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### Publication Date

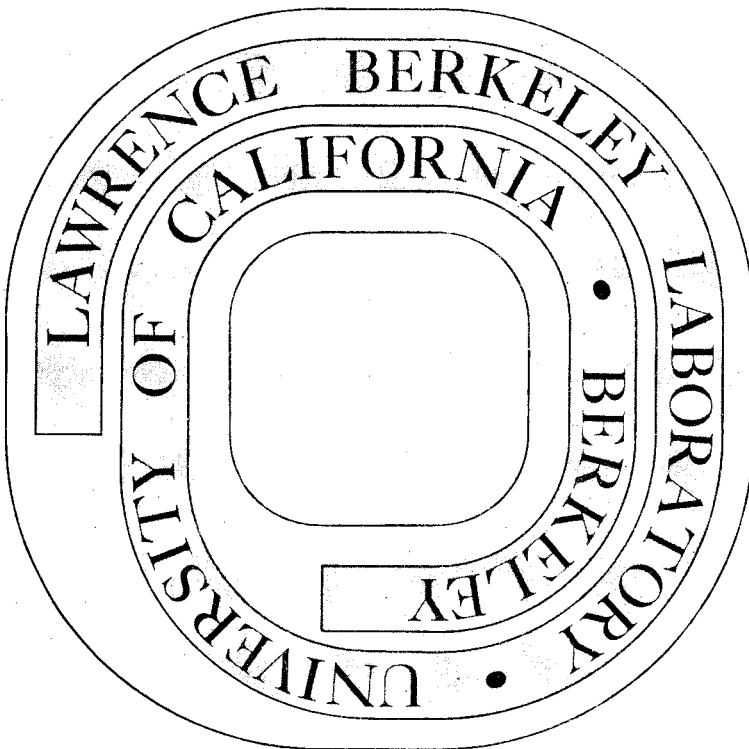
1971-07-01

A SIMPLE TEST FOR THE EXISTENCE OF  
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Jerome H. Friedman and Clifford Risk

July 27, 1971

AEC Contract No. W-7405-eng-48



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A SIMPLE TEST FOR THE EXISTENCE OF MULTIPERIPHERALISM  
AT HIGH ENERGY\*

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ABSTRACT

It is shown that the correlation in transverse angle between pairs of particles with dissimilar center of mass longitudinal momentum can provide a sensitive test between multiperipheralism and most other models of high-energy multiparticle production.

Recently, the study of inclusive processes has become a popular means of probing the dynamics of high-energy particle 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.

At one extreme is the multi-Regge model<sup>1</sup> 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 leads to peripheral-two-body exchanges between neighboring produced pions and correlates them in a manner similar to a two-body scattering process.

On the other hand, most other models of multiparticle production produce the secondary pions in an uncorrelated manner limiting only the magnitude of their transverse momentum, and distributing their longitudinal momentum with a more or less phase space distribution.<sup>2</sup> In these models the only correlations between produced particles are those dictated by overall momentum and energy conservation. Thus, in these models correlations in transverse momentum between particles with similar and dissimilar longitudinal momentum should be the same.

However, for the multi-Regge type model, the sequential emission of pions might lead to different transverse momentum correlations between particles with similar values of longitudinal momentum and those with dissimilar ones.

In this note we present the results of calculations of the transverse angle correlations between pairs of particles as a function of their difference in center of mass longitudinal momentum for both types of models. We find that while the two models predict qualitatively similar behavior for these correlations at low energy, their predictions are quite different at high energies.

To characterize the multi-Regge type model we use the formulation and parametrization of Ref. 3. This model gives a good description of the inclusive spectra in the reaction  $K^+p \rightarrow \pi^- + \text{anything}$  at 12 GeV/c and  $\pi^-p \rightarrow \pi^+ + \text{anything}$  at 25 GeV/c.

The second class of models, uncorrelated pion production, is characterized by a peripheral phase space model that includes the known properties of high-energy collisions--namely, elasticity of the incident leading particles and limited transverse momenta of both the leading and produced particles. These properties can be summarized by the matrix element squared

$$|M|_N^2 = \exp \left[ a(t_1 + t_N) - b \sum_{i=2}^{N-1} p_i^2(T) \right]. \quad (1)$$

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  $p_i(T)$  are the components of the  $(N - 2)$  produced pions' momentum transverse to the beam direction.

