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Exp. 385

Characteristics of Fireballs in 400 GeV/c Proton-Nucleon Collisions

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FNAL Experiment # 385

On the basis of model resembling the repeated one-pion exchange and the assumption that strong damping of large momentum transfer is a characteristic of amplitudes above a few GeV/c only, Frautschi (1) has made some predictions about the characteristics of isobars and fireballs in high energy hadron-hadron collisions. The prediction about the production of fireballs is that, upto a laboratory energy of 30 GeV, no fireball is likely to be created; from 30 GeV onwards one fireball may be produced and their number may be about two at 10^4 GeV. Infact he finds that their number varies approximately as the logarithm of the laboratory energy. Experimentally, the general features of fireballs at various energies have been known from the interactions produced by cosmic ray particles (5-7). Recently some quantitative studies have been carried out at a few accelerator energies (8-10). Kitamura et al.(8) have found that the muon collisions at 5 GeV (events recorded in nuclear emulsions at Brookhaven) are dominated by contribution from isobars, whereas from 10 GeV to 100 GeV (cosmic ray muon events in cloud chamber), there are also some events in which one fireball is produced. Similarly, the results of the 60 GeV π^--nucleon interactions in emulsion by Agnese et al (10) clearly reveal the production of one fireball in 15% of the cases. In the present work, we have studied some general characteristics of fireballs in 400 GeV p-N collisions and compared them with the predictions of Frautschi (1) and a few more models on the subject (2-4).

A stack of 50 K5 pellicles each of size 15 x 10 x 0.06 cm^3 was exposed to a flux of $\sim 5 \times 10^4$ particles per cm^2 of the 400 GeV/c proton beam at FNAL. The stack was area scanned under 45X objective and the interactions were picked up after 1 cm from the leading edge but within a maximum distance of 3 cm along the beam direction. In the present work, a random sample of 154 p-N evens with $n_s > 6$ has been analysed. To select a highly enriched sample of such events, we have followed the following criteria. Events having $n_b = 0$ and $n_g = 0$ or 1 in the forward direction were considered. Furthermore the events must not have any Auger electron or recoil nucleus ($< 10\mu$) associated with itself. The detection efficiency of such events has been estimated to be 97%.* The other experimental details have been given in an earlier report (11).

In order to group the particles which might be the decay products of the fireballs, we have made use of the Duller-Waker plot (13) in conjunction with the target plot for each interaction as described in ref. (6). However, the particle which in the p-N collision could be the incoming proton after scattering i.e. the leading particle, and also the particle which could be the target proton in p-p collision, has been discarded. In the first case, the particle which makes the smallest angle with the primary direction has been regarded as the leading particle. In the second case, either the particle making the largest angle with the primary direction or the grey itself, if present in p-p interaction,

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* The percentage of p-N events with $n_s > 6$ and $n_g = 0$ in our sample is 10.5 which may be compared with the line scanned data of Babecki at al. at 200 GeV (12) who give the value as 9.4 for such events.

has been associated with the target proton.

In p-N collisions, the intermediate states which are produced can be resonances as well as fireballs. A resonance is expected to decay into twoor three particles. Thus, in the cluster of two or three particles, there will always be an admixture of resonances and fireballs. Therefore, in the present work, we have picked up probable candidates for fireball which have at least four charged decay products. The plots for 154 events show that there are 67 events in which one fireball is present and there are 9 events having two fireballs as well, thus making a total of 75 fireballs.

Berger (14) has suggested that the particles constituting a fireball must have strong correlation amongst themselves. Assuming that a fireball decays isotropically in its rest frame, the dispersion Δ should be $\leqslant 0.91$. The dispersion parameter is defined as:

$$\Delta = \left[\frac{1}{n_c - 1}\sum (\bar{Y} - Y_i)^2\right]^{1/2} \tag{1}$$

where n_c = number of charged particles into which a fireball decays,

$\bar{Y}$ = average rapidity of n_c particles,

Y_i = rapidityof ith particle.

Out of the 75 fireball candidates 2 did not fulfill Berger's criterion. These have been excluded from further consideration.

