SLAC–PUB–5608
July 1991
T/E

Soft and Hard Pomerons: Is There a Distinction?[★]

J. D. BJORKEN

Stanford Linear Accelerator Center

Stanford University, Stanford, California 94309

Invited talk presented at the
4th International Conference on Elastic and Diffractive Scattering
La Biodola, Isola D'Elba, Italy
May 22-25, 1991

[★] Work supported by the Department of Energy, contract DE–AC03–76SF00515.

1. Introduction

One of the big unsolved problems of QCD remains the problem of the Pomeron: what is the relation of high energy elastic and diffractive phenomena to the underlying theory? This is not a subject in which I have actively worked. But my interest in it has in this year increased greatly. The reason has to do with ideas for experimentation at SSC/LHC which either directly address the problem or which require the understanding of strong-interaction diffractive phenomena as backgrounds for discovery-physics processes involving electroweak boson exchanges.

I will in this talk omit these motivations, which can be found elsewhere,[1] and instead concentrate on some personal viewpoints regarding the Pomeron which may or may not be conventional. The main question has to do with the distinction between the original, old-fashioned "soft" Pomeron of the 1960s, built out of multiperipheral hadron-exchanges, and the more modern perturbative-QCD "hard" Pomeron, built out of multiperipheral gluon exchanges. The perspective I offer comes mainly from two sources: one is heavy-flavor physics, and the other is the Manohar-Georgi view of constituent quark physics.

2. Heavy Flavors

Protons are complicated. I find it easier to conceptualize the problems of high energy scattering in the context of heavy-quark physics. In particular, consider the processes of B-B scattering and Υ-Υ scattering at hadron-collider energies. While data will be hard to come by, it is not hard to imagine what the answers would be.[2] For sufficiently massive b-quarks, the Υ-Υ scattering becomes purely perturbative;

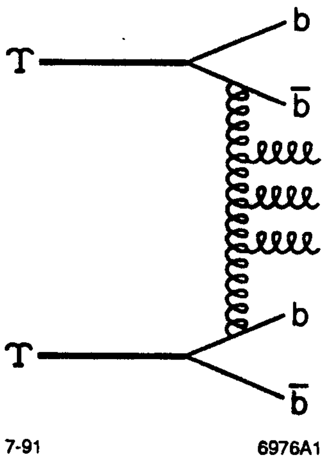


Figure 1. Dominant process underlying multiparticle final states in high energy Υ-Υ scattering.

namely, the interaction of two small color dipoles via single-gluon exchange:

$$\sigma_{\text{tot}} \sim \alpha_s^2 \left\langle r^2 \right\rangle \ . \tag{2.1}$$

In the formal $M \to \infty$ limit, $\left\langle r^2 \right\rangle \sim 1/\alpha_s^2 M^2$, so that $\sigma_{\text{tot}} \sim 1/M^2$. Elastic-scattering requires a two gluon-exchange amplitude, so that one would expect

$$\sigma_{\text{el}} \sim \alpha_s^4 \left\langle r^2 \right\rangle \ . \tag{2.2}$$

At large energies, multigluon production will dominate σ_{tot} (Fig. 1), as calculated[3] within perturbative QCD. Examination of the typical final state would reveal, at sufficiently high energy, gluon minijets as seen at the $SP\overline{P}S$ and Fermilab Tevatron. And in leading order, there are no more double diffractive final states (containing rapidity-gaps) than in $e^+e^- \to$ hadrons because of the color-octet-exchange.

Now contrast this with B-B scattering. We view the B meson as a b-quark around which orbits a light constituent-quark. The total inelastic cross-section is estimated from the additive quark-model

$$\sigma_{BB} = \sigma_{qq} \approx \frac{1}{9}\,\sigma_{pp}^{\text{inel}} \ . \tag{2.3}$$

Using

$$\sigma_{qq} = 2\pi \left\langle r_\perp^2 \right\rangle_q \tag{2.4}$$

leads to a constituent-quark size of

$$\left\langle r_\perp^2 \right\rangle_q \sim (0.25\, f)^2 \ . \tag{2.5}$$

The size of the B-meson itself is larger (and independent of m_b as $m_b \to \infty$), roughly

$$\left\langle r_\perp^2 \right\rangle_B \sim (0.5\, f)^2 \ . \tag{2.6}$$

This leads to the estimate

$$\frac{\sigma_{\text{el}}}{\sigma_{\text{inel}}} \sim \frac{\left\langle r_\perp^2 \right\rangle_q}{\left\langle r_\perp^2 \right\rangle_B} \sim \frac{1}{4} \ . \tag{2.7}$$

The inelastic final states in B-B scattering should look very much like those in, *e.g.*, π-π or pp scattering. These processes in turn do not exhibit prominent minijet structure until extremely high energies. Below that scale, the "old-fashioned" (*e.g.* multiperipheral[4]) mechanisms yield inelastic final states characterized by at most short-range correlations in rapidity. And in any case highly inelastic diffraction is prevalent, not as suppressed as in Υ-Υ scattering.

