Cross Section and Parity Violating Spin Asymmetries of $W^\pm$ Boson Production in Polarized $p + p$ Collisions at $\sqrt{s} = 500$ GeV

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D'Orazio,37 O. Drapier,32 A. Drees,57 K.A. Drees,4 J.M. Durham,57 A. Durum,21 Y.V. Efremenkov,46 T. Engelmore,12 A. Enokizono,46 H. Enyo,50,51 S. Esumi,60 B. Fedam,40 D.E. Fields,43 M. Finger, Jr.,7 M. Finger,7 F. Fleuret,32 S.L. Fokin,30 J.E. Franz,45 A. Franz,5 A.D. Frawley,17 Y. Fukuda,50 T. Fusayasu,42 I. Garishvili,58 A. Glenn,33 M. Gonin,32 Y. Goto,50,51 R. Granier de Cassagnac,32 N. Gran,12 S.V. Greene,61 M. Grossi Perdekamp,22 T. Gunji,10 L. Guo,34 H.-A. Gustafsson,36 J.S. Haggerty,5 K.I. Hahn,16 H. Hamagaki,10 J. Hambleton,57 J. Hanks,12 R. Han,48 K. Hashimoto,52,50 E. Hashum,36 R. Hayano,10 T.K. Hemmick,57 T. Hester,6 X. He,18 J.C. Hill,64 R.S. Hollis,9 W. Holzmann,12 K. Homma,20 B. Hong,29 T. Horaguchi,60 Y. Hori,30 D. Hornback,46 S. Huang,61 T. Ichihara,50,51 R. Ichimichi,50 H. Ifu,27 Y. Ikeda,50,52,60 K. Inami,31,50 M. Inaba,60 A. Iordanova,6 I. Ishihara,50 M. Issah,61 A. Isupov,25 D. Ivanichev,49 Y. Iwanaga,20 B.V. Jacak,57 J. Jia,5,56 X. Jiang,34 B.M. Johnson,5 T. 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Milov,62 J.T. Mitchell,5 Y. Miyachi,50,59 A.K. Mohanty,3 H.J. Moon,41 Y. Morino,10 A. Morreale,6 D.P. Morrison,57 T.V. Moukanov,39 T. Murakami,31 J. Murata,52,50 S. Nagam,J,27 L.L. Nagle,13 M. Naglis,62 M.J. Nagy,28 I. Nakagawa,50,51 Y. Nakamukai,20 K.R. Nakamura,31,56 T. Nakamura,50 K. Nakano,50 J. Newby,33 M. Nguyen,57 M. Nishashi,20 R. Noi,37 A.S. Nyanin,30 C. Oakley,18 E. O'Brien,5 C.A. Ogilvie,64 K. Okada,51 M. Oka,60 A. Oskarsson,36 M. Ozawa,10 K. Ozawa,50 R. Pak,5 V. Pantuev,57 V. Papavassiliou,44 B.H. Park,19 I.H. Park,16 S.K. Park,29 S.F. Pate,44 H. Pei,44 J.-C. Peng,22 H. Pereira,14 V. Peresedov,25 D.Yu. Peressounko,30 R. Petti,57 C. Pinkenburg,5 R.P. Pisani,5 M. Plois,57 M.L. Purschke,5 H. Qu,18 J. Rak,20 I. Ravinovich,62 K.F. Read,46,58 K. Reygers,39 V. Ribakov,49 Y. Ribakov,49 E. Richardson,37 D. Roach,61 G. Roche,35 S.D. Rolnick,9 M. Rosati,64 S.S.E. Rosendahl,36 P. Rukoyatkin,25 B. Sahnhuebler,39 N. Saito,27 T. Sakaguchi,5 V. Samsonov,49 S. Sano,10 M. Sarsour,18 T. 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Large parity violating longitudinal single-spin asymmetries $A_L^{+} = -0.86^{+0.30}_{-0.14}$ and $A_L^{-} = 0.85^{+0.12}_{-0.71}$ are observed for inclusive high transverse momentum electrons and positrons in polarized $p+p$ collisions at a center of mass energy of $\sqrt{s} = 500$ GeV with the PHENIX detector at RHIC. These $e^\pm$ come mainly from the decay of $W^\pm$ and $Z^0$ bosons, and their asymmetries directly demonstrate parity violation in the couplings of the $W^\pm$ to the light quarks. The observed electron and positron yields were used to estimate $W^\pm$ boson production cross sections for the $e^\pm$ channels of $\sigma(pp \to W^+X) \times BR(W^+ \to e^+\nu_e) = 141.1 \pm 21.2 (\text{stat})^{+13.4}_{-10.3} (\text{syst}) \pm 15\% (\text{norm}) \text{ pb}$, and $\sigma(pp \to W^-X) \times BR(W^- \to e^-\bar{\nu}_e) = 31.7 \pm 12.1 (\text{stat})^{+8.2}_{-5.9} (\text{syst}) \pm 15\% (\text{norm}) \text{ pb}$.

