Longitudinal Double Spin Asymmetries with $\pi^0$ - Jet Correlations in Polarized Proton Collisions at $\sqrt{s} = 510$ GeV at STAR

Yaping Wang (for the STAR Collaboration)

Central China Normal University
Outline

• Introduction

• STAR experiment at RHIC

• $\pi^0$ - Jet double spin asymmetry ($A_{LL}$) measurements at STAR
  - Analysis methodology
  - $\pi^0$ – Jet $A_{LL}$ analysis status

• Conclusion and Outlook
The observed spin of the proton can be decomposed into contributions from the intrinsic quark and gluon spin and orbital angular momentum.

\[
\langle S_p \rangle = \frac{1}{2} = \frac{1}{2} \left[ \Delta \Sigma + \Delta G + L \right]
\]

- DIS data measure the integral of quark polarization well to be around ~ 30%
- Both DSSV and NNPDF, with 2009 RHIC results integrated in the fits, find evidence for positive gluon polarization:
  - DSSV: $0.19^{+0.06}_{-0.05}$ at 90% c.l. for $x > 0.05$
- Uncertainties on integral over low $x$ region are still sizeable.
The Relativistic Heavy Ion Collider (RHIC), the world’s first polarized hadron collider, is designed to collide many particle species energies.

- World’s only polarized hadron-hadron collider
- Spin direction changes from bunch to bunch
- Spin rotators provide choice of spin orientation
The polarized p+p program at Solenoidal Tracker at RHIC (STAR):
- Study proton intrinsic properties
- QCD
- Forward program

Detectors used for gluon polarization study:
- **Time Projection Chamber**
  \[|\eta| < 1.1, \ 0 \leq \phi < 2\pi\]
- **Barrel EM Calorimeter**
  \[|\eta| < 1, \ 0 \leq \phi < 2\pi\]
- **Endcap EM Calorimeter**
  \[1.08 < \eta < 2, \ 0 \leq \phi < 2\pi\]
- **FMS**
  \[2.5 < \eta < 4, \ 0 \leq \phi < 2\pi\]
Exploring gluon Polarization at RHIC

Measure Longitudinal double spin asymmetries ($A_{LL}$):

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \otimes \Delta f_b}{f_a \otimes f_b} \otimes a_{LL} \otimes D^h_f$$

$\Delta f$: polarized parton distribution functions;
$D^h_f$: fragmentation functions.

Sensitive probes:
- inclusive jets
- neutral pions ($\pi^0$)
- correlations (di-jets, h-jet, ...)

For most RHIC kinematics, $gg$ and $qg$ dominate, making $A_{LL}$ for jets sensitive to gluon polarization.
Longitudinally polarized $p+p$ collisions at 200 GeV and 510 GeV allow both cross section and double spin asymmetry $A_{LL}$ measurements at STAR on:

- **Inclusive Jet**
  - $x$ down to $\sim 0.05$ for jets in the mid-rapidity

- **Inclusive $\pi^0$**
  - $x$ down to $\sim 0.02$ for forward $\pi^0$ $0.8 < \eta < 2.0$

- **Di-jet**

  Correlation unfolds $x_1, x_2$ at the leading order
\[ \pi^0 - \text{Jet } A_{LL} \text{ measurements at STAR} \]

**Channel:** Using a jet in the mid-rapidity region correlated with an opposite-side neutral pion in the forward rapidity region \(1.08 < \eta < 2.0\) in the STAR EEMC provides a new tool to access the \(\Delta G(x)\) distribution at Bjorken-\(x\) down to 0.01.

\[
x_1 = \frac{p_T^{\text{jet}}}{\sqrt{s}} (e^{\eta_{\text{jet}}} + e^{\eta_{\pi^0}}),
\]

\[
x_2 = \frac{p_T^{\text{jet}}}{\sqrt{s}} (e^{-\eta_{\text{jet}}} + e^{-\eta_{\pi^0}}),
\]

\[
\sqrt{\hat{s}} = \sqrt{x_1 x_2 s}.
\]

- Compared to inclusive jet measurements, this \(\pi^0 - \text{jet}\) channel also allows to constrain the initial parton kinematics, such as \(x_1, x_2\) and \(\sqrt{\hat{s}}\).
- Theoretical description of hadron-jet \(A_{LL}\) by next-to-leading order (NLO) model calculation: Daniel de Florian, PRD 79 (2009) 114014.
π⁰ - Jet $A_{LL}$ measurements at STAR

Parton vs. Reconstructed kinematics:

- **Find** that most of the generated events in the Monte Carlo implementation of the NLO corrections give the same value for the 'real' and 'measured' momentum fractions.

