A CONTRIBUTION TO THE ARGO-YBJ COLLABORATION

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Abstract. *The available high-order mathematical model for the quiescent geomagnetic field (IGRF 1995) has been used to estimate the geomagnetic shielding of extraterrestrial charged particles to the ARGO-YBJ location (30° 06' 38" N - 90° 31' 50" E). Particle access studies were made in the rigidity interval 100.00 - 4.10 GV. A detailed report of our results is given. In particular, we discuss the structure of the cosmic ray penumbra evaluated by steps of 0.01 GV.*

1. Introduction

The ARGO-YBJ (Astrophysical Radiation with Ground-based Observatory at YangBaJing, Tibet) Collaboration† is an Italian-Chinese joint venture under way for the next years with the objective of registering small size extensive air showers (see Abbrescia et al., 1996 and De Vincenzi et al., 1999 for details).

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Potentially, the above instrument (located at 30° 06’ 38” N - 90° 31’ 50” E geographic coordinates and 4300 m a.s.l.) will be also useful to record the solar modulation of galactic cosmic rays and energetic relativistic particles coming from the Sun. In preparation for these studies, we are investigating what is the minimum rigidity (i.e. momentum per unit charge) that a charged particle must possess to reach the detecting area from a specified direction. However, the cosmic ray rigidity cutoff is not an unique value. For each zenith and azimuthal direction there is an upper cutoff (R_U) above which all particles have allowed access to the experiment and a lower cutoff below which the incoming particles are completely forbidden (R_L). Often R_U and R_L are different and a penumbral (P) region exists in the particle rigidity range. In the penumbral region a complex series of allowed and forbidden cosmic ray trajectories coexist and a practical value for the rigidity cutoff is introduced taking into account the transmission through the penumbra; it is the effective rigidity cutoff (R_C). For a discussion of cosmic ray cutoff rigidity terminology see Cooke et al. (1991). In this paper we report our evaluations using only the quiescent International Geomagnetic Reference Field (IGRF) model for 1995 (Sabaka et al., 1997).

2. Trajectory-derived asymptotic directions and vertical cutoff rigidities

The trajectory-tracing technique introduced many years ago (e.g. Shea and Smart, 1967 and references therein) has been used to compute the asymptotic directions and cutoff rigidities of charged particles arriving at ARGO-YBJ. It utilise the fact that the trajectory of a negative particle moving outward from a specific measurement site and direction is identical to the trajectory of a positive particle of equal rigidity approaching to the Earth in the same direction. Parameter evaluations were started at 20 km above the Earth surface using a variable rigidity step range (S) as shown in the upper panel of Figure 1. Computations were made for the rigidities up to 100 GV. The lower panel of the same Figure illustrates the allowed and forbidden rigidities in the vertical direction.

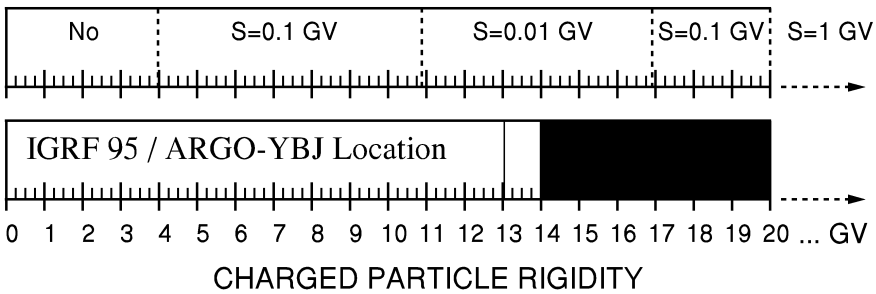

Fig. 1 - *Charged-particle access at ARGO-YBJ location for vertically incident cosmic rays (lower panel) and data step (S) used in the computation for the investigated particle rigidities (upper panel). Allowed particle rigidities are reported as dark areas while the forbidden ones by white areas. Note that the rigidity range 0-4 GV has not been considered.*

The computed asymptotic directions of vertically incident charged particles for the ARGO-YBJ experiment are shown in Figure 2 in the longitudinal interval 0°-360° E. The directions are indicated with different markers to better appreciate the dependence on the rigidity of the spread in the direction of motion which the particles had in interplanetary space prior to their interaction with the geomagnetic field. The station position is also indicated.

