CHAPTER II

SCALING PROPERTIES OF THE INCLUSIVE REACTION $K^- + p \rightarrow \Lambda$ + anything

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ABSTRACT:

The scaling properties of the reaction $K^- + p \rightarrow \Lambda$ + anything (1) are studied at 4.2 and 10.1 GeV/c. In this energy range, this reaction is peculiar, as it practically coincides with the hypercharge annihilation reaction $K^- + p \rightarrow \Lambda$ + pions (2) and has a cross section rapidly decreasing with increasing energy. It is found that while the Feynman function $\frac{E^*}{\pi p^*_{max}} \cdot \frac{d\sigma}{dx}$ and the function $\frac{d\sigma}{dx}$ do not scale in the energy range studied, the distributions at 4.2 and 10.1 GeV/c of the function $\frac{1}{\sigma(\Lambda)} \cdot \frac{d\sigma}{dx}$, where $\sigma(\Lambda)$ is the cross section for Λ-production, coincide over the entire x-range. Comments are made on the facts that the inclusive reaction (1) is undeveloped and that the hypercharge annihilation reaction (2) is neither inclusive nor exclusive.

1. INTRODUCTION

This paper reports on a study of the scaling properties of the reaction

$$K^- + p \to \Lambda + \text{anything} \qquad (1)$$

between 4.2 and 10.1 GeV/c.

This reaction, though of the general "inclusive" type $a + b \to c$ + anything, is in several ways fundamentally different from the other inclusive reactions commonly studied, where the particle c is proton, kaon or pion. The reason for this is the following:

At the energies considered in this work, reaction (1) hardly differs from the reaction

$$K^- + p \to \Lambda + \text{pions}. \qquad (2)$$

In fact, the contribution of the channels containing $K\bar{K}$, $p\bar{p}$, $\Lambda\bar{\Lambda}$, etc. is so small that reaction (2) constitutes more than 90 % of reaction (1) at 4.2 GeV/c and about 85% [ref. 1] at 10.1 GeV/c. Thus, at these energies, the scaling properties of reaction (1) will be essentially the same as those of reaction (2). Reaction (2) can be considered as a hypercharge annihilation reaction, in analogy with the baryon annihilation reaction $p + \bar{p} \to$ pions. Annihilation reactions have cross sections decreasing with increasing energy and probably tending to zero at asymptotic energies, whereas the usual inclusive reactions have cross sections tending to a finite constant value. Our inclusive reaction (1), dominated by the hypercharge annihilation (2), has a cross section that decreases by a factor of 1.6 between 4.2 and 10.1 GeV/c, in contrast to, e.g., the cross section for $K^- + p \to K^0$ + anything which remains practically constant in this range [2].

A few additional comments can be made:

a) While at the energies considered here, the inclusive reaction (1) and the hypercharge annihilation (2) are essentially the same, for higher energies the two are expected to differ, reaction (2) becoming an increasingly smaller fraction of reaction (1).

b) It may be interesting to remark that reaction (2), $K^- + p \rightarrow \Lambda$ + pions, is neither exclusive, since it has no precise final state, nor inclusive, since only a given type of secondaries are allowed to accompany the lambda. It is thus an example of the fact that the adjectives inclusive and exclusive do not cover the entire set of reactions.

c) In reaction (1) it is required that the selected secondary particle (the lambda) have the same strangeness as the incoming kaon and the same baryon number as the target proton. Consequently, this reaction has small cross section: 4.2 mb at 4.2 GeV/c and 2.6 mb at 10.1 GeV/c, i.e. ∿ 16% and ∿ 11% of the corresponding total K^-p cross sections.

2. EXPERIMENTAL RESULTS

The results we present are based on measurements of K^-p interactions at 4.2 GeV/c by the Amsterdam-Nijmegen Collaboration and at 10.1 GeV/c by the Aachen-Berlin-CERN-London-Vienna Collaboration. The experiments were performed at the CERN proton synchrotron using the 150 cm British and 200 cm CERN hydrogen bubble chambers. The events of reaction (1) were selected by requiring that the decay of the lambda be observed in the chamber(*). Whether the lambdas observed are directly produced or derive from the decay of another hyperon is of no concern for the purpose of our investigation.

