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POSSIBLE CONNECTIONS BETWEEN HARD AND SOFT PROCESSES*

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ASTRACT

Three topics in constituent hadron models are reviewed: the connection between fixed angle and Regge behavior, the validity of the hard scattering expansion and restrictions on the effects of the transverse momentum of constituents, and the x-distribution in the fragmentation region at low transverse momentum.

In this talk I would like to restrict myself to a brief discussion of three topics: (A) connections between fixed angle scattering and Regge theory, (B) the validity of the hard scattering expansion and possible internal motion of constituents, and (C) the x-distributions of beam fragments at low transverse momentum.

A

There seems to be nothing new in this subject but the original treatment[1,2] was sufficiently long ago (1973) and sufficiently obscure so that a review is probably warranted. In the normal Regge treatment one assumes that the cosine of the crossed angle is large and makes an appropriate power series expansion. Since this requires that $s \simeq -u >> -t$, the fixed angle region of $t \approx u$ is not allowed. However, let us approach this problem from another point of view. Write the scattering amplitude as a sum of Mandelstam double spectral terms (the full Mandelstam analyticity is not really necessary for the argument) $M(s,t)$, $M(s,u)$, and $M(u,t)$. Then <u>if</u> for $|s| > s_0(t)$ M has the behavior

$$M(s,t) \sim (-s)^{\alpha(t)}\beta(t) + \ldots, \tag{1}$$

then the full amplitude is a sum of terms of the form

$$\beta(t)\left[(-u)^{\alpha(t)} \pm (-s)^{\alpha(t)}\right] + \ldots \tag{2}$$

where the sign depends on the symmetry. If $s_0(t)$ turns out to be small, this might be termed <u>precocious Regge behavior.</u> In any case, an expansion of the above form (which becomes the Regge expansion if one can approximate (-u) by s) could hold in the large angle domain. Are there any models of the strong interactions which lead to the above form at large angles? There are many conceivable ones but for reasons of prejudice, I will discuss a limited class of composite models of hadrons.

With a suitable neglect of logarithmic factors in a renormalizable model (QCD, for example) of composite hadrons, Brodsky-Farrar[3] have shown that at fixed angle, exclusive cross sections obey the scaling law

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$$\frac{d\sigma}{dt} = s^{-n} f(\cos\theta) , \tag{3}$$

where n+2 is equal to the total number of fundamental fields in the initial and final states. More detailed assumptions are required to predict $f(\cos\theta)$. One much model is the CIM,[2,4] in which the dominant force is assumed to arise from the interchange of the constituents of the hadrons (see Fig. 1). These terms are dominant because the coupling for the emission of a quark from a bound state, such as a meson or proton, is very large[5] compared to the QCD gluon coupling constant $\alpha_s \sim 0.2$.

For example, meson-proton scattering at large t can be written in the form

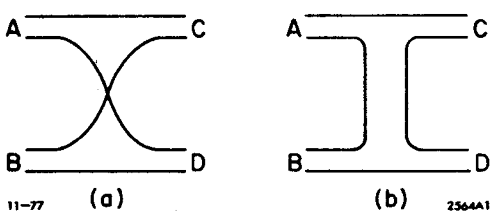

Fig. 1. The Bare Interchange Graphs—(ut) and (st) Topology.

$$\frac{d\sigma}{dt}(s,t,u) \cong F_p^2(t)\frac{d\hat{\sigma}}{dt}(s' = \langle x\rangle s, t' = t, u' = \langle x\rangle u) + \ldots \tag{4}$$

where $d\hat{\sigma}/dt$ is the cross section for meson-quark scattering at reduced kinematics s', t', u', $F_p(t)$ is the target form factor and $\langle x\rangle$ is the average fractional momentum carried by the quark in the target (for a proton, one expects $\langle x\rangle \sim 1/3$). The fact that the collision described by $d\hat{\sigma}/dt$ occurs at a lower energy is, in fact, the origin of Regge behavior as we shall see. At smaller t, graphs such as illustrated in Fig. 2 play a more and more important role.

As an example, consider $K^+p \rightarrow K^+p$. The basic cross section is $d\hat{\sigma}/dt \propto (su)^{-2}$, and hence $d\sigma/dt \propto (sut^2)^{-2}$. Thus we are lead to identify $\alpha(t = -\infty) = -1$ and $\beta(t) \sim F_p(t) \sim t^{-2}$. This type of a smooth connection between fixed angle and Regge behavior is a natural property of composite models.

