Recent PHENIX Efforts on Probing the Gluon Polarization in the Proton

Haiwang Yu
(New Mexico State University)
for PHENIX Collaboration

22nd International Spin Symposium
Hosted by: University of Illinois and Indiana University
September 25-30, 2016 at UIUC
Current Knowledge on Gluon Polarization

DSSV NLO Global Fit*
PRD80, 034030 (2009)

- Quark polarization was relatively well constrained by DIS, SIDIS experiments.
- Sea quark polarization not so well known.
- The Gluon polarization was poorly constrained.

*Including DIS, SIDIS data and RHIC data before 2006.


- Quark polarization was relatively well constrained by DIS, SIDIS experiments.
- Sea quark polarization not so well known.

S. Park's Talk

RHIC 2009 $\pi^0$ and Jet data

S. Park's Talk
Gluon Polarization and Double Helicity Asymmetries ($A_{LL}$)

Theoretically:

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{\sum_{a,b,c=q,\bar{q},g} \Delta f_a \otimes \Delta f_b \otimes \Delta \hat{\sigma} \otimes D_{h/c}}{\sum_{a,b,c=q,\bar{q},g} f_a \otimes f_b \otimes \hat{\sigma} \otimes D_{h/c}}$$

Experimentally:

$$A_{LL} = \frac{1}{P_B P_Y} \frac{N^{++} - R N^{+-}}{N^{++} + R N^{+-}}$$

Where $P_{B,Y}$ is the polarization of Blue (Yellow) beam. And R is the relative luminosity:

$$R = \frac{L^{++}}{L^{+-}}$$
PHENIX

PHENIX Central Arm

2012

PHENIX Detector

Muon Piston Calorimeter (MPC)

- Energy measured in EM Calorimeter (PbSc + PbGl)
- Momentum/Tracking in Drift Chamber (DC) + Silicon Barrel (VTX)
- PID with Ring Imaging Cherenkov Counter (RICH)
- $|\eta| < 0.35$, $\Delta \phi = 2 \times \frac{\pi}{2}$

Forward Muon Spectrometer

- Silicon strip tracking and vertexing (FVTX)
- Momentum measured in cathode strip tracking chambers (MuTr)
- $\mu^\pm$ ID from Iarocci tubes interleaved with steel absorbers (MulD)
- $1.2 < |\eta| < 2.2$, $\Delta \phi = 2\pi$
- Muon Piston Calorimeter (MPC) $3.1 < |\eta| < 3.9$
Recent PHENIX Measurements Sensitive to Gluon Polarizations

- **Finalized Analyses:**
  - 2012, 2013 510 GeV $\pi^0 A_{LL}$ at central rapidity
    - Phys. Rev. D 93, 011501(R) – Published 7 January 2016
  - 2013 510 GeV $J/\psi A_{LL}$ at forward rapidity

- **Ongoing analyses:**
  - Central:
    - 2013 charged pion $A_{LL}$
    - 2013 direct photon $A_{LL}$
    - 2013 Jet $A_{LL}$
    - 2009, 2011 di-$\pi^0 A_{LL}$
  - Forward:
    - 2011, 2013 500, 510 GeV $\pi^0 A_{LL}$
$\pi^0 A_{LL}$ and Gluon Polarization

\[ A_{LL} = \frac{d \Delta \sigma}{d \sigma} \approx a_{gg} \Delta g \Delta g + a_{qg} \Delta q \Delta g \]

arXiv1501.01220

NLO CTEQ6M, DSS
\( \pi^0 A_{LL} \) measurement procedure

- Reconstruct \( \pi^0 \) peak with \( \gamma \) pair in Electromagnetic Calorimeter at PHENIX (PbSc and PbGl).

- Workhorse channel at PHENIX:
  - large cross section
  - finely segmented EMCal:
    - \( \Delta \eta: 0.01, 0.008, \Delta \phi: 0.01, 0.008 \) for PbSc and PBGl
  - high \( p_T \) photon trigger.

- Inclusive asymmetry and side band background asymmetry:

\[
A_{LL}^{\pi^0} = \frac{A_{LL}^{(\pi^0+BG)} - rA_{LL}^{BG}}{1 - r}
\]
Cross section results are given for $0.5 < p_T < 30$ GeV/c.

The cross section is well described by NLO perturbative QCD.
$\pi^0 A_{LL}$ results at central rapidity ($|\eta|<0.35$)


  - The results follow positive trend with $p_T$ and $\sqrt{s}$ as predicted by NLO pQCD.
  - Additional constrains on gluon polarization and extended Bjorken $x$ coverage down to $\sim 0.01$. 

![Graph](image-url)
Further improve the knowledge of $\Delta g$
$J/\psi$ production at RHIC

At RHIC energies $J/\psi$ production is dominated by gluon-gluon fusion.

