Transverse single asymmetries in π^0 production in p + p, p+Al and p+Au collisions at mid-rapidity using the PHENIX detector system

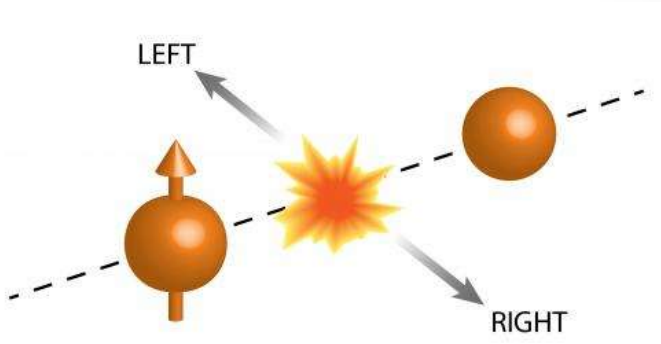
Norbert Novitzky

Stony Brook University

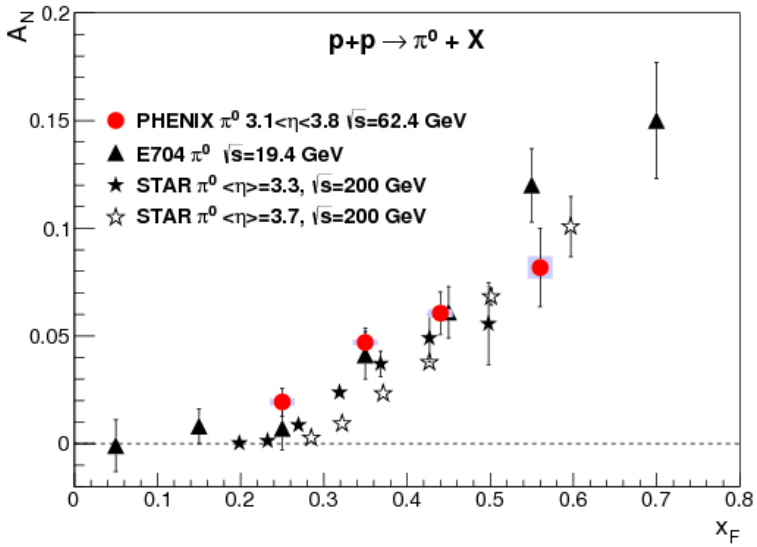
Transverse Spin

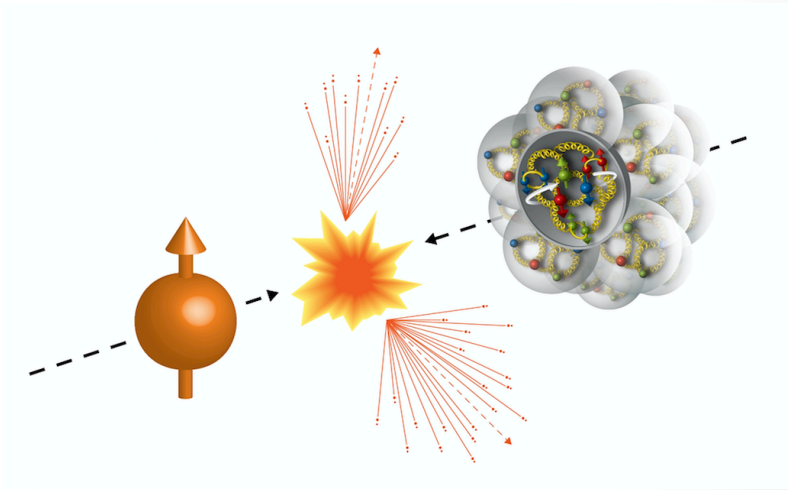
Large asymmetries in the forward π^0:

