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Hard Diffraction at CDF

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HARD DIFFRACTION AT CDF

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We present new evidence for events with a rapidity gap between jets in pbar-p collisions at $\sqrt{s} = 1.8$ TeV based on data collected by triggering the Collider Detector at Fermilab on two high transverse momentum forward jets and results of a search for diffractive $W^{\pm}$ and dijet production where diffraction is tagged by the rapidity gap technique. We also present the results of a search for diffractive dijets using data collected by triggering on a very-forward particle in the recently-installed roman-pot detectors. The dijet events exhibit additional diffractive characteristics such as rapidity gaps and boosted center-of-mass system, however the recoil antiproton measured in the roman-pots is in a regime in which the non-pomeron contribution is significant.

1 Introduction

"Hard Diffraction" refers to the study of hard processes produced diffractively. Within Regge theory the pomeron trajectory is used to describe high energy diffractive processes[1]. It has been proposed[2] that diffractive interactions may be factorized so that the SD cross section is given by $\frac{d^2\sigma_{SD}}{d\xi\, dt} = \sigma_T^{\mathcal{P}p} \; f_{\mathcal{P}/p}(\xi, t)$ where the pomeron flux $f_{\mathcal{P}/p}(\xi, t)$ gives the probability of getting a pomeron with a certain (ξ, t), where $\xi = 1 - x$ is the fraction of momentum lost by the proton and carried by the pomeron, and t is the square of the 4-momentum transfer or the negative mass squared of the virtual pomeron. The pomeron-proton total cross section, $\sigma_T^{\mathcal{P}p}$, is assumed to be constant. Single diffraction is visualized in Fig. 1 as a pomeron emitted by the $\bar{p}$ and interacting with the proton to produce a final-state with mass $M = s\sqrt{\xi}$, where s is the center-of-mass energy of the $p - \bar{p}$ system.

The hard diffraction processes considered in these studies are dijet and W-boson production. The rate and kinematics of these diffractively produced high-p_T final states are predicted using the pomeron flux to generate ξ and t for the pomeron, and then colliding the pomeron with a proton to produce the

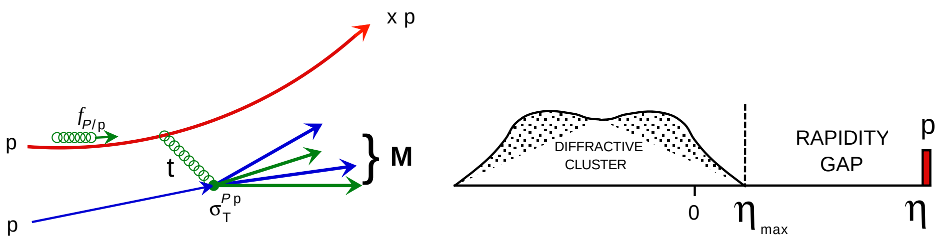

Figure 1: Single Diffraction

dijet or W final state, assuming different parton distributions for the pomeron. There is evidence from other experiments[3,4] that the pomeron has a hard parton distribution which may be modelled as $x(1-x)$, where the momentum is shared between two gluons ("hard-gluon") or two quarks ("hard-quark"). Assuming the hard-quark pomeron structure and using a "standard" pomeron flux, a prediction was made[5] that 17% of all W's produced at tevatron energies would be diffractive! If the pomeron had a hard-gluon structure it would produce dijets efficiently, but significantly less W's.

An additional complication is that the standard-flux does not agree with the soft single-diffractive cross-section. For this reason we will also quote the diffractive rates using a "renormalized" flux[6] which agrees with the s-dependence of soft diffraction and is significantly lower than the standard-flux at $\sqrt{s} = 1.8$ TeV.

