DIFFRACTION IN CDF:
RUN I RESULTS AND PLANS FOR RUN II

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Results on diffraction obtained by the CDF Collaboration in Run I of the Fermilab Tevatron $\bar{p}p$ collider are reviewed. New results are reported on soft double diffraction and diffractive J/ψ production. The CDF program for diffractive studies in Run II is briefly discussed.

1 Introduction

The signature of a diffractive event in $\bar{p}p$ collisions is a leading proton or antiproton and/or a rapidity gap, defined as a region of pseudorapidity, $\eta \equiv -\ln\tan\frac{\theta}{2}$, devoid of particles (see Fig. 1).

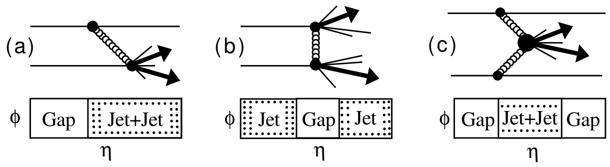

Figure 1: Dijet production diagrams and event topologies for (a) single-diffraction, (b) double-diffraction, and (c) double Pomeron exchange.

In Run I, CDF studied the following diffractive processes:

- soft single-diffraction (SD) at $\sqrt{s} = 546$ and 1800 GeV [1] and soft double-diffraction (DD) at $\sqrt{s} = 630$ and 1800 GeV [2]
- W-boson [3], dijet [4], b-quark [5] and J/ψ [6] production at $\sqrt{s} = 1800$ GeV using rapidity gaps to identify diffractive events
- dijets with a rapidity gap between jets at $\sqrt{s} = 630$ [7] and 1800 GeV [8,9]
- dijets with a leading antiproton at $\sqrt{s} = 630$ [10] and 1800 GeV [11]
- double Pomeron exchange (DPE) dijet production with a leading antiproton and a rapidity gap on the proton side [12]

In our discussion below, we address the issues of universality in rapidity gap formation and of Regge and QCD factorization in hard diffraction.

2 Soft diffraction

Measurements of pp and $\bar{p}p$ SD cross sections have shown that Regge theory correctly predicts the shape of the rapidity gap dependence for $\Delta\eta > 3$, corresponding to a leading proton fractional momentum loss of $\xi = e^{-\Delta\eta} < 0.05$, but fails to predict the correct energy dependence of the overall normalization, which at $\sqrt{s} = 1800$ GeV is found to be suppressed by approximately an order of magnitude [1,13,14]. A new CDF measurement of the double diffraction differential cross section gives similar results (see Fig. 2).

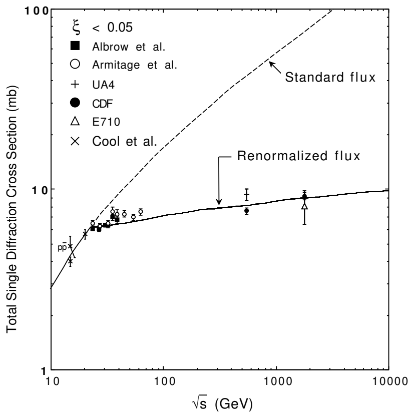

Figure 2a: The $pp/\bar{p}p$ σ^T_{SD} versus $\sqrt{s}$.

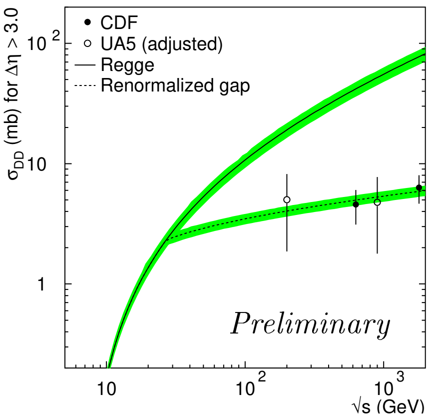

Figure 2b: The $\bar{p}p$ σ^T_{DD} versus $\sqrt{s}$.

The SD and DD cross sections have very similar forms in terms of $\Delta\eta$:

$$d^2\sigma_{SD}/dt\, d\Delta\eta = \quad [K e^{bt} e^{[2\alpha(t)-1]\Delta\eta}] \cdot [\kappa\beta^2(0)(s')^{\alpha(0)-1}] \tag{1}$$

$$d^3\sigma_{DD}/dt\, d\Delta\eta\, d\eta_c = \quad [\kappa\, K\, e^{[2\alpha(t)-1]\Delta\eta}] \cdot [\kappa\beta^2(0)(s')^{\alpha(0)-1}] \tag{2}$$