We have verified that integrating over all longitudinal momenta, the transverse momentum distributions of the lambda particles produced at 4.2 and 10.1 GeV/c are essentially the same. The average values of $p_\perp$ were 460 MeV/c and 470 MeV/c at 4.2 and 10.1 GeV/c, respectively. We have thus studied only longitudinal momentum distributions.

Feynman [3] has suggested that in inclusive reactions of the type a + b → c + anything, the Lorentz invariant cross section at the total energy W

$$f(W, p_\perp, p_L^*) = \frac{E^*}{\pi} \frac{d^3\sigma}{d^2p_\perp \, dp_L^*} \qquad (3)$$

(*) In the 10 GeV/c experiment, the sample available did not include the events where more than one V^0 were seen to decay. These events correspond to 0.1 mb, i.e. less than 4% of the total cross section of 2.6 mb for reaction (1).

for production of the particle c (with c.m. energy E^* and momenta $p_\perp$ and p_L^*) should, for $W \to \infty$ scale in the variable $x = p_L^*/p_{max}^*$ (where p_{max}^* is the maximum momentum available) tending to $f'(p_\perp, x)$ independent of W. Integrating over $p_\perp$, energy independence should thus be observed for

$$f''(x) = \frac{E^*}{\pi p_{max}^*} \cdot \frac{d\sigma}{dx} \quad . \tag{4}$$

In fig. 1a we show the distribution of the Feynman function (4) as a function of the variable x of the lambdas, at 4.2 and 10.1 GeV/c. Positive values of x correspond to p_L^* oriented in the direction of the incoming kaon, i.e. forwards. As can be seen, function (4) definitely does not scale.

In fig. 1b are plotted the two distributions of the function $d\sigma/dx$. Again no scaling is observed. However, the two curves appear similar in shape, differing only in the absolute scale. This is tested in fig. 1c, where the two curves are normalized to the same total number of events. The points at 4.2 and 10.1 GeV/c coincide remarkably well, within errors, over the entire x-range (*).

Since the normalisation constant introduced is the cross section $\sigma(\Lambda)$ for Λ-production in reaction (1), we conclude that the function

$$\frac{1}{\sigma(\Lambda)} \cdot \frac{d\sigma}{dx} \tag{5}$$

"scales" very well in the energy range explored. As pointed out before, in the range between 4.2 and 10.1 GeV/c, the ratio of these cross sections is 1.6, while the total K^-p cross section σ_T, decreases by only about 15%. It is thus obvious that the function $\frac{1}{\sigma_T}$ $d\sigma/dx$ would not scale. It has been verified that the two curves in fig. 1a do not coincide when normalized to the same integrated value.

3. DISCUSSION OF THE RESULTS

Now the question arises of whether or not the result of fig. 1c is surprising. The following comments can be made:

(*) The possible small difference in the two distributions in the very backward region ($x \simeq -1$) is not significant with the present statistics.

a) Reaction (1) is an inclusive reaction, since - by design - it sets no limitations on the momentum, nature and multiplicities of the "anything" accompanying the lambda. However, in these experiments at 4.2 and 10.1 GeV/c, this reaction is very far from the asymptotic situation envisaged by Feynman, where the "anything" contains all the multiplicities of secondary particles, and in particular all the multiplicities of the particle studied, the lambda in our case, i.e. all the channels in which one, two, three, ... lambdas are produced.

Reaction (1) is thus, in our case, what we shall call an "undeveloped-inclusive" reaction. At present accelerator energies, in inclusive reactions of the type $a + b \rightarrow c$ + anything, only when c is a pion, are the multiplicities developed enough (the average pion multiplicity is about 4 at 10-20 GeV/c) to justify looking for Feynman scaling. When c is a hyperon, proton and even kaon, the reactions are "undeveloped" as the $Y\bar{Y}$, $p\bar{p}$ and $K\bar{K}$ cross sections are either negligible or very small. Thus, the result of fig. 1a that the Feynman function does not scale for reaction is not unexpected.

b) For the reaction

$$p + p \rightarrow p + \text{anything} \qquad (6)$$

at energies below $p\bar{p}$-production (and hence similarly for other undeveloped reactions) Feynman predicts that the spectrum $d\sigma/dx$ should be flat for small values of $|x|$. This is in first approximation confirmed by experiment [4]. Also for reaction (1) the spectrum $d\sigma/dx$ is fairly flat between $-0.6 < x < +0.3$.

c) It has been reported that for the protons [4] in reaction (6) and for the K^0, ref. 2, in the reaction

$$K^{\pm} + p \rightarrow K^0 + \text{anything} \qquad (7)$$

the function

$$d\sigma/dx \qquad (8)$$

is approximately energy independent, at least over the small ranges of energies explored. This has been called "naïve scaling" by Michejda [5].

