The Altazimuthal Counter Telescope with a Magnet Spectrometer in the Low Momentum Region

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Abstract

The altazimuthal counter telescope with a magnet spectrometer is able to move by servomechanism for any azimuth and zenith angles. It is also possible to measure the arrival time, the incident direction, the momentum and the charge sign of incident atmospheric muons. We had measured zenith and azimuthal angular dependence of atmospheric muons in the low momentum region 1.5-100 GeV/c at sea level using the altazimuthal counter telescope.

1 Introduction:

Much experimental work has been reported to be concerned with muon intensities at sea level. But all experiments were performed and reported upon only in near-vertical or near horizontal regions(Alkofer et al., 1971,1981,1985, Rastin, 1984, Ayre, 1975, Nandi & Sinha, 1972, Bateman et al.,1971, Hayman & Wolfendare, 1962, Matsuno et al., 1984, Jokish et al., 1979, Kellog & Kasha, 1978). The significant difference concerned with neutrino fluxes between some experiments(Hirata et al., 1988, Becker-Szendy et al., 1992, Fukuda et al.,1998) and calculations(Honda et al., 1995, Gaisser et al., 1988,1989, Lee & Koh, 1990) is reported. These calculations should include various terrestrial conditions that are the geomagnetic effect the solar activity and so on. The validity of the calculations is only examined for the comparison of muon intensity measurements in all directions.

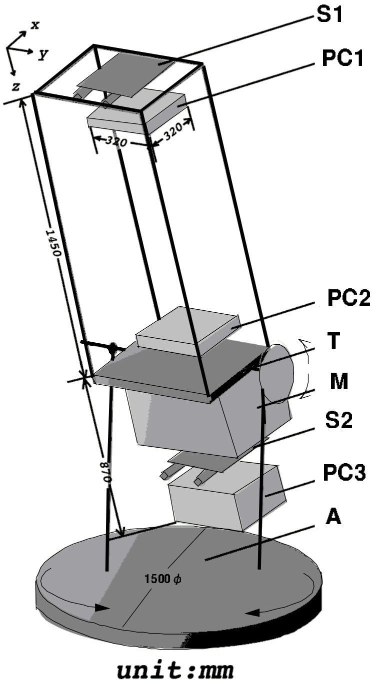

Figure 1: A sketch of OKAYAMA cosmic-ray telescope. S1 and S2: scintillation counters, PC1, PC2 and PC3: position chambers, M: iron core magnet, A: altazimuthal turntable, T: telescope mounting.

The OKAYAMA cosmic-ray telescope is suitable for the measurement of wider zenith or azimuthal angular dependence of muon intensities at sea level, for various reasons.
1). It moves by a servomotor mechanism thus allowing any azimuthal and zenith angles to be used.
2). It measures the incoming directions, the momentum and the charge sign of incident cosmic-ray muon.

We measured the zenith and the azimuthal angular dependence of cosmic-ray muons. The zenith-angle dependence are reported in the momentum range 12.5± 2.5 GeV/c, 22.5 ± 2.5 GeV/c and 45.0 ± 5.0GeV/c, in the zenith angle range 0° to 81°. The azimuth-angle dependence are reported in the momentum range 2.5 to 3.5 GeV/c, and 3.5 to 100 GeV/c in the zenith angle range 5° ± 5°, 20° ± 5° and 40° ± 5°.

2 The OKAYAMA telescope:

The OKAYAMA cosmic-ray telescope is installed in the building of Okayama University at sea level. A Sketch of the telescope is shown in Figure 1 and the main characteristics are summarized in Table 1. The telescope consists of trigger counters (scintillators)(S1 and S2), position chambers(multi-wire proportional chambers used as drift chambers)(PC1,PC2 and PC3), an iron core magnet(M), a telescope mounting(T) and altazimuthal turntable(A). More detail constructions are described in the reference(Yamashita et al., 1996).

We identified an observed particle as a muon if it passed through the telescope in a straight line without substantial interactions and if it penetrated at least 300 g/cm^2 of material including the telescope mounting and the solid iron magnet loaded in the telescope.

Table 1: The main characteristics of the OKAYAMA cosmic-ray telescope

Geographical environment	
Location	34°40’ N latitude, 133°56’ E longitude
Height	5.3 m above sea level
Geomagnetic field	48°15’ N inclination, 6°52’W declination horizontal component 3.14×10^{-5} T
Properties of the telescope	
Opening angle	15.5°
Trigger counters	Scintillation counters (40 × 50 cm^2) S1,S2
Position chambers *)	Drift chambers (40×40 cm^2, unit cell: 20×20×400 mm^3) PC1X (3 layers) PC1Y (2 layers) PC2X (3 layers) PC2Y (2 layers) PC3X (8 layers) PC3Y (2 layers)
Zenith angle (movable)	0°- 80°
Azimuthal angle (movable)	0°-360°
Solid iron magnet data	
Useful magnetic Volume	32 cm× 32 cm × 32 cm
Current, coil	350A,15 turns
Magnet induction	18±0.4 kG
Cut-off momentum by the magnet material	0.43 GeV/c
Maximum detectable momentum (maximum value)	270 GeV/c
Geometrical acceptance solid angle (3 5GeV/c, the distance between the top of PC1 and the bottom of PC3)	16.9cm^{2}sr
Coulomb scattering effect	0.37

* In detail in the reference(Yamashita et al., 1996).

