LOW TRANSVERSE MOMENTUM FRAGMENTATION PROCESSES AND QUARK STRUCTURE OF HADRONS

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The study of the fragmentation processes in the hadron-hadron interactions is a possible way of investigating a quark-gluon structure of hadrons. In this paper we discuss the fragmentation of mesons and antibaryons into baryons. We have found that these processes are not very well described by different quark models, indicating possibility of an unknown mechanism. We have studied the momentum-charge correlations as a way of measuring the quark charges. The obtained charges are conventional 2/3, $-1/3$ Gell-Mann-Zweig ones. The study of these correlations has enabled us to determine the average number of the low momentum quark-antiquark pairs, which turns out to be ~ 4.

Introduction

In spite of a great success of quantum chromodynamics the theory of hadronic interactions is not well understood in terms of quarks and gluons. As a matter of fact we *do not know* whether the notion of quarks and gluons has anything to do with explaining low transverse momentum hadronic reactions. Thus we have to:

— use models and distinguish between them,

— try to recover some basic properties of quarks (and gluons) in low p_T hadronic processes i.e. the number of quarks, their charges etc.

This paper aims to try along both indicated lines. In the first part we discuss predictions of various models for the beam and target fragmentation in hadron–hadron collisions, and present single particle distributions for several fragmentation processes. In the second part we investigate two particle momentum correlations in the proton fragmentation region. We also study charge correlations as a possible way of measuring the charges of the quarks. The third part contains our conclusions.

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1. Single particle distributions in the fragmentation region as a test of quark and gluon models of hadronic production

1.1. Models

There are three basic types of quark models for hadronic production:
(a) statistical, e.g. proposed by Anisovitch and Shekhter [1],
(b) fragmentation, e.g. Constituent Interchange Model [2], or Feynman, Field and Fox model [3],
(c) recombination models, e.g. model proposed by Das and Hwa [4].
We shall not discuss models of a type (a), as their predictions of single particle distributions are very vague if any. We concentrate on the reactions

$$A+B \to C+X \tag{1.1}$$

and

$$A+B \to C+D+X \tag{1.2}$$

where particles C and D are both mesons in the fragmentation region of particle A. For these reactions we investigate invariant inclusive cross-sections:

$$\frac{\bar{x}_C}{\sigma_{tot}} \frac{d\sigma}{dx_C} = \frac{1}{\sigma_{tot}} \int \frac{2E_C}{\pi\sqrt{s}} \frac{d^2\sigma}{dp_T^2 dx_C} dp_T^2 \tag{1.3}$$

and (in the second part of this paper):

$$\frac{\bar{x}_C\bar{x}_D}{\sigma_{tot}} \frac{d^2\sigma}{dx_C dx_D} = \frac{1}{\sigma_{tot}} \iint \frac{4E_C E_D}{\pi^2 s} \frac{d^4\sigma}{dp_{T_C}^2 dx_C dp_{T_D}^2 dx_D} dp_{T_D}^2 dp_{T_C}^2. \tag{1.4}$$

Expressions for the cross-section (1.3) in models of the type (b) and (c) are:

$$\frac{\bar{x}_C}{\sigma_{tot}} \frac{d\sigma}{dx_C} = \sum_q \int_{x_C}^{1} F_{q/A}(x_1) D_{C/q}\left(\frac{x_C}{x_1}\right) \frac{dx_1}{x_1} \tag{1.5}$$

for fragmentation models, and

$$\frac{\bar{x}_C}{\sigma_{tot}} \frac{d\sigma}{dx_C} = \int F_{q_1,\bar{q}_2}(x_1, x_2) R^C_{q_1,\bar{q}_2}(x_1, x_2, x_C) \frac{dx_1}{x_1} \frac{dx_2}{x_2} \tag{1.6}$$

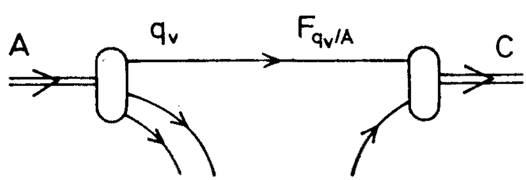
for recombination models, where $F_{q/A}$ is the structure function of quark q inside particle A, $D_{C/q}$ is the decay function of quark q into particle C; $F_{q_1,\bar{q}_2}$ is the quark-antiquark joint structure function and $R_{q_1,\bar{q}_2}$ is the recombination function.

