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Electroweak Cross Sections, Asymmetries, and Diboson Results from the Tevatron

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Electroweak cross sections provide a great deal of vital information. Large inclusive cross sections (and asymmetries within those processes) are sensitive to parton distribution functions. Much smaller diboson cross sections are sensitive to trilinear coupling vertices, and are also common backgrounds to new physics searches. Measurements of these cross sections and asymmetries from the CDF and D0 experiments, with emphasis on the most recent results, will be presented.

1. Introduction

With the large amount of delivered luminosity at the Tevatron, the CDF and D0 experiments are gathering much larger samples of inclusive W and Z bosons than were available in the past. These samples can provide important information, both about parton distribution functions, and the underlying next-to-leading order (NLO) theory. At the same time, samples of diboson events of all cross sections, which probe the underlying gauge structure of the Standard Model, also become available. These proceedings summarize the most recent of the current Electroweak results from the Tevatron [1], and make use of 1-1.5 fb^{-1}.

2. Differential Z Boson Cross Sections

Inclusive Z boson cross sections are sensitive to the underlying parton distribution functions (PDFs). Differential cross sections, versus such variables as rapidity[1] and transverse momentum[2] can yield more detailed information about not only the PDFs, but also the theoretical predictions.

2.1. CDF Z Rapidity Measurement

The Z rapidity distribution is sensitive to the parton distribution functions at leading order[3]. At NLO however (and NNLO), gluons radiated off of the initial state quarks are included in the production process, which also influence the rapidity of the produced γ^*/Z. By measuring this differential cross section, one gains information about both of these effects. The CDF experiment has measured the γ^*/Z rapidity distribution (in the invariant mass range of $66 < M_{\ell\ell} <$116 GeV) using 1.1 fb^{-1} of data. The final unfolded distribution is shown in Figure 1. The distribution is found to be most consistent with the NNLO calculation (utilizing CTEQ6.1M parton distribution functions).

2.2. D0 Z p_T Measurement

The Z p_T distribution is a marriage of perturbation theory at large boson recoil momentum, and soft gluon resummation at low recoil momentum. The measured Z boson p_T distribution must be composed of both regimes, and thus serves as a test of both. Further, precision measurements such as the W boson mass and width, are dependent on the underlying W transverse mometum

[1]Rapidity is defined as $y = \frac{(E+p_z)}{(E-p_z)}$, where the z-axis is aligned with the proton direction.

[2]Transverse momentum is the momentum component perpendicular to the beam axis.

[3]This is conceptually simple: parton one with momentum fraction x_1 collides with parton two with momentum fraction x_2, which together influence the resultant γ^*/Z boson rapidity distribution.

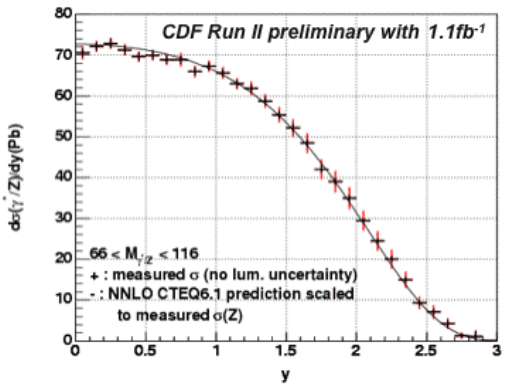

Figure 1. Measured γ^*/Z rapidity distribution from CDF, with NNLO theory curve.

distribution. Since similar processes give transverse momentum to the Z and the W, this measurment is important for these other precision measurements. The D0 experiment has measured the Z boson p_T spectrum. The final unfolded spectrum is shown in Figure 2.

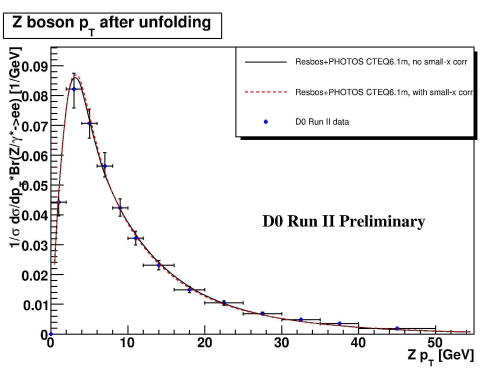

Figure 2. Measured Z boson transverse momentum distribution from D0, with RESBOS+PHOTOS theory curve.

