Fermi National Accelerator Laboratory

FERMILAB-Conf-93/209-E
CDF

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August 1993

Submitted to the *International Symposium on Lepton and Photon Interactions*, Cornell University, Ithaca, New York, August 10-15, 1993

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

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CDF/PUB/ELECTOWEAK/PUBLIC/2148
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Abstract

The charge asymmetry as a function of rapidity, $A(y_l)$, has been measured using the W decays to electrons and muons recorded by CDF during the 1992-93 run of the Tevatron Collider at Fermilab. The luminosity used, approximately 20 pb^{-1}, and detector improvements have lead to a six fold increase in statistics (in the plug region the increase is almost an order of magnitude) making discrimination between sets of parton distributions possible. Our data favors the most recent parton distributions and demonstrates the growing value of collider data in the measurement of the proton's structure.

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. So the charge asymmetry in the production of W's as a function of rapidity is related to the difference in the quark distributions at very high Q^2 ($\approx M_W^2$) and low x ($0.007 < x < 0.24$ for $\sqrt{s} = 1.8$ TeV and $-1.8 < y_W < 1.8$).

However, because the W decay involves a neutrino, the boson's boost cannot be reconstructed. So 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

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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:

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

where $d\sigma^+$ ($d\sigma^-$) is the cross section for W^+ (W^-) decay leptons as a function 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 (all efficiencies and acceptances as well as the luminosity cancel). 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^-.

The CDF detector is described elsewhere [1]. W boson decays to leptons are identified by the presence of a large amount of missing transverse energy ($\not{E}_T$) accompanied by a track in the central tracking chamber (CTC) which points at either hits in the muon chambers or a cluster of energy in the electromagnetic (EM) calorimeters. Electron candidates are required to fall within the fiducial regions of either the central (pseudorapidity $|\eta| < 1.1$) or the plug ($1.1 < |\eta| < 2.4$) EM calorimeters and to pass identification cuts (determined with test beam electrons) based on the EM shower's profile. Muon candidates are required to have a track in the muon tracking system, in addition to a minimum ionizing particle signal in the hadronic and EM calorimeters traversed by the muon track. The curvature of the track had to be well measured and was required to pass within 2mm of the beam line (to reject cosmic rays as well as poorly measured tracks). Events were required to have a well defined vertex, within 60 cm of the center of the detector, and $\not{E}_T > 25GeV$ (in the case of muons after correcting for the muon's momentum). The transverse energy (E_T) of the lepton was required to be $> 25GeV$. To further reduce QCD background, events with a jet whose E_T exceeded $20GeV$ were rejected. Because of the limited range in eta covered by the CTC, data taken with detector $|\eta| > 1.7$ is not usable (but the spread of the interaction point in z allows for event $|\eta|$ out to 1.8). Preliminary estimates of the backgrounds and trigger acceptances suggest that any corrections will be at the 0.01 (in units of $A(y_l)$) level or lower while the statistical errors are 0.02 - 0.05, so systematic errors are not expected to 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 data from the plug electrons, central electrons and central muons are plotted separately to show the good agreement between the different data sets in spite of each suffering very different systematics. The level of agreement strongly suggests that systematic effects are small. Figure 2 shows the asymmetry in the combined data set along with a next-to-leading order (NLO) calculation [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 [4], whereas the $F_2^{\mu n}/F_2^{\mu p}$ measurements are sensitive to the magnitude of this ratio. Figure 3 shows the d/u ratio for the range in x over which the asymmetry data extends at CDF. The lepton charge asymmetry, measured in the region $1.0 < |\eta_{lep}| < 1.8$, is sensitive to the difference between the d/u ratio at $x \sim 0.1-0.26$ and $x \sim 0.007-0.02$. Figure 4 illustrates how the lepton charge asymmetry can yield information on the quark distributions at low x. The d/u ratios have been shifted by a constant so that 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 ($x = 0.2$), also predict the largest charge asymmetry. Recently NMC has measured $F_2^{\mu n}/F_2^{\mu p}$ over the range $x = 0.01 - 0.7$ [5]. Their data, after correcting for shadowing effects, is plotted in figure 5 [6] along with the NLO predictions made using several sets of parton distributions. The shadowing correction at low x for $F_2^{\mu n}/F_2^{\mu p}$ could be as large as 4-6% [7]; this is more then the difference between the two modern sets of parton distributions (MRS D_0' and CTEQ 1M). 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 $\overline{u}$ and $\overline{d}$ distributions, whereas the $A(y_l)$ asymmetry is not. For example, the CTEQ's sea parameterization of the $\overline{u}$ and $\overline{d}$ 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) asymmetry measurement.

