Diffractive Production of Jets and Vector Bosons at the Tevatron

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Abstract
Recent results on diffractive dijet and vector boson production and exclusive dijet production from the Collider Detector at Fermilab (CDF) experiment are presented.

1 Introduction

CDF Collaboration performed various measurements on inclusive diffraction and exclusive production using $p\bar{p}$ collision data from the Fermilab Tevatron collider collected in Run I (1992–1996) and Run II (2001–). One of the important results from the Run I studies is the observation of the QCD factorization breakdown in hard single diffractive (SD) processes [1–5]; the rate of hard SD processes, in which one of the incoming proton or antiproton is scattered quasielastically and a hard partonic scattering (such as dijet production) occurs, was found to be lower than theoretical predictions by a factor of $\mathcal{O}(10)$. In [4, 5], the diffractive structure function $F^D(Q^2, x, \xi, t)$ was measured using SD dijet events and found to be suppressed with respect to the one measured in ep collisions at HERA by $\mathcal{O}(10)$, where ξ is the fractional momentum loss of the diffracted (anti)proton and t is the four-momentum transfer squared. This suppression is similar to the one observed in soft diffractive processes with respect to the Regge theory predictions, and is generally attributed to additional color exchanges in the same $p\bar{p}$ collision which spoil the diffractive rapidity gap [6–8].

Another important result from the Run I diffractive studies is from a study on F^D using double pomeron exchange (DPE) dijet events [9], $p + \bar{p} \rightarrow p + jjX + \bar{p}$. The diffractive structure function F^D measured in DPE dijet events was found to be approximately equal to expectations from HERA. This observation is consistent with the expectations from, *e.g.*, the gap probability renormalization model [8]. The main goal of the Run II diffractive studies is to study the characteristics of diffractive events more in detail with help of the upgraded detectors and larger statistics in order to deepen our understanding of diffractive exchange and the QCD nature of the pomeron.

In addition, there has been an increased interest in studies on *exclusive* events, mainly due to a possibility of finding the Higgs boson in exclusive events at the Large Hadron Collider (LHC). Exclusive events in pp ($p\bar{p}$) collisions contain nothing but the leading proton and (anti)proton and the object(s) of interest such as dijet, diphoton, dielectron, and most importantly the Higgs boson, as shown in Fig. 1. We do not expect to observe the exclusive Higgs production at the Tevatron; however, we can study other exclusive processes that can provide a calibration for theoretical predictions of exclusive Higgs production at the LHC.

The recent Run II studies on hard diffraction and exclusive dijet production are presented below. Studies on exclusive dilepton, diphoton, and charmonium states are presented in [10].

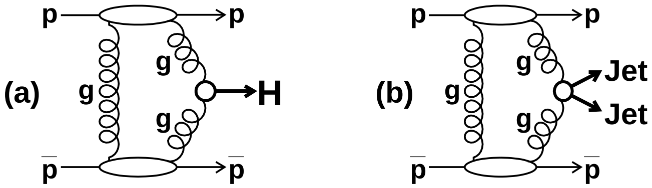

Fig. 1: Diagrams for exclusive production of (left) Higgs and (right) dijet production.

2 Diffractive Dijet Production

The diffractive structure function F^D was studied using Run II SD dijet data using a similar way to that used in Run I studies [4, 5], *i.e.*, by taking a ratio of SD to non-diffractive (ND) dijet rates as a function of x, which is in leading-order QCD approximately equal to the ratio of diffractive to ND structure function.

One of the major challenges in Run II diffractive studies is the rejection of multiple $p\bar{p}$ interaction events, in which diffractive rapidity gaps are spoiled by overlapping $p\bar{p}$ interactions (overlaps) and the hard scattering cannot be associated with the diffracted leading (anti)proton accurately. This rejection was done by reconstructing ξ from the calorimeter towers by $\xi^{cal} = \sum_{\text{towers}} E_T^i \eta^i / \sqrt{s}$; $\xi^{cal} \sim \xi^{RP} < 0.1$ in SD events without overlaps, while $\xi^{cal} > 0.1$ in events with overlaps, where ξ^{RP} refers to the ξ value reconstructed based on the information from the Roman pot (RP) detector which detects the diffracted antiproton.

