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Measurements of the W and Z Inclusive Cross Sections and Determination of the W Decay Width[1,2]

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Recent results on the production of W and Z gauge bosons in $p\bar{p}$ collisions at $\sqrt{s} =$ 1.8 TeV at the Fermilab Tevatron Collider from the DØ and CDF experiments are reviewed. Measurements of the inclusive cross sections times leptonic branching ratios in both the electron and muon decay channels are summarized and compared to QCD predictions. Using the ratio $R = \sigma_W \cdot B(W \rightarrow l\nu)/\sigma_Z \cdot B(Z \rightarrow ll)$ and assuming standard model couplings, an indirect determination of the W decay width is obtained. By comparing this measured value with the predicted value for the W width, a limit on the deviation from the standard model is obtained.

The production cross sections times leptonic branching ratios of W and Z gauge bosons are one of the fundamental measurements that can be performed at a hadron collider. These measurements are of interest in their own right and, in addition, the ratio $R \equiv \sigma_W \cdot B(W \rightarrow l\nu)/\sigma_Z \cdot B(Z \rightarrow ll)$ provides a measurement of the W decay width. While the Z boson properties (including its decay width) have been measured to great precision at LEP, hadron colliders provide the only means of measuring the basic properties of the W boson at present.

In this paper, I summarize the recent results obtained by the DØ and CDF experiments on the production of W and Z bosons. Decays to final states including electrons and muons have been analyzed. The data samples used here are from the 1992–3 run of the Tevatron collider (Run 1a) for which the integrated luminosity was ~ 13 pb^{-1} and ~ 20 pb^{-1} for DØ and CDF, respectively. Preliminary results are also presented from DØ using a partial data sample from the 1994–95 run.

THE CROSS SECTION MEASUREMENTS

At $\sqrt{s} = 1.8$ TeV, vector boson production in $p\bar{p}$ collisions proceeds primarily via $q\bar{q}$ annihilation accompanied by the emission of gluons. In the cross section measurements described here there are no requirements on the jets or transverse momentum of the vector boson, so we are integrating over all orders of QCD processes. At this center of mass energy, processes such as $t\bar{t}$ or vector boson pair production contribute about a factor of a thousand less than $q\bar{q}$ annihilation to the inclusive cross section. Absolute predictions for σ_W and σ_Z have been calculated to order

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α_s^2 by van Neerven *et al.* [1]. The first order correction to the Born term is approximately a 20% increase; the change at the second order is approximately a 2% increase. The ratio σ_W/σ_Z, however, changes by only $\sim$ 0.6% in going from the Born approximation to the second order calculation. The major source of uncertainty in the calculation is due to the choice of parton distribution function (pdf).

Event Selection and Data Analysis

The W boson inclusive cross section is calculated as

$$\sigma_W \cdot B(W \rightarrow l\nu) = \frac{N_{obs} - N_{bkgd}}{\mathcal{A}_W \cdot \epsilon_W \cdot \mathcal{L}} \tag{1}$$

where N_{obs} is the observed number of candidate events, N_{bkgd} is the calculated number of expected background events, $\mathcal{A}_W$ is the kinematic and geometric acceptance, ϵ_W is the detection efficiency, and $\mathcal{L}$ is the integrated luminosity used in the analysis. The Z boson cross section, $\sigma_Z \cdot B(Z \rightarrow ll)$, is calculated in a similar fashion. In computing the cross section ratio, the luminosity and part of the systematic error cancels:

$$R = \frac{\sigma_W \cdot B(W \rightarrow l\nu)}{\sigma_Z \cdot B(Z \rightarrow ll)} = \frac{N_W \mathcal{A}_Z \epsilon_Z}{N_Z \mathcal{A}_W \epsilon_W} \tag{2}$$

where $N_W(N_Z)$ is the background corrected number of $W(Z)$ candidates.

In DØ [2], electrons are detected in hermetic, uranium liquid-argon calorimeters with an energy resolution of about $15\%/\sqrt{E(\mathrm{GeV})}$. The central and end calorimeter regions are used in both the W and Z analyses, covering pseudorapidity (η) range: $|\eta| < 1.1$ and $1.5 < |\eta| < 2.5$ respectively.

Muons are detected as tracks in three layers of proportional drift tube chambers outside the calorimeter: one 4-plane layer is located inside a magnetized iron toroid and two 3-plane layers are located outside. The muon momentum resolution is $\sigma(1/p) = 0.18(p-2)/p^2 \oplus 0.008$ (with p in GeV/c). Muons that passed through the central iron toroid ($|\eta| < 1.0$) were used in the analyses described here.

