W properties at CDF

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Abstract.
W properties measured at CDF collaboration using up to 200 \( pb^{-1} \) are presented here. Measurements of the W inclusive cross sections in leptonic channels using different parts of the detector (central and forward) are shown. From these cross section measurements, lepton universality and W width are obtained. In addition, W charge asymmetry and W mass results from CDF are revised.

1. Introduction
Tevatron accelerator is currently the only accelerator which is able to produce W bosons. Measuring the W cross section precisely is an important check of the Standard Model. Furthermore, from the measured W cross section, other indirect measurements like the W width and lepton universality can be extracted.

The probability of finding a parton carrying a momentum fraction \( x \) in the incoming proton is expressed in the parton distribution function (PDF). The knowledge of PDFs is really important for a better understanding of MC simulation and physic analysis. Measuring the W charge asymmetry provides information on the ratio of \( d(x) \) and \( u(x) \) quarks in proton. Results helps to further constrain parton distribution functions.

The W boson mass measurement is a test to the Standard Model, but a precise determination gives also information on hypothetical new particles out of the Standard Model. In addition to top quark mass precise measurement, the W boson mass constrains the mass of the Higgs boson, giving an important input for the future accelerator LHC.

2. Inclusive cross section measurements
In hadronic colliders like Tevatron, the detection of W bosons trough their hadronic decay is overwhelmed by the QCD background. The decay of W bosons in leptons is the easier way to identify them. The signature of this decay is a high energy lepton and large missing transverse momentum originated from the neutrino. Due to the neutrino, mass can not be measured, thus transverse mass is measured:

\[
M_T = \sqrt{2p_T \cdot E_T(1 - \cos(\phi_\ell - \phi_{E_T}))}
\]  

(1)

The cross section times branching ratio is calculated as follows:

\[
\sigma \times BR(W \rightarrow \ell\nu) = \frac{N_{\text{cand}} - N_{\text{bkg}}}{A \times \epsilon \times \mathcal{L}}
\]  

(2)

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where $A$ is the detector kinematical acceptance, $\epsilon$ is the efficiency of the selection and $L$ is the luminosity. Even in the leptonic decays, QCD is one of the main contributions to the total background ($N_{bkg}$): one jet fakes a lepton and other gives missing energy. The W cross section has been measured at CDF [1] and DØ using different data and decays. Figure 1 shows a summary of the measurements in all leptonic decay modes. Measurements are in agreement with the NNLO calculations (vertical band) [2].

![Tevatron W→lν cross section measurements](image)

**Figure 1.** Summary of CDF and DØ W cross section measurements in all three leptonic decay channels.

2.1. W cross section measurement in the forward region

A new measurement has been performed at CDF taking advantage of the upgrade of the detector. W cross section has been performed using electrons in the forward region. W boson candidates are selected by requiring a high $E_T$ electron ($E_T > 20$ GeV in the region $1.2 < |\eta| < 2.8$) and large missing transverse energy coming from the neutrino ($E_T > 25$ GeV). Further cuts are applied to the electron candidate to increase sample purity. The energy deposit in the electromagnetic calorimeter is required to match a track from the tracking system and electron has to be isolated. The W cross section value obtained\(^1\) is $2.796 \pm 0.013 (\text{stat}) ^{+0.095}_{-0.090} (\text{sys}) \pm 0.168(\text{lum})$ nb. The result is in agreement with CDF measurements in the central region and with theoretical estimates.

2.2. Lepton universality in W decays

Lepton universality in W decays can be tested by extracting the ratio of the electroweak couplings $g_\mu/g_e$ and $g_\tau/g_e$ from the measured ratio $W \rightarrow \ell\nu$ cross sections. The $W \rightarrow \ell\nu$ couplings are related to the measured production cross sections as follows:

$$U = \frac{\sigma \times BR(W \rightarrow \ell\nu)}{\sigma \times BR(W \rightarrow e\nu)} = \frac{\Gamma(W \rightarrow \ell\nu)}{\Gamma(W \rightarrow e\nu)} = \frac{g_\ell^2}{g_e^2}$$

(3)

\(^1\) This is the last result from this analysis. The cross section value quoted was obtained just after the conference.
The results obtained are $g_\mu/g_e = 0.998 \pm 0.012$ and $g_\tau/g_e = 0.99 \pm 0.04$.

2.3. Indirect W width determination
The total width of the W boson can be extracted using known experimental and theoretical quantities. The ratio R of the cross section measurement for W and Z bosons is:

$$ R = \frac{\sigma \times BR(W \rightarrow \ell \nu)}{\sigma \times BR(Z \rightarrow \ell \ell)} = \frac{\sigma(p\bar{p} \rightarrow W)}{\sigma(p\bar{p} \rightarrow Z)} \frac{\Gamma(W \rightarrow \ell \nu)}{\Gamma(Z \rightarrow \ell \ell)} \frac{\Gamma(Z)}{\Gamma(W)} \quad (4) $$

Using equation 4, W width can be extracted using: precise measurements for the Z boson from LEP, NNLO calculation for W and Z production cross sections and the Standard Model prediction for $\Gamma(W \rightarrow \ell \nu)$. Considering $72 \, pb^{-1}$ for electron and muon channel the result obtained with this method is $2079 \pm 41 \, MeV$, which is compatible with Standard Model prediction.

