ASYMMETRIES IN $W^{\pm}$ AND Z^0/γ^* PRODUCTION AT THE TEVATRON

E. HALKIADAKIS
(ON BEHALF OF THE CDF AND D0 COLLABORATIONS)
University of Rochester, Department of Physics & Astronomy,
Rochester, NY 14627-0171, USA
E-mail: evah@fnal.gov

We describe a measurement of the charge asymmetry of electrons from $W^{\pm}$ boson decays using $p\bar{p} \to W \to e\nu$ events. We also present a measurement of the forward-backward charge asymmetry of electron-positron pairs resulting from the process $p\bar{p} \to Z^0/\gamma^* \to e^+e^-$, from which we extract the Z^0-quark and Z^0-electron coupling constants and measure the sensitivity of the CDF experiment to these couplings. These analyses use integrated luminosities of 170 pb^{-1} and 72 pb^{-1}, respectively, of data collected by the CDF Run II detector at the Fermilab Tevatron.

1 Introduction

The production of $W^{\pm}$ and Z^0 bosons at the Tevatron allows us to carefully study their properties. For example, a precise measurement of the charge asymmetry and the boson rapidity spectrum in $p\bar{p} \to W^{\pm}$ production provides a constraint on parton fluxes. The theoretical uncertainty on the parton distribution functions (PDFs) of the proton is a significant uncertainty on the measurement of the $W^{\pm}$ boson mass as well as many other measurements at the Tevatron. Additionally, we can put constraints on new physics by looking at the Drell-Yan invariant mass distribution and the forward-backward charge asymmetry in the polar angle spectrum in $p\bar{p} \to Z^0/\gamma^* \to \ell^+\ell^-$ production.

2 $W^{\pm}$ Charge Asymmetry

$W^+(W^-)$ bosons are produced in $p\bar{p}$ collisions primarily by the annihilation of $u(d)$ quarks from the p and $\bar{d}(\bar{u})$ quarks from the $\bar{p}$. As the u quark tends to carry a larger fraction of the proton's momentum than the d quark, the $W^+(W^-)$ is boosted, on average, in the p ($\bar{p}$) direction. This results in a non-zero forward-backward charge asymmetry, defined as:

$$A(y_W) = \frac{d\sigma_+/dy_W - d\sigma_-/dy_W}{d\sigma_+/dy_W + d\sigma_-/dy_W},$$

where the subscript denotes the charge of the $W^{\pm}$ boson, y_W is the rapidity of the $W^{\pm}$ bosons and $d\sigma/dy_W$ is the differential cross section for $W^{\pm}$ production. y_W is a sensitive probe of the difference between u and d quarks in the region $Q^2 \approx M_W^2$.

Since the $W^{\pm}$ rapidity is experimentally undetermined because of the unknown longitudinal momentum of the ν from the $W \to \ell\nu$ decay, we measure the lepton charge asymmetry which is a convolution of the $W^{\pm}$ production charge asymmetry and the $V-A$ asymmetry from the $W^{\pm}$ decay. The lepton charge asymmetry is defined as:

$$A(\eta_\ell) = \frac{d\sigma_+/d\eta_\ell - d\sigma_-/d\eta_\ell}{d\sigma_+/d\eta_\ell + d\sigma_-/d\eta_\ell},$$

where η_ℓ is the pseudo-rapidity of the lepton, in this case $e^{\pm}$. This charge asymmetry is one of the best determinations of $d(x)/u(x)$, the d to u quark PDF ratio as a function of x, the fraction of the nucleons momentum carried by the quarks, and plays an important role in global fits. The sensitivity to $d(x)/u(x)$ is more pronounced at high values of η_ℓ, the region where it is least constrained.