The first sum in the exponent causes the leading particles to be produced elastically with large longitudinal momentum while limiting their transverse momentum. The second sum limits the transverse momentum of the produced pions while distributing their longitudinal momentum according to phase space. The parameters  $a$  and  $b$  determine the extent to which the transverse momenta are limited and the leading particles are produced elastically.

The transverse and longitudinal inclusive momentum spectra were calculated for the pions and protons separately from the multi-Regge model for the reaction  $pp \rightarrow pp(N - 2)\pi$ ,  $N = 6, 8, \text{ and } 10$  at 25, 100, and 400 GeV/c.<sup>4</sup> For each of these multiplicities at each energy the parameters of the peripheral phase space model [ $a$  and  $b$  in Eq. (1)] were adjusted to produce a good correspondence to these inclusive spectra. Thus, by construction the two models yield the same predictions for the inclusive pion and proton spectra at each of these energies at each of these multiplicities. We then calculate the predictions of these two models for the correlation in transverse angle between pairs of final state particles as a function of their difference in center of mass longitudinal momentum.

In many experiments it is difficult to distinguish pions from protons at high energy, therefore in making the comparison all of the particles were assigned pion masses for the Lorentz transformation to the center of mass of the reaction.<sup>5</sup> After this transformation the particles are ordered in longitudinal momentum from most negative to most positive. Particles with corresponding positive and negative longitudinal momentum are assigned to conjugate pairs. That is, the two particles with the most positive and most negative longitudinal momentum form the first pair, the two with the next largest form the

next pair and so on. The transverse angle

$\phi = \cos^{-1}[\vec{p}_1(T) \cdot \vec{p}_2(T) / (|\vec{p}_1(T)| |\vec{p}_2(T)|)]$  ( $0 \leq \phi \leq 180^\circ$ ) is calculated for each pair.

Figure 1 summarizes the comparison of the predictions of the two models for these transverse angular distributions by presenting their asymmetry about  $\phi = 90^\circ$  for each conjugate pair at the energies and multiplicities discussed above. Figure 2 shows the actual angular distributions for  $N = 8$  at 100 GeV/c.

Inspection of Figs. 1 and 2 show that except possibly for the lowest energy (25 GeV/c) the predictions of the two models are quite different. The peripheral phase space model predicts a negative asymmetry that is roughly the same for all of the conjugate pairs.<sup>6</sup> On the other hand (except for the lowest energy), the multi-Regge model predicts almost no asymmetry for the first conjugate pair, slightly larger for the next and so on, approaching substantial asymmetry only for the innermost conjugate pairs.

This qualitative behavior is very general and is independent of the detailed parametrizations of the models. The independence of the asymmetry with conjugate particle pair in the peripheral phase space model is simply a consequence of the uncorrelated production of the pions. The behavior exhibited by the multi-Regge model is due to the correlation in the longitudinal momentum of the produced pions required by the limiting of the successive four-momentum-transfers squared in the multiperipheral chain.<sup>7</sup>

In the analysis described above resonance production has largely been ignored. It is taken into account only in the multi-Regge model in the dualistic sense of including baryon exchange at the ends of the multi-Regge

chains. However, at high energy the production of resonances along with the other final-state particles does not alter the qualitative predictions of the two models for the transverse angle correlations. The principal effect of resonance production for both models is to increase the available phase space for the  $N$  particle final state and produce transverse angle correlations characteristic of an  $N - R$  particle final state, where  $R$  is the number of relatively narrow resonances produced on the average.

A more serious effect that could tend to dilute the difference between the predictions of the two classes of models is the presence of unobserved neutral particles in the final state. This will have the opposite effect as narrow resonance production, namely, the final state will have the transverse angle correlations characteristic of a  $C + M$  particle final state where  $C$  is the number of charged particles observed and  $M$  is the number of missing neutral particles present on the average. Inspection of Fig. 1 shows that in general this is not a serious problem since for both models the qualitative predictions are largely independent of final-state multiplicity. The potentially most serious problem comes when a substantial fraction of the very fastest and very slowest particles in the laboratory are neutral for an event. However, these events should be easily identifiable by their relatively large amount of missing energy as well as their lack of low momentum particles. Events with these characteristics can simply be deleted from samples used for the comparison.

