

A SEARCH FOR DIFFUSE EMISSION OF UHE GAMMA-RAYS IN SOUTHERN SKY FROM OBSERVATION OF HADRON-LESS AIR SHOWERS

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The lateral distributions of hadrons in air showers have been determined precisely as a function of core distance, shower size, zenith angle and age, and hadron-less showers as candidates of gamma-ray initiated air showers could be discriminated with this average lateral distribution. There are no evidences for detection of gamma-rays from any diffused regions with an enough significance, but arrival directions of hadron-less air showers selected with a strict condition have anisotropy in equatorial coordinates.

Introduction. A study of diffuse gamma-rays has been attracted by one's attention. Galactic Plane has been recognized as a possible region for the detection of diffuse gamma-rays in the energy region from 100 MeV to 10 TeV ¹⁻⁶. In the energy region greater than 100 TeV, Nikolsky et al ⁷ reported the detection of diffuse gamma-rays as the flux of $(3.4 \pm 1.1) \times 10^{-13} \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{sr}^{-1}$ at energies greater than $4 \times 10^{14} \text{eV}$. They pointed out that this flux was concentrated at higher galactic latitude. Also Berezhinsky et al ⁸ suggested that the expected integral flux of diffuse gamma-rays from Galactic Center with energies greater than 10^{14}eV would be $6.6 \times 10^{-13} \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{sr}^{-1}$. Lodz group ⁹ also reported a small excess (1 ~ 2%) of muon-less air showers with energies above 10^{16}eV from the direction of Galactic Plane, but they observed no significant excess in the energy region less than 10^{16}eV . An anisotropy of cosmic rays above 10^{14}eV was reported by Wdowczyk et al ¹⁰. They suggested that the excess of air showers from the direction of Galactic Center existed in the energy region of $10^{14} \sim 10^{16} \text{eV}$, and concluded that gamma-rays would play a key role in explaining this anisotropy.

At the energy region less than 10^{15}eV , an effective reduction of hadronic air showers is required rather than an increasing air shower collecting area. For this purpose, it is important to pay attention to the different character between gamma-ray initiated showers and proton/nucleus ones. Recent calculations ^{11,12} indicate that the muon component should be presented 10% of that of proton initiated air shower, and even a much fewer compared with heavy-nucleus initiated air shower. However, muon discrimination for gamma-ray initiated air showers is not effective by reason of its wider geometrical spread in an air shower and a small number of muons in this energy region. With same interaction backbone, a few hadronic component is also expected to be in gamma-ray air shower ¹³.

A hadronic component concentrates in rather small area near the core with a steep lateral distribution, so that this can provide a good measurement of hadron content in air showers with less ambiguity being due to particle sampling effect, as compared with a measurement of muon component. Besides, the observation at high altitude (5200m) in which air shower development reaches its maximum stage, would be able to observe showers initiated with lower gamma-ray energies. Observation of UHE gamma-rays with hadron discrimination is the most suitable way because of abundant hadron component in its development stage at 5200m.

Experimental. Observation of UHE gamma-rays with energies greater than $6 \cdot 10^{13}$ eV has been carried out at Mt.Chacaltaya ($S16^{\circ}21'$ $W68^{\circ}08'$ and 5200m a.s.l.) with SYS air shower array since February 1986¹⁴, especially paying attention to hadron-less air showers. Air shower array consisted of thirty-one 0.25m^2 and four 1.0m^2 scintillation detectors for density measurement of air showers. Air shower parameters; electron size (N_e), shower age (s) and core location are determined from these local densities of each detector. Five 0.25m^2 fast timing (FT) detectors were located at the corners of a pyramid with a base of 12m and a height of 4m in the center of air shower array, for determination of the arrival direction of individual air shower. In October 1987, three 0.25m^2 FT detectors and five density detectors were installed, to improve the accuracies of each air shower parameter.

Hadronic component in the shower core can be detected with an 8m^2 hadron detector, which consists of thirty-two 0.25m^2 scintillation detectors (burst detectors) covered with 15cm-thickness lead absorber. These counters are used for detecting the bursts produced in the lead absorber by hadrons. The burst size (the number of burst particles) is considered as the quantity proportional to the energy flow of hadronic component in a detector. In this experiment, a threshold level of burst size for a burst detector is set to be 5 particles (corresponding to a hadron energy of about 10GeV).

