NOTE ON THE DETECTION OF HIGH ENERGY PRIMARY COSMIC GAMMA RAYS BY AIR SHOWER OBSERVATION

KASAHARA,K., TORII,S.*, AND YUDA,T.

Institute for Cosmic-Ray Research, University of Tokyo, Tanashi, Tokyo
**Kanagawa University, Rokkakubashi, Kanagawa*

Basic materials are given which are indispensable to searching for point sources of gamma rays in the PeV energy region by observing air showers. Advantage of a mountain level observation is stressed. The possibility that all the existing Cygnus X3 data for > PeV are of gamma ray origin seems not so high.

1. Introduction A mountain altitude experiment is being planned at Mt. Norikura(735g/cm^2, latitude 36°) in a form capable of searching for point sources of astrophysical high energy gamma rays in the PeV energy region.

As well known, several groups[1] have reported observations of air showers exceeding PeV (=10^{15} eV) energy that are supposed to be originated by particles coming from Cyg X3. Similar results[2] have also reported on Vela X1 and Crab pulsar. Gamma rays would be the only reasonable candidate which arrives at earth without being deflected from such objects and is detectable by air shower. Should they be other exotic particles, it is rather difficult to conceive such ones without abundant gamma rays.

However, the observations so far seem not to show the characteristics of air showers by gamma rays: for example, showers of the Kiel group contain as many muons as hadronic origin and a shower selection condition of s (age) > 1.1 does not put a substantial weight on gamma primaries. Akeno group selelcted muon poor showers but s is $\sim$ 1 which is, as gamma showers, so young that one may afraid of showers induced by protons penetrating deep in the atmosphere; the number of such showers might not be negligible as the angular resolution is $\Delta\theta\sim 10^\circ$.

In confirming the existence of PeV energy gamma primaries from Cyg X3, in knowing their intensity and spectrum, and in searching for other similar point sources, mountain level observations have advantage. By assuming an observation at Mt. Norikura, we shall show it in many respects by using Monte-Carlo showers.

2. Characteristics of air showers in the PeV energy region Figure 1 shows a superposition of the transition of the number of electrons (size, N_e) of 1000 simulated air showers, each of which is generated by a 10^{15} eV gamma ray. The effective depths for zenith angles 0, 20, 30, and 45 degrees at observation depths 735 g/cm^2 (Mt. Norikura) and 927 g/cm^2 (say, Akeno) are indicated in the figure. It is to be noted that the fluctuation of the size is minimum at mountain levels.

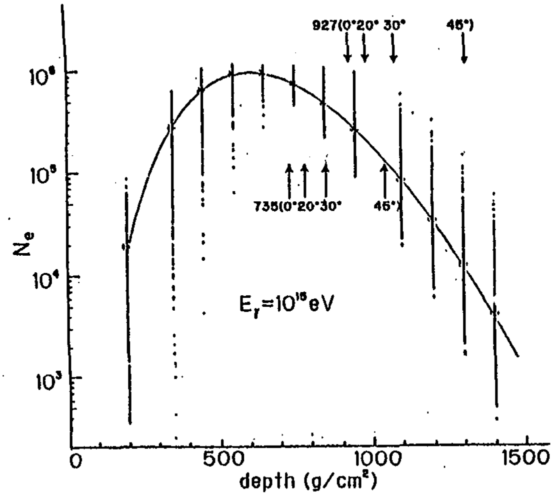

Fig.1 Transition of N_e by 10^{15}eV gamma primary in the atmosphere. 1000 showers are superposed. Effective depths for zenith angles 0,20,30,45^o at 735 and 927 g/cm^2 are indicated.

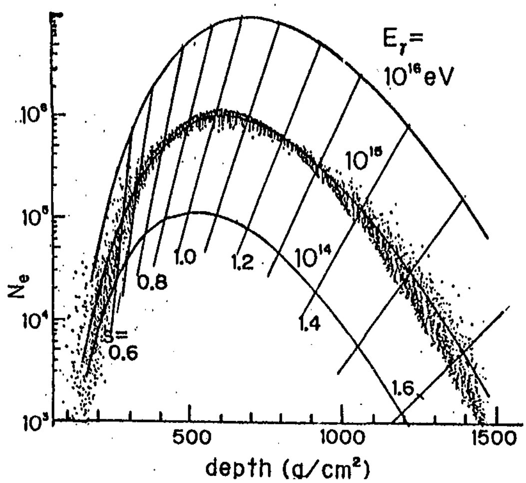

Fig.2 Showers in Fig.1 are superposed by reference to their centre of gravity. Solid lines show analytical result for average N_e and age s.

The apparent large fluctuation is reduced if the showers are shifted and superposed by reference to their centre of gravity (of which the average is 650 g/cm^2) as shown in Fig.2, i.e., each shower has almost the same shape very close to the simple average in Fig.1. The average transition of N_e and age parameter s under approximation B (analytical calculation) is also inlaid. The figure tells that there is almost a unique relation among the primary energy E_0, N_e and s.

