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RECENT RESULTS IN ELECTROWEAK PHYSICS AT THE TEVATRON

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Abstract

The Run II physics program of CDF and DØ has just begun with the first 72 pb^{-1} of analysis quality data collected at the center-of-mass energy of 1.96 TeV. The Electroweak measurements are among the first and most important benchmarks for the best understanding of the detectors and testing the Standard Model. We present measurements of the W and Z inclusive cross sections and decays asymmetries, recent results in di-boson physics and searches for new physics which make use of distinct electroweak signatures.

1 Introduction

Studying the electroweak sector is crucial in the CDF and DØ physics programs for Run II at the Tevatron. The measurement of the W mass, one of the most difficult goals of this program, is central to constraining the mass of the SM Higgs boson and thus to a deep and complete understanding of the Standard Model. W and Z cross section measurements are key milestones in the understanding and calibration of the detectors, and a starting point for any advanced measurement or discovery. Studies of boson asymmetries and di-boson production processes produce clean and well-understood signatures which are robust tests the Standard Model and allow one to explore beyond-the-Standard-Model scenarios with the total integrated luminosity of 4 to 8 fb^{-1} expected in the next decade. Both the accelerator and the detectors have undergone major upgrades in order to handle the increase in luminosity and energy achieved during Run II. The introduction of the Main Injector has allowed the optimization of the use and production of anti-protons, resulting in 36×36 bunches and an instantaneous luminosity almost an order of magnitude higher than in Run I. The increase in center-of-mass energy from 1.8 to 1.96 TeV is directly mirrored in an increase of the production cross sections, which in the case of the top quark is of 30%[1]. The upgraded CDF and DØ detectors have completely new tracking systems, extended muon coverage and redesigned trigger and DAQ systems. CDF has a new drift chamber ($|\eta|<1.0$) and three silicon detectors

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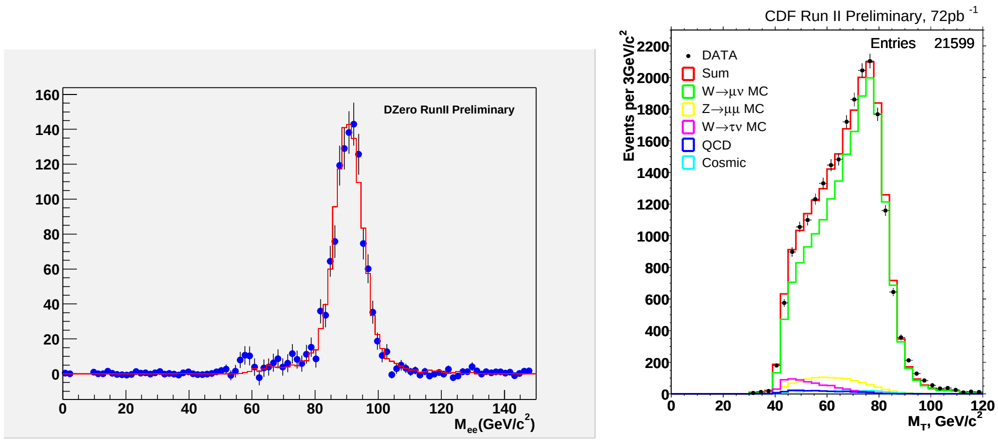

Figure 1: $Z^0 \to e^+e^-$ invariant mass distribution from the DØ experiment (left) and $W^\pm \to \mu^\pm\nu$ transverse mass distribution for the CDF experiment (right). In the latter the contributions from all sources of background are also shown.

($|\, \eta \,|$<1.8) along with the new calorimeter in the forward region covering all the range up to $|\, \eta \,|$= 3.6. The introduction of a silicon detector and fiber tracker in a magnetic field of 2 T, together with an innovative system of scintillators in the forward region, enormously improves the physics program at DØ with respect to Run I.

