Over the past several years the STAR experiment at RHIC has been contributing to our understanding of the proton structure. Through its instrumentation, STAR is well equipped to measure $W \to \nu + e$ in $\sqrt{s} = 500/510$ GeV proton-proton collisions at mid-rapidity (-1.1 $\leq \eta \leq$ 1.1). The $W$ cross section ratio ($W^+/W^-$) is sensitive to unpolarized $u$, $d$, $\bar{u}$, and $\bar{d}$ quark distributions. At these kinematics, STAR is able to measure the quark distributions near Bjorken-$x$ values of 0.1. The RHIC runs in 2011, 2012 and 2013 at $\sqrt{s} = 500/510$ GeV saw a significant increase in delivered luminosity from previous years. This resulted in a total data sample being collected of about 352 pb$^{-1}$ of integrated luminosity. The increased statistics will lead to a higher precision measurement of the $W^+/W^-$ cross section ratio than was previously measured by STAR’s 2009 run, as well as allow for a measurement of its $\eta$ dependence at mid-rapidity. Presented here is an update of the $W$ cross section ratio analysis from the STAR 2011, 2012 and 2013 runs.
1. Motivation

Over the past several years parton distribution functions (PDFs) have been becoming more and more precise [1, 2, 3]. However, there are still regions in which more precision data is needed which can be used to help constrain the PDFs. For example the sea quark distributions near the valence region, \( x \sim 0.1 \text{-} 0.3 \), still have sizable uncertainties [4].

One of the data sets used to determine the anti-quark PDFs is the \( \bar{d}/\bar{u} \) measurement from E866 [5], which measured \( \bar{d}/\bar{u} \) to good precision at lower \( x \) (\( x < 0.15 \)). However, their precision quickly deteriorates as they approach higher \( x \) (\( x > 0.2 \)). These data suggest an interesting behavior, as \( x \) increases there seems to be a transition from being \( \bar{d} \) dominated to \( \bar{u} \) dominated around \( x \sim 0.25 \). Many models are able to describe the general \( \bar{d} > \bar{u} \) behavior seen at low \( x \), but fail to predict the suggested \( \bar{u} > \bar{d} \) transition [6]. To better determine the behavior of \( \bar{d}/\bar{u} \) the experiment SeaQuest (E-906) [7] has been designed and is currently running. Through Drell-Yan scattering, SeaQuest will probe the sea quark distribution at lower \( Q^2 \) than E866, but increase the precision and \( x \) reach of the \( \bar{d}/\bar{u} \) measurement. Although this will help constrain the PDF fits, ideally one would like more data to fit from different scattering processes and \( Q^2 \) scales. This will help to add more independent data to global fits, and serve as a cross check of our understanding of the QCD sea.

The \( W \) boson production in proton-proton collisions is also sensitive to the sea quarks. The \( W^+ \) boson is sensitive to the \( \bar{d} \) quark, while the \( W^- \) boson is sensitive to the \( \bar{u} \) quarks which can be seen in equation 1.1, and probes the distribution at \( Q^2 \sim M_W^2 \). The leptonic decay from \( W \) bosons can be detected by looking for leptons with a high transverse momentum, \( p_T \), near \( M_W/2 \). Then a charge separation of the leptons can be used to determine which charged \( W \) boson they decayed from.

\[
u + \bar{d} \rightarrow W^+ \rightarrow e^+ + \nu, \quad d + \bar{u} \rightarrow W^- \rightarrow e^- + \nu. \tag{1.1}
\]

By considering the leading order expression for the charged \( W \) cross section ratio [8], \( \frac{\sigma_{W^+}}{\sigma_{W^-}} (R_W) \), the direct relationship to the sea quarks can be seen

\[
R_W \equiv \frac{\sigma_{W^+}}{\sigma_{W^-}} \approx \frac{u(x_1) \bar{d}(x_2) + \bar{d}(x_1) u(x_2)}{\bar{u}(x_1) \bar{d}(x_2) + d(x_1) \bar{u}(x_2)}. \tag{1.2}
\]

It should be noted that although \( R_W \) can be measured at the LHC, the region of \( x \) that would be probed is below the valence region near \( x \sim 0.08 \) (assuming a \( \sqrt{s} = 1 \) TeV and \( \eta = 0 \)).