The electromagnetic calorimeter, located at a radial distance of $\sim 5$ m from the beam line, is used to measure the energy, position, and time of flight of electrons. In this analysis, the $p_T$ dependence of the reconstructed $\pi^0$ and $\eta$ mass peaks was used to confirm the energy scale and linearity to within 2.5%. The $p_T$ dependence of the peak widths was used to determine the energy resolution $\sigma_E/E = 8.1/\sqrt{E(\text{GeV})} \oplus 5.0\%$.

A trigger with a nominal 10 GeV threshold in the electromagnetic calorimeter selected events for this analysis. This trigger was fully efficient for $e^\pm$ with transverse momentum $p_T$ above 12 GeV/c. Charged tracks reconstructed in the drift chambers and the pad chambers which match the calorimeter cluster with $|\Delta\phi| < 0.01$ were used to reconstruct the $z$ position of the event vertex. Only events with $|z| < 30$ cm that are well within the acceptance of the central arm spectrometers were analyzed. Loose cuts on the time of flight measured by the calorimeter and energy-momentum matching suppressed accidental matches and cosmic rays.

The analyzed data sample corresponds to an integrated luminosity of 8.6 pb$^{-1}$, which was determined from beam-beam counter coincidences and corrected for a small (6%) effect from multiple collisions per beam crossing. The beam-beam counters are two 64 channel quartz Čerenkov counters $\pm 1.44$ m from the center of the detector and cover a pseudorapidity range of $3.1 < |\eta| < 3.9$. The cross section for coincidences within $|z| \lesssim 30$ cm was found to be $32.5 \pm 3.2$ mb from the van der Meer scan technique.

The resulting yield of positive and negative electron candidates is shown in Fig. 1 where $p_T$ has been determined from the calorimeter cluster energy. The charge sign is determined from the bend angle, $\alpha$, measured in the drift chamber, and the nominal transverse beam position. The angular resolution and stability of beam position were monitored by frequent runs with no magnetic field. The resolution $\sigma_\alpha$ was typically about 1.1 mrad, to be compared to a 2.3 mrad bend angle for 40 GeV/c tracks. The variation in the average transverse beam po-
FIG. 1: (color online) The spectra of positive (upper panel) and negative (lower panel) candidates before (solid histogram) and after (dashed histogram) an isolation cut. The estimated background bands are also shown. The computation of the background before the isolation cut is described in the text. The background band after the isolation cut is computed by scaling the background before the isolation cut by the isolation cut efficiency measured in the background region (12 < \(p_T\) < 20 GeV/c).

FIG. 2: (color online) Background subtracted spectra of positron (upper panel) and electron (lower panel) candidates taken from all counts compared to the spectrum of \(W\) and \(Z\) decays from an NLO calculation [12, 13] (see text). The gray bands reflect the range of background estimates.
and $|\Delta\phi| < \pi$ is estimated to be $\sim 11\%$ of positrons from $W^+$ and $\sim 7.5\%$ of electrons from $W^-$ from these calculations. The variation of the calculation is small compared to other sources of systematic uncertainty. With these corrections, $\sigma(pp \to W^+X) \times BR(W^+ \to e^+\nu_e) = 144.1 \pm 21.2 \text{(stat)}^{+3.4}_{-10.3} \text{(syst)} \pm 15\% \text{(norm)}$ pb, and $\sigma(pp \to W^-X) \times BR(W^- \to e^-\bar{\nu}_e) = 31.7 \pm 12.1 \text{(stat)}^{+10.1}_{-8.2} \text{(syst)} \pm 15\% \text{(norm)}$ pb, where $BR$ is the branching ratio. These are shown in Fig. 3 and compared to published Tevatron and $SppS$ data.

