Ring events in high-energy hadron processes

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Some of the events observed in 400-GeV proton-nucleon interactions have dense clusters of particles on the pseudorapidity scale, corresponding to a ring-shaped structure for the target diagram. Events of this type have been singled out and studied. It is found that such clusters are emitted preferentially at c.m. angles of about 55°, 90°, and 125°.

In inelastic interactions of hadrons the secondary pions are usually produced with an average density of two or three charged particles per unit interval along the rapidity scale. In contrast, events have been observed both in cosmic ray research and on accelerators[1–3] in which groups of particles have a density more than three times this average. The appearance of groups of particles with approximately equal pseudorapidities (i.e., with approximately equal polar angles) means that the particles of this group form a noticeable ring[1)] on the target diagram for the event. We will accordingly call these events "ring events."

The reason for the special interest in such events is that the dynamic mechanism for their appearance may be related to quark confinement, which imposes a restriction on the gluon emission length,[4] or to Čerenkov gluons,[5] which arise when the refractive index of the quark-gluon medium exceeds unity. In either case the theory indicates that the gluon emission angle and thus the emission angle of the jets produced by the gluons should be quite large.

We have accordingly undertaken a systematic search for such events in 400-GeV proton-nucleon interactions in a nuclear emulsion,[6] in which the angles can be measured most accurately. Since ring events can be identified only at high multiplicities, we selected for the analysis 284 events with from 12 to 18 secondary charged particles. We used several criteria for distinguishing ring events; here we will describe only two typical criteria.

First, we identify as ring events those in which there are groups of at least six particles ($k \geqslant 6$) where the following two conditions hold: (1) The average distance between the particles of the groups along the pseudorapidity scale is less than 0.15; (2) the distance between adjacent particles within this group does not exceed either (a) twice the average distance, if the average distance lies between 0.1 and 0.15, or (b) 0.2, for dense groups with an average distance less than 0.1.

Condition (1) thus selects groups that are roughly three times as dense as ordinary average events. The other requirements rule out large gaps within a group, i.e., rule out the interpretation of a group as two separate groups.

This criterion was satisfied by 59 of the 284 events studied. In each, we determined the position of the center (the arithmetic mean) of the rapidities of the group.

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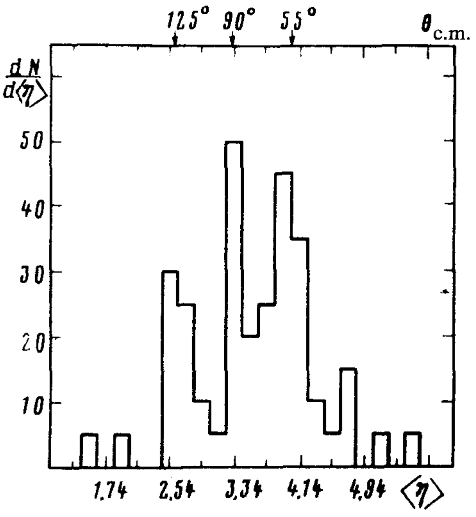

FIG. 1. Pseudorapidity distribution of the centers of dense groups of particles (see the text proper).

Figure 1 shows the pseudorapidity distribution of the centers of the groups. There is a tendency for the groups of particles to appear more frequently near the c.m. angles of 55°, 90°, and 125° (the corresponding pseudorapidities are about 2.7, 3.34, and 4.0). The cross section for the production of ring events in the forward and backward directions in the c.m. frame (near 55° and 125°) is about 1 mb after subtraction of the background.

The second criterion singles out groups of seven or more particles ($k \geqslant 7$) in a rapidity interval of less than 0.9 (i.e., $\langle \Delta\eta \rangle < 0.15$), with adjacent particles (in the group) separated by less than 0.2. Only 36 events passed this test. Although the statistical base was considerably smaller here, a structure with three peaks in the pseudorapidity distribution of the centers of the groups remains the most plausible hypothesis.

There is some asymmetry between the distributions in the forward and rear c.m. hemispheres because of the particular way in which events in the emulsions are selected. We wish to emphasize that dense groups of particles appear only in the pionization region, and the fraction of ring events increases with increasing multiplicity (from $\sim 5\%$ at n_{ch} between 12 and 15 to $\sim 30\%$ at n_{ch} between 16 and 18).

The azimuthal distributions of the particles within rings for the groups of particles emitted at 55° and 125° differ from the azimuthal distribution of the groups emitted at 90°. Specifically, the former distributions are significantly more isotropic.

Figure 2 shows a representative target diagram of one of the ring events.