The main point in elaborating all this is that B-B phenomenology and Υ-Υ phenomenology appear superficially rather different. If this is really the case, it then becomes necessary to consider two kinds of Pomeron, the "hard" Pomeron which dominates in high-energy Υ-Υ scattering and the "soft" Pomeron, dominant in moderate-energy B-B scattering. In the next section we add another reason why this distinction might be a very meaningful one.

3. The Manohar-Georgi Viewpoint

Manohar and Georgi[5] have addressed the question of why the constituent quark model of spectroscopy works so well. Their conclusions can be summarized as follows:

1. The constituent quarks get their effective mass of 350 MeV (for u and d) through spontaneous chiral symmetry breaking.
2. The constituent quarks are physically small, so that the distance scale for which the chiral breaking is operative extends to rather small values, perhaps as small as 0.2 f (or momenta $\lesssim$ 1 GeV).
3. Throughout this range of distances the pionic degrees of freedom play the important role of providing the collective (Nambu-Goldstone) modes of the chiral condensate. According to the Goldstone theorem, they cannot be omitted.
4. Therefore, it makes sense at these scales to utilize an effective Lagrangian whose primary degrees of freedom are *constituent* quarks and *pions.*
5. While the gluonic degrees of freedom cannot be totally neglected at these scales, their effects are rather modest. An estimated effective $\alpha_s \sim 0.35$

suffices to provide the weak binding force needed to produce a satisfactory spectroscopy. A larger value would lead to a loss of self-consistency of the scheme.

6. The pion appearing in the effective Lagrangian is a collective mode, not to be directly identified with the $^1S_0$ hyperfine partner of the $^3S_1$ rho. However the spectroscopist's $^1S_0$ pion and the Nambu-Goldstone pion will mix. Consequently the massive state is driven, via level repulsion, into the region of higher resonances, *i.e.* obscurity.

The primary evidence for the Manohar-Georgi viewpoint is the success of the constituent-quark model. There are other arguments as well which have been recently put forward by Weinberg.[6] He argues for a compact constituent quark on the basis of its not having any observed excited states in the domain of hadron spectroscopy, as well as not having any anomalous magnetic moment: constituent quarks have Dirac moments.

Additional arguments for this picture come from recent deep-inelastic muon-nucleon scattering data. There is evidence[7] for violation of the Gottfried sum rule in particular. Standard parton-model considerations give the sum rule

$$\int_0^1 \frac{dx}{x} \left[F_{2p}(x) - F_{2n}(x)\right] = \frac{1}{3} - \frac{2}{3}\int_0^1 \frac{dx}{x} \left[\overline{d}(x) - \overline{u}(x)\right]_p \ . \tag{3.1}$$

The assumption entering the Gottfried sum rule is that the sea distributions are isospin-symmetric $[\overline{d}(x) = \overline{u}(x)]$, so that the right-hand side of Eq. (3.1) is predicted to be 0.33. However, experimentally the number is 0.24 ± 0.02, leading to an excess of $\overline{d}$ over $\overline{u}$ in the proton.

A simple interpretation of this follows from the idea that a constituent quark is surrounded by a pion cloud.[8] Because there is an excess of valence u quarks in the proton, this leads to an excess of $\pi^+(=\overline{d}u)$ over $\pi^-(=\overline{u}d)$ in the pion clouds surrounding the quarks, hence to an excess of $\overline{d}$ over $\overline{u}$ in the antiquark distributions.

This same picture also helps in understanding the "spin-crisis" data, which argues that the spin transfer Δs from a longitudinally polarized proton to its strange quark distribution is nonvanishing and negative.[9] The spin transfer from proton to the up quark excess is known to be large and positive. There will be kaon as well as pion clouds around the quarks. But the transition $u \rightarrow s + K$ flips the quark helicity, leading to the negative correlation between the spin transfer Δu to up quarks and Δs to strange quarks.

The bottom line from all these arguments is that it may make sense to consider the high energy B-B interaction as predominantly the collision of the pion clouds attached to the constituent quarks. This would, from a multiperipheral viewpoint, argue that the "soft" Pomeron ladders be built from the degrees of freedom contained in the Manohar-Georgi effective Lagrangian; namely, $q\overline{q}$, $\pi\pi$, some gg and perhaps some $\sigma\sigma$ if the linear σ-model version of the chiral Lagrangian is used. In any event, this picture is distinctly different from what was described for Υ-Υ scattering. And since the origin and detailed dynamics of chiral symmetry breaking in QCD is not understood, it seems prudent to maintain this distinction in the phenomenology until chiral breaking is better understood.

