Transverse Single-Spin Asymmetries of Midrapidity Eta Mesons at PHENIX

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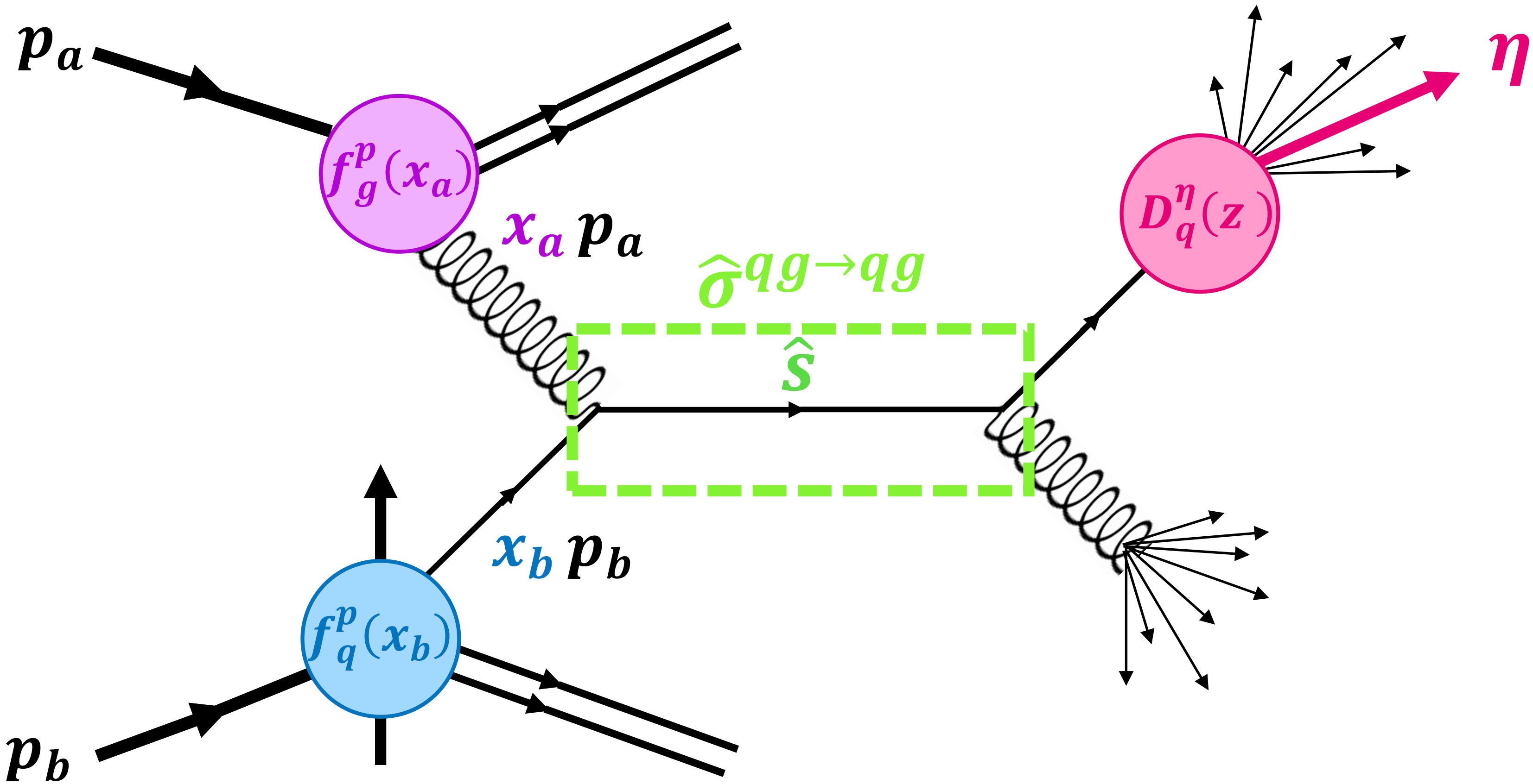
23rd International Spin Symposium

9/11/18

U.S. DEPARTMENT OF ENERGY
Office of Science

UNIVERSITY OF MICHIGAN

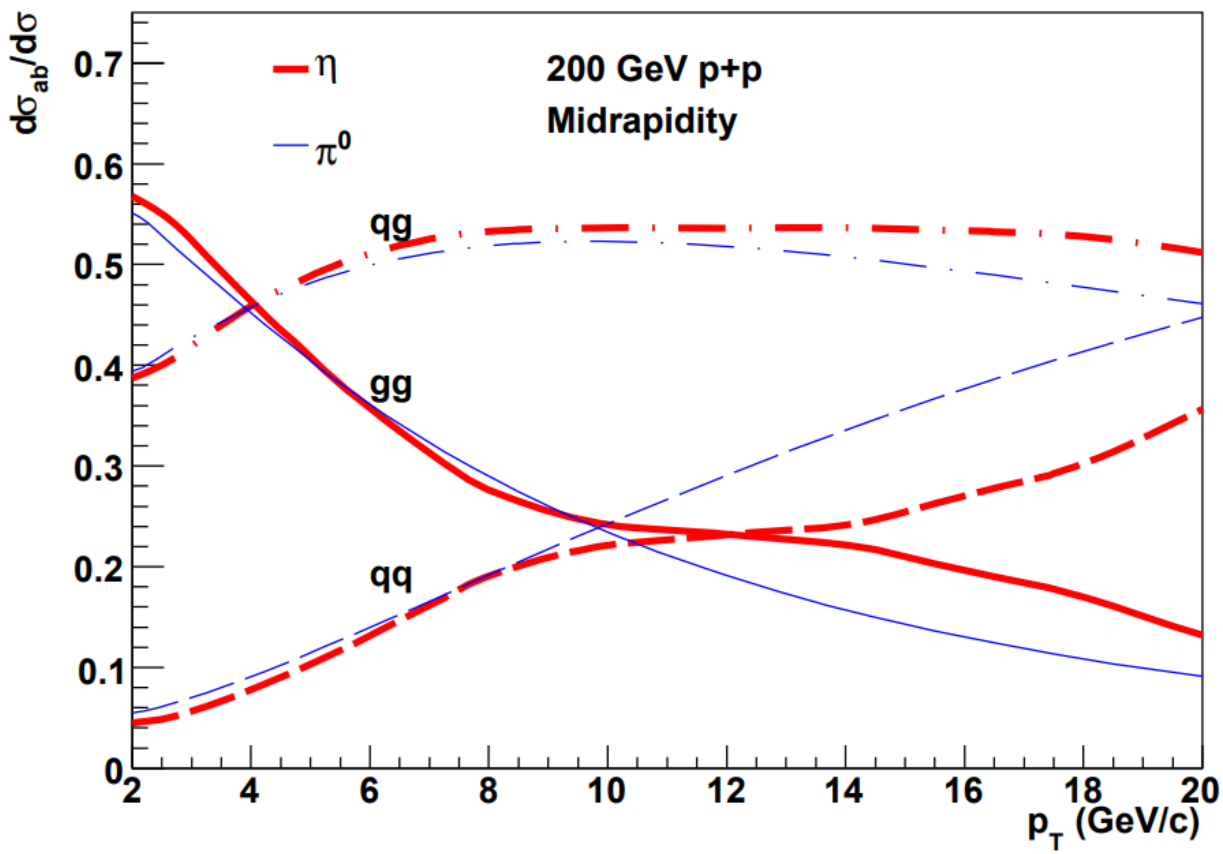
Initial- and Final- State Nonperturbative Effects



$$\sigma(p\,p \to \eta\, X) \propto f_g^{p_a} \otimes f_q^{p_b} \otimes \hat{\sigma}^{qg\to qg} \otimes D_q^\eta$$

Partonic Contributions

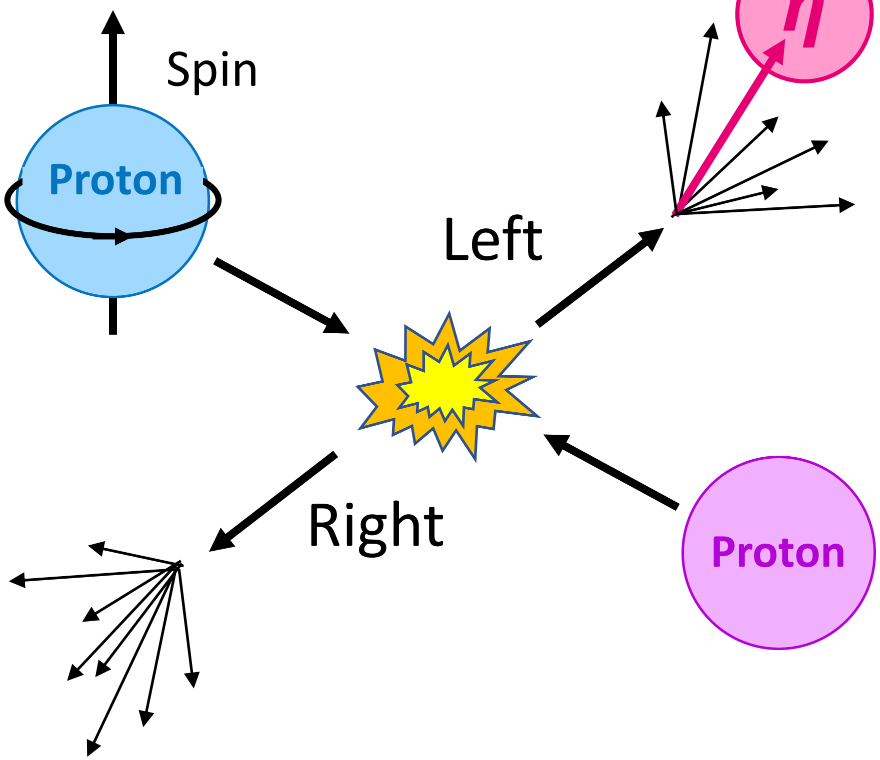
- At low p_T dominated by $gg \rightarrow gg$ and $gg \ \rightarrow q\bar{q}$
- $qg \rightarrow qg$ fraction increases with p_T
- $q\bar{q} \rightarrow q\bar{q}$ dominates at very high p_T, but that is beyond the scope of this measurement



