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EXISTENCE OF THREE SCALING REGIONS AT LARGE TRANSVERSE MOMENTUM

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A model for large $p_\perp$ production, yielding three different scaling relations in different regions of s and $p_\perp$ is presented. The couplings may be chosen such that $1/s^4$ scaling is valid at present energies while at higher energies $1/s^2$ scaling should manifest itself.

A variety of models have been proposed for the dynamics repsonsible for scattering involving large transverse momenta. Some of these [1] interpret the mechanism for large $p_\perp$ events as a smooth extrapolation of those at low $p_\perp$. There is another class of models which regard these large $p_\perp$ phenomena as manifestations of fundamental dynamics involving partons. For Berman, Bjorken and Kogut [2] an elementary vector gluon exchange is responsible for these hard events. The resulting inclusive cross section has the scaling form

$$E\frac{\mathrm{d}\sigma}{\mathrm{d}^3p}=\frac{1}{s^2}f(x_\parallel, x_\perp)\,, \tag{1}$$

with $x_\parallel = 2p_\parallel/\sqrt{s}$ and $x_\perp = 2p_\perp/\sqrt{s}$. Blankenbecler, Brodsky and Gunion [3] have the interchange between constituent partons lead to these large $p_\perp$ processes. The inclusive cross section is then

$$E\frac{\mathrm{d}\sigma}{\mathrm{d}^3p}=\frac{m^4}{s^4}\,g(x_\parallel, x_\perp)\,, \tag{2}$$

where $1/m$ is a distance characteristic of the parton wave function. Further elaborations and reviews of these models exist [4]. It should be noted that extant data [5–7] follows the scaling predictions of eq. (2).

In this article we propose a model akin to that of ref. [2] which exhibits at very large energies a cross section of the form of eq. (1), while at lower energies it has the form of eq. (2). We view large $p_\perp$ events as arising in a two step process. In the first step a soft collision occurs producing a large number of particles, mostly pions, at low $p_\perp$. In the second stage a hard interaction occurs involving the exchange of a vector gluon between any two of the produced particles. At this point we shall consider two extreme possibilities that describe the interaction of the gluon with the particles produced in the first stage; the particle may remain intact, scattering through a large momentum transfer, t, governed by an appropriate form factor $F(t)$, or a deep inelastic collision may occur leading to a multiparticle final state. Thus there are three possibilities for this second scattering.

i) Both particles scatter elastically through a large t and we observe one of them. We refer to this as the no fragmentation (NF) process, fig. 1(a).

ii) The observed particle is the one scattered elastically while the other particle fragments. This is a single fragmentation (SF) process, fig. 1(b). (The process where the observed particle emerges from the multiparticle cluster while the elastically scattered one is unobserved contributes much less than the other mechanisms discussed.)

iii) Both particles fragment and the observed particle is a product of one of these fragmentations. We call this double fragmentation (DF), fig. 1(c).

Evaluation of cross sections of each process is straight-forward. For simplicity we consider one type of produced particles, pions. The important contributions to large $p_\perp$ processes occur from collisions of pions with large rapidity differences. We may then make the simplification that the pion intensity after the first stage is of a factorized form, $P(x_1)P(x_2)$, where x_1, x_2 are the longitudinal momentum fractions of the pions. For $P(x)$ we will use the experimentally observed form. (One may instead view each proton as having a pion cloud, with the pions' distribution given by $P(x)$.)

The interaction of pions with the vector gluons will parallel electromagnetic interactions. The strength of the elastic interaction will be denoted

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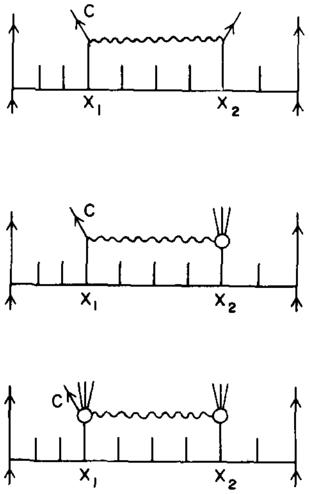

Fig. 1. Three mechanisms for pion-vector gluon interaction leading to a large $p_\perp$ production of particle c: (a) no fragmentation (NF), (b) single fragmentation (SF), and (c) double fragmentation (DF).