The $A_{LL}$ for $J/\psi$ can be written (LO):

$$A_{LL} = \frac{\Delta \sigma}{\sigma} = \hat{a} g g \rightarrow J/\psi \frac{\Delta g(x_1)}{g(x_1)} \frac{\Delta g(x_2)}{g(x_2)}$$
**$J/\psi$ production at RHIC**

At RHIC energies $J/\psi$ production is dominated by gluon-gluon fusion.

The $A_{LL}$ for $J/\psi$ can be written (LO):

$$A_{LL} = \frac{\Delta \sigma}{\sigma} = \hat{a}_{gg \to J/\psi} \frac{\Delta g(x_1) \Delta g(x_2)}{g(x_1) g(x_2)}$$

from Pythia simulation
Outline

• Analyze south and north arm separately, and divide data from each arm into $3 \ p_T$ bins. So 6 subsets total.

• Fit each subsets for $2\sigma \ J/\psi$ mass window and background fraction "r".
  • CB shape for $J/\psi$, Gaussian for $\psi'$
  • Gaussian Process Regression (GPR) for background shape

• Sideband region is defined as $M_{\mu\mu} \in [1.5GeV, 2.5GeV]$

• Calculate $A_{LL}^{incl.}$ in the $2\sigma \ J/\psi$ mass window

• Estimate the background asymmetry from a sideband

$$A_{LL}^{J/\psi} = \frac{A_{LL}^{incl.} - r \ * \ A_{LL}^{BKG.}}{1 - r}$$

$$\Delta A_{LL}^{J/\psi} = \sqrt{(\Delta A_{LL}^{incl.})^2 + r^2 \ * \ (\Delta A_{LL}^{BKG.})^2} \frac{1}{1 - r}$$

Gaussian Process Regression (GPR) background fraction extraction
$J/\psi \, A_{LL}$ at Forward Rapidity Results

Submitted to PRD. arXiv:1606.01815

- Currently the constraining power on gluon polarization limited by large production mechanism uncertainty.

- Favors positive gluon polarization under assumption that $\hat{a}^{gg\rightarrow J/\psi} = 1$. We are looking forward to future experimental and theoretical progress to pin down the $\hat{a}^{gg\rightarrow J/\psi}$.

- Universality test of the helicity-dependent gluon densities and QCD factorizations.

Ongoing Forward $\pi^0 A_{LL}$ Analyses

- Muon Piston Calorimeter (MPC) $3.1 < |\eta| < 3.9$
- 2011 MPC cluster ALL result is finalized. 2013 data analysis underway.
- Could extend the constraints on $\Delta g$ down to $x \sim 10^{-3}$.
Charged Pion $A_{LL}$

T. Moon's Talk

- Charged Pion $A_{LL}$ Analysis on-going with PHENIX 2013 data.
- Complementary measurement to neutral pion $A_{LL}$ measurements with large statistics.

\[
A_{LL}^{\pi^+} \approx a_{gg} \Delta g \Delta g + a_{ug} \Delta u \Delta g
\]

\[
A_{LL}^{\pi^-} \approx a_{gg} \Delta g \Delta g + a_{dg} \Delta d \Delta g
\]

Previous Charged Pion $A_{LL}$ Results and expected statistical precisions for currently on-going analysis based on 2013 PHENIX data.

$A_{LL}$ in $\pi^\pm$ production at $\sqrt{s} = 200$ and 510 GeV
• Jet $A_{LL}$ measurements on-going with PHENIX 2013 data.

• Comparable statistical uncertainty to the STAR 2012 Jet measurement.

• Independent check of STAR data.
Direct Photon $A_{LL}$

$A_{LL} = \frac{\Delta g}{g} A_1^{\hat{a}}(qq \rightarrow \gamma q)$

- Direct Photon $A_{LL}$ Analysis on-going with PHENIX 2013 data.
- Large statistics.
- Very clean production mechanism.
- No fragmentation function involved.
- Better constrained of the kinematics than $\pi^0 A_{LL}$. 

arXiv:1609.04769
Impact on Gluon Polarization of the RHIC Data

Projection with and without pseudo-data for current and future RHIC measurements up to PHENIX Run-2015.

2015 - 2016:

- Published Include in Global fittings
  - 2009 200GeV Central $\pi^0 A_{LL}$
- Published/Submitted Not Include in Global fittings
  - 2012, 2013 510GeV Central $\pi^0 A_{LL}$
  - 2013 510GeV Forward $J/\psi A_{LL}$
- Ongoing
  - 2013 510GeV Central $\pi^{\pm} A_{LL}$
  - 2013 510GeV Central direct photon $A_{LL}$
  - 2013 Jet $A_{LL}$ at central rapidity
  - 2009, 2011 di-$\pi^0 A_{LL}$
  - 2011, 2013 500, 510GeV Forward $\pi^0 A_{LL}$

arXiv:1602.03922
Opportunities at PHENIX IP beyond 2020

Proposed sPHENIX:
• Tracking, EMCal and HCal covering \(-1 < \eta < 1\) and \(|\phi| < 2\pi\)
• Expecting CD0 soon
• \(\sim 8\) times acceptance of PHENIX EMCal
• \(\sim 2\) time DAQ rate of PHENIX
• Better Jet Energy Scale uncertainty
• Significantly improve the statistical precision of the \(\pi^0 A_{LL}\), Jet \(A_{LL}\) and Direct Photon \(A_{LL}\) measurements.