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

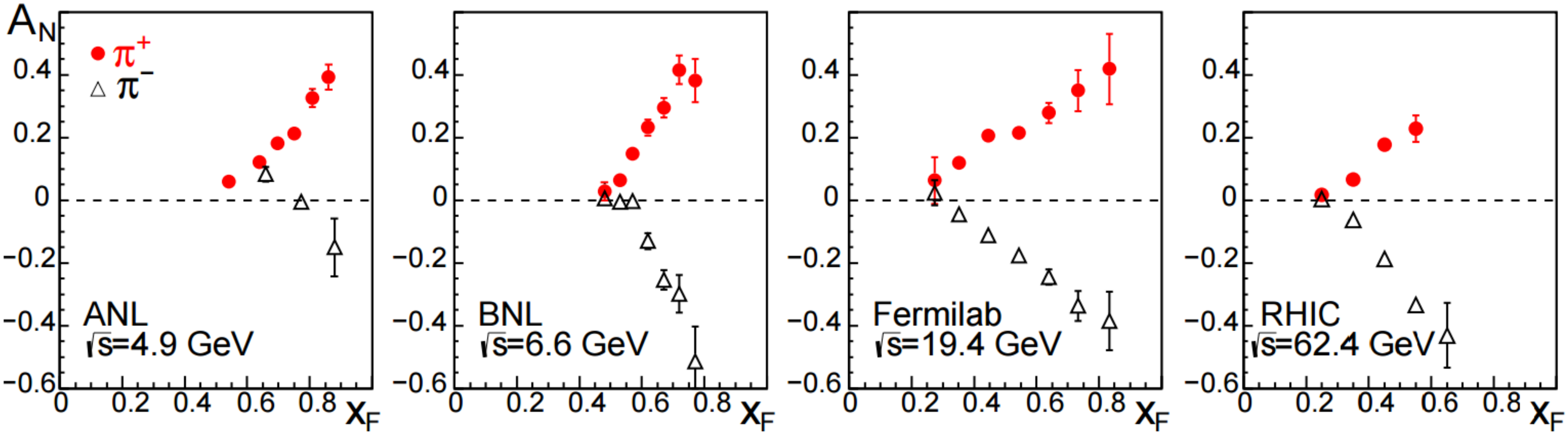
Transverse Single-Spin Asymmetries (TSSAs)

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



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

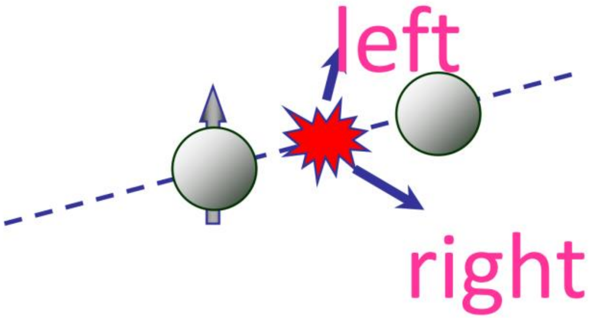
Transverse Single-Spin Asymmetries



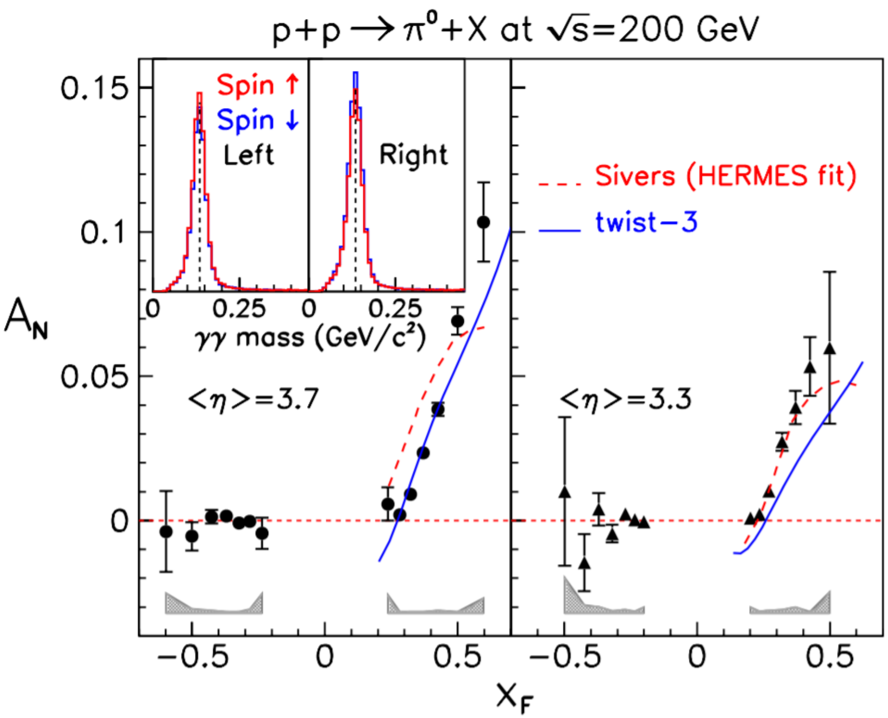
C. A. Aidala, S.D. Bass, D. Hasch, and G. K. Mallot, Rev. Mod. Phys. **85** 655 (2013).

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

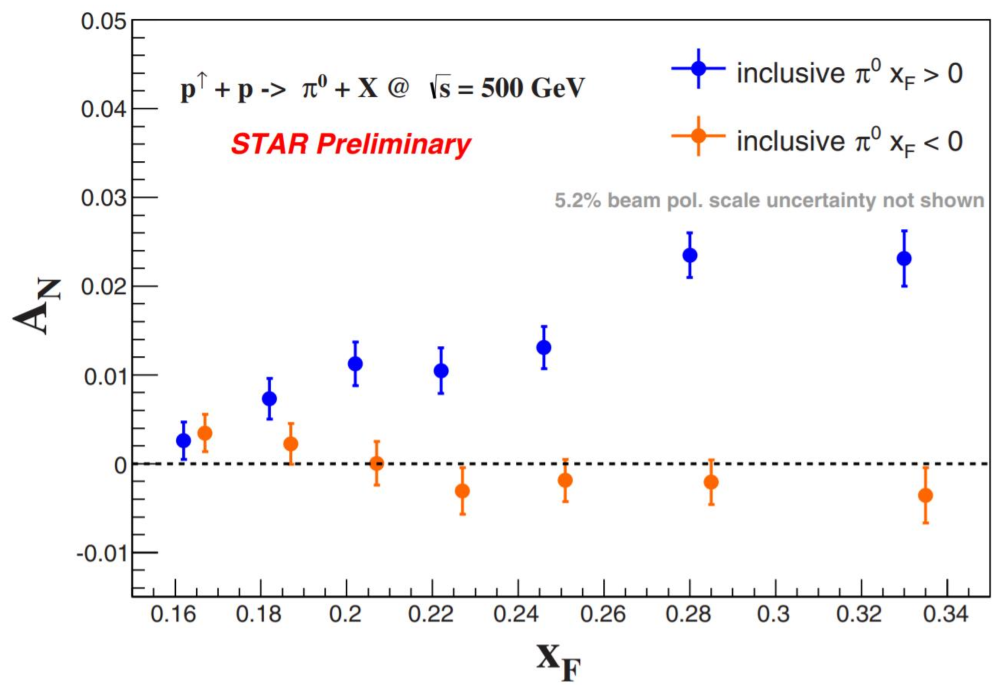
$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$



TSSA at Higher Energies



(STAR Collaboration) *Phys. Rev. Lett.* **101**, 222001 (2008)



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

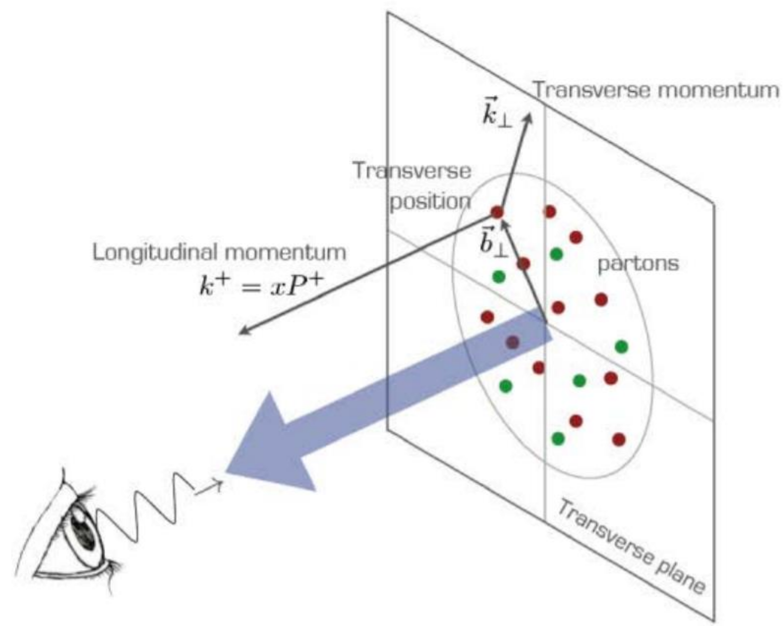
Transverse Momentum Dependent Nonperturbative Functions

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

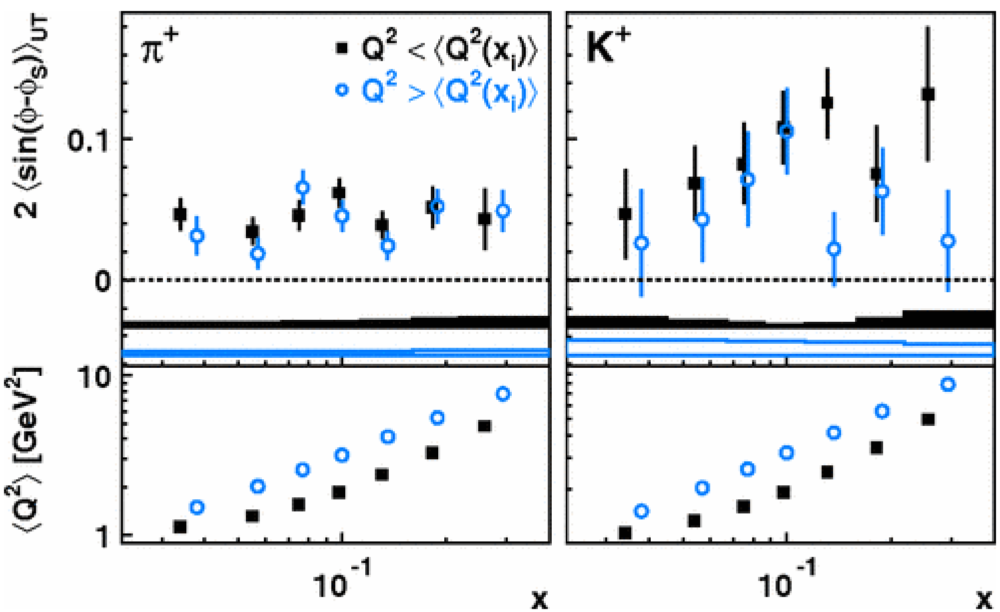
Transverse Momentum Dependent (TMD): functions explicitly depend on the nonperturbative transverse momentum k_T

