Mass dependence of the momentum-transfer distributions in $\pi^+ p \to p 8\pi$ at 11.0 GeV/c *

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(Received 8 April 1971; revised manuscript received 1 April 1974)

Bubble-chamber data for the reaction $\pi^+ p \to p 8\pi$ at 11.0 GeV/c have been analyzed from the standpoint of a new procedure which emphasizes the mass dependence of the momentum-transfer distribution. The technique shows a promise of resolving different types of production mechanisms. It is shown that analysis of the structure observed in these variables allows discrimination among some types of models for this extraordinarily complex reaction.

I. INTRODUCTION

Recent theoretical attention has been directed to the problem of the momentum-transfer dependence of reactions of the form $A+B \to C+D$,[1] where D actually is a system consisting of two or more long-lived particles, not necessarily resonant, and thus has a broad continuous spectrum of mass. It has been shown[1] that if the four-momentum transfer dependence is described by an expression of the form

$$\frac{d\sigma}{dt_{AC}} \sim \exp(\mu t_{AC}), \tag{1}$$

where μ is a function of M_D, the mass of D, then μ is expected to decrease with increasing M_D. The symbol t_{AC} represents $(P_A - P_C)^2$, where P_A and P_C are the four-momenta of particles A and C, respectively. This result is obtained under a variety of different dynamical assumptions, and is in qualitative agreement with the experimental data.[1,2]

It is also of interest to study and similarly attempt to understand the behavior of the momentum-transfer under the much more complicated conditions present in high-multiplicity reactions. In this case both "particle" C and "particle" D may be assumed to be systems consisting of more than one long-lived particle, and thus both may have broad continuous mass spectra. It may be possible to shed some light on the production mechanism of such events from this type of study.

We have chosen a reaction of very high multiplicity. Most of the particles produced in this reaction do not participate in clear, well-defined resonance production, though the number of combinations per event renders statements about resonances extremely difficult. Because the momentum transfers to produce them are necessarily large, such multiparticle production reactions are associated with relatively deep penetration into the incident particles.

This paper will discuss a systematic study of the properties of the four-momentum transfer, as described by a single exponential slope parameter. The motivation for such a choice of parameter will be discussed in Sec. III. That section will also present a discussion of the characteristics of the data, analyzed in this manner. It will then be shown in Sec. IV that these results may be interpreted with the use of general characteristics of the multiperipheral model. In particular, the fact that the model implies an ordering of the particles in the production process will be discussed. Section V will compare the results with two model calculations.

II. EXPERIMENTAL PARAMETERS

The BNL 80-in. bubble chamber, filled with liquid H_2, was exposed to an 11-GeV/c π^+ beam for 25 000 pictures. All eight-prong events were measured on film plane digitizers and processed through MATCH-TVGP-SQUAW-SUMX. The ionization estimated for each track on the basis of the fit was compared with the actual ionization observed on the scanning table, and inconsistent fits were rejected. Each kinematic fit was required to have a confidence level of at least 3%. Of the eight-prong events, 171 events were found to belong to the final state[3]

$$\pi^+ p \to p 4\pi^+ 3\pi^- \pi^0 . \tag{2}$$

All proton-π^+ ambiguities were removed by the ionization consistency requirement. Assisting in this procedure is the experimental fact that most of the protons are produced backward in the center-of-mass system, and are therefore slow in the laboratory. The total number of eight-prong events can be accounted for, with reasonable assumptions, with no necessity to assume that any events of reaction (2) have been improperly eliminated by this procedure, or any other (excluding unmeasurable events).

The possibility of contamination in the data has been studied in great detail. The most obvious sources are from events belonging to the final states $\pi^+ p \to p 4\pi^+ 3\pi^- 2\pi^0$ and $\pi^+ p \to 5\pi^+ 3\pi^- \pi^0 n$, and incorrectly identified as reaction (2). However, in these data we are fortunate that these channels are kinematically suppressed, relative to (2), because of the large number of particles for the available energy. Experimentally, the distribution of the square of the mass missing when only charged tracks are counted (which may be negative when the missing momentum exceeds the missing energy) is symmetric about $m_{\pi^0}^2$ for these events. This is in agreement with expectations and indicates the lack of serious contamination from the above reactions.

The reactions $\pi^+ p \to p 4\pi^+ 3\pi^-$ and $\pi^+ p \to 5\pi^+ 3\pi^- n$ may be fitted with four and one constraints, respectively. Ambiguities between the 4C fit and reaction (2) were resolved in favor of the 4C fit. Ambiguities between reaction (2) and the 1C neutron channel were largely removed by the ionization requirement. In any case, each of these reactions accounts for no more than 50 fits, and cannot therefore seriously affect the results, which are intended to be qualitative.

