

Transverse Single Spin Asymmetry (TSSA) of π^0 and η Mesons at RHIC/PHENIX

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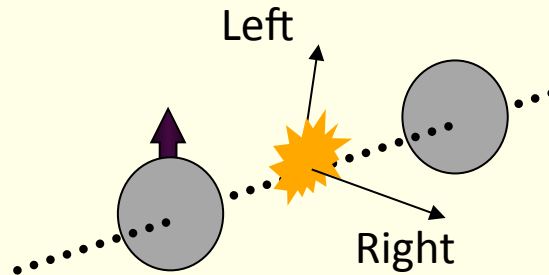
Outline

- Motivation
 - non zero TSSA at forward rapidity
 - Experiment and theory
- PHENIX measurements
 - Experimental setup
 - Central Arm π^0 and η meson A_N at $\sqrt{s} = 200$ GeV
 - Forward π^0 meson A_N at $\sqrt{s} = 62.4$ GeV
 - Forward cluster at $\sqrt{s} = 200$ GeV
 - Forward η meson $\sqrt{s} = A_N$ at 200 GeV
 - [PRD90, 012006 \(2014\)](#) and [arxiv:1406.3541](#)
- Summary and outlook

Non-zero TSSA at Forward Rapidity

Transverse Single Spin Asymmetries A_N

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



Theory Expectation:

Small asymmetries at high energies

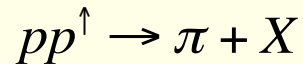
(Kane, Pumplin, Repko, PRL 41, 1689–1692 (1978))

$$A_N \propto \frac{m_q}{\sqrt{s}}$$

$A_N \sim O(10^{-4})$ theory

Experiments:

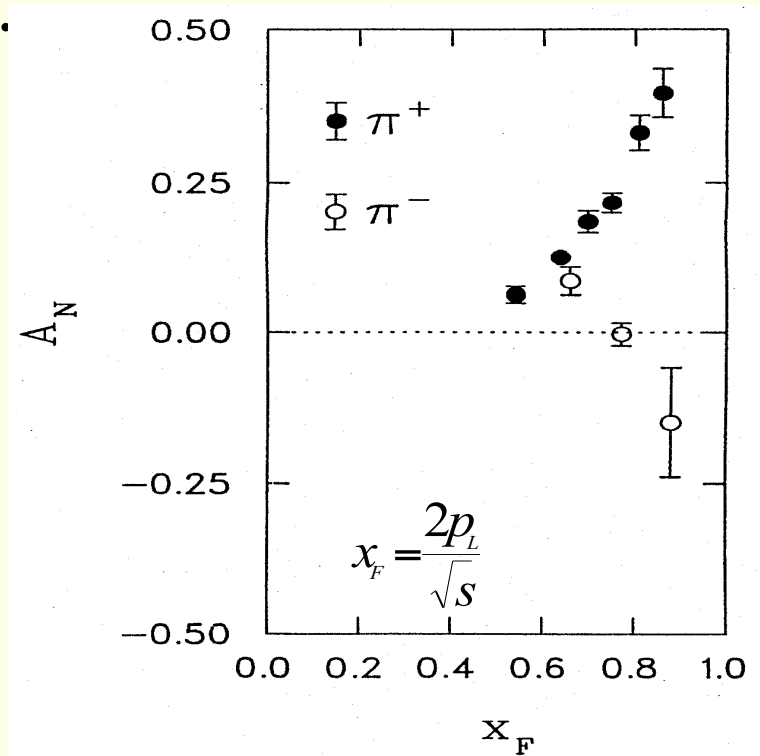
ZGS, AGS, FERMILAB to RHIC



$A_N \sim O(10^{-1})$ observed

$$\sqrt{s} = 5 \sim 500 \text{ GeV}$$

Argonne ZGS, $p_{\text{beam}} = 12 \text{ GeV}/c$



W.H. Dragoset et al., PRL36, 929 (1976)