To determine the fireball parameters we have followed the procedure described by Agnese et al. (10). First we determine the centre of gravity (δ_G, η_G) of the selected cluster of particles,

where δ_G and η_G correspond to dip and projected angles respectively in Lab. system (L.S.). This allows us to calculate the Euler angles $(\alpha, \psi, 0)$ of the fireball as follows:

(2) $$\cos\alpha = \cos\delta_G \cos\eta_G$$

(3) $$\psi = \frac{\pi}{2} - \tan^{-1}(\sin\eta_G / \tan\delta_G)$$

If θ_j and ϕ_j are respectively the emission and azimuthal angles of the jth particle with respect to the primary direction, the new emission angle θ_{Rj} with respect to the fireball direction is given by the expression

(4) $$\cos\theta_{Rj} = \cos\alpha \sin\theta_j \sin(\psi + \phi_j) + \cos\alpha \cos\theta_j$$

From the isotropy consideration of fireball decay products in its rest system, the integral angular distribution is given by (15),

(5) $$F(\theta_R) = 1 - \frac{\sqrt{1-(r^2-1)\gamma_f^2 \tan^2\theta_R}}{1+\gamma_f^2 \tan^2\theta_R}$$

where γ_f = Lorentz factor of the fireball in L.S.

$r = \beta_f / \beta_0$, β_0 is the average velocity of the shower particles in the fireball rest system.

One expects a good fit of $F(\theta_R)$ against $\tan\theta_R$ for shower particles actually belonging to a fireball obeying the assumptions of Agnese's method. This test has been applied for all the candidates and in 2 cases the fit was not satisfactory (we have accepted good fits as those having $P(\chi^2) > 0.90$). We excluded these candidates also

for further consideration. So ultimately we have 53 events having one fireball and 9 events having two fireballs.

Using γ_f and r calculated from eqn.(5) by least square fit, and assuming that the decay products are pions, one can calculate the average momentum of the decay products in fireball rest system (p_o), the fireball mass (m_f), and transverse momentum of the fireball (p_t) using the relations:

$$p_o = m_\pi \beta_o / \sqrt{\beta_o^2 - 1} \tag{6}$$

$$m_f = 1.5\, n_c \sqrt{p_o^2 + m_\pi^2} \tag{7}$$

$$p_t = m_f \sqrt{\gamma_f^2 - 1}\, \sin\alpha \tag{8}$$

We can also find the angle of emission $\bar{\alpha}$ of the fireball in the C.M. system using the transformation:

$$\gamma_c \tan\bar{\alpha} = \frac{\sin\alpha}{\cos\alpha - \beta_e/\beta_f} \tag{9}$$

where γ_c = Lorentz factor of C.M. system.

According to Fraustschi's model (1), the mass of the fireball is expected to lie between 1 and 5 GeV and average decay multiplicity is about six irrespective of the incoming particle energy. The mass distribution for the fireballs observed in our investigation is displayed in Fig. 1a. The average mass is 2.13±0.13 GeV with a spread from 0.5 to 5 GeV. The charged decay multiplicity is shown in Fig. 1b and its average value is 5.76±0.14. The observed charged

decay multiplicity, 5.76, seems to be in reasonable agreement with the predicted multiplicity (1). These results are in agreement with the predictions of the hybrid model of Rajaraman (2) whichis based upon single Regge like exchange for the production of clusters in the collision processes.

Figures 2a and 2b show p_o and p_t distributions respectively. Average p_o is found to be 184±13 MeV/c which is in good agreement with the value obtained by other investigators given in the table. It seems to be independent of energy. This constantancy was predicted by Hagedorn (3) where p_o pawas regarded as the decay temperature of the fireball (T=160 MeVc). The average transverse momentum of fireball is 754±85 MeV/c which is in agreement with the value obtained by Agnese et al.(10) at 60 GeV. Figure 3a gives the frequency distribution of the fireball emission angle in L.S. with respect to primary direction. The average emission angle of fireballs is 1.87±0.29 degree which is at variance with the assumption of zero emission angle by Frautschi (1). In Fig. 3b we have plotted the emission angle of fireballs in the C.M. system. It is interesting to note that, the distribution is quite symmetric (F/B=36/35). This shows that, in the C.M. system fireballs are emitted in both the directions with equal probability. Howeverthe distribution is sharply anisotropic. This is because fireballs are emitted with a small angles with the collision axis.

