Cosmic Ray Mass Composition Estimated from the Geomagnetic Effect on EAS Muons

Sandip Dam* and Rajat K. Dey†
Department of Physics, University of North Bengal, Siliguri, West Bengal, INDIA 734013

Introduction

We are getting steadily better understanding of long standing problems such as origin, composition of primary cosmic rays (CRs) with improved experimental techniques and methods of measurements. To arrive at any specific conclusions from their indirect investigation it is very important to know how they interact with the atmosphere and how the EAS develops. This knowledge is obtained by comparison of data with Monte Carlo (MC) predictions.

The radial distribution of EAS particles is generally assumed to be symmetrical in the plane perpendicular to the shower axis. But presence of intrinsic fluctuations (due to stochastic nature of EAS development) from shower to shower, in addition, zenith angle and geomagnetic effects etc. can perturb this axial symmetry noticeably.

Apart from geomagnetic effect (GE), asymmetries may arise from azimuthal variation of the charged EAS particles and unequal attenuations accounted from different locations of the EAS in the ground plane (GP) with inclined incidence. These are known as geometrical and atmospheric attenuation effects to azimuthal asymmetries. To retain the GEs on the EAS charged particle distribution alone, geometrical and attenuation effects must be isolated out in the analysis.

Here, we address the influence of the geomagnetic field (GF) on secondary muons with zenith angle $\geq 55^0$ at KASCADE site [1] and express the separation between positive and negative muons as l_d from the perturbed configuration. This l_d is found quite sensitive to the nature of the primary particle and hence in principle the parameter can be exploited to estimate primary mass.

*Electronic address: sandip_dam@rediffmail.com
†Electronic address: rkdey2007phy@rediffmail.com

Effects due to Earth's magnetic field on muons

During the progress of a CR cascade in the atmosphere, the GF affects the propagation of the secondary charged particles in the shower: the perpendicular component of this field causes the trajectories of secondary charged particles to become curved, with positive and negative charged particles separating to form an electric dipole moment. This aspect was first pointed out by Cocconi nearly sixty years back [2]. The positive to negative muons ratio could evaluate the signature of neutrons emitted from close pulsars. The GF induces an azimuthal modulation of the densities of air shower particles, particularly for large angle incidence. For that reason, the estimated energy of CRs may deviate from the true value up to the $\sim 2\%$ level at large zenith angles.

After their generation from pion and kaon decays muons travel much longer path without scattering and hence come under the influence of GF in a big way. As a result GE should be more pronounced in low momentum muons than very energetic ones, particularly for very large and strongly inclined showers.

Simulation of EAS and data analysis

In the framework of the air shower MC simulation program version 6.970 [3], the EAS events are simulated by combining high energy hadronic interaction model EPOS 1.99 and the low energy hadronic interaction model UrQMD with electromagnetic interaction model EGS4. The EAS events have been simulated at KASCADE level. The EAS events have been generated for Proton (p) Oxygen (O_2) and Iron (Fe) primaries at fixed primary energy 10^{15} eV taking zenith angles of incidence, between 50^o and 68^o. About 10000 EAS events have been generated for this work.

In the absence of GF lateral distribution of EAS charged particles should possess a symmetry for all radial distances from the axis in a plane normal to the shower axis. In the GP, however, such cylindrical symmetry is distorted for inclined EAS due to geometrical and atmospheric attenuation effects. Since the effect (azimuthal asymmetry) of GF is superimposed with those caused by geometric and attenuation effects, it is convenient to transform the density information of charge particles of air showers in the GP to shower plane (SP) so that the effect of the GF can be isolated out. To extract the actual variation introduced by the GE in EAS observables, it is necessary to take away the contribution added through geometric and attenuation effects.

Let Z and A denote the primary zenith and azimuth angles respectively, and (r_g, ϕ_g) are polar coordinates of a point of impact of an EAS charged particle under consideration at the GP while (r_n, β_n) represent the polar coordinates of the same point at the corresponding SP plane, and simple transformation relations are as under:

$$r_n = r_g\sqrt{1 - sin^2Z cos^2(\phi_g - A)} \qquad (1)$$

$$x_n = r_g cos(\phi_g - A) cosZ \qquad (2)$$

$$y_n = r_g sin(\phi_g - A) \qquad (3)$$

Employing the equations (2)-(3) we then transform the simulated density or other quantities of interest at GP to the normal plane/SP.

Results and conclusions

To quantify the influence of GF as well as to identify some typical signatures of the primary particle we have calculated the coordinates of positive and negative muons barycenters and thereby estimated the average muon

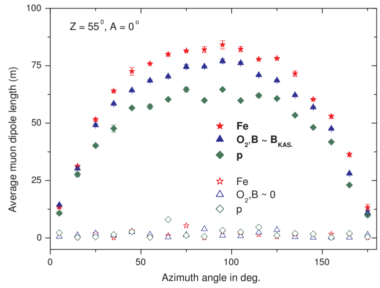

FIG. 1: Azimuthal variation of muon dipole length for p, O_2 and Fe primaries arriving from the North direction.

dipole length per shower, which is the separation of centre of gravities of negative and positive charged muons in the SP. The variation of average muon dipole length/event with azimuthal angle for p, O_2 and Fe initiated EASs of zenith angle of incidence 55^o from North direction is shown in Fig. 1. In this Fig. the azimuthal variation of average muon dipole length/event is also shown when the GF is switched off. The parameter is found sensitive to primary mass and therefore the parameter can be used, at least in principle for extracting the nature of primary particles.

Conclusions

For very inclined showers the Earth's magnetic field might be used as magnetic separator at least for muons in the GeV energy regime. It seems very interesting to the experimental detection of these features for the understanding of the EAS development under GF. Few ongoing experiments, such as the WILLI detector in Bucharest or the Okayama University, Japan EAS installation with increased detection area where the present proposal can be exploited to extract the nature of primary CRs.

References

[1] T. Antoni *et al* Astro-ph/0505413 (2005).
[2] G.Cocconi, Phys. Rev. 93, 646 (1954).
[3] D. Heck J. Knapp J. N. Capdevielle G. Schatz and T. Thouw 1998.