Neutrinos are inferred from the observed missing transverse energy ($\not\!\!E_T$) which is calculated using all the energy detected in the calorimeter cells out to pseudorapidity of 4.2. For electron channel decays, the $\not\!\!E_T$ resolution is dominated by the underlying event and is $\sim$ 3 GeV. For the muon channel decays, the muon transverse momentum is added to the calorimeter energy to calculate the total $\not\!\!E_T$, and the muon momentum resolution dominates the $\not\!\!E_T$ resolution.

The DØ W and Z electron channel analyses [3] base their event selection on a sample obtained with a single electron trigger ($Et > 20$ GeV). Offline, it is required that there be at least one electron with $E_T > 25$ GeV that passes "tight" electron identification cuts. Details of the electron identification are given in Ref. [4], with the main features being an electromagnetic (EM) cluster in the calorimeter with a matching track in the central tracking chambers. The electron is required to be isolated, with isolation fraction $I < 0.1$. The isolation variable is defined as $I = (E_{\mathrm{tot}}(0.4) - E_{\mathrm{EM}}(0.2))/E_{\mathrm{EM}}(0.2)$, where $E_{\mathrm{tot}}(0.4)$ is the total calorimeter energy inside a cone of radius $\sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.4$ and $E_{\mathrm{EM}}(0.2)$ is the electromagnetic energy inside a cone of 0.2. The cluster is also required to have transverse and longitudinal shapes consistent with those expected for an electron based on test beam measurements and Monte Carlo simulations.

To select $W \rightarrow e\nu$ candidates, in addition to the "tight" electron with $E_T > 25$ GeV, events are required to have missing transverse energy $\not\!\!E_T > 25$ GeV. To select $Z \rightarrow ee$ candidates, in addition to the "tight" electron with $E_T > 25$ GeV, events are required to have a second electron

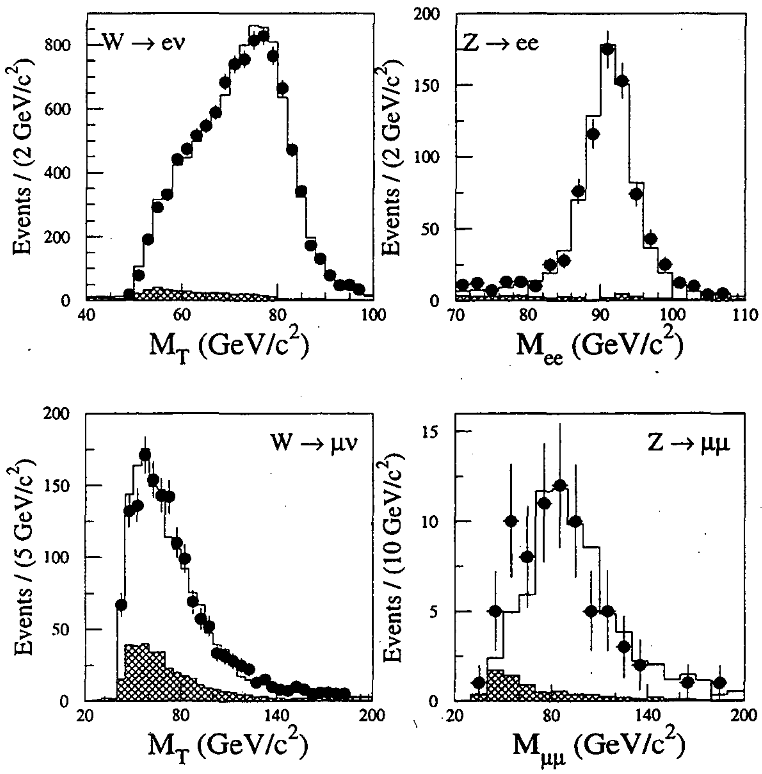

FIG. 1. Mass spectra from the DØ 1992–93 run. The points are the data, the shaded areas are the estimated backgrounds, and the histograms are the sum of the MC predictions and estimated backgrounds.

with $E_T > 25$ GeV but the electron identification requirements are loosened by not requiring the track match in order to increase the efficiency. The invariant mass of the electron pair is required to be in the range $75 < M_{ee} < 105$ GeV/c^2.

In an analysis of the 1992–93 data sample, corresponding to 12.8 ± 0.7 pb^{-1}, 10338 W and 775 Z candidate events were found. The mass spectra for the $W \to e\nu$ and $Z \to ee$ events are shown in Fig. 1.

