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Structure Function Dependence of W/Z and Lepton Pair Production at the Tevatron *

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ABSTRACT

We look in the CDF data from our 1988-1989 run at $\sqrt{s}$=1.8 TeV for those aspects of W/Z and lepton pair (Drell-Yan) production at the Tevatron which appear most sensitive to parton distribution functions, namely, the W^+ and W^- rapidity distributions and the low mass region of Drell-Yan production. The W rapidity distributions are sampled through the lepton asymmetries in the $e\nu$ and $\mu\nu$ decay channels. The analysis on low-mass Drell-Yan production is just beginning and future prospects are briefly discussed.

1. Introduction

CDF data at $\sqrt{s}$=1.8 TeV allows us to probe the parton distribution functions at high values of q^2 and generally low values of x. Data from deep-inelastic scattering (DIS) experiments constrain the quark and anti-quark distributions fairly well down to $x \approx 0.01$. Since the leading diagrams for W/Z and lepton pair production depend on the quark and anti-quark distributions, the production cross-sections for these processes are well predicted by existing data, with a couple of *important* exceptions: the rapidity distribution of W production, and the production of low-mass and/or high-rapidity Drell-Yan pairs.

The rapidity distribution of W particles depends sensitively on the ratio d(x)/u(x) in the region of x<0.2 or so. At $\sqrt{s}$=1.8 TeV, more

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than 85% of the W's are created by a valence-valence or valence-sea interaction (at all rapidities). Thus, a W^+ will be produced primarily by a u quark from the proton striking a d quark from the antiproton. Because the u quarks have, on average, higher momentum than the d quarks, the W^+ will tend to be boosted along the proton direction, while a W^- will tend to be boosted along the anti-proton direction. By measuring the W rapidity distributions, we can reduce the systematic uncertainties in two important measurements. First, the W mass is measured by fitting the W transverse mass spectrum for different W mass hypotheses. This spectrum is distorted by the finite acceptance in rapidity of our detector. Corrections for this acceptance introduce a systematic uncertainty in the W mass measurement. The size of this uncertainty, on the order of 60 MeV at present[1], will become more significant in future collider runs in which we expect much smaller statistical errors on the W mass measurement. In addition, the measurement of the cross-section ratio $R \equiv \sigma(p\bar{p} \rightarrow W \rightarrow e\nu)/\sigma(p\bar{p} \rightarrow Z \rightarrow ee)$ contains systematic uncertainties from the low-x behavior of the u and d quark distributions. This ratio, which has given us our best knowledge of the total W decay width, suffers systematic uncertainties both in the theoretical prediction of the W and Z production cross-sections[2], and in the calculated CDF detector acceptances for the two final states[3]. Both sources of uncertainty can be reduced by an accurate measurement of the W rapidity distributions.

The measurement of low-mass and/or high-rapidity Drell-Yan cross-sections is sensitive to the general behavior of the parton distribution functions at low x. Because of the high center-of-mass energy, very low values of x (down to 10^{-3} or less) can be probed with pairs of moderate mass (>10 GeV/c^2). The large uncertainty in SSC cross-sections for W/Z and Drell-Yan production because of the unknown small-x behavior of the parton distributions has been previously pointed out[4] in the 1988 Snowmass workshop. Measurements of Drell-Yan production at the Tevatron should help reduce this uncertainty.

II. W Rapidity Distributions (Asymmetry)

The data sample which we are using comes from 4.3 pb^{-1} collected in the '88-'89 CDF data run. We have isolated W samples in the electron and muon final states by requiring the lepton to have transverse energy E_T>20 GeV, as well as by imposing tight cuts on the identification of the lepton candidates. Because it is important to know the charge of the leptons, we use only leptons detected in the central region, $|\eta|<1.0$ for electrons and $|\eta|<0.7$ for muons. In the electron channel, we also require missing-E_T>20 GeV. We then impose a transverse mass cut, $M_T>50$ GeV/c^2, and require that no jets with observed E_T>10 GeV be found in the W candidate events. The no-jet requirement not only reduces background, but should also reduce the effect of higher-order W production diagrams, making it easier to compare the data with leading-order calculations. We find 923 $W^+\rightarrow e^+\nu$, 994 $W^-\rightarrow e^-\nu$, 411 $W^+\rightarrow\mu^+\nu$, and 386 $W^-\rightarrow\mu^-\nu$ candidate events in our data sample.