As noted above, the difference between the predictions of the two models increases with increasing energy, while the invariance of the predictions in the presence of resonance production and missing neutrals

decreases with decreasing energy. These considerations coupled with the predictions for the lowest energy shown in Fig. 1, 25 GeV/c, suggest that energies in this lowest region are probably too low for using this test to discriminate between the two classes of models.

However, the results of Fig. 1 indicate that beam momenta above 100 GeV/c are clearly adequate for the comparison.

In our analysis of the multi-Regge model we have neglected possible dependence of the vertex functions on the Toller angles.<sup>8</sup> Large effects of this type have been shown not to be present in low-energy interactions<sup>9</sup> and it is unlikely that these effects could be strong enough at high energies to overcome the effect of the limiting of the four-momentum-transfers squared along the multiperipheral chain.<sup>10</sup>

FOOTNOTES AND REFERENCES

- \* This work was supported in part by the U. S. Atomic Energy Commission.
- † Participating guest at Lawrence Berkeley Laboratory, Berkely.
- 1. G. F. Chew and A. Pignotti, Phys. Rev. Letters 20, 1078 (1968); G. F. Chew and A. Pignotti, Phys. Rev. 176, 2112 (1968).
- 2. Discussions and references concerning properties of the various models of high-energy multiparticle production are contained in High Energy Collisions, edited by C. N. Yang, J. A. Cole, M. Good, R. Hwa, and J. Lee-Franzini (Gordon and Breach, Inc., New York, 1969); See also R. Hagedorn, Nucl. Phys. B24, 93 (1970), and L. Van Hove, Phys. Reports 1C, 349 (1971).
- 3. J. H. Friedman and C. Risk, Lawrence Radiation Laboratory Report UCRL-20278, Feb. 1971 (unpublished).
- 4. The N-particle phase space integrals were performed exactly with the Lawrence Berkeley Laboratory Monte Carlo program SAGE; J. Friedman, Group A programming Note P-189 (Rev.), July 1969 (unpublished).
- 5. The Monte Carlo events were generated with the correct mass assignments in the laboratory frame and assigned pion masses only for the transformation to the center of mass frame.
- 6. The asymmetry is larger for the first conjugate pair in most cases because the protons were given on the average larger transverse momenta than the pions in order to conform to the predictions of the multi-Regge model. These large values make the protons more important in balancing transverse momentum.
- 7. Reggeization of the meson exchange amplitudes has a negligible effect on this behavior.

3. M. Toller, Nuovo Cimento 37, 631 (1965).
9. E. L. Berger, Phys. Rev. Letters 21, 701 (1968).
10. It is even less likely that these possible Toller angle effects would conspire in the exact manner necessary to cause the multi-Regge model to emulate the peripheral phase-space model.

FIGURE CAPTIONS

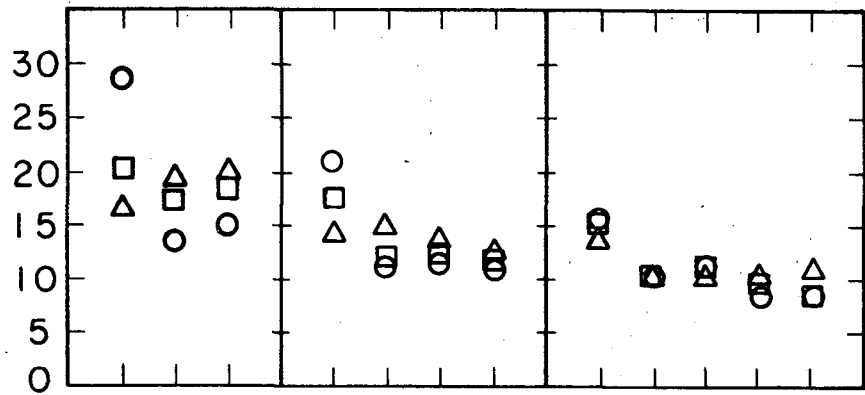
- Fig. 1. Asymmetry about  $90^\circ$  (in percent) predicted by the two models for the transverse angular distribution ( $0^\circ \leq \phi \leq 180^\circ$ ) of conjugate particle pairs. The asymmetry is defined as  $(N_G - N_L)/(N_G + N_L)$  where  $N_{G/L}$  is the number of events with angle greater/less than 90 degrees.
- Fig. 2. Transverse angular distributions of conjugate particle pairs as predicted by the two models for the reaction  $pp \rightarrow pp6\pi$  at 100 GeV/c.



