Diffractive production of dijets by double Pomeron exchange processes

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A phenomenological description of diffractive dijet hadroproduction via double Pomeron exchange is presented. This description is based on a modified version of the Ingelman-Schlein model which includes the evolution of the Pomeron structure function and corrections regarding rapidity gap suppression effects. The same quark-dominant Pomeron structure function employed in a previous report to describe diffractive dijet and *W* production via single Pomeron processes is shown here to yield results consistent with the available data for double Pomeron processes as well.

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I. INTRODUCTION

Since the seminal proposal by Ingelman and Schlein [1], the study of hard diffractive processes has become one of the most active and challenging fields in high-energy physics. Diffractive dijet production, in particular, has been the object of extensive experimental and theoretical analyses via several processes and in quite different kinematical domains (see, for instance, Ref. [2] for a recent summary overview).

In a recent paper [3], we presented an analysis of diffrative hadroproduction of dijets and *W*'s via single Pomeron exchange (SPE). In the present paper, we apply basically the same picture to analyze dijet measurements performed by the Collider Detector at Fermilab (CDF) Collaboration [4], but this time via double Pomeron exchange (DPE) processes. Such processes, produced through quasielastic $\bar{p}p$ collisions, are characterized by large rapidity gaps in the fragmentation regions of both hemispheres and an isolated central hadronic system within which dijet events are found. A phenomenological view inspired by Regge theory allows one to conceive these processes as pure Pomeron-Pomeron interactions (Fig. 1).

DPE phenomenology has been the focus of intense theoretical investigation not only for its intrinsic interest in quite different scenarios [5], but also because DPE processes are considered to be one of the main mechanisms leading to Higgs boson production and new physics signals within a very clean experimental environment [6]. These aspects and the availability of experimental data [4] make evident the importance of further phenomenological studies on central diffractive dijet production via DPE aiming at describing these and more rare events possible to occur by the same reaction channel.

We show here a description of diffractive dijet production via DPE by using a modified version of the Ingelman-Schlein (IS) model [1] in which the Pomeron structure function is evolved according to the Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) evolution formalism [7]. The results obtained via IS model are corrected in order to consider the effect of rapidity gap suppression. This is done according to the scheme developed by Goulianos in Refs. [8,9].

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II. SPE AND DPE CROSS SECTIONS

We start by recalling the expressions used to calculate dijet production via SPE, which are detailed elsewhere [10]. From these expressions, the cross section for dijet production via DPE are readily obtained.

Let us initially consider hadrons *A* and *B* colliding and giving rise to ordinary, *nondiffractive* (ND) dijet production. In this case, the cross section in terms of the dijet rapidities (η,η') and transversal energy E_T is given by

$$\left(\frac{d\sigma}{d\eta}\right)_{jj} = \sum_{\text{partons}} \int_{E_{T\min}}^{E_{T\max}} dE_T^2 \int_{\eta'_{\min}}^{\eta'_{\max}} d\eta' \times x_a f_{a/A}(x_a,\mu^2) x_b f_{b/B}(x_b,\mu^2) \left(\frac{d\hat{\sigma}}{d\hat{t}}\right)_{jj}, \quad (1)$$

where

$$x_a = \frac{E_T}{\sqrt{s}}(e^{-\eta}+e^{-\eta'}), \quad x_b = \frac{E_T}{\sqrt{s}}(e^{\eta}+e^{\eta'}), \quad (2)$$

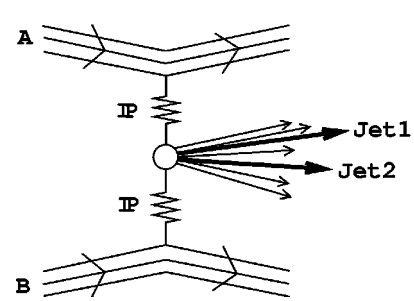

FIG. 1. Schematic view of hadrons *A* and *B* interacting via double Pomeron exchange and giving rise to dijets in the central region.

with

$$\ln\frac{E_T}{\sqrt{s}-E_T e^{-\eta}}\leqslant\eta'\leqslant\ln\frac{\sqrt{s}-E_T e^{-\eta}}{E_T} \tag{3}$$

and

$$E_{T\max}=\frac{\sqrt{s}}{e^{-\eta}+e^{\eta}}, \tag{4}$$

being that $E_{T\,\min}$ and the η range are determined by the experimental cuts.