Experimentally we search for evidence of diffraction in W and dijet samples by looking for rapidity gaps in the forward region caused by the colorless exchange of a pomeron. More recently we have installed roman-pot detectors that can measure the recoil $\bar{p}$ kinematics in diffractive events. We present limits on diffractive W and dijet production based on rapidity gaps and evidence for dijets produced with roman-pot tracks.

An experimentally related phenomenon is the color-singlet exchange between interacting partons. This process has been predicted to produce rapidity gaps between jets in 0.3 to 3.0% of the dijet events[7]. In normal quark or gluon color octet exchange there are soft-hadrons produced by the color field in the region between the jets. The experimental observation of color-singlet exchange requires a significant excess of zero or low particle multiplicity between the jets compared to that expected from color-octet exchange. There are two previously published results measuring the fraction of dijet events with gaps between the jets of $(0.85 \pm 0.12(\text{stat})^{+0.24}_{-0.12}(\text{syst}))\%$ by CDF[8] and $(1.07 \pm 0.10(\text{stat})^{+0.25}_{-0.13}(\text{syst}))\%$ by DØ[9].

2 Diffractive W measurement

A sample of W's (1720 in electron and 1084 in muon channel) taken with the CDF detector during the 1992-93 Tevatron run, was used to search for diffractive W's. For both this sample, and the diffractive dijet sample discussed later, the data were taken without the usual requirement of a forward, east-west coincidence in order to accept diffractive events, and requiring only one primary vertex (interaction) per event in order to assure the survival of any rapidity gap. Standard W selection requirements[10] on lepton identification, lepton E_T, and missing E_T, were used.

Diffractive events tend to have zero multiplicity at high rapidity in the direction of the recoil proton (Fig. 1). The definition of the gap region multiplicity is, for both the diffractive W and dijet searches, the number of calorimeter towers with $E_T > 200$ MeV within the region $2.0 < |\eta| < 4.2$. The CDF calorimetry has towers that are segmented $\Delta\eta \times \Delta\phi = 0.1 \times 0.26$ for $|\eta| < 1.1$ and 0.1×0.087 out to $|\eta| < 4.2$. Figure 2a shows the tower multiplicity in the gap region for the electron W sample. There are clearly events with multiplicity gaps, although the zero bin may be consistent with normal statistical fluctuations of the overall distribution. In order to extract any significant diffractive signal for events with a multiplicity gap, additional diffractive characteristics are used.

In the diffractive event topology (Fig. 1) the W, and to a lesser extent the observed lepton, will tend to be produced with a rapidity in the hemisphere opposite to the rapidity gap. In the top plot of Fig. 2a, the multiplicity of towers in the forward region is shown for the electron W-channel. The multiplicity is shown for the gap region opposite (correlated - solid histogram), and on the same side (anticorrelated - dashed) as the lepton rapidity. The presence of diffractive W's would produce a net excess in the zero bin for the correlated compared to the anticorrelated distribution, where the comparison is made in the bottom asymmetry plot (corr-anticorr)/(corr+anticorr) of Fig. 2a.

Another feature of diffractive W's would be a correlation between the W-lepton charge and the direction of the rapidity gap. Within a diffractive event in which the pomeron interacts with the $\bar{p}$, and therefore the rapidity gap is in the proton direction, a naive argument would predict that the W charge is biased two-to-one negative by the two $\bar{u}$-quarks in the $\bar{p}$, while the pomeron is naturally flavor and charge symmetric.

The electron and muon subsamples were independently analyzed looking for both charge and rapidity correlations in the zero multiplicity bins, and no excess consistent with diffraction was observed. The combined upper limit for the amount of diffraction in our W sample is $< 6\%$ at the 95% confidence level. This is to be compared with the 24% (flux is modified from previous prediction) standard-flux and 2.7% renormalized-flux predictions for a full hard-quark structure of the pomeron.

