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Electroweak and Higgs physics at DØ

Nikos Varelas, representing the DØ Collaboration

University of Illinois at Chicago, Department of Physics, Chicago, IL 60607, USA

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Abstract. We present recent results from the DØ experiment on W and Z boson production using $\approx$ 50 pb^{-1} of Run II data recorded at the center of mass energy of 1.96 TeV at the Fermilab Tevatron. Initial studies of $W/Z + 2$ jets production that are relevant to Higgs searches are also discussed.

PACS. 13.38.Be Decays of W bosons – 13.38.Dg Decays of Z boson – 14.80.Bn Standard-model Higgs boson

1 W and Z production

At Tevatron energies, W and Z bosons are produced in $p\overline{p}$ collisions primarily by head on collisions of $q\overline{q}$ constituents of the proton and antiproton without any transverse momentum (p_T). Consequently, the fact that observed W and Z bosons have finite p_T is attributed to initial state gluon emission. The measurement of the W and Z production cross sections and their branching ratios into leptons in $p\overline{p}$ collisions test the consistency of the standard model couplings, the contributions from higher-order QCD diagrams, and the parton distribution functions in the proton.

Since the start of Run II, DØ has collected large numbers of W and Z bosons, both in their electronic and muonic decay channels. These samples have been very useful to benchmark the performance of the upgraded DØ detector.

27,370 $W \to e\nu$ candidates are selected from 42 pb^{-1} of data by requiring one isolated electron with transverse energy $E_T > 25$ GeV, $|\eta| < 1.1$, and missing transverse energy $\not{E}_T > 25$ GeV. 1139 $Z \to e^+e^-$ candidates are selected from the same data set by requiring two isolated electrons with $E_T > 25$ GeV, pseudorapidity $|\eta| < 1.1$, and a dielectron invariant mass in the range 70 GeV $<$ $\mathrm{m_{ee}}$ $<$ 110 GeV. In order to increase the statistics in this sample, no track match is required to either electron. Figure 1 shows the invariant mass distribution for the $Z \to e^+e^-$ candidates (left), and the transverse mass distribution for the $W \to e\nu$ candidates (right).

7,352 $W \to \mu\nu$ candidates are selected from a subsample of 17 pb^{-1} of data by requiring one isolated muon with $p_T > 20$ GeV, $|\eta| < 1.6$, and $\not{E}_T > 20$ GeV. 1585 $Z \to \mu^+\mu^-$ candidates are selected from a subsample of 32 pb^{-1} of data by requiring two oppositely-charged muons with $p_T > 15$ GeV, $|\eta| < 1.6$, and $(\Delta R)^2 = (\Delta\phi_{\mu\mu})^2 + (\Delta\eta_{\mu\mu})^2 \geq 4.0$. At least one muon was required to appear isolated both in the calorimeter and in the central tracker. To ensure a proper momentum determination, both muons are matched to a central detector track. Figure 2 shows the invariant mass distribution for the $Z \to \mu^+\mu^-$ candidates (left), and the transverse mass distribution for the $W \to \mu\nu$ candidates (right).

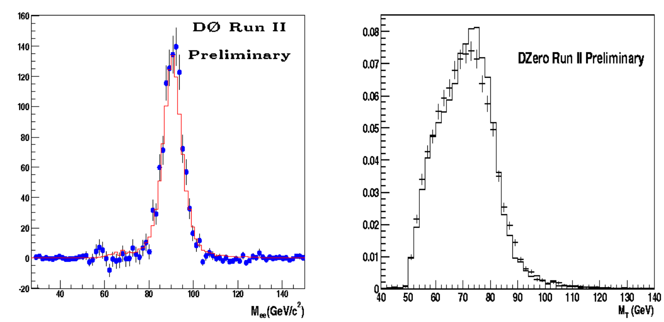

Fig. 1. The plot on the *left* (*right*) shows the dielectron invariant mass (electron+$\not{E}_T$ transverse invariant mass) for 42 pb^{-1} of Run II data. The *points* are the background subtracted data, and the histogram is the Monte Carlo prediction from PYTHIA [1]

Using these candidate samples, DØ measures the production cross section times branching ratio for W and Z bosons in the electron and the muon channels:

$$\sigma(p\overline{p} \to W + X) \cdot B(W \to e\nu) = 2844 \pm 21_{\mathrm{stat}} \pm 128_{\mathrm{syst}}\ \mathrm{pb}$$

$$\sigma(p\overline{p} \to W + X) \cdot B(W \to \mu\nu) = 3226 \pm 128_{\mathrm{stat}} \pm 100_{\mathrm{syst}}\ \mathrm{pb}$$

$$\sigma(p\overline{p} \to Z + X) \cdot B(Z \to ee) = 275 \pm 9_{\mathrm{stat}} \pm 9_{\mathrm{syst}}\ \mathrm{pb}$$

$$\sigma(p\overline{p} \to Z + X) \cdot B(Z \to \mu\mu) = 264 \pm 7_{\mathrm{stat}} \pm 17_{\mathrm{syst}}\ \mathrm{pb}$$

