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DUALITY, STRING MODEL, AND TWO FORWARD LEADING PARTICLE EFFECT

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ABSTRACT

The dual or string model implies that, in high-energy multiproduction, there are generally, in each hemisphere, two leading particles. Inclusive two-particle spectra from K^-p , π^+p and π^-p reactions are analyzed with this idea in mind, as well as exclusive data on $K^-p \rightarrow K^-p 2\pi^+ 2\pi^-$. The results agree with the qualitative predictions for this effect. The conventional multiperipheral approach is compared. Theoretical improvements are suggested in the duality framework. Experiments using hyperon beams are proposed to see the effect more clearly.

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1. INTRODUCTION

When a high-energy baryon hits a target, the most energetic final particle is, in most cases, a baryon which is then called the leading particle. This "leading particle effect" is also observed with high-energy kaons. Generally speaking, the quantum numbers of the projectile like to be carried away by the most energetic final particle. There are natural explanations for this effect. In the quark-parton picture, one says that the initial valence quarks are not slowed down too much. In the multiperipheral approach, one says that the exchange of a non-strange meson is easier than the exchange of a strange meson, which is in turn easier than the exchange of a baryon. The formulation of this statement, in terms of Regge intercept, is

$$\alpha_{\text{Pomeron}} > \alpha_{\rho, \omega \dots} > \alpha_{K^* \dots} > \alpha_{N, \Delta \dots} > \alpha_{\text{exotic} (?) \quad (1.1)$$

However, there is no reason to believe that the incident quarks are found in the same final particle; in fact, the planar duality diagrams for meson-meson scattering (Fig. 1a) imply this is not generally so.

In the conventional duality scheme ¹⁾, diagrams (a) and (c) are supposed to yield a constant cross-section, while the contribution of diagrams b is in $s^{-\frac{1}{2}}$ (and they require a non-exotic channel). Diagram (c) corresponds to single diffractive dissociation, which amounts to no more than 15% of the inelastic cross-section (in pp scattering). We are therefore led to the conclusion that, in most events, there are two leading particles (L_1 and L_2 in Fig. 1a) associated with a meson projectile ^{*)}.

The two leading particles have been given a diagrammatic definition. Why should they have a "kinematic" leadership? Our opinion is that dual amplitudes decrease very fast when the invariant mass (or the rapidity difference) of two adjacent particles in diagram 1a becomes large. We have roughly the same explanation as in multiperipheral models, and in fact, dual amplitudes do have multi-Regge limits at high energy.

The plausible existence of a "two-leading particle effect" was, in fact, brought to our attention by a classical approach to the string model ²⁾. Although such a classical treatment is questionable, its simplicity and good features make it an intuitive tool of investigation and we shall often refer to it for a phenomenological description (see Fig. 2).

*) This way of speaking presupposes that each event is due to one type of diagram, i.e., ignores interference terms.

Now it may happen that in the $(L_1 L_2)$ team, one is nearly always much more leading than the other, so that we only see a "one-leading particle effect". In fact, this seems to be the case with a proton or a kaon beam. Experimenters have not noticed any second leading particle so far, and we should explain this. Therefore, the problem is to look for experimental data which could reveal the existence of two leading particles: for instance, a two-particle inclusive spectrum $f(x_1, x_2)$ (x is the Feynman variable $2p_{||}^* s^{-\frac{1}{2}}$) which remains important in the region $x_1 \sim x_2 \sim \frac{1}{2}$ and cannot be explained by another mechanism (e.g., a two-body resonance). Observation of such an effect would be welcome to those who believe in the dual or string model.

We have analyzed data on K^-p , π^+p and π^-p reactions at CERN PS, and the answer turns out to be rather positive: a beam-like particle can share its leadership with a pion of the same charge. We have also analyzed exclusive data on $K^-p \rightarrow K^-p 2\pi^+ 2\pi^-$. Here again, the fastest π^- seems to be a second leading particle.

