Arrival Directions of Large Air Showers, Low-Mu Air Showers and Old-Age Low-Mu Air Showers Observed at Mt. Chacaltaya

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ABSTRACT

Arrival directions of air showers with primary energies in the range $10^{16.5}$eV to $10^{18.0}$eV show the first harmonic in right ascension(RA) with amplitude of 2.7±1.0% and phase of 13-16h. However, the second harmonic in RA slightly seen for showers in the range $10^{18.0}$eV to $10^{19.0}$eV disappeared by accumulation of observed showers. The distribution of arrival directions of low-mu air showers with primary energies around 10^{15}eV observed at Chacaltaya from 1962 to 1967 is referred to, relating to the above-mentioned first harmonic.

Also presented in this paper are arrival directions of old-age low-mu air showers observed at Chacaltaya from 1962 to 1967, for recent interest in gamma-ray air showers.

1. Arrival directions of large air showers

Arrival directions of large air showers observed at Mt. Chacaltaya (16°20'52"S in latitude and 68°7'57"W in longitude, 5200m a.s.l. or 550 gcm^{-2} atmospheric depth) until 1979 were reported at the Paris Conference (1). In the present paper we report on arrival directions of large air showers observed at Chacaltaya until 1984. The air-shower array and the detectors after 1979 were same as those described in the previous paper (1). Procedures to determine the arrival directions(θ,ϕ) and the electron sizes(N_e) as well as the uncertainties for showers observed after 1979 are also same as those described in the previous report(1). The primary energies(E_o) of showers observed after 1979 were determined from a relation between E_o and N_e at the maximum development($N_{e\,max}$) given as $E_o(eV)=2.0\times 10^9(eV)\cdot N_{e\,max}$ described also in the previous report(1). $N_{e\,max}$ was estimated from N_e and the effective atmospheric depth where the shower was observed($550gcm^{-2}\times\sec\theta$), following the longitudinal development of electrons determined at Chacaltaya(2).

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Table 1 and 2 show the results of harmonic analyses in right ascension of the arrival directions of showers with zenith angles smaller than 60°. In the tables, figures in upper row correspond to the first harmonic and those in the lower row correspond to the second harmonic. As is seen in tables 1 and 2, the first harmonic is predominant at primary energies in the range $10^{16.5}$eV to $10^{18.0}$eV as was seen for showers observed until 1979(1). However, the second harmonic slightly seen for showers observed until 1979 with primary energies in the range $10^{18.0}$eV to $10^{19.0}$eV disappeared by including the showers observed until 1984.

Table 1.

Energy (E_0 in eV)	Number of showers	Amplitude (r in %)	Phase (in hour)	k_0	p(>r)	period
$10^{16.5}$–$10^{17.0}$	17477	2.7± 1.1 1.2± 1.1	13.1±1.5 11.2±2.8	3.11 0.61	0.05 0.55	1981 –1984
$10^{17.0}$–$10^{17.5}$	12914	2.6± 1.1 0.9± 1.2	15.5±1.7 0.2±3.6	2.21 0.28	0.11 0.76	1977 –1984
$10^{17.5}$–$10^{18.0}$	3372	4.9± 2.4 1.9± 2.4	16.3±1.8 10.0±3.5	1.99 0.30	0.14 0.74	1977 –1984
$10^{18.0}$–$10^{18.5}$	593	6.6± 5.8 4.4± 5.8	7.0±2.7 10.0±3.5	0.65 0.29	0.52 0.75	1977 –1984
$10^{18.5}$–$10^{19.0}$	117	6.0±13.1 17.8±13.1	12.2±4.4 2.0±2.4	0.10 0.93	0.90 0.39	1977 –1984

Table 2.

Energy (E_0 in eV)	Number of showers	Amplitude (r in %)	Phase (in hour)	k_0	p(>r)	period
$10^{17.0}$–$10^{18.0}$	21534	2.7± 1.0 0.6± 1.0	15.0±1.3 8.8±3.9	3.94 0.19	0.02 0.83	1964 –1984
$10^{18.0}$–$10^{19.0}$	1118	3.5± 4.2 6.2± 4.2	2.7±3.3 8.7±2.3	0.35 1.01	0.71 0.34	1972 –1984

