Multiparticle Measurement in Polarized Proton-Proton Collisions at PHENIX

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Kenichi Nakano (Tokyo Tech/RIKEN)
for the PHENIX Collaboration
Introduction

- Gluon polarization in proton (spin puzzle)

\[ \frac{1}{2} \text{proton} = \frac{1}{2} \sum_q \Delta q + \Delta g + L_{q,g} \]

\[ \Delta q / \Delta g: \text{quark/gluon spin} \]

\[ L_{q,g}: \text{orbital angular momenta} \]

- reactions accessible to \( \Delta g \) ... jet, inclusive \( \pi^0 \), direct photon, etc.

- Can jet production be observed by measuring particle clusters with PHENIX Central Arm (\( \Delta \phi = 90^\circ \times 2, |\eta| < 0.35 \))?

- Double helicity asymmetry (\( A_{LL} \)) of jet production

\[ A_{LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}, \quad R \equiv \frac{L_{++}}{L_{+-}} \]

- \( A_{LL} \) has an information on \( \Delta g \)

- \( g+g \) and \( q+g \) reactions are dominant in mid-\( p_T \) jet productions

- for \( gg \rightarrow gg \) reaction, \( A_{LL}^{gg\rightarrow gg} = \int dx_1 dx_2 \frac{\Delta g(x_1)}{g(x_1)} \cdot \frac{\Delta g(x_2)}{g(x_2)} \cdot \hat{a}_{LL}^{gg\rightarrow gg} \)

- \( A_{LL} \) in multiparticle measurement is a modified \( A_{LL} \) of jet production
PHENIX Detector and Data Set

- Longitudinally polarized proton-proton collision
  - RHIC Run2003
  - polarization 26%
  - $\sqrt{s} = 200$ GeV
  - luminosity 0.25 pb$^{-1}$

- PHENIX Central Arms: $\Delta \phi = 90^\circ \times 2$, $|\eta| < 0.35$

- Event selection
  - $p_T(\text{photon}) > 2$ GeV/c (offline trigger)

- Particle selection
  - photon: detected with EMCal
    - $p_T > 0.4$ GeV/c
    - charged veto
    - shower shape cut
  - charged particle: detected with DC & PC1
    - $0.4 < p_T < 4.0$ GeV/c
    - track quality cut
Method of Multiparticle Measurement

- Particle clustering with cone
  - photons \( (p_T > 0.4 \text{ GeV}/c) \) and charged particles \( (0.4 < p_T < 4.0 \text{ GeV}/c) \)
  - make cones by using all particles as seed
    - cone radius \( R = 0.3 \)
    - cone momentum = vector sum of momenta of particles in the cone
    - cone axis = direction of cone momentum (dir. of seed particle at first)
  - use highest-\( p_T \) cone in events

- Definition of kinematic variables; \( p_T^{\text{cone}} \) and \( p_T^{\text{sum}} \)

\[
p_T^{\text{cone}} \equiv \sum_{i \text{ in cone}} p_{Ti}
\]

\[
p_T^{\text{sum}} \equiv \sum_{i \text{ in arm}} p_{Ti}
\]
Method of Multiparticle Measurement

- $A_{LL}$ of multiparticle production
  - measured as a function of $p_T^{\text{cone}}$
  - compared with theoretical $A_{LL}$ predictions
    - the ratio $p_T^{\text{cone}}/p_T^{\text{jet}}$ was evaluated with simulation
    - the reproducibility of simulation was checked with event shape

- PYTHIA (Ver. 6.220) + GEANT simulation
  - Two settings to study the effect of the underlying event
    - PYTHIA default
    - PYTHIA Multi-Parton Interaction (MPI) ... "Rick Field Tune A"
  - experimental losses/contaminations are included in simulation
    - detector masked/dead channels ... <5%
    - non-vertex emc clusters ... 1.9% @ 1~2 GeV/c, 0.7% @ 5~6 GeV/c
    - neutral hadron contamination etc.
Results – Event Shape

$p_T$ density $D_{pT}$

$$D_{pT}(\Delta \phi) = \left\langle \frac{d}{d\phi} \left( \sum_{i \in \{ |\eta| < 0.35 \}} p_{T,i} \right) \right\rangle_{\text{event}}$$

- trigger photon within $20^\circ$ from edge ... not affected by edge up to $\Delta \phi = 70^\circ$

![Graphs showing $p_T$ density comparison between real data and PYTHIA default/MPI models at different $p_T$ sums.](image)

- real data and PYTHIA default/MPI match at small $\Delta \phi$
- clear difference between PYTHIA default and MPI at large $\Delta \phi$
- real data agrees better with PYTHIA MPI
Results – Event Shape

PHENIX thrust $T_{PH}$

\[ T_{PH} = \frac{\sum |p_i \cdot \hat{p}|}{\sum |p_i|}, \quad \hat{p} = \frac{\sum p_i}{|\sum p_i|} \]

- calculated with one arm
- “$N \geq 3$” cut is applied

4 < pT sum < 5 GeV/c

10 < pT sum < 11 GeV/c

- PYTHIA MPI has more gradual distribution than PYTHIA default
- real data agrees better with PYTHIA MPI
Results – Double Helicity Asymmetry $A_{LL}$

- $A_{LL}$ is evaluated with PHENIX Run2003 p+p data

$$A_{LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}, \quad R \equiv \frac{L_{++}}{L_{+-}}$$

- Theory predictions
  - PHENIX Central Arm acceptance ($|\eta|<0.35$) and $R=0.3$ cone
  - $p_T^{jet}$ in theory calculation is scaled to $p_T^{cone}$ by ratios estimated with PYTHIA+GEANT
    - at $6 < p_T^{cone} < 7 \text{ GeV/c}$, $<p_T^{cone}/p_T^{jet}> = 0.72$ with PYTHIA default, 0.87 with PYTHIA MPI
  - trigger bias effect is evaluated with PYTHIA as the modification of subprocess fractions ($qq, qg, gg$)
    - $gg$ subprocess are suppressed by trigger photon requirement at low $p_T$
Results – Double Helicity Asymmetry $A_{LL}$

$A_{LL}$ is evaluated with PHENIX Run2003 p+p data

$$A_{LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$

The difference between $p_T^{jet}$ in theory and $p_T^{parton}$ in PYTHIA is included in $p_T^{cone}$ scale uncertainty.

