EXPERIMENTAL STUDIES OF DIFFRACTIVE PROCESSES
AT THE TEVATRON

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(FOR THE CDF AND DØ COLLABORATIONS)

We review the diffractive measurements made by the CDF and DØ collaborations during Run I at the Tevatron and summarize the detector upgrades relevant for the Run II diffractive physics program.

1 Introduction

Run I at the Tevatron lasted from 1992 to 1996. During that time, the CDF and DØ experiments conducted an extensive program of diffractive studies on soft single and double diffraction, several diffractively produced hard processes, and double-Pomeron exchange. After reviewing the results obtained by each experiment, we describe the forward detector upgrades for Run II.

2 Run I diffractive physics results from CDF

CDF measured the single diffraction differential cross section at $\sqrt{s} = 546$ and 1800 GeV. A fit of the data at both energies to the standard triple-Pomeron Regge formula for single diffraction dissociation shows that Regge theory correctly predicts the dependence on the rapidity-gap width $\Delta \eta (\eta = -\ln \tan \frac{\theta}{2})$ for $\Delta \eta > 3$, which corresponds to a leading proton fractional momentum loss $\xi < 0.05$. However, the $\sqrt{s}$ dependence of the overall normalization is not correctly modeled, the data being an order of magnitude lower than the prediction at $\sqrt{s} = 1800$ GeV.

The double-diffraction differential cross section was recently studied with a sample of minimum-bias events, i.e. events collected by triggering on a beam-beam counter coincidence between the proton and antiproton sides of the detector. The diffractive event rate is approximately flat in $\Delta \eta_{\exp}^0 \equiv \eta_{\max} - \eta_{\min}$, where $\eta_{\max}$ ($\eta_{\min}$) is the pseudorapidity of the particle closest to $\eta = 0$ in the (anti)proton direction. In contrast, the non-diffractive event rate decreases exponentially with increasing $\Delta \eta_{\exp}^0$. The data at both $\sqrt{s} = 630$ and 1800 GeV clearly exhibit a double-diffractive component for $\Delta \eta_{\exp}^0 > 3$, and the $\Delta \eta_{\exp}^0$ dependence of this component is correctly described by Regge
Table 1. Ratio $R$ of diffractive to non-diffractive event rates for various processes.

| Process          | $\sqrt{s}$ (GeV) | $R$ (%)  | Kinematic region                                      |
|------------------|------------------|----------|------------------------------------------------------|
| $W(\rightarrow e\nu)$ | 1800             | 1.15 ± 0.55 | $E_T^W > 20$ GeV, $E_T^{\nu} > 20$ GeV               |
| Dijet            | 1800             | 0.75 ± 0.10 | $E_T^{\text{jet}} > 20$ GeV, $|\eta^{\text{jet}}| > 1.8$ |
| $b(\rightarrow eX)$ | 1800             | 0.62 ± 0.25 | $E_T^b > 9$ GeV, $|\eta^b| < 1.1$                     |
| $J/\psi(\rightarrow \mu\mu)$ | 1800             | 1.45 ± 0.25 | $p_T^\mu > 2$ GeV, $|\eta^\mu| < 1.0$               |
| Jet-G-Jet        | 1800             | 1.13 ± 0.16 | $E_T^{\text{jet}} > 20$ GeV, $|\eta^{\text{jet}}| > 1.8$ |
| Jet-G-Jet        | 630              | 2.7 ± 0.9   | $E_T^{\text{jet}} > 8$ GeV, $|\eta^{\text{jet}}| > 1.8$ |

theory and factorization. The measured double diffraction cross sections are:

$$\sigma_{DD}(\sqrt{s} = 630 \text{ GeV}, \Delta \eta > 3) = 4.58 \pm 0.02 \text{ (stat)} \pm 1.5 \text{ (syst)} \text{ mb},$$

$$\sigma_{DD}(\sqrt{s} = 1800 \text{ GeV}, \Delta \eta > 3) = 6.32 \pm 0.03 \text{ (stat)} \pm 1.7 \text{ (syst)} \text{ mb}.$$  

These measurements are about an order of magnitude lower than expectations based on the triple-Pomeron amplitude.

Single diffractive events can be identified by the presence of a “rapidity gap”, i.e. a rapidity interval devoid of particles, in the forward region on one side of the detector. Using this signature, CDF has measured the ratio $R$ of single-diffractive to non-diffractive rates of events containing a $W$-boson, a dijet, a $b$-quark, and a $J/\psi$ meson at $\sqrt{s} = 1800$ GeV. As shown in Table 1, all these ratios are of order 1%. Since the processes listed have different sensitivities to the quark and gluon content of the Pomeron, the ratios can be used to extract the gluon fraction $f^g_{IP}$ in the Pomeron. An analysis of the $W$, dijet, and $b$ results yields $f^g_{IP} = 0.54^{+0.16}_{-0.14}$. The same analysis also shows that all the diffractive to non-diffractive ratios are consistently suppressed by a factor $D = 0.19 \pm 0.04$ with respect to expectations based on HERA measurements and QCD factorization, indicating a breakdown of the latter. Even though $J/\psi$ and $b$ production both occur mainly via initial-state gluon fusion, their $R$ values disagree. This discrepancy can be entirely ascribed to the difference in kinematic region probed by the two processes.

