Cumulative Rapidity Gap-distribution and Cluster Characteristics in Proton-emulsion Interaction at 300 GeV/c

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Multiparticle rapidity clustering in proton-emulsion interactions at 300 GeV/c is studied using cumulative rapidity-gap distributions. Both 2-particle and 3-particle clusters have been observed.

Introduction

The study of high energy interactions of hadrons with nuclei can provide fundamental information about the space-time evolution of multiple production. It has long been recognized that the high energy multiparticle production is a two-step process [1—3]: production of a highly excited hadronic state (cluster) with following decay into hadrons. It has been suggested that clusters are droplets of gluons [2], resonances [4, 5], collective phenomena without dynamical significance [6, 7] or excited hadronic states [8—10]. Further detailed experimental information at different energies is needed to arrive at a confident conclusion about clusters.

The rapidity-gap distribution can give information about clustering in high-energy multiparticle production. The rapidity Y is defined as

$$Y = \tfrac{1}{2}\ln(E + p_{11})/(E - p_{11}), \qquad (1)$$

where E and p_{11} are the energy and longitudinal momentum of a shower particle, respectively. Since shower particles are primarily pions with a mean transverse momentum of ~ 0.4 GeV/c,

$$p_{11}^2 \gg p_T^2 \gg m,$$

(p_T and m denote the transverse momentum and mass, respectively) so that (1) becomes

$$Y = -\ln\tan\theta/2\,(=\eta),$$

where θ is the spatial emission angle.

The existence of clustering is indicated if there is an excess of small rapidity gaps as compared to an exponential distribution which is expected if the particles occur randomly in rapidity. Although some work has been done to study "clustering" by the two particle rapidity gap distribution in high energy hadronic collisions, there is no significant work where higher order clustering has been studied. In this paper we study rapidity correlations for any arbitrary number of particles produced in proton-emulsion interactions at 300 GeV.

Method of Analysis: Cumulative rapidity gap.

We represent the charged secondary particles (designated by strokes) for an event in rapidity space as in Figure 1. The η-scale will be different

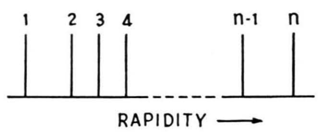

Fig. 1. Schematic representation of charged secondary particles in rapidity space.

for different events. We do not consider the particles at the ends of the rapidity space since they constitute the leading and target particles. We want to study the non-diffractive component of the cross-section only. For a group of n charged particles adjacent in rapidity, the sum of $n-1$ consecutive rapidity gap lengths is

$$r(n) = Y_{i+n-1} - Y_i,$$

where Y_i is the rapidity of the first particle, i.e. the particle with the lowest rapidity. $r(n)$ may be called "cumulative rapidity-gap length". As mentioned earlier, clustering will be evident if there is a peak in the distribution of $r(n)$ for small rapidity-gaps.

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Experimental Data

The data have been obtained from emulsion plates exposed horizontally to the FNAL 300 GeV proton beam [11]. These plates were scanned on a Leitz-Ortholux Microscope provided with a Brower travelling stage. The plates were area scanned under an oil emulsion 53.1 $\times$ objective in conjunction with a 16.8 $\times$ ocular. Every region was scanned by two independent observers. The criteria for accepting an event were i) the beam track falls within $< 2^\circ$ of the mean beam direction in the pellicle ii) the interactions are not situated within the top or bottom 20 μm thicknesses of the pellicle. All primary beam tracks were followed back to be sure that the events chosen did not include interactions from the secondary tracks of other interactions. The primaries originating from other interactions were observed and the corresponding events were removed from the sample. With these criteria 400 events were finally selected for analysis. The shower tracks are selected according to the criterion $b < 1.4$, where b is the normalised blob density. The emission angles θ for all shower tracks were obtained from coordinate measurements (taking four points on shower track and primary track), and hence the rapidities $\eta = -\ln\ (\tan \theta/2)$ were calculated for all showers.

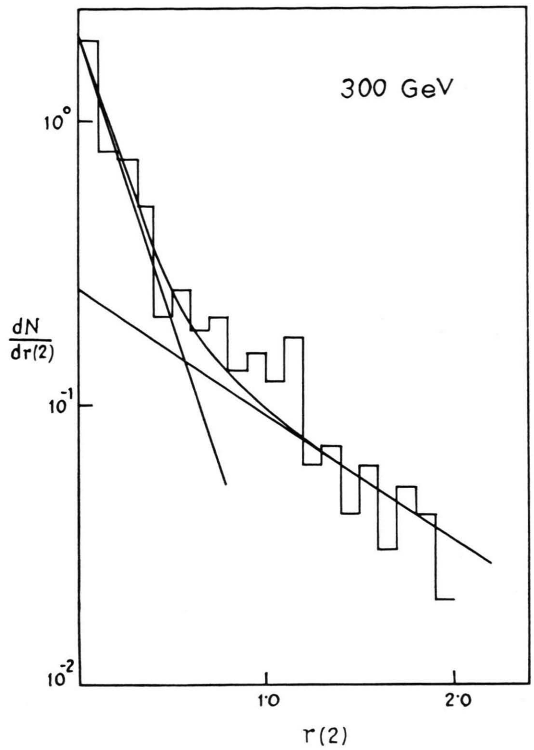

Fig. 2. Distribution of cumulative rapidity-gap length $r(2)$ (vertical scale normalised).

