Precision Measurements of W and Z Boson Production at the Tevatron

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Abstract. Measurements of the inclusive W and Z boson production cross section times leptonic branching ratio in proton anti-proton collisions at $\sqrt{s} = 1.96$ TeV are presented. The ratio of the W and Z cross sections is used to derive an indirect measurement of the W boson width. CDF results[5] derive from 72pb^{-1} of integrated luminosity. Preliminary DØ results presented here use 177pb^{-1} integrated luminosity for the electron channels and 148 pb^{-1} and 96 pb^{-1} for the $Z \to \mu\mu$ and $W \to \mu\nu$ channels respectively.

Keywords: W boson, Z boson, production cross-section, cross-section ratio, W Boson Width
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INTRODUCTION

The measurements of the inclusive W and Z boson production cross section times leptonic branching ratios at the upgraded Run II Tevatron are presented. The Run II Tevatron collides proton and anti-proton beams with a centre of mass energy of $\sqrt{s} = 1.96$ TeV. Previous measurements carried out during Run I at $\sqrt{s}$ = 1.8 TeV have been reported in [1, 2, 3, 4]. The CDF results presented here are derived from a data sample representing a total of 72pb^{-1} of integrated luminosity. For the DØ results the data comprises an integrated luminosity of 177 pb^{-1} for the electron channels and 148 pb^{-1} and 96 pb^{-1} for the $Z \to \mu\mu$ and $W \to \mu\nu$ channels respectively.

W AND Z PRODUCTION

Precise measurements of the inclusive W and Z boson production cross sections allow tests of the Standard Model predictions and represent benchmark analyses for the CDF and DØ collaborations. Assuming the predicted values for these cross sections the measurement can also be turned into a standard candle for measuring or making a cross check of the luminosity - a procedure which may prove valuable at the LHC. Taking the Standard Model predictions for the ratio of the total cross sections; the partial width of the W decaying to leptons and the LEP measurements of the Z boson width, an indirect measurement of the total W width can be derived from the measured ratio of the W and Z production cross section times leptonic branching ratios.

Events are selected by requiring an isolated high transverse momentum $pT > 25$ (20) GeV electron (muon) which must have fired the trigger. Electrons are identified by their deposits in the calorimeter and by the presence of a matching charged track reconstructed in the tracking detectors. Outside the coverage of the central tracking

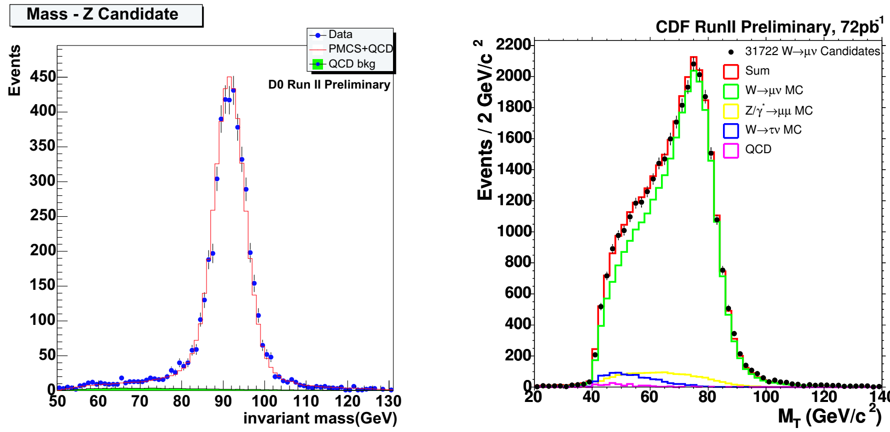

FIGURE 1. Distributions of di-electron invariant mass in the $Z \to e^+e^-$ channel at DØ (left) and transverse mass in the $W \to \mu\nu$ channel at CDF (right)

detectors at CDF, pseudo-rapidity $|\eta| > 1$ calorimetry alone is used to identify electrons. Candidate electrons are required to have a large fraction of their energy deposited in the electromagnetic calorimeter and the shower shape is required to be consistent with that expected for an electron. Muons are identified by matching reconstructed stubs in the muon detector with central charged tracks and by having energy deposits in the calorimeter consistent with the passage of a minimum ionising particle. Further selection criteria are applied to the track quality and timing to remove muons from decays in flight and from cosmic rays. For muon reconstruction at DØ the allowed fiducial region extends out to $|\eta| < 1.8$.