A problem may also arise from misidentified e^+e^- and K^+K^- pairs. The former can often be identified on the scanning table, and therefore rejected. Further, such tracks might be expected to produce an excess of events at relatively low mass in the $\pi^+\pi^-$ mass distribution. Although background in the $\pi^+\pi^-$ effective mass is, of course, large, the low-mass region is adequately explained by Lorentz-invariant phase space, with no excess required by the data. Therefore this problem cannot be large.

The results of this paper are based on statistical samplings over groups of particles. No anomalous effect is observed for two-body groupings. We therefore conclude that the present results are not sensitive to contamination from incorrectly identified particle pairs (e.g., $e^+e^-, K^+K^-, \bar{p}p$).

III. EXPERIMENTAL BEHAVIOR OF THE FOUR-MOMENTUM TRANSFER

This section will develop in a systematic way the principal characteristics of the data. Interpretation of these results will be postponed until later sections.

To reduce purely kinematical effects due to the boundaries of phase space, the data were fitted[4] to an expression of the form

$$\frac{d\sigma}{dt'} \propto \exp(-\lambda t') , \tag{3}$$

where $t' = t_{AC}^{\max} - t_{AC} > 0$, and $t_{AC}^{\max}$ is the largest (signed) value of t_{AC} (which is negative). In other words, $t_{AC}^{\max}$ is the value of t_{AC} for production of particle C in the forward direction. The "slope" λ is a positive quantity measured in $(\mathrm{GeV}/c)^{-2}$.

The choice of Eq. (3) is motivated by Regge theory. A single parameter exponential does not always give a good fit to the data; however, for most regions of M_C, M_D, and t', the fit is more than adequate. The introduction of additional parameters does not appear to be justified for the present analysis.

The slope and its error (assumed purely statistical) were estimated by a maximum-likelihood method.[4] To ensure sufficient statistics in the low-t' region, all calculations were required to include at least 25 combinations with $t' \leq 3.0$ $(\mathrm{GeV}/c)^2$, though the fit accepted events with t' up to 7.0 $(\mathrm{GeV}/c)^2$.

The outgoing particles from the reaction (2) were arbitrarily grouped into two "bodies," called C and D. Figure 1 illustrates such a grouping and its possible relationship to a multiperipheral-model production mechanism.[5]

In this experiment, the predominantly backward (in the center-of-mass system) production characteristics of the proton imply that it is most naturally placed in D. Further, placement of the proton in C almost invariably results in extremely poor fits to (3) (usually because of a dip at low t'). Therefore, for the present analysis the proton will always be included as a member of "particle" D. To assist in the discussion, we will define the term "submultiplicity" to refer to the number of particles (in this case, pions) which are grouped to form body C.

The variation of λ with the mass of C or D for

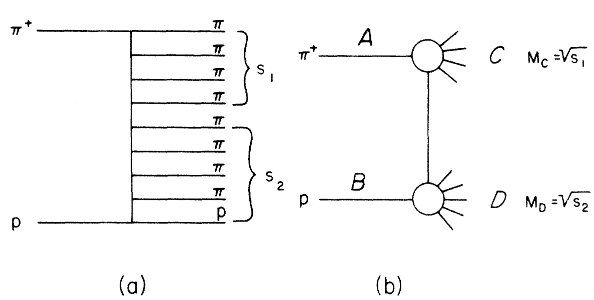

FIG. 1. Schematic of the restructuring of a multiperipheral diagram into the single-peripheral form. Pions from the multiperipheral diagram, (a), are considered as grouped in two "blobs," C and D, as shown in (b). The term submultiplicity shall be used to refer to the number of particles assigned to C.

the particular configuration with six pions in C and the proton plus two pions in D is shown in Fig. 2 in 100-MeV/c^2 bins. By definition, the submultiplicity is six. Overlapping data points are displaced slightly from the center of the bin for greater clarity. This configuration illustrates behavior which is typical of all submultiplicities. Figure 2(a) shows λ as a function of M_C, averaged over M_D. Figure 2(b) shows λ as a function of M_D, averaged over M_C. The three nonexotic (i.e., singly charged or neutral) states of combination C are displayed. There are twelve positive, six negative, and four neutral combinations per event for this case. The following conclusions are supported by this presentation:

(i) No statistically significant differences exist among charge states for a given submultiplicity.

(ii) The slope λ is an increasing function of M_C, and a decreasing function of M_D.

(iii) The largest values of λ (i.e., steepest slopes) encountered are approximately 1 (GeV/c)$^{-2}$, and are thus an order of magnitude smaller than typical slopes for elastic scattering, which are of the order of 7–10 (GeV/c)$^{-2}$.

Conclusion (i) is not significantly altered by resonance production.[6] This is possibly a consequence of poor signal-to-background ratios for resonances in these data.

