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W production Asymmetry measurements with partial reconstruction

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Abstract

We describe a measurement of the W production asymmetry. Because the neutrino from W decay is not detected in the CDF detector, we partially reconstruct the W rapidity using measured lepton momentum, the missing E_T, and a given world average W mass.

1. Introduction

W bosons are produced primarily by the annihilation of $u(d)$ quarks in the proton-antiproton collisions. The momentum fraction carried by the partons, x_1 of $u(\bar{u})$ and x_2 of $d(\bar{d})$ in the proton (antiproton) are related to the rapidity, y, of a produced W boson as:

$$x_{1,2} = \frac{M_W^2}{\sqrt{s}} e^{\pm y}$$

where W rapidity is defined as:

$$y = ln(\frac{E + P_z}{E - P_z}) \tag{1}$$

This indicates that momentum fractions of u and d quarks in the proton are related to the produced $W^+(W^-)$ rapidity. The rapidity distributions of

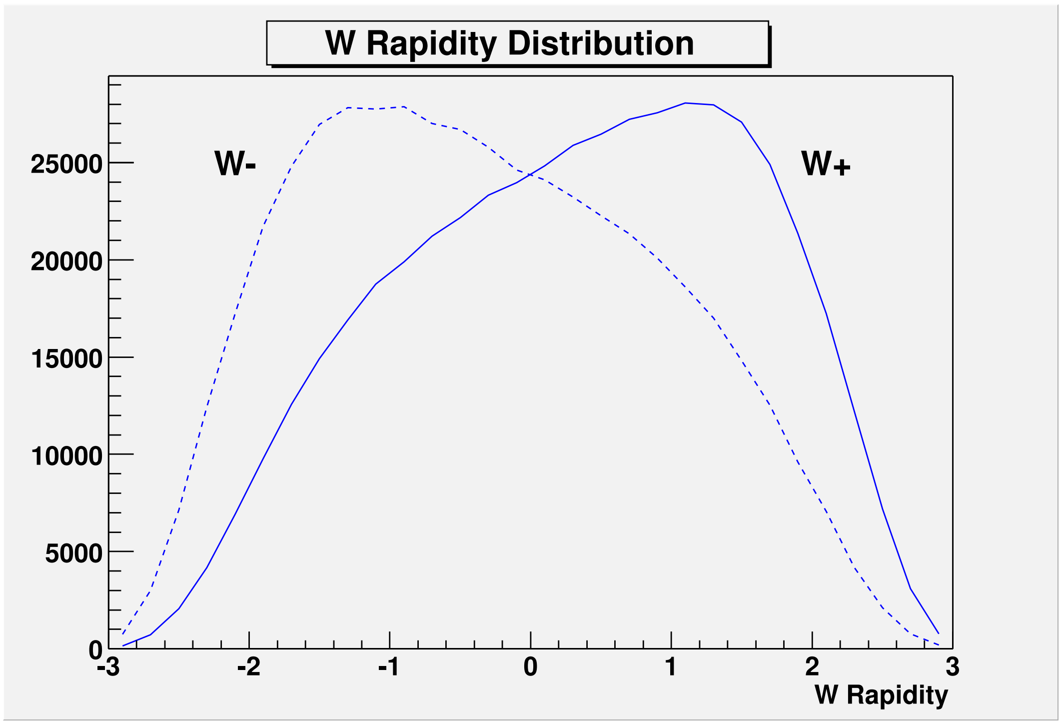

Figure 1: The $W^+(W^-)$ rapidity distributions in the $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV calculated with Pythia Monte Carlo. The $W^+(W^-)$ tends to follow the direction of the incoming proton (antiproton).

$W^+(W^-)$ at $\sqrt{s} = 1.96$ TeV calculated with the Pythia Monte Carlo are shown in Figure 1.

Since on average u quarks carry more momentum than d quarks, the produced W^+ tends to follow the direction of the incoming proton and the W^- that of the antiproton. Therefore, the W production asymmetry is highly sensitive to parton distributions. The W production asymmetry is defined as:

$$A(y) = \frac{d\sigma^+/dy - d\sigma^-/dy}{d\sigma^+/dy + d\sigma^-/dy} \qquad (2)$$

where $d\sigma^+(d\sigma^-)$ is the cross section for $W^+(W^-)$ production as a function of W rapidity, with positive rapidity being defined in the proton beam direction. The asymmetry simulated with Pythia Monte Carlo is shown in Figure 2.