Functions $F_{q/A}$ and $D_{C/q}$ are well-known structure and decay functions introduced in Ref. [3]. These functions are measurable in deep inelastic lepton-hadron scattering and in e^+e^- annihilation. The fragmentation models [2, 3] were designed to explain large momentum transfer processes, and in these processes they seem to work very well. The extension of models [2, 3] to low p_T hadron-hadron interactions is not so successful. The reason of this is that parametrisations of functions $D_{C/q}$ and $F_{q/A}$ found in lepton-nucleon and e^+e^- provide very strong constraints on low p_T production. Experimentally determined functions F_q and D give $\bar{x}d\sigma/dx$ distribution in the pp $\to \pi^-$X process hundred times smaller than the data [4]. Nevertheless the shapes of spectra $\bar{x}d\sigma/dx$ computed within the fragmentation model [3, 4] agree reasonably well with the data. The simplest reason for this discrepancy seems to be an underestimation of quark-antiquark pair production by interactions of gluons. As our knowledge of gluon interactions is, at present, very limited, the cure proposed in Ref. [3], namely the introduction of new function $R(x_1, x_2, x_C)$ (called recombination function) is only of phenomenological value.

Justification of the use of impulse approximation in low transverse momentum reactions is weak. Authors of Ref. [4] suggest that the impulse approximation is justified on the basis of short range correlations.

Thus situation is as follows: fragmentation models predict more or less correct spectra of $\bar{x}d\sigma/dx$ with wrong normalization, whereas recombination model agrees with the data both in shape and normalization paying the price of introducing new function $R(x_1, x_2, x_C)$. This function cannot be extracted from other (than low p_T strong interaction) experiments.

Single particle spectra $\bar{x}d\sigma/dx_C$ in the fragmentation region of particle A have similar shape to structure function of a valence quark q_v passing from A to C [5, 6]:



$$\bar{x}_c \frac{d\sigma}{dx_c} \sim F_{q_v/A}(x_c)$$

This phenomenological rule can be accomodated in fragmentation and recombination models. At present the CIM model seems to have difficulties in explaining fragmentation of mesons into baryons, where phenomenological rule [5, 6] seems to work well. We shall discuss it in the next section.

1.2. Predictions of CIM and OKP rule and comparison with experimental data

Predictions of CIM for process (1.1) are based on dimensional quark counting rules and expressed by the formula [2]:

$$\bar{x}_C \frac{d\sigma}{dx_C} = A_1(1-x_C)^{2n(\bar{A}C)-3}, \tag{1.8}$$

where $n(\bar{A}C)$ is the minimal number of parton fields in carrying quantum numbers of the system $(\bar{A}C)$.

Predictions of this model are listed in Table I together with prediction of phenomenological rule [5, 6] (called OKP rule). Predictions of CIM and OKP for mesons and baryons

TABLE I

Invariant cross-sections $\bar{x}\frac{d\sigma}{dx}$ in the fragmentation region predicted by CIM [2] and by OKP rule [5, 6].

M — meson, B — baryon

Process	Prediction of CIM [2]	Fragmentation model [5,6]
M → M; $\pi \to \pi, \varrho, K, K^*, \omega, \eta$; $K \to \pi, \varrho, K^*$	$1-x$	$1-x$
M → B; $\pi \to p, \Lambda, \ldots$; $K^- \to \Lambda, \ldots$	$(1-x)^3$	$1-x$
B → M; $p \to \pi, \varrho, K, \ldots$	$(1-x)^3$	$(1-x)^3$
B → B; $p \to \Lambda, n, \Sigma^0$; $p \to \bar{\Lambda}$	$1-x$	?
B → B; $p \to \Xi$	$(1-x)^5$	$(1-x)^3$
B → $\bar{B}$; $p \to \bar{\Lambda}$, $\bar{p} \to \Lambda$	$(1-x)^9$	$(1-x)^5$

fragmenting into baryons are the same, and different for mesons and baryons fragmenting into baryons.

