A COSMIC RAY SUPER HIGH ENERGY MULTICORE FAMILY EVENT (II) STRUCTURE AND FRAGMENTATION CHARACTERISTICS OF THE JETS

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I. Introduction. Quarks and gluons are not directly observable, but may be displayed through fragmentation in the form of hadronic jets, the evidence of which was first revealed in cosmic ray interactions before the advent of the modern theory of strong interactions. Experimental results from ISR(1) and SP$\bar{P}$S collider rendered the jet phenomena more confident and definite. All the properties of jets observed up to now at ISR and SP$\bar{P}$S collider are in agreement with the predictions of QCD(2-4). In order to make further test of QCD in still higher energy regions, detailed study of super high energy jet events in cosmic rays is very desirable. The event KO E19 observed in Mt. Kambala emulsion chamber is an interesting event for such study. The general features of KO E19 is described in (5). Its total visible energy is ΣE_γ=1537 TeV(E_{min}=1.5 TeV) and production height H=(70±30)m, with a hadron as its primary particle. Besides about forty small clusters, there are five super high energy cores or jets, one lying near the center of the event while the other four surrounding it, having incident directions making small angles (about 5°-6° in CMS) with that of the primary particle. Detailed analysis is done on the emulsion plates inserted in the chamber, making full use of their fine granularity, superior in detecting and analyzing jet events, especially their substructures.

II. Jets and jetty event. By jet we generally mean a bundle of fairly collimated hadrons in the final states of high energy interactions. It can also be considered as a cluster of particles in the pseudorapidity-azimuth (η-φ) space. We adopt a procedure for the jet clusterization similar to that in accelerator experiments as follows. Assign an energy vector to every shower (track), directed from the vertex of the event to the point of recording. Find out the largest of these vectors and compute the quantities d of other ones relative to the largest in η-φ space, where $d=\sqrt{(\Delta\eta)^2+(\Delta\varphi)^2}$. Add all energy vectors with d≤1.0 to the largest one vectorially, we then obtain a jet. Next find out the largest vector among the remaining ones and repeat the above procedure to get another jet, etc. A transverse energy threshold is taken, which may be 10-60 GeV. For the four outer jets in KO E19, the minimum E_t=10 GeV and the maximum d=0.82-1.0, corresponding to φ=38°—44° and θ=4.8°—6.1°. Adopt $\sum_n (E_{jet})_n/\Sigma E_\gamma \geq 70\%$ as a criterion for the so-called jetty events, conforming to the convention in accelerator experiments. In our case, the total energy of the four outer jets is 756 TeV and corresponds a fraction of 76% of the total visible energy 994 TeV(E_{min}=4TeV). If the energy of the central jet is also included, the fraction will increase to 79%. Therefore we may consider KO E19 as a jetty event. The characteristics of jetty events are closely related to the production and fragmentation behaviors of jets.

III. Structures and fragmentation characteristics of jets. The transverse momentum p_t of a jet can be obtained by vector addition of the p_t's of all its constituent particles. If the jet particles are assumed to be π's, then the p_t of the four outer jets are 12.77,11.42,6.81 and 8.63 GeV/c. Fig.1 gives the vector diagram of these jets. The sphericity of a jet is defined as $S_n = 3(\Sigma j_{ti}^2)_n / 2(\Sigma j_i^2)$, where j_i is the momentum

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of the i-th particle and j_{ti} is its transvers component relative to the axis of the n-th jet. For an event with n jets, the total sphericity is the sum over all jets. The total sphericity of KO E19 is S=0.0074 and the total neutral transverse energy E_t^o =148 GeV, which are compared with accelerator results qualitatively in Fig.2, showing no inconsistency

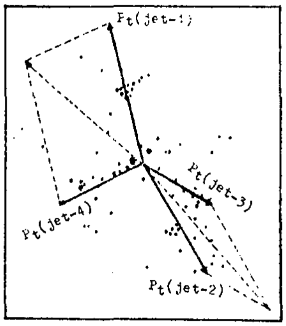

Fig. 1

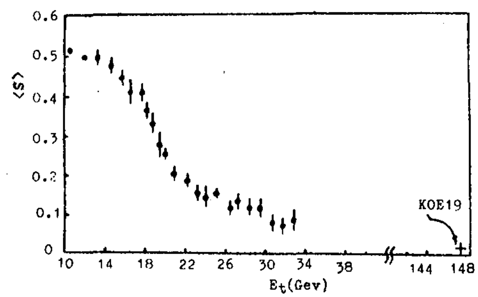

Fig. 2

in its trend. The distribution of θ_j^* , the angle between the particle momentum and the jet axis in CMS, is shown in Fig.3 for the four outer jets. The peak value of θ_j^* for KO E19 lies near 0.5°, consistent with the most probable values 7° and 2° in ISR and SP$\bar{P}$S collider energy regions, respectively. Take H=70m, $\langle J_{t\gamma}\rangle$ =0.04 GeV/c, corresponding to $\langle j_t\rangle$=0.08 GeV/c, smaller than the average from p$\bar{p}$ collider.

