Recent Results on Diffraction from CDF

Christina Mesropian

The Rockefeller University
1230 York Avenue, New York NY - USA

We report recent results on diffraction and exclusive production obtained by the CDF collaboration in $p\bar{p}$ collisions at the Fermilab Tevatron collider at $\sqrt{s}$=1.96 TeV. A measurement of the Q^2 and t dependence of the diffractive structure function extracted from diffractive dijet production in the range of $10^2 < Q^2 < 10^4$ GeV^2 and $|t| < 1$ GeV^2 is presented. Results are also presented for exclusive e^+e^-, $\gamma\gamma$, and dijet production.

1 Introduction

The diffractive process in hadron-hadron colliders can be defined as a reaction in which the leading nucleon remains intact, and/or a large, non-exponentially suppressed, rapidity gap (region devoid of particles) is present. In the framework of Regge theory diffractive reactions are characterized by the exchange of a *pomeron*, a hypothetical object with vacuum quantum numbers. Diffractive reactions involving hard processes, such as production of jets, allow to study the nature of the exchanged object, the *pomeron*, in the framework of perturbative QCD (pQCD).

The CDF collaboration at the Fermilab $p\bar{p}$ collider investigated various diffractive reactions at three center of mass energies, $\sqrt{s}$=1800 GeV (Run I), $\sqrt{s}$=630 GeV (Run IC), and $\sqrt{s}$=1960 GeV (Run II). In this paper we present the latest results from Run II studies in diffractive dijet production and central exclusive e^+e^-, $\gamma\gamma$, and dijet production.

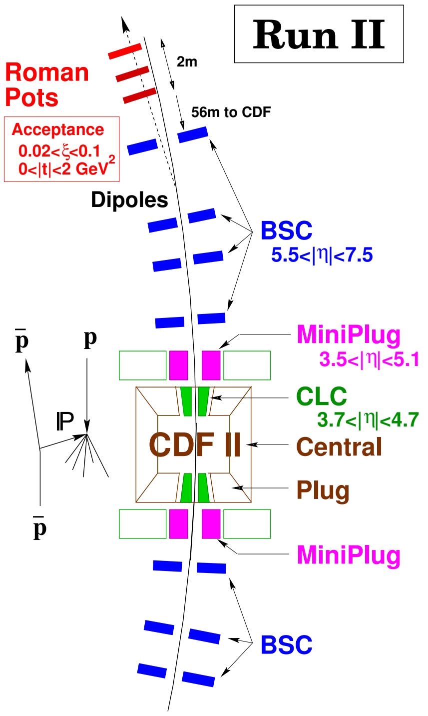

Figure 1: Layout of CDF Run II forward detectors along the beam-pipe (not to scale).

2 CDF Forward Detectors

Since the identification of diffractive events requires either tagging of the leading particle or observation of a rapidity gap, the forward detectors are very important for the implementation of a diffractive program. The schematic layout of the CDF detectors in Run II is presented in Fig. 1. The Forward Detectors include the Roman Pot fiber tracker Spectrometer (RPS) to detect leading anti-protons; the Beam Shower Counters (BSCs) [2], covering the pseudorapidity range $5.5 < |\eta| < 7.5$, to detect particles from the interaction point traveling in either direction along the beam-pipe, used to select diffractive events by identifying forward rapidity gaps, thus reducing non-diffractive background on the trigger level; the MiniPlug calorimeters (MP) [3], designed to measure energy and lateral position of both electromagnetic and hadronic showers in the pseudorapidity region of $3.5 < |\eta| < 5.1$. The ability to measure the event energy flow in the very forward rapidity region is extremely valuable for identification of diffractive events in the high luminosity environment of Run II.

3 Diffractive Dijet Production

The data sample for the study of the Single Diffractive (SD) dijet production is collected by triggering on a leading anti-proton in RPS in combination with at least one jet in the event. By comparing two samples of dijet events, diffractive and non-diffractive, the diffractive structure function is extracted. This study extends our previous results from Run I by studying the Q^2 dependence of the diffractive structure function, where Q^2 is defined as an average value of the squared mean dijet E_T. In the range of $100 < Q^2 < 10000$ GeV^2 no significant Q^2 dependence is observed, which indicates that the QCD evolution of the *pomeron* is similar to that of the proton. CDF also studied the Q^2 dependence of the four-momentum transfer squared, t, distributions in soft and hard single diffractive processes. Fig. 2 shows t distributions for different Q^2 values. The slope of the distribution at $|\ t\ |$=0 (GeV/c^2) does not show any dependence on Q^2.