To select the W sample, in addition to a high pT lepton reconstructed in the central region $|\eta| < 1$, a large imbalance in the transverse momentum of the event - measured using the calorimetry - is required $\not{E}_T > 25$ (20) GeV for the electron (muon) channel. This arises from the momentum carried away by the undetected neutrino.

Z candidates are selected by requiring an additional oppositely charged muon candidate or loose electron candidate for the muon and electron channels respectively. The selection criteria on the second electron are relaxed - for example, the track matching requirement is dropped - in order to maintain a high efficiency. CDF requires at least one electron to be reconstructed in the central region, allowing the second to be reconstructed in the plug calorimeter. In the results presented here DØ requires both electrons to be reconstructed in the central cryostat of the calorimeter.

Single lepton trigger, reconstruction and identification efficiencies are measured directly using $Z \to l^+l^-$ events in the data. Events are selected with standard cuts applied to one leg of the decay leaving the other unbiased leg to be tested to see if it passes the selection criteria. Biases have been investigated in full Monte-Carlo simulations and found to be small.

Primary backgrounds come from multi-jet events or from those events containing W and Z decays such as: $Z \to l^+l^-$ where one lepton is not reconstructed, and $W \to \tau\nu$ in W decays and $W \to l\nu$ in Z decays. Additionally, muons from cosmic rays contribute to backgrounds in the muon channels. Electroweak boson backgrounds are estimated using full Monte-Carlo simulation and estimates of the multi-jet background are extracted from the data.

Figure 1 shows the reconstructed di-electron invariant mass distribution from the $Z \rightarrow e^+e^-$ analysis at DØ (left) and the W transverse mass distribution in the $W \rightarrow \mu\nu$ channel at CDF (right). In the left plot electroweak backgrounds have been subtracted from the data (points) and the QCD multi-jet backgrounds are shown as the shaded area beneath the peak. The right hand plot shows the various estimated signal and background contributions as histograms and the measured data as points. In both cases good agreement between measurement and expectation is demonstrated.

RESULTS

TABLE 1. Summary of published CDF cross-section, ratio and indirect W width results [5]

Channel		stat	sys	lum	
$\sigma_W(e+\mu)$	2775	± 10	± 53	± 167	pb
$\sigma_Z(e+\mu)$	254.9	± 3.3	± 4.6	± 15.2	pb
$R(e+\mu)$	10.92	± 0.15	± 0.14		
Γ_W	2.079	± 0.042			GeV

TABLE 2. Summary of preliminary DØ cross section and ratio results

Channel		stat	sys	pdf	lum	
$\sigma_W \times Br(W \rightarrow e\nu)$	2865.2	±8.3	±62.8	± 40.4	± 186.2	pb
$\sigma_W \times Br(W \rightarrow \mu\nu)$	2989	±15	±81		± 194	pb
$\sigma_Z \times Br(Z \rightarrow e^+e^-)$	264.9	±3.9	± 8.5	± 5.1	± 17.2	pb
$\sigma_Z \times Br(Z \rightarrow \mu^+\mu^-)$	291	±3.0	± 6.9		± 18.9	pb
R(electron)	10.82	±0.15	± 0.25	± 0.13		

