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PROTON FRAGMENTATION INTO PIONS AND PION SYSTEMS IN K^-p INTERACTIONS
AT 110 GeV/c AND COMPARISON TO MODEL PREDICTIONS

Aachen-Berlin-CERN-Cracow-Innsbruck-London IC-Vienna-Warsaw Collaboration

R. Göttgens and P. Sixel
III. Physikalisches Institut der Technischen Hochschule Aachen, Germany

H. Böttcher
Institut für Hochenergiephysik der Akademie der Wissenschaften
der DDR, Berlin-Zeuthen

Y. Goldschmidt-Clermont, D.R.O. Morrison and R.T. Ross
CERN, European Organisation for Nuclear Research, Geneva, Switzerland

M.W. Krasny, J. Chwastowski and K. Dziunikowska
Academy of Mining and Metallurgy and Institute of Nuclear Physics,
Cracow, Poland

P. Girtler, D. Kuhn and J. Weiss(*)
Institut für Experimentalphysik der Universität Innsbruck, Austria

K.W.J. Barnham and P.R.S. Wright
The Blackett Laboratory, Imperial College, London, U.K.

H.R. Gerhold and F. Mandl(*)
Institut für Hochenergiephysik der Österreichischen Akademie der
Wissenschaften, Vienna, Austria

M. Bardadin-Otwinowska and M. Szczekowski
Institut of Experimental Physics, University of Warsaw, and Institute
of Nuclear Research, Warsaw, Poland

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ABSTRACT

The x dependence of single pion and multi pion production is studied in the proton fragmentation region of K^-p interactions at 110 GeV/c. A recombination and a string fragmentation model have been tuned to describe the single particle distributions well and are then used to describe two and three pion production when one particle or particle system is selected in a given interval of longitudinal momentum. The string fragmentation model reproduces most of the observed distributions correctly, but fails in the case of multi π^+ production.

1. INTRODUCTION

The application of the quark parton picture to low p_t hadronic interactions has reproduced sufficient general features of the observed inclusive distributions to stimulate a more detailed study of the proton fragmentation region in meson induced reactions [1].

Since single particle distributions can be described fairly well by a variety of models of recombination and fragmentation type [2], it has been suggested [3] that the study of pion systems of different charge combinations provide a much more stringent test for different pictures of low p_t reactions especially when used in combination with various trigger particles, i.e. particles or systems of particles required to lie in a given Feynman x interval.

In this paper, the inclusive production of single pions and pion systems with and without triggers is studied in the proton fragmentation region of 110 GeV/c K^-p interactions and is compared to the predictions of recent versions of a recombination and a string fragmentation model. Special attention has been given to those features of the models which go beyond mere longitudinal phase-space including leading particle effects.

The paper is organized as follows: In sect. 2, the experimental procedure and the data sample used are discussed. In sect. 3, data on the inclusive single particle production and the Feynman x dependence of pions and pion systems in the proton fragmentation region are presented. In sect. 4, scaling behaviour in the reduced Feynman x variable is studied and triggered particle distributions are presented. These distributions are then compared in detail to model predictions. To conclude, the most important results are summarized in sect. 5.

2. EXPERIMENTAL PROCEDURE

The present study is based on a sample of 14 739 events corresponding to 0.7 events/ μ b obtained in an exposure of the 3.5 m European Bubble Chamber BEBC to an r.f. separated, tagged, K^- beam of 110 GeV/c [4,5].

In order to obtain an enriched sample of fragmentation processes, elastic and diffractive events were removed by applying the following cuts:

(a) Elastic events

Elastic events were selected from the two-prongs by applying the cuts: $|MM|^2 < 2.5 \text{ GeV}^2$ and $|\Delta\phi| < .5 \text{ mrad}$, where MM is the missing mass to the positive recoil track assigned the proton mass, and $\Delta\phi$ is the difference between the measured direction of the negative particle and the direction predicted for it assuming an elastic process. 914 events were removed from the sample by this cut.

(b) Proton diffraction dissociation

A cut on the fastest negative particle, h^- , was made for $x_h > 0.85$, where x is the Feynman x variable. 1246 events were thereby removed.

(c) K diffraction dissociation

Here a cut on protons with $x < -0.94$ was chosen, corresponding to a maximum proton laboratory momentum of roughly 1 GeV/c. 713 events were removed by this cut. In addition corrections for non-identified protons were applied as discussed below.

(d) Contamination of the π sample

Since the influence of misidentified particles on the distributions studied here is expected to be substantial in certain kinematic regions, a special effort has been made to reduce contamination, which in the proton fragmentation region is mainly due to unidentified protons. Fragmentation in the beam hemisphere was not studied in this analysis.