In the next section we state the expected features of the two-leading particle effect, both from dual diagrams and string picture. In Section 3, we present the experimental two-particle spectra of K^-p , π^+p and π^-p reactions, and in Section 4 exclusive data on $K^-p \rightarrow K^-p 2\pi^+ 2\pi^-$. We discuss these results in Section 5, referring to the conventional multiperipheral approach. We summarize and give our conclusions in Section 6. Further experimental and theoretical developments are proposed in Section 7.

2. TWO- VERSUS ONE-LEADING PARTICLE EFFECT

Let us now discuss more precisely what are the specific features expected from a two-leading particle effect, i.e., let us compare the $(L_1 L_2)$ system of diagram 1a with the $(L\ell)$ system of diagram 1b, or with the $(L_1 \ell_1)$ system.

(a) The $(L_1 L_2)$ system can be exotic, contrary to $(L\ell)$. Conversely $(\bar{A}\ell_1)$, $(\bar{A}\ell_2)$ or $(\bar{A}\ell)$ can be exotic contrary to $(\bar{A}L_1)$ and $(\bar{A}L_2)$. Therefore the two-leading particle effect would be cleaner in inclusive experiments, such that ^{*})

$$\pi^+ \rightarrow \pi^+ \pi^+ \dots, \quad K^+ \rightarrow K^+ \pi^+ \dots$$

^{*}) In the following the notation $A \rightarrow CD \dots$ means $A + B \rightarrow C + D + \text{anything}$.

than in

$$\pi^+ \rightarrow \pi^+ \pi^0 \dots, \quad K^+ \rightarrow K^0 \pi^+ \dots$$

and absent in

$$\pi^+ \rightarrow \pi^+ \pi^- \dots$$

(b) L_1 and L_2 do not resonate, whereas L and ℓ do. More generally, there are few dynamical correlations between L_1 and L_2 ; the dual N point function is such that particles are less and less correlated as they are more and more distant in the cyclic order. The correlations between L_1 and L_2 are therefore mainly kinematical (conservation of energy momentum). If we could ignore the restriction $x_1 + x_2 < 1$, we would have

$$f(x_1, x_2) \approx g(x_1) h(x_2) \quad (2.1)$$

(c) According to the inequalities (1.1), there is an asymmetry in the two-leading particle effect. For instance, a kaon projectile will usually give a leading kaon and a leading pion, but with more momentum for the kaon. This is easily seen by considering the different multi-Regge limits of diagram 1a (see, for instance, Fig. 12). All those with a pion at the beginning of the chain have a K^* exchange and are therefore relatively suppressed. This is one of the reasons why only single leading particle effects have been observed so far.

(d) For the diffractive events in which the projectile is dissociated, one expects also a two-leading particle effect; in Fig. 1c, the quark and the antiquark of B do not go in the same final particle. In the classical string model, we can also derive the same result: there exist analogues of the Pomeron exchange which consist of two rearrangements (Fig. 3). We show that the decay of each of them gives two leading particles. This classical realization of Pomeron exchange must not be taken too seriously because quantum effects are predominant in diffractive phenomena, but sometimes classical predictions appear to be correct. Whatever approach we use, in diffractive reactions such as

$$K^- \xrightarrow{\text{diff. diss.}} K^- \pi^+ \pi^- , \quad (2.2)$$

$$\pi^- \xrightarrow{\text{diff. diss.}} \pi^- \pi^+ \pi^- , \quad (2.3)$$

one expects the π^+ to be the slowest particle.

In this last example, where a state of only three particles is diffractively produced, the two leading particles may not be independent, contrary to the non-diffractive case. For instance, if both of them were to resonate simultaneously with the π^+ , they would become correlated in the longitudinal phase space.

(e) Experimentally, if we look for a leading pion with an apparatus which detects only one charge state (π^- , π^+ or π^0), we miss it about half of the time. Therefore, in an inclusive two-particle spectrum like

$$K^- \rightarrow K^- \pi^- \dots ,$$

there is an additional source of asymmetry which consists of events where a π^0 is the second leading particle. In

$$\pi^- \rightarrow \pi^- \pi^- \dots ,$$

one or two π^0 's (undetected) can be leading. In these two examples the two-particle spectrum will have an apparent "one-leading particle effect" component superimposed on the two-leading particle effect.