- 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

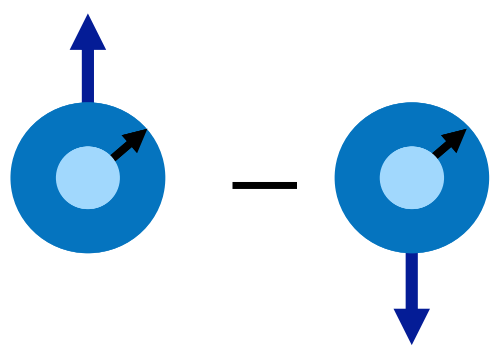


Initial State Example: Sivers TMD PDF



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

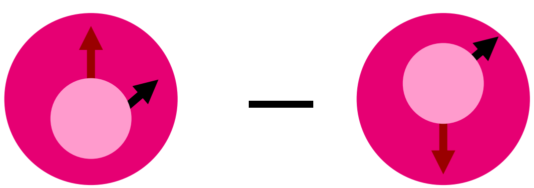
$$f_{1T}^{\perp} =$$



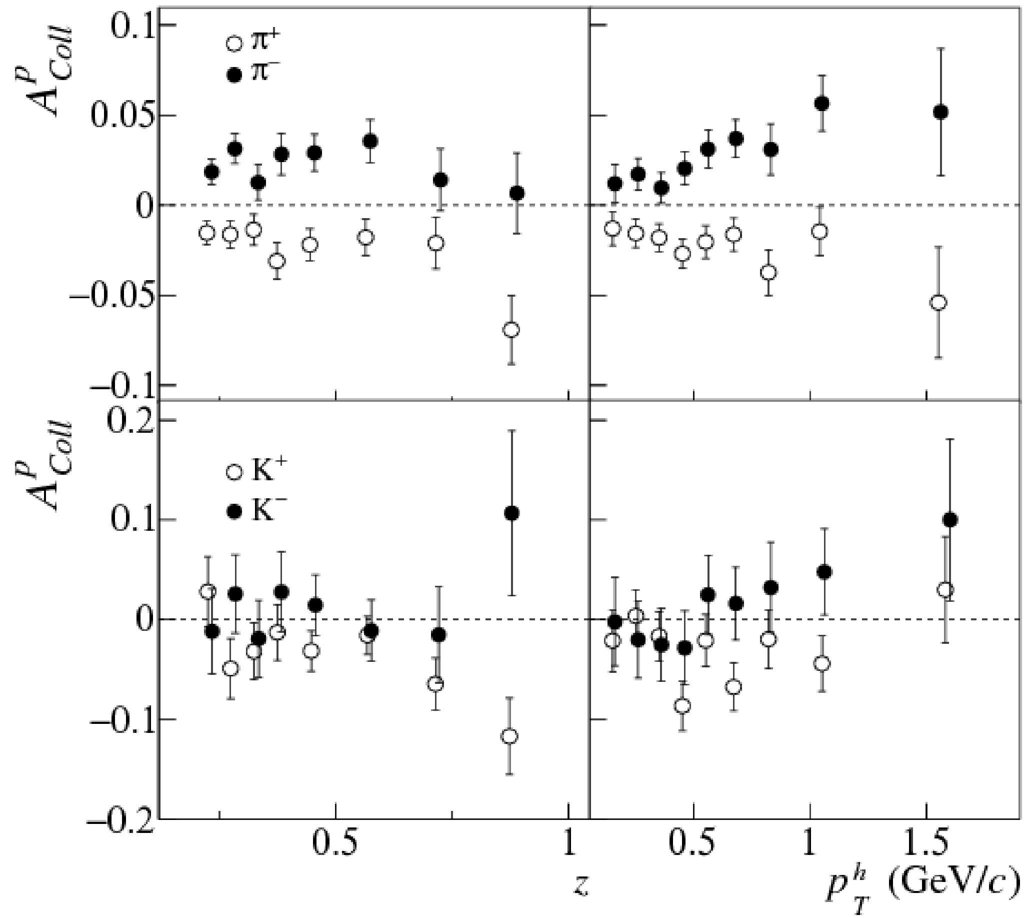
- Correlation between transverse spin of the proton and the transverse momentum of a quark or a gluon
- PT-odd (naïve-time-reversal-odd)
- In SIDIS possible to measure both soft and hard scale and to isolate particular TMD functions
- Some indication that the Sivers asymmetry slightly larger for K^+ than for π^+? Larger spin-momentum correlations for strange quarks in the proton?

Final State Example: Collins TMD FF

- Correlation between quark transverse spin and unpolarized hadron transverse momentum
- Chiral odd → needs coincide with another chiral odd function like the Transversity PDF or another Collins FF

$H_1^{\perp} =$ 

Transversity ⊗ Collins Asymmetry from SIDIS

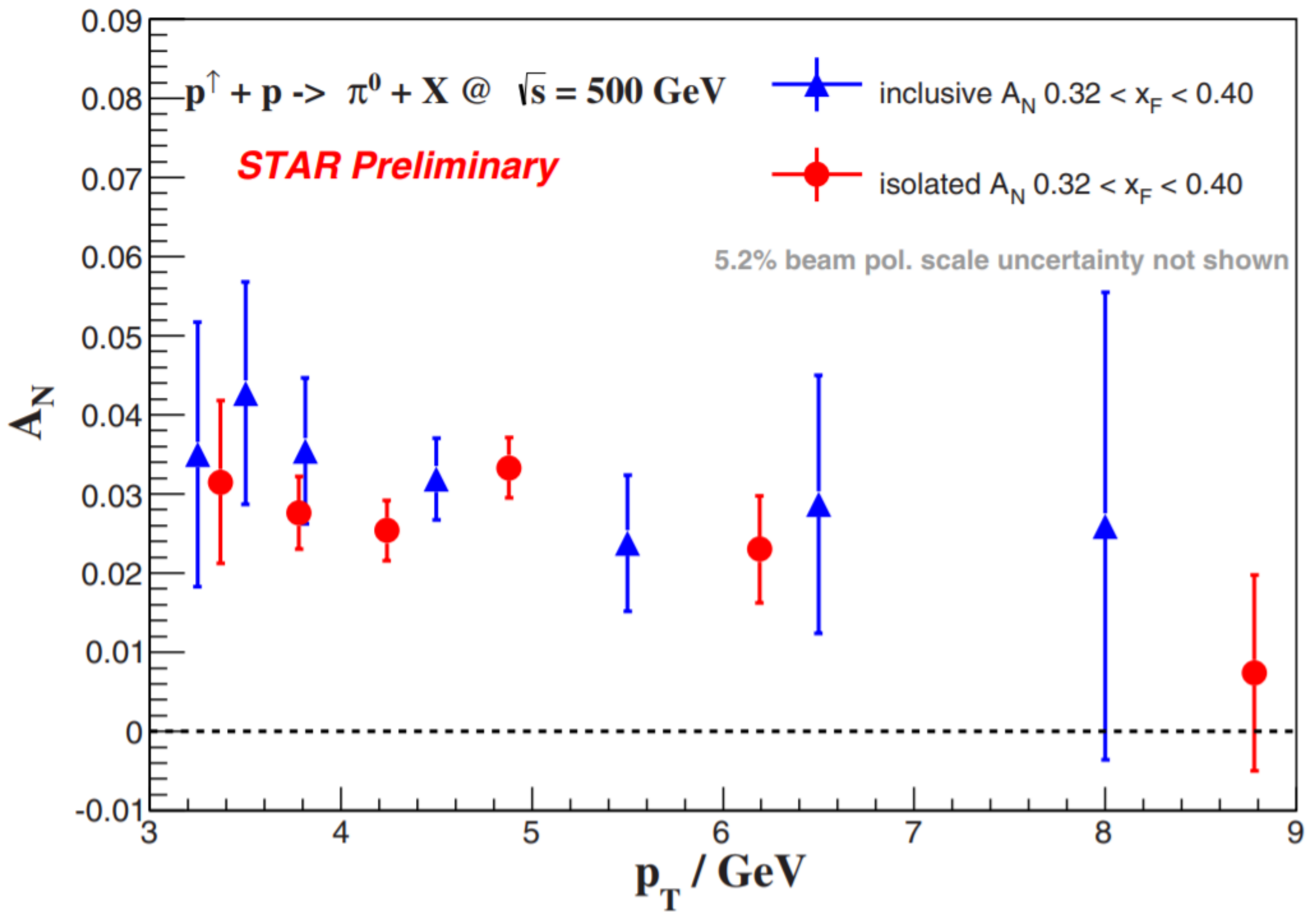


(COMPASS Collaboration) *Phys.Lett. B* **744** (2015) 250-259

TSSAs in $p^{\uparrow} + p$

Large TSSA in $p^{\uparrow} + p \rightarrow h + X$

- Uncovered the need for a TMD framework
- Not sensitive to soft scale k_T $\rightarrow$ Only one (hard) scale available: p_T