That in the case of reaction (1), scaling is observed not for $d\sigma/dx$, but for $\frac{1}{\sigma(\Lambda)} \cdot \frac{d\sigma}{dx}$ may simply reflect the fact that the $\sigma(\Lambda)$ cross section for reaction (1) decreases fairly rapidly with increasing energy, while $\sigma(p)$ and $\sigma(K^o)$ for reactions (6) and (7), respectively, are essentially energy independent. So, it may be that function (5) is a generalisation of function (8).

d) The most interesting feature of our results is probably the fact that the distribution at 4.2 GeV/c overlaps so closely the distribution at 10.1 GeV/c over the entire x-range. Of course, having i) introduced the reduced longitudinal momenta, ii) normalized by dividing by the cross section $\sigma(\Lambda)$ and iii) considered such a limited range of incoming energies, one may think this not surprising. However, resonance production plays a different role at the two energies and, as for the exchange mechanisms involved in Λ-production, the situation is not simple. In fact, in terms of an exchange mechanism, e.g. of the ABFST type [6], lambda production in reaction (1) can proceed only by baryon and/or strange meson (e.g. K^*) exchanges, as illustrated in fig. 2a. Thus, the region of negative x-values is expected to be dominated by K^*-exchange, while baryon exchange should be more frequent for positive x-values. These two exchange mechanisms are thought of, as having cross sections with very different energy dependence, and thus the observation of scaling at all x-values is surprising. It would be very interesting to extend this investigation over a wider energy range.

e) The fragmentation model [7], often invoked to describe multi-body reactions (see fig. 2b), does not seem well suited to shed light on lambda production in reaction (1), as it is difficult to say even where should the lambda be emitted at these energies. It should be noted that the most probable value of x for Λ-production is near zero.

4. CONCLUSIONS

The study of the scaling properties of the reaction $K^- + p \rightarrow \Lambda$ + anything, at energies where it essentially coincides with the hypercharge annihilation reaction $K^- p \rightarrow \Lambda$ + pions, indicates that

i) Neither the "Feynman function" $\frac{E^*}{\pi p^*_{max}} \cdot \frac{d\sigma}{dx}$ nor the "naïve" function $d\sigma/dx$ are energy independent between 4.2 and 10.1 GeV/c. However, the function $\frac{1}{\sigma(\Lambda)} \cdot \frac{d\sigma}{dx}$ scales very well over the entire range of x and is approximately flat for $-0.6 < x < 0.3$.

ii) At the energy considered, this reaction $K^- + p \rightarrow \Lambda$ + anything, is an "undeveloped inclusive" reaction and the behaviour observed for it is not inconsistent with that observed for other undeveloped inclusive reactions. It would be very interesting to study reactions (1) and (2) at higher energies where they are different.

iii) That in the energy range considered any form of scaling is observed for reactions (1) or (2) for the entire x-range, is an interesting fact, as resonance production and reaction mechanisms are supposed to play different roles at different energies.

