DIFFRACTIVE HARD SCATTERING*

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ABSTRACT

I discuss events in high energy hadron collisions that contain a hard scattering, in the sense that very heavy quarks or high P_T jets are produced, yet are diffractive, in the sense that one of the incident hadrons is scattered with only a small energy loss.

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1. INTRODUCTION

In this talk, I discuss the diffractive production of systems such as very heavy quarks or jets in hadron-hadron collisions. Our treatment¹⁾ uses both perturbative QCD, to describe the hard scattering in which the heavy quarks or jets are made, and Regge theory, to describe the diffraction. Our results apply to processes involving any kind of hard scattering at the partonic level. For the sake of definiteness, I discuss the particular case of very heavy quark production²⁾.

The treatment presented depends heavily on the argument³⁾ that the bulk of the production of *sufficiently heavy* quarks is correctly described by the standard factorization theorem of perturbative QCD. I presented this argument at the Rencontre de Moriond last year. An important calculation by R. K. Ellis presented in his talk in these proceedings⁴⁾ confirms this conclusion and shows that at least one class of higher order perturbative corrections is not unusually large. From this conclusion it follows that if there is a significant diffractive component of very heavy quark production, then it must be true that this diffractive component is included in the standard perturbative QCD cross section. That is, diffractive production is not to be *added* to perturbative production: it is *part* of perturbative production. The issue here is: how big a part is it?

A number of authors have treated diffractive hard scattering recently: Ingelman and Schlein described jet production⁵⁾, then Fritzsche and Streng discussed heavy quark production⁶⁾. Streng has discussed Pomeron-Pomeron collisions⁷⁾. In the paper on which this talk is based¹⁾, we develop a detailed formulation of the basic physical picture contained in the paper of Ingelman and Schlein. We discuss the open questions raised by this picture and give estimates in some detail for the distribution of gluons in the Pomeron.

2. KINEMATICS

Let us consider diffractive heavy quark production:

$$A + B \rightarrow (Q\bar{Q}) + X + C, \quad (2.1)$$

where C is the label for hadron B in the final state and Q represents a heavy quark of mass M_Q . By a diffractive event, we mean an event in which hadron B goes through the collision nearly unscathed. It is deflected through a small angle, while retaining most of its incident energy. We let z denote the fraction of its energy that hadron B loses in the collision and we let t denote the invariant momentum transfer from hadron B.

For a *diffractive* event, we demand t be no more than $(\text{a few hundred MeV})^2$ and that the momentum fraction z lost by the hadron obey $z \ll 1$. Normally we will integrate over t , so the

important variable is z . It is the momentum fraction carried by what we shall interpret as a Pomeron in the figure. The invariant mass squared of the system $(Q\bar{Q}) + X$ is $M^2 = (p_A + q)^2 \approx zs$; M^2 is large, but is much less than s .

I should point out that, although hadron B is diffractively scattered, the system $(Q\bar{Q}) + X$ cannot be a low mass, diffractively excited version of hadron A. The invariant mass M of this system must necessarily be very large: $M \geq 2M_Q \gg 1 \text{ GeV}$. This situation contrasts with the situation for the production of low mass quark flavors.

We have defined the kinematics of the diffraction in terms of the diffracted hadron. However, in a typical collider experiment, this hadron will not be observed. The fact that this hadron carried a momentum fraction $(1-z)$ close to 1 will be signaled by the existence of a large rapidity gap between the incident beam and the other hadrons in the final state. It is possible to measure z directly using the particles in the system $(Q\bar{Q}) + X$.

3. REGGE THEORY AND DIFFRACTIVE HARD SCATTERING

Consider first the ordinary high-mass diffractive process $A+B \rightarrow C+X$, where we have eliminated the requirement of a heavy quark pair. In the region where z is small and $M_X^2 = zs$ is large, this cross-section is represented by the Reggeon graph shown below.