Here, energy is measured in GeV, $\alpha(t) = \alpha(0) + \alpha' t$ is the Pomeron trajectory, $\beta(t)$ is the coupling of the Pomeron to the proton, $K = \beta^2(0)/16\pi$, $\kappa = g_{I\!P I\!P I\!P}/\beta(0)$, where $g_{I\!P I\!P I\!P}$ is the triple-Pomeron coupling, e^{bt} is the square of the proton form factor, η_c the center of the rapidity gap, and $s' = M_1^2 M_2^2$ (M is the diffractive mass) can be thought of as the s-value of the diffractive sub-system(s), since $\ln s' = \ln s - \Delta\eta$ is the rapidity space where particle production occurs. The second factor in the equations can be thought of as the sub-energy total cross section, which allows the first factor to be interpreted as a rapidity gap probability, P_{gap}. For SD, it has been shown that renormalizing the Pomeron flux [13], which is equivalent to normalizing P_{gap} over all phase space to unity, yields the correct energy dependence. The new CDF results show that this also holds for DD, as predicted by a generalization of the Pomeron flux renormalization model [15].

3 Hard diffraction using rapidity gaps

Using forward rapidy gaps to tag diffractive events, CDF measured the ratio of SD to non-diffractve (ND) rates for W-boson [3], dijet [4], b-quark [5] and J/ψ [6] production at $\sqrt{s}$ = 1800 GeV, and using central gaps determined the fraction of jet-gap-jet events as a function of E_T^{jet} and of rapidity gap separation between the two jets ($\Delta\eta^{jet}$) at $\sqrt{s} = 630$ and 1800 GeV.

Forward gaps were defined as no hits in one of the beam-beam counters, BBC ($3.2 < |\eta| < 5.9$), and no towers with energy $E > 1.5$ GeV in the forward calorimeters, FCAL ($2.4 < |\eta| < 4.2$). Using the POMPYT Monte Carlo (MC) simulation with a flat gluon/quark Pomeron structure, the measured SD/ND ratios were corrected for 'gap acceptance', defined as the ratio of diffractive events with a gap to all diffractive events generated with $\xi = x_{I\!P} < 0.1$ in the selected kinematical range of the hard scattering products.

For jet-gap-jet events, the gap was defined as no tracks or towers with energy above $\sim$ 300 MeV in the region $|\eta| < 1$. The ND background was estimated using events with both jets at positive or negative η.

Table 1: Ratios of diffractive ($\xi < 0.1$) to non-diffractive rates.

Hard process	$\sqrt{s}$	$R = \frac{\text{DIFF}}{\text{ALL}}$ (%)	Kinematical region
$W(\rightarrow e\nu)$+G	1800	1.15 ± 0.55	E_T^e, $\not\!\!E_T > 20$ GeV
Jet+Jet+G	1800	0.75 ± 0.1	$E_T^{jet} > 20$ GeV, $\eta^{jet} > 1.8$
$b(\rightarrow e + X)$+G	1800	0.62 ± 0.25	$\lvert\eta^e\rvert < 1.1$, $p_T^e > 9.5$ GeV
$J/\psi(\rightarrow \mu\mu)$+G	1800	1.45 ± 0.25	$\lvert\eta^\mu\rvert < 0.6$, $p_T^\mu > 2$ GeV
Jet-G-Jet	1800	1.13 ± 0.16	$E_T^{jet} > 20$ GeV, $\eta^{jet} > 1.8$
Jet-G-Jet	630	2.7 ± 0.9	$E_T^{jet} > 8$ GeV, $\eta^{jet} > 1.8$

The results are summarized in Table 1. At $\sqrt{s}$=1800 GeV the DIFF/ALL ratios are approximately equal. Since the processes under study have different sensitivities to the quark and gluon content of the Pomeron, these results indicate that the value of the gluon fraction in the Pomeron, $f_g^{I\!P}$, is not very different from that in the proton. From the W, dijet and b-quark ratios, $f_g^{I\!P}$ was determined to be [5] $0.54^{+0.16}_{-0.14}$. In addition, a suppression of a factor $D = 0.19 \pm 0.04$ was found in these ratios relative to POMPYT predictions using the standard Pomeron flux. This discrepancy indicates a breakdown of factorization [5]. The value of D is approximately the same as that in soft SD (see Fig. 2), as predicted in Ref. [13].

The ratio of jet-gap-jet fractions at $\sqrt{s}$ = 630 to 1800 GeV is 2.4 ± 0.8. The $\Delta\eta^{jet}$, E_T^{jet} and x-Bjorken distributions are consistent with being flat [9].