Identification of protons by ionization was possible up to a laboratory momentum of $\sim 1 \text{ GeV/c}$ in this experiment. Accordingly, two different methods were applied to determine the sample of unidentified protons for $p_{\text{lab}} < 1 \text{ GeV/c}$, called sample L (low momentum) in the following and in the case of $p_{\text{lab}} > 1 \text{ GeV/c}$, called sample H (high momentum). The nonidentified protons of L contribute to nearly the whole backward x region, when assigned a pion mass, whereas protons from sample

H with pion mass assignment mostly end up at $x > -0.3$, depending on their transverse momenta, thus in general not influencing seriously the proton fragmentation region studied here.

Sample L was determined using the sample of elastic events as found by the kinematical procedure described above, where the protons populate a similar region of phase-space as in the case of K diffraction. Starting from the number of protons actually seen in this sample, an efficiency E was calculated as a function of p_{lab} , where E is the ratio of the number of protons identified by ionization to the number of protons identified kinematically. A weight of $1/E$ was then given to all identified protons and for each of them an additional contribution of $(1/E-1)$ was assumed to enter all distributions using the π^+ sample, i.e. sample L is equivalent to the sample of all seen protons weighted by this factor $(1/E-1)$.

Sample H, i.e. the nonidentified protons with $p_{lab} > 1$ GeV/c in the proton hemisphere, was determined using a Monte-Carlo calculation with the Lund model as described in sect. 3.2.2 below. This sample was found never to exceed 15% of all positive particles observed in the backward hemisphere. To correct for the contamination of the π^+ sample by non-identified protons from samples L and H, the following procedure was adopted:

All distributions where misidentified protons could contribute were produced three times. Once, using all observed positive hadrons except the identified protons, and then a second and a third time using the sample L and H alone, assigning a pion mass to all particles used in all three cases. Finally, the sum of the distributions produced with the L and the H sample was subtracted from the first one, thus removing all contributions from misidentified protons contained in L and H.

In order to allow for systematic errors introduced by this procedure, the contributions were set to their maximal and minimal values before subtraction. In L the acceptance A was changed by $\pm$ one standard deviation for this purpose. In H, the number of unseen protons with $p_{lab} > 1$ GeV/c given by the Monte-Carlo calculation was multiplied by a factor of 0.5 and 2, respectively. The difference in the result, when the

highest and lowest possible proton contamination thus obtained was subtracted, was taken as an estimate for the systematic error, which together with the statistical error was used to evaluate the total error finally shown in the figures.

In order to estimate the contamination of the data sample by kaons, the Lund Monte-Carlo was used. As a result the kaon contamination was found to be less than 5% in the whole $x < 0$ region.

More experimental details can be found in ref. [6].

3. ANALYSIS OF DATA AND MODEL COMPARISON

3.1 Introductory remarks

The aim of the presentation in this section is twofold: first of all, experimental data on single pion and pion system production in the proton hemisphere are presented. In addition, these distributions are compared quantitatively with the predictions of several models for low p_t particle production. The main consideration in applying these models was to try and obtain a good description of the single particle distributions and then to study to what extent more subtle effects such as the deviation from scaling behaviour of distributions using a trigger particle or particle systems could be qualitatively reproduced by them.

3.2 The models used for comparison

3.2.1 The recombination model

Here, a parametrization for the recombination model as proposed by Takasugi and Tata was used [7]. As an additional feature, analytical expressions taking into account the production of non strange pseudoscalar and vector meson resonances were incorporated. The standard values for the parameters g_u , g_d , g_s , g_g governing the strength of the $u\bar{u}$, $d\bar{d}$, $s\bar{s}$, quark and gluon content of the proton wave function, as given in [7], were changed in order to obtain an optimal description of the single particle

distribution^(*). The parameter set used in this tuned and extended version of the recombination model (VMRM) as well as the values for the standard version (SRM) [7] are summarized in the table below. A change of these values by 15% was found to give no significant change in the results.

	g_u	g_d	g_s	g_g	R	a
SRM	.648	.300	.048	1.274	-	.31
VMRM	.32	.32	.08	2.09	.5	.31
where						
	R	ratio of vector to pseudoscalar meson production				
	a	universal normalization parameter for the recombination function, which is independent of the partons and mesons involved in the recombination process.				

