Central Exclusive Production in $p\bar{p}$ Collisions at CDF II

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We report central exclusive production results studied at the Run II Collider Detector at Fermilab with focus on our recently published paper on the first observation of exclusive $\gamma\gamma$ production in $p\bar{p}$ collisions at $\sqrt{s}$ =1.96 TeV at the Tevatron. In particular, starting from earlier studies by the CDF collaboration, we discuss exclusive dijet, dilepton, Z, J/Ψ and χ_c productions and finally our recent observation of exclusive diphoton production. Whereas the lepton pairs are purely QED produced, the J/Ψ and the Z boson are produced by photo-production, mediated by photon-pomeron exchange ($\gamma + I\!P$). The double pomeron exchange producing the exclusive dijet, charmonium and diphotons via quark-loop is of great interest looking towards the possibilities of finding an exclusive Higgs at the Large Hadron Collider (if it exists). The production mechanism for an exclusive Higgs is similar via a heavy quark-loop with no other particles produced.

1 Introduction

At the Run II Collider Detector at Fermilab (CDF II) central exclusive production (CEP) has been studied extensively with great success. CEP belongs to the class of diffractive processes here with a centrally produced system X and both proton and antiproton staying intact after the collision. This can happen via a strong exchange of a colorless object (Pomeron $I\!P$, see Fig:1 (left))[1] or a purely QED exchange of virtual photons or a mixture of both (photoproduction). Large observable pseudorapidity gaps on both sides are characteristic for such processes.

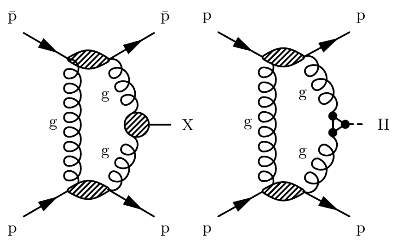

Figure 1: Leading order diagrams for (left) CEP via double pomeron exchange and (right) CEP of a Higgs boson in $p\bar{p}$ collisions.

At CDF II we are equipped with forward detectors to study CEP. In addition to the central, azimuthal and forward-backward symmetric, multipurpose detector with its excellent tracking system and projective calorimetry, we find: the Miniplug, a liquid scintillator calorimeter covering a pseudorapidity region of $3.6 < |\eta| < 5.2$; beam shower counter stations (BSC) from $5.4 < |\eta| < 7.4$; and Roman pot spectrometers (RPS) at 57 m from the interaction point on the antiproton side, accepting momentum fraction losses of $0.02 < \xi < 0.1$.

In addition to the general interest in CEP a motivation boost comes from the possibility of

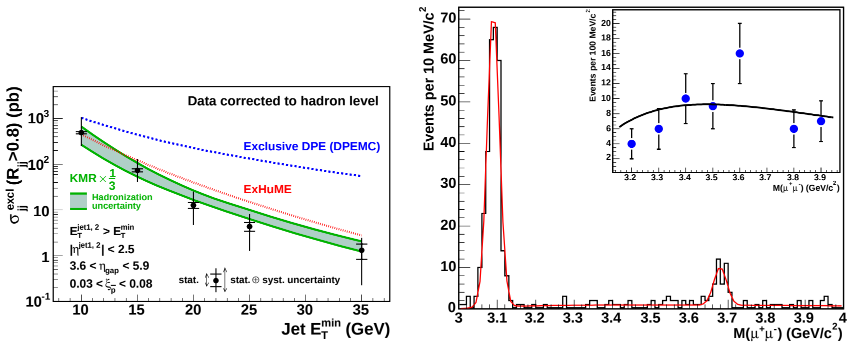

Figure 2: Exclusive dijet cross sections compared to Monte Carlo and LO analytical predictions (left). Invariant exclusive dimuon mass distribution with two Gaussian fits of the J/Ψ and $\Psi(2s)$ peak (right). The inlay graphic shows the exclusive dimuon QED continuum with the $\Psi(2s)$ peak excluded.

observing a standard model Higgs boson at LHC in the same way (see Fig:1 (right)) with direct access to its quantum numbers. Although not possible at Tevatron, several similar processes can and have been studied at CDF II to test and calibrate theoretical predictions. In particular we observed QED production of e^+e^- and $\mu^+\mu^-$, searched for Photoproduction of the Z boson and J/Ψ concluding in an observation of the latter, and observed double pomeron exchange (DPE) processes such as exclusive dijets, charmonium, χ_c and our most recent, the CEP of diphotons, observed for the first time in hadron-hadron collisions.