The high statistics Run II data allowed the SD/ND dijet ratio measurement in Q^2 up to 10^4 GeV^2, and no appreciable Q^2 dependence was observed. Also in the Run II study, the t distribution in SD dijet events was measured up to $Q^2 \sim 4500$ GeV^2, and no dependence of the shape of the t distribution on Q^2 was found.

3 Diffractive W/Z Production

CDF studied diffractive W/Z production using the Run II data recently. The study of diffractive W/Z production is important to determine the quark content of the pomeron; the production by gluons is suppressed by a factor of α_s and it can also be identified by an additional jet.

In Run I, CDF studied diffractive W production by identifying diffractive events using rapidity gaps [2], and found the fraction of W events which are diffractive to be $[1.15 \pm 0.51(\text{stat}) \pm 0.20(\text{syst})]$%. In addition, the gluon content of the pomeron was determined to be $[54^{+16}_{-14}]$% in combination with results on diffractive dijet and b-quark production [1, 3]. D0 made measurements on diffractive W production and also Z production [11], and reported the fractions of W and Z events with a rapidity gap to be $[0.89^{+0.19}_{-0.17}]$% and $[1.44^{+0.61}_{-0.52}]$% [11], respectively. These fractions are not corrected for the gap acceptance correction A_{gap}, *i.e.*, the fraction for diffractive events that satisfy the experimental definitions of the rapidity gaps. The estimate on A_{gap} ranges from 0.2 to 1.0 depending on the diffractive models considered.

In the new CDF Run II measurement, the RP detector is used to detect the leading antiproton in diffractive W/Z events. The RP detector provides an accurate ξ measurement, and also eliminates the ambiguity associated with A_{gap}. As in diffractive dijet production, ξ can be reconstructed from both the energy depositions in the calorimeters (ξ^{cal}) and hits in the RP detector (ξ^{RP}). The ξ^{cal} distributions in W/Z events with a leading antiproton are shown in Fig. 2. The diffractive W and Z candidate events without overlaps are selected by requiring $\xi^{cal} < \xi^{RP}$ and $\xi^{cal} < 0.1$, respectively.

In diffractive $W \rightarrow l\nu$ events without overlaps, the difference between ξ^{cal} and ξ^{RP} is related to missing E_T ($\not{E}_T$) and η_ν as $\xi^{RP} - \xi^{cal} = \frac{\not{E}_T}{\sqrt{s}} e^{-\eta_\nu}$, which allows to determine the neutrino kinematics, and consequently the W kinematics. The reconstructed W mass is shown in Fig. 2.

The fractions of W and Z events which are diffractive are measured to be $[0.97 \pm 0.05(\mathrm{stat}) \pm 0.11(\mathrm{syst})]\%$ and $[0.85 \pm 0.20(\mathrm{stat}) \pm 0.11(\mathrm{syst})]\%$ in $0.03 < \xi < 0.10$ and $|t| < 1$ GeV/c. The measured diffractive W fraction is consistent with the Run I CDF result when corrected to the ξ and t range in this measurement.