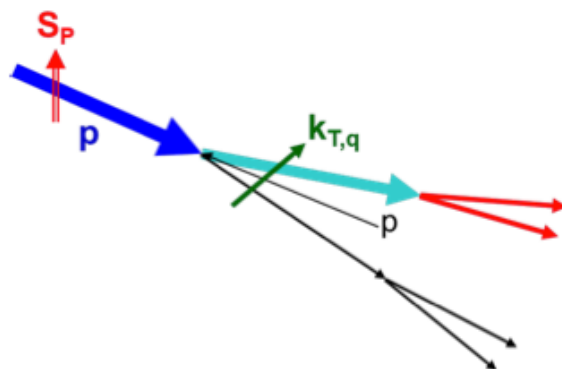
Theoretical Models of TSSA

(I) Initial State Effects: "Sivers"

Correlation between proton-spin and intrinsic transverse quark momentum

$$\propto \underbrace{\bar{f}_{1T}^{\perp q}(x, k_{\perp}^2)}_{\text{Sivers distribution (initial state)}} \cdot D_q^h(z)$$

Sivers distribution (initial state)



D. Sivers, Phys. Rev. D **41**, 83 (1990)

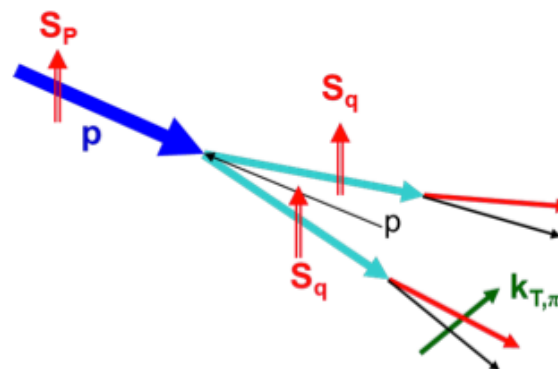
Twist-3 quark-gluon/gluon-gluon correlators in polarized hadron.

(II) Final State Effects: "Collins"

Correlation between proton & quark spin + spin dependant fragmentation function

$$\propto \underbrace{\delta q(x)}_{\text{Quark transverse spin distribution}} \cdot \underbrace{H_1^{\perp}(z_2, \bar{k}_{\perp}^2)}_{\text{Collins FF (final state)}}$$

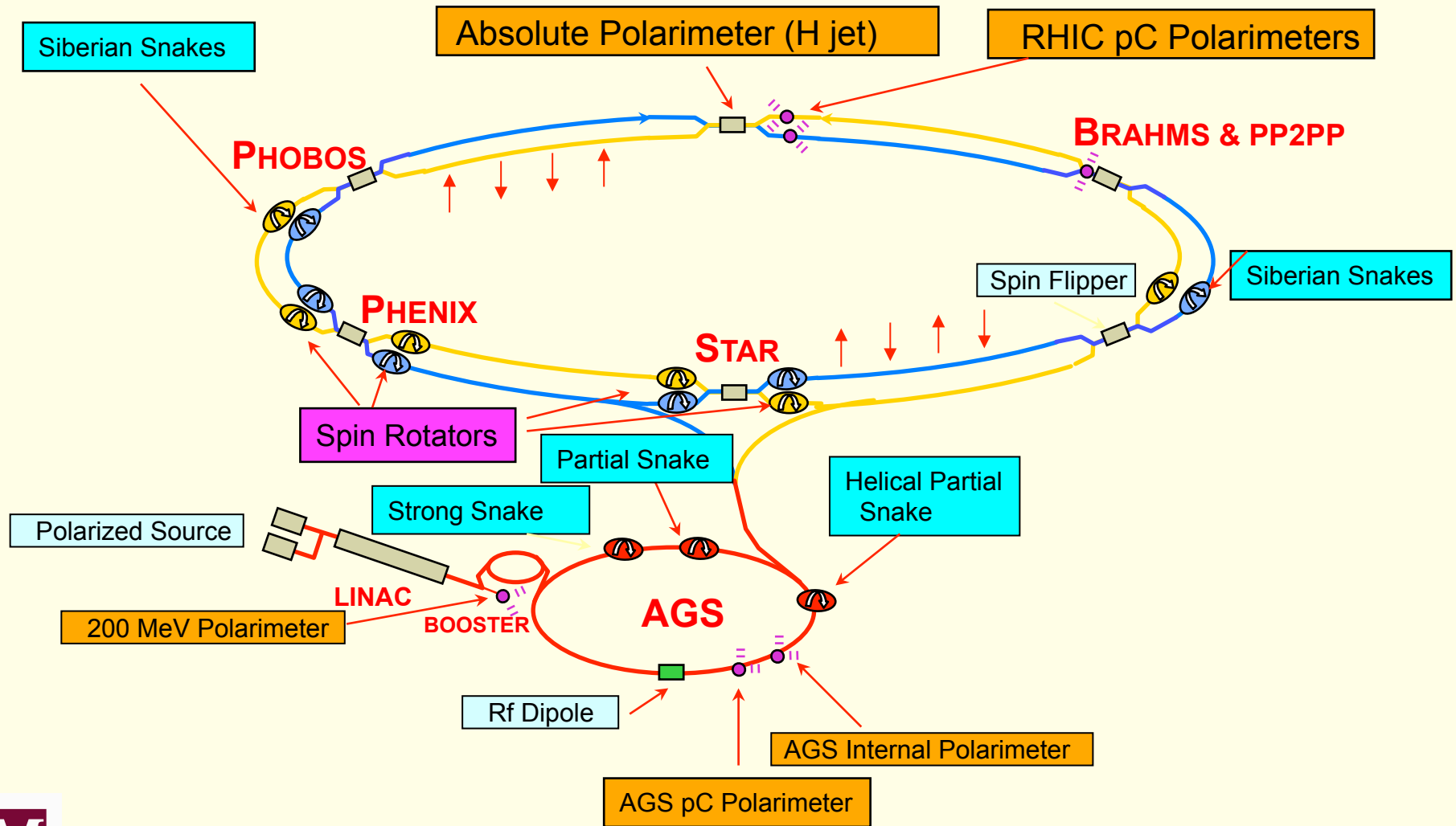
Quark transverse spin distribution Collins FF (final state)



