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Lepton Charge Asymmetry from W Decay and Search for New Gauge Bosons at DØ

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Lepton Charge Asymmetry from W Decay and Search for New Gauge Bosons at DØ

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A measurement is described of the charge asymmetry in the pseudorapidity distribution of muons from W boson decay in proton-antiproton collisions at $\sqrt{s} = 1.8$ TeV using the DØ detector. We also report on a search for extra gauge bosons in the electron decay channel. Mass limits of $M_{W'} > 600$ GeV and $M_{Z'} > 440$ GeV are obtained at 95% confidence level under the assumption of standard model couplings.

1 Charge Asymmetry

1.1 Introduction

W boson production in $\overline{p}p$ collisions proceeds mainly by $u\overline{d}$ (or $\overline{u}d$) annihilation [1]. Simple structure function models of the proton predict that u-quarks carry more momentum on average than d-quarks, so the produced W^+ boson tends to be boosted in the proton direction and W^- in the antiproton direction. The V–A coupling of the W gives rise to angular distribution for the decay $W^\pm \to \ell^\pm \nu$ which is described by

$$\frac{d\sigma}{d\cos\hat{\theta}} \propto (1+\cos\hat{\theta})^2,$$

where $\hat{\theta}$ is the angle between the incoming proton and the outgoing charged lepton in the W^+ rest frame. Since the decay distribution in the W rest frame is known, the observed lepton charge asymmetry in the lab frame can be used as a probe of W production properties, and therefore of proton structure functions. The W charge asymmetry is sensitive to the slope of the u/d ratio as a function of Feynman x, since the average boost of the W is determined by the difference between u and d momentum distributions in the proton.

The folded charged lepton asymmetry (A) is defined for positive pseudorapidity (η) as follows:

$$A(\eta_\ell) \equiv \frac{N^+(\eta_\ell) - N^-(\eta_\ell)}{N^+(\eta_\ell) + N^-(\eta_\ell)},$$

where N^+ is the number of events in which a positive charged lepton is detected in a positive η region, or a negative charged lepton in a negative η region. Likewise N^- is the number of negative leptons in a positive η region and vice versa. Errors in trigger and reconstruction efficiencies and in luminosity cancel in the asymmetry.

The DØ detector [2] does not have a central magnetic field, so the charge signs of electrons and positrons are not determined. Consequently, only the muon decay mode is used for the asymmetry study. The muons are detected by a system of toroidal magnets and proportional drift chambers which surround the calorimeter. In the W analysis, the muon chambers in the region $|\eta| \leq 1.7$ are used. The momentum resolution is given by

$$\frac{\sigma_{1/P}}{1/P} = \sqrt{0.2^2 + (0.01P)^2},$$

where P is the muon momentum in GeV.

