CDF RESULTS ON DIFFRACTION AND EXCLUSIVE PRODUCTION

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Recent CDF results on diffraction and exclusive production in proton-antiproton collisions obtained at the Fermilab Tevatron are briefly reviewed and compared with theoretical expectations. We report updates on diffractive production of W and Z bosons, on measurements of the diffractive structure function in dijet production, on rapidity gaps between jets, and present evidence for exclusive di-photon production, which constitutes the first observation of exclusively produced di-photon final states in hadron-hadron interactions.

1 Introduction

Diffraction in hadron-hadron interactions is defined as the process in which a strongly interacting color singlet quark/gluon combination with the quantum numbers of the vacuum (the *Pomeron*, $I\!P$) is exchanged [1,2,3]. As no radiation is expected from vacuum exchange, a large non-exponentially suppressed pseudorapidity region devoid of particles, called a *rapidity gap* [4], is produced and can serve as an experimental signature for diffraction. The CDF Collaboration (CDF) has been pursuing an intensive broad program of diffractive studies in $\bar{p}p$ collisions since the beginning of Tevatron $\bar{p}p$ operations more than a quarter century ago. The aim of these studies has been to decipher the parton distribution function (PDF) of $I\!P$-exchange. Since the diffractive component of all inelastic $\bar{p}p$ collisions at energies $\sim$1 TeV is about 25%, it contributes significantly to the underlying event (UE) of hard (high transverse momentum) processes. Therefore, understanding diffraction is essential to all data analysis where the UE influences trigger efficiencies and acceptance corrections. Depending on the p and/or $\bar{p}$ dissociation pattern, diffractive processes are classified as single dissociation or single diffraction (SD), characterized by one forward gap adjacent to a surviving p or $\bar{p}$, double-dissociation or double-diffraction (DD), which has a central gap, and central dissociation or double-Pomeron exchange (CD or DUPE), a process with two forward gaps).

2 Mini-review of CDF Results on Diffraction

In Run I (1992–1995), CDF studied soft SD, DD, CD (DPE) and SDD, a SD process with a DD gap withing the diffractive dissociation particle cluster, as well as hard diffraction processes with W, *dijet*, J/ψ or *b-quark* production using the rapidity gap signature for diffractive event selection, and in some cases a Roman Pot Spectrometer (RPS) to detect a surviving antiproton. While all CDF results were self-consistent within the RENORM model [5], which is based on a Regge phenomenology renormalized to account for overlapping rapidity gaps, there were two striking disagreements with results from other experiments. First, the D0 Collaboration measured a larger fraction of diffractive W events, F_{SD}^{W}, by a factor up to ~ 3.5, depending on the model used for estimating gap acceptance/survival; and second, CDF measured a ratio of dijet diffractive to non-diffractive (ND) structure functions that was $\sim 20\%$ greater than extrapolations from HERA *ep* measurements.

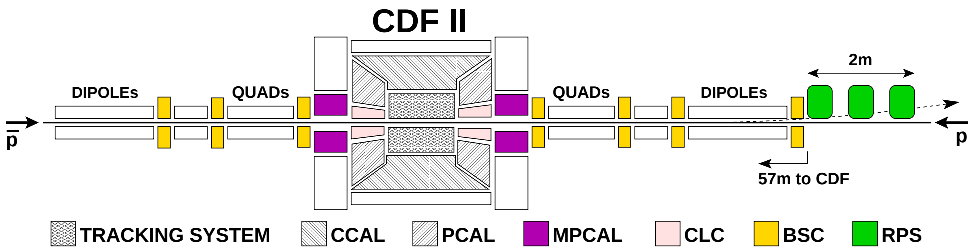

Figure 1: Plan view of the CDF II detector (not to scale) showing the MiniPlug calorimeters (MPCAL, $3.5 < |\eta| < 5.1$), Beam Shower Counters (BSC, $5.4 < |\eta| < 7.4$), and Roman Pot Spectrometer (RPS, $0.03 < \xi <\sim 0.10$).

