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LOW p_T FRAGMENTATION IN QCD*

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Abstract: A brief summary of the applications of quantum chromodynamics to low p_T processes is presented.

Résumé: Nous présentons un bref sommaire des applications de la chromodynamique quantique aux processus à flaible moment transverse.

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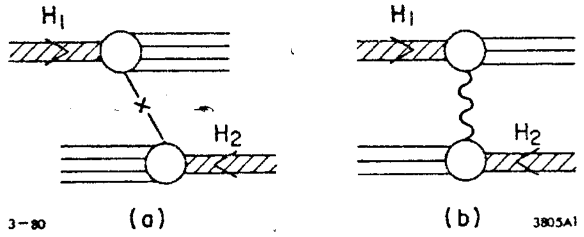

Fig. 1. (a) Hadron collision by quark exchange, (b) Hadron collision by gluon exchange

In the framework of QCD two basic interaction mechanisms for hadron-hadron collisions can be envisioned:

a) "wee" quark exchange or interaction,1)

b) gluon exchange.2)

As discussed in Reference 1, quark exchange leads to long range correlations between the fragmentation regions of the colliding hadrons H_1 and H_2. Those correlations have not been observed in recent experiments.3) In contrast a mechanism such as soft gluon exchange, which leaves the initial hadron quark momentum states undisturbed leads to the observed "constant" cross section, factorization and lack of correlation.3)

Given a soft gluon-exchange-like mechanism, how do we extract a fast secondary after the collision? We will concentrate on the type of mechanism illustrated in Figure 2. There the initial quark state of H_1 is essentially unperturbed (except for a color change) by the collision mechanism; the final H_1' jet fragments to the observed fast hadron H' with (light-cone) momentum fraction x_F. It is this latter fragmentation process which we wish to study in a QCD framework. We will consider those QCD diagrams which are dominant4) as $x \rightarrow 1$.

In order to warm up we consider the fragmentation $\pi \rightarrow q_V(x)$, $V = \text{valence}$, in lowest order QCD, Figure 3. Beginning with a q and $\bar{q}$ each with (on the average) one half of the π's momentum, the lowest order means of obtaining a quark with momentum x near 1 is to transfer momentum from the $\bar{q}$ to the q via gluon exchange. The probed quark with momentum fraction x is off-shell with four momentum squared given by

$$|k^2| = \frac{k_\perp^2 + m^2(x)}{1 - x} \quad . \tag{1}$$

As $x \rightarrow 1$, $|k^2| \rightarrow \infty$ and the x-near-1 momentum measurement acts as a short distance probe. In this limit Brodsky and Lepage

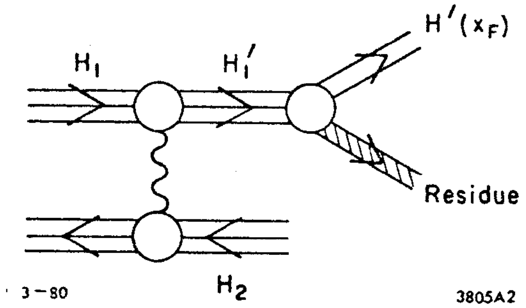

Fig. 2. Fragmentation of H_1' to H' — with light cone momentum fraction, x_F, relative to H_1 — following collision by gluon exchange.

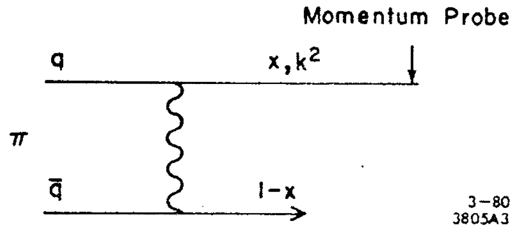

Fig. 3. Obtaining a quark with $x \rightarrow 1$ from a π.

have shown[5)] that the lowest order power law,

$$G_{q_V/\pi}(x) \sim (1-x) \quad , \tag{2}$$

is not modified by the inclusion of all other leading log diagrams — these include vertex and propagator renormalizations as well as a ladder graph sum (in axial gauge). For a proton $p \to q_V$ occurs in lowest order as shown in Figure 4.

