Fermi National Accelerator Laboratory

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CDF

Charged Lepton Asymmetry in W Decays from CDF

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Charged Lepton Asymmetry in W Decays from CDF

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The charge asymmetry of W-bosons produced in $p\bar{p}$ collisions has been measured using 110,000 $W \to e\nu$ and $W \to \mu\nu$ decays recorded by the CDF detector during the 1992-93 and 1994-95 Tevatron collider runs.

1 Charged lepton asymmetry in W Decays

W^+ (W^-) bosons are produced in $p\bar{p}$ collisions primarily by the annihilation of u (d) quarks from the p with $\bar{d}$ ($\bar{u}$) quarks from the $\bar{p}$. Since the u quark tends to carry a larger fraction of the proton's momentum than the d quark, the W^+ (W^-) tends to be boosted in the p ($\bar{p}$) direction. The resulting charge asymmetry in the production of W's as a function of rapidity is related to the slope of the $d(x)/u(x)$ quark distribution ratio at low x ($0.006 < x < 0.35$) and $Q^2 \approx M_W^2$ [1,2]. This measurement complements the F_2^n/F_2^p measured via deep inelastic scattering.

The W charge asymmetry is defined as:

$$A(y_W) \equiv \frac{d\sigma_W^+(y)/dy_W - d\sigma_W^-(y)/dy_W}{d\sigma_W^+(y)/dy_W + d\sigma_W^-(y)/dy_W} \tag{1}$$

Since $A(y_W)$ is a ratio, most systematic errors cancel. For SU(2) symmetric sea $\bar{u}(x) = \bar{d}(x) = s(x) = \bar{s}(x)$, we have:

$$A(y_W) \simeq \frac{u_1 d_2 - d_1 u_2}{u_1 d_2 + d_1 u_2 + 2 s_1 s_2} \simeq \frac{d_2/u_2 - d_1/u_1}{d_2/u_2 + d_1/u_1 + 2 s_1 s_2/u_1 u_2} \tag{2}$$

Hence A(y) is related to difference in d/u between x_1 of the quark of proton and x_2 of the quark of the antiproton.

The W-bosons are identified by their $W \to e\nu$ and $W \to \mu\nu$ decays. At the Tevatron ($\sqrt{s} = 1.8$ TeV), the longitudinal momentum of the neutrino cannot be reconstructed. Since the $W^\pm$ rapidity is indeterminate, the charge asymmetry of the decay leptons is measured:

$$A(\eta) = \frac{d\sigma(l^+)/d\eta - d\sigma(l^-)/d\eta}{d\sigma(l^+)/d\eta + d\sigma(l^-)/d\eta} \tag{3}$$

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where $d\sigma(l^{\pm})/d\eta$ is the cross section for $W^{\pm}$ decay leptons as a function of lepton rapidity, η [3]. (Positive η is along the proton beam direction.) V - A theory describes the decay of the W-boson. This decay creates another charge asymmetry. The charge asymmetry from structure functions and the charge asymmetry from the decay of the W-boson are in opposite directions. For the range $-1.5 < \eta < 1.5$ structure functions charge asymmetry dominates.

The data sample is taken from approximately 20 pb^{-1} from the 1992-93 Run [4], 91 pb^{-1} from the 1994-95 Run (central and plug regions) and 72 pb^{-1} forward μ data from the 1994-95 Run. The data sample has about 110,000 $W \rightarrow e, \mu\nu$ events. They are obtained by selecting isolated, identified, and well-tracked e's and μ's with $E_T > 25$ GeV and $|\eta| < 2.3$. Central μ have $|\eta| < 1.0$, while forward μ have $1.9 < |\eta| < 2.3$. The charge must be identified. In the central region, the CTC track identifies the charge. For plug electrons, $1.1 < |\eta| < 2.3$, the charge is identified using one of two procedures. The CTC track can identify the charge. However, the track finding efficiency falls off at high η and becomes zero for $|\eta| > 1.8$. The charge can be determined by comparing the ϕ calculated from the SVX track and the plug electromagnetic shower. The SVX trackfinding efficiency is about 55% (depends on z vertex) and is fairly constant vs η. Hence, plug electrons have charge identification out to $|\eta|$=2.3. In addition, the SVX method doubles the number of plug electrons that can be used for the W-asymmetry measurement. Figure 1 is a plot of $\delta\phi_{measured}/\delta\phi_{expected}$ for the plug W sample which uses the PEM strips ($1.2 < |\eta| < 1.8$). The charge mis-identification is estimated to be .8% ± .2%. For $\eta > 1.8$ the charge misidentification is about 5%.

