Measurement of W single spin asymmetries at PHENIX

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W production: access to quark helicities

• Probing light quark sea via maximally parity violating W production and its lepton decay
• W couples only to left-handed quarks and right-handed anti-quarks
• W⁺/W⁻ distinguishes between quarks and anti-quarks
• No fragmentation needed
• High Q² set by W mass

\[ u_L \bar{d}_R \rightarrow W^+ \]
\[ d_L \bar{u}_R \rightarrow W^- \]

Experimental Observable

– $\mathcal{A}_L$

\[ \text{Collide polarized and unpolarized protons} \]
\[ \text{interactions mediated by P.D.F.s} \]
\[ $q_L$, $q_R$ interaction creates real W. \]
\[ \text{Maximal parity violating interaction} \]
\[ u_L (x_1) \rightarrow W^+ \]
\[ d_R (x_2) \rightarrow W^- \]
\[ \text{Count helicity combinations of decay leptons} \]
\[ \text{Calculate } \mathcal{A}_L \text{, use knowledge of } '\text{valence quark}' \text{ polarization to access to sea-quark polarized parton distribution functions.} \]
A$^W_L$ Measurement

- Longitudinal single spin asymmetries directly access to quark helicity PDFs
- Combined with weak decay kinematics
  - quark flavor mixed at mid-rapidity
  - sensitive to anti-quark at forward and backward rapidity

\[
A_{L}^{W^+} = \frac{\Delta \bar{d}(x_1)u(x_2) - \Delta u(x_1)\bar{d}(x_2)}{\bar{d}(x_1)u(x_2) + u(x_1)d(x_2)}
\]

\[
A_{L}^{W^-} = \frac{\Delta \bar{u}(x_1)d(x_2) - \Delta d(x_1)\bar{u}(x_2)}{\bar{u}(x_1)d(x_2) + d(x_1)u(x_2)}
\]

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A_L^W \textbf{Measurement}

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\[
A_{L}^{W \rightarrow \ell^{+}} \approx \frac{\Delta \bar{d}(x_1) u(x_2)(1 + \cos \theta)^2 - \Delta u(x_1) \bar{d}(x_2)(1 - \cos \theta)^2}{\bar{d}(x_1) u(x_2)(1 + \cos \theta)^2 + u(x_1) d(x_2)(1 - \cos \theta)^2}
\]

\[
A_{L}^{W \rightarrow \ell^{-}} \approx \frac{\Delta \bar{u}(x_1) d(x_2)(1 - \cos \theta)^2 - \Delta d(x_1) \bar{u}(x_2)(1 + \cos \theta)^2}{\bar{u}(x_1) d(x_2)(1 - \cos \theta)^2 + d(x_1) \bar{u}(x_2)(1 + \cos \theta)^2}
\]

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PHENIX W measurements
PHENIX W measurements

• $W^\pm \rightarrow e^\pm + \nu_e$ channel
• Two arm detector: $\Delta \phi = (\pi/2) \times 2$, $|\eta| < 0.35$
• High energy electron trigger by Electromagnetic Calorimeter
• Drift chamber (DC) and Pad chamber (PC) for tracking and charge separation
• $W^\pm \rightarrow \mu^\pm + \nu_\mu$ channel
• Two arm detector: $1.2 < |\eta| < 2.4$, Full azimuthal coverage
• Muon tracking chamber (MuTr)
• Muon Identifier (MuID) for PID
• Upgrade in 2012: high $p_T$ trigger, Resistive Plate Chambers (RPC), Forward Silicon Trackers (FVTX)
$W^\pm \rightarrow \ell^\pm$ Kinematics

- Different kinematics at mid-rapidity and forward rapidity
- Jacobian peak at mid-rapidity
- Suppressed/no Jacobian peak at forward rapidity
- Access via two decay channels: electrons at mid-rapidity and muons at forward rapidity
- Different analyses to identify $W$ signals in mid- and forward rapidities
Mid-rapidity measurement