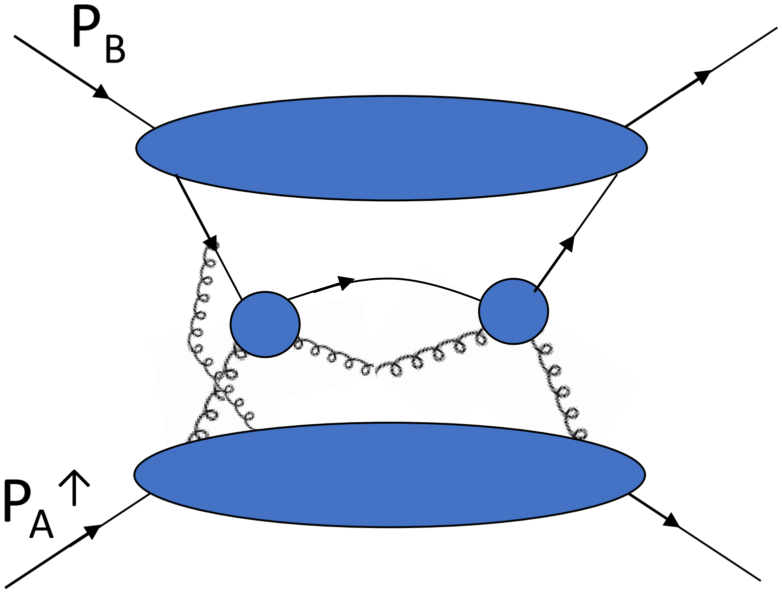


Yuxi Pan for the STAR Collaboration *International Journal of Modern Physics: Conference Series* **40**, 1660037 (2016)

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

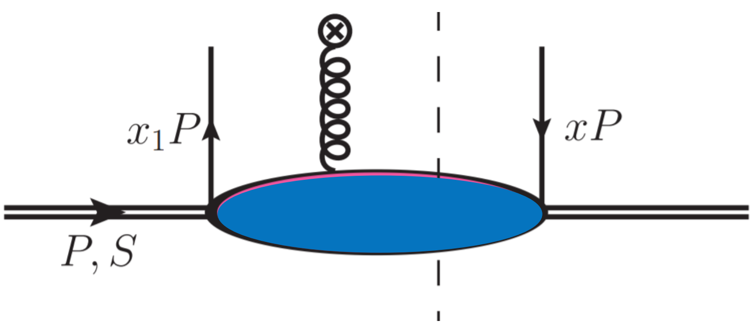


Twist 3: Quantum mechanical interference between one parton versus interacting with two partons at the same relative x

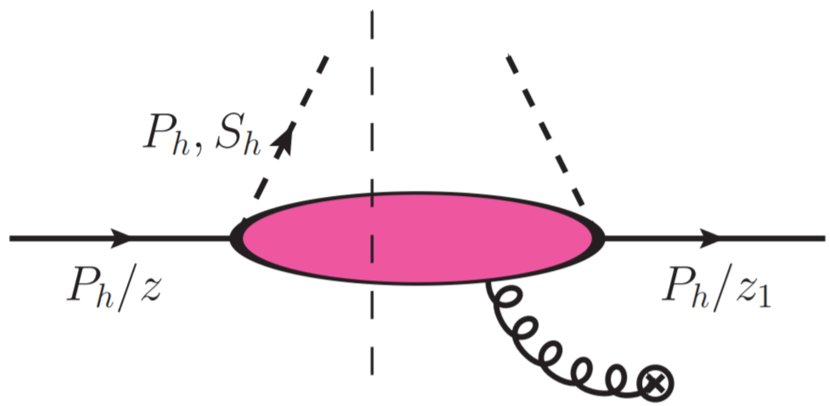
- Can describe spin-momentum correlations in the proton and in hadronization

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

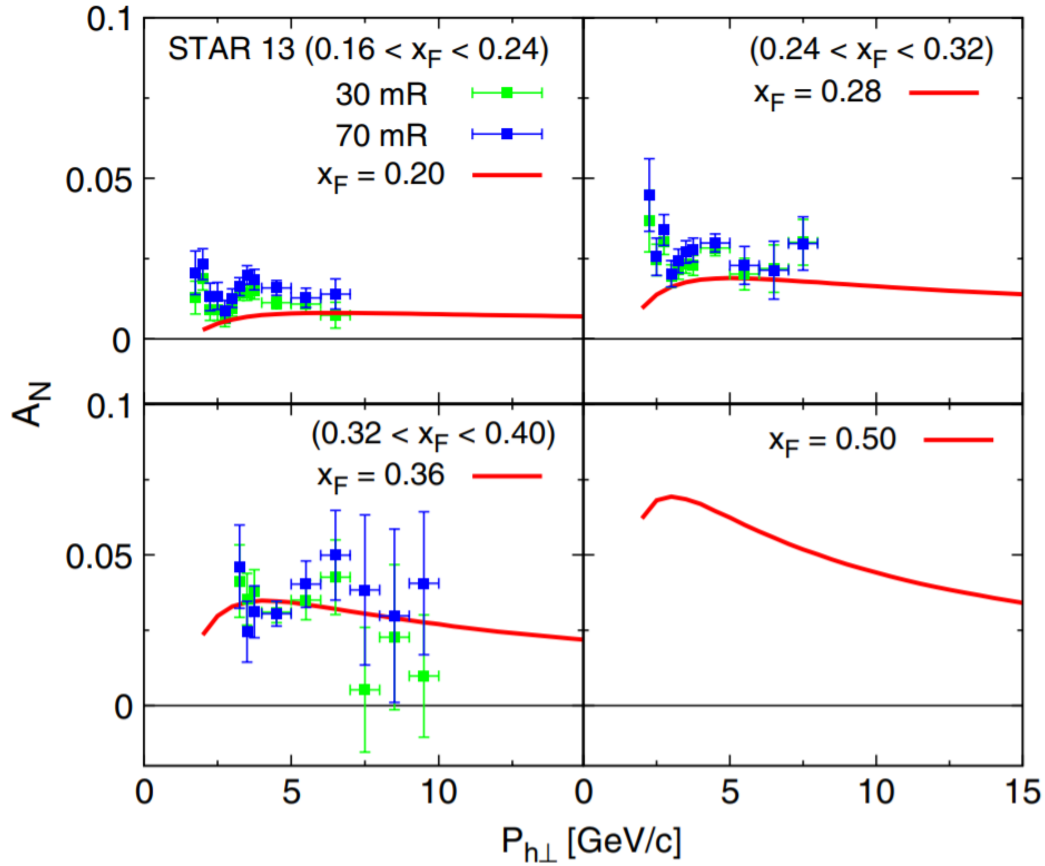
Daniel Pitonyak *International Journal of Modern Physics A* **31**, No. 32, 1630049 (2016)

Twist 3 Functions

Collinear: No explicit dependence on transverse momentum k_T

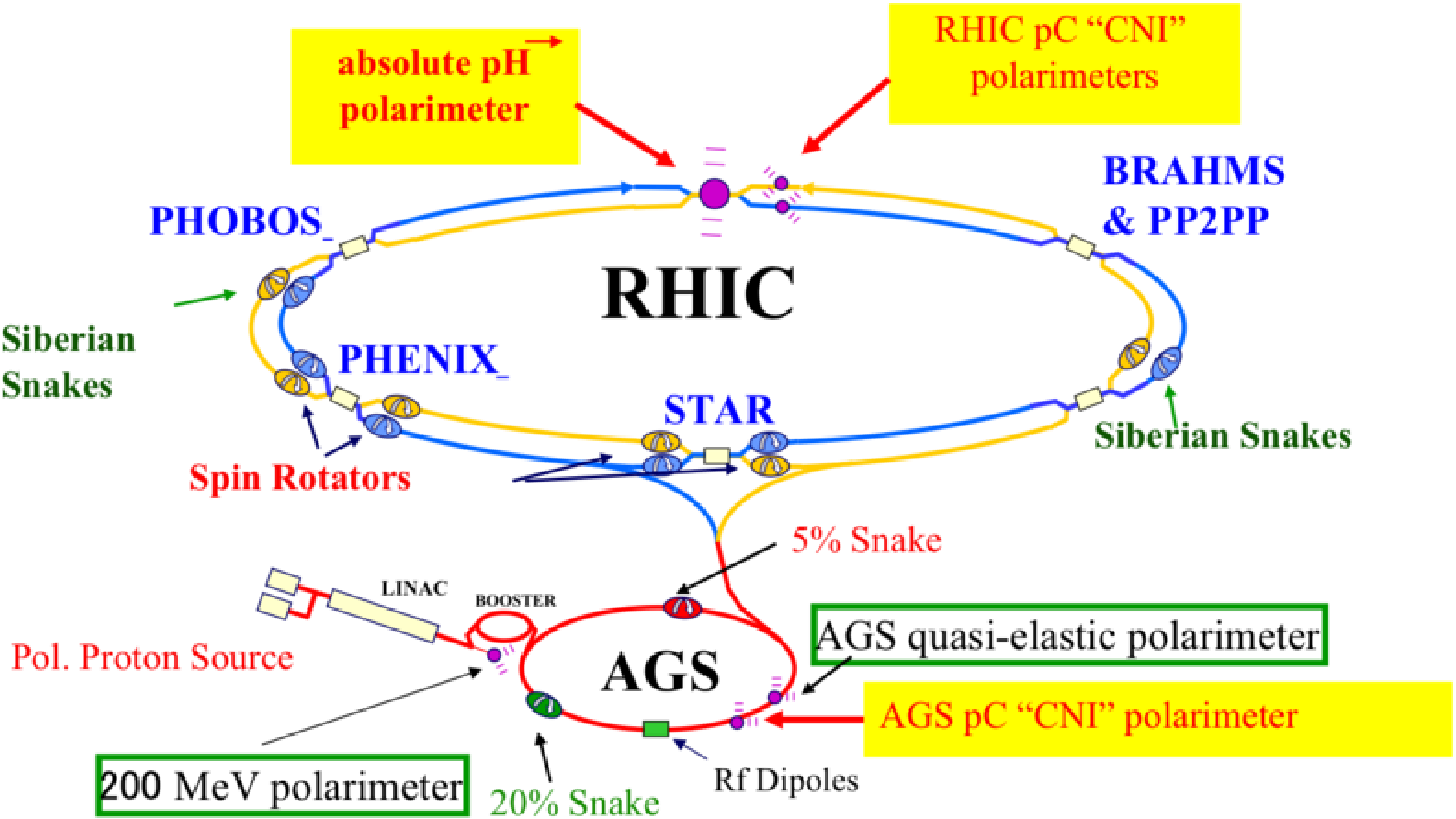
- Only need to be sensitive to a single scale: hard scale $Q \sim p_T$
- Related to k_T moments of twist-2 TMD PDFs and fragmentation functions
- At very large Q: $A_N \sim \frac{1}{Q}$

