Electroweak and Hints of New Phenomena at the Tevatron

Andrew Askew
Department of Physics
Florida State University
Tallahasse FL, U. S. A

1 Introduction

The CDF and D0 experiments at Fermi National Accelerator Laboratory Tevatron collider have carried out a diverse program of electroweak measurements which test the predictions of the standard model. Many of these tests are also sensitive to alternative theories that enhance the standard model at high energies. In addition to these searches, the Tevatron experiments have performed extremely precise measurements of the W mass, which along with the top mass provide a constraint on the allowed mass of the Higgs boson within the standard model. These measurements are made at a center of mass energy of $\sqrt{s}$=1.96 TeV in proton-antiproton collisions, utilizing between 2.1-8.6 fb^{-1} of integrated luminosity.

2 Searches for New Phenomena

2.1 $Z \to ee$

The dielectron final state is one of the best measured topologies at the Tevatron as both experiments have excellent electron resolution. The CDF experiment has produced a new measurement of the Z p_T distribution [1] (the invariant mass range selected is $66 < M_{ee} < 115$ GeV), which utilizes the same well understood 2.1 fb^{-1} dataset as an earlier measurement of the Z angular coefficients [2]. At low transverse momentum the Z p_T is sensitive to the effects of soft gluon emission, while at high p_T the distribution tests higher order QCD effects. The shape of the distribution at low p_T is also an important ingredient in describing the shape of the W p_T distribution, needed for precision measurement of the W mass. The measured differential cross section is shown in Figure 1. When compared to the RESBOS [3] theoretical prediction, there appears to be general agreement over the full range of p_T^Z.

Also utilizing the dielectron final state, the D0 experiment has produced a measurement of the e^+e^- forward-backward asymmetry, and extracted the corresponding

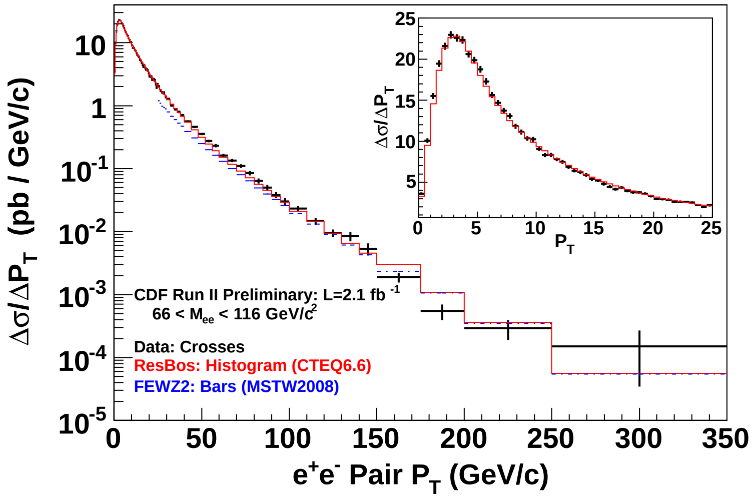

Figure 1: CDF measurement of differential Z cross section as a function of dielectron p_T.

value of $\sin^2\theta_W$ in the vicinity of the Z resonance ($70 < M_{ee} < 130$ GeV), using 5 fb^{-1}. If an additional heavy resonance were being produced and decaying to dielectrons, the forward-backward asymmetry would deviate from the standard model prediction in that invariant mass range (see Figure 2). No such deviation is observed.

D0 extracts a value of $\sin^2\theta_W$=0.2309±0.0010 and also uses this measurement to set limits on the u- and d-quark vector and axial couplings [4]. CDF has also produced a preliminary measurement corresponding to $\sin^2\theta_W$=$0.2320\pm0.008^{+0.001}_{-0.0009}$ using 2.1 fb^{-1}. With the full Run II dataset utilizing CDF and D0 combined, the precision of this result will have a substantial impact on the world average.

2.2 Diboson Final States

Diboson production provides an excellent test of the standard model. Since the trilinear gauge couplings are specified exactly (with no room for tuning), each measurement is also a search for new physics, particularly at high boson transverse momentum.

The D0 experiment has performed a measurement of the differential cross section for $Z\gamma$ production as a function of photon transverse momentum using 6.2 fb^{-1} of integrated luminosity (electron and muon decays of the Z are used) [5]. In multiboson final states often a parametrized lagrangian is used to detail consistency with the standard model couplings. In this particular case however, models of gauge mediated supersymmetry breaking would also give rise to additional events with a photon and a Z boson. In these models, the next-to-lightest supersymmetric particle (NLSP)