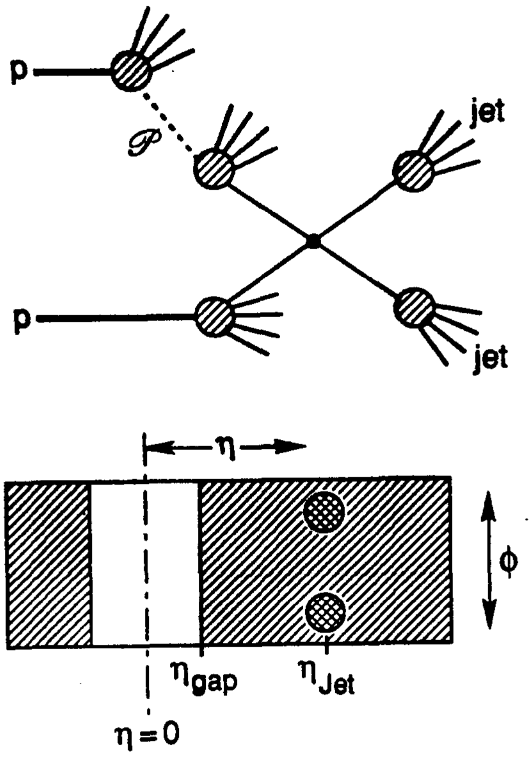
4. Soft Pomerons and Hard Collisions

By definition elastic scattering is mediated by Pomeron exchange. This process can also be described in s-channel optical-model language.[10] From that point of view, the Pomeron is a quite shadowy object, not necessarily closely related to exchange of quanta such as quarks and gluons.

But highly inelastic diffraction is a different matter. It is clear, when viewed in the rest frame of the projectile which dissociates, that a lot of four-momentum is delivered to that particle. This four-momentum must in turn be carried by the quanta of QCD; namely, quarks and gluons.

A very important suggestion has been made by Ingelman and Schlein.[11] They suggest probing this Pomeron via hard-collision processes. This can be done by searching for coplanar dijets within the high-mass diffractive final state. Indeed the jets have been found and very interesting measurements have been made, as presented to this meeting.[12] This in turn allows determination of the parton distributions of the Pomeron. It is to be emphasized that these parton-distributions are *operationally* defined. This may mean that they may not factorize, but depend in some ways on the hadron that emitted the Pomeron (*e.g.* spin, identity, recoil structure if the vertex is inelastic, etc.). But leaving such nuances aside, one may anticipate quite different parton distributions for soft and hard Pomerons. For the soft Pomeron, the $\pi\pi$ and $\sigma\sigma$ components would probably have a $(1-x)^{4\pm1}$ leading behavior. A "harder" behavior might be anticipated from a $q\overline{q}$ component (meson-like; $(1-x)^{1-2}$) or a gg component: $(1-x)^1$. In any case the mix of quarks and gluons in the soft Pomeron should be roughly 50/50, as is typical of hadrons in general. On the other hand, dominance of gluons over quarks should be expected in the case of the "hard" Pomeron parton distributions. The upcoming

HERA program, together with the new measurements from CERN, will be most valuable in distinguishing between these options.



7-91 6976A2

Figure 2. Jet production in Pomeron-proton collisions: (a) the hard-collision process, and (b) the event structure in the lego plot.

This is not the place to delve into the details of the phenomenology. However, I wish to add one comment[13] which may help to normalize parton distributions of the Pomeron at small x. Consider the Ingelman-Schlein process illustrated in Fig. 2, as viewed in a frame of reference where $\eta = 0$ is centered in the middle of the rapidity-gap. In that frame, the "decision" not to radiate soft hadrons into the gap occurs on a time scale no longer than $t_{\rm gap} \sim 1f \times (\exp \eta_{\rm gap})$. During that time interval, the jet pair has not significantly evolved. Its time scale is

$$\begin{aligned} t_{\text{Jets}} &= (1f) \times \exp \eta_{\text{Jet}} \\ &\approx t_{\text{gap}} \times \exp(\eta_{\text{Jet}} - \eta_{\text{gap}}) \qquad (4.1) \\ &\approx t_{\text{gap}}/x \end{aligned}$$

where x is the fraction of Pomeron momentum carried by the jet (in an appropriate reference frame). Therefore it is extremely reasonable to assume that the presence of the incipient jet pair does not influence the probability that the rapidity gap is formed. This implies factorization of the cross-section as follows:

$$\sigma_{\text{inel}}(i) \cdot \frac{d\sigma(i)}{d\Gamma_1 d\Gamma_2 d\eta_1 d\eta_2} = \frac{d\sigma(i)}{d\Gamma_1 d\Gamma_2} \cdot \frac{d\sigma(i)}{d\eta_1 d\eta_2} \ . \qquad (4.2)$$

Here η_1 and η_2 are the boundaries of the rapidity gap and $d\Gamma_1$ and $d\Gamma_2$ are the differential phase-space elements for the produced jets. The indices $\{i\}$ are important and represent the parameters defining the internal conditions of the projectiles at impact, most importantly the impact parameters and longitudinal momentum fractions of the valence-(constituent) quarks of the projectiles. It is not clear after averaging over $\{i\}$ that factorization will survive for the observable quantities. It should be emphasized that failure of factorization is very *interesting*, not a failure per se, because it may provide a classification of event morphologies which project onto a more limited set of initial-state configurations $\{i\}$. In other words, it may be possible to divide the *final* state configurations into subsets A

$$d\sigma = \sum_A d\sigma_A \qquad (4.3)$$

such that factorization approximately works at this level. An idealization of how this could occur is that subsets of initial-state configurations $\{i_A\}$ map more or less one-to-one onto the subsets $\{A\}$ of the final-state-configurations.[14] A familiar example is the conjectured correlation between final-state multiplicity and initial-state impact parameter.[15]

