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Width at CDF**

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MEASUREMENT OF THE W BOSON PRODUCTION ASYMMETRY AND W BOSON WIDTH AT CDF

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Abstract

We describe two measurements using $110 \pm 7 \text{ pb}^{-1}$ of data collected by the CDF detector during 1992-95. The first is a new measurement of the charge asymmetry in the lepton rapidity range $0 < |y_l| < 2.5$ using $W \rightarrow \mu\nu, e\nu$ events. The asymmetry data constrain the ratio of d and u quark momentum distributions in the proton over the x range of 0.006 to 0.34 at $Q^2 \approx M_W^2$. Although the data in the central rapidity region ($|y_l| < 1.1$) are reproduced by modern parametrizations of parton distributions, there are differences in the high rapidity regions. The second measurement is a direct measurement of the W width using the lineshape of the transverse mass spectrum. The extracted W width is in good agreement with the standard model value, and with values obtained from the indirect method using the measured ratio of W and Z events.

1 Measurement of the W Asymmetry

At Tevatron energies, W^+ (W^-) bosons are produced in $p\bar{p}$ collisions primarily by the annihilation of u (d) quarks in the proton and \bar{d} (\bar{u}) quarks from the antiproton. Because u quarks carry on average more momentum than d quarks [1] [2] [3], the W^+ 's tend to follow the direction of the incoming proton and the W^- 's that of the antiproton. The charge asymmetry in the production of W 's as a function of rapidity (y_W) is related to the u and d quark distributions at $Q^2 \approx M_W^2$, and is roughly proportional [4] [5] to the ratio of the difference and the sum of the quantities $d/u(x_1)$ and $d/u(x_2)$, where x_1 and x_2 are the the fraction of nucleon momentum carried by the quarks in the p and \bar{p} , respectively.

Previously published W asymmetry results from an analysis of the 1992-93 data [6] collected by the Collider Detector at Fermilab (CDF) demonstrated this sensitivity for the first time at a level better than that of deep inelastic scattering (DIS) experiments within the x range accessible by the W data at the Tevatron. These data, together with those from DIS experiments, are used in a global analysis to extract parametrizations of parton distribution functions (PDFs) in the nucleon [1] [2] [3]. In hadron colliders, these functions are used in the calculation of all hadronic cross-sections. CDF's previous asymmetry data [6] improved the understanding of the u and d quark momentum distributions in the proton in the x range of W production ($0.007 < x < 0.24$). The use of these previous data resulted in a reduction in the uncertainty from PDFs in the W mass measurement [7] from ≈ 75 to ≈ 50 MeV/ c^2 . A further reduction of this error to ≈ 20 MeV/ c^2 is possible [7] using the new data presented here.

The previous W asymmetry measurements (with an initial sample of ≈ 20 pb^{-1} from 1992-93) are dominated by statistical uncertainties. In this letter, we describe the asymmetry results at $\sqrt{s} = 1.8$ TeV using data from the entire 1992-95 period. The new data agree with the 1992-93 results, and increase the integrated luminosity to 110 ± 7 pb^{-1} , a 5 fold increase relative to the 1992-93 data. Furthermore, the asymmetry measurement is extended to larger rapidity ($|y_l| < 2.4$) by the introduction of a new charge determination technique [8] for electrons, and also by using data from the forward muon detector ($1.9 < |y_l| < 2.5$). These electron and muon data at large rapidity provide information about PDFs at a larger range ($0.006 < x < 0.34$) than previously available.