Our results along with those of previous investigators (9,10) are shown in the Table. The results given in the table show that,

leaving asid the average angle of emission, which has to be different because of p_t constraint, the rest of the characteristics of the fireball are the same at different energies.

At incident proton energy of 400 GeV, we see fireball production in about 45% of the events, with $n_s > 6$. However for events having $7 < n_s < 10$ the percentage of fireball is 21. This value may be compared with the production frequency of 15% at 60 GeV (10). Thus there seems to be a logarithmic rise in the fireball production cross-section as the incident energy increases from 60 GeV to 400 GeV. At 400 GeV we found two fireballs in 9 events out of 154 while at 60 GeV no such events was found. Further analysis about the rapidity correlation in these fireballs and its interpretation in terms of some multiperipheral cluster models (16) is in progress.

The experiment on 400 GeV/c p-nucleus interactions in nuclear emulsion was undertaken initially as a collaborative effort of the High energy Physics Groups of the Universities of Delhi, Jaipur, Jammu and Panjab. Our grateful thanks are due to our erstwhile collaborators especially Prof. Y. Prakash, Dr. N.K. Rao, Prof. S. Lokanathan, Dr. K.B. Bhalla and Dr. J.M. Kohli. Thanks are due to the University Grants Commission, Govt. of India for financial assistance. The tiring work of all the scanners is gratefully acknowledged.

Table

Energy	α (degree)	m_f (GeV)	n_c	p_t (MeV/c)	p_o (MeV/c)	Ref.
60 GeV π^--N	4.59±0.59	2.61±0.37	6.9±0.3	658±224	213±59	(10)
70 GeV p-N	----	2.8±0.1	----	----	169	(9)
400 GeV p-N	1.87±0.29	2.13±0.13	5.76±0.14	754±85	184±13	Present work

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FIGURE CAPTIONS

1. Distributions of (a) mass (m_f) and (b) charged multiplicity (n_c) of the fireballs.

2. Distribution of (a) average momentum of the fireball decay products (p_o) in its rest system and (b) transverse momentum of the fireballs (p_t) in L.S.