Theoretical remark: the concept of "leading particle" is classical and has no foundation in quantum theory, strictly speaking. For instance, looking at one event like

$$K^- p \rightarrow K^- \pi^- \pi^0 + \text{anything}$$

the question "which of the two pions was the second leading particle?" has no theoretical meaning because there are interferences between differently ordered dual diagrams. Only when one of the pions is much faster than the other, can one consider it as a leading particle, because in this case one class of diagrams dominates the other.

3. EXPERIMENTAL TWO-PARTICLE DISTRIBUTIONS

Data from the Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-London-Vienna-Varsaw Collaboration for the reactions

$$K^- p \rightarrow K^- \pi^- + \text{anything} \quad (3.1)$$

$$K^- p \rightarrow K^- \pi^+ + \text{anything} \quad (3.2)$$

at 10 and 16 GeV/c, and

$$\pi^+ p \rightarrow \pi^+ \pi^+ + \text{anything} \quad (3.3)$$

$$\pi^+ p \rightarrow \pi^+ \pi^- + \text{anything} \quad (3.4)$$

$$\pi^- p \rightarrow \pi^- \pi^- + \text{anything} \quad (3.5)$$

$$\pi^- p \rightarrow \pi^- \pi^+ + \text{anything} \quad (3.6)$$

at 16 GeV/c, have been used to test the two-leading particle conjecture. We looked at the two-particle distributions $f(x_1, x_2)$ where

$$x = p_{\parallel}^* / p_{\parallel \text{ max}} \quad (3.7)$$

refer to the fastest particles of the species which are observed. Figures 4 to 7 represent these distributions as functions of $x_1 - x_2$ for different intervals in $x_1 + x_2$.

In reactions (3.1) and (3.2), there were many K^-/π^- ambiguities. To give an idea, in reaction (3.1), the percentage of ambiguous events was 30-40% for four-prong events, 50-80% for six or more prongs. For such events, all the hypotheses were given an equal weight ^{*)}. In all the reactions, the p/π^+ ambiguous events are negligible, since we are only interested in fast positive pions.

^{*)} This procedure introduces a bias in the plotted $K^- \pi^-$ and $K^- \pi^+$ spectra. It reduces the leading character of the kaon and the asymmetry of the $K^- \pi^-$ spectrum.

Except for Fig. 6, all the curves show a strong asymmetry which is the conventional leading particle effect. There is always a shoulder (A) at $x_1 \gtrsim 0.7$, $x_2 \lesssim 0.2$ (from now on, 1 will refer to the beam-like particle). This shoulder can be interpreted as due to diffractive events where only the target is excited (Fig. 1c, where A is the projectile). In Figs. 8 and 9 we represent, by dual diagrams, the mechanisms which are supposed to dominate in the different regions of the longitudinal phase space. The particularities which seem relevant to us are the following.

(1) In $K^- \rightarrow K^- \pi^-$ a maximum (B) is seen at $x_K - x_\pi = 0$ for $x_K + x_\pi > 0.8$. This maximum ^{*)} we interpret as being due to diffractive events; if we restrict ourselves to events with six or more charged outgoing particles (Fig. 4b), this maximum disappears (up to statistical fluctuations). The fact that the kaon and the pion share about equally the incident momentum, may then be interpreted as a two-leading particle effect in diffractive dissociation.

The strong correlation at $x_K = x_\pi$ is not quite unexpected (see paragraph 2d). It may be understood as a positive interference between a ρ^0 and a $\bar{K}^{*0}$ mechanism in reaction (2.2) which overlaps precisely for $x_K = x_\pi$.

A similar enhancement B, although much less pronounced, is seen in $\pi^+ \rightarrow \pi^+ \pi^+$... and in $\pi^- \rightarrow \pi^- \pi^-$... (Fig. 6). It may have the same origin as in the $K^- \pi^-$ case.

After elimination of the events with $n_{ch} \leq 4$ (Fig. 4b), the maximum B observed in $K^- \pi^-$ is not replaced by a "valley". This is an indication of a two-leading particle effect in the non-diffractive component also ^{*)}.

