29th International Cosmic Ray Conference Pune (2005) **00**, 101–106

The Effect of the Geomagnetic Field on the Trigger Efficiency of the ARGO Experiment

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The distortion of the secondary charged particle trajectories of EAS in the geomagnetic field affecting the lateral distribution of the secondaries and the variation of the geomagnetic parameter with the azimuth angle in different zenith angle intervals for the ARGO experiment are studied using Monte Carlo simulation. The geomagnetic field leads to a stretched lateral distribution of the secondaries, thus both the density of the secondaries near the shower axis and the trigger efficiency of the array decrease. This effect is larger for the showers coming from the north than that from the south, such that the trigger efficiency for the former is lower than that for the latter. This non-uniformity becomes more evident with larger zenith angles.

1. Introduction

The non-uniformity of the primary azimuth angle distribution in Extensive Air Shower (EAS) experiments, which was first pointed out by Johnson in 1933, has been studied by various cosmic ray experiments. Recent results include: the east-west anisotropy of atmosphere neutrinos by Super-Kamiokande[1], the south-north asymmetry of the trigger efficiency by Yakutsk[2] EAS array, etc. There may exist different explanations for the above phenomenons in different cosmic ray experiments, while for EAS experiments, the asymmetry of the trigger efficiency can be explained partly by the geomagnetic effect. The geomagnetic field causes not only the east-west effect of the primary cosmic rays but also affects the trajectory of the secondary charged particles thus makes the trigger efficiency dependant on the primary direction. This effect in the ARGO experiment[3] is studied using Monte Carlo simulation.

2. Geomagnetic Parameter

In the geomagnetic field, the secondary charged particles generated in EAS are rotated by Lorentz force, with its lateral distribution stretched. Takeing secondary electron as an example, the average shift in the shower plane[2]:

$$d = \frac{h^2 B sin\chi}{2E_e cos^2\theta} \tag{1}$$

where h is the average vertical height of the electron trajectory, B is the geomagnetic field, E_e is the average energy of electron, θ is the primary zenith, and χ is the angle between the primary momentum and the geomagnetic field

$$\chi = arccos(cos\theta cos\theta_H + sin\theta sin\theta_H cos\phi) \tag{2}$$

where ϕ is the primary azimuth with ϕ=0 referring to the geomagnetic north , θ_H is the geomagnetic declination. The geomagnetic parameter g is defined as

$$g = \frac{sin\chi}{cos^2\theta} = \frac{\sqrt{A + Bcos2\phi + Ccoscos\phi}}{cos^2\theta} \tag{3}$$

with $A = sin^2\theta + sin^2\theta_H(cos^2\theta - \frac{1}{2}sin^2\theta)$, $B = -\frac{1}{2}sin^2\theta sin^2\theta_H$, $C = -\frac{1}{2}sin2\theta sin2\theta_H$, thus d is proportional to g, while g is approximately a harmonic function of ϕ with B and C being the amplitudes of the first and second harmonics. When $cot\theta_H >> \frac{tan\theta}{4}$, the first harmonic is dominant, vice versa. At YBJ, where $\theta_H \sim 45^o$, with small θ the amplitude of the first harmonic is larger than that of the second one, while at larger zenith angles, they go close. The geomagnetic parameter at YBJ (Fig.1) is larger in the north than that in the south, that becomes more evident for larger zenith angles.