For the CDF run I data, we measured the lepton charge asymmetry in

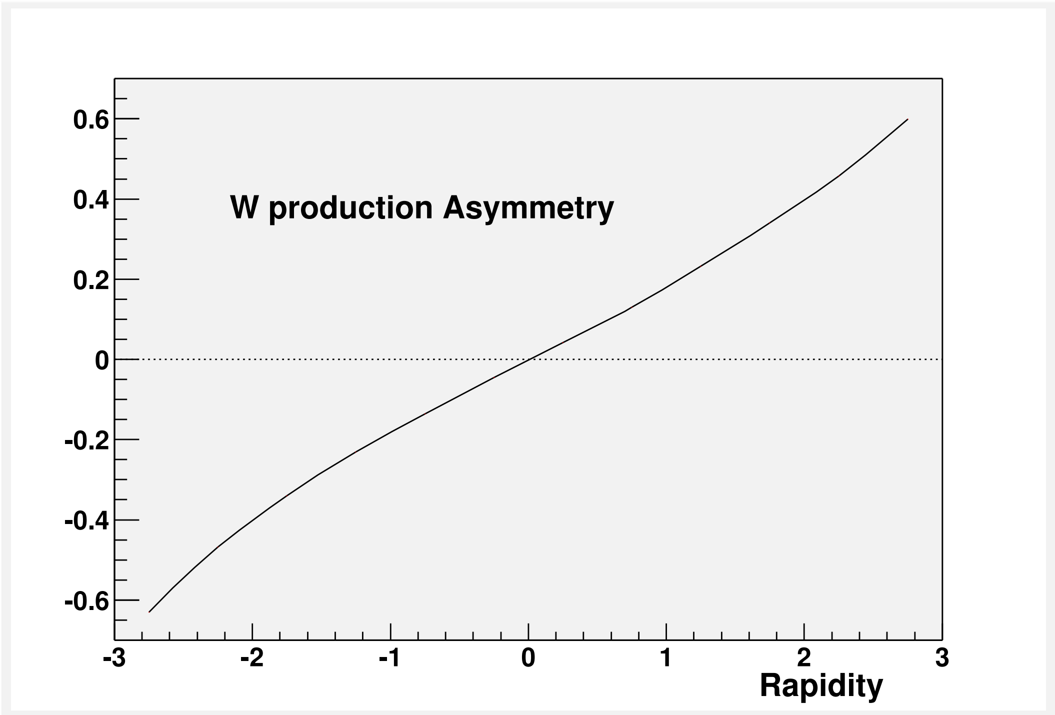

Figure 2: The W production asymmetry as a function of W rapidity in the $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. The asymmetry exists because u quarks carry more momentum than d quarks on average.

W decays [1)] because the rapidity of W boson was not measured. The lepton charge asymmetry is a convolution of the W production asymmetry and the asymmetry from W decay, V-A. The lepton charge asymmetries with different lepton transverse momentum selections are shown in Figure 3. The lepton charge asymmetry is closer to the W production asymmetry as the lepton momentum are harder.

The W production asymmetry and the asymmetry from the W decay are opposite and tend to cancel each other, especially in the large values of rapidity. However, the measurement of the lepton charge asymmetry is still sensitive to the parton distributions.

Our approach is to assume measured missing E_t as neutrino E_t and partially reconstructs W rapidity and measure its production asymmetry in the $p\bar{p}$ collision. A detailed procedure for the W reconstruction is described in

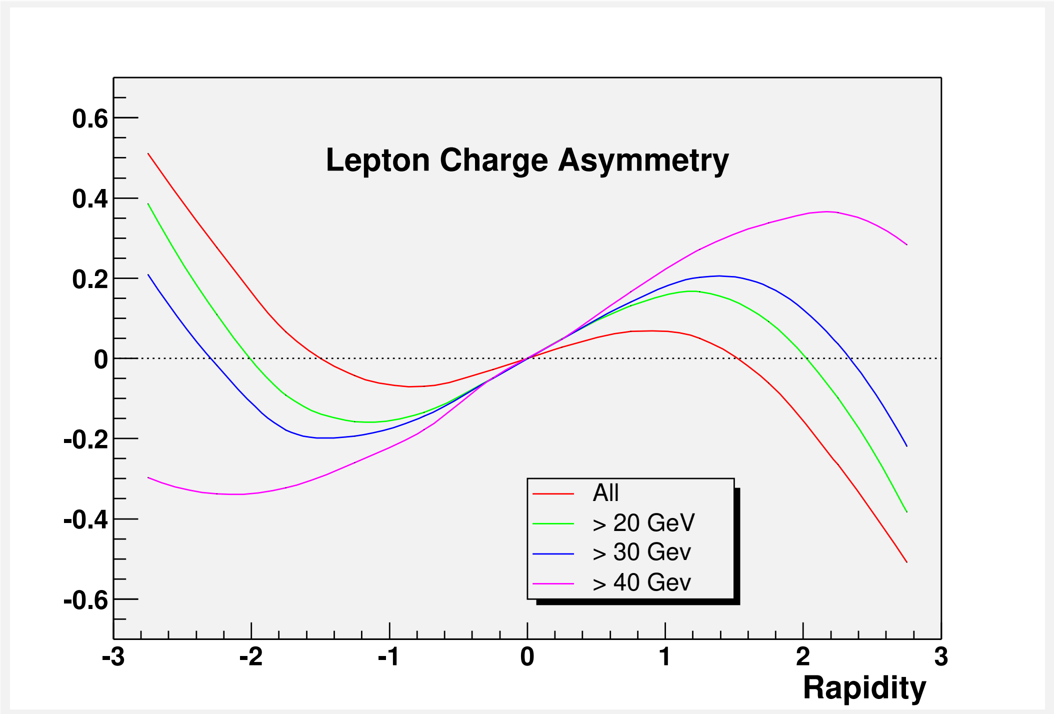

Figure 3: The lepton charge asymmetry calculated with Pythia Monte Carlo in the $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. The lepton charge asymmetry tends to close to the W production asymmetry as the lepton momentum are harder.

the following section.