fsPHENIX:
• Forward Spectrometer.
• LOI stage
• Small \(x\): \(\pi^0\), Jet and Direct Photon

J. Lajoie's Talk

Cold QCD topical group formed recently

Detector at PHENIX IP for EIC
Run12, Run13 $\pi^0 A_{LL}$ at central rapidity ($|\eta| < 0.35$) published at PRD Rapid Communications.

- Could reduce the global fit uncertainties on $\Delta g(x)$
- Extend the $\Delta g(x)$ constraints down to $x \sim 10^{-2}$.
- We are looking forward to the new global fit including this data.

Run13 $J/\psi A_{LL}$ at forward rapidity submitted to PRD.

- Sensitive to gluon polarization down to $x \sim 2 \times 10^{-3}$.
- Universality check for the QCD factorization of the gluon helicity dependent P.D.F.
- Could improve the gluon polarization precision at smaller $x$ with further knowledge on the production mechanism.

Many analyses also sensitive to $\Delta g$ are on-going.

Possible opportunities at PHENIX IP for gluon polarization measurement with new detectors beyond 2020.
Backups
<table>
<thead>
<tr>
<th>Year</th>
<th>√s (GeV)</th>
<th>Delivered Luminosity</th>
<th>Scientific Goals</th>
<th>Observable</th>
<th>Required Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>$p^+p @ 510$</td>
<td>400 pb⁻¹ 12 weeks</td>
<td>Sensitive to Sivers effect non-universality through TMDs and Twist-3 $T_{qF}(x,F)$ Sensitive to sea quark Sivers or ETQS function Evolution in TMD and Twist-3 formalism Transversity, Collins FF, linearly polarized gluons, Gluon Sivers in Twist-3 First look at GPD $E_g$</td>
<td>$A_N$ for $\gamma$, $W^\pm$, $Z^0$, $DY$ $A_{UT}^{\sin(\phi_2-2\phi_h)}$ $A_{UT}^{\sin(\phi_2-\phi_h)}$ modulations of $h^\pm$ in jets, $A_{UT}^{\sin(\phi_2)}$ for jets $A_{UT}$ for $J/\Psi$ in UPC</td>
<td>$A_N^{DY}$: Postshower to FMS@STAR None</td>
</tr>
<tr>
<td>2023</td>
<td>$p^+p @ 200$</td>
<td>300 pb⁻¹ 8 weeks</td>
<td>subprocess driving the large $A_N$ at high $x_F$ and $\eta$ evolution of ETQS femto-distance properties and nature of the diffusive exchange in $p+p$ collisions</td>
<td>$A_N$ for charged hadrons and flavor enhanced jets</td>
<td>Yes Forward instrum. None</td>
</tr>
<tr>
<td>2023</td>
<td>$p^+Au @ 200$</td>
<td>1.8 pb⁻¹ 8 weeks</td>
<td>What is the nature of the initial state nuclear collision? Nuclear dependence of TMDs Clear signatures for Sivers and ETQS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2023</td>
<td>$p^+Al @ 200$</td>
<td>12.6 pb⁻¹ 8 weeks</td>
<td>$A$-dependence of $T_{qF}(x,F)$ $A$-dependence of TMDs $A$-dependence for Sivers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>202X</td>
<td>$p^+p @ 510$</td>
<td>1.1 fb⁻¹ 10 weeks</td>
<td>TMDs at low and large $x$ Quantitative comparisons of the various factorization and universality in large $x$ proton collisions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>202X</td>
<td>$p^-p @ 510$</td>
<td>1.1 fb⁻¹ 10 weeks</td>
<td>$A_g(x)$ at small $x$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If the beams are longitudinally polarized at either STAR or sPHENIX during the proposed √s = 200 GeV p+p running in 2023, it would be possible to increase the data sample for the two main channels of the RHIC ΔG program, inclusive mid-rapidity jets and neutral pions, by a factor of 3. With the projected integrated luminosity of 300 pb⁻¹ (see Table 1-2) the other channels such as direct photons and charged pions are expected to show sensitivity to a non-zero ΔG for moderate $x$ ($x > 0.05$), though with significantly smaller statistical power compared to jets and neutral pions.
FIG. 1. (color online) The probability for two photons from $\pi^0$ decay to be separated by the PHENIX EMCal clustering algorithm vs $\pi^0 p_T$; obtained from GEANT [19] simulation for the two-photon energy asymmetry cut $\alpha < 0.8$.

PRD 93, 011501(R) (2016)

arxiv: 0810.0694