To my knowledge it is customary to largely ignore such questions of initial-state impact-parameter correlations. In the context of multiperipheral mechanisms, these correlations are quite weak. Hereafter we ignore this issue, and assume approximate factorization occurs.[16] Then we may relate the parton distributions of a *proton* to the parton distributions of the Pomeron. Since

$$\frac{1}{\sigma_{\text{inel}}}\,\frac{d\sigma}{d\Gamma_1 d\Gamma_2} \approx f_{\mathcal{P}}(x_1)\, f_p(x_2)\, \sigma_{\text{parton}}(\Gamma_1, \Gamma_2) \tag{4.4}$$

and by definition

$$\frac{1}{\left(\frac{d\sigma}{d\eta_1 d\eta_2}\right)}\,\frac{d\sigma}{d\Gamma_1 d\Gamma_2 d\eta_1 d\eta_2} \approx f_{\mathcal{P}}(x_1')\, f_p(x_2)\, \sigma_{\text{parton}}(\Gamma_1, \Gamma_2) \tag{4.5}$$

we have, according to the factorization ansatz, Eq. (4.2),

$$f_{\mathcal{P}}(x_1') \approx f_p(x_1)\ . \tag{4.6}$$

Here the parameters are

$$x_1 x_2 = \frac{\hat{s}}{s} \qquad x_1' x_2 = \frac{\hat{s}}{s'} \tag{4.7}$$

where $\sqrt{\hat{s}}$ is the dijet mass, $\sqrt{s}$ is the overall cms energy, and $\sqrt{s'}$ is the total mass of the diffractive system containing the high-p_T jets. Also the parton distributions are, to good approximation, given by the effective distributions[17]

$$x\,\frac{dn}{dx} \equiv f(x) = g(x) + \frac{4}{9}\,q(x)\ . \tag{4.8}$$

In all cases, all values of x are required to be small enough that the x-dependences are very weak.

The conclusion, Eq. (4.6), is disquieting, since the Pomeron structure function becomes nonuniversal, and depends upon the hadron that emitted it. There is clearly more to be studied here. Nevertheless, we believe that the factorization *ansatz*, Eq. (4.2), is a useful reference-point for any such effort.

5. The Hard Pomeron

In contrast to the soft Pomeron, the first approximation to the structure function of the hard Pomeron, at least for reasonably large x, might be that of a two-gluon system, with perhaps even a predominantly asymmetric partition of momentum. Were this really to occur, hard-Pomeron exchange might have manifestations quite similar to single-photon exchange. Indeed this view underlies much work in Pomeron-physics, especially nowadays that of Donnachie and Landshoff.[18]

From the point of view taken here, the role of hard Pomeron might emerge in large-t elastic scattering and the large-p_t-exchange generalizations to single and double diffraction. It becomes an especially interesting question whether the event structure for large p_t double-diffraction really looks like photon-exchange at the same p_t.

Photon exchange at large p_t, assuming "factorization", namely that absorption corrections from spectator interactions can be neglected,[19] has an event morphology as shown in Fig. 3a. At the edge of the rapidity gap appear "tagging-jets." In parton language, these are created by the quarks emitting and absorbing the virtual photon. While one knows (just from kinematics and existing data) that these tagging jets occur at the edge of the gap,[#1] this may not be the generic case for

---

[#1] This can be stated precisely: if the jet is defined as the contents within a circle-of-radius 0.7 in the lego-plot, and the edge of the rapidity gap is defined as a tangent to that circle, then on average about 0.5 hadrons per jet per event leak into the rapidity-gap.

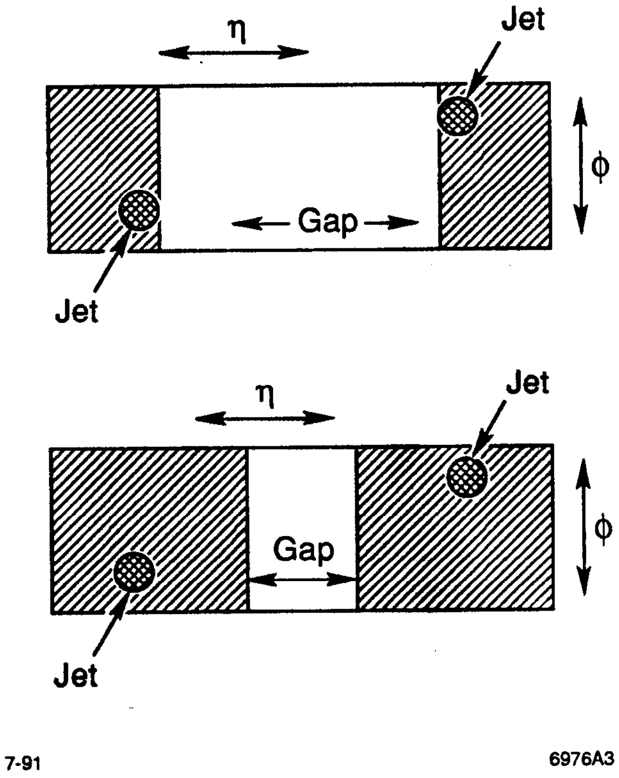


Figure 3. Event structure in the lego plot for (a) photon-exchange at large t, and (b) conjectured strong double-diffraction at large t.