Indirect confirmation of this three-peak structure can be found from an analysis of data on the binary correlations of secondary particles in pp interactions at an energy $\sqrt{s} = 31$ GeV (this energy is equivalent to an energy of 480 GeV in the laboratory frame), reported in Ref. 7. Carrying out measurements over a rather broad interval of the emission of the trigger particle, $\Delta\eta_1 = 0.5$, Cavasinni *et al.*[7] found the correlation

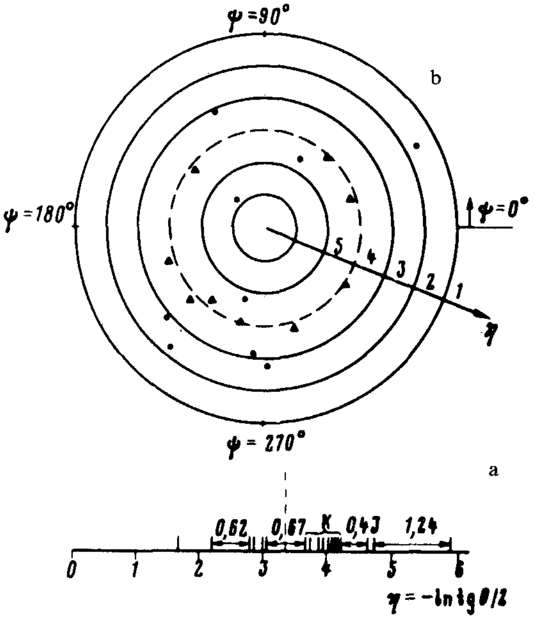

FIG. 2. a—Distribution in the pseudorapidity η; b—target rapidity-azimuthal-angle diagram for pN events of the type $0 + 0 + 18p$ (ring: $k = 9$; $\langle\eta\rangle = 4.02$, $\langle\Delta\eta\rangle = 0.066$). The triangles show the particles of a ring, and the points show other particles.

$\left(R_2 = \dfrac{\sigma_{in} d^2\sigma/d\eta_1 d\eta_2}{d\sigma/d\eta_1 d\sigma/d\eta_2} - 1\right)$ of the second particle as a function of η_2. The shift of the center of the interval along the pseudorapidity scale, $\Delta\eta_1$, can be used to study the change in the correlation function R_2 with the angular interval into which the first particle is emitted. It can be seen from Fig. 2 in Ref. 7 that the correlations of the secondary particles peak near c.m. angles of 90° and 55°, showing that the particles tend to cluster in pseudorapidity near these angles. For $\Delta\eta_1^{\text{c.m.}}$ intervals from -0.35 to 0.15, from 0.15 to 0.65, and from 0.65 to 1.15, the corresponding peaks in the function R_2 have height ratios 0.48:0.42:0.58. In other words, these height ratios show that the correlation of the particles in the two limiting intervals tends to increase even over such a broad pseudorapidity interval $\Delta\eta_1^{\text{c.m.}}$. Our own data in Fig. 1 show that the area under the curve in Fig. 1 is roughly the same in the same intervals. We also see that the structure observable in Fig. 1 indicates an increase in the correlations of particles near angles of 90° and 55°.

The nonmonotonic behavior of the particle-correlation peak as a function of the emission angle of the trigger particle seems to us to be far from trivial.

The selection of events with a high multiplicity and the appearance of a correlation structure at large c.m. angles show that this structure cannot be attributed to inelastic processes of a diffractive type.

The interpretation of the dense groups of particles as a manifestation of an overlap of parton ladders would most likely mean a monotonic dependence with a single broad maximum near 90°.

The results of this experiment can be described more readily by the model of a bremsstrahlung of gluons over a finite distance.[4] We have accordingly analyzed the data on this basis. According to the model of Ref. 4, the peak in the forward emission in the c.m. frame would occur at a laboratory angle on the order of

$$\theta_{\mathrm{lab}} \cong \sqrt{2\pi / \omega l} > \sqrt{2\pi / El}, \tag{1}$$

where ω is the energy of the emitted gluon (group of particles), E is the primary energy, and l is the emission formation length, determined by the particular nature of the quark confinement.

If the peaks at c.m. angles of 55° and 125° are attributed to the gluon emission of quarks from primary nucleons that are emitted respectively forward and backward, then the positions of these peaks tell us that the formation length for the gluon emission is on the order of the size of a hadron or larger, since (1) implies

$$l \gtrsim 2\,\mathrm{fm}. \tag{2}$$

One might attempt to explain the peaks at 90° as resulting from the overlap of two rings emitted simultaneously (in the same event) by the two colliding nucleons. The narrowness of this peak makes it very difficult to explain it in terms of background events.

We wish to emphasize that the structure observed by us in the angular correlations of the secondary particles in high-energy inelastic processes may prove to be an important source of information on the particular nature of quark confinement. This structure deserves a further and detailed study in experiments with a large statistical base and a good angular resolution.

1) Or part of a ring (or, in the extreme case, a jet, if the spread in azimuthal angles is also small).

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