3.2.2 The string fragmentation model

A recent version of the Lund string fragmentation model [9] was used with its standard parameter set (SLFM). In order to obtain a good description of the ρ^0 production, it was found that the standard value of one for the ratio R of the production of vector to pseudoscalar mesons had to be changed to about .5, in agreement with the corresponding value used in the VMRM, as described above. This is also in agreement with observations from other experiments [10]. However, since the influence of these changes [6], on the reproduction of the pion distributions is only minimal, the standard parameter set (SLFM) was used in this analysis.

3.2.3 Longitudinal phase space effects

In order to see to what extent the features observed in the distributions studied here can already be explained by phase-space effects, the Uncorrelated Jet Model [11], which is based on the simple idea of

(*) During preparation of this paper a new set of parameters was published by the same authors [8]. The ratios of these newly proposed g_u , g_d and g_s values are similar to the ones obtained by the tuning procedure applied here.

statistical emission of pions including limited p_t and a leading particle effect and makes no use of the quark parton picture, was applied. Since the features of this model therefore are mainly determined by longitudinal phase-space, we call the version used here LPSM and also show its predictions in some figures.

3.3 Data on inclusive production of pions and pion systems and correlations

3.3.1 Invariant cross section in the proton hemisphere

The distribution of

$$F(x) = \frac{2}{\sqrt{s}} \int E \frac{d^2\sigma}{dx d^2_{P_T}} dp_T^2 \quad (1)$$

using the corrected data sample, is given for $x < 0$ in figs 1(a) and 1(b) for π^+ and π^- , respectively, and compared to lower energy K^-p experiments, where m^+ and m^- denote positive and negative hadrons, respectively. After the corrections for contamination applied as discussed above, the m^+ and m^- can be regarded as relative clean samples of positive and negative pions, respectively, for this experiment. In both cases, scaling holds to a good approximation. In figs. 2(a) and 2(b), the invariant π^+ and π^- cross sections are compared to data from experiments with other beam particles at similar energies. In the case of π^+ production (fig. 2(a)), a slight deviation from factorization seems to appear, namely the distributions of backward m^+ from experiments with negative beam particles such as K^- , π^- systematically are lower than those from experiments with positive beam particles such as π^+ , K^+ , p . Apart from a possible proton contamination it has been suggested [12] that this deviation from independent proton fragmentation might be due to annihilation effects between target and beam quarks and antiquarks. This point will be further discussed in the next section.

As a parametrization of the x dependence of inclusive particle production, LPSM and accordingly most low p_t models suggest a behaviour for $F(x)$ like $(1-|x|)^n$. The n value for the π^+ and π^- invariant cross sections were fitted in this experiment, and depending on the x interval

used, fit values of n between 3 and 4 were obtained, as shown in fig. 3. In addition to the inclusive backward production of single pions, the invariant cross section

$$f(x) = \int \left(\prod_{i=1}^N E_i \right) \frac{d\sigma}{d\vec{p}_1 \cdots d\vec{p}_N} \delta(x - \sum_{i=1}^N x_i) d\vec{p}_1 \cdots d\vec{p}_N \quad (2)$$

for a number of 2 and 3 pion systems were also extracted from the data and fitted to $(1 - |x|)^n$. The resulting n values are also shown in fig. 3 together with results from other experiments. Bearing in mind that some of the other results were determined from different quantities like $x(d\sigma/dx)$ and $(E_1 \dots E_N)d\sigma/dx$, which are similar only for $x \rightarrow 1$ and $n \gtrsim 3$, and that they use different cuts, no significant dependence on energy or beam particle used can be observed in this comparison.

3.3.2 Study of forward-backward correlations

Before making any model comparisons, it is necessary to check that the data satisfy the basic assumptions of these models, i.e. Feynman x scaling and independent beam and target fragmentation. As seen above, scaling seems to be satisfied to a good approximation. Independent beam and target fragmentation were checked studying the correlations between forward pions and backward pions or pion systems as given by

$$\left(\frac{NdN}{dx_{A_b} dx_{m_f}} \right) / \left(\frac{dN}{dx_{A_b}} \cdot \frac{dN}{dx_{m_f}} \right) \quad (3)$$

for different intervals of x_{mf} , where x_{mf} represents the Feynman x of the forward going pion ("trigger particle"), and x_{Ab} describes the backward going hadron or hadron system A , where again all hadrons remaining in the corrected sample were assumed to be pions. In case of independent production of forward and backward particles, this quantity is constant.

Generally the data as shown in figs. 4(a)-4(l), are in fair agreement with this and are close to a value of one except for the low x region of the lowest x_{mf} trigger intervals, i.e. 0. -0.1, where positive correlations appear in agreement with the known short range correlations in central pion production.

