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CDF

Measurement of W and Z Boson Production and Extraction of the W Width and Branching Ratios at CDF

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Abstract

We present results from W and Z boson production in proton-antiproton collisions at $\sqrt{s} = 1.8\ TeV$ using the CDF detector. We measure the W and Z cross sections times lepton branching ratio, $\sigma(p\bar{p} \to W) \cdot B(W \to l\nu_l)$ and $\sigma(p\bar{p} \to Z) \cdot B(Z \to l^+l^-)$ $l = e, \mu$. We also measure the ratio: $R_l = \sigma \cdot B(W \to l\nu_l)/\sigma \cdot B(Z \to ll)$. From R_l, we extract the W electron and muon branching ratios, $BR(W \to l\nu_l)$, and the total W width, Γ_W. In addition, high transverse mass $W \to e\nu_e$ candidates provide an alternate, direct measurement of Γ_W.

1. Introduction

The Tevatron $p\bar{p}$ collider, operating at a center of mass energy of $\sqrt{s} = 1.8\ TeV$ provides a unique window into the electroweak and QCD sectors at an energy scale capable of producing real W and Z bosons. The measurement of W and Z production and decay rates simultaneously probes electroweak theory, the structure of the proton and tests QCD theory through associated jet production. Using the CDF detector we measure the W and Z cross sections times leptonic branching ratio in the electron and muon channels:

$$\sigma_W^l = \sigma(p\bar{p} \to W^\pm) \cdot (W^\pm \to l\nu_l) \qquad \sigma_Z^l = \sigma(p\bar{p} \to Z^0) \cdot (Z^0 \to l^+l^-) \qquad l = e, \mu$$

With the dramatically increased data sample from the 1992-93 Tevatron collider run and a substantially improved luminosity measurement, we can measure W and Z production and decay rates with significantly improved precision. We compare our results to recent next-to-next-to-leading order QCD predictions using the latest proton structure functions.

The ratio of cross sections times branching ratios can be expressed as:

$$R_l = \frac{\sigma_W^l}{\sigma_Z^l} = \frac{\sigma(p\bar{p} \to W)}{\sigma(p\bar{p} \to Z)} \cdot \frac{\Gamma(W \to l\nu_l)}{\Gamma(W)} \cdot \frac{\Gamma(Z)}{\Gamma(Z \to l^+l^-)} \qquad l = e, \mu$$

With the theoretical prediction of the production cross sections and the partial and total width measurements from the LEP experiments, we can extract the W leptonic branching ratios and the W total width (Γ_W). The W width is well predicted by the standard model, so the comparison represents a precision test of the consistency of electroweak theory. We also present a direct measurement of the the W total width from the high transverse mass region of the $W \to e\nu$ candidate sample, independent of the theoretical assumptions and values.

2. Measurement of Cross Sections and Ratios

Experimentally, the individual cross sections and their ratio can be expressed as:

$$\sigma_W = \frac{N_W - B_W}{\epsilon_W \cdot A_W \cdot \int \mathcal{L}} \qquad \sigma_Z = \frac{N_Z - B_Z}{\epsilon_Z \cdot A_Z \cdot \int \mathcal{L}} \qquad R = \frac{\sigma_W}{\sigma_Z} = \frac{N_W - B_W}{N_Z - B_Z} \cdot \frac{\epsilon_Z}{\epsilon_W} \cdot \frac{A_Z}{A_W}$$

Where N = number of candidates; B = background; A = geometric/kinematic acceptance; ϵ = trigger and event selection efficiencies; $\int \mathcal{L}$ = Integrated Luminosity. In the ratio, the

	$W \to \mu\nu$	$Z \to \mu\mu$	$W \to e\nu$	$Z \to ee$
Candidates	6222	423	13796	1312
Background	818 ± 123	1.7 ± 0.8	1700^{+171}_{-163}	21 ± 9
Signal	$5404 \pm 69 \pm 141$	$421 \pm 21 \pm 1.6$	$12096 \pm 117^{+163}_{-171}$	$1291 \pm 36 \pm 9$
A	0.163 ± 0.004	0.159 ± 0.003	0.342 ± 0.008	0.409 ± 0.005
ϵ	0.742 ± 0.027	0.747 ± 0.027	0.754 ± 0.011	0.729 ± 0.016
$\int \mathcal{L}^{vis}$, pb^{-1}	17.99 ± 0.68		19.03 ± 0.72	
$\sigma_W \cdot B$, nb	$2.484 \pm 0.031 \pm 0.129 \pm 0.094$		$2.508 \pm 0.024 \pm 0.072 \pm 0.095$	
$\sigma_Z \cdot B$, nb	$0.2029 \pm 0.0099 \pm 0.0090 \pm 0.0077$		$0.2314 \pm 0.0065 \pm 0.0058 \pm 0.0088$	
R_l	$12.24 \pm 0.62 \pm 0.48$		$10.90 \pm 0.32 \pm 0.29$	
$B(W \to l\nu)$	$0.1237 \pm 0.0062 \pm 0.0051$		$0.1094 \pm 0.0033 \pm 0.0031$	
Γ_W, GeV	$1.825 \pm 0.092 \pm 0.077$		$2.064 \pm 0.061 \pm 0.059$	

Table 1: W and Z production results; errors: statistical, systematic, luminosity

luminosity completely cancels, eliminating a large source of uncertainty in the individual cross sections. Common efficiency terms also cancel in the ratio and the uncertainty in the kinematic/geometrical acceptance is somewhat reduced by taking the ratio.