2. W Partial Reconstruction

We partially reconstruct the W rapidity with electron momentum, transverse momentum of neutrino, and a given world average W mass. For the reconstructed Monte Carlo and real data, we use a measured missing E_t as a neutrino transverse momentum. Because the longitudinal component of neutrino momentum is not measured, the energy momentum relation,

$$M_W^2 = (E_l + E_\nu)^2 - (P_l + P_\nu)^2 \tag{3}$$

results in two W momentum solutions.

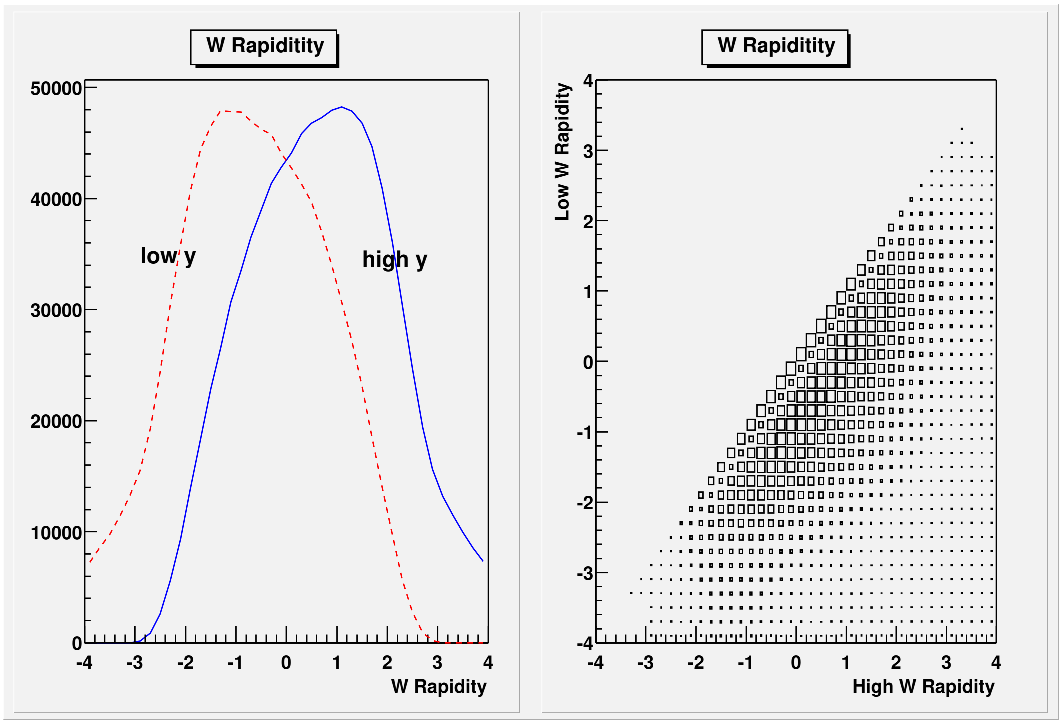

Figure 4: The reconstructed W rapidity distributions in the $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. We choose solutions with $high \;\; y \geq low \;\; y$. The rapidity is in generator level with Pythia Monte Carlo.

The W rapidity in equation (1) is empirically measured as:

$$y = \frac{1}{2} \times ln[\frac{(E + E_z)^2}{({M_W}^2 + {E_t}^2)}] \tag{4}$$

By putting all information into the equation 4, we obtain two rapidity solutions (y1 and y2) and the distributions of the two solutions are shown in Figure 4. Our studies so far are in the generator level and the momentum of up to a radiated photon in an event is added to the momentum of electron because most energy of radiated photons is reconstructed as an electron.

For events in which radicals of the quadratic equation (3) are not physical due to detector smearing, the radicals are set to be the same.