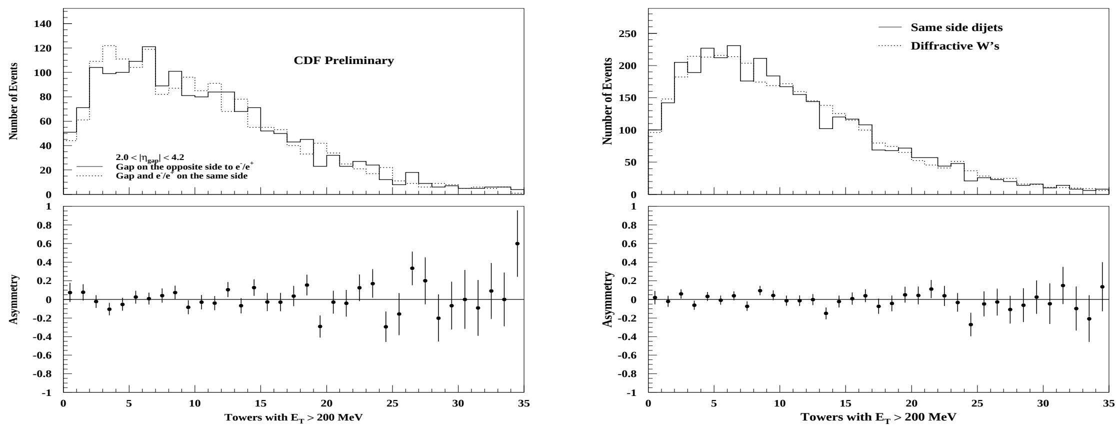

Figure 2: **left to right a)** Forward multiplicity opposite, and the same side as, e^-/e^+ for W events. **b)** Forward multiplicity opposite the same-side jets, with W superimposed.

3 Diffractive dijet measurement

3.1 Diffractive-dijets with rapidity-gaps

The search for diffractive dijets was similar to that of the W's and used a sample of 3415 forward dijet events taken with the CDF detector during the same running period. The events were selected by requiring that both jets have $20 < E_T < 60$ GeV and $|\eta| > 1.8$, and be on the same side in η and back-to-back in ϕ to within one radian. The multiplicity of towers in the gap region ($2.0 < |\eta| < 4.2$) opposite in η from the dijets is shown in the top plot of Fig. 2b, with the W gap multiplicity (shown previously to contain insignificant diffraction) superimposed. The bottom plot shows the asymmetry between the two distributions, which would show an excess for low gap multiplicities if there was a significant diffractive-dijet component. Based on the observation of no excess in the 0-multiplicity bin, the limit on the amount of diffraction in this forward dijet sample is $< 1.75\%$ (95% confidence level). This can be compared to predictions of 5% (2%) using the standard-flux and 0.56% (0.22%) using the renormalized-flux and assuming a full hard-gluon (quark) pomeron structure.

3.2 Diffractive-dijets with roman-pot tracks

A set of 3 roman-pot detectors were installed and used together with the CDF detector during the run 1C Tevatron run. Each roman-pot contained trigger-scintillators and x, y position detectors using scintillating-fibers read out by multi-channel photomultiplier tubes. For diffractive events in which the antiproton looses 90 to 94% of its momentum by the emission of a pomeron ($0.06 < \xi < 0.10$), the antiproton gets bent out of the beam into the acceptance of the roman-pot detectors. The x, y track measured in the 3 roman-pots can be projected back to the event vertex, using the accelerator magnetic transport matrix, to determine the ξ, t of the interaction.

The data sample used to search for diffractive-dijets was taken during a special low-luminosity (few 10^{29}) running period in which a triple roman-pot coincidence triggered the CDF readout. There are 0.47 million events with a good x, y reconstructed track and $0.06 < \xi < 0.10$, which is consistent with coming from the CDF event vertex. These events show the expected correlations between the CDF event and the ξ measured in the roman-pots 55 meters away. Figure 3a shows the expected correlation between the event mass, measured using calorimeter towers, and $\sqrt{\xi}$, where the center-of-mass energy available in a pomeron-proton collision is $1800\sqrt{\xi}$ GeV. Figure 3b shows the correlation between the detected η_{max} (tower η at the edge of rapidity) and $\ln \xi$, where the size of the rapidity gap scales with $\ln \xi$. In addition to the tagged antiproton, rapidity gaps are also observed in the forward detectors on the same side.

