tomography. In this study, a dry cask container has been simulated which contains the UO2 rods (varying in number) and muon scattering has been observed [4]. This shows that when the dry cask is filled with the rods, muons are scattered to the maximum angle and if the dry cask is empty, the muon will pass through it straight without getting scattered. The scattering of energetic muons of range 3 GeV – 10 GeV from these containers with dimensions from Narora Nuclear plant, Uttar Pradesh (U.P.). The parameters measured are energy loss, radiation length and scattering angle for different number of rods gives us patterns that describe the inside of the containers without opening them. The radiation length is the average distance required for an electron to lose 1/e of its energy and measured in cm. The multiple scattering of the muons is mostly due to Coulomb scattering of muons in the target with charge Z, calculated analytically.

Muon with energy 3 GeV loses 3.64 MeV/c energy in concrete and we found the scattering angle to be 4.14 mrad(milli radian) whereas the radiation length was 10.91 cm. These calculations have been done for different energy muons scattered from Iron, Lead and Uranium targets in this paper.

5 Conclusion

These studies prove that high energy quantum fields consciously assist us in applications beyond the accelerating sources they arrive and reach far beyond the human-machine interface. Neutrinos, although nearly massless give solutions to Dark matter, Dark energy in cosmology, muons being tiny particles that can scan structures like nuclear plants,submarines . Hadron fields have applications in medical physics such as hadron therapy and carbon ion therapy for cancer patients.

The importance of cosmic ray studies at DEASA is that students can understand quantum sensors, the electronics for fast pulses and the analysis of count rates over the different seasons. Another critical aspect of these studies is the Monte Carlo simulations in Geant4 and CORSIKA. These codes give a wide-angle view to the user and applications in space physics, nuclear science and many other areas.

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