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LONG RANGE CORRELATIONS AND THE DYNAMICS OF MULTIPARTICLE PRODUCTION*

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ABSTRACT

It is shown that the negative transverse angle correlation between leading particles in multiparticle production, required by momentum and energy conservation, is substantially reduced if the secondaries are correlated in longitudinal momentum with the leading particles. The multiperipheral model, which produces the pions with ordered longitudinal momenta, and a pionization model that produces each pion randomly in longitudinal phase space are both compared to experimental results for $pp \rightarrow pp\pi^+\pi^+\pi^-\pi^-$ at 23 GeV/c. The data strongly favor random pion production.

Recently, the study of single particle inclusive spectra has become a popular means of probing the dynamics of high-energy multiparticle production. However, these studies have so far been unable to discriminate between the various dynamical models of high-energy production processes. The fact that the various models all describe the experimental inclusive data is a consequence of their sharing several properties in common. They all incorporate peripheral phase space and provide the incident particles with large elasticity. Hence, they all reproduce the limited transverse momenta dependence of the produced and leading secondaries and the large longitudinal momentum behavior of the leading particles. However, where the models differ is in the mechanism they provide for the production of the secondary pions.

These mechanisms can be classified into two general groups: those that associate the produced secondaries with one or the other of the leading particles and those that do not. In the first group the secondaries associated with a particular leading particle are produced with similar longitudinal momentum to the leading particle. For models in the second group, each produced secondary has no favored direction in the center of mass frame. The first group will be referred to as associated models and the second as unassociated.

A general prediction of associated models is that particles associated with different leading particles (including the leading particles themselves) will tend to become uncorrelated with each other as the energy increases, becoming completely uncorrelated at extreme energies.[1] For unassociated models, leading as well as produced particles will retain long range correlations even at extreme energies.

An often used measure of the correlation between two particles is the distribution of the transverse angle

$$\phi = \cos^{-1}(\vec{q}_i \cdot \vec{q}_j / |\vec{q}_i|\ |\vec{q}_j|) \tag{1}$$

between them. Here $\vec{q}$ is the component of the particles momentum transverse to the beam direction. Particles that are uncorrelated will produce an even distribution in ϕ.

Unassociated models will predict asymmetric distributions about $\phi = 90°$, peaking at $\phi = 180°$. This behaviour is mainly due to transverse momentum conservation which requires that each particle be produced in the opposite direction of the others on the average. Associated models overcome this effect by preferentially conserving transverse momentum locally with neighbors of similar longitudinal momentum.

At low enough energies, all models predict the same results, namely, the correlations predicted by momentum and energy conservation. However, with increasing energy the predictions will begin to differ, and at extreme energies associated models will completely uncorrelate particles with sufficiently dissimilar longitudinal momentum.

In order to become more quantitative, we have selected a specific model from each of the two categories and calculated the transverse angle distributions between the two final state nucleons in pp interactions for several laboratory beam momenta. From the first group we take the multiperipheral model of Chew and Pignotti,[2] as modified by Chan, Loskiewicz and Allison,[3] in which the basic mechanism is peripherality. As an exchanged meson propagates from the fast incident particle to the target, it sequentially emits pions in the beam direction in order to lose its high momentum and be absorbed by the target at rest in the laboratory. This process of sequential

pion emission results in the ordering of the longitudinal momentum of the pions in approximately equal intervals in rapidity.[4] As discussed in Ref. (3) the matrix element squared for this model can be expressed as

$$|M_N(s,t)|^2 = c \prod_{i=1}^{N-1} \left(\frac{b + s_i}{b}\right)^{2\alpha_i(t_i)} \beta^2(t_i) \tag{2}$$

Here the s_i and t_i are the subenergies squared and four-momentum transfers squared, corresponding to the links in the multipheral chain. As advocated in Ref. (3) the constant b is introduced to allow the s_i dependence to reduce to phase space for small sub-energies. In all cases we have taken its value to be 1 GeV^2.
The $\alpha(t)$ were taken to be the effective ρ-meson trajectory determined by Fox.[5] The $\beta^2(t)$ are taken to be simple exponentials $\beta_m^2(t) = e^{at}$ for pion production and $\beta_n(t) = e^{bt}$ for leading nucleons.

As an example of an unassociated model we take a pionization model where the final state nucleons emerge peripherally with relatively large elasticity and small transverse momentum. Each of the pions is produced with limited transverse momenta while the longitudinal momentum is equally distributed in the available longitudinal phase space. These properties are characterized by the matrix element squared

$$|M_N|^2 = \exp\left[g(t_1 + t_N) - b \sum_{i=2}^{n-1} |\vec{q}_i|^2\right] \tag{3}$$

Here, N is the number of particles in the final state, t_1 and t_N are the four-momentum-transfers squared from the incident particles to the leading elastic particles and the $\vec{q}_i$ are the components of the (N - 2) produced pions' momentum transverse to the beam direction.