Equations (1)–(4) summarize the leading-order QCD procedure to obtain the *nondiffractive* dijet cross section (next-to-leading-order contributions are not essential for the present purposes; see Ref. [10]). In order to obtain the corresponding expression for SPE processes according to the IS approach, we assume that one of the hadrons, say hadron *A*, emits a Pomeron whose partons interact with partons of the hadron *B*. Thus the parton distribution $x_a f_A(x_a,\mu^2)$ in Eq. (1) is replaced by the convolution between a putative distribution of partons in the Pomeron, $\beta f_{\mathbb{P}}(\beta,\mu^2)$, and the "emission rate" of Pomerons by *A*, $g_{\mathbb{P}}(\xi,t)$. This last quantity, $g_{\mathbb{P}}(\xi,t)$, is the so-called Pomeron flux factor whose explicit formulation in terms of Regge theory is given below. By using this procedure and defining $g(\xi)\equiv\int_{-\infty}^{0}dt g_{\mathbb{P}}(\xi,t)$, one obtains [10]

$$x_a f_A(x_a,\mu^2)=\int d\xi\; g(\xi)\;\frac{x_a}{\xi}f_{\mathbb{P}}\left(\frac{x_a}{\xi},\mu^2\right). \tag{5}$$

By inserting the above structure function into Eq. (1), the cross section for diffractive hadroproduction of dijets via single Pomeron exchange can be expressed as

$$\left(\frac{d\sigma_{SPE}}{d\eta}\right)_{jj}=\sum_{a,b,c,d}\int_{E_{T_{\min}}}^{E_{T_{\max}}}dE_T^2\int_{\eta'_{\min}}^{\eta'_{\max}}d\eta'\int_{\xi_{\min}}^{\xi_{\max}}d\xi\;\; g(\xi)\times\beta_a f_{a/\mathbb{P}}(\beta_a,\mu^2)x_b f_{b/\bar{p}}(x_b,\mu^2)\left(\frac{d\hat{\sigma}_{ab\to cd}}{d\hat{t}}\right)_{jj}, \tag{6}$$

where $\beta_a=x_a/\xi$, with x_a and x_b given by Eq. (2), and ξ_{min} and ξ_{max} established by experimental cuts.

The process we are interested in, however, is a particular form of diffractive production in which both p and $\bar{p}$ emit Pomerons giving rise to dijet production in the central region, accompanied by rapidity gaps in both hemispheres (Fig. 1).

In terms of the IS model, the reaction that effectively occurs is $\mathbb{P}\mathbb{P}\to$jet jet and so the respective cross section must involve two convolution products of flux factor and structure function. From Eq. (6), the differential cross section in terms of variables appropriate for the present analysis becomes

$$\left(\frac{d\sigma_{DPE}}{d\eta_{\text{boost}}}\right)_{jj}=\sum_{a,b,c,d}\int 2d\eta^*\int dE_T^2\int\beta_a f_{\mathbb{P}}(\beta_a,\mu^2)\times g_N(\xi_p)d\xi_p\int\beta_b f_{\mathbb{P}}(\beta_b,\mu^2)g_N(\xi_{\bar{p}})d\xi_{\bar{p}}\times\left(\frac{d\hat{\sigma}_{ab\to cd}}{d\hat{t}}\right)_{jj}, \tag{7}$$

where the new rapidity variables are $\eta_{\text{boost}}=(\eta+\eta')/2$, $\eta^*=(\eta-\eta')/2$, and $\beta_{a(b)}=x_{a(b)}/\xi_{p(\bar{p})}$, with $\xi_{p(\bar{p})}$ giving the momentum fraction carried by the Pomeron emitted by the proton (antiproton) vertex. In the flux factors $g_N(\xi_{p,\bar{p}})$, the index *N* indicates that the normalization procedure described below has been applied.

An important element of the IS approach is the Pomeron flux factor, which enters the calculations via Eq. (5). It was originally proposed to be taken from the invariant cross section of (soft) diffractive dissociation processes as it is given by the triple Pomeron model [1]. Here we apply for $g_{\mathbb{P}}(\xi,t)$, the Donnachie-Landshoff parametrization [11] that, before integration over *t*, reads

$$g_{\mathbb{P}}(\xi,t)=\frac{9\beta_0^2}{4\pi^2}F_1^2(t)\;\xi^{1-2\alpha_{\mathbb{P}}(t)}, \tag{8}$$

where $F_1(t)$ is the Dirac form factor,

$$F_1(t)=\frac{(4m^2-2.79t)}{(4m^2-t)}\;\frac{1}{\left(1-\frac{t}{0.71}\right)^2}. \tag{9}$$

Our choice for the Pomeron trajectory in Eq. (8) has been $\alpha_{\mathbb{P}}(t)=1.2+0.25t$, which is compatible with both Fermilab Tevatron and DESY *ep* collider HERA data.