In order to determine the longitudinal spin asymmetry with a sample of $W$ decays with minimal background contamination, two additional requirements were imposed on the candidate events. An isolation cut requiring the sum of cluster energies in the calorimeter and transverse momenta measured in the drift chamber be less than $2$ GeV in a cone with a radius in $\eta$ and $\phi$ of 0.5 around the candidate track was used to remove remaining events with jets. About $80\%$ of the signal is kept, while the background is reduced by a factor $\sim 4$ as shown in Fig. 1. The second cut is to reject tracks with $|a| < 1$ mr, which reduces charge misidentification to negligible levels. There are $42$ candidate $W^+ + Z^0$ decays to positrons with a background of $1.7 \pm 1.0$ and $13$ candidate $W^- + Z^0$ decays to electrons with a background of $1.6 \pm 1.0$ events within $30 < p_T < 50$ GeV/c after these two additional cuts.

The measured asymmetry is given by

$$\epsilon_L = \frac{N^+ - R \cdot N^-}{N^+ + R \cdot N^-}$$

where $N^+$ is the number of events from a beam of positive helicity and $N^-$ is the number of events from a beam of negative helicity, and $R$ is the ratio of the luminosity for the positive and the negative helicity beams. The longitudinal spin asymmetry is then calculated from the measured asymmetry according to

$$A_L = \epsilon_L \cdot \frac{D}{P}$$

where $P$ is the beam polarization and $D$ is a dilution correction to account for the remaining background in the signal region.

**TABLE I: Comparison of measured cross sections for electrons and positrons with $30 < p_T < 50$ GeV/c from $W$ and $Z$ decays with NLO \([12]\) and NNLO \([20]\) calculations. The first error is statistical; the second error is systematic from the uncertainty in the background; the third error is a 15% normalization uncertainty due to the luminosity (10%), multiple collision (5%), and acceptance and efficiency uncertainties (10%).**

| Lepton  | Data    | NLO   | NNLO   |
|---------|---------|-------|--------|
| $e^+$   | 50.2 ± 7.2$^{+1.2}_{-1.1}$ ± 15% | 43.2  | 46.8   |
| $e^-$   | 9.7 ± 3.7$^{+1.2}_{-1.5}$ ± 15% | 11.3  | 13.5   |
| $e^+$ and $e^-$ | 59.9 ± 8.1$^{+3.1}_{-6.0}$ ± 15% | 54.5  | 60.3   |
TABLE II: Longitudinal single-spin asymmetries

| Sample | $\epsilon_L$ | $A_L^e(W + Z)$ | 68%CL | 95%CL |
|--------|-------------|----------------|--------|--------|
| Bkgrd + | $-0.015 \pm 0.04$ | | | |
| Signal + | $-0.31 \pm 0.10$ | $-0.86$ | $[ -1, -0.56 ]$ | $[ -1, -0.16 ]$ |
| Bkgrd - | $-0.025 \pm 0.04$ | | | |
| Signal - | $0.29 \pm 0.20$ | $+0.88$ | $[ 0.17, 1 ]$ | $[ -0.60, 1 ]$ |

FIG. 4: (color online) Longitudinal single-spin asymmetries for electrons and positrons from $W$ and $Z$ decays. The error bars represent 68% CL. The theoretical curves are calculated using NLO with different polarized PDFs [12].

upgrades in progress will make it possible in the future to significantly reduce the uncertainties for $A_L$ and to extend the measurement to forward rapidity, which will improve our knowledge of flavor separated quark and antiquark helicity distributions.

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