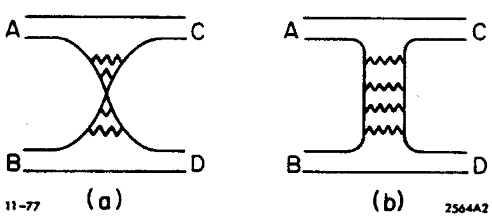

Fig. 2. Gluon corrections to Interchange Graphs that leads to Regge Behavior.

For the general process $AB \rightarrow CD$, Brodsky and I have examined the dominant (or what seem to be the dominant) graphs and found that

$$\alpha(-\infty) = \tfrac{1}{2}(4 - n_A - n_B - n_I) - f , \tag{5}$$

and

$$\beta(t) \sim (-t)^b, \quad b = \tfrac{1}{2}(n_I - n_C - n_D) , \tag{6}$$

where n_A is the number of quarks in particle A and n_I is the number of interchanged quarks. The constant f is 0 for n_I even (boson exchange) and $\frac{1}{2}$ for n_I odd. This result is not correct in every case, however, and one should examine each model and given process carefully.

The above form predicts the limits of trajectories for exotic, as well as more familiar, trajectories. For example, for Mp → Mp, one gets $\alpha(-\infty) = -1$ for both elastic and CEX reactions. For pp → pp, one gets $\alpha(-\infty) = -2$ although in this case there are certain graphs that yield $\alpha = -1$ terms. For $\bar{p}p \to \bar{p}p$, an exotic 6 quark exchange, one predicts $\alpha(-\infty) = -4$, $b = 0$. If, for exotic channels, one makes the natural assumption that the trajectory does not rise significantly as $t \to 0$ (since there is not as much attraction as for nonexotic systems), this prediction for α can be checked. For backward $\bar{p}p$ scattering, one predicts a behavior $\beta^2(u)\,(s)^{-10}$, which is consistent with the data even in the backward exotic peak. Clearly a more careful analysis of theory and experiment is needed here.

Since a trajectory in meson-baryon scattering must contribute to baryon-baryon scattering, how is it possible for $\alpha_{\pi p} = -1$ and $\alpha_{pp} = -2$? Even if $\alpha_{pp} = -1$, the residues computed from a composite model need not factorize since they involve completely independent wave functions. How does the theory arrange this? When in doubt (at least in Regge theory), turn to potential scattering as a guide. Consider a coupled two channel problem with a potential of the Yukawa form $V_{ij}(t) = v_{ij}(\mu^2 - t)^{-1}$. If $\det v \neq 0$, v has two eigenvalues, $v_\pm$, say.

Following familiar arguments, one finds that the scattering matrix at large t is of the form

$$f \sim \beta_+ (-t)^{\alpha_+(s)} + \beta_- (-t)^{\alpha_-(s)} \tag{7}$$

where $\alpha_\pm(s) = -1 + v_\pm/\sqrt{-s} + \ldots$ and

$$v = \beta_+ + \beta_- \,. \tag{8}$$

Thus the two eigentrajectories become degenerate as $s \to \infty$ in order to reproduce the full Born term V(t).

The next step in the standard argument is to write down a relativistic two body equation, sum the ladder graphs, and see that the same phenomena happens in the same way. This has been done.[1] One typically finds in this case that nonexotic trajectories $\alpha(\pm)$ rise as $t \to 0$, whereas their asymptotically degenerate partner is much flatter and may even decrease as $t \to 0$. In any case, these pairs of trajectories can produce strong breaking of factorization at large t and should be searched for. It also should be noted that the cuts arising from these asymptotically flat trajectories are not always above their parents, as in a linear trajectory model, but also become flat (at the same values for pomeron-pomeron cuts).

Low energy elastic data has been analysed[6] using the above formulas (not the Regge forms) and the results for pion-nucleon and proton-proton scattering are shown in Figs. 3 and 4. These are quite different as large t from the Regge extractions using the same data. It would be very interesting to do the same extraction at large t for inclusive scattering which have a large rate and are more independent of the particular form used to extract the trajectory.

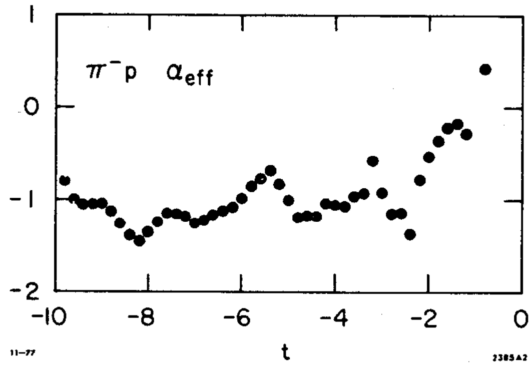

Fig. 3. Effective Trajectory Extracted for π^-p Scattering.

