Cosmic ray asymptotic directions for Yangbajing (Tibet) experiments

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Abstract. Using the International Geomagnetic Field model for Epoch 1995.0 (IGRF 95) we have made a particle access study for the Yangbajing experiments located in Tibet (30° 06’ 38” N – 90° 31’ 50” E, 4300 m a.s.l.). A summary of the obtained results is reported for the use of the cosmic ray scientific community.

1 Introduction

Yangbajing (Tibet) location has been selected over the years as one of the best sites for ground-based cosmic ray experiments. Several international research programs are under development at this location (see, for instance, Amenomori et al., 1992; Kohno et al., 1999; Katayose et al., 1999; Bacci et al., 1999; Aloisio et al., 2001). Among these research projects the Italian-Chinese joint venture (ARGO-YBJ Collaboration) is aimed toward registering small size extensive air showers. The detector consists of a single layer of RPC’s (Resistive Plate Counters), covering an active area of about 6700 m^2. Details on the proposed experiment can be found in Abbrescia et al. (1996).

In preparation for ARGO-YBJ data investigation, we have been evaluating the charged particle access to the instrument by computing cosmic ray trajectories through a high-order mathematical model (10th order) of the quiescent geomagnetic field.

Applying the International Geomagnetic Reference Field for Epoch 1995.0 (IGRF 95; Sabaka et al., 1997), Storini et al. (2000a) analysed the cosmic ray penumbra in the low rigidity interval (~ 10 - 20 GV). Storini et al. (2001) also considered the possible use of the ARGO-YBJ experiment for solar relativistic particle studies.

Here we mainly report on the asymptotic direction variability in the rigidity range of 20 - 100 GV for the use of the international scientific community.

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2 Yangbajing location and effective cutoff rigidities

The Yangbajing Cosmic Ray Laboratory is only 90 km from Lhasa, Tibet. Its geographic coordinates are 30.11° N and 90.53° E (see Fig. 1); the altitude is 4300 m a.s.l. (atmospheric vertical depth: 606 g/cm^2).

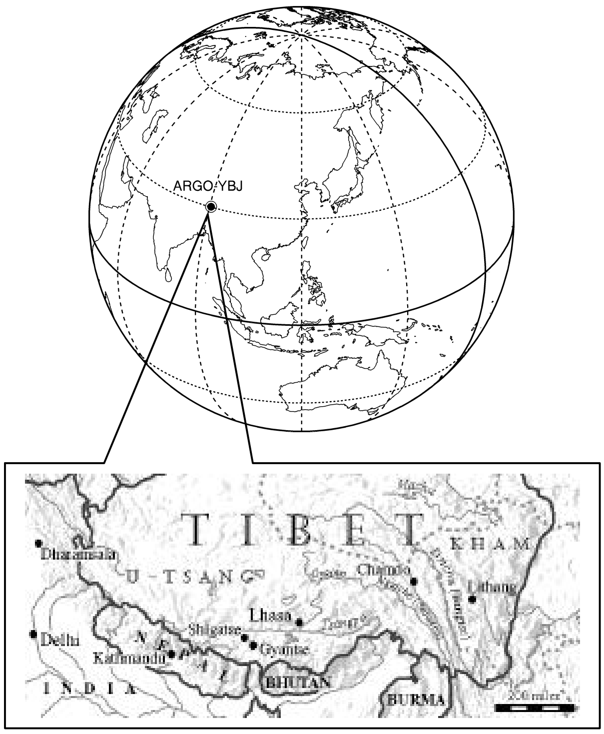

Fig. 1 - Location of the Italian-Chinese ARGO-YBJ experiment.

Asymptotic directions and cutoff rigidities were calculated for the 100.00 – 4.10 GV rigidity (R) interval for the following directions: vertical (zenith = 0°); and zenith angles 15° and 30° for 8 azimuthal directions: N (0°), NE (45°), E (90°), SE (135°), S (180°) , SW (225°), W (270°), and NW (315°). The trajectory calculations were initiated at an altitude 20 km above the Earth's surface (i.e. an altitude above which particle collisions resulting in nuclear cascades through the atmosphere would be minimal), using a variable step range (S) as reported in Table 1 for R < 20 GV and S = 1 GV for R ≥ 20 GV.

Table 1. Rigidity steps (S) used for the evaluation of the particle asymptotic directions at Yangbajing location.

