Spin Physics Results from PHENIX

Diffraction 2014 Primošten, Croatia
Sept 13, 2014
Paul Kline (for the PHENIX collaboration)
Motivation

• What is the spin structure of the proton?
  • DIS (quarks) only accounts for 25-30%
  • Longitudinally polarized proton collisions directly probe gluon structure
  • W production separates quark flavors

• Surprising asymmetries in transversely polarized fixed target experiments persist to RHIC energies
  • Study and disentangle effects
  • Sivers, Collins, higher twist . . .
• **Central Arms**
  - $|\eta| < 0.35$, $\Delta \phi = 2 \times (\pi/2)$
  - Tracking
    - Drift Chamber
    - Pad Chambers
  - Electromagnetic Calorimeter
    - PbSc and PbGl technologies
    - $\Delta \phi \sim 0.01$ and $\Delta \eta \sim 0.01$

• **Forward Arms**
  - Muon System
    - ID, tracking
  - Forward vertex detector
  - Muon Piston Calorimeter
  - Zero Degree Calorimeter
    - Local polarimetry
  - Beam Beam Counter
    - Luminosity, vertexing
Parton Helicity Structure
What do we measure?

Helicity Class:

Theory:

\[ A_{LL} = \frac{\sum_{a,b,c} \Delta f_a \otimes \Delta f_b \otimes \Delta \sigma^{a+b\rightarrow c+X} \otimes D_c^h}{\sum_{a,b,c} f_a \otimes f_b \otimes \sigma^{a+b\rightarrow c+X} \otimes D_c^h} \]

YIELDS

Experiment:

\[ A_{LL} = \frac{1}{P^2} \left[ N^{++} - R_L N^{+-} \right] \left[ N^{++} + R_L N^{+-} \right] \]

Polarization Luminosity Normalization

PDFs Partonic Crosssection Fragmentation Function

Paul Kline (Stony Brook University)
Neutral Mesons

- $\pi^0$, $\eta$ two photon peak reconstruction
  - EMCal triggers
  - Fine granularity in detectors
  - Fit peak over background

$$A_{LL}^{Sig} = \frac{A_{LL}^{Sig+BG} - w_{BG} A_{LL}^{BG}}{1 - w_{BG}}$$

- $q$-$g$ and $g$-$g$ processes contribute

- $\pi^0$ a high statistics probe
  - $\sqrt{s} = 62.4$ & 200 GeV in global analysis
  - 500 GeV analysis ongoing
  - Rel. Lumi limited at low $p_T$

- $\eta$ has different flavor structure, subprocess mix
  - Get to $p_T$ due to later merge of photons
  - Global analysis requires better determination of fragmentation function
π^0 Impact on Global Fits

- RHIC probes in 0.05 < x < 0.2
  \[ \Delta G_{DSSV08}^{[0.05,0.2]} = 0.005^{+0.129}_{-0.164} \]

- π^0 recently included in new DSSV fits
- Systematic errors are important to full understanding on uncertainties
  - DSSV08 + Run 9 π^0 gives \( \Delta G = 0.06 \)
  - Plus rel. lumi gives \( \Delta G = 0.12 \)
  - Minus rel. lumi gives \( \Delta G = 0.02 \)
Charged Pion

- Complimentary to $\pi^0$ probe
  - Favored fragmentation from flavor structure of $\pi^\pm$
  - Well determined quark polarizations lead to hierarchy

$$\Delta G > 0 \Rightarrow A_{LL}^{\pi^+} > A_{LL}^{\pi^0} > A_{LL}^{\pi^-}$$
$$\Delta G < 0 \Rightarrow A_{LL}^{\pi^+} < A_{LL}^{\pi^0} < A_{LL}^{\pi^-}$$

- Fragmentation functions need refinement for global analysis inclusion
**π⁰ Correlations**

- First pair correlation $A_{LL}$ in PHENIX
- Brings in strong kinematic constraint due to correlation
- Similar to single $π⁰$ analysis with new backgrounds
- Requires large integrated luminosity
- Can be extended to other channels
  - $π⁰$ + hadron
  - $π⁰$ + forward cluster

![Graph showing $A_{LL}$ vs. $M_{π⁰π}$]

PHENIX preliminary

8.8% polarization uncertainty not included
Forward Cluster Analysis

- Forward clusters dominated by $\pi^0$
  - Low x reach
  - Systematic limited
- 500 GeV analysis underway
  - Trigger upgrade increased purity of sample by a factor of 4
  - Expected uncertainty $\sim 1\times 10^{-4}$
Weak Bosons as a Probe

- W couplings are parity violating
  - Exploit kinematics for (almost) direct sea quark determination

\[
A_{LL}^{W^+} = -\frac{\Delta ud(1 - \cos \theta)^2 + \Delta \bar{d}u(1 + \cos \theta)^2}{ud(1 - \cos \theta)^2 + \bar{d}u(1 + \cos \theta)^2}
\]

\[
A_{LL}^{W^-} = -\frac{\Delta d\bar{u}(1 + \cos \theta)^2 + \Delta \bar{u}d(1 - \cos \theta)^2}{d\bar{u}(1 + \cos \theta)^2 + \bar{u}d(1 - \cos \theta)^2}
\]

