Transverse Single-Spin Asymmetries of Midrapidity Eta Mesons at PHENIX

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Deep Inelastic Scattering 2019

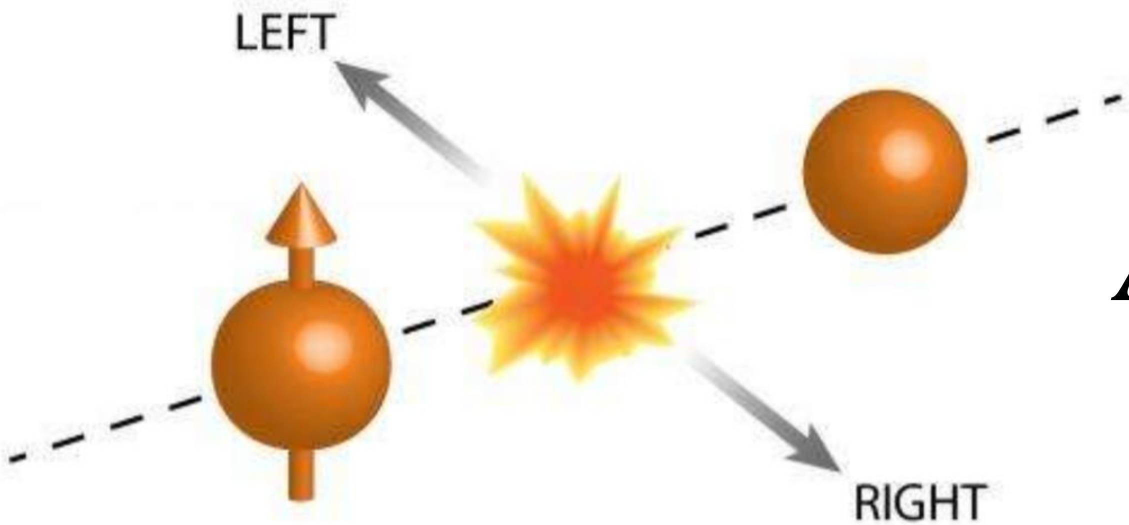
4/9/19

U.S. DEPARTMENT OF ENERGY

Office of Science

UNIVERSITY OF MICHIGAN

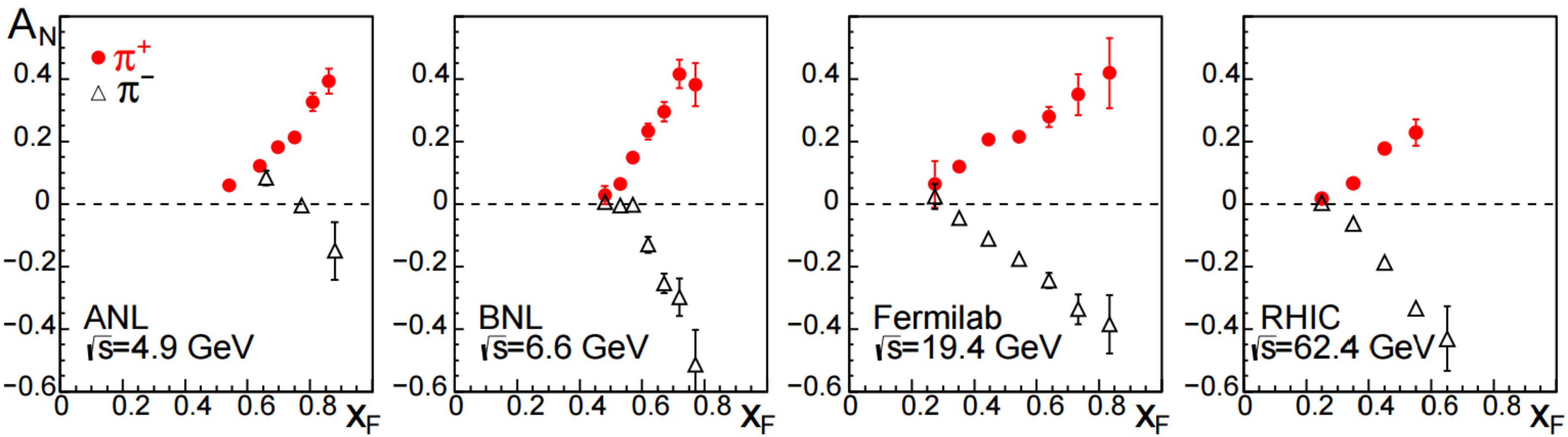
Transverse Single-Spin Asymmetries (TSSAs)



$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

G. L. Kane, J. Pumplin, and W. Repko PRL **41**, 1689 (1978) predicted that the perturbative QCD contributions to TSSAs would make them less than 1%.

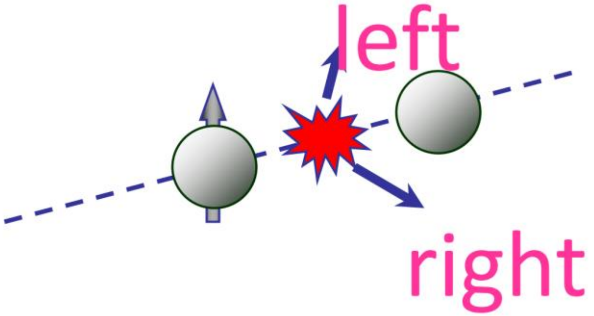
Transverse Single-Spin Asymmetries (TSSAs)



C. A. Aidala, S.D. Bass, D. Hasch, and G. K. Mallot, Rev. Mod. Phys. **85** 655 (2013).

$$x_F = \frac{p_z}{\sqrt{s}/2}$$

$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$



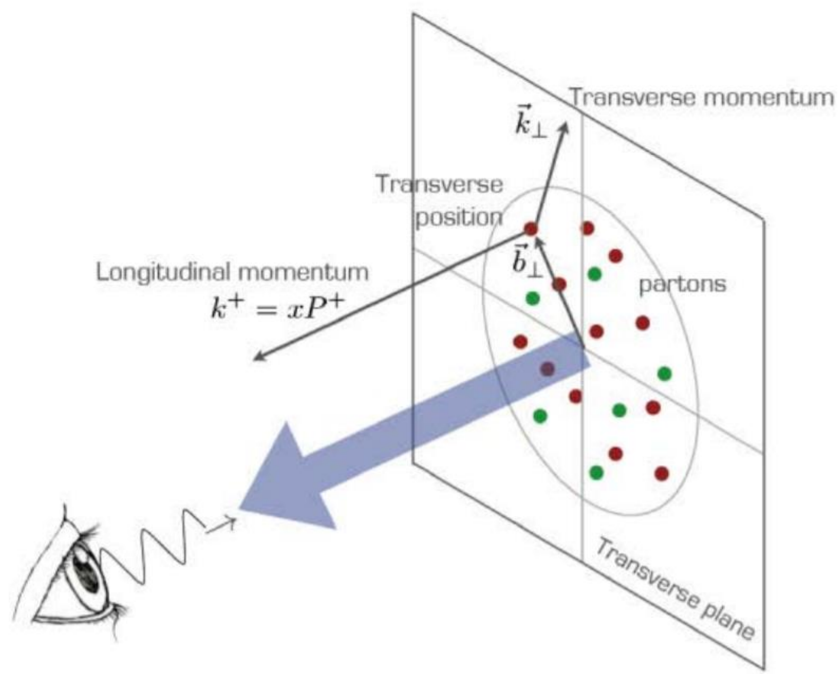
Transverse Momentum Dependent Nonperturbative Functions

Collinear: The parton model integrates over the internal dynamics of the proton

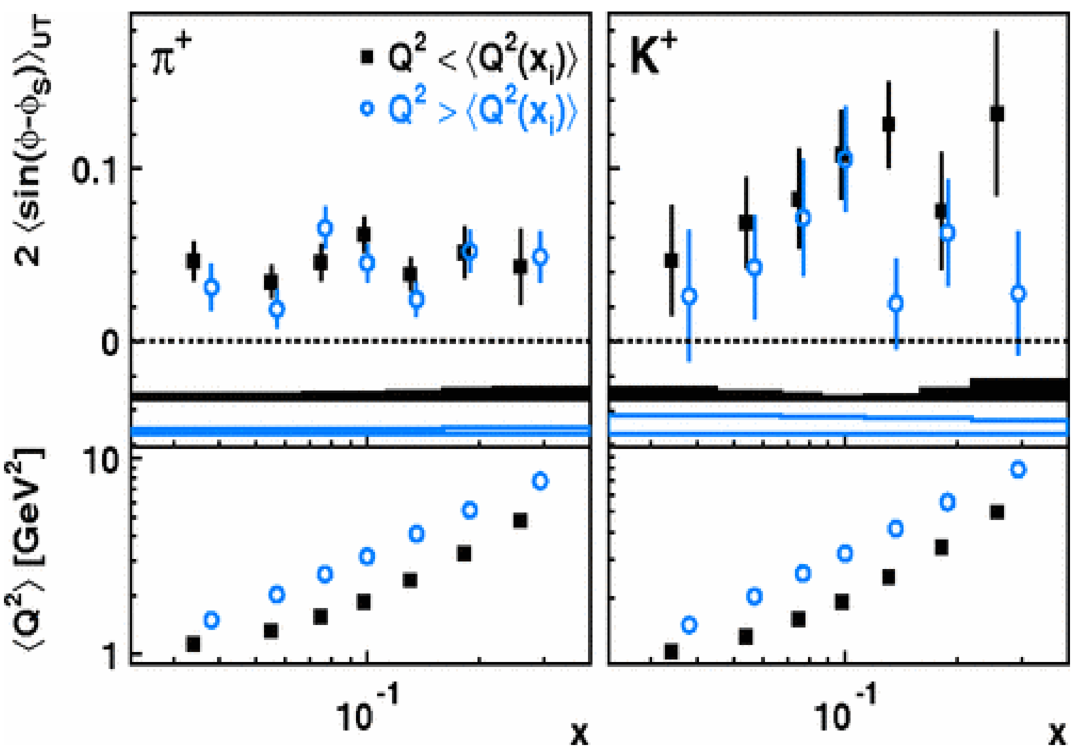
Transverse Momentum Dependent (TMD): functions explicitly depend on the nonperturbative transverse momentum k_T

