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HARD DIFFRACTION IN CDF*

Koji Terashi

for the CDF Collaboration

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

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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.

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1. Introduction

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 pseudo-rapidity[1] region devoid of particles. Diffractive events with hard processes ("hard diffraction"), such as production of high $P_{\rm T}$ 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

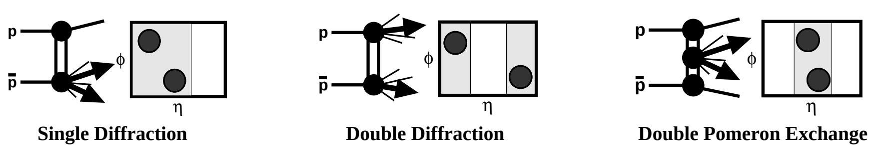

Fig. 1. Diagrams and event topologies of dijet production in single diffraction (left), double diffraction (middle) and double Pomeron exchange (right).

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[1] The pseudo-rapidity 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.

processes is whether they obey QCD factorization, in other words, whether the Pomeron has a universal (process independent) structure function. Various hard diffractive processes have been studied in CDF by measuring the diffractive production rates and/or diffractive structure function of the (anti)proton, and results will be presented below.

2. Hard diffraction with rapidity gaps

Using forward rapidity gaps to tag single diffractive events, we have measured the ratio of Single Diffractive (SD) to inclusive rates for W boson [1], dijet [2], b-quark [3] and J/ψ [4] production at $\sqrt{s} = 1800$ GeV. We have also measured the rates for events with Double Diffractive (DD) dijet (central rapidity gap between jets) at $\sqrt{s} = 1800$ GeV [5] and 630 GeV [6]. 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 I. 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 [7], f_g was determined to be $0.54^{+0.16}_{-0.14}$ and D was found to be 0.19 ± 0.04. The discrepancy of D from unity indicates a breakdown of factorization. The value of D is approximately the same as that observed in the soft SD cross section, as predicted in the Ref. [8].

TABLE I

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

Hard process	$\sqrt{s}$	$R^{\mathrm{DIFF}}_{\mathrm{ALL}}$ (%)	Kinematical region
$W(\to e\bar{\nu}_e)$ + G	1800	1.15 ± 0.55	E^e_{T}, $\not{E}_{\mathrm{T}} > 20$ GeV, $\lvert\eta^e\rvert < 1.1$
Jet + Jet + G	1800	0.75 ± 0.10	$E^{1,2}_{\mathrm{T}} > 20$ GeV, $1.8 < \lvert\eta^{1,2}\rvert < 3.5$
$b(\to eX)$ + G	1800	0.62 ± 0.25	$p^e_{\mathrm{T}} > 9.5$ GeV/c, $\lvert\eta^e\rvert < 1.1$
$J/\psi(\to \mu^+\mu^-)$ + G	1800	1.45 ± 0.25	$p^\mu_{\mathrm{T}} > 2.0$ GeV/c, $\lvert\eta^\mu\rvert < 1.0$
Jet + G + Jet	1800	1.13 ± 0.16	$E^{1,2}_{\mathrm{T}} > 20$ GeV, $1.8 < \lvert\eta^{1,2}\rvert < 3.5$
Jet + G + Jet	630	2.7 ± 0.9	$E^{1,2}_{\mathrm{T}} > 8$ GeV, $1.8 < \lvert\eta^{1,2}\rvert < 3.5$

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 [9] and 630 GeV [10]. In leading order QCD, the ratio $R^{\rm SD}_{\rm ND}$ 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, $F^{\rm D}_{jj}(x, Q^2, \xi)$, integrated over four momentum transfer squared t, is given by $F^{\rm D}_{jj}(x, Q^2, \xi) = x[g^{\rm D}(x, Q^2, \xi) + \frac{4}{9}q^{\rm D}(x, Q^2, \xi)]$, where x is the momentum fraction of the struck parton in the antiproton and $g^{\rm D}(q^{\rm D})$ the diffractive gluon (quark) density function. The $q^{\rm D}$ is multiplied by 4/9 to account for color factors. $F^{\rm D}_{jj}$ was obtained by multiplying the measured $R^{\rm SD}_{\rm ND}$ by the known ND structure function of the antiproton $F_{jj}(x, Q^2)$. The diffractive structure function was then expressed as a function of β (integrated over Q^2 and ξ) by using $x = \beta\xi$, where β is interpreted as the momentum fraction of the Pomeron carried by the struck parton. Fig. 2 shows the measured diffractive structure function $F^{\rm D}_{jj}(\beta)$ for the kinematic region $|t| < 1$ GeV^2, $0.035 < \xi < 0.095$ and $E_{\rm T}^{\rm jet1,2} > 7$ GeV. Comparison between the measured $F^{\rm D}_{jj}$ and expectations from the parton densities of the proton extracted from diffractive DIS shows a discrepancy in both normalization and shape of β dependence of the diffractive structure function, which in-