The roman-pot cross-section at 1800 GeV has been previously measured in 1989 with roman-pots at CDF[11]. The cross-section for $0.06 < \xi < 0.10$ is expected to be 0.49 mb, of which the pomeron-induced diffractive component is $\sigma^{\mathcal{P}} \sim 0.15$ mb and the remaining is a non-diffractive background possibly made up of π and ρ exchange.

Within our roman-pot triggered sample, there are 616 dijets defined as two jets with $E_T > 10$ GeV. Figure 4 shows a dijet event with roman-pot tracks in x and y (top) and a dijet seen in the lego plot of calorimeter towers (bottom). Figure 5 (top plots) shows significantly lower activity (rapidity gaps) in the forward detectors on the roman-pot side (west) compared to the east side (superimposed) for these roman-pot dijet events (left plots) and for non-diffractive events (right plots).

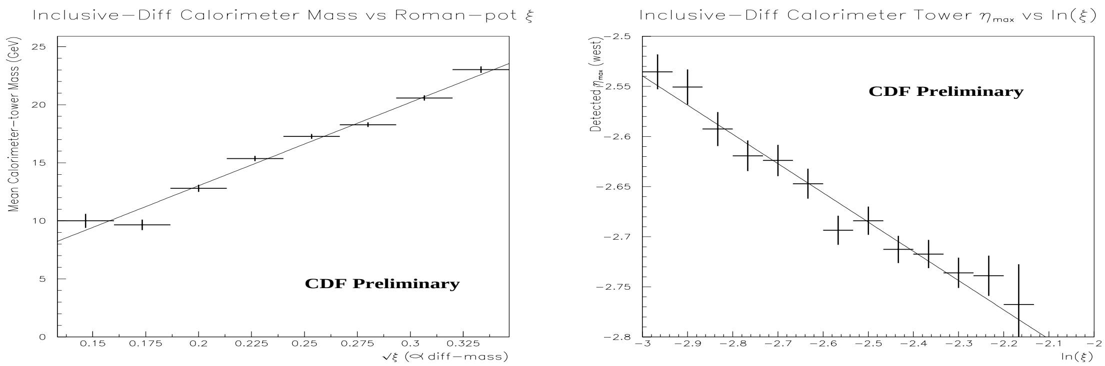

Figure 3: Calorimeter Mass vs sqrt(ξ) and η_{max} vs ln(ξ).

