if the resolution is less than or approximately equal to it. Thus, an upper limit must be quoted using the variance of the χ^2 function to get the 95%-confidence-level upper limit, i.e., $2\sqrt{2}$ (No. degrees of freedom)$^{1/2}$ must be added, which is $2(2\times 8)^{1/2}=8$ (see, e.g., Ref. 9). This gives via Table I of Ref. 7, $\Gamma(\eta')<2.8$ MeV (95% C.L.).

[12]R. H. Dalitz, Philos. Mag. 44, 1068 (1953); E. Fabri, Nuovo Cimento 11, 479 (1954).

[13]V. I. Ogievetsky, W. Tybor, and A. N. Zaslavsky, Phys. Lett. 35B, 69 (1971); S. Giler *et al.*, Acta Phys. Pol. A37, 475 (1970).

[14]J. Klosinski, J. Rembielinski, and W. Tybor, Acta Phys. Pol. B1, 359 (1970); A. N. Zaslavsky, V. I. Ogievetsky, and W. Tybor, Yad. Fiz. 9, 852 (1969) [Sov. J. Nucl. Phys. 9, 498 (1969)], and private communications.

[15]G. R. Kalbfleisch *et al.*, Phys. Rev. Lett. 31, 333 (1973).

[16]D. L. Cheshire *et al.*, Phys. Rev. Lett. 28, 520 (1972).

[17]M. Aguilar-Benitez *et al.*, Phys. Rev. Lett. 25, 1635 (1970); and the third paper in Ref. 4; we note that a majority of their $M(953)$ events (if not all) are possibly $\eta'(958)$.

[18]B. Maglich *et al.*, Phys. Rev. Lett. 27, 1479 (1971); we note that H. Brody [*ibid.* 28, 1217 (1972); 28, 1497(E) (1972)] gives evidence that $\xi^0(953)$ is possibly the $\eta'(958)$.

[19]W. Kienzle *et al.*, Phys. Lett. 19, 438 (1965).

[20]The observation of $\delta^+(963)$ by J. Oostens *et al.* [Phys. Lett. 22, 708 (1966)] was contradicted by the data of M. A Abolins *et al.* (see Ref. 21).

[21]M. A. Abolins *et al.*, Phys. Rev. Lett. 25, 469 (1970).

[22]See reviews by B. Maglich [in *Proceedings of the Fifth International Conference on Elementary Particles, Lund, 1969,* edited by G. von Dardel (Berlingska Boktryckeriet, Lund, Sweden, 1970), p. 271], and by M. Derrick [in *High Energy Physics*, edited by K. T. Mahanthappa, W. D. Walker, and W. E. Britten (Colorado Associated Univ. Press, Boulder, 1970), p. 291].

[23]C. Defoix *et al.*, Nucl. Phys. B44, 125 (1972).

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Inclusive Reactions from π^+p at 4.1 GeV/c *

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At a π^+ beam momentum of 4.1 GeV/c, in reactions of the type $a+b\to c+X$, limiting fragmentation of the beam and target particles is observed where $ab\bar{c}$ is exotic, and is not observed for $ab\bar{c}$ not exotic. Single-particle distributions in several different variables have been studied for π^- and π^+ mesons. The two-particle distributions and correlation functions from the reaction $\pi^++p\to\pi^-+\pi^-+X$ are also presented.

I. INTRODUCTION

There has been much interest in inclusive reactions of the type $a+b\to c+X$, where X represents all other particles produced with c. There is considerable evidence that the distributions of certain kinematic quantities of particle c exhibit limiting behavior at very high energies,[1,2] and there are also theoretical arguments concerning just how high the energy has to be before "limiting" becomes discernible. Chan *et al.*[3] have argued from duality considerations that, if the combination $ab\bar{c}$ has quantum numbers that are exotic, the limiting may in fact show up at relatively low energies. In this paper, we present data from π^+p interactions at 4.1 GeV/c, corresponding to a center-of-mass energy of 2.92 GeV. For the inclusive reaction

$$\pi^++p\to\pi^-+X\,, \tag{1}$$

in which $ab\bar{c}$ is $\pi^+p\pi^+$, which has charge 3, baryon number 1, and is therefore exotic, it is of interest to see whether limiting behavior is observed at this low momentum. Results from previously published papers[4-6] at higher energies are shown for comparison and for indications of how limiting is approached. Data for

$$\pi^++p\to\pi^++X\,, \tag{2}$$

in which $ab\bar{c}$ is not exotic, are also shown for contrast. In addition, some information is presented concerning the two-body inclusive interaction

$$\pi^++p\to\pi^-+\pi^-+X\,. \tag{3}$$

The pictures in this experiment were taken with the Argonne-MURA 30-inch hydrogen bubble chamber. The sample considered here consisted of 22 000 events of all topologies, produced by 4.1-GeV/c π^+ mesons. About half of the sample was measured on the MIT PEPR (precision encoding and pattern recognition) system, and the rest on semiautomatic precision machines. TVGP and SQUAW were used for geometrical reconstruction and kinematic fitting of the events. No strange-particle hypotheses were considered; the probability of the resulting misidentification of a π^- meson is estimated to be less than one percent. However, in the case of positive particles, a substantial number of events have tracks which are not unambiguously identified; they could be either fast proton or π^+ tracks. This is particularly true for events with zero constraints. After correction for losses due to scanning and measuring, the data were normalized to counter measurements of the π^+p total cross section. The final sample represents 1.19 μb/event. A detailed description of the sample is presented in another paper.[7]

In examining the approach to scaling, it is useful to consider different kinematic regions separately: the regions of limiting target and projectile fragmentation, where outgoing particles have small momenta relative to the target and projectile particles, respectively, and the intermediate region (the region of pionization). Different variables are appropriate to the examination of limiting behavior in these regions. In particular, single-particle distributions of the following variables were studied for the outgoing π^- and π^+ mesons of reactions (1) and (2), and are plotted in Figs. 1–9:

(i) P_L (target), the longitudinal momentum in the target frame (i.e., the laboratory frame),

(ii) P_L (projectile), the longitudinal momentum in the projectile frame (i.e., the rest frame of the beam particle),

(iii) the Feynman variable $x \equiv 2P_L^*/\sqrt{s}$, where P_L^* is the longitudinal momentum in the c.m. frame of the interaction and $\sqrt{s}$ is the total invariant energy, and

(iv) the rapidity in the c.m. frame $y \equiv \ln[(E^*+P_L^*)/(Q^2+m_\pi^2)^{1/2}] = \frac{1}{2}\ln[(E^*+P_L^*)/(E^*-P_L^*)]$, where m_π is the pion mass, and Q, P_L^*, and E^* are the transverse momentum, the longitudinal momentum, and the energy of the outgoing $\pi^\pm$ in the c.m. frame of the interaction.