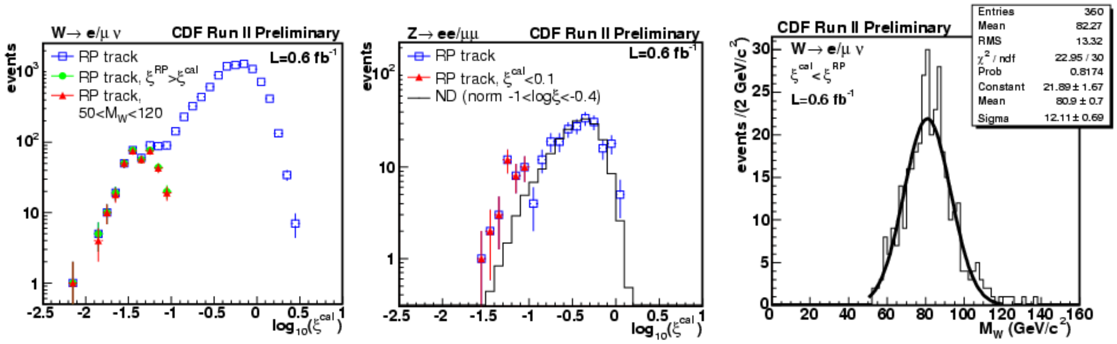

Fig. 2: Calorimeter distribution in W (left) and Z (center) events with a Roman-pot track. (right) Reconstructed W mass in diffractive W candidate events.

4 Rapidity Gaps between Very Forward Jets

The double diffractive (DD) dissociation refers to a class events in which two colliding particles dissociate into clusters of particles (including jets in the case of hard DD events) with a large rapidity gap between them. Measurements on DD events were made by CDF [12–15] and D0 [16] in Run I in $p\bar{p}$ collisions at $\sqrt{s} = 1800$ and 630 GeV. Recently, CDF reported new preliminary results on events with a rapidity gap between forward jets from the Run II data. In CDF II, the miniplug (MP) calorimeters covering $3.5 \lesssim |\eta| \lesssim 5.1$ allow a study of very forward jets with a larger rapidity gap between them than in Run I. Figure 3 (left) shows the kinematic characteristics of the leading two jets in an event both in MPs with $E_T > 2$ GeV and $\eta_1\eta_2 < 0$. Since these jets are in a very forward region, they have high energies despite their relatively low E_T's.

The dependence of the gap fraction $R_{gap} = N_{gap}/N_{all}$ was studied as a function of $\Delta\eta = \eta_{max} - \eta_{min}$ in these MP dijet events in a similar way as in [15]. $\eta_{max(min)}$ is the pseudorapidity of the tower closest to $\eta = 0$ in the proton(antiproton) outgoing direction. The comparison of R_{gap} as a function of $\Delta\eta$ in min-bias events and MP dijet events with $E_T^{jet1,2} > 2$ GeV and $E_T^{jet1,2} > 4$ GeV is shown in Fig. 3. A rapidity gap in $|\eta| < 1.1$ (CCAL gap) is always required.

The event fraction with a central rapidity gap is about 10% in soft events, while it is about 1% in dijet events, which is consistent with the results from Run I [12–16]. It is interesting to note that the shape of the R_{gap} distribution is similar between the soft and hard events. A study on the azimuthal decorrelation between the two leading jets in these forward dijet events is underway in order to investigate the effect of the Muller-Navelet jets [17].

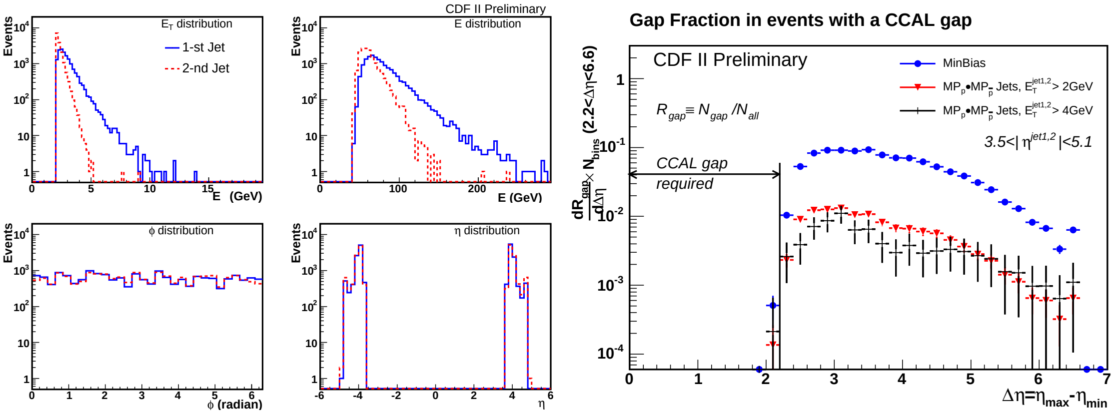

Fig. 3: (left) Kinematic distributions for the two leading jets in an event, both in the MP calorimeters. (right) The gap fraction R_{gap} vs. $\Delta\eta$ for min-bias and MP dijet events of $E_T^{jet1,2} > 2$ GeV and $E_T^{jet1,2} > 4$ GeV.