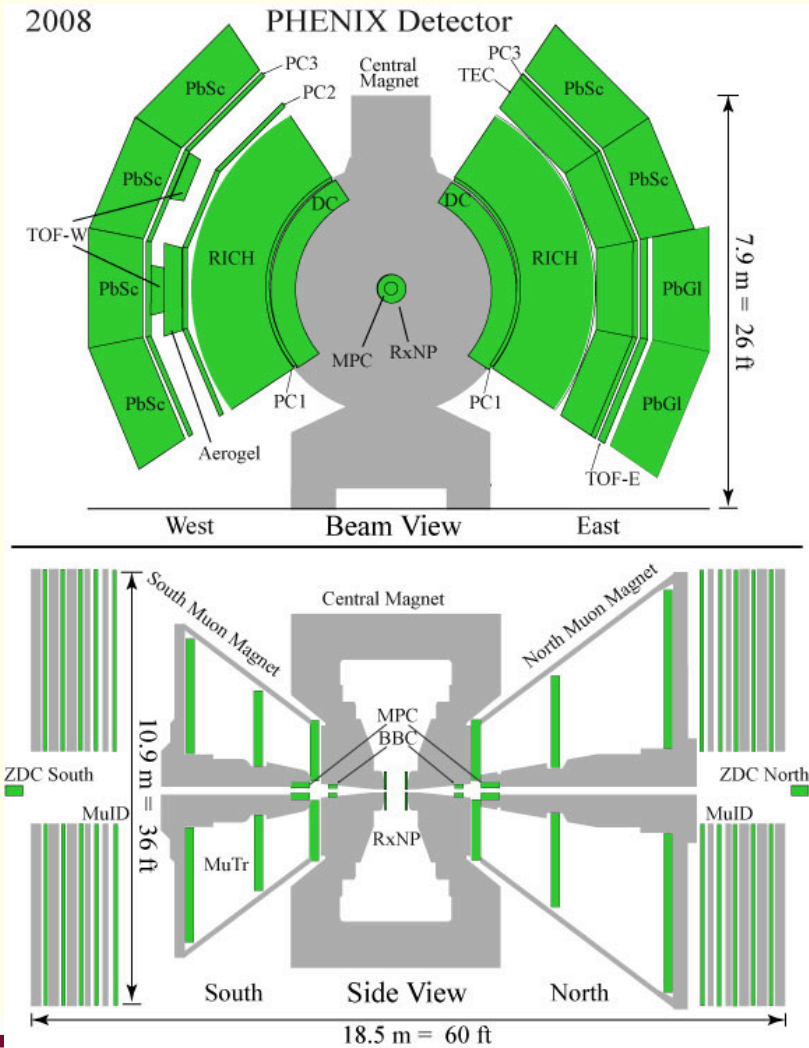
J. C. Collins, Nucl. Phys. **B396**, 161 (1993)

Twist-3 quark-gluon fragmentation function.

