Transverse single-spin asymmetries in $W^{\pm}$ and Z^0 bosons production in p+p collisions at RHIC

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The non universality of the quark Sivers function is a fundamental prediction from the gauge invariance of QCD. The experimental test of the Sivers function sign change between semi-inclusicve DIS and Drell-Yan processes is one of the open questions in hadronic physics, and can provide a direct verification of TMD factorization. While a precise measurement of asymmetries in Drell-Yan production is challenging, $W^{\pm}/Z^0$ production is equally sensitive to the predicted sign change. We present the preliminary measurement of the transverse single spin asymmetry of weak bosons by the STAR experiment at RHIC using transversely polarized proton-proton collisions at $\sqrt{s} = 500$ GeV.

1 Introduction

Transversely polarized spin effects are connected to transverse momentum dependent (TMD) distributions, leading to a multi-dimensional picture of the proton and a possible test of the framework and the underlying theory of perturbative QCD. For a quantitative application of the TMD framework to transverse single-spin asymmetries measured in proton-proton collisions, the required two scales (typically Q^2 and P_T) are not well defined, with Drell-Yan di-lepton (DY) and $W^{\pm}/Z^0$ boson production two of the exceptions. Thus, DY and weak boson production can be used to test the so-called Sivers TMD function [1], $f_{1T}^{\perp}$, which describes the correlation of parton transverse momentum with the transverse spin of the nucleon. There is evidence of a quark Sivers effect in semi-inclusive DIS (SIDIS) measurements [2] where the quark Sivers function is associated with a final state effect from the gluon exchange between the struck quark and the target nucleon remnants. On the other hand, for the virtual photon production in the DY process, the Sivers asymmetry originates from the initial state of the interaction. As a consequence, the quark Sivers functions are of opposite sign in SIDIS and in DY [3]

$$f_{q/h^{\uparrow}}^{\mathrm{SIDIS}}(x, k_{\perp}) = -f_{q/h^{\uparrow}}^{\mathrm{DY}}(x, k_{\perp}), \tag{1}$$

and this non-universality is a fundamental prediction from the gauge invariance of QCD.

The experimental test of this sign change is one of the open questions in hadronic physics, and can provide insights on the TMD factorization. While luminosity and experimental requirements for a meaningful measurement of asymmetries in Drell-Yan production are challenging, weak boson production is equally sensitive to the predicted sign change and can be well measured at STAR. The results can also provide essential input to study the TMD evolution effects, because of the high Q^2 in the $W \to e\nu$ production due to the large boson mass. The STAR experiment at RHIC is currently the best place where these effects can be tested.

The transverse single spin asymmetry, A_N, solely calculated from the lepton decay is predicted to be diluted [4] due to smearing, thus a full reconstruction of the produced boson kinematics is crucial for a meaningful measurement. Based on the transversely polarized data sample collected in the year 2011 at $\sqrt{s} = 500$ GeV ($L_{int} = 25$ pb^{-1}), an analysis has been performed at STAR to fully reconstruct the $W^{\pm}$ bosons from the lepton decay and all other particles in the recoil from the initial hard scattering. This analysis also includes a first look at A_N in Z^0 production. A proposed measurement with increased statistics will be directly competitive with a Drell-Yan measurement in pion-proton scattering at CERN.

2 Weak boson selection and asymmetry measurement

A data sample characterized by the $W \to e\nu$ signature as in Ref. [5], requires an isolated high $P_T > 25$ GeV electron and a total recoil $P_T > 18$ GeV. In order to fully reconstruct the W kinematics, the momenta of all decay products must be measured. The momentum of the neutrino produced in the leptonically decayed W can only be indirectly deduced from conservation of the transverse momentum.

We define the missing transverse energy as a vector restoring the balance in the event

$$\vec{\not{E}}_T = - \sum_{\substack{i \in \text{tracks,} \\ \text{clusters}}} \vec{P}_{i,T}. \tag{2}$$

At the STAR detector, due to a limited tracker acceptance of $|\eta| \sim 1$, the problem with measuring the missing momentum from the hadronic recoil is that particles with high rapidities escape the detector. At the same time, the beam remnants with high longitudinal momentum carry away only a little portion of the total transverse momentum. We accounted for the unmeasured tracks and clusters by using an event-by-event Monte Carlo correction to the data, using PYTHIA 6.4 with "Perugia 0" tune. Knowing its transverse momentum, the longitudinal component of the neutrino's momentum can be reconstructed solving the quadratic equation for the invariant mass of the produced boson

$$M_W^2 = (E_e + E_\nu)^2 - (\vec{P}_e + \vec{P}_\nu)^2, \tag{3}$$

where we assumed the nominal value of the W-mass. Eq. 3 leads to two possible solutions for P_L^ν, and we chose the smaller one in magnitude which, as shown by a Monte Carlo study, leads to a more truthful reconstruction of the original kinematics.