We note that resonance production and decay may change the slope of $\bar{x}d\sigma/dx$ distribution of final particles (π, p, etc.). Resonances can be produced diffractively with spectrum $\bar{x}d\sigma/dx$ which slope k_R is smaller than that resulting from CIM or OKP rule. The two-body decay of resonances such as ϱ^0 produces pions with the spectrum:

$$\bar{x}_\pi \frac{d\sigma}{dx_\pi} \sim (1-x_\pi)^{k_R+1}. \tag{1.9}$$

It is also true for protons from $N^* \to p\pi$ decay. Thus when we observe spectrum which is steeper than predictions of CIM or OKP rule, the difference may be due to large production of resonances. When the observed slope is smaller than that predicted by CIM or OKP rule one has to conclude that the predictions were wrong or a large percentage of pions come from diffractively produced systems. In processes discussed in this section diffraction is negligible.

In this section we concentrate on fragmentation of mesons into baryons and baryons into baryons. For these processes predictions of CIM are different from those of OKP rule. We also present data on antibaryons fragmenting into mesons. We have at our disposal the following data:

$$\pi^- p \to pX \text{ at } 12\ \text{GeV}/c\ [7], \tag{1.10}$$

$$\bar{p}p \to \bar{\Lambda}X, \tag{1.11}$$

$$\bar{p}p \to \Lambda X \tag{1.12}$$

$$\bar{p}p \to K^0(\bar{K}^0)X \text{ at } 12\ \text{GeV}/c\ [8], \tag{1.13}$$

Data from the reaction (1.10) were taken in the proton x interval 0.5–0.99 and are very well suited to study fragmentation of a π^- meson into proton (baryon). The contribution of diffractively produced $p\bar{p}$ pairs in this kinematic region is negligible (less than 1%).

The data in $\bar{p}p$ interactions were taken in the whole x range from -1.0 to 1.0. Thus we are able to check predictions for baryon fragmenting into a strange baryon, a strange antibaryon or a strange meson. The results of fit of a formula

$$\bar{x}\frac{d\sigma}{dx} = A(1-x)^k \tag{1.14}$$

to the data from reactions (1.10–1.12) are listed in Table II.

TABLE II

Results of the fit to the $xd\sigma/dx$ distribution with a formula $A(1-x)^k$

Reaction	x range	A	k
$\pi^- p \to pX$	$0.8 \div 1$	0.673 ± 0.034	0.614 ± 0.021
	$0.5 \div 1$	2.38 ± 0.03	1.150 ± 0.001
$\bar{p}p \to \bar{\Lambda}X$	$0 \div -0.5$	13.80 ± 1.0	2.99 ± 0.30
$\bar{p}p \to \Lambda X$	$0 \div 0.5$	15.12 ± 1.2	3.64 ± 0.34

The $\bar{x}d\sigma/dx$ distribution for the reaction (1.10) are shown in Fig. 1. The data exhibit a two-slope structure. The slope k in the x-region 0.8–0.99 (0.614 ± 0.021) is inconsistent with the CIM value of 3. In the smaller x region the slope grows, but is smaller than 3.

Data for reactions (1.11) and (1.12) are shown in Fig. 2a and 2b. The fragmentation of protons into antilambdas and of antiprotons into lambdas is inconsistent with predictions listed in Table I. It is not suprising as fragmenting particles have no common valence quarks with "daughters".

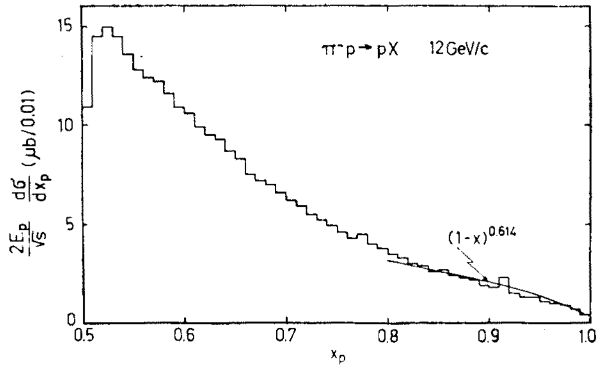


Fig. 1. Invariant inclusive cross-section for the reaction $\pi^- p \rightarrow pX$ at 12 GeV/c as a function of the Feynman x of the proton

