Fermilab FERMILAB-Conf-02/143-E July 2002

CDF/PUB/JET/PUBLIC/6011
June 25, 2002

Hard Diffraction in CDF

Presented at X International Workshop on
Deep Inelastic Scattering (DIS2002),
Cracow, Poland, 30 April - 4 May 2002

Koji TERASHI
(For the CDF Collaboration)

The Rockefeller University
1230 York Avenue, New York, NY 10021, USA

Hard Diffraction in CDF *

Koji TERASHI
(For the CDF Collaboration)

The Rockefeller University
1230 York Avenue, New York, NY 10021, USA

We present Run I results on hard diffraction obtained by the CDF Collaboration in proton-antiproton collisions at the Fermilab Tevatron. They are compared with results from the DESY ep collider HERA and/or theoretical predictions to test factorization in hard diffraction. In addition, the CDF program for diffractive studies in Run II is presented briefly.

1. Introduction

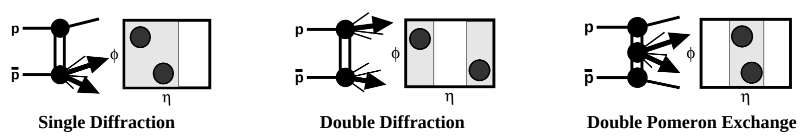

Fig. 1. Diagrams and event topologies of dijet production in single diffraction (left), double diffraction (middle) and double pomeron exchange (right).

Diffractive events in $\bar{p}p$ collisions are characterized by a leading proton or antiproton which remains intact, and/or a rapidity gap, defined as a pseudorapidity[1] region devoid of particles. Diffractive events with hard processes ("hard diffraction") such as production of high P_T jets in diffractive interactions (See Fig 1) have been studied to understand the nature of the exchanged "Pomeron", which is a color singlet object with vacuum quantum numbers. One of the most interesting questions in hard diffractive processes would be whether they obey QCD factorization, in other words, the Pomeron has a universal (process independent) structure function. Various hard diffractive

* Presented at X International Workshop on Deep Inelastic Scattering (DIS2002), Cracow, Poland, 30 April - 4 May 2002

[1] The pseudorapidity η is defined as $\eta \equiv -\ln(\tan\theta/2)$, where θ is the polar angle of a particle with respect to the proton beam direction.

Table 1. Measured ratio of diffractive ($\xi < 0.1$) to inclusive production rates

Hard Process	$\sqrt{s}$	$R_{\rm ALL}^{\rm DIFF}$ (%)	Kinematical Region
$W(\rightarrow e\bar{\nu}_e)$ + G	1800	1.15 ± 0.55	E_T^e, $\not{E}_T > 20$ GeV, $\|\eta^e\| < 1.1$
Jet + Jet + G	1800	0.75 ± 0.10	$E_T^{1,2} > 20$ GeV, $1.8 < \|\eta^{1,2}\| < 3.5$
$b(\rightarrow eX)$ + G	1800	0.62 ± 0.25	$p_T^e > 9.5$ GeV/c, $\|\eta^e\| < 1.1$
$J/\psi(\rightarrow \mu^+\mu^-)$ + G	1800	1.45 ± 0.25	$p_T^\mu > 2.0$ GeV/c, $\|\eta^\mu\| < 1.0$
Jet + G + Jet	1800	1.13 ± 0.16	$E_T^{1,2} > 20$ GeV, $1.8 < \|\eta^{1,2}\| < 3.5$
Jet + G + Jet	630	2.7 ± 0.9	$E_T^{1,2} > 8$ GeV, $1.8 < \|\eta^{1,2}\| < 3.5$

processes have been studied in CDF by measuring the diffractive production rates and/or diffractive structure function of the (anti)proton, and their results will be presented below.