Since the W rapidity is experimentally undetermined because of the unknown longitudinal momentum of the neutrino from the W decay, we measure the lepton charge asymmetry which is a convolution of the W production charge asymmetry and the well known asymmetry from the $V - A$ W decay. The two asymmetries are in opposite direction and tend to cancel at large values of rapidity. However, since the $V - A$ asymmetry is well understood, the lepton asymmetry is still sensitive to the parton distributions. The lepton charge asymmetry is defined as:

$$A(y_l) = \frac{d\sigma^+/dy_l - d\sigma^-/dy_l}{d\sigma^+/dy_l + d\sigma^-/dy_l}, \quad (1)$$

where $d\sigma^+$ ($d\sigma^-$) is the cross section for W^+ (W^-) decay leptons as a function of lepton rapidity, with positive rapidity being defined in the proton beam direction. If the detection efficiencies and acceptances for l^+ and l^- are equal, then the uncertainties from acceptance, efficiencies and luminosity cancel in $A(y_l)$. By CP invariance $A(y_l) = -A(-y_l)$ and the two values are combined.

The tracking detectors at CDF are the Vertex Time Projection Chambers (VTX), the Central Tracking Chamber (CTC, $|\eta| < 1.8$), the Silicon Vertex Detector (SVX, $|\eta| < 2.3$), the

Central Muon Chambers, and the Forward Muon Detector (FMU, $1.9 < |\eta| < 3.5$).

The data are divided into five samples: central electrons ($|y_l| < 1.1$), central muons ($|y_l| < 1.0$), forward muons ($1.9 < |y_l| < 2.5$), plug electrons within the SVX fiducial region (plug-SVX, $1.1 < |y_l| < 2.4$), and plug electrons outside the SVX geometrical acceptance region but with a CTC track (plug-CTC, $1.1 < |y_l| < 1.8$). A reliable charge determination and a good energy measurement are essential for this analysis. Central electrons, central muons, and plug electrons outside the SVX are required to have an associated CTC track.

A new charge determination technique [8] is introduced to identify the charge of plug electrons within the SVX geometrical fiducial region. At CDF, positively (negatively) charged particles are bent in increasing (decreasing) ϕ inside the solenoidal magnetic field. The SVX track stub measures the precise initial track direction in ϕ . The plug EM calorimeter (PEM) shower centroid measurement combined with the location of the vertex position yields another measurement of ϕ , and the sign of the difference of the two ϕ measurements determines the charge.

The transverse energy (E_T) of the lepton and the missing transverse energy (\cancel{E}_T) are required to be greater than 25 GeV. To further reduce the QCD background from dijet events where one jet may be misidentified as a lepton, events with an extra jet with $E_T^J > 30$ GeV are rejected.

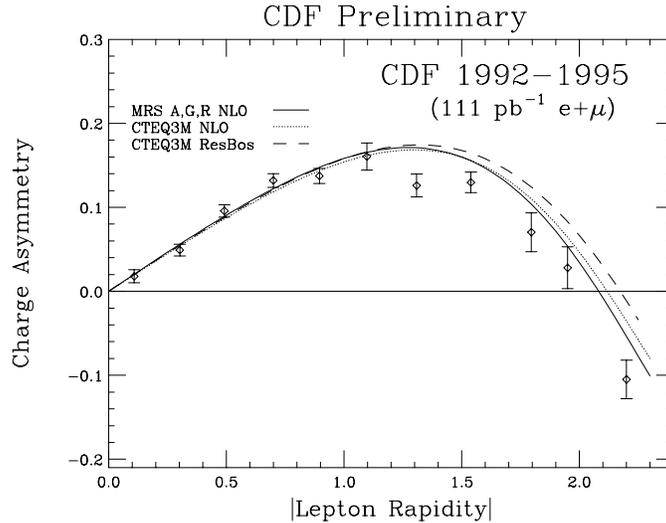


Figure 1: The fully corrected charge asymmetry. Data from all the detectors for positive and negative y_l are combined. The statistical and systematic errors are added in quadrature.

