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INTRODUCTION

Inclusive reactions, $a + b \to c +$ "anything", have been the subject of theoretical and experimental investigations during the last few years. Various approaches to the limiting behaviour as a function of energy have been proposed. As in the case of the total cross section, some of the properties of the inclusive cross section are expected to depend upon the quantum numbers of external particles and, in particular, upon the channels which exhibit exotic quantum numbers. The problem of combining duality with the theory of inclusive reactions has received considerable attention recently. Guided by Mueller's paper[1], many authors have studied the restrictions which duality imposes on inclusive processes. They have given several different conditions when the cross section for an inclusive process is energy-independent (or has only a weak energy dependence) in a fragmentation limit.

In this paper we present the available experimental data on πN reactions to study

which of different conditions seem to be sufficient for an early scaling in the fragmentation regions of incident particles (target or projectile) at low energies.

This analysis also includes some experimental data* on π^-n inclusive reactions at 40 GeV/c for which there is no previously published data. It should be noted that the $\pi^-n \to \pi^\mp$ reactions are isotopically conjugated ones of the well-studied $\pi^+p \to \pi^\pm$ reactions, so we can also get some information on the isotopic invariance of inclusive reactions.

1. COMPARISON OF EXPERIMENTAL DATA ON INCLUSIVE πN REACTIONS IN THE FRAGMENTATION REGIONS

The reactions of particular interest to us are

$$\pi^+p \to \pi^-(\pi^+)... \qquad (1\text{-}2)$$

$$\pi^-p \to \pi^-(\pi^+)... \qquad (3\text{-}4)$$

$$\pi^-n \to \pi^-(\pi^+)... \qquad (5\text{-}6)$$

The reactions (1)-(4) are well-studied in a wide range of incident energies both in the target and projectile fragmentation

*The experimental data from the Dubna 2-m propane bubble chamber /2/ make it possible to investigate pion-neutron interactions using quasi-free neutrons of carbon nuclei as the target particle.

regions, except for the $\pi^- \xrightarrow{p} \pi^+$ fragmentation, which is crucial for our conclusions concerning the conditions of the early scaling.

We use some data on reactions (1)-(4) and conclusions reported in a number of earlier papers /3-9/ and add new data on reactions (3)-(6) at 40 GeV/c. The 40 GeV/c data are based on a sample of about 8500 π^-p and 3500 π^-n interactions ($\approx$46000 and 18000 charged pions, respectively) obtained in an exposure of the Dubna 2-m propane bubble chamber to π^- mesons at Serpukhov. The details of the experiment are described in ref. /2/.

A short summary of the experimental results and conclusions is as follows:

(i) Reactions $\pi^+p \to \pi^-...$ scales both in the target and projectile fragmentation regions at a relatively low energy beginning at about 4 GeV/c. The set of data from which one can draw these conclusions are the following*: 3.7, 7 and 18.5 GeV/c,

It should be emphasized that a unique comparison of all these data is difficult because different authors use various methods to compare their own samples of data. For instance, they compare the invariant $E\,d\sigma/dp_{||}$ or noninvariant $(d\sigma/dp_{||})$ single-particle distributions in a certain range of $p_{||}$ values of the integrals of these distributions over some $p_{||}$ intervals. Despite these difficulties, we find that the conclusions we arrived at in the text are in agreement for all different data samples.

for some typical energies. The $I(\pi)$ value in Table I is integrated over the whole range of $p_\perp^2$ and over a limited range of $p_{||}$ ($p_{||}$(lab) $\leq$ 0.3 GeV/c or $p_{||}$(projectile) $\leq$ 1.2 GeV/c), and σ_T is the total cross section. The data are taken from refs. [5,7] and from the present paper. As is seen from Table I, the above-mentioned scaling seems to be well-established in a wide range of energies.

(ii) Reaction $\pi^+ p \to \pi^+ \ldots$ scales neither in the target nor in the projectile fragmentation region [3-6]. A strong energy dependence of this reaction is seen from the comparison of the $I(\pi)$ values collected in Table I.

Before proceeding to the analysis of the $\pi^- p$ reactions, we present here some experimental data on the inclusive reactions $\pi^- n \to \pi^\pm \ldots$, obtained by us at 40 GeV/c, which are isotopically conjugated to the $\pi^+ p \to \pi^\mp$ reactions. Unfortunately, there ref. [3] ; 8 and 16 GeV/c, ref. [4] ; 6 and 22 GeV/c, ref. [5] and 4-24 GeV/c, ref. [6].