The bottom two lines of Table 1 give the ratios of dijet event rates with and without a gap between the jets. The measured fraction of color-singlet exchange is constant as function of $\Delta \eta^{\text{jet}}$, $E_T^{\text{jet}}$ and $x_{bj}$. A Roman pot spectrometer allows CDF to detect leading antiprotons and to determine $\xi$ and the four-momentum transfer squared $t$. CDF measured the ratio of single-diffractive to non-diffractive dijet production rates at $\sqrt{s} = 1800$ and $630$ GeV as a function of the $x_{bj}$ of the struck parton in the Pomeron amplitude.
the $\bar{p}$). In leading order QCD, this ratio equals the ratio of the corresponding structure functions and can therefore be used to extract the diffractive structure function of the proton. The CDF diffractive structure function is steeper than, and severely suppressed relative to predictions based on extrapolations of the diffractive parton densities extracted by the H1 collaboration from DIS measurements at HERA.

A search for exclusive dijet production by double-Pomeron exchange ($p + \bar{p} \rightarrow p' + \text{jet}_1 + \text{jet}_2 + \bar{p}'$) yielded a 95% C.L. upper limit of 3.7 nb for $0.035 < \xi_{\bar{p}} < 0.095$ and jets with $E_T > 7$ GeV and $-4.2 < \eta < 2.4$.  

### 3 CDF forward detector upgrades

The CDF forward detector for Run II is shown schematically in Figure 1. This system comprises a Roman Pot spectrometer to detect leading antiprotons and measure $\xi$ and $t$, beam shower counters on both sides of the central detector ($5.5 < |\eta| < 7.5$) for triggering on events with forward rapidity gaps, and two “miniplug” calorimeters in the region $3.5 < |\eta| < 5.5$.

![Figure 1. Layout of the CDF forward detectors for Run II, on the antiproton side of the central detector. The proton side does not have a Roman pot spectrometer.](image)

### 4 Run I diffractive physics results from DØ

The DØ collaboration extensively studied events with two jets separated by a rapidity gap at $\sqrt{s} = 1800$ and 630 GeV. The measured color-singlet fraction at $\sqrt{s} = 1800$ GeV is $(0.94 \pm 0.13)$% and tends to increase with dijet $E_T$ and $\Delta \eta$. This observation is consistent with a soft-color rearrangement model preferring initial quark states. Photon-like, U(1), and current two-gluon models do not adequately describe the data.
More recently, DØ studied hard single diffraction at \(\sqrt{s} = 630\) and 1800 GeV. At each energy, a sample of forward dijets (with the two leading jet pseudorapidities \(\eta_1, \eta_2 > 1.6\) or \(< -1.6\)) and a sample of central dijets (with \(|\eta_1|, |\eta_2| < 1\) are defined. Diffractive events are then identified by the rapidity-gap method. Table 2 shows the fractions of gap event s for the four data samples and compares them with various models for the Pomeron structure function. The predictions for a hard-gluon structure are far higher than supported by the data. A quark structure yields better agreement, but has been shown by CDF to predict an excessive rate of diffractive \(W\) bosons.

Ratios of gap fractions provide additional information, as the Pomeron flux factor cancels in ratios evaluated at the same \(\sqrt{s}\). The bottom two lines of the table show that, in spite of this cancellation, a hard-gluon structure still does not model the data. DØ concludes that a gluon-dominated Pomeron, containing both soft and hard components, and combined with a flux factor that decreases with increasing \(\sqrt{s}\), could describe all the data samples.

### Table 2. Measured and predicted gap fractions and their ratios for the 630 and 1800 GeV forward (F) and central (C) dijet samples. Predictions are given for four different Pomeron structure functions \(s(\beta)\): hard gluon \((s(\beta) \propto \beta(1 - \beta))\), flat gluon \((s(\beta) \text{ const.})\), soft gluon \((s(\beta) \propto (1 - \beta)^5)\) and quark \((s(\beta) \propto \beta(1 - \beta))\).

| Sample | Data     | Hard G. | Flat G. | Soft G. | Quark  |
|--------|----------|---------|---------|---------|--------|
| 1800 F | 0.65 ± 0.04 | 2.2 ± 0.3 | 2.2 ± 0.3 | 1.4 ± 0.2 | 0.79 ± 0.12 |
| 1800 C | 0.22 ± 0.05 | 2.5 ± 0.4 | 3.5 ± 0.5 | 0.05 ± 0.01 | 0.49 ± 0.06 |
| 630 F  | 1.19 ± 0.08 | 3.9 ± 0.9 | 3.1 ± 0.8 | 1.9 ± 0.4 | 2.2 ± 0.5 |
| 630 C  | 0.90 ± 0.06 | 5.2 ± 0.7 | 6.3 ± 0.9 | 0.14 ± 0.04 | 1.6 ± 0.2 |

