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NEW DIFFRACTIVE RESULTS FROM THE TEVATRON

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New diffractive results from the Tevatron are presented. We report first observation of diffractive $J/\psi(\rightarrow \mu^+\mu^-)$ production in $\bar{p}p$ collisions at $\sqrt{s}$=1.8 TeV. In a sample of events with two muons of transverse momentum $p_T^\mu > 2$ GeV/c within the pseudorapidity region $|\eta|$ <1.0, the ratio of diffractive to total J/ψ production rates is found to be $R_{J/\psi} = [1.45 \pm 0.25]\%$. The ratio $R_{J/\psi}(x)$ is studied as a function of the momentum fraction $x_{\rm bj}$ of the struck parton in the (anti)proton. By combining this measurement with a similar one of diffractive dijet production with a leading antiproton, the gluon fraction of the (anti)proton diffractive structure is found to be 0.59 ± 0.15. The results from a study of double diffraction dissociation events are also discussed. The production cross section for events with a central pseudorapidity gap of width $\Delta\eta^\circ > 3$ (overlapping $\eta = 0$) is found to be 4.43 ± 0.02(stat) ± 1.18(syst) mb [3.42 ± 0.01(stat) ± 1.09(syst)] at $\sqrt{s} = 1800$ [630] GeV. These results are compared with previous measurements and with predictions based on Regge theory and factorization.

1 Diffractive J/ψ Production

In the course of our studies of high energy $\bar{p}p$ interactions at the CDF, we have observed a class of events combining both a hard partonic scattering and the characteristic signature of single diffraction dissociation, namely a leading (anti)proton and/or a forward rapidity gap, defined as the absence of particles in a forward (pseudo)rapidity region. The rapidity gap in such "hard diffraction" processes is attributed to the exchange of a pomeron[1], which in QCD is a gluon/quark color singlet construct with the quantum numbers of the vacuum. In order to probe *directly* the gluon content of the pomeron, we have studied diffractive production of J/ψ mesons, a process dominated by gluon-gluon fusion reactions.

The J/ψ is identified by its decay into two muons, $J/\psi \rightarrow \mu^+\mu^-$. The events selected have muons of $p_T^\mu > 2$ GeV within central region of the detector $|\eta| < 1.0$. The dimuon mass of

J/ψ candidates is required to be in the window $3.05 < M_{\mu\mu} < 3.15$ GeV/c^2. In a data sample satisfying J/ψ selection requirements, we look for events with a rapidity gap in either one of the two forward regions of the detector within $2.4 < |\eta| < 5.9$. Our rapidity gap definition is no hits in the beam-beam counters (BBC), which cover the region $3.2 < |\eta| < 5.9$, and no calorimeter towers with energy above 1.5 GeV within $2.4 < |\eta| < 4.2$.

The fraction of J/ψ's from B-hadron decays is determined by fitting the lifetime, $c\tau$, distribution using the appropriate function for each of the three dimuon components: prompt or directly produced J/ψ's, J/ψ's from B-hadron decays, and non-J/ψ background. The fraction of J/ψ's from B-hadron decays obtained from the fit is $(16.8 \pm 0.4)\%$. By applying the lifetime cut $c\tau < 100\mu$m, the fraction of B-hadron decay component was reduced to 3.3%. The total number of events in the prompt-J/ψ sample is 15824.

The diffractive signal is evaluated by counting BBC hits, $N_{\rm BBC}$, and adjacent forward calorimeter towers, $N_{\rm CAL}$. Figure 1a shows the correlation between $N_{\rm BBC}$ and $N_{\rm CAL}$. The multiplicity in this figure is for the side of the detector with minimum BBC hit multiplicity. The (0,0) bin, $N_{\rm BBC} = N_{\rm CAL} = 0$, contains 92 events. The excess of events in this bin is attributed to diffractive production. The non-diffractive content of the (0,0) bin is evaluated from the diagonal of Fig. 1a with $N_{\rm BBC} = N_{\rm CAL}$, shown in Fig. 1b. An extrapolation to bin (0,0) of a linear fit to the data of bins (2,2) to (12,12) yields 19.9 ± 3.9 non-diffractive events. Figures 1c and 1d show the J/ψ transverse momentum and pseudorapidity distribution, respectively, for the diffractive and total event samples. In Fig. 1d, the sign of the J/ψ pseudorapidity for events with a gap at positive η is reversed. The number of diffractive events in the (0,0) bin is corrected for the single vertex cut efficiency, $\varepsilon^{\rm SD}_{\rm 1vtx}$, as well as for the BBC and forward calorimeter occupancy. After applying the above corrections, we obtain a diffractive to total J/ψ production ratio of $R^{\rm gap}_{J/\psi} = (0.33 \pm 0.08)\%$. The gap acceptance for $\xi < 0.1$ was calculated using the POMPYT Monte Carlo generator [2], followed by a detector simulation. For a Pomeron structure function of the form [3] $\beta f(\beta) = 1/\beta$, where β is the fraction of the momentum of the Pomeron carried by a parton, $\mathcal{A}_{\rm gap}$ was found to be 0.29. Dividing $R^{\rm gap}_{J/\psi}$ by $\mathcal{A}_{\rm gap}$ yields a diffractive to total production ratio of $R_{J/\psi} = (1.45 \pm 0.25)\%$.