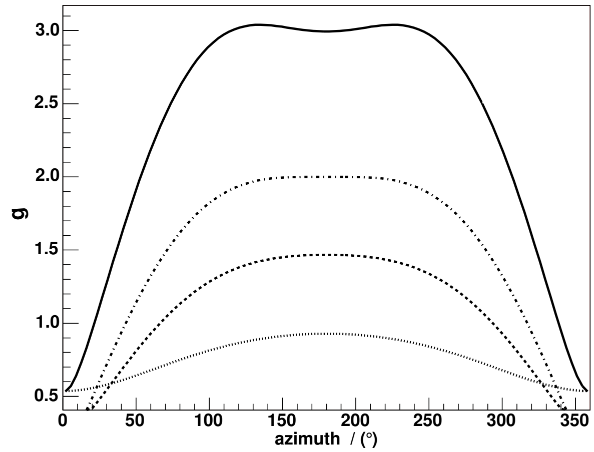

Figure 1. Geomagnetic parameter at YBJ varying with azimuth angle at different zenith angles (from bottom to top: 15^o, 35^o, 45^o, 55^o).

The difference of the average shift of secondary electrons for primary from the geomagnetic south and that from the geomagnetic north is:

$$\Delta d = \frac{h^2 B sin\theta_H}{2E_e cos\theta} \qquad (4)$$

which is proportional to $sec\theta$.

Geomagnetic parameter leads directly to the stretch of the EAS lateral distribution, thus affects the trigger efficiency of an EAS array. That differs in the geomagnetic south from the north.

3. Monte Carlo Simulation

A full Monte Carlo simulation of proton primaries (energy: 1TeV-5TeV, spectrum index: -2.7, azimuth angle: $0^o - 360^o$, zenith angle: $0^0 - 60^o$) was done for the ARGO experiment using CORSIKA562 (QGSJET, GHEISHA, and EGS4 were used for hadronic and electromagnetic interaction respectively) [4] and ARGOG-V131 (trigger multiplicity: HM100, no noise, sample area: 200m$\times$200m, with Pb) [5].

Table1 shows the triggered events with primary from the north and the south when the geomagnetic field is considered (On) or not (Off) for 6×10^4 primaries with $\theta = 30^o$, together with the average lateral distance of the secondaries ($< r >$). The density difference of the secondaries varying with lateral distance with/without geomagnetic field ($\delta\rho = \rho_{On} - \rho_{Off}$) is shown in Fig2. With the geomagnetic field the EAS lateral distribution is stretched and the secondary density falls, thus the trigger efficiency decreases. That becomes more evident for primaries from the north.

Table 1. Trigger Efficiency and the Average Lateral Distance

	0^o/Off	0^o/On	180^o/Off	180^o/On
Triggers	5593	5493	5580	5366
r(m)	263.0	264.0	263.1	268.4

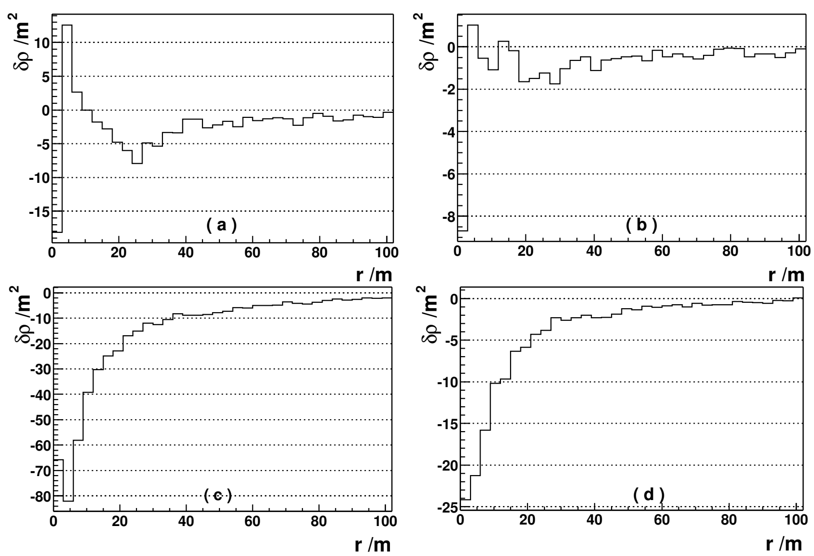

Figure 2. The density difference varying with lateral distance, a: $\phi = 0^o$, photon; b: $\phi = 0^o$, electron; c: $\phi = 180^o$, photon; d: $\phi = 180^o$, electron