**Graphical Description:**
- Black line: theory without correction
- Blue/green line: PYTHIA default/MPI
- Solid/dash: with/without trigger bias
- Shade: max. scale uncertainty of pT cone

**Legend:**
- $\Delta g = g$ input
- GRSV-std

**Data Points:**
- 0.25 pb$^{-1}$, 26% pol.

**PHENIX Preliminary**
Results – Double Helicity Asymmetry $A_{LL}$

$A_{LL}$ error estimation for Run2005 statistics
- polarization 26% $\rightarrow$ 45%, luminosity 0.25 pb$^{-1}$ $\rightarrow$ 4.0 pb$^{-1}$

Run2005 statistics and further systematic study will bring suggestive result
Summary

- Gluon polarization in proton (spin puzzle)
  \[ \frac{1}{2} \text{proton} = \frac{1}{2} \sum_{q} \Delta q + \Delta g + L_{q,g} \]

- Longitudinally polarized proton-proton collision
  - RHIC-PHENIX Run2003
  - √s = 200 GeV
  - polarization 26%
  - luminosity 0.25 pb⁻¹

- Double helicity asymmetry \( A_{LL} \) of multiparticle production
  - particle clustering with \( R=0.3 \) cone
  \[ p_{T \text{cone}} \equiv \sum_{i \text{ in cone}} p_{T \text{i}} \]
  - \( A_{LL} \) as a function of \( p_{T \text{cone}} \) with PHENIX Central Arm (\( \Delta \phi = 90^\circ \times 2, |\eta| < 0.35 \))
  - the relation between \( p_{T \text{cone}} \) and \( p_{T \text{jet}} \) was evaluated with PYTHIA + GEANT simulation
  - PHENIX Run2005 statistics and further systematic study will bring suggestive result
Backup Slides...
**Results – Double Helicity Asymmetry $A_{LL}$**

- $A_{LL}$ is evaluated with PHENIX Run2003 p+p data
  
  \[
  A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}} , \quad R = \frac{L_{++}}{L_{+-}}
  \]

- Theory predictions

  - PHENIX Central Arm acceptance ($|\eta| < 0.35$) and $R=0.3$ cone
  - $p_T^{jet}$ in theory calculation is scaled to $p_T^{cone}$ by ratios estimated with PYTHIA+PISA
  - trigger bias effect is evaluated with PYTHIA as the modification of subprocess fractions ($qq$, $qg$, $gg$)

- $A_{LL}$ without trigger photon

  
  \[\Delta g = \text{g input}\]

  \[\Delta g = -\text{g input}\]

  \[\Delta g = 0 \text{ input}\]

  by W. Vogelsang

- $6 < p_T^{cone} < 7 \text{ GeV/c}$

  - mean 0.72
  - 0.87

  PYTHIA default

  PYTHIA MPI
Results – Double Helicity Asymmetry $A_{LL}$

$A_{LL}$ is evaluated with PHENIX Run2003 p+p data

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{NN_{++} + RN_{+-}} , \quad R = \frac{L_{++}}{L_{+-}}$$

Theory predictions

- PHENIX Central Arm acceptance ($|\eta|< 0.35$) and $R=0.3$ cone
- $p_T^{\text{jet}}$ in theory calculation is scaled to $p_T^{\text{cone}}$ by ratios estimated with PYTHIA+PISA
- trigger bias effect is evaluated with PYTHIA as the modification of subprocess fractions ($qq$, $qg$, $gg$)

$A_{LL}$ without trigger photon by W. Vogelsang

GRSV-std

$\Delta g = g$ input

$\Delta g = -g$ input

$\Delta g = 0$ input

$6 < p_T^{\text{cone}} < 7 \text{ GeV/c}$

mean 0.72

0.87
Results – Event Shape

Multiplicity ... the number of photons \((p_T > 0.4 \text{ GeV/c})\) and charged particles \((0.4 < p_T < 4.0 \text{ GeV/c})\)

- PYTHIA MPI has larger multiplicity in arm than PYTHIA default
- this difference is small in cone
- real data agrees with PYTHIA MPI
$p_T$ Density (1/2)
$p_T$ Density (2/2)
$p_T^{\text{cone}}/p_T^{\text{parton}} (1/2)$
$p_T^{\text{cone}} / p_T^{\text{parton}}$ (2/2)

- $8 < p_T^{\text{cone}} < 9 \text{ GeV/c}$
- $9 < p_T^{\text{cone}} < 10 \text{ GeV/c}$
- $10 < p_T^{\text{cone}} < 11 \text{ GeV/c}$

PYTHIA default

PYTHIA MPI

$11 < p_T^{\text{cone}} < 12 \text{ GeV/c}$

PYTHIA default

PYTHIA MPI

$0.55 \leq p_T^{\text{cone}} / p_T^{\text{parton}} \leq 1.00$

$p_T^{\text{cone}} [\text{GeV/c}]$

$p_T^{\text{cone}} / p_T^{\text{parton}}$
Trigger Bias for Fraction of Subprocesses

PYTHIA default

PYTHIA default with trigger photon

PYTHIA MPI

PYTHIA MPI with trigger photon