W → μ measurements at

DIS 2014, Warsaw, Poland,
May 29, 2014

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(RIKEN)
For the PHENIX collaboration
Most recent global analysis: DSSV

de Florian et al., PRL 101, 072001 (2008)

- NLO analysis
- Inclusion of SIDIS data before COMPASS
- Inclusion of RHIC $A_{LL}$ data (from 200GeV)
- Using most recent NLO fragmentation functions (DSS)
- Large uncertainties still for sea quarks
- Decay data forces $\Delta s$ to become negative at small $x$
- RHIC data results in node to $\Delta g$
Real W production as access to quark helicities

- Maximally parity violating V-A interaction selects only **left-handed** quarks and **right-handed** antiquarks:
  - Having different helicities for the incoming proton then selects spin parallel or antiparallel of the quarks
  - Difference of the cross sections gives quark helicities $\Delta q(x)$
- No Fragmentation function required
- Very high scale defined by W mass

Sea quark polarization via $W$ production

- Single spin asymmetry proportional to quark polarizations
- Large asymmetries
- Forward/backward separation smeared by $W$ decay kinematics

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

$$A_{L}^{W^-} \approx \frac{-\Delta d(x_1)\bar{u}(x_2)(1 + \cos \theta)^2 + \Delta \bar{u}(x_1)d(x_2)(1 - \cos \theta)^2}{d(x_1)\bar{u}(x_2)(1 + \cos \theta)^2 + \bar{u}(x_1)d(x_2)(1 - \cos \theta)^2}$$
W kinematics
W kinematics

$\eta - p_T$ correlation $W^+ \rightarrow \mu^+$

$\eta - p_T$ correlation $W^- \rightarrow \mu^-$

$p_T$ projection $-1.0 < \eta < 1.0$
W kinematics

\[ \eta - P_T \text{ correlation } W \rightarrow \ell^+ \]

\[ \eta - P_T \text{ correlation } W \rightarrow \ell^- \]

\[ P_T \text{ projection } -1.0 < \eta < 1.0 \]
W kinematics

\[ \eta - P_T \text{ correlation } W^+ \rightarrow \pi^+ \]

\[ \eta - P_T \text{ correlation } W^- \rightarrow \pi^- \]

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\[ P_T \text{ projection } 1.2 < \eta < 3.0 \]
W kinematics

\[ \eta - P_T \text{ correlation } W^{-} \rightarrow \pi^{-} \]

\[ \eta - P_T \text{ correlation } W^{+} \rightarrow \pi^{+} \]

\[ P_T \text{ projection } -1.0 < \eta < 1.0 \]

\[ P_T \text{ projection } 1.2 < \eta < 3.0 \]
W⁻ → µ⁻ case: almost entirely forward d quarks and backwards u̅ quarks
Pythia: quark flavors and x ranges

$W^- \rightarrow \mu$ case: almost entirely forward d quarks and backwards $\bar{u}$ quarks

$W^+ \rightarrow \mu$ case: predominantly forward $\bar{d}$ quarks and backwards u quarks
Forward W analysis

- W momentum cannot be ignored
- Jacobian peak only visible for forward moving $W^+$ decaying at close to 90 degrees
- Need to understand and suppress backgrounds lacking distinct signal signature

Pythia 6.4, muons in rapidities 1.2 – 2.4
PHENIX Muon trigger upgrade

- \( \sigma(\text{tot}) = 60 \text{mb} \), \( L = 3 \times 10^{32} \text{cm}^{-2}\text{s}^{-1} \) (500GeV)
  - collision rate = 18MHz
  - (after luminosity upgrade)
- DAQ rate limit < 2kHz (for muon Arm)
- Therefore, required rejection ratio
  - > 9000
- But, MuID-trigger rejection ratio (500GeV)
  - < 100
- A higher momentum trigger was needed
PHENIX Muon Trigger Upgrade detectors

MuID trigger selecting muon momentum > 2GeV/c

MuTR FEE upgrade fast selection of high-momentum-tracks

RPC provide timing information and rough position information

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Forward Muon Backgrounds

- Real muons from heavy flavor and DY decays get smeared to higher transverse momenta.
- Low energetic hadrons (huge cross section) decay within the muon tracker, mimicking a straight track.
- Raw yields 3 orders above signal.
Reducing the background components

- Apply sensitivity to multiple scattering to reduce hadronic backgrounds
- Initially (2011) cut based removal of backgrounds
- Improved by using likelihood based pre-selection and unbinned max likelihood fit
Define \( W_{ness} \) likelihood using 5-9 kinematic variables based on signal MC and data ( = mostly BG)

\[
\begin{align*}
W_{ness} &= \frac{\lambda(SIG)}{\lambda_{SIG} + \lambda_{BG}} \\
\lambda &= \left[p(DG0, D DG0), p(DCA_r), p(\chi^2), \\
p(RPC1, 3\_DCA), p(FVTX\_Match), p(FVTX\_Cone)\right]
\end{align*}
\]
After preselecting W like events (>0.92) perform unbinned max likelihood fit in independent variables rapidity and effective bending angle.