- In order for TMD factorization to apply $k_T^2 \ll Q^2$.
- 2 scale process: for the TMD regime to be applied a measurement needs sensitivity to both k_T and Q

from Alessandro Bacchetta



Effects of Strangeness



(HERMES Collaboration) *Phys. Rev. Let* **103**, 15002 (2009)

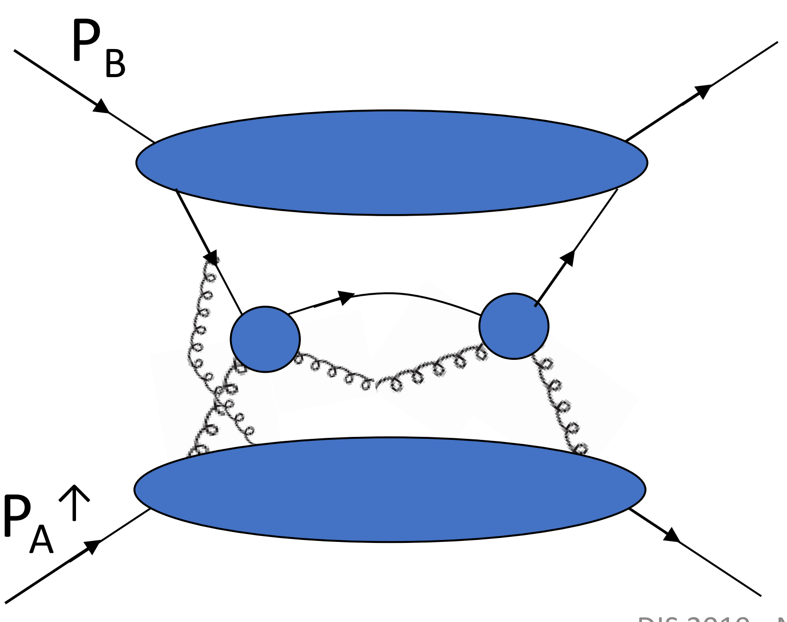
- Some indication that the Sivers asymmetry in SIDIS is slightly larger for K^+ than for π^+?
- Larger spin-momentum correlations for strange quarks in the proton?

Similar effects seen in the final-state Collins asymmetry

Higher Twist Functions

Formal definition of twist: “mass dimension minus spin” of the operator in a matrix element within the Operator Product Expansion

Twist 2: traditional PDFs and FFs only consider interactions between one parton in the proton at a time



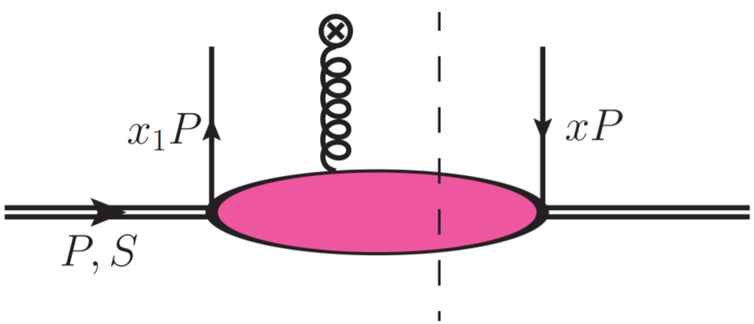
Twist 3: Quantum mechanical interference between one parton versus interacting with two partons at the same relative x

- Can describe spin-momentum correlations in the proton and in hadronization

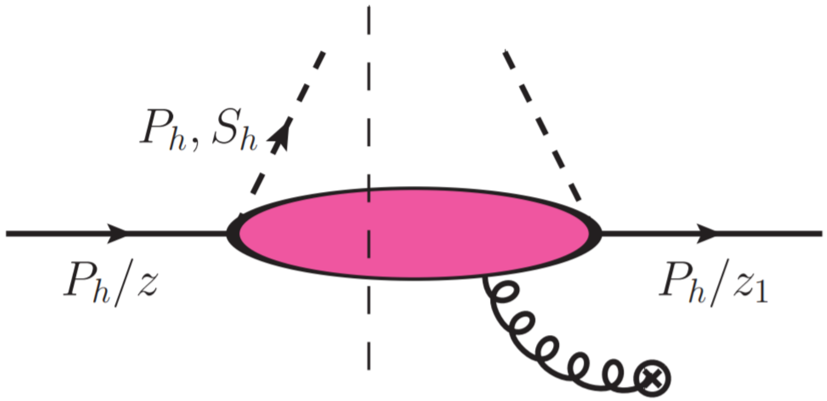
Twist 3 Functions

Multiparton correlations: quantum mechanical interference between scattering off of one versus two partons at the same x

- Quark-Gluon-Quark (qgq) Correlation Function: scattering off of quark and a gluon versus a single quark of the same flavor
- Three-gluon Correlation Function (ggg): two gluons versus one gluon



qgq Twist-3 Initial State



qgq Twist-3 Final State

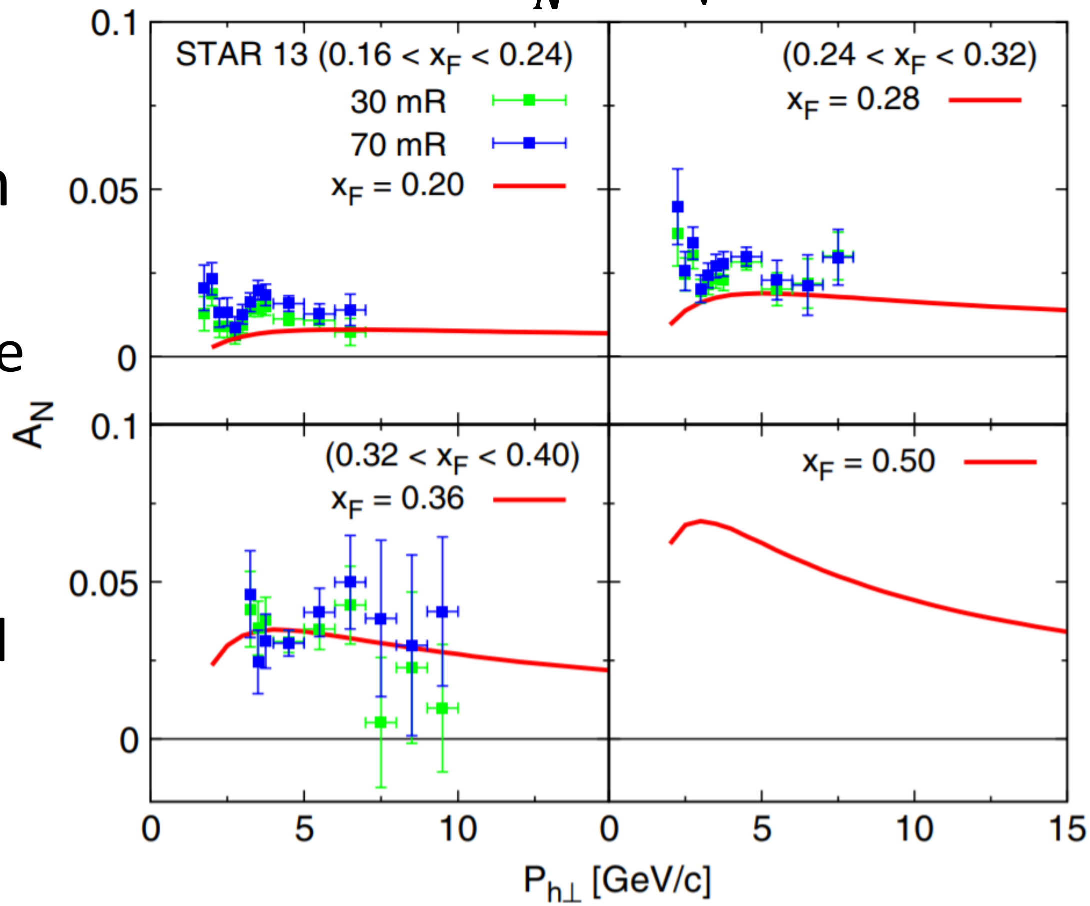
Daniel Pitonyak *International Journal of Modern Physics A* **31**, No. 32, 1630049 (2016)