Over the next few years the Tevatron will deliver an additional $75pb^{-1}$, increasing the statistics by a factor of four. Because the measurement's systematic errors are

small, this additional data will essentially cut the error in half. It is clear that the W charge asymmetry is becoming a strong constraint on the quark distributions.

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U. S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Science, Culture, and Education of Japan; the National Science and Engineering Council of Canada; and the A. P. Sloan Foundation.

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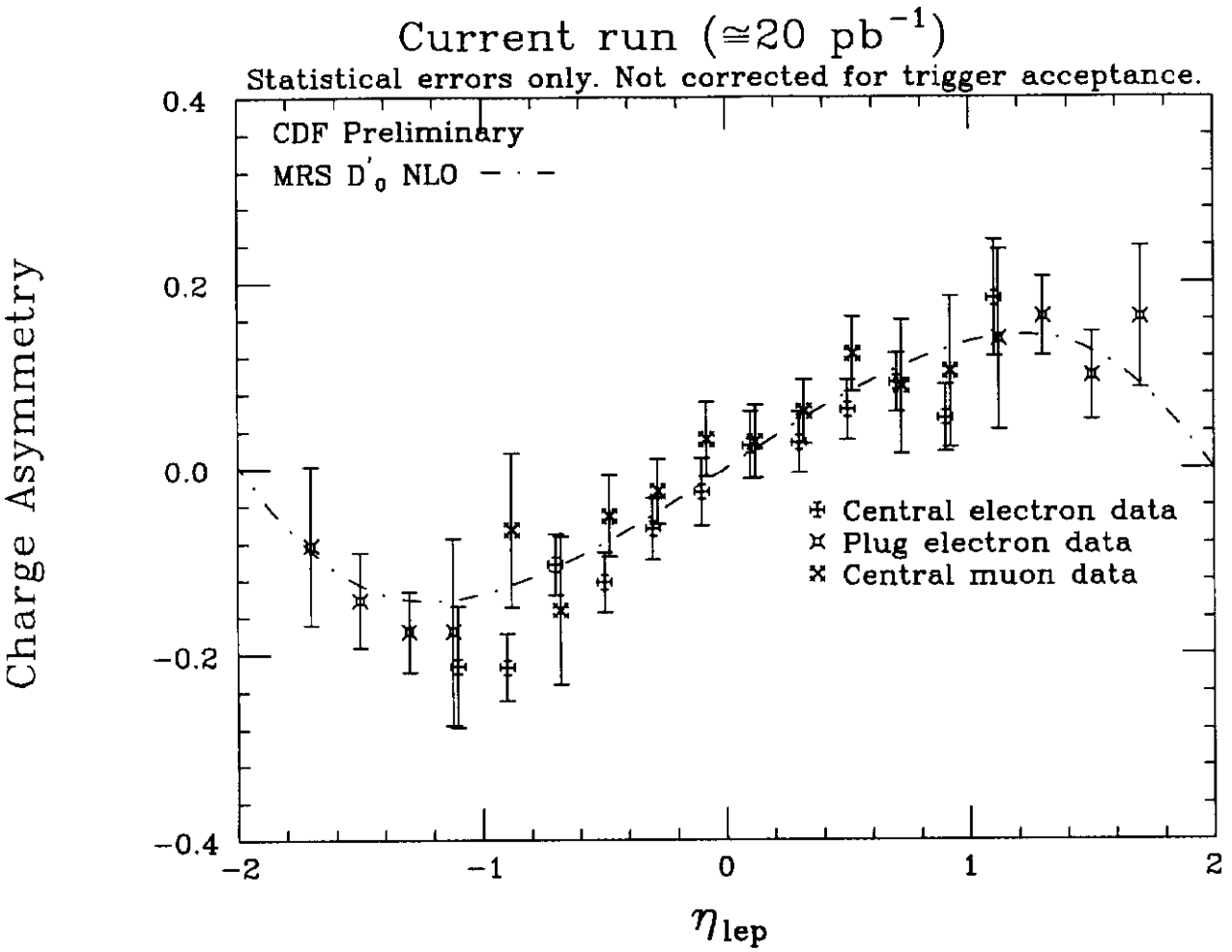

Figure 1: The charge asymmetry, as a function of lepton η found in each of the detector types (Central EM, Plug EM and Central Muon).