We actually do not observe the rapidity of the W particles themselves, but rather the rapidity distributions of the charged leptons from the $W\rightarrow\ell\nu$ decay. Finding the rapidity of the parent W particle from the lepton energy and direction and the missing transverse energy involves an equation having two solutions. At CERN collider energies, the rapidity distribution of W production is sufficiently peaked near zero that the ambiguity between these solutions can usually be resolved by taking that solution which minimizes $|Y_W|$. At our energies, the rapidity distribution of W's is sufficiently broad so that this "trick" works very poorly for leptons detected in the central region of our detector. Therefore, we base our comparisons to the predictions from different parton distribution functions on the charged lepton rapidity distributions alone.

In order to reconstruct the lepton rapidity distributions, one must know the reconstruction efficiencies quite precisely as a function of rapidity. It is much easier to just measure the lepton asymmetry defined by the ratio:

$$A(\eta) = \frac{\sigma_+(\eta) - \sigma_-(\eta)}{\sigma_+(\eta) + \sigma_-(\eta)} \quad . \qquad (1)$$

In this ratio, the reconstruction efficiency drops out if it is the same for +/- leptons. We must demonstrate that this is true, and also that the backgrounds in the W sample are negligible.

A number of studies have been performed using our W samples, Monte Carlo events, cosmic ray events, and inclusive muon events to test our assumption that the reconstruction efficiencies are the same for both lepton charges. These studies test this assumption down to the level of 1%. No discrepancies are observed.

The backgrounds from normal QCD events are estimated at less than (1.0±0.5)% in the electron sample and (0.7±0.7)% in the muon sample. The effect of this source of background is to dilute any observed asymmetry (which, as will be shown, is typically less than 15%). Backgrounds from $W \rightarrow \tau\nu \rightarrow e\nu\nu\nu$ sequential decays are estimated at 3% in both samples. This source of background has the same asymmetry as the signal except for a very small correction due to the transverse mass cut. The net effect of all sources of background is to change the observed asymmetry by less than 1%, and can thus be ignored.

The CDF asymmetry data are shown in Fig. 1 together with curves from a leading-order calculation. This calculation numerically integrates the W rapidity spectrum with the expected angular distribution $\propto(1-\cos\theta^*)^2$ of the leptons in the W rest frame. In the CDF convention, θ is defined from the proton beam direction. We have plotted the lepton asymmetry as a function of $|\eta|$, having combined the asymmetry measurements from $\eta<0$ with the opposite sign (assuming CP conservation) to the measurements from $\eta>0$. The curves represent predictions of EHLQ[5], DO[6], DLFM[7], and HMRS[8] parton distribution function sets. The order of the curves, from largest to smallest asymmetries, is: HMRSB, EHLQ1, EHLQ2, DFLM3, DFLM2, HMRSE, DFLM1, DO2, and DO1. It is apparent that the parton distribution sets which predict the largest asymmetries also agree best with the CDF data.