The candidate event selection for both the muon and electron channels follows a scheme to maximize the cancellation of the efficiency terms in the ratio and to minimize background in the W sample by making very tight, identical cuts on the primary lepton in both the W and Z candidate samples. We require the inclusive, high P_T electron or muon trigger at Levels 1,2 and 3 for both W and Z candidates. For the primary muon, the more important selection criteria are: track $P_T \geq 20$ GeV; minimum ionizing; muon chamber ($|\eta| <\sim 0.6$) track stub matches to central track; isolation in a surrounding cone $E_T(\Delta R \leq 0.4) \leq 2.0$ GeV [1]. For the primary electron, the main selection criteria are: central calorimeter ($|\eta| <\sim 1.1$) $E_T \geq 20$ GeV; small lateral tower energy sharing; $0.5 < E/p < 2.0$; track to strip chamber matching; isolation $E_T(\Delta R < 0.4)/E_T) < 0.1$. The event vertex in the longitudinal direction must be $|z| \leq 60$ cm from the detector center (electron and muon).

The secondary lepton requirements are much looser. For both electron and muon candidates, W candidates must have at least $\not{E}_T \geq 20$ GeV of unbalanced transverse energy, indicating the presence of a neutrino. For Z candidates, the secondary muon must fall anywhere within the central tracking chamber $|\eta| \leq 1.2$ with $P_T \geq 20$ GeV and be minimum ionizing. The secondary electron is allowed to fall in any calorimeter section: central, plug ($1.2 < |\eta| < 2.4$) or forward ($2.4 < |\eta| < 4.0$), with transverse energy cuts of $E_T \geq 20, 15, 10$ GeV respectively. The Z candidate dilepton invariant mass must be 66 $GeV \leq M_{ll} \leq 116$ GeV.

The geometric/kinematic acceptances (A) come from a simple Monte Carlo model and include the efficiency of the lepton and neutrino P_T cuts. The dominant uncertainties include: PDFs (MRS D'_- nominal), boson P_T spectrum and higher order QCD processes, underlying event model and neutrino resolution, and tracking and calorimeter resolution. The selection quality cuts and trigger efficiencies are factored out of the geometric and kinematic acceptance (ϵ); these selection/trigger efficiencies are computed using various control data samples and tend to be statistics limited.

The dominant backgrounds in the W sample include the processes $W \to \tau \to e$ or μ, $Z \to ll$ (one lepton is lost), and generic QCD jet events. In the muon sample, there are also small contributions from pion decay in flight and cosmic rays. For the $W \to e\nu$ sample, QCD processes dominate the background; for the $W \to \mu\nu$ sample, the $Z \to \mu\mu$ background dominates. The Z sample is almost background free. The $Z \to ee$ background comes mostly

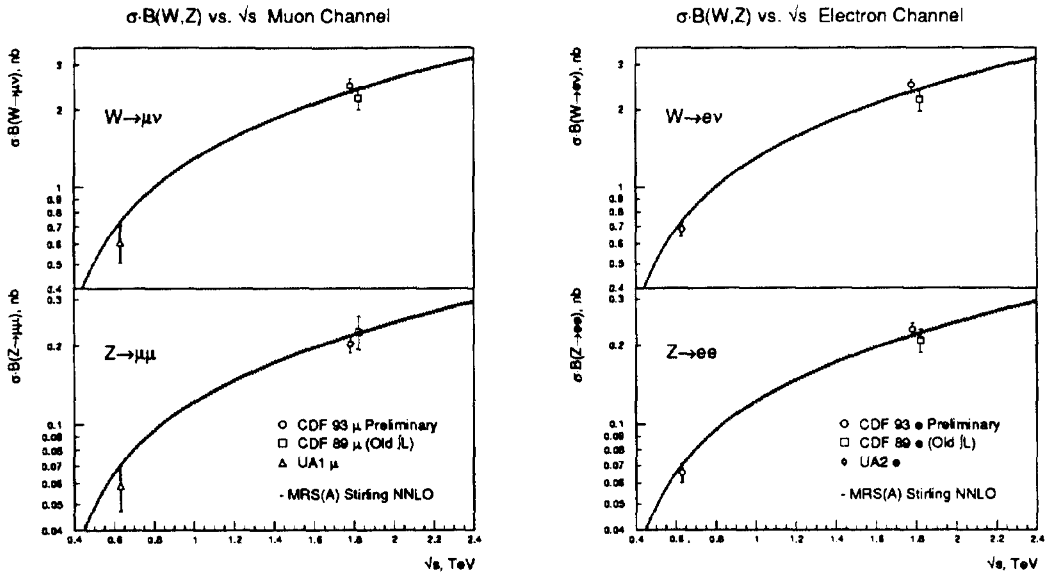

Figure 1: W and Z Cross Sections vs. center of mass energy; muon (left), electron (right)

from QCD processes; most of the $Z \rightarrow \mu\mu$ background comes from cosmic rays. In both Z samples, we apply a correction to remove the Drell-Yan continuum (and interference) terms from the Z cross section (1.005 ± 0.002 electrons; 1.03 ± 0.01 muons).