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FIGURE CAPTIONS

Fig. 1 Distributions of the functions

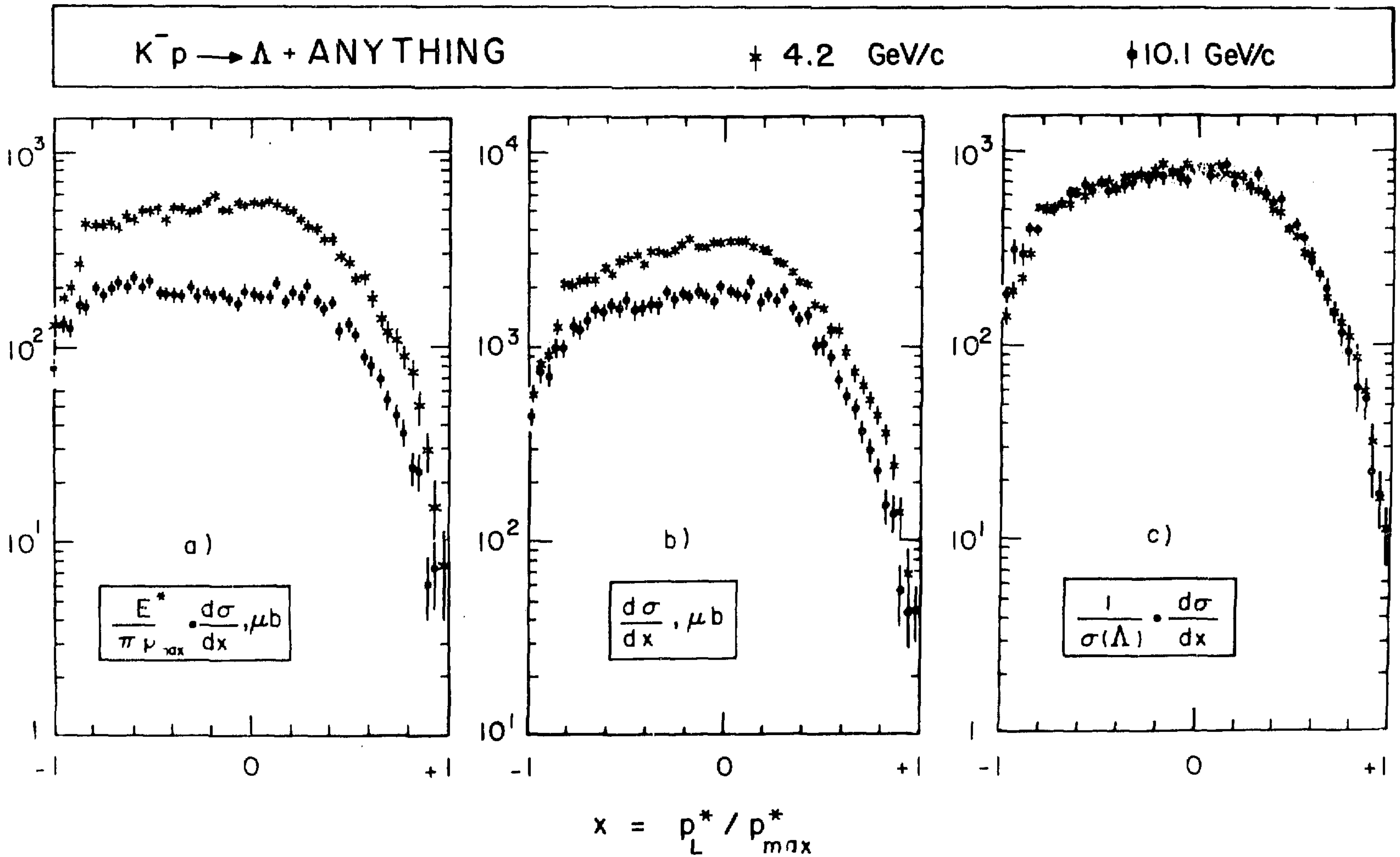
a) $\frac{E^*}{\pi p^*_{max}} \cdot \frac{d\sigma}{dx}$, b) $\frac{d\sigma}{dx}$ and c) $\frac{1}{\sigma(\Lambda)} \cdot \frac{d\sigma}{dx}$

for the lambda particles produced at 4.2 and 10.1 GeV/c in the reaction $K^- + p \rightarrow \Lambda$ + anything . The variable x is the reduced c.m. longitudinal momentum of the lambda and E^* its c.m. energy.

Fig. 2 Schematic description of the Kp interactions studied, using :