For a more direct study of the diffractive structure function, we extended our analysis to events in which at least one jet was reconstructed. The x_{bj} of the parton in the (anti)proton participating in J/ψ production is evaluated using the equation $x^{\pm}_{bj} = p_T^{J/\psi}(e^{\pm\eta_{J/\psi}} + e^{\pm\eta_{jet}})/\sqrt{s}$, where the + (-) sign stands for $p(\bar{p})$. In LO QCD, the ratio of diffractive to non-diffractive production is equal to the ratio of the corresponding structure functions. For J/ψ production, the ratio $R_{J/\psi}(x)$ per unit ξ was evaluated for the events in the region $0.01 < \xi < 0.03$ and is shown on the right plot in Fig. 1 along with the same ratio for dijet production, $R_{jj}(x)$, obtained from Ref. [3]. The structure function relevant to dijet production is $F_{jj}(x) \sim g(x) + \frac{4}{9}q(x)$ [3], where $g(x)$ and $q(x)$ are the gluon and quark densities in the proton and $\frac{4}{9}$ is a color factor. For J/ψ production, which is dominated by gg interactions, $R_{J/\psi}(x) \simeq g^D(x)/g(x)$. The ratio of $R_{jj}(x)$ to $R_{J/\psi}(x)$ is given by

$$R^{J/\psi}_{jj}(x) \equiv \frac{R_{jj}(x)}{R_{J/\psi}(x)} = \frac{1 + \frac{4}{9}\frac{q^D(x)}{g^D(x)}}{1 + \frac{4}{9}\frac{q(x)}{g(x)}} \tag{1}$$

where the superscript D is used to label the diffractive parton densities. Evaluating this ratio of ratios by integrating the x_{bj} distributions for R_{jj} and $R_{J/\psi}$ in the region $0.004 \leq x \leq 0.01$ (kinematic boundaries for full acceptance) yields $[R_{jj}(x)/R_{J/\psi}(x)]_{\rm exp} = 1.17 \pm 0.20$(stat). Using this value in Eq. 1 and the ratio of $q(x)/g(x) = 0.274$ at $x = 0.0063$ and $Q = 6$ GeV calculated from the GRV98LO parton distribution functions [4], the gluon fraction of the diffractive structure function is found to be $f^D_g = 0.59 \pm 0.11(\text{stat}) \pm 0.08(\text{syst})$, where the systematic uncertainty includes in quadrature the uncertainties of all correction factors. This gluon fraction is consistent

with the value 0.54 ± 0.15 obtained by combining the results of diffractive W, dijet, and b-quark production [5].