Analyses for Hadron-less Air Showers. The present analyses have been made for showers taken from October 1987 to April 1990. Accuracy of N_e is estimated as $\pm 50\%$ and $\pm 30\%$ for showers with energies at 10^{14} eV and greater than 10^{15} eV, respectively. The position of air shower core is determined with an accuracy of ± 0.5 m for shower with energy greater than 10^{14} eV and with that core location inside the radius of 20m from the hadron detector. Arrival directions of individual air showers have been determined by the fast timing method. The ambiguity of determination of arrival direction is estimated by a simulation method. Uncertainties of arrival direction are evaluated with the angle of difference between a true and a simulated angle, in which the $> 90\%$ simulated air showers are contained. Values of ± 3.5 and $\pm 2.2^{\circ}$ are obtained for air showers with N_e of $10^{4.8}$ and $10^{6.0}$, respectively, for this experiment.

The number of hadrons in 8m^2 hadron detector can be estimated from the number of detectors that detected hadronic bursts, out of thirty-two burst detectors. Hadron-less air showers should be selected by the quantitative parameter (here, we used R_H) as a criterion compared with the average content of hadron component in general air showers. For this purpose, reliable lateral distributions of hadrons as the function of N_e, θ, s and core distance for general air showers are required.

This hadron detector consists of 32 burst detectors, so we treat it as independent groups of burst detectors located at the same core distance band with width of 1 m (here, the number of detectors is T in the group). When Δ is a hadron

density per detector in a certain core distance band, the probability $P(\Delta, n, m)$, where n is the number of detectors detected hadronic burst and the remaining m ($=T-n$) do not detect, is determined with a statistical way:

$$P(\Delta, n, m) = \frac{(m+n)!}{m!n!} (e^{-\Delta})^m (1 - e^{-\Delta})^n$$

For a given combination of n and m , the most probable density, Δ_0 , can be calculated from the value of the maximum of $P(\Delta, n, m)$, then:

$$\Delta_0 = \ln \frac{m+n}{m}$$

For the extreme cases, to say $m=0$, the hadron density is assumed to be a density for $P(\Delta, T, 0) = 0.5$. Inside of each core distance band, there must be at least 5 detectors (T) for the determination of Δ_0 , in this analysis.

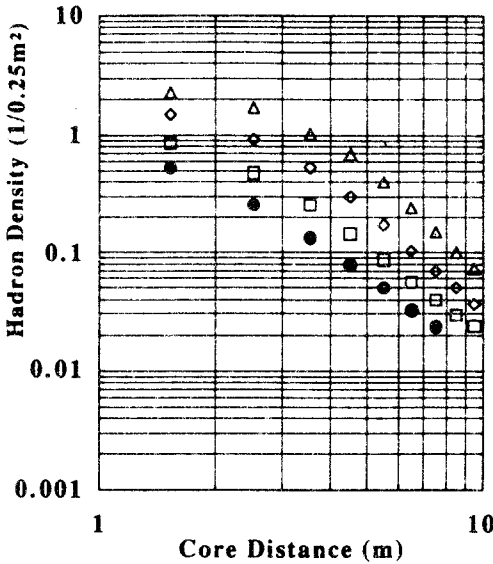


Fig.1.

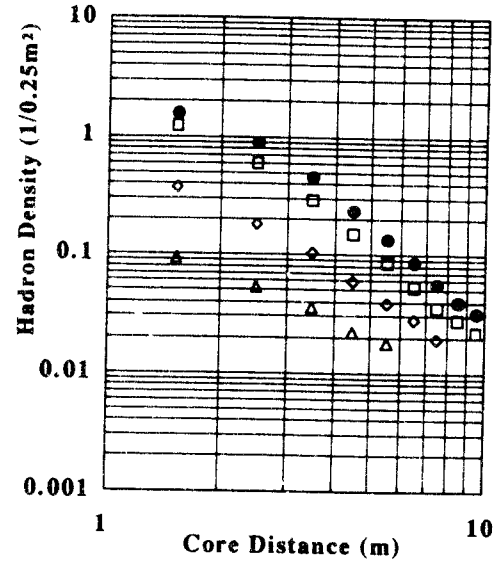


Fig.2.