The DØ muon channel W and Z analyses use an event sample that fired a single muon trigger that had a threshold of $p_T > 15$ GeV. Offline, the events were required to have a reconstructed muon with $p_T > 20$ GeV. For $W \to \mu\nu$ events, the missing transverse energy was required to be $\not\!\!E_T > 20$ GeV. For $Z \to \mu\mu$ events, the offline threshold on the second muon was lowered to 15 GeV and the muon identification criteria were loosened.

The main features of the DØ muon identification (see Refs. [3,4] for details) include a good quality muon track that has a calorimeter confirmation signal and has a stringent match with a track in the central detector. Cosmic ray background was reduced by rejecting muons that also had hits or tracks within 10° in θ and 20° in ϕ in the muon chambers on the opposite side of the interaction point. For the $W \to \mu\nu$ selection, events that were $Z \to \mu\mu$ candidates were removed.

From an analysis of the 1992–93 data sample, corresponding to 11.4 ± 0.6 pb^{-1}, 1665 W and 77 Z candidate events were found. The observed mass spectra for the $W \to \mu\nu$ and $Z \to \mu\mu$ events are shown in Fig. 1.

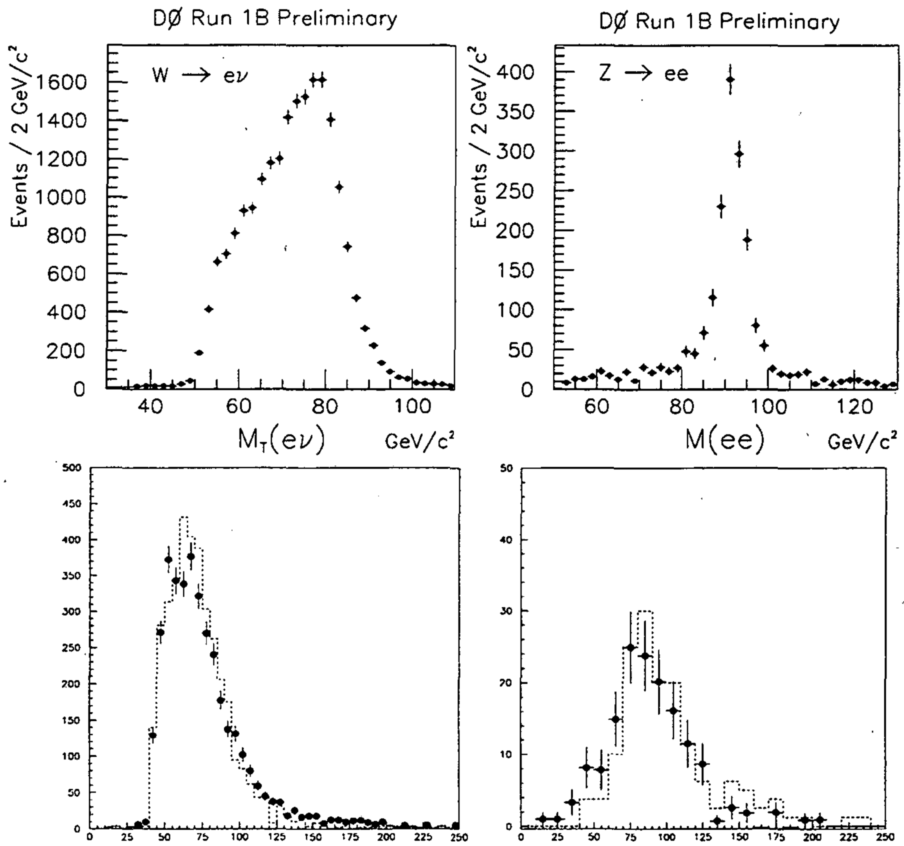

FIG. 2. Mass spectra (electron decay channels above, muon decay channels below) from a partial sample of the DØ 1994–95 data.

A preliminary analysis of a partial sample of the 1994–95 data, using the same requirements as described here, corresponding to 25.1 ± 1.4 pb^{-1}, yielded 20998 $W \rightarrow e\nu$ and 1634 $Z \rightarrow ee$ candidates; an analysis of 30.7 ± 1.7pb^{-1} yielded 4516 $W \rightarrow \mu\nu$ and 168 $Z \rightarrow \mu\mu$ candidates. The spectra are shown in Fig. 2.

