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Hard Diffraction At CDF *

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Abstract. We present results on diffractive production of hard processes in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV at the Tevatron using the CDF detector. The signatures used to identify diffractive events are the forward rapidity gap and/or the detection of a recoil antiproton with high forward momentum. We have observed diffractive W-boson, dijet, and heavy quark production. We also present results on double-pomeron production of dijets.

INTRODUCTION

The pomeron ($I\!P$) is a hypothetical particle with quantum numbers of the vacuum, used within Regge phenomenology to describe elastic, diffractive, and total cross sections. Using this model, the cross section for single diffraction dissociation, $\bar{p} + p \to \bar{p} + X$, is given by:

$$\frac{d^2\sigma(s,\xi,t)}{d\xi\, dt} = \left[\frac{\beta^2_{\bar{p}I\!P}(t)}{16\pi}\, \xi^{1-2\alpha(t)}\right] \cdot \left[g(t)\beta_{pI\!P}(0)\left(\frac{\xi s}{s_0}\right)^{\epsilon}\right] = f(\xi,t)\cdot \sigma^{I\!P p}(s',t) \quad (1)$$

where $\xi = M_X^2/s$ is the fraction of the momentum of the $\bar{p}$ taken by the pomeron, $\beta_{\bar{p}I\!P}$ is the coupling of the pomeron to the $\bar{p}$, $\alpha(t) = 1 + \epsilon + \alpha' t$ is the pomeron trajectory, $g(t)$ is the triple-pomeron coupling, s_0 is a constant set to 1 GeV^2 and $s' = \xi s = M_X^2$ is the energy in the $I\!P$-p center of mass system. The cross section factorizes into a *pomeron flux factor*, $f(\xi, t)$, and the $I\!P$-p total cross section, $\sigma^{I\!P p}(s', t)$.

We use the POMPYT Monte Carlo [1], which assumes factorization, and the flux as defined in Eqn. 1 (standard flux), to make predictions for diffractive production of hard processes. We consider a "hard" momentum distribution of partons within the pomeron (pomeron structure) of the form $\beta(1 - \beta)$,

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where β is the momentum fraction of the pomeron carried by the parton. POMPYT interfaces with PYTHIA, which generates the hard parton-parton collision. PYTHIA is used to generate the non-diffractive events. The results are presented as ratios of diffractive to non-diffractive production and therefore reduce systematic uncertainty.

The aim of the ongoing hard diffractive studies at CDF is to describe the pomeron in terms of its partons. For instance, if the pomeron flux is defined as in Eqn. 1, then the rate of diffractive W-boson production can be used to estimate the quark or gluon distributions within the pomeron. However, the normalization of the pomeron flux is not uniquely determined [2]. Despite this, the combination of the diffractive-W rate, which is primarily sensitive to quarks, and the diffractive-dijet rate, which is more sensitive to gluons, can be used to determine the partonic content of the pomeron. The diffractive heavy flavor rate can help determine the pomeron's intrinsic heavy flavor content.

In diffractive-dijet events, the dijet kinematics are sufficient to determine the momentum distribution of the partons in the pomeron, if the pomeron momentum is known. A set of Roman pot detectors was installed for the 95/96 Tevatron Run 1C to tag the leading $\bar{p}$. These new detectors allowed us to measure the momentum loss by the recoil $\bar{p}$, which is carried away by the pomeron. The rate of dijets produced with recoil $\bar{p}$'s corresponding to pomeron momenta fractions $0.05 < \xi < 0.10$ has been measured. This sample was also used to search for double-pomeron dijet production, looking for the forward rapidity gap opposite the Roman pot detectors, produced by the emission of a pomeron from the proton.

RESULTS USING FORWARD RAPIDITY GAPS

One signature of diffraction is an excess, above the continuum non-diffractive background, of events with rapidity gaps in the forward region. The relevant components of the CDF detector [3] are the Beam-Beam Counters (BBC) and the forward electromagnetic and hadronic calorimeters. The BBC consist of a square x, y array of 16 scintillators placed at $z = \pm 6$ m from the center of the detector, and cover approximately $3.2 < |\eta| < 5.9$. The forward electromagnetic and hadronic calorimeters are segmented in projective towers of size $\Delta\eta = 0.1$ by $\Delta\phi = 5^\circ$ and cover the region $2.4 < |\eta| < 4.2$. The number of hit BBC scintillators and the number of calorimeter towers with $E > 1.5$ GeV (electromagnetic+hadronic) represent the forward activity when searching for rapidity gaps. The rapidity gap events due to diffraction can be identified by plotting the BBC versus tower multiplicity distribution and observing the excess in the (0,0) bin, above the background extrapolated from neighboring bins. An excess is also observed in the one-dimensional distributions, for instance the BBC multiplicity, if compared to a sample, or model, with no diffraction.