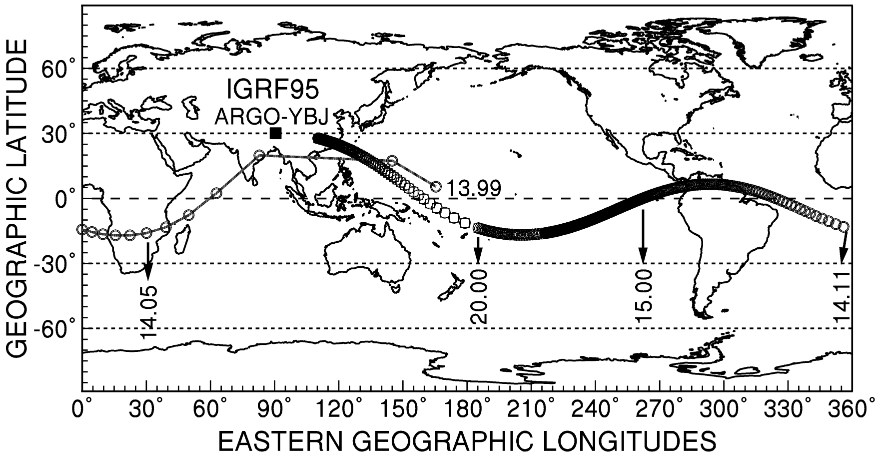

Fig. 2 - *Asymptotic directions for vertically incident cosmic ray particles at ARGO-YBJ location (filled square) obtained using the IGRF95 model. Squares surrounded by circles show 100-20 GV, open circles illustrate 19.9-13.99 GV and a continuous line the lower part of the allowed rigidity interval (14.10-13.99 GV).*

3. Cosmic ray access from non-vertical directions

We also investigated the cosmic ray access to the instrument from non-vertical directions. We selected two zenith angles: 15° and 30° for different azimuthal directions: 0° (North), 45° (North-East), 90° (East), 135° (South-East), 180° (South), 225° (South-West), 270° (West), 315° (North-West) and 360° (North). The results are displayed in Figures 3 and 4.

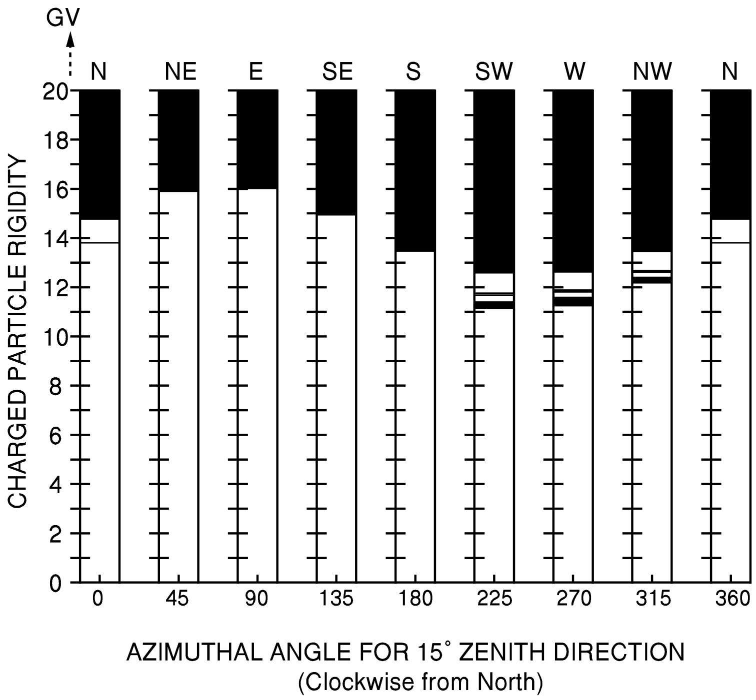

Fig. 3 - *Illustration of the geomagnetic cutoff transition from forbidden to allowed (bottom to top) access at ARGO-YBJ as determined by cosmic ray trajectory calculations using IGRF95 model (white intervals: forbidden rigidities; black intervals: allowed rigidities) with a 15° zenith direction. Azimuthal angles are clockwise from North (N) direction.*