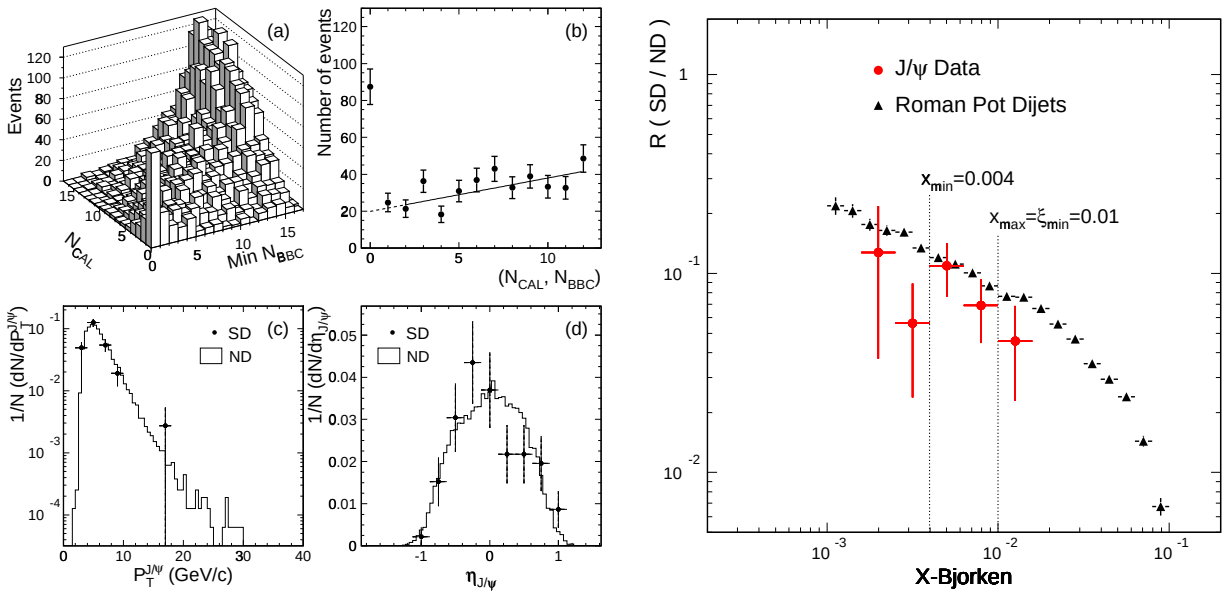

Figure 1: Left plots: (a) Beam-beam counter multiplicity, $N_{\rm BBC}$, versus forward calorimeter tower multiplicity, $N_{\rm CAL}$; (b) multiplicity distribution along the diagonal with $N_{\rm BBC} = N_{\rm CAL}$ in the plot of (a); (c) p_T and (d) J/ψ pseudorapidity distribution for diffractive (points) and total (histogram) event samples. Right plot: Ratio of diffractive to non-diffractive J/ψ (circles) and dijet (triangles) rates per unit $\xi_p(\xi_{\bar{p}})$ as a function of x-Bjorken.

2 Double Diffraction

In double-diffractive (DD) events, the exchange of the Pomeron causes both incident hadrons to dissociate. Since the exchanged object is a color singlet and does not radiate, a rapidity gap is formed in the region in between the resulting diffractive mass clusters. From Regge theory and factorization, the DD differential cross section has the form

$$\frac{d^3\sigma_{DD}}{dt\,d\Delta\eta\,d\eta_\circ} = \left[\frac{\kappa\beta^2(0)}{16\pi}e^{2[\alpha(t)-1]\Delta\eta}\right]\left[\kappa\beta^2(0)\left(\frac{s'}{s_\circ}\right)^{\alpha(0)-1}\right] \tag{2}$$

where $\alpha(t)$ is the pomeron trajectory, $\beta(t)$ the coupling of the pomeron to the (anti)proton, and $\kappa \equiv g(t)/\beta(0)$ the ratio of the triple-pomeron to the pomeron-proton couplings; we use $\alpha(t) = \alpha(0) + \alpha' t = 1.104 + 0.25t$, $\beta(0) = 4.1$ mb $^{1/2}$ [6], and $g(t) = 0.69$ mb$^{1/2}$ [7]. The width $\Delta\eta$ and the center $\eta_\circ$ of the rapidity gap are related to the diffractive masses as $\Delta\eta \approx \ln(ss_\circ/M_1^2M_2^2)$ and $\eta_\circ \approx \ln(M_2/M_1)$, respectively. The first factor in Eq. 2 depends on $\Delta\eta$, and can be thought of as a rapidity gap probability, while the second factor has the form of the pomeron-proton total cross section at the sub-energy squared $s' = se^{\Delta\eta}$.

We have studied double diffraction by looking for central rapidity gaps in minimum-bias events which have hits in the BBC's. The η of the track or calorimeter tower above a given threshold with the smallest $|\eta|$ for $\eta > 0 (\eta < 0)$ is defined to be $\eta_{max(min)}$. The SD contribution is fixed by known cross section [8] and the fraction of events passing the BBC trigger in the Monte Carlo (MC). The ND and DD contributions are determined by fitting the MC-generated distributions to the data on the left plot in Fig. 2, which shows the number of events versus $\Delta\eta^\circ = \eta_{max} - \eta_{min}$. The DD MC uses the differential cross section 2, so the agreement between data and MC seen in Fig. 2 justifies the fact that the gap-width, or equivalently mass, dependence appears to be consistent with Regge theory.