2 $W^\pm \to \ell^\pm\nu$ and $Z^0 \to \ell^+\ell^-$ cross sections

The W and Z cross section measurements are of crucial importance. With their high event yields and relatively clean signatures, these signals not only provide a solid test of the Standard Model but they are also extensively used in the calibration of the calorimeter. Furthermore, the ratio of the cross sections is sensitive to new physics states which might decay preferentially in either W or Z. In addition, confidence in these measurements is of key importance as they can be used as normalization for successive measurements (such as the top production cross section or the luminosity), for which systematic or theoretical uncertainties would cancel in the ratio. Events are selected requiring one central high-p_{T} isolated lepton and a second lepton (with slightly looser requirements) for the Z, or large missing transverse energy in the case of the W. Distributions of the W transverse mass and the Z invariant mass in the muon and electron channels are shown in Figure 1. The candidate event yield for each channel, background fraction and measured cross-section per experiment are shown in Table 1. These measurements are to be compared with the NNLO theoretical calculations at 1.96 TeV [2] of $\sigma(p\overline{p} \to Z^0 \to \ell^+\ell^-) = 252\pm9$ pb and $\sigma(p\overline{p} \to W^\pm \to \ell^\pm\nu) = 2.69\pm0.10$ nb, and previous measurements in literature [4], as shown in Figure 2. From the $W^\pm \to \tau^\pm\nu$ and $W^\pm \to e^\pm\nu$ cross-section measurements CDF has extracted the ratio of the coupling constants $g_\tau^W/g_e^W = 0.99 \pm 0.02_{stat} \pm 0.04_{syst}$, probing lepton universality. While the signal $Z^0 \to \tau_{lep}\tau_{had}$ has been observed, a measurement of the cross section still needs further studies of backgrounds, largely dominated by QCD di-jet events. Once finalized, this channel will be the ideal starting point for all analyses including taus, particularly searches for Supersymmetry in models with high values of tanβ, for which the branching ratio $A/h \to \tau\tau$ is enhanced [3]. From the ratio of the cross sections $\sigma(p\overline{p} \to W^\pm \to \ell^\pm\nu)$ to $\sigma(p\overline{p} \to Z^0 \to \ell^+\ell^-)$ CDF has extracted the value of the total decay width of the W boson, which has been found to

Channel(mode)	Experiment	$\mathcal{L}$	Raw yield	Background	$\sigma \cdot \mathrm{Br}$
$Z^0 \to e^+e^-$	CDF	72	1830	0.6%	$267 \pm 6_{stat} \pm 15_{syst} \pm 16_{lum}$ pb
$Z^0 \to \mu^+\mu^-$	CDF	72	1631	0.9%	$246 \pm 6_{stat} \pm 12_{syst} \pm 15_{lum}$ pb
$Z^0 \to e^+e^-$	DØ	42	1139	1.7%	$294 \pm 11_{stat} \pm 8_{syst} \pm 29_{lum}$ pb
$Z^0 \to \mu^+\mu^-$	DØ	32	1585	1.5%	$264 \pm 7_{stat} \pm 17_{syst} \pm 26_{lum}$ pb
$W^\pm \to e^\pm\nu$	CDF	72	38625	6.0%	$2.64 \pm 0.01_{stat} \pm 0.09_{syst} \pm 0.16_{lum}$ nb
$W^\pm \to \mu^\pm\nu$	CDF	72	21599	11.0%	$2.64 \pm 0.02_{stat} \pm 0.12_{syst} \pm 0.16_{lum}$ nb
$W^\pm \to \tau^\pm\nu$	CDF	72	2345	26.0%	$2.62 \pm 0.07_{stat} \pm 0.21_{syst} \pm 0.16_{lum}$ nb
$W^\pm \to e^\pm\nu$	DØ	42	27370	6.0%	$3.05 \pm 0.10_{stat} \pm 0.09_{syst} \pm 0.31_{lum}$ nb
$W^\pm \to \mu^\pm\nu$	DØ	17	7352	11.0%	$3.23 \pm 0.13_{stat} \pm 0.10_{syst} \pm 0.32_{lum}$ nb

Table 1: The raw event yields and resulting cross sections measured by the CDF and DØ experiments.

be: $\Gamma(W^\pm \to \ell^\pm\nu) = 2.146 \pm 0.078$ GeV, where the value is the combined value in the electron and muon channels and the uncertainty includes the statistical and systematic contributions. This value is consistent with the LEP direct measurement of 2.150 ± 0.091 GeV and the Run I combined measurement of CDF and DØ $\Gamma(W^\pm \to \ell^\pm\nu) = 2.115 \pm 0.105$ GeV. The Run I values of the mass of the W boson have also been combined for CDF and DØ , leading to $M(W) = 80.456 \pm 0.059$ GeV, which is 1.8σ higher than the SM indirect prediction, indicating the presence of a light Higgs boson. The improved resolution of about 30 MeV on the W mass and of 2.5 GeV on the top mass (CDF and DØ combined) expected for Run II will further constrain this result before the advent of the LHC.