Diffractive W production

We made the first observation, and measured the rate of diffractive W production [4] using a sample of 8246 events with an isolated *central* ($|\eta| < 1.1$) e^+ or e^- of $E_T > 20$ GeV and missing transverse energy $\not{E}_T > 20$ GeV. The statistics are such that an excess in the (0,0) bin of BBC versus tower multiplicity is difficult to observe. However there are additional signatures for diffractive-W production. In a diffractive $W^\pm \to e^\pm\nu$ event produced by a $\bar{p}$ collision with a pomeron emitted by a proton, there is an "angle-correlation" because the rapidity gap will be in the proton direction, while the lepton from W decay will tend to be boosted in the $\bar{p}$ direction. There is also a "charge-correlation", in which the lepton tends to carry the charge of the hadron colliding with the pomeron, because the pomeron is u-d quark symmetric and W boson production involves mainly valence quarks from the hadron.

In Fig. 1a we plot the BBC multiplicity distribution for double-correlated (angle+charge) W events (solid histogram), which should be diffraction enhanced, with the double-anticorrelated events (dotted histogram), which should have very little diffractive signal. The excess of double-correlated events with no BBC hits (rapidity gap), compared to the double-anticorrelated events, is the diffractive W signal. Figure 1b shows the bin-by-bin difference, divided by the sum, of the these distributions. A consistent excess has been observed in both the angle and charge single-correlated versus uncorrelated multiplicity distributions (not shown). The probability that this excess is consistent with fluctuations was estimated to be 1.1×10^{-4} (3.8σ). The excess, assuming a hard-quark pomeron with $\xi < 0.1$ and correcting for gap acceptance using POMPYT, is found to be: $R_W = [1.15 \pm 0.51(stat) \pm 0.20(syst)]\%$.

We use the POMPYT Monte Carlo, assuming the standard flux, and predict the fraction of diffractive W production to be 24% (16%) for a full hard-quark pomeron with two (three) quark flavors, and 1.1% for a full hard-gluon pomeron. Although the measured rate favors the full hard-gluon structure, in this case we would expect most of the diffractive W events to be associated with a jet. However we observe relatively few jets, which is more consistent with production from a hard-quark pomeron. The measured diffractive dijet rate helps to resolve the parton content of the pomeron as described below.

Diffractive dijet production (Gap-Jet-Jet)

The dijet sample consisted of 30352 dijet events with a single vertex, collected with a forward dijet trigger, where the jets have $E_T > 20$ GeV and both jets are in the same forward hemisphere with $|\eta| > 1.8$. When we plot the multiplicity of BBC versus forward calorimeter towers opposite the dijet system (not shown), there is a clear excess of events with a rapidity gap, i.e.

zero BBC and tower multiplicity, which is attributed to diffractive dijet production. The ratio of diffractive to non-diffractive dijet events is calculated from the observed excess of gap events and corrected for gap acceptance using POMPYT with a hard-gluon pomeron for $\xi < 0.1$. The measured fraction of diffractive dijet events ($E_T^{jet} > 20$ GeV, $|\eta|^{jet} > 1.8$) is then:

$$R_{GJJ} = [0.75 \pm 0.05(stat) \pm 0.09(syst)]\% \quad \text{(preliminary)}$$

For comparison, the POMPYT prediction is 5% for a full hard-gluon pomeron, and 2% for a hard-quark pomeron.

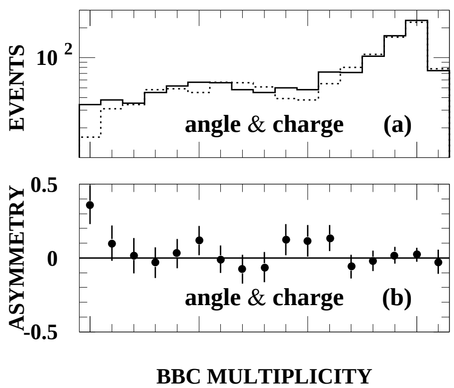

Figure 1: Double-correlated (solid) and anti-correlated (dotted) BBC multiplicity distributions for W events.