To address these issues, special forward detectors were built by CDF and commissioned in Run II (2003–2011), as shown in Fig.2 and described in more detail in [6]. The forward detectors were also used to make a series of measurements on exclusive production of specific final states, whose cross sections are relevant to pre49dicting diffractive Higgs boson production at the large Hadron Collider (LHC).

Below, we report on the status of the Run II CDF program on diffractive W/Z, *dijet* and rapidity gaps between jets (JGJ), and in Sec.3 we briefly review the exclusive production results and present the first evidence for exclusive $\gamma\gamma$ production.

2.1 Diffractive W and Z Production

This analysis was fully reviewed in *DIFFRACTION 2010* [7] and then published in PRD [9]. Here we present the results obtained in the region of $\bar{p}$ momentum loss, ξ, within $0.01 < \xi < 0.10$ and 4-momentum transfer squared $-1 < t < 0$ GeV^2.

Figure 2 shows LO diagrams for diffractive W/Z production (left) and the W mass distribution, $M_{\rm W}^{\rm diff}$ (right), for events passing the diffractive event selection requirements.

- The SD/ND ratios for SD events within $0.03 < \xi < 0.10$ and $-1 < t < 0$ GeV^2 are:
$$R_{\rm W} = [1.00 \pm 0.05\,({\rm stat}) \pm 0.10({\rm syst})], R_{\rm Z} = [0.88 \pm 0.21({\rm stat}) \pm 0.08({\rm syst})]\%. \quad (1)$$
- The $M_{\rm W}^{\rm diff} = 80.9 \pm 0.7$ GeV agrees with the world average $M_W^{\rm PDG} = (80.399 \pm 0.023)$ GeV [10]

The $M_{\rm W}^{\rm diff}$ result confirmed our Run I rapidity gap based measurement. M_W was obtained from fully reconstructed diffractive W events using the momentum of the undetected neutrino in $W \to \mu/e + \nu$ decays obtained from the difference between the RPS measured ξ value, $\xi_{\bar{p}}^{\rm RPS}$, and that obtained from the calorimeters, $\xi_{\bar{p}}^{\rm cal}$:

$$\xi_{\bar{p}}^{\rm cal} = \sum_{i=1}^{N_{\rm towers}} \frac{E_{\rm T}^i}{\sqrt{s}} e^{-\eta^i},\ \xi^{\rm RPS} - \xi_{\bar{p}}^{\rm cal} = \sum_{i=1}^{N_{\rm towers}} \frac{\not{E}_T^i}{\sqrt{s}} e^{-\eta^\nu},\ p_z^\nu = \not{E}_T / \tan\left[2\tan^{-1}\left(e^{-\eta^\nu}\right)\right]. \quad (2)$$

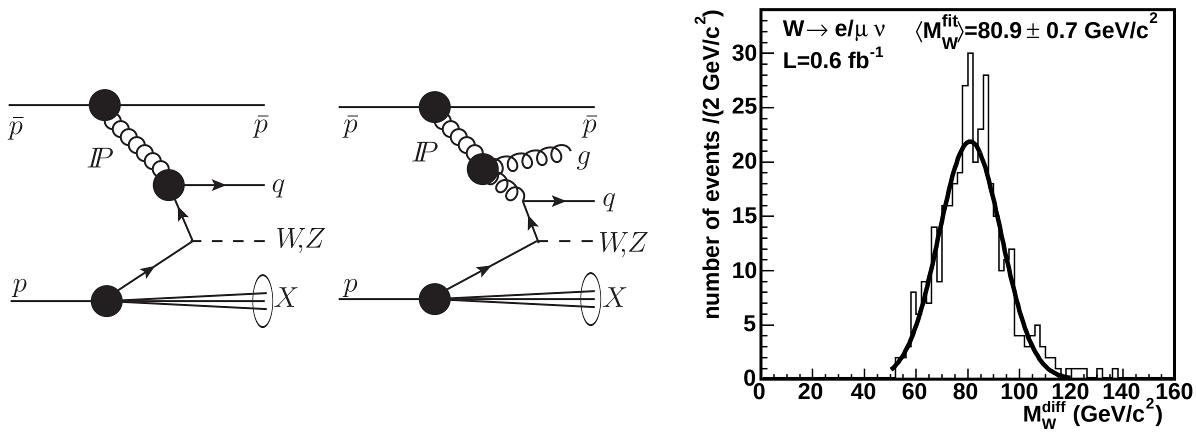

Figure 2: Diffractive W/Z diagrams (left), and W mass for events passing the diffraction W requirements (right).