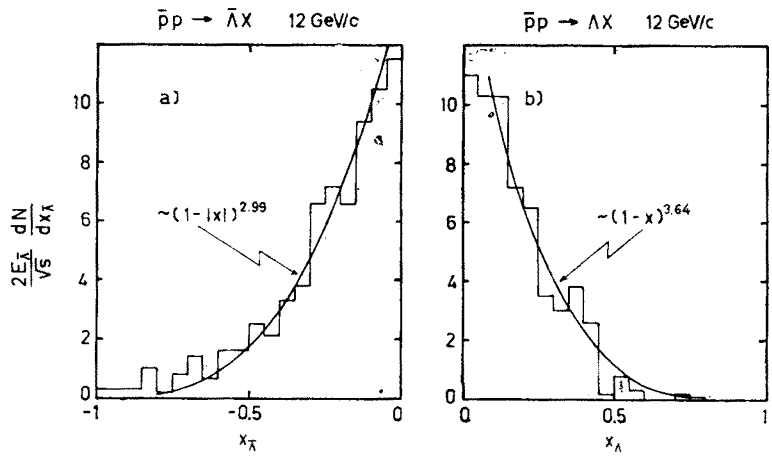


Fig. 2. Invariant inclusive x distributions for the reactions: (a) $\bar{p}p \rightarrow \bar{\Lambda}X$, (b) $\bar{p}p \rightarrow \Lambda X$ at 12 GeV/c

Nevertheless small values of slope parameter k (around 3.0) are suprising, and may indicate the presence of "enhanced" sea of quark-antiquark pairs from gluonic interactions [4]. The higher energy results for the $\pi^- p \rightarrow pX$ and $pp \rightarrow \bar{p}X$ reactions obtained by Toy [9] are shown in Table III. At FNAL energies the agreement with CIM is better, but the values of the slope k are slightly smaller than expected by this model. We note, however, that results of Ref. [8] were obtained in the different range of x: 0.1–0.7. In this x range we expect bigger values of k due to central production. From Table II we conclude that, at our momentum:

— fragmentation of mesons into baryons is inconsistent with CIM, but in agreement with OKP-rule,

— fragmentation of baryons into strange antibaryons is inconsistent with CIM and OKP rule, and

— falls down much slower than antiquark structure functions in a proton, indicating that other mechanism plays a role here.

This mechanism may be:

— "enhanced sea" as in Ref. [4],

— Tripple Regge mechanism [13].

TABLE III

Results of the fit to the high energy $\bar{x}\, d\sigma/dx$ distribution [9] with a formula $A(1-x)^k$. The x range, in which data were taken, is 0.1–0.7

Reaction	Incident momentum [GeV/c]	k
$\pi^- p \to pX$	100	2.54 ± 0.22
$pp \to \bar{p}X$	100	7.81 ± 3.4
	175	8.49 ± 0.57

2. *Correlations in the proton fragmentation region in the reactions* $\pi^{\pm}p \to \pi_L X$ [1] *at 16 GeV/c*

In this section we discuss two topics:

— charge correlations leading to the determination of the quarks charges,

— two pion longitudinal correlations and their connection with the average number of quark-antiquark pairs in the proton sea.

To begin with, we define proton fragmentation region as the region $x < 0.0$ in the CMS. In course of this section we shall discuss the dependence of our results on the position of the fragmentation region boundary. We use $\pi^{\pm}p$ inclusive data obtained by Aachen–Bonn–Berlin–CERN–Cracow–Heidelberg–Warsaw Collaboration.

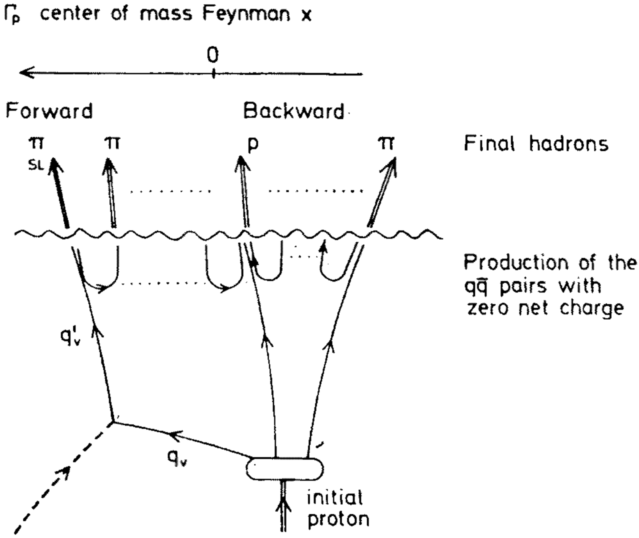
2.1. Charge correlations

We consider the process $\pi^- p \to \pi_L^- X$ at 16 GeV/c and examine properties of the system X. We take Feynman x of the leading π^- to be larger than some x^{cut} and discuss the dependence of our results on x^{cut}.