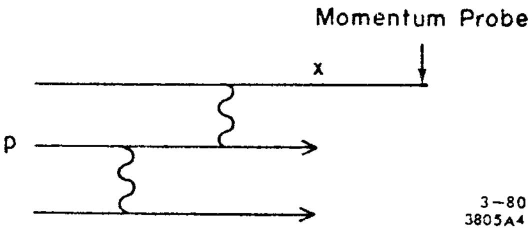

Fig. 4. Diagram for $p \to q_{\text{valence}}(x)$ as $x \to 1$.

This diagram yields

$$G_{q_V/p} \sim (1-x)^3 \quad ; \tag{3}$$

again Brodsky and Lepage show that the leading log renormalization and ladder graphs leave this power law unaltered. Logarithmic modifications to (2) and (3) through powers of $\alpha_s(|k^2|)$ and an anomalous $\ln|k^2|$ power modification to (3) from the ladder sum are being ignored. This is a good quantitative approximation if the QCD Λ^2 parameter is as small as the latest fits indicate.[6)]

For $\pi \to q_S$, $S = \text{sea}$, the leading QCD diagram as $x \to 1$ is shown in Figure 5. This "point-like" bremstrahlung diagram[7)] yields

$$G^{\text{point-like}}_{q_S/H}(x) \sim (1-x)^3 \quad . \tag{4}$$

This result differs from that obtained from the quark spectator counting rule,[8)] based on the hadronized 4-quark wave function diagram of Figure 6, which yields

$$G^{\text{hadronized wavefunction}}_{q_S/H} \sim (1-x)^5 \quad . \tag{5}$$

The general rule is[7)]

$$G(x) \sim (1-x)^{2n_H + n_{PL} - 1} \tag{6}$$

where n_H is the number of spectators originating from the hadronic wave function and n_{PL} is the number of spectators emerging from point-like bremstrahlung interactions. In Figures 5 and 6 these are $n_{PL} = 2$ $n_H = 1$ and $n_{PL} = 0$ $n_H = 3$ respectively. Note that the final states are the same for the two diagrams and that the

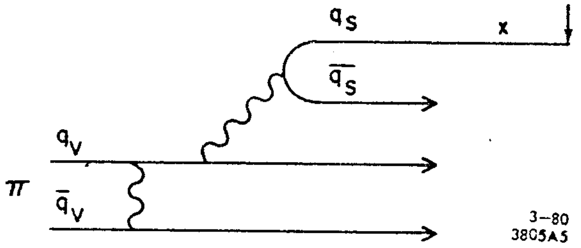

Fig. 5. Lowest order $x \to 1$ diagram for $\pi \to q_{\text{sea}}$.

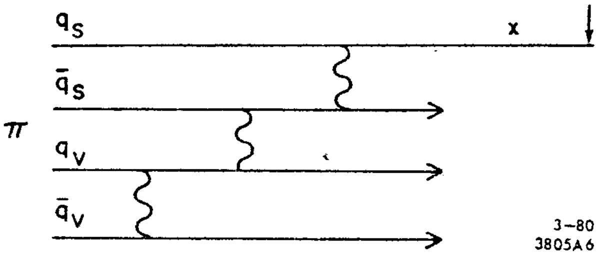

Fig. 6. Diagram for $\pi \to q_{\text{sea}}$ based on a "hadronized" π wave function which contains the q_{sea} initially.

different power laws result from different dynamical mechanisms for generating the given final state.

Analogous to (4) and (5) we have

$$G^{\text{point-like}}_{q_{\text{sea}}/p} \sim (1-x)^5$$

$$G^{\text{hadronized wavefunction}}_{q_{\text{sea}}/p} \sim (1-x)^7 \quad . \tag{7}$$

In all cases the point-like diagrams will dominate as x→1 though at intermediate x values some mixture of the two mechanisms might be present. (It should be noted that scaling violations will tend to increase all these powers in the deep inelastic structure function situation.)