The two parameters in each model were adjusted to reproduce the experimental transverse momentum distributions for the pions and protons separately, in the reaction $pp \to pp\pi^+\pi^+\pi^-\pi^-$ at 23 GeV/c. For calculations at other momenta the parameters of the multiperipheral model were held fixed while those of the pionization model were adjusted to give the same transverse momentum distributions as the multiperipheral model.

Figure 1 summarizes the transverse angle distributions between the final state nucleons for both models by plotting their backward-forward asymmetry in the reactions $pp \to pp(N\pi)(N = 4, 6, 8)$ for several beam momenta. For comparison the asymmetry is also shown for the reaction $pp \to pp$ + anything using the multiperipheral model of Ref. 1.[6]

As expected from the qualitative discussion above, as the energy increases the multiperipheral model causes the protons to become less correlated approaching almost zero correlation at 400 GeV/c. On the other hand, the pionization model retains substantial correlation at these highest energies. However, even at the lowest energy considered (23 GeV/c) Fig. 1 shows substantial difference between the predictions of the two models. For this reason, we compare the predictions of the two models to experimentally measured distributions for the reaction $pp \to pp\pi^+\pi^+\pi^-\pi^-$ at 23 GeV/c.[7] Fig. 2 shows various transverse angle distributions between the final state particles for this reaction; namely between the two protons (Fig. 2a), between the pions with largest positive and negative CM longitudinal momentum (Fig. 2b), between the pions with smallest longitudinal momentum (Fig. 2c), between the protons and the pions with the largest magnitude CM longitudinal momentum (Fig. 2d), and between the two pions with second and third largest longitudinal momenta (Fig. 2e).

While the distributions involving only pions are slightly better described by the pionization model, these distributions clearly do not distinguish between the two models. However, the distributions involving the protons, while being adequately described by the pionization model, completely disagree with the predictions of the multiperipheral model. As expected from the qualitative discussion above, the multiperipheral model predicts a large short range correlation and a smaller long range correlation while the pionization model predicts approximately the same for both. The data clearly exhibit the latter behaviour.

As discussed above (and illustrated in Fig. 1 for the two specific models) the differences between the predictions of associated and unassociated models increase with increasing CM energy. The distributions shown in Fig. 2 indicate that at 23 GeV/c beam momentum there is no evidence of decrease of long range correlations in pp collisions. Although the multiperipheral model of Eq. 2 predicts an appreciable decrease by these energies, this may not be true of all associated models. However, if this model is at all characteristic of associated models, then beam momenta in the 100 to 400 GeV/c range should be high enough to distinguish between the two classes of models.

To summarize, it has been shown that the transverse angle correlation between final state leading particles is a sensitive indicator of the nature of secondary production in high energy collisions. Data from pp interactions at 23 GeV/c show no indication of decrease of long range correlations predicted by associated models. Calculations from the multiperipheral model, a particular associated model show that (for this model) such deviations should be present at these

NOTES AND REFERENCES

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6. In calculating $d\sigma/d\phi$ for this model, we have assumed only $M = 0$ Toller quantum number exchange (see Ref. 1).

7. The six-pronged events resulting from a proton exposure in the BNL 80" H_2 - B.C. were fitted to the reaction $pp \to pp\pi^+\pi^+\pi^-\pi^-$ in the beam momentum range 18 - 28 GeV/c, yielding 970 examples of this reaction. For a detailed description of the experiment see: D. B. Smith, Ph. D. Thesis, UCRL-20632, March 1971 (unpublished).

FIGURE CAPTIONS

Fig. 1: Backward-forward asymmetry in transverse angle distributions for final state nucleons in pp interactions as predicted by pionization and multiperipheral models, for several beam momenta.

Fig. 2: Experimental transverse angle distributions between various final state particles for $pp \to pp\pi^+\pi^+\pi^-\pi^-$ at 23 GeV/c. The dashed lines are the predictions of a multiperipheral model while the solid ones are the predictions of a pionization model (see text).