the more complicated Pomeron. It is an important experimental and theoretical problem to determine how often coplanar-jet final states occur with a rapidity-gap in between (Fig. 3b), and how the gap boundaries distribute themselves relative to the jet locations. I suspect that the configurations with the jets some distance away from the edges of the rapidity gap are much more frequent than those with jets on the edges of the gap. But I do not have a good way of estimating this, and am not aware of much theoretical work on it either.[20]

Returning to the configurations with jets on the edge of the gap, we may ask whether, as p_t increases, the exchange of Pomeron ever becomes less important than exchange of photon (or other electroweak bosons such as W or Z). If it

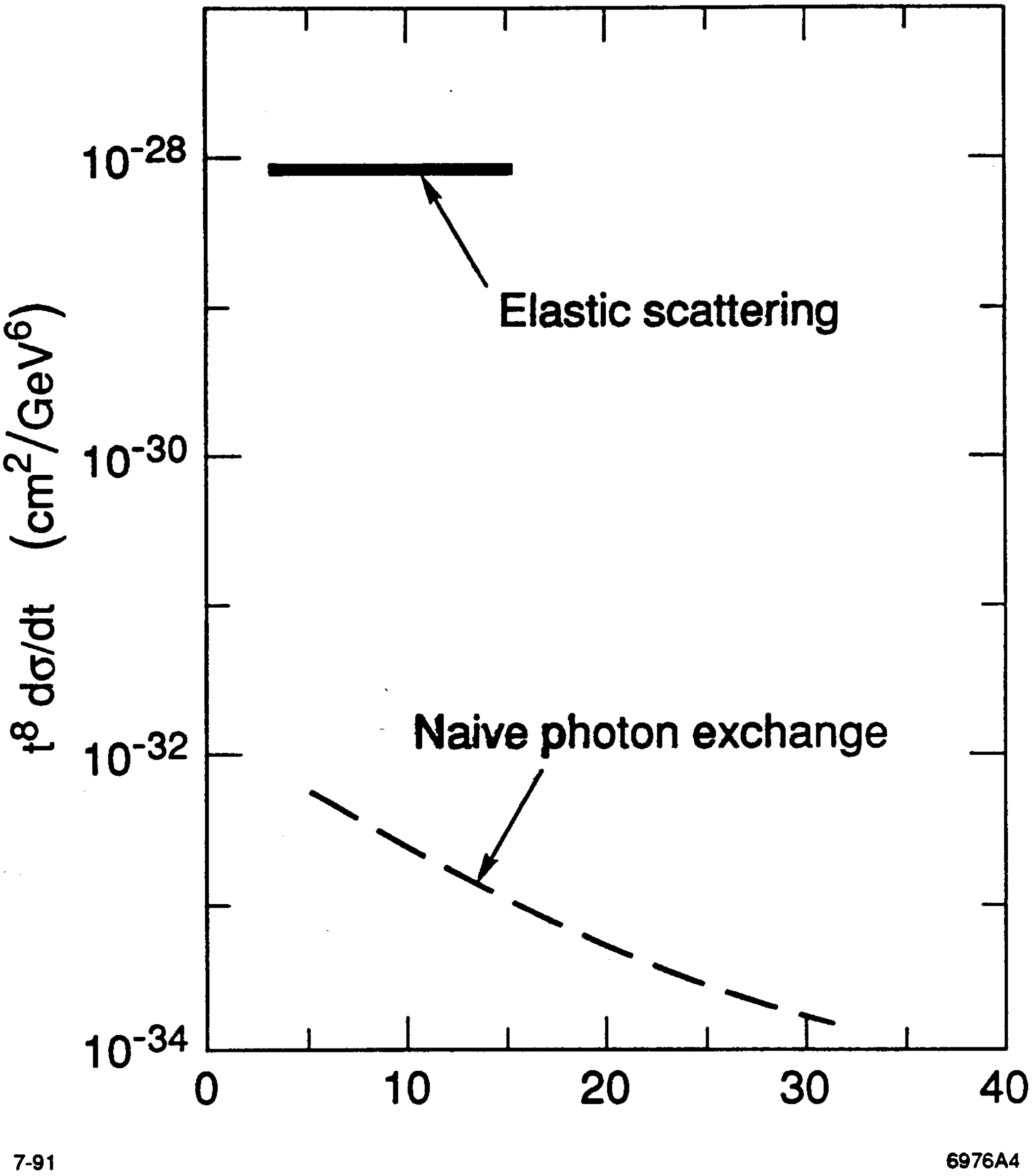


Figure 4. Comparison of elastic pp scattering with a "naive" photon-exchange contribution. What is plotted is $t^8\, d\sigma/dt$ (solid curve), along with the naive photon-exchange contribution (dashed curve).