3.3.3 Comparison to models

The results presented so far will now be compared to the predictions of the models described above. In figs. 5(a), (b) and (c) the Lund string fragmentation model is compared to the data of single particle production for $\pi^\pm$, $K^\pm$ (i.e. K^0 and $\bar{K}^0$); the agreement in these cases is quite good even using the standard set of parameters (SLFM). It should be noted however, that in order to obtain a good description of ρ^0 production, the ratio R of vector to pseudoscalar production has to be lowered to a value of .5, as mentioned earlier. The effect of this modification can be seen in fig. 5(d). Since it has very little effect on the pion distributions used here, as is shown in figs 5(a) and 5(b), the standard set of parameters was used in the following analysis.

In figs. 6(a), 6(b) and 6(c) the data for pion and $K^\pm$ production are now compared with the predictions of the standard and tuned version of the recombination model, SRM and VMRM respectively. It can be seen that the inclusion of vector meson resonances in the recombination model improves the agreement with the observed pion distributions, especially for low $|x|$ values. In fig. 6(d), the influence of changing R from a value of 1 to 0.5 is illustrated. In fig. 7, the experimentally observed n values for the $(1 - |x|)^n$ dependence of the invariant cross section for single pion and pion system production are compared to the predictions of longitudinal phase-space, LPSM, the string fragmentation model SLFM and the standard version of the recombination model SRM which for pion systems give practically the same distributions in the region used for fitting n, namely $x < -.5$ as the tuned and extended version VMRM. The invariant cross section used here is the form $x \, d\sigma/dx$, which is most convenient for a comparison with low p_t model predictions. The observed similarity of the n values for systems of 1,2 and 3 pions is a feature already predicted by longitudinal phase-space and as can be seen in this figure, the value of $n = 3.8$ as given by LSPM for all reactions studied here gives already a remarkably good general description of the data, despite the simplicity of the underlying ideas. Using SRM, the slight differences of the n values for different groups of pion systems containing different numbers of valence quarks can be reproduced fairly well. Finally, SLFM is able to describe qualitatively the differences observed between the single points quite well, although its predictions are systematically low in comparison to the data by up to one standard deviation.

3.4 The π^+/π^- ratio in the backward hemisphere

In contrast to what is expected from a naive picture of proton fragmentation, the π^+/π^- ratio R in the backward hemisphere is known to depend strongly on the charge of the beam and of the type of beam particle used. For positive meson beams, R increases with $|x|$, whereas for negative beams it stays approximately constant for $-1 < x < -0.2$ [12]. In the latter case, $u\bar{u}$ annihilation is supposed to remove one of the u valence quarks of the fragmenting proton thereby reducing backward π^+ production. If annihilation was indeed the main reason for the observed beam dependence, a decrease of this effect like $s^{-1/2}$ with increasing energy could be expected giving a higher value of R at 110 GeV/c than at lower energies. In fig. 8(a), the ratio R obtained from the corrected sample of this experiment is compared to data from other experiments. Indeed, for $x < -0.3$ R seems to increase more strongly with $|x|$ than the data from an K^-p experiment at 32 GeV/c [12(d)]. However, inspection of figs. 1(a) and 1(b) shows that this increase of the π^+ to π^- ratio might rather be due to a decrease in π^- production than to an increase in π^+ production as expected from a reduced quark-antiquark annihilation process. In fig. 8(b) the data on R of this experiment are compared to the predictions of the models and to an asymptotic extrapolation from data assuming an x dependent power law s dependence of R [12(b)]. The data from the present experiment are very close to these asymptotic values.

4. TRIGGERED DISTRIBUTIONS AND THEIR SCALING BEHAVIOUR

4.1 Introductory remarks

Following general phase-space arguments and neglecting transverse momentum, the invariant structure function for two particle production can be written as

$$f(x_t, \tilde{x}) = G(x_t) h(\tilde{x}) \quad (4)$$

where x_t is the Feynman x of a selected particle or particle system, (the "trigger" particle or system), and $\tilde{x} = x/x_{\max}$ with $x_{\max} = 1 - |x_t|$ describes the momentum of the second particle (the "observed particle"), relative to the maximal possible value of this quantity. In this picture,

the distribution of the observed particle in $\tilde{x}$ should be independent of the Feynman x of the trigger x_t , i.e. mere longitudinal phase-space exhibits scaling in $\tilde{x}$. Therefore, all information about the dynamics involved are expected to show up in deviations from such behaviour.

