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HARD DIFFRACTION AT THE TEVATRON

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Experimental results on hard diffraction from CDF and DØ at the Tevatron are reviewed and compared with results from H1 and ZEUS at HERA and with theoretical expectations.

1 Introduction

Hard diffraction refers to hadronic interactions incorporating a high transverse momentum (hard) partonic scattering while carrying the characteristic signature of diffraction, namely leading beam particles and/or large rapidity gaps. In a typical hadronic event, the rapidity space is usually occupied by a "carpet" of soft (low transverse momentum) particles, which represent the radiation emitted by the acceleration of the quantum numbers of the exchanged particle. *Rapidity gaps*, defined as regions of pseudorapidity devoid of particles, are caused by exchanges which carry the quantum numbers of the vacuum. The prevailing theoretical concept is that the exchanged "particle" in diffractive processes is the Pomeron of Regge theory, originally introduced to account for the high energy behavior of elastic and total hadronic cross sections. In QCD, the Pomeron is viewed as a gluon/quark color-singlet state with vacuum quantum numbers. A question of great theoretical interest is whether the Pomeron has a unique particle-like partonic structure. This question can be addressed experimentally by studies in hard diffraction.

At the Tevatron, there are three types of hard diffraction processes accessible to experimentation: single diffraction (SD), double-diffraction (DD) and double pomeron exchange (DPE). The event topology of dijet events produced in these processes is shown, respectively, in Figs. 1(a), 1(b) and 1(c). All three processes can be tagged by the rapidity gap signature. Single diffraction and DPE can also be tagged by detecting the leading particle(s) on the gap side. Using rapidity gap tagging, the CDF and DØ collaborations have studied dijet production in all three processes. In addition, CDF has studied (single) diffractive W-boson, b-quark and J/ψ production using rapidity gaps, and dijet production in SD and DPE using a "roman pot" magnetic spectrometer to detect leading antiprotons (in the CDF DPE study the events were tagged by a leading antiptoton and a rapidity gap on the proton side).

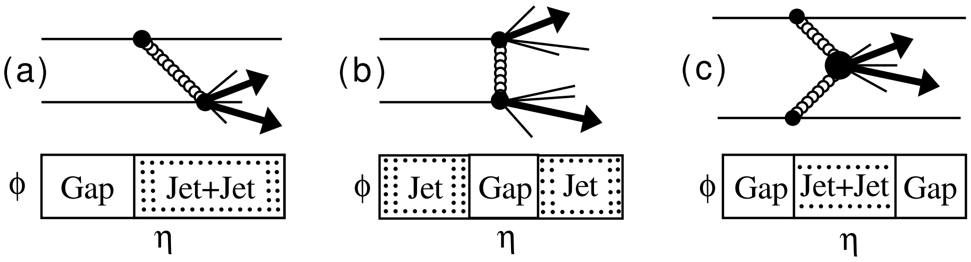

Fig. 1: Event topology of dijet production in (a) SD, (b) DD and (c) DPE.

In this brief review, we will focus on three topics of hard diffraction: production rates, determination of the gluon content of the exchange, and a measurement of the diffractive structure function of the antiproton as "viewed" by dijet production. We will use the following notation: ξ for the fractional momentum loss of the (anti)proton, x for the (anti)proton's momentum fraction carried by its parton, and $\beta \equiv x/\xi$. In the Pomeron paradigm, $\xi\sqrt{s}/2$ is the Pomeron momentum and β is its fraction carried by its parton.

2 Production Rates

The hard diffraction production rates measured at the Tevatron are summarized in Table 1.

Table 1: Diffractive to total production ratios at the Tevatron (G≡rapidity gap).