Tables of the data of Figs. 1–9 have been deposited with the National Auxiliary Publication Service.[8]

II. LIMITING FRAGMENTATION

The concept of limiting fragmentation of the target or projectile as proposed by Benecke *et al.*[2] states that, as target and projectile particles encounter each other at sufficiently high relative momentum, the resultant excitation and consequent breakup of the two particles have a definite limitation and are independent of the relative momentum. Consequently, the momentum distributions of particle c in the reaction $a+b \to c+X$ would be expected to be independent of the total energy in the initial system at very high energies.

These distributions may be expressed in terms of the Lorentz-invariant differential cross section $E(d^3\sigma/d^3p)$, where E and p are the energy and momentum, respectively, of particle c. Generally the data are integrated over the transverse momenta and the quantity $(E/\sigma_T)(d\sigma/dP_L)$ is determined, where σ_T, the "asymptotic" π^+p total cross section at infinite energy (taken to be 23.4 mb), is inserted for normalization. If this differential cross section is independent of $\sqrt{s}$, the total energy, in the region of small P_L(target) or small P_L (projectile), limiting fragmentation is said to exist.

Figures 1 and 2 show the P_L(target) and

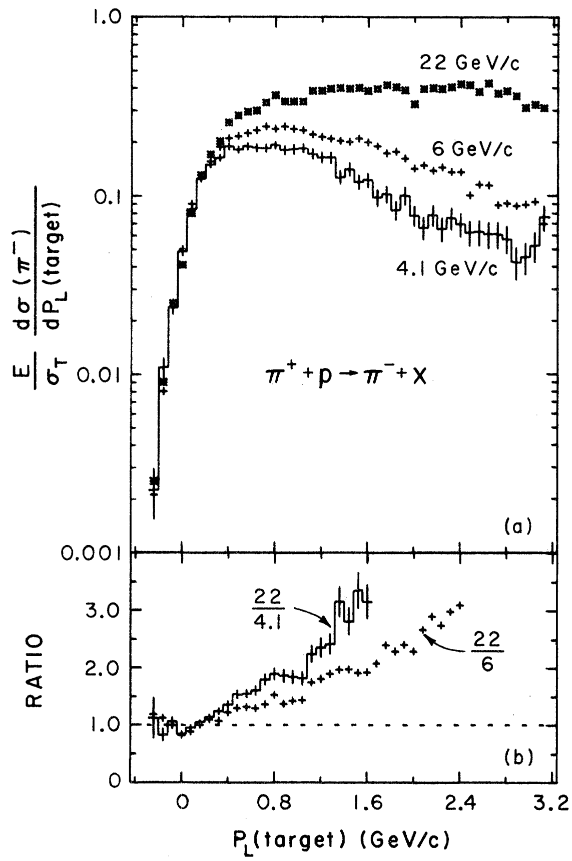

FIG. 1. (a) Normalized invariant single-particle differential cross section as a function of the longitudinal component of momentum of the π^- from $\pi^+ + p \to \pi^- + X$, evaluated in the target frame [P_L(target)]. The histogram represents the data of this experiment at a beam momentum of 4.1 GeV/c. The ■ and + points represent data at 22 GeV/c and 6 GeV/c, respectively (Ref. 4). (b) Bin-by-bin ratios of the distributions in P_L (target) for the π^-. The histogram represents the ratio of the 22-GeV/c data to the 4.1-GeV/c data, and the + points represent the ratio of the 22-GeV/c data to the 6-GeV/c data. The error bars are statistical uncertainties.

P_L(projectile) distributions for π^- mesons from reaction (1) at 4.1 GeV/c. For comparison, we also show the data of Crennell *et al.* from Ref. 4, for π^+ interactions at 22 GeV/c ($\sqrt{s}=6.5$ GeV), and at 6 GeV/c ($\sqrt{s}=3.5$ GeV). For low values of P_L the three sets of data indeed coincide, within experimental uncertainties, in agreement with the fragmentation picture. In Figs. 1(b) and 2(b) are plotted point-by-point ratios of the 4.1- and 6-GeV/c distributions to the 22-GeV/c distribution. In the target frame, the distributions appear to be independent of s for $P_L <\sim 0.3$ GeV/c, while in the projectile frame the region of independence is $P_L <\sim 1.2$ GeV/c.

For a more quantitative indication of the limiting behavior, the distributions have been integrated over the fragmentation regions in P_L:

$$I(\pi^-)=\frac{1}{\sigma_T}\int\left(\int\frac{d^2\sigma}{dP_L dQ^2}\,dQ^2\right)dP_L.$$

At 4.1 GeV/c, for P_L (target) ≤ 0.3 GeV/c, the value of $I(\pi^-)$ is 0.159 ± 0.010; for P_L (projectile) ≤ 1.2 GeV/c, it is 0.123 ± 0.010. These are to be compared with 0.134 ± 0.007 and 0.108 ± 0.005, respectively, at 22 GeV/c.[4]

The experimental data at the above momenta are also in agreement with those of Beaupré *et al.*[9] at 8 and 16 GeV/c, and of Alston-Garnjost *et al.*[10] at 3.7, 7.0, and 18.5 GeV/c.