To characterize quantitatively the energy dependence of the reactions under study, in Table I we collect some quantity of the integrated cross section defined in ref [7]

$$I(\pi) = \int \sigma_T^{-1} \left(d^2\sigma / dp_\perp^2 \, dp_{||}\right) dp_\perp^2 \, dp_{||}$$

are no more available data on $\pi^- n$ inclusive reactions, so we cannot carry out a direct analysis of the energy dependence of these reactions. However, we find a good agreement between the $\pi^- n$ and $\pi^+ p$ data which supports the conclusion that the isotopic invariance is satisfied well in inclusive reactions.

Figure 1 displays the normalized invariant cross sections as a function of $p_{||}$ in the laboratory system for the reactions $\pi^- n \to \pi^+ \ldots$ at 40 GeV/c, $\pi^+ p \to \pi^- \ldots$ at 7 GeV/c and $pp \to \pi^-$ at 28.5 GeV/c [8]. The agreement between the pp and $\pi^+ p$ reactions shows evidence for factorization, as it was pointed out by Chen et al. [7], while

Table I.

Reaction	Momentum (GeV/c)	Target fragmentation $I(\pi)^a$	Projectile fragmentation $I(\pi)^b$
$\pi^+ p \to \pi^-$	6.	0.134 ± 0.007	0.113 ± 0.006
$\pi^+ p \to \pi^-$	22.	0.134 ± 0.007	0.108 ± 0.005
$\pi^- n \to \pi^+$	40.	0.126 ± 0.009	0.110 ± 0.009
$\pi^- p \to \pi^+$	40.		0.115 ± 0.005
$\pi^+ p \to \pi^+$	6.	0.449 ± 0.022	0.447 ± 0.022
$\pi^+ p \to \pi^+$	22.	0.335 ± 0.017	0.363 ± 0.018
$\pi^- n \to \pi^-$	40.	0.226 ± 0.015	0.269 ± 0.014
$\pi^- p \to \pi^+$	24.8		0.077 ± 0.007[c]
$\pi^- p \to \pi^+$	40.		0.085 ± 0.007[c]

integrated over: a) $p_\perp < 0.3$, b) $p_\perp < 1.2$, c) $p_\perp < 1.0$ GeV/c

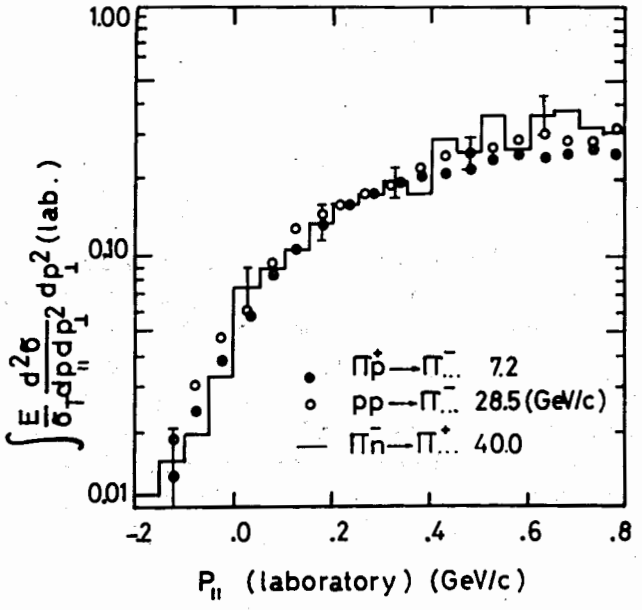


Fig. 1. Invariant inclusive cross sections for proton fragmentation.

the good agreement between the π^-n and π^+p reactions is an evidence for isotopic invariance of the investigated reactions. Moreover, this agreement holds in the projectile fragmentation region (these agreements can be seen quantitatively from table I). It is interesting that the $n \xrightarrow{\pi^-} \pi^+$ and $n \xrightarrow{\pi^-} \pi^-$ fragmentation differ almost by a factor of two although the absolute value of charge exchange between "parent particles" and their fragments is the same. This is also a strong argument in favour of studying the dual structure of inclusive reactions.