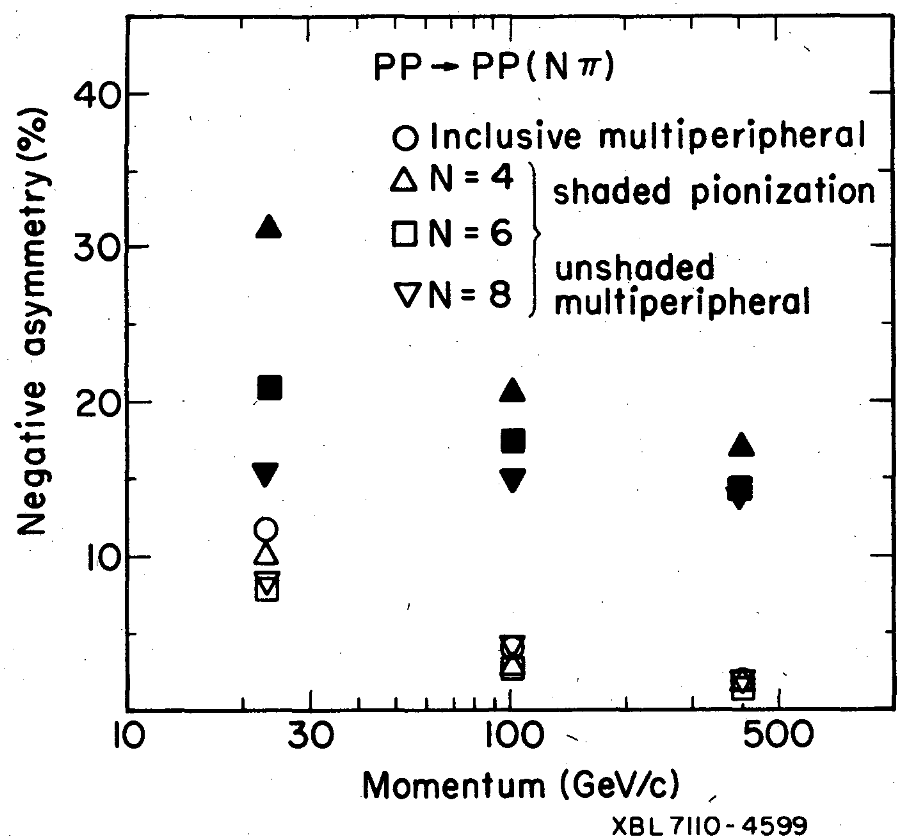
PP → PP(Nπ)
Inclusive multiperipheral
N = 4
N = 6
N = 8
shaded pionization
unshaded multiperipheral
Negative asymmetry (%)
Momentum (GeV/c)
10
20
30
40
10
30
100
500
XBL 7110-4599

Fig. 1

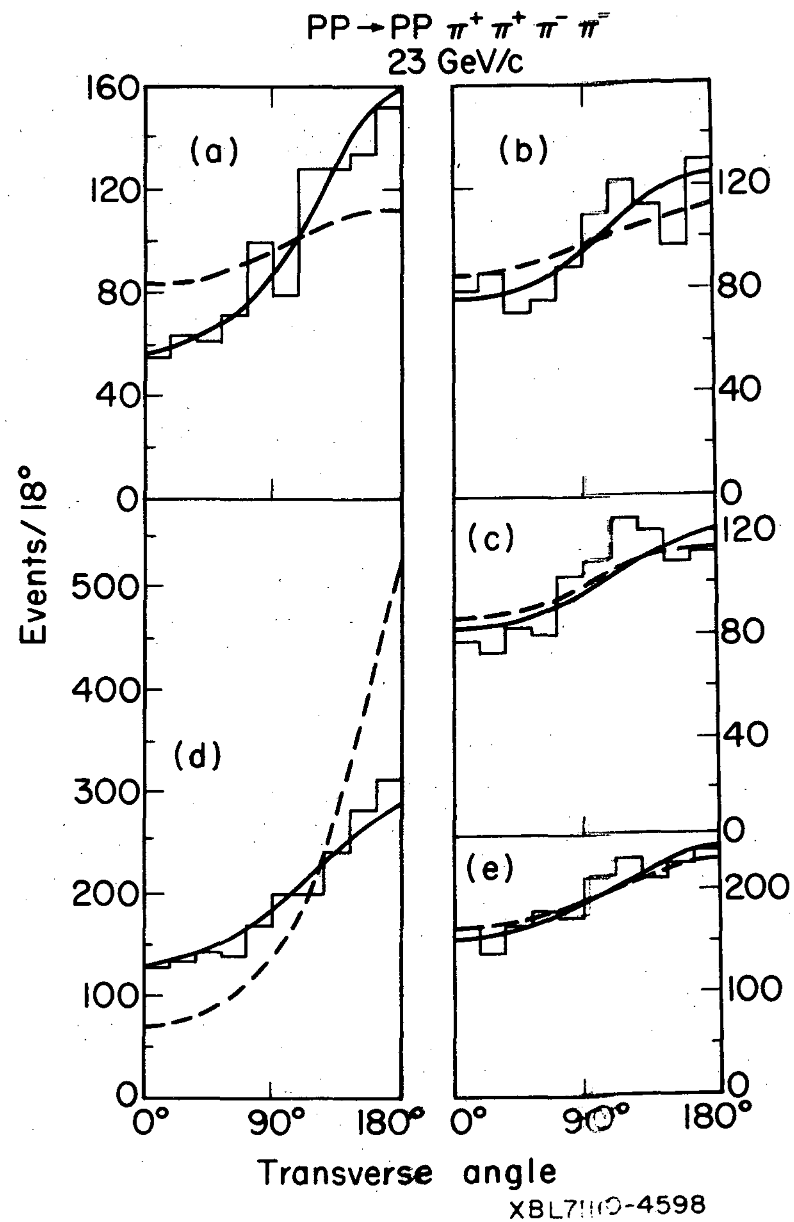
PP → PP π+ π+ π- π=
23 GeV/c
(a)
(b)
(c)
(d)
(e)
Events/18°
Transverse angle
0°
90°
180°
XBL7110-4598

Fig. 2

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