The corresponding plots for π^+ mesons from reaction (2) are shown in Figs. 3 and 4. Com-

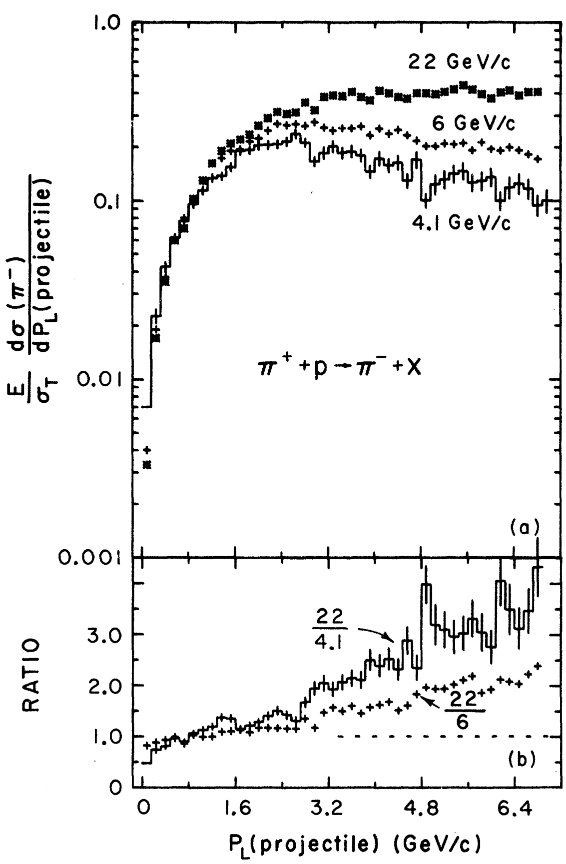

FIG. 2. (a) Distribution in the longitudinal component of momentum of the π^- from $\pi^+ + p \to \pi^- + X$, evaluated in the projectile frame [P_L(projectile)]. The histogram represents the data of this experiment at a beam momentum of 4.1 GeV/c. The ■ and + points represent data at 22 GeV/c and 6 GeV/c, respectively (Ref. 4). (b) Bin-by-bin ratios of the distributions in P_L (projectile) for the π^-. The histogram represents the ratio of the 22-GeV/c data to the 4.1-GeV/c data, and the + points represent the ratio of the 22-GeV/c data to the 6-GeV/c data.

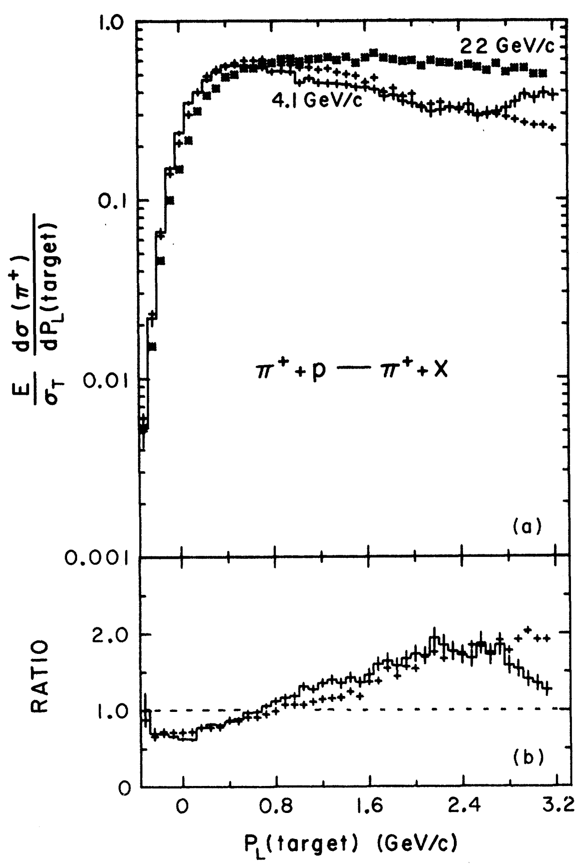

FIG. 3. (a) Distribution in the longitudinal component of momentum of the π^+ from $\pi^+ + p \to \pi^+ + X$, evaluated in the target frame. This histogram represents the data of this experiment at a beam momentum of 4.1 GeV/c. The ■ and + represent data at 22 GeV/c and 6 GeV/c, respectively (Ref. 4). For P_L(target) $<\sim 1.4$ GeV/c, there is little ambiguity in the identification of the π^+. (b) Bin-by-bin ratios of the distributions in P_L (target) for the π^+. The histogram represents the ratio of the 22-GeV/c data to the 4.1-GeV/c data, and the + points represent the ratio of the 22-GeV/c data to the 6-GeV/c data.

parison of the distributions at 4.1, 6, and 22 GeV/c shows no limiting in either the target or the projectile frame. This contrasting behavior for exotic and nonexotic $ab\bar{c}$ combinations is consistent with the ideas of Chan *et al.*[3]

III. THE FEYNMAN VARIABLE

The invariant distribution in the Feynman scaling variable x is plotted in Fig. 5 for the π^- particle of reaction (1) at 4.1 GeV/c. Also plotted for comparison are the data of Ref. 4 for incident π^+ mesons of 6 and 22 GeV/c. The Feynman prediction is that the quantity $(2E/\sigma_T\sqrt{s})\times(d\sigma/dx)$, a function of s, x, and Q^2, becomes independent of s as $s\to\infty$.