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



Persists to high collision energies



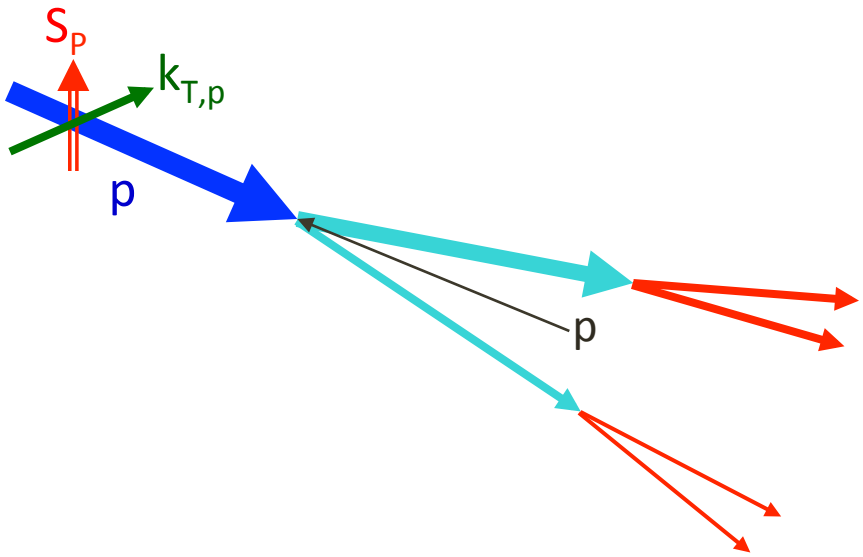


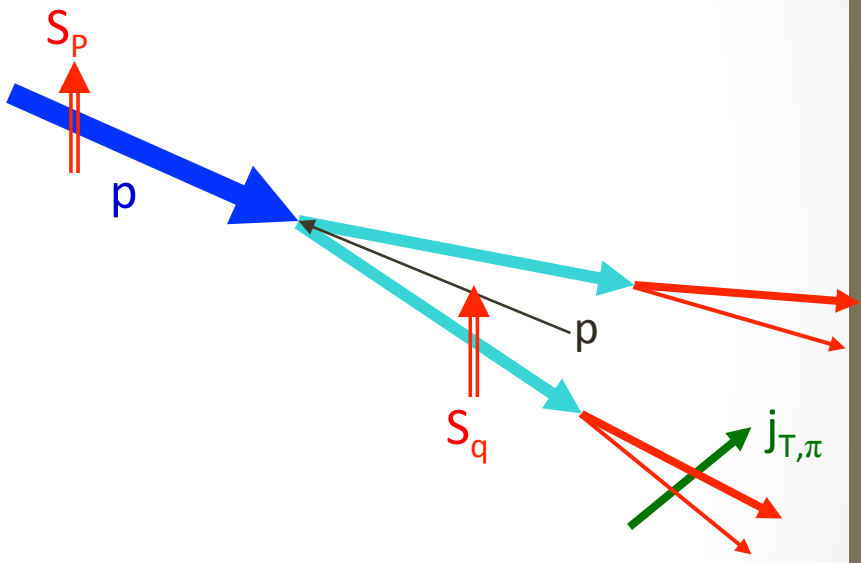
PRD90, 012006 (2014)

p_T dependent distributions

Sivers Effect (Phys.Rev.D41,83): Introduce transverse momentum of parton relative to proton.

Collins Effect (Nucl.Phys.B396,161): Introduce transverse momentum of fragmenting hadron relative to parton.





Correlation between Proton spin (S_p) and parton transverse momentum $k_{T,p}$

$$\bar{f}_{1T}^{\perp q}(x, k_{T,P}^2) \cdot D_q^h(z)$$

Correlation between Proton spin (S_p) and quark spin (S_q) + spin dep. frag. function

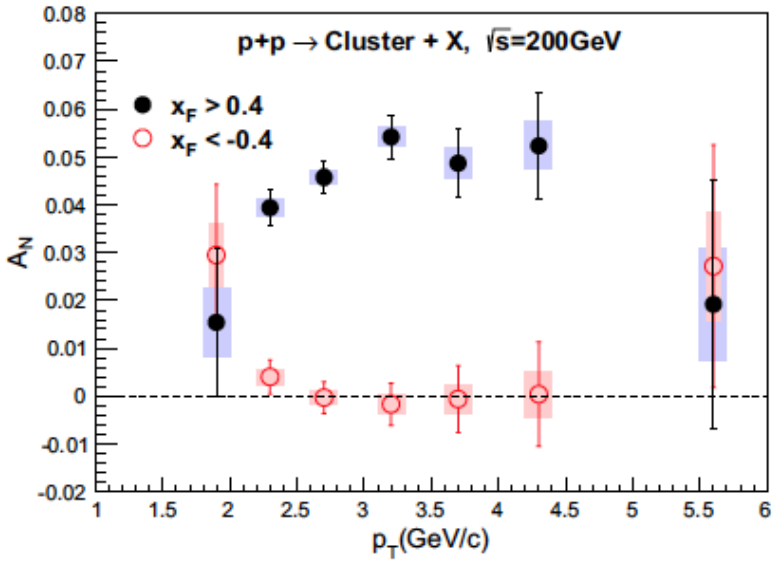
$$\delta q(x) \cdot H_1^{\perp}(z_2, \bar{k}_{\perp}^2)$$

Graphics from L. Nogach (2006 RHIC AGS Users Meeting)