No such bump is present in $\pi^\pm \rightarrow \pi^\pm \pi^\mp$... (Fig. 7). On the contrary, there is a valley (C) which means that the π^+ and the π^- cannot be leading at the same time. Let it be said, incidentally, that the enhancement (D) at $x_1 - x_2 < -0.5$ is somewhat surprising because it corresponds, in multiperipheral language, to a double charge exchange. In fact, it can be explained by the decay of a fast ρ^0 of zero helicity, where half the time the beam-like pion is emitted backwards.

*) Taking care of the bias due to K^-/π^- ambiguities does not affect the existence of a bump or a valley at $x_K = x_\pi$.

In $K^- \rightarrow K^- \pi^+$ also (Fig. 5), the bump at $x_1 - x_2 = 0$ is absent. Instead, we have one (E) at $x_1 - x_2 = -0.25$ and a valley (F) at $x_1 - x_2 = +0.25$. Again, the explanation by a resonance effect (here a $\bar{K}^{*0}$) works satisfactorily.

(2) Except for the (diffractive?) bumps A and B, the $K^- \pi^-$, $\pi^- \pi^-$ and $\pi^+ \pi^+$ spectra are smooth and show, on a logarithmic scale, a linear behaviour in x_1 and x_2 . We have, roughly (within a factor 2)

$$\frac{d^2 N}{dx_1 dx_2} \begin{cases} = c^{st} 13^{-x_1} 63^{-x_2}, \text{ for } K^- \pi^- \\ = c^{st} 115^{-x_1 - x_2}, \text{ for } \pi^+ \pi^+ \\ = c^{st} 570^{-x_1 - x_2}, \text{ for } \pi^- \pi^- \end{cases} \quad (3.8)$$

in a region G in the middle of the positive x_1 and x_2 sector. The region G for each case is delimited in Figs. 8a and 9a. The behaviour expressed by (3.8) is of the form of (2.1) and means some independence between the two particles. On the contrary, there seems to be much structure in the $K^- \pi^+$ spectrum, as we have seen above. The $\pi^+ \pi^-$ spectra, for their part, have a region G of exponential behaviour indicated in Fig. 9b

$$\frac{d^2 N}{dx_1 dx_2} \begin{cases} = c^{st} 70^{-x_1} 130^{-x_2}, \text{ for } \pi^- \rightarrow \pi^- \pi^+ \dots \\ = c^{st} 43^{-x_1} 200^{-x_2}, \text{ for } \pi^+ \rightarrow \pi^+ \pi^- \dots \end{cases} \quad (3.9)$$

We conclude that (2.1) is more or less satisfied in the cases where we expected a two-leading particle effect, although in the two-pion case this is not characteristic.

(3) Another way to compare the even charge pion spectra to the $\pi^+ \pi^-$ spectra is to look at the shape of the valley along the line $x_1 = x_2$. For the $2\pi^\pm$ cases, this valley is flat (region G) or even has a bump in the middle (B), in accordance with a two-leading particle effect. The hills (A) on each side are probably due to diffractive events, as we have said before, and also to events where the leading particles are a $\pi^\pm$ and a π^0 . To see if this flatness is characteristic or not, we have symmetrized the $\pi^+ \pi^-$ spectrum for comparison:

$$f_{\text{sym}}(x_1, x_2) = f(x_1, x_2) + f(x_2, x_1) \quad (3.10)$$

f_{sym} is plotted in Fig. 10. We see also a flatness in this case, but it breaks down at large values of $x_1 + x_2$; the height of the middle of the valley, i.e., $f(x/2, x/2)$, decreases much faster for $x \rightarrow 1$, in the $\pi^+\pi^-$ cases, than in the $2\pi^\pm$ cases. It is this last feature which, in our opinion, can be called in the least ambiguous fashion, a "two-leading particle effect", no matter what theoretical interpretation we give to it.