Polarized p+p Collider -- RHIC



The PHENIX Detectors



- **Central Arm** $|\eta| < 0.35, x_F \sim 0$
 - Identified charged hadrons
 - π^0 and η meson, direct photon
 - J/ψ , heavy flavor

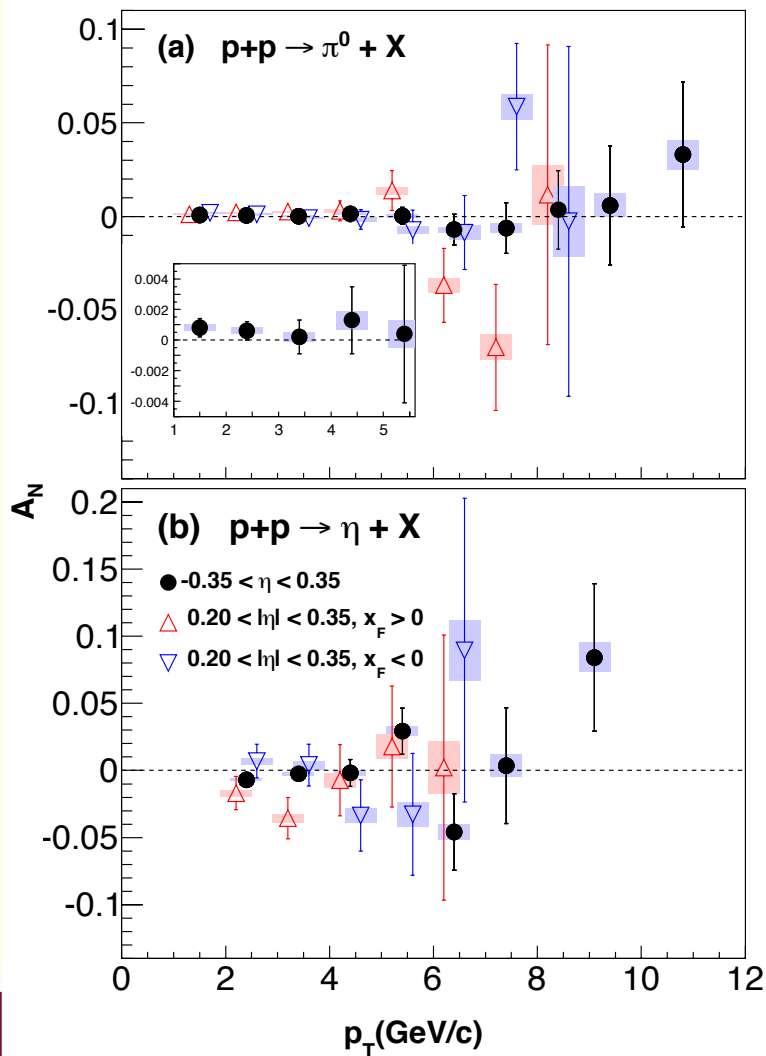
- **Forward Muon Piston Calorimetry**
MPC $3.1 < |\eta| < -3.9$
 - π^0 and η meson,
 - single Cluster

- **Global Detectors (Luminosity, Trigger)**
 - BBC $3.0 < |\eta| < 3.9$
 - ZDC/SMD (Local Polarimeter)

