A new approach for PeV gamma-ray search by studying GeV muons in extensive air shower

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Introduction

A Monte Carlo (MC) simulation study of cosmic ray (CR) extensive air shower (EAS) has been carried out aiming to identify the γ-ray primaries in the PeV region from the background component of hadronic CR primaries. Our main focus is to investigate how the earth's geomagnetic field (GMF) may affect the dipole separation of secondary charged muons (μ^+ & μ^-) in the EAS and how this may be used to distinguish between γ-ray and hadron-induced showers.

Accurate discrimination of γ-ray-induced showers from hadron-induced ones is crucial in CR air shower physics for identifying and examining the γ-ray sources and associated high-energy processes. This discrimination of the high energy γ-ray shower from the background of hadron induced ones is the key to unlocking the secrets of most powerful and distant astronomical objests in the universe like-supernovae, pulsars, black holes, gamma-ray bursts, active galactic nuclei, etc.[1].

The study of EAS involves the analysis of the lateral density distribution (LDD) of secondary CRs in the ground plane. The analysis of EAS data is primarily performed by projecting the signal information obtained in the detector plane (DP) onto the shower-front plane (SP). The LDD of EAS particles is assumed to be symmetrical on SP about the shower axis. The polar symmetry of the LDD is perturbed by the attenuation effect [2], geomagnetic effect (GE) etc. Being hard-component, muons experience less interaction and thereby negligible attenuation while propagating through the atmosphere than the electrons [3]. Consequently, the muons are influenced significantly by the GMF. The charged muons, μ^+ and μ^-, are deflected by the magnetic Lorentz force while advancing through the GMF and experience transverse separation. The linear distance between the barycenter of the μ^+ and μ^- is coined as d_{tr}. The parameter d_{tr} is found to be sensitive to the primary CRs.

Simulation of EAS & data analysis

The MC simulation code *CORSIKA* of version 7.690 with the hadronic interaction models EPOS-LHC and UrQMD are used. The EAS events have been simulated in the environment of KASCADE experiment centre. About 50 events are generated each for Proton (p) and Gamma (γ) primaries at average primary energy 10^{18} eV taking zenith angles (Θ) of incidence in between 58^o and 62^o and azimuth angle $\Phi = 0^o$. A little number of events are also generated by switching off the Earth's magnetic field to examine the effect distinctly. A projection method is applied for transforming the position of hit of each muon from the ground plane (r_g, β_g or x_g, y_g) onto the SP (r_s, β_s or x_s, y_s). The transformation relations are-

$$r_s = r_g\sqrt{1 - sin^2\Theta cos^2(\beta_g - \Phi)} \quad (1)$$

$$x_s = x_g cos\Theta = r_g cos(\beta_g - \Phi)cos\Theta \quad (2)$$

$$y_s = y_g = r_g sin(\beta_g - \Phi) \quad (3)$$

The influence of GMF is emphasized for high momentum muons (10^1-10^3 GeV/c) when collected within the annular region having core distance between 60 m and 90 m [4].

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Result and discussion

For the primary particles coming from the North, the μ^+ and μ^- experience GMF greatly around $\beta_s \sim 90^o$ and $\sim 270^o$ respectively which is evident in the Fig. 1. To quantify the influence of GMF, we have estimated the coordinates of the barycenters of μ^+ and μ^- on the SP and thereby d_{tr} has been evaluated. To calculate d_{tr}, the linear distance between the barycenters of μ^+ and μ^- from two opposed regions in a hypothetical interior quadrant sector (IQS) is estimated. The IQS represents a region in the interior between two circles enclosed by a pair of arcs on opposite sides and a pair of diagonally aligned straight lines passing through the EAS core making a central angle of 15^o. Fig. 2 illustrates how the parameter d_{tr} varies with polar angle (β_s) for p and γ initiated EASs with $\Theta = 60^o$ coming from the North. When the GMF is turned off, the azimuthal fluctuation of d_{tr} is also displayed in this figure. The maximum value of the parameter, Md_{tr}, is also estimated for both primary species. Md_{tr} takes values 114.22 $\pm$ 4.30 and 80.43 $\pm$ 5.21 respectively for p and γ primaries. It has also been observed that the parameter exhibits primary mass sensitivity. So, the parameter might be useful for selecting γ-ray showers from hadron initiated showers in ground based cosmic ray EAS experiments.

Conclusion

In this work, attempts have been made to discriminate γ-ray induced EAS from p (or hadron) initiated shower on the basis of the average muon dipole separation per shower, d_{tr}. The number of truncated muons is estimated within a narrow-annular region (60 m - 90 m) to evaluate the parameter Md_{tr}, which in turn reduces the requirement of large area muon detector. By applying the present technique, the high energy gamma rays, which are very vital for the cosmic ray physics, can be distinguished from the background of hadron EASs.

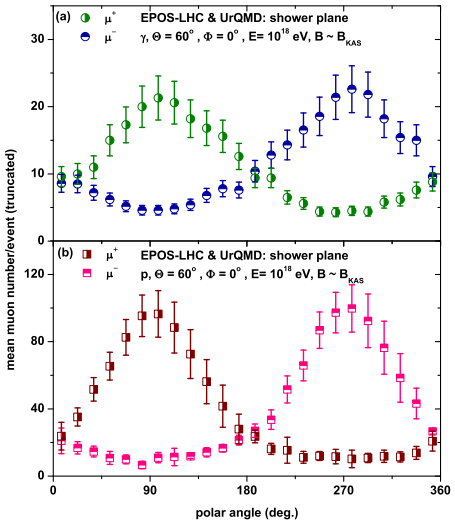

FIG. 1: Fig. a: The mean polar variation of secondary muons, μ^+ and μ^-, for γ primary arriving from the North. Fig. b: The same variation for p primary.

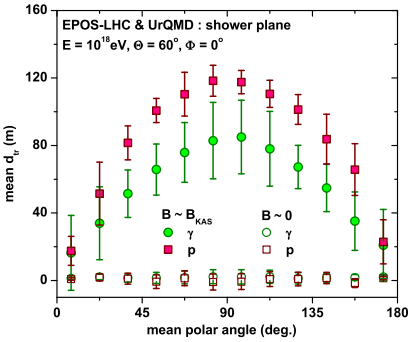

FIG. 2: Polar variation of the mean d_{tr} for γ and p showers arriving from North.

References

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