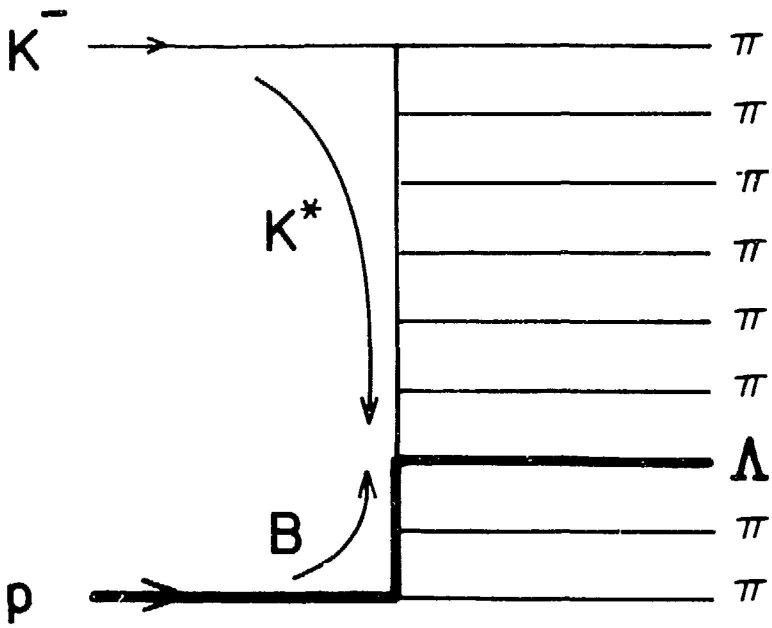
a) a multiperipheral model

b) a fragmentation model.



K⁻p → Λ + ANYTHING
4.2 GeV/c
10.1 GeV/c
a)
$\frac{E^*}{\pi p_{max}} \cdot \frac{d\sigma}{dx}$, μb
b)
$\frac{d\sigma}{dx}$, μb
c)
$\frac{1}{\sigma(\Lambda)} \cdot \frac{d\sigma}{dx}$
$x = p_L^* / p_{max}^*$

Fig. 1



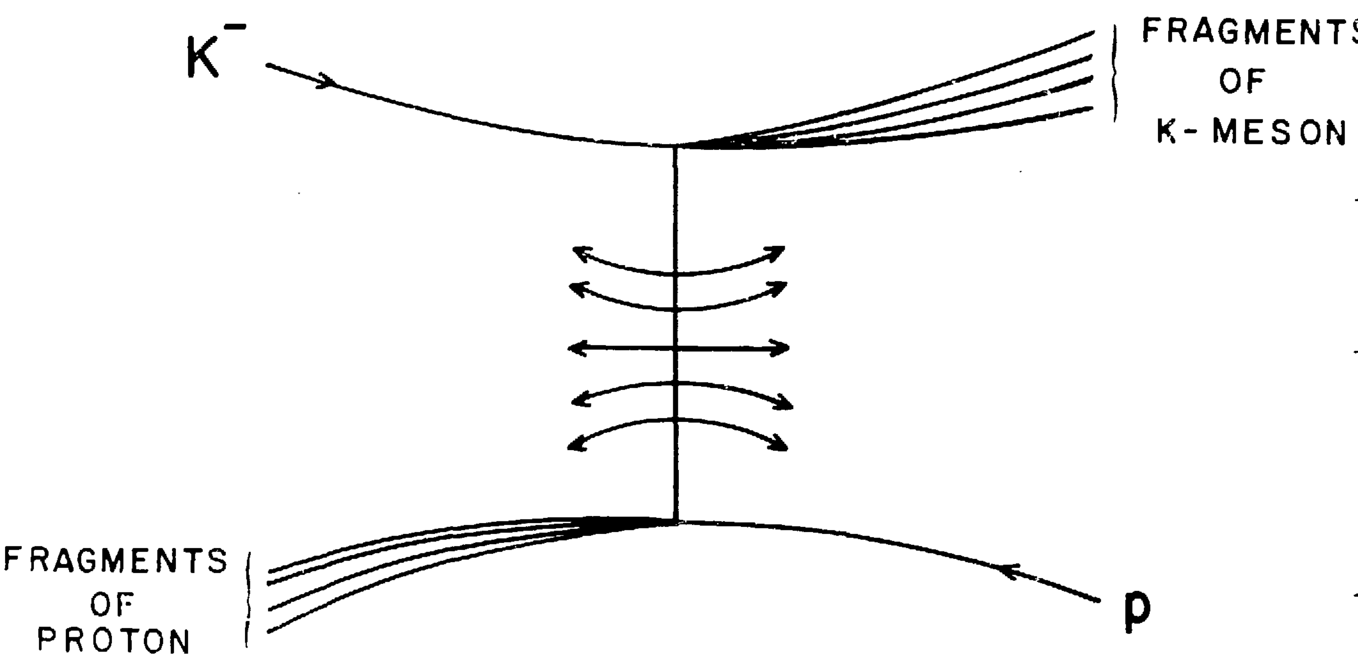


Fig. 2