Fig.1. Lateral distributions of hadrons for showers with $\sec \theta < 1.2$ and $s=0.7-1.5$. Their distributions are shown in different Ne regions: $10^{4.8} - 10^{5.0}$ (\bullet), $10^{5.0} - 10^{5.2}$ (\square), $10^{5.2} - 10^{5.4}$ (\circ), $10^{5.4} - 10^{5.6}$ (Δ)

Fig.2. Lateral distributions of hadrons for showers with $Ne=10^{5.0} - 10^{5.2}$ and $\sec \theta < 1.2$. They are shown in different s values: $0.7-0.9$ (\bullet), $0.9-1.1$ (\square), $1.1-1.3$ (\circ), $1.3-1.5$ (Δ)

Average lateral distributions of hadrons for four different size regions (Ne : $10^{4.8} \sim 10^{5.6}$ in every 0.2 logarithmic bins), age value of $0.7 \sim 1.5$ and $\sec \theta \leq 1.2$, are presented in Fig.1. The best function which we have found to fit these lateral distributions is:

$$\rho(Ne, R, \theta) = A(\theta) B(Ne) \left(\frac{R}{R_m} \right)^{-\alpha} \left(1 + \frac{R}{R_m} \right)^{-\beta},$$

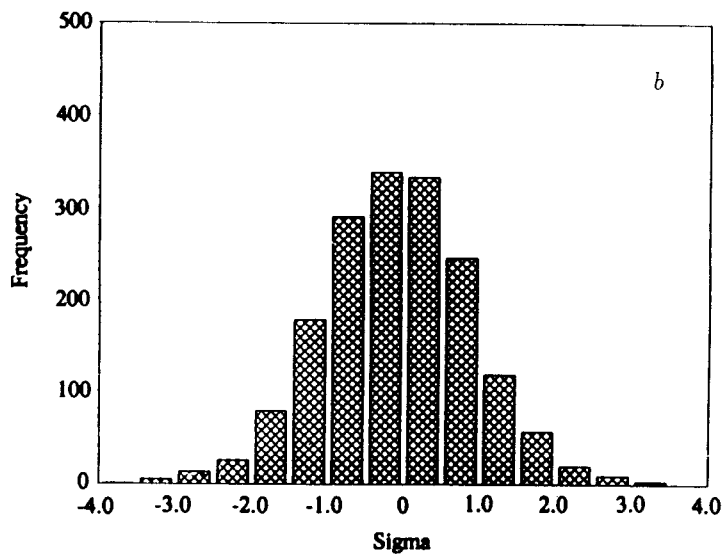
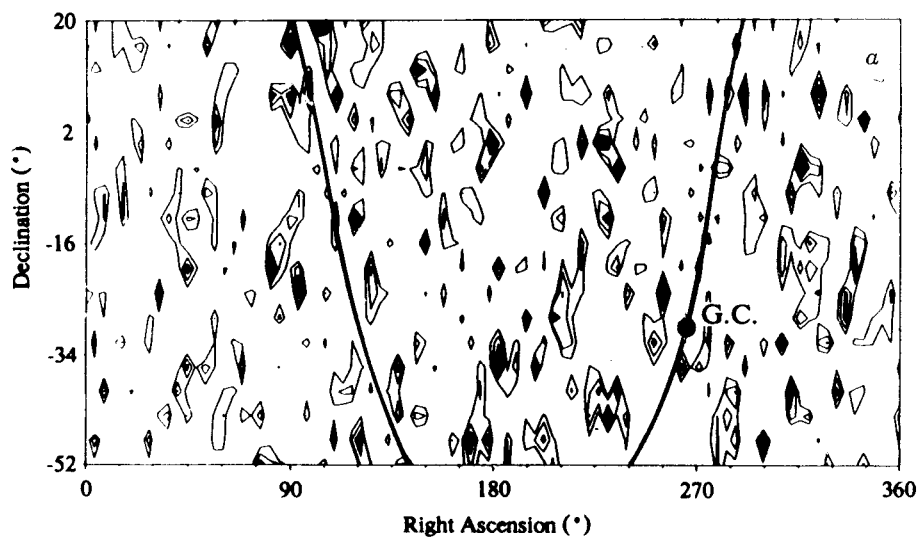