Phys. Rev. D 93, 051103(R)

- Clear electron signal via Jacobian peak
- 97% (94%) of signal remains for $e^+$ ($e^-$) in the signal region (30-50 GeV/c)
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• Large asymmetries
• Data above latest global fit (DSSV14) for $e^-$
• Consistent with the STAR data

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**Mid-rapidity measurement**

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Forward measurement

- Suppressed/no Jacobian peak
- Real muon decays from Heavy flavour and Drell-Yan get smeared into high pT region.
- Large hadron BG contamination (low pT charged kaons, pions) → fake high pT muons
- Looking for W at pT > 16 GeV/c
- Signal/background separation is challenging
Forward measurement

courtesy of C. Kim

- Reducing BG by likelihood based pre-selection
- Multivariate analysis: 5-9 signal/BG sensitive kinematic variables
- Define likelihood ratio (Wness) based on signal (MC) and BG shapes (data)

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Forward measurement

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\[
\text{Wness} \equiv \frac{\lambda_{\text{sig}}(x)}{\lambda_{\text{sig}}(x) + \lambda_{\text{BGs}}(x)}
\]

\(\text{Wness} \to 1: \) signal-like event
\(\text{Wness} \to 0: \) background-like event
Forward measurement

- Performed 2D unbinned maximum likelihood fit to estimate Signal-to-Background ratio
- Two independent variables: rapidity($\eta$), azimuthal bending angle ($dw23$)
Forward measurement

- First results from muon decay channel published
- Cross sections consistent with previous measurements and theoretical calculations within uncertainties

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Summary

• W measurement provides clean access to light sea quark helicity PDFs

• PHENIX W results with dedicated RHIC longitudinal data (2011-2013) have been published:
  - Phys. Rev. D 93, 051103(R) (mid-rapidity),
  - Phys. Rev. D 98, 032007 (forward rapidity)

• PHENIX results will be an important constraint on the extraction of light sea quark helicity PDFs.
Backup
Polarized Proton Data

• First mid-rapidity $A_L$ measurement at 500 GeV in 2009
• Followed by over 300 pb$^{-1}$ data taken with higher beam polarization (2011-2013)
• Average beam polarization of ~57% in 2012 and 55% in 2013
Proton sea polarization measurement

Introduction

Figure 2:
Left plots: $x_1$ and $x_2$ distributions stacked by quark flavor for $W^-$ decay leptons in central (top) and forward (bottom) rapidities. Right plots: same for $W^{+-}$ decays.

Figure 3 shows the effect of the full 2011-2013 RHIC $W$ measurements on the extracted antiquark helicity uncertainties including all published SIDIS data to date as detailed in the RHIC spin 2013 whitepaper.

The extraction of $W$ decay muon candidates is in principle very simple at mid-rapidity where the Jacobian peak at about half the $W$ mass makes it easy to identify $W$ decays. At forward rapidities the extraction is limited by the large background to the single muon data sample collected in the forward PHENIX arms. As will be discussed later (see Section 1.2), even though the background processes are supposed to decrease quickly with the muon.

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Mid-rapidity Measurement

- Jacobian peak at $p_T \sim \frac{M_W}{2}$
- Backgrounds (BG):
  
  **Reducible:**
  - Photons from neutral pion/eta decays followed by $e^\pm$ pair production
  - Cosmic rays
  - Beam related backgrounds

  **Irreducible:**
  - $Z$, charm and bottom, other $W$ decay
Mid-rapidity Measurement

• Measure high pT electrons using EMCal
• DC-EMCal matching (Δφ<0.01 rad)
• Relative isolation cut - Main BG discriminator
  – Energy in a cone of R=0.4 devided by energy of the candidate
  – Reduces background by a factor of 10
Gaussian Process Regression

- Use background control region to extrapolate a shape in the signal region (30 to 50 GeV/c)
- The GPR gives a background contribution and uncertainty
- Cross check with a classical functional form (modified power law) showed good agreement
In this W analysis one is interested in removing most lower momentum particles which originate predominantly from background processes while keeping most of the W decay muons. With the above cuts, we aim to reduce part of the fake muons background assuring a good muon track reconstruction (DG_0, DDG_0 and 2 cuts) and selecting tracks with momentum smaller than the maximum possible physical energy. After applying these basic cuts, the background will be further reduced via a likelihood method, described in chapter 1.2, where background and signal features will be studied in detail.