Twist 3 Functions

Collinear: No explicit dependence on transverse momentum k_T

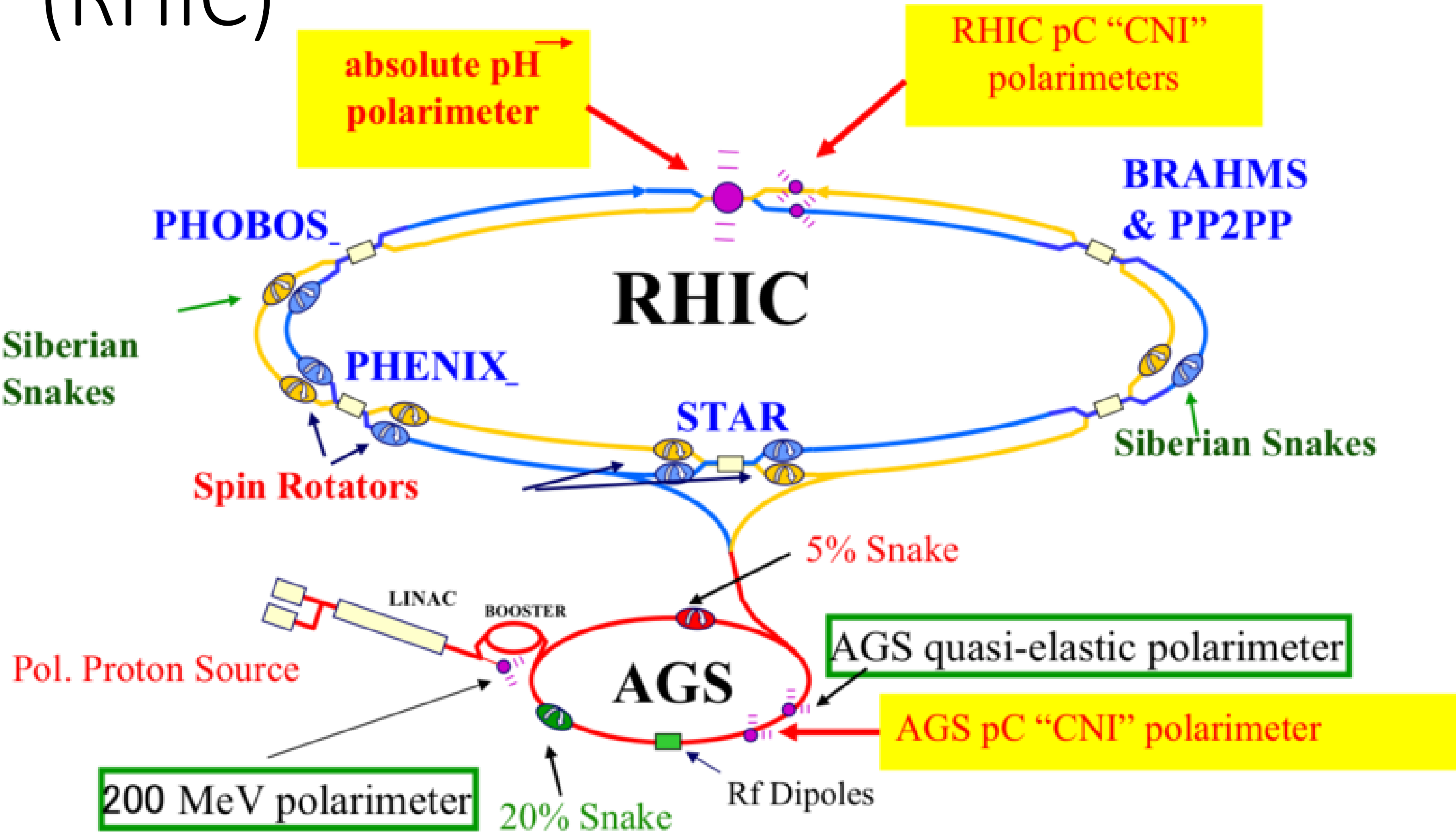
- Only need to be sensitive to a single scale: hard scale $Q \sim p_T$
- Related to k_T moments of twist-2 TMD PDFs and fragmentation functions
- At very large Q: $A_N \sim \frac{1}{Q}$

STAR forward $A_N^{\pi^0}$ for $\sqrt{s} = 500\ GeV$

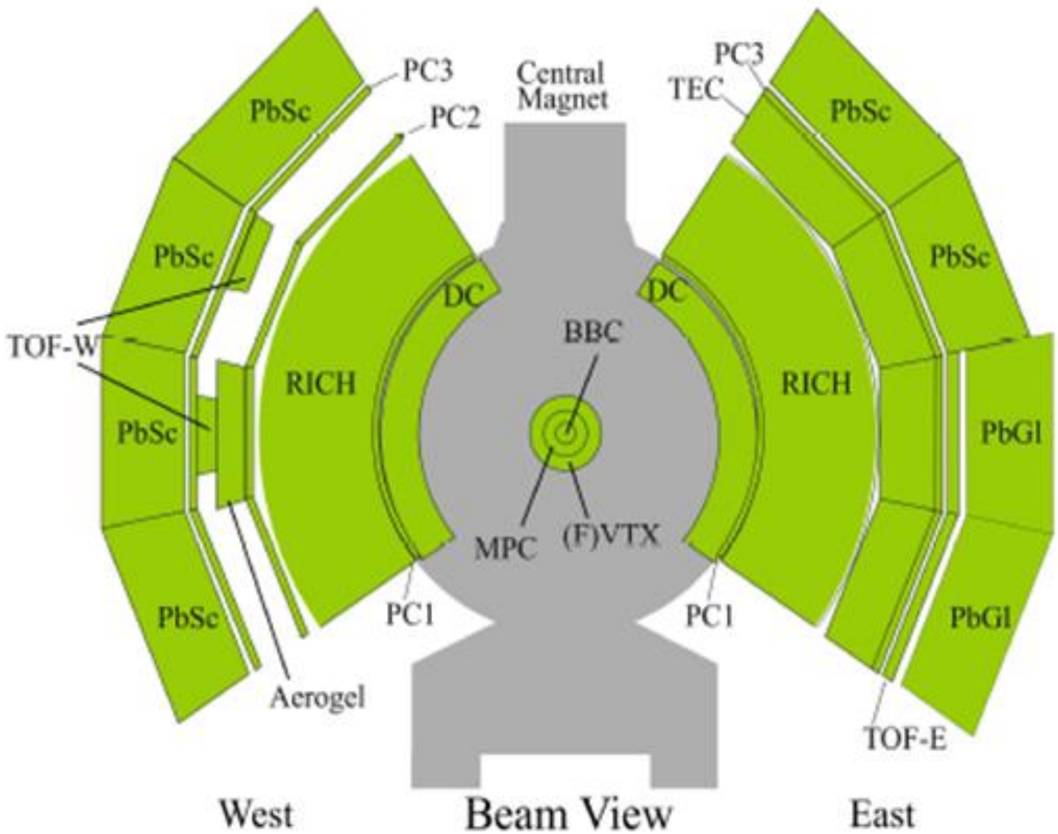


Koichi Kanazawa, Yuji Koike, Andreas Metz, and Daniel Pitonyak *Phys. Rev. D* **89**, 111501(R) (2014)

Relativistic Heavy Ion Collider (RHIC)