3 Results:

3.1 Zenith angular dependence of muons: The absolute differential muon fluxes are compared with the results of other experiments in vertical and near the horizontal, and theoretical models. They are plotted in Figure 2 for three momentum regions, 12.5 ± 2.5, 22.5 ± 2.5 and 45.0 ± 5.0 GeV/c, The data sets were binned according to the interval of the zenith angle 2° and the azimuthal angle within 10°. The error bars show statistical errors only. The plotted experimental data consist of Nottingham(Rastin, 1984) in the vertical, DEISE(Alkofer et al., 1981,1985) and Kiel-Desy(Jokish et al., 1979) near the horizontal. The lines represent the theoretical models of a muon intensity studied by Smith and Duller(1959) and by Maeda(1973). Their models were adopted as atmospheric muons were produced by only pions, since pions are strongly dominate over kaons.

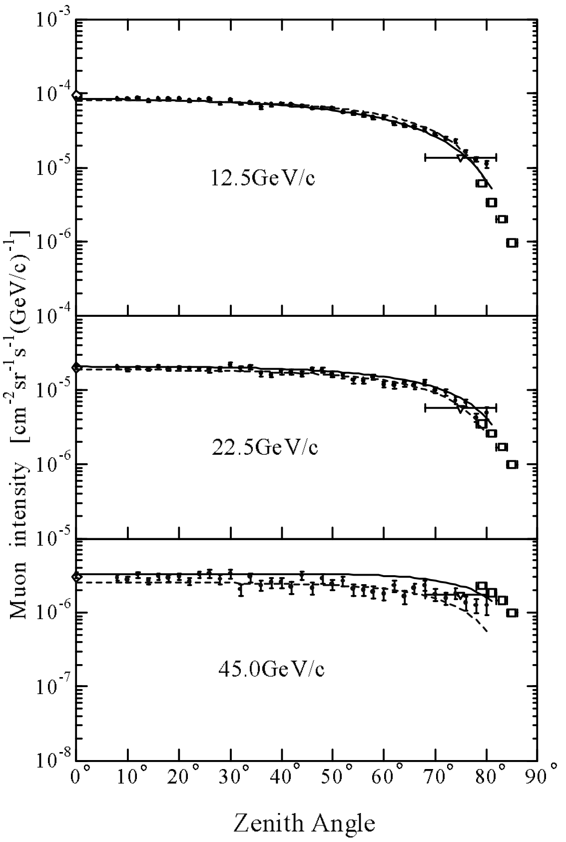

Figure 2: The zenith-angular dependence of the absolute differential muon fluxes for each momentum, 12.5 ± 2.5 GeV/c, 22.5± 2.5 GeV/c and 45.0 ± 5.0 GeV/c. •, present flux; □, observed flux by DEIS(Alkofer et al., 1981,1985); ◇, observed flux in Nottingham(Rastin, 1984); ▽, observed flux by Kiel-Desy(Jokish et al., 1979); solid lines, theoretical spectra by Smith and Duller(1959); dashed lines, theoretical spectra by Maeda(1973).

3.2 Azimuthal angular dependence of muons: One azimuthal angular dependence of muons can be shown in the positive excess of muons in each azimuthal angles. The positive excess has been defined as follows:

$$\text{positive excess} \equiv 2\frac{f^{+}-f^{-}}{f^{+}+f^{-}}$$

where f^{+} and f^{-} show the flux of positive and negative muons.
The errors, one standard deviation σ, has been determined by the following equation:

$$\sigma = 4\frac{\left((N^{+})^{2}N^{-}+(N^{-})^{2}N^{+}\right)^{1/2}}{(N^{+}+N^{-})^{2}}$$

where N^{+} and N^{-} show the number of positive and negative muons. The muon positive excess of verious azimuthal angles are presented in Figure 3, in the zenith angles, $5° \pm 5°$, $20° \pm 5°$, $40° \pm 5°$. The theoretical positive excess employed the calculations Smith and Duller(1959) in the geomagnetic field effects are drawn as dashed lines. The ratios of theoretical positive and negative fluxes are assumed as being average charge ratios of the results. The dash-dotted lines show average value of possitive excess. Kamiya et al.,(1962) reported the altazimuthal angler dependence of positive excess