Figure 3 shows the distribution of s in the integral form. Note that the fitting of a lateral distribution by NKG function will result in a younger age than here. (see Ref.3). The distribution of the size can well be approximated by log-Gauss form at depth Z=600 to 1500 g/cm^2 and the dispersion is given by $\sigma = \Delta N_e/N_e \sim \sigma_0 (Z\sec\theta - 735) + \sigma_1$ (%) where $\sigma_0 = -0.01\log_{10}(E_0/\mathrm{PeV}) + 0.04\ g^{-1}cm^2$, $\sigma_1 = -4\log_{10}(E_0/\mathrm{PeV}) + 10$ and θ is the zenith angle.

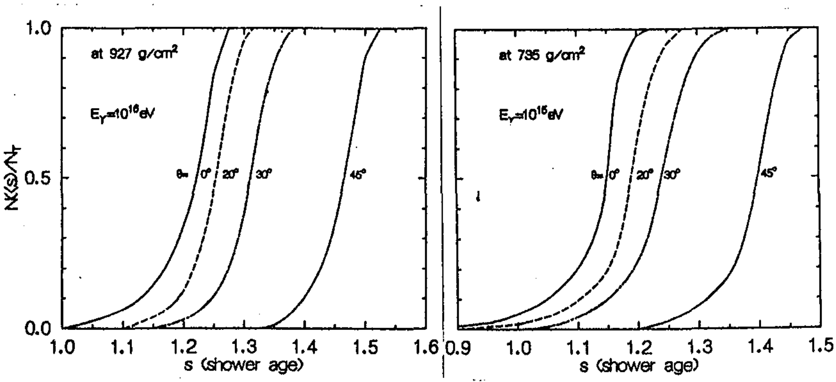

Fig.3 Normalized integral distribution of shower age s. 10^{16} eV primary (at 927 g/cm^2, left). and 10^{15}eV primary (at 735 g/cm^2, right). Parameters are the zenith angle.

To see characteristics of background showers, 1000 proton initiated showers at 10^{15} eV are superposed in Fig.4 as in Fig.1. The hadronic cases give lower maxima than the gamma case (denoted by dash in this fig.) by ~1/1.5, while at deeper depths they have larger values than the gamma. This means that the background intensity at mountain levels is $(\sim 1/1.5)^2 \sim$ 1/2 of the one at the near-sea-level depth.

3. Fast timing efficiency To know the arrival direction of air showers by fast timing (FT) technique within, say, $\Delta\theta \sim 1°$ with time resolution of $\Delta t = 1 \sim 4$ ns, a certain number of electrons must fall in a detector at $r = 10 \sim 40$ m from the air shower centre. We require this number to be more than 30 at r=10 m and 10 at r=20,30,40 m. In figure 5 is shown the percentage of the showers that fill such conditions for a primary energy of 10^{15} eV and a 1 m^2 detector. The assumed lateral distribution is the one obtained by our Monte-Carlo calculation and is consistent with Ref. 3.

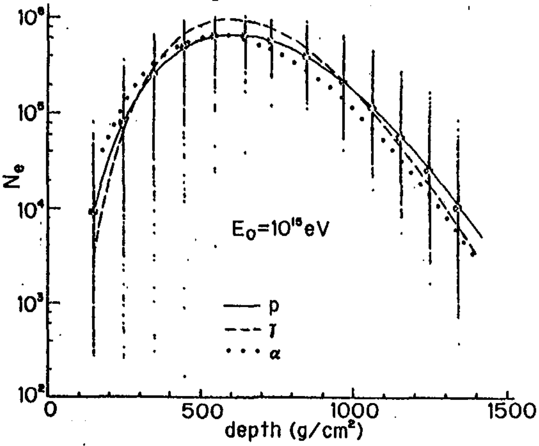

Fig.4 Transition of Ne by 10^{15} eV protons. 1000 showers are superposed. Solid line is average. Average curve by gamma and alfa of the same energy is shown by dash and dot, respectively.

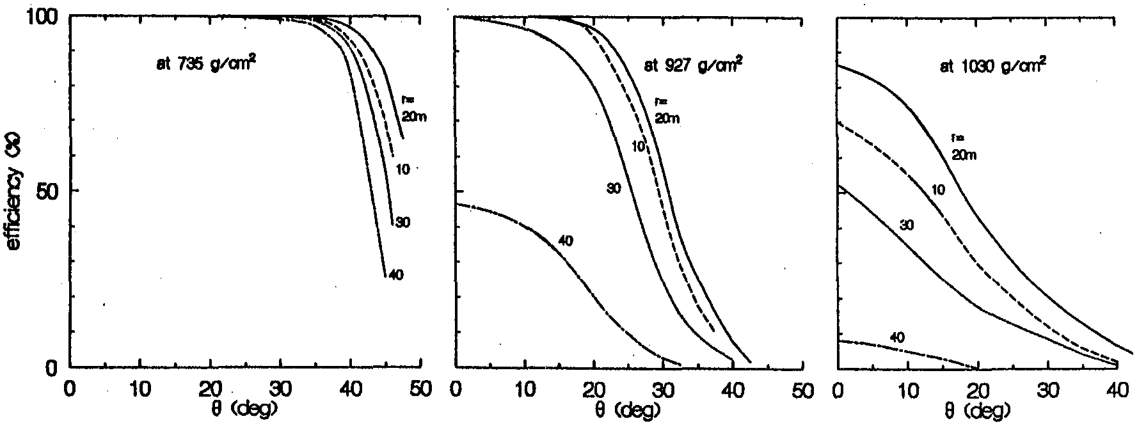

Fig.5 Percentage of showers that satisfy $N_e/m^2 > 30$ at r=10 m from the air shower core, or $N_e/m^2 > 10$ at r=20, 30, or 40 m as a function of zenith angle for primary of 10^{15}eV.