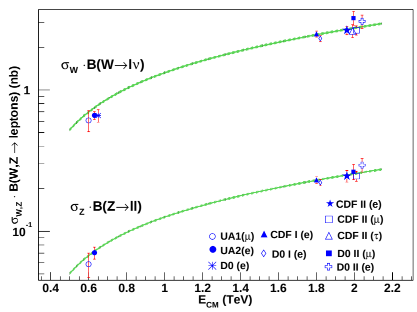

Figure 2: Recent $Z^0 \to \ell^+\ell^-$ and $W^\pm \to \ell^\pm\nu$ cross section measurements as a function of the center-of-mass energy for the CDF and DØ experiments, compared to other measurements in the literature [4] and to the NNLO calculation [2].

3 Z^0 forward-backward asymmetry and high-mass resonances searches

A forward-backward asymmetry can be observed in the decay of the leptons in the process $\bar{q}q \to Z^0/\gamma \to \ell^+\ell^-$, due to the presence of both vector and axial-vector couplings of electroweak bosons to fermions. The measurement of A_{fb}, defined as $A_{fb} = \frac{N_F - N_B}{N_F + N_B}$, where N_F and N_B are the number of forward and backward events (in the rest frame of the lepton pair) respectively, is a direct probe of the strengths of the couplings involved. Furthermore, a measurement of A_{fb} is sensitive to the presence of high-mass Drell-Yan(DY) resonances outside the Standard Model. The CDF measurement of A_{fb} in 72 pb^{-1} (shown in Figure 3) is the first analysis in Run II to make use of the full coverage $\mid \eta \mid < 3.6$ provided by the new calorimeter. The selection of the events requires a high-p_{T} electron in the central region and a second one anywhere in the detector, with main background consisting of di-jet QCD events. While the LEP measurement [5] is better in the low invariant mass region, the measurement for $\mathrm{M}_{ee} > 200$ GeV/c^2 is unique to the Tevatron.

Complementary to this measurement are searches for extra neutral gauge bosons decaying into electron or muon pairs. These states, predicted by models for physics beyond the Standard Model, are particles such as the E_6 Z' [6] or the Randall-Sundrum [7] graviton. The analyses conducted by both CDF and DØ require the presence of two high-$p_{\rm T}$ electrons or muons and search the invariant mass spectrum above the Z pole for an excess from the Standard Model expectations. As no excess has been found (Figure 4), a 95% CL upper limit on the production $\sigma \cdot Br(\ell^+\ell^-)$ has been set as a function of the Z' and the Randall-Sundrum graviton masses. A 95% CL lower limit on the Z' mass has been estabilished by CDF at 650 GeV(electron channel) and 455 GeV(muon channel), and by DØ at 620 GeV in the electron channel only.

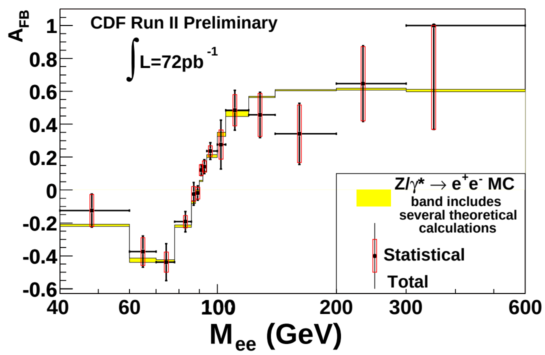

Figure 3: CDF measurement of the forward-backward asymmetry in the di-electron channel for the entire electron-positron invariant mass spectrum, compared to the theory predictions.

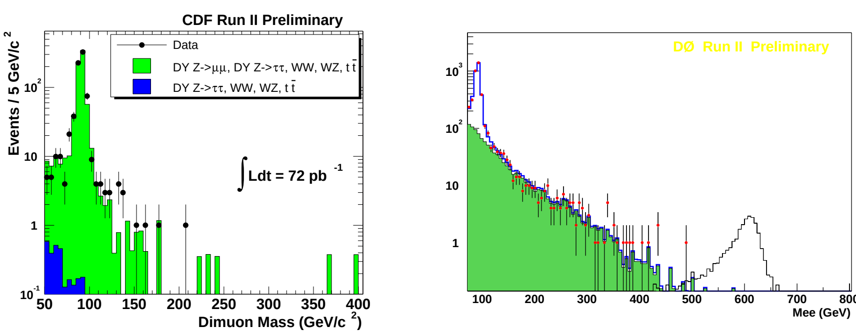

Figure 4: On the left, di-muon invariant mass distribution from the CDF experiment in 72 pb^{-1} , where the background contribution is highlighted. On the right, M_{ee} spectrum in 50 pb^{-1} collected by the DØ experiment. The peak from an hypothetical Z' is shown, enlarged by a factor ten.