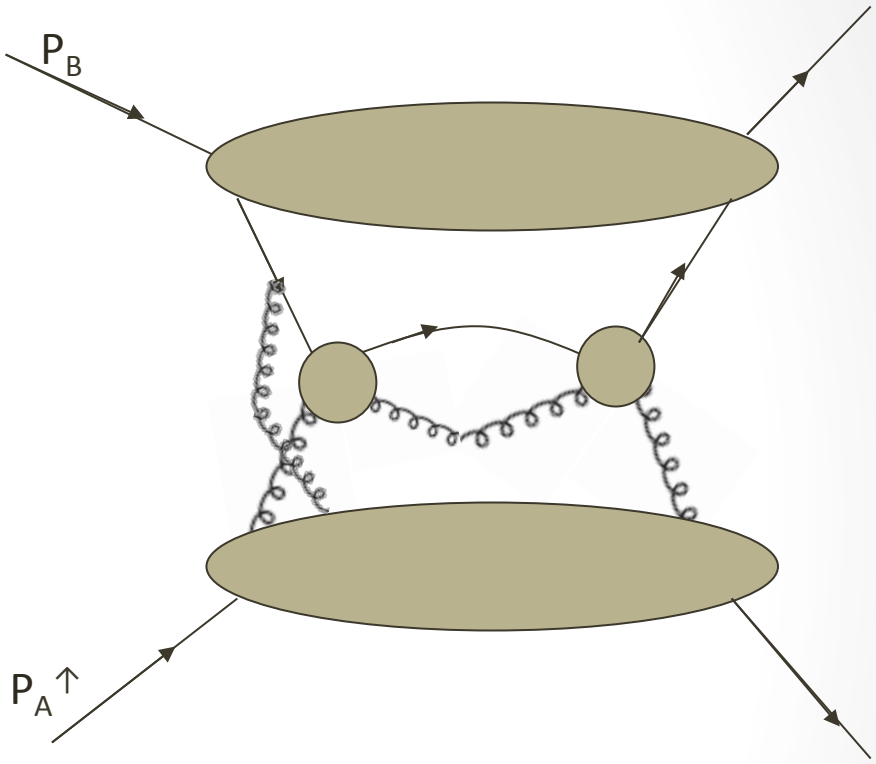
Higher twist correlation functions

- QCD, collinear partons
- Multiple parton scattering

Higher twist interaction contributions expected to drop like $1/p_T$



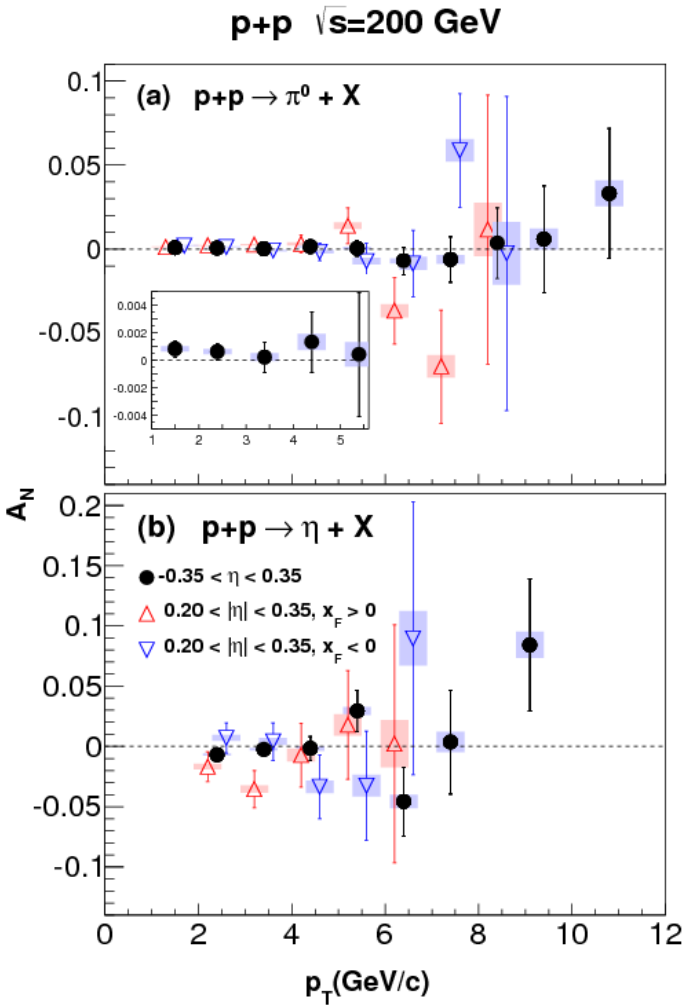
PRD90, 012006 (2014)



What is expected A_N dependence on p_T?

p_T large, $A_N \sim 1/p_T$

Asymmetry in mid-rapidity



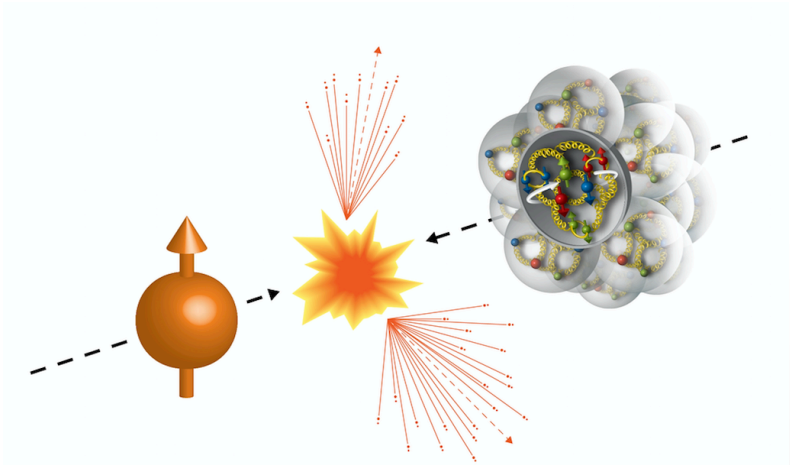
PRD90, 012006 (2014)

The asymmetry of π^0 and η in midrapidity:

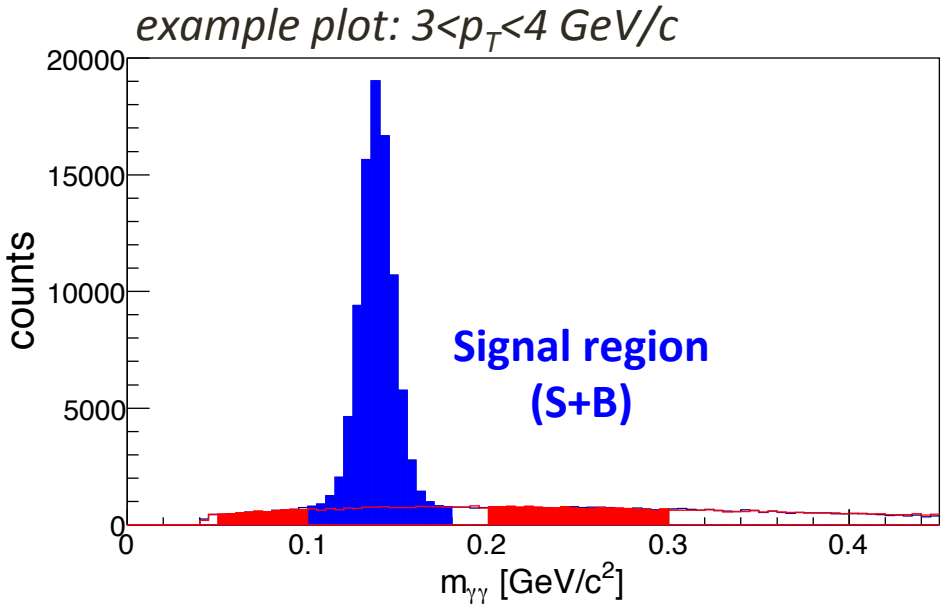
- Both agree very well
- Consistent with zero within errors

How does it change from p+p to p+A collisions?