The correlations between the several cut variables are shown in Fig. 1.1 for data and for the W-signal simulation. One generally sees some correlation within the different groups, especially for the signal, while the correlation between groups is mostly small. The only exception is the correlation between the vertex extrapolated variables DCA_z and DCA_r and the FVTX related matching variables. This is not entirely unexpected as both should be sensitive to the amount of multiple scattering in the central magnet yoke and initial shielding.

**Figure 1.1:** Correlation coefficients between various kinematic variables used in the analysis. The left panel shows the MC simulated signal while the other panel show the data.
Systematic uncertainty sources
Impact of the RHIC data

\[
\Delta\bar{u} = \frac{d}{dx} (u(x,Q^2) - \bar{u}(x,Q^2))
\]

\[
\Delta d = \frac{d}{dx} (d(x,Q^2) - \bar{d}(x,Q^2))
\]

These data are recorded 2011 to 2013.

Also shown is the predicted \[
\Delta S = \frac{d}{dx} (s(x,Q^2) - \bar{s}(x,Q^2))
\]

The STAR experiment has recently measured the production charge ratios as a function of the rapidity of the kinematics of the charged leptons of the decays, which is relevant to confirm the E866 findings.

The theoretical uncertainties for the experimental data are based on one point being 1.5 statistical standard deviations below zero.

The calculations used were MCFM 6.8, \[NLO\], \[CT10\].

The expected uncertainties for the experimental data are based on the current knowledge of the unpolarized quark distributions, i.e. \[CT10\].

It can also be seen that in addition to measuring the decay leptons of the hadron decays, the experiment has recorded 2011 to 2013.

Negligible uncertainties for the own calculations using MCFM 6.8 are shown.

Also shown is the anticipated deviation of the ratio at \[Q^2 = 10 \text{ GeV}^2\] and in particular whether there is a difference between the polarized light sea quark and the non-polarized light sea quark

Also shown is the result of the DSSV++ incl. proj. W data and the DSSV++ incl. proj. W data

The STAR projection based on one point being 1.5 statistical standard deviations below zero.
PHENIX Detector System (in the past)

Run11 500 GeV Projection

\[ \sigma_{\text{tot}} = 60 \text{mb} \]
\[ L = 1.5 \times 10^{32} \text{cm}^{-2} \text{s}^{-1} \]

BBC×MuID Rejection Power
\[ \text{RP} \sim 100 \]

Trigger Upgrade
\[ \text{RP} \sim 45 \]

PHENIX Band Width for Muon
\[ \text{RP}_{\text{tot}} \sim 4500 \]

- Data acquisition system limit (< 2 KHz)
- Low momentum threshold of MuID (~2 GeV)
  - MuID rejection power ~100
  - Collision rate ~9 MHz at designed luminosity
- Required rejection power ~ 4500
W Trigger System

Resistive Plate Counter (RPC) (Φ segmented)

Trigger events with straight track (e.g. Δstrip <= 1)

RPC / MuTRG data are also recorded on disk.
Introduction of New W Trigger in 2012

• RPC (Resistive Plate Chamber)

  - RPC has good timing resolution (< 3ns).
    → align events with correct beam crossing.
  - Better online tracking than MuID
  - Provides additional hit information.
  - Background rejection in offline analysis

→ New W Trigger gives higher rejection power

2011: SG1xMUIDxBBC trigger
2012: SG1xRPC3xBBC trigger (main)
     SG1xMUIDxBBC trigger (backup)