The azimuth distribution of registered events (Fig.3) follows approximately a harmonic function

$$f(\phi) = \frac{1}{2\pi}(1 + A_I cos\phi + A_{II} cos2\phi) \quad (5)$$

with the fitted parameters A_I and A_{II} shown in Table2. The asymmetry of azimuth angle distribution can be described by

$$\Delta N = \frac{2(N_s - Nn)}{Ns + Nn} \quad (6)$$

where N_s and N_n are the registered events from the south and north respectively.

Table 2. Fitted Parameters and South-North Asymmetry

	$0^o - 15^o$	$15^o - 25^o$	$25^o - 40^o$	$0^o - 40^o$
A_I	0.0067	0.0163	0.0183	0.014
A_{II}	0.0004	0.0008	0.0037	0.0012
ΔN	0.0108	0.0162	0.0178	0.0156

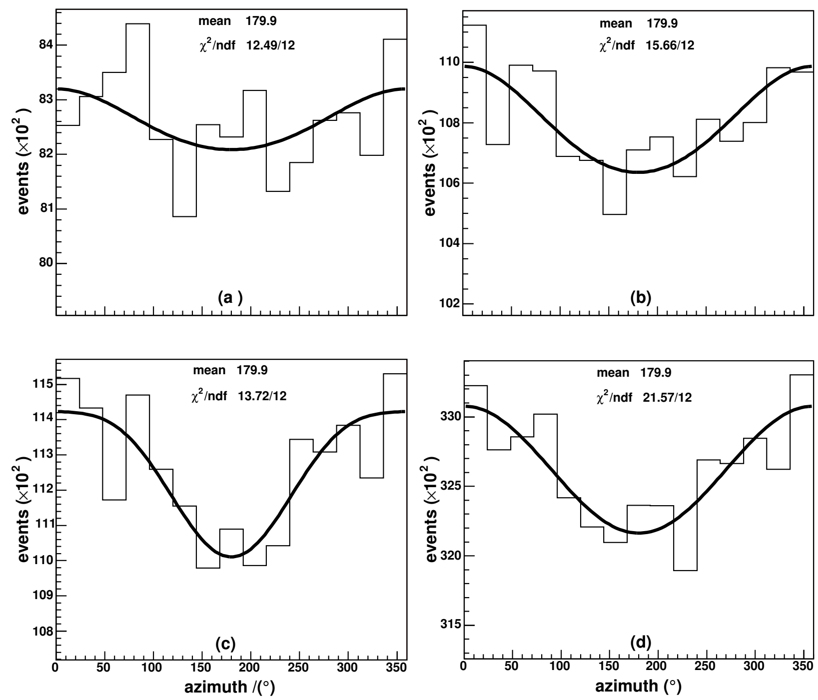

Figure 3. Azimuth angle distribution of registered events in different zenith ranges (together with the fitted curves according to Eq.5), a: $5^o - 15^o$, b: $15^o - 25^o$, c: $25^o - 40^o$, d: $0^o - 40^o$.

4. Conclusion

The secondary charged particles in EAS rotate due to the geomagnetic field, with its lateral distribution being stretched, i.e. the density of secondary particles near the core gets smaller, thus decreasing the trigger efficiency of ARGO experiment. The corresponding geomagnetic parameter is smaller for primaries from the geomagnetic south than that from the geomagnetic north, so the trigger efficiency to primaries from the geomagnetic south is larger than that from the north, thus leading to the south-north asymmetry of about $1 - 2\%$.

5. Acknowledgements

This work is supported in part by NSFC(10120130794), the Chinese Ministry of Science and Technology, the Chinese Academy of Sciences, the Key Laboratory of Particle Astrophysics, IHEP, CAS, and INFN, Italy.

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