2. Hard Diffraction with Rapidity Gaps

Finding forward rapidity gaps to tag single diffractive events, the ratio of single diffractive (SD) to inclusive rates for W-boson, dijet, b-quark and J/ψ production at $\sqrt{s} = 1800$ GeV has been measured [1, 2]. Also, we have measured rates for events with double diffractive (DD) dijet (central rapidity gaps between jets) at $\sqrt{s} = 1800$ GeV [3] and 630 GeV [4]. The measured SD rates were corrected for "rapidity gap acceptance", defined as the ratio of events with a rapidity gap in the forward detectors to all diffractive events with ξ (momentum fraction of the (anti)proton carried by the Pomeron) less than 0.1. The measured diffractive to inclusive rates for $\xi < 0.1$ are listed in Table 1. Since the measured SD processes have different sensitivity to the quark and gluon content of the Pomeron, the gluon fraction in the Pomeron f_g can be determined by comparing the ratio D of measured to predicted SD rates for different processes with varying f_g from 0 to 1. By using the POMPYT simulation [5], the f_g was determined to be $0.54^{+0.16}_{-0.14}$ and the D was found to be 0.19 ± 0.04. This discrepancy of the D from unity indicates a breakdown of factorization, and the value of D is approximately the same as that observed in the soft SD cross section, as predicted in the Ref. [6].

3. Hard Diffraction with a Leading Antiproton

Detecting a leading antiproton with the Roman Pot spectrometer, CDF has studied single diffractive dijet production at $\sqrt{s} = 1800$ GeV [7] and 630 GeV [8]. In leading order QCD, the ratio R_{ND}^{SD} of SD to non-diffractive (ND) dijet production rates is equal to the ratio of diffractive to ND structure functions of the antiproton. The diffractive structure function in terms of dijet production, $F_{jj}^D(x,Q^2,\xi)$, integrated over four momentum transfer squared t is given by $F_{jj}^D(x,Q^2,\xi) = x[g^D(x,Q^2,\xi) + \frac{4}{9}q^D(x,Q^2,\xi)]$, where x is the momentum fraction of the struck parton in the antiproton, $g^D(q^D)$ the diffractive gluon (quark) density functions. The q^D is multiplied by $\frac{4}{9}$ to account for color factors. Therefore, by measuring the R_{ND}^{SD} for dijet production, the F_{jj}^D can be obtained by multiplying the R_{ND}^{SD} by the known ND structure function of the antiproton $F_{jj}(x,Q^2)$. Finally, the diffractive structure function was measured as a function of β (integrated over Q^2 and ξ) by $x = \beta\xi$, and β is interpreted as the momentum fraction of the Pomeron carried by the struck parton. Fig. 2 shows the measured diffractive structure function $F_{jj}^D(\beta)$ for the kinematic region $|t| < 1$ GeV^2, $0.035 < \xi < 0.095$ and $E_T^{jet1,2} > 7$ GeV. Comparison between our measured F_{jj}^D and the expectations from the parton densities of the proton extracted from diffractive DIS shows a discrepancy in both normalization and the shape of β dependence for diffractive structure function, which indicates a breakdown of factorization. The ξ dependence of diffractive structure function has also been studied. The results (Fig. 3) show the measured F_{jj}^D is well represented by the form $F_{jj}^D = C\,(1/\beta^n)\,(1/\xi^m)$ for $\beta < 0.5$, where the power n and m are given by $n = 1.0 \pm 0.1$ and $m = 0.9 \pm 0.1$, respectively. The observed ξ dependence of F_{jj}^D is much steeper than the $dN/d\xi$ distribution for the inclusive SD sample, and the ξ dependence for the Pomeron and the Reggeon exchanges in Regge theory indicates the diffractive dijet sample in our analysis is dominated by the Pomeron exchange.

The diffractive structure functions has been measured at $\sqrt{s} = 630$ GeV and compared with that at $\sqrt{s} = 1800$ GeV [8]. For the kinematic region $|t| < 0.2$ GeV^2, $0.035 < \xi < 0.095$ and $0.1 < \beta < 0.5$, the ratio of 630 to 1800 GeV diffractive structure function was obtained to be $R_{1800}^{630} = 1.3 \pm 0.2(\text{stat})^{+0.4}_{-0.3}(\text{syst})$. The ratio R_{1800}^{630} is consistent with the factorization ($R_{1800}^{630} = 1$), but also consistent with the value of 1.55 predicted in the renormalized Pomeron flux model [6], and with the value of 1.8 in the rapidity gap survival model of Ref [9].