Following Ref. [12], we adopt a very simple-minded model for the discussion of the charge properties of the system X. In this naive fragmentation model (NFM) we describe the production of X as a result of the collision between initial proton and virtual object Γ, which has electric charge $Q = 0$. System X contains mainly pions and one baryon, which may not be charged. In the Γp center of mass there is a particle which goes in the same direction as a virtual object Γ and is the fastest particle going in this direction. We call it second-leading particle (SL) and limit ourselves to the case when it is π^+ or π^-. In

[1] Subscript L stands for "leading", i.e. for pion produced with a considerable fraction of the longitudinal momentum of the initial pion.

NFM we assume that this particle is produced in the hard collision between Γ and one of the valence quarks q_v from the proton:



After a hard collision colour and charge separate in the forward and backward hemispheres, and as the result a number of quark-antiquark pairs is produced. We assume that the average charge in the forward and backward hemispheres reflect the initial charge separation. Thus if a second leading pion is a π^+ then the interacting valence quark was u and the average charge in the forward hemisphere $\langle Q_\Gamma \rangle$ is the charge of this quark and equals 2/3. The average charge in the backward hemisphere $\langle Q_p \rangle$ is the charge of remaining valence quarks and is equal to 1/3. In the case of the second leading pion being π^- the average charges are: $\langle Q_\Gamma \rangle = -1/3$, $\langle Q_p \rangle = 4/3$. Thus in the framework of NFM we can measure the charges of the quarks[2].

The important question is whether it is possible to obtain similar values for $\langle Q_\Gamma \rangle$ and $\langle Q_p \rangle$ from other models, e.g. these which do not refer explicitly to the quarks.

TABLE IV

The average charges in the forward ($\langle Q_\Gamma \rangle$) and backward ($\langle Q_p \rangle$) hemispheres in the $\pi^- p \to \pi_L^- \pi_{SL}^\pm X$ reaction predicted by: (a) NFM, (b) M1, (c) M2

	Naive fragmentation model	Statistical model	
		with leading π^- (M1)	with leading π^- and proton (M2)
$\pi_{SL}^+ \langle Q_\Gamma \rangle$	2/3	0.9÷1.0	0.85
$\langle Q_p \rangle$	1/3	0.0÷0.10	0.15
$\pi_{SL}^- \langle Q_\Gamma \rangle$	−1/3	−0.300÷ −0.346	−0.40
$\langle Q_p \rangle$	4/3	1.300÷ 1.346	1.48

[2] The charges, measured in this way, are averaged over colour.

We tested two such simple minded models: simple statistical model incorporating leading π^- effect (M1), and statistical model incorporating both leading π^- and leading proton effects (M2). The predictions of these two models are summarised in Table IV, together with the predictions of NFM. We conclude that it is possible to measure quark

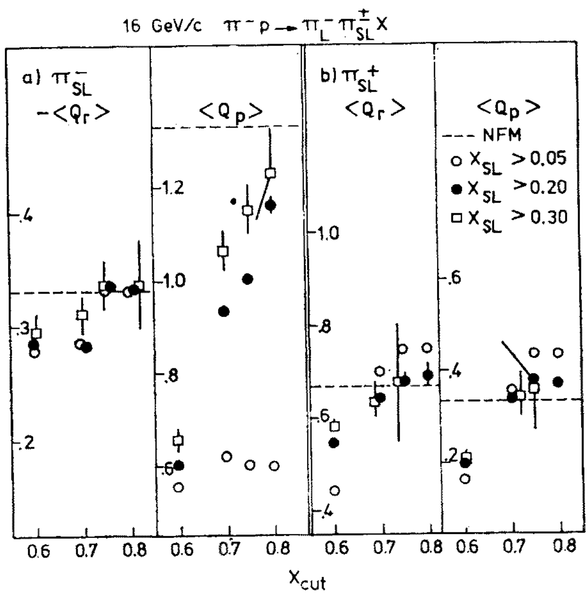


Fig. 3. The dependence of the average charges in the forward ($\langle Q_\Gamma \rangle$) and backward hemisphere ($\langle Q_p \rangle$) in the reaction $\pi^- p \to \pi_L^- \pi_{SL}^\pm X$ on the Feynman x of the leading π^- ($x_L > x_{cut}$)