Direction	S=0.1 GV	S=0.01 GV	S=0.1 GV
Vertical	4.1 - 10.9	11.00 - 16.99	17.0 - 19.9
15°N	4.1 - 11.9	12.00 - 17.99	18.0 - 19.9
15°NE	4.1 - 11.9	12.00 - 17.99	18.0 - 19.9
15°E	4.1 - 13.3	13.40 - 19.99	-
15°SE	4.1 - 11.3	11.40 - 17.99	18.0 - 19.9
15°S	4.1 - 10.3	10.40 - 16.99	17.0 - 19.9
15°SW	4.1 - 9.3	9.40 - 15.99	16.0 - 19.9
15°W	4.1 - 9.3	9.40 - 15.99	16.0 - 19.9
15°NW	4.1 - 10.3	10.40 - 16.99	17.0 - 19.9
30°N	4.1 - 12.3	12.40 - 18.99	19.0 - 19.9
30°NE	4.1 - 12.3	12.40 - 19.05	19.1 - 19.9
30°E	4.1 - 13.3	13.40 - 19.99	-
30°SE	4.1 - 12.3	12.40 - 18.99	19.0 - 19.9
30°S	4.1 - 9.3	9.40 - 15.99	16.0 - 19.9
30°SW	4.1 - 8.3	8.40 - 14.99	15.0 - 19.9
30°W	4.1 - 8.3	8.40 - 14.99	15.0 - 19.9
30°NW	4.1 - 10.3	10.40 - 16.99	17.0 - 19.9

Using the cosmic ray cutoff terminology (Cooke et al., 1991 and references therein), we have determined for each of the investigated directions the effective rigidity cutoff (Rc) for the charged particle arrival at ARGO-YBJ location. Figure 2 summarises the results. The vertical direction (zenith = 0°) is characterised by an effective cutoff rigidity of 13.98 GV (lower panel of Fig. 2). From the upper panel of Fig. 2 it is clear that the highest effective cutoff (Rc = 18.98 GV) is at a zenith angle of 30° in the East direction while the lowest effective cutoff (Rc = 11.23 GV) is at a zenith angle of 30° in the West direction. We did not find any cosmic ray penumbra for zenith angles of either 15° or 30° having azimuthal angles equal to 45°, 90°, 135° and 180°; however, cosmic ray penumbra were present for all other zenith angles. The maximum penumbra, 1.60 GV in width, was at zenith angle 30° in the NW direction. When considering the allowed particle access over the entire cone for which calculations were performed we note that all cosmic rays having rigidities above the highest cutoff of 18.98 GV are allowed and all cosmic rays having rigidities below the lowest allowed rigidity value of 10.37 GV (at 30° SW) are forbidden. Particle access between these two values is a function of the degree of access in the penumbra (see Storini et al., 2000a for details).

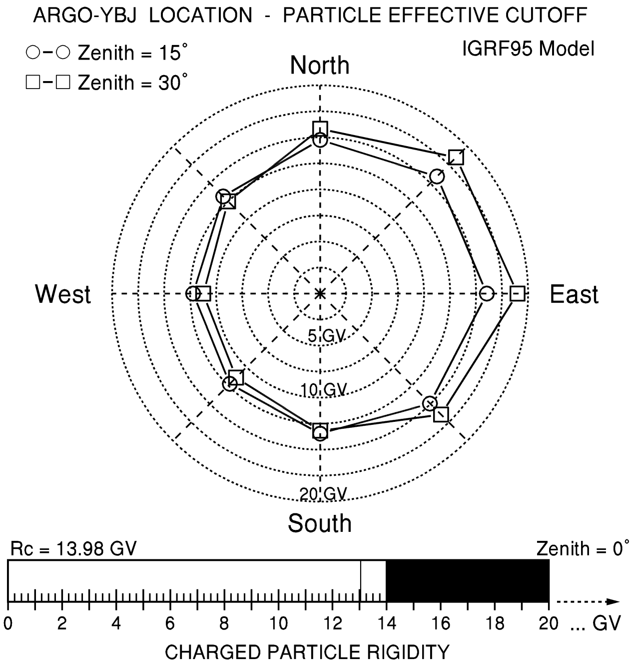

Fig. 2 - Charged-particle access at ARGO-YBJ location for vertically incident cosmic rays (zenith = 0°, lower panel: allowed particle rigidities are reported as dark areas while the forbidden ones by white areas) and Rc for two different zenith angles (upper panel; the azimuthal angle is clockwise from North; the radius is in units of 2.5 GV).

