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MEASUREMENTS OF THE W AND Z PRODUCTION CROSS SECTIONS TIMES THE LEPTONIC BRANCHING RATIOS AT THE FERMILAB TEVATRON

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We report measurements of inclusive cross sections times branching ratios in electrons, muons or taus for W and Z bosons produced in $p\overline{p}$ collisions at 1.96 TeV using data collected with the DØ and CDF detectors in 2002-2004. Using the ratio of the cross sections times branching ratios for the W and Z bosons we also obtain constraints on the total decay width of the W boson.

Keywords: W-width; Electroweak boson production.

1. Introduction

Run II of the Fermilab Tevatron presents us with a unique opportunity to study W and Z boson physics. Compared to the LEP and SLD accelerators, where many of best measurements of electroweak parameters have been made to date, the Fermilab Tevatron has three unique advantages:

- The Tevatron produces a large flux of W bosons.
- The Tevatron is able to produce Z/γ^* bosons at high masses.
- As the colliding particles are protons and anti-protons, the W and Z bosons produced are particularly sensitive to up and down quarks.

These unique features, along with new detectors in the forward regions of the experiments, allow CDF and DØ to probe a wide range of electroweak physics.

The first electroweak physics results from run II of the Tevatron are measurements of the inclusive W and Z cross sections times the branching ratio into leptonic final states [1]. As an example, the cross section times branching ratio for Z decaying into muons may be calculated as:

$$\sigma \cdot \mathrm{BR}(p\overline{p} \to Z \to \mu^+\mu^-) = \frac{N_{cands} - N_{backg}}{A \cdot \epsilon \cdot L}. \tag{1}$$

Where N_{cands} is the number of $Z \to \mu^+\mu^-$ candidate events; N_{backg} is the estimated number of background events; $A \cdot \epsilon$ is the acceptance times efficiency for finding

Table 1. Integrated luminosity, number of candidate events, background estimates and acceptance times efficiency for used for the CDF and DØ measurements of $p\overline{p} \to W \to \ell\nu$.

Signal		L	N_{signal}	background	$A \cdot \epsilon$
CDF central:	$W \to e\nu$	72 pb^{-1}	37584	$(4.4 \pm 0.8)\%$	$(18.0 \pm 0.4)\%$
CDF forward:	$W \to e\nu$	64 pb^{-1}	10461	$(8.7 \pm 0.6)\%$	$(5.2 \pm 0.2)\%$
DØ:	$W \to e\nu$	194 pb^{-1}	57109	$(7.3 \pm 0.5)\%$	$(9.6 \pm 0.2)\%$
CDF:	$W \to \mu\nu$	177 pb^{-1}	175572	$(33.6 \pm 0.4)\%$	$(22.6 \pm 0.5)\%$

Table 2. Integrated luminosity, number of candidate events, background estimates and acceptance times efficiency for used for the CDF and DØ measurements of $p\overline{p} \to Z \to \ell^+\ell^-$.

Signal			L	N_{signal}	$A \cdot \epsilon$
CDF:	$Z \to e^+e^-$	$66 < m_{ee}/\mathrm{GeVc}^{-2} < 116$	72 pb^{-1}	4242	$(22.7 \pm 0.5)\%$
DØ:	$Z \to e^+e^-$	$70 < m_{ee}/\mathrm{GeVc}^{-2} < 110$	177 pb^{-1}	4712	$(9.6 \pm 0.4)\%$
CDF:	$Z \to \mu^+\mu^-$	$66 < m_{\mu\mu}/\mathrm{GeVc}^{-2} < 116$	194 pb^{-1}	3568	$(7.3 \pm 0.2)\%$
DØ:	$Z \to \mu^+\mu^-$	$m_{\mu\mu} > 40$ GeV/c^2	148 pb^{-1}	14353	22.1% to 31.6%

$Z \to \mu^+\mu^-$ candidate events and L is the integrated luminosity of the sample. The integrated luminosity is measured separately by both the CDF and DØ experiments with an uncertainty of ±6%. For the W and Z signals, backgrounds come from QCD processes where a jet may fake a lepton signal, other electroweak processes and cosmic rays (for muon final states). The acceptance (A) is calculated from Monte Carlo samples; all of the other efficiencies (ϵ) are calculated directly from the data.