Hard process	$\sqrt{s}$ (GeV)	$R = \frac{\text{DIFF}}{\text{TOTAL}}$ (%)	Comments	Exp't
$\boxed{\text{SD}}$				
$W(\rightarrow e\nu)$+G	1800	1.15 ± 0.55	E_T^e, $\not{E}_T > 20$ GeV	CDF [1]
Jet+Jet+G	1800	0.75 ± 0.1	$E_T^{jet} > 20$ GeV, $\eta^{jet} > 1.8$	CDF [2]
Jet+Jet+G	1800	0.76 ± 0.08	$E_T^{jet} > 12$ GeV, $\eta^{jet} > 1.6$	DØ *
Jet+Jet+G	630	1.11 ± 0.23	$E_T^{jet} > 12$ GeV, $\eta^{jet} > 1.6$	DØ *
$b(\rightarrow e+X)$+G	1800	0.62 ± 0.24	$\lvert\eta^e\rvert < 1.1$, $p_T^e > 9.5$ GeV	CDF*
$J/\psi(\rightarrow \mu\mu)$+G	1800	$(0.64 \pm 0.12)/\mathcal{A}^\dagger$	$\lvert\eta^\mu\rvert < 0.6$, $p_T^\mu > 2$ GeV	CDF*
$\boxed{\text{DD}}$				
Jet-G-Jet	1800	1.13 ± 0.16	$E_T^{jet} > 20$ GeV, $\eta^{jet} > 1.8$	CDF [3]
Jet-G-Jet	1800	0.54 ± 0.17	$E_T^{jet} > 12$ GeV, $\eta^{jet} > 1.6$	DØ [4]
Jet-G-Jet	630	2.7 ± 0.9	$E_T^{jet} > 8$ GeV, $\eta^{jet} > 1.8$	CDF [5]
Jet-G-Jet	630	1.85 ± 0.37	$E_T^{jet} > 12$ GeV, $\eta^{jet} > 1.6$	DØ [4]
$\boxed{\text{DPE}}$				
$\bar{p}$-(Jet+Jet)-G	1800	$\sim 10^{-3}/\mathcal{A}_{DPE}{}^\ddagger$	$E_T^{jet} > 7$ GeV, $0.04 < \xi_{\bar{p}} < 0.1$	CDF*
G-(Jet+Jet)-G	1800	$\sim 10^{-3}/\mathcal{A}_{DPE}{}^\ddagger$	$E_T^{jet} > 12$ GeV	DØ *
G-(Jet+Jet)-G	630	$\sim 10^{-3}/\mathcal{A}_{DPE}{}^\ddagger$	$E_T^{jet} > 12$ GeV	DØ *

* Preliminary

† $\mathcal{A}\sim 0.4$ (estimated rapidity gap acceptance)

‡ $\mathcal{A}_{DPE}\sim 0.1$ (estimated **double**-gap acceptance for DPE)

In evaluating the results listed in Table 1, one must keep in mind that a *rapidity gap* can be defined experimentally **only** by the absence of particles **above a certain E_T threshold.** This threshold requirement must be taken into account in determining the “rapidity gap acceptance”, which is done by simulations and is somewhat (up to $\pm \sim 20\%$) model dependent. The ratios listed in the table are corrected for gap acceptance, except for the J/ψ and DPE, for which rough estimates of the acceptance are given in the footnotes.

There are three striking features in the Tevatron data:

- At $\sqrt{s} = 1800$ GeV, all **single-gap** to total production ratios are of $\mathcal{O}(1\%)$.
- The **double-gap** to total ratios (corrected for gap acceptance) are of $\mathcal{O}(0.01\%)$.
- The well measured DD ratios are $\sim 2 - 3$ times larger at $\sqrt{s} = 630$ GeV.

In ep collisions at $\sqrt{s} \approx 280$ GeV at HERA, the single-gap to total production ratios, measured by the H1 [6] and ZEUS [7] Collaborations, are of $\mathcal{O}$(5-10%).

3 Gluon Content

The gluon content of the diffractive structure function of the proton, also referred to as the gluon content of the Pomeron, was determined by CDF, by comparing hard single-diffraction rates of processes with different sensitivity to gluons and quarks, by ZEUS, by comparing diffractive deep inelastic scattering (D-DIS) with dijet photoproduction rates, and by H1, through a QCD analysis of the Q^2 evolution of the diffractive structure function measured in D-DIS. All determinations yield a high gluon content with a substantial quark component. From the measured W and dijet production rates, CDF obtained a gluon fraction of $f_g = 0.7 \pm 0.2$ [2]; including the (preliminary) measurement of the b-quark production rate yields $f_g^D = 0.54^{+0.16}_{-0.14}$ (see Fig. 2).

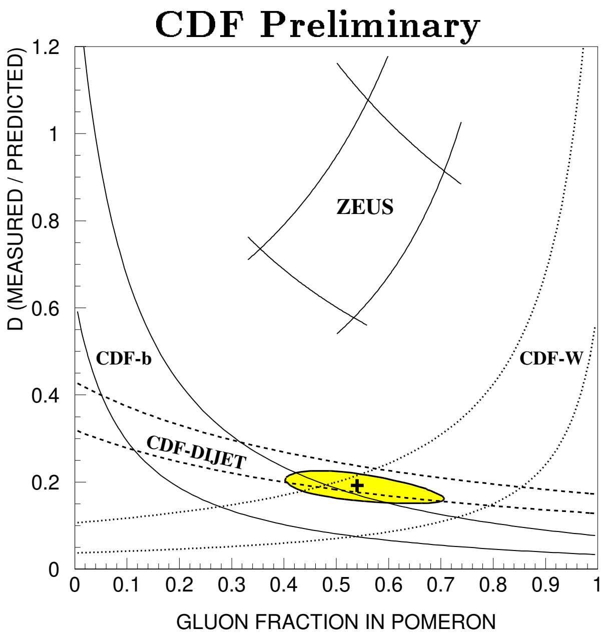

Figure 2: The ratio, D, of measured to predicted diffractive rates as a function of the gluon content of the Pomeron. The predictions are from POMPYT using the standard Pomeron flux and a hard Pomeron structure.