Fig.3.(a) Contour map of excess for ha dron-less air showers ($R_H(\%)=30\%$ and $s:1.1-1.5$). Lines of sigma greater than 1.0 are drawn in this figure and the regions with sigma>2.0 are shown with black areas; (b) sigma distribution derived from the analysis of contour map (Fig.(a))

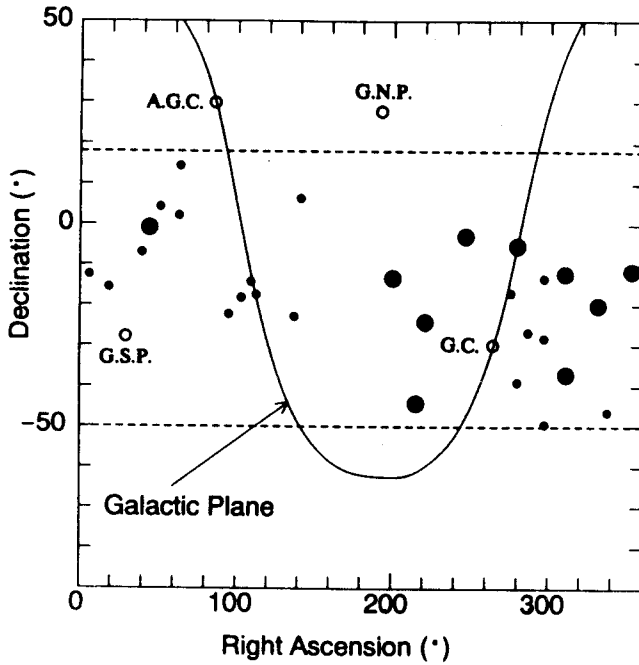


Fig.4. Arrival directions for selected hadron-less air showers with $Ne > 10^{5.0}$ and $\sec\theta < 1.2$, together with a line of Galactic Plane. Showers with $Ne > 1.5 \cdot 10^{5.0}$ are shown with large closed circles in this figure. Showers are selected with a strict regulation (see in the text) on their core positions which are located just above the area of hadron detector.

$$A(\theta) = 0.5609 \cdot 10^{0.0114\theta}.$$

The lateral distributions of hadrons for different values of s are shown in Fig.2. The absolute value of number of hadrons at a certain core distance depends strongly on s in the fixed Ne region. The shape of electron lateral distribution derived from NKG function is also related to s in the smaller core distance region. S has been considered as the parameter presenting the stage of air shower development, namely an air shower with a large age value has been already developed and one with a small age is the stage of developing at the observation level. The number of hadrons correlates closely with air shower development because hadron is still the energetic component in air shower, especially at the level of Chacaltaya. From a better correlation between s and the number of hadrons, s can be taken into account for the effective rejection of proton/nucleus initiated air showers, independently with hadron-less air showers.

For the analysis of hadron-less air shower, we assume that the cross section of the photo-pionization does not increase strongly increasing the energy of photon, that is, the number of hadrons resulting from a gamma-ray initiated shower is much less than the number of hadrons from a hadron/nucleus initiated shower in comparable energy. When the shower s is different core distance bands inside hadron detector, values of density ρ_{ob}^i are calculated, respectively. To preserve the dynamic range of available hadron density for hadron-less air showers, we have defined an "effective core distance" region for each Ne bin. At each core distance

band, the individual ratio R_j to the expected hadron density ρ_{exp}^i , derived from the lateral function mentioned above, are defined by the quantity:

$$R_j = \frac{\rho_{obs}^j}{\rho_{exp}^i}, \quad j = 1, 2, \dots, i.$$

A degree of hadron-less for the shower is estimated after making average, as follow:

$$R_H = \langle R_j \rangle, \quad j = 1, 2, \dots, i, \quad R_H(\%) = R_H \cdot 100.$$