The primary experimental challenge in this measurement is tracking in the forward region to obtain charge identification for electrons. The technique uses high energy electromagnetic clusters in the forward calorimeter to seed tracks through the silicon detec-

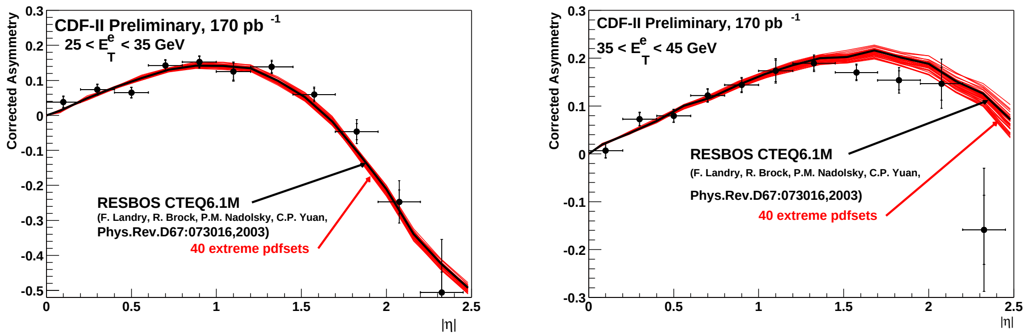

Figure 1. The measured charge asymmetry vs. electron η. We compare to the expectation from NLO RESBOS with the CTEQ6.1M PDF. Left: $25 < E_T^e < 35$ GeV. Right: $35 < E_T^e < 45$ GeV.

tor. Using the event vertex and the centroid of the shower in the calorimeter as two endpoints, the energy deposited in the calorimeter is used to predict the two trajectories for the candidate electron depending on the charge. A search for hits in the silicon detector along the two trajectories is performed and the better match is chosen. This algorithm is efficient and has low background. The resolution of the forward calorimeter's shower-maximum position determination is improved to about 1 mrad after careful alignment of this detector. This is sufficient to determine the charge quite robustly over the range $|\eta| < 2$, where the silicon has full coverage.

We select $W^\pm$ candidates from CDF Run II data corresponding to an integrated luminosity of 170 pb^{-1}. The signature of a $W \to e\nu$ decay is a high E_T electron, isolated in the calorimeter and large missing transverse energy accounting for the ν. Additional track quality requirements are applied to reduce QCD backgrounds and improve the quality of the the charge identification. We find 49124 candidate $W \to e\nu$ events in the central calorimeter ($|\eta| < 1$) and 28806 in the forward region ($1 < |\eta| < 2.8$).

To extract the true asymmetry, two corrections need to be applied to the raw asymmetry: charge misidentification and background subtraction. Both bias the asymmetry low. We can correct for the former if we know the rate at which the charge is misidentified. We measure this rate in each η bin, $f_Q(\eta)$, with $Z^0 \to e^+e^-$ events where a track in the central tracker matched to one leg provides a charge tag for the other leg. We also correct the asymmetry measurement by subtracting contributions of three backgrounds in each η bin: $Z^0 \to e^+e^-$, $W \to \tau\nu \to e\nu\nu$ (measured from Monte Carlo) and QCD jets which fake electrons and missing energy (measured from data). Uncertainties in $f_Q(\eta)$ and the background corrections go directly into the measurement of $A(\eta)$.

We would like to measure the $W^\pm$ production asymmetry but that is complicated by the ν ambiguity. However, we can gain additional sensitivity by looking at $A(\eta)$ as a function of the electron's transverse energy, E_T^e. At higher E_T^e, the electron direction corresponds more closely to the $W^\pm$ direction. Thus, the measurement is divided into two ranges: $25 < E_T^e < 35$ GeV and $35 < E_T^e < 45$ GeV. At lower E_T^e the effect of the decay asymmetry is enhanced while at higher E_T^e the effect of the production asymmetry is enhanced. Figure 1 compares the measured asymmetry to the prediction from a NLO RESBOS calculation using CTEQ6.1M [1]. The uncertainty in the CTEQ prediction is illustrated by the band of red curves which are from varying the 40 error PDF sets. Future inclusion of this new data in the PDF fits will reduce this uncertainty.