We apply the following kinematic cuts:

- E_t of electron > 25 GeV

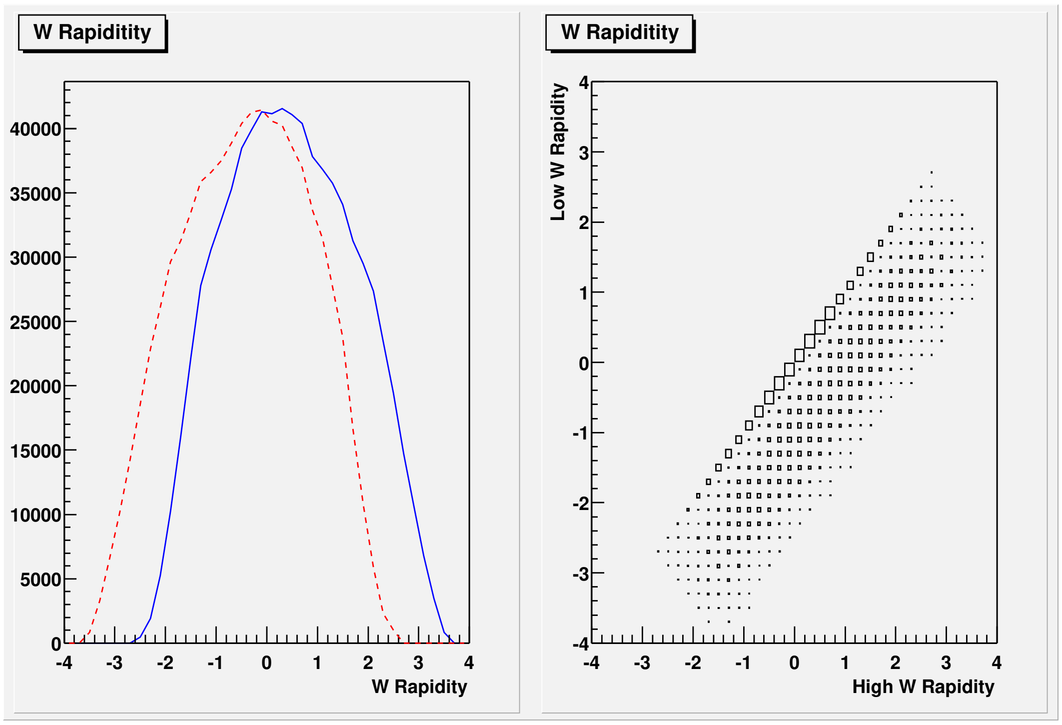

Figure 5: The partially reconstructed W rapidity distributions after all kinematic cuts in the $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. We choose the solutions with $high\ \ y \geq low\ \ y$. The rapidity is simulated by Pythia Monte Carlo and CDF detector simulation packages.

- Missing $E_t > 25$ GeV
- Fiducial of Electron $|\eta| < 2.5$

These kinematic cuts are used for W charge asymmetry analysis with Run I data and are considered to be our analysis cuts.

The rapidity distributions with reconstructed data after all kinematic cuts are shown in Figure 5.

2.1. Corrections

The 2-d W asymmetry of A(i,j) in the two W rapidity solutions, y_i and y_j, is written as,

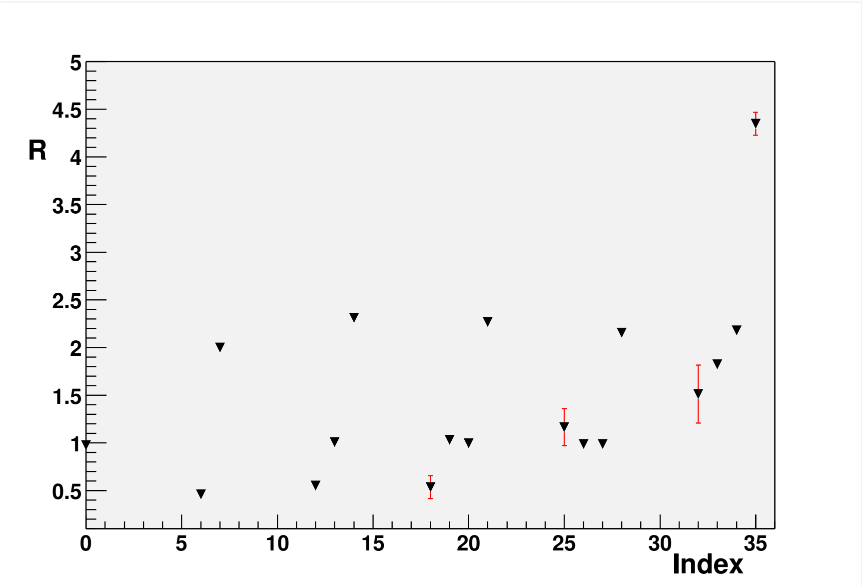

Figure 6: The $R(i,j)$ distribution predicted from Pythia Monte Carlo. Here we use 6x6 rapidity bins and indices are as, 1=(-2.5,-2.5), 2=(-2.5,-1.5), ..., and 35=(2.5,2.5) bin.

$$A(i,j) = \alpha(i,j)A_i + \beta(i,j)A_j \tag{5}$$

where $A_{i(j)}$ is 1-d W production asymmetry when $y_{i(j)}$ is the true rapidity solution. If we choose $y_i \geq y_j$,

$$\alpha(i,j) = 1/(1 + R(i,j))$$

$$\beta(i,j) = R(i,j)/(1 + R(i,j))$$

with

$$R(i,j) = N_j/N_i$$

where $N_{i(j)}$ is the total number of events in the $y_{i(j)}$ bin when $y_{i(j)}$ is true rapidity solution. The $R(i,j)$ can be determined only with theory prediction. The R distribution for 6x6 bins is shown in Figure 6. The R for the y_i=2.5 for 30x30 bins is shown in Figure 7.