Results and Discussions

For all interactions the cumulative rapidity gap lengths $r(n)$ were calculated for $n = 2, 3, 4, 5$. Figure 2 shows the distribution of r (2). The sharp peak in the distribution for low values of r clearly indicates the existence of a two particle correlation. Figure 3 shows a similar sharp peak in the distribution of r (3), indicating the existence of a three particle correlation. No sharp peak is observed in the distributions of r (4) and r (5). Hence higher order correlations do not exist in these interactions.

These distributions can be represented by equations of the form

$$dn/dr = A\,e^{-Br} + C\,e^{-Dr}\,. \qquad (1)$$

It has been shown in some works that 2-particle rapidity gap distributions in high energy hadron collisions follow the form (1). It is interesting to note that also here the distributions of $r(2)$ and $r(3)$ follow this form. The numerical expressions for the solid lines in Figs. 2 and 3 are, respectively, (the

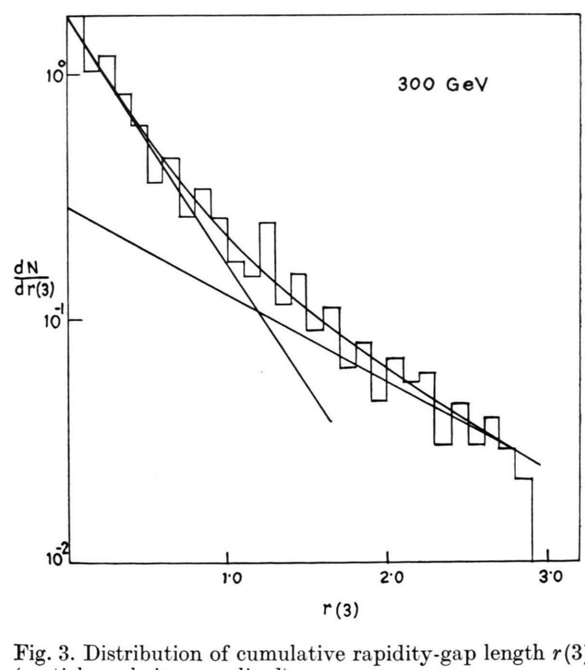

Fig. 3. Distribution of cumulative rapidity-gap length $r(3)$ (verticle scale is normalised).

Table 1.

	A	B	C	D	χ^2/D.O.F.
Two-particle	7.38 ± 0.52	4.50 ± 0.39	1.28 ± 0.11	1.20 ± 0.13	0.8
Three-particle	3.66 ± 0.34	2.30 ± 0.20	1.49 ± 0.13	0.90 ± 0.08	0.9

fits have been performed by the CERN optimization programme MINUIT):

$$dn/dr(2) = 7.38\, e^{-4.50r} + 1.28\, e^{-1.20r}, \qquad (2)$$

$$dn/dr(3) = 3.60\, e^{-2.31r} + 1.49\, e^{-0.90r}. \qquad (3)$$

The contributions of the two individual terms in (2) and (3) are also shown in the Figures. The fast decrease at the small values of $r(n)$ and the slow decrease at the large values indicate the presence of short- and long-range correlations, respectively. Evidently the main contribution to the term $dN/dr(n)$ comes from the short-range correlation.

The value of the slope B provides a measure of the strength of the correlation in the first region of the rapidity difference distribution. The reason is obvious: The more particles are closely spaced in rapidity, the smaller is the rapidity difference and the longer the slope of the rapidity difference distribution and the correlation. The strength of the correlation will indicate whether cluster production is the predominant mode of particle production or not. We find from (2) and (3) that with increasing number of particles in a cluster the strength of the correlation decrease. Further, from the above equations we find that the value of the slope D in the second term remains more or less constant. This indicates an independent emission of particles producing that part of the $r(n)$ distribution. These observations are in agreement with those of [12].

Recent understanding of the strong interaction at high energies is based on the quark-parton hypothesis and the production of jets or clusters through the interaction of quark matter. Our results provide some information about the quark-parton model description of the clusters. It may be remark that in relativistic heavy ion collisions it is expected that due to the high density and temperature a phase of quasi-free quarks should appear [13—14]. The collisions among the quarks will then result in a large number of clusters and strong correlations.

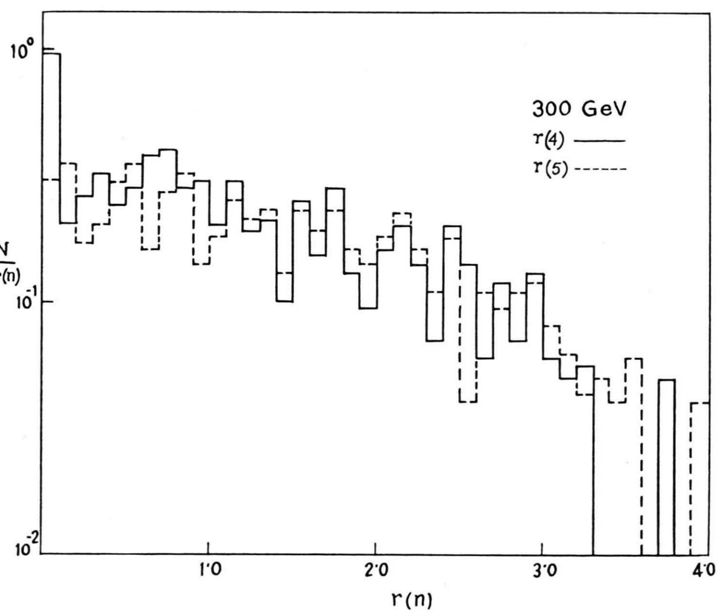

Fig. 4. Distribution of cumulative rapidity-gap lengths $r(4)$ (Solid) and $r(5)$ dashed (vertical scale is normalised).

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