We find cross sections at $\sqrt{s} = 1800(630)$ GeV by measuring $\sigma_{DD}\mathcal{A}$, where $\mathcal{A}$ is the gap acceptance for DD events triggering the BBC's. From the DD MC, $\mathcal{A} = (57 \pm 7)\%[(63 \pm 7)\%]$, which yields $\sigma_{DD}(\Delta\eta^0 > 3) = 4.43 \pm 0.02(\text{stat} \pm 1.18(\text{syst})$ mb $[3.42 \pm 0.01(\text{stat}) \pm 1.09(\text{syst})]$ mb.

The extrapolation to all gaps of width $\Delta\eta > 3$ using Eq. 2 yields cross sections 1.43(1.34) times larger. These cross sections are shown on the right plot in Fig. 2 with results from UA5 [9]. The measured DD cross sections are much smaller than the Regge theory prediction (solid curve), but are in general agreement with predictions found by normalizing the gap probability in Eq. 2 to unity [10] (dashed curve).

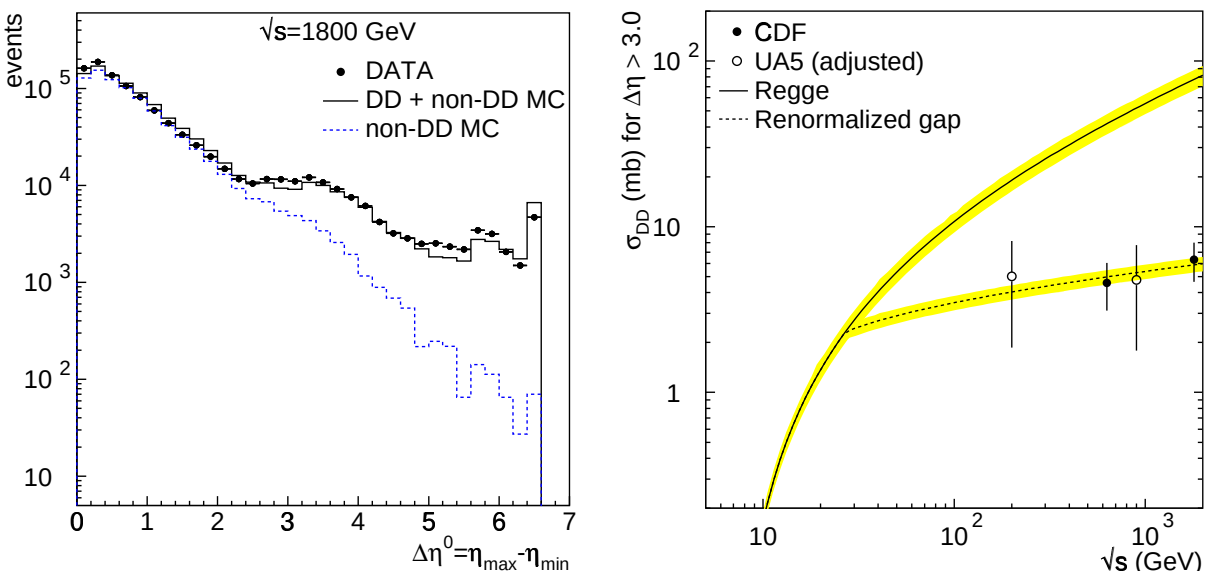

Figure 2: Left plot: The number of events as a function of $\Delta\eta^{\circ}_{exp} = \eta_{max} - \eta_{min}$ for data at $\sqrt{s} = 1800$ GeV (points), for double diffractive (DD) plus non-DD (MC) generated events (solid line), and for only non-DD MC events (dashed line). The non-DD events are a mixture of 97.3% non-diffractive and 2.3% single diffractive. Right plot: The total double diffractive cross section for $p(\bar{p}) + p \to X_1 + X_2$ versus $\sqrt{s}$ compared with predictions from Regge theory based on the triple-Pomeron amplitude and factorization (solid curve) and from the renormalized gap probability model (dashed curve).

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