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

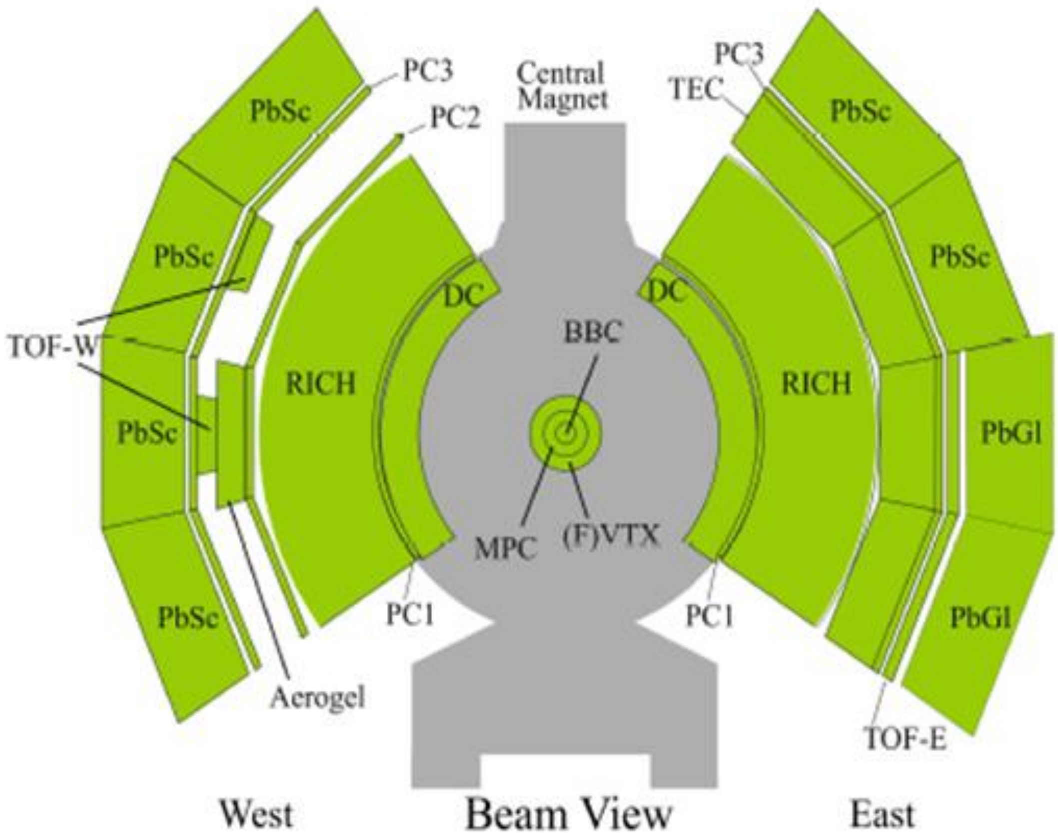


Koichi Kanazawa, Yuji Koike, Andreas Metz, and Daniel Pitonyak *Phys. Rev. D* **89**, 111501(R) (2014)

Relativistic Heavy Ion Collider (RHIC)

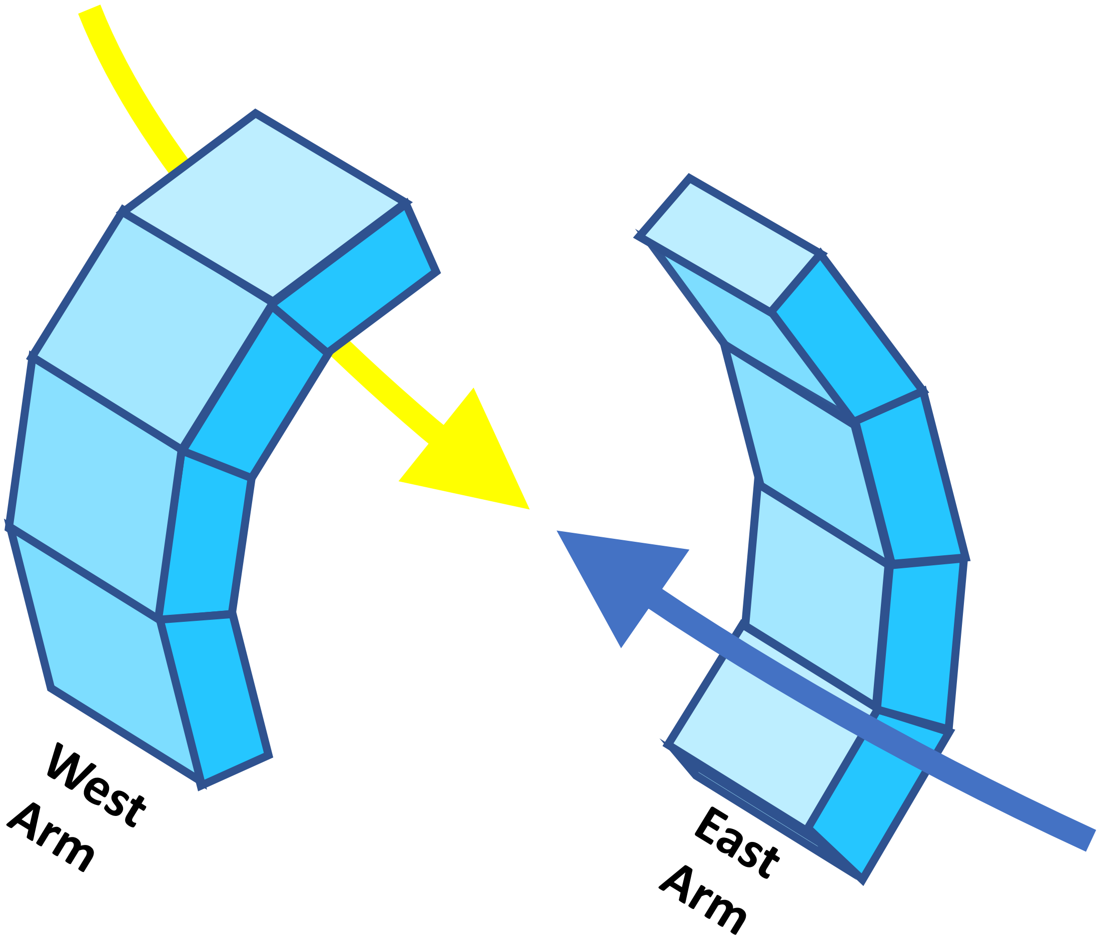


PHENIX detector



- PHENIX Central Arms
  - $\Delta\phi \sim \pi$
  - $|\eta| < 0.35$
- Electromagnetic Calorimeter used for $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$ detection
  - PbSc sectors: $\Delta\phi \times \Delta\eta \approx 0.011 \times 0.011$ $\frac{\sigma_E}{E} = 2.1\% \oplus \frac{6.2\%}{\sqrt{E}}$
  - PbGl sectors $\Delta\phi \times \Delta\eta \approx 0.008 \times 0.008$ $\frac{\sigma_E}{E} = 0.8\% \oplus \frac{5.9\%}{\sqrt{E}}$

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

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

$\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$

- Using Run 2015 data
  - $60\ pb^{-1}$ integrated luminosity
  - Mean polarization: 57%
  - Using the EMCal Rich Trigger that selects for high energy clusters
- Midrapidity π^0 and η mesons
  - Comparing π^0 to η results may provide information on potential effects due to strangeness, isospin, or mass.

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

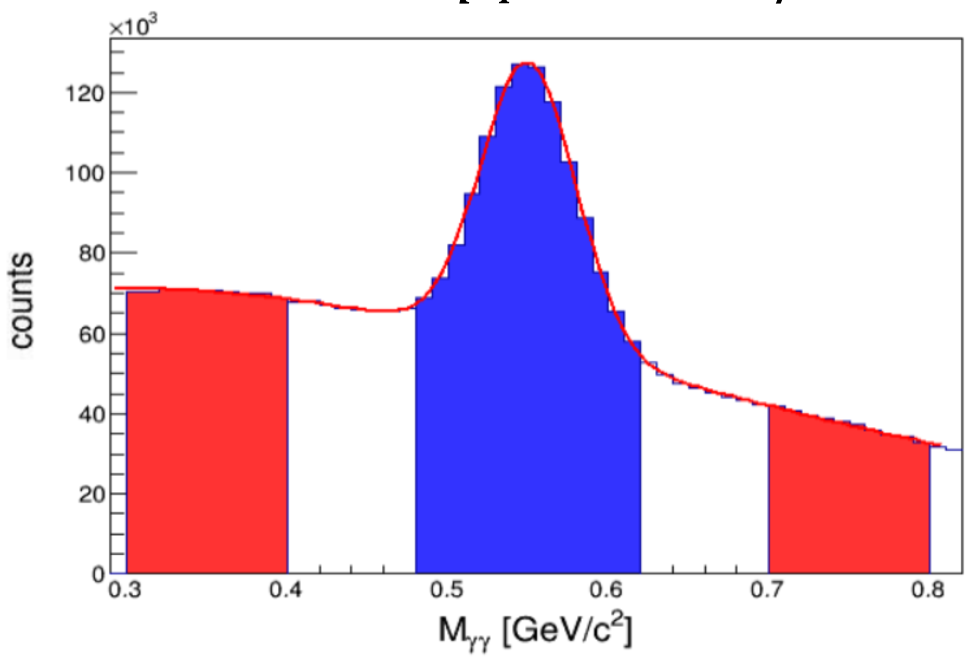
- Measuring A_N as a function of a single scale, large p_T $\to$ Twist 3 formalism applies