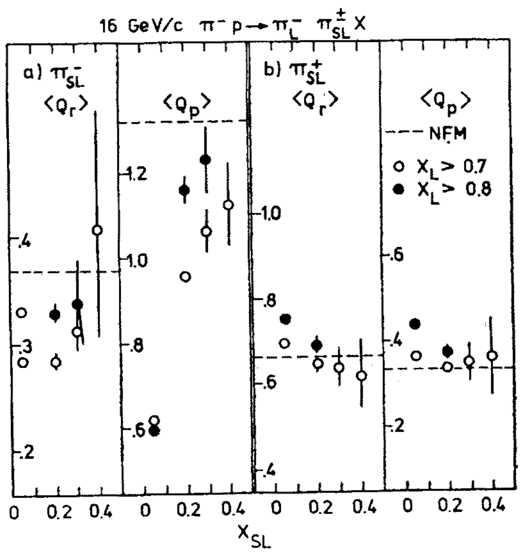


Fig. 4. The dependence of the average charges in the forward ($\langle Q_\Gamma \rangle$) and backward ($\langle Q_p \rangle$) hemispheres in the reaction $\pi^- p \to \pi_L^- \pi_{SL}^\pm X$ on the Γp center of mass Feynmann x of the second leading π — x_{SL}

charges by studying the average charges in the reaction $\pi^- p \to \pi_L^- \pi_{SL}^+ X$, whereas in the reaction $\pi^- p \to \pi_L^- \pi_{SL}^- X$ the three models considered give similar results.

The experimental results are shown in Fig. 3 and Fig. 4. In Fig. 3 we show the dependence of $\langle Q_\Gamma \rangle$ and $\langle Q_p \rangle$ on the longitudinal momentum of the leading π^-. We select events with $x(\pi_L^-) < x^{cut}$ in various regions of x_{SL} — the Feynman x of the second leading pion in Γp center of mass.

We conclude that: (a) in the process $\pi^- p \to \pi_L^- \pi_{SL}^+ X$ results are consistent with NFM and inconsistent with the two other models discussed M1 and M2, (b) in the process $\pi^- p \to \pi_L^- \pi_{SL}^- X$ the values of $\langle Q_p \rangle$ are inconsistent with all discussed models.

It turns out that the last inconsistency is mainly due to the events with the small longitudinal momentum of the second leading π^+. Such events cannot be explained in terms of hard collisions and it is not surprising that NFM cannot account for them. In Fig. 4 we show the dependence of $\langle Q_\Gamma \rangle$ and $\langle Q_p \rangle$ on the Γp center of mass Feynman x of the second leading pion — x_{SL}. We plotted there points for different regions of the leading pion momentum. As longitudinal momentum of second leading pion grows the average charges agree better with the predictions of NFM.

We conclude that it is possible to select a sample of events in the reaction $\pi^- p \to \pi_L^- \pi_{SL}^\pm X$, in which one of the valence quarks from the proton produced a $\pi_{SL}^\pm$, undergoing hard collision. In this sample it is possible to measure the charges of the quarks.

2.2. Determination of the average number of quark-antiquark pairs in the proton "sea"

To measure the average number of qq pairs in the proton "sea" we use the idea proposed by Miettinen [10]. This idea is consistent with the general principles of a recombination model, in the framework of which we can express two particle inclusive cross-section (1.4) for the process (1.2):

$$\frac{\bar{x}_C \bar{x}_D}{\sigma_{tot}} \frac{d^2\sigma}{dx_C dx_D} = \int F_{q_1,q_2,\bar{q}_3,\bar{q}_4/p}(x_1, x_2, x_3, x_4) R^C_{q_1\bar{q}_3}(x_1, x_3, x_C) \times R^D_{q_2,\bar{q}_4}(x_2, x_4, x_D) \frac{dx_1}{x_1} \frac{dx_2}{x_2} \frac{dx_3}{x_3} \frac{dx_4}{x_4}. \tag{2.1}$$

The function $F_{q_1,q_2,\bar{q}_3,\bar{q}_4/p}$ is the two quark-two antiquark joint structure function in the fragmentation region of a particle A. The recombination functions R were already introduced in part (1.1).