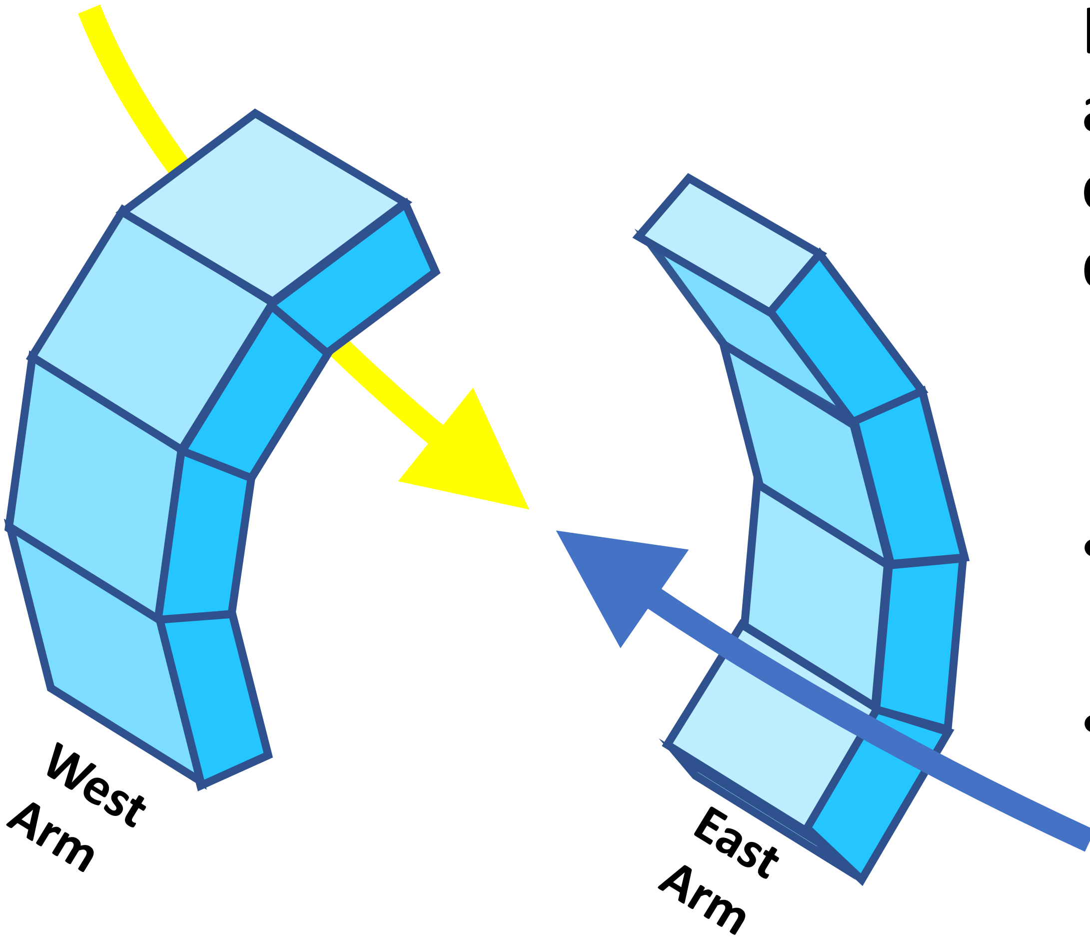


PHENIX detector



- PHENIX Central Arms
  - $\Delta\phi \sim \pi$
  - $|\eta| < 0.35$
- Electromagnetic Calorimeter used for $\eta \rightarrow \gamma\gamma$ detection
- Using Run 2015 data
  - $60\ pb^{-1}$ integrated luminosity
  - Mean polarization: 57%
  - Using the EMCal Rich Trigger that selects for high energy clusters

Midrapidity Transverse Single-Spin Asymmetries at PHENIX



Limited PHENIX acceptance, so integrate over one side of the detector at a time:

$$A_N^{raw} = \frac{N_L^{\uparrow} - R \cdot N_L^{\downarrow}}{N_L^{\uparrow} + R \cdot N_L^{\downarrow}}$$

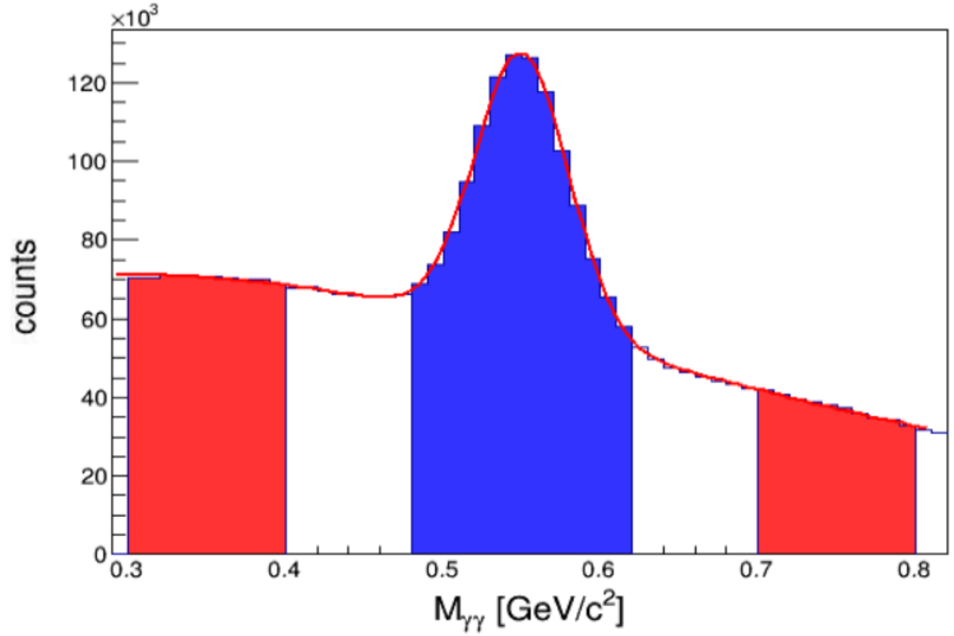
- $R = L^{\uparrow}/L^{\downarrow}$ is the relative luminosity
- Equivalent formula for the right side, but with a minus sign

Background Correction for $\eta \rightarrow \gamma\gamma$

$$A_N^{\eta} = \frac{A_N^{peak} - r\, A_N^{bg}}{1 - r}$$

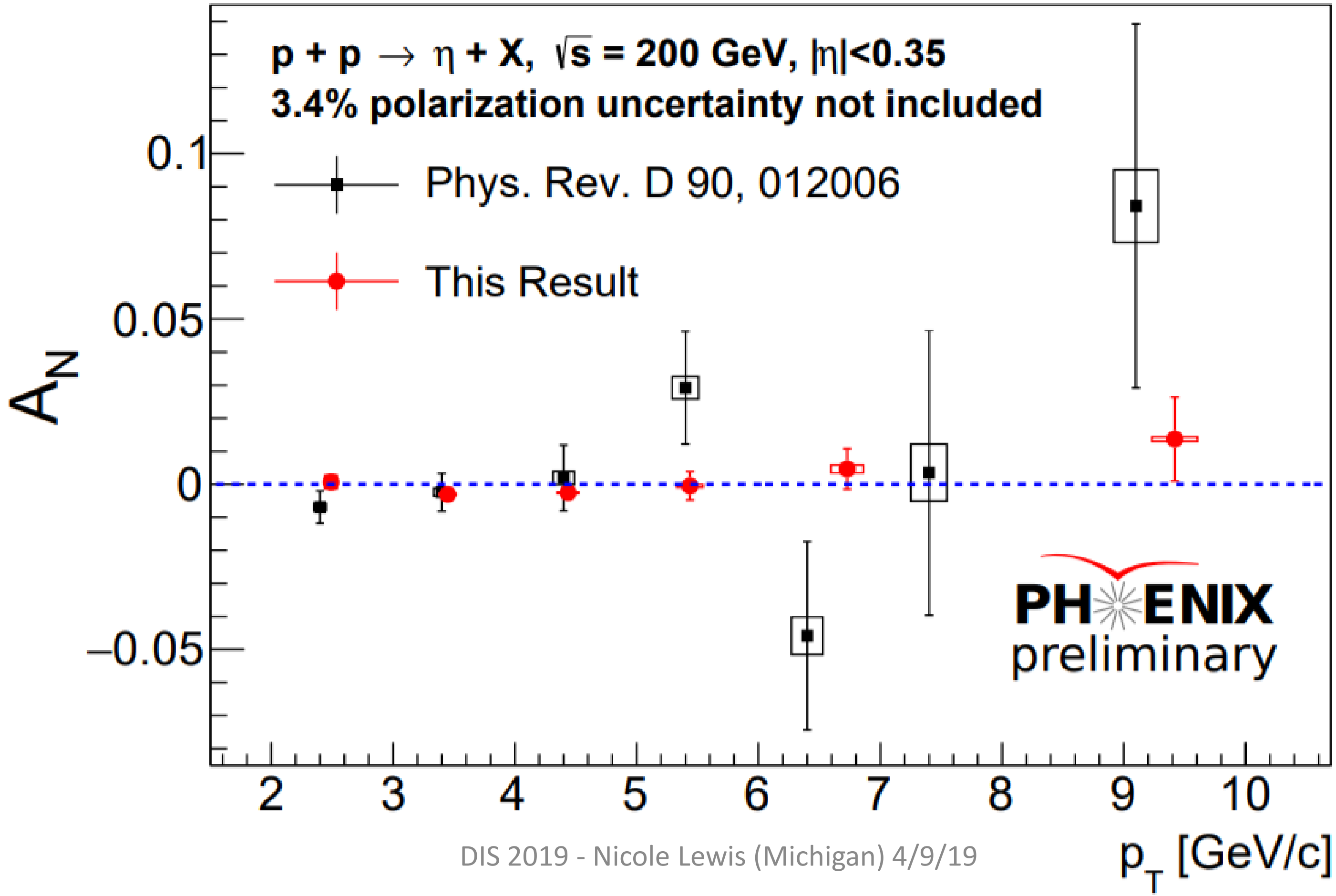
- Where $r = \frac{N_{bg}}{N_{sig}+N_{bg}}$ in the invariant mass peak region
- Peak:
  $480 < M_{\gamma\gamma} < 620\ MeV/c^2$
- Background:
  $300 < M_{\gamma\gamma} < 400\ MeV/c^2$
  $700 < M_{\gamma\gamma} < 800\ MeV/c^2$

Example invariant mass histogram for photon pairs in the West Arm with $4 < p_T < 5\ GeV/c$