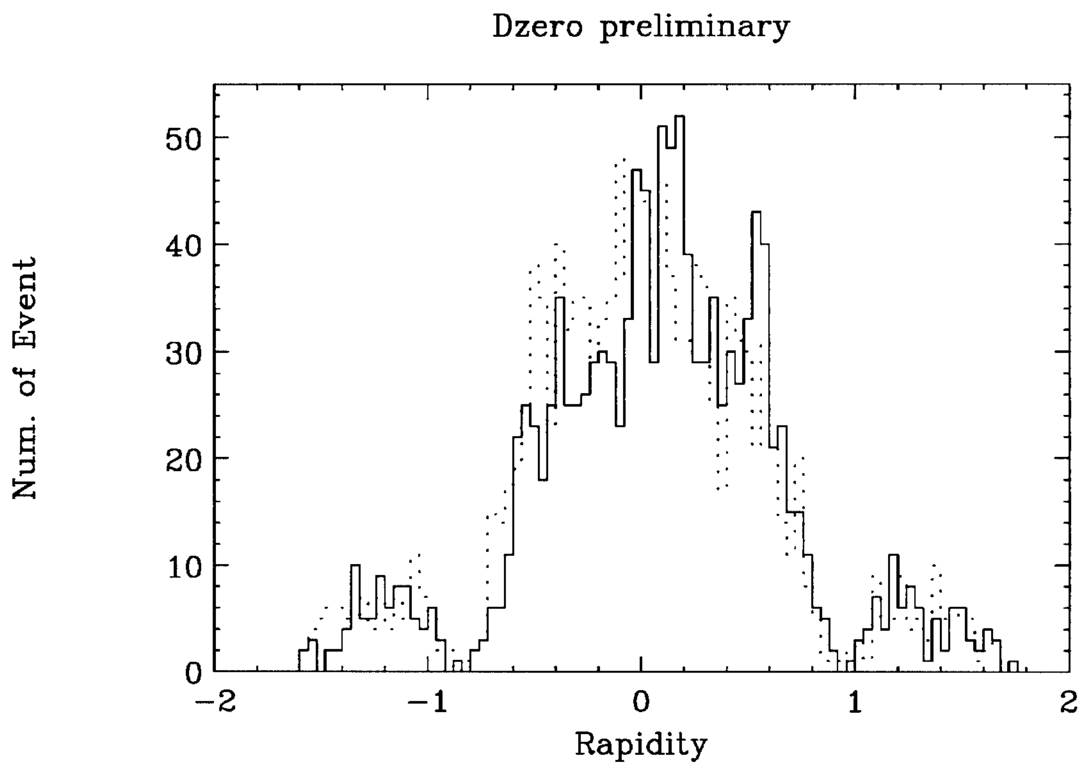

Figure 1: The muon pseudorapidity distribution from W boson decay. Solid and dotted lines show positively and negatively charged muons respectively.

1.2 Event Selection

A data sample corresponding to an integrated luminosity of 12.6 pb^{-1} is used for the asymmetry analysis. The trigger used in this analysis requires at least one muon candidate with $|\eta_\mu| < 1.7$ and $P_t^\mu \geq 15$ GeV. Offline, muon track quality cuts are imposed, and $P_t^\mu \geq 20$ GeV and $\not{P}_t \geq 20$ GeV are required. These requirements are the same as for the W cross section measurement [2]. 1263 μ^+ and 1319 μ^- events survive these cuts. Fig. 1 shows the

μ^+ and μ^- pseudorapidity distributions. In depletions in the regions $-1.0 < \eta < -0.8$ and $0.8 < \eta < 1.0$ correspond to gaps between toroid where muons do not traverse enough iron and are removed. Triggers in the region $|\eta| \geq 1.0$ have been prescaled.

1.3 Systematic Effects

1.3.1 Sign Mismeasurement

If the muon sign is misidentified, the asymmetry is diluted. Since the muons from Z^0 decays have almost the same P_t^μ and η_μ distribution as those from W decays, the $Z^0 \to \mu^+\mu^-$ event sample is used to estimate the sign flip probability. The same muon identification criteria as used in the W selection are applied to both muons, but no cut is made on sign of the two muons. We define the misidentification ratio,

$$R \equiv \frac{\#\text{same sign}}{\#\text{total}}.$$

This ratio is related to the misidentification probability per track F by

$$R = 2 \times (1-F) \times F.$$

The measured asymmetry A_{meas} is diluted by misidentified tracks as

$$\begin{aligned} A_{meas} &= \frac{N^+(1-F) + N^-F - N^-(1-F) - N^+F}{N^+ + N^-} \\ &= A_{true}(1-2F), \end{aligned}$$

where A_{true} is the true asymmetry. The correction factor $1/(1-2F)$ is 1.17 ± 0.07, where the error corresponds to the statistical error on the Z^0 sample. A detailed Monte Carlo study shows no significant η dependence for this correction.

1.3.2 Detector Asymmetry

If the efficiencies for detecting μ^+ and μ^- are different, the measured asymmetry is altered according to

$$\begin{aligned} A_{meas} &= \frac{N^+\epsilon^+ - N^-\epsilon^-}{N^+\epsilon^+ + N^-\epsilon^-} \\ &\cong A_{true} - \frac{\Delta_\epsilon}{2}(1 - A_{true}^2), \end{aligned}$$

where ϵ^+ and ϵ^- are the efficiencies for μ^+ and μ^- respectively, and Δ_ϵ is a normalized efficiency difference $(\epsilon^- - \epsilon^+)/\epsilon^+$. Such an efficiency difference can arise, for example, from geometric effects where muons of different signs are bent into different regions outside of the toroid. An estimate of Δ_ϵ is obtained by measuring the μ^+/μ^- ratio in each η region and comparing data taken with both magnet polarities. The measured value of Δ_ϵ varies from -0.2 to +0.4 depending on η. The sample used in these comparisons is selected with a cuts of $P_t^\mu \geq 10$ GeV to increase statistics. Since these muons typically bend more than the tracks in the W sample, the obtained values of Δ_ϵ may overestimate the detection asymmetry for the W sample.