Accordingly, the distribution $h(\tilde{x})$ was extracted from the data by plotting the quantity

$$\langle n_{\pi^\pm} \rangle_t(\tilde{x}, x_t) = \eta \frac{d^2 N}{d\tilde{x} dx_t} \bigg/ \frac{dN}{dx_t} \quad (5)$$

where $\langle n \rangle$ refers to the number of observed particles and index t to the trigger used, going over all possible combinations within the final state of an event in case of a particle system used as trigger, i.e. treating particles as distinguishable. Accordingly, the parameter η in formula (5) was set to values of 1, 2 or 3 depending on the particle system used.

Data on this kind of triggered distribution have also been studied in other experiments, e.g. [13], but so far these results have only been qualitatively compared to predictions of the basic ideas of the recombination and fragmentation picture. Here, a systematic quantitative study of scaling behaviour of triggered distributions is attempted and comparison is made with explicit predictions of the models used here. As trigger for π^+ and π^- production, single π^+ and π^- as well as $\pi^+\pi^+$ and $\pi^+\pi^-$ systems were used in this analysis with three intervals of Feynman x_t of the trigger.

4.2 Presentation of the data on triggered distributions

In figs. 9(a)-9(h) the resulting distributions are presented and compared with the predictions of LPSM. Two general observations can be made in these figures:

- The distributions agree roughly with the LPSM predictions.
- x scaling seems to be fulfilled by the data to a reasonable approximation over about three orders in magnitude of cross section.

However a more detailed inspection of the deviations of the data from the LPSM predictions suggests the classification of the distributions into three groups, according to the kind of correlations between observed particle and trigger.

- (a) Nearly no such correlations appear: the observed particle is produced independently from the trigger, its distributions in $\tilde{x}$ therefore correspond to the LPSM predictions. This is the case for $\langle n_{\pi^+} \rangle_{\pi^+}$, $\langle n_{\pi^-} \rangle_{\pi^+}$ and $\langle n_{\pi^+} \rangle_{\pi^+ \pi^+}$ shown in figs. 9(a), 9(c) and 9(e), respectively.
- (b) Positive correlations between observed particle and trigger exist, i.e. observed particles are produced more strongly than predicted by LPSM. This occurs for $\langle n_{\pi^+} \rangle_{\pi^-}$, $\langle n_{\pi^+} \rangle_{\pi^+ \pi^-}$ and $\langle n_{\pi^-} \rangle_{\pi^+ \pi^+}$, shown in figs. 9 (b), 9(f) and 9(g).
- (c) Negative correlations between observed particle and trigger exist, i.e. the production of the observed particle is less strong than predicted by LPSM, in the case of $\langle n_{\pi^-} \rangle_{\pi^-}$ and to some extent $\langle n_{\pi^-} \rangle_{\pi^+ \pi^-}$, shown in figs 9(d) and 9(h).

4.3 Violation of scaling in $\tilde{x}$

In order to investigate deviations from $\tilde{x}$ scaling, all the distributions studied here were divided by the corresponding LPSM distribution so that the dominant decrease with increasing $|x|$ due to phase-space is removed. The resulting distributions are shown in figs. 10(a)-10(h). In all cases at low $|\tilde{x}|$, the low x trigger curves are higher than the high x_t trigger curves in agreement with known short range correlations in the central region, but with respect to the behaviour with increasing $|\tilde{x}|$ the data can be divided into two distinct classes, depending on the relation between the charges of the observed particle and of the trigger.

- (a) In the case of the same charge for observed particle and trigger, e.g. $\langle n_{\pi^+} \rangle_{\pi^+}$, $\langle n_{\pi^-} \rangle_{\pi^-}$ and $\langle n_{\pi^+} \rangle_{\pi^+ \pi^+}$, as shown in figs. 10(a), 10(d) and 10(e) respectively, the high trigger x_t data stays below to that of the latter.

- (b) If the charge of the observed particle and the trigger is not the same, as in the case of $\langle n_{\pi^+} \rangle_{\pi^-}$ (fig. 10(b)), $\langle n_{\pi^-} \rangle_{\pi^+}$ (c), $\langle n_{\pi^+} \rangle_{\pi^+ \pi^-}$ (f), $\langle n_{\pi^-} \rangle_{\pi^+ \pi^+}$ (g) and $\langle n_{\pi^-} \rangle_{\pi^+ \pi^-}$ (h), then with exception of the distribution $\langle n_{\pi^+} \rangle_{\pi^+ \pi^-}$, where the scaling violations at high $|\tilde{x}|$ are very small the high x_t trigger data cross the low x_t trigger and become higher with increasing $|\tilde{x}|$.