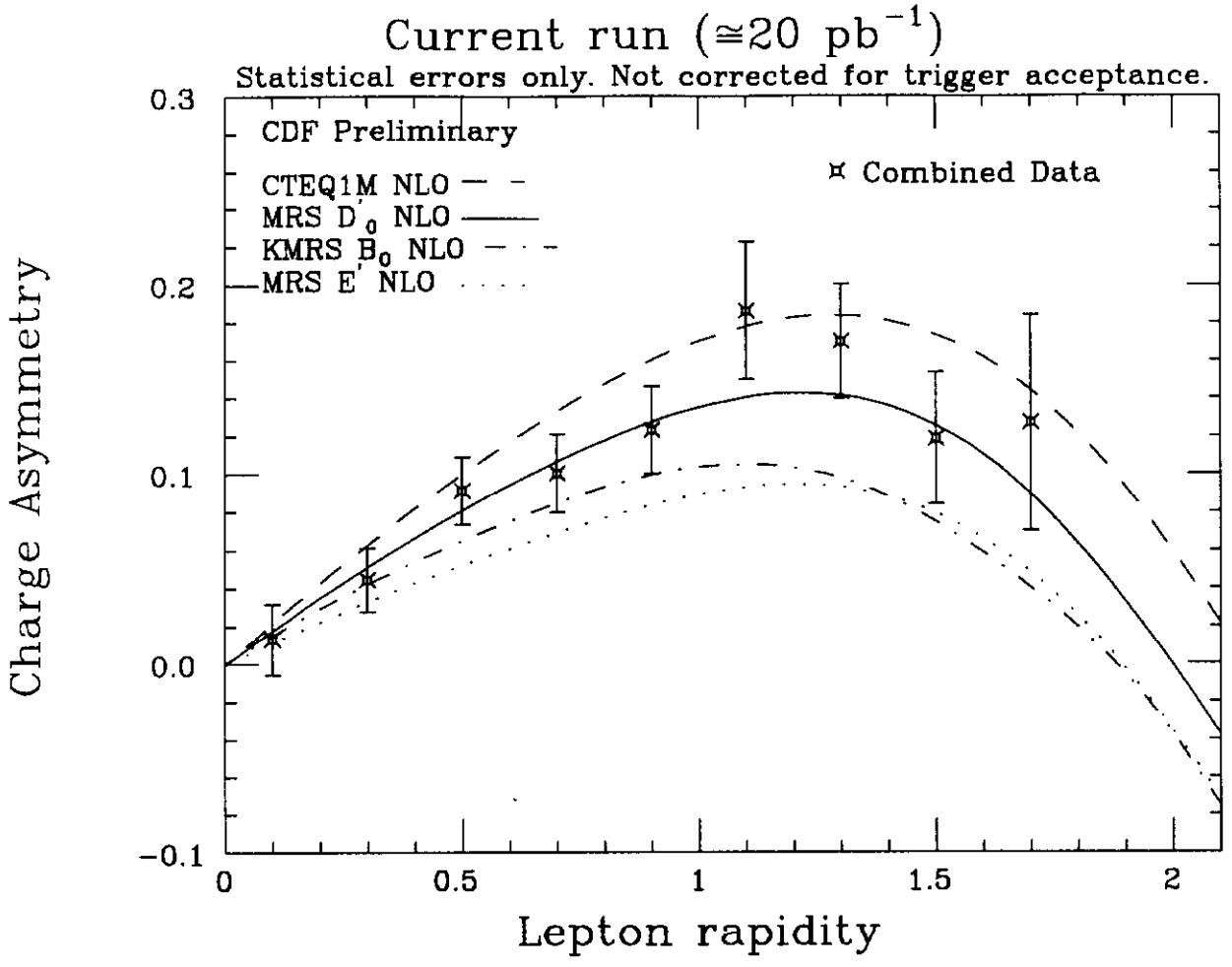

Figure 2: The charge asymmetry of the combined electron and muon data (after the values at $+\eta$ have been combined with the opposite at $-\eta$) compared with the NLO predictions found using several sets of parton distributions.