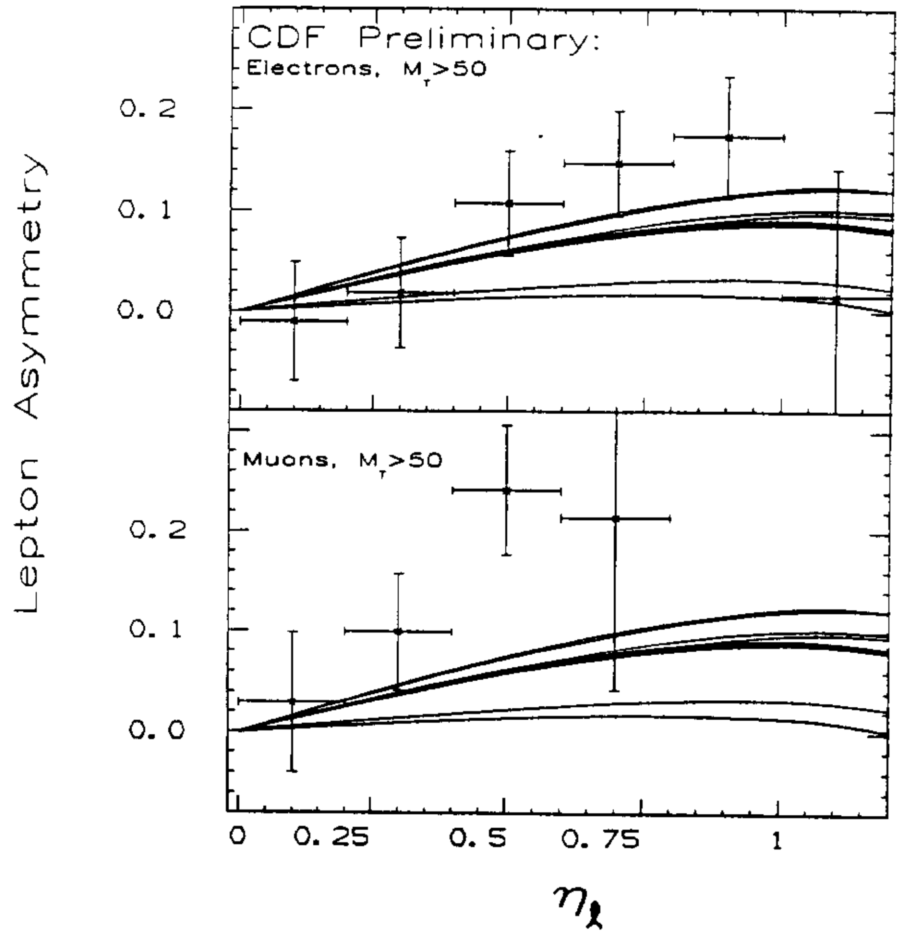

Figure 1: The observed lepton asymmetries in electron and muon event samples, compared to the predictions of a leading-order calculation for various parton distributions.

The effect of higher-order corrections on the observed asymmetry has been investigated with the Papageno Monte Carlo. W+1-jet events were produced requiring E_T(jet)>5 GeV. Fig. 2 shows the resulting variation of the predicted asymmetry (integrated over $|\eta|<1.0$) with $P_T(W)$. From the lines drawn to fit the Monte Carlo data, we estimate that the mean observed $P_T(W)$ of 4.7 GeV/c in our data sample raises the observed asymmetry by approximately 0.5% from that predicted by the leading-order calculation. Thus, we have limited the corrections due to higher-order effects to a negligible level.

The results of fitting the curves shown in Fig. 1 to the observed data are listed in Table 1. The large χ^2 observed for the DO1 and DO2 distribution functions appear to rule them out. The low asymmetry predicted from Duke&Owens is directly related to a particularly slow fall-off in the d(x)/u(x) ratio in the range 0.01<x<0.2.