4. EXCLUSIVE ANALYSIS OF A PARTICULAR REACTION: $K^-p \rightarrow K^-p 2\pi^+ 2\pi^-$

The conventional leading particle effect is seen in exclusive final states as well as in inclusive ones. The same should be true for the two-leading particle effect. We have considered the reaction

$$K^-p \rightarrow K^-p 2\pi^+ 2\pi^- \quad (4.1)$$

and analyzed a sample of 600 events at 16 GeV/c from the Aachen-Berlin-CERN-London-Vienna Collaboration. Instead of the longitudinal momentum, we considered the variable

$$Z = \log(E + p_{\parallel}) \quad (4.2)$$

which we call "semi-rapidity". It has the same transformation property under a longitudinal boost as the rapidity itself. In the projectile fragmentation regions, it is equivalent to $\log x$. Therefore, it is an adequate variable both in the central region and in the projectile fragmentation region. We have displayed, for illustration, a lot of 20 events on the Z axis (Fig. 11). The leadership of the kaon is easily seen. In order to see what comes next, we divided the events into six groups:

Group	p	:	proton leading
"	+		π^+ "
"	-		π^- "
"	pK		K^- leading, then the proton
"	+K		" a π^+
"	-K		" a π^-

The results are summarized in Table 1. There were 88 ambiguous events, nearly all K^-/π^- ; the remainder being p/π^+ . For these events we adopted

successively the following two procedures:

- a) equal weight for all hypotheses;
- b) p/π^+ ambiguity, equal weight. K^-/π^- ambiguity, retain only the hypothesis $Z_K > Z_{\pi^-}$.

The actual repartition must lie between the two results, but probably close to prescription (a); in fact, most K^-/π^- ambiguities occur at small $|Z_K - Z_{\pi^-}|$ where the two hypotheses must not have very different probabilities (look at the non-ambiguous events in the same region).

This table shows that, on the average, the π^- is slightly faster than the π^+ . This is consistent with duality diagrams (Fig. 12). However, when the K^- is leading, the π^+ usually comes next. In other words, the π^+ is more dependent on the K^- than the π^- . To see this effect in more detail, we have plotted in Fig. 13 the distributions of

$$\begin{aligned} d^+ &= Z_{\pi^+ \text{ fast}} - Z_K \\ d^- &= Z_{\pi^- \text{ fast}} - Z_K \end{aligned} \quad (4.3)$$

The d^- distribution is broader than the d^+ one. This relative independence between the K^- and the π^- is an important property expected from the two-leading particle effect. For the $K^-\pi^+$ system, on the contrary, the $\bar{K}^{*0}$ mechanism allows only a limited range in d^+ which is shown in Fig. 13a.

Also, in Fig. 14, we have plotted the single-particle distributions of Z_{K^-} , $Z_{\pi^+ \text{ fast}}$ and $Z_{\pi^- \text{ fast}}$. The π^- spectrum is broader than the π^+ one, especially towards higher Z .

5. COMPARISON WITH THE CONVENTIONAL MULTIPERIPHERAL APPROACH

Reggeized multiperipheral models, in their simplest versions, assume that the high-energy multiproduction amplitudes are dominated by comb diagrams as in Fig. 15a, where the wavy line represents a Reggeon. Qualitatively, these models are successful in predicting small transverse momenta, leading particle effect, limiting fragmentation, and pionization. The ordering of the final particles in the multiperipheral chain corresponds grosso modo to the ordering in longitudinal momentum. Each diagram of type (a) defines only one leading particle (in each hemisphere). If we allow K^* exchange but no exotic exchange in, for instance, reaction (4.1), the leading particle can be either the K^- or a π^- , but not a π^+ . This

is sufficient to explain why the fastest π^- is, on the average, more rapid than the fastest π^+ . Duality is not required (although the absence of exotic is most easily derived from dual diagrams). What is specific of dual diagrams is that the K^- and the π^- can be leading at the same time. In fact, the multi-Regge model cannot give the probability of such an event, because it applies only when all subenergies in the final state are large. If not, one has to replace diagram (a) by (b), which involves low-energy Reggeon-particle amplitudes.