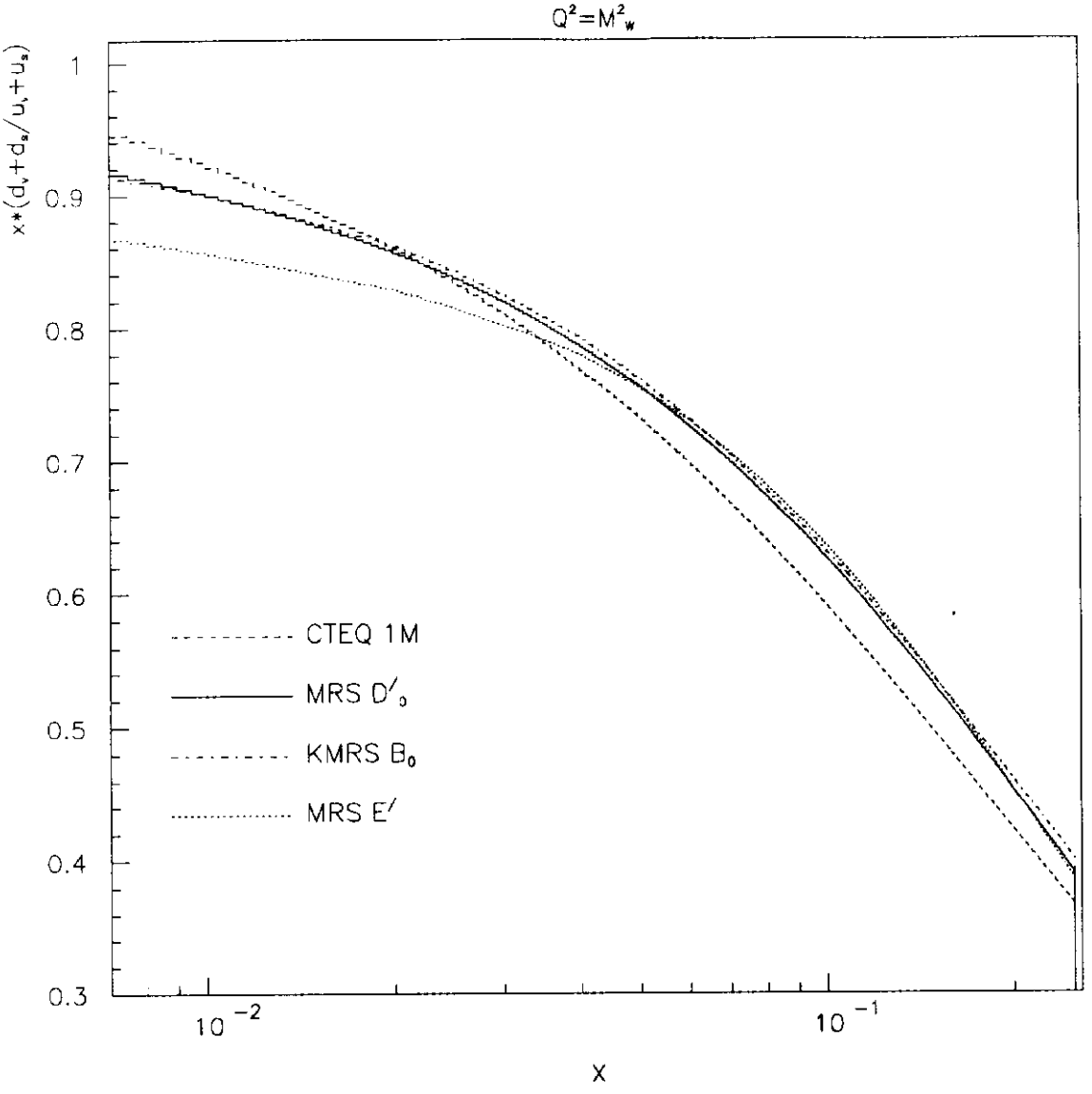

Figure 3: The ratio $x * d/u$ at $Q^2 = M_W^2$ for the range in x which contributes to W boson production at CDF (where $-1.8 < \eta_{lep} < 1.8$).