3. Frequency distributions of fireball emission angles (α) (a) in L.S. and (b) in C.M. system.

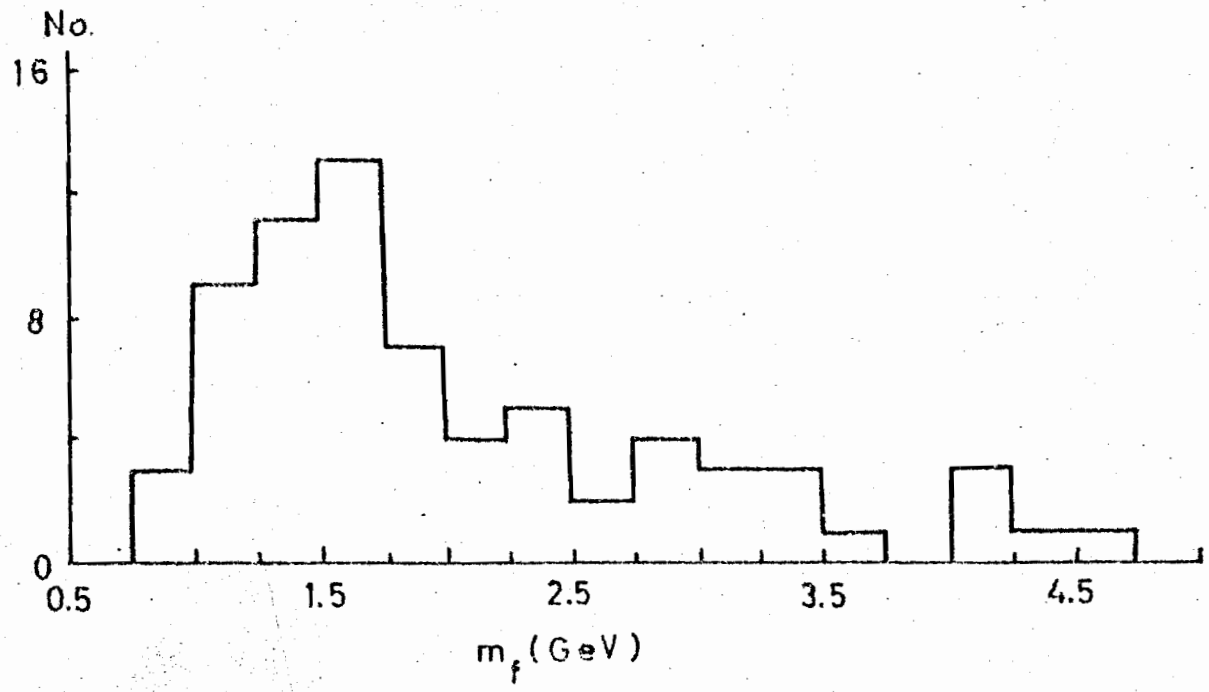

FIG.-1a.

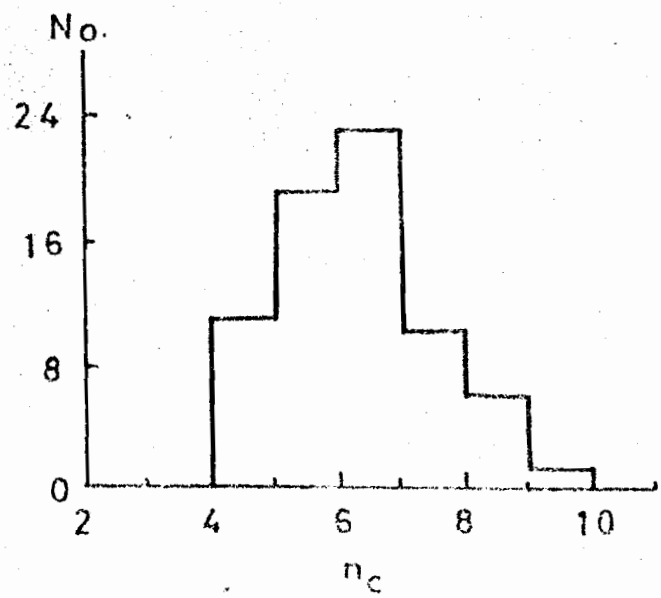

FIG.-1b.

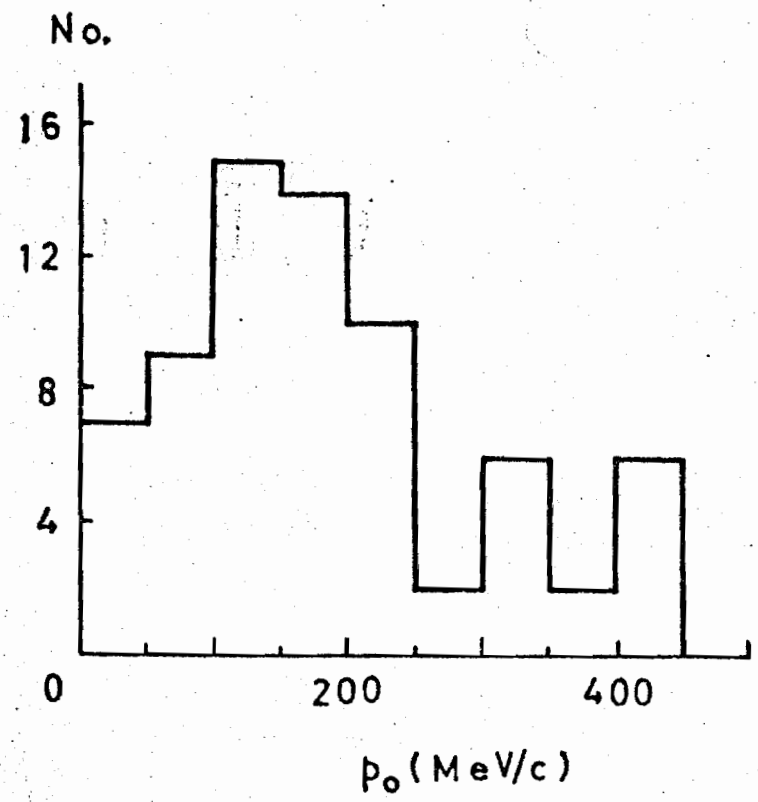

FIG.-2a.