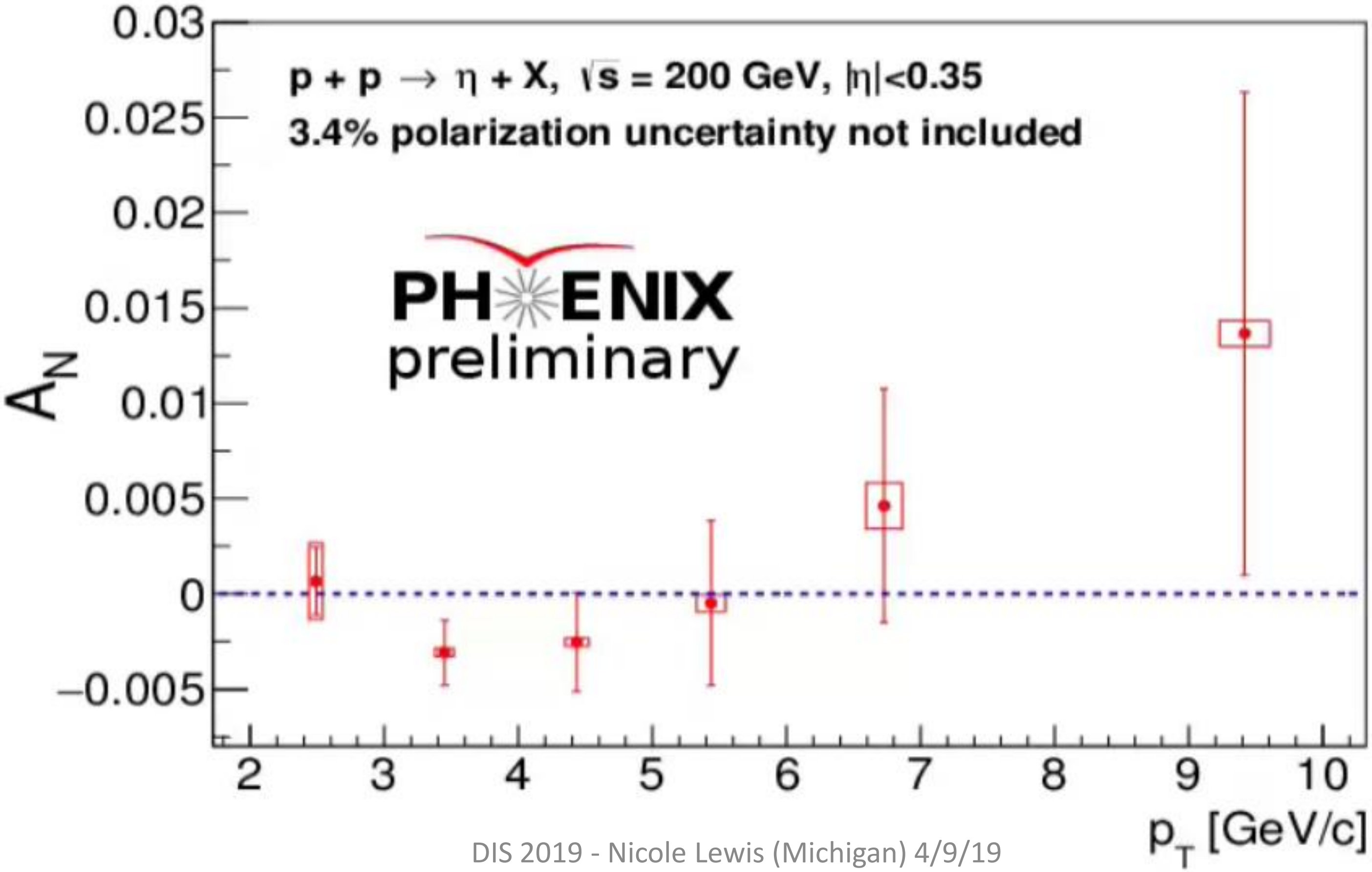
Results

About a factor of 3-4 increase in precision from previous PHENIX result



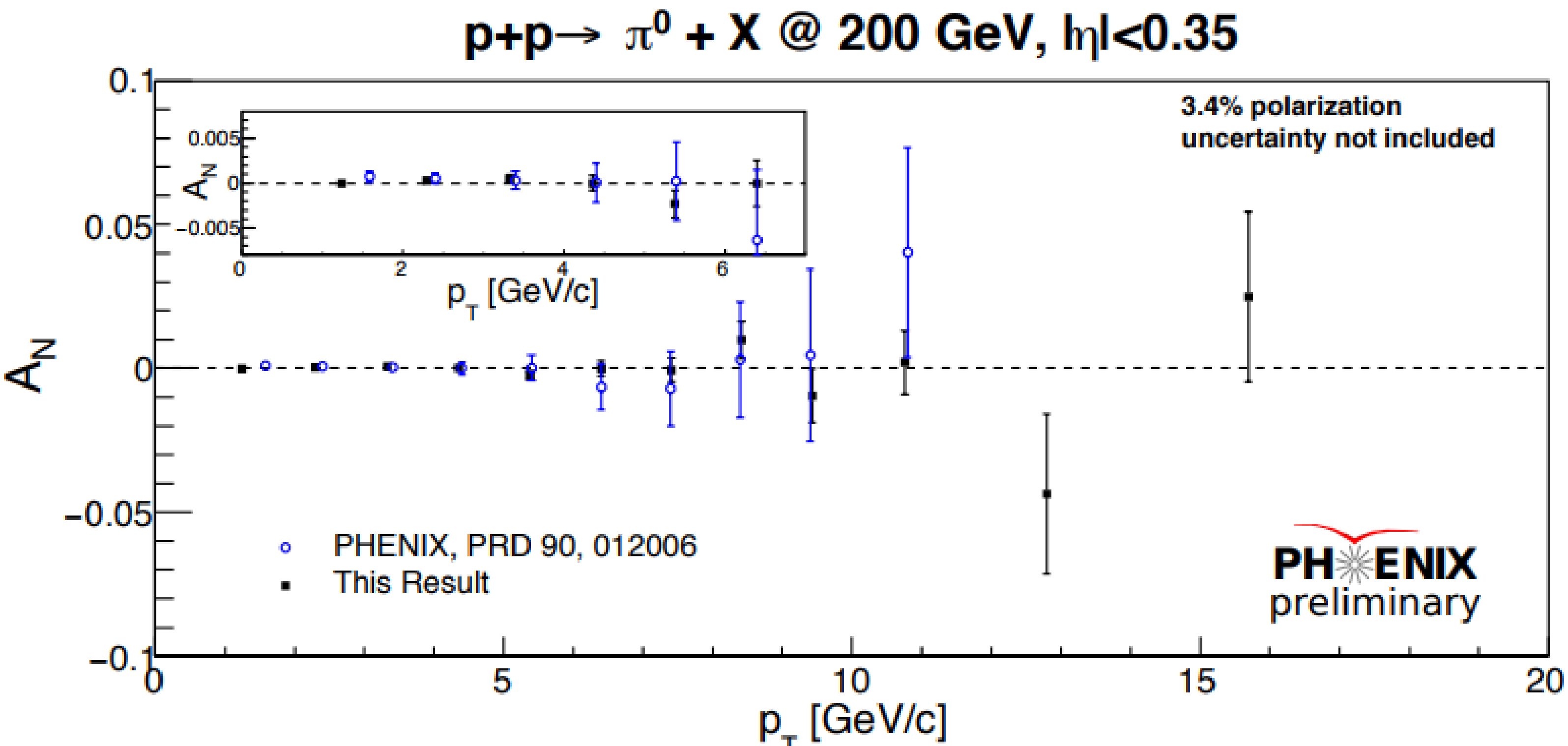
Results

Consistent with zero to within 0.005 at low p_T but may show a hint of a trend?



