PROCEEDINGS OF SCIENCE

Measurements of parity violating spin asymmetries of the W boson, $W^{\pm} \to e^{\pm}$, at mid-rapidity with the PHENIX Detector at RHIC

Ciprian GAL[*†]
Stony Brook University, NY, USA
E-mail: ciprian.gal@stonybrook.edu

Precision measurements of helicity parton distributions functions (hPDFs) lie at the heart of unraveling the nucleon spin puzzle. The u and d quark distributions are significantly better constrained than the anti-quark $\overline{u}$ and $\overline{d}$ distributions. A clean way to measure the anti-quark distributions directly, without the dilution of poorly known fragmentation functions, is to measure the parity violating W production with p+p collisions at $\sqrt{s} = 500$ GeV and its subsequent decay $W \to e/\mu$. The PHENIX detector is capable of measuring both in the central and forward rapidity respectively. In this talk we will present the status of $W^{\pm} \to e^{\pm}$ asymmetry measurement based on $\sim$160 pb^{-1} data collected in 2011, 2012, and 2013.

XXII. International Workshop on Deep-Inelastic Scattering and Related Subjects,
28 April - 2 May 2014
Warsaw, Poland

[*] Speaker.
[†] For the PHENIX Collaboration.

PoS(DIS2014)219

1. Introduction

With the advent of the spin puzzle a series of measurements have been done to not only unravel how the spin of the proton is made out of the spins and interactions of the partons contained within, but also measurements on the flavor decomposition of these contributions. Deep Inelastic Scattering (DIS) measurements have established not only the overall contribution of the quarks to the proton spin as approximately 30% but also have pinned down the helicity parton distributions functions (hPDFs) of the sum between u and $\bar{u}$ and d and $\bar{d}$ ($\Delta u(x) + \Delta\bar{u}(x)$ and $\Delta d(x) + \Delta\bar{d}(x)$). Flavor decomposed measurements have been done with Semi Inclusive DIS (SIDIS) experiments, however these results had to take into account the fragmentation function (FF) uncertainty that is needed to correlate the final state measured hadron with the struck quark in the interaction.

A measurement method that avoids the FF uncertainties, involves the determination of the decay leptons from $W^{\pm}$ bosons [1, 2]. Due to the parity violating nature of the $W^{\pm}$ coupling to quarks and anti-quarks, a single spin asymmetry measurement of Ws can be directly related to the quark and anti-quark hPDFs. This measurement has been performed by the PHENIX collaboration, and the results of the single spin asymmetries from $W^{\pm} \rightarrow e^{\pm}$ decay are presented here. This measurement makes use of the increased beam polarizations ($\sim$55%) provided by the RHIC accelerator in 2011, 2012 and 2013. Compared to the initial measurement in 2009 [3] that was based on an integrated luminosity of 8.6 pb^{-1}, these results are based on approximately 160 pb^{-1}.

2. Measurement

The parity violating single spin asymmetries from W boson decays into electrons/positrons makes use of two PHENIX central arm spectrometers, covering a total area of $\Delta\phi = \pi$ $(2 \times \pi/2)$ in azimuth and $|\eta| < 0.35$ in pseudorapidity. High energy clusters measured with the help of the electromagnetic calorimeter (EMCal) are matched to tracks that are determined in the drift chambers and pad chambers. The tracks are measured using their curvature in the central arm magnetic field. The curvature is used as the main charge discriminator. The pad chambers provide z coordinate information as the particle exits the drift chamber. The EMCal is used as the primary trigger for this data (being fully efficient above 10 GeV/c). Using the z coordinate information from the two subsystems the interaction vertex can be determined. Only events with z smaller than 30 cm from the nominal PHENIX origin were used in this result to ensure that the event was fully contained within the central arms.

By measuring the transverse momentum (p_T) spectrum of W decay electrons, the typical Jacobian peak structure can be seen at approximately half the W mass ($\sim$40 GeV/c). This can be used to identify and discriminate signal from background events. The main sources of backgrounds are photon conversions and meson decays together with Z decays into a positron electron pair where one particle in the pair goes outside of the PHENIX acceptance. Furthermore charm and bottom decays produce high energy electrons as well, while general QCD backgrounds (like jets) can produce high energy charged mesons that can be misidentified as electrons. The main background discriminator used in this analysis is the relative isolation cut. By measuring the activity (energy collected in the EMCal and momentum from the drift chambers) in a cone of $R = \sqrt{\Delta\phi^2 + \Delta\eta^2} = 0.4$ and dividing it by the energy of the W decay candidate, one can reduce the background events by more than a factor of 10 while leaving the signal events untouched. The cut used in this analysis for the relative isolation was 10%, meaning that no more than 10% of the energy of the W decay candidate was accepted in the cone. The spectra obtained for the 2013 data is shown in figure 1. One can immediately see the typical Jacobian peak structure for both charges. Even with the relative isolation cut a significant background contribution can be seen in the spectrum (particularly at lower p_T). These high background regions can be used further to determine the background contribution in the signal region (30 to 50 GeV/c).