does, then the critical, crossover p_t probably does not depend too much on the diffractively excited masses M_1^2 and M_2^2. While there is insufficient data on high-mass double diffraction to resolve the question, we may, under the (dangerous?) assumption that the M^2 dependences don't matter much, retreat all the way to elastic scattering and ask the question there. The naive *pp* elastic cross section from photon exchange, uncorrected for absorption effects,[#2] is given by the formula

$$\frac{d\sigma}{dt} = \frac{4\pi\alpha^2}{t^2} \left[G_E^2 + \frac{\mu^2|t|}{4M^2} G_M^2\right]^2 \cdot \left[1 + \frac{|t|}{4m^2}\right]^{-2} . \tag{5.1}$$

Asymptotically, the elastic cross-section seems to fall[21] roughly as t^{-8}. So we plot $t^8\, d\sigma/dt$ for the data and for the above equation (Fig. 4), assuming $G_E = G_M$ and taking extant data for G_M.[22] It is clear that there is no tendency for photon-exchange to ever compete with Pomeron-exchange.

Thus a good case can be made that Pomeron-exchange processes will turn out to be just as pointlike as single-photon, or even single-gluon exchange processes. My instincts rebel against this conclusion. It may be that elastic processes may not be a reliable indicator for highly inelastic, large p_T phenomena. In any case, very much is at stake. For example, there already exist suggestions that Higgs bosons may be produced by Pomeron-Pomeron fusion,[23] namely in the process

$$p + p \to p + p + \text{Higgs} + \ldots \tag{5.2}$$

where the dots stand for "not much else," and where the final state protons are diffractive (Fig. 5a). Bialas and Landshoff estimate that this would be, at SSC/LHC energies, ~ 1% or so of the total yield of Higgs bosons produced via gluon-gluon fusion, the mechanism relevant here.

This conclusion is both remarkable and suspect. If this process is big, should not the process shown in Fig 5b, where the mass of the system produced by the colliding Pomerons is much larger than the Higgs-mass, be much bigger? And

---

[#2] We expect this to be a factor of order 5 or so, with at most logarithmic variation with s.

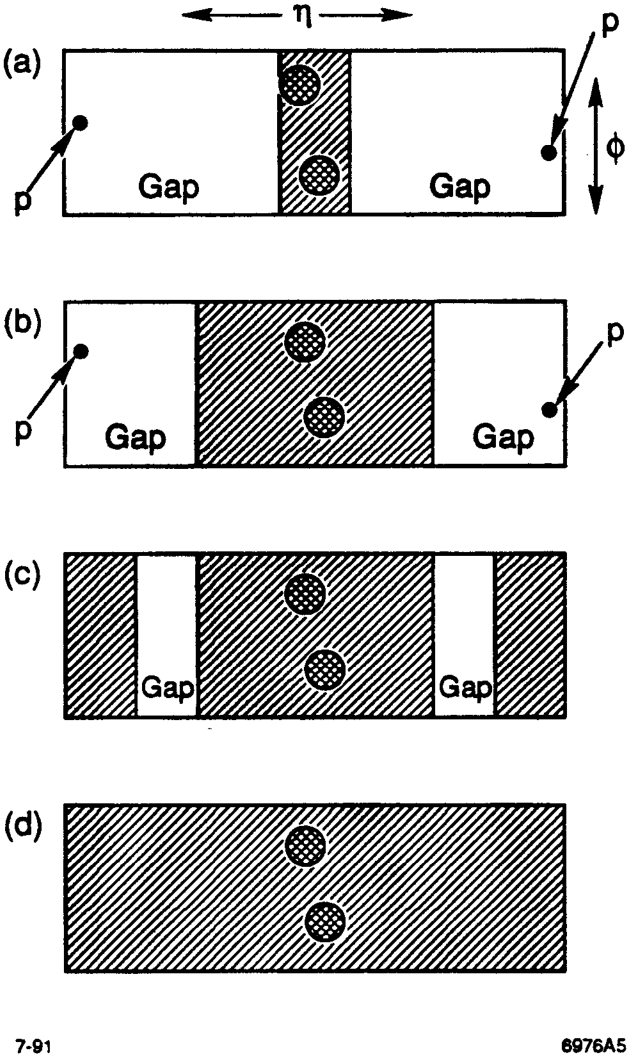


Figure 5. Event structures in the lego plot for (a) elastic double-diffraction production of a Higgs boson, (b) elastic double-diffraction production of a Higgs boson immersed in Pomeron-Pomeron "beam-fragments," (c) inelastic double-diffraction production of a Higgs-boson, immersed in Pomeron-Pomeron "beam fragments," and (d) overall inclusive production of a Higgs boson via gluon-gluon fusion.

should not the yield increase still more if the beam protons are excited into high mass diffracted states (Fig. 5c)? And then the absence of any rapidity-gap in the final-state costs another factor, which we take to be 5. The total yield is reliably estimated by standard parton-model techniques. So putting all this together gives

High m_X for $pp \to X$	$\sim 10^{2-3}$?
Large diffracted masses	10^2 ?
Rapidity gap	5
Overall ratio	$\gtrsim 10^5$??