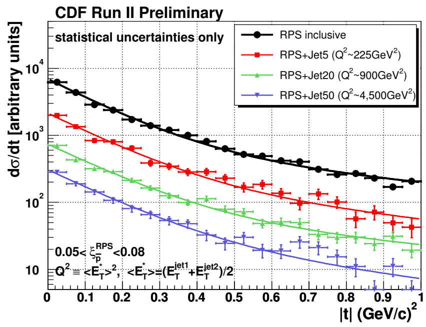

Figure 2: t distributions in soft and hard SD events for different Q^2 ranges. Data sample of 128 pb^{-1}.

4 Exclusive Dijet Production

Central exclusive production became a very interesting topic of study at CDF. In leading order QCD such exclusive processes can occur through the exchange of a color-singlet two gluon system between the nucleons, leaving large rapidity gaps in the forward regions. One of the gluons participates in a hard interaction, and an additional screening gluon is exchanged to cancel the color of the interacting gluons, and allowing the leading hadrons to stay intact. This is also a special case of dijet/diphoton production in Double *Pomeron* Exchange (DPE), $p+\bar{p} \to p+X+\bar{p}$. Central exclusive production is generally suppressed by the Sudakov form factor, however, it is a potentially useful channel to search for the light Standard Model Higgs boson, predominantly decaying to $b\bar{b}$, at the LHC, since exclusive $b\bar{b}$ production is expected to be significantly suppressed by a helicity selection ($J_Z = 0$) rule. Although the cross section for exclusive Higgs production is too small to be observed at the Tevatron, several processes mediated by the same mechanism but with the higher production rates can be studied to check theoretical predictions.

A data sample of 313 pb^{-1} for exclusive dijet production was collected with a dedicated trigger requiring a BSC gap on the proton side in the addition to a leading anti-proton in the RPS and at least one calorimeter tower with $E_T > 5$ GeV. The events in this data sample

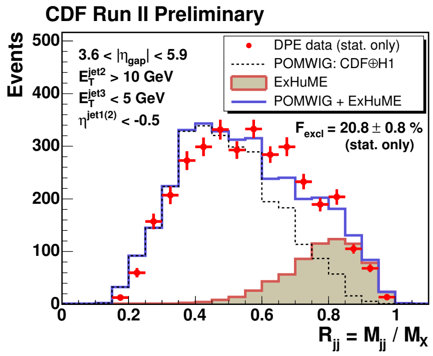

Figure 3: Dijet mass fraction R_{jj} in data (crosses) and best fit (solid line) obtained using inclusive (dashed line) and exclusive ExHuME (shaded area) MC predictions.

tower with $E_T > 5$ GeV. The events in this data sample also passed the offline requirement of an additional gap in MP on the proton-side. The observable sensitive to the amount of energy concentrated in dijet, is the dijet mass fraction $R_{jj} = M_{jj}/M_X$, where M_{jj} is the invariant mass of the two highest E_T jets, and M_X is the mass of the whole system with the exception of the leading particles. R_{jj} of exclusive dijets is expected to peak around $R_{jj} \sim 0.8$ and have a long tail toward low values due to hadronization of partons causing energy spills from the jet cones and gluon radiation in initial and final states. The exclusive signal is extracted by comparing the dijet data with inclusive DPE Monte Carlo predictions, using the POMWIG [4] event generator and detector simulation, and by looking for an excess at high R_{jj} values. The comparison of the R_{jj} distributions shows a clear excess of data at high R_{jj}. This excess is compared to different exclusive dijet production models [5, 6] implemented in ExHuME [7] and DPEMC [8] MC simulations. Fig. 3 shows the R_{jj} distribution for the data and the best fit to the data shape obtained from the inclusive POMWIG and exclusive ExHuME predictions. As can be seen from this plot, the data excess at high R_{jj} can be well described by exclusive dijet production. From the MC fits to the data, we measure the cross section of exclusive dijet production as a function of the minimum second jet E_T, see Fig. 4(left). The data prefer the ExHuME MC and pQCD calculations at LO (KMR) [5].

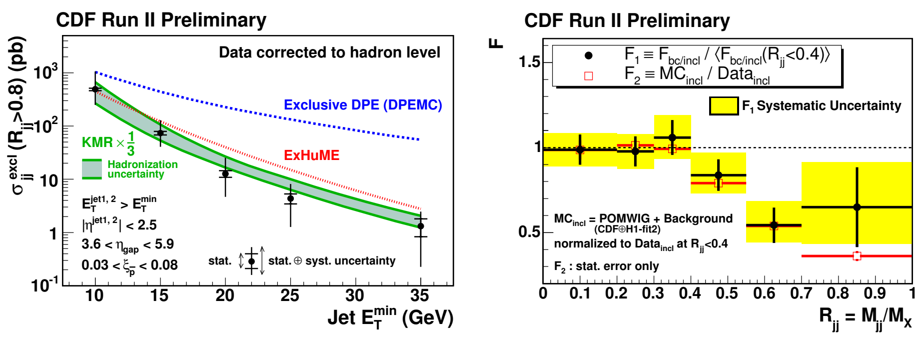

Figure 4: (left) Measured exclusive dijet cross section for $R_{jj} > 0.8$ as a function of the minimum second jet E_T. The dashed (dotted) lines show the ExHuME (DPEMC) Monte Carlo predictions, the shaded band indicates the KMR calculations at LO parton level, scaled down by a factor 3; (right) Values of F_1 (full points) and F_2 (open squares) as a function of R_{jj}, where F_1 is the ratio of heavy flavor jets to all inclusive jets, normalized to the weighted average value in the region of $R_{jj} > 0.4$, and F_2 is the ratio of the POMWIG MC to the inclusive DPE dijet data. The systematic error is indicated by the shaded band.