Since the flux factor above violates unitarity, we have employed the (re)normalization procedure proposed by Goulianos [8],

$$g_N(\xi)=\frac{g(\xi)}{\int_{\xi_{\min}}^{\xi_{\max}}g(\xi)d\xi}, \tag{10}$$

which has been recast in terms of rapidity gap survival probability in Ref. [9].

The final element to compose the model, the Pomeron structure function, was chosen to be a three-flavor quark singlet at the initial scale, $\mu_0^2=2\ \text{GeV}^2$, with the gluon component being generated by DGLAP evolution. The parametrization used for the valence quark distribuition bas been

$$\beta\Sigma(\beta,Q_0^2)=[A_1\exp(-A_2\beta^2)+B_1(1-\beta)^{B_2}]\;\beta^{0.001}+C_1\exp[-C_2(1-\beta)^2](1-\beta)^{0.001}, \tag{11}$$

which includes different contributions of soft, hard, and superhard profiles according to the chosen parameters. The results presented below were obtained with the following pa-

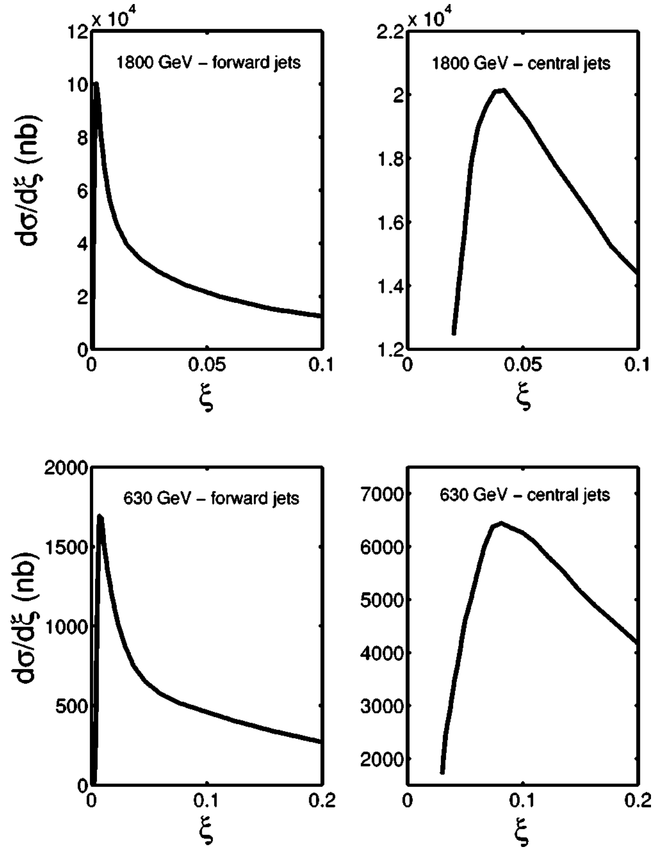

FIG. 2. Dijet differential cross sections for single Pomeron processes corresponding to the constraints of the D0 experiment [14]. Forward jets correspond to $|\eta|>1.6$ and central jets to $|\eta|<1.0$. The corresponding center-of-mass energy is specified in each figure.

rameters: $A_1=4.75$ and $A_2=228.4$ for the soft part, $B_1=1.14$ and $B_2=0.55$ for the hard one, and finally $C_1=2.87$ and $C_2=100$ for the superhard term. DGLAP evolution of the Pomeron parton densities has been processed by using the program QCDNUM [12].

This parametrization has been successfully employed in a recent study [3] aiming at describing diffractive dijet and W production via SPE (see discussion below). Besides the Pomeron structure function described above, some calculations for nondiffractive and SPE processes presented below require ordinary parton densities. Those were taken from Ref. [13].