2. Experiment

The STAR experiment at RHIC [9] serves as an excellent place to measure the charged \( W \) cross section ratio, which was first measured in the STAR 2009 run [10]. The STAR experiment measured \( R_W \) using proton-proton collisions at center of mass energies of \( \sqrt{s} = 500/510 \) GeV in the mid-rapidity region (\(-1.1 \leq \eta \leq 1.1 \)). Several sub-detectors were used to select the \( W \) events and separate their charge: the time projection chamber (TPC) [11], used for particle tracking, and the barrel electromagnetic calorimeter (BEMC) [12], used to measure particle energy. A third
sub-detector, the endcap electromagnetic calorimeter (EEMC) [13], was used to estimate the background contributions. The mid-rapidity region of STAR corresponds to about $0.1 \leq x \leq 0.3$ and $Q^2 \sim M_W^2$, which could have an impact on constraining PDFs as this is the $x$ region where E866’s precision starts to drop off and is the region where the data suggests that the $\bar{u}$ quark density is greater than the $\bar{d}$ quark density. STAR has taken advantage of the yearly increase in luminosity that RHIC has provided. This luminosity increase has led to roughly $352 \text{ pb}^{-1}$ of integrated luminosity being collected during the 2011-2013 runs. With the 2013 data set still under analysis, a preliminary $R_W$ result is presented using only a fraction ($102 \text{ pb}^{-1}$) of the collected 2011-2013 data.

3. Results

The leptons from $W$ decay are selected by following the methodology previously established by STAR [10]. Several cuts which include matching high $p_T$ tracks to BEMC clusters, a series of isolation cuts used to isolate the leptons, a $p_T$-balance cut which looks for the large missing neutrino momentum, and a charge separation cut are applied to select leptons that are likely produced from $W$ decay. Figure 1 shows the application of several isolation cuts and charge separation cuts to the data. In panel a), one can see that as more isolation cuts are applied there is a decrease in background events, which populate the kinematic region $E_T < 25$ GeV, and an enhancement of the lepton signal near $E_T \sim M_W/2$. Panels b) and c) show cuts applied to the data in order to select events which have likely originated from $W^+$ or $W^-$ decays. Panel b) shows the charge separation as a function of $E_T$, while panel c) projects the charge separation as a function of $E_T$ on to the charge separation axis. The charge separation cuts are indicated by the red lines and were chosen to avoid contamination from the opposite charge.

The charged $W$ cross section ratio can be measured experimentally as

$$\frac{\sigma_{W^+}}{\sigma_{W^-}} = \frac{(N_O^- - N_B^-)}{(N_O^+ - N_B^+)} \epsilon^-,$$

where $\pm$ corresponds to positively or negatively charged lepton, $N_O$ are the number of events that pass the lepton selection cuts, $N_B$ are the number of background events estimated to be contaminating the data set, and $\epsilon$ is the efficiency at which $W$ events are detected.

Figure 2 shows the various background contributions, Monte Carlo simulation of the $W$ decay (based on Pythia 6.4.22 [14] and GEANT [15]), and a comparison of the data to Monte Carlo $W$ signal with background contributions included for the 2011 and 2012 data sets. The background contribution labeled Second End Cap is an estimate of the background caused by an escaping jet’s $p_T$ being misidentified as the neutrino’s missing $p_T$. This is predominately a QCD like background. When the final cut of $E_T > 25$ GeV is applied, there is very little background contributions from $W \to \tau + \nu$ and $Z \to ee$ decays. The background was found to be dominated by QCD background.

A Monte Carlo based on Pythia 6.4.22 [14] and GEANT [15] is used to determine the $W^\pm$ detection efficiencies, shown in Fig. 3. These efficiencies account for all cut and detector efficiencies. The 2011 data was found to have a higher efficiency than the 2012 data due to running at a higher luminosity rate in 2012. Running at a higher instantaneous luminosity lead to more pile-up in the TPC, which resulted in less efficient track reconstruction and hence less efficient $W$ detection.
Figure 1: Some cuts applied to data used to select leptons which likely originated from W decay. a) Application of several isolation cuts including a minimum $E_T$ cut, electron energy ratio cuts, and a signed $p_T$ cut. b) Charge separation cut vs. $E_T$. c) Projection of the charge separation vs. $E_T$ projected onto the charge separation axis.

Figure 2: Background and Monte Carlo contributions compared to data. a) Run-11 $W^+$, b) Run-11 $W^-$, c) Run-12 $W^+$, and d) Run-12 $W^-$. 