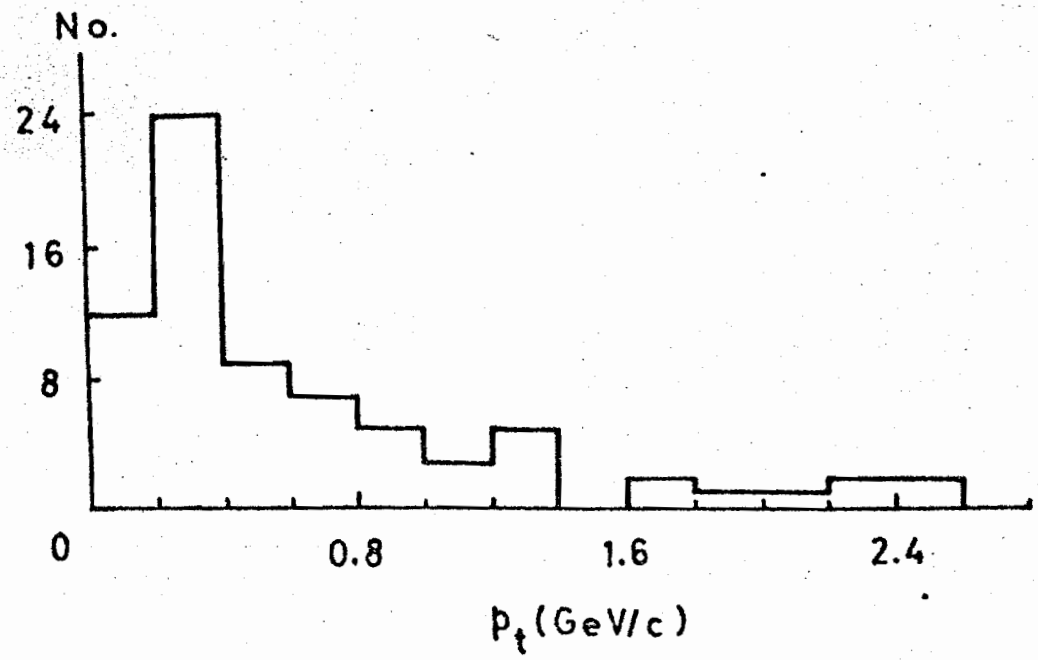

FIG.-2b.