The "mirror-symmetry" effect of conclusion (ii) is at least partly a consequence of kinematics, since for large M_D only a small range of M_C (at low M_C) is available for the reaction, and so forth. Also, the specific effects observed, namely decreasing λ for increasing M_D, are related to the momentum-transfer distribution of the proton, which can be fitted to a slope of ~1 (GeV/c)$^{-2}$. Then a low-mass proton-plus-pions grouping (low M_D) will not have steeper slope than the proton alone. High-mass proton-plus-pions groupings require pions which are not well aligned with the proton; their presence will act to increase the average momentum transfer from the incident proton.

Conclusion (ii) is not valid at large M_D (for submultiplicities not depicted in Fig. 2). A rise toward steeper slopes is observed [see Fig. 3(c)]. Since the range of t' is restricted for many events in this region by the boundary of phase space, there is a kinematically induced concentration at low t'.

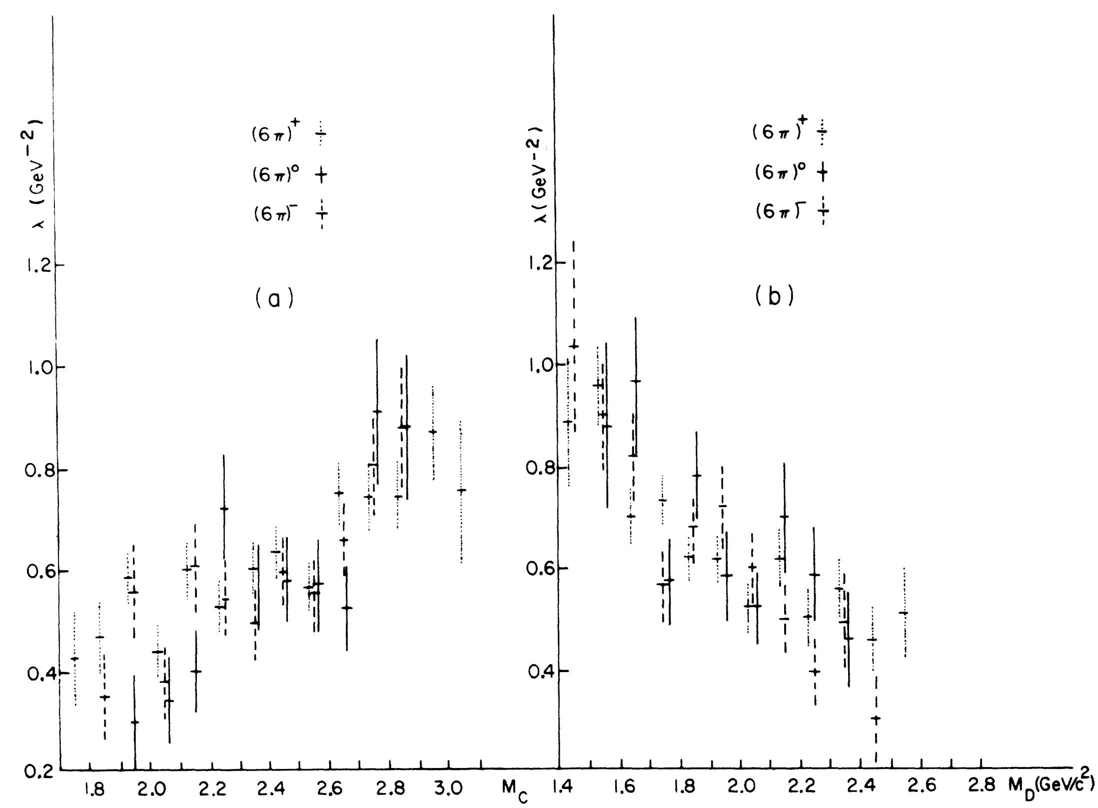

FIG. 2. The slope λ as a function of (a) M_C averaged over M_D, and (b) M_D averaged over M_C. Three different charge modes are plotted in the case of six pions assigned to C. The small horizontal bars indicate the location of the maximum-likelihood value, and are not error bars. Overlapping points are shifted slightly to permit easy resolution.