In CDF [5,6], central electrons are detected in a lead–scintillator EM calorimeter that covers the rapidity range $|\eta| < 1.05$ with energy resolution of $13.5\%/\sqrt{E(\mathrm{GeV})}$. Forward electrons are detected in lead–proportional tube calorimeters that cover $1.1 < |\eta| < 2.4$ (plug) and $2.4 < |\eta| < 4.2$ (forward), with an energy resolution of $28\%/\sqrt{E(\mathrm{GeV})}$ (plug) and $25\%/\sqrt{E(\mathrm{GeV})}$ (forward). Neutrinos are identified using the missing transverse energy ($\not{E}_T$) in the event, where $\not{E}_T$ is the magnitude of the vector sum of all calorimeter tower transverse energies using towers $|\eta| < 3.6$. For W events, where the neutrino p_T is of order 20 – 40 GeV, the resolution on $\not{E}_T$ is ~ 3 GeV.

The electron channel W and Z analyses are based on a common set of inclusive electrons with $E_T > 20$ GeV in the central region. It is required that the event was triggered by a central electron. Tight selection criteria [6] are placed on this first, central electron including an isolation cut of $I < 0.1$ where I is defined as $I = ({E_T}^{Cone} - {E_T}^{Cluster})/{E_T}^{Cluster}$, and ${E_T}^{Cone}$ is the total transverse energy in a cone of 0.4 and ${E_T}^{Cluster}$ is the EM transverse energy in the electron

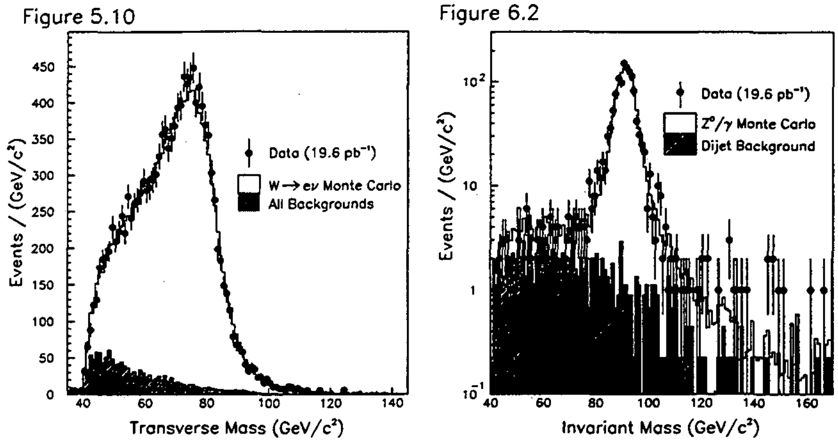

FIG. 3. Mass spectra from the CDF 1992–93 data.

TABLE 1. Estimates of Backgrounds

D0 1992–93 data	$W \to e\nu$	$Z \to ee$	$W \to \mu\nu$	$Z \to \mu\mu$
$N_{\rm obs}$	10338	775	1665	77
Backgrounds(%):				
Multijet	3.3 ± 0.5	2.8 ± 1.4	5.1 ± 0.8	2.6 ± 0.8
$Z \to ee, \mu\mu, \tau\tau$	0.6 ± 0.1	—	7.3 ± 0.5	0.7 ± 0.2
$W \to \tau\nu$	1.8 ± 0.1	—	5.9 ± 0.5	—
Cosmic/Random	—	—	3.8 ± 1.6	5.1 ± 3.6
Drell-Yan	—	1.2 ± 0.1	—	1.7 ± 0.3
Total Background(%)	5.7 ± 0.5	4.0 ± 1.4	22.1 ± 1.9	10.1 ± 3.7
CDF 1992–93 data	$W \to e\nu$	$Z \to ee$		
$N_{\rm obs}$	13796	1312		
Backgrounds(%)				
Multijet	6.5 ± 1.1	1.5 ± 0.7		
$Z \to ee$	2.0 ± 0.3	-		
$W \to \tau\nu$	3.4 ± 0.2	-		
$Z \to \tau\tau$	0.4 ± 0.1	0.1 ± 0.1		
Drell-Yan	—	0.5 ± 0.2		
Total Background(%)	12.3 ± 1.2	2.1 ± 0.7		

cluster.

W candidates are selected from the inclusive electron sample by requiring that the event is not a Z candidate and that the missing transverse energy of the event be $\not{E}_T > 20$ GeV. To select Z candidates, a second electron with looser identification criteria is required and is not restricted to the central region but can be in the plug or forward regions. The energy of this second electron is required to be $E_T > 20$ GeV if in the central, $E_T > 15$ GeV if in the plug, or $E_T > 10$ GeV if in the forward region. The invariant mass of the electron pair was required to be in the range $66 < M_{ee} < 116$ GeV/c^2.