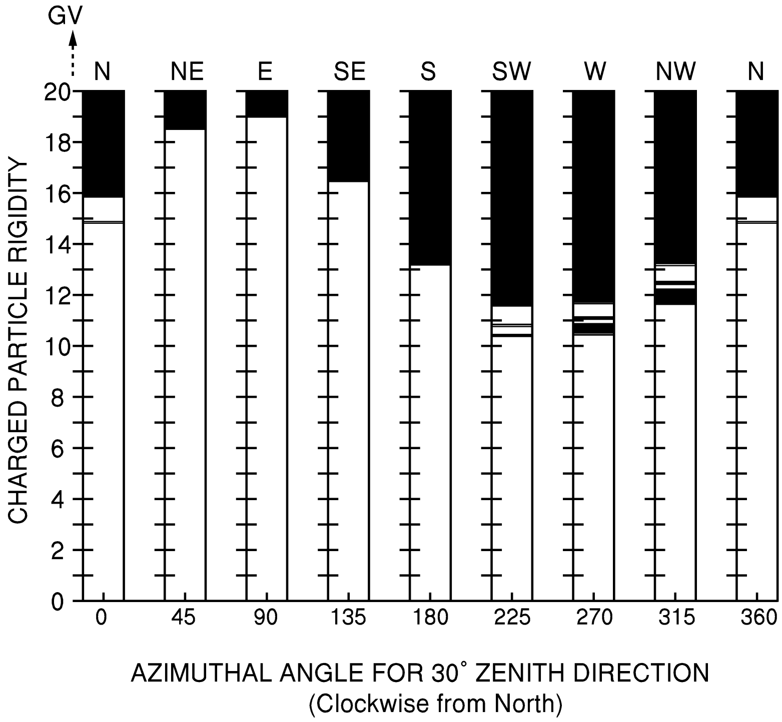

Fig. 4 - *Illustration of the geomagnetic cutoff transition from forbidden to allowed (bottom to top) access at ARGO-YBJ as determined by cosmic ray trajectory calculations using IGRF95 model (white intervals: forbidden rigidities; black intervals: allowed rigidities) with a 30° zenith direction. Azimuthal angles are clockwise from North (N) direction.*

4. Summary and conclusion

The study of the cosmic ray access to the ARGO-YBJ experiment using the IGRF95 model shows that the vertical direction (zenith = 0°) is characterised by a 0.95 GV penumbra and an effective cutoff rigidity of 13.98 GV. The evaluated rigidity parameters for all considered directions are listed in Tables I and II.

Table I - *1995 rigidity parameters for ARGO-YBJ location (30.11°N, 90.53°E) considering the 15° zenith direction.*

Zenith	Azimuth	R_U (GV)	R_L (GV)	P (GV)	Effective Cut-off
15°	0°	14.77	13.80	0.97	14.75 GV
15°	45°	15.90	15.90	-	15.90 GV
15°	90°	16.02	16.02	-	16.02 GV
15°	135°	14.94	14.94	-	14.94 GV
15°	180°	13.47	13.47	-	13.47 GV
15°	225°	12.58	11.14	1.44	12.28 GV
15°	270°	12.62	11.25	1.37	12.22 GV
15°	315°	13.46	12.18	1.28	13.17 GV
15°	360°	14.77	13.80	0.97	14.75 GV

Table II - *1995 rigidity parameters for ARGO-YBJ location (30.11°N, 90.53°E) considering the 30° zenith direction.*

Zenith	Azimuth	R_U (GV)	R_L (GV)	P (GV)	Effective Cut-off
30°	0°	15.84	14.82	1.02	15.82 GV
30°	45°	18.50	18.50	-	18.50 GV
30°	90°	18.98	18.98	-	18.98 GV
30°	135°	16.45	16.45	-	16.45 GV
30°	180°	13.17	13.17	-	13.17 GV
30°	225°	11.56	10.37	1.19	11.43 GV
30°	270°	11.72	10.43	1.29	11.23 GV
30°	315°	13.23	11.63	1.60	12.51 GV
30°	360°	15.84	14.82	1.02	15.82 GV

In conclusion we find that the range in geomagnetic cutoff values for the ARGO-YBJ location (for the directions considered) is from a low cutoff rigidity of 11.23 GV at 30° zenith in the West direction to a high cutoff rigidity of 18.98 GV at 30° zenith in the East direction. The cosmic ray penumbra is significant only for the North, North-West, West and South-West directions, in agreement with the so-called *East-West effect* of positive charged particles in the geomagnetic field.

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