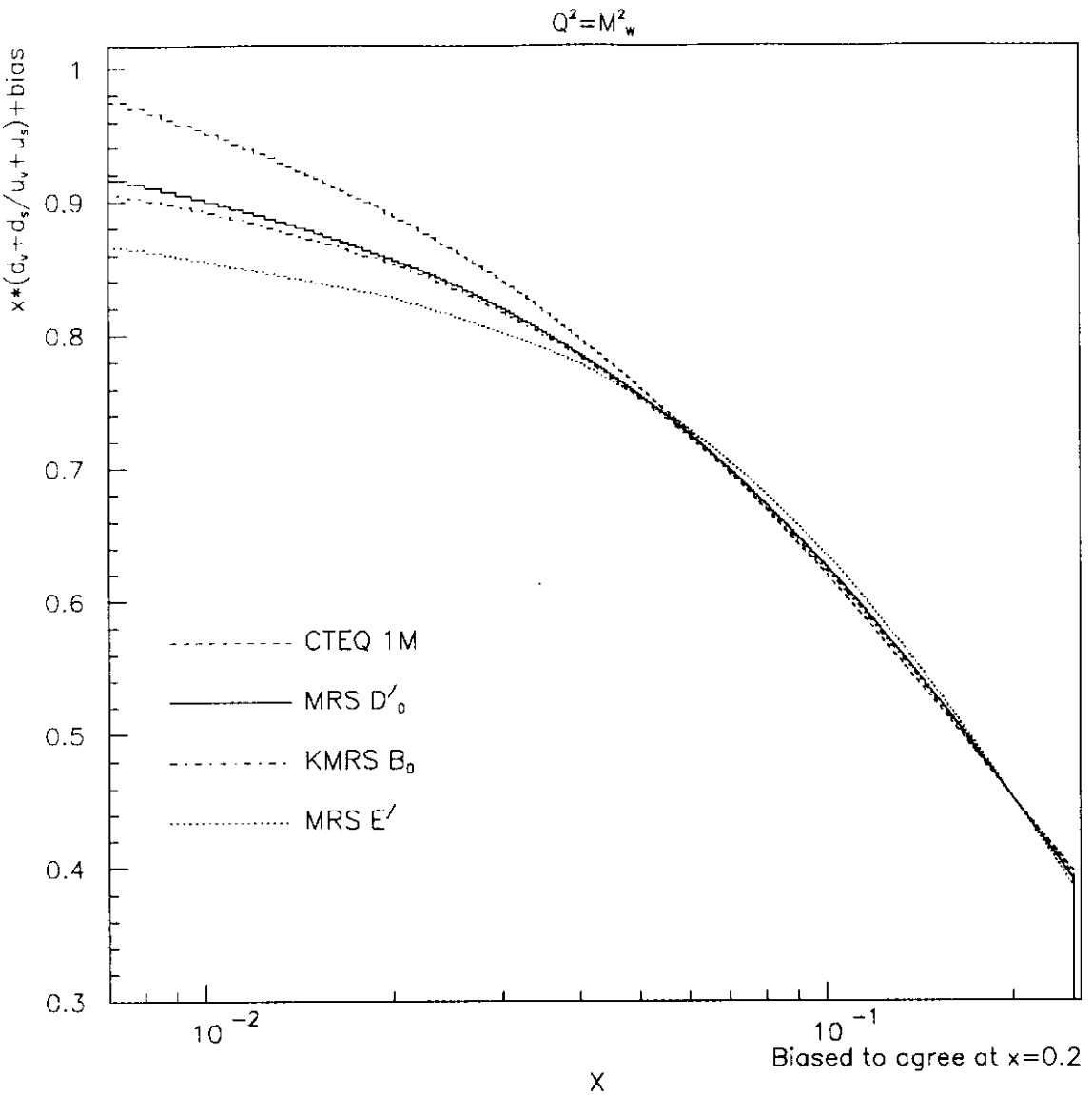

Figure 4: The ratio $x * d/u$, after shifting by a constant such as to agree with MRS D_0' at $x = 0.2$, for the various parton distribution. Note the disagreements at small x follow the same pattern as the disagreements in the predicted W lepton charge asymmetry (figure 2).