3. Diboson Results

Diboson production, as the name implies, is the search for processes which produce pairs of vector bosons in the final state. In some cases, such as $W\gamma$, there is a trilinear vector boson vertex (i.e. a vertex at which three vector bosons are present). In the Standard Model these vertices are required. In other cases, these vertices are expressly forbidden at leading order, such as $Z\gamma$. Any deviation from the Standard Model prediction is a sign of new physics at work. No mechanism within the Standard Model exists for changing these values, and thus for studying other coupling models, a parametrized Lagrangian is used. In this parametrized Lagrangian, the most general set of couplings is written down, with arbitrary strengths, so that different models may be compared with data distributions.

3.1. Wγ

The $W\gamma$ process has the highest cross section of the Standard Model diboson processes. It also contains the trilinear vector boson vertex at leading order. The three (s-, t-, and u-diagrams) in which the photon is in turn radiated off of the initial state quarks, or at the trilinear vertex, interfere destructively, and the Standard Model is the point of minimum cross section. Thus any change in the coupling strength causes an increase in cross section, which is especially visible at high photon transverse energy. Using central photons, in the muon channel, with 1 fb^{-1} of data, the CDF experiment has measured the $W\gamma$ cross section, and the photon E_T spectrum (shown in Figure 3). The measured cross section of $19.11\pm1.04_{(stat.)}\pm2.40_{(syst.)}\pm1.11_{(lumi.)}$ pb is in good agreement with the Standard Model value of 19.3±1.4 pb. Using both central and forward photons, the D0 experiment further attempts to make a measurement of the charge signed rapidity different. Due to the underlying gauge nature of the Standard Model, an angular zero exists within the center of momentum frame of the collision, which correlates to the charge signed photon-lepton rapidity difference. Using 0.9 fb^-1 of data, the charge signed rapidity difference from D0 is shown in Figure 4.

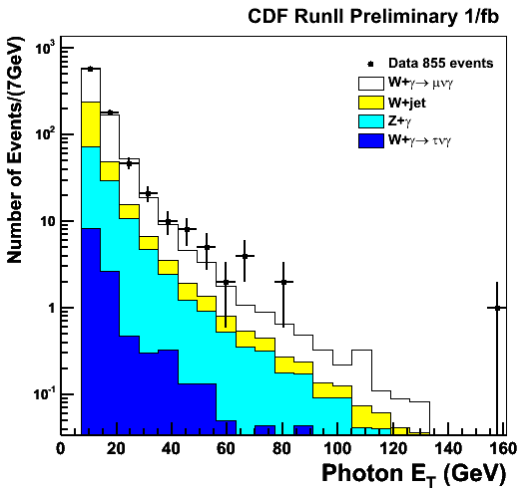

Figure 3. Measured $W\gamma$ E_T spectrum from CDF. No significant deviation is observed over the Standard Model expectation.

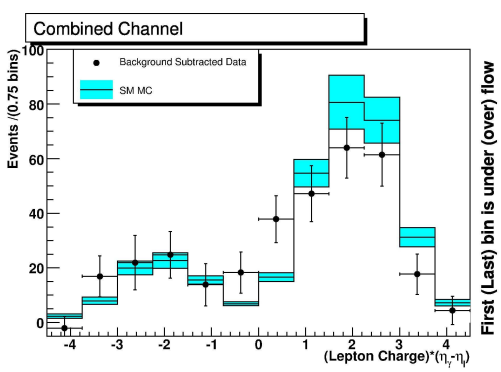

Figure 4. Measured $W\gamma$ charge signed rapidity difference from D0 (electron and muon channels combined). The dip between two peaks is indicative of the predicted destructive interference.

3.2. Zγ

The $Z\gamma$ process does not contain a trilinear vector boson vertex. In the Standard Model (at leading order), the photon may only be radiated off of one of the initial state quarks (Initial State Radiation (ISR)), or one of the final state leptons (Final State Radiation (FSR)). The CDF experiment has measured the $Z\gamma$ cross section to be $4.9\pm0.3_{(stat.)}\pm0.3_{(syst.)}\pm0.3_{(lumi.)}$ pb (using 1.1 fb^{-1}), in comparison with the Standard Model prediction of 4.7±0.4. The plotted dilepton mass versus the three body dilepton+photon mass is shown in Figure 5, in which one can see both the FSR and ISR components, along with the semi-diagonal band of γ^* events. The D0 experiment has also measured the $Z\gamma$