Figure 5 does not agree with this prediction, except in the limiting-fragmentation regions of large $|x|$. The behavior in the central region of the distribution in x shows no approach to scaling in the interval of s covered. On the other hand, the distributions for π^+ mesons from reaction (2), shown in Fig. 6, are notably independent of s, except for large positive x. Ferbel[11] has pointed out that the invariant cross section, evaluated at $x=0$, for various values of incident π^+ momentum, is consistent with a $p_{\text{incident}}^{-1/4}$ dependence.[12] We have included our data point at 4.1 GeV/c in a plot[11] of

$$\frac{1}{\sigma_T}\int E\,\frac{d^2\sigma}{dP_L^* dQ}\,dQ\,|_{P_L^*=0} \text{ vs } p_{\text{incident}}^{-1/4}$$

(Fig. 7), where it lies close to the straight line for $\pi^+ + p \to \pi^- + X$. Also included in Fig. 7 is our data point for $\pi^+ + p \to \pi^+ + X$. The plot for the

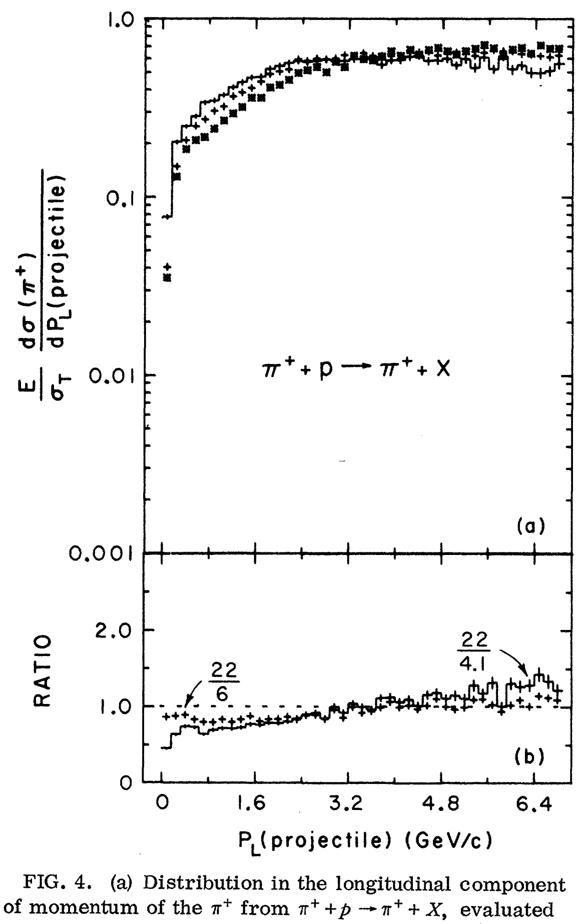

FIG. 4. (a) Distribution in the longitudinal component of momentum of the π^+ from $\pi^+ + p \to \pi^+ + X$, evaluated in the projectile frame. The histogram represents the data of this experiment at a beam momentum of 4.1 GeV/c. The ■ and + points represent data at 22 GeV/c and 6 GeV/c, respectively (Ref. 4). (b) Bin-by-bin ratios of the distributions in P_L(projectile) for the π^+. The histogram represents the ratio of the 22-GeV/c data to the 4.1-GeV/c data, and the + points represent the ratio of the 22-GeV/c data to the 6-GeV/c data.

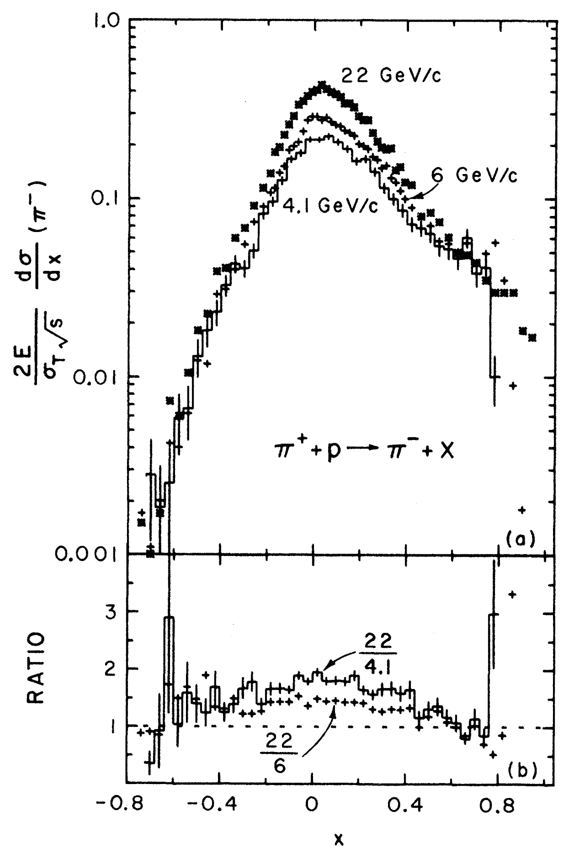

FIG. 5. (a) Distribution in the Feynman variable x for the π^- from $\pi^+ + p \to \pi^- + X$. The histogram represents the data of this experiment at a beam momentum of 4.1 GeV/c. The ■ and + points represent the data at 22 GeV/c, and 6 GeV/c respectively (Ref. 4). (b) Bin-by-bin ratios of the distributions in x for the π^-. The histogram represents the ratio of the 22-GeV/c data to the 4.1 GeV/c data, and the + points represent the ratio of the 22-GeV/c data to the 6-GeV/c data.

latter reaction, like that of Fig. 6, displays the relative constancy of the distribution in x of the π^+ from reaction (2) as p_{incident} or s is varied.

IV. THE RAPIDITY y

In addition to the momenta P_L in target and projectile frames and the Feynman variable x, another kinematic variable introduced to characterize the longitudinal momentum component of a particle is the rapidity y. One advantage of the variable y is that under a Lorentz transformation in the relative direction of the original particles, any distribution in y is simply shifted along the rapidity axis. y also provides a measure of the correlation among particles: According to the correlation-length hypothesis,[13] correlation is limited to particles whose y values are not very different. That is, two particles i and j in the interaction are uncorrelated if $|y_i - y_j| \gg L$, where L is the correlation length whose magnitude remains to be specified.