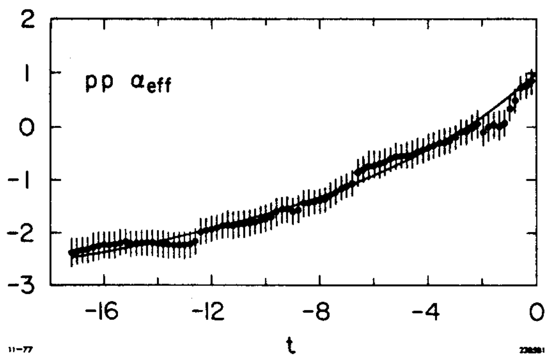

Fig. 4. Effective Trajectory Extracted for pp Scattering.

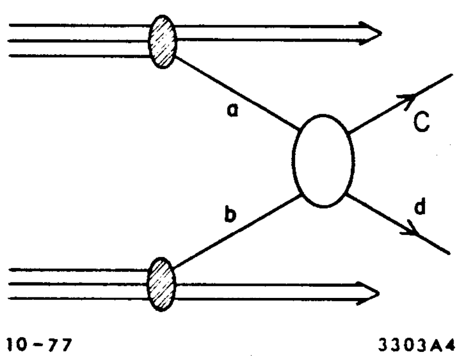

Fig. 5. Typical Term in the Hard Scattering Expansion.

B

The hard scattering expansion for inclusive reactions is generally derived for basic interactions that fall as a power of momentum transfer (not exponentially) and consists of a sum over terms of the form given in Fig. 5. The basic assumption is that each term in the expansion is incoherent, and this requires examining the final states in detail. The sum over a, b, and d as well as the structure functions used to describe the emission of a and b from the beam and target must be chosen to preserve this incoherence. In particular, it is easy to violate the validity conditions if one allows large transverse momentum to be generated in the wave functions since the necessary large k_T recoil particle can be coherent with one arising in the central process from a different term in the sum.

While the inconsistency of adding large transverse momentum to the structure functions is clear for any reaction, it is particularly easy to see for processes involving photons such as massive lepton pair production, the Drell-Yan process[4], because of gauge invariance. The same is true in QCD, for example, because of the gauge invariance of the gluon couplings. Normally, the Drell-Yan process is described as $\bar{q}q$ annihilation into a virtual photon as in the first diagram of Fig. 6. As was emphasized by Drell-Yan in their original paper, this term is only (approximately) gauge invariant if all the transverse momenta involved are small (this allows the $\bar{q}$ and q to be near shell). If one adds a large k_T to the quarks, one must add[8] diagrams such as

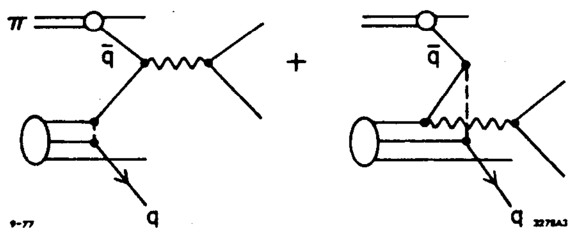

Fig. 6. Two coherent Contributions to Massive Lepton Pair Production.

the second in Fig. 6 to retain gauge invariance. This second term turns out to be small at low Q_T's of the photon but, in fact, exactly cancels the leading contribution of the first at large Q_T. The final result is of the form[8]

$$Q^4 \frac{d\sigma}{d^4Q} = (1 + Q_T^2/\mu^2)^{-2} (1 + Q_T^2/(\mu^2 + Q^2))^{-1} F(\epsilon), \qquad (9)$$

where F is a scaling function. Because of this cancellation, the Q_T distribution of the photon does not directly reflect the k_T distribution of the wave function.

Is this a general phenomena? It seems as though it is. While a general proof has not yet been given in the relativistic case, Amado and Woloshyn have proved[9] a related theorem in potential scattering. They have shown that the final state interactions cancel the leading relative $\vec{k}^2$ behavior of the wave function in certain break-up reactions. I refer you to their paper for a full discussion of this remarkable and hitherto overlooked result. Beware of calculations that simply add k_T distributions to the quarks; the burden of proof of consistency is on the user!

C

Let us now turn to a discussion of the x_F (or, better, x_R) dependence of the production of hadrons in the fragmentation region at low transverse momentum. We will use extensively the spectator counting rules for structure functions[10] which, incidently, should not be confused with the dimensional counting rules for fixed angle elastic scattering[3]. The spectator counting rules have even proven useful in describing the yields from relativistic nucleus + nucleus reactions[11], and seem to work well over a large A range.