The zigzag line in the figure represents the exchange of a Pomeron. In QCD, the Pomeron presumably arises from high energy limit of the exchange of complicated gluon ladders, as suggested in the right hand side of the figure. The Reggeon graph gives

$$d\sigma^{\text{diff}}/dtdz = (1/16\pi) |\beta_{BP}(t)|^2 z^{1-2\alpha(t)} \sigma_{\text{tot}}(AP). \quad (3.1)$$

where⁸⁾

$$\sigma_{\text{tot}}(AP) = G_{PPP}(t) \beta_{AP}(0) (M_X^2)^{\alpha(0)-1}. \quad (3.2)$$

Now let us consider the case that heavy quarks are produced. In the usual case, without the diffractive trigger, the cross-section is

$$d\sigma^{\text{tot}}[A+B \rightarrow (Q\bar{Q})+X] =$$

$$\sum_{a,b} \int dx_a \int dx_b f_{a/A}(x_a; \mu) f_{b/B}(x_b; \mu) d\sigma_{\text{hard}}[a+b \rightarrow (Q\bar{Q})+X]. \quad (3.3)$$

Here a and b label the partons, typically gluons, that take part in the hard scattering. The hard scattering cross section $d\sigma_{\text{hard}}[a+b \rightarrow (Q\bar{Q})+X]$ is to be computed perturbatively in powers of $\alpha_s(\mu)$, $\mu \sim M_Q$, with the lowest order graphs consisting of the usual gluon-fusion graphs.

In order to obtain a leading twist contribution to the diffractive cross-section to make heavy quarks, we demand that the parton b that enters the hard scattering be found as a constituent of the Pomeron that was exchanged from the diffractively scattered hadron B, as illustrated below.

The diffractive hard scattering cross-section is obtained by substituting $d\sigma_{\text{tot}}[A+P \rightarrow (Q\bar{Q})+X]$ from the hard scattering equation (3.3) for $\sigma_{\text{tot}}(AP)$ in the diffraction formula (3.1):

$$d\sigma^{\text{diff}}[A+B \rightarrow C+(Q\bar{Q})+X]/dtdz = (1/16\pi) |\beta_{BP}(t)|^2 z^{1-2\alpha(t)} \quad (3.4)$$

$$\times \sum_{a,b} \int dx_a f_{a/A}(x_a; \mu) \int d(x_b/z) f_{b/P}(x_b/z, t; \mu) d\sigma_{\text{hard}}[a+b \rightarrow (Q\bar{Q})+X].$$

The hard scattering cross-section $d\sigma_{\text{hard}}$ is the same as in eq. (3.3). The function $f_{b/P}(x_b/z, t; \mu)$ is the distribution of partons in a Pomeron, defined in the usual manner of a parton distribution; x_b/z is the ratio of the minus momentum, $x_b P$, carried by the parton to the minus momentum, zP , carried by the Pomeron. The distribution $f_{b/P}(x_b/z, t; \mu)$ obeys the same Altarelli-Parisi equation in μ as the usual parton distributions.

The formula (3.4) represents the class of graphs shown in the figure. There are, however, graphs with extra Pomerons. Thus we cannot expect the diffractive cross-section to satisfy eq. (3.3) exactly, but only at the level at which multiple Pomeron exchange is ignored.

4. DISTRIBUTION OF PARTONS IN THE POMERON

Although the distribution of partons in a Pomeron, $f_{b/P}(x/z, t, \mu)$, is a non-perturbative quantity, we can find some information on its functional form. The arguments presented in detail in ¹⁾ suggest the following parameterization for the gluon distribution in the Pomeron.

$$f_{g/P}(\xi) = \{ A/\xi + B \} [1-\xi]^1. \quad (4.1)$$

The $1/\xi$ behavior arises from Pomeron dominance at small ξ . The coefficient A of the $1/\xi$ behavior is determined from the triple Pomeron coupling and the measured distribution of gluons in the proton at small momentum fraction. We find $A \approx 0.18$. The power of $[1-\xi]$ is estimated from the power counting argument for the simplest Feynman graph. Then the coefficient B is determined by the momentum sum rule to be $B \approx 5.5$.

5. PHENOMENOLOGICAL RESULTS

In the figures below, we show the result of a calculation of diffractive b-quark and t-quark production at the CERN collider. In each case we show the total heavy quark production cross section $d\sigma/dy$ and the diffractive part ($z < 0.1$) of the cross section. We have let the distribution function of gluons in a proton evolve from $\mu = \mu_0$ to $\mu = M_Q$ (the quark mass), but have simply taken eq. (4.1) for the distribution of gluons in a pomeron at $\mu = M_Q$, without evolution. The lightly shaded curve in the b-quark graph represents the diffractive cross section using $f_{g/P}(\xi) = 6[1-\xi]^5/\xi$ for the distribution of gluons in the Pomeron. This was one of the forms suggested by Ingelman and Schlein. The other form they suggested is very similar to our favored form.

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