There is an additional 10% systematic uncertainty in the four measurements which comes from the uncertainty in the integrated luminosity, where DØ is still using the Run I value for the total $p\overline{p}$ production cross section at a lower center of mass energy. We expect the luminosity to

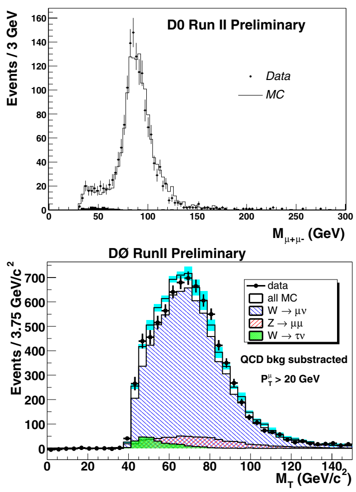

Fig. 2. The plot on the *left* (*right*) shows the dimuon invariant mass (muon+$\not{E}_T$ transverse invariant mass) for 32 (17) pb^{-1} of Run II data. The *points* are the data, compared to a parametric Monte Carlo simulation. Various sources of background are indicated in the $W \to \mu\nu$ plot, where the shaded light *blue band* on the Monte Carlo prediction represents the uncertainty from the detector simulation

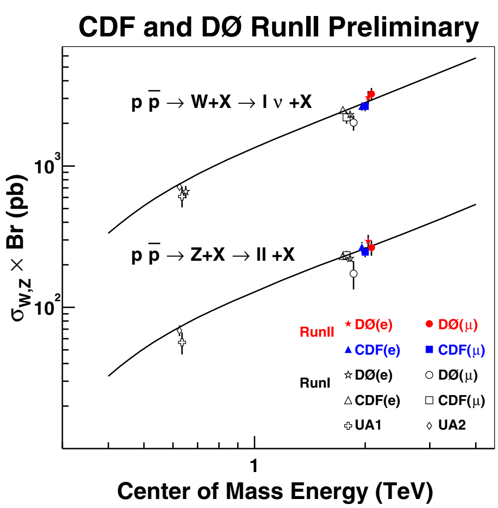

Fig. 3. $W \to l\nu$ and $Z \to l^+l^-$ cross section as a function of center of mass energy as measured by DØ and CDF, compared to the NNLO prediction [2]

be recalculated for the Run II center of mass energy and the uncertainty reduced in the near future. The new DØ results are in good agreement with the standard model expectations, as can be observed in Fig. 3.

1.1 *W* width measurement

The ratio of the W and Z production cross sections times branching ratio,

$$\mathcal{R} \equiv \frac{\sigma(p\bar{p} \to W + X) \cdot B(W \to e\nu)}{\sigma(p\bar{p} \to Z + X) \cdot B(Z \to ee)}$$

allows a precise determination of the W width since theoretical and experimental uncertainties each tend to cancel. The width can be calculated from this measurement using

$$\mathcal{R} = \frac{\sigma_W}{\sigma_Z} \cdot \frac{\Gamma_Z}{\Gamma_{Z\to ll}} \cdot \frac{\Gamma_{W\to l\nu}}{\Gamma_W}.$$

Both σ_W/σ_Z and $\Gamma_{W\to l\nu}$ can be calculated theoretically to high precision [2], and depend only on the couplings of the W and Z bosons to the lepton and quark doublets, and the ratio $\Gamma_Z/\Gamma_{Z\to ll}$ has been measured precisely by experiments at LEP [3].

Both CDF and DØ have measured the ratio $\mathcal{R}$ using their Run II preliminary W and Z cross section results. The CDF result is based on both the electron and muon channels:

$$\mathcal{R}_e^{CDF} = 9.88 \pm 0.24_{\rm stat} \pm 0.47_{\rm sys}$$

$$\mathcal{R}_\mu^{CDF} = 10.69 \pm 0.27_{\rm stat} \pm 0.33_{\rm sys}$$

The DØ result is based on the electron channel:

$$\mathcal{R}_e^{DØ} = 10.34 \pm 0.35_{\rm stat} \pm 0.48_{\rm sys}$$

The Tevatron Electroweak Working Group (TeVEWWG) has recently combined the Run II CDF and DØ $\mathcal{R}$ results to extract a Tevatron average:

$$\mathcal{R}^{TeV} = 10.36 \pm 0.31$$

Using this Tevatron average value of $\mathcal{R}$ the TeVEWWG extracted the first Run II preliminary measurement of the full width of the W:

$$\Gamma_W^{RunII} = 2.181 \pm 0.073 \text{ GeV}$$

The Run II preliminary results were combined with the results from Run I to get a full width of:

$$\Gamma_W^{RunI+II} = 2.150 \pm 0.054 \text{ GeV}$$

which is in agreement with the standard model prediction of 2.090 ± 0.008 GeV.