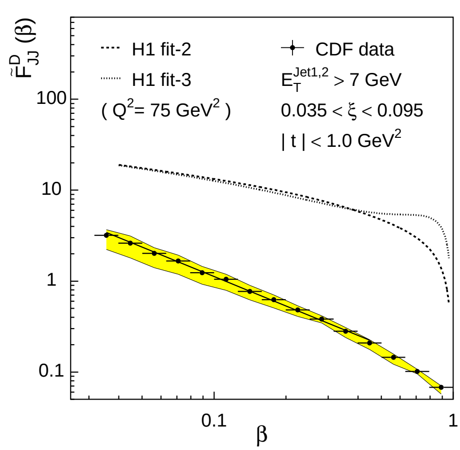

Fig. 2. Data β distribution (points) compared with expectations from diffractive DIS by the H1 Collaboration (dashed and dotted lines). The straight line is a fit to the data of the form β^{-n}. The lower (upper) boundary of the filled band represents the data distribution obtained by using only the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

dicates a breakdown of factorization. The ξ dependence of the diffractive structure function has also been studied. The results (Fig. 3) show that the measured F_{jj}^{D} is well represented by the form $F_{jj}^{\mathrm{D}} = C\,(1/\beta^n)\,(1/\xi^m)$ for $\beta < 0.5$, where the powers 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 that of the $dN/d\xi$ distribution of the inclusive SD sample, indicating that the diffractive dijet sample in our analysis is dominated by Pomeron exchange.

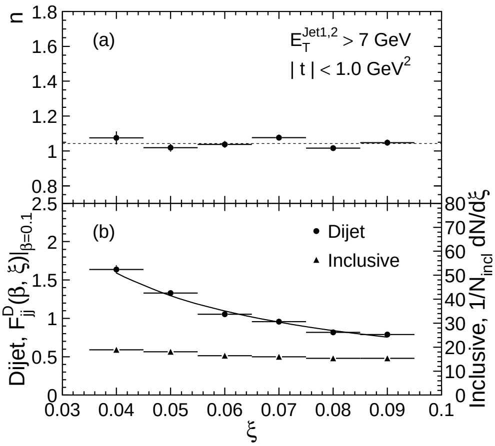

Fig. 3. (a) ξ dependence of the parameter n (circles) of a fit to the F_{jj}^{D} of the form $C\beta^{-n}$ at fixed ξ for $\beta < 0.5$ with a one parameter straight line fit (dashed line); (b) ξ dependence of F_{jj}^{D} (circle points) at $\beta = 0.1$ fitted to the form $C\xi^{-m}$ (curve), and the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

The diffractive structure function has also been measured at $\sqrt{s} = 630$ GeV and compared with that at $\sqrt{s} = 1800$ GeV [10]. In the kinematic region $|t| < 0.2$ GeV^2, $0.035 < \xi < 0.095$ and $0.1 < \beta < 0.5$, the ratio of the 630 to 1800 GeV diffractive structure functions was found to be $R^{630}_{1800} = 1.3 \pm 0.2(\mathrm{stat})^{+0.4}_{-0.3}(\mathrm{syst})$. The ratio R^{630}_{1800} is consistent with factorization ($R^{630}_{1800} = 1$), but also consistent with the value of 1.55 predicted by the renormalized Pomeron flux model [8] and with the value of 1.8 of the rapidity gap survival model of Ref [11].