$W^\pm$ Cross Section Ratios Measured at STAR

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However in both data sets there was only a small (∼1-2%) charge dependence measured between the $W^+$ and $W^-$ efficiencies, which means the $\frac{\varepsilon^-}{\varepsilon^+}$ factor will have a negligible contribution to the charged $W$ cross section ratio.

**Figure 3:** $W^+$ and $W^-$ efficiencies as a function of electron pseudo-rapidity for a) Run-11 and b) Run-12.

**Figure 4:** $W^+/W^-$ cross section ratio as a function of electron pseudo-rapidity.

**Figure 5:** $W^+/W^-$ cross section ratio as a function of the $W$ boson rapidity.

Figure 4(5) shows the charged $W$ cross section ratio for the combined 2011 and 2012 runs, computed using equation 3.1, as a function of the electron pseudo-rapidity, $\eta_e$ ($W$ boson rapidity,
More information on how the $W$ boson kinematics were reconstructed can be found in [16, 17]. The error bar on the data points represents the statistical uncertainty, while the shaded boxes correspond to the systematic uncertainty. The yellow band and colored curves serve as a comparison to different PDF sets [18, 19] and theory frame works [20, 21]. Note that the systematic uncertainties for the charged $W$ cross section ratios as a function of $\eta_e$ are well under control and we are dominated by our statistical precision. Further studies into the newly established $W$ boson reconstruction process [16, 17] should reduce the systematic uncertainties on the $W^\pm$ cross-section ratio dependence on the boson kinematics.

4. Summary

We have measured and presented charged $W$ cross section ratios from combined 2011 and 2012 proton-proton STAR data at $\sqrt{s} = 500/510$ GeV. The inclusion of this data into global PDF analysis should help constrain the sea quark distributions and provide additional insight into the $d/\bar{u}$ ratio near the valance region. Furthermore, with the inclusion of the STAR 2013 data ($\sim 250$ pb$^{-1}$), we will be able to further improve on the precision of our charged $W$ cross section ratios.

References

[1] J. Gao et al., Phys. Rev. D, 89, 3, 033009 (2014).
[2] S. Alekhin, et al., arXiv:1410.4412 [hep-ph] (2015).
[3] R. D. Ball, et al., The NNPDF Collaboration, arXiv:1410.8849 [hep-ph] (2015).
[4] J. Gao and P. Nadolsky, JHEP, 1407, 035 (2014).
[5] R. S. Towell et al., Phys. Rev. D, 64, 052002 (2001).
[6] Wen-Chen Chang and Jen-Chieh Peng, Progress in Particle and Nuclear Physics, 79, 95(2014).
[7] P. E. Reimer (SeaQuest), J. Phys. Conf. Ser. 295, 012011 (2011).
[8] C. Bourrely and J. Soffer, Nucl. Phys. B 423, 329 (1994).
  J. Soffer, C. Bourrely, and F. Buccella, arXiv:1402.0514 (2014).
[9] K. H. Ackermann et al. (STAR), Nucl. Instrum. Meth. A 499, 624 (2003).
[10] L. Adamczyk et al. (STAR), Phys. Rev. D 85, 092010 (2012).
[11] M. Anderson et al. (STAR), Nucl. Instrum. Meth. A 499, 659 (2003).
[12] M. Beddo et al. (STAR), Nucl. Instrum. Meth. A 499, 725 (2003).
[13] C. Allgower et al. (STAR), Nucl. Instrum. Meth. A 499, 740 (2003).
[14] T. Sjostrand, S. Mrenna, and P. Skands, Pythia 6, https://pythia6.hepforge.org.
[15] S. Agostinelli et al., Nucl. Instrum. Meth. A 506, 250 (2003).
[16] S. Fazio and D. Smirnov (STAR), PoS, DIS2014, 237, (2014).
[17] S. Fazio (STAR), These Proceedings (2015).
[18] H. L. Lai et al., Phys. Rev. D, 82, 074024 (2010).
[19] C. Bourrely, F. Buccella, and J. Soffer, Eur. Phys. J. C 23, 487 (2002).

[20] J. Campbell, K. Ellis, and C. Williams, *MCFM - Monte Carlo for Fermibarn Processes*, mcfm.fnal.gov.

[21] P. M. Nadolsky and C.-P. Yuan, Nucl. Phys. B 666, 3 (2003).