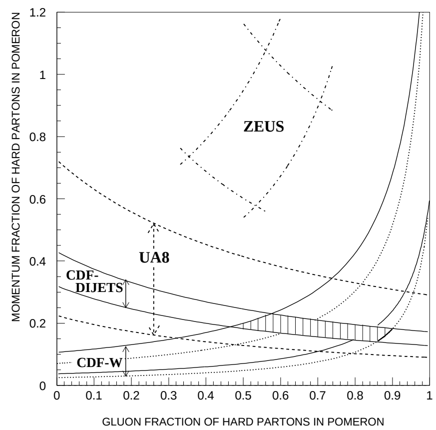

Figure 2: Fraction of pomeron momentum carried by hard-partons versus gluon fraction in pomeron.

The gluon fraction of the pomeron

By comparing our diffractive W and dijet measurements with POMPYT hard-quark and gluon predictions, using the standard flux, we can extract the hard-gluon fraction of the pomeron. Figure 2 shows the allowed regions of the momentum fraction of the pomeron carried by hard partons versus the fraction of gluons in the pomeron, where the quarks are assumed to make up the remainder. For example, in the diffractive W case, the rate is consistent with all the pomeron's momentum (momentum fraction 1.0) being carried by the hard-gluons in the pomeron (gluon fraction 1.0). If we assume a full-quark (zero gluon fraction) pomeron then the fraction of momentum carried by the partons is only 0.05, which is the ratio of the measured rate (1.15%) compared to the POMPYT prediction with a full hard-quark pomeron (24%). The curves in Fig. 2 give the allowed region ($\pm 1\sigma$) of momentum fraction versus the gluon fraction based on the measured diffractive W rate assuming two (solid curves) or three (dotted) quark flavors in the pomeron. Similarly the allowed regions are shown based on the measured diffractive dijet rates for CDF (solid) and UA8 (dashed).

The overlap of the allowed regions corresponds to a gluon fraction in the pomeron of 0.7 ± 0.2. This gluon fraction is consistent with that obtained by ZEUS [5] (shown dashed-dotted in Fig. 2) based on DIS and dijet photoproduction at HERA. The overlap region for the Tevatron diffractive measurements corresponds to a momentum fraction carried by the hard partons in the pomeron of 0.18 ± 0.04. This is in disagreement with all the momentum being carried by the partons in the pomeron (a momentum fraction of 1), which we would expect if the momentum sum rule were obeyed. However this is consistent with the proposed decrease of the pomeron flux normalization with $\sqrt{s}$ [2].

Diffractive heavy-flavor production

A sample of 713,000 electron candidates with $E_T > 7$ GeV and $|\eta| < 1.1$ were used to search for diffractive heavy flavor production. This sample contains 65% electrons from the decay of b and c quarks, 22% electrons from γ-conversions in the detector material, and 13% due to hadrons faking electrons. Figure 3 shows the forward multiplicity, towers versus BBC, for the electron sample. There is a clear excess of events with no tower or BBC multiplicity (rapidity gap), which we interpret as the diffractive signal. The ratio of diffractive to non-diffractive production of electrons from heavy (b or c) quarks is: $R_{HQ} = [0.18 \pm 0.03(stat)]\% \quad (preliminary)$.

In comparing this ratio with the $\mathcal{O}(1)\%$ forward diffractive dijet ratio, we must remember the heavy flavor ratio has not been corrected for gap acceptance. The diffractive to non-diffractive ratio should be higher for the forward dijets because diffractive events tend to be boosted forward, while the heavy flavor sample is central.

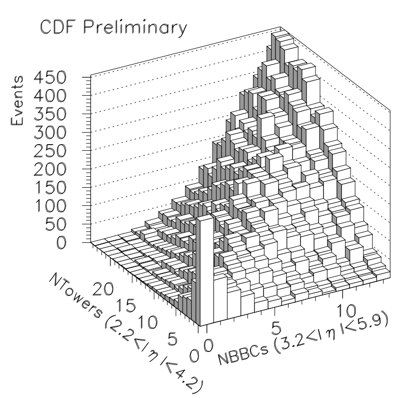

Figure 3: Tower versus BBC multiplicity for inclusive electron sample, 65% of which is due to b/c quark production.