The CDF 1992–93 data sample, which corresponds to 19.6 ± 0.7 pb^{-1}, yielded 13796 $W \to e\nu$ candidates and 1312 $Z \to ee$ candidates; the spectra are shown in Fig. 3.

The total backgrounds estimated for these event samples are shown in the spectra as hashed areas in Fig. 1 and Fig. 3 and are listed as a percentage of the observed number of events in Table 1.

TABLE 2. Analysis results

DØ 1992–93	$W \rightarrow e\nu$	$Z \rightarrow ee$	$W \rightarrow \mu\nu$	$Z \rightarrow \mu\mu$
Nobs	10388	775	1665	77
Background (%)	5.7 ± 0.4	4.0 ± 1.4	22.1 ± 1.9	10.1 ± 3.7
Acceptance (%)	46.0 ± 0.6	36.3 ± 0.4	24.8 ± 0.7	6.5 ± 0.4
Efficiency (%)	70.4 ± 1.7	73.6 ± 2.4	21.9 ± 2.6	52.7 ± 4.9
Integrated L (pb^{-1})	12.8 ± 0.7	12.8 ± 0.7	11.4 ± 0.6	11.4 ± 0.6
DØ 1994–95 *(Preliminary)*	$W \rightarrow e\nu$	$Z \rightarrow ee$	$W \rightarrow \mu\nu$	$Z \rightarrow \mu\mu$
Nobs	20988	1634	4516	168
Background (%)	17.3 ± 2.2	11.0 ± 2.4	17.3 ± 1.1	10.1 ± 3.7
Acceptance (%)	46.1 ± 0.6	36.3 ± 0.4	22.0 ± 0.9	5.1 ± 0.6
Efficiency (%)	66.9 ± 4.1	70.6 ± 4.6	28.6 ± 1.9	60.9 ± 2.6
Integrated L (pb^{-1})	25.1 ± 1.4	25.1 ± 1.4	30.7 ± 1.7	30.7 ± 1.7
CDF 1992–93	$W \rightarrow e\nu$	$Z \rightarrow ee$		
Nobs	13796	1312		
Background (%)	12.3 ± 1.2	2.1 ± 0.7		
Acceptance (%)	34.2 ± 0.8	40.9 ± 0.5		
Efficiency (%)	72.0 ± 1.3	69.6 ± 1.7		
Integrated L (pb^{-1})	19.6 ± 0.7	19.6 ± 0.7		

A major background to all the analyses is from QCD multijet events where a jet fluctuated so as to pass the lepton criteria. The details of how this is estimated in each analysis vary but the basic idea is to estimate the number of events in a background–dominated sample, such as non–isolated electrons, and extrapolate this into the signal region. The contamination in both the W and Z samples arising from $W \rightarrow \tau\nu$ and $Z \rightarrow \tau\tau$ decays is estimated by Monte Carlo. The W samples also contain background from $Z \rightarrow ll$ decays where one lepton is missed or misidentified. The DØ muon channel analyses have a residual cosmic ray background (Table 1). Finally, in determining the $Z \rightarrow ll$ cross section, a correction (which is listed as a background in Table 1) is made for the Drell–Yan process where the lepton pair is produced via a virtual photon. This correction is sensitive to the choice of Z mass window.

The combined kinematic and geometric acceptance for these analyses (Tables 2) are calculated by Monte Carlo, using a parton level generator. The transverse momentum distribution of the W and Z bosons are simulated in the DØ analyses using the NLO calculation of Arnold and Kauffman [7], while in the CDF analysis the MC 4-vectors are given the p_T distribution observed in the data. The 4-vectors are then run through a fast detector simulation which models the detector fiducial volume as well as the various resolutions. The largest contribution to the systematic error in the acceptance (Table 2) arises from the choice of pdf. Other errors included are from varying the W mass, the simulation of the $p_T(W)$ and $p_T(Z)$ distributions, radiative corrections, the detector simulation of the missing E_T distributions and the detector energy scale. In computing the ratio of the acceptances, $\mathcal{A}_W/\mathcal{A}_Z$, part of the systematic errors cancel. The ratios obtained are: 1.26 ± 0.013 (DØ electron), 3.82 ± 0.22 (DØ muon), and 0.835 ± 0.013 (CDF electron).

