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# W Asymmetry and Z Rapidity Measurements

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**Abstract.** The measurements of W charge asymmetry and Z rapidity distributions are inputs to constrain the parton distribution functions at high $Q^2$. The CDF and DØ experiments at the Tevatron have analyzed up to 340 $pb^{-1}$ of Run 2 data to measure the W charge asymmetry and Z rapidity. The measurements are in generally good agreement with predictions.

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## INTRODUCTION

The W and Z bosons are primarily produced by a quark and anti-quark annihilation in $p\bar{p}$ collisions at the Tevatron. Many precision measurements at the Tevatron are limited by the uncertainties on the parton distribution functions (PDFs). These include the W mass, cross section, transverse momentum distributions of W and Z bosons, and so on. For the W mass measurement in the CDF experiment, the current systematic uncertainty from PDF uncertainties is about 15 MeV/$c^2$ [1] and will become more significant as data accumulated.

The measurement of the W charge asymmetry provides input to the ratio of $u$ and $d$ quark components of PDFs, especially at the medium/high $x$. In the $p\bar{p} \to Z$ process, the momentum fraction of a parton is related to the Z rapidity ($y$)[1]. Analysis of the high $y$ region probes the PDFs at both high and low momentum fraction.

## W ASYMMETRY MEASUREMENT

The $W^+(W^-)$ bosons at the Tevatron are produced primarily by the annihilation of $u(d)$ quarks in the proton and $d(\bar{u})$ quarks in the anti-proton. Because u quarks carry, on average, more momentum than d quarks, the $W^+$ tend to follow the direction of the incoming proton and the $W^-$ that of the anti-proton.

The $W^\pm$ charge asymmetry

$$A(y_W) = \frac{d\sigma_+/dy_W - d\sigma_-/dy_W}{d\sigma_+/dy_W + d\sigma_-/dy_W}, \tag{1}$$

where the subscript (+,-) denotes the charge of the $W$ and $y_W$ is the rapidity of the $W$ bosons is a sensitive probe of the momentum fraction difference between $u$ and $d$ quarks

[1] $y = \frac{1}{2} \ln \frac{(E+P_z)}{(E-P_z)}$

in the $Q^2 \approx M_W^2$ region. A precise measurement of the $W$ asymmetry serves as a valuable constraint on the $u$ and $d$ quark momentum distributions. For $p\bar{p}$ collisions in leading-order parton model, $A(y_W)$ is given approximately by

$$A(y_W) \approx \frac{u(x_1)d(x_2) - d(x_1)u(x_2)}{u(x_1)d(x_2) + d(x_1)u(x_2)}, \tag{2}$$

where $x_{1,2} = x_0 e^{\pm y_W}$, $x_0 = M_W/\sqrt{s}$, and $s$ is the center of mass energy. The asymmetry, $A(y_W)$, is related to the slope of d/u at $Q^2 = M_W^2$ and in the moderate $x$ region of W production.

The rapidity of the W boson is not measured because the longitudinal momentum of the neutrino can not be experimentally determined. Therefore, we measure the lepton asymmetry, which is a convolution of the W production charge asymmetry and the V-A couplings in the W decay. The lepton asymmetry is still sensitive to PDFs and is defined as:

$$A(y_l) = \frac{d\sigma_+/dy_l - d\sigma_-/dy_l}{d\sigma_+/dy_l + d\sigma_-/dy_l}. \tag{3}$$

The CDF experiment measured the forward-backward charge asymmetry of electrons from W boson decays in $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV using a data sample of 170 $pb^{-1}$ of Run 2 data [2]. Candidate W $\rightarrow e\nu$ events were required to have exactly one electron candidate of $E_T$> 25 GeV, with $\not{E}_T$>25 GeV and transverse mass in the range 50 GeV/$c^2$ < $M_T$ < 100 GeV/$c^2$.

The CDF experiment improved its sensitivity to the PDFs by reducing the decay asymmetry. The measurement separates the asymmetry measurement into two bins: 25 GeV < $E_T$ < 35 GeV and 35 GeV < $E_T$ < 45 GeV (Figure 1 and 2). This is done for the first time and the separation into different bins is a novel addition to the previous measurements. Predictions from CTEQ [3] and MRST [4] PDFs using a NLO RESBOS calculation [5] are shown for comparison.

The CDF Collaboration is additionally developing a new method to measure the W asymmetry directly by partially reconstructing W rapidity using a W mass.

## Z RAPIDITY DISTRIBUTION

Measurement of the rapidity distribution of Drell-Yan pairs in the Z boson mass region provides a stringent test of PDFs. At leading order (LO), the momentum fraction, $x_+(x_-)$, carried by the parton from the proton (anti-proton) is related to the rapidity of the Z boson via the equation:

$$x_\pm = \frac{M_Z}{\sqrt{s}} e^{\pm y} \tag{4}$$

where $M_Z$ is the mass of Z boson. Therefore the analysis of the high $y$ region probes the high $x$ as well as low $x$ region.