Now turning to the π^-p reactions, the following conclusions can be drawn:

(iii) the cross sections in the target fragmentation region fall rapidly both for the π^- and π^+ productions [3,6,9].

(iv) unfortunately, there are almost no experimental data on the π^- fragmentation. Comparing our data with the available results obtained at 24.8 GeV/c [7,9], we conclude that the limiting behaviour has been reached for the $\pi^- \xrightarrow{p} \pi^+$ fragmentation (see Table I). Moreover, a relatively good agreement between the fragmentations $\pi^- \xrightarrow{p} \pi^+$ and $\pi^+ \xrightarrow{p} \pi^-$ in a wide range of incident energy support this conclusion as well (see also fig. 2 and Table I).

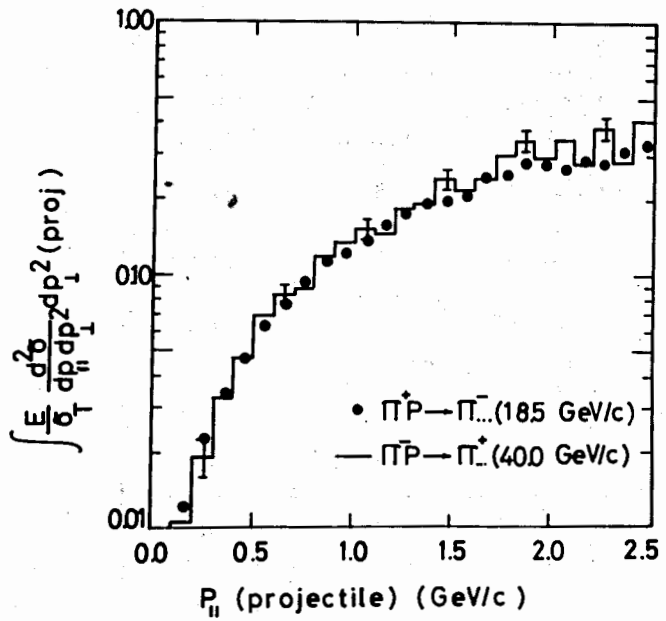


Fig. 2. Invariant inclusive cross sections for pion fragmentation.

A further step is to compare the $\pi^- \xrightarrow{p} \pi^+$ and $\pi^- \xrightarrow{n} \pi^+$ processes which can be a test for factorization. A χ^2 test of the hypothesis that the invariant cross sections $(E\,\sigma_T^{-1} d\sigma/dp_{||})$ are the same for both reactions at 40 GeV/c over the range $0 \leq p_{||}(\text{proj.}) \leq 1$ GeV/c, gives $\chi^2/\text{DF} = 0.93$. This good agreement is the reason why in fig. 2 we show only the $\pi^- p$ distribution. Replacing the $\pi^- \xrightarrow{p} \pi^+$ distribution in fig. 2 by $\pi^- \xrightarrow{n} \pi^+$, the agreement with the isotopically conjugated $\pi^+ \xrightarrow{p} \pi^-$ reactions serves as a further test for the isotopic invariance of inclusive reactions.

The conclusions listed in (i)-(iv) are summarized in Table II. A "yes" in the column "scaling" means that the limiting behaviour for these processes is reached at low energies or, at least, the energy dependence is weak as compared to other reactions. Using these results in the next paragraph, we reexamine different conditions proposed by many authors to understand various energy dependencies of the fragmentation cross sections in the framework of dual models.

Table II.

	Reaction $a \xrightarrow{b} c$	Diagrams present	Scaling yes/no
1	$p \xrightarrow{\pi^+} \pi^-$	3	yes
2	$\pi^+ \xrightarrow{p} \pi^-$	3	yes
3	$\pi^- \xrightarrow{p} \pi^+$	2 3	yes
4	$p \xrightarrow{\pi^-} \pi^+$	1 3	no
5	$p \xrightarrow{\pi^+} \pi^+$	1 2 3	no
6	$p \xrightarrow{\pi^-} \pi^-$	1 2 3	no
7	$\pi^+ \xrightarrow{p} \pi^+$	1 2 3	no
8	$\pi^- \xrightarrow{p} \pi^-$	1 2 3	no