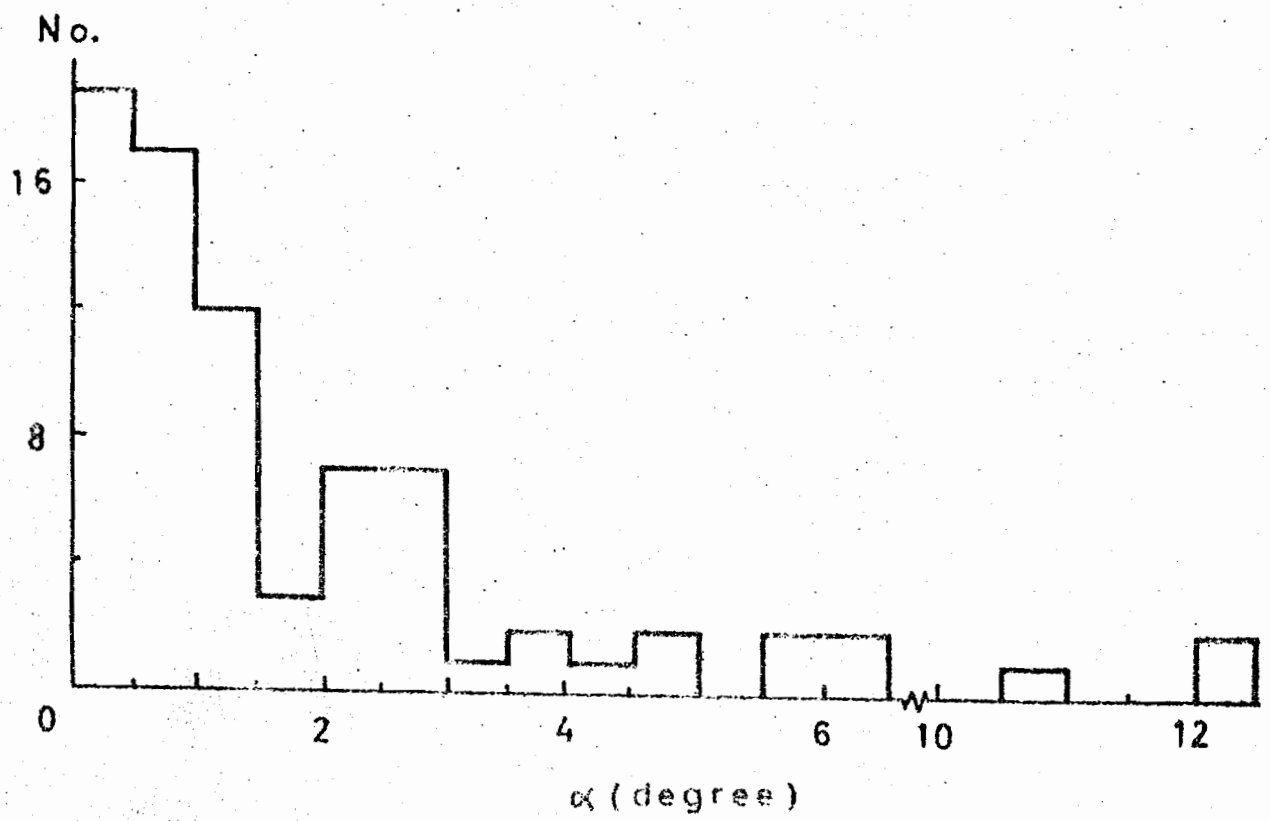

FIG.-3a.

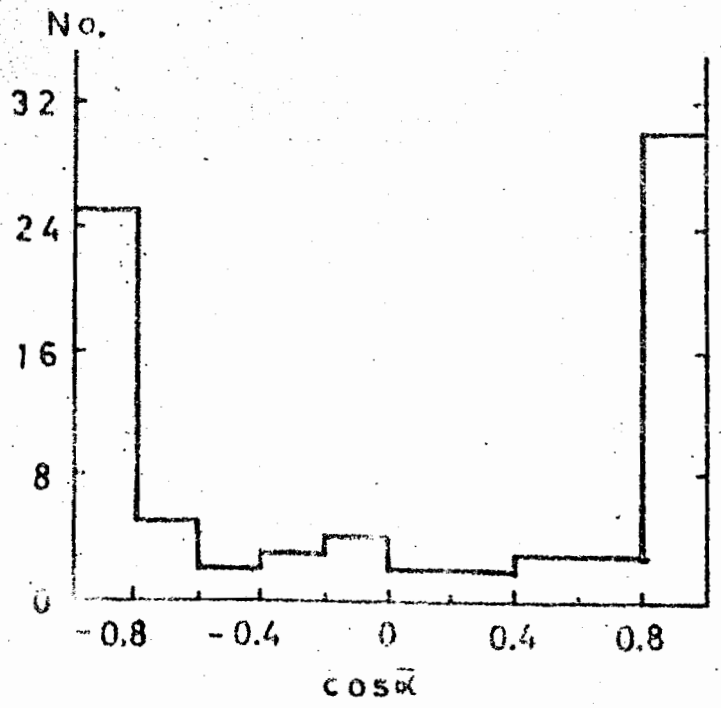

FIG.-3b.