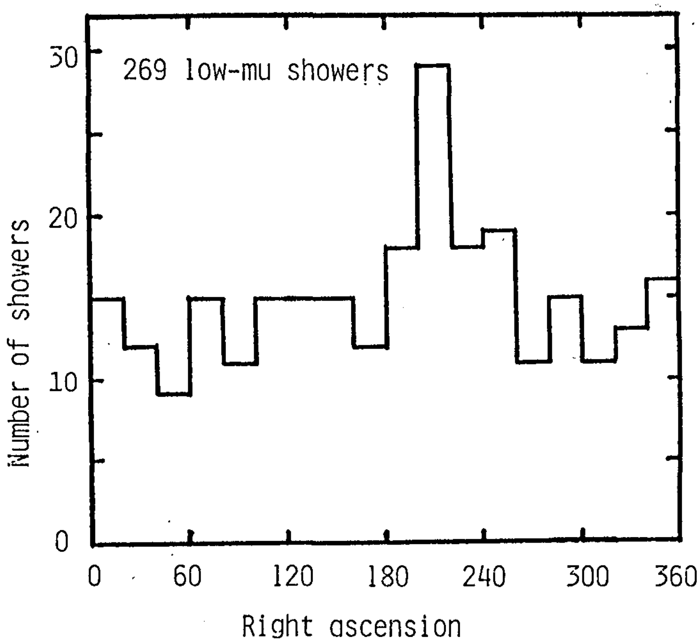

Fig. 1

2. Arrival directions of low-mu showers

Relating to first harmonic at primary energies in the range $10^{16.5}$eV-$10^{18.0}$eV, arrival directions of low-mu showers observed at Chacaltaya should be mentioned. Figure 1 shows the distribution of low-mu showers with zenith angles smaller than 60° along right ascension. The average size of the showers is about 3×10^5 and the proportion of the low-mu showers is about one thousandth of all showers. This figure was drawn in 1978 after the Calgary Conference in 1967 (3) by including all showers observed from 1962 to 1967. An excess of the showers is observed between 180°(12.0h) and 260°(17.3h) in right ascension. At that time, we assumed that these low-mu showers were candidates of gamma-ray showers. However, these low-mu showers may be showers produced by primary protons which encountered the first interactions in the deep atmosphere or produced mainly neutral pions at the first interactions, referring to the argument described in section 3. Then, it is very interesting that the right ascension where the excess of low-mu showers are observed coincides with the phase of the first harmonic described in section 1 at primary energies in the range $10^{16.5}$eV to $10^{18.0}$eV, since that fact may be related with the composition of primary cosmic rays.

3. Arrival directions of old-age low-mu showers

Relating to the low-mu showers, it is worth while mentioning the arrival directions of old-age low-mu showers observed at Chacaltaya from 1962 to 1967. Arrival directions of these showers were plotted on the celestial sphere in 1967 as shown in figure 2 but was not published(4).

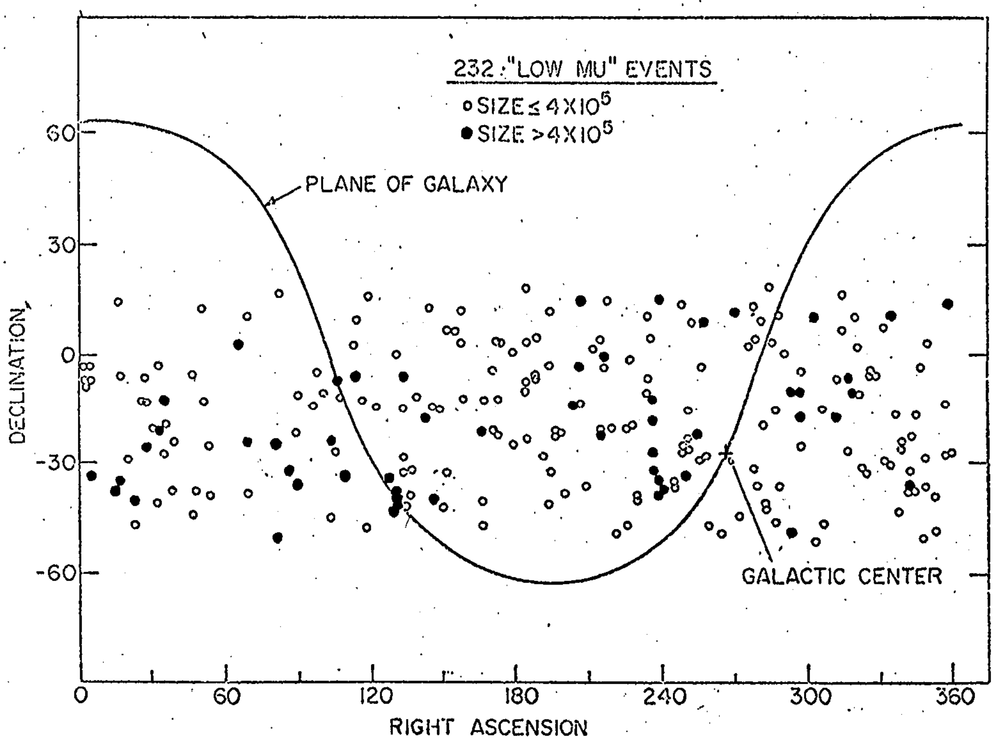

Fig. 2

The following criteria were imposed to select these showers:

(1) The zenith angle of shower is smaller than 37°(secθ<1.25).

(2) The number of muons observed in the 60m^2 shielded detector is smaller than four.

(3) The expected number of electrons at the muon detector is larger than 2000/60m^2.

(4) The shower initiation point is in the first 80gcm^{-2} of the atmosphere. The point is estimated from the zenith angle (550gcm$^{-2}\times$secθ: depth of observation), the electron size and the lateral distribution(s) by comparing the value of s with those of s for gamma-ray initiated purely electromagnetic showers. This is a criterion effective to select old-age showers produced probably primary gamma rays.

Areas in which the densities of arrival directions were several times higher than average are found near (α:135°,δ:-40°),(240°∿255°,-20°∿-40°) and at some locations adjoining the blank area seen around(10°,-20°). The first location corresponds exactly to that of Vera X-1(09h00m13.18s,-40°21'25.3"). The Adelaide group reported recently gamma-ray air showers from this X-ray source synchronized with period of the eclipsing binary [5]. There are some X-ray sources in the second location and a strong X-ray eclipsing binary X1700-377(3.4d period;17h00m32.70s,-37°46'28.8") is neaby. Regarding to the third location, a high peak is seen at galactic latitude of -60° to -70° when the distribution of the arrival directions is examined in galactic latitude. The expected number of showers for this region is 13.5: the number observed is 27. For showers with N_e smaller than 4×10^5, the corresponding number are 10.4 and 25.

Stimulated by the interesting old BASJE results looked back upon the past and mentioned in sections 2 and 3, the BASJE group has begun the preparation for a new project to observe low-mu and gamma-ray showers with 32 $1m^2$ unshielded scintillation detectors located around the $60m^2$ muon detectors, among which 12 detectors are moved from the locations in the present large array, and to determine the arrival directions within an uncertainty of 1°. The observation will be begun in the middle of 1986.

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