2. EXOTIC CHANNELS AND APPROACH TO SCALING

The role of duality and exotics in inclusive reactions has first been investigated by Chan et al. [10]. They have shown that for the inclusive fragmentation $a \xrightarrow{b} c$, if $ab\bar{c}$ are exotic, the limiting behaviour occurs at low energies. Stimulated by this work, a number of other sufficient conditions have been proposed theoretically for the early scaling [11-14]. These consitions are the following:

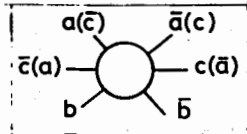
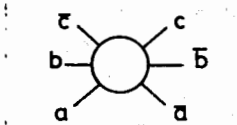
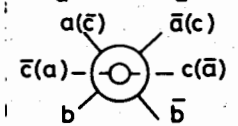
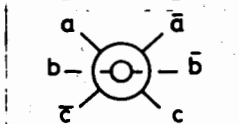
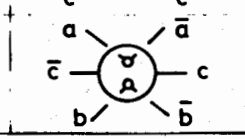
- in ref. [11]: ab and $b\bar{c}$ are exotic;
- in ref. [12]: ab and $ab\bar{c}$ are exotic;
- in ref. [13]: $a\bar{c}$ are exotic;
- in ref. [14]: all channels are exotic.

Our opinion is that these conditions do not contradict each other, they differ only in the level of strickness. The origin of this great variaty results from the fact that theoretically one cannot estimate relative strengths of different diagrams having discontinuities in the three-particle $(ab\bar{c})$ amplitude. Therefore, the solution of this problem is mainly an experimental subject. Based on the experimental results, presented

in paragraph 2 (Table II), and guided by papers[10-14], we attempt to estimate quantitatively the contributions of some dual diagrams describing the inclusive processes $a + b \longrightarrow c + X$ in the region of the a into c. $(a \xrightarrow{b} c)$ fregmentation.

The relevant diagrams[14] are summarized in Table III*. Diagrams 4 and 5 have Pomeranchukon in the $b\bar{b}$ channel and comtribute to the limiting fragmentation while diagrams 1-3 have Reggeons in the $b\bar{b}$ channel, so they can make dominant contributions to the energy dependence in the fragmentation region.

Table III.

	Duality diagrams for $ab\bar{c} \to ab\bar{c}$	Nonexotic channels	Pomeron exchange
1		$ab\bar{c}$, $a\bar{c}$, $b\bar{c}$ ($ab\bar{c}$, ab, $a\bar{c}$)	—
2		$ab\bar{c}$, $b\bar{c}$, ab	—
3		ab ($b\bar{c}$)	$c\bar{c}$ ($a\bar{a}$)
4		$a\bar{c}$	$b\bar{b}$
5		—	$a\bar{a}$ $b\bar{b}$ $c\bar{c}$

*We neglect the diffractive dissociation which does not change these conclusions[14]

Analyzing the experimental results on the πN reactions, collected in Table II, we find that in the reactions 1-3, where the scaling is achieved, the contribution of diagram 1 is absent. At the same time in all energy-dependent reactions this diagram contributes (see reactions 4-8 in Table III). Moreover, diagrams 2 and 3 are present in those reactions where the scaling is achieved at low energy. Therefore one can suppose that these diagrams are independent of energy (or are only negligibly energy-dependent). So, the elimination of diagram 1 will imply an energy-independent cross section*. It is easy to check that for this it is sufficient to have $ab\bar{c}$ or $a\bar{c}$ exotic.

More rigorous conditions (see, for example, refs.[11,12,13]) will eliminate, of course, more or all diagrams including the most important first diagram as well. In the phenomenological hierarchy of different conditions for the early scaling the "minimum" condition is the following: $a\bar{c}$ is exotic. This case is realized in the $\pi^- \xrightarrow{p} \pi^+$ (or $K^- \xrightarrow{p} \pi^+$) reactions where both diagrams 2 and 3 are present. As one can see,

*It should be noted that the elimination of both diagrams marked by 1 in Table III seems to be essential. It is supposed in ref.[15] that $b\bar{c}$ is exotic enough to guarantee the scaling behaviour. This condition eliminated only one of the diagrams 1 (nonbracketed). However, a relatively strong energy dependence of the $p \xrightarrow{\pi^-} \pi^+$ fragmentation is inconsistent with this hypothesis.

the experimental data support the validity of this "minimum" condition both for $\pi^- p$ (see this paper) and for $K^- p$ reactions (see ref. [16]) at relatively low energy.

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