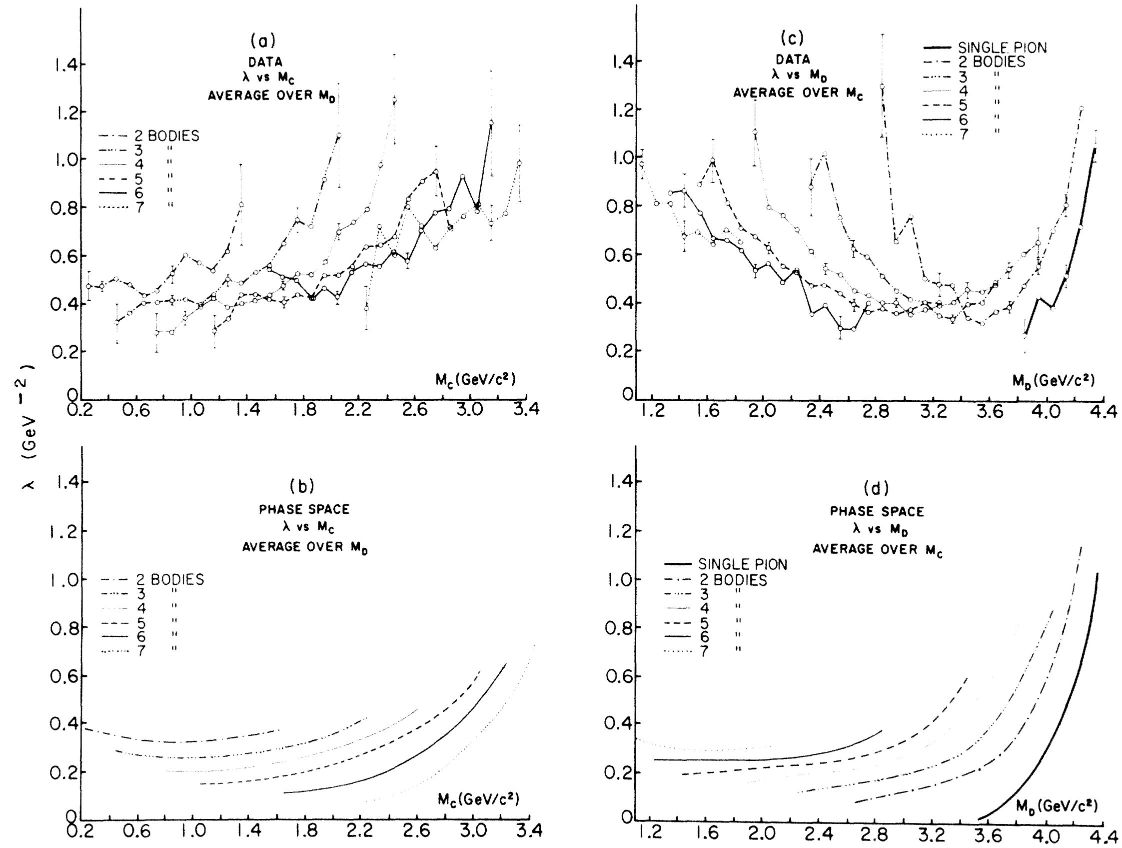

FIG. 3. The slope for different submultiplicities (number of pions assigned to C), as indicated by the key, averaged over all charged states, (a) as a function of M_C (averaged over M_D); (b) the same as (a), phase-space prediction; (c) as a function of M_D (averaged over M_C); (d) the same as (c), phase-space prediction. Most error bars have been removed for greater clarity. See discussion in text.

Noting that λ is not strongly dependent upon charge, in what follows we sum over all charge states (including exotics)[7] for a given submultiplicity. Then the behavior of λ may be studied as in Fig. 3. The legend "2 BODIES," etc. refers to the submultiplicity. Most error bars are omitted for clarity. Curves involving only one data point, or two points with large error bars, are also omitted.[8] The slope as a function of M_C and multiplicity is shown in Fig. 3(a); the phase-space predictions are shown in Fig. 3(b). These curves are smoothed approximations to the results of a Monte Carlo calculation with ten times the statistics of the real data,[9] and with a center-of-mass proton longitudinal-momentum cut as in the actual data.[3] Similarly, Figs. 3(c) and 3(d) give λ as a function of M_D. The phase-space curves are given for comparison to reveal possible effects due to kinematics.

General conclusions can be drawn from these distributions as follows:

(iv) There is a clear submultiplicity dependence of the behavior of λ.

(iv a) For a fixed M_C [Fig. 3(a)], this dependence takes the form of an ordering, such that an increase in submultiplicity results in a decrease in slope (i.e., "flatter" t' distribution). This ordering agrees with the phase-space ordering. However, the magnitude of the slope at any point is not consistent with phase space.

(iv b) For a fixed M_D less than 3 GeV/c^2 [Fig. 3(c)], the ordering of the data is opposite to the phase-space prediction [Fig. 3(d)], in contrast with the above. For M_D greater than a "crossover" region between 3.0 and 3.5 GeV/c^2, both the ordering and the magnitude of the data appear to be the same as predicted by phase space, i.e., the kinematic rise at high mass shows clearly.

(v) The extrema (maximum and minimum λ) attained by the data are consistent with being independent of submultiplicity; these extrema occur at different values of M_C (or M_D) for each submultiplicity.

We now investigate the behavior of λ for simultaneous M_C and M_D selections. Previous distributions have involved averages over the entire range of M_D when M_C is plotted, and vice versa. Typical results are presented in Fig. 4(a). The slope is plotted as a function of M_C for M_D in the interval 2.0 to 2.2 GeV/c^2. As before, all charge states (including exotics) are included for each submultiplicity. Only submultiplicities of four, five, or six have sufficient data (for M_D in this range) to be plotted.