Figure 1 shows the fully corrected asymmetry after taking the weighted mean of the various data sets and combining the bins for positive and negative y_l . Also shown are the predictions of Quantum Chromodynamics [9] (QCD) calculated to Next-to-Leading-Order (NLO) using the program DYRAD [9] with several parametrizations of parton distributions as input. Note that recent PDFs (MRS A [1], CTEQ3M [2] and GRV94 [3]) have been extracted with the inclusion of the 1992-93 asymmetry data in the global fit. As shown in Figure 1, the recent PDFs are in good agreement with the new data in the central region ($|y_l| < 1.1$). However, at high rapidity, the various predictions are generally higher than the data, indicating that the PDF

parametrizations should be modified in the range $0.006 < x < 0.34$

Although, the W decay lepton charge asymmetry is mostly sensitive to the d/u ratio, at large rapidity it is also affected by the W production P_t spectrum. The NLO QCD calculations do not reproduce the production P_t spectrum of W 's at very low P_t . Therefore, it is necessary to check how well the DYRAD-NLO QCD calculation compares to an independent calculation. The DYRAD-NLO QCD prediction is compared to a calculation including soft gluon resummation at all orders in perturbation theory implemented in the program ResBos [10]. Both programs yield identical results for the W rapidity distribution, but different results for the W P_t distribution. At Tevatron energies soft gluon radiation is mainly responsible for the P_T of W 's and Z 's in the range of $P_T < 30$ GeV, and ResBos can reproduce the P_T spectrum of Z 's. Figure 1 also shows the comparison between predictions from DYRAD-NLO and ResBos for the CTEQ3M [2] structure functions. The two calculations agree very well in the central region ($|y_l| < 1.1$), which is the region used in the W mass determination [7]. The difference between two calculations is mainly at $|y_l| > 1.7$. The disagreement between our data and the resummed Monte Carlo ResBos calculation is even bigger at high lepton rapidity than the disagreement of the data with the DYRAD-NLO calculation.

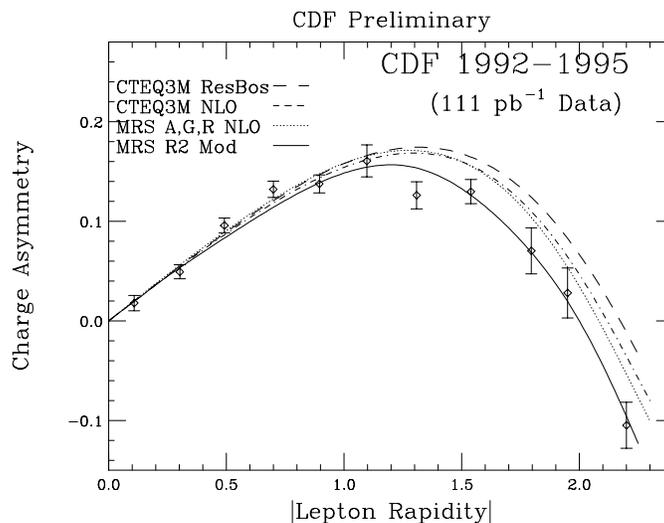


Figure 2: The fully corrected charge asymmetry is compared with predictions of several PDF's. In addition to the predictions of DYRAD-NLO and ResBos using the standard PDF's, the solid curve shows the prediction using DYRAD-NLO with a modified MRS R2 PDF, in which the ratio d/u is modified by adding the form $\delta(d/u) = 0.1x(1+x)$.

Figure 2 also shows the prediction using DYRAD-NLO with the MRS R2 PDF in which the ratio d/u is modified by adding the form $\delta(d/u) = 0.1x(1+x)$. This form has been extracted from a recent reanalysis [11] of NMC muon scattering data on hydrogen and deuterium with improved corrections for nuclear binding effects in the deuteron. It is interesting to note that unlike the standard PDF's in which $d/u = 0$ at $x = 1$, the d/u ratio in the modified PDF's is 0.2 for $x = 1$, in agreement with a prediction [12] from QCD based models which was published years ago. As can be seen in Figure 2, the DYRAD-NLO predictions using MRS R2 PDF with

the modified d/u parton distributions are also in much better agreement with the CDF W asymmetry data.