Background sources coming from $W^{\pm} \to \tau^{\pm}\nu_\tau$, $Z^0 \to e^+e^-$ and QCD events have been estimated to be at most a few percent of the selected sample, as shown in table 1.

Proc.	$W^{\pm} \to \tau^{\pm}\nu_\tau$	$Z^0 \to e^+e^-$	QCD
B/S	1.88% (W^+); 1.39% (W^-)	0.88% (W^+); 2.94% (W^-)	1.59% (W^+); 3.40% (W^-)

Table 1: Background over signal in the W^+ and W^- samples respectively.

The transverse single spin asymmetry is expressed as: $A_N = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow}$. We bin our data sample in three observables: the rapidity y, the azimuthal angle ϕ, and the P_T of the produced boson. Thus, we calculate A_N using the formula in Eq. 4, which helps to cancel out unwanted effects due to geometry and luminosity [6].

$$A_N \sin(\phi) = \frac{1}{<P>} \frac{\sqrt{N_{\uparrow}(\phi_i)N_{\downarrow}(\phi_i+\pi)} - \sqrt{N_{\uparrow}(\phi_i+\pi)N_{\downarrow}(\phi_i)}}{\sqrt{N_{\uparrow}(\phi_i)N_{\downarrow}(\phi_i+\pi)} + \sqrt{N_{\uparrow}(\phi_i+\pi)N_{\downarrow}(\phi_i)}}, \tag{4}$$

where N is the number of recorded events in the $i-th$ bin with a certain spin ($\uparrow\downarrow$) configuration in the "left" (ϕ_i) or in the "right" ($\phi_i + \pi$) side of the detector and $< P > \simeq 53\%$ is the average RHIC beam polarization for 2011 transverse p+p run.

The STAR preliminary results for the A_N measurement of the W^+ and W^- boson production are shown separately in Fig. 1 as a function of y^W and P_T^W. The systematic uncertainties, added in quadrature, have been evaluated via a Monte Carlo challenge using a theoretical prediction for the asymmetry from [7]. The 3.4% overall systematic uncertainty on beam polarization measurement is not shown in the plots.

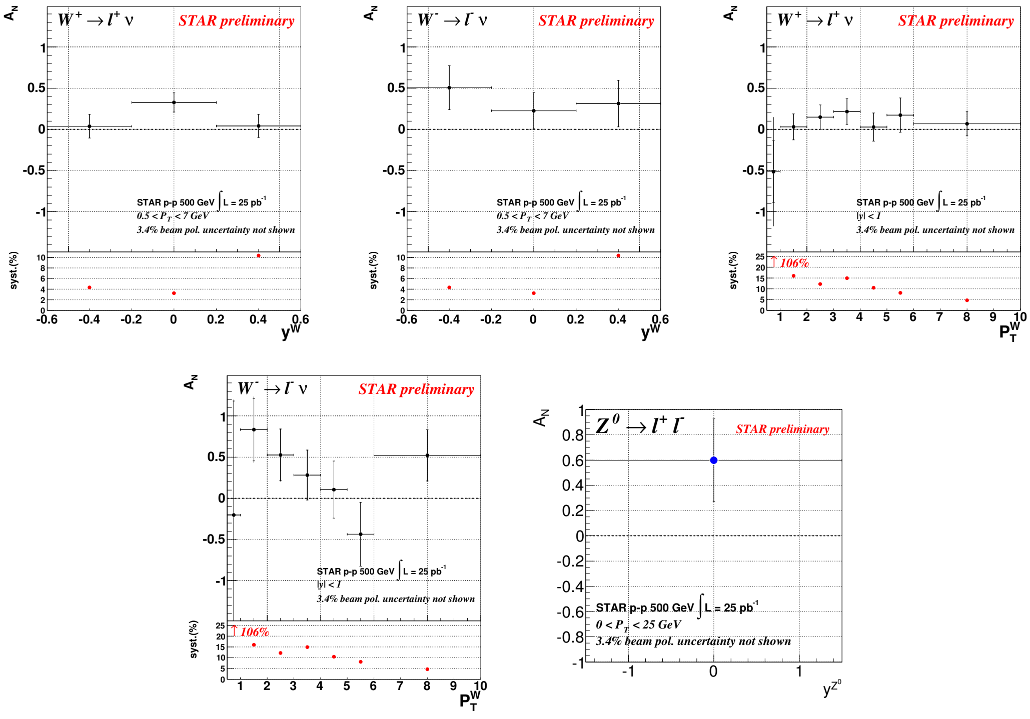

Figure 1: Transverse single spin asymmetry amplitude for $W^{\pm}$ and Z^0 boson production measured at STAR in a pilot run at $\sqrt{s} = 500$ GeV with a recorded luminosity of 25 pb^{-1}.