Already some surprises, see
Neutron A_N M. Kim's talk (Tuesday)
J/ψ A_N C. Xu's talk (Tuesday)



π^0 reconstruction with PHENIX



Background region on left and right side of the peak

Transverse asymmetry:

$$A_N = \frac{1}{P}\frac{\sqrt{N_L^{\uparrow}N_R^{\downarrow}} - \sqrt{N_L^{\downarrow}N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow}N_R^{\downarrow}} + \sqrt{N_L^{\downarrow}N_R^{\uparrow}}}$$

Signal/Background:

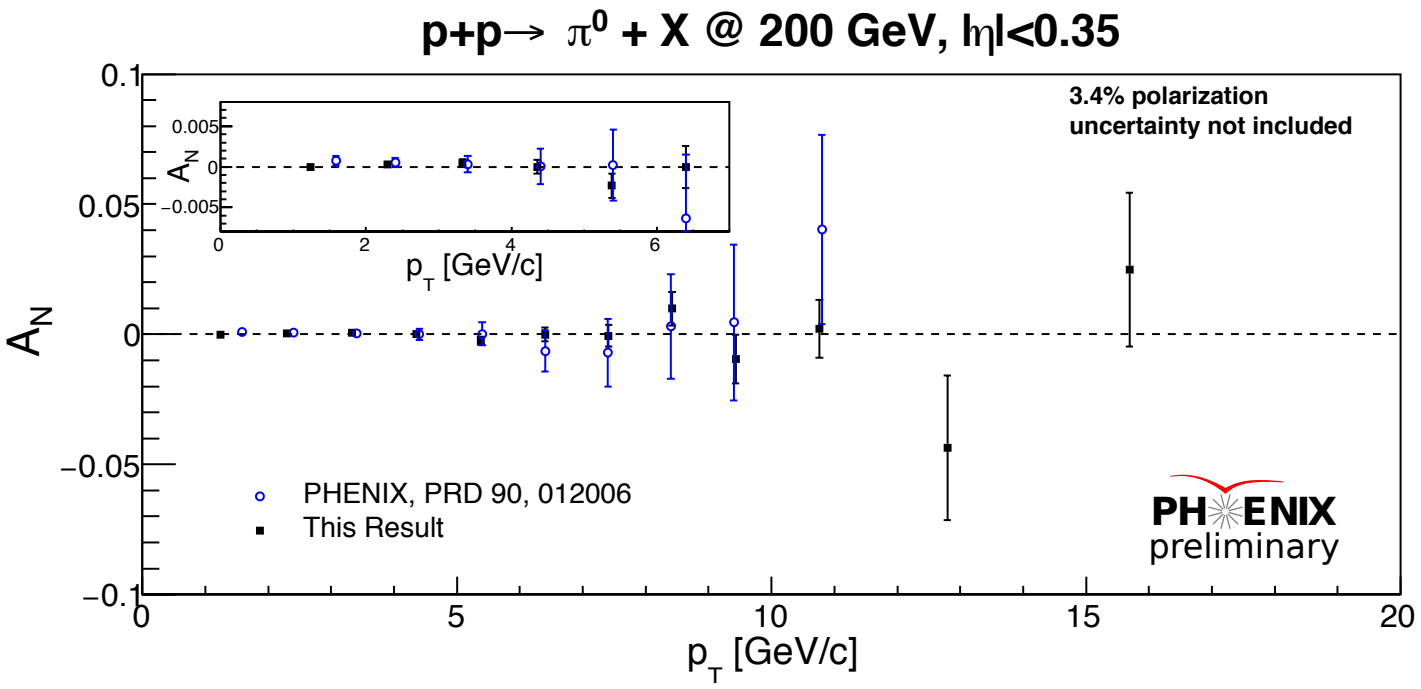
- Estimated by mix-event technique
- Assuming the background A_N under the π^0 mass has no mass dependency

Extracting the signal asymmetry:

$$A_N^S = \frac{N_{S+B}}{N_\pi} A_N^{S+B} - \frac{N_B}{N_\pi} A_N^B$$

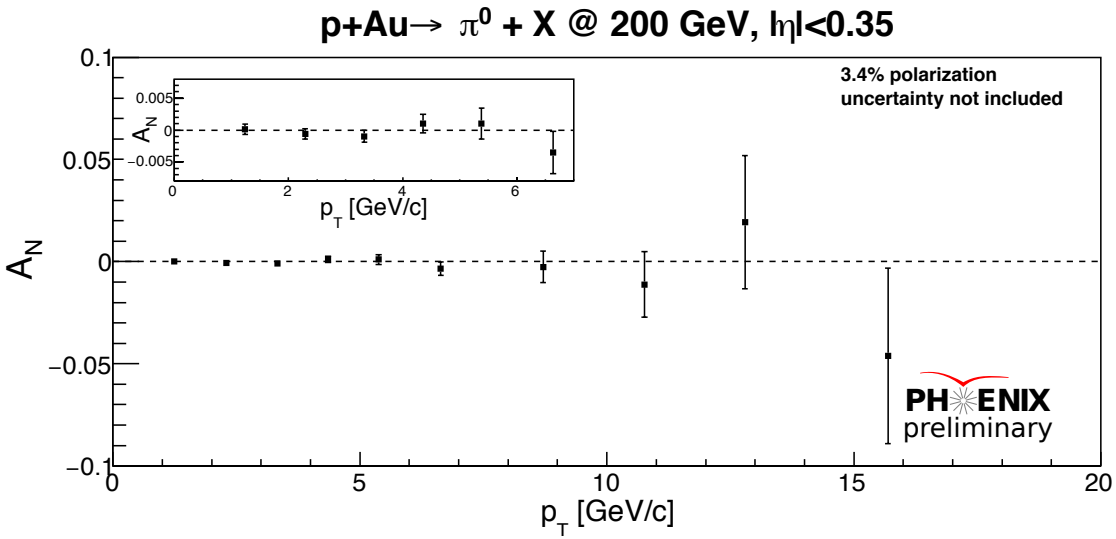
- *N_{S+B} = number of counts in π^0 mass window*
- *N_π = number of π^0 counts*
- *N_B = number of background counts in π^0 window*

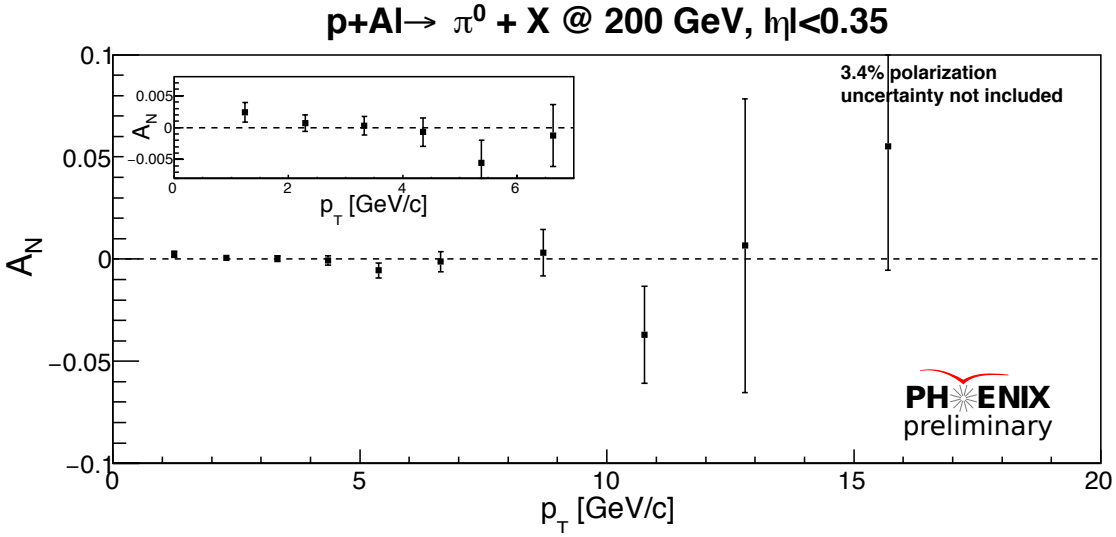
A_N in p+p



- Factor of 3 increase precision in the statistical uncertainty with the previous result, precision at low p_T **< 3 x 10^{-4}**
- Higher p_T reach
- A_N is consistent with zero within uncertainties
- Mid-rapidity π^0 A_N has been used to constrain the Sivers gluon function:
  - *Anselmino et al, PRD 74, 094011 (2006)*
  - *U. D'Alesio, F. Murgia, C. Pisano, JHEP 09, 119 (2015)*