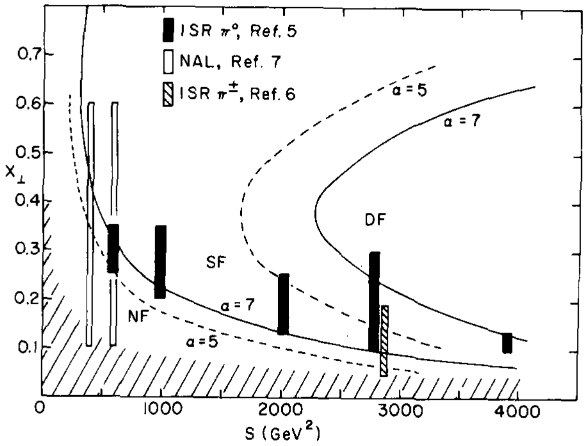

Fig. 2. Regions of $s - x_\perp$ space dominated by the different mechanisms discussed in the text. The boundary curves are for two α's ($\alpha = g_\pi m^2/g_p$). The shaded area indicates the low $p_\perp$ ($p_\perp < 1.5$ GeV) region.

by g_π and we choose a monopole form factor

$$F(t) = \frac{m^2}{m^2 - t} . \tag{3}$$

The fragmentation of the pion by the gluon is treated analogously to scaling in deep inelastic electron scattering. We assume that the pion may be viewed as a distribution of partons

$$\mathrm{d}N(\pi \to \text{parton})/\mathrm{d}x = F_2(x)/x \tag{4}$$

and the distribution of pions in a parton [2] is

$$\mathrm{d}N(\text{parton} \to \pi)/\mathrm{d}x = G(x)/x . \tag{5}$$

Consistent with eq. (3), $F_2(x)$ is chosen as [8]

$$F_2(x) = 2(1-x) . \tag{6}$$

We also assume spin $\frac{1}{2}$ partons. The same form is taken for $G(x)$,

$$G(x) = 2(1-x) . \tag{7}$$

The strength of the interaction of the exchanged gluon with the partons has a strength g_p.

With the above assumptions the cross sections for the three different processes are:

$$\text{NF:}\quad E\,\mathrm{d}\sigma/\mathrm{d}\boldsymbol{p} = (1024\, m^8 \gamma_\pi^2 / s^6 x_\perp^{10})$$
$$\times \int_{x_+}^{1-x_-} \mathrm{d}y\, P(x_+/y)\, P(x_-/(1-y))\, y^4 \left(\frac{1+y}{1-y}\right)^2$$
$$+ (x_+ \leftrightarrow x_-) \tag{8a}$$

$$\text{SF:}\quad E\,\mathrm{d}\sigma/\mathrm{d}\boldsymbol{p} = (1024\, \gamma_\pi \gamma_p m^4 x_+ / s^4 x_\perp^8)$$
$$\times \int_{x_+}^{1-x_-} \mathrm{d}y\, P(x_+/y)\, F'(x_-/(1-y))\, \frac{y^3}{1-y}$$
$$+ (x_+ \leftrightarrow x_-) \tag{8b}$$

$$\text{DF:}\quad E\,\mathrm{d}\sigma/\mathrm{d}\boldsymbol{p} = (32\, \gamma_p^2 / s^2 x_\perp^4)$$
$$\times \int_{x_+}^{1-x_-} \mathrm{d}y_a \int_{x_-}^{1-y_a} \mathrm{d}y_b\, F'(x_+/y_a) F'(x_-/x_b)$$
$$\times G(y_a + y_b) \frac{y_a y_b}{(y_a + y_b)^2} [(y_a/y_b)^2 + (1 + y_a/y_b)^2]$$
$$+ (x_+ \leftrightarrow x_-) . \tag{8c}$$