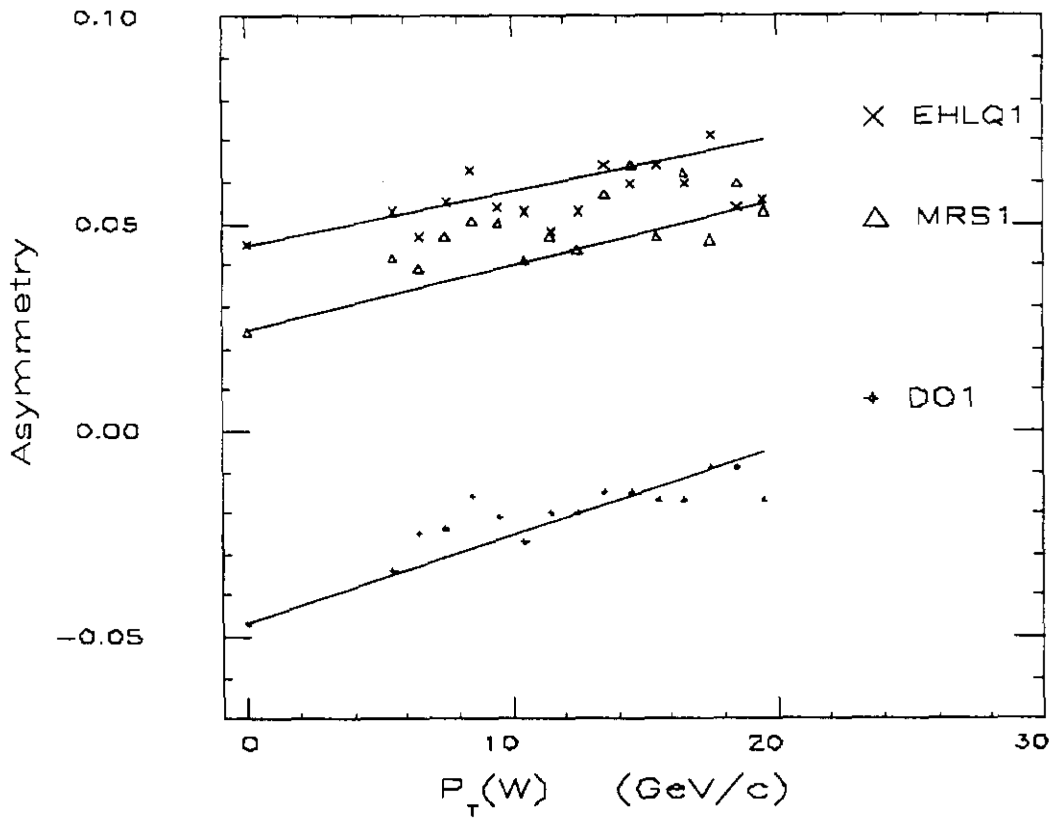

Figure 2: The mean asymmetry in the central region predicted by Papageno vs. $P_T(W)$.

Table I

Function Set	Electrons χ^2, 6 d.o.f.	Muons χ^2, 4 d.o.f.	Combined χ^2,10 d.o.f.	Combined $P(\chi^2)$
HMRSB	3.5	7.8	11.3	34%
EHLQ1	3.6	8.1	11.8	30%
EHLQ2	4.9	9.3	14.2	16%
DFLM3	5.1	9.3	14.5	15%
DFLM2	5.4	9.5	15.0	13%
HMRSE	5.4	9.8	15.2	12%
DFLM1	5.7	9.8	15.4	11%
DO2	13.6	14.8	28.4	0.16%
DO1	16.6	16.1	32.6	0.03%

III. Drell-Yan Production

We now turn to the case of Drell-Yan production at $\sqrt{s}$=1.8 TeV. In general, one can access di-lepton masses down to about twice the lepton P_T threshold. In our di-electron and di-muon triggers, we ran with nominal P_T thresholds of 5 and 3 GeV/c, respectively. In addition, the di-lepton rapidities (Y^*) which can be accessed are roughly the same as the pseudo-rapidity coverage of the detector systems: $|\eta|<1.0$ for central electrons and $|\eta|<0.7$ for central muons. The relevant equations in the Drell-Yan process are:

$$m^2_{\ell^+\ell^-}=sx_1x_2\,,\qquad x_1=\sqrt{\frac{m^2}{s}}e^{-Y_{\ell\ell}}$$

Central Drell-Yan production ($Y_{\ell\ell}\approx0$) accesses x ranges $x_1\approx x_2\approx\sqrt{\frac{m^2}{s}}$, whereas forward Drell-Yan (x_2 close to 1) can probe x regions all the way down to $x_1(\text{min})=\frac{m^2}{s}$. At the Tevatron, di-lepton masses of 10 GeV/c^2 are in principle sensitive down to $x\approx6\cdot10^{-3}$ in the central region and $x\approx3\cdot10^{-5}$ in the most forward region. These x values are low enough to be applicable to calculations of SSC cross-sections for W/Z and Drell-Yan production.