A_N in p+Au and p+Al in midrapidity

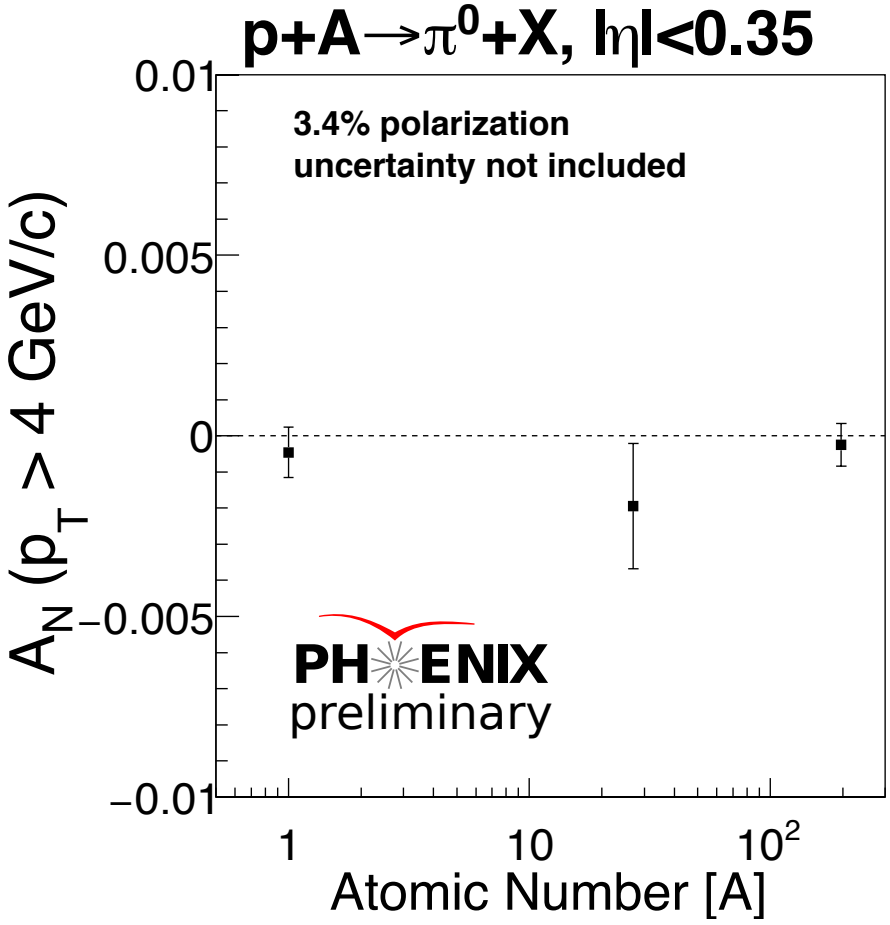




A_N in p+A collisions @ 200 GeV in mid-rapidity:

- Asymmetry is consistent with zero within the uncertainties
- The precision in low-p_T is **< 10^{-3}**

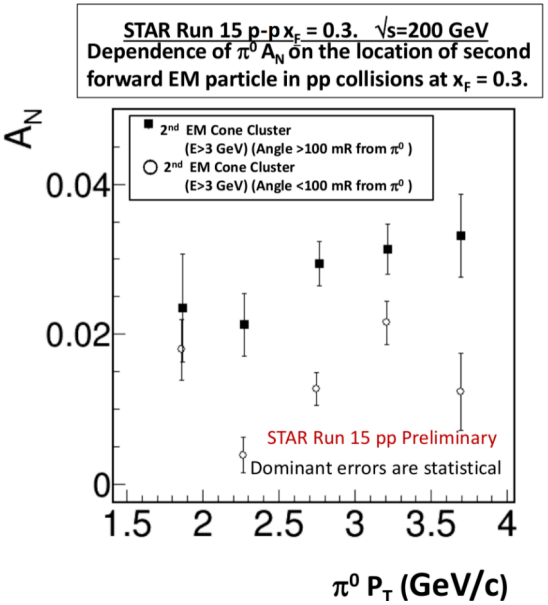
A_N versus A

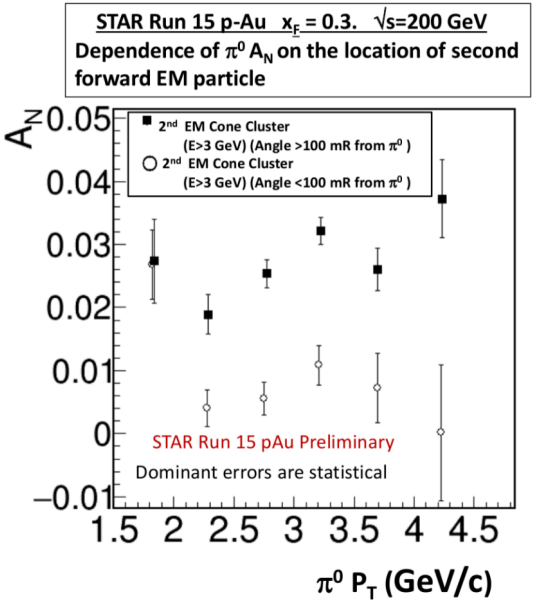


Integrated A_N for $p_T > 4$ GeV/c

- In pQCD region in mid-rapidity
- Combined result for p+p, p+Al and p+Au
- The asymmetry is consistent with zero (< 3 x 10-3)
- Potential to constrain theoretical models using pA collisions

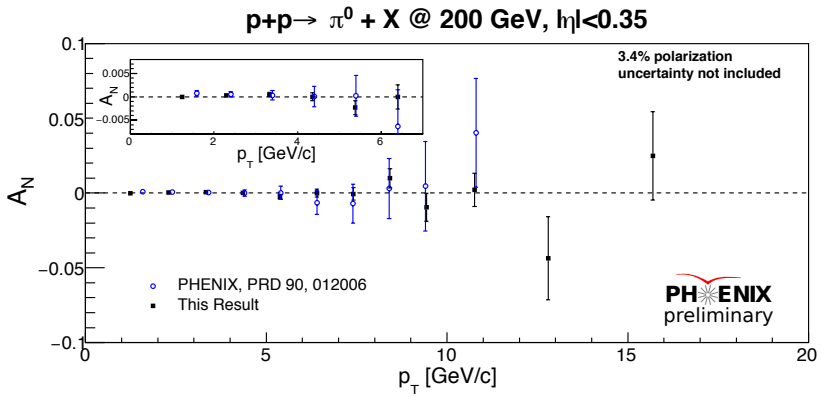
Forward and Mid-rapidity π^0

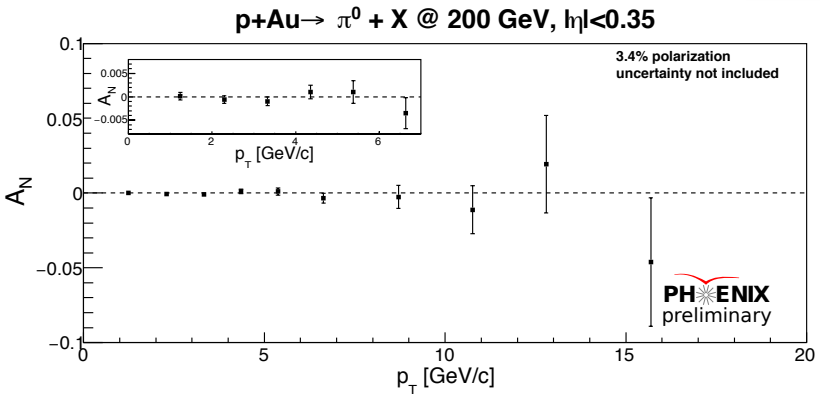




The π^0 asymmetries are comparable from p+p to p+Au (Al) collisions

slide from Christopher Dilks (STAR)