The distribution in y has a total width $Y \cong \ln(s/m_\pi^2)$. The target and projectile particle rapidities lie near the two extremes of the distribution, $y_{\min}$ and $y_{\max}$. Scaling in y calls for the distribution to approach the following form[13,14] as the energy is increased and $Y \gg 2L$:

$$\frac{E}{\sigma_T}\frac{d^3\sigma}{dp^3} \to \begin{cases} f(Q, y-y_{\min}) & \text{for } y < y_{\min}+L \\ g(Q) & \text{for } y_{\min}+L < y < y_{\max}-L \\ h(Q, y_{\max}-y) & \text{for } y > y_{\max}-L\,. \end{cases}$$

The first of these regions in the y spectrum is the target-fragmentation region, the third is the projectile-fragmentation region. In the central region a plateau develops, whose length increases with increasing s.

In interactions at low energies, $Y < L$, the

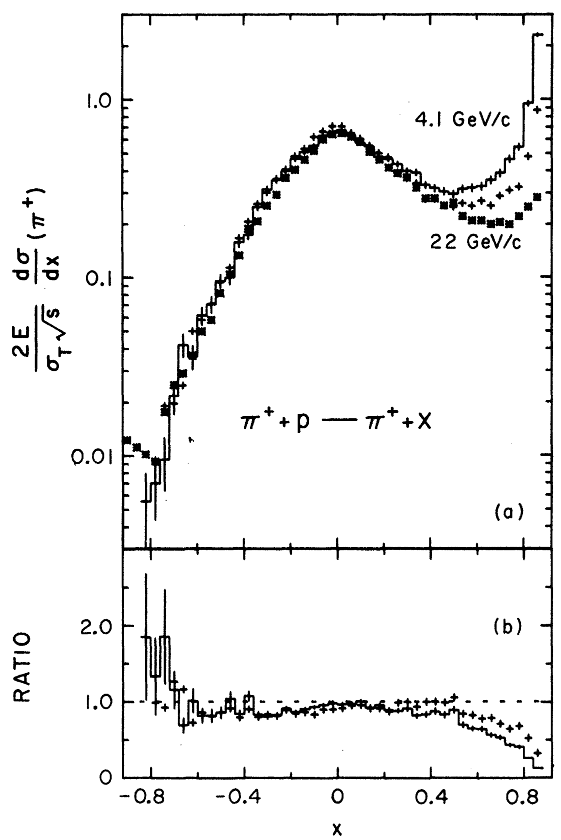

FIG. 6. (a) Distribution in the Feynman variable x for the π^+ from $\pi^+ + p \to \pi^+ + X$. The histogram represents the data of this experiment at a beam momentum of 4.1 GeV/c. The ■ and + points represent the data at 22 GeV/c and 6 GeV/c, respectively (Ref. 4). For $x <\sim 0$, there is little ambiguity in the identification of the π^+. (b) Bin-by-bin ratios of the distributions in x for the π^+. The histogram represents the ratio of the 22-GeV/c data to the 4.1-GeV/c data, and the + points represent the ratio of the 22-GeV/c data to the 6-GeV/c data.

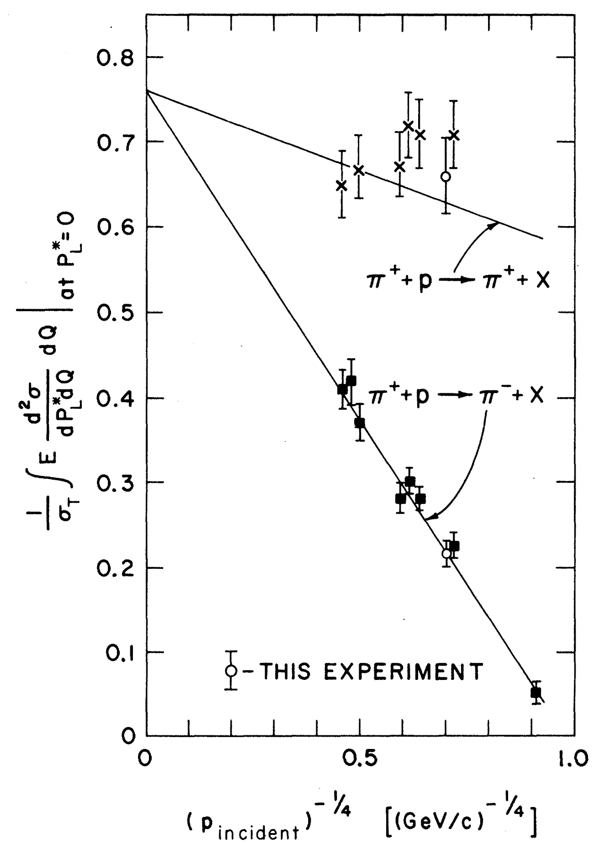

FIG. 7. Normalized invariant single-particle differential cross section at $x = P_L^* = 0$ as a function of $p_{\text{incident}}^{-1/4}$. The points represented by circles are the data of this experiment for inclusive production of π^- and π^+. The other data and the straight lines are from Ref. 11.

entire plot is narrower than one correlation length, so no part of the distribution is limiting and correlation exists among all the particles.

At higher energies, where $Y > L$, particles with y values at one end of the spectrum decouple from particles at the opposite end, and limiting fragmentation of target and projectile particles sets in. As the energy increases further and Y becomes large compared with $2L$, every value of y is distant from at least one end of the spectrum by an amount much greater than L. A central plateau should then begin to develop, and as s and hence Y increase further, a lengthening of the plateau is expected to occur.