|       |         |         |         |         |        |
|-------|---------|---------|---------|---------|--------|
| 630   | 1.8 ± 0.2 | 1.7 ± 0.4 | 1.4 ± 0.3 | 1.4 ± 0.3 | 2.7 ± 0.6 |
| 1800  | 4.1 ± 0.9 | 2.1 ± 0.4 | 1.8 ± 0.3 | 3.1 ± 1.1 | 3.2 ± 0.5 |
| \(\frac{630}{1800}\) | 3.0 ± 0.7 | 0.88 ± 0.18 | 0.64 ± 0.12 | 30. ± 8. | 1.6 ± 0.3 |
| \(\frac{630}{1800}\) | 1.3 ± 0.1 | 0.75 ± 0.16 | 0.48 ± 0.12 | 13. ± 4. | 1.4 ± 0.3 |

5  **DØ forward detector upgrades**

The Run II upgrade of the DØ detector includes a Forward Proton Detector (FPD) whose layout is shown in Figure 2. The FPD consists of nine independent spectrometers, each of which uses magnets in the accelerator...
lattice together with position measurements along the (anti)proton track to determine the (anti)proton momentum and scattering angle. There are eight quadrupole spectrometers, four on each side of the central detector, measuring tracks in both the horizontal and vertical planes, and one dipole spectrometer on the antiproton side. This configuration has several advantages:

- Having quadrupoles on both sides allows detection of elastic scattering events for alignment purposes and to monitor luminosity.
- Halo backgrounds can be rejected by diagonally opposite spectrometers, as in-time halo tracks on one side appear as early hits on the other.
- The possibility to tag both protons and antiprotons will allow unambiguous measurements of double-Pomeron exchange.
- A quadrupole spectrometer requires a minimum scattering angle, or $|t|$, to accept a proton, whereas a dipole spectrometer requires a minimum momentum loss $\xi$. Therefore, the dipole spectrometer on the $\bar{p}$ side is crucial to calculate the acceptance of the quadrupole spectrometers, to avoid uncertainties in the extrapolation to $|t|=0$, and to provide large acceptance for high-mass events and double-Pomeron exchange.

The spectrometers are incorporated into the standard DØ triggering and data acquisition system, thereby enabling the collection of large samples of diffractive events. For 1 fb$^{-1}$ of integrated luminosity, DØ expects to collect about 1K diffractive $W$ bosons, 3K hard double-Pomeron events, and 500K diffractive dijets.

6 Diffractive physics program for Tevatron Run II

Significant forward detector upgrades implemented by both DØ and CDF will allow for a detailed study of the diffractive structure function of the proton, including its process dependence, if any. It should be possible to observe exclusive production of dijets by double Pomeron exchange, as well as low-mass exclusive states (glueballs?) Jet-gap-jet events at high $\Delta\eta^{jet}$ will provide a testing ground for BFKL. Finally, there is always the hope of making some unexpected discovery.

Acknowledgments

I would like to thank Dino Goulianos and Andrew Brandt for their help with the preparation of this summary, and the symposium organizers and secretaries for a very interesting and successful meeting.
Figure 2. Layout of the DØ forward proton detector, showing the central detector (not to scale) at $Z = 0$, the quadrupole magnets $Q_i$, dipole magnet $D$, and electrostatic separators $S$ from the accelerator lattice, and the roman pots housing the detectors for the quadrupole spectrometers $A_1$, $A_2$, $P_1$, and $P_2$ and for the dipole spectrometer $A_D$.

References

1. F. Abe et al., Phys. Rev. D 50, 5535 (1994).
2. T. Affolder et al., Phys. Rev. Lett. 87, 141802 (2001).
3. F. Abe et al., Phys. Rev. Lett. 78, 2698 (1997).
4. F. Abe et al., Phys. Rev. Lett. 79, 2636 (1997).
5. T. Affolder et al., Phys. Rev. Lett. 84, 232 (2000).
6. T. Affolder et al., [hep-ex/0107071], to be published in Phys. Rev. Lett.
7. F. Abe et al., Phys. Rev. Lett. 74, 855 (1995).
8. F. Abe et al., Phys. Rev. Lett. 80, 1156 (1998).
9. F. Abe et al., Phys. Rev. Lett. 81, 5278 (1998).
10. T. Affolder et al., Phys. Rev. Lett. 84, 5043 (2000).
11. T. Affolder et al., [hep-ex/0109025], submitted to Phys. Rev. Lett.
12. T. Affolder et al., Phys. Rev. Lett. 85, 4215 (2000).
13. S. Abachi et al., Phys. Rev. Lett. 72, 2332 (1994).
14. S. Abachi et al., Phys. Rev. Lett. 76, 734 (1996).
15. B. Abbott et al., Phys. Lett. B 440, 189 (1998).
16. B. Abbott et al., [hep-ex/9912061], submitted to Phys. Rev. Lett.
17. A. Brandt et al., “Proposal for a Forward Proton Detector at DØ”, Fermilab PUB-97-377.