We aim to study the fragmentation of a proton into two pions in πp collisions. The relevant joint structure function $F_{q_1,q_2,\bar{q}_3,\bar{q}_4/p}$ contains two valence quarks and two antiquarks from the "sea", which momenta are small compared to the momenta of valence quarks. (The "sea" here is probably not identical with the "sea" encountered in the deep inelastic lepton scattering because some additional $q\bar{q}$ pairs are produced in the central region in πp collisions). Thus we shall assume that all antiquark momenta are zero. Then the joint structure function $F_{q_1,q_2,\bar{q}_3,\bar{q}_4/p}$ is proportional to the two-quark joint structure function in a proton:

$$F_{q_1,q_2,\bar{q}_3,\bar{q}_4/p}(x_1, x_2, 0, 0) \sim F_{q_1,q_2/p}(x_1, x_2). \tag{2.2}$$

The two-quark joint structure function is not directly measurable. We shall assume that this function obeys Kuti–Weisskopf scaling [11] i.e. partially factorises:

$$F_{q_1,q_2}(x_1, x_2) = f_{q_1}(x_1) f_{q_2}\left(\frac{x_2}{1-x_1}\right), \tag{2.3}$$

where f_{q_1} and f_{q_2} are two unknown functions vanishing outside the [0, 1] interval. Taking into account the dominant role of valence quarks momenta in the determination of the hadron momenta in the fragmentation region [5, 6] we find that cross-section (2.1) is proportional to:

$$f_{q_1}(x_C) f_{q_2}\left(\frac{x_D}{1-x_C}\right). \tag{2.4}$$

This last result enables us to test Kuti–Weisskopf scaling. We find that the average number of particles of type D per one particle of type C – $\langle D_C \rangle$ — should only depend on the variable:

$$\tilde{x}_D = \frac{x_D}{1-x_C}.$$

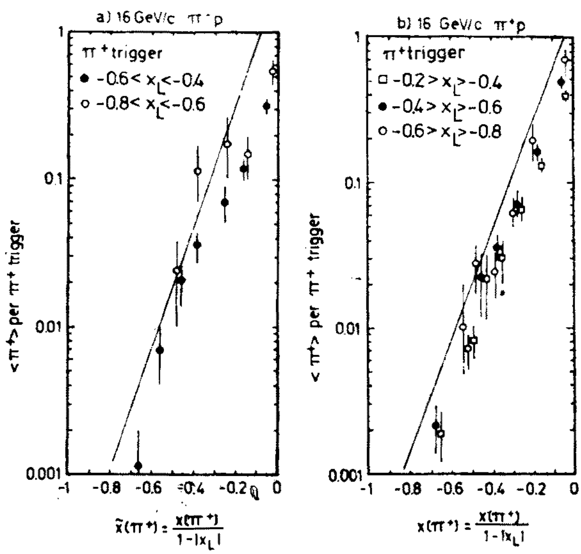


Fig. 5. The average number of π^+ mesons per π^+ "trigger" as a function of $\tilde{x}(\pi^+)$ variable, in the reactions: (a) $\pi^-p \to \pi^+_{\text{trigger}}X$, (b) $\pi^+p \to \pi^+_{\text{trigger}}X$ at 16 GeV/c. The solid curve represents the 360 GeV/c $\pi^-p \to \pi^-_{\text{trigger}}X$ data of Lehman et al. [10]. The different points correspond to various momenta of the π^+ "trigger"

Experimental results for the fragmentation $p \to \pi^+\pi^+$ and $p \to \pi^-\pi^-$ in $\pi^\pm p$ interactions at 16 GeV/c are shown in Fig. 5 and Fig. 6. The solid curve shows the data for the fragmentation $p \to \pi^-\pi^+$ in 360 GeV/c π^-p [10].