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

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

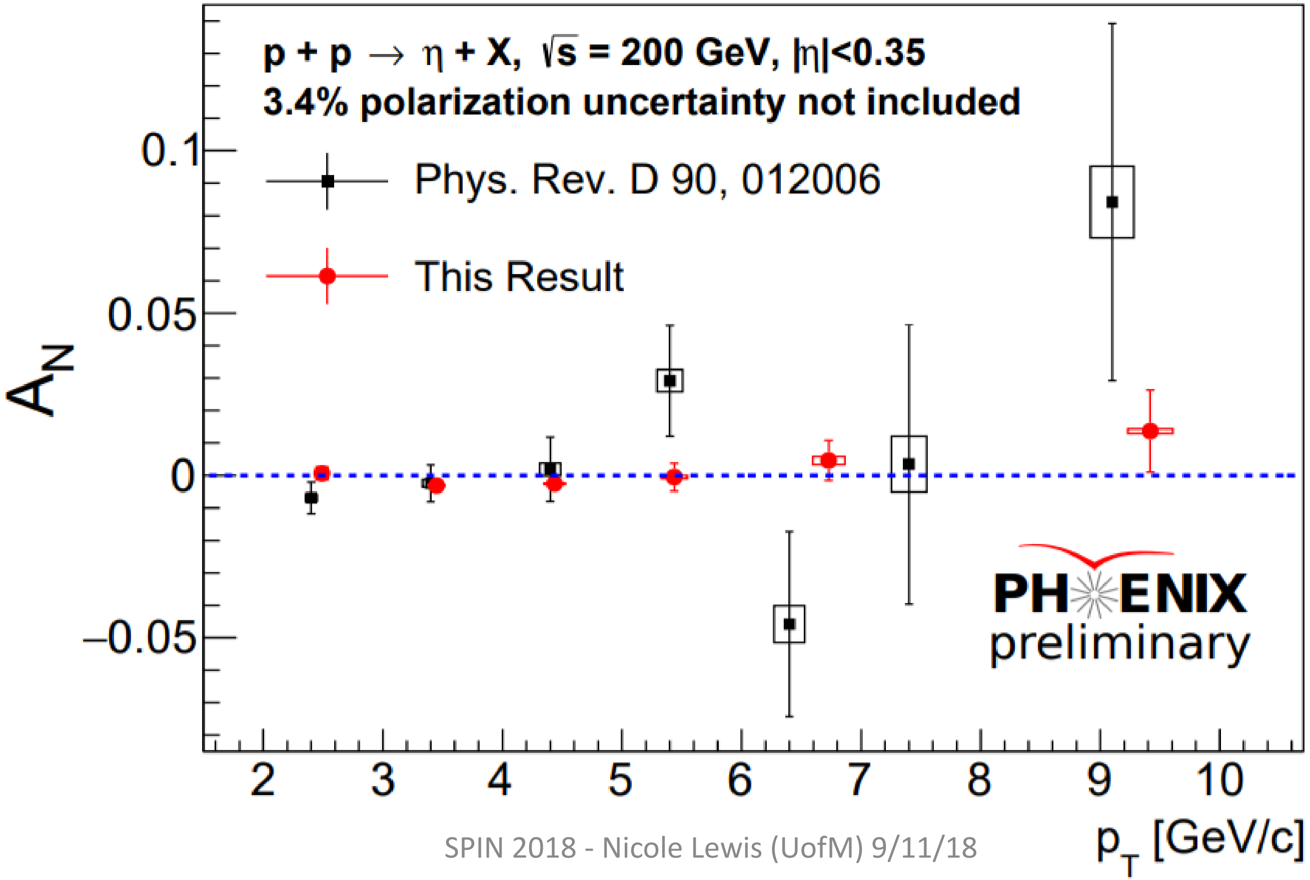
- Where $r = \frac{N_{bg}}{N_{sig}+N_{bg}}$ in the invariant mass peak region
- Peak: $480 < M_{\gamma\gamma} < 620\ MeV/c^2$
- Background: $300 < M_{\gamma\gamma} < 400\ MeV/c^2$ $700 < M_{\gamma\gamma} < 800\ MeV/c^2$