4. Hard double Pomeron exchange with a leading antiproton

CDF has studied events with a double Pomeron exchange (DPE) topology (Fig. 1) using a data sample with a leading antiproton at $\sqrt{s} = 1800$ GeV and reported the first conclusive observation of dijet production in DPE [12]. The diffractive structure function of the antiproton was evaluated from the ratio $R_{\rm ND}^{\rm SD}$ 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 $R_{\rm SD}^{\rm DPE}$ of DPE to SD dijet rates as a function of x_p (Bjorken-x of the parton in the proton). In leading order QCD, factorization demands that the two ratios $R_{\rm ND}^{\rm SD}$ and $R_{\rm SD}^{\rm DPE}$ be equal at fixed x and ξ. Therefore, comparing the two ratios provides another factorization test at the Tevatron. Fig. 4 shows $R_{\rm SD}^{\rm DPE}(x_p)$ and $R_{\rm ND}^{\rm SD}(x_{\bar{p}})$ (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 $R_{\rm SD}^{\rm DPE}$ ($R_{\rm ND}^{\rm SD}$) data points in the range $10^{-2.8} < x < 0.01$ (within dashed lines) at $\xi = 0.02$ is $\tilde{\rm R}_{\rm SD}^{\rm DPE} = 0.80 \pm 0.26$ ($\tilde{\rm R}_{\rm ND}^{\rm SD} = 0.15 \pm 0.02$, evaluated from a straight line fit to the $\tilde{\rm R}_{\rm ND}^{\rm SD}$ points shown in the inset), which yields the ratio $D \equiv \tilde{\rm R}_{\rm ND}^{\rm SD}/\tilde{\rm R}_{\rm SD}^{\rm DPE} = 0.19 \pm 0.07$. The discrepancy of D from unity represents a breakdown of factorization.

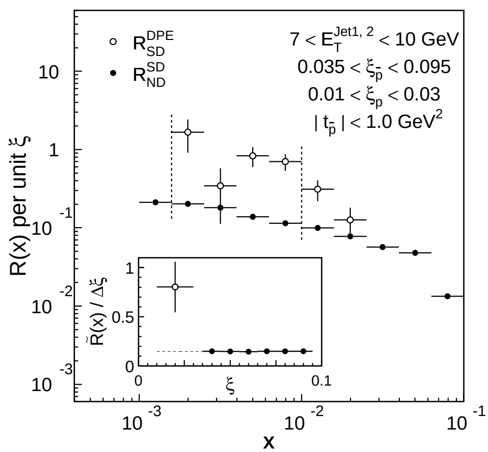

Fig. 4. Ratios of DPE to SD (SD to ND) dijet event rates per unit ξ_p ($\xi_{\bar{p}}$), shown as open (filled) circles, as a function of x_p ($x_{\bar{p}}$). The errors are statistical only. The inset shows $\tilde{R}(x)$ per unit ξ versus ξ, where $\tilde{R}$ is the weighted average of the $R(x)$ points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

The absolute DPE dijet cross section was measured to be $\sigma_{jj}^{\rm DPE} = 43.6 \pm 4.4\,({\rm stat}) \pm 21.6\,({\rm syst})$ $[3.4 \pm 1.0\,({\rm stat}) \pm 2.0\,({\rm syst})]$ 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 $E_{\rm T} > 7$ $[E_{\rm T} > 10]$ GeV confined within $-4.2 < \eta < 2.4$. We also measured the 95% C.L. upper bound for events in which the dijet energies could account for the total energy of the central system ($\bar{p} + p \to \bar{p}' + {\rm jet1} + {\rm jet2} + p'$) to be 3.7 nb for $0.035 < \xi_{\bar{p}} < 0.095$ and $E_{\rm T}^{\rm jet1,2} > 7$ GeV confined within $-4.2 < \eta < 2.4$.

5. Run II diffraction in CDF

In Run II being currently under way, CDF is planning to study various topics on diffraction. These include detailed studies of F^{D}, as process dependence of F^{D} and Q^2 dependence of F_{jj}^{D} in SD, and dependence of F_{jj}^{D} on the gap width in DPE. In addition, the production of exclusive dijets, $b\bar{b}$ and low mass state in DPE will be studied. With two recently installed "Miniplug" calorimeters covering the region $3.5 < |\eta| < 5.5$, we will also study events with a large rapidity gap in-between jets in DD to test the BFKL model.

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