In Sec. II, we have shown that limiting fragmentation is apparent for reaction (1) at the incoming momentum of 4.1 GeV/c, $\sqrt{s} = 2.92$ GeV. In Fig. 8(a) are plotted the c.m. rapidity spectra for the

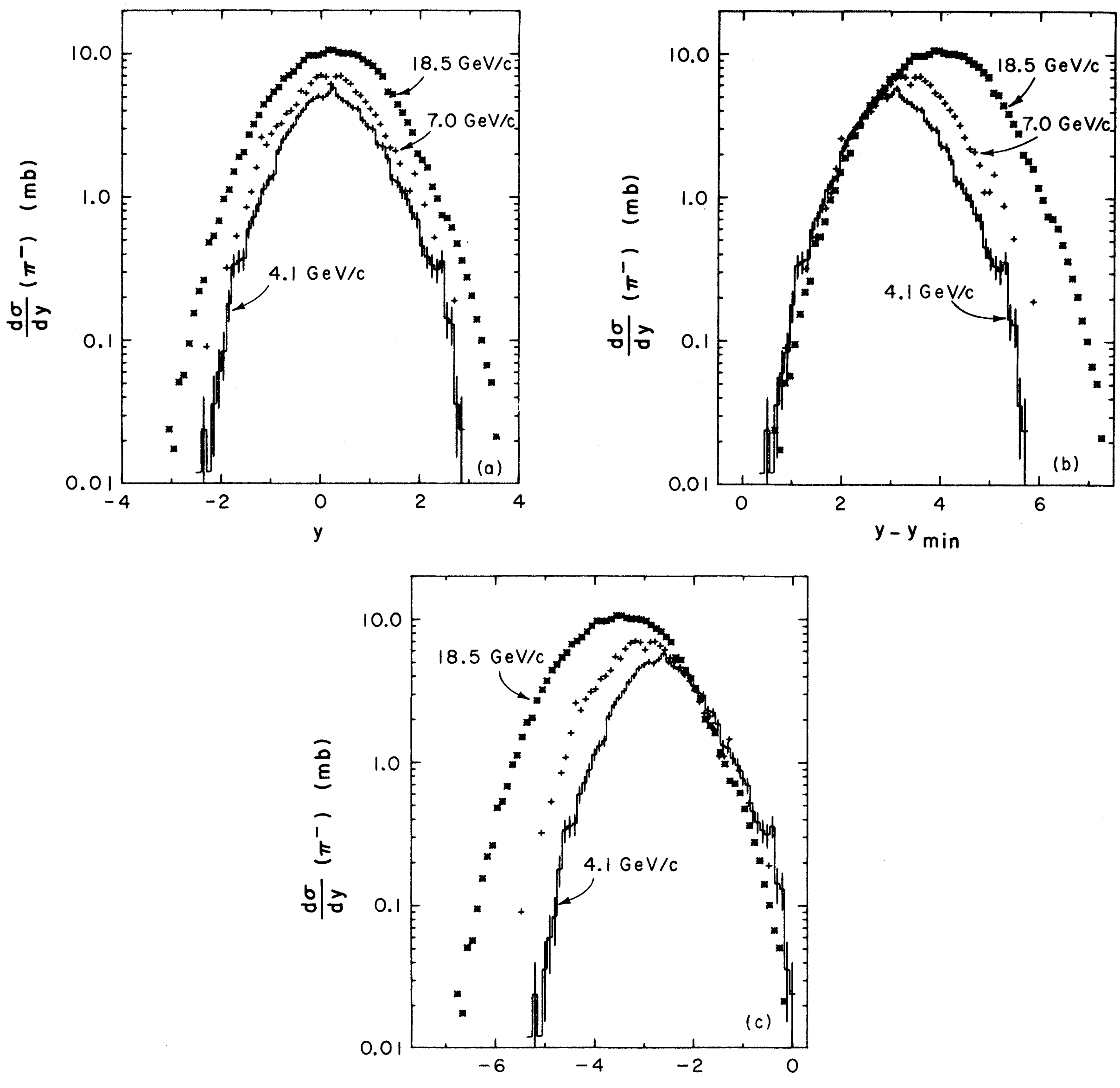

FIG. 8. (a) Distribution in the rapidity variable y for the π^- from $\pi^+ + p \to \pi^- + X$, evaluated in the over-all center-of-mass frame. The histogram represents the data of this experiment, the ■ points the corresponding data at 18.5 GeV/c (Ref. 5), the + the corresponding data at 7 GeV/c (Ref. 6). (b) and (c) show the distributions at the three incoming momenta, plotted vs $y - y_{min}$ and $y - y_{max}$, respectively, to show that the data at 4.1 GeV/c, 7 GeV/c, and 18.5 GeV/c coincide at the extremes of the distributions.

π^- from reaction (1) for the 4.1-GeV/c data of this experiment, the 7.0-GeV/c data of Stone *et al.*,[6] and the 18.5-GeV/c data of Shephard *et al.*[5] In Figs. 8(b) and 8(c), the distributions in $y-y_{\min}$ and $y-y_{\max}$ for reaction (1) are shown in order to demonstrate that the rapidity spectra for the three sets of data coincide near their extremes, in the regions of target and projectile fragmentation, respectively. No plateau has formed at these energies although a relative flattening of the peak may be seen at the higher energies. We therefore may consider the above data to be in an energy range such that Y is large compared with L, but not very large compared with $2L$. Abarbanel[12] has estimated $L\approx 2$; this is consistent with these data, as Y at 4.1 GeV/c is 5.7.

If we take $p_{\text{incident}}=4.1$ GeV/c, $\sqrt{s}=2.92$ GeV, to be near the threshold of limiting fragmentation for reaction (1), then the threshold for the development of the expected plateau in the central region of the y spectrum should be reached by doubling $Y_{4.1}$. Since $s\cong m_\pi{}^2 e^Y$, doubling Y corresponds to squaring s, and the plateau might start to be evident at $\sqrt{s}\cong(2.92)^2=8.5$ GeV, $p_{\text{incident}}\cong 38$ GeV/c.

In contrast to the π^- from reaction (1), the π^+ rapidity spectra from reaction (2), shown in Fig. 9, exhibit no limiting behavior at 4.1 GeV/c. The threshold for limiting fragmentation has not been reached at $\sqrt{s}=2.92$ GeV, for the case of nonexotic $ab\bar{c}$.