2.2 Diffractive Structure Function in Dijet Production

Results reported at *EDS2009* [8] have been updated but have not yet been released. The main conclusions remain the same:

- The measured x_{Bj} rates confirm the factorization breakdown observed in Run I;
- Within $10^2 < Q^2 < 10^4$ GeV^2, where the inclusive E_T distribution falls by a factor of $\sim 10^4$, the ratio of the SD/ND distributions increases by less than a factor of ~ 2.
- The slope parameter $b(Q^2)|_{t=0}$ of an exponential fit to t distributions near $t = 0$ shows no Q^2 dependence in the measurement range of $\sim 1 < Q^2 < 10^4$ GeV^2.

These results support a picture of a composite Pomeron formed from color singlet combinations of the underlying parton densities of the nucleon (see, e.g., [5]).

Currently, the measurement of the t distribution is being extended to $t \sim -4$ GeV^2 to search for a diffraction minimum.

2.3 Rapidity Gaps Between Jets

An update of this analysis has been recently presented in [7]. Jet-Gap-Jet (JGJ) event rates can be used to test perturbative gap-creation models, such as the BFKL hypothesis (see, e.g., [3]). To reduce model dependence, we measured ratios of gap to all events, $R_{gap} \equiv N_{gap}/N_{all}$, as a function of the width of the gap and studied the suppression relative to expectations between JGJ and soft DD events selected by their activity in the MiniPlug calorimeters covering the η range $3.5 < |\eta| < 5.1$. The R_{gap}^{jet} ratios are found to be suppressed relative to R_{gap}^{DD}, as expected, but the suppression does not depend on the width of the gap. A BFKL contribution to the JGJ distribution would be expected to be concentrated at high $\Delta\eta$. We did not find any such excess that could be attributed to a BFKL contribution.

3 Review of CDF Results on Exclusive Production

The main interest in studying diffractively produced exclusive final states is to use the results to check/calibrate QCD models of diffraction that can be applied to calculate production rates of exclusive *Higgs* production at the LHC. Exclusive final states studied at CDF include *dijet* (or JJ) [11], χ_c [13], $\gamma\gamma$ [14], and J/ψ and $\psi(2s)$ [15]. A recent review of the results and their theoretical significance is included in [12]. All results are in good agreement with the model of [16].

Below, we report on a new CDF measurement of exclusive $\gamma\gamma$ production [18], which represents the first evidence for exclusive $\gamma\gamma$ production in hadron-hadron collisions.

3.1 Evidence for Exclusive $\gamma\gamma$ Production

Exclusive $\gamma\gamma$ events in $\bar{p}p$ collisions are produced by $gg \to \gamma\gamma$ through a quark loop, with another gluon being exchanged to cancel the color transfer allowing the $\bar{p}$ to emerge intact with no hadrons produced in the final state. This process is of great theoretical interest as it proceeds through a similar mechanism that can produce a neutral Higgs boson, as shown in Fig. 3 (left).

A CDF measurement of exclusive $\gamma\gamma$ production was previously reported in [14], but it lacked the statistical significance to pass the threshold to "observation." Here, we report the first observation of exclusive $\gamma\gamma$ production at a Tevatron collider energy of 1.96 TeV [18], based on a data sample of 1.11 ± 0.07 fb^{-1} collected by the CDF II detector.