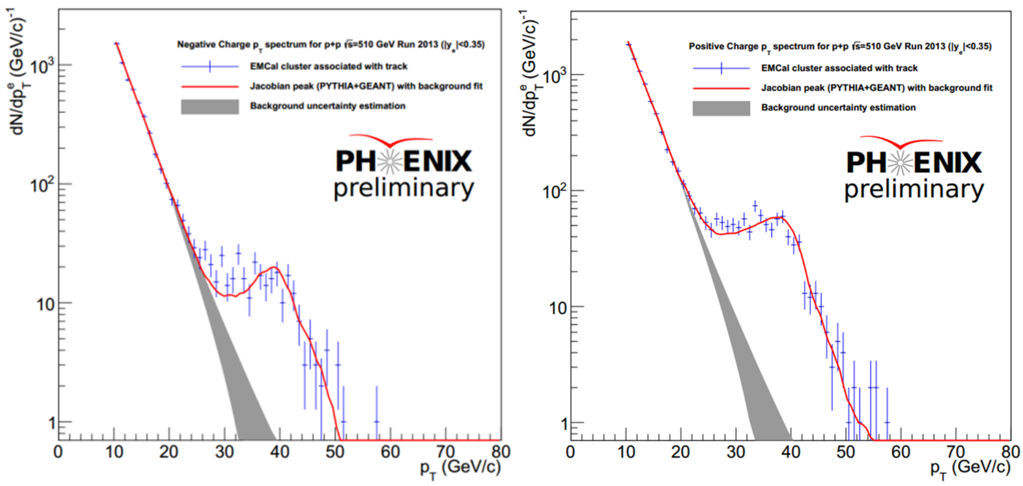

Figure 1: The electron (left) and positron (right) p_T spectra for the 2013 data sets (blue data points). The gray band represents the Gaussian Process Regression determined background, while the red curve is the overall fit of the background and signal shape to the data.

For this analysis the method of Gaussian Process Regression (GPR) [4, 5] was used to characterize the background shape. By assuming a smooth spectrum, the data between 10 and 22 GeV/c can be used to determine the fraction of background events in the 30 to 50 GeV/c region. Making use of the general Gaussian Kernel the shape of the background can be determined from the data directly. Using this shape to extrapolate in the region of interest, one can determine not only the background fraction but also an appropriate uncertainty related to the background contribution. For example figure 2 shows in this procedure as performed on simulated data. A known background and signal shape (having high similarities to the actual signal and background shapes) were used to produce a "data" spectrum as can is shown in the left panel. The red points were used for the GPR background determination and extrapolations were made for all the points until 60 GeV/c (as can be seen in the black point and blue band in the right hand side panel).

The shape of the background was determined individually for each data set and each charge. Together with a PYTHIA/GEANT simulation determined W decay to electron signal shape, very good agreement to the data was obtained by fitting. The overall fit to the data is the red line in figure 1, while the GPR background contribution can be seen in the gray band. An alternative method employing a classical fitting procedure (using a modified power law $f(p_T) = 1/p_T^{[0]+[1]\log p_T}$ as the background shape) produced consistent results with the GPR approach.

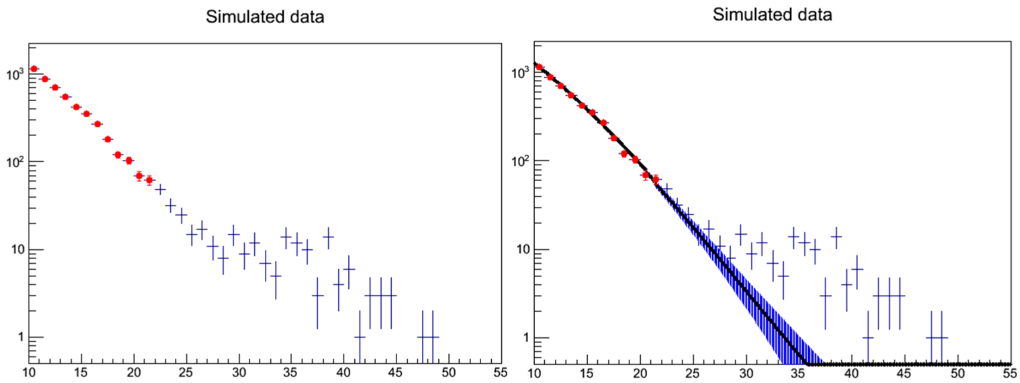

Figure 2: Left: Simulated spectrum with known background and signal shapes in blue and data used for the GPR background shape determination in red. Right: GPR determined background in blue band.