Of the 12.6 pb^- used in the W analysis, 3 pb^{-1} were taken with reversed magnet polarity. This should cancel the efficiency asymmetries in an equal amount of forward polarity data, so only the remaining 6.6 pb^{-1} is affected. The systematic error coming from the detector asymmetry is less than

$$\frac{|\Delta_\epsilon|}{2} \cdot \frac{6.6\ pb^{-1}}{12.6\ pb^{-1}}.$$

1.3.3 Background

There are several background sources. The techniques for determining the size of these backgrounds are identical to those in the cross section measurement [3]. The results are given as a function of η, in Table 1. In addition, it is necessary to determine how these sources contribute to the asymmetry. The contribution from cosmic rays and combinatorics is estimated from out-of-time events. $W^\pm \to \tau^\pm \to \mu^\pm$ has the same asymmetry as $W^\pm \to \mu^\pm$ and no correction is needed. The asymmetry in QCD events (b decays, etc.) is measured in a di-muon event sample with $P_t^\mu \geq 10$ GeV, and is found to be negligible. The asymmetry from $Z^o \to \mu(\mu)$ (where only one μ is detected) and $Z^o \to \tau \to \mu$ is estimated from Monte Carlo and is also found to be negligible. $W^\pm \to \tau^\pm \to \mu^\pm$ has exactly same asymmetry as $W^\pm \to \mu^\pm$ and no correction is needed. The symmetric backgrounds from QCD and Z^0 events dilute the observed asymmetry. If b is the background ratio from symmetric sources,

$$A_{meas} = \frac{A_{true}}{1+b}.$$

Table 1: Background ratio for each rapidity range.

η	0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	1.0-1.7
QCD	.11±.05	.11±.06	.11±.06	.16±.08	.09±.05
$Z^o \to \mu(\mu)$	.06±.01	.07±.01	.07±.01	.06±.01	.05±.02
$Z^o \to \tau \to \mu$	.008±.004	.009±.004	.009±.005	.009±.004	.006±.003

1.4 Results

Fig. 2 shows the muon charge asymmetry versus η with some comparisons with theoretical predictions for different sets of parton distribution functions. The points are corrected for sign flips and symmetric backgrounds. The observed asymmetry is somewhat larger than that any of the predictions, but it is qualitatively similar. The errors are too large at this time to exclude any parton distribution set.

Table 2 shows the asymmetry values and errors. The systematic error is dominated by detector asymmetry errors. This error can be reduced in future runs by balancing the amount of data taken with forward and reversed magnet polarity. The reconstruction used

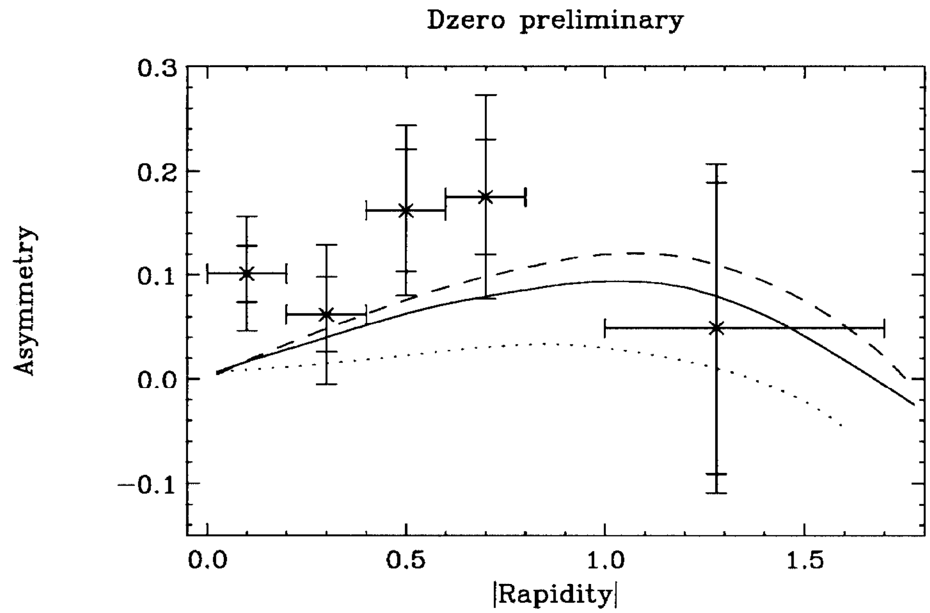

Figure 2: Muon charge asymmetry as a function of pseudorapidity. Inner and outer error bars show the statistical error and combined statistical-systematic error respectively. The solid line indicates predictions using the MRSD0 parton distributions. The dotted and dashed lines show MRSE and MTB2.

Table 2: Asymmetry and errors ($\times 10^{-3}$) for each rapidity range.