4 Hard diffraction using a leading antiproton spectrometer

Using a Roman pot spectrometer to detect leading antiprotons and determine their momentum and polar angle (hence the t-value), CDF measured the ratio of SD to ND dijet production rates at $\sqrt{s}$=630 [10] and 1800 GeV [11] as a function of x-Bjorken of the struck parton in the $\bar{p}$. In leading order QCD, this ratio is equal to the ratio of the corresponding structure functions. For dijet production, the relevant structure function is the color-weighted combination of gluon and quark terms given by $F_{jj}(x) = x[g(x) + \frac{4}{9}\sum_i q_i(x)]$. The diffractive structure function, $\tilde{F}^D_{jj}(\beta)$, where $\beta = x/\xi$ is the momentum fraction of the Pomeron's struck parton, is obtained by multiplying the ratio of rates by the known F^{ND}_{jj} and changing variables from x to β using $x \to \beta\xi$ (the tilde over the F indicates integration over t and ξ, as specified in each case).

Results for $\sqrt{s} = 1800$ GeV are presented in Fig. 3:

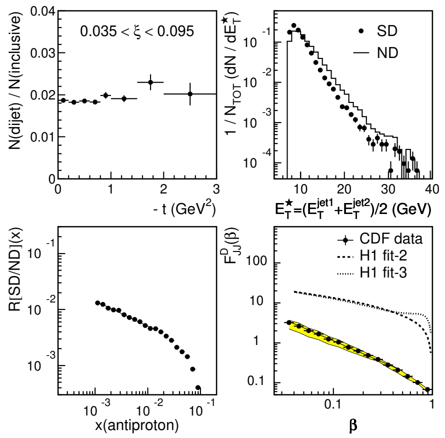

Figure 3: Results from inclusive and dijet diffractive data with a leading $\bar{p}$:
(top left) the ratio of dijet to inclusive SD event rates is independent of t;
(top right) the E_T^{jet} distribution is slightly steeper for SD than for ND events;
(bottom left) the ratio of SD to ND rates increases with decreasing x_{bj};
(bottom right) 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.

The above results confirm the breakdown of factorization observed in the rapidity gap data presented in section 3. Differences in suppression factors can be traced back to differences in kinematical acceptance.

Factorization was also tested *within CDF data* by comparing the ratio of DPE to SD to that of SD to ND dijet production rates. The DPE events were extracted from the leading antiproton data by demanding a rapidity gap in the forward detectors on the proton side, defined as in section 3. At $\langle\xi\rangle = 0.02$ and $\langle x_{bj}\rangle = 0.005$, the ratio of SD/ND to DPE/SD rates normalized per unit ξ was found to be [12] 0.19 ± 0.07, violating factorization.

A search for the process $p + \bar{p} \to p' + (jet1 + jet2) + \bar{p}'$ yielded [12] an upper limit of 3.7 nb for $0.035 < \xi(\bar{p}) < 0.095$ and jets of $E_T > 7$ GeV and $\eta < 1.7$.

5 Plans for Run II

The CDF program for diffractive studies in Run II will include:

(a) Hard single diffraction

– Process dependence of F^D (compare at the same ξ and x_{bj})

– Q^2 dependence of F_{jj}^D

(b) Double Pomeron exchange

– Soft DPE

– $F_{jj}^D(x_p)$ versus width of gap on the $\bar{p}$ side

– Exclusive dijet and $\bar{b}b$ production

– Low mass exclusive states (glueballs?)

(c) Hard double diffraction

– jet-gap-jet events at high $\Delta\eta^{jet}$ (test BFKL)

(d) Unexpected discoveries!

The Run II program will be implemented by upgrading CDF to include the forward detector system shown schematically in Fig. 4. This system comprises: 1. A Roman Pot Specrometer (RPS) on the antiproton side to detect leading antiprotons and measure ξ and t
2. Beam Shower Counters (BSC) covering the region $5.5 < |\eta| < 7.5$ to be used for triggering on events with forward rapidity gaps
3. Two 'MiniPlug' calorimeters in the region $3.5 < |\eta < 5.5$

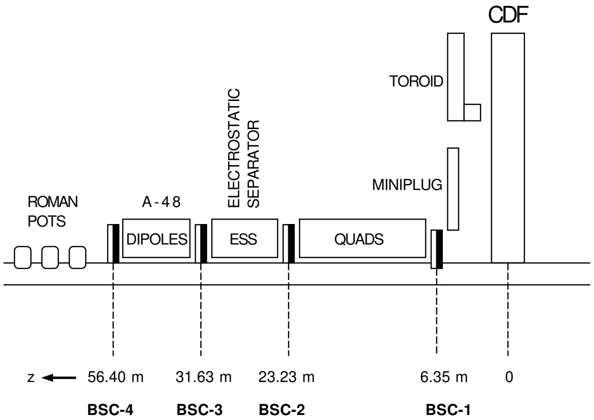

Figure 4: CDF forward detectors for Run II

The RPS and BSC systems are already installed, and the MiniPlug installation is scheduled for September 2001.

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