3 Yangbajing asymptotic directions for cosmic rays

The knowledge of the asymptotic directions for cosmic rays reaching a terrestrial site allows one to identify the direction of motion which the charged particles have in the interplanetary medium, i.e. prior to their interaction with the geomagnetic field. Hence, the computation of the asymptotic direction of approach of charged particles to a terrestrial site is relevant for any detailed study of the cosmic radiation. The geomagnetic field has been rapidly decreasing (in geologic terms) over the past half century, and this changing magnetic field is sufficiently large to affect cosmic ray access to many regions of the world (Shea and Smart, 1990). Smart and Shea (these proceedings) have calculated the cutoff rigidity values for several cosmic ray stations using geomagnetic field models appropriate for several Epochs. This work will be extended for all cosmic ray stations in operation from 1950 until 2000. In this first step of our trajectory-tracing process we analysed the orbit of a negative charged particle moving outward from the Earth (for each selected direction), through the geomagnetic field, to a distance sufficiently far from the terrestrial environment (25 Earth radii) that the field effects on the orbit became negligible. However, in a second step of this analysis the influence of magnetospheric disturbances on the charged particle access at Yangbajing should be determined.

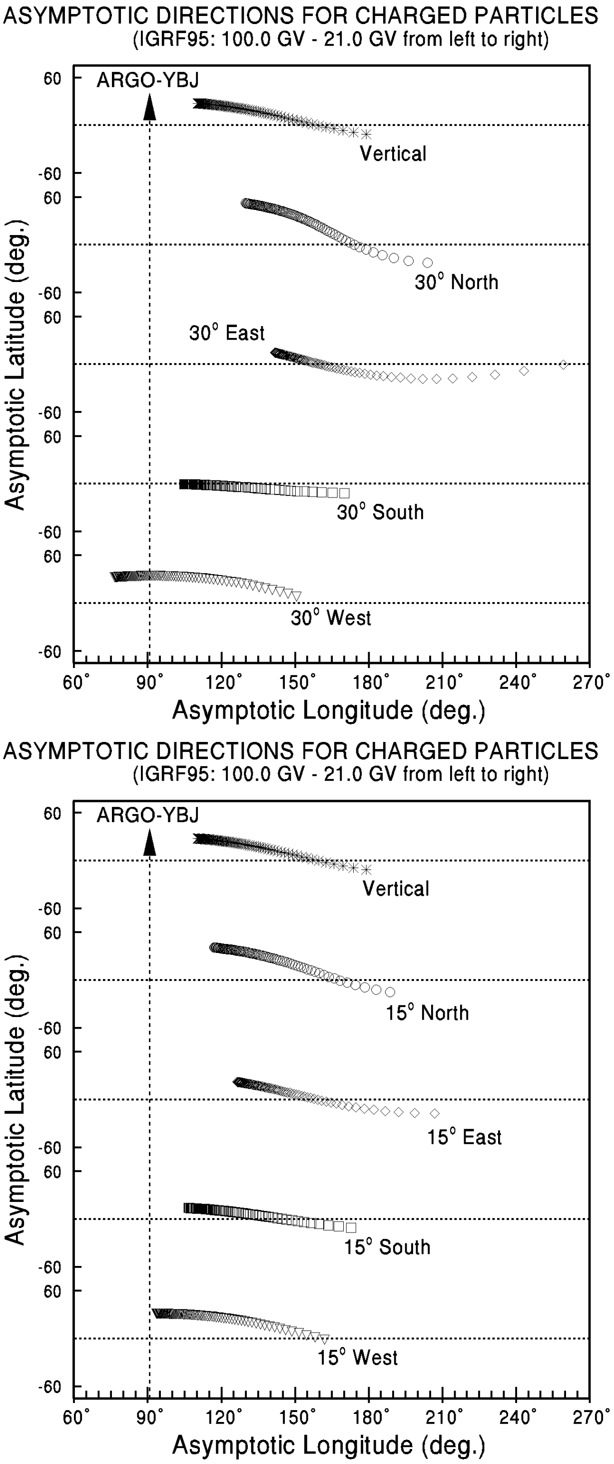

Fig. 3 - Cosmic ray asymptotic directions for vertical and non-vertical (15° and 30° ; S=1) incident particles at ARGO-YBJ location (the 0° latitude is shown by a dotted line). The geographic longitude of ARGO-YBJ detector is indicated by a vertical arrow.