4.4 Comparison of triggered distributions with model predictions

4.4.1 Standard version of the recombination model

In figs 11(a-h) the triggered distributions normalized to LPSM as described in the preceeding section are compared to the predictions of the standard version of the recombination model SRM as described in sect. 3.2.1. The main feature of these distributions, namely the relative strength of low and high x_t trigger data can be qualitatively reproduced by SRM in the case of $\langle n_{\pi^+} \rangle_{\pi^-}$ (fig. 11(b)), $\langle n_{\pi^-} \rangle_{\pi^+}$ (c), $\langle n_{\pi^-} \rangle_{\pi^-}$ (d) and to some extent for $\langle n_{\pi^+} \rangle_{\pi^+ \pi^+}$ (e), i.e. in these cases SRM predicts correctly whether the higher x_t trigger data is higher or lower than the lower x_t trigger data with increasing $|\tilde{x}|$ of the observed particle. Quantitatively however, the absolute values of the predicted curves do not agree well with the data. In the other distributions of figs. 11, the observed dependence of the data on the x_t trigger interval x_t cannot be reproduced even qualitatively. It has to be kept in mind, however, that when studying triggered distributions the $|\tilde{x}|$ range used is extended to such low values that the validity of the recombination model cannot be safely assumed there.

4.4.2 Extended recombination model

Here only single pion triggers were evaluated due to the complexity of the cases with multiparticle trigger systems. The main result which can be seen in figs. 12(a)-12(d) is that the difference between high and low x_t data, i.e. scaling violation now is larger than for SRM, but in the case of $\langle n_{\pi^+} \rangle_{\pi^+}$ (fig. 12(a)) the scaling violation predicted by VMRM is now opposite to that which is observed in the data. Apart from the scaling violations, VMRM describes correctly the deviation of the data in these figures from the value of one, i.e. the existence of positive, negative or no correlations between observed particle and trigger.

The description of the data in the low $|\tilde{x}|$ region does not improve when using VMRM instead of SRM in contrast to what is observed in the case of non triggered distributions although most of the decay pions from the resonances included additionally in VMRM are expected to populate this region.

4.4.3 Lund string fragmentation model

This comparison is shown in Figs. 13(a)-13(h). It can be seen that SLFM qualitatively describes the main features of the observed distributions quite well, i.e. it is able to predict correctly in nearly all cases the existence of positive or negative correlations between observed particle and trigger, i.e. values of the normalized distributions as shown in these figures larger or smaller than one (with the exception of $\langle \pi^+ \pi^+ \rangle$, fig. 13(e)), as well as it predicts the type of scaling violation, i.e. the dominance of high or low trigger data for high $|\tilde{x}|$. Quantitatively some deficiencies can be observed, e.g. the small x_T data for low $|\tilde{x}|$ of the observed particles are too low by a factor up to two where $\tilde{x}^+$ are the observed particles i.e. in figs. 13(a), 13(b), 13(e) and 13(f). In the case of π^- production, the SLFM curves for low x_T are too high for higher $|\tilde{x}|$ values, as e.g. to be seen in figs. 13(c), 13(g) and 13(h).

The fact that the SLFM curves for the low and middle trigger interval in the distribution of $\langle n^+ \rangle +$ (fig. 13(a)) and in $\langle n^+ \rangle + +$ (fig. 13(e)) are too low, seems to indicate that short range correlations between positive pions governing the central region are present in the data in excess of what is incorporated in SLFM.

An attempt was made to check if the superiority of SLFM over VMRM in describing triggered distributions was due to the fact that baryonic resonances are not included in the recombination model used here. For this purpose, the observed distributions were produced by SLFM without the contribution of decay pions from baryonic resonances. The qualitative agreement of SLFM did not change significantly.

In conclusion, SLFM seems to be better suited for the description of the triggered distributions than the recombination model VMRM used here, possibly due to the fact that the Lund model incorporates stronger correlations between partons in the proton structure function than the recombination model used here. In the case of multi π^+ production however, these correlations seem to be still not strong enough. This fact is further illustrated in fig. 14 where ratios of two pion productions are shown. Whereas the ratio $\langle \pi^+ \pi^- \rangle / \langle \pi^- \pi^- \rangle$ is reproduced fairly well by both models (fig. 14(b)), in the case of $\langle \pi^+ \pi^- \rangle / \pi^+ \pi^+$ as shown in fig. 14(a) the prediction of SLFM is too high by several standard deviations over nearly the full x range, in agreement with the observation made above, namely that this model fails to reproduce a sufficiently strong multi π^+ production in the proton fragmentation region of the interactions studied here.