The net detection efficiency (Table 2) includes both the trigger and offline efficiencies. These are estimated from the data using $Z \rightarrow ll$ events since the trigger required only one lepton. In DØ, the electron channel trigger is found to be $\sim$ 95% efficient; the muon trigger efficiency is 40% (70%) efficient for $W(Z)$ boson events. The CDF efficiencies in Table 2 include a factor of (0.955 ± 0.011) which is the efficiency of the requirement that the primary vertex of the event be within 60 cm of the nominal interaction point. The systematic error partially cancels in forming the efficiency ratio, ϵ_W/ϵ_Z, and the values obtained are: 0.957 ± 0.017 (DØ electron), 0.416 ± 0.023

TABLE 3. Cross Section Results for electron (e), muon (μ), and combined ($e+\mu$) channels. When two errors are given the first is the statistical error and the second is total systematic error.

	$\sigma_W \cdot B(W^\pm \to l^\pm \nu)$ (nb)	$\sigma_Z \cdot B(Z \to l^+ l^-)$ (nb)	R
1992–93			
DØ (e)	$2.36 \pm 0.02 \pm 0.15$	$0.218 \pm 0.008 \pm 0.014$	$10.82 \pm 0.41 \pm 0.30$
DØ (μ)	$2.09 \pm 0.06 \pm 0.25$	$0.178 \pm 0.022 \pm 0.023$	$11.8^{+1.8}_{-1.4} \pm 1.1$
DØ ($e+\mu$)			10.90 ± 0.49
CDF (e)	2.51 ± 0.12	0.230 ± 0.012	$10.90 \pm 0.32 \pm 0.29$
1994–95 *(Preliminary)*			
DØ (e)	$2.24 \pm 0.02 \pm 0.20$	$0.226 \pm 0.006 \pm 0.021$	$9.9 \pm 0.3 \pm 0.8$
DØ (μ)	$1.93 \pm 0.04 \pm 0.20$	$0.159 \pm 0.014 \pm 0.022$	$12.3 \pm 1.1 \pm 1.2$
1988–89			
CDF (e)	$2.19 \pm 0.04 \pm 0.21$	$0.209 \pm 0.013 \pm 0.017$	$10.2 \pm 0.8 \pm 0.4$
Standard Model	$2.42^{+0.13}_{-0.11}$	$0.226^{+0.011}_{-0.009}$	

(DØ muon), and 1.035 ± 0.016 (CDF electron).

In both experiments, the luminosity is measured by scintillator hodoscopes. DØ [8] uses its Level 0 trigger hodoscope at $z = \pm 1.4$ m. The north-south coincidence rate is measured and corrected for multiple interactions. The visible cross section is calculated to be $\sigma_{L\emptyset} = 46.7 \pm 2.5$ mb, which results in a 5.4% relative error on the luminosity determination. This calculation is based on an average of the published CDF [9] and E710 [10] measurements of the total, elastic, and single diffractive cross sections, with the MBR [11] and Dual Parton Model DTUJET-93 [12] Monte Carlo routines used to determine the hodoscope acceptance. CDF uses for its luminosity measurement its BBC scintillator planes at $z = \pm 5.8$ m. The visible cross section, based on the CDF measurement [9] is $\sigma_{BBC} = 51.15 \pm 1.6$ mb, which yields a 3.6% relative error on the luminosity determination.

The resulting cross sections, which are calculated using Eq. 1, are listed in Table 3, where the first error given is statistical and the second is the total systematic error, including the luminosity. These values are compared to the theoretical prediction (taken from Ref. [3]) in Fig. 4. The total cross sections are calculated to be $\sigma_W = 22.35$ nb and $\sigma_Z = 6.708$ nb using a numerical calculation program from Ref. [1] and using the CTEQ2M pdf [13], $M_Z = 91.19$ GeV/c^2 [14], $M_W = 80.23 \pm 0.18$ GeV/c^2 [15], and $\sin^2\theta_W \equiv 1 - (M_W/M_Z)^2 = 0.2259$. The branching ratios used are $B(W \to l\nu) = (10.84 \pm 0.02)\%$ (calculated following Ref. [16] but with the above M_W), and $B(Z \to ll) = (3.367 \pm 0.006)\%$ [14]. The width of the band in Fig. 4 indicates the error in the predicted value, due primarily to the choice of pdf (4.5%) and to the use of a NLO pdf with the van Neerven *et al.* NLLO calculation [1] (3%).