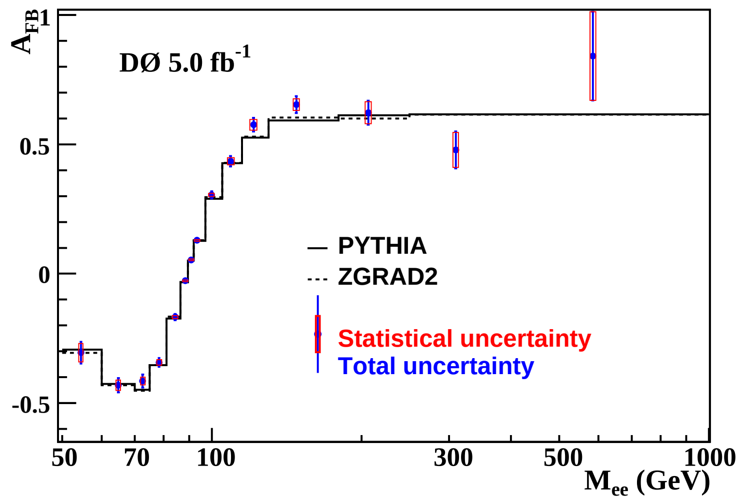

Figure 2: A_{FB} measurement from D0 using dielectron events.

decays to a neutral gauge boson and the gravitino, which results in a final state with missing transverse energy (the escaped gravitino) and multiple gauge bosons. The typical final state which is used in these searches is two photons and missing transverse energy, but a complementary channel is when one NLSP decays to a Z boson and the other decays to a photon. No excess in the missing transverse energy is observed and limits are set on the production cross section [6].

Likewise, measurements of the WZ and ZZ cross sections have been made by the D0 experiment. The WZ cross section is measured in the $eee\nu$, $ee\mu\nu$, $e\mu\mu\nu$ and $\mu\mu\mu\nu$ decay modes using 8.6 fb^{-1}. The same dataset is used to measure the ZZ cross section in the $ee\nu\nu$ and $\mu\mu\nu\nu$ decay modes. No discrepancy with the standard model prediction is observed.

In an inclusive search for new physics with multiple leptons, CDF examines final states using trileptons in events where there are two electrons, or two muons, and one additional reconstructed lepton (e, μ or τ) or an isolated track. This search makes use of 5.8 fb^{-1} of integrated luminosity. All backgrounds are measured in data control regions of dilepton invariant mass, jet multiplicity and missing transverse energy. After ascertaining that the backgrounds are well modeled by using the control regions, specific kinematic requirements particular to supersymmetry are crafted. No excess is observed, and cross section limits are set.

In a separate search for new physics with leptons, CDF has performed a dedicated analysis searching for a heavy resonance decaying to Z boson pairs. Initially, an excess was observed in the four charged lepton channel (see Figure 3, left panel). Additional searches in the dilepton plus missing transverse energy, and dilepton plus

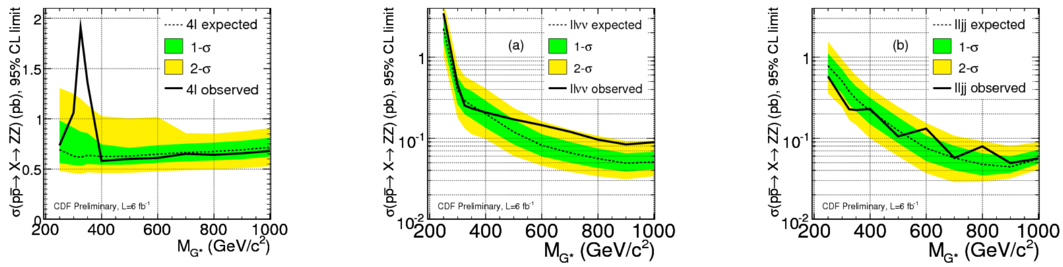

Figure 3: CDF limits on a heavy resonance decaying to ZZ.

dijet topologies, which should have larger branching fractions, revealed no additional excess events (see Figure 3, center panel and right panel), and cross section limits were set [8].

3 Precision Measurement of the W Mass

A full description of the precision measurement of the W mass by the Tevatron experiments is beyond the scope of these proceedings. The basic method used is to build detailed parametrized simulations of the experiment response, and then generate template shapes corresponding to different values of the W mass. These templates are then used to fit the data distributions. The differences in the individual experimental designs manifestly affect the performance of each detector, as well as how these descriptions were developed. A brief description of the characterization of the lepton energy scales and resolutions is included here.

Measurement of the W mass with the CDF detector begins with precision tracking. The alignment of the individual detectors is verified using cosmic muon events. Then, using inclusive samples of $J/\psi \to \mu\mu$ events, the momentum scale and linearity of the tracking is verified, and cross checked using $Z \to \mu\mu$ events (yielding an independent measurement of the Z mass). With the tracking momentum scale verified, the E/p distribution for electrons is used to set the energy scale for the calorimeter. The radiative tail of this distribution is also used to verify the energy loss and radiative components of the calorimeter response. The calorimeter energy scale for electrons is then cross checked using $Z \to ee$ events (yielding a similarly unbiased estimate of the Z mass). With the lepton energy scale verified, and the recoil distributions modeled using Z events, the lepton transverse momentum, missing transverse energy and transverse mass are used to measure the W mass. Taking into account the correlations between these distributions, the measured value of the W mass using 2.2 fb^{-1} in both the electron and muon channels from CDF is M_W=80387±19 MeV [9].

