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Tests of Structure Functions using Leptons with CDF

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ABSTRACT

The charge asymmetry as a function of lepton rapidity, $A(y_l)$, has been measured at $\sqrt{s} = 1.8$ TeV for $|y_l| < 1.8$, using the W decays to electrons and muons recorded by CDF during the 1992-93 run of the Tevatron Collider. The luminosity used, approximately 20 pb^{-1}, and detector improvements have lead to a six fold increase in statistics making discrimination between sets of parton distributions possible. Our data favors the most recent parton distributions and demonstrates the value of collider data in the measurement of the proton's structure. In addition, the Drell-Yan cross section has been measured using 4.13 pb^{-1} of dielectron and 2.77 pb^{-1} of dimuon data taken during the 1988-89 run. These measurements probe the quark distributions to $x < 0.01$ at high Q^2 where nonperturbative effects are minimal.

W^+ (W^-) bosons are produced in $p\overline{p}$ collisions primarily by the annihilation of u (d) quarks from the proton and $\overline{d}$ ($\overline{u}$) quarks from the antiproton. Because 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 proton (antiproton) direction. The charge asymmetry in the production of W's, as a function of rapidity, is therefore related to the difference in the quark distributions at very high Q^2 ($\approx M_W^2$) and low x ($0.007 < x < 0.24$). The differential Drell-Yan cross section provides information on the magnitude of the quark distributions in the x range 0.006-0.03 over a Q^2 range of 121-3600 GeV^2.

The Drell-Yan events are easily reconstructed from the measured properties of the decay leptons. However, the W decay involves a neutrino, whose longitudinal momentum is undetermined. Therefore the quantity measured is the charge asymmetry of the decay leptons, which has an added contribution due to the V-A decay of the W. This portion of the asymmetry has been well measured by muon decay experiments; thus in comparisons to theory, one can attribute any deviations (between prediction and measurement) to the parton distributions used in the calculations. The asymmetry is defined as:

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

where $d\sigma^+$ ($d\sigma^-$) is the cross section for W^+ (W^-) decay leptons as a function of lepton rapidity (positive rapidity is defined in the proton beam direction). As long as the acceptance and efficiencies for detecting l^+ and l^- are equal, this ratio of cross sections becomes simply the difference in the number of l^+ and l^- over the sum. Further, by CP invariance, the asymmetry at positive eta is equal in magnitude and opposite in sign to that at negative eta, so the value at positive eta is combined with that at negative eta reducing the effect of any differences in the efficiencies for l^+ and l^-.

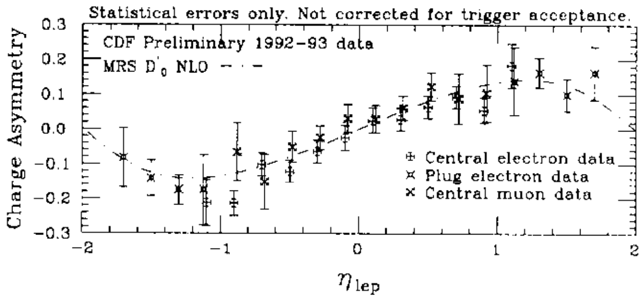

Figure 1: The charge asymmetry, as a function of lepton η found in each of the detector types (Central EM, Plug EM and Central Muon).

The CDF detector is described elsewhere [1]. W candidate events were required to have missing transverse energy $\not{E}_T > 25GeV$ (in the case of muons after correcting for the muon's momentum) and lepton transverse energy $E_T > 25GeV$. To further reduce QCD background, events with a jet whose E_T exceeded $20GeV$ were rejected. Preliminary estimates of the backgrounds and trigger acceptances suggest that systematic errors will not impact the measurement greatly.

Figure 1 shows the asymmetry before the values at positive η are combined with the opposite asymmetry at negative η. The level of agreement between the various detector types strongly suggests that systematic effects are indeed small. Figure 2 shows the asymmetry in the combined data along with next-to-leading order (NLO) calculations [2] made using several sets of parton distributions [3]. Our data favors the MRS D_0' (and also MRS D_-' and MRS S_0') and clearly excludes the older MRS E' distribution. Already the asymmetry is showing sensitivity to the proton's structure at the level of the deep inelastic scattering experiments.