For simultaneous M_C and M_D selection the phase-space solution is nearly independent of submultiplicity.[10] The single curve thus obtained is indicated on the figure. Figure 4(a), in conjunction with the distributions obtained with the other possible M_D selections (not shown), supports the following statement:

(vi) For fixed M_C and M_D the data indicate a submultiplicity dependence inconsistent with phase space. The ordering is the same as in Fig. 3(a), namely, lower submultiplicities have larger slopes.

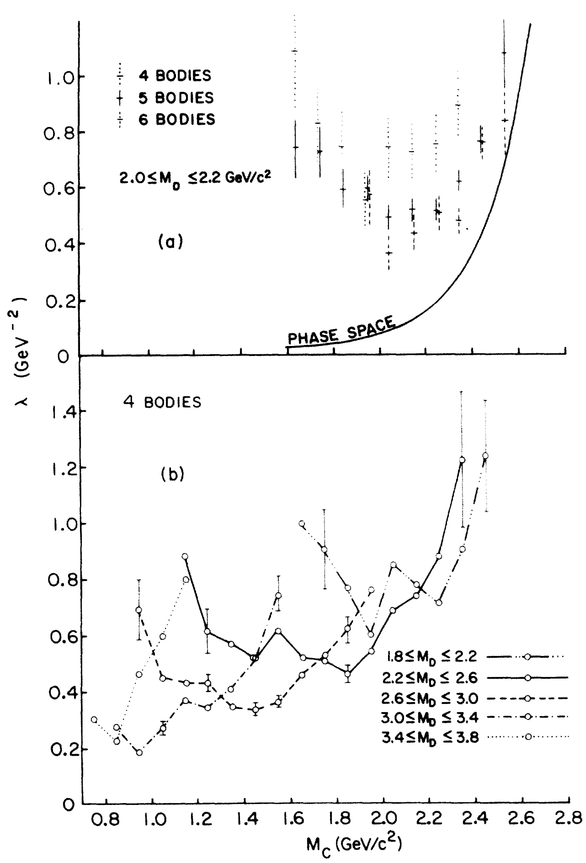

FIG. 4. (a) The slope λ as a function of M_C for $2.0 \le M_D \le 2.2$ GeV/c^2, for submultiplicities as indicated. Also sketched is the phase-space prediction, which does not depend on submultiplicity. (b) λ as a function of M_C, for broad M_D selection as indicated, with a fixed submultiplicity of four (i.e., four pions in C). Most error bars have been omitted for greater clarity.

The dependence of λ on M_C and M_D for a given submultiplicity is shown in Fig. 4(b) for a submultiplicity of four. The general behavior of the data for a relatively narrow M_D selection is established by Fig. 4(a); broad mass selections (400 MeV/c^2 in width) are employed in Fig. 4(b) to improve the statistics and reduce the total number of curves. Representative error bars are shown.

A family of U-shaped and J-shaped curves is observed. The corresponding phase-space curves form a family of J-shaped curves only [as in Fig. 4(a)]. As M_D increases for fixed M_C the data approach the phase-space prediction (not shown). Symmetrically, as in Fig. 4(a), the data approach the phase-space prediction at large M_C for fixed M_D. Thus,

(vii) The data are in maximum disagreement with phase space for values of M_C and M_D intermediate between their maximum and minimum. For either large M_C or large M_D, the data are very nearly identical to phase space, and in consequence show no dependence upon submultiplicity.

A further point is obtained from a comparison of the results for the different submultiplicities (not shown):

(viii) The maximum λ obtained for simultaneous selections in M_C and M_D is approximately the same for each submultiplicity. The same is also true for the minimum λ, with the exception of the highest submultiplicities.

The other submultiplicities exhibit the same characteristic behavior in these variables. A measure of submultiplicity independence seems to be achieved if the data are plotted as a function of $M_C(\max) - M_C$ and $M_D(\max) - M_D$ (not shown). However, even in this case, a weak dependence may exist.

IV. MULTIPERIPHERAL INTERPRETATION

These results may be qualitatively understood with the aid of multiperipheral concepts.[11] Only general properties of the multiperipheral model will be used in this section; no attempt has been made to fit a specific model. Further, no distinction will be made between models with "particle" exchange and models with "Reggeon" exchange. Complications involving more than one particle emitted at a given vertex, resonance production, and so forth, are inessential.

An important consequence of the multiperipheral picture, Fig. 1, is the concept of an ordering of the final-state particles. The effects of this ordering could reasonably be expected to be visible in the momentum-transfer dependence $\pi^+ \to C$, where C (and thus D) is chosen by an arbitrary partitioning of the particles,[12] as in Fig. 1(b). The argument proceeds as follows: If peripheral production occurs, then the distribution of the momentum transfer is damped, i.e., $d\sigma/dt'$ falls with increasing t'. This damping would be correctly measured only if the emitted particles were correctly assigned to C and D. The effect of misarranging the particles would, on the average, be to increase the measured momentum transfer. In the limit in which all particles in D are incorrectly assigned to C, then the measured momentum transfer $\pi^+ \to$ "C" would in physical reality be the cross-channel momentum transfer u, which is usually large for t-channel exchange.