The threshold energy as seen from FT is about 0.3, 1, 3 PeV for depths 735, 930, 1030 g/cm^2, respectively. An energy three times higher than this would be needed for high quality data at the respective depth.

4. Background showers Assuming an appropriate primary cosmic ray spectra above 70 TeV with compositions ranging from protons to irons, background showers of hadronic origin are computed and the size distribution is shown in Fig.6 where the angular resolution is assumed to be $\Delta\theta=1^\circ$ ($=2\sigma$). No cut by muon number or age is imposed here. For reference, the size distribution by primary gamma rays with an energy spectrum $E^{-\beta-1} * (1+E/E_c)^{\beta-\gamma} dE$ is also shown, where $\beta=1, \gamma=2, E_c=10^{16}$ eV and the intensity is adjusted to be compatible with the Cyg X3 observation so far. Cut by the age would not be effective for reducing the background; muon number cut will be needed for further reduction.

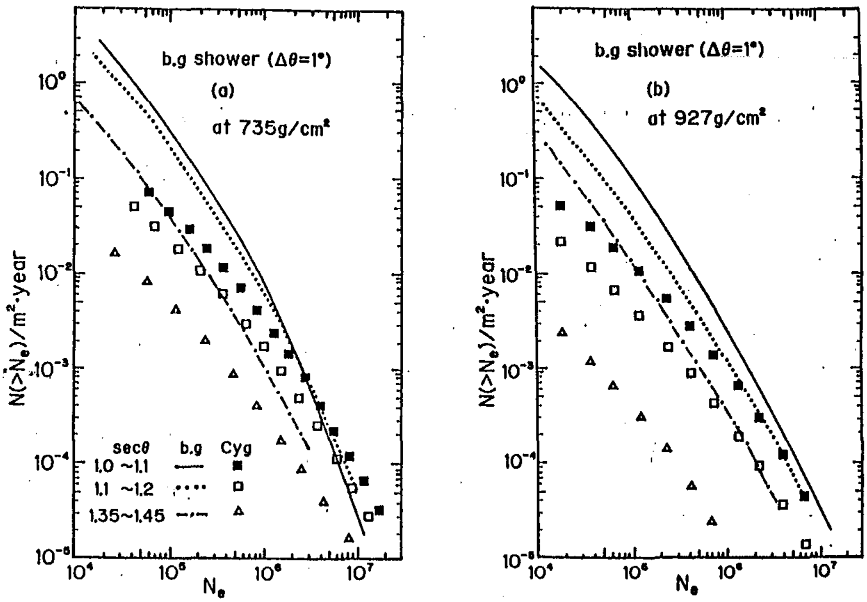

Fig.6 Integral shower size distribution by background hadrons. Solid line for $\sec\theta=1\sim1.1$, dot $1.1\sim1.2$, dot-dash $1.35\sim1.45$. $\Delta\theta=1^\circ$ is assumed. At 735 g/cm^2 (left) and 927 g/cm^2 (right). For reference, a model of signals from Cyg X3 is also shown by symbols in respective range of θ.

5. On the determination of energy and intensity. To determine the primary energy at a near-sea-level, we need accurate age which, however, cannot be obtained easily in the experiment. In this sense, mountain level observation has advantage because of small size fluctuation for a given primary energy. If a size is determined, it's primary energy is estimated by $\langle E_0\rangle \sim 0.14\exp((Z/735+\sec\theta-2)/0.27)\times(N_e/10^5)^{0.84}$ (PeV) with an error, $\sigma=\Delta E/E\sim 9\exp((Z/735+\sec\theta-2)/0.46)\times(E/\mathrm{PeV})^{-0.15}$ (%) A special care must be paid to deriving the primary intensity because the detection efficiency changes from 0 to 100 % in a narrow range of primary energy around PeV, if the detection threshold is set by a constant value of the size (say, $10^5\sim5\times10^5$).

FACOM M380 of INS was used for the present simulation.

References

1. M.Samorsky and W.Stamm, Ap.J.,268,L17(1983).
   J.Lloyd-Evans etal Nature, 305, 784(1983).
   T.Kifune etal, this conference.
2. J.Boon etal, 18th ICRC, Bangalore, XG 57(1983).
   R.J.Protherore and P.R.Gerhardy, Ap.J.,Lett., 280,L47(1984).
3. M.Hillas and J.Lapikens, 15th ICRC, Plovdiv, 8,460(1977).
   A.A.Lagutin etal, 16th ICRC, Kyoto, 7,18(1979).