A Halo Event Created at 200 m above the Chacaltaya Emulsion Chamber

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1. Introduction

We present the results of analysis on a cosmic-ray induced nuclear event with the total visible energy ~1300 TeV which is characterized by the central (halo) part of a strong energy concentration and the outer part of a large lateral spread. The event (named as P06) was detected in the 18th two-storied emulsion chamber exposed at Chacaltaya by Brasil-Japan Collaboration. As the nuclear emulsion plates were inserted at every layer of the concerned blocks in the upper and the lower chambers together with RR- and N-type X-ray films, we can study the details of the event.

Some results on P06 have already been reported [1] based on the general measurement of opacity on N-type X-ray films: (1) the total energy of halo is ~1000 TeV; (2) the shower transition reaches its maximum at ~16 cu; and (3) the radius of halo is 6.5 mm (at the level of 10^6 electrons/cm^2). The results in more details will be described here.

2. Results

Fig.1 shows the target diagram of P06, where we notice a large lateral spread of the event and richness in hadrons in the outer region.*

Fig.2 shows the contour map of opacity (D=.2, .3, .4, .6, .8 and 1.) for the central part of halo on RR-type X-ray film at 14 cu in the upper chamber with slit diameter 113 μ, together with the high energy shower cores (E >10 TeV). A clear asymmetry is seen in both distributions of D and shower cores. Notice that it also holds for both γ-rays and hadrons.

Fig.3 shows the distributions of opacity in the upper and the lower chambers, where the measurement was made along the straight line on the film passing through the two hadronic cores (#40 and #58) which can be well recognized in both chambers because of their strong and sharp penetration. We notice that the halo part contains at least two peaks.

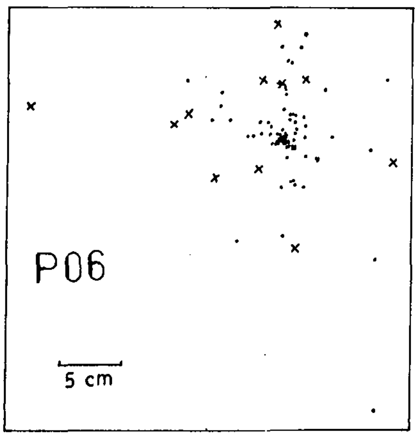

Fig.1 Target diagram of P06. γ-rays (•) and identified hadrons (×).

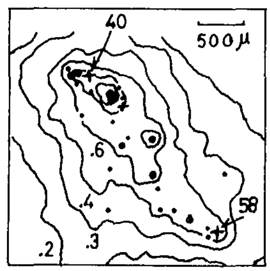

Fig.2 Contour map of opacity of RR-type X-ray film at 14 cu and shower cores: γ-rays (●: >20 TeV, • :10-20 TeV) and hadrons (+). The cores (#40 and # 58) are indicated .

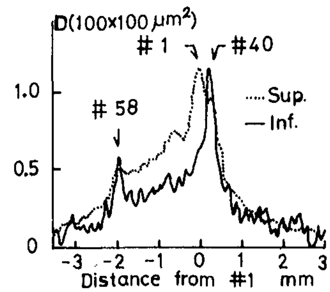

Fig.3 Distributions of opacity on RR-type X-ray film at 14 cu in the upper chamber(Sup) and on N-type X-ray film at 4 cu in the lower chamber (Inf).

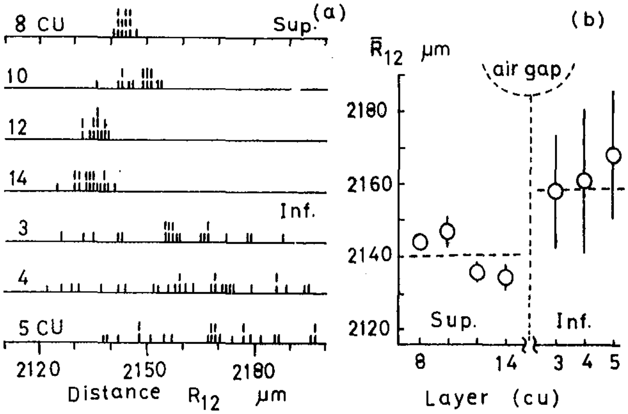

Fig.4(a) Measurement of the relative distances, R_{12}, between #40 and #58 in the upper (Sup) and the lower (Inf) chambers. 4(b) Variation of $\bar{R}_{12}$ at 8, 10, 12 and 14 cu in the upper chamber and at 3, 4 and 5 cu in the lower chamber. The best fitted straight line is also shown.