2 Review of earlier results

2.1 Exclusive dijet production

Exclusive dijets have been observed in CDF II data [2]. Exclusive dijets have been extracted from data of 310 pb^{-1} integrated luminosity using the ratio of the dijet mass to the total mass $R_{jj} = M_{jj}/M_x$ of the final state. At high $R_{jj} > 0.8$ exclusive dijets can be separated from inclusive diffractive dijets. Protons tagged by the RPS ensure a good separation of diffractive and non-diffractive events. The cross sections measured (see Fig. 2 left) clearly favor the KMR prediction [3].

2.2 Exclusive e^+e^- production

Introducing a special trigger requiring two EM showers in the calorimeter and a void of particles in the forward using BSC-1, we observed for the first time QED production of exclusive e^+e^- via virtual radiated photons in data of 532 pb^{-1} integrated luminosity in $p\bar{p}$ collisions [4]. A special method to ensure exclusiveness is used. The calorimetry including the forward detectors are divided into sections. For each section the noise level is defined. After subtracting the signal each event is filtered for additional activity above noise within $|\eta| < 7.4$. We found 16 exclusive e^+e^- candidates with $E_T > 5$ GeV and $|\eta| < 2$ The measured cross section of $\sigma = 1.6^{+0.5}_{-0.3}(\text{stat}) \pm 0.3(\text{syst})$ pb is in good agreement with theoretical predictions.

2.3 Exclusive charmonium and $\mu^+\mu^-$ production

In parallel we started to look at exclusive dimuon states [5]. With a special trigger for central muons and forward gaps we extracted 402 back to back $\mu^+\mu^-$ candidates with $M_{\mu\mu}$ between 3 and 4 GeV and $|\eta| < 0.6$ in $p\bar{p}$ collisions of 1.48 fb^{-1} integrated luminosity. The invariant mass distribution is shown in Fig. 2 on the right. Clearly seen are the J/Ψ and $\Psi(2s)$ peaks and the QED continuum in the inlay graphic. The first observations of the exclusive photoproduction of charmonium and the exclusive QED production of $\mu^+\mu^-$ in hadron-hadron collisions are also in good agreement with theoretical predictions. Allowing an additional photon in the final state we find an increase of 66 events in the J/Ψ compared to only one event in the $\Psi(2s)$ peak. This is clear evidence for exclusive χ_c production via DPE, decaying to J/Ψ plus photon.

2.4 Search for exclusive Z production

We did a search for exclusive photoproduction of the Z boson [6]. Due to its small cross section we did not expect to find this process at Tevatron. Any sign would have been an indication for beyond standard model physics. We set an upper limit on the production cross section. As a side product we measured exclusive high mass dilepton production ($40 < M_{ll} < 75$ GeV/c^2) that is in good agreement with theoretical predictions.

3 Exclusive $\gamma\gamma$ production

Our latest result is the first observation of exclusive $\gamma\gamma$ production in hadron-hadron collisions [8]. Similar to the exclusive Higgs (see Fig. 1 (left)), the diphoton system is produced via gluon-gluon fusion through a quark loop ($gg \to \gamma\gamma$). The other so-called *screening* gluon cancels the color-flow such that the (anti)proton stays intact and no soft hadronization occurs. In an earlier study in Run II we already found evidence for this process [7], but with only three candidate events. With an updated trigger with lower threshold for EM showers in the calorimeter and an forward gap-trigger we could record data of 1.11 fb^{-1} integrated luminosity. We selected events with exact two back to back EM object with $E_T > 2.5$ GeV in the central detector region of $|\eta| < 1.0$. No other activity above noise was allowed in the entire calorimetry including the forward detectors covering $|\eta| < 7.4$. First a subset of 34 events having exactly two charged particle tracks was extracted. Those events are consistent with exclusive e^+e^- and serve as a control channel to the diphoton study. Up to the tracking cut electrons and photons do not show any difference at the detector level. The number of exclusive e^+e^- events and the measured cross section is in perfect agreement with theoretical predictions and our earlier observation study [4]. A class of 43 events with no charged tracks are identified as exclusive $\gamma\gamma$ candidates. The invariant mass and $\Delta\phi$ distribution is shown in Fig. 3 (left, middle). Possible background contamination was discussed. Non negligible backgrounds has been identified as a small fraction of undetected proton dissociation (0.14 events) due to limited forward coverage and exclusive $\pi^0\pi^0$ production. The latter was be estimated using proportional wire