4. Hard Double Pomeron Exchange with a Leading Antiproton

CDF has studied events with a double pomeron exchange (DPE) topology (Fig. 1) in data sample with a leading antiproton at $\sqrt{s} = 1800$ GeV, and reported the first conclusive observation of the dijet production in DPE [10]. Diffractive structure function of the antiproton was evaluated from the ratio R_{ND}^{SD} of SD to ND dijet rates as a function of $x_{\bar{p}}$ (Bjorken-x of the parton in the antiproton). Similarly, the diffractive structure function of the proton can be obtained from the ratio R_{SD}^{DPE} of DPE to SD dijet rates as a

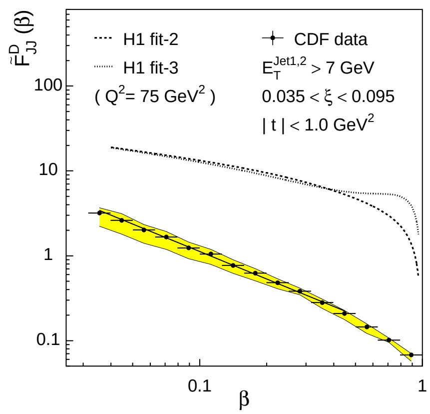

Fig. 2. Data β distribution (points) compared with expectations from diffractive DIS by the H1 Collaboration (dashed and dotted lines). The straight line is a fit to the data of the form β^{-n}. The lower (upper) boundary of the filled band represents the data distribution obtained by using only the two leading jets (up to four jets of $E_T > 5$ GeV) in evaluating β. The systematic uncertainty in the normalization of the data is $\pm 25\,\%$.

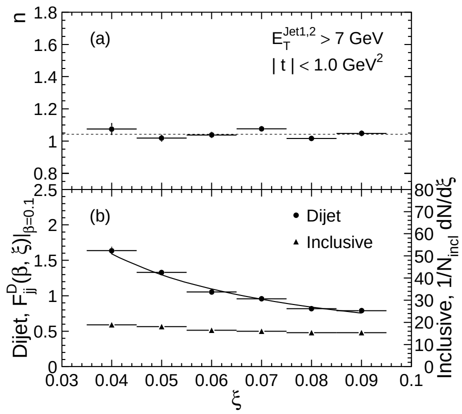

Fig. 3. (a) ξ dependence of the parameter n (circles) of a fit to the F_{jj}^D of the form $C\beta^{-n}$ at fixed ξ for $\beta < 0.5$, with one parameter straight line fit (dashed line). (b) ξ dependence of the F_{jj}^D (points) at $\beta = 0.1$ fitted to the form $C\xi^{-m}$ (curve), and the inclusive SD distribution (triangles). The errors shown are statistical only.

function of x_p (Bjorken-x of the parton in the proton) in leading order QCD. Factorization demands two ratios R_{ND}^{SD} and R_{SD}^{DPE} should be equal at fixed x and ξ, so comparing the two ratios will be another factorization test at the Tevatron. Fig. 4 shows $R_{SD}^{DPE}(x_p)$ and $R_{ND}^{SD}(x_{\bar{p}})$ (normalized per unit ξ) at $x_p = x_{\bar{p}} = x$ as a function of x for the kinematic region denoted in the figure. The weighted average of the R_{SD}^{DPE} (R_{ND}^{SD}) data points in the range $10^{-2.8} < x < 0.01$ (within dashed lines) at $\xi = 0.02$ is $\tilde{R}_{SD}^{DPE} = 0.80 \pm 0.26$ ($\tilde{R}_{ND}^{SD} = 0.15 \pm 0.02$ evaluated from a straight line fit to the $\tilde{R}_{ND}^{SD}$ points shown in the inset), which gives the ratio $D \equiv \tilde{R}_{ND}^{SD}/\tilde{R}_{SD}^{DPE}$ to be $D = 0.19 \pm 0.07$. The discrepancy of D from unity represents a breakdown of factorization.