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



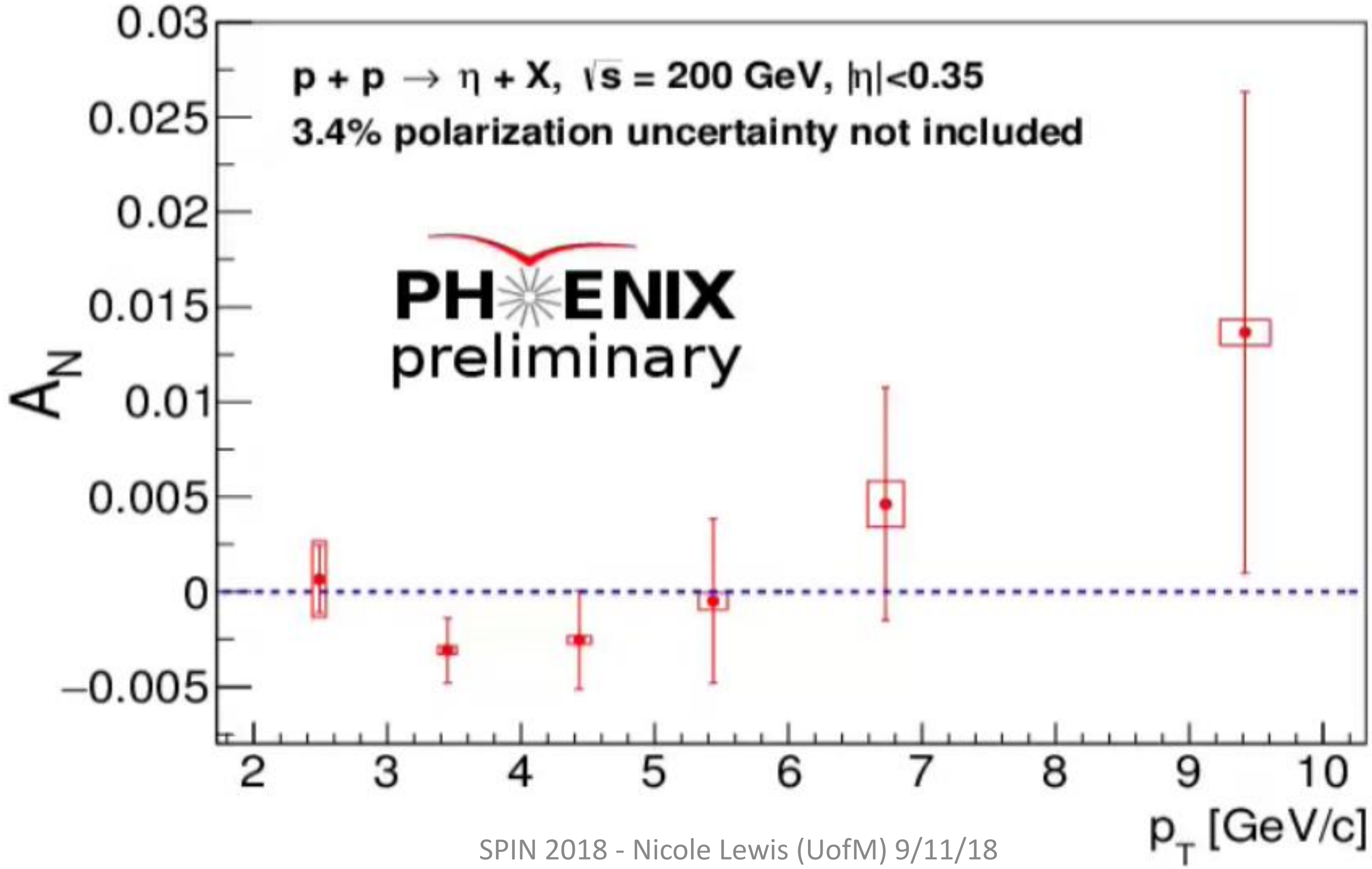
Results

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

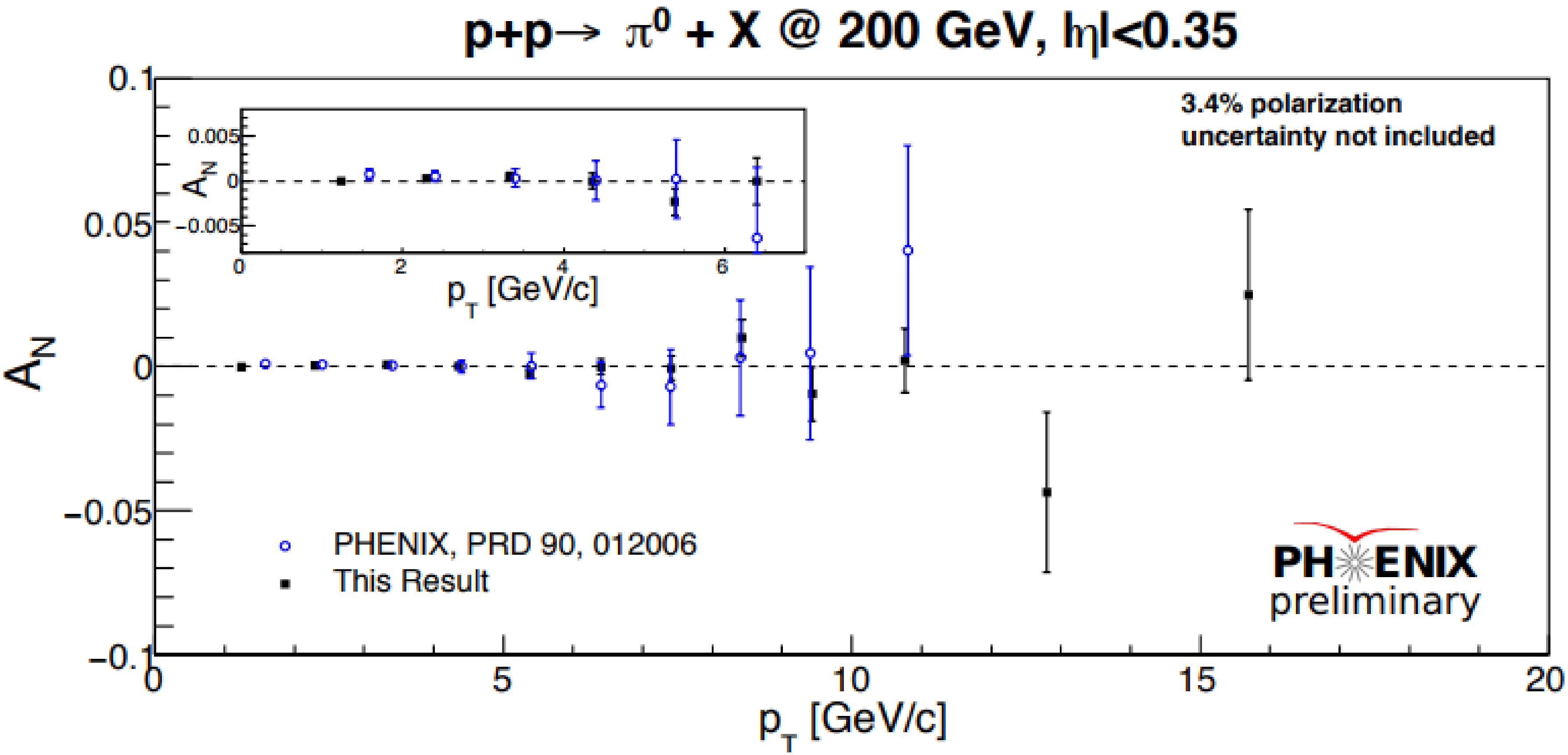


Results

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

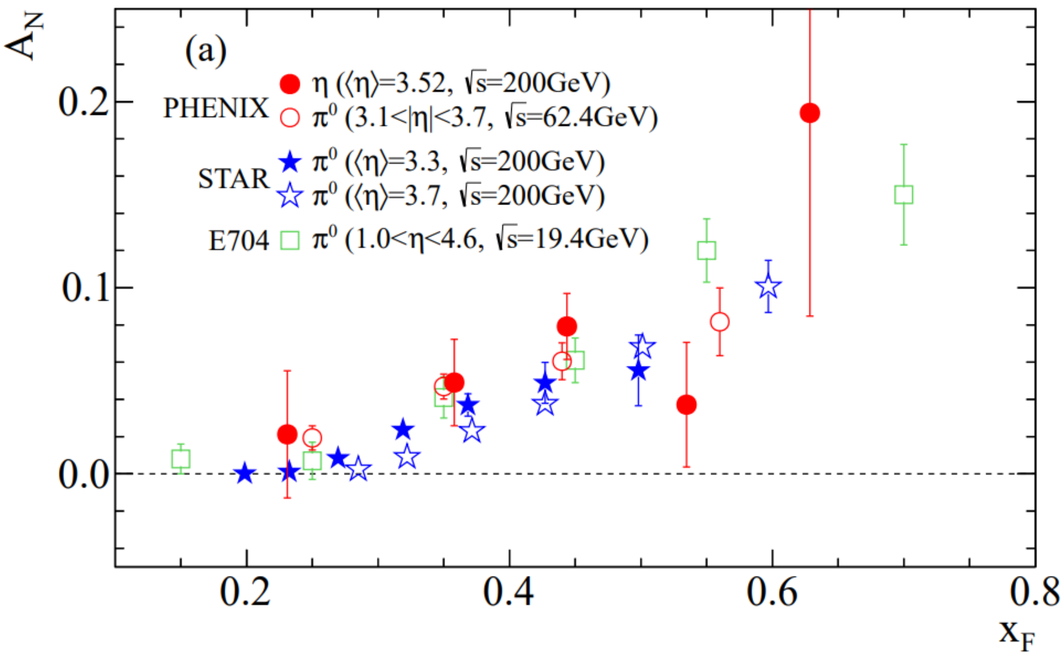


$A_N^{\pi^0}$ at midrapidity

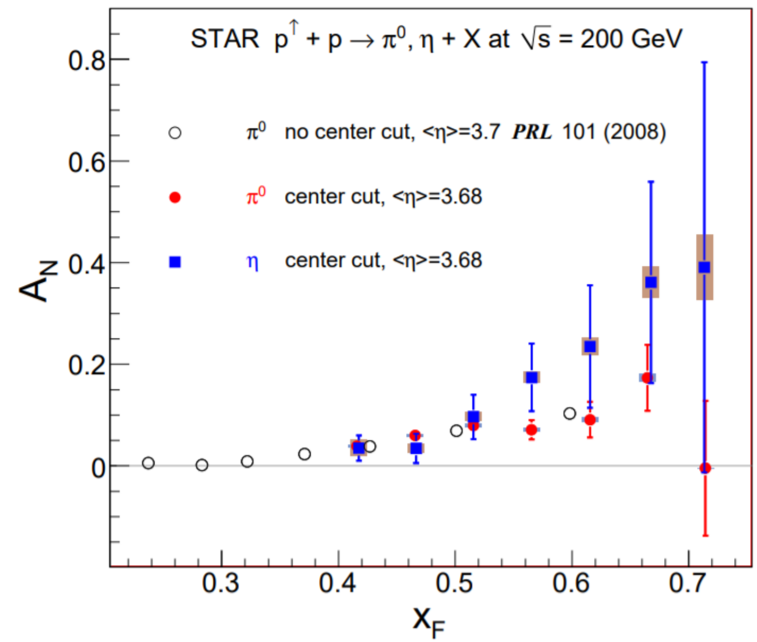


Consistent with zero to within 10^{-4} at low p_T

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



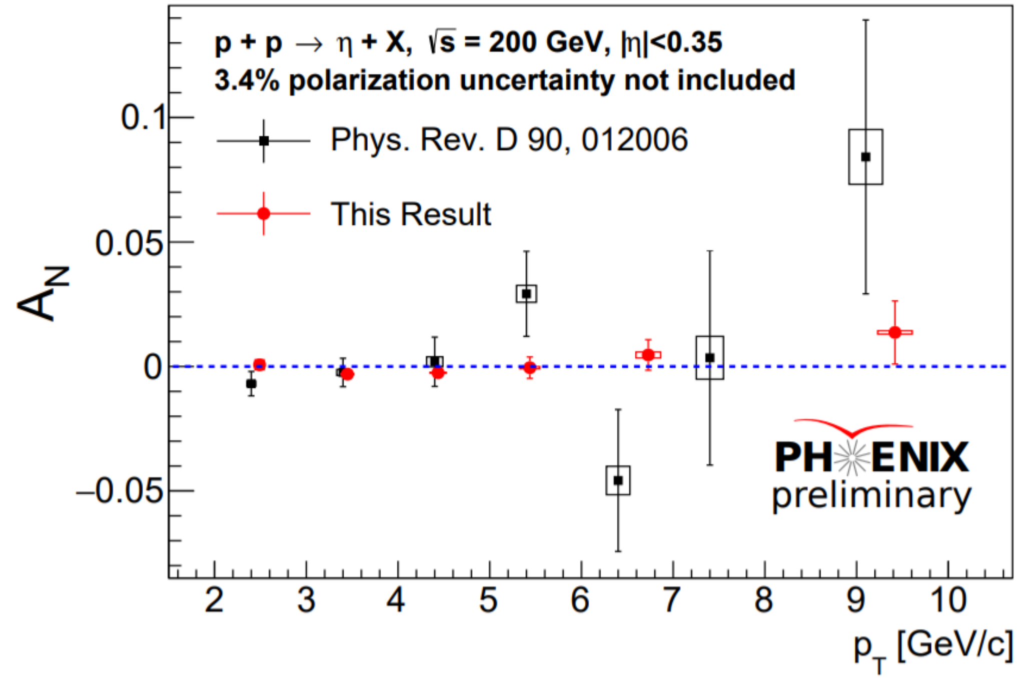
(PHENIX Collaboration)
PRD **90**, 012006 (2014)

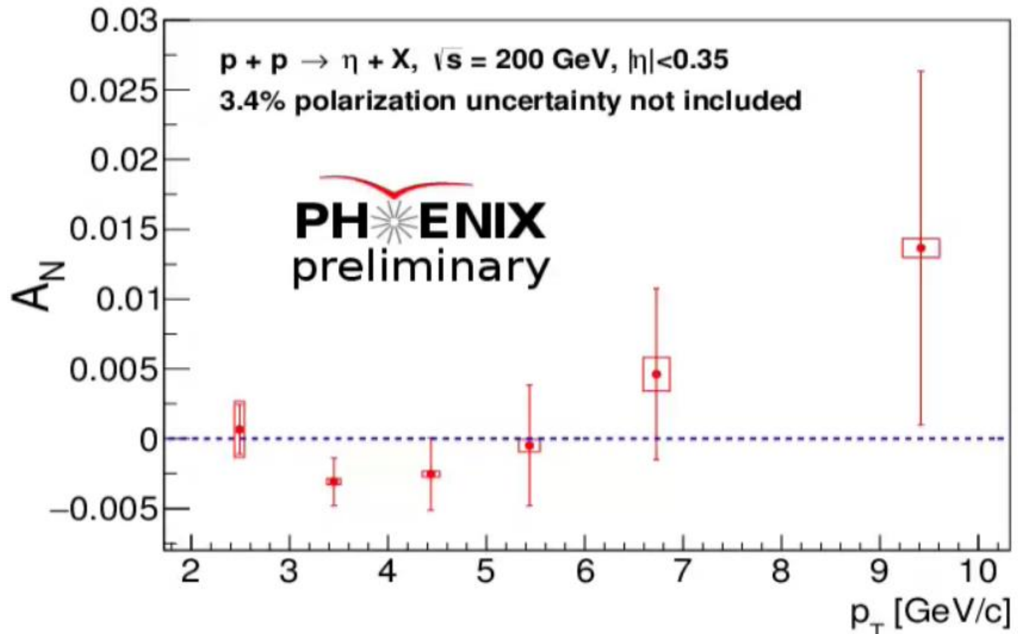


(STAR Collaboration)
PRD **86**, 051101(R) (2012)