3. W charge asymmetry
Cross section measurements are limited by the PDF uncertainties. More precise measurements can be obtained with a better knowledge of the parton distribution functions. One way to get information on PDFs is through the study of the W charge asymmetry.

\begin{figure}[h]
\centering
\includegraphics[width=0.45\textwidth]{figure2}
\caption{Measured asymmetry corrected for the effects of charge misidentification and background contamination.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.45\textwidth]{figure3}
\caption{Measured asymmetry corrected for the effects of charge misidentification and background contamination for the $\eta$ absolute value.}
\end{figure}

The W bosons at the Tevatron are produced through annihilation of $u$ and $d$ quarks. As the $u$ quarks carries on average a higher fraction of the proton momentum ($x$), process $u\bar{d} \rightarrow W^+$ tends to be boosted in the proton direction, while $W^-$ is boosted in the anti-proton direction. This leads to a forward-backward asymmetry for the $W^\pm$ boson production defined as:

$$ A(y_W) = \frac{d\sigma(W^+)/dy_W - d\sigma(W^-)/dy_W}{d\sigma(W^+)/dy_W + d\sigma(W^-)/dy_W} \quad (5) $$

where $y_W$ is the rapidity of the W bosons and $d\sigma(W^\pm)/dy_W$ is the differential cross section for $W^\pm$ boson production. Because it is not possible to know the neutrino momentum, the rapidity of the W bosons can not be measured directly from the W decay. The quantity that it is measured is:

$$ A(\eta_e) = \frac{d\sigma(e^+)/dy_e - d\sigma(e^-)/dy_e}{d\sigma(e^+)/dy_e + d\sigma(e^-)/dy_e} \approx \frac{d(x)}{u(x)} \quad (6) $$
where $\eta_e$ is the electron pseudo-rapidity. The observed asymmetry is a convolution of the W charge asymmetry with the $V-A$ couplings. This measurement is sensitive to the ratio of the $u$ and $d$ quark components of the parton distribution functions. CDF has measured this asymmetry in the electron channel [3] ($\eta_e < 2.5$) using $170 \text{ pb}^{-1}$. Figure 2 and figure 3 show the asymmetry corrected for the effects of charge misidentification and background contributions. Figure 3 includes the predictions from the CTEQ and MRST PDF sets for the asymmetry.

4. W mass

Final precision reached by the LEP experiments for the W mass was 42 MeV. At the end of Run I, Tevatron measured the W mass with an uncertainty of 59 MeV [4]. CDF has used the first $200 \text{ pb}^{-1}$ of Run II to estimate the W boson mass in the electron and muon decay channels. The measurement uncertainty includes contributions from simulation of the W boson production decay, lepton calibration and hadronic recoil energy and measurement modeling. There are main issues in the W mass measurement: calibration of the detector and good simulation of the transverse mass spectrum. The muon momentum scale is set using $J/\Psi \rightarrow \mu\mu$ and $\Upsilon \rightarrow \mu\mu$ signals. The electron energy scale is set using the ratio of the energy measured in the calorimeter with the electron momentum measured in the tracking. The $Z \rightarrow ee$ invariant mass is used to tune and cross-check the energy scale.

The list of systematics uncertainties in both the electron and muon channels is shown in Table 1. Combining all these uncertainties leads to a global systematic error of 76 MeV which is already lower than the CDF Run I systematic error (79 MeV).

![Figure 4. The reconstructed invariant mass of muon candidate pairs in the $\Upsilon(1S)$ region.](image)

![Figure 5. The $M_T$ distribution in W boson decays to muons. Points correspond to data, the histogram from the simulation is shown in blue.](image)

5. Summary

New more precise results have been issued using the first $200 \text{ pb}^{-1}$ of data from Tevatron. The W boson physics program at CDF is very successful. Cross sections have been measured in leptonic channels showing good agreement with NNLO calculations. Lepton universality and W width cross section values have been obtained using cross section measurements. CDF has measured the W charge asymmetry helping to improve the parton distribution functions. This new results will be included in the next generation of PDFs. A first measurement of the W mass has been performed obtaining an uncertainty of 76 MeV. With the additional data, uncertainty will be further reduced. CDF goal is to reduce it up to 40 MeV for 1-2 $fb^{-1}$. 

Table 1. The uncertainties on the W boson mass measurement in $MeV/c^2$ using 0.2 fb$^{-1}$ of Run 2 CDF data. The combined uncertainty is 76 $MeV/c^2$.

| Systematic Uncertainty          | Electrons | Muons |
|---------------------------------|-----------|-------|
| Production and Decay Model      | 30        | 30    |
| Lepton $E$ Scale and Resolution | 70        | 30    |
| Recoil Scale and Resolution     | 50        | 50    |
| Backgrounds                     | 20        | 20    |
| Statistics                      | 45        | 50    |
| Total                           | 105       | 85    |

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