The $Z^0 \rightarrow e^+e^-$ process has many advantages: it is experimentally very clean and the boson kinematics are easy to reconstruct since there is no neutrino in the final decay (thus it carries only the overall systematics coming from the polarization measurement), it is background free and the asymmetry is expected to be the same size as the $W^{\pm}$ one. The only big disadvantage is the much lower cross section which makes the measurement very statistics hungry.

A data sample characterized by the Z^0 signature has been selected, requiring two isolated high $P_T > 25$ GeV electrons, of opposite charge and with an invariant mass within $\pm 20\%$ of the nominal value. The STAR preliminary result for the A_N measurement of the Z^0 boson production in a single y^Z, P_T^Z bin is shown in Fig. 1.

3 Conclusions and outlook

This preliminary study, based on a pilot run of transverse polarized p+p collisions at $\sqrt{s} =$ 500 GeV with a recorded integrated luminosity of 25 pb^{-1}, is a proof-of-principle which shows that STAR is capable of measuring the transverse single spin asymmetry for fully reconstructed $W^{\pm}$, Z^0 bosons. The preliminary results from Fig. 1 can be compared with the most up-to-date theoretical A_N predictions for $W^{\pm}$, Z^0 boson production including TMD-evolution from reference [7], shown in Fig. 2, where the error bands have been updated accounting for the current almost complete uncertainty on sea-quark functions in the fits [8]. RHIC is capable of delivering 900 pb^{-1} in 14 weeks running using a dynamic $\beta*$ squeeze [9] through the fill. Future STAR measurements of weak boson production , with a much higher collected luminosity (for projections see [10]), can lead to the first experimental test of the sign change of the Sivers function. Furthermore, it will provide an ideal tool to study the spin-flavor structure of sea quarks inside the proton, in an x-range where the measured asymmetry in the $\bar{u}$ and $\bar{d}$ unpolarized sea quark distribution [11] can only be explained by strong non-pQCD contributions.

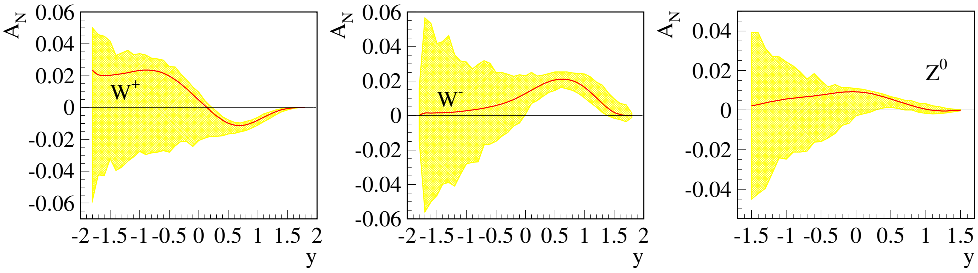

Figure 2: Theoretical prediction of A_N for $W^{\pm}$ and Z^0 boson production in p+p collisions at $\sqrt{s} = 500$ GeV including TMD-evolution [7].

References

[1] D. W. Sivers, Phys. Rev. **D41**, 83 (1990), 43, 261 (1991)

[2] M. Anselmino *et al.*, Eur. Phys. J. **A39**, 89 (2009)

[3] J. C. Collins, Phys. Lett. **B536**, 43 (2002)

[4] Z.-B. Kang and J. -W. Qiu, *Phys. Rev. Lett.* **103**, 172001 (2009)

[5] L. Adamczyk *et al.*,The STAR Collaboration, arXiv:1404.6880 [nucl-ex]

[6] Bültmann S *et al.*, Phys. Lett. **B632** 167 (2006)
Bültmann S *et al.*, Phys. Lett. **B647** 98 (2007)
Ohlsen G G and Keaton Jr P W, Nucl. Instr. Meth. **109** 41 (1973)

[7] M. G. Echevarria, A. Idilbi, Z.-B. Kang, I. Vitev, Phys. Rev. D**D89**, 074013 (2014)

[8] Z.-B. Kang, private communication

[9] D. Trbojevic, J. Yichao, Y. Luo, BNL-102458-2013-CP

[10] S. Fazio and D. Smirnov (for the STAR Collaboration), PoS (DIS2014) 237

[11] E. A. Hawker *et al.*, Phys. Rev. Lett. **80**, 3715 (1998)