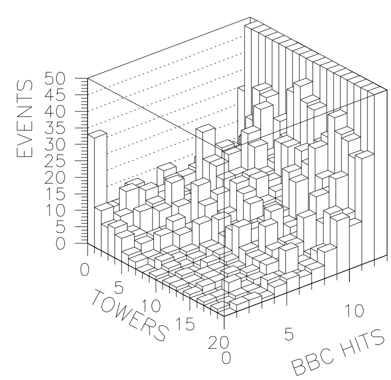

Figure 4: Tower versus BBC multiplicity opposite in η from the Roman pot tag for $E_T > 7$ GeV dijets.

RESULTS USING A LEADING ANTIPROTON TAG

The Roman pot spectrometer was used to trigger and measure the momentum of the recoil antiproton during the Tevatron run 1C. A sample of 1.8 million Roman pot triggered events, collected during special low luminosity ($\sim 10^{29}\text{cm}^{-2}\text{s}^{-1}$) conditions, was used to measure the rate of single diffractive and double pomeron production of dijets. The analysis is restricted to the region in which the Roman pot spectrometer has good acceptance, $0.05 < \xi < 0.10$ and $|t| < 1$ GeV^2. We have verified that the inclusive Roman pot triggered events have forward rapidity gaps and are consistent in cross-section and kinematics (ξ, t) with the published 1989 CDF Roman pot data [6].

Diffractive dijet production ($\bar{p}$-Jet-Jet)

The inclusive $\bar{p}$-triggered data contain 2503 single-vertex events with two jets of $E_T^{jet} > 10$ GeV. After corrections for non-diffractive contamination (8%) and single-vertex selection cut efficiency ($72 \pm 5\%$), the ratio of diffractive to non-diffractive events with $E_T^{jet} > 10$ GeV, $0.05 < \xi < 0.1$, and $|t| < 1$ is:

$$R_{\bar{p}JJ} = [0.109 \pm 0.003(\text{stat}) \pm 0.016(\text{syst})]\% \quad \text{(preliminary)}.$$

There appears to be no t dependence for Roman pot dijet production compared to the inclusive Roman pot sample.

Assuming a hard gluon and hard quark pomeron structure with $f_g = 0.7$ and $f_q = 0.3$, as suggested by our W and rapidity gap dijet rates, the prediction using the standard (renormalized) pomeron flux is 1.35% (0.15%). Our result favors the renormalized flux.

Double-pomeron Dijet production ($\bar{p}$-Jet-Jet-Gap)

In the $\bar{p}$-triggered data sample of dijets with $E_T > 7$ GeV (we had to lower the jet threshold), there is evidence for excess rapidity gaps in the forward detectors opposite the Roman pot tag, as shown in Fig. 4. The $\bar{p}$ trigger requires the ξ of the pomeron from the $\bar{p}$ to be within the range $0.05 < \xi_{I\!P/\bar{p}} < 0.1$, while from the rapidity interval covered by the BBC and from energy considerations we estimate that the ξ of the pomeron on the p side lies approximately within the range $0.015 < \xi_{I\!P/p} < 0.035$. With these ξ-values, the energy in the $I\!P - I\!P$ center of mass system, $\sqrt{\xi_{I\!P/\bar{p}} \cdot \xi_{I\!P/p} \cdot s}$, is approximately in the range 50-100 GeV. We have made a comparison of the double pomeron (DP), single diffractive (SD), and non-diffractive (ND) cross sections for $E_T^{jet} > 7$ GeV dijets. The preliminary results are:

DP/SD	$[0.170 \pm 0.036(stat) \pm 0.024(syst)]\%$
SD/ND	$[0.160 \pm 0.002(stat) \pm 0.024(syst)]\%$ -
DP/ND	$(2.7 \pm 0.7) \times 10^{-6}$

CONCLUSIONS

We have presented results for diffractive W, dijet, b/c quark, and double pomeron dijet production for $\sqrt{s} = 1.8$ TeV $\bar{p}p$ collisions. The diffractive W and dijet rates can be used to determine the hard-gluon fraction in the pomeron as 0.7 ± 0.2. However, using the standard flux, only 18% of the momentum is carried by the hard partons in the pomeron. One proposed explanation is to modify the flux normalization [2].

REFERENCES

1. P. Bruni and G. Ingelman, Phys. Lett. **B311** (1993) 317.
2. K. Goulianos, Phys. Lett. **B358** (1995) 379.
3. F.Abe *et al.*, Nucl. Instrum. Meth. **A 271** (1988) 387.
4. F.Abe *et al.*, Phys. Rev. Lett. **78** (1997) 2698.
5. M.Derrick *et al.*, Phys. Lett. **B356** (1995) 129.
6. F.Abe *et al.*, Phys. Rev. **D50** (1994) 5535.