III. RESULTS AND DISCUSSION

The magnitudes of the different components of the Pomeron structure function (soft, hard, and superhard) given above have been established such that not only would the integrated cross sections of several processes approximately match the experimental data, but also the shape of differential cross sections would resemble those obtained by the experiments. The former aspect has already been shown in Ref. [3], the latter is presented in this section for both SPE and DPE processes in Figs. 2 and 3.

Figure 2 shows dijet differential cross sections for SPE processes calculated with a version of Eq. (6) in which $d\sigma/d\eta$ is transformed into $d\sigma/d\xi$. These results have been obtained with the kinematical constraints corresponding to those of the D0 experiment [14] in which both central ($|\eta|<1.0$) and forward ($|\eta|>1.6$) jets have been measured for the center-of-mass energies 630 and 1800 GeV. The different components of the Pomeron structure function mentioned above have been established such that the $d\sigma/d\xi$ cross sections shown here would reproduce the main features presented by the corresponding experimental ξ distributions (see Fig. 4 of Ref. [14] for comparison). We refer the reader to Ref. [3] for results in terms of integrated cross sections.

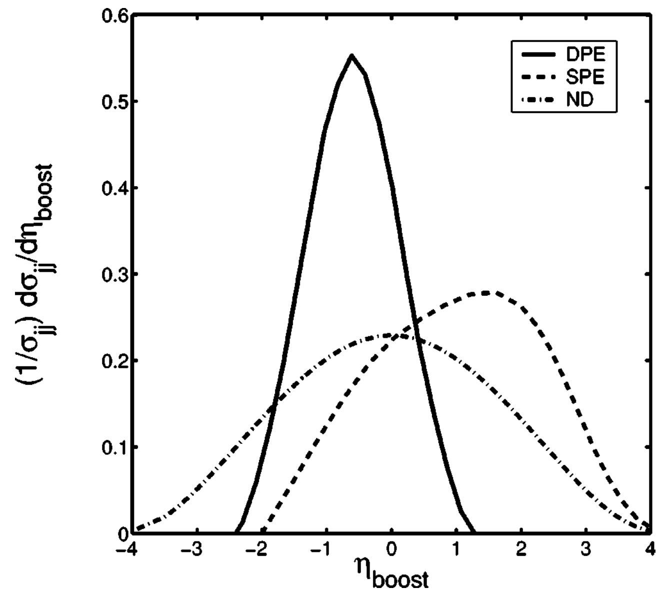

FIG. 3. Theoretical predictions of dijet rapidity distributions for nondiffractive (ND), single Pomeron exchange (SPE), and double Pomeron exchange (DPE) processes (see text for details).

The normalized dijet rapidity distributions presented in Fig. 3, corresponding to ND, SPE, and DPE processes, were constructed assuming that antiprotons are coming from the right-hand side (RHS) while protons from the left-hand side (LHS). For the ND case, we have a symmetrical distribution peaked at the central region with no gaps, as it is supposed to be. For SPE processes, antiprotons are quasielastically scattered, keeping around 90% or more of their momenta. Slow partons from the Pomeron (emitted by $\bar{p}$) interact with on average much faster partons from the protons, giving rise to a dijet distribution shifted to the RHS hemisphere and leaving a rapidity gap on the LHS hemisphere, where the antiproton is detected. For DPE processes, we have rapidity gaps in both sides, as expected. In this case, the central distribution is slightly shifted to the left because we have applied

TABLE I. Integrated cross section for dijet production via double Pomeron exchange. The model prediction by the present analysis is compared with the upper limit for this process established by the CDF Collaboration [4].

	CDF	Present analysis
σ_{DPE} ($E_T>7$ GeV)	<3.7 nb	2.3 nb

cuts corresponding to the experiment [4], $0.035<\xi_{\bar{p}}<0.095$ and $0.01<\xi_p<0.03$, and consequently the distribution is boosted towards the antiproton fragmentation region.

Although these theoretical distributions are not appropriate for direct comparison with the available experimental information, we notice that they bear great resemblance with the CDF data (see Fig. 3(b) of Ref. [4]).

Finally, in Table I, we show that our prediction for the DPE cross section, obtained by integrating Eq. (7) within the experimental limits, is below but close to the upper limit established in Ref. [4].

In summary, we have presented here a variation of the Ingelman-Schlein model which allows one to obtain a reasonable description of the available experimental information on diffractive dijet production via double Pomeron processes. Taken as a whole, the results presented above and those shown in Ref. [3] lend a considerable support to the picture presented here in spite of the existing theoretical objections [15].

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