$A_N^{\pi^0}$ at midrapidity

Consistent with zero to within 10^{-4} at low p_T

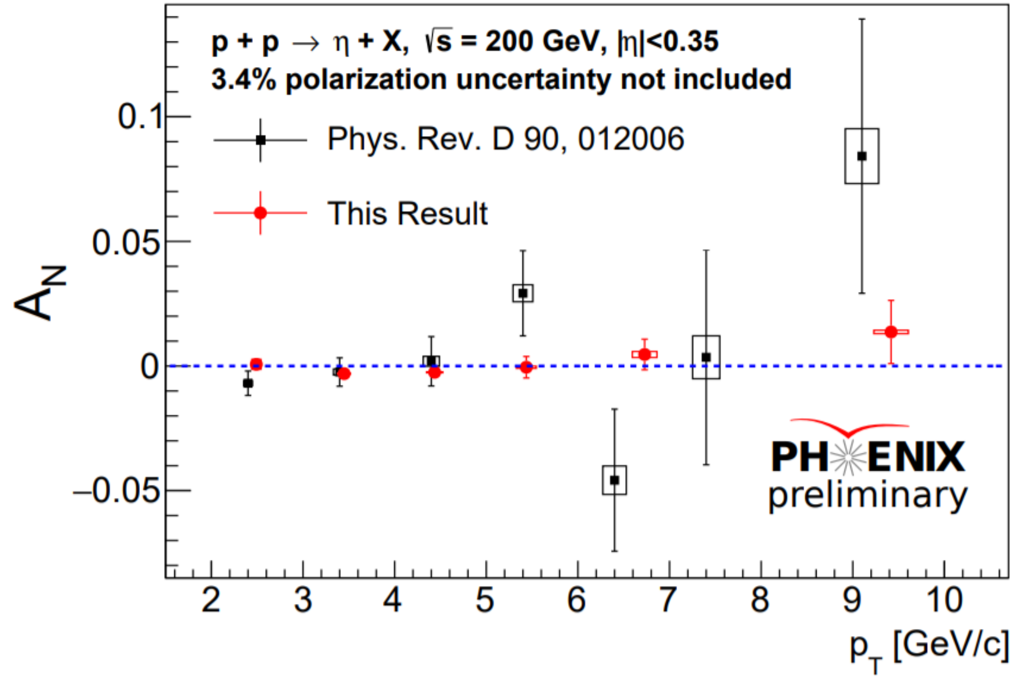


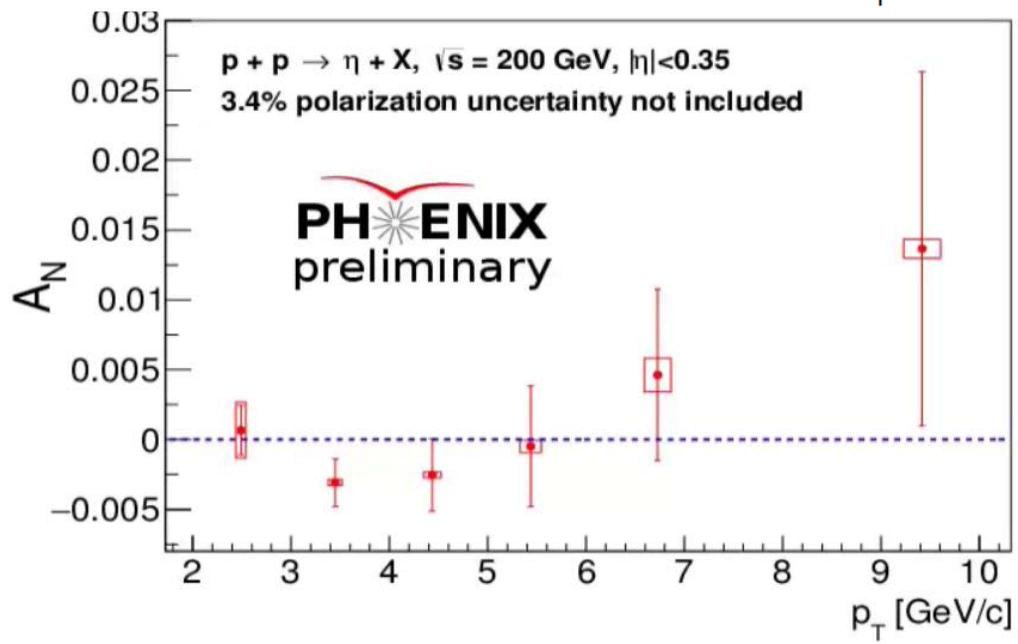
Comparing π^0 to η results may provide information on potential effects due to strangeness, isospin, or mass.

$$\pi^0 = \frac{1}{\sqrt{2}}\left(u\bar{u} - d\bar{d}\right) \quad \eta = \frac{1}{\sqrt{3}}\left(u\bar{u} + d\bar{d} + s\bar{s}\right)$$

Conclusion

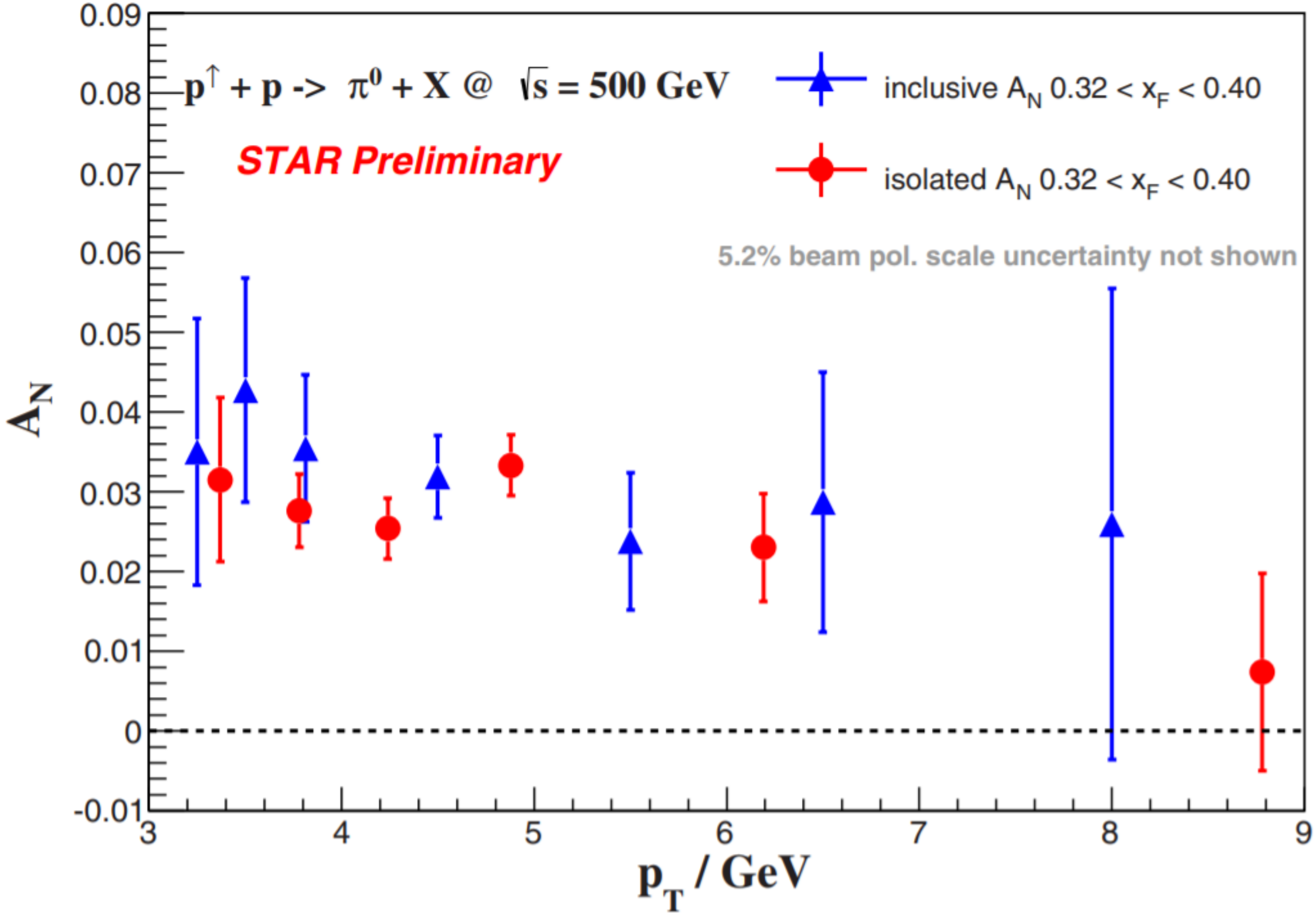
- TSSAs probe the parton dynamics in the proton as well as the process of hadronization
  - Twist 3 only require a single hard energy scale to be measured directly
- η A_N at midrapidity $\sqrt{s} = 200$ GeV shown
  - Factor of 3-4 higher precision than the previous PHENIX result
  - Consistent with zero
  - Sensitive to impact of strangeness to twist-3 functions