η	0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	1.0-1.7
Asymmetry	101	62	162	175	49
Statistical Err.	27	36	59	55	140
Systematic Err.	33	40	51	98	142
Total Err.	55	67	82	106	158
Systematic Error Contents					
Flip Sign	7	4	11	12	3
Detector Asy.	25	15	33	50	32
Cosmic/comb.	5	32	47	14	136
QCD	5	4	10	14	2
$Z^o \rightarrow \mu(\mu)$	1	1	2	2	1
$Z^o \rightarrow \tau \rightarrow \mu$	0	0	1	1	0

for the present results is preliminary, and it is anticipated that the final processing and selection will reduce the backgrounds and associated errors.

2 New Gauge Boson Search

2.1 Introduction

Many extensions to the standard model predict additional gauge bosons [3]. The signature for these particles is similar to that for W and Z bosons: either a single high P_t lepton accompanied by a large $\not{E}_t$, or a high mass dilepton pair. The search for new gauge bosons uses EM and hadron calorimetry in the region $|\eta| \leq 4.4$. The energy resolution is $0.15/\sqrt{E}$ for EM showers and $0.50/\sqrt{E}$ for hadrons where E is energy in GeV. Since the DØ calorimeter has excellent energy resolution and large η coverage, only electron decay modes are used in the search. In order to set mass limits, we assume that new gauge bosons have the same couplings to quarks and leptons as ordinary W and Z bosons, and compare the number of events observed with the number expected from W' and Z' production.

2.2 Event Selection

A data sample of 15.2 pb^{-1} is used for the search. The event selection procedure is the same as that for the W and Z cross section measurements [2]. The trigger requires an isolated electron candidate in $|\eta| \leq 3.2$. One electron with $E_t^e \geq 20$ GeV is required for W' candidates and two electrons are required for Z'. Offline, further quality and fiducial cuts are imposed on each electron, and a matching central detector track is required. Events with activity in the inter-cryostat region are also removed. For W', $E_t^e \geq 25$ GeV and $\not{E}_t \geq 25$ GeV are required. To avoid high $\not{E}_t$ due to fake calorimeter hits, $P_t^W \leq 100$ GeV is required. For the Z' case, two electrons with $E_t^e \geq 25$ GeV are required.

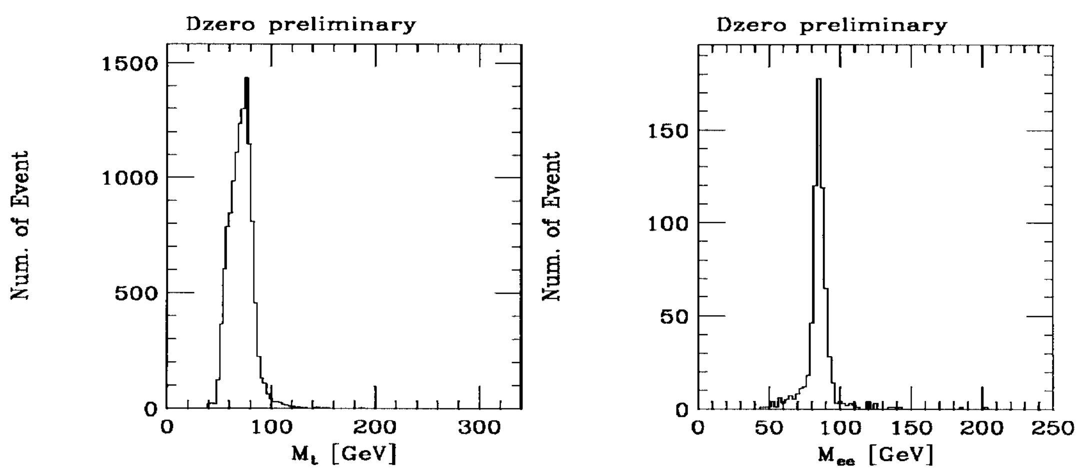

Figure 3: Left: Transverse mass distribution of electron + $\not{E}_t$events. Right: Invariant mass distribution of electron pair events.

Fig. 3 shows the distribution of the transverse mass of electron + $\not{E}_t$ events, and the invariant mass distribution of electron pair events. No evidence for high mass states is found. We observe 5 and 0 events for $M_t^{e\nu} > 150$ GeV and 350 GeV, respectively. In the Z' case, 2 and 0 events are observed for $M_{ee} > 150$ GeV and 250 GeV, respectively.

