A Proposal of a Multi Directional Neutron Telescope for Observations of Galactic Cosmic Rays

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Abstract: For the purpose of observing solar neutrons produced at solar flares, the solar neutron telescope has been using, which has veto detectors to reject the incidence of charged particles and catches the recoil proton from production layers as the signal of neutron incidence. In this paper, by taking advantage of the detector to discriminate the directions of incident neutron, we propose a new application to investigate the time variations and anisotropies of galactic cosmic rays.

Keywords: neutron, telescope, anisotropies of galactic cosmic rays, GRAPES-3.

1 Introduction

Both intensity variations and anisotropies of galactic cosmic rays could be organized into two different types such as stable variations and temporal variations. These are believed to be related to the most important mystery of the origin of galactic cosmic rays and their propagation. The stable variations in galactic cosmic rays are formed by the structure of the magnetic field of the inner solar system which could be modulated by the solar activity and solar wind. The temporal variations, on the other hand, are related to sudden phenomena like Forbush decreases caused by solar flares.

1.1 Stable variations of cosmic rays

Solar wind plasma and the solar magnetic field form a spiral structure of the magnetic field of the inner solar system which is known as Parker's spiral. But the spiral structure could be varying in time moderately by the variation of solar wind velocity. The propagation or transport of galactic cosmic rays in such a magnetic field can be described by the Parker's theory of diffusion and convention of cosmic rays. A fluctuation of such an interplanetary magnetic-field strength is thought to affect the propagation of galactic cosmic rays, because of an interaction between magnetic field and electric charges of cosmic rays.

1.2 Temporal variations of cosmic rays

Solar flares liberate an enormous magnetic energy at the surface of the sun and provide the energy to a shock wave which would be created in the solar wind plasma. The shock wave causes several electromagnetic phenomena in the interplanetary space including the earth's neighborhood space. The turbulences of such an electromagnetic field leads to a sudden variation of the galactic cosmic ray intensity, like Forbush decreases.

The stable and temporal variations observed in the intensities and anisotropies of galactic cosmic rays, which propagate in the spiral structure of interplanetary magnetic field, are thought to be typical electromagnetic phenomena that might happen in the universe. Therefor the detail study of both the intensity variations and the anisotropies of galactic cosmic rays in the inner solar system will lead to a basic understanding of mechanisms of various phenomena caused by astronomical plasma.

The effect of the magnetic shock wave accompanied by solar wind plasma on the electromagnetic environment of the earth is quite serious because that our modernized society is supported by highly developed electronic devices. The study of galactic cosmic rays in the inner solar system, especially near earth is important for our real life on earth as a space weather.

So far, such a research mentioned above has been carried by using radio wave, visible right, x-ray satellite and particle rays. However the observables from these measurements are based on the direct images of a phenomenon on the surface of the sun, or some physical quantities of solar wind plasma or of interplanetary magnetic field measured at the earth's neighborhood space. Furthermore, observations of atmospheric neutrons induced by galactic cosmic rays at the top of the earth's atmosphere have only been carried by the equipment without the functionality of measuring particle energy and directions.

Here, we propose a new type of telescope of atmospheric neutrons, which will be installed at the site of GRAPES-3 experiment, to investigate the time variations and anisotropies of galactic cosmic rays.

2 GRAPES-3

The experimental system of the GRAPES-3 (**G**amma **R**ay **A**stronomy at **P**eV **E**nergy**S** Phase-**3**) experiment consists of a densely packed array of scintillator detectors and a large area tracking muon detector. The EAS array consists of 350 plastic scintillator detectors , each of 1 m^2 in area. These detectors are deployed with an inter-detector separation of only 8m. The array is being operated at Ooty in south India (11.4°N, 76.7°E, 2200m altitude).

The 560 m^2 GRAPES-3 muon detector consists of 4 super-modules, each in turn having 4 sub-modules. Each sub-module with a sensitive area of 35 m^2 consists of a total of 232 proportional counters (PRCs) arranged in 4 layers, with alternate layers placed in orthogonal directions. Two successive layers of PRCs are separated by 15 cm thick concrete. The energy threshold of 1 GeV for vertical muons, has been achieved by placing a total of 15 layers of concrete blocks (total absorber thickness $\sim$550 g$\cdot$cm^{-2}) above the top layer. The concrete blocks have been arranged in the shape of an inverted pyramid to provide adequate shielding up to a zenith angle of 45°.