2. Inclusive *W* Signals

The signature of W boson decay into a charged lepton and a neutrino is a reconstructed electron or muon and a large missing-E_T signal ($\not\!\!E_T$). Missing-E_T is a measure of the imbalance of the calorimeter energy transverse to the beam direction. We calculate the 'transverse mass' of the lepton-neutrino system using only the transverse components of the lepton and neutrino as follows:

$$m_T = \sqrt{E_T(\nu) \cdot E_T(\ell) - p_x(\nu) \cdot p_x(\ell) - p_y(\nu) \cdot p_y(\ell)}. \qquad (2)$$

The neutrino momentum is taken from the $\not\!\!E_T$ calculation. Figure 1 shows the reconstructed transverse mass of electrons and neutrinos from CDF. Table 1 gives the number of signal events, background, luminosity and acceptance times efficiency for the $W \to \ell\nu$ measurements. The results for the cross sections times branching ratio for $p\overline{p} \to W \to \ell\nu$ decays are shown in figure 2.

3. *Z* Decays into Electrons and Muons

In order to reconstruct $Z \to e^+e^-$ and $Z \to \mu^+\mu^-$ events, both CDF and DØ select events with two oppositely-charged leptons. One lepton is required to satisfy a set of 'tight' identification requirements; looser requirements are made on the second lepton. Backgrounds to these events are less than 2%, coming mainly from QCD processes and cosmics. Table 2 gives the number of $Z \to \mu^+\mu^-$ and $Z \to e^+e^-$ candidate events, $A \cdot \epsilon$ and luminosity used for each measurement. Results for the cross section times branching ratio of $p\overline{p} \to Z \to \ell^+\ell^-$ events are shown in figure 2.

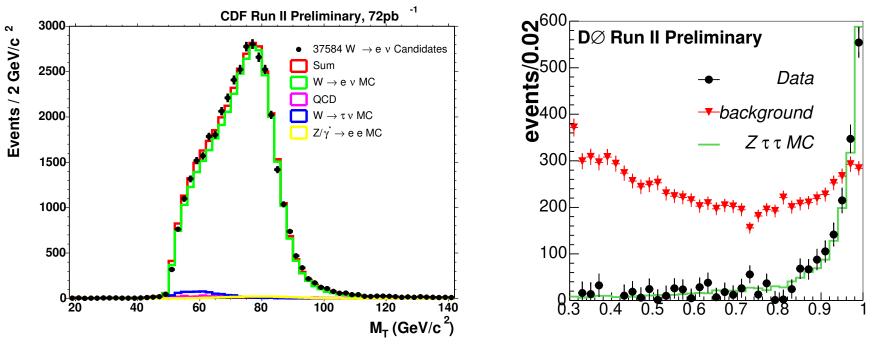

Fig. 1. Left: transverse mass for $W \to e\nu$ candidate events from CDF. Right: Output of a neural net for $Z \to \tau^+\tau^-$ events and backgrounds from DØ.

4. Tau-Lepton Reconstruction

Tau-leptons decay before they reach the detector and are therefore more difficult to reconstruct than electrons or muons. DØ uses a neural net (NN) to identify τ-lepton decays. The neural net uses electromagnetic energy and track momentum information and is trained using MC sample to find $\tau \to$ hadrons and $\tau \to e\nu_e\nu_\tau$ signals. Figure 1 shows the output of the neural net compared a simulation of the signal and the backgrounds. A cut is made on the output > 0.8 to select tau candidates. The NN is used to reconstruct $Z \to \tau^+\tau^-$ decays from a muon trigger sample; one of the taus is reconstructed using the NN, and the other by looking for $\tau \to \mu\nu_\mu\nu_\tau$ decays. 1946 $Z \to \tau^+\tau^-$ candidate events are found in 207 pb^{-1}. The background and acceptance times efficiency are estimated to be $(55 \pm 2)\%$ and $(1.65 \pm 0.09)\%$ respectively.