THE W DECAY WIDTH

The ratio of these cross sections can be used to obtain an indirect measurement of the W leptonic branching ratio, B($W \to l\nu$), and the W total decay width, Γ_W. Using the measurement of R (Eq. 2), we obtain a measurement of the W leptonic branching ratio:

$$B(W \to l\nu) = \frac{B(Z \to ll)}{\sigma_W/\sigma_Z} \times R \tag{3}$$

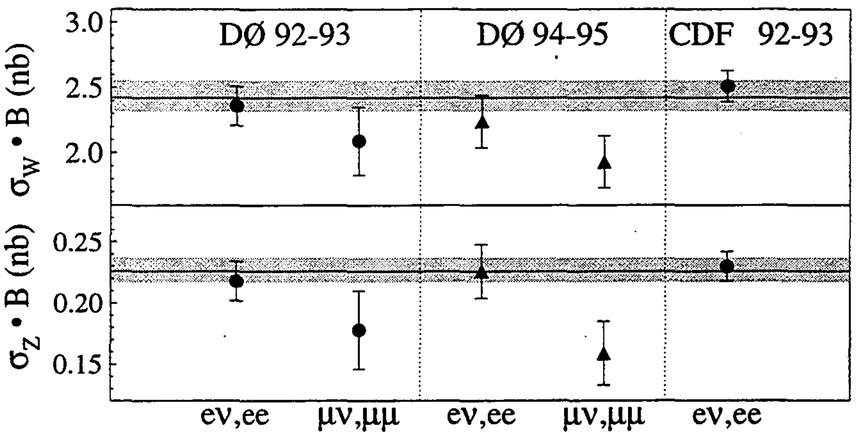

FIG. 4. $\sigma \cdot B$ for inclusive W and Z boson production from DØ and CDF for the 1992–93 data and preliminary results from DØ from part of the 1994-95 data. The error bars indicate the combined statistical and systematic errors. The solid lines are the predicted values calculated using the CTEQ2M pdf and the shaded bands indicate the uncertainty in the predictions.

where the factor multiplying R is computed from quantities independent of this measurement. $B(Z \to ll)$ is measured at LEP to be $(3.367 \pm 0.006)\%$ [14]. The predicted ratio of total cross sections σ_W/σ_Z has been calculated using the procedure and parameters given above to be $\sigma_W/\sigma_Z = 3.33 \pm 0.03$. The uncertainty in this ratio is dominated by the choice of pdf; the 1% error given here covers the variation obtained when using various CTEQ2 and MRS pdf's.

By further assuming the standard model partial width $\Gamma(W \to l\nu)$, we obtain a value for the W total decay width:

$$\Gamma_W = \frac{\Gamma(W \to l\nu)}{B(W \to l\nu)} = \frac{\Gamma(W \to l\nu) \cdot \sigma_W/\sigma_Z}{B(Z \to ll)} \times \frac{1}{R}. \tag{4}$$

The standard model W partial width is given [16] by:

$$\Gamma(W \to l\nu) = \frac{G_F}{\sqrt{2}} \frac{M_W^3}{6\pi}(1 + \delta) \tag{5}$$

where $\delta \sim -0.35\%$; there are no "oblique" corrections (i.e. through loops of new particles) beyond those to M_W itself. Using the value for M_W given above, this yields $\Gamma(W \to l\nu) = 225.2 \pm 1.5$ MeV. (In computing Γ_W from Eq. 4, the correlation of the error on $\Gamma(W \to l\nu)$ with that on σ_W/σ_Z through their common dependence on M_W is taken into account in the results given below.)

The values of the experimental ratio R are listed in Table 3. DØ combines its results from the electron and muon decay channels to obtain a combined value for R. Using Eq. 3, this yields a measurement of the leptonic branching ratio of $B(W \to l\nu) = (11.02 \pm 0.50)\%$ and, using Eq. 4, yields a measurement of the W width of $\Gamma_W = 2.044 \pm 0.092$ GeV.

From analysis of their electron channel data, CDF obtains [5,6] a value of R (Table 3) which yields a branching ratio of $B(W \to e\nu) = (10.94 \pm 0.33 \pm 0.31)\%$. From this they obtain a measurement of the W width of $\Gamma_W = 2.064 \pm 0.061 \pm 0.059$ GeV, where the input quantities used differed slightly from those given above. Using the the above input quantities and the CDF measured value of R yields $\Gamma_W = 2.043 \pm 0.082$ GeV. Assuming the values of R measured by each experiment are independent, they can be combined to give $R = 10.90 \pm 0.32$. Using the above input quantities this yields $\Gamma_W = 2.043 \pm 0.062$ GeV, where the 3.0% error predominately comes from the experimental error on R.