V. THE TWO-PARTICLE INCLUSIVE REACTION $\pi^++p\to\pi^-+\pi^-+X$

The differential cross section for the reaction

$$\pi^++p\to\pi_c^-+\pi_d^-+X$$

can be written as

$$G=\frac{1}{\pi^2}\frac{d^4\sigma}{dy_c\,dQ_c{}^2dy_d\,dQ_d{}^2}\,.$$

This function, integrated over all $Q_c{}^2$ and $Q_d{}^2$, is plotted in Fig. 10, where the distributions in y_d are shown for various intervals in y_c. The data here are statistically very limited, as only three percent of the events in the total sample yielded two or more negative mesons. Since the $\pi^-\pi^-$ system is exotic, any correlations observed in the variables describing particles c and d should give information about the multiparticle production mechanism rather than about final-state interactions such as resonances.[15] The degree of correlation between particles c and d can be measured by a correlation function, defined as[5]

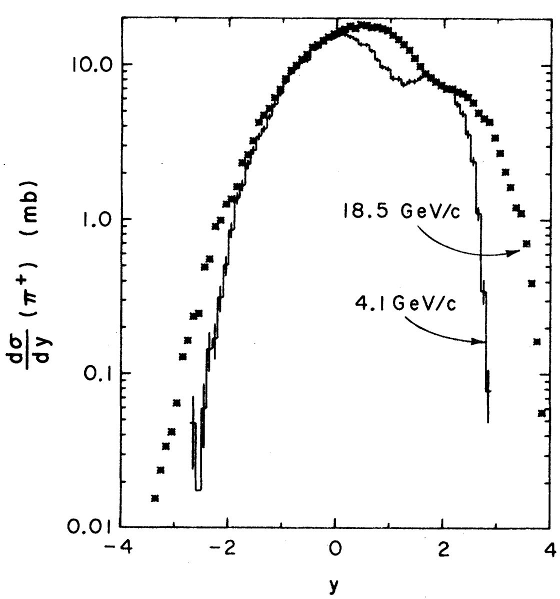

FIG. 9. Distribution in the rapidity variable y for the π^+ from $\pi^+p\to\pi^++X$, evaluated in the over-all center-of-mass frame. The histogram represents the data of this experiment and the ■ points the corresponding data at 18.5 GeV/c (Ref. 5).

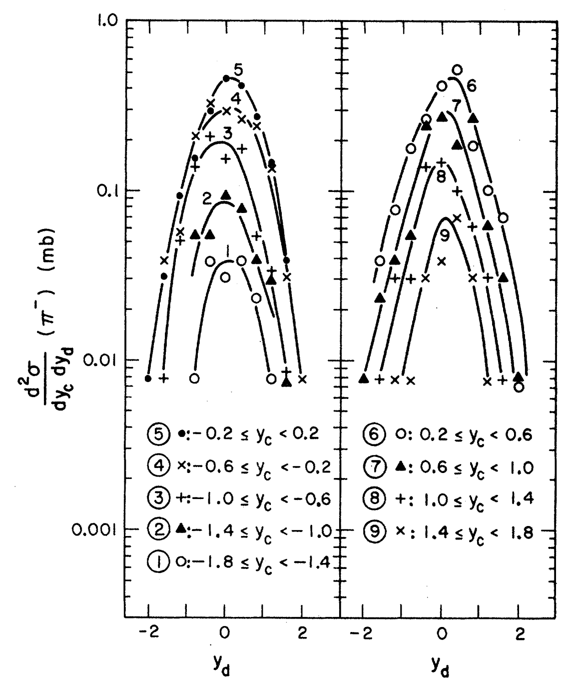

FIG. 10. The distribution $d^2\sigma/dy_c\,dy_d$ for the reaction $\pi^++p\to\pi_c^-+\pi_d^-+X$, plotted as a function of y_d for various intervals in y_c. The lines between points are drawn to guide the eye.

$$C(y_c, Q_c^2, y_d, Q_d^2, s) = \sigma_T^{-1} G - \sigma_T^{-2} (d^2\sigma/dy_c\, dQ_c^2)(d^2\sigma/dy_d\, dQ_d^2).$$

In terms of the hypothesis of short-range correlations, discussed in Sec. IV in connection with the single-particle distributions, one would expect to have $C \approx 0$, for $|y_c - y_d| \gg L$.

The function C, integrated over all Q_c^2 and Q_d^2 and plotted against y_d for various ranges of y_c, is shown by the points with error bars in Fig. 11. $|C|$ is largest for y_c and y_d both close to zero; where $|y_c|$ is large, $|C|$ is very small, almost zero, but this appears to be a reflection of the smallness of the cross sections for large $|y_c|$. The second term of C predominates throughout for the data at 4.1 GeV/c and the distribution $d^2\sigma/dy_c\, dy_d$ is not as wide as the single-particle distributions. To show the separate contributions of the two terms, the second term alone is also plotted in Fig. 11. The correlation function for reaction (3) with 18.5-GeV/c π^+ mesons[5] is very different in form, but again is close to zero for large $|y_c|$ and has its largest values for y_c and y_d both near zero.

It is interesting to plot a related correlation function C':

$$C' = \frac{C(y_c, y_d, s)}{(1/\sigma_T^2)(d\sigma/dy_c)(d\sigma/dy_d)} = \frac{G(y_c, y_d, s)}{(1/\sigma_T)(d\sigma/dy_c)(d\sigma/dy_d)} - 1,$$

which is drawn in Fig. 12. Here $C(y_c, y_d, s)$ and $G(y_c, y_d, s)$ are the previously defined functions C and G integrated over the transverse momenta. Near the extremes of $|y_d|$, where $G = 0$ while the single-particle cross sections are not zero, $C' = -1$. The function C' at 18.5 GeV/c (Ref. 16) is similar in form to that at 4.1 GeV/c, with $C'_{4.1} < C'_{18.5}$ over the whole range of y_d in each interval of y_c.

These data suggest a production mechanism that yields pions with low momentum in the center-of-mass system,[15] and indicate that there is substantial correlation, increasing with incident momentum, among these pions.

