PHYSICAL REVIEW D VOLUME 15, NUMBER 7 1 APRIL 1977

Cluster production in cosmic-ray interactions

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(Received 15 June 1976)

The existence of positive two-particle correlations is shown in interactions at cosmic-ray energies ($\sim 10^{12}$ eV). The results indicate independent emission of clusters and their dynamical significance.

I. INTRODUCTION

Recently, a number of authors[1] have investigated the dynamics of multiparticle production on the basis of cluster formation at Fermilab and CERN ISR energies. This approach has opened a new and attractive dimension on the production mechanism of multiple secondary particles at high energies. An interesting point to determine is whether the proposition of cluster formation is merely a phenomenological artifice or is a dynamical effect. In order to determine this, it would be extremely useful to verify whether the two-particle correlation is "universally" exhibited at different primary energies from a few GeV up to the highest energy. All the work reported so far has been confined to machine energies, and none has been reported at cosmic-ray energies ($\sim 10^{12}$ eV), which still remain the highest available energy. Another merit of investigating two-particle correlations at cosmic-ray energies is that we can get an idea of the distributions to expect as the primary energy is increased in the future at Fermilab and CERN ISR machines.

We present below a study of two-particle rapidity correlations in cosmic-ray interactions having primary energy less than 1 TeV and greater than 1 TeV. The reactions studied are the semi-inclusive processes since the rapidities of only the charged-secondary particles were determined. The secondary particles in the central plateau region in rapidity have been investigated in the present work. Thus the secondary particles considered are those which contribute predominantly to the nondiffractive component of the total cross section. The parameter which best reflects the cluster behavior is the gap length in rapidity.

We write the rapidity as

$$y = \frac{1}{2}\ln\left(\frac{E+P_L}{E-P_L}\right), \qquad (1)$$

where E and P_L are the energy and longitudinal momentum of the secondary particle, respectively. At cosmic-ray energies it can be assumed that $P_L \gg P_T \gg m$, where P_T and m denote respectively the transverse momentum and mass of the secondary particle. Hence, we get from Eq. (1)

$$y = \ln(2/\tan\theta), \qquad (2)$$

where θ is the lab angle of the secondary particle.

The experimental data used here are taken from the ICEF data sheet,[2] and the following criteria were adopted to select the events:

1. The primary energy of the interaction must be greater than 0.1 TeV.
2. The number of low-energy particles[3] (heavy tracks, n_h) should be equal to zero. This criterion was followed in order to ensure that there is no momentum transfer to the nucleus and that the collision is effectively a nucleon-nucleon type.

The number of events satisfying the above criteria was found to be 36. The data for 16 nucleon-nucleon interactions from the Chicago stack reported earlier[4] have also been considered in the present analysis. Thus the total number of events is 52, yielding the number of secondary particles equal to 801. The complete details of the events such as their primary energy, the number of low- and high-energy tracks, and the rapidity values of secondary particles are given elsewhere.[5] The value of the primary energy in an interaction was determined by using the formula of Castagnoli *et al.*[6],

$$\ln\gamma_c = \frac{1}{n_s}\langle \ln\cot\theta\rangle, \qquad (3)$$

where $\gamma_c = 1/(1-\beta_c^2)^{1/2}$, β_c is the velocity of the center of mass, and n_s is the multiplicity of charged secondary particles in an event. The value of primary energy (E_p) was found from the relation

$$E_p = M_N(2\gamma_c^2 - 1),$$

where M_N is the nucleon mass. The contribution of a persisting primary in an interaction was not considered in the determination of γ_c as it is not a secondary particle, and this procedure[7] leads to a better estimate of the primary energy. The primary energy of the interactions ranges from 0.1 to 2600.0 TeV.