In Figs. 3 and 4 it was shown that there are maxima in the λ distribution as a function of the masses which are not of kinematic origin. This fact suggests that damping of the momentum-transfer distributions can be observed experimentally, and further suggests that a study of the masses M_C and M_D may provide a means of selecting the correct orderings of the particles.

Thus, it is suggested by Fig. 4 that it is possible to select a group C of n particles according to criteria which depend only on the number n, the effective mass M_C, and the effective mass M_D (of the remaining $9-n$ particles), such that the four-momentum transfer $t'_{\pi^+ \to C}$ shows a statistically significant damping when compared with random phase space. For $n=4$, it follows from the figure that it is necessary only that M_C and M_D are chosen such that if plotted in Fig. 5 the event would fall in the closely shaded region. A diagram similar to Fig. 5 can be constructed for other values of n. The lighter shading indicates the limits of phase space.

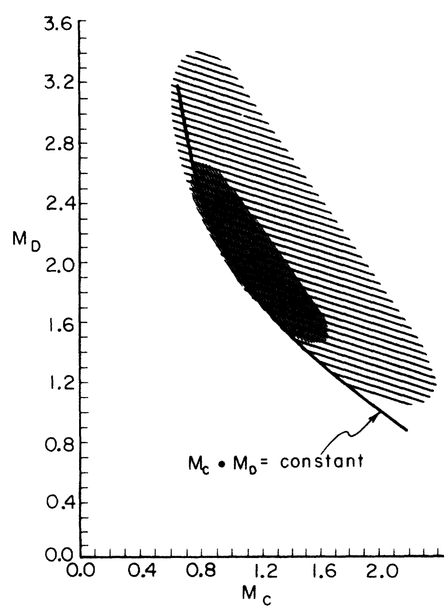

FIG. 5. M_C vs M_D phase space for a submultiplicity of four (shaded region). The region of steepest momentum-transfer slope is indicated by the darker shading. A contour of fixed $(M_C M_D)^2/s$ is also shown.

The multiperipheral[11] model imposes the condition

$$\lambda \frac{M_C{}^2 M_D{}^2}{s} \lesssim 1, \tag{4}$$

where s is the usual square of the center-of-mass energy, equal to 21.5 (GeV^2) in this reaction. Further, a maximum in the probability amplitude is expected to occur near minimum $M_C{}^2 M_D{}^2/s$.[13] A contour of constant $M_C{}^2 M_D{}^2/s$, near minimum, is sketched in Fig. 5, and passes through the closely shaded region. Further, for $\lambda = 1$ (see discussion below), condition (iv) is satisfied in this region.

If for each $1 < n < 9$ we assign particles to groups by the prescription suggested by Fig. 5 (or its analog, for $n \neq 4$), then the multiperipheral conditions are satisfied, and we observe the predicted peripheral four-momentum-transfer dependence. It is not difficult to show that for a given n, we can obtain the proper conditions for $n+1$ by transferring one properly selected particle from group D to C, on the average. We therefore conclude that an ordering of the particles as suggested by the multiperipheral model is consistent with what we observe.

The value $\lambda \cong 1$ (GeV$/c)^2$ can be read from Fig. 4 as the slope of the t' distribution for the proper choice of C and D. The same value obtains for other n [conclusion (viii) above]. Selection of a given n corresponds to selection of a given exchange. Therefore, this analysis suggests that the average amount of four-momentum transferred by each exchange of Fig. 1 is the same.

V. COMPARISON WITH OTHER MODELS

An attempt has been made to describe these results in terms of two models designed for high-multiplicity reactions. The calculations were performed by means of the Monte Carlo technique, with ten times the "statistics" of the actual data.

First, the CŁA (Chan Hong-Mo–Łoskiewicz–Allison[14]) model, which attempts to include in an average sense both the fully Reggeized limit of high subenergy for neighboring particle pairs on a multiperipheral diagram [Fig. 1(a)] and a featureless phase-space limit at low subenergy, is discussed. Only diagrams with nonexotic meson exchange were included.[15]

The results are shown in Fig. 6, which should be compared with Fig. 3. The CŁA model has correctly predicted the gross features of the data, including the "cross-over" region of Fig. 3(c).