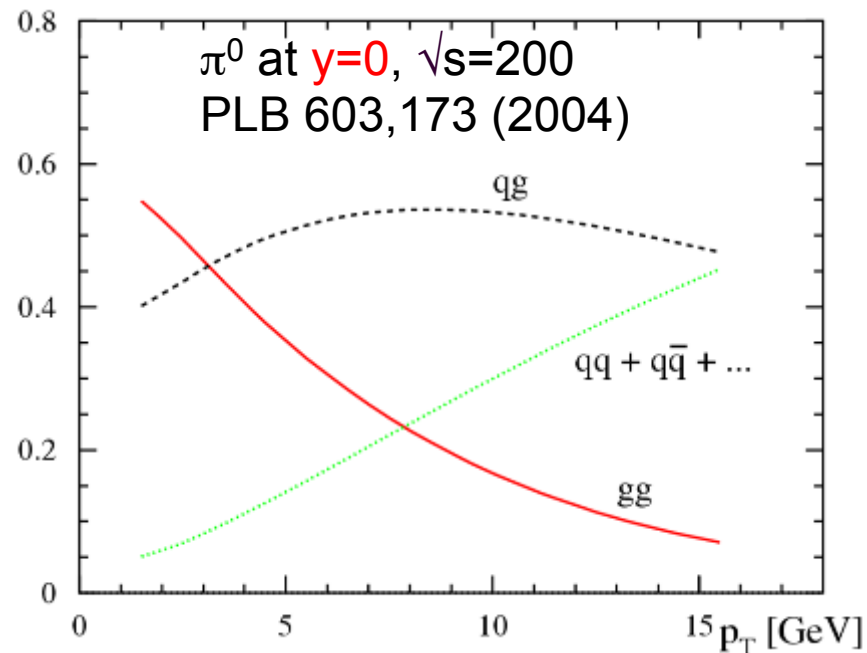
- **Forward Muon Arms** $1.2 < |\eta| < 2.4$
 - unidentified charged hadrons
 - J/ψ , heavy flavor

Central Arm π^0 and η A_N at $\sqrt{s} = 200$ GeV

p+p $\sqrt{s}=200$ GeV



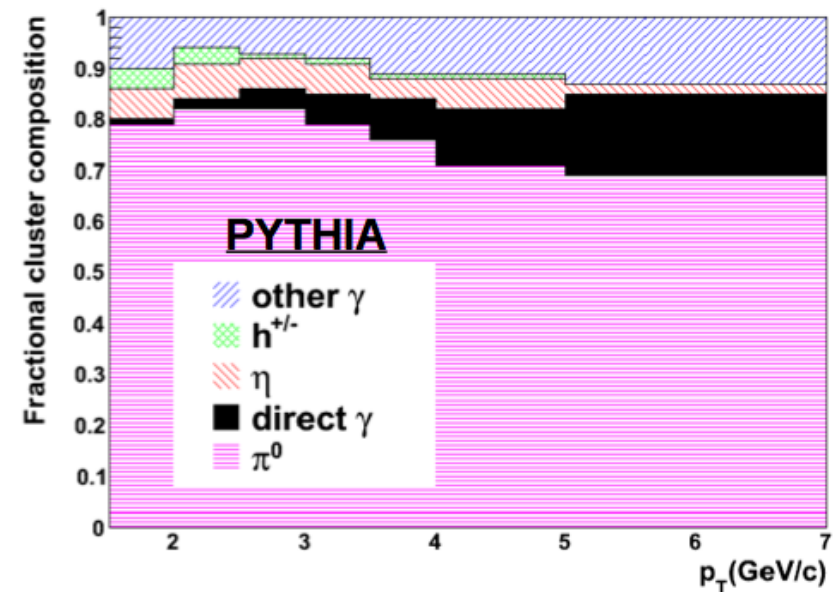
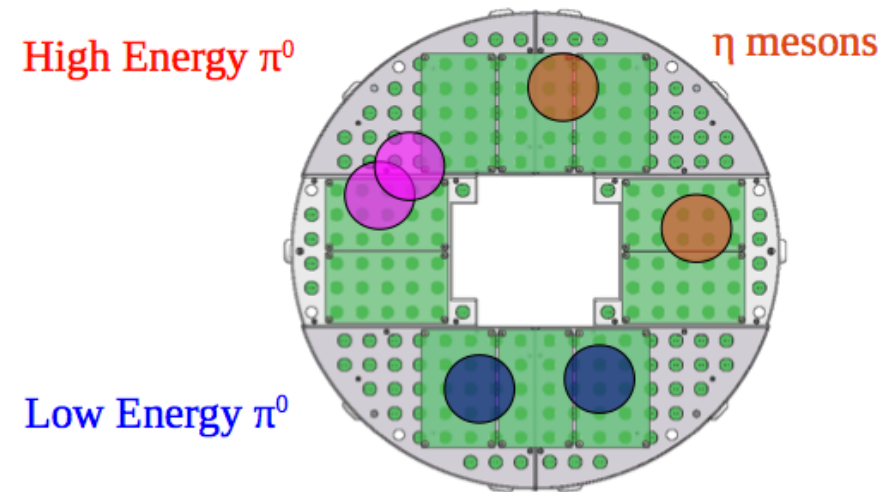
PHENIX collaboration: PRD90, 012006 (2014)