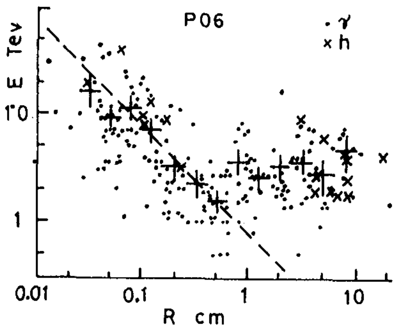

Fig.5 Correlation Diagram between energy and distance of P06. γ-rays(•) and hadrons(×). + are for the average values.

Fig.4-a shows the results of measurement on the relative distance, R_{12}, between #40 and #58 on the nuclear emulsion plates which was done repeatedly after some blank days enough long to forget the previous measurement. Fig.4-b shows the average values of R_{12} at 7 layers together with the best fitted straight line given by the least-square method which corresponds to the interaction height $H = 208 {}^{+245}_{-73}$ m. The value of χ^2 is rather large, 16.4 for the 7 points, of which 4 points in the upper chamber share 98% of the total; we could not resolve the fluctuation seen in the upper chamber. If we use the average value of 4 points, $H = 177 {}^{+165}_{-58}$ m; if we take only the point at 10 cu, $H = 263 {}^{+784}_{-112}$m. In the following, we take 208 m as the vertical height above the chamber which corresponds to $H_0 \sim 250$ m after the correction on zenith angle (35°).

Fig.5 shows the diagram of energy, E, and distance, R, for all the shower cores observed in P06, where R is measured from the energy-weighted center of shower cores which are located inside the halo radius, 6.5 mm. The dashed line stands for the fit to the averages in the central region,

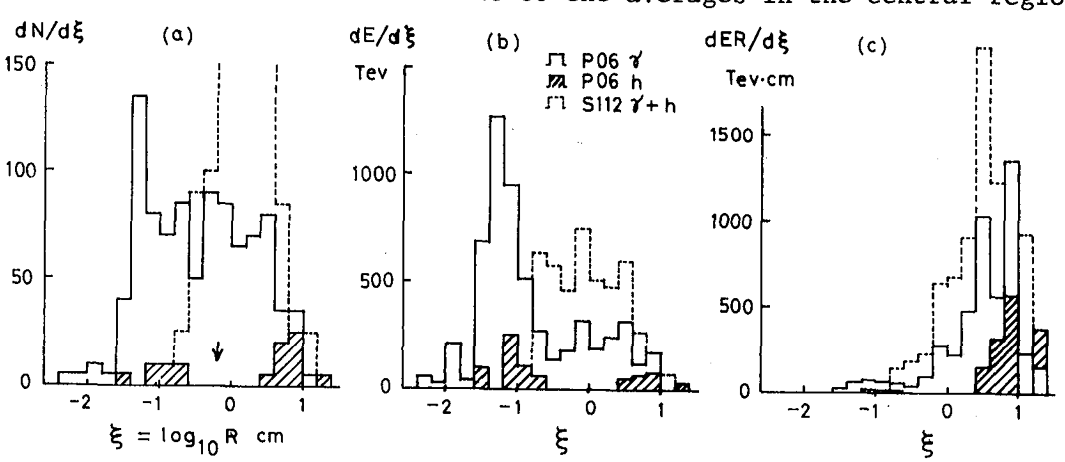

Fig.6 (a) Histogram of $\log_{10}R$, (b) energy-flow and (c) energy-weighted lateral distance ER-flow in $\log_{10}$ R , for γ-rays and hadrons in P06, and for all the shower cores in the event S112.

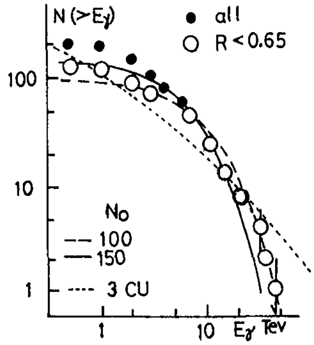

Fig.7 Energy distribution. All the γ-rays(•) and γ-rays in the halo radius (o) in P06.

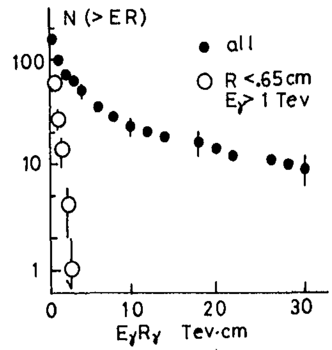

Fig.8 ER distribution. All the γ-rays (•) and γ-ray inside the halo radius (o) in P06.

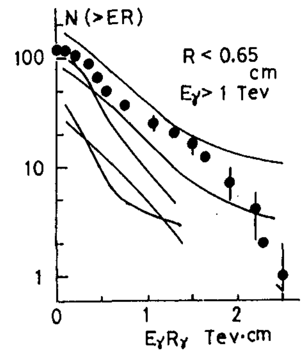

Fig.9 ER distribution for γ-rays in the halo of P06, and those for other 5 events [3].