The most serious factor is the first. If that one is omitted, should not the parton-distribution of the Pomeron as seen in Ingelman-Schlein processes show a δ-function peak at $x = 1$?

I have no crisp answers to all these questions. But I do believe they deserve much more attention than they now are getting. Rapidity-gap signatures for new-physics searches[24] promise to be a powerful new diagnostic tool in high energy hadron-hadron collisions, one as yet not at all considered seriously, either theoretically or experimentally. Two extreme scenarios can be envisaged. The first has Pomeron-exchange processes suppressed relative to electroweak boson exchange processes at the mass and p_t scales of interest, say 100 GeV and above. In this case the presence of rapidity-gap signatures for γ, W, and/or Z exchanges are a powerful suppressor of backgrounds.[25]

On the other hand, if the Pomeron behaves much as a single gluon, then it can itself be used as a producer of new physics, with cross-sections enhanced relative to the electroweak-boson cross-sections, and with signatures stronger than what are conventionally utilized. In either case, the Pomeron deserves to be rescued from its present torpid state.

6. Concluding Comments

The main points which we wish to emphasize are as follows:

1. We have, using Υ-Υ and B-B scattering as examples, highlighted two distinct candidate Pomerons. "Soft" Pomeron exchange is the interaction of pion-clouds surrounding light constituent quarks, and controls most hadron-hadron total cross sections at moderate energies (*e.g.* ISR and below). It is operative in B-B scattering. Hard Pomeron-exchange processes have to do with the perturbative-QCD mechanism of interaction of the gluon fields surrounding the quarks. It is dominant in Υ-Υ scattering.

   While B-B and Υ-Υ scattering processes are experimentally remote, a promising candidate process for probing these questions is the scattering of a virtual (or real) photon of momentum q from another of momentum p. When q^2 and p^2 are large and spacelike, and $s = (q+p)^2 \gg q^2, p^2$, it is arguable[26] that the interaction is dominated by exchange of the hard Pomeron. This occurs because the quark pairs to which the photons convert have typical sizes $\sim q^{-1}, p^{-1}$. In the vector-dominance limit, when q^2 and p^2 go timelike, of order m_ρ^2, the soft Pomeron dominates. The issue thus focuses on the behavior of the photon structure functions for large $s = (q+p)^2$ as q^2 and p^2 are varied.

2. The case for a distinct "soft" Pomeron was defended in terms of the Manohar-Georgi viewpoint. The constituent quark and pion are argued to be basic degrees of freedom in the mass range of 200 MeV to 1 GeV, with the role of gluon interactions of lesser importance.

   Perhaps the weakest point in the Manohar-Georgi line of argument is the special role of their "Nambu-Goldstone, chiral pion," which is not the $^1S_0$ hyperfine partner of the rho. That state mixes with the chiral pion, and presumably is driven upward in mass via level repulsion. It is an interesting question whether this state has been identified experimentally. Diffractive excitation would seem to be the ideal probe. There does exist a broad 0^- state under the $a_1(1260)$, and a strange partner under the $K_1(1400)$. But these, especially the latter, might be regarded as "radial excitations."

3. The Pomeron can be probed via hard-collision processes, as suggested by Ingelman and Schlein. The Pomeron structure-functions measured, and indeed defined, by such processes can distinguish between the soft Pomeron, characterized by larger quark content and not much leading-parton content, and the hard Pomeron, characterized by overwhelming gluon content, including perhaps a large component at large x. The measurements reported at this meeting, when normalized, along with upcoming observations[27] at HERA, will be extremely valuable.
4. We have suggested approximate factorization in Ingelman-Schlein processes, motivated by a space-time causality argument, as a way of normalizing the structure functions of the Pomeron at small x. Such an approach, while approximate at best, indicates that at small x the distributions ought to be similar to those of typical hadrons. Pomeron exchange amplitudes may, however, be non-factorizable. In this case there may be ways of exploiting this feature to learn more about correlations between the impact-plane structure of the projectiles at impact and the final state morphologies.
5. Study at hadron-hadron collider energies of events containing rapidity gaps is important for many reasons, and thus far has been largely neglected, both ex-

perimentally and theoretically. The rapidity-gap signature can be important for new physics searches. As emphasized by Khoze and discussed elsewhere, processes involving γ, W, and/or Z exchanges may often contain rapidity gaps. Their presence can provide powerful suppression of backgrounds.