- **π⁺ - jet correlation in mid-rapidity** from Daniel de Florian, PRD 79 (2009) 114014

- **Forward π⁰ - barrel jet correlation** using Daniel's NLO model calculation for this work

**π⁰ - jet correlation in mid-rapidity** from Daniel de Florian, PRD 79 (2009) 114014

**Forward π⁰ - barrel jet correlation** using Daniel's NLO model calculation for this work
Analysis cuts for Run12 pp 510 GeV data:

**π⁰ reconstruction:**
- π⁰ p_T: > 4.0 GeV/c
- π⁰ mass: (0, 0.6)
- π⁰ physics eta: (1.086, 2.0)

**π⁰ - jet pairing:**
- |Δφ| > 2.0 (back-to-back)

**Jet reconstruction:**
- Anti k_T algorithm, R=0.6
- Leading jet with p_T > 8.0 GeV/c
- Jet physics eta: (-0.9, 0.9)
- Jet points to a jet patch (JP) trigger
- Contribution from the calorimeters to the total jet energy (R_t) was required to be less than 0.95
- Sum track p_T > 0.5 GeV/c

**Triggers:**
- JP triggers (EM calorimeter triggers, and the size of a JP is 1.0×1.0 in η-φ coverage):
  - JP0: jet p_T > 5.4 GeV/c
  - JP1: jet p_T > 7.3 GeV/c
  - JP2: jet p_T > 14.4 GeV/c
$\pi^0$ - Jet $A_{LL}$ measurements at STAR

Reconstructed kinematics from data:

\[ x_1 = \frac{p_T^{\text{jet}}}{\sqrt{s}} (e^{\eta_{\pi^0}} + e^{\eta_{\pi^0}}) \]

\[ x_2 = \frac{p_T^{\text{jet}}}{\sqrt{s}} (e^{-\eta_{\pi^0}} + e^{-\eta_{\pi^0}}) \]
$\pi^0$ - Jet $A_{LL}$ measurements at STAR

Pythia simulation:

- The reconstructed $x_1$, $x_2$, and $\sqrt{s}$ of matched $\pi^0$-jet pair show a good linearity with MC (Pythia6426-Perugia0).

$$x_1 = \frac{p_T^{\text{jet}}}{\sqrt{s}}(e^{\eta_{\text{jet}}} + e^{\eta_{\pi^0}}),$$

$$x_2 = \frac{p_T^{\text{jet}}}{\sqrt{s}}(e^{-\eta_{\text{jet}}} + e^{-\eta_{\pi^0}}),$$

$$\sqrt{s} = \sqrt{x_1 x_2 s}.$$
π^0 - Jet $A_{LL}$ measurements at STAR

Pythia simulation VS. data:

• Ratio of leading jet $p_T$ from Run12 data to the leading jet $p_T$ from generator MC was taken as jet reconstruction efficiency.

• Weighted by the jet reconstruction efficiency, the $\pi^0$/jet $p_T$ spectrum and $\Delta\phi$ distribution from MC are consistent with data.

MC generator:
Pythia6426-Perugia0

PANIC2017@Beijing, Yaping Wang
Background subtraction:

The invariant mass spectrum (weighted by relative luminosities and beam polarizations), are fitted to estimate signal yield for each kinematic variable bin, respectively.

- **Signal**: A reconstructed photon pair is associated with the $\pi^0$ signal
- **Conversion background**: A reconstructed photon pair is associated with the conversion background
- **Other background**: Photon pairs that are not identified as signal or conversion background

- The raw yield of $\pi^0$-jet are well fitted by extended likelihood formalism in RooFit, in which the signal shape was described by skewed Gaussian function
- The shapes of signal and backgrounds are determined by fitting the spectrum summed over spin states
- Signal yield and background yields are estimated as free parameters by fitting over $[0., 0.6]$ GeV/c$^2$ with the fixed signal and background shapes
- Signal (background) asymmetries, $A_{LL}^S$ ($A_{LL}^B$), are calculated by the estimated yields
Uncertainty projections of $\pi^0$-jet $A_{LL}$:

- Theoretical predictions by NLO model calculations: PRD 79 (2009) 114014.
Conclusion

• STAR has been making significant contributions to the gluon polarization program via inclusive jets, inclusive neutral pions and di-jets measurements.

• $A_{LL}$ measurements via correlations between forward neutral pion and barrel jet allow to constrain the initial partonic kinematics. Analysis results using this channel is underway.

• More data have been taken by STAR and more precision measurements are expected.
Thanks for your attention!