Results and Discussions. For analysis of contour map which shows the excess region of hadron-less air showers, we divided the sky into 1710 spaced directions ($4^\circ \cdot 4^\circ$ square bins in right ascension (α) and declination (δ)) that cover the sky in a declination band from -54° to $+22^\circ$. The excess in each bin, above the expected background is determined with the statistics of Li and Ma¹⁵. Analysis was made for showers with Ne greater than $10^{4.8}$ and θ less than 35° . Analysis was also done for hadron-less air showers with $R_H(\%)=30\%$ and s value of $1.1 \sim 1.5$, which are expected as developed air showers (starting their developments at higher altitude). Consequently, 37027 showers (11%) were selected with these conditions. Contour map of excess in equatorial coordinates is shown in Fig.3a with the position of Galactic Plane, and sigma distribution is also shown in Fig.3b for this contour map. Contour lines of sigma greater than 1.0 are drawn in every 0.5 and the regions with sigma >2.0 are shown with black areas in the figure. No significant anisotropy in any positions of several potential X-ray binary objects, Galactic Center, Galactic Plane and supernova remnant LOOP I could be found, and the distribution of sigma is almost consistent with one expected from the statistical fluctuation. An upper-limit of intensity for hadron-less air showers ($E > 2.1 \cdot 10^{14}$ eV) is estimated to be $(6.18 \pm 3.1) \cdot 10^{-12} \text{ cm}^{-2} \cdot \text{s}^{-1} \cdot \text{sr}^{-1}$ with 90% C.L.

The most strict selection for hadron-less air showers was made an attempt with a regulation for showers detecting no burst particles in any burst detectors, in spite of the fact that their core locations were inside an area of hadron detector. Generally, many hadrons remain in a region within 1m from the air shower core, especially at high mountain altitude. We selected air showers without any signals from thirty-two burst detectors, under conditions with Ne greater than $10^{4.6}$, s of $0.7 \sim 1.5$ and $\sec\theta < 1.2$. In consequence, 291 showers could be selected with these conditions from total 22283 showers with core locations inside an area of hadron detector. Moreover, 99 showers of which core locations are within 1m from the center of hadron detector, are selected from such 291 showers, in an attempt to reduce effects due to an ambiguity of the determination of core locations. However, it is possible that some background proton/nucleus initiated air showers with smaller Ne may still remain in such selected showers, as a result of large fluctuations of a small hadron density. Therefore, Ne regulation of greater than $10^{5.0}$ is applied for emphasizing the peculiarity of number of hadrons, and the distribution of arrival directions for selected 29 showers in equatorial coordinates is obtained as shown in Fig.4. In the figure, arrival directions of showers with $Ne > 1.5 \cdot 10^{5.0}$ are shown with large closed circles. Such hadron-less air showers distribute in a rather larger declination region for the range α of $10^\circ \sim 130^\circ$, on the other hand, in a smaller declination region for the range α

of $200^\circ \sim 330^\circ$. Furthermore, an apparent concentration of showers with large Ne can be found in a certain region surrounding Galactic Center. On the other hand, the arrival directions of general air showers show uniform distribution in equatorial coordinates and different tendency from hadron-less air showers. These hadron-less air showers have been selected with very strict hadron-less condition although a quantitative estimation of degree of hadron-less is difficult in this case. Therefore, hadron-less air showers with these special selections could be supposed as candidate showers initiated by gamma-rays with the best confidence. Tien Shan experiment ⁷ pointed out that the arrival directions of muon-less showers were concentrated in galactic latitude $> 50^\circ$ from the observation covering $\delta: 15^\circ \sim 70^\circ$ which could be summarized with our results in a different δ region. No definite answers can be given for the origin of these air showers in conjunction with Tien Shan results, but it is possible to speculate that gamma-rays may be produced ($p + p \rightarrow \pi^0 + X$) in inter gas which would densely near to our solar system with large structure, because no significant anisotropy of cosmic rays with energy of $10^{15} \sim 10^{16}$ eV has been observed. Otherwise, very different gamma-ray production rate in the Galaxy, which depends on cosmic ray energy and density of inter gas and/or quite different origin of gamma-rays (Galactic/Extragalactic) are expected from both results. Anyhow, to get final conclusions, it is important to observe different declination regions at different latitude in order to confirm the present results.

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