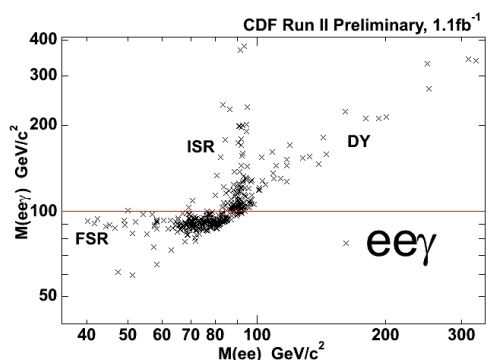

Figure 5. CDF $Z\gamma$ Dilepton mass versus Dilepton+photon mass. The three contributions (ISR, FSR, DY) are labelled.

cross section (using 1 fb^{-1}), giving a value of $5.0\pm0.3_{(stat.+syst.)}\pm0.3_{(lumi.)}$ pb, again, in good agreement with the Standard Model value. The $Z\gamma$ photon transverse energy spectrum is shown in Figure 6. Since the spectrum is observed to be consistent with the Standard Model prediction, anomalous coupling limits are found, and the two dimensional 95%CL contours are shown in Figures 7 and 8.

3.3. WZ

In analogy with $W\gamma$, the WZ process also contains the trilinear vector boson vertex. Analy-

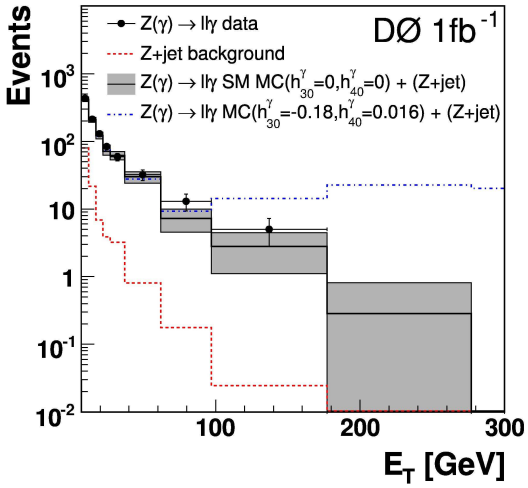

Figure 6. D0 $Z\gamma$ measured photon E_T Spectrum.

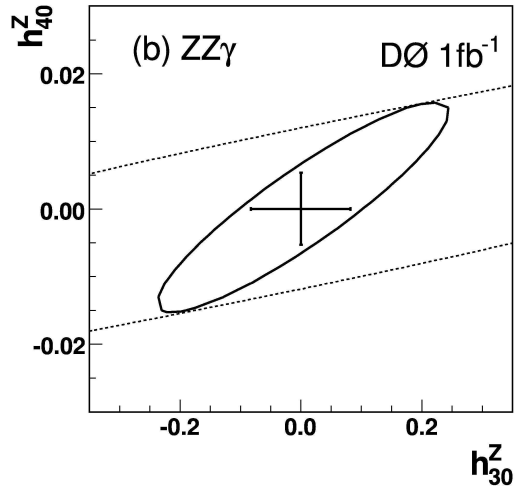

Figure 7. D0 $Z\gamma$ anomalous coupling limits on $h^Z_{30,40}$. $h^Z_{30,40}$ are parameters in a generalized Lagrangian for arbitrary Z-γ couplings, and at leading order are zero in the Standard Model.

ses dedicated to WZ production events in the trilepton channels are by their nature highly dependent on lepton efficiency. The D0 experiment performs a search for WZ in the trilepton channel and observes 12 events across the four lepton channels, on an estimated background of 3.6±0.2 (in 0.9 fb^{-1}). This consitutes greater than 3 σ evidence for WZ production. Figure 9 shows the dilepton invariant mass versus the missing transverse energy for the Monte Carlo signal, the estimated backgrounds and the WZ candidate events. The CDF experiment uses specially designed more efficient lepton criteria to expand the detector lepton efficiency for analyses (WZ and ZZ) which require high lepton efficiency[4]. With these new definitions, 16 candidates are observed on an estimated background of 2.7±0.2 (in 1.1 fb^{-1}), which consitutes greater than 5 sigma observation of WZ production in the trilepton mode. Figure 10 shows the Z boson transverse momentum distribution for the candidate sample along with signal and background. In analogy with $W\gamma$, anomalous WWZ couplings would manifest as an excess of events at large Z p_T.