2 Search for a heavy neutral gauge boson

Many extensions of the standard model predict the existence of particles that decay to lepton-antilepton pairs. Examples are heavy gauge bosons (Z') and technihadrons (ρ_T, ω_T). The lepton-antilepton signature is a preferred channel for particle searches in strong interactions because of the relatively low backgrounds compared to hadronic decay channels. Experimental searches for Z' are typically based on a reference model assuming the same couplings to quarks and leptons as the standard model Z.

DØ used a sample of 50 pb^{-1} to search for a heavy neutral gauge boson decaying through the channel $Z' \to ee$. Events were selected with two isolated electrons with $E_T > 25$ GeV and $|\eta| < 1.1$ or $1.1 < |\eta| < 2.5$. The dominant background contributions to the Z' signal are

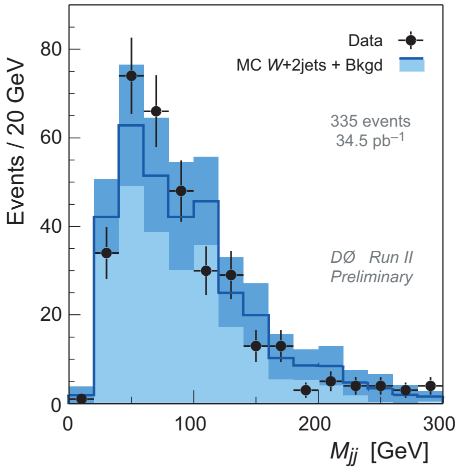

Fig. 4. Dijet mass distribution for DØ W+jets sample. The *points* are data and the *shaded band* is PYTHIA Monte Carlo simulation. The *darker color band* shows the systematic uncertainty imposed by the energy scale added to the Monte Carlo

from Drell-Yan and QCD processes. After subtracting the QCD multijet background we observe 2817 $Z \to ee$ and Drell-Yan events. No excess of events was observed. We set limits on the ratio of cross section for Z' production compared to the Z boson production (so that many systematic uncertainties cancel) as a function of the Z' mass. Using a likelihood approach with Poisson statistics we exclude a Z', assuming the same couplings to quarks and leptons as the Z, at a 95% C.L. with mass below 620 GeV.

3 Higgs searches

One of the primary goals of present and future colliders is to discover the mechanism responsible for the spontaneous symmetry breaking of the $\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$ electroweak interaction. The simplest model for this mechanism is the standard Higgs model, based on the doublet of fundamental scalar fields. The current best limit on the mass of a SM Higgs boson, H, is $M_H > 114.4$ GeV, at the 95% C. L. limit from the LEP experiments [4]. The LEP Electroweak Working Group has recently reported, that the global fit to electroweak data gives a Higgs boson mass of 96^{+60}_{-38} GeV with an upper limit of 219 GeV at 95% C. L. [5]. Furthermore, in the Minimal Supersymmetric Standard Model (MSSM), the lightest scalar neutral Higgs (h) has a mass of less than ≈ 135 GeV [6] and its discovery could be the first signal of Supersymmetry. Results from LEP have put a lower constraint on the mass of the MSSM neutral Higgs of $M_h > 90$ GeV for all values of tanβ above 0.4 [7]. Therefore, both the experimental evidence and the theoretical prejudice, point to a light Higgs boson.

The dominant production mode for the standard model Higgs boson at the Tevatron is gluon fusion $gg \to H$. However, for a light Higgs ($m_H < 140$ GeV) the dominant decay mode is $H \to b\bar{b}$, making this mode hopeless due to the large backgrounds of $b\bar{b}$ production from other sources.

The most promising modes for a light Higgs discovery at the Tevatron are those where the Higgs is produced in association with a W or Z boson, with $(W/Z) \to$ leptons and $H \to b\bar{b}$ [8]. With the limited luminosity currently available at the Tevatron, Higgs studies at DØ have been focusing on understanding the properties of W and Z bosons produced in association with jets (background processes to standard model Higgs production), and searches relevant to extensions to the standard model that predict enhancements to various Higgs boson channels [9].

A sample of $W/Z+$jets events was selected by requiring one or two isolated high p_T leptons with large $\not{E}_T$ (for W), and two jets with $E_T > 20$ GeV and $|\eta| < 2.5$. Figure 4 shows the invariant mass distribution of the two leading-E_T jets from the W+jets sample, based on an integrated luminosity of 35 pb^{-1}. The data and Monte Carlo spectra are normalized to the same total yield. There is good shape agreement between data and predictions from PYTHIA with full detector simulation. Several other kinematic distributions for the leptons and jets in these events exhibit similar agreement with the Monte Carlo simulation.

4 Conclusions

We have reported the first electroweak results on W and Z boson cross sections in both electronic and muonic decay channels, on W total width, and on Z' search, along with initial studies on standard model Higgs searches from the DØ experiment using data recorded at the new center of mass energy of 1.96 TeV. We also reported the first CDF and DØ combined measurements of the W total width from Run II. In the next few years we expect to accumulate several fb^{-1} of luminosity per experiment that would provide an exciting program for precision electroweak measurements, and enable stringent constraints on the Higgs mass.

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