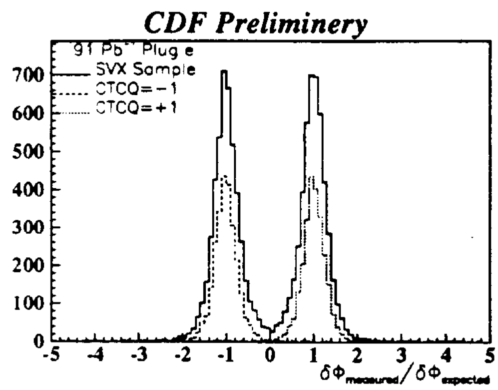

Figure 1: $\delta\phi_{measured}/\delta\phi_{expected}$ for the plug W sample for $1.2 < |\eta| < 1.8$. The average bend an electron has from the magnetic field at the PEM corresponds to 5mm, and the shower position resolution is about 1.5mm.

Since CP invariance gives $A(+\eta) = -A(-\eta)$, data at $-\eta$ is combined with that at $+\eta$ to increase the statistics in η bins and to further reduce the effect of small undetected differences in the efficiencies for l^+ and l^-. Systematic errors are about 1/5 the statistical errors and corrections to the raw measurement are small (5% or less). Hence, the asymmetry measurement is robust.

2 Comparisons with Predictions

Figure 2 shows the asymmetry measurement and predictions of the recent PDF's from Martin, Roberts, and Stirling (MRS) [6 7]; the CTEQ [8] collaboration; and Gluck, Reya, and Vogt [9]. Predictions are calculations of $d\sigma(l^{\pm})/d\eta$ which use next to leading order (NLO) QCD partonic cross sections [5], NLO parton distribution functions (PDF), and the well-known, purely leptonic V-A decay of the W. Experimental cuts and detector effects [4] are included in the calculations. GRV94, CTEQ3M. and MRSA include the W-asymmetry measurement [4] from the 1992-93 Run in their fits.

The deep inelastic scattering $F_2^{\mu n}/F_2^{\mu p}$ and $p\bar{p}$ W charge asymmetry ($A(\eta)$) measurements provide complementary information on the proton structure. $A(\eta)$ is sensitive to the slope of the $d(x)/u(x)$ ratio [1,2] in the x range $0.006-0.35$, whereas the $F_2^{\mu n}/F_2^{\mu p}$ is sensitive to the magnitude of this ratio. $F_2^{\mu n}/F_2^{\mu p}$ is more sensitive to the $\bar{u}$ and $\bar{d}$ sea distributions than $A(\eta)$, since $A(y_W)$ is quadratic in $\bar{q}/q$, while F_{2n}/F_{2p} is linear in $\bar{q}/q$. Both the MRS [6] and CTEQ [10] predictions on $F_2^{\mu n}/F_2^{\mu p}$ agree (at the level of the 100% uncertainty in the deuteron shadowing corrections [12]), with the recent NMC [13] measurement. What is different is that PDF's which predict the largest difference between the d/u ratio at small x relative to moderate x, also predict the largest W charge asymmetries. Thus, the fact that the charge asymmetry discriminates between PDF's which fit the NMC $F_2^{\mu n}/F_2^{\mu p}$ measurements demonstrates that its sensitivity to the d/u ratio (and not to $\bar{u}$ or $\bar{d}$) at very low x is better than that of the muon scattering experiments. In addition to having very low systematics, the asymmetry data does not have the deuteron shadowing uncertainties, nor is it sensitive to any low Q^2 higher twist corrections.

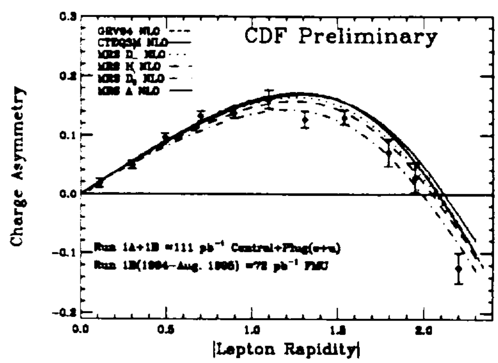

Figure 2: The measured charge asymmetry and predictions from the most recent PDF's. The data are fully corrected for trigger efficiencies and backgrounds. Systematic errors are included.

The W-asymmetry measurement has been used to reduce the error on the W mass [14]. The fitted W mass is strongly correlated with W charge asymmetry. If the weighted means $(\bar{A}(y))$ between the charge asymmetry data and the prediction for a structure function differs by more the 2σ, then that structure function is not used in the calculation of the error in the W mass measurement. This requirement reduces the calculated error from structure functions to 50 MeV from 100 MeV.

3 Conclusion and Outlook

The W-asymmetry measured with the 1994-95 data agrees with the W-asymmetry from the 1992-93 data. W-asymmetry measurements from for the 1992-93 Run [4] are published. They resulted in a new set of PDF's from MRS (MRS G), CTEQ (CTEQ 3M), and GRV (GRV 94) groups. The W lepton charge asymmetry is measured with 110 pb^{-1}. This represents a 5-fold increase in statistics relative to the 1994-95 Run. The measurement has been extended up to $\eta = 2.3$. The data provides tight constraint on PDF's. By restricting the shape of PDF's, the W asymmetry measurement reduced the systematic uncertainty in the W mass measurement.

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