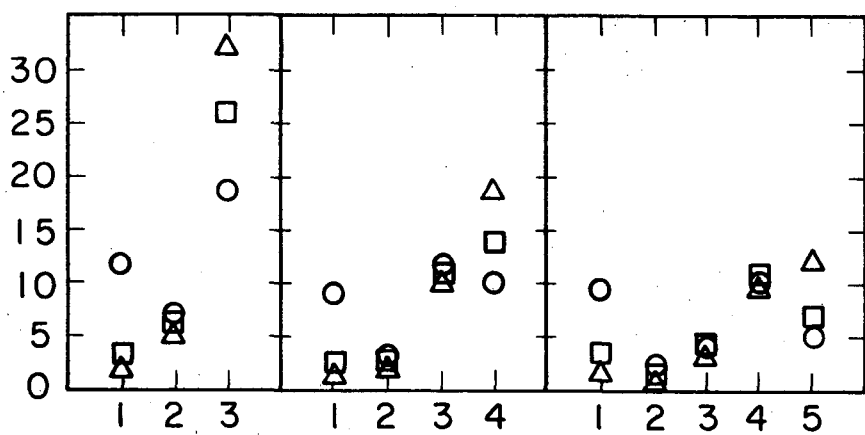
$pp \rightarrow pp (N-2) \pi$

○ 25 GeV/c    □ 100 GeV/c    △ 400 GeV/c  
N = 6            N = 8            N = 10

Peripheral phase space



Multiperipheral

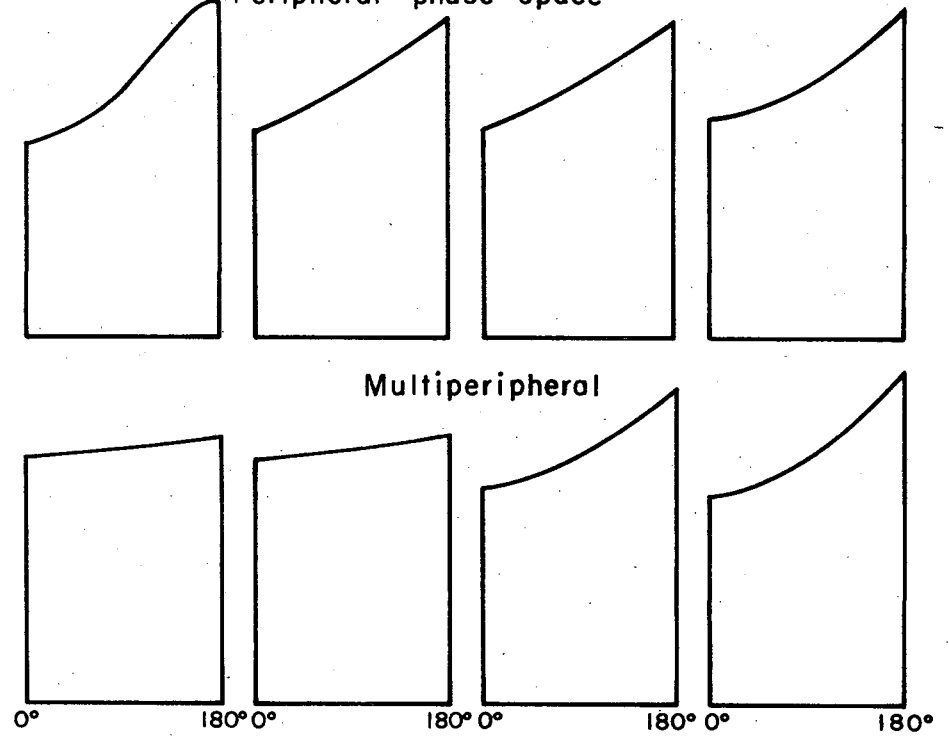


Conjugate particle pair

XBL717-3931

Fig. 1

$pp \rightarrow pp 6 \pi$  100 GeV/c  
Peripheral phase space



Multiperipheral

Transverse angle - conjugate particle pairs

XBL717-3932

Fig. 2

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