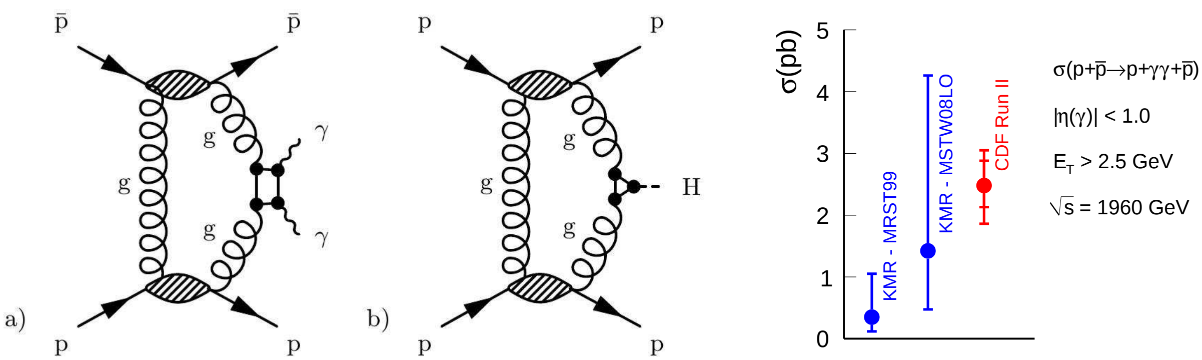

Figure 3: (left) Leading order exclusive production diagrams for (a) high E_T $\gamma\gamma$ and (b) Standard Model neutral Higgs boson production; (right) the measured exclusive $\gamma\gamma$ cross section compared to theory (see text)

The measurement reported here is based on events from ~ 1 fb^{-1} integrated luminosity with two electromagnetic showers of $E_T > 2.5$ GeV in $|\eta| < 1.0$ and no other particles within $|\eta| < 7.4$. The two showers were required to be of similar E_T and have an azimuthal angle separation $\Delta\phi \approx \pi$. A total of 77 such events were observed. Of these, 34 are associated with two charged particle tracks, consistent with $e^+(e^-)$ from the QED process $\bar{p}p \to \bar{p} + e^+e^+p$ by two-photon exchange, ehile 43 have no charged tracks. No $\pi^0\pi^0$ candidates were identified among these events, setting an upper limit of 15 at 95% C.L. for such contamination. The cross section for $\bar{p}p \to \bar{p} + \gamma\gamma + p$ with $\eta(\gamma) < 1.0$ and $E_T(\gamma) > 2.5$ GeV is $2.48^{+0.40}_{-0.35}(\text{stat})^{+0.40}_{0.51}(\text{syst})$ pb. The parameters used in the measurement are summarized in Table 1, and the candidate exclusive event propertoies are shown in in Fig. 4.

4 Conclusion

We present final results by the CDF II collaboration on diffractive W and Z production and report on the status of ongoing analyses on diffractive *dijet* production and on rapidity gaps between jets.

The diffractive W/Z analysis has been completed and the results are published [9]. We find that in the range of $\bar{p}$ forward momentum loss $0.03 < \xi_{\bar{p}} < 0.10$ and for $-1 < t < 0$ GeV ^{2} the fraction of diffractive events in W and Z production is $R_{\rm W} = [1.00 \pm 0.05\,(\text{stat.}) \pm 0.10(\text{ syst})]\%$ and $R_{\rm Z} = [0.88 \pm 0.21(\text{ stat.}) \pm 0.08(\text{ syst})]\%$, respectively. The R_W value is compatible with our Run I rapidity-gap based result.