2.3 Mass limit

The number of observed high mass events is compared to that expected from extra gauge bosons in order to obtain mass limits. The number of expected W' events is estimated as,

$$N_{W'}^{exp} = \frac{\epsilon_{W'} \cdot \sigma_{W'}}{\epsilon_W \cdot \sigma_W} \cdot N_W^{observed},$$

and similarly for Z', where ϵ and σ are reconstruction efficiencies and the production cross sections, respectively. The PYTHIA [4] event generator with MRSD0 structure function and a fast detector simulator are to obtain $\epsilon \cdot \sigma$. It simulates cell-by-cell calorimeter response with energy resolution smearing, track reconstruction efficiency in the central detector, and vertex position smearing. Several backgrounds are subtracted from the observed number of W and Z, but no backgrounds are subtracted from the observed high mass distributions. Fig. 4 shows the comparisons between the expected numbers from W' and Z' and observed upper limits.

We compare the number of events observed above two different values of a transverse mass cut to exclude both low mass (near M_W) and high mass regions for W', and similarly for Z'. We obtain the mass limits, $M_{W'} > 600$ GeV and $M_{Z'} > 440$ GeV at the 95% confidence level.

3 Reference

[1] A.D.Martin, *et al.*, *Modern Phys. Lett. A* **Vol.4, No. 12** (1989) 1135

[2] N.A.Graf in this proceedings.

[3] See, for example, G.G. Ross, *Grand Unified Theories* (Cambridge Univ. Press, Cambridge, England, 1987); and R.N. Mohapatra, *Unification and Supersymmetry* (Springer, New York, 1986), and references therein.

[4] Hans-Uno Bengtsson *et al,*. *Computer Physics Commun.* **46**(1987) 43.

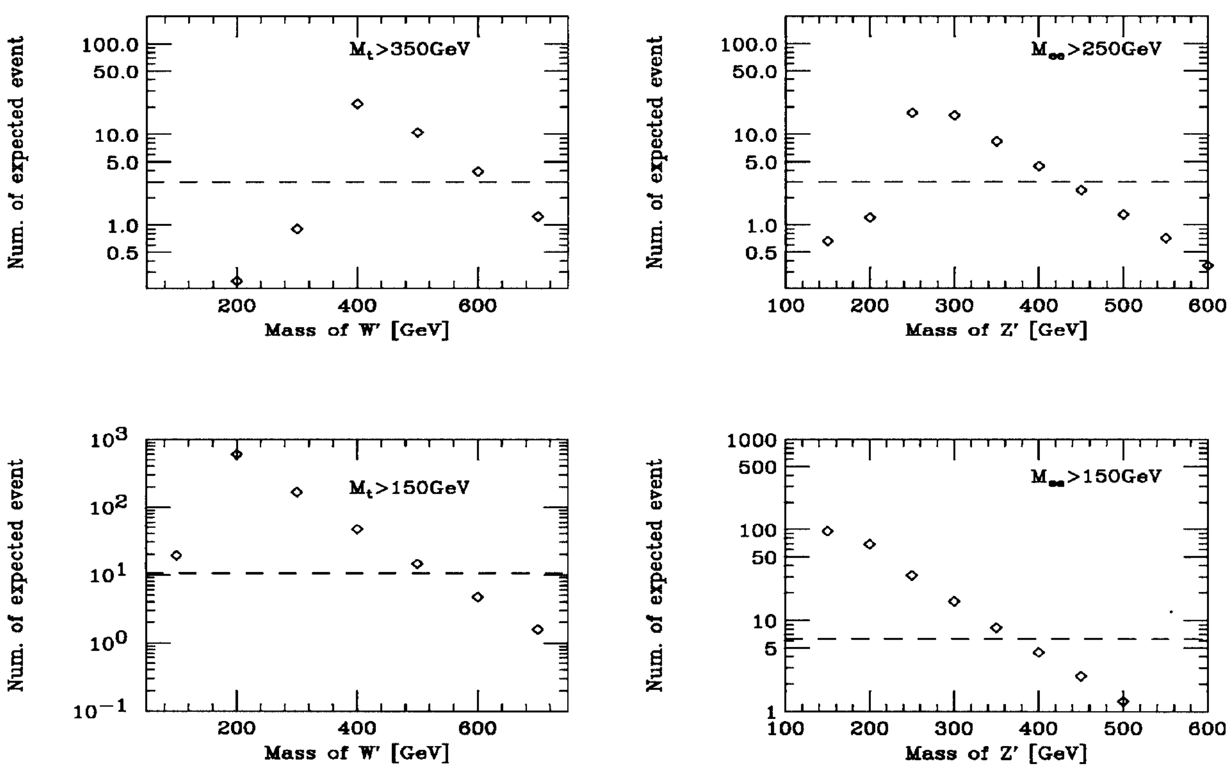

Figure 4: Number of events expected from W', Z' as a function of the mass of extra gauge bosons are shown on left and right respectively Dashed lines indicate the 95% confidence level number of observed event for each mass cut.