3. Results and conclusions

Using the events between 30 and 50 GeV/c a single spin asymmetry was calculated using:

$$A_L = \frac{1}{P}\frac{1}{\beta}\frac{N^+ - RN^-}{N^+ + N^-} \tag{3.1}$$

where P is the polarization of the beam, β is the background dilution factor, R is the relative luminosity between positive and negative helicity beams and $N^{\pm}$ are the number of events occurring during collisions of positive/negative helicity beams.

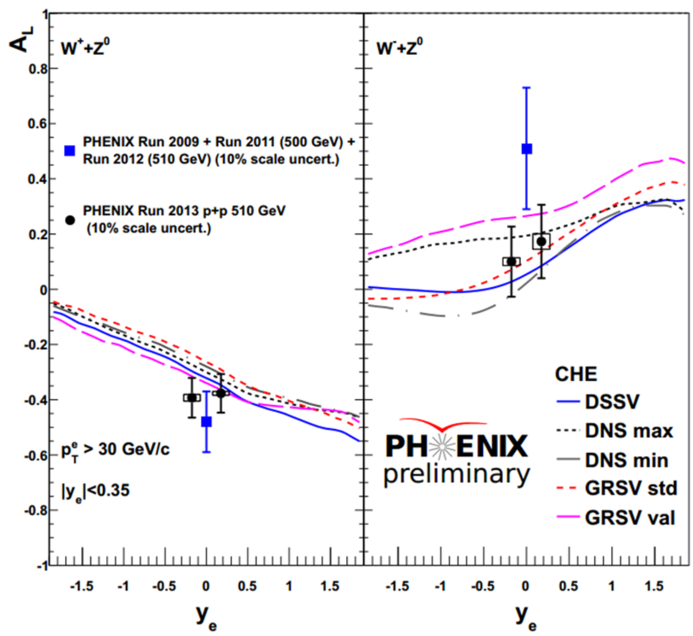

Figure 3: Asymmetry results from the 2011 and 2012 data sets combined (blue square) and the 2013 data set split into two pseudorapidity bins (black circle with $-0.35 < \eta < 0$ for left point and $0 < \eta < 0.35$ for the right).

The results for all the PHENIX data sets can be seen in figure 3. The 2011 and 2012 data set results were combined in order to provide higher statistical accuracy and can be seen as the blue (square) points in figure 3. These points span the entire PHENIX pseudorapidity range of -0.35 to 0.35. The high statistics available in the 2013 data set enabled the split of the data into positive and negative pseudorapidity ranges. These results are depicted in the black (circle) points in figure 3. The left hand side point for the 2013 data is for the $-0.35 < \eta < 0$ pseudorapidity range while the right hand side point represents the $0 < \eta < 0.35$ range. The different curves in the figure represent the asymmetry predictions obtained from the global analyses using different fragmentation functions. The asymmetry predictions come mainly from DIS and SIDIS data sets available at the time when the global analysis was performed. It can be concluded that there is quite good agreement between the theoretical predictions and the experimental result. It is expected that the new data will provide significant constraints on the anti-quark hPDFs once included in the global analysis.

References

[1] C. Bourrely and J. Soffer,*Parton distributions and parity violating asymmetries in W+- and Z production at RHIC, Phys. Lett. B* **314** (1993)

[2] G. Bunce, N. Saito, J. Soffer, and W. Vogelsang, *Prospects for spin physics at RHIC,Ann. Rev. Nucl. Part. Sci.* 50, 525 (2000)

[3] A. Adare et al., *Cross Section and Parity Violating Spin Asymmetries of $W^{\pm}$ Boson Production in Polarized $p+p$ Collisions at $\sqrt{s}$ = 500 GeV,Phys. Rev. Lett.* 106, 062001 (2011)

[4] C. E. Rasmussen and K. I. Williams, *Gaussian Processes for Machine Learning*, MIT Press, Boston, USA, 2006.

[5] D. J. C. MacKay, *Information Theory, Inference, and Learning Algorithms*, Cambridge University Press, New York, USA, 2003.