We are now ready to turn to the $H_1' \to H'$ fragmentation. Our first examples are $\pi^+ \to \pi^0$ and $p \to \pi^+$. The leading diagrams are shown in Figure 7. They yield

$$G_{\pi^0/\pi^+} \sim (1-x)$$

$$G_{\pi^+/p} \sim (1-x)^3 \quad . \tag{8}$$

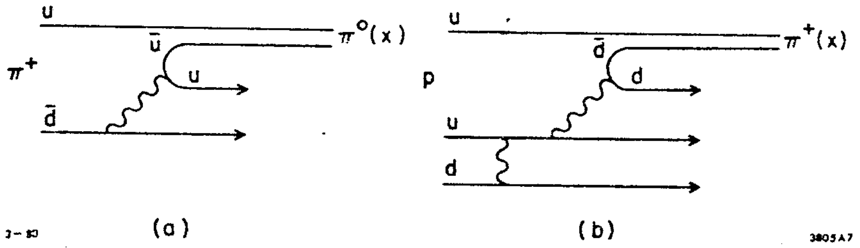

Fig. 7. Point-like bremstrahlung diagrams for: (a) $\pi^+ \to \pi^0$ and (b) $p \to \pi^+$.

For $p \to \pi^-$ we must use the valence d of the proton. Phenomenologically this always causes an additional suppression in the (1 - x) behavior by approximately one power of (1 - x). Thus

$$G_{\pi^-/p} \sim (1-x)^4 \quad . \tag{9}$$

This may be merely an approximation to a complicated numerical suppression discussed by Farrar and Jackson[9] but is adequate for our purposes.

Experimentally these point-like power predictions work very well. The cleanest example is $p \to \pi^+$ where the very accurate data of Singh et al.,[10] indicates a power law $(1-x)^3$ at, for instance, $p_T = .75$ GeV/c. Certainly only a small mixture of the original quark counting power law, $(1-x)^5$, can be present.

Two further examples will suffice to illustrate other important features of these point-like bremstrahlung diagrams.

i) For $\pi^+ \to p$ a dominant diagram is shown in Figure 8(a) yielding

$$G_{p/\pi^+} \sim (1-x)^2 \quad . \tag{10}$$

Note that this is not the same power law as for the line reversed reaction $G_{\pi^+/p}$; the bound states enter differently in the two cases.

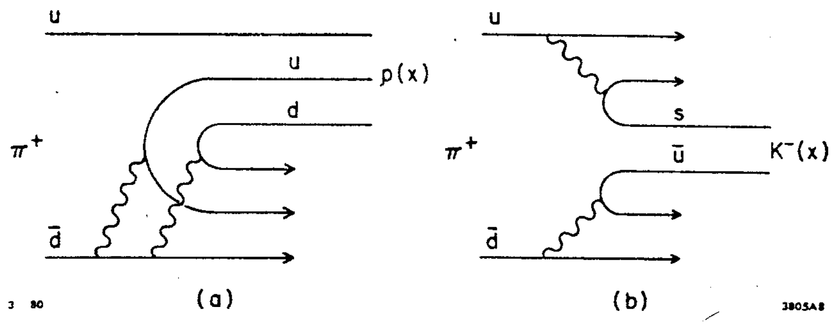

Fig. 8. Point-like bremstrahlung diagrams for: (a) $\pi^+ \to p$ and (b) $\pi^+ \to K^-$.

ii) For $\pi^+ \to K^-$ a leading diagram is shown in Figure 8(b) yielding

$$G_{K^-/\pi^+} \sim (1-x)^3 \quad . \tag{11}$$

The important point here is that exotic fragmentations are relatively weakly suppressed compared to the original "hadronized wavefunction" counting rules which would have predicted $(1-x)^7$ for the above fragmentation. Of course resonance production can also yield low fragmentation powers for exotic fragmentation.

Experimentally both (10) and (11) agree well with the data though a small admixture of higher powers may be present. Figure 9 presents a global comparison between the predictions of this approach for various fragmentation powers and the data. Where the d quark of the proton enters a single unit has been added to the predicted power law. Overall the agreement is encouraging, though there is some inconsistency between experiments and some reactions which should have the same $n_{\text{Fragmentation}}$ do not. Particular note should be taken of the clear experimental violation of line reversal as predicted in this approach and of the generally low values of $n_{\text{Fragmentation}}$ for exotic reactions. We conclude that simple perturbative QCD diagrams could be the underlying mechanism for producing fast forward fragments in hadronic collisions in the region $.3 < x_F < .9$. The restriction to $x_F < .9$ is due to the fact that as $x_F \to 1$ one eventually has commingling of the backward jet with the residue jet left by the forward fragmentation (see Figure 2); in this region the standard "Triple Regge" phenomenology should dominate and the predictions of this approach, based on independent jets, will cease to be relevant. Alternative approaches to the $x_F < .9$ region are also phenomenologically successful[12] and further effort to discriminate between them and the present QCD diagrammatic approach is necessary.