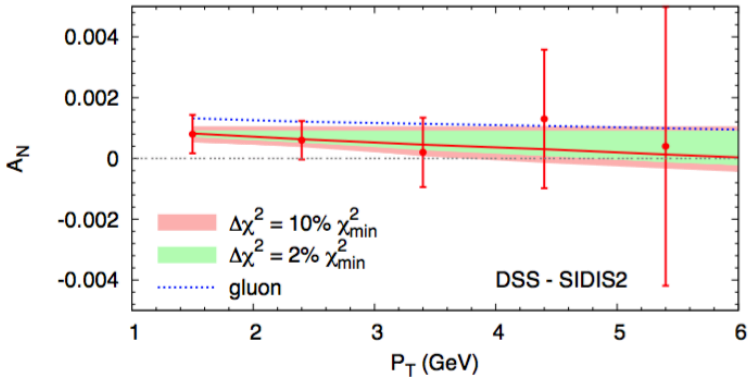
Summary

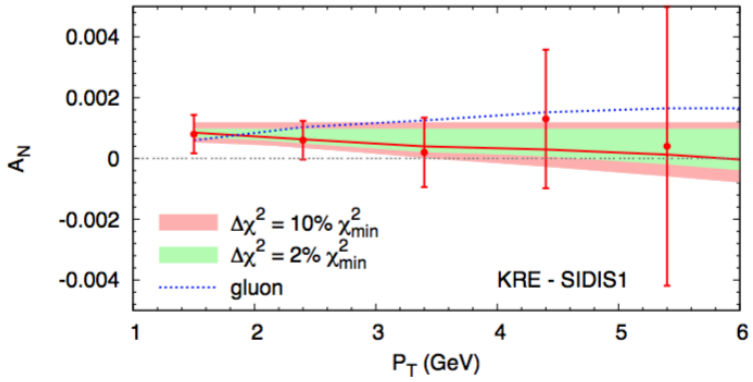
- The π^0 A_N in mid-rapidity in p+p, p+Au and p+Al collisions at sqrt(s) = 200 GeV was measured by PHENIX:
  - All asymmetries are consistent with zero
  - Higher p_T reach as previously measured p+p result
  - Factor of 3 higher precision in p+p, low-p_T < 4 x 10^{-4}
  - precision at low-p_T in p+A < 10^{-3}
- π^0 transverse asymmetry from p+p to p+A are comparable in mid- (PHENIX) or forward-rapidity (STAR)
- The π^0 production in p+p vs p+A (R_{pA}) will answer outstanding question considering *nuclear effects*
- Theoretical input for the mid-rapidity π^0 asymmetries is needed