It is possible that, if the Pomeron contains a hard component, the electroweak processes are immersed in a large strong-interaction background. If this turns out to be the case, then the Pomeron itself may be utilized as a producer of new physics. Examples of this possibility exist in the suggestion that Higgs-boson production might be observable, indeed enhanced, in double-diffraction processes. All this is very speculative and not in good theoretical control. A good experimental program, along with an increased level of attention by theorists and phenomenologists, is very much needed.

ACKNOWLEDGMENTS

I thank the organizers of the Elba meeting, especially Franco Cervelli, for providing an excellent environment for me to discuss and learn much about these problems. Many colleagues have been of help. I especially wish to thank W. Dunwoodie, L. Frankfurt, E. Predazzi, N. Nikolaev, and P. Landshoff for most helpful discussions.

REFERENCES

1. J. Bjorken, SLAC-PUB-5545, submited to the SSC Laboratory, is an "expression of interest" (EoI-19) in a full acceptance detector. This document will be published in the *Proceedings of the Sixth J. A. Swieca Summer School: Particles and Fields*, Campos do Jordao, Brazil (1991).
2. The motivation here is the Isgur-Wise infinite-mass limit of QCD; N. Isgur and M. Wise, Phys. Lett. B232, 113 (1989); ibid B237, 527 (1990). See also J. Bjorken in "Results and Perspectives in Particle Physics," ed. M. Greco, La Thuile, March, 1990 (Editions Frontieres, Gif-sur-Yvette, Cedex, France), p. 583 and in particular Section X.
3. L. N. Lipatov, Sov. Phys. JETP 63, 904 (1986).
4. D. Amati, S. Fubini and Stanghellini, Nuovo Cimento 26, 896 (1962).
5. A. Manohar and H. Georgi, Nucl. Phys. B234, 189 (1984).
6. S. Weinberg, Phys. Rev. Lett. 65, 1177 (1990).
7. P. Amaudruz, *et al.* (NMC Collaboration), Phys. Rev. Lett. 66, 2712 (1991).
8. This idea, but at the nucleon—not constituent quark—level, is due to E. Henley and G. Miller, Phys. Lett. 251B, 453 (1990).
9. A recent summary of the situation is given by A. Manohar, UC San Diego preprint UCSD-PTH-90-28 (1990).
10. See for example M. Block and R. Cahn, Phys. Lett. B188, 143 (1987).
11. G. Ingelman and P. Schlein, Phys. Lett. 152B, 256 (1985).
12. A. Brandt, these proceedings. See also R. Bonino *et al.*, Phys. Lett. 211B, 239 (1988).

13. What follows bears a close relationship to arguments of E. Berger, J. Collins, D. Soper, and G. Sterman, Nucl. Phys. B286, 704 (1987), regarding issues of "double-counting" in diffractive hard processes. See in particular Section 4.

14. The general problem of defining final state morphologies which project onto specific initial-state impact-plane configurations is important in its own right, one to which I hope to return in the future. See the discussion in Ref. 1, Section III.3.

15. This has been especially emphasized by S. Barshay, *e.g.* Phys. Rev. D29, 1010 (1984).

16. This is due to the phenomenon of "random-walk" in the impact plane. See J. Bjorken, *Proceedings of the International Conference on Duality and Symmetry in Hadron Physics*, Tel-Aviv, 1971, ed. E. Gotsman (Weizmann Press, Jerusalem), p. 98, for a heuristic discussion and for further references.

17. B. Combridge and C. Maxwell, Phys. Lett. 151B, 299 (1985).

18. P. Landshoff, these proceedings (Cambridge University preprint DAMPT 91/20), and references therein.

19. They cannot. However we estimate (elsewhere) that of order 20% of photon-exchange events will have this factorizable structure.

20. Some discussion can be found in E. Levin and M. Ryskin, Phys. Repts. 189, 267 (1990), and in L. Frankfurt and M. Strikman, Phys. Rev. Lett. 63, 1914 (1989).

21. A. Donnachie and P. Landshoff, Z. Phys. C2, 55 (1979); see also Ref. 18.

22. R. Arnold *et al.*, Phys. Rev. Lett. 57, 174 (1982).

23. A. Bialas and P. Landshoff, Cambridge University preprint DAMPT 90-39 (1990); A. Schafer, O. Nachtmann and R. Schöpf, Phys. Lett. B249, 331 (1990).

24. Y. Dokshitser, S. Troyan, and V. Khoze, Yad. Fis. 46, 1220 (1987).

25. See Ref. 1, Sections II.4–II.7, for some more discussion of these questions.

26. But not inevitable. Even at large spacelike q^2 and p^2 the quark pair configurations with asymmetric longitudinal momentum partition and low transverse momentum may well contain "pion clouds." While those configurations are rare, they may dominate the total cross section anyway. The issue is delicate. See also N. Nikolaev and B. Zakharov, Torino preprint DFTT-5/91.

27. M. Arneodo and C. Peroni, Nucl. Phys. B12 (Proc. Suppl.), 149 (1990).