Back Up

TSSAs at Higher Energies

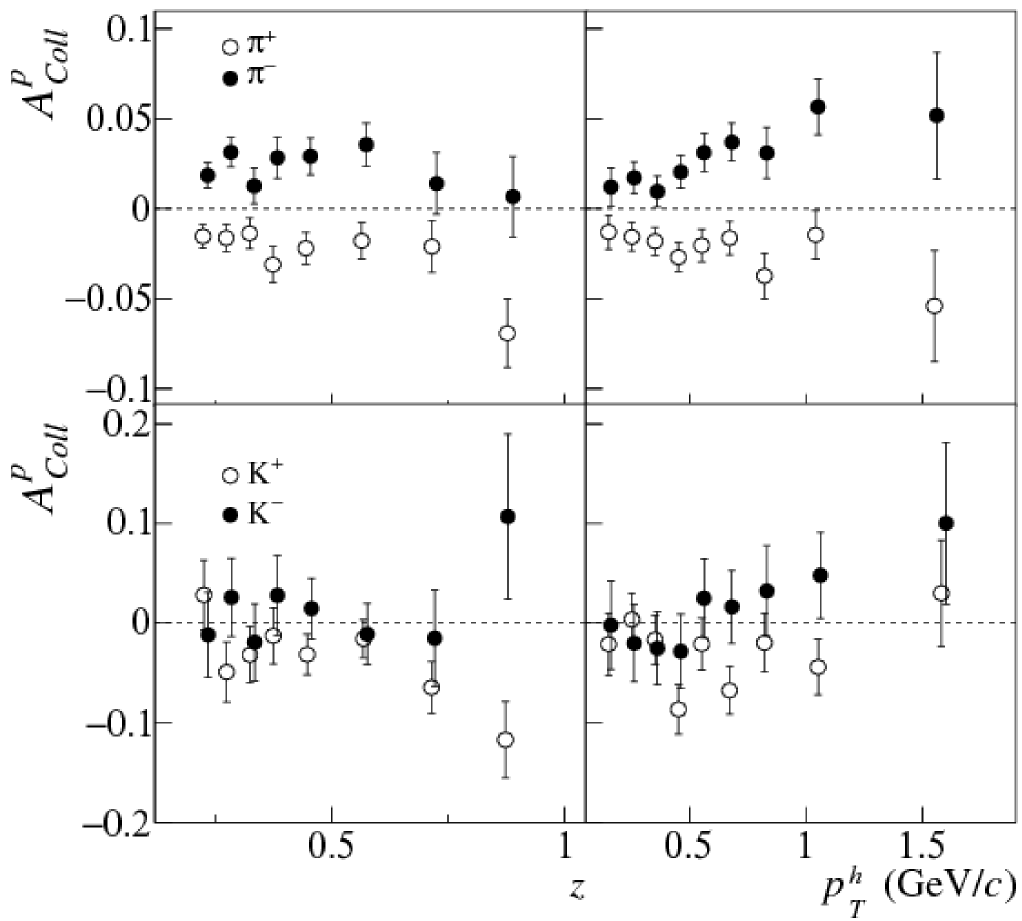


Yuxi Pan for the STAR Collaboration *International Journal of Modern Physics: Conference Series* **40**, 1660037 (2016)

Collins Asymmetry in SIDIS

- Correlation between quark transverse spin and unpolarized hadron transverse momentum
- Some indication that the $K^{\pm}$ Collins asymmetry might be larger than the $\pi^{\pm}$ asymmetry, but not statistically significant

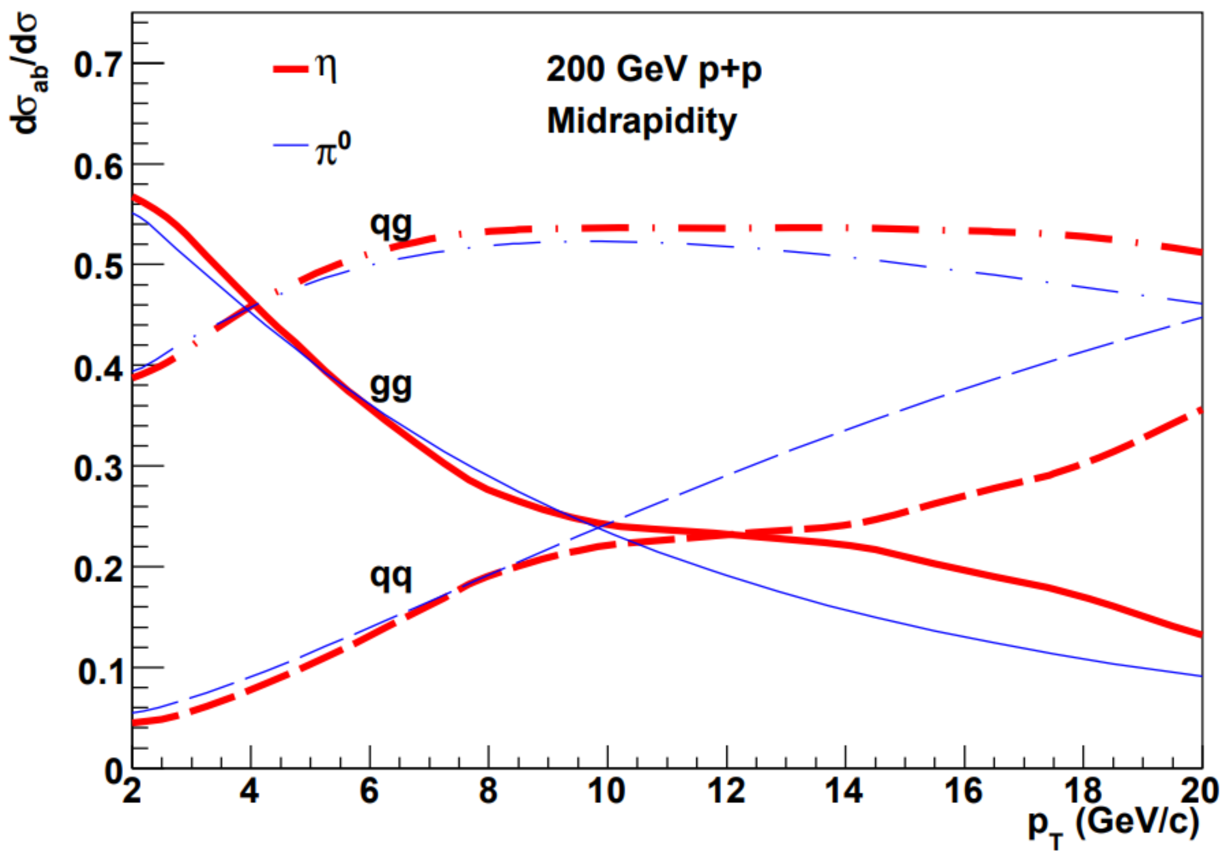
Transversity ⊗ Collins Asymmetry



(COMPASS Collaboration) *Phys.Lett. B* **744** (2015) 250-259

Partonic Contributions

- At low p_T dominated by $gg \rightarrow gg$ and $gg \rightarrow q\bar{q}$
- $qg \rightarrow qg$ fraction increases with p_T
- $q\bar{q} \rightarrow q\bar{q}$ dominates at very high p_T, but that is beyond the scope of this measurement



(PHENIX Collaboration) *Phys. Rev. D* **83**, 032001 (2011)

Systematic Studies

- Alternative A_N formula: Square Root formula

$$A_N^{raw} = \frac{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}$$

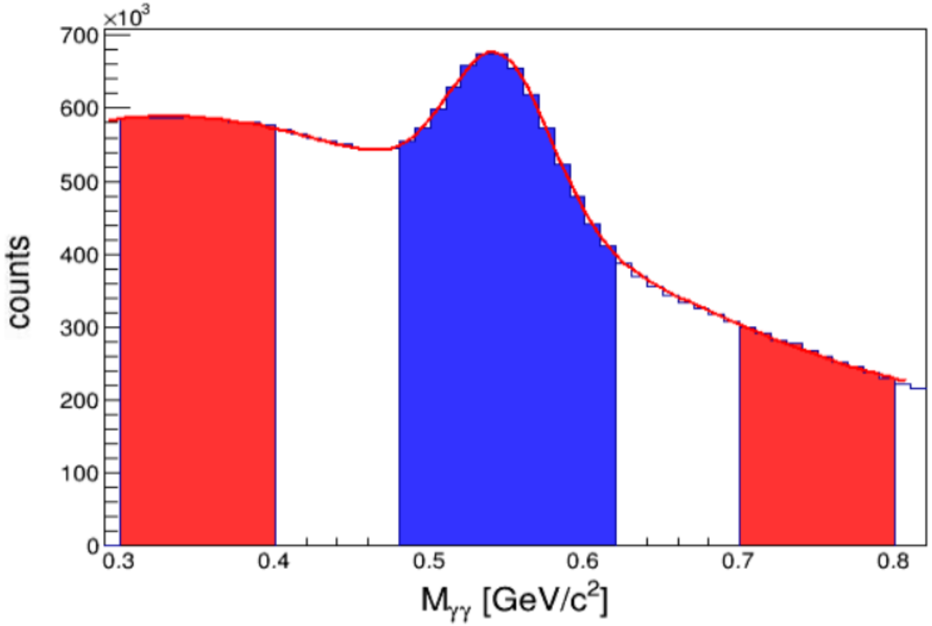
- $\sin\phi$ modulation cross check:

$$A_N^{raw} \sin\phi_s = \frac{N^{\uparrow}(\phi_s) - RN^{\downarrow}(\phi_s)}{N^{\uparrow}(\phi_s) + RN^{\downarrow}(\phi_s)}$$