A standard approach, which considers Reggeon exchange together with resonance production (diagram 15c), is, however, appropriate to study most of the detailed structures of the longitudinal phase space distributions. As an example, we have given an explanation of the bumps and valleys observed in the $K^-\pi^+$ and $\pi^+\pi^-$ spectra in terms of ρ^0 and $\bar{K}^{*0}$ production.

6. CONCLUSIONS

By considering quark-duality diagrams, or a classical string model for multiproduction, we have been led to expect a two-leading particle effect having the following properties:

- a) it is most easily seen in the two-particle spectrum of a pair with exotic quantum numbers;
- b) in non-diffractive events, there is little correlation between the two-leading particles, except for energy-momentum conservation;
- c) for an incident kaon or baryon, the two-leading particle effect is asymmetric, in favour of the beam-like particle, which explains the usual observation of only one leading particle;
- d) the two-leading particle effect is also present in the projectile diffractive dissociation, but here correlations may occur (in the case of three-body dissociation).

To test these properties, we have analyzed experimental data on K^-p and $\pi^\pm p$ reactions, most of them at 16 GeV/c. The two-particle spectra $f(x_1, x_2)$ of $K^- \rightarrow K^-\pi^- \dots$, $\pi^\pm \rightarrow 2\pi^\pm \dots$, show a significant abundance of events in the region $x_1 \sim x_2 \sim \frac{1}{2}$ which is, phenomenologically at least, a two-leading particle region. By comparison, the $K^- \rightarrow K^-\pi^+$ and $\pi^\pm \rightarrow \pi^+\pi^-$ spectra, which involve only one-leading particle, are relatively depleted in this region.

We interpret these bumps at $x_1 \sim x_2 \sim \frac{1}{2}$ as due mainly to diffraction dissociation combined with the two-leading particle effect, but after eliminating, in the $K^-\pi^-$ case, the diffractive components by requiring $n_{ch} \geq 6$, there remain enough events to indicate a two-leading particle effect in the non-diffractive component also.

The absence of dynamical correlation between the two leading particles, in the case of non-diffractive events, has been tested in several ways: approximate factorization in x_1 and x_2 ; absence of structure in $x_1 - x_2$ (compared with the $K^- \pi^+$ and $\pi^+ \pi^-$ cases).

In the exclusive channel $K^- p \rightarrow K^- p 2\pi^+ 2\pi^-$, we found that the fastest pion is more frequently a π^- than a π^+ , and a relative independence between the fastest π^- and the K^- , as predicted.

As a first conclusion, these experimental data seem to be consistent with the existence of two leading particles.

We have compared our approach with the standard analysis in terms of multi-Regge exchange together with resonance production. This last approach does not contradict, nor predict, the two-leading particle effect. The two approaches seem, in fact, complementary. The classical string model would give a background shape for the two-particle spectrum, while the standard analysis explains the detailed structure; by this method we have proposed an interpretation for the most significant bumps observed in the non-exotic spectra as resonance effects.

7. PROPOSED FURTHER DEVELOPMENTS

7.1 Towards more quantitative predictions

The dual resonance model may be used to assert the two-leading particle effect in a more quantitative form. Let us consider the two-particle inclusive experiment

$$A + B \rightarrow C_1 + C_2 + X,$$

where X is the set of undetected particles. According to Mueller's approach, the two-particle spectrum is the discontinuity of a forward $4 \rightarrow 4$ scattering amplitude ³⁾, apart from some kinematic factor:

$$\frac{d\sigma}{d^3 p_1 d^3 p_2} \approx \text{disc} \frac{M_X^2}{M_X^2} T(A+B+\bar{C}_1+\bar{C}_2 \rightarrow A+B+\bar{C}_1+\bar{C}_2). \quad (7.1)$$