$\langle ER\rangle$ = 8 GeV m which corresponds to $p_T = 32$ MeV/c under $H_0 = 250$ m. In the central region, the correlation between E and R shows some constancy of ER (or p_T) but the behavior in the outer region is quite different.

Fig.6 (a-c) show the flows of number, energy and energy-weighted lateral spread in the space of $\log_{10} R$, respectively. The γ-rays and the hadrons are shown separately. Also shown for the comparison are the results of the event S112 which is classified as Guaçu-type meson production characterized by the large p_T and the high multiplicity [2]. As the total energy (878 TeV) and the interaction height (~250 m) of S112 are nearly equal to those of halo part of P06, we can compare the two events with each other without any normalization. We notice that P06 contains a strong concentration of particles and energy in the small angular region as a clear peak of halo (75% of the total energy being inside the radius) but S112 not, and that the outer region of P06 is similar to S112.

Fig.7 shows the energy distribution of γ-rays in P06 in an integral form. The dashed and the solid lines stand for the exponential distributions of the form $N_0 \exp(-E_\gamma/\Sigma E_\gamma)$ with $N_0 = 100$ and 150, respectively. The dotted line is the result of analytic calculation with t=3 cu and $N_0=6$ where required are 1 TeV for the energy threshold and 1000 TeV for the total visible energy. We notice that a long passage in air does multiplicate the number of γ-rays and electrons, but that the original exponential form is greatly distorted.

Fig.8 shows the distributions of energy-weighted lateral spread, ER, of γ-rays in P06. A large difference of lateral spread between the halo and the outer region is impressive (of a factor ~30). The average value of ER for the outer region is obtained from the slope to be ~0.2 GeV km.

Fig.9 shows the distribution of ER in the halo of P06. The average value of ER is 7.2 GeV m, which corresponds to $\langle p_T\rangle$ = 29 MeV/c under $H_0 = 250$ m. Also shown are those of other five events similar to the halo of P06 [3].

3. Discussions and Conclusion

The event P06 is realized in the upper part of the upper chamber as a rather small size of dark spot on N-type X-ray films, but it develops remarkably in the lead material of the chamber and appears as a generally darkened wide area [1]. This area is called as "halo".

The total visible energy is 1275 TeV, 217 shower cores being observed on the nuclear emulsion plates. Within the halo radius (0.65 cm), 965 TeV is emitted in 127 shower cores. To explain this large particle density in a small region, one might imagine a long passage in the atmosphere to include the cascade multiplication process. But the experimental results of P06 do not seem to support such a naive consideration:

(1) The halo energy estimated by the general measurement of opacity is nearly equivalent to the energy sum, ΣE_γ, of shower cores. The former should include the contribution of low energy showers which are not visible in the latter. In case of the event Andromeda, E(halo) ~ 3.5 ΣE_γ [4];

(2) The depth of shower maximum is very deep in P06 (~16 cu). In case of Andromeda, it is ~10 cu [4];

(3) The sharp alignment on azimuth is seen for both γ-rays and hadrons;

(4) The energy distribution is almost exponential.

The above results indicate that the halo of P06 does not suffer from a large cascade degradation during its passage in the atmosphere, and that the high energy shower cores observed on the nuclear emulsion plates play a decisive role in the halo.

The triangulation method gives us a direct check on that point. The interaction height is obtained to be ~250 m although some fluctuation is seen in four layers in the upper chamber. Taking 250 m, the halo part of P06 comes to be of abnormally small p_T (~30 MeV/c on the average) and of high γ-ray density in rapidity (~59 at the maximum). There is a possibility that a new phenomena happens to appear in the super high energy region which is characterized by a very small p_T (a few tens of MeV/c).

The large lateral spread with richness in hadrons is seen in the outer region of P06, which seems to be a common feature in the halo events [5]. It may be plausible to speculate that the mechanism of large p_T phenomena could produce some new character to create the halo.

The new characteristics seen in the halo of P06 could be compared with those of the so-called "mini-cluster" which is also characterized by the small p_T, 10-20 MeV/c [6].

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References

[1] N.M.Amato et al., Proc. of Internat. Symposium on Cosmic Rays and Particle Physics, Tokyo, 1984, p.123.
[2] H.Semba, Nuovo Cimento 49A (1979) 247.
[3] S.Hasegawa, Proc.of Internat.Symposium (see [1]), Tokyo,1984, p.62.
[4] A.Ohsawa, ICR-Report-112-83-6 (1983) 65.
[5] S.Yamashita, Journal of Phys.Soc.Japan 54 (1985) 529.
[6] Brasil-Japan Collaboration, AIP Conf.Proc., 85 (1981) p.500.

* We used the following criteria to identify hadrons: the starting point of cascade is estimated to be deeper than 4 cu and/or the transition curve indicates a successive interaction.