Conclusion

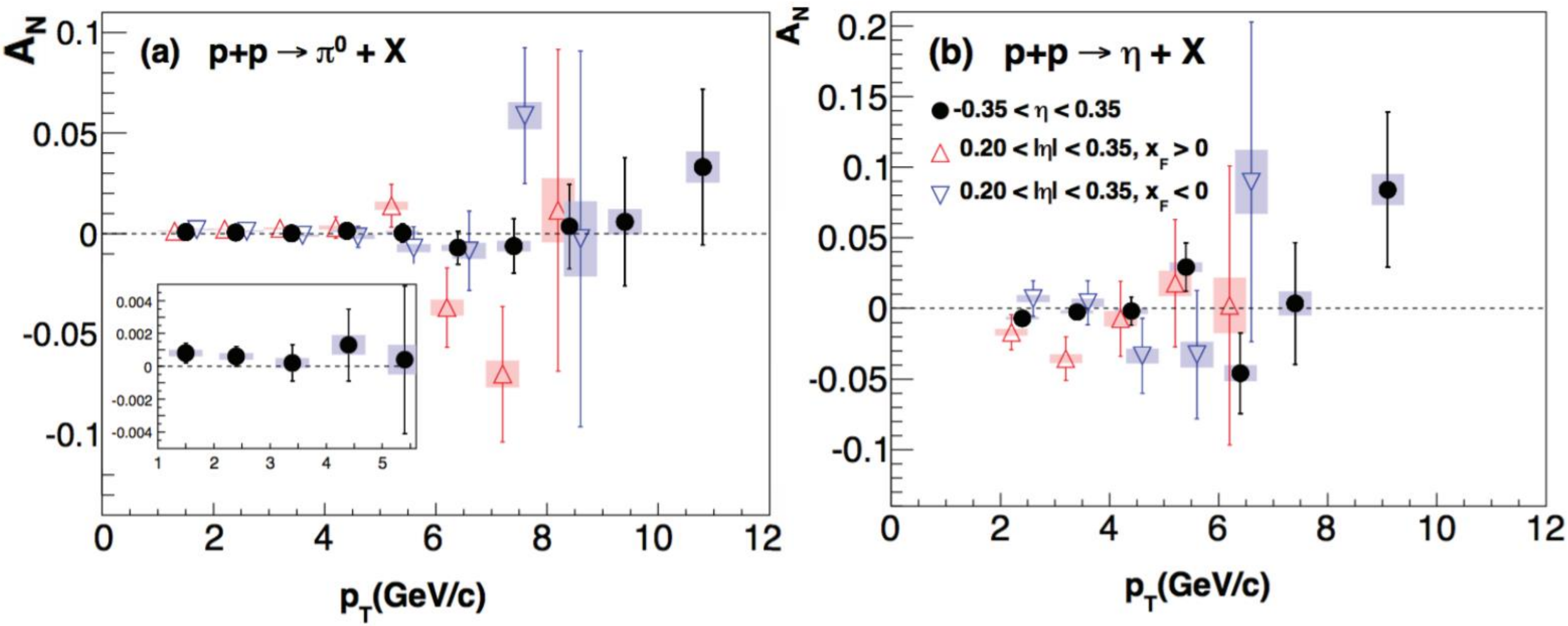
- Transverse single-spin asymmetries probe parton dynamics in the nucleon as well as the process of hadronization
  - Transverse momentum dependent functions
  - Twist 3
- New η A_N at midrapidity $\sqrt{s} = 200\ GeV$ shown
  - Factor of 3-4 higher precision than the previous PHENIX result
  - Consistent with zero
  - Will help constrain twist-3 functions
  - Sensitive to impact of strangeness to twist-3 functions





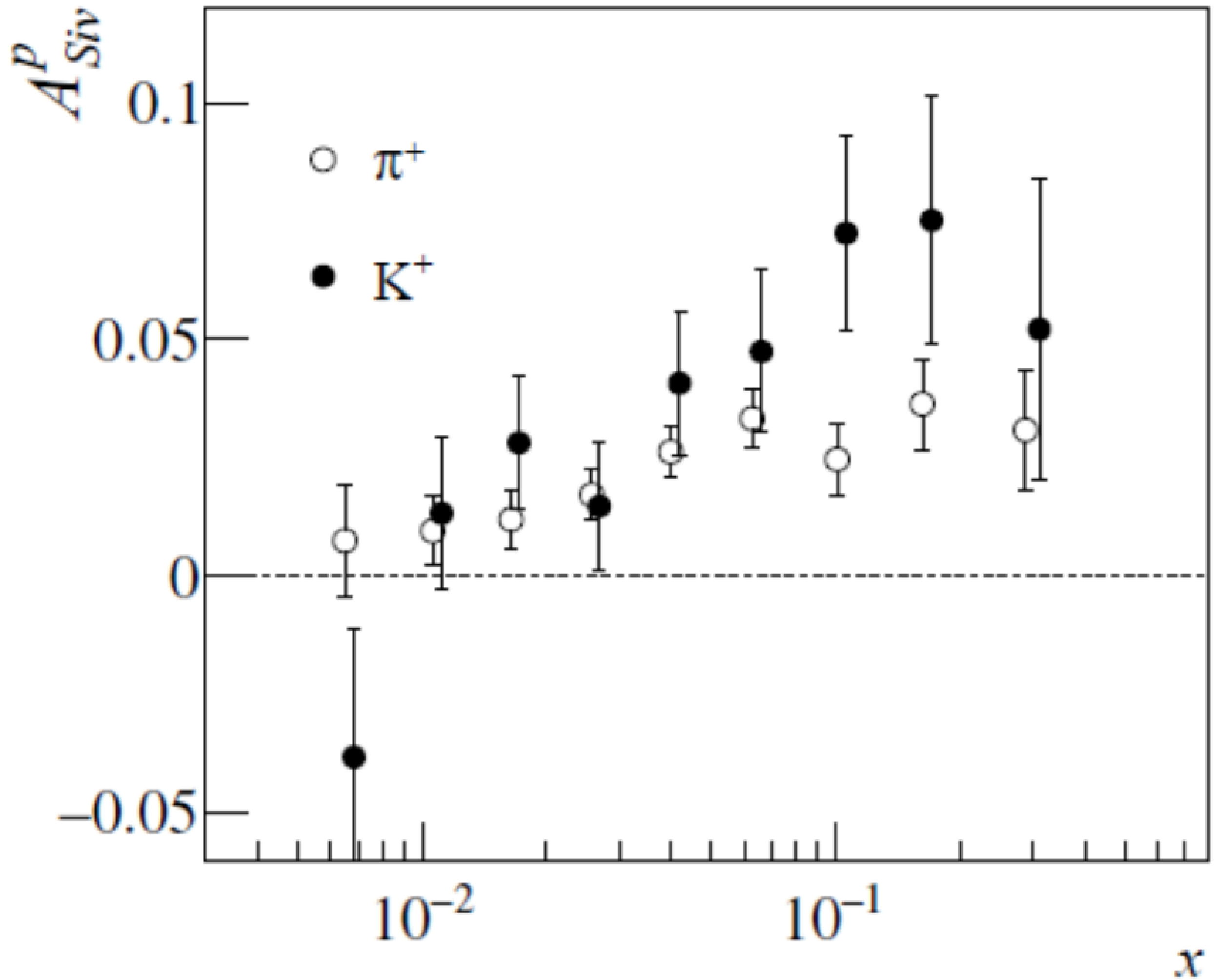
Back Up

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



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

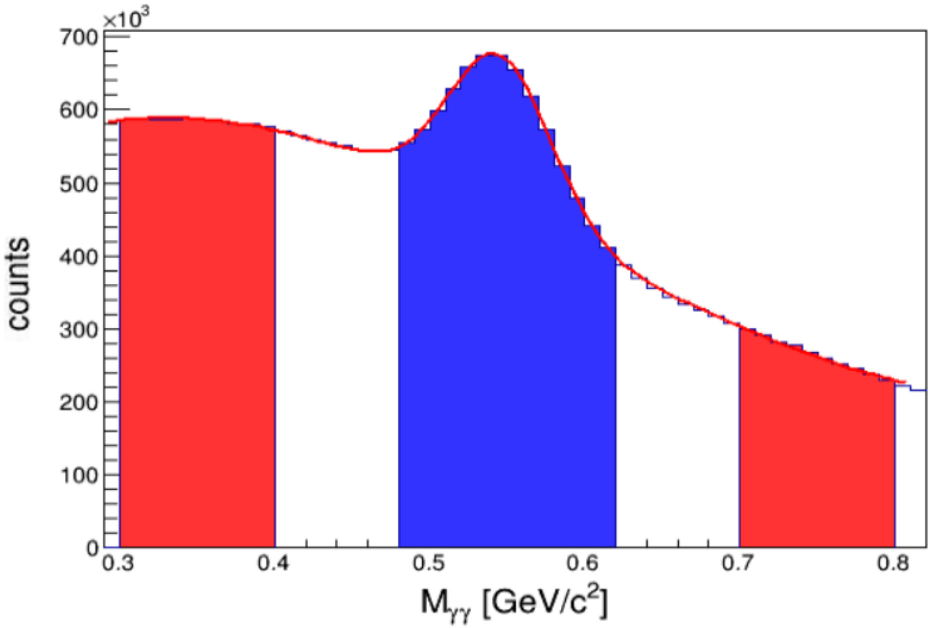
Sivers Asymmetry at COMPASS



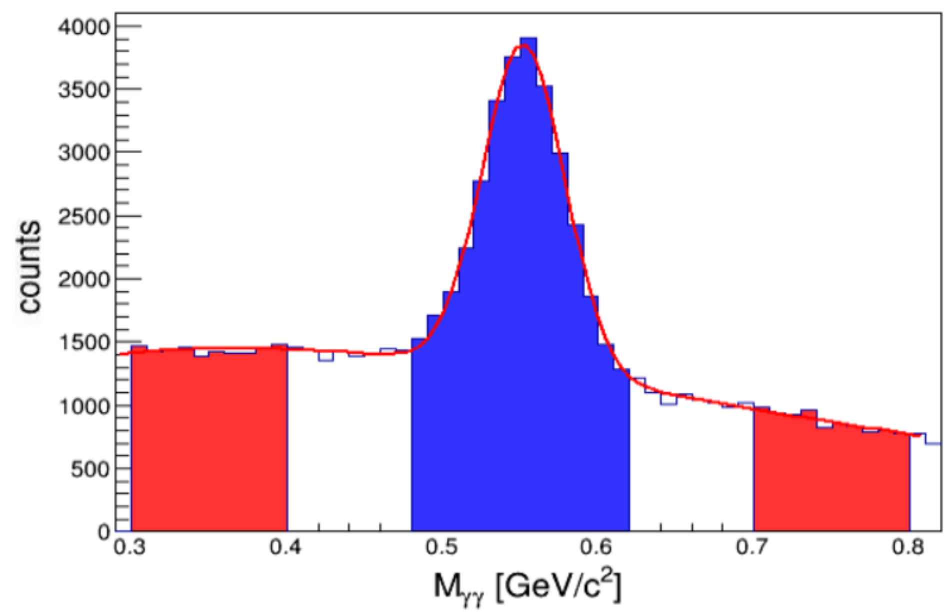
(COMPASS Collaboration) *PLB* **744**, 250 (2015)

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 $8 < p_T < 15\ GeV$



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