- sensitive to qg and gg scattering
- A_N are consistent with zero for both π^0 and η mesons

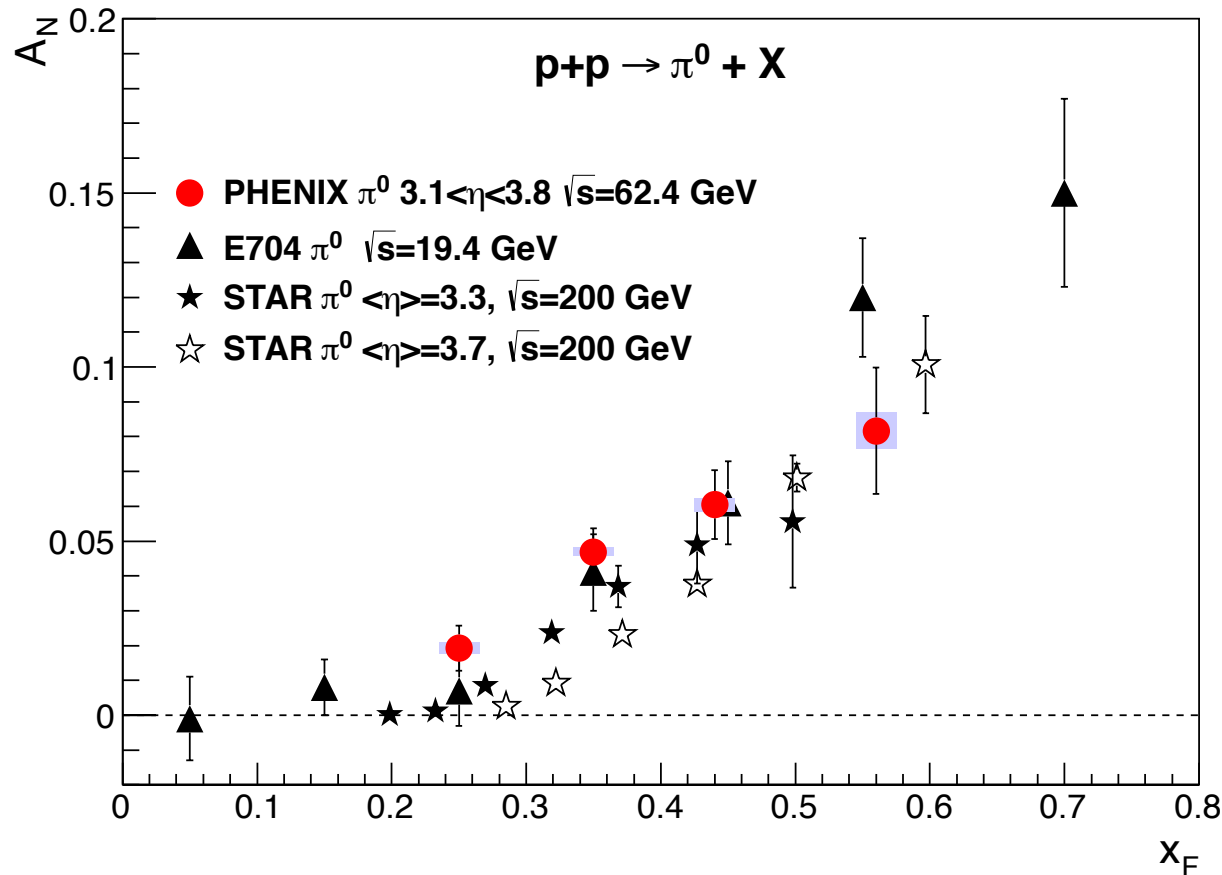
Muon Piston Calorimeter (MPC)