The fragmentation variable is a useful quantity in jet analysis. It is defined as $z=2E_{\parallel\gamma}/3(\Sigma E_\gamma)_j$, representing the fraction of the component of shower energy along the jet axis in total visible jet energy. The factor 2/3 takes account of the fact that the secondary particles are mainly γ-rays, coming from the decay of π^o's. The distribution of z is called the fragmentation function of jet: $D(z)=(1/N_j)dN_{ch}/dz$. Fig.4 gives the fragmentation function of the five jets in KO E19, Which

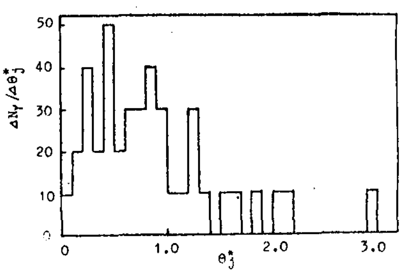

Fig. 3

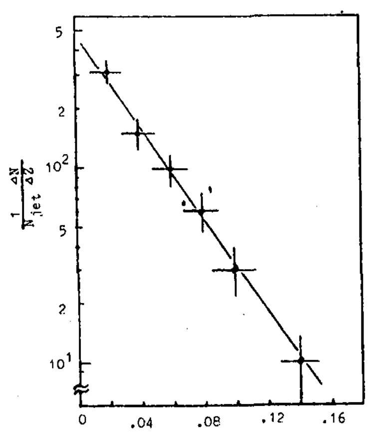

Fig. 4

is in the exponential form Exp(-Bz), with B=27.4. Data from ISR and FNAL are also included for comparison. In the ISR range, ABCS Collaboration gave an exponential D(z) for small z, with B≅7, while CCOR Collaboration obtained B≅5.3 at lower energies. FNAL(9) obtained B≅4.6, using jets with p_t lower than ABCS Collaboration. As noted in (7), when the energy of the scattered parton increases, the number of fragmentations increseases also, resulting in a decrease in z and an increase in the slope. KO E19 is a super high energy event and the value of B should be correspondingly larger. By integration of the jet fragmentation function, we can obtain the charged particle multiplicity in the jet. For the five jets of KO E19, $\langle N_{ch} \rangle \cong 18$, $\langle E_{jet} \rangle \cong 95$ GeV in CMS. A comparison between KO E19 and accelerator results(10) is shown in Fig.5. There is an evident increase in N_{ch} in KO E19.

IV. Comparison with QCD calculations at TeV energies. It is shown in the phenomenological QCD study of the properties of the jets produced in hadronic collisions in $\sqrt{s}$ = 10 TeV range(11), that hadronic jets are mixtures of quark jets and gluon jets and that 50% of the energy of quark jets is carried by particles with z=0.06 while the corresponding value for gluon jets is z=0.025. From KO E19 data, 50% of the jet energy is carried by particles with z=0.045, in reasonable agreement with the above estimation. The particle multiplicity of jets as a function of jet energy is shown in Fig.6(11). The value of $\langle N_{ch} \rangle$ is

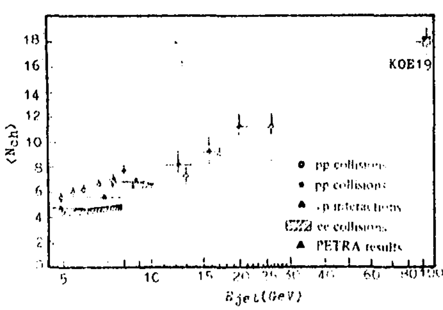

Fig. 5

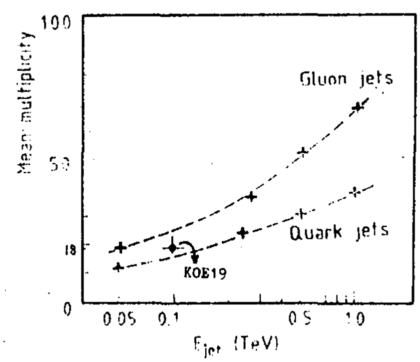

Fig. 6

about 18 and lies between the theoretical values for quark and gluon jets. The fractions of the numbers and energies of jet particles outside the jet cone in KO E19 are also close to the theoretical results. The high p_t Monte Carlo events generated by the ISAJET program are shown to have core structures. This is also the case for the four outer jets in KO E19. Fig.7 gives the jet number distribution reconstructed from

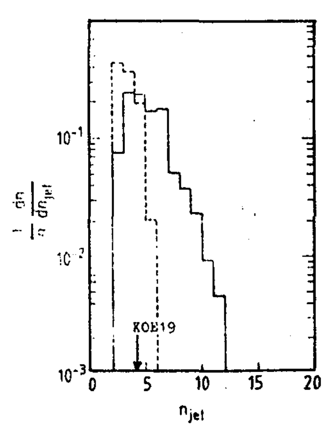

Fig.7

the TeV range Monte Carlo events by means of the clusterization technique, where the solid line represents events with $E_t > 10$ GeV and the dotted line those with $E_t > 100$ GeV. For the four outer jets in KO E19, $E_t > 10$ GeV, $N_{jet} = 4$, lying within the theoreticlal prediction. From the above analysis, it can be seen that the characteristics of KO E19 are in agreement or not inconsistent with the predictions of the phenomenological QCD. Further analysis and confirmation require more events.

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