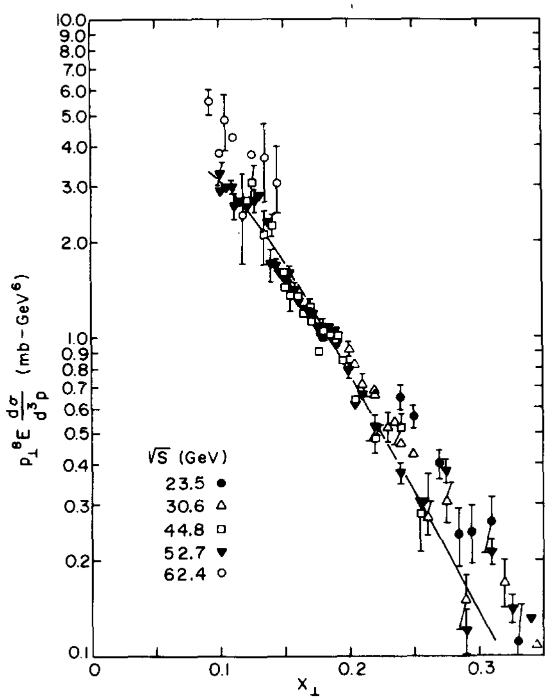

Fig. 3. Single fragmentation fit to 90° c.m. data of ref. [5] (inclusive π^0 spectrum).

In the above $\gamma_\pi = g_\pi^2/4\pi$, $\gamma_p = g_p^2/4\pi$, $x_\pm = \frac{1}{2}(\sqrt{x_\parallel^2 + x_\perp^2} \pm x_\parallel)$ and

$$F'(x) = \int_x^1 dy\, P(y) F_2(x/y) . \tag{9}$$

The calculational techniques are discussed in ref. [2]. Note that the cross section for the DF process, eq. (8c), has the same form as that of ref. [2], and, in fact, is identical with it if we assume that the process by which two colliding protons disassociate into partons is by first producing pions which evolve into partons. The cross section for the SF process, eq. (8b) has the same scaling behavior as the parton interchange form, eq. (2).

It is clear that at fixed $x_\perp$ and sufficiently high energies the DF process will dominate. Is it possible that at lower energies the SF mechanism will be most important? The answer depends on the ratio of coupling strengths $\alpha = g_\pi m^2/g_p$. In fig. 2 we show an $s - x_\perp$ plot ($x_\parallel = 0$). For $\alpha = 5$ and $\alpha = 7$ we show the boundaries of regions where each of the three mechanisms dominate. The shaded area is the region of $p_\perp < 1.5$ GeV where low $p_\perp$ mechanisms dominate. Note that for $\alpha = 7$ most of the experimental results presently available fall into the SF region. *We view the present* $1/s^4$ *behavior as transitory and expect the* $1/s^2$ *scaling to become evident at the larger values of s.* In fig. 3 we present a fit of the SF eq. (8b) to the large $p_\perp$ data at 90° c.m. Within the context of the assumption discussed above, the overall magnitude is the only free parameter.

A question may arise as to the consistency of having various diagrams dominate various regions of $s - x_\Gamma$ space with Bloom–Gilman [8] duality. According to this duality principle the DF process should average all other mechanisms. The different behaviors predicted by these mechanisms are due to strong local deviations from duality near various production thresholds.

References

[1] M. Barnett and D. Silverman, Phys. Lett. 44B (1973) 28; Phys. Rev. D8 (1973) 2108;
D. Amati, L. Caneschi and M. Testa, Phys. Lett. 43B (1973) 186 and CERN preprint TH-1644.

[2] S.M. Berman, J.D. Bjorken and J.B. Kogut, Phys. Rev. D4 (1971) 3388.

[3] R. Blankenbecler, S.J. Brodsky and J.F. Gunion, Phys. Lett. 42B (1972) 461; Phys. Rev. D6 (1972) 2652.

[4] S.D. Ellis and M.B. Kislinger, NAL preprint NAL-PUB-73/40-THY;
J.F. Gunion, in Experiments in high energy particle collisions, ed. R.S. Panvini (American Institute of Physics, New York 1973);
R. Jaffe, Proc. Conf. on Recent advance in particle physics (1973), New York Academy of Sciences (to be published);
P.V. Landshoff and J.C. Polkinghorne, Phys. Rev. D8 (1973) 927; preprint DAMTP 73/10;
J.D. Bjorken, SLAC preprint SLAC-PUB-1280.

[5] F.W. Büsser et al., Phys. Lett. 46B (1973) 471.

[6] B. Alper et al., Phys. Lett. 44B (1973) 521 and 527.

[7] J. Cronin et al., Chicago-Princeton Collaboration preprint.

[8] M. Bander, Nucl. Phys. B13 (1969) 587;
S.D. Drell and T.M. Yan, Phys. Rev. Lett. 24 (1970) 181;
E. Bloom and F. Gilman, Phys. Rev. Lett. 25 (1970) 1140.