II. RESULTS AND DISCUSSION

A two-particle correlation necessarily implies that a distribution of rapidity-gap length between two adjacent particles must have a sharp peak at small values of the rapidity difference (r). In an interesting work Snider[8] has proposed a multiperipheral model which describes the two-charged-particle correlations and the rapidity-gap distributions for the nondiffractive component of the hadronic cross section at high energies. The secondary particles in the central region have been considered here and the two leading particles on each end of the rapidity space have been neglected. Thus the contribution of a Pomeron at the ends of the rapidity distribution is eliminated. In the present work the rapidity difference was calculated for all neighboring charged particles and the contribution of the two leading particles on each side of the rapidity distribution was neglected. Thus an event with multiplicity n contributed to the distribution $n-3$ times. The rapidity-difference distribution thus obtained is for the central plateau of the rapidity distribution. Figures 1(a) and 1(b) show the two-particle rapidity-difference distribution for primary energy less than 1 TeV and greater than 1 TeV, respectively. The average energy of the events for $E_p < 1$ TeV and $E_p > 1$ TeV is 0.5 and 118.7 TeV, respectively. In Fig. 1(a) and Fig. 1(b) the solid curves represent the following relations respectively:

$$dn/dr = 4.0e^{-4.8r} + 0.3e^{-0.7r} \tag{4}$$

and

$$dn/dr = 4.2e^{-5.1r} + 0.3e^{-1.0r} \; . \tag{5}$$

These relations compare well with the following relation given by Snider[8] for 205-GeV/c p-p interactions:

$$dn/dr = 2.40e^{-3.1r} + 0.20e^{-0.9r} \; . \tag{6}$$

The similar forms of the exponential relations (4) and (5) show that the two-particle correlations in the central region are energy-independent (scaling). This is in conformity with the independent emission of clusters in a multiperipheral mechanism.[1] According to this model the characteristics of secondary particles in the central region are independent of the primary energy of the particle at high energy. The single-particle rapidity distribution of secondary particles also shows this behavior by exhibiting a plateau in the central region which has been explained in terms of the multiperipheral model.[9] Thus in the central region the proposition of cluster formation follows as a natural consequence from the existence of positive short-range correlations and their energy independence. An increase in energy does not result in modifying the cluster characteristics but only in their number. The independence of two-particle correlations with energy and multiplicity even at cosmic-ray energies strongly supports the dynamical significance of clusters.

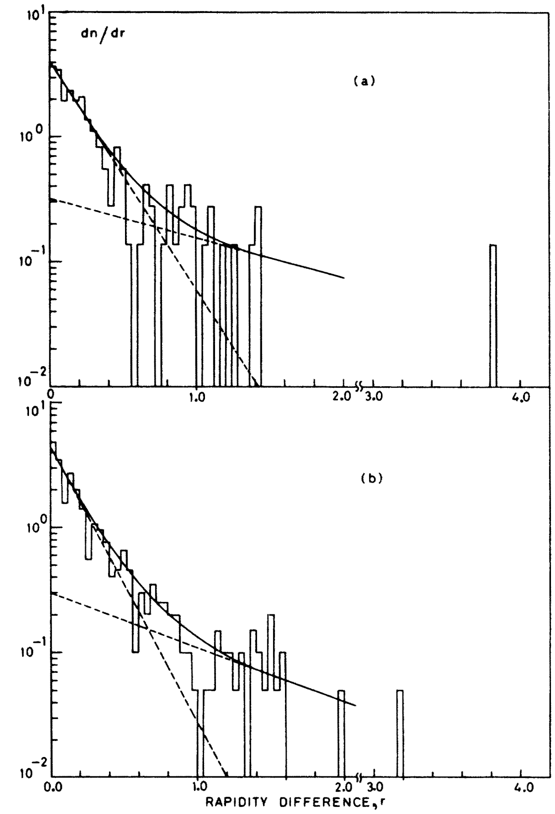

FIG. 1. Rapidity-difference distribution for neighboring charged particles in cosmic-ray interactions having primary energy (a) less than 1 TeV and (b) greater than 1 TeV, respectively. The solid curves in (a) and (b) show the respective contribution of Eqs. (4) and (5) in the text and the dashed lines show the individual contribution of the two terms in the two equations.

ACKNOWLEDGMENT

I am grateful to Professor A. N. Mitra for his interest and encouragement in this work.

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