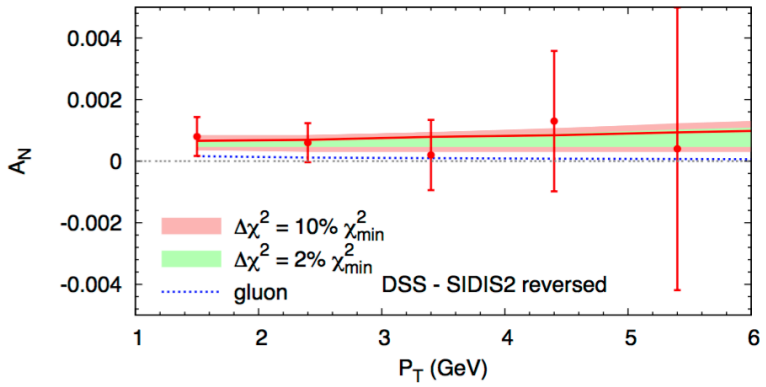
Backup

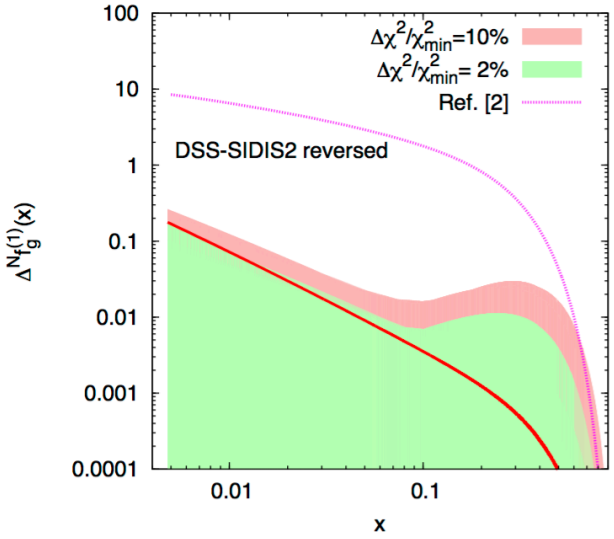
Gluon Sivers function

U. D'Alesio, F. Murgia, C. Pisano, JHEP 09, 119 (2015)

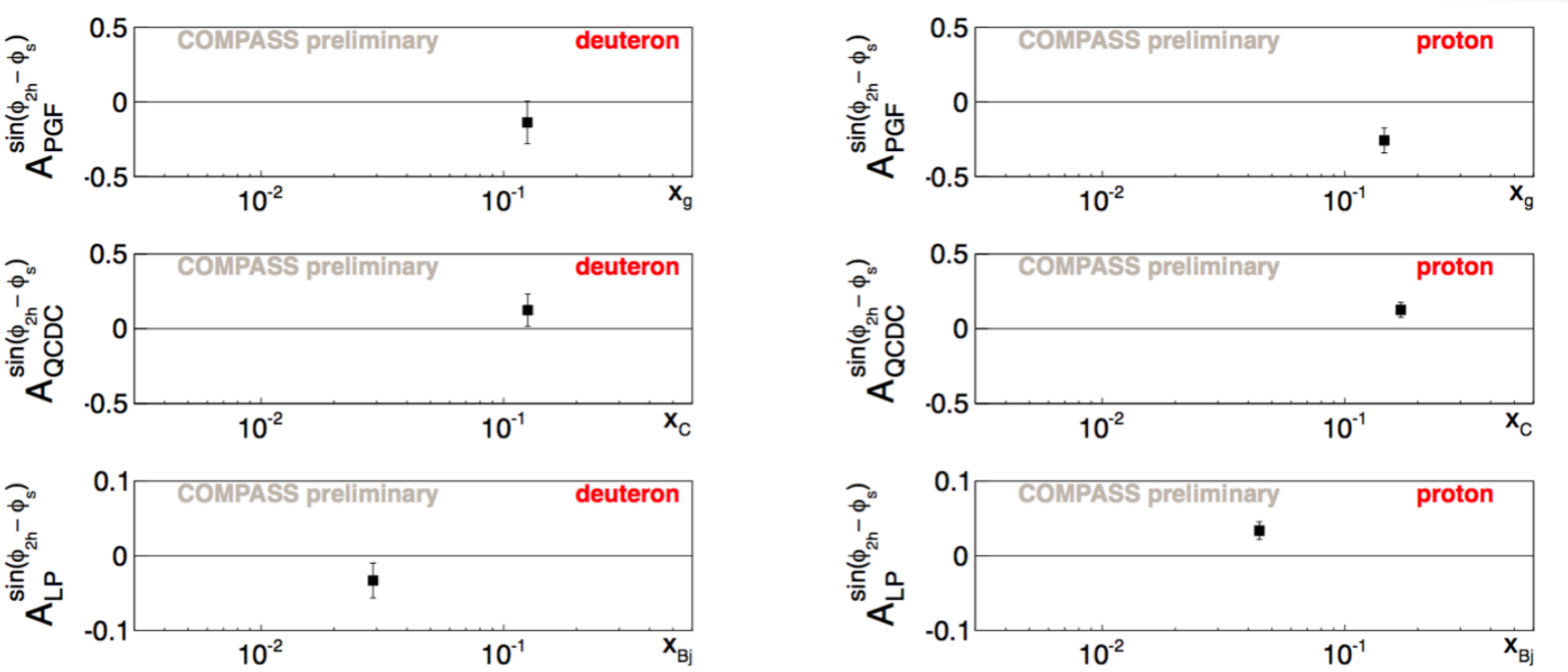








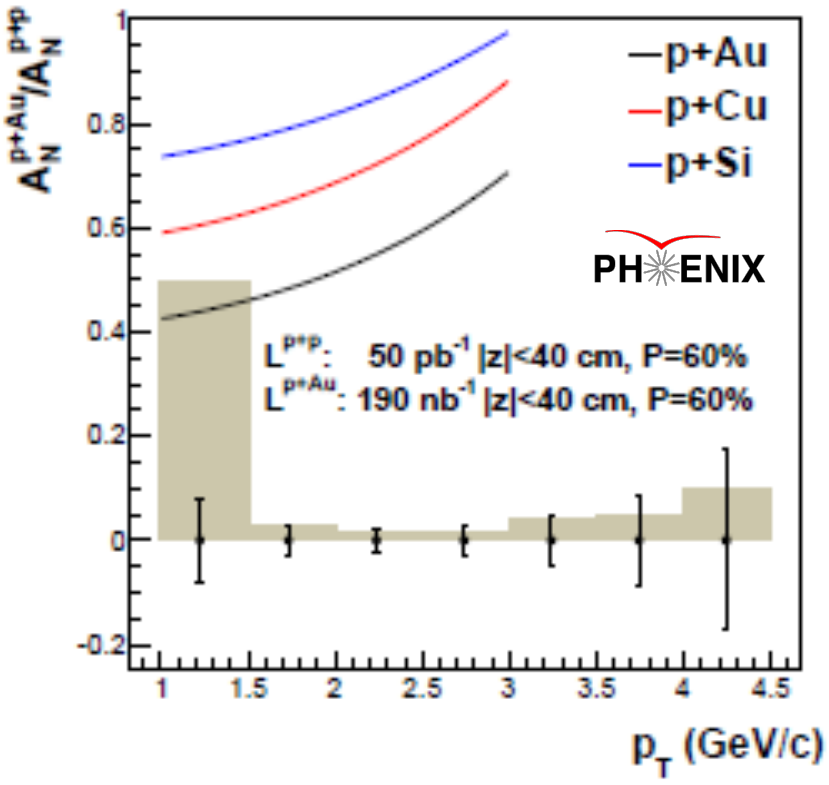
Gluon Sivers at COMPASS



- **Deuteron is zero within the uncertainties:**
  The central value is negative with similarly large error

- **Proton is negative to 3σ precision**
  Also comparable with the deuteron result within uncertainties

π^0 A_N in p+A collisions



Kang, Yuan: PRD84, 034019
Kovchegov, Sievert: PRD86, 034028