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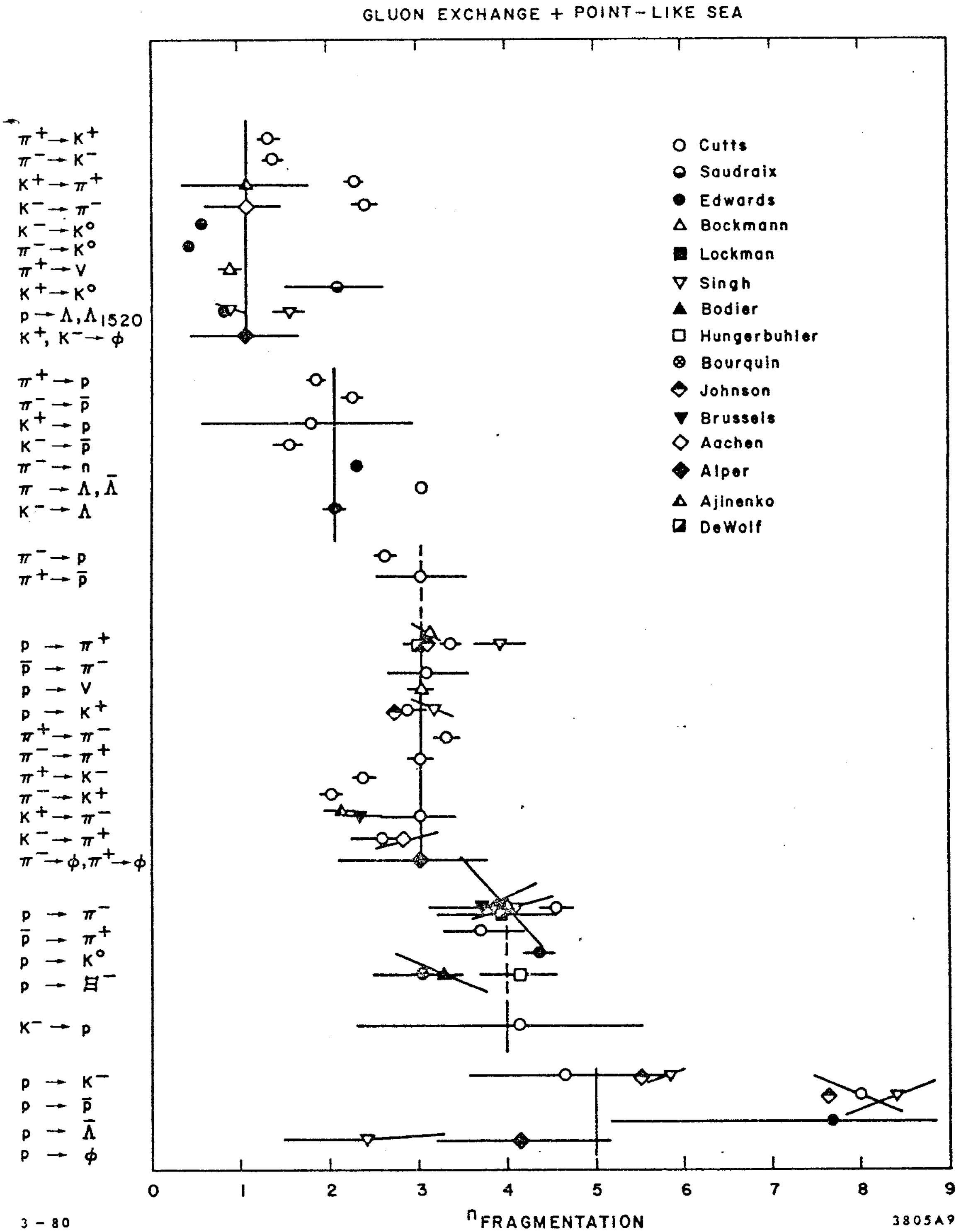

Fig. 9. A summary of experimental results[11)] and theoretical predictions (as obtained here) for all available single particle fragmentations. Here solid lines indicate predictions for gluon exchange and point-like pair creation. Broken lines indicate that one unit has been added to the naive point-like prediction because a proton's d quark is used in the fast fragmentation.

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