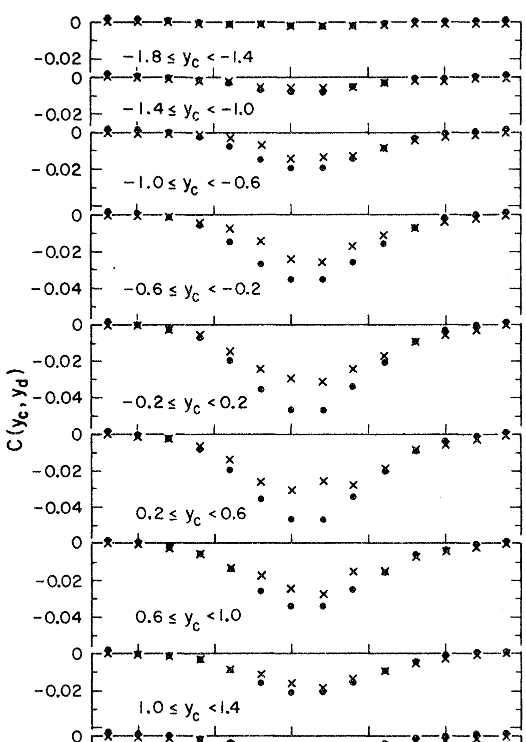

FIG. 11. The correlation function integrated over Q^2, $C(y_c, y_d)$, as a function of y_d for various intervals in y_c. The $\times$ points represent C, while the dots represent only the second term of C (see text).

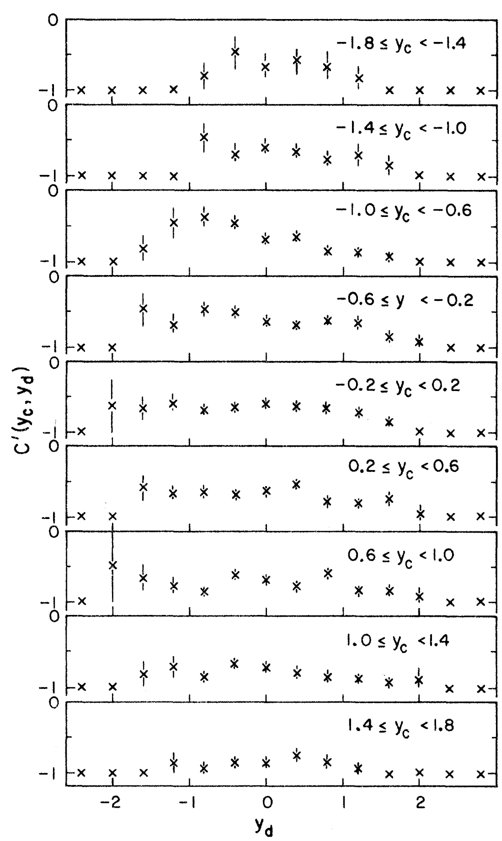

FIG. 12. The correlation function $C'(y_c, y_d)$ as a function of y_d for various intervals in y_c.

VI. CONCLUSIONS

We have found that at the low beam momentum of 4.1 GeV/c, in a reaction of the type $a+b \to c+X$, limiting fragmentation of beam and target particle appears where $ab\bar{c}$ is exotic, and does not appear for $ab\bar{c}$ not exotic. These results are seen in the single-particle distributions in longitudinal momentum in beam and target frames and in the rapidity variable. Limiting behavior has not been reached over the central range of the Feynman variable x for reaction (1) at incident momenta up to about 20 GeV/c; the differential cross section in x, evaluated at $x=0$, and compared with data at other beam momenta, is found to be consistent with a $p_{\text{incident}}^{-1/4}$ dependence.

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[1]R. P. Feynman, Phys. Rev. Lett. 23, 1415 (1969).

[2]J. Benecke, T. T. Chou, C. N. Yang, and E. Yen, Phys. Rev. 188, 2159 (1969).

[3]Chan Hong-Mo, C. S. Hsue, C. Quigg, and J.-M. Wang, Phys. Rev. Lett. 26, 672 (1971).

[4]D. J. Crennell, H. A. Gordon, M. L. Ioffredo, and K.-W. Lai, Phys. Rev. Lett. 28, 643 (1972).

[5]W. D. Shephard *et al.*, Phys. Rev. Lett. 28, 703 (1972).

[6]S. Stone, T. Ferbel, P. Slattery, and B. Werner, Phys. Rev. D 5, 1621 (1972).

[7]D. G. Fong *et al.* (unpublished).

[8]The data of this experiment for all the figures from 1 through 9 (the single-particle inclusive data) are contained in four tables which have been deposited with the National Auxiliary Publications Service (NAPS). See NAPS document No. 02222 for seven pages containing these four tables. Order from ASIS/NAPS, c/o Microfiche Publications, 305 East 46th Street, New York, N. Y. 10017. Remit with order for this document $1.50 for microfiche or $5.00 for photocopies. Make checks payable to Microfiche Publications.

[9]J. V. Beaupré *et al.*, Phys. Lett. 37B, 432 (1971).

[10]M. Alston-Garnjost *et al.*, Phys. Lett. 39B, 402 (1972).

[11]T. Ferbel, Phys. Rev. Lett. 29, 448 (1972). Figure 7 in our paper is a partial copy of Fig. 1 in this paper of Ferbel. Some of the points taken from Ferbel's Fig. 1 have been readjusted $\lesssim 10\%$ upon a closer examination of the original data and the calculations therefrom [T. Ferbel, private communication and Rochester Report No. COO-3065-41 (unpublished)]. The straight lines drawn in Fig. 7 are essentially the same as those in Ferbel's paper, although these also probably should be readjusted.

[12]H. D. I. Abarbanel, Phys. Rev. D 3, 2227 (1971).

[13]C. E. DeTar, Phys. Rev. D 3, 128 (1971).

[14]W. R. Frazer *et al.*, Rev. Mod. Phys. 44, 284 (1972).

[15]See, for example, E. L. Berger and M. Jacob, Phys. Rev. D 6, 1930 (1972).

[16]W. D. Shephard, in *Proceedings of the International Conference on Inclusive Reactions, University of California, Davis, 1972,* edited by R. L. Lander (Univ. of Calif. Press, Davis, 1972).