The W charge asymmetry is particularly sensitive to the slope of the d/u ratio versus x [4], whereas the

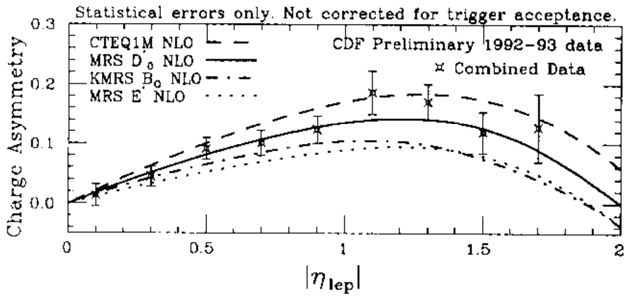

Figure 2: The charge asymmetry of the combined electron and muon data.

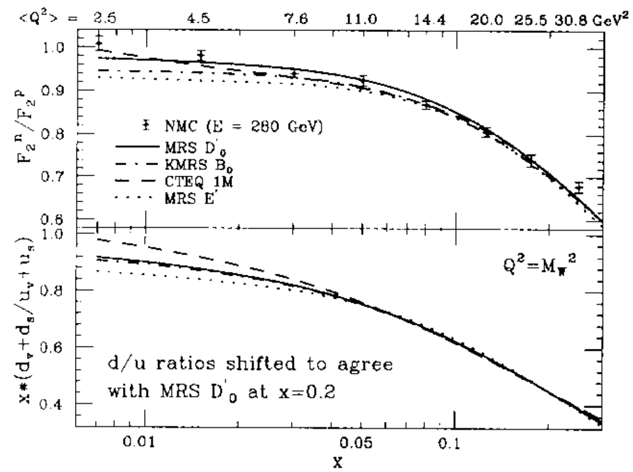

Figure 3: NMC data [4] corrected for shadowing effects [5,6] compared to a NLO calculation of F_2^n/F_2^p and the d/u ratios (shifted to agree at $x = 0.2$) for the same x range.

$F_2^{\mu n}/F_2^{\mu p}$ measurements are sensitive to the magnitude of this ratio. Recently NMC has measured $F_2^{\mu n}/F_2^{\mu p}$ [5] over an x range comparable to that accessible at CDF (though at a very different Q^2). Their data, after correcting for shadowing effects [6, 7], is plotted in figure 3 along with several NLO predictions. Also shown are the d/u ratios after being shifted by a constant so they agree with MRS D_0' at $x = 0.2$. The distributions which predict the largest difference between the d/u ratio at small x and that at moderate x, also predict the largest charge asymmetry. One sees that even though MRS D_0' and CTEQ 1M have very different d/u distributions (and thus very different charge asymmetry predictions) the $F_2^{\mu n}/F_2^{\mu p}$ predictions are similar. This is because $F_2^{\mu n}/F_2^{\mu p}$ ratio is also sensitive to the differences in the $\bar{u}$ and $\bar{d}$ distributions, whereas the $A(y_l)$ asymmetry is not. For example, the CTEQ's parameterization of the $\bar{u}$ and $\bar{d}$ sea distributions compensates for their steep d/u ratio and leads to a prediction for $F_2^{\mu n}/F_2^{\mu p}$ which is somewhat consistent with the NMC data but is much less consistent with our $A(y_l)$ asymmetry measurement.

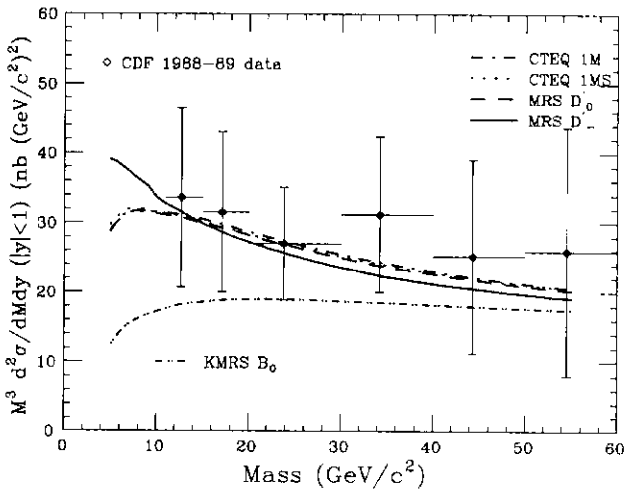

Figure 4: Drell-Yan electron and muon pair production compared to NLO predictions.

The CDF Drell-Yan measurement favors those distributions which have the largest quark contribution in the x interval 0.006 to 0.03 (in particular the sets which used the most recent DIS data). Using the 1992-93 data we can look forward to a factor of two improvement in the errors. In addition, because the $A(y_l)$ systematic errors are small, the upcoming run promises to cut this measurement's error in half also. It is clear that $p\bar{p}$ data is providing strong constraints on the quark distributions.

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