We have analyzed di-electron candidate events in a preliminary analysis which is geared more toward exploring high di-lepton masses for signals from additional Z^0's and quark-lepton compositeness than for measuring the Drell-Yan cross-section down to the lowest possible masses. Nonetheless, the analysis retains reasonable efficiency down to masses of about 30 GeV/c^2. Fig. 3 demonstrates this with an acceptance curve derived from Isajet v6.10. In Fig. 4 is shown the differential cross-section for lepton pairs as a function of pair mass after acceptance corrections. The curve plotted is also from Isajet v6.10, setting parameters $q_T(W)=0$ and using EHLQ1 parton distributions. The data and the Monte Carlo predictions agree down to a mass of 30 GeV/c^2.

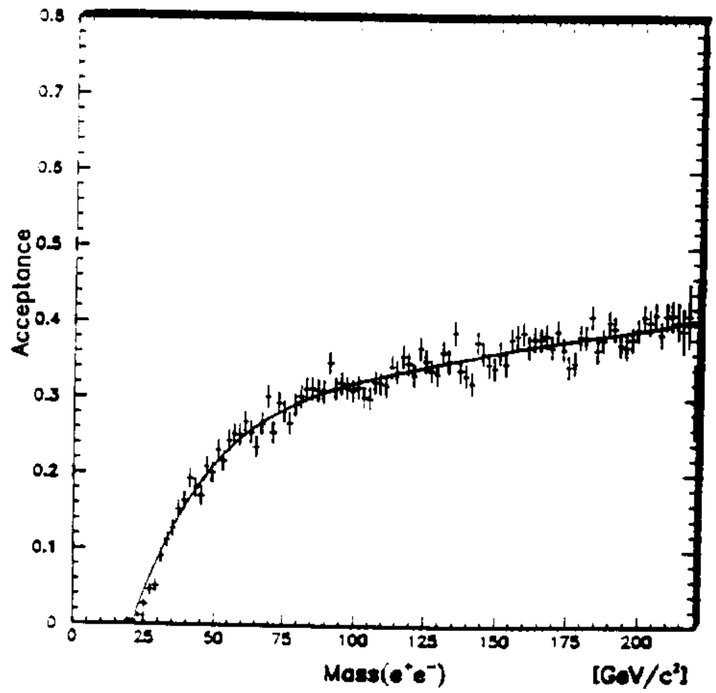

Figure 3: Acceptance curve (from Isajet) for the di-electron analysis.

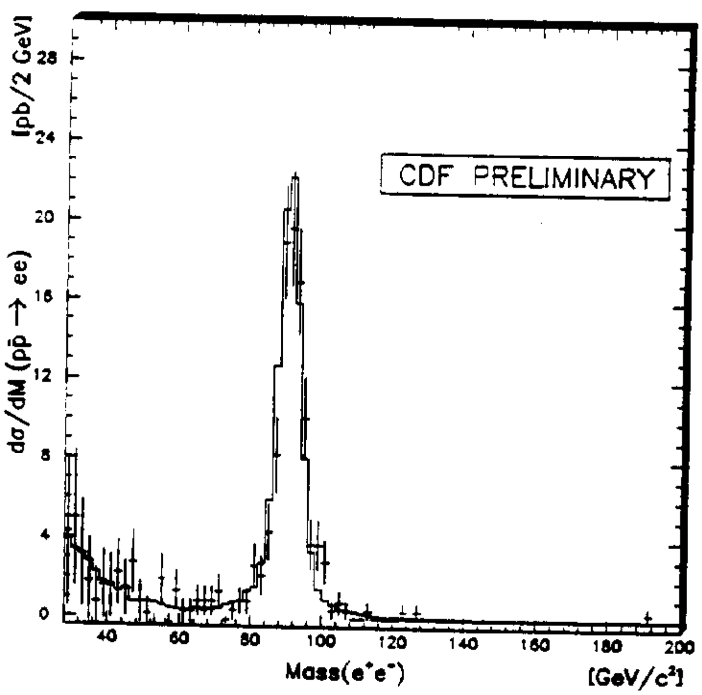

Figure 4: Differential cross-section for $p\bar{p} \rightarrow X \rightarrow e^+e^-$.

We have also begun work on an analysis of the central di-muon data from the '88-'89 data run. Again using Isajet to simulate Drell-

Yan production, we find that our central di-muon analysis becomes quite efficient when pair masses exceed 10 GeV/c^2.