Our picture[12] is that an incident beam particle B scatters from the target (or rather a constituent of the target) and there is a resultant, forward moving fast fragment b* which contains essentially all the incident beam momentum. The fragment b* then decays into the detected particle of interest C. The x distribution of C will then depend directly on $G_{C/b^*}(x)$, the probability function for finding a constituent C with momentum fraction x in the state b*. The behavior for sufficiently large x is

$$G_{C/b^*}(x) \sim (1-x)^F, \qquad F = 2n(\bar{c}b^*) - 1, \qquad (10)$$

where $n(\bar{c}b^*)$ is the minimum number of quarks that must be emitted by b* to make C. The main question that must be settled is—what quark configurations are allowed for b*?

There are many models included in the above picture which are normally described by quite different words. For example, some models assume that a fast forward quark can pick up, for free, quarks from the sea of the beam or target. This is just one of the possible time orderings contained in our dynamical picture.

Some time ago,[10] motivated by Triple-Regge ideas and successes, it was proposed that one important term should be that in which b* contains the same number of quarks as the beam. This would happen if the dominant interaction with the target was pomeron, reggeon, or gluon exchange. This configuration is surely present but does not seem to play an important role, at least for x_F a finite distance below 1.

Ochs[13] has assumed that the produced hadrons directly reflect the quark distribution in the incident beam and has found reasonable agreement with experiment. This was generalized by Brodsky and Gunion[14] who gave a definite dynamical mechanism—the lost quark model. One assumes that in the primary interaction with the target, one wee but valence quark of the beam interacts with the target and is thereby lost (it ends up with low momentum). This means that the (1-x) power F is in general smaller by 2 than the previous model and good agreement with experiment is obtained.

For example, for a pion beam, b* is a q or a $\bar{q}$. Thus to make an allowed meson, $C = \pi, K^+, \rho, \ldots, F = 1$, while for a K^-, $F = 5$. To make a baryon or antibaryon, one requires $F = 3$, and their rates are expected to be ≈ equal.

For a proton beam, b* = (qq), a diquark system. To make a pion, for example, one has $F = 3$, whereas the proton and lambda yields should be described by $F = 1$. For this beam, the predicted antibaryon yield has $F = 9$.

These results should be compared with those expected from a pure quark-quark scattering model. In this case, independent of the incident beam, b* is a q or a $\bar{q}$. Thus for the proton yield, one expects $F \geq 3$ and for the pion yield, $F \geq 1$ since the initial quark distribution must also be folded into the distribution. It seems as if the present data prefers the "lost quark" model, but clearly more extensive experimental tests and more theoretical work (for example, a calculation of the various expected rates) would be very welcome.

Further tests of this picture of fragmentation can be made by performing coincidence experiments. A large variety of possibilities exist, but one of the most interesting is an associated Drell-Yan process. The physical point is that the production of a large mass lepton pair selectively annihilates up quarks from the beam and hence the charge ratios in the fragmentation region are strongly affected. An interesting calculation has been made by DeGrand and Miettinen[15] using a slightly different model but the physics is very similar. The forward π^-/π^+ ratio $R(\tau, x_F)$ is a function of two variables, $\tau = Q^2/s$ and x_F. At small τ, the photon is produced mainly by sea quarks and the valence ones should remain intact. However at large τ, the valence quarks participate and since the photon prefers up quarks, the charge ratio is strongly influenced by their disappearance.

More detailed tests[15] can be performed by examining pairs of particles in the fragmentation region and plotting the distribution in their total x variable. Tests that involve both the mechanisms for fragmentation and large transverse momentum processes can also be made. The production of massive hadron pairs with at least one of them having a large p_T has been discussed[16] and counting rules derived for this process for the general case. Since one now knows that only a few basic processes are involved in large p_T reactions[5], these predictions can be considerably tightened.

Finally, I would like to comment that nowhere in our discussion have we been forced to include direct dynamical effects arising from gluons. All of the quark interchange processes discussed here are present in QCD and must be included for consistency.[5] They dominate in selected regions of phase space because their couplings are large compared to α_S. Where are the gluons hiding? Aside from possible small effects due to nonscaling, which in the present experimental range have alternative interpretations[17], is there a clean experimental necessity for their dynamical existence? The decays of heavy narrow states in the ψ family offer possibilities but they are not very simple tests. Perhaps the cleanest possibility is a study of jets in electron-positron annihilation[18] and ultra-large p_T processes. In any case, it is probably appropriate to end this talk with these embarrassing questions about a fundamental degree of freedom of the currently popular (fad?) theory, QCD, which seems to be missing (or at least very bashful).

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