By choosing $y_i \geq y_j$, the W production asymmetries, A_i and A_j in equation (5) are different in the same rapidity bin due to the V-A interaction in

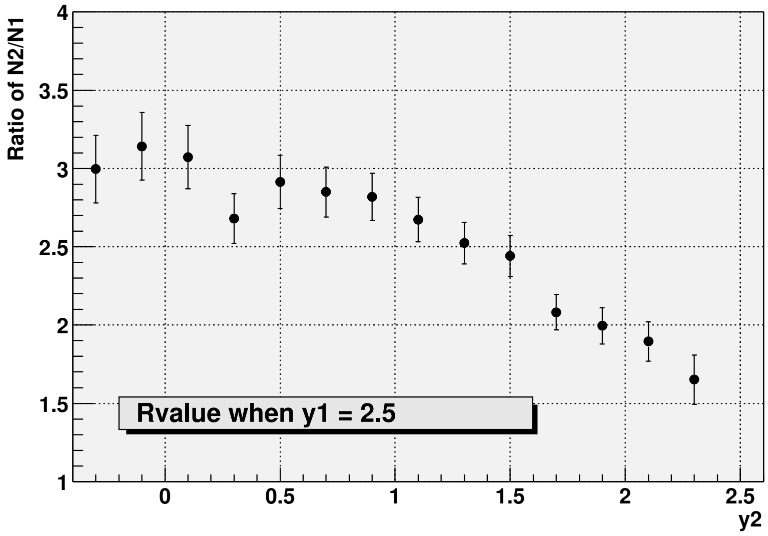

Figure 7: The $R(i,j)$ distribution for y_i=2.5 with 30x30 bins.

the W decay. Therefore, we need additional corrections, C1(i,j) and C2(i,j) for that A_i and A_j are equal in the same rapidity bin as:

C1(i,j) = two dimentional correction of measured asymmetry when y_i is true and y_j is false solution to the predicted W asymmetry in 1-d y_i bin.

C2(i,j) = two dimentional correction of measured asymmetry when y_i is false and y_j is true solution to the predicted W asymmetry in 1-d y_j bin.

The corrections (C1 and C2) for the y=2.5 in the 30x30 bins are shown in Figure 8.

3. Measurements

The $\alpha(i,j)$ and $\beta(i,j)$ in the equation (5) are re-written with corrections described in the previous section as:

$$\alpha(i,j) = C1(i,j)\frac{1}{[1+R(i,j)]}$$

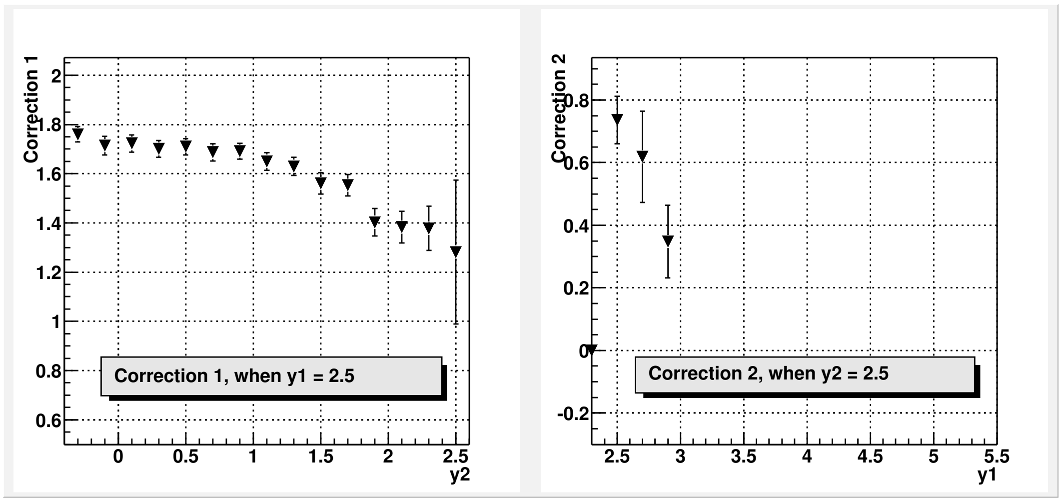

Figure 8: The V-A corrections, C1 and C2 distributions for rapidity=2.5 in 30x30 bins.

$$\beta(i,j) = C2(i,j)\frac{R(i,j)}{[1 + R(i,j)]}$$

Here A_i and A_j in the equation (5) are equal in the same rapidity bin.