- MPC is forward EM calorimeter.
 - $2.2 \times 2.2 \times 10 \text{ cm}^3$ PbWO_4
 - 2.2m from collision point
- Capability of MPC detector
 - Low energy π^0 ($\gamma\gamma$) 7-20GeV
 - η meson ($\gamma\gamma$), 7-20GeV
- Photon merging effects are significant for $E > 20 \text{ GeV}$ ($p_T > 2 \text{ GeV}/c$)
 - 62.4GeV: two photon π^0 Analysis
 - 200GeV: merged single cluster
- Dominant cluster process at high p_T from PYTHIA simulation
 - π^0 are the dominant source
 - Sizable increase from direct γ



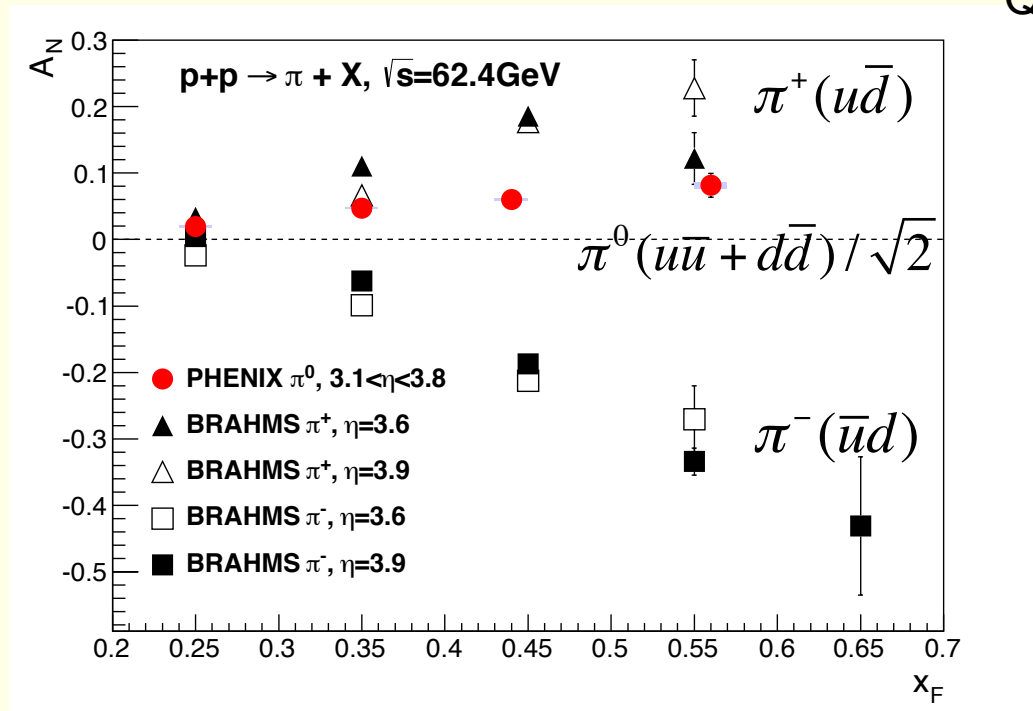
Forward π^0 A_N at $\sqrt{s} = 62.4$ GeV

- Compared to other π^0 A_N measurements, A_N for π^0 is not strongly dependent on collision energy from 19.6 to 200 GeV



Isospin comparison of πA_N

- Compared to charged πA_N measurements, Origin of A_N can not be explained by initial state effects of quarks (Sivers) alone if we assume u and d quark Sivers function extracted from SIDIS



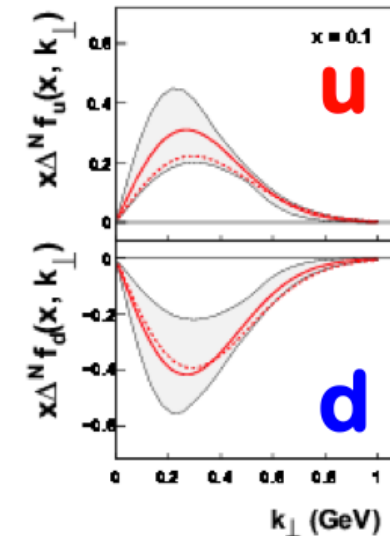
Quark origins of π from PYTHIA

$$u \rightarrow \pi^+ / d \rightarrow \pi^+ : 100 / 0$$