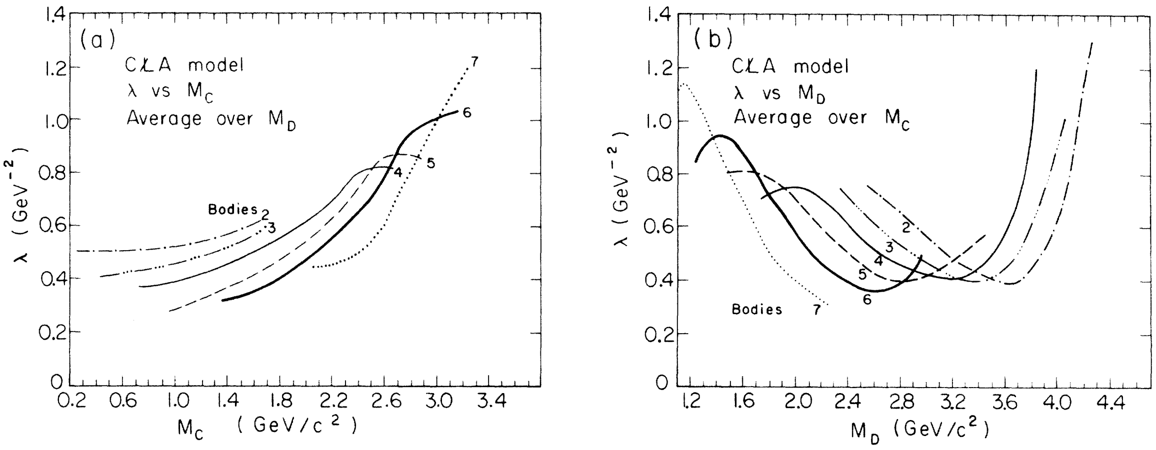

FIG. 6. CℒA-model prediction. The slope λ for different submultiplicities, averaged over all charge states, (a) as a function of M_C (averaged over M_D), (b) as a function of M_D (averaged over M_C). The curves are hand-smoothed approximations to the results of a Monte Carlo calculation. Compare with Figs. 3 and 7.

We note that this model incorporates as input an average slope of the momentum-transfer distribution between neighboring particles roughly equal to unity, in agreement with the present results for the data. Analysis of the CℒA "events" by this technique successfully recovers this average slope.

The second model to be studied was the Zieminski $F(t)$ model.[16] In this model, one attempts to account for the over-all features of the data in terms of a single quantity, namely the proton four-momentum transfer. For the current data, a single-parameter exponential, with a fitted slope of $\lambda = 1.24$, was adequate to describe that distribution. No pion dynamics is included in the model.

The results are displayed in Fig. 7, which should be compared with Figs. 3 and 6. The most striking effects appear in Fig. 7(b), showing the slope as a function of M_D. Until phase-space effects take over at large M_D, the predicted curves are indistinguishable within the accuracy of the Monte Carlo errors.

It would appear that the effect of the $F(t)$ model is only to displace the phase-space curves [Fig. 3(d)] until they coalesce at low M_0, and that some pion dynamics is needed in order to displace them still further to agree with the data, consistent with our earlier discussion on the evidence for an ordering of the pions.

VI. CONCLUSIONS

We have demonstrated a new analytical tool for the study of high-multiplicity final states. Ap-

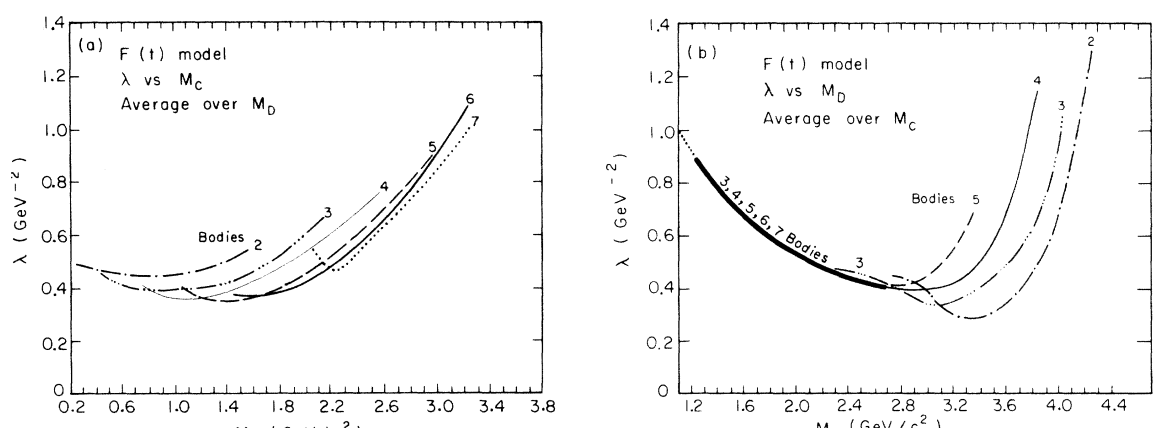

FIG. 7. $F(t)$-model prediction. The slope λ for different submultiplicities, averaged over all charge states, (a) as a function of M_C (averaged over M_D), (b) as a function of M_D (averaged over M_C). The curves are hand-smoothed approximations to the results of a Monte Carlo calculation. Compare with Figs. 3 and 6.

plied to reaction (2), it has been shown to give results consistent with multiperipheral concepts. In particular, a "favored" ordering of the pions may be indicated. Properly extended, this technique may make possible the study of particular exchanges in a multiperipheral chain. It has been demonstrated that this technique is useful in the attempt to distinguish types of models. In this case, it has been successful even though the data are at such an extreme multiplicity for the available energy that it might be assumed that they would resemble only uniform phase space. It is to be hoped that application of the technique may prove useful at the high energies and correspondingly high multiplicities encountered at the new accelerators.