The absolute DPE dijet cross section was also measured to be $\sigma_{jj}^{DPE} = 43.6 \pm 4.4(\text{stat}) \pm 21.6(\text{syst})$ $[3.4 \pm 1.0(\text{stat}) \pm 2.0(\text{syst})]$ nb for the region $|t_{\bar{p}}| < 1$ GeV^2, $0.035 < \xi_{\bar{p}} < 0.095$, $0.01 < \xi_p < 0.03$ and jets of $E_T > 7$ $[E_T > 10]$ GeV confined within $-4.2 < \eta < 2.4$. We also obtained the $95\,\%$ C.L. upper bound for events in which the dijet energies could account for the

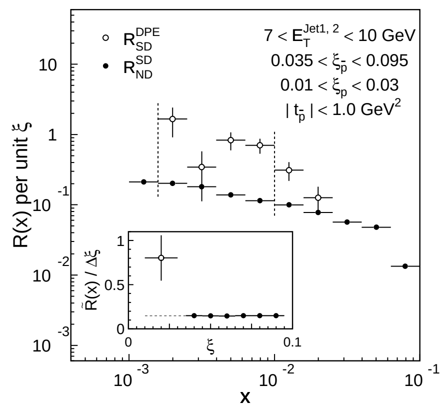

Fig. 4. Ratios of DPE to SD (SD to ND) dijet event rates per unit ξ_p ($\xi_{\bar{p}}$), shown as open (filled) circles, as a function of x_p ($x_{\bar{p}}$). The errors are statistical only. The inset shows $\tilde{R}(x)$ per unit ξ versus ξ, where $\tilde{R}$ is the weighted average of the $R(x)$ points within the vertical dashed lines, which mark the DPE kinematic boundary (left) and the value of $x = \xi_p^{min}$ (right), in the main figure.

total energy of the central system ($\bar{p} + p \to \bar{p}' + \mathrm{jet1} + \mathrm{jet2} + p'$) to be 3.7 nb for $0.035 < \xi_{\bar{p}} < 0.095$ and $E_T^{jet1,2} > 7$ GeV confined within $-4.2 < \eta < 2.4$.

5. Run II Diffraction in CDF

CDF is going to study various topics for diffraction in Run II. They will include detailed study of F^D, *e.g.* process dependence of F^D and Q^2 dependence of F_{jj}^D in SD, dependence of F_{jj}^D on the gap width in DPE. Also, the production of exclusive dijet, $b\bar{b}$ and low mass state will be studied. With two installed "Miniplug" calorimeters which cover the region $3.5 < |\eta| < 5.5$, we will be able to study events with a large rapidity gap in-between jets in double diffraction to test BFKL model.

REFERENCES

[1] F. Abe *et al.*, Phys. Rev. Lett. **78**, 2698 (1997); **79**, 2636 (1997).
[2] T. Affolder *et al.*, Phys. Rev. Lett. **84**, 232 (2000); **87**, 241802 (2001).
[3] F. Abe *et al.*, Phys. Rev. Lett. **74**, 855 (1995); **80**, 1156 (1998).
[4] F. Abe *et al.*, Phys. Rev. Lett. **81**, 5278 (1998).
[5] P. Bruni, A. Edin and G. Ingelman, Report No. DESY-95, ISSN 0418-9833.
[6] K. Goulianos, Phys. Lett. B **358**, 379 (1995); B **363**, 268 (1995).
[7] T. Affolder *et al.*, Phys. Rev. Lett. **84**, 5043 (2000).
[8] T. Acosta *et al.*, Phys. Rev. Lett. **88**, 151802 (2002).
[9] A.B. Kaidalov, V.A. Khoze, A.D. Martin and M.G. Ryskin, Eur. Phys. J. C. **21**, 521 (2001).
[10] T. Affolder *et al.*, Phys. Rev. Lett. **85**, 4215 (2000).