5. SUMMARY OF MAIN RESULTS

Distributions of single charged pions and pion systems were studied in the proton hemisphere of 110 GeV/c K^-p reactions and compared to the predictions of a recombination and a string fragmentation model. The main results of this analysis are:

The single particle inclusive spectra show no significant deviation from Feynman x scaling when compared to data from K^-p experiments at 32 and 70 GeV/c. No significant long range correlations between forward pions and backward pions and pion systems are observed. The n values fitted for the $(1-|x|)^n$ behaviour of single pions and multi pion systems agree with the values obtained in other experiments and show no strong dependence on energy or beam particle used.

The recombination and string fragmentation models applied here reproduce the Feynman x distributions of single pion and multi pion systems quite well. The descriptive power of the recombination model in the low x region is improved significantly by the inclusion of vector meson resonances.

The ratio of π^+/π^- observed in the backward hemisphere increases more strongly with $|x|$ than is the case in other experiments with negative beam particles at lower energies.

Distributions for pions with pion and pion system triggers are presented. They can be divided into three distinct classes, depending on whether positive, negative or no correlations exist between observed particle and the trigger. This behaviour is generally well reproduced by the recombination and the string fragmentation model.

A detailed study of the observed violations of scaling in reduced Feynman x suggests a systematic relation between these effects and the charges of the particles involved. These scaling deviations are better reproduced by the string fragmentation model since it seems to include stronger, but in case of multi π^+ production still not sufficiently strong correlations than the version of the recombination model used here.

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The following data are used for comparison:
 - (a) 70 GeV/c K^+p : M. Barth et al. Zeitschr. f. Physik C7 (1981) 187.
 - (b) 147 GeV/c π^+p : D. Brick et al., Zeitschr. f. Physik C13 (1982) 11.
 - (c) 405 GeV/c pp : A. Suzuki et al., Phys. Rev. D24 (1981) 605.
 - (d) 32 GeV/c K^-p : M.L. Faccini et al., Nucl. Phys. B 127 (1977) 109.
- [13] U. Gensch et al., Zeitschr. f. Physik C17 (1983) 21;
CERN-USSR and France-USSR Collaboration, paper submitted to EPS Int. Conf. on High Energy Physics, Lisbon, 1981;
A.E. de Wolf et al., Zeitschr. f. Physik C8 (1981) 189;
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FIGURE CAPTIONS

Fig. 1 (a) m^+ invariant cross section vs. Feynman x for K^-p interactions at different energies.

(b) m^- invariant cross section vs. Feynman x for K^-p interactions at different energies. The m sample of this experiment is considered to consist of pions with a kaon contamination below 10% (see text).

Fig. 2 (a) m^+ invariant cross section vs. Feynmann x for different beam particles.

(b) m^- invariant cross section vs. Feynman x for different beam particles.

Fig.3 Result of the $(1-|x|)^n$ fits to the invariant cross section for the production of several pion configurations.

Fig. 4 (a) to (l) Correlations of the backward produced π^+ , π^- , $\pi^+\pi^+$, $\pi^+\pi^-$ with m^+ and m^- produced forward.

Fig. 5 Comparison of the invariant cross sections with the Lund model predictions. The solid curve corresponds to the standard version of the model, the dashed curve corresponds to the version where the ratio of vector to pseudoscalar production is set to a value of one.

(a) for π^+ , (b) for π^- , (c) for K^n and (d) for ρ^0 .

Fig. 6 Comparison of the invariant cross sections with the versions of the recombinations model used here.

(a) for π^+ , (b) for π^- , (c) for K^n and (d) for ρ^0 .

Fig. 7 Results of the $(1-|x|)^n$ fits to $|x_{\text{sum}}| d\sigma/dx_{\text{sum}}$ compared to the prediction of models.