We reconstruct χ^2 as:

$$\chi^2 = \sum_{i,j} \frac{[A(i,j) - (\alpha(i,j)A_i + \beta(i,j)A_j)]^2}{\sigma^2_{A(i,j)}}$$

where $\sigma_{A(i,j)}$ is an error in the measurement of A(i,j). Since the error is sensitive to the stastistics in each bin, we consider to use errors from MC predictions.

We minimize χ^2 to get the W asymmetry as a function of rapidity. Figure 9 shows the fit results. Our procedures to measure W production asymmetry with partially reconstructed W rapidities reproduce the input W asymmetry.

4. Data Reconstruction

Since approaches to masure the W production asymmetry are based on a single prediction and the asymmetry is sensitive to W kinematics and parton distributions, we need to check our procedures with different W kinematics and different parton distributions.

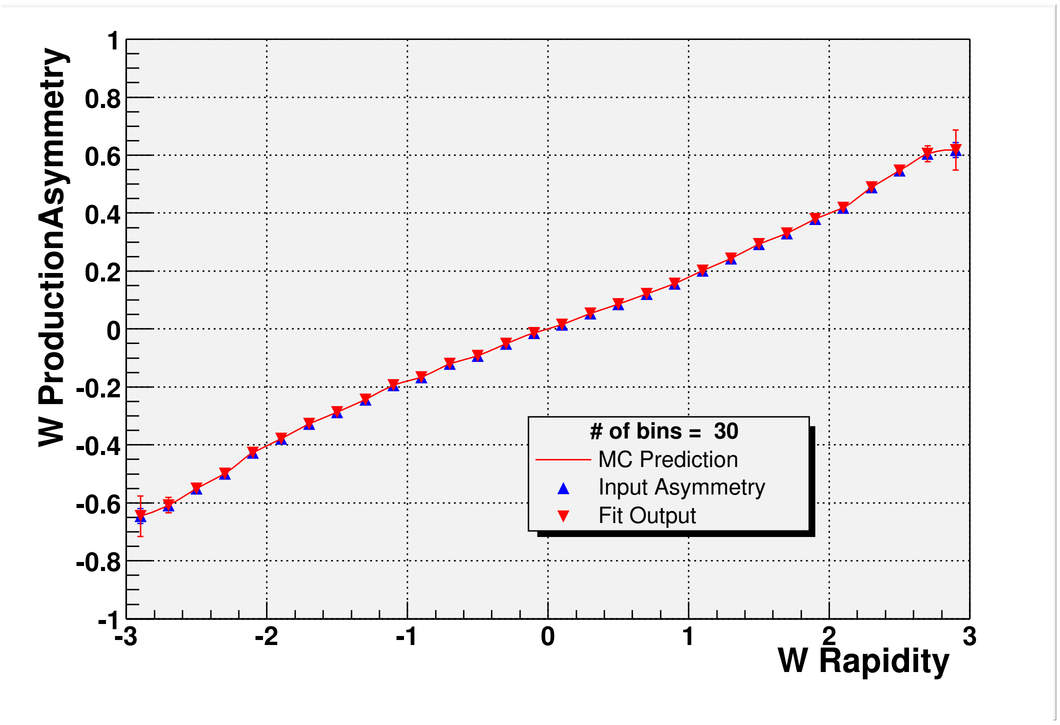

Figure 9: The fit result for the W production asymmetry. Fit results reproduce the input W asymmetry.

4.1. the d/u ratio of variuos Parton Distributions

The W charge asymmetry as a function of rapidity constrains the ratio of d and u quark momentum in the proton. The production asymmetry is roughly propotional to the ratio of the difference and the sum of the quantities $d/u(x_1)$ and $d/u(x_2)$. Yang and Bodek [2)] pointed out that the difference in the W charge asymmetry between measurement and prediction is due to the fact that the d quark distribution is somewhat underestimated at high x in the standard PDF parametrizations. The predictions for the W asymmetry using PDF's with the modified d/u ratio are in much better agreement with the CDF Run I measurement.

Therefore, we need to check the effect of the d/u ratio difference in our procedures. Instead of generating two sizable Monte Carlo data with different d/u ratios, we use following weighting factors $(F\pm(y))$ and re-weight existing