Exclusive dijet production at LO is dominated by $gg \to gg$, while contributions from $gg \to q\bar{q}$ are strongly suppressed [5] by the helicity selection. Confirming this suppression will provide additional evidence to support the results obtained from MC based extraction of the exclusive dijet signal. We measure the ratio F_1 of heavy flavor quark jets to all jets as a function of R_{jj} using a data sample of 200 pb^{-1}, triggered by the presence of an anti-proton in the RPS, a forward gap on the proton side, dijets in the central region and at least one displaced vertex track with p_T >2 GeV/c. The last requirement enhances the heavy flavor content of the sample. The results, see Fig. 4(right), show the normalized ratio of heavy flavor jets to all jets as a function of R_{jj}. The trend of the F_1 ratio decreasing toward high R_{jj} values is compared with MC based results presented as F_2, where F_2 is the ratio of the inclusive MC predicted events, which are normalized to the data at R_{jj} >0.4. The two results are consistent with each other.

5 Exclusive e^+e^- and $\gamma\gamma$ Production

Here we report on the observation of exclusive e^+e^- production at hadron colliders. The data sample used for this study, corresponds to an integrated luminosity of 532 pb^{-1}, and was collected with a dedicated trigger requiring the absence of any particle signatures in the detector, except for e^+ or e^- candidates, each with transverse energy $E_T > 5$ GeV and pseudorapidity $|\eta| < 2$. With these criteria 16 events were observed compared to a background expectation of 1.9 ± 0.3 events. These events are consistent in cross section and properties with the Quantum Electro-Dynamics process $p\bar{p} \to p + e^+e^- + \bar{p}$ through two photon exchange. The measured cross section is $1.6^{+0.5}_{-0.3}(\mathrm{stat}) \pm 0.3(\mathrm{syst})$ pb, which agrees well with the theoretical prediction of 1.71 ± 0.001 pb. This agreement is provides evidence that the cuts we make to define the central exclusive processes are correct.

The search for exclusive diphoton events, $p\bar{p} \to p+\gamma\gamma+\bar{p}$ demands the same event criteria as the exclusive e^+e^- search, and is using the same date sample. The photon candidates are defined as electromagnetic clusters with $E_T > 5$ GeV and $|\eta| < 1$ and no tracks pointing to them. Three events pass these criteria. Backgrounds to $\gamma\gamma$ production can arise from exclusive pair production of neutral mesons, ($\pi^0\pi^0$ and $\eta\eta$). These processes cannot be unambiguously distinguished from $\gamma\gamma$ production on an event by event basis. Therefore, a 95% C.L. upper limit on the exclusive $\gamma\gamma$ production cross section of 410 fb is reported, approximately a factor of 10 higher than the theoretical prediction [9].

References

[1] Slides: `http://indico.cern.ch/contributionDisplay.py?contribId=103&sessionId=7&confId=9499`

[2] M. Gallinaro, Procs. *"CDF forward detectors and diffractive structure functions at the Fermilab Tevatron* (2004) arXiv:hep-ph/0407255.

[3] K. Goulianos *et al.*, Nucl. Instrum. Methods A **518** (2004) 24 [arXiv:physics/0310156].

[4] B.E. Cox and J.R. Forshaw, Comput. Phys. Commun. **144** (2002) 104 [arXiv:hep-ph/0010303].

[5] V.A. Khoze, A.D. Martin, and M.G. Ryskin, Eur. Phys. J. C **34** (2004) 327 [arXiv:hep-ph/0401078]; A.B. Kaidalov *et al.*, Eur. Phys. J. C **33** (2004) 261 [arXiv:hep-ph/0311023].

[6] A. Bialas and P.V. Landshoff, Phys. Lett. B **256** (1991) 540.

[7] J. Monk and A. Pilkington, Comput. Phys. Commun. **175** (2006) 232 [arXiv:hep-ph/0502077].

[8] M. Boonekamp and T. Kucs, Comput. Phys. Commun. **167** (2005) 217 [arXiv:hep-ph/0312273].

[9] V.A. Khoze *et al.*, Eur. Phys. J. C **38** (2005) 475 [arXiv:hep-ph/0409037].