Shapes for fit are extracted from:
- Hadron Background: extrapolation from lower wness data
- Muon from MC (fixed)
- Signal MC
W signal fit

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Analysis status - efficiencies

- All relevant efficiencies have been calculated
  - Trigger efficiencies
  - Detector and reconstruction efficiencies and their rate dependence
  - Pile-up luminosity correction in progress
Luminosities

2011: BBC < 30cm 18.50 pb$^{-1}$
2012: BBC < 30cm 31.47 pb$^{-1}$
2013: BBC < 30cm 156.49 pb$^{-1}$

FOM: LP$^2$

2011: BBC < 30cm 4.97 pb$^{-1}$
2012: BBC < 30cm 9.83 pb$^{-1}$
2013: BBC < 30cm 45.03 pb$^{-1}$
### PHENIX luminosities

<table>
<thead>
<tr>
<th>Run</th>
<th>Energy [GeV]</th>
<th>Polarization [%]</th>
<th>Longitudinal L [pb⁻¹]</th>
<th>LP⁴ [pb⁻¹]</th>
<th>LP² [pb⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>500</td>
<td>36</td>
<td>8.6</td>
<td>0.32</td>
<td>1.3</td>
</tr>
<tr>
<td>2011</td>
<td>500</td>
<td>52</td>
<td>18</td>
<td>1.4</td>
<td>5.0</td>
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<tr>
<td>2012</td>
<td>510</td>
<td>55</td>
<td>30</td>
<td>3.1</td>
<td>9.8</td>
</tr>
<tr>
<td>2013</td>
<td>510</td>
<td>54</td>
<td>156</td>
<td>13.9</td>
<td>45.0</td>
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</tbody>
</table>

#### FOM: LP²

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R.Seidl: PHENIX W-->mu results
After extracting S/BG ratios (in 2012 preliminary data ~0.3) extract asymmetries and correct for BG (BG asymmetries are consistent with zero).

Inclusion of FVTX information will improve BG rejection (isolation, multiple scattering).

2011 and 2012 Analysis will be finalized soon.

2013 data analysis is ongoing.
Forward W asymmetries

1. After extracting S/BG ratios (in 2012 preliminary data ~0.3) extract asymmetries and correct for BG (BG asymmetries are consistent with zero).
2. Inclusion of FVTX information will improve BG rejection (isolation, multiple scattering).
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Outlook

- Real W boson production as clean access to sea quark helicities
- RHIC has delivered 510 GeV polarized pp collisions from 2009-2013
- Run 13 analysis will significantly improve sea quark helicity knowledge

RHIC Spin NSAC write-up:
Aschenauer et. al: arXiv:1304.0079
Expected impact of full data set

- Substantial uncertainty improvement of the sea quark helicities
- DSSV framework ready to include $W$ asymmetries
- NNPDF in the process of including $W$ asymmetries
Backup
DSSV/CHE predictions

- Only 1% uncertainties shown, actual uncertainties larger
- Potential impact of turnaround of $\Delta d$ at high $x$ visible in forward $W$-asymmetries

**DSSV, PRD80 (2009) 034030**
Muon Trigger Upgrade

- **RPC project**
- **MuTRG project**
- **Level-1 trigger board**
- **Level-1 trigger**
- **digitized hit signal**
- **digitized hit signal**
- **digitized hit signal**
- **timing information**
- **rough position information**

**RPC**

- **Station 1**
- **Station 2**
- **Station 3**

**MuTr**

- **sagitta**

**B**

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R.Seidl: PHENIX W-->mu results
PHENIX Forward W trigger upgrade installation and commissioning

Run11 Forward Muon Triggers

North Side
W Cross sections

- Correcting acceptance and efficiencies one can obtain the absolute W/Z cross sections:
- Excellent agreement of the scale dependence from RHIC to LHC

PRL 106:062001(2011)
PRD 85 (2012) 092010
W Outlook $^3$He p collisions

Marco Stratman (BNL)

pp @ 500 GeV

$^3$He p @ 432 GeV

R. Seidl: PHENIX W→μ results
W Outlook $^3$He p collisions

Marco Stratman (BNL)

$caveat: A_L$ study assumes 216 GeV $^3$He beam

but 325 GeV × Z/A was too optimistic

conservative: 250 GeV × 2/3 = 166 GeV

does not affect $A_L$ much but cross section smaller
Forward W decays

- Forward W decays advantages:
  - largest sensitivity to the anti-u quark polarization
  - some sensitivity to the anti-d quark polarization (due to decay kinematics)
  - With high statistics possibility to test d pol sign change
- But no Jacobian peak, experimentally more difficult
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Decay kinematics due to helicity conservation

\[ \bar{d}^+(x_1) \rightarrow u^-(x_2) \rightarrow W^+ \]
\[ u^-(x_1) \rightarrow \bar{d}^+(x_2) \rightarrow W^+ \]
\[ d^-(x_1) \rightarrow \bar{u}^+(x_2) \rightarrow W^- \]
\[ \bar{u}^+(x_1) \rightarrow d^- (x_2) \rightarrow W^- \]

\[ \nu_e \quad \theta^* = 0 \quad e^+ \]
\[ e^+ \quad \theta^* = \pi \quad \nu_e \]
\[ \nu_e \quad \theta^* = 0 \quad e^- \]
\[ e^- \quad \theta^* = \pi \quad \bar{\nu}_e \]

\[ \sigma \text{[pb/0.15]} \]

\[ \eta_{\text{Lepton}} \]

\[ W^+ \]
\[ W^- \]

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W vs lepton asymmetries

- Clear correlation for $W$: valence quark polarization $\rightarrow$ forward sea quark $\rightarrow$ backward
- However, not for decay muon/electron: enhanced for $W^-$, mixed for $W^+$
- reversed effect for neutrino asymmetry
- neutron target reverses that due to isospin asymmetry $\rightarrow$ run He3 collisions eventually?
- $x$ is not affected by this; still forward is larger $x$, backward smaller $x$