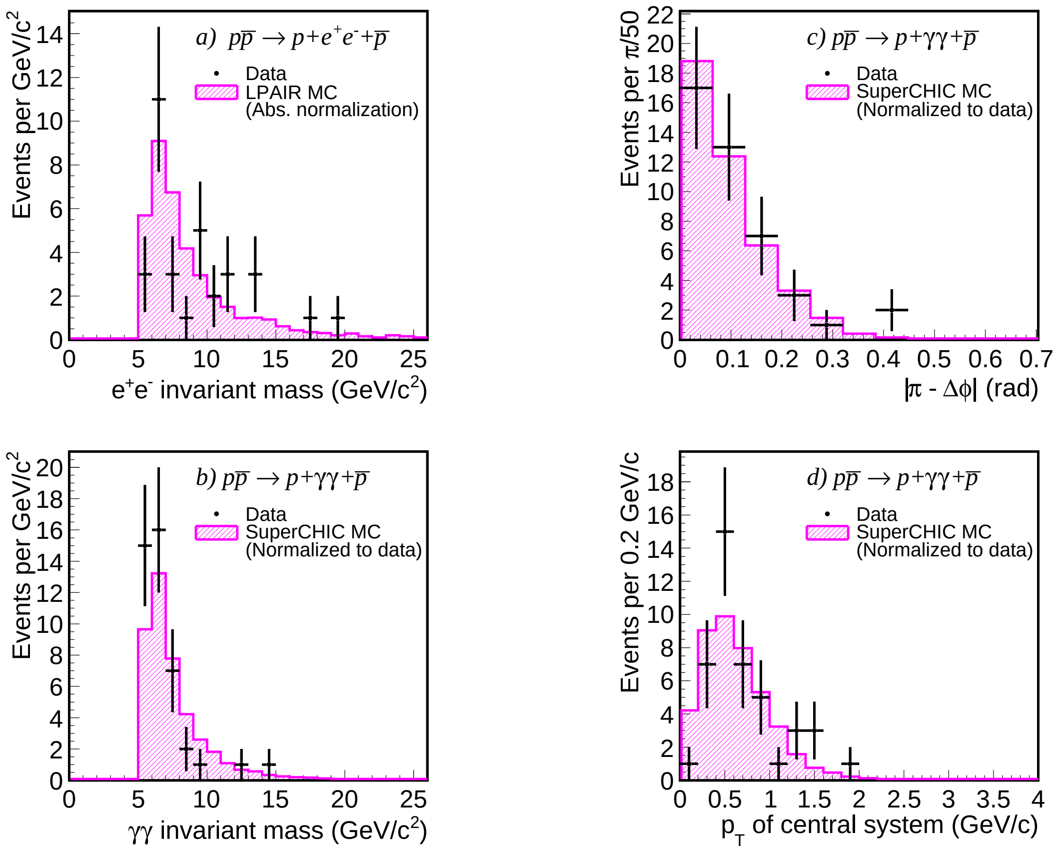

Figure 4: Exclusive candidate event distributions: (a) e^+e^- mass; (b) $\gamma\gamma$ mass; (c) $|\pi - \Delta\phi|$ of the two γ's; (d) p_T of the $\gamma\gamma$ system. Errors are statistical, MC predictions for $\gamma\gamma$ (LPAIR [17]) are normalized to data, and QED prediction for e^+e^- is normalized to the delivered luminosity and efficiencies.

Integrated luminosity $\mathcal{L}_{\text{int}}$	$1.11 \pm 0.07 \text{fb}^{-1}$
Exclusive efficiency	0.068 ± 0.004 (syst)
Exclusive $\gamma\gamma$	
Events	43
Photon-pair efficiency	0.40 ± 0.02 (stat) ± 0.03 (syst)
Probability of no conversions	0.57 ± 0.06 (syst)
$\pi^0\pi^0$ b/g (events)	0.0, < 15 (95% C.L.)
Dissociation b/g (events)	0.14 ± 0.14 (syst)
Exclusive e^+e^-	
Events	34
Electron-pair efficiency	0.33 ± 0.01 (stat) ± 0.02 (syst)
Probability of no radiation	0.42 ± 0.08 (syst)
Dissociation b/g (events)	3.8 ± 0.4 (stat) ± 0.9 (syst)

Table 1: Summary of parameters used for the measurement of the exclusive photon-pair cross section for $E_T(\gamma) > 2.5$ GeV and $\eta(\gamma) < 1.0$. Values for the e^+e^- control study are also given. Note that b/g stands for background.

In the analysis focused on the measurement of the diffractive structure function in *dijet* production, we have been working to extend the measurement of the t-distribution to $t \sim -4$ GeV ^{2} to search for a diffraction minimum; and in the *gaps between jets* analysis, we are re-evaluating the result in a format more suitable for comparison with theoretical predictions.

As of the writing of the proceedins paper, the dijet analysis has been completed and a paper will be sumbitted to PRD this Spring.

We also briefly summarize results on exclusive production, pointing to their relevance to calibrating theoretical models used to predict exclusive *Higgs* production at the LHC, and we report the first observation of exclusive $\gamma\gamma$ production in hadron-hadron collisions.

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