3 Design of Neutron Telescope

For the purpose of detecting atmospheric neutrons produced by high energy cosmic rays, the neutron telescope has been using, which has veto detectors to reject the incidence of charged particles, detection of the recoil proton from production layers as the signal of neutron incidence. In our proposal, the newly designed neutron telescope can detect recoiled protons which might be kicked out by neutrons in the production layer as a typical neutron detector, and furthermore it can record their incident directions also.

We show the schematic image of the newly designed neutron telescope in Figure.1. The telescope consists of several layers of the detector for a specific purposes each. Two layers of proportional counter tubes at the top of telescope perform as the veto detectors rejecting an electromagnetic component and muon component of the secondary particles. The layers made up of timbers and scintillators, which has an area of 9 m^2, are the production layers for conversion of atmospheric neutrons to recoiled protons. The remained 6 layers of proportional counter tubes will be operated as a particle tracking detectors that can record the direction of the recoiled protons. Each layer of proportional counter tubes consists of 58 tubes and has the area of 35 m^2 as a sensitive area. They are arranged with alternate layers placed in orthogonal directions to identify the particle tracks.

4 Simulation

This work shows the results of Monte Carlo simulations to quantify the characteristics of atmospheric neutrons due to high energy cosmic rays of various primary energies. the characteristics of atmospheric neutrons at an observation level have been calculated to estimate the possible observables derived from the new neutron telescope. COSIKA (COsmic Ray Simulations for KAskade), which is widely used by high energy cosmic ray experiments around the world, was used for this purpose. The CORSIKA was set up with the parameter of QGSJII for high energy hadronic interaction and with GEISHA for low energy. The energy range of primary particles was set from 1GeV to 1TeV because that the median rigidity of primary protons at the geomagnetic latitude at the GRAPES-3 site is about 100 GV. Since the CORSIKA doesn't trace hadrons with energies less than 50MeV in the simulation, the atmospheric neutrons also were able to be followed up to the energy of 50MeV. The zenith angle of incident primaries were set uniformly between 0 and 50 degrees.

5 Results

We've simulated development of the secondary particles in the atmosphere with primary protons of energy from 1 GeV to 1 TeV that have been divided into 12 points at equal interval in logarithmic scale. To quantify the primary angular information of which the secondary neutrons can keep through the development in the atmosphere, we took the value of an opening angle between vector of a neutron and of the primary proton.

Because that the secondary neutrons have undergone several scattering in their passages, the distribution of opening angle of secondary neutrons has broad distribution with the width of about 10 degrees. The opening angle distribution of secondary neutrons induced by the primary with an energy of 23.1 GeV in the Figure.2. In this figure, we set a threshold energy for secondary neutrons at 1 GeV and 2 GeV respectively, and found that there is no significant difference in the opening angle even though the neutron energies are different. As in the Figure.3, the distribution of opening angle of the primary energy of 1 TeV is similar to that of Figure.2.

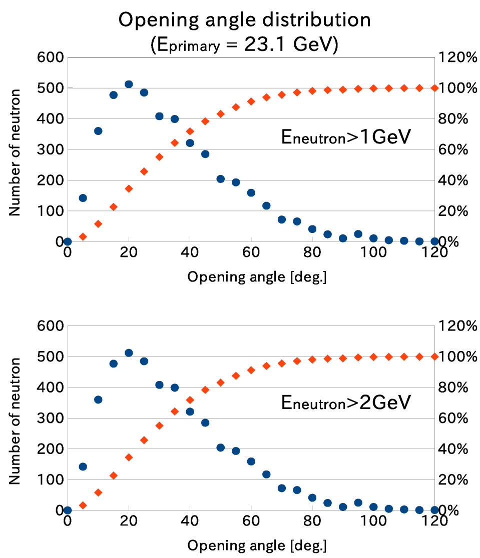

Figure 2: Opening angle distribution of the secondary neutrons relative to the incident direction of primary protons. The energy of the primary is fixed at 23.1GeV