3 A_{FB} in e^+e^- Pairs, Z^0 Couplings

The presence of both vector and axial vector couplings of electroweak bosons to fermions in the process $p\bar{p} \to Z^0/\gamma^* \to \ell^+\ell^-$ give rise to an asymmetry in the polar angle of the lepton momentum in the rest frame of the lepton pair. If the number of forward events, N_F, is defined as the number of events with positive $\cos\theta^*$ and the number of backward events, N_B, as the number of events with negative $\cos\theta^*$, then the forward-backward charge asymmetry, A_{FB} is:

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B} = \frac{\sigma_{\cos\theta^*>0} - \sigma_{\cos\theta^*<0}}{\sigma_{\cos\theta^*>0} + \sigma_{\cos\theta^*<0}},$$

where $\cos\theta^*$ is evaluated in the Collins-Soper frame [2] to minimize ambiguity of the transverse momentum of the incoming quarks. A_{FB} is a direct probe of the relative strengths of the vector and axial-vector couplings over the range of Q^2 being considered. Additionally, A_{FB} constrains the properties of any additional non-Standard Model (SM) amplitudes contributing to $q\bar{q} \to \ell^+\ell^-$ and is complementary to direct searches for these amplitudes via excesses in the total cross section. Although it will be very difficult for the Tevatron to compete with the LEP measurements for Q^2 below 200 GeV, we can probe beyond the energies that were available at LEP.

This measurement takes advantage of both the central and forward calorimeters identifying isolated high E_T electrons out to $|\eta| < 3$. We find 5211 candidate dielectron events with $40 < M_{ee} < 600$ GeV/c^2 from CDF Run II data corresponding to an integrated luminosity of 72 pb^{-1}. We estimate the background to be about 3% of the sample and is dominated by QCD di-jet production.

To correct A_{FB} and obtain the *true* A_{FB} we must account for any acceptance and detector effects which can change the number of forward and backward events in each M_{ee} bin. The dominant contributions to the detector acceptance are kinematic, geometric and electron identification selections. The major effects which contribute to event migration between M_{ee} bins are the energy resolution of the detector and radiation (such as bremsstrahlung). We parametrize our acceptance and event migration in order to map events in a reconstructed M_{ee} bin to a true M_{ee} bin. The bin migration is not negligible at the Z^0 pole but at high masses smearing is not a large effect. We perform an unconstrained unfolding analysis and use a maximum log likelihood method to compare to data at the detector level. A smoothing regularization function is used near the Z^0 pole to reduce variances. This analysis makes no SM assumptions about A_{FB} and the results are shown in Figure 2.

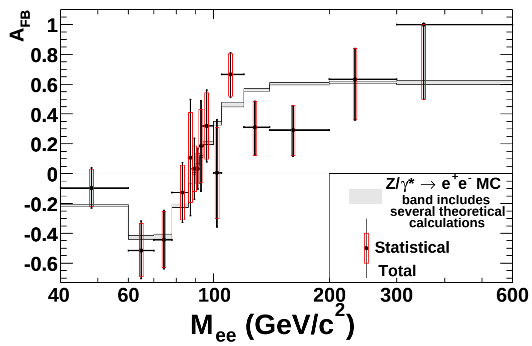

Figure 2. A_{FB} with statistical and systematic uncertainties (crosses) and theoretical predictions (bands).

We use the parametrized acceptance and event migration for an unbiased measurement of the Z^0-quark and Z^0-electron coupling constants. We vary the Z^0-quark couplings at generator level and perform a χ^2 fit between the smeared theoretical calculations and the raw A_{FB} to extract the couplings. All other parameters were fixed to the SM values. The theoretical calculation

Table 1. Measured effective q (left/right) and e (vector/axial-vector) coupling constants compared to SM prediction.