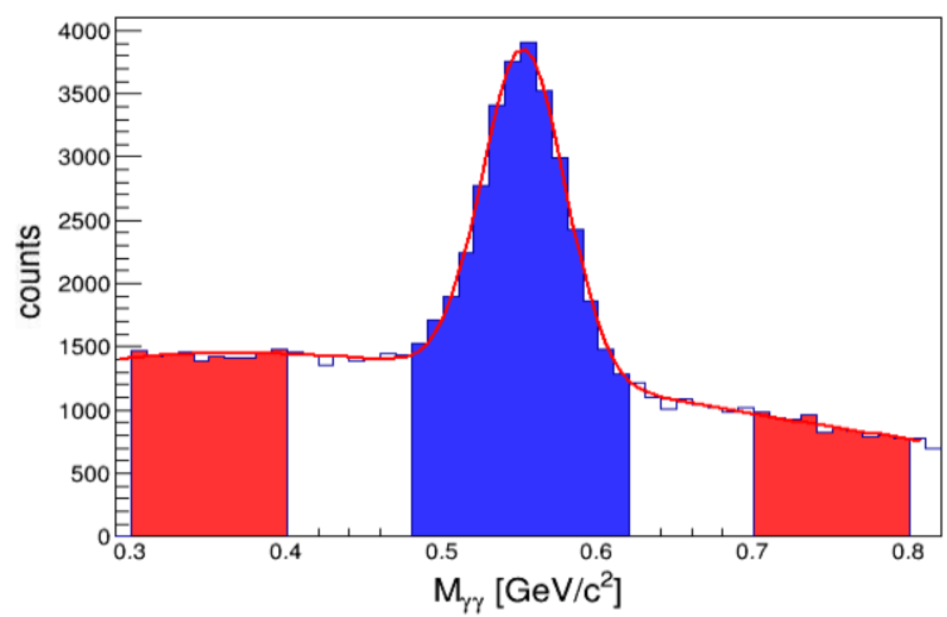
- Yellow vs Blue beam asymmetry
    - Both beams have alternating transverse polarization → consider one beam polarized at a time and average over the polarization direction of the other
    - Two statistically independent measurements
    - Final measurement is the weighted average of these two results

Invariant Mass Spectrum at Different p_T

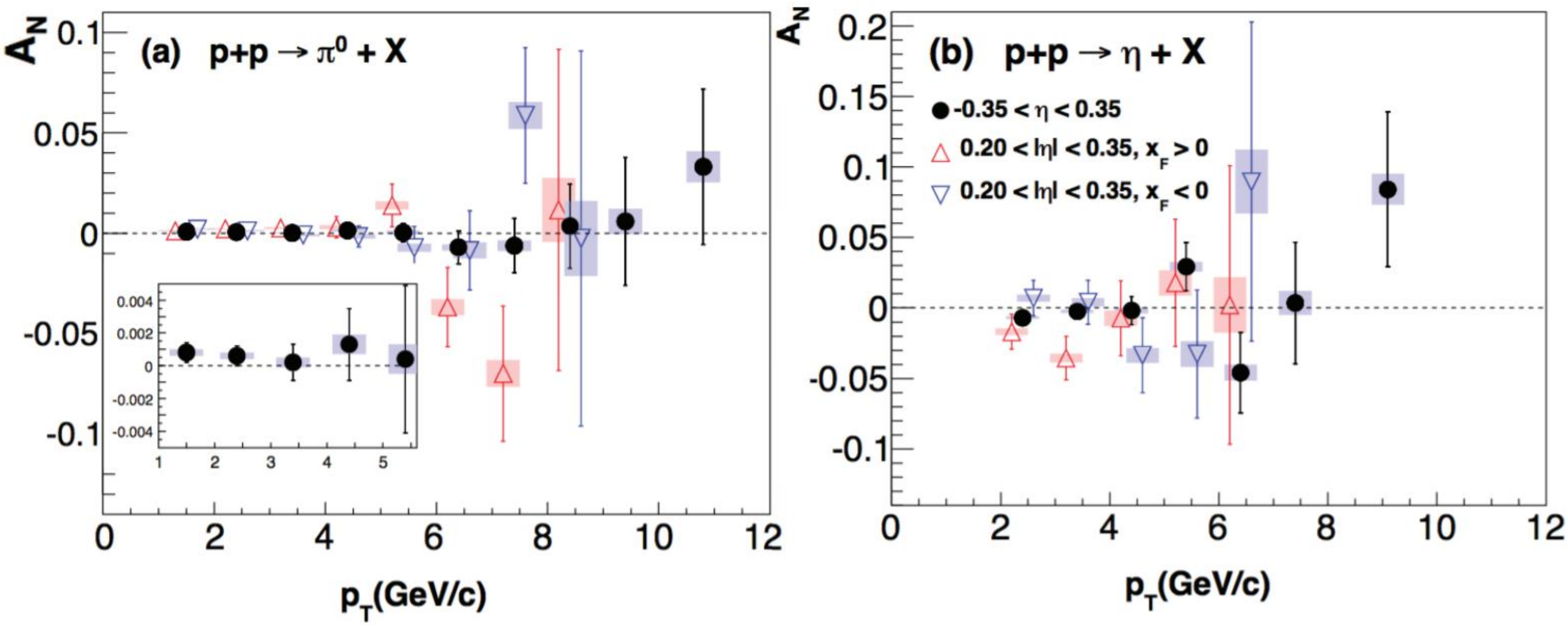
Photon pairs in the West Arm with $2 < p_T < 3\ GeV$



Photon pairs in the West Arm with $8 < p_T < 15\ GeV$

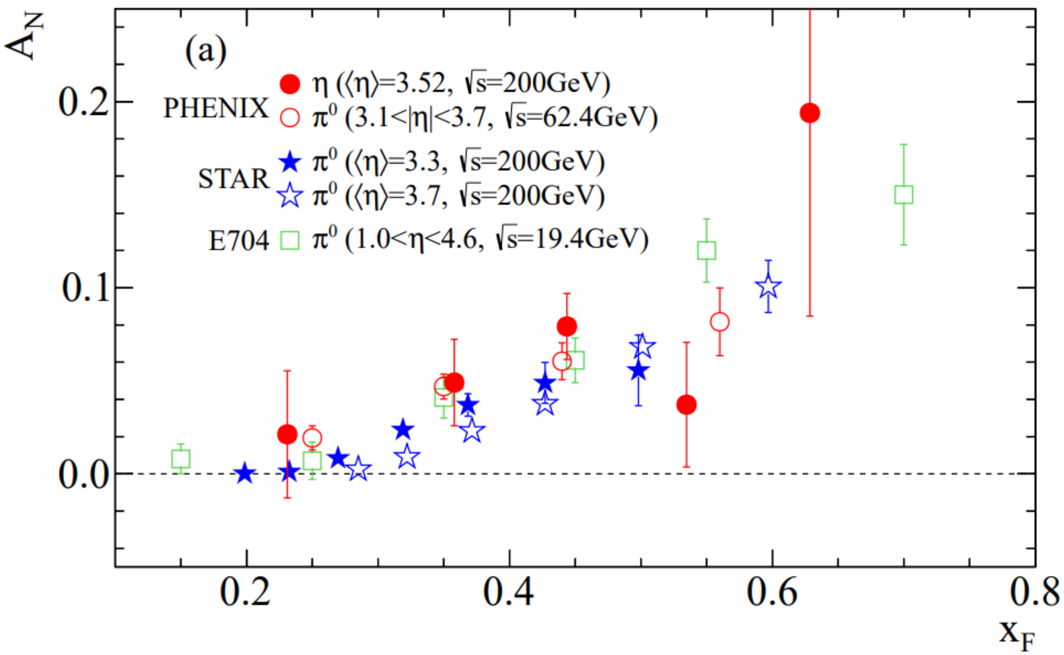


Previous PHENIX $A_N^{\pi^0}$ and A_N^{η} Result

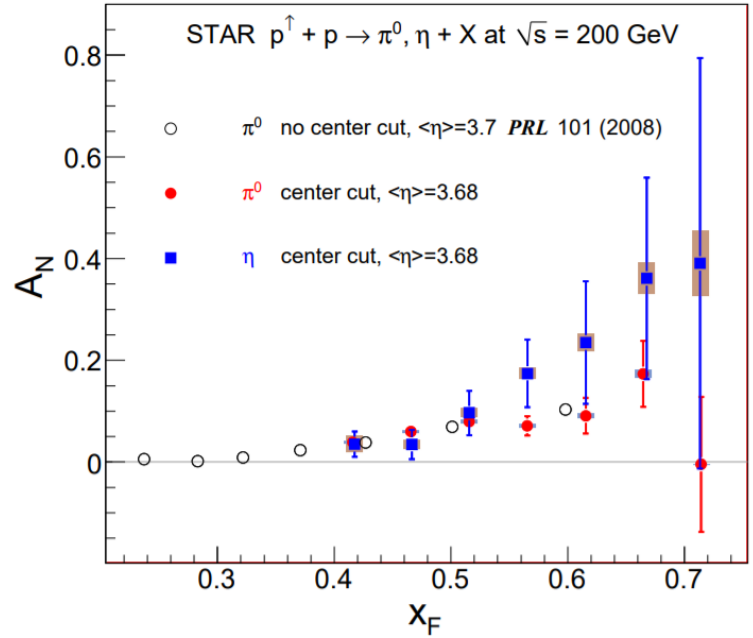


(PHENIX Collaboration) *PRD* **90**, 012006 (2014)

Comparing **forward** A_N^{η} to forward $A_N^{\pi^0}$



(PHENIX Collaboration)
PRD **90**, 012006 (2014)



(STAR Collaboration)
PRD **86**, 051101(R) (2012)

$A_N^{\pi^0}$ in $p^\uparrow + A$