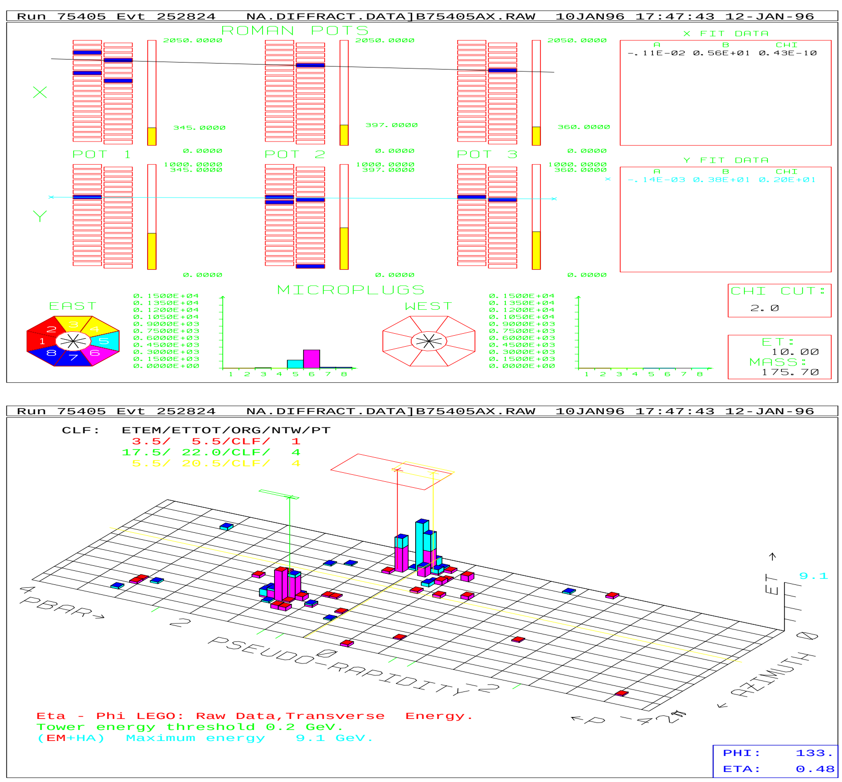

Figure 4: Diffractive dijet candidate ($E_T \sim 25$ GeV) showing roman-pot track and calorimeter lego plot