At present, an "exact" calculation of this eight-point function seems practically beyond our possibilities. However, in asymptotic regions of the phase space, one can approximate it by a partially Reggeized form, for instance, in the "triple-Regge" limit

$$s, M_X^2 \text{ and } s/M_X^2 \rightarrow \infty \quad (7.2)$$

Using

$$M_X^2 \approx s (1 - x_1 - x_2) \quad (7.3)$$

we see that this region is close to the kinematical boundary $x_1 + x_2 = 1$. The corresponding Mueller-Regge graph is shown in Fig. 16a. The two-particle distribution should be written

$$\frac{E_1 E_2 d\sigma}{d^3 p_1 d^3 p_2} = s^{-1} g_{BBP} M_X^2 \alpha_P^{(0)} \sum_{R, R'} g_{RR'P}(t) \quad (7.4)$$

$$\left(\frac{s}{M_X^2} \right)^{\alpha_R(t) + \alpha_{R'}(t)} T(A+R \rightarrow C_1 + C_2) T^*(A+R' \rightarrow C_1 + C_2)$$

What is not known is the "Reggeon particle scattering amplitude" $T(A+R \rightarrow C_1 + C_2)$, which a priori depends on $x_1 \simeq 1 - x_2$, $p_{\perp 1}$ and $p_{\perp 2}$ (limiting fragmentation hypothesis). This is precisely what the dual resonance model is able to give, for instance, by considering the triple-Regge limit of the planar diagram 16b. By doing so, we hope to get an expression of the form (7.4), which could be compared quantitatively with experiments.

7.2 Case of a baryonic projectile

So far, we have discussed the two-leading particle effect in the case of a mesonic projectile. For a baryon, which has three quarks, one might expect a three-leading particle effect. To investigate this problem, let us consider a string model in which a baryon is made of three strings connected with one junction and carrying the quarks at their free ends ⁴⁾. Some multiproduction diagrams, which we think to be the most important, are represented in Fig. 17. Diagrams (a) and (d) give two-leading particles, while (b) and (c) give three. When we stretch these diagrams into multiperipheral configurations, a) has a meson or a baryon exchange (dual to each other) at the beginning of the multiperipheral chain, b) has a baryon or an exotic meson exchange, c) has (at least) twice a baryon exchange or one baryon, then an exotic meson exchange. Therefore, one expects b) to be dynamically suppressed relative to a), and c) still smaller. Therefore, we should have essentially a two-leading particle effect.

7.3 Experiments with hyperon beams

The question of the existence of two-leading particles seems to us important enough as to make more appropriate experiments than those we analyzed here. Hyperon-nucleon collisions in which one leading particle

takes the strangeness, while the other one takes the baryonic number, seem a priori cleaner to analyze. Let us make a list of such reactions, requiring that diagram a) contributes. For experimental reasons, we consider only Λ , Σ^- and Ξ^- beams and eliminate those reactions where one of the leading particles is a neutron or a Σ^0 . There remains

$$\Lambda \rightarrow p K^- \dots \quad (1)$$

$$\Lambda \rightarrow p \bar{K}^0 \dots \quad (2)$$

$$\Xi^- \rightarrow \Lambda K^- \dots \quad (3)$$

$$\Xi^- \rightarrow \Lambda \bar{K}^0 \dots \quad (4)$$

$$\Xi^- \rightarrow \Sigma^- K^- \dots \quad (5)$$

$$\Xi^- \rightarrow \Sigma^- \bar{K}^0 \dots \quad (6)$$

Reactions (1), (3) and (6) also receive a contribution from diagram d) (diffraction dissociation).

Finally, it should be possible to observe a three-leading particle effect in the reactions

$$\Xi^- \rightarrow p K^- K^- \dots$$

$$\Xi^- \rightarrow p K^- \bar{K}^0 \dots$$

where diagram b) contributes, but not a) nor d).

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Table 1
 Repartition of the events in the reaction $K^- p \rightarrow K^- p 2\pi^+ 2\pi^-$ (notation explained in the text)

a) equal weight procedure

+	111	18.5%	-	160	26.8%	p	16	2.7%	K non-leading	287	47.8%
+K	137	22.8%	-K	109	18.2%	pK	67	11.2%	K leading	313	52.2%
sum	248	41.3%	sum	269	45%	sum	83	13.9%	total	600	

b) $Z(K^-) > Z(\pi^-)$ hypothesis

+	112	18.7%	-	125	20.8%	p	15	2.5%	K non-leading	252	42%
+K	145	24.2%	-K	134	22.4%	pK	69	11.5%	K leading	348	58%
sum	257	42.8%	sum	259	43.2%	sum	84	14%	total	600	