[4]This is achieved by making special lepton definitions for each area of the detector where the available information is different. For example, in a place where geometry constrains the muon detector coverage, an isolated track plus a minimum ionizing particle signature is accepted instead. In the far forward plug region, an electromagnetic cluster without a track is accepted. This forms a more uniform lepton acceptance at the cost of complicating the different available varieties of final states.

3.4. ZZ

Again, in comparison with $W\gamma/Z\gamma$, the Standard Model ZZ process contains no trilinear vertex. This analysis is very similar to that of WZ, with the addition of the requirement for an additional lepton. In the four lepton mode, D0 and CDF both observe only one event each (D0 observes an $ee\mu\mu$ event in 1 fb^{-1}, while the CDF event is a $\mu\mu\mu + isolated\ track$ event in 1.5 fb^{-1}). Neither experiment is able to claim evidence based only on the four lepton channel. The CDF experiment, using a matrix element technique (in analogy to those used in top quark analyses), to attempt to separate ZZ events from

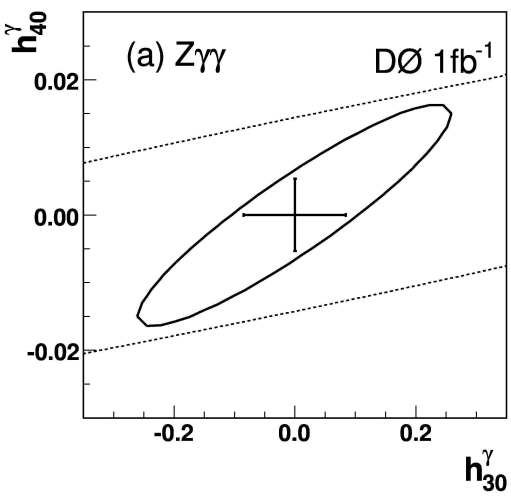

Figure 8. D0 $Z\gamma$ anomalous coupling limits on $h^{\gamma}_{30,40}$.

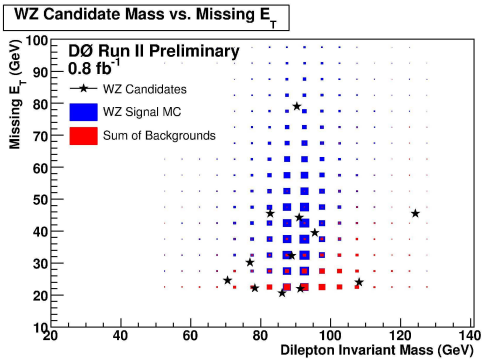

Figure 9. Dilepton Mass versus Missing Tranverse energy for the D0 WZ result.

their mainly physics backgrounds, chief among them WW. Though no statistically significant evidence is found in this channel alone (in 1.1 fb^{-1}), in combination with the single event in the four lepton channel (which has a very small estimated

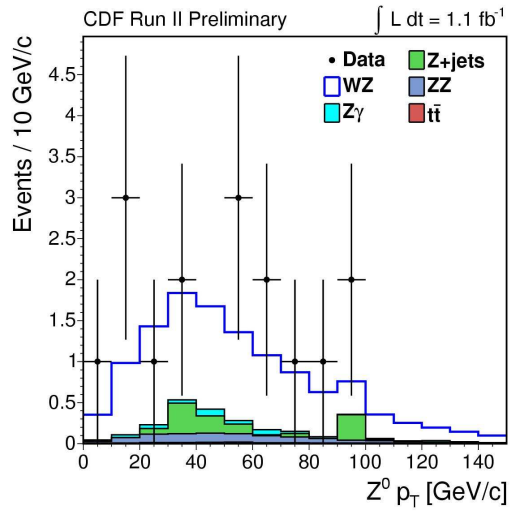

Figure 10. CDF Measured Z Boson Transverse Momentum in WZ events.

background) this yields 3 σ evidence for ZZ production, the first such evidence at a hadron collider.

4. Summary

As the Tevatron continues to deliver greater amounts of instantaneous luminosity, both the high statistics inclusive analyses and the low cross section diboson analyses give important information about the Standard Model (at successively higher orders of theoretical computations) and its underlying gauge structure (through studies of trilinear vector boson vertices).

REFERENCES

1. All results herein discussed originate from the publically accessible web pages from CDF and D0. Please see http://www-cdf.fnal.gov/physics/ewk/ and http://www-d0.fnal.gov/Run2Physics/WWW/results/ew.htm for detailed documentation on each result.