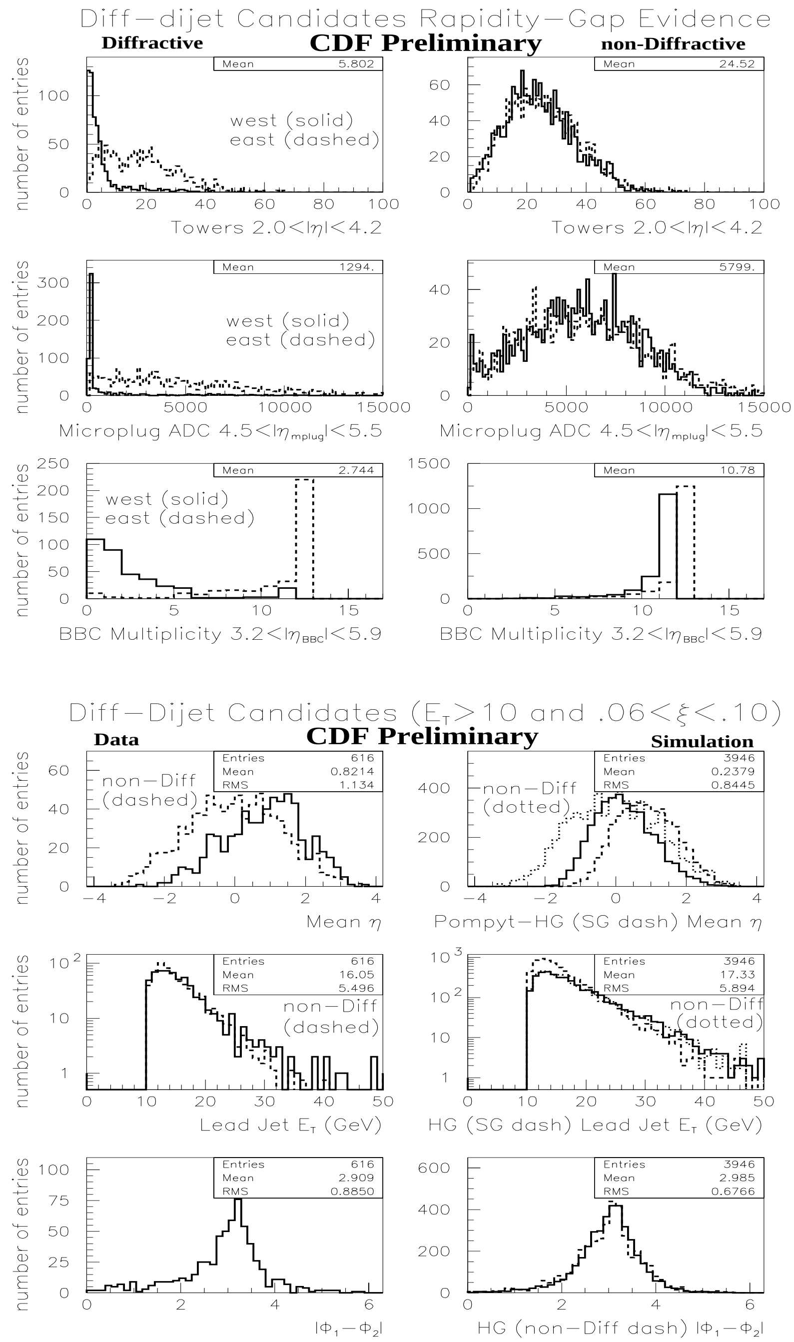

Figure 5: Dijet Sample: Rapidity Gaps (top plots) and Jet Kinematics (bottom plots)

The plots show the multiplicity of forward calorimeter towers $2 < |\eta| < 4.2$, the energy deposited in the microplug calorimeter $4.5 < |\eta| < 5.5$, and the multiplicity of beam-beam counters $3.2 < |\eta| < 5.9$. The bottom plots in Fig. 5 show some kinematic variables of the dijets with roman-pot tracks compared to the non-diffractive (superimposed) distributions and distributions generated using the Pompyt simulation (right plots). The mean dijet η, $(\eta_1+\eta_2)/2$, shows the expected boost towards positive η (away from roman-pots) compared to the η-symmetric non-diffractive sample. The leading jet E_T is similar for both roman-pot and non-diffractive dijets and the $|\phi_1-\phi_2|$ indicates that the roman-pot dijets are well balanced in ϕ. The simulations show distributions assuming a hard-gluon (HG) or soft-gluon (SG) pomeron structure and non-diffractive (dotted). The hard-quark distributions are very similar to the hard-gluon.

Based on the number of dijets observed, and the roman-pot cross-section, the detected cross-section for dijet production is

$$\sigma = \frac{616 \text{ dijet} - \text{candidates}}{0.47E6 \text{ inclusive}} \times 0.49\text{mb} \sim 0.6\mu\text{b}.$$

The roman-pot track reconstruction efficiency and acceptance should cancel when taking the ratio of dijet to inclusive events. The rates predicted by Pompyt for a fully hard-gluon pomeron structure is $\sim 4.5\mu$b assuming the standard-flux and $\sim 0.5\mu$b with the renormalized flux. The comparison with the Pompyt diffractive simulation must be interpreted with the prevision that we have not proven that all these dijets with roman-pot tracks are due to pomeron exchange (diffractive), as opposed to other colorless Regge exchanges, and that the cross-section for these relatively low-E_T jets is not very well modelled.

4 Rapidity gaps between jets

The search for rapidity gaps between jets uses the central tracking to count the multiplicity of charged tracks with $p_T > 300$ MeV between jets within $|\eta| < 1.1$. The 1054 dijets were selected in the same way as the diffractive dijet search described above, with the exception that the jet rapidities were required to be in opposite hemispheres. Figure 6a shows the track multiplicity between the jets for these events. The evidence for the color-singlet signal is the clear excess in the zero bin, with no need for fitting! The non-singlet contribution (shown dashed in Fig. 6) is subtracted by using the analogous track multiplicity from the same-side dijet sample. The excess gap events were measured to be $(2.0 \pm 0.7)\%$ of the opposite-side jet sample. The signal is relatively insensitive to reasonable variations in E_T or p_T threshold and $\Delta\eta$-interval.