The DØ experiment measures the rapidity distribution, $d\sigma/dy$, of the Drell-Yan process in the dielectron's mass range between 71 and 111 GeV/$c^2$ [6]. The data were collected with the DØ detector in Tevatron $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV using a data

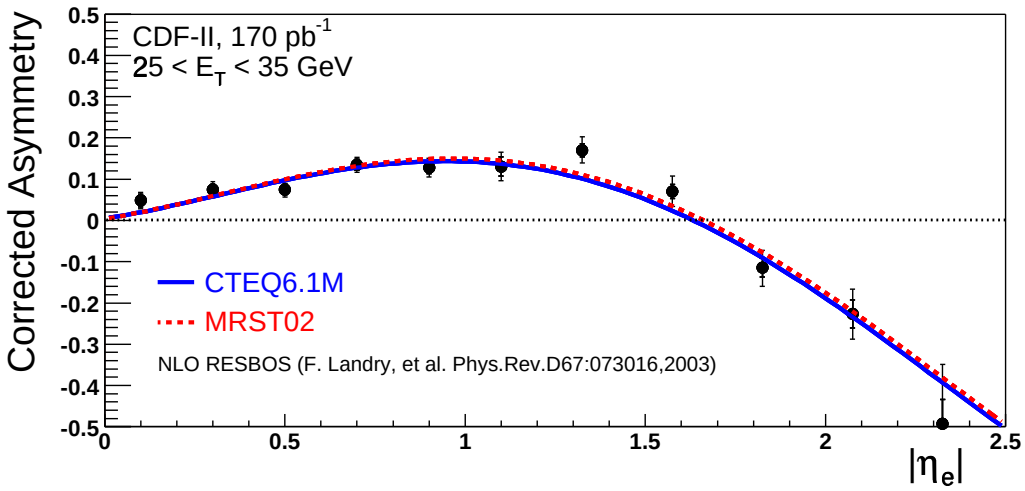


**FIGURE 1.** The measured lepton charge asymmetry for 25 GeV < $E_T$ < 35 GeV with predictions from CTEQ6.1M (solid) and MRST02 (dashed) PDFs using a NLO RESBOS calculation. Both statistical and total (statistical+systematic) uncertainties are shown.

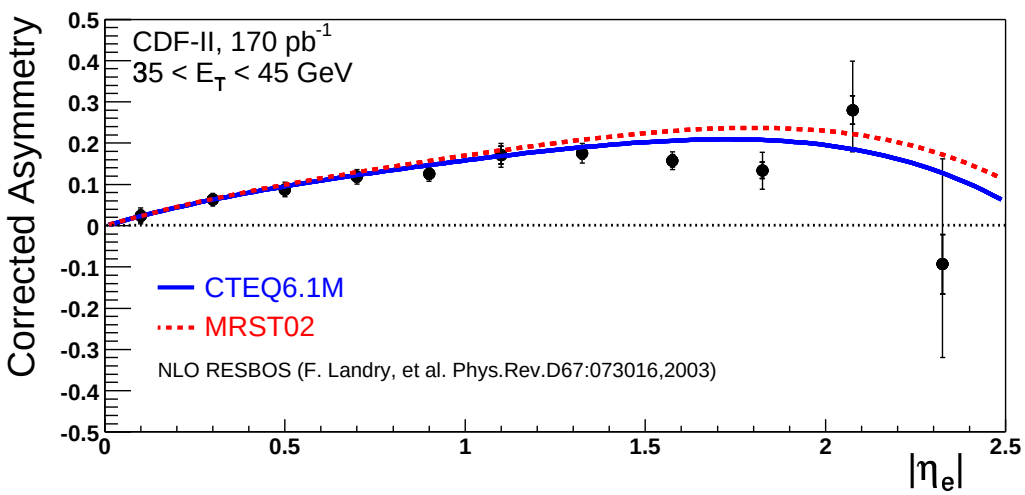


**FIGURE 2.** The measured lepton charge asymmetry for 35 GeV < $E_T$ < 45 GeV with predictions from CTEQ6.1M (solid) and MRST02 (dashed) PDFs using a NLO RESBOS calculation. Both statistical and total (statistical+systematic) uncertainties are shown.

sample of 337 $pb^{-1}$ of Run 2 data. The final result, with statistical and systematic errors, is shown in Figure 3. The measurement of $d\sigma/dy$ is compared with a prediction using an NNLO calculation based on the MRST 2001 PDFs [7]. The DØ forward calorimeters provide data over almost the entire rapidity range accessible at Tevatron. Measurements are in generally good agreement with the prediction.

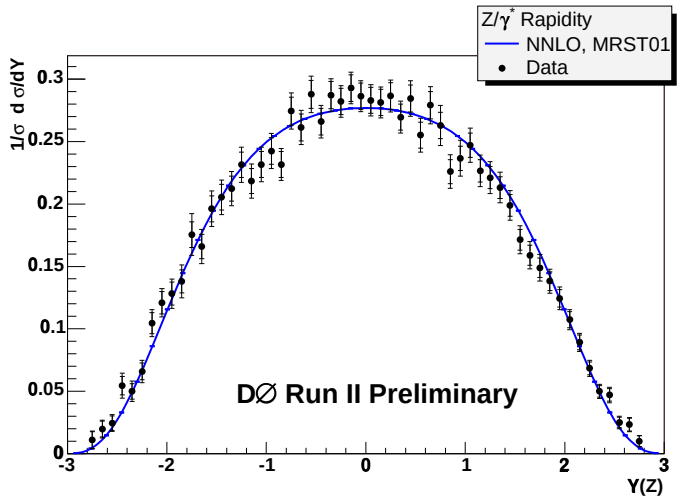


**FIGURE 3.** The DØ measurement of the Z rapidity distribution. The outer error bars show the total error (statistical+systematic), while the inner error bars indicate the statistical error alone. The solid line shows the NNLO prediction based on the MRST 2001 PDFs.

## CONCLUSIONS

The CDF experiment have measured the W charge asymmetry. Since the previous measurements upon which the current predictions are based are least constraining for $|\eta|>1$ and do not separate the $E_T$ dependence, inclusion of the new W asymmetry results will further constrain future fits and improve the predictions. The DØ measurement of the Z rapidity distribution is in generally good agreement with theory prediction. We expect that Tevatron Z and W measurements will provide important input to constrain the PDFs, especially in the high *x* region.

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