- Single spin asymmetry (same determination as double)
  - Detect outgoing leptons
  - No fragmentation function
  - “Unpolarized” beam is averaged over, leading to two measurements

- Electron channel detected in Jacobian peak
  - Isolation cut reduces background, not signal

- Muon channel measured via multivariate analysis and unbinned max likelihood fit
  - Extract signal-to-background in W rich region
$W^\pm \rightarrow e^\pm \ & \mu^\pm$

- Electron data close to publication
- 2011, 2012 muons being finalized
  - 2013 data benefits from FVTX tracking
Transverse Spin Physics
What do we measure?

\[
\frac{d^3 \sigma(pp \rightarrow hX)}{dx_1 dx_2 dz} \propto q(x_1)q(x_2) \times \frac{d^2 \sigma(q_i q_j \rightarrow q_k q_l)}{dx_1 dx_2} \times F F_{q_k q_l}(z, p_h)
\]

- Single (transverse) spin asymmetries
  - Modified production in azimuth w.r.t. proton spin direction

- Transversity distributions coupled to Collins TMD fragmentation
  - Correlation of proton spin with quark spin coupled with spin dependent FF

- Sivers quark distribution
  - Correlation between proton spin and quark transverse momentum

- Twist-3 effects in tri-parton correlators
Forward $A_N$ of Neutral Mesons

- Cross section well described by pQCD
- $A_N$ independent of collision energy
  - $x_F$ scaling?
- Similar for pions and etas
• Little variation with $p_T$

• Naïve expectation of $A_N \sim 1/Q \sim 1/p_T$

• Recent theoretical work describes plateau
Central $A_N$ of Neutral Mesons

- New results 20x better statistics
- Sensitive to $q$-$g$ and $g$-$g$ processes
- Consistent with zero, compared to forward production
Forward Heavy Flavor

- Heavy flavor probes tri-gluon correlation
- $A_N$ consistent with zero
- Future data will significantly constrain $A_N$
  - 2012 data close to finished
  - 2015 data to be taken
  - FVTX for both sets helps with reconstruction/background rejection

\[ p+p \rightarrow \mu^{-}+X \text{ at } \sqrt{s} = 200 \text{ GeV} \]
\[ 1.4 < |p_T| < 1.9 \]
\[ 1.0 < p_T < 5.0 \text{ GeV/c} \]
\[ <p_T> = 2.4, 1.4, 1.4, 2.4 \text{ GeV/c} \]
Scale uncertainty 5% not shown

Paul Kline (Stony Brook University)
MPC-EX

- New tracking and pre-shower in front of MPC
- Reject merged $\pi^0$ photon clusters
- Future measurement of direct photon $A_N$ and cross section

- Excited for physics in 2015
  - p-p and p-Au
• $\Delta G$ probed at PHENIX
  • High statistics $\pi^0$ included in global analysis
  • Other channels available
  • New measurements coming from 500 GeV runs

• Sea quark helicity accessed via W boson production
  • Clean probe, clean interpretation
  • Full dataset close to analyzed

• Transverse spin asymmetries persist to RHIC energies
  • Forward production of mesons consistent with previous measurements
  • Mid-rapidity asymmetries consistent with zero
  • Promising new results with FVTX, MPC-EX in coming run

Thank You
Backup
$\pi^0 \; \& \; \eta$

200 GeV $p+p$ Midrapidity

$A_L^\eta$

Run5+6+9 Not Included:
4.8% Global Scaling Uncert.
4.2x10^{-4} Global Shift Uncert.

(a) $\pi^0$

4 < $p_T$ < 5 GeV/c

(b) $\eta$

4 < $p_T$ < 5 GeV/c

Paul Kline (Stony Brook University)
W Spectra

Positive Charge $p_T$ spectrum for p+p $\sqrt{s}$=510 GeV Run 2013 ($|y|<0.35$)

- EMCal cluster associated with track
- Jacobian peak (PYTHIA+GEANT) with background fit
- Background uncertainty estimation

Negative Charge $p_T$ spectrum for p+p $\sqrt{s}$=510 GeV Run 2013 ($|y|<0.35$)

- EMCal cluster associated with track
- Jacobian peak (PYTHIA+GEANT) with background fit
- Background uncertainty estimation

PHENIX preliminary

W+

W−
Forward $A_N$ for MPC

\[ p+p \rightarrow \pi^0 + X \]

- PHENIX $\pi^0$ $3.1 < |\eta| < 3.8$, $|s|=62.4$ GeV
- E704 $\pi^0$, $|s|=19.4$ GeV
- STAR $\pi^0$ $<|\eta|=3.7$, $|s|=200$ GeV
- STAR $\pi^0$ $<|\eta|=3.3$, $|s|=200$ GeV

\[ p+p \rightarrow \text{Cluster} + X, \ |s|=200\text{GeV} \]

- $3.5 < |\eta| < 3.8$
- $3.1 < |\eta| < 3.5$

\[ p+p \rightarrow \pi^0 + X, \ |s|=62.4\text{GeV}, \ x_F > 0 \]

\[ p+p \rightarrow \text{Cluster} + X, \ |s|=200\text{GeV} \]

- $x_F > 0.4$
- $x_F < -0.4$