ACKNOWLEDGMENTS

The data for this analysis were gathered some time ago, so we wish at this point to acknowledge the contributions of many people who helped in various ways in the exposure at the Brookhaven National Laboratory and the early stages of the measurements here at F. S. U. In particular, we want to express our appreciation to E. B. Brucker, Ben Harms, W. C. Harrison, J. S. O'Neall, and W. H. Sims for their assistance. In addition, we must compliment the scanning and measuring technicians at F. S. U., who strained to measure carefully the many tracks in each event.

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*Work supported in part by the U. S. Atomic Energy Commission under Contract No. AT-(40-1)-3509. Computational costs were supported in part by National Science Foundation under Grant No. GJ 367 to The Florida State University Computing Center. Partial support for this work also came from National Science Foundation under Grant No. GP-28647.

[1]See Y. Eisenberg and L. Lyons, in *Proceedings of the Colloquium on High Multiplicity Hadronic Interactions, Paris, 1970*, edited by A. Krzywicki *et al.* (Ecole Polytechnique, Paris, 1970), and H. Satz, *ibid.* The contribution by H. Satz is also published in Phys. Lett. 32B, 380 (1970); a more complete set of references may be found there.

[2]Aachen-Berlin-CERN and Aachen-Berlin-CERN-London (I.C.)-Vienna Collaboration, Phys. Lett. 27B, 336 (1968).

[3]Events with a proton center-of-mass longitudinal momentum >0.3 GeV/c were removed. This cut removes fits with extremely energetic protons in the laboratory, which could not be distinguished from pions by ionization or by the kinematic fitting procedure. Virtually all remaining fits had identifiable protons. Analysis indicates that probably fewer than 5% of the genuine reaction (2) events were lost by this procedure, since nearly all of the protons were produced backward in the center-of-mass system.

[4]See G. P. Yost, FSU-HEPL Internal Report (unpublished). The one-standard-deviation limits were defined as those values of λ at which the logarithm of the likelihood function was 0.5 less than its value at the maximum. In all cases discussed, symmetrical error estimates resulted. These errors are nearly proportional to λ, given a fixed number of events.

[5]In the figure, particles A and B are labeled appropriately for reaction (2).

[6]There are no resonances observed in the configuration plotted in Fig. 1, but some resonance production is observed in other configurations.

[7]Conclusion (i) applies to the exotic states of C (not shown) as well as the nonexotic.

[8]These are the single-pion and eight-pion distributions on Figs. 3(a) and 3(b), and the eight-pion distribution on Figs. 3(c) and 3(d). These data points are consistent with expectations based on those shown, and contribute no new information of any significance.

[9]The distribution of confidence levels for the fit of Eq. (3) to the Monte Carlo "data" indicates that many of these t' distributions are poorly described by Eq. (3). Nevertheless, a useful qualitative picture emerges for comparison with the data.

[10]No statistically significant submultiplicity dependence (with limited exceptions) is observed within the statistics of the Monte Carlo calculation, with statistics an order of magnitude greater than the data.

[11]Properties of the multiperipheral model are reviewed by G. F. Chew, in *Multiperipheral Dynamics*, 1971 Coral Gables Conference on Fundamental Interactions at High Energy, edited by G. F. Chew (Gordon and Breach, New York, 1971), Vol. 5, p. 1.

[12]These blobs could be further broken down, into subgroups, as desired for a particular model. This does not affect the discussion.

[13]The factor $M_C{}^2M_D{}^2/s$ is a measure of the quantity here named $t_{AC}^{\max}$, in absolute value. Inasmuch as $t' = t_{AC}^{\max} - t_{AC}$ is the variable under discussion, large λ, implying small average t', is not a direct kinematical consequence of small $t_{AC}^{\max}$.

[14]Chan Hong-Mo, J. Łoskiewicz, and W. Allison, Nuovo Cimento 57A, 93 (1968).

[15]Parameter values were assigned as suggested by the original authors, Ref. 14, without fitting to the data. Inclusion of baryon-exchange diagrams was tried, but resulted in poorer fits to the data. No resonance production was included.

[16]A. Zieminski, Nucl. Phys. B14, 75 (1969).