6 Summary

The median rigidity of primary protons observed by GRAPES-3 muon telescope is around 100 GV with the assumption that the strength of interplanetary magnetic field is about 5 nT. On the other hand, the median rigidity of primary protons observed by the neutron telescope, which

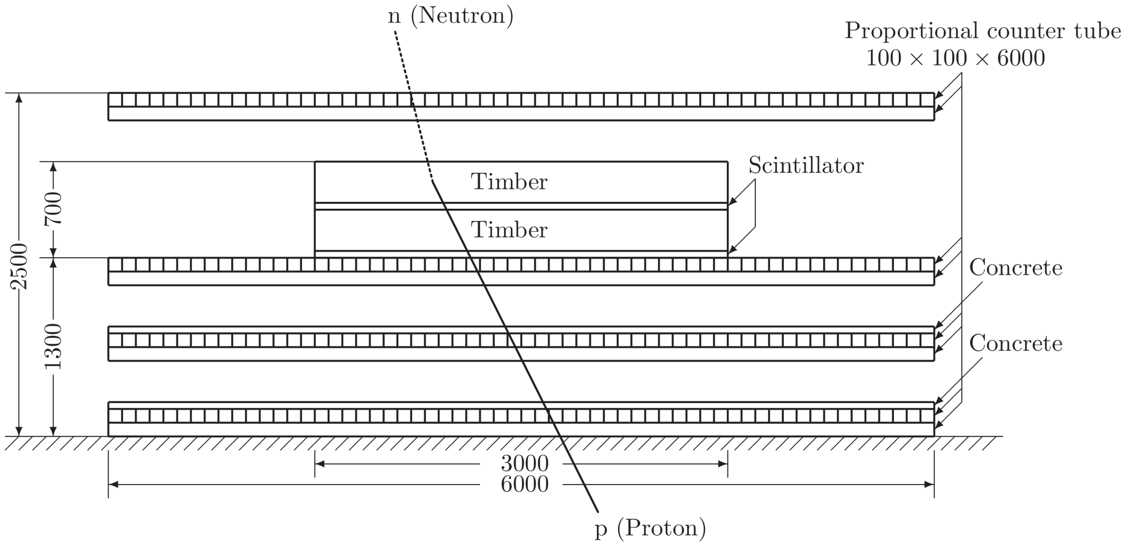

Figure 1: The schematic image of the newly designed neutron telescope.

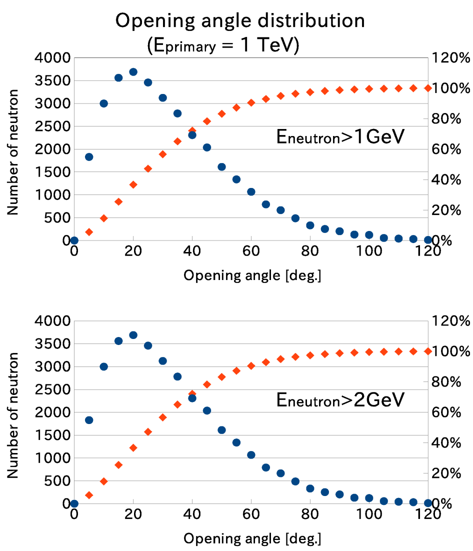

Figure 3: Opening angle distribution of the secondary neutrons relative to the incident direction of primary protons. The energy of the primary is fixed at 1000GeV

has been introduced in this paper, is about 30 GV at the site of GRAPES-3, India. The Larmor radius of primary protons at the median rigidity in the interplanetary magnetic field observed by both the telescope has been estimated to be about 0.5 AU and 0.15 AU respectively. It implies that we can explore the earth neighborhood space with diffrent scale of space by observing the primary protons of different rigidity. However, in this work, we've found that the secondary neutrons, which are produced by the high energy cosmic rays or produced by the secondary nuclei in the atmosphere, can have large fluctuations in an angular information that is three times larger than the muon telescope. The angular resolution of the muon telescope is approximately 10 degrees. Therefore the capability of resolving the space of the neutron telescope is almost the same as that of the muon telescope.

As we mentioned above, neutron components and muon components of secondary particles can reflect the different energy region of the primary cosmic rays. This allows us to prove the structure of Inter magnetic field at different energy region.

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