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FIGURE CAPTIONS

- Fig. 1 : Typical lowest order duality diagrams for multiproduction.
- Fig. 2 : Classical history of a typical multiproduction event, corresponding to a diagram of type a).
- Fig. 3 : Classical histories corresponding to Pomeron exchange: two rearrangements, separated by (a) a time-like interval; (b) a space-like interval.
- Fig. 4 : Two-particle distribution in an $x_1 - x_2$ versus $x_1 + x_2$ plot. The bin size is 0.1×0.1 . Only the forward sector ($x_1 > 0$, $x_2 > 0$) is represented. Points of equal $x_1 + x_2$ are joined by broken line curves. The figures between them indicate the separations of the strips in $x_1 + x_2$. Only the fastest particle of each species is considered.
- Fig. 5 : Same presentation as for Fig. 4. The structures E and F are interpreted as a $\bar{K}^{*0}$ decaying in $\cos^2 \theta$ (θ being the $\bar{K}$ emission angle in the K^* frame).
- Fig. 6 : Same presentation as for Fig. 4.
- Fig. 7 : Same presentation as for Fig. 4. The bump D is interpreted as ρ^0 decays with the beam-like pion emitted backwards.

Fig. 8 : Different regions of the two-particle longitudinal phase space and their corresponding relevant dual diagram (K^-p reactions). G is the region where formula (3.8) is approximately valid.

Fig. 9 : Same as for Fig. 8, but for πp reactions.

Fig. 10 : Symmetrized plot of the two-particle distribution of $\pi^+ \rightarrow \pi^+ \pi^- \dots$, by the mean of formula (3.10).

Fig. 11 : Visualization of 20 events $K^-p \rightarrow K^-p 2\pi^+ 2\pi^-$ on the $Z = \log(E + p_{\parallel})$ axis. $Z_{\max} = \log(E + p_{\parallel})_{\text{total}}$. Each line corresponds to one event, except for ambiguous events where the various hypotheses are gathered by a $\{$.

Fig. 12 : Duality diagrams for $K^-p \rightarrow K^-p 2\pi^+ 2\pi^-$. Pomeron exchange is not included. Diagrams with two different quarks of the proton participating are also discarded. Some corresponding multi-Regge diagrams are shown.

Fig. 13 : Histograms of the semi-rapidity difference between the fastest $\pi^{\pm}$ and the kaon [formula (4.3)] in reaction $K^-p \rightarrow K^-p 2\pi^+ 2\pi^-$. The bin size is 0.3. We indicate the range in d^+ of the $\bar{K}^{*0}$ mechanism (θ is the K^- emission angle in the K^* frame).

Fig. 14 : Histograms of the semi-rapidities Z of the kaon and the fastest π^+ and π^- in reaction $K^-p \rightarrow K^-p 2\pi^+ 2\pi^-$ (see Fig. 11). The bin size is 0.3 except for $Z > Z_{\max} - 0.6$, where it is 0.1.

Fig. 15 : Various types of multiperipheral diagrams for multiproduction: (a) simple multi-Regge diagram; (b) partially Reggeized diagram for the emission of low mass clusters; (c) multi-Regge exchange together with resonance production.

Fig. 16 : Mueller graphs for the inclusive two-particle spectrum: (a) triple-Regge limit; (b) planar duality diagram for the eight-point function.

Fig. 17 : Quark-duality diagrams for multiproduction with a baryon projectile, assuming the Y shaped string model. — quark line; $\llcorner\llcorner\llcorner$ baryonic junction line. The last diagram represents diffractive dissociation.

FIG.2

(a)

(b)

FIG. 3

FIG. 4 a

FIG.5

FIG. 6 a

FIG. 6 b

$\pi^+p \rightarrow \pi^+ \pi^- \dots 16 \text{ GeV}/c$

FIG. 7a

FIG. 7b

FIG. 8

FIG.9

FIG.10

FIG.12

FIG.13

FIG.14

FIG. 15

FIG.16

FIG.17