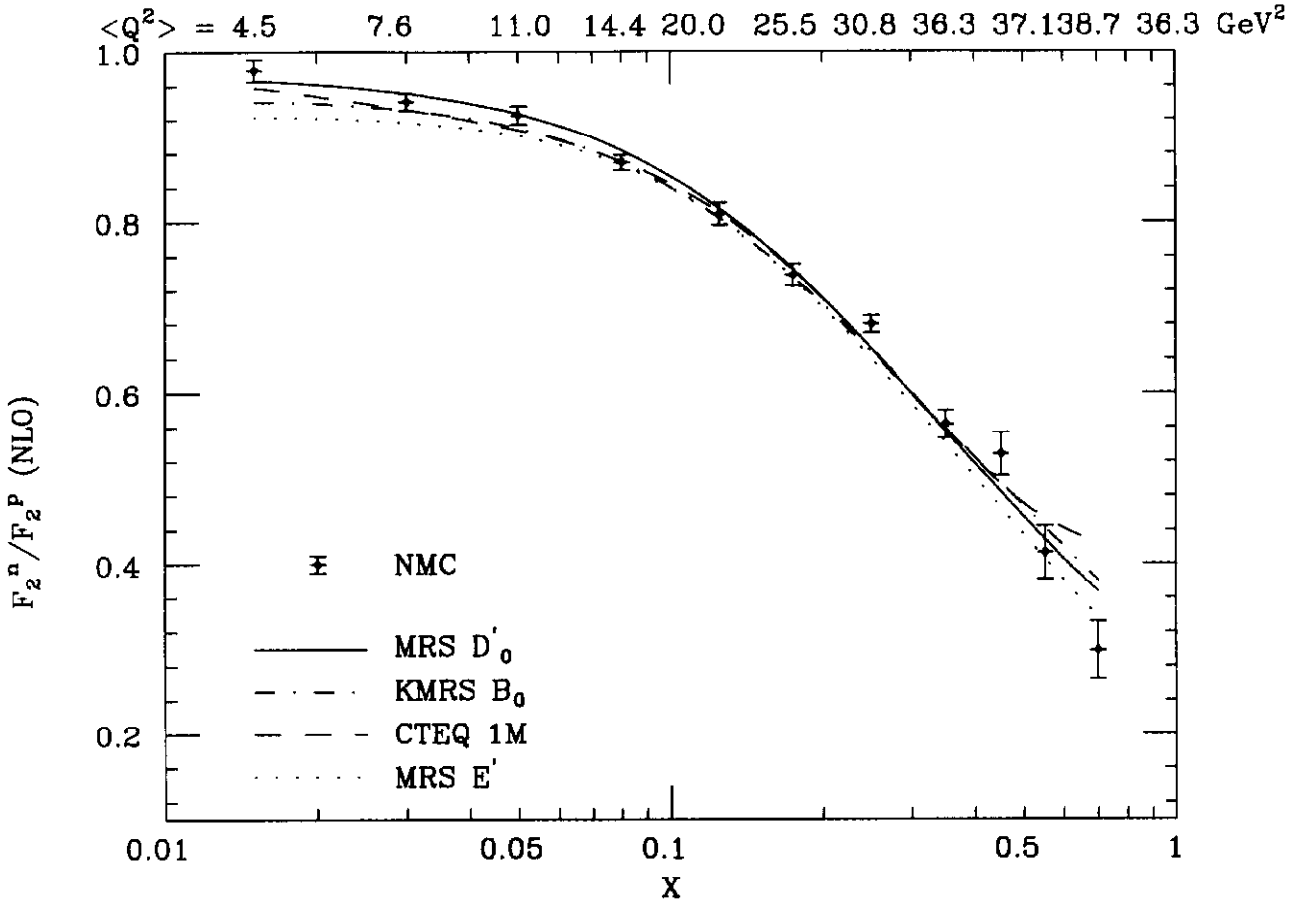

Figure 5: NMC data [5] (E=274 GeV) corrected for shadowing effects [6],[7] compared to a NLO calculation of F_2^n/F_2^p.