5 Exclusive Dijet Production

The exclusive dijet production was first searched for by CDF in Run I data, and the limit of $\sigma_{excl} < 3.7$ nb (95% CL) was placed [9]. In the Run II search [18], first a sample of inclusive DPE dijet events is selected. The exclusive signal is then searched for examining dijet mass fraction R_{jj} which is the ratio of dijet mass M_{jj} to system mass M_X. This observable should be sensitive to how much the event energy is concentrated in the dijet. The R_{jj} of exclusive dijet events is expected to be peaked around $R_{jj} \sim 0.8$ and have a long tail toward lower values due to hadronization effects causing energy leak from jet cones and also the presence of gluon radiations in the initial and final states. Figure 4 shows R_{jj} distributions for data, inclusive DPE dijet Monte Carlo (MC) events from the POMWIG Monte Carlo with various sets of pomeron structure functions, and the non-DPE events. The data clearly show an excess at high R_{jj} over the non-DPE background events and inclusive DPE predictions. The shape of the excess is well described by exclusive dijet MC based on two models (ExHuME [19], DPEMC [20]); however, the measured cross section disfavors DPEMC. Predictions by Khoze *et al.* [21] are found to be consistent with data within its factor of 3 uncertainty.

6 Summary

The long-standing diffractive program at CDF has substantially improved our understanding of diffractive processes. In Run II, the measurements on diffractive dijets and the diffractive structure function are extended to $Q^2 \sim 10^4$ GeV^2, and the measurement of diffractive W/Z production was made using the RP detector. The study on events with a rapidity-gap between forward

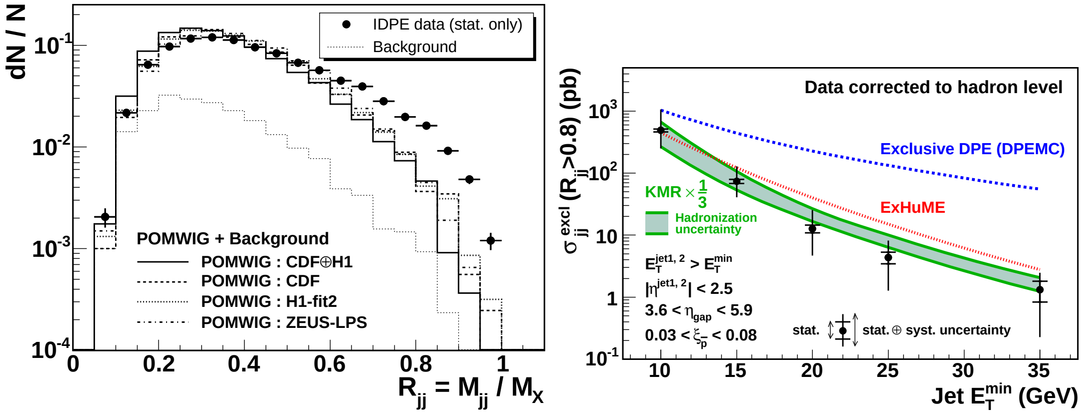

Fig. 4: (left) Dijet mass fraction R_{jj} in inclusive DPE dijet data (left). An excess over predictions at large R_{jj} is observed as a signal of exclusive dijet production. (right) The measured cross section for exclusive dijet production compared to predictions.

jets is underway. In addition, CDF reported a first observation of exclusive dijet production which provides a valuable calibration for the predictions on exclusive Higgs production at the LHC.

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