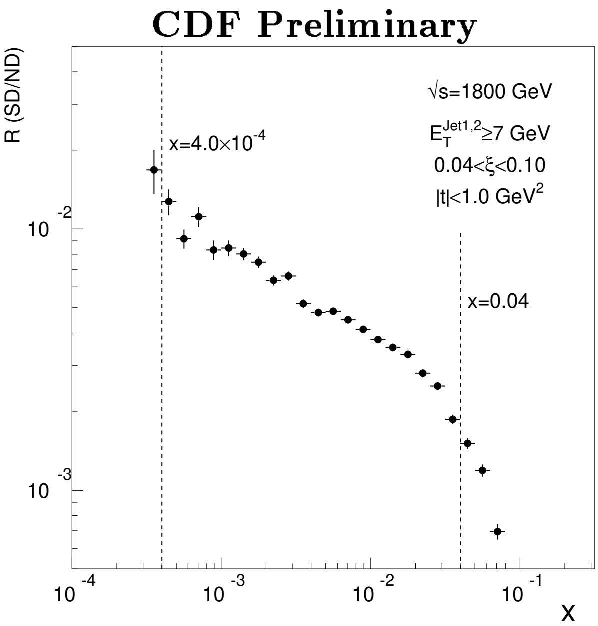

Figure 3: The ratio of diffractive to ND dijet rates as a function of x (momentum fraction of parton in $\bar{p}$) for $0.04 < \xi < 0.1$ and $|t| < 1$ GeV^2. The dashed vertical lines indicate the boundaries for full detector acceptance.

4 Diffractive Structure Function

The diffractive structure function of the proton has been measured in D-DIS at HERA [6,7]. A new measurement has been performed by CDF using a sample of dijet events of $E_T^{jet} > 7$ GeV collected by triggering the detector on a leading antiproton of beam momentum fraction $0.9 < x_F \equiv 1 - \xi < 0.98$ and $|t| < 3$ GeV^2 at $\sqrt{s} = 630$ and 1800 GeV. First, CDF determines the ratio of the diffractive to total event rates, $R(x)$, where x is the fraction of the $\bar{p}$'s momentum carried by its hard-scattered parton. The value of x is calculated for each event from the E_T and η of the two jets: $x = (E_T^1 e^{-\eta_1} + E_T^2 e^{-\eta_2})/\sqrt{s}$. In LO QCD, $R(x)$ represents the ratio of the diffractive to total structure functions of the antiproton, as "viewed" by dijet production. These structure functions can be written as $F_{jj}(x) = x[g(x) + \frac{4}{9}q(x)]$, where $g(x)$ is the gluon and $q(x)$ the quark *pdf*; the latter is multiplied by $\frac{4}{9}$ to account for the effect of color factors. The diffractive $F_{jj}^{D(2)}(x,\xi)|_{\xi=0.07}$ (integrated over t) is given by the product $R(x) \times F_{jj}^{ND}(x)$.

Figure 2 shows the $R(x)$ distribution of the $\sqrt{s} = 1800$ data for $0.04 < \xi < 0.1$ and $|t| < 1$ GeV^2. $R(x)$ decreases with increasing x as $\sim x^{-0.4}$. The value of $< R(x) >$ is about an order of magnitude smaller than predictions based on the structure functions measured at HERA, confirming the breakdown of factorization established by the results in Fig. 2.

5 Summary and Conclusions

Hard diffraction has been studied at the Tevatron in three types of processes: single-diffraction (one forward gap), double diffraction (one central gap) and double pomeron exchange(two forward gaps).The following general characteristics are observed:
(a) At $\sqrt{s} = 1800$ GeV, all single-gap diffractive to total production ratios are of $\mathcal{O}(1\%)$;
(b) The diffractive to total ratios measured at $\sqrt{s} = 630$ are larger than the corresponding ones at $\sqrt{s} = 1800$ GeV by a factor of $\sim 2 - 3$;
(c) The (corrected for gap acceptance) double-gap to total ratios are of $\mathcal{O}(0.01\%)$;
(d) The ratio of the diffractive to ND dijet rates, which in LO QCD is proportional to the ratio of the diffractive to ND structure functions, increases with decreasing x as $x^{-0.4}$;
(e) The single-gap rates are consistent with a gluon content of 40-70%.

Comparison of the Tevatron rates with predictions based on the diffractive structure function measured at HERA show that factorization breaks down[8,9]. The relative suppression of Tevatron to HERA diffractive rates is in general agreement with predictions based on the renormalized Pomeron flux model[8].

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