Table 1: Parameters for the exclusive $\gamma\gamma$ cross section ($E_T(\gamma) > 2.5$ GeV, $|\eta(\gamma)| < 1$).

$\gamma\gamma$ CEP	Value
Events	43
$\mathcal{L}_{\text{int}}$	1.11 ± 0.07fb^{-1}
$\varepsilon_{\text{exclusive}}$	0.068 ± 0.004 (syst)
$\varepsilon_{\text{photon-pair}}$	0.40 ± 0.02 (stat) ± 0.03 (syst)
$\varepsilon_{\text{no conversion}}$	0.57 ± 0.06 (syst)
$\pi^0\pi^0$ b/g	0.0, < 15 (95% C.L.) events
Dissoc. b/g	0.14 ± 0.14 (syst) events

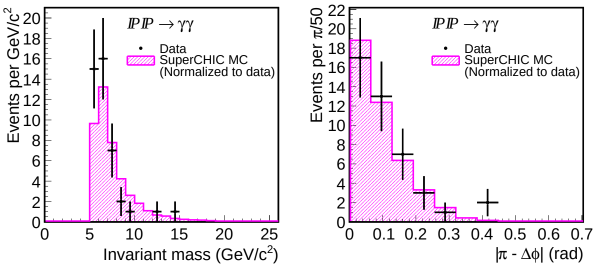

Figure 3: Two-photon candidates: invariant mass distribution (left), $|\pi - \Delta\phi|$ distribution (middle) compared to MC prediction. Distribution of reconstructed CES showers per events for data and $\gamma\gamma$ and $\pi^0\pi^0$ MC simulations (right).

chambers at shower maximum position in the EM calorimeter (CES). Neutral pions decay to two photons with a minimal opening angle of around 3° in our energy region. With the CES detector we reconstructed the number of showers to distinguish two close-by photons from π^0 decays with single signal photons. The most probable fraction of exclusive $\pi^0\pi^0$ was found to be zero with an upper limit of 15 events at 95%CL. Other possible backgrounds were found to be negligible. We measured a cross section of $\sigma(|\eta| < 1, \mathrm{E_T} > 2.5\mathrm{GeV}) = 2.48\,^{+0.40}_{-0.35}(\mathrm{stat})\,^{+0.40}_{-0.51}(\mathrm{syst})\,\mathrm{pb}$ using the parameters listed in Tab. 1. A comparison to KMR model predictions [9] using different parton density functions is shown in Fig. 4. We find a good agreement to the theoretical prediction and can create some constraint on the PDF's used.

4 Conclusions

CEP results of the CDF collaboration are presented. They certainly constraint theoretical predictions and help understanding non-perturbative soft QCD dynamics. Especially the exclusive $\gamma\gamma$ production is helpful as the cleanest DPE process. Recently we published successfully the exclusive $\gamma\gamma$ result as *first observation*. The Higgs boson produced by DPE, if it exists, could be found at the LHC. Our results help tuning and calibrating forward detectors and analysis tools at LHC.

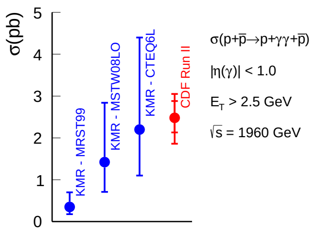

Figure 4: Comparison of measured to predicted cross sections.

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