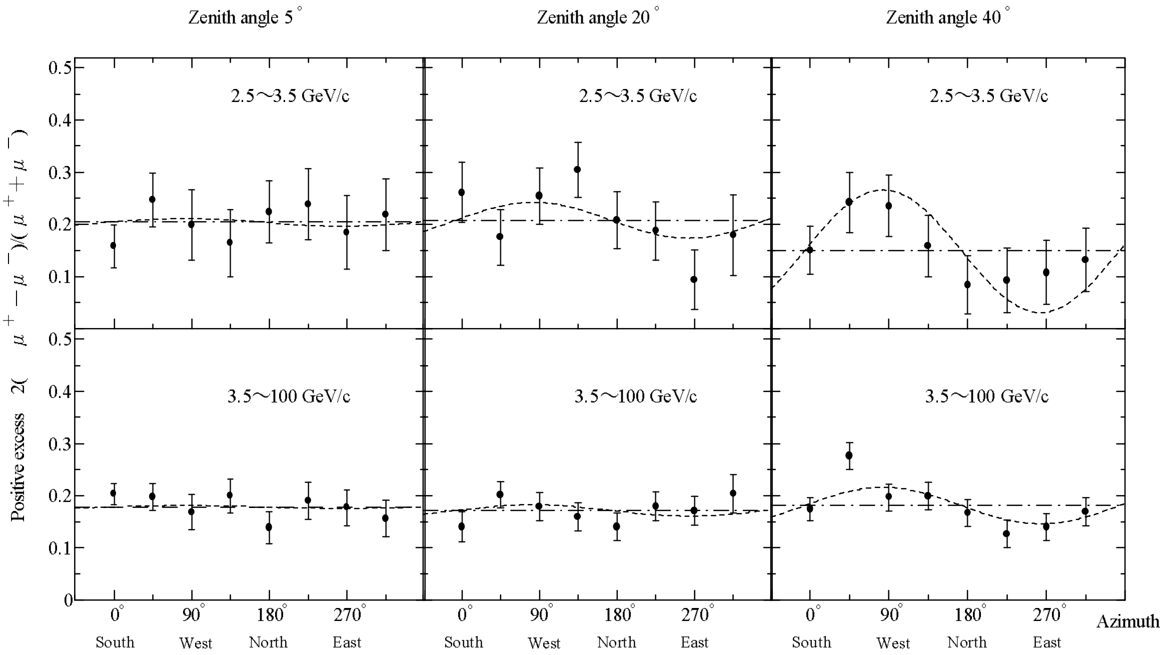

Figure 3: The azimuthal-angular dependence of the positive excess of muon for each zenith angle 5° ± 5°, 20° ± 5°, 40° ± 5°, for each momentum region, 2.5 GeV/c ~ 3.5GeV/c, 3.5 GeV/c ~ 100 GeV/c. •, positive excess of muon; dashed lines, theoretical positive excesses calculated by Smith and Duller(1959) considering geomagnetic field; dash-dotted lines, average ratio of positive excess.

at sea level for the zenith angle 78°.Our results show the same tendency of the Kamiya et al. results.

References

Allkofer, O.C. et al., Proc. 12th ICRC (Hobart, 1971) Vol.4,1314; 1971, Phys.Lett. 36, 424
Allkofer, O.C. et al., Proc. 17th ICRC (Paris, 1981) Vol. 10, 254;1985, Nucl.Phys.B259, 1
Ayre, C.A. et al., 1975, J. Phys.G 1, 584
Barr, G., Gaisser, T. K. & Stanev, T. 1989, Phys. Rev. D 39, 3532
Becker-Szendy, R. et al., 1992 Phys. Rev. D 46, 3720
Bugaev, E. V. & Naumov, V. A. 1989, Phys. Lett. B 232, 391
Fukuda, Y. et al., 1998, Phys. Rev.lett. 81, 1562
Gaisser, T. K., Stanev, T. & Barr, B. 1988, Phys. Rev. D 38, 85
Hayman, P.J. & Wolfendale,A.W. 1962 Proc. Phys. Soc. 80, 710
Hirata, K. S. et al., 1988, Phys. lett. B 205, 416
Honda, M. et al., 1995, Phys. Rev. D 52, 4985
Jokisch, H. et al., 1979, Phys. Rev., 19 D, 1368
Kamiya, Y 1962, J. Phys. Soc. Japan (Suppl.) 17, 315
Kellogg, R.G. & Kasha,H. 1978, Phys. Rev. 17 D, 98
Lee, H. & Koh, Y. 1990, Nuovo Cimento B 105, 884
Maeda, K 1973, Fortschr. Phys. 21, 113
Matsuno, S. et al., 1984, Phys. Rev., 29 D, 1
Nandi, B.C. & Sinha,M.S. 1972, J. Phys. G 5, 1384
Rastin, B.C. 1984, J. Phys.G 10, 1609
Smith, J.A. & Duller, N.M. 1959, J.Geophys. Res. 64, 2297
Yamashita, Y. et al., 1996, Nucl.Instr. Meth. A 374, 245