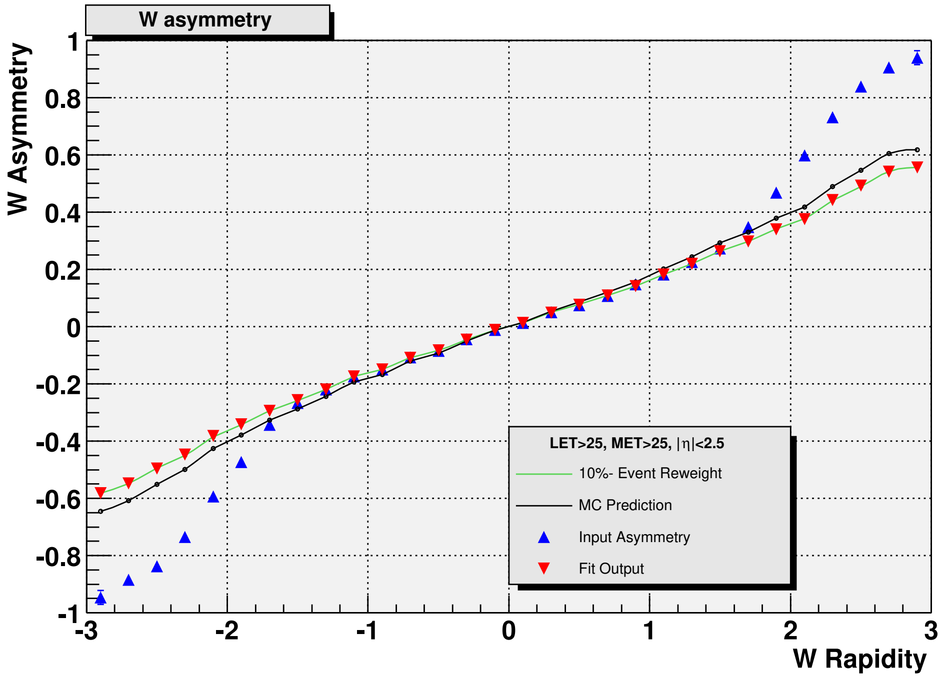

Figure 10: The fit result with different ratio of d and u quark momentum in the proton. Fit results predict the wrong W production asymmetry.

events to mimic the different d/u ratio.

$$F \pm (y) = 1.0 \pm Q\frac{\sigma(W^+) - \sigma(W^-)}{\sigma(W^\pm)}$$

where Q is the variation factor and Q=0.05 corresponds to the 10% to the W charge asymmetry. It is noticed that the $d\sigma/dy$ is kept before and after re-weighting to have the effect only from the d/u ratio difference.

The fit results with the different d and u quark momentum ratio is shown in Figure 10. The different ratio of d and u quark momentum in the proton results in the wrong prediction. This indicates that the corrections, R(i,j), C1(i,j), and C2(i,j) are sensitive to the d/u ratio. Therefore, we need to understand the relation between the corrections and the d/u ratio.

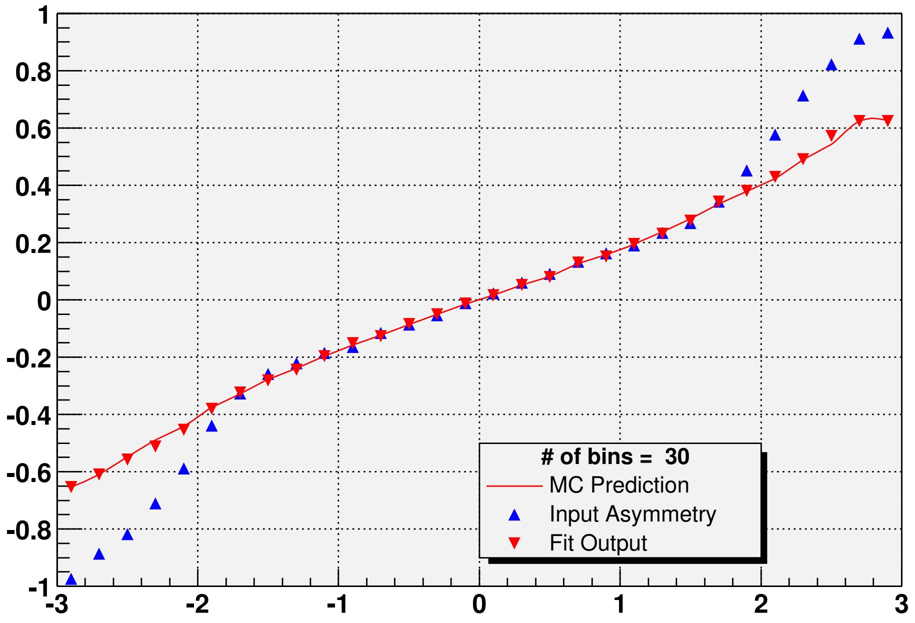

Figure 11: The fit result with the missing E_t, but corrections from neutrino E_t. The effect from the reconstruction of missing E_t is small.

4.2. the Missing E_t

Modeling missing E_t with CDF detectors is not simple task. Studies show that x and y components of missing E_t need to be smeared properly and independently.

To measure a sensitivity of missing E_t measurement to our fit, we compare a fit result using neutrio E_t in the generator level with that of the reconstructed missing E_t. The fit results with the missing E_t, but corrections from neutrino E_t are shown in Figure 11 The difference is small and the effect can be igonored.