Tables 1 and 2 summarise the published results from CDF and the preliminary results from DØ respectively. For the CDF Z cross section results the quoted value represents the cross section including virtual photon effects within a di-electron mass window $66 < M_{ee} < 116$ GeV. The corresponding DØ results represent the pure Z cross section corrected for the full acceptance over the whole mass range. Seeing no evidence for breaking of lepton universality CDF have produced combined muon and electron cross section results. Work to combine the equivalent analyses at DØ is still underway. Separate columns are used for each of the contributing errors to the measurements. Where estimates of the uncertainties arising from the choice of parton density function (PDF) used in determining the acceptance corrections were available separately these have been quoted - in all other cases such effects are included in the total systematic error. These results are systematics limited at around the 2-3 % level, ignoring the uncertainty in the luminosity which contributes at around 6%. The uncertainties in the determination of the efficiency and acceptance corrections dominate the non-luminosity systematic errors. The contribution to systematic error deriving from the uncertainty in the PDFs used in the acceptance correction is between 1.7 and 2.0 % depending on the channel. The uncertainty on the luminosity is correlated between the two experiments with approximately 4% coming from understanding the performance of the luminosity detectors and around 4.5% from the error on the total $p\bar{p}$ cross section.

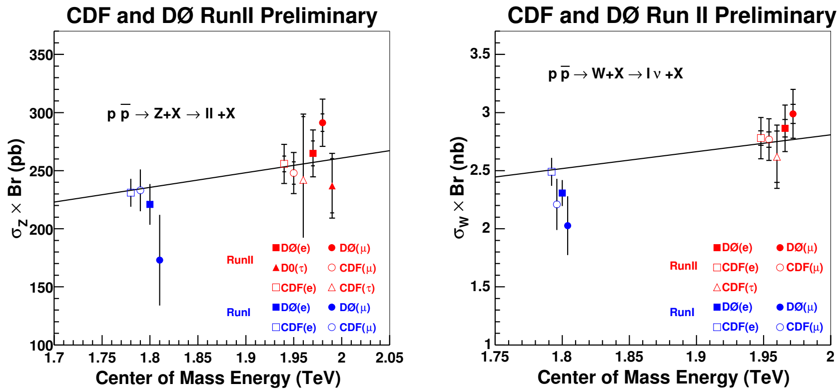

FIGURE 2. Summary of Z (left) and W (right) boson production cross-section times leptonic branching ratio results from Run I and Run II

Figure 2 summarises graphically the results from Run I and the results reported here. The points have been displaced horizontally for clarity but represent results from $\sqrt{s} = 1.8$ TeV and $\sqrt{s} = 1.96$ TeV. The solid curve shows the Standard Model predictions.

The ratio of the cross sections times branching fractions can be defined as in Equation 1. From the measured value of $Br(Z \to l^+l^-) = 0.033658 \pm 0.000023$ [7] and a theoretical calculation at NLO of the production cross section ratio [6] CDF extract a measurement of the W leptonic branching ratio: $Br(W \to l\nu) = 0.1089 \pm 0.0022$. With these numbers and the theoretical value of the W partial width, $\Gamma(W \to l\nu) = 226.4 \pm 0.3$MeV [7] the total width of the W can be extracted: $\Gamma_W = 2079 \pm 42$ MeV.

$$R = \frac{\sigma_W \times Br(W \to l\nu)}{\sigma_Z \times Br(Z \to ll)} = \frac{\sigma_W}{\sigma_Z} \frac{\Gamma_Z}{\Gamma_{Z \to ll}} \frac{\Gamma_{W \to l\nu}}{\Gamma_W} \quad (1)$$

CONCLUSIONS

CDF and DØ have measured the W and Z boson production times leptonic branching fractions and their ratios. These are high precision, systematics limited measurements at the 2-3% level with an uncertainty from the luminosity of around 6%. Good agreement is found between data and Standard Model predictions.

REFERENCES

1. T. Affolder *et al.* (CDF Collab.), Phys. Rev. Lett., **84**, 845, (2000)
2. F. Abe *et al.*, (CDF Collab.), Phys. Rev., **D59**, 052002, (1999)
3. B. Abbott *et al.* (DØ Collab.), Phys. Rev., **D60**, 05203, (1999)
4. F. Abe *et al.*, (CDF Collab.), Phys. Rev. Lett., **76**, 3070, (1996)
5. D. Acosta *et al.*, (CDF Collab.), Phys. Rev. Lett., **94**, 091803, (2005)
6. See [5] and references therein.
7. K. Hagiwara *et al.*, Phys. Rev., **D66**, 010001, (2002)