FIGURE CAPTIONS (Cont'd)

- Fig. 8 Ratio of positive to negative pion distributions as a function of x in the backward hemisphere compared to other experiments 8(a) and to model predictions 8(b). In addition, in fig. 8(b) the result of an asymptotic extrapolation for this ratio is shown [8(b)]. The error bars in the 110 GeV/c K^-p data include the systematic error caused by the correction made for unidentified protons.
- Fig. 9 (a) to (h): $\tilde{x}$ distributions of $\pi^\pm$ associated with π^+ , π^- , $\pi^+\pi^+$ and $\pi^+\pi^-$ triggers.
- Fig. 10 (a) to (h): $\tilde{x}$ distributions of $\pi^\pm$ associated with $\pi^+\pi^+$ and $\pi^+\pi^-$ triggers, normalized to LPS.
- Fig. 11 (a) to (h): $\tilde{x}$ distributions of $\pi^\pm$ associated with π^+ , π^- , $\pi^+\pi^+$ and $\pi^+\pi^-$ triggers, compared to predictions of SRM.
- Fig. 12 (a) to (d): $\tilde{x}$ distributions of $\pi^\pm$ associated with π^+ , π^- , $\pi^+\pi^+$ and $\pi^+\pi^-$ triggers, compared to predictions of VMRM.
- Fig. 13 (a) to (h): $\tilde{x}$ distributions of $\pi^\pm$ associated with π^+ , π^- , $\pi^+\pi^+$ and $\pi^+\pi^-$ triggers, compared to SLFM predictions.
- Fig. 14 Ratio of the x distributions of pion pairs and comparison to model predictions.

Fig. 1 (a)

Fig. 1 (b)

Fig. 2 (a)

Fig. 2 (b)

Fig. 3

Fig. 4 (a) (b) (c) (d) (e) (f)

$$K^- p \longrightarrow m_f^- + A_b + X \quad 110 \text{ GeV}/c$$

$$\circ A_b = \pi_b^+$$

$$\bullet A_b = \pi^-$$

$$\square A_b = (\pi^+ \pi^+)$$

$$\blacksquare A_b = (\pi^+ \pi^-)$$

Fig.4 (g) (h) (i) (j) (k) (l)

Fig. 5 (a)

Fig. 5 (b)

Fig. 5 (c)

Fig. 5 (d)

Fig. 6 (a)

Fig. 6 (b)

Fig. 6 (c)

Fig. 6 (d)

Fig. 7

Fig. 8 (a)

Fig. 8 (b)

Fig. 9 (a) (b) (c) (d)

Fig. 9 (e) (f) (g) (h)

$K^- p \rightarrow 1+2+X \quad 110 \text{ GeV}/c$

$\dagger \quad 0 < |X_{tr}| < 0.1 \quad \text{--- LPSM}$
 $\bullet \quad 0.1 < |X_{tr}| < 0.3$
 $\circ \quad 0.3 < |X_{tr}| < 1.0$

Fig. 10 ((a) (b) (c) (d))

$$K^- p \rightarrow 1+2+3+X \quad 110\text{GeV}/c$$

- $\dagger$ $0 < |X_{tr}| < 0.1$
 $\bullet$ $0.1 < |X_{tr}| < 0.3$ — LPSM (=1)
 $\circ$ $0.3 < |X_{tr}| < 1.0$

Fig. 10 (e) (f) (g) (h)

$K^- p \rightarrow 1+2+X$ 110 GeV/c

DATA

SRM

- $+$ $0 < |X_{tr}| < 0.1$ ———
- $\bullet$ $0.1 < |X_{tr}| < 0.3$ - - - -
- $\circ$ $0.3 < |X_{tr}| < 1.0$

Fig. 11 (a) (b) (c) (d)

$K^- p \rightarrow 1+2+3+X$ 110 GeV/c

DATA

SRM

- $+$ $0 < |X_{tr}| < 0.1$ ———
 $\bullet$ $0.1 < |X_{tr}| < 0.3$ - - - -
 $\circ$ $0.3 < |X_{tr}| < 1.0$

Fig. 11 (e) (f) (g) (h)

$K^- p \rightarrow 1+2+X$ 110 GeV/c

DATA

VMRM

- + $0 < |X_{tr}| < 0.1$ —
- $0.1 < |X_{tr}| < 0.3$ - - -
- $0.3 < |X_{tr}| < 1.0$ ·····

Fig. 12 (a) (b) (c) (d)

$K^- p \rightarrow 1+2+X$ 110 GeV/c

DATA

SLFM

- $+$ $0 < |X_{tr}| < 0.1$ ———
- $\bullet$ $0.1 < |X_{tr}| < 0.3$ - - - -
- $\circ$ $0.3 < |X_{tr}| < 1.0$

Fig. 13 (a) (b) (c) (d)

$K^- p \rightarrow 1+2+3+X$ 110 GeV/c

DATA

$\dagger$ $0 < |X_{tr}| < 0.1$

$\bullet$ $0.1 < |X_{tr}| < 0.3$

$\circ$ $0.3 < |X_{tr}| < 1.0$

SLFM

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Fig. 13 (e) (f) (g) (h)

Fig. 14