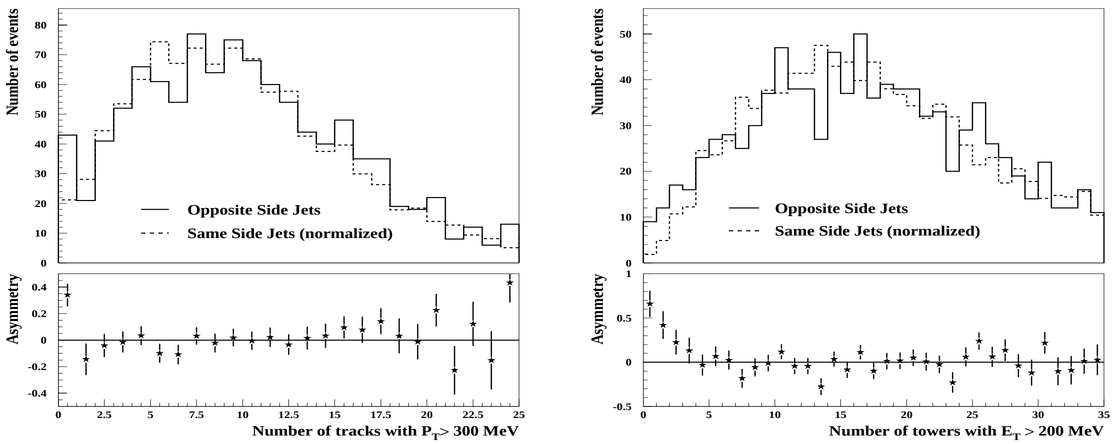

Figure 6: **left to right a)** Track multiplicity between jets compared to same-side jets. **b)** Tower multiplicity between jets compared to same-side jets.

The signal is also evident as an excess in the low multiplicity bins (0-3) of the tower multiplicity distribution between the jets, Fig. 6b, when compared to the diffractive dijet multiplicity. The signal shows up in multiplicities 0-3 with towers, as opposed to zero with tracks possibly because: the towers are sensitive to γ's from π^0; the towers have a lower threshold (tower $E_T > 200$ MeV compared to track $p_T > 300$ MeV); the tracks are restricted to $|\eta| < 1.1$ and therefore more isolated from the jets than the towers; and it is easier to fake a tower than a track (tower noise).

5 Conclusions

We observe rapidity gaps between jets, in excess of those expected from color-octet exchange at the level of $(2.0 \pm 0.7)\%$ of opposite-side dijets with $|\eta| > 1.8$ and $E_T > 20$ GeV.

For W events with a rapidity-gap (zero towers with $E_T > 200$ MeV), we do not observe a correlation between the side of the gap and the lepton charge or η, which we would expect if the sample contained diffractive-W events. An upper limit of 6% (95% CL) is set for W's diffractive in origin. Comparing this result to the standard-flux prediction of 24% for a full hard-quark structure, it rules out a significant hard-quark component to the pomeron. However, compared to the renormalized flux prediction of 2.7%, the current limit can't rule out a fully hard-quark pomeron.

We do not observe an excess of rapidity-gap events opposite from the same-side forward dijets with $|\eta| > 1.8 and E_T > 20$ GeV. A 95% CL upper limit of 1.75% is set on the amount of diffraction in this sample. Once again this limit restricts the hard-gluon structure of the pomeron using the standard-flux, where the completely hard-gluon prediction is 5%. However the limit does not constrain the hard-gluon structure in the renormalized-flux case, which predicts a 0.5% diffractive content. All three of the above results will improve with the $\sim 5\times$ more statistics available from the Tevatron run 1B data.

We presented the characteristics of dijets with a roman-pot track. The events have the expected diffractive characteristics, rapidity gaps, event boost away from roman-pot side, and correlations between the recoil $\bar{p}$ momentum and event energy and η_{max}. The rate of dijet production is $\sim 0.6\mu$b, which is much smaller than the standard-flux full hard-gluon structure prediction of $\sim 4.5\mu$b, but on the same order as the renormalized-flux prediction of $\sim 0.5\mu$b. However we have not established what fraction of the dijets are produced by the pomeron (diffractive) as opposed to reggeon exchange and non-diffractive processes.

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