In summary, the significant reduction in the errors of CDF's new W asymmetry data in the central region can be used to reduce the uncertainties from PDFs to measurements of the W mass using collider data [7] to $\approx 20 \text{ MeV}/c^2$. Updated values of the d/u ratio extracted from deep inelastic muon scattering data (with new corrections for nuclear effects in the deuteron) are in agreement with the new CDF W asymmetry results. However, the uncertainty in these nuclear effects is hard to estimate. The asymmetry data, which is free from these uncertainties, demonstrate the value of collider data in the measurement of proton structure functions and place the strongest constraint on the d/u ratio of quark momentum distributions in the proton over the range of 0.006 to 0.34 at $Q^2 \approx M_W^2$.

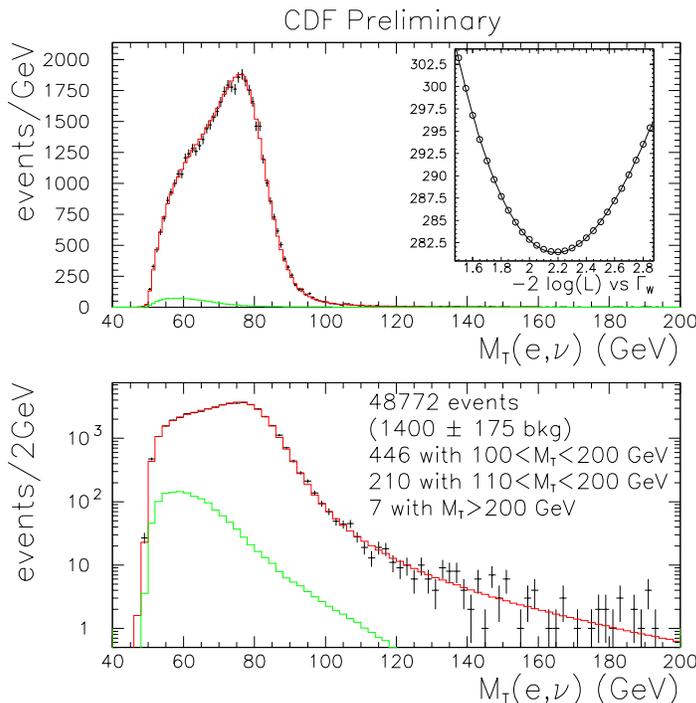


Figure 3: The transverse mass distribution of final state electrons from W decays. The fit to the lineshape is used to extract the W Width.

2 Measurement of the W Width

There are two methods of extracting the W width from hadron collider data. The first is the *indirect* method in which the width is extracted from observed ratio of W and Z events [13]. The second method is the *direct* method in which the width is extracted from the line shape of the transverse mass distribution of events in which the W decays to a lepton and neutrino [14].

The *indirect* method is sensitive to the knowledge of the relative trigger efficiency and acceptance for W and Z bosons, and also to the theoretical uncertainty in the prediction from QCD for the ratio of the production cross sections for W and Z bosons. The *direct* method is sensitive to the experimental uncertainties in the calibration and resolution of the detector.

The W width has been extracted [13] from the electron data in CDF 1A using the *indirect* method. A similar extraction from the CDF run 1B data is currently under analysis. A

preliminary extraction of the W width using the *direct* method from run 1B data is shown in Figure 3. The value extracted from a fit to the transverse mass line shape over the 110 to 200 GeV region is $2.19 \pm 0.17(stat) \pm 0.09(syst)$ GeV. Note that the fit is normalized to the total number of events. The ratio of the total number of events to the number of events on the tail of the transverse mass distribution is sensitive to the W width.

The average value of all current measurements of the W width (released by the Particle Data Group in December 1997) is 2.062 ± 0.059 GeV, as compared to the standard model value of 2.093 ± 0.010 GeV. The expected error on the *direct* measurement of the W Width in the next CDF run (Run II, 2 fb^{-1}) is 0.03 GeV.

The standard model prediction for the W width is sensitive to α_s , the QCD coupling constant. The standard model value quoted above is for α_s (at the Z mass) of 0.120 ± 0.003 . The error of 0.003 on α_s corresponds to an error of 0.010 GeV on the standard model prediction for the W width.

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