Evidence of geomagnetic effect on the azimuthal distribution of cosmic rays in the ARGO-YBJ experiment

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The geomagnetic field (GMF) acts on the charged particles of the Extensive Air Showers (EAS) and their lateral distribution is stretched mainly in the East-West direction[1].
The average particle shift (d) on the shower plane is:

$$d = \frac{q}{2p}\left(\frac{h}{\cos\theta}\right)^2 B\sin\chi \qquad (1)$$

where χ is the angle between the magnetic field **B** and the particle momentum **p**, q is electric charge, h the vertical height of the particle path, θ the zenith angle.

MonteCarlo simulations for ARGO-YBJ detector (Fig.1) show that the trigger efficiency decreases as B or $\sin^2\chi$ values increase (for $\sin^2\chi \sim 1$ the effect of GMF is maximum). Similarly data show a linear decrease of collected events with respect to $\sin^2\chi$ (Fig.2).

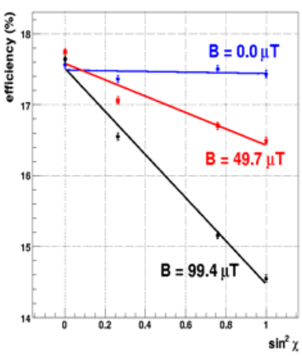

Fig. 1 – Simulation: trigger efficiency versus $\sin^2\chi$ for different magnetic fields (49.7μT is the actual GMF at the ARGO-YBJ site). Linear fit is superimposed.

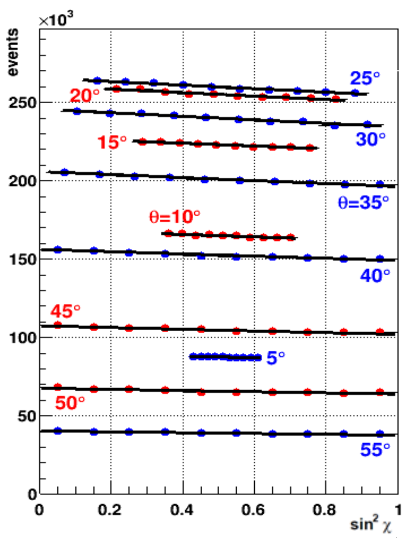

Fig. 2 – Data: collected events (from all azimuth angles) versus $\sin^2\chi$ for different zenith angles (θ). Linear fit is superimposed.

The shower spread modifies the detector trigger efficiency and introduces a modulation in EAS azimuthal distribution.
A proper simulation (primary protons with E=1TeV, $\theta=27°$, null GMF) allows to study the detector acceptance as a function of the azimuth angle. The results show a modulation with phase ~90° and periodicity 180° due to trigger and analysis cuts. The amplitude is of the order of ~0.3%.

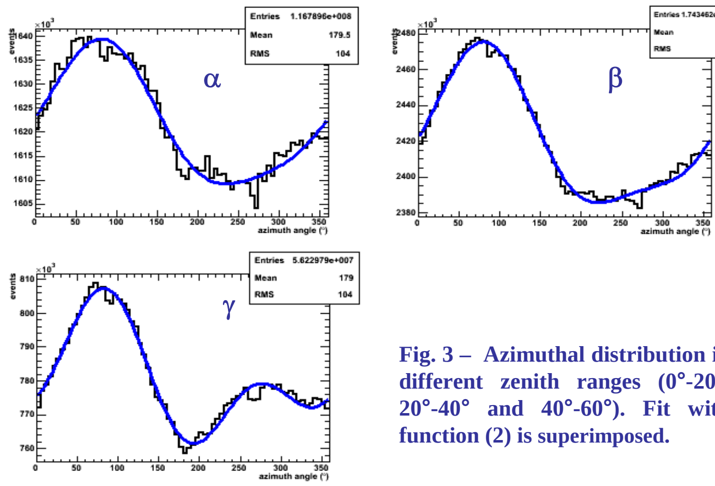

Fig. 3 – Azimuthal distribution in different zenith ranges (0°-20°, 20°-40° and 40°-60°). Fit with function (2) is superimposed.

Thus the azimuthal distribution can be described by means of two harmonics (Eq.2). The first one is due to GMF on EAS charged particles; the second can be considered the sum of GMF (2B) and detector (2A) effect (i=α, β, γ indicates different zenith ranges)

$$\frac{dN_i}{d\phi} = N_{0i}\left\{1 + k_1\langle\sin 2\theta\rangle_i \cos(\phi-\phi_1) + k_{2B}\langle\sin^2\theta\rangle_i \cos[2(\phi-\phi_1)] + g^i_{2A}\cos[2(\phi-\phi_{2A})]\right\} \qquad (2)$$

where $\phi_1 = \phi_B$ (ϕ_B = 71.89° is the GMF azimuth angle in the ARGO-YBJ reference frame), $g_1=k_1\sin 2\theta$ and $g_{2B}=k_{2B}\sin^2\theta$ describe the dependence of amplitude of the first and the second magnetic harmonic on the zenith angle.
The subsamples (i=α, β, γ) are fitted together (Fig.3) with function (2) and the parameters are what expected:

$k_1 = (2.078 \pm 0.010)\%$	$k_{2B} = (0.68 \pm 0.20)\%$
$\phi_1 = 72.18° \pm 0.28°$	
$g^{\alpha}_{2A} = (0.139 \pm 0.015)\%$	$g^{\beta}_{2A} = (0.341 \pm 0.038)\%$
$g^{\gamma}_{2A} = (1.236 \pm 0.083)\%$	$\phi_{2A} = 92.1° \pm 1.8°$

The phase ϕ_1 is compatible with GMF azimuth (ϕ_B). The coefficients g_{2A}^i increase with θ and ϕ_{2A} is compatible with 90° as expected for the detector effect. It is remarkable that the amplitude of detector effect given by simulation is of the same order of g_{2A}^{β}=0.34%.

Conclusion – The geomagnetic effect on EAS flux has been deeply investigated and verified. Results are also confirmed by MonteCarlo simulation.

[1] G. Cocconi, Phys. Review, 1954, 93:646-647