3. Cross Section and Ratio Results

The results for the cross sections, branching ratios and W width are summarized in table 1. Note that a correction factor has been applied to the luminosity to account for the event longitudinal position cut $|z| \leq 60\ cm$ of $\epsilon_{vertex} = (95.6 \pm 1.1)\%$, included in the luminosity uncertainty. We plot the cross section measurements in figure 1, with the theoretical prediction for $\sigma \cdot B$ vs. $\sqrt{s}$ using the MRS(A) parton distribution functions from a calculation by Stirling [4]. The former CDF, UA1, and UA2 published values are also plotted, from references [6, 7, 8, 9]. The dotted lines around the theory curve represent the spread in predictions due to variations in the parton distribution functions and the QCD scale. The error on $\sigma \cdot B$ is still too large to have discriminating power between the different sets of PDFs, but represents an important, independent test of their magnitude at this Q^2 and x scale (see reference [3]).

To extract the branching ratio and total width, we take the Z total and partial widths from LEP [5] and the production cross section ratio and ratio of partial widths from references [4, 3]. In figure 2 on the left, we plot the world values of the W width from the UA1, UA2, CDF and DØ published and preliminary numbers [6, 7, 8, 9, 10]. The theory value $\Gamma_W = 2.064 \pm 0.021\ GeV$ is from reference [2].

4. Direct Γ_W Measurement

We also extract the W total width directly from the high mass region of the W transverse mass spectrum, defined as $M_T \equiv \{2E_T^e E_T^\nu [1 - \cos(\Delta\phi)]\}^{1/2}$. Figure 2 (right) plots the transverse mass distribution for a special $W \rightarrow e\nu$ sample. This sample relaxes the quality cuts on the electron in order to avoid biasing against very high E_T electrons; extra cuts are applied to reduce the background: $E_T^e \geq 30\ GeV$, $P_T^W < 20\ GeV$, and more stringent

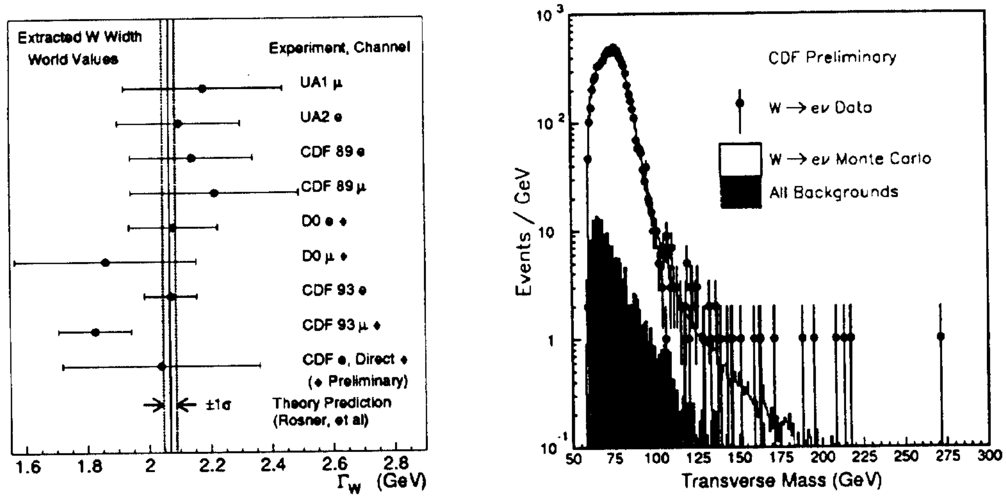

Figure 2: W Width world values (left); best fit W width to $W \to e\nu$ transverse mass (right)

Z candidate removal. Above the point $M_T \geq 110\ GeV$, the Breit-Wigner line shape starts to dominate over the gaussian resolution, and we perform a binned log-likelihood fit to the transverse mass shape in this region, using Monte Carlo templates of varying Γ_W. The fit yields a result of:

$$\Gamma_W = 2.04 \pm 0.28(stat) \pm 0.16(syst) \quad (direct,\ CDF\ preliminary)$$

The total uncertainty on this measurement is not competitive with the indirect extracted value from R_l, but represents the best direct measurement of the W width thus far. The statistical error dominates, which can be easily reduced during the current Tevatron run; the systematic error is dominated by uncertainty in the W boson P_T distribution, which can smear the M_T distribution; the next largest systematic error includes the neutrino resolution modelling.

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