4 Di-boson results

Associated $W^pm\gamma$ and $Z^0\gamma$ production is an important test of the non-Abelian nature of the SM as it is sensitive to triple-gauge boson interactions. Furthermore, anomalies in these interactions can lead to discovery of physics beyond the Standard Model. Using the same selection as in the cross section measurements but with the addition of a high-energy ($E_T^\gamma > 7$ GeV) photon isolated from the electron ($\Delta R(\gamma - \ell) > 0.7$), CDF measured the cross sections $\sigma(p\overline{p} \rightarrow W^\pm\gamma) \cdot Br(W^\pm \rightarrow \ell^\pm\nu)$ and $\sigma(p\overline{p} \rightarrow Z^0\gamma) \cdot Br(Z^0 \rightarrow \ell^+\ell^-)$ in 72 pb^{-1} of Run II data. The values along with the background fractions and the event yields are shown in Table 2. All the measurements are consistent with the SM predictions of $\sigma(p\overline{p} \rightarrow W^\pm\gamma) \cdot Br(W^\pm \rightarrow \ell^\pm\nu) = 18.7 \pm 1.3$ pb and $\sigma(p\overline{p} \rightarrow Z^0\gamma) \cdot Br(Z^0 \rightarrow$

Channel(mode)	Raw yield	Background	$\sigma \cdot \mathrm{Br}$
$W^{\pm}\gamma \to e^{\pm}\nu_e\gamma$	43	33%	$17.2 \pm 3.8_{stat} \pm 2.8_{syst} \pm 1.0_{lum}$ pb
$W^{\pm}\gamma \to \mu^{\pm}\nu_\mu\gamma$	38	29%	$19.8 \pm 4.5_{stat} \pm 2.4_{syst} \pm 1.2_{lum}$ pb
$Z^0\gamma \to e^+e^-\gamma$	11	4.6%	$5.5 \pm 1.7_{stat} \pm 0.6_{syst} \pm 0.3_{lum}$ pb
$Z^0\gamma \to \mu^+\mu^-\gamma$	14	4.0%	$6.0 \pm 1.6_{stat} \pm 0.7_{syst} \pm 0.4_{lum}$ pb

Table 2: The raw event yields and resulting $W, Z\gamma$ cross sections measured by the CDF in 72 pb^{-1} of data.

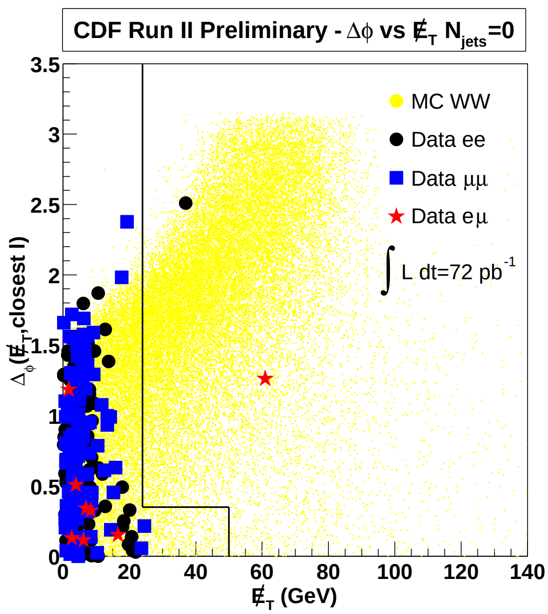

Figure 5: $\Delta\phi(\not{E}_T\ , \ell)$ as a function of $\not{E}_T$ for the 2 WW candidate events in 72 pb^{-1} at CDF.

$\ell^+\ell^-) = 5.4 \pm 0.4$ pb. Heavy di-boson measurements such as WW, WZ and ZZ also lead to new limits on triple gauge boson couplings and are important background to $t\bar{t}$ production, Higgs and exotic signatures. Two WW candidates have been observed in the di-lepton channel in CDF with 72 pb^{-1} of data. The selection requires two oppositely charged high-p_{T} leptons with large missing energy and the exclusion of additional jets in the event. The observation is consistent with the SM expectations. Figure 5 shows the kinematic distribution of these events compared with the Monte Carlo prediction.

5 Conclusions and prospects

Run II at the Tevatron is well under way. Both CDF and DØ are fully commissioned and are taking high-quality physics data. Their Electroweak physics programs have reestablished the basic measurements, and the precision measurements are already competitive with the Run I results. We expect to finalize results on di-boson and differential cross sections for winter 2004, along with a preliminary measurement on the W mass.

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