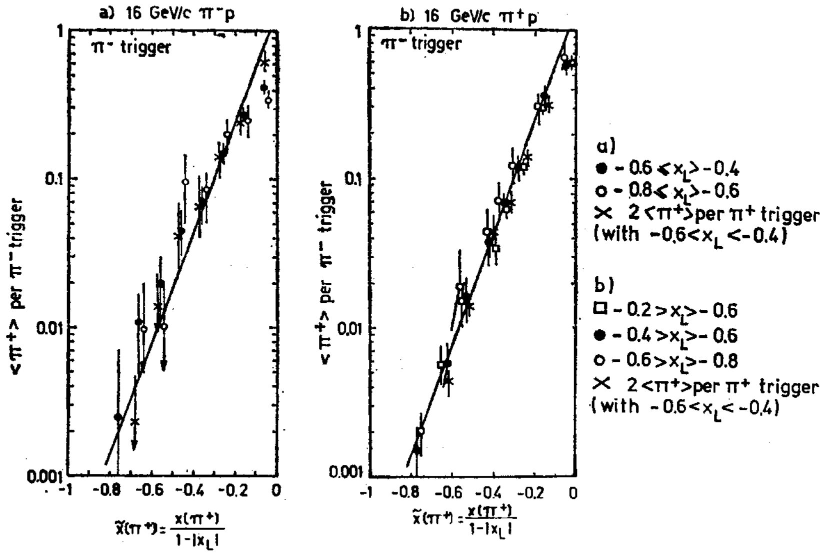


Fig. 6. The average number of π^+ per π^- "trigger" as a function of $\tilde{x}(\pi^+)$ variable, in the reactions: (a) $\pi^-p \to \pi^-_{trigger}X$, (b) $\pi^+p \to \pi^-_{trigger}X$ at 16 GeV/c. The solid curve represents the 360 GeV/c $\pi^-p \to \pi^-_{trigger}X$ data of Lehman et al. [10]. The different points correspond to the various momenta of the π^- "trigger"

We see that:

— Kuti–Weisskopf scaling holds;

— Both the slope and the normalization of our data at 16 GeV/c are consistent with these of Lehman et al., at 360 GeV/c;

— The $\langle\pi^+\rangle_{\pi^-}$ is roughly twice the $\langle\pi^+\rangle_{\pi^+}$ (see Fig. 5).

This last result is a reflection of the quark content of a proton. There are roughly twice as many possibilities of making a π^+ from valence u quarks together with a fast π^-, than together with a fast π^+. Assuming that the average number of $(u\bar{u})$ and $(d\bar{d})$ pairs in the sea is m we obtain (after simple combinatorics) the relation [10]:

$$\langle\pi^+\rangle_{\pi^-} = 2\,\frac{m}{m-1}\,\langle\pi^+\rangle_{\pi^+} \tag{2.5}$$

Thus we can compute the average number m of $(u\bar{u})$ and $(d\bar{d})$ pairs. The average number of π^+, and consequently the average number of $(u\bar{u})$ and $(d\bar{d})$ pairs — m, in the formula (2.5) depend on the range of x which we define as the proton fragmentation region. The dependence of m on the right side boundary x_{cut} of the fragmentation region is shown on Fig. 7. We see that:

— π^+ mesons with x less than -0.2 are pions from the proton fragmentation;

— the average number of (uu) and (dd) pairs is (1.8–2.0) consistent with the result at 360 GeV/c. It means that on the average a proton contains 3 valence quarks and 8 quarks from the sea.

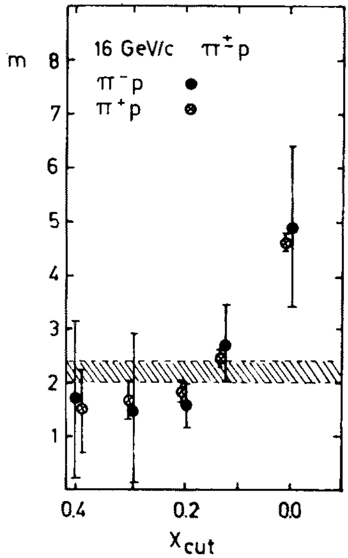


Fig. 7. The dependence of the average number m of $(u\bar{u})$ and $(d\bar{d})$ pairs in the "sea" on the right hand side boundary of the proton fragmentation region in the $\pi^{\pm}p$ interactions at 16 GeV/c. The shaded region represents 360 GeV/c $\pi^{-}p$ result of Lehman et al. [10]

3. Conclusions

1) We found that single particle inclusive spectra $\bar{x}d\sigma/dx$ for the beam fragmentation processes at low energy $\pi^{-}p \to pX$, $\bar{p}p \to \Lambda X$, $p\bar{p} \to \bar{\Lambda}X$ are flatter than expected [2, 5, 6]. This conclusion is supported by higher energy data in the FNAL range [9].

2) Measuring charge correlations is a way of measuring quark charges. Our data agree with Gell-Mann–Zweig quark charges.

3) Two quarks distribution functions inside a proton obey Kuti–Weisskopf scaling, independently of incident momentum in the range 16–360 GeV/c.

4) The average number of quark-antiquark pairs in 16 GeV/c $\pi^{\pm}p$ interactions is found to be in good agreement with high energy data [10]. This large number may indicate the presence of the "enhanced sea".

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