4.3. W P_t distribution

The charge asymmetry is sensitive to the W P_t distribution. In Run I analysis, there was a large difference on the W P_t predictions between NLO DYRAD calculation and a gluon resummation technique (ResBos) and the

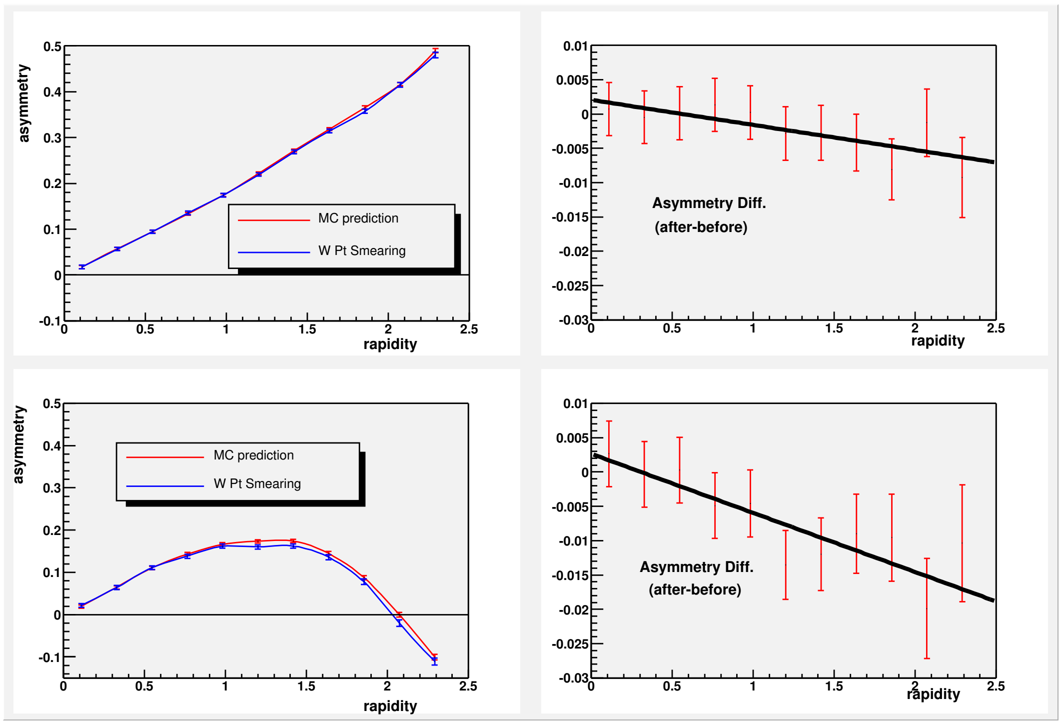

Figure 12: The sensitivity of W production asymmetry and Lepton Charge Asymmetry to the W P_t variation. W P_t distribution is smeared.

difference was mainly in the high η region. Figure 12 shows a sensitivitity of W P_t prediction to the W production asymmetry and Lepton charge asymmetry. Our studies show that W P_t variation is less senstive to the W production asymmetry than to the lepton charge asymmetry.

5. Constraints on PDFs with the d/u ratio and Z rapidity distributions

The rapidity distribution of W produced in the proton and anti-proton collisions constrains the W production asymmetry. Because the W is not fully reconstructed, we use Z rapidity distribution to measure W asymmetry with better PDF constraints.

The 2-d W asymmetry A(i,j) in equation 5 is dependent on both the d/u ratio and the rapidity distribution, $d\sigma/dy$.

We define $R^i_W(y)$ as:

$$R^i_W(y) = \frac{(d\sigma/dy)\ data}{(d\sigma/dy)\ MC} \tag{6}$$

and the relation between W and Z rapidity distributions is derived with different parton distributions as:

$$R_{WZ}(y) = \frac{(d\sigma/dy)_{W^+W^-}/\sigma_W}{(d\sigma/dy)_Z/\sigma_Z} \tag{7}$$

where σ_W and σ_Z are total cross sections of W and Z, respectively. The ratio $R_{WZ}(y)$ depends on PDFs and the dependence is derived from predictions.

From equation 6 and 7, we can rewrite the $R^i_W(y)$ as,

$$R^i_W(y) = \frac{\frac{(d\sigma/dy)_W}{\sigma_W}\ data}{R_{WZ}(y)\frac{(d\sigma/dy)_Z}{\sigma_Z}\ MC}$$

The W production asymmetry are sensitive to the d/u ratio and $d\sigma/dy$. Therefore, A(i,j) is fitted with corrections, R(i,j), C1(i,j), and C1(i,j) which depend on the d/u ratio and $R^i_W(y)$ which is related to $d\sigma/dy$ to constrain PDFs.

For the CDF Run I, the rapidity distribution of Z boson is measured with y up to 2.8, which is close to the kinematic limit. We expect to measure the rapidity distribution of Z boson up to the same kinematic limit by including Plug-Plug dielectron events.

References

1. Qun Fan "A Measurement of the Charge Asymmetry in W Decays Produced in $p\bar{p}$ Collisions", Ph.D. thesis, University of Rochester, Jan., 1997
2. U.K. Yang and A. Bodek, Phys. Rev. Lett. **82**, 2467(1999).