Measurement of the W mass with the D0 detector is done differently, the precision

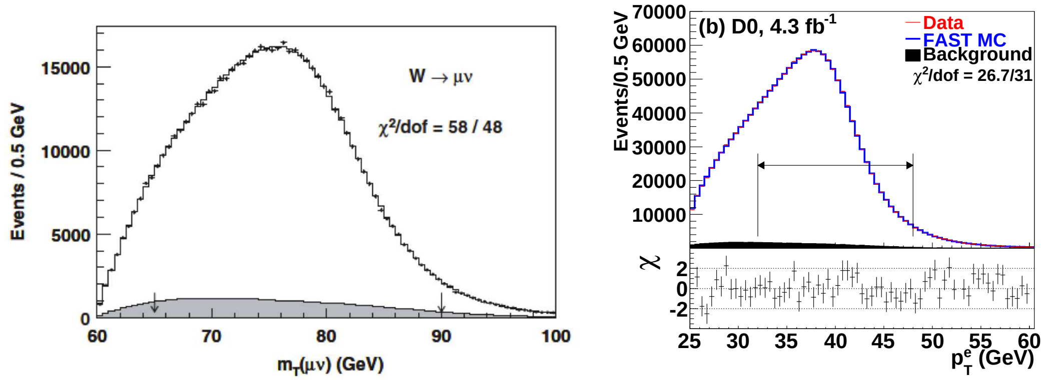

Figure 4: Distributions used for measurement of the W mass at the Tevatron. Left: CDF W transverse mass distribution from the muon channel. Right: D0 electron p_T distribution.

of the tracking is not sufficient to carry out the same momentum scale determination and transfer. The electron channel alone is used, utilizing only the central calorimeter ($|\eta|$ <1.1). In order to model the amount of material prior to the active layers of the sampling calorimeter, the energy scale of each layer of the electromagnetic part of the calorimeter along with the material is allowed to vary and is fit to the longitudinal shower profile from $Z \to ee$ events in data. These Z events must be split into categories according to the rapidity of each electron, since different impact angles will encounter different amounts of material. The individual layers are independently varied in order to check the robustness of the description. The energy scale and offset are then set using the Z mass, using the corrected material distribution, and verified in different ranges of instantaneous luminosity in order to check for pileup dependent effects. After taking into account the correlations between the lepton transverse momentum, the missing transverse momentum and transverse mass, only the transverse momentum and transverse mass distributions contribute to the final value (combined with the earlier D0 measurement), yielding M_W=80375±23 MeV [10].

With the combination of the Run II W mass measurements from CDF and D0 (along with the Run 0/I measurements), the Tevatron measurements of the W mass now dominate the world average (as shown in Figure 5). It is worth noting that there is still a significant amount of the uncertainty which can be reduced by additional statistics, and by higher precision parton distribution function fits when available.

4 Summary

A limited set of results from electroweak measurements and their implications for searches for new phenomena have been presented. The precision measurement of the

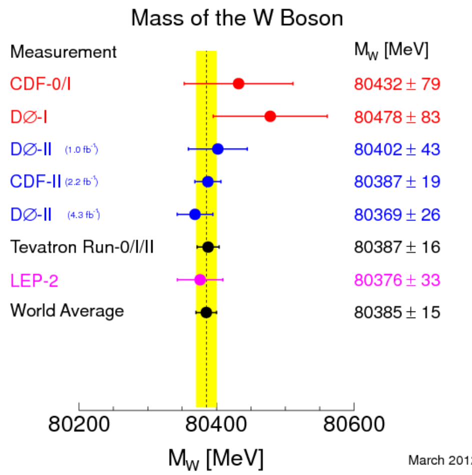

Figure 5: Summary of W mass measurements and new world average.

W mass at the Tevatron now dominates the world average, which along with the top mass constrains the allowed standard model value of the Higgs mass.

References

[1] CDF Collaboration, arXiv:1207.7138.

[2] T. Aaltonen *et al.*, Phys. Rev. Lett. **106**, 241801 (2011).

[3] C. Balazs and C .-P. Yuan, Phys. Rev. D **56**, 5558 (1997).

[4] V. M. Abazov *et al.*, Phys. Rev. D. **84**, 012007 (2011).

[5] V. M. Abazov *et al.*, Phys. Rev. D. **85**, 052001 (2012).

[6] D0 Collaboration, arXiv:1203.5311.

[7] V. M. Abazov *et al.*, Phys. Rev. D. **85**, 112005 (2012).

[8] CDF Collaboration, arXiv:1111.3432.

[9] T. Aaltonen *et al.*, Phys. Rev. Lett. **108**, 151803 (2012).

[10] V. M. Abazov *et al.*, Phys. Rev. Lett. **108**, 151804 (2012).