In principle, we could use also analyze di-muon events from our forward muon toroid system, which covers pseudo-rapidities between 1.9 and 3.6. However, during our '88-'89 data run, we collected only a very small integrated luminosity while running with a forward di-muon trigger. Unfortunately, the high-rapidity data which is accessible to the forward muon system probes the lowest values of x. This is shown in Fig. 5, where the minimum x probed is plotted versus di-lepton rapidity ($Y_{\ell\ell}$) for several different cases: the present electron analysis, reaching down to pair masses of 30 GeV/c^2; a di-electron analysis in progress which should reach down to about 16 GeV/c^2; the central muon analysis reaching down to 10 GeV/c^2, and a hypothesized analysis based on forward di-muon data from our next ('91) CDF data run which might reach down to 16 GeV/c^2 as well. Given the lack of reliable data from DIS experiments below $x \approx 0.01$, it is clear that the CDF Drell-Yan data can probe the parton distribution functions in a previously unexplored region of x.

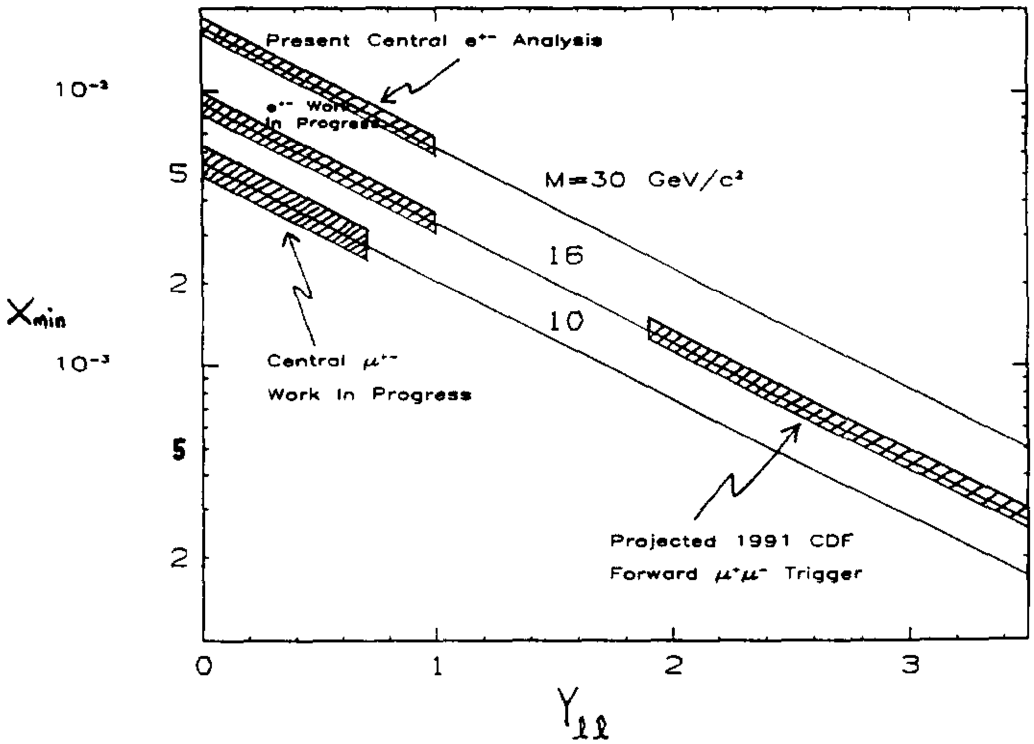

Figure 5: The minimum x probed by Drell-Yan at several pair masses relevant to CDF data analysis.

IV. Conclusions

We have shown that the CDF data can supply some useful information about the parton distribution functions in the low x region responsible for W/Z production and below. The lepton asymmetry in the W sample is on the high side of expectations, and appears to rule out Duke&Owens structure functions. Drell-Yan data down to pair masses of 30 GeV/c^2 agrees with expectations. Further analyses are in progress attempting to measure Drell-Yan production down to lower masses. Finally, with the improvement in luminosity and our increasing knowledge of our detector's capabilities, we expect to measure these processes with much better precision in future CDF data runs.

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