The calculated asymptotic directions for vertically incident cosmic rays at ARGO-YBJ location from the upper rigidity cutoff to 100 GV were published as Fig. 2 by Storini et al. (2000a). The complete set of calculations, in tabular form, can be found in Storini et al. (2000b) for vertically incident charged particles, while those for the 15° and 30° zenith and the eight azimuthal angles will be published as IFSI/CNR reports during the current year.

Here, in the upper and lower panels of Fig. 3, we show the asymptotic directions for the interval 20 GV < R ≤ 100 GV (asymptotic longitudinal interval: 60° - 270°, which contains the entire range of particle rigidity values). The vertical values can be compared with the asymptotic directions calculated for the two zenith angles (15° and 30°) and the cardinal directions (North, East, South and West). The directions are indicated with different markers to better appreciate the rigidity dependence of the asymptotic spread.

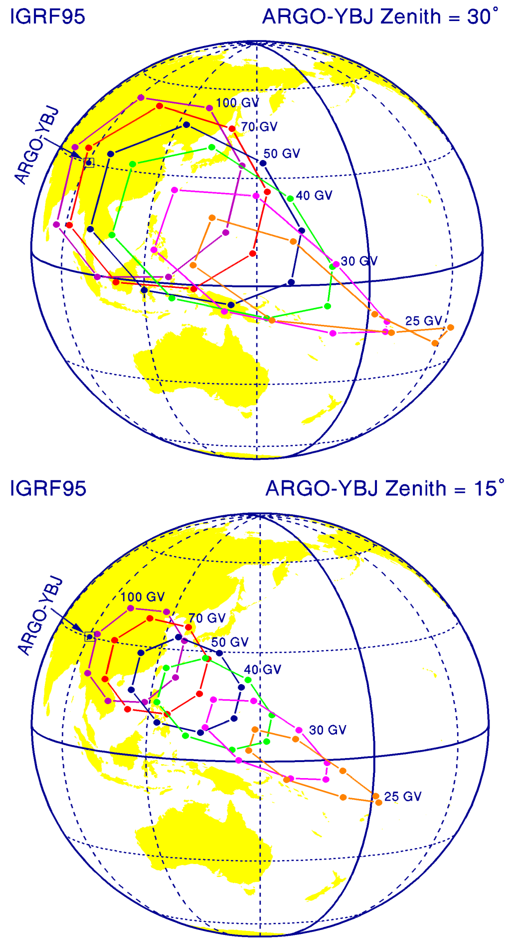

Fig. 4 – Sky map of the asymptotic directions of approaching cosmic ray particles to the Yangbajing location. The cardinal directions: N, NE, E, SE, S, SW, W and NW were considered for particle rigidities of 25 GV, 30 GV, 40 GV, 50 GV, 70 GV, 100 GV and two zenith angles: 15° (bottom) and 30° (top).

Figure 4 illustrates, for the 15° (bottom) and 30° (top) zenith direction, the particle asymptotic directions for the eight azimuthal angles considering only the rigidity values of R = 25, 30, 40, 50, 70 and 100 GV. While at high rigidities (100 GV - 70 GV) the asymptotic directions tend to be circular, at low rigidities (50 GV - 25 GV) there is an increasing spread in longitude and a decrease in latitude toward the equator. This implies that at the lower rigidity values a particle detector would have a greater response to particles that penetrate the magnetosphere in the equatorial regions. This is also the detector sensitivity for vertical particles approaching the instrument with R ≤ 20 GV.

4 Summary and conclusion

The ARGO-YBJ experiment exploits the concept of terrestrial high-altitude "full coverage" to reach the best sensitivity with ground-based instruments to many items of astroparticle physics (e.g. gamma-astronomy at ≥ 100 GeV, diffuse gamma-rays at energies never observed, gamma ray bursts up to the GeV/TeV energy range, primary proton spectrum…). The study of the asymptotic directions of charged particles at the ARGO-YBJ site (30.11°N, 90.53°E) for rigidities R ≤ 100 GV (IGRF95) demonstrates that the instrument will be able to monitor the free-space of the Northern hemisphere for particles in the rigidity range of about 100 GV - 50 GV. At lower rigidities the free-space equatorial region will be also scanned.

Solar cosmic rays exceeding 20 GV were recorded during the 29 September 1989 solar cosmic ray event (Swinson and Shea, 1990). Since the effective cutoff rigidities for zenith = 0°, 15° and 30° cover the rigidity range from 11.23 GV to 18.98 GV, it would be expected that the very energetic solar cosmic rays will be able to leave their imprints on ARGO-YBJ records. In addition, this site is also an excellent location for the detection of solar neutrons.

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