It is of interest to compare and combine this with the previous measurements of Γ_W which were done at the CERN $Sp\bar{p}S$ collider [17,18]. These measurements, which were done at $\sqrt{s} =$ 630 GeV, obtained:

$$R = 9.5^{+1.1}_{-1.0} \qquad \Gamma_W = 2.18^{+0.26}_{-0.24} \pm 0.04\text{GeV} \quad \text{(UA1)}$$
$$R = 10.4^{+0.7}_{-0.6} \pm 0.3 \quad \Gamma_W = 2.10^{+0.14}_{-0.13} \pm 0.09\text{GeV} \quad \text{(UA2)}$$

The R values from these experiments can be combined to give $R = 10.11 \pm 0.59$. Using a theoretical total cross section ratio [18] of $\sigma_W/\sigma_Z = 3.26 \pm 0.09$ for this center of mass energy and using the same values for $B(Z \to ll)$ and $\Gamma(W \to l\nu)$ as above, these measurements give a combined value of $\Gamma_W = 2.16 \pm 0.14$ GeV. Finally, the CERN and Fermilab measurements can be combined to obtain a world average of $\Gamma_W = 2.062 \pm 0.059$ GeV. In forming this average, in order to allow for a correlation of the errors on the predicted cross section ratio σ_W/σ_Z at the two center of mass energies through the choice of pdf, the errors due to the input quantities are combined linearly, while the experimental errors (i.e. due to R) are combined in quadrature.

The standard model prediction of the W total width is a function of the W mass, and using the value of M_W given above we obtain:

$$\Gamma_W = (3 + 6(1 + \alpha_s(M_W)/\pi) \cdot \Gamma(W \to l\nu) = 2.077 \pm 0.014 \text{ GeV} \tag{6}$$

with which the experimental value is in very good agreement. In the past this comparison of measured and theoretical values of Γ_W was used to set a model independent limit on the mass of the top quark for the case of $m_t < M_W$. Given that the top quark is in fact much heavier than the W boson, this comparison can be used to set an upper limit on the "excess width", $\Delta\Gamma_W \equiv \Gamma_W(\text{meas}) - \Gamma_W(\text{SM})$, allowed by experiment for non–standard model decay processes, such as decays into supersymmetric charginos and neutralinos [19], or into heavy quarks [20]. Comparing the above world average value of Γ_W with the standard model prediction gives a 95% CL upper limit of $\Delta\Gamma < 109$ MeV on unexpected decays.

While the indirect method gives the most precise measurements of Γ_W, there is much interest in performing a direct measurement from the W lineshape itself. CDF has performed such an analysis [21] on their 1992–93 electron channel data. Using the W Breit–Wigner, a fit is performed to the transverse mass distribution far above the W pole ($M_T > 110$ GeV) where the Breit–Wigner tail dominates over the Gaussian resolution of the detector. A binned log–likelihood fit is performed to this region of the M_T distribution and the data is compared to Monte Carlo generated templates generated with $0.667 \leq \Gamma_W \leq 3.667$ GeV in steps of 200 MeV. Restricted to the tail of the distribution, the measurement is at present limited by statistics. They obtained $\Gamma_W = 2.11 \pm 0.28 \pm 0.16$ GeV, where the systematic error (8%) is dominated by uncertainty in modelling the W transverse momentum distribution (6%) and the missing E_T resolution (5%).

Summary and Prospects

From their analysis of their 1992–93 data, both DØ and CDF have obtained new measurements of the inclusive vector boson production cross sections. The ratio of these cross sections is measured to a precision of $\sim 4-5\%$ by each experiment. Combining these results with theoretical calculations we obtain a measurement of Γ_W that has an uncertainty of ~ 60 MeV ($\sim 3\%$). This is presently the most precise measurement of Γ_W. An independent method of directly fitting the lineshape is at present limited by statistics to a $\sim 15\%$ uncertainty. The 1994–95 run of the Tevatron is expected to yield integrated luminosities of ≥ 100 pb^{-1}, which will permit the experiments to reduce their errors on Γ_W to the $\sim 2\%$ level, limited by the uncertainties on the acceptance and efficiency. Also, the theoretical cross section ratio, which is limited by pdf uncertainties, will also make it difficult to significantly improve on this. By comparison, the direct method has been estimated [21] to result in a $\sim 5\%$ measurement, given a 200 pb^{-1} data sample and combining results from both experiments.

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