CDF has looked for τ-leptons using a more conventional method. To reconstruct tau decays into hadrons, CDF selects narrow, isolated jets with low track multiplicity. The invariant mass of the tracks and π^0s in the jet must be less than the τ-lepton mass. Using 72 pb^{-1} CDF reconstructs 50 $Z \to \tau^+\tau^-$ and 2345 $W \to \tau\nu$ candidate events with estimated backgrounds of $(21 \pm 6)\%$ and $(26 \pm 3)\%$ respectively. The acceptance times efficiency is about 0.5% for the $Z \to \tau^+\tau^-$ channel and $(0.91 \pm 0.05)\%$ for the $W \to \tau\nu$ channel.

The results for the cross sections times branching ratios are shown in figure 2.

5. Physics Results

The ratio R of the inclusive W and Z cross sections is defined as:

$$R = \frac{\sigma \cdot \mathrm{BR}(p\overline{p} \to W \to \ell\nu)}{\sigma \cdot \mathrm{BR}(p\overline{p} \to Z \to \ell^+\ell^-)} = \frac{\sigma(p\overline{p} \to W)}{\sigma(p\overline{p} \to Z)} \cdot \frac{\Gamma(Z)}{\Gamma(Z \to \ell\ell)} \cdot \frac{\Gamma(W \to \ell\nu)}{\Gamma(W)} \qquad (3)$$

Many uncertainties, including the largest uncertainty from the luminosity measurement, cancel in the ratio. Furthermore, R may be used to extract a value for the

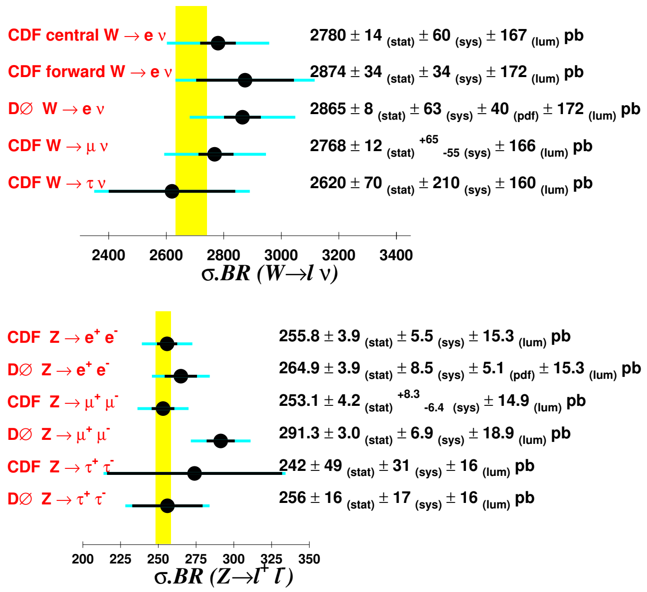

Fig. 2. Measured cross section time branching ratio for $p\overline{p} \to W$ and $p\overline{p} \to Z$ production at the Tevatron. The light colored part of each error bar indicates the uncertainty from the luminosity measurement. The yellow band indicates the NNLO prediction.

width of the W-boson, $\Gamma(W)$. Using 72 pb^{-1} of data, CDF has measured:

$$R = 10.92 \pm 0.15(stat) \pm 0.14(sys) \tag{4}$$

Using Standard Model values for the ratio of the production cross sections and $\Gamma(W \to \ell\nu)$ [2,3], and the measured value of $\mathrm{BR}(Z \to \ell\ell)$ [3], we obtain:

$$\Gamma(W) = 2079 \pm 41\ \mathrm{MeV/c^2} \tag{5}$$

which is as accurate as the 2004 world average value of $\Gamma(W) = 2124 \pm 41$ MeV/c^2 [3].

6. Conclusions

CDF and DØ have measured the cross section times branching ratios of W and Z bosons into all three lepton types, the first electroweak physics measurements from the Tevatron. These results have been used to obtain a value for the width of the W-boson.

References

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