	Coupling	SM prediction [3]
u_L	$0.419\ ^{+0.131}_{-0.167}$	0.3459 ± 0.0002
d_L	$-0.116\ ^{+0.418}_{-0.352}$	-0.4291 ± 0.0002
u_R	$0.020\ ^{+0.145}_{-0.150}$	-0.1550 ± 0.0001
d_R	$0.105\ ^{+0.128}_{-0.315}$	0.0776 ± 0.0001
e_V	-0.058 ± 0.017	-0.0397 ± 0.0003
e_A	-0.528 ± 0.136	-0.5064 ± 0.0001

uses ZGRAD [4], a Monte Carlo cross section calculation program for Drell-Yan production with $\mathcal{O}(\alpha)$ electroweak corrections. We then assume the SM values for the Z^0-quark couplings to determine the Z^0-electron couplings. The results are summarized in Table 1. The CDF sensitivity, with $\sim 72\ pb^{-1}$ of analyzed data, is rather limited, but the values of the couplings are consistent with the SM. Finally a fit where the quarks as well as the electron couplings to the Z^0 boson are expressed as a function of $\sin^2\theta_W$ gives:

$$\sin^2\theta_W = 0.2238 \pm 0.0040_{\rm stat} \pm 0.0030_{\rm syst},$$

with $\chi^2/\text{ndf} = 12.5/14.0$. The present CDF sensitivity on $\sin^2\theta_W$ is provided by the Z^0-electron couplings and is expected to improve with higher statistics.

4 Conclusions

We present the first CDF Run II measurement of the W charge asymmetry. The uncertainty on d to u quark PDFs could be reduced by inclusion of this data in global fits. We measure A_{FB} as a function of M_{ee} in $Z^0/\gamma^* \to e^+e^-$ events without any SM assumptions. We observe agreement with the SM and find nothing new above the Z^0 pole yet. We also fit for Z^0-quark and Z^0-electron coupling constants. The couplings are statistically dominated and the CDF sensitivity is expected to improve with the new data being analyzed.

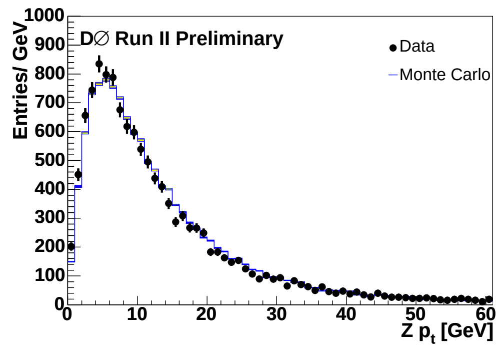

Figure 3. Z^0 transverse momentum distribution from $Z^0/\gamma^* \to \mu^+\mu^-$ events for 148 pb^{-1} of data collected with the D0 Run II detector (dots) compared to Pythia Monte Carlo (histogram).

We look forward to future measurements from both the CDF and D0 experiments of the rapidity distribution in Z^0 production to further constrain PDF uncertainties. Additionally, measurements of $d\sigma/dp_T$ (see Figure 3) in both $W^\pm$ and Z^0 will further test QCD predictions and will have a direct impact on the uncertainty of the $W^\pm$ mass measurement.

Acknowledgments

I would like to thank the CDF and D0 Collaborations, in particular those whose hard work went into the results presented here. I also thank the conference organizers for hosting a wonderful conference.

References

1. F. Landry, R. Brock, P. M. Nadolsky, C. P Yuan, *Phys. Rev.* D **67**, 073106 (2003).
2. J. C. Collins and D. E. Soper, *Phys. Rev.* D **16**, 2219 (1977).
3. K. Hagiwara, *et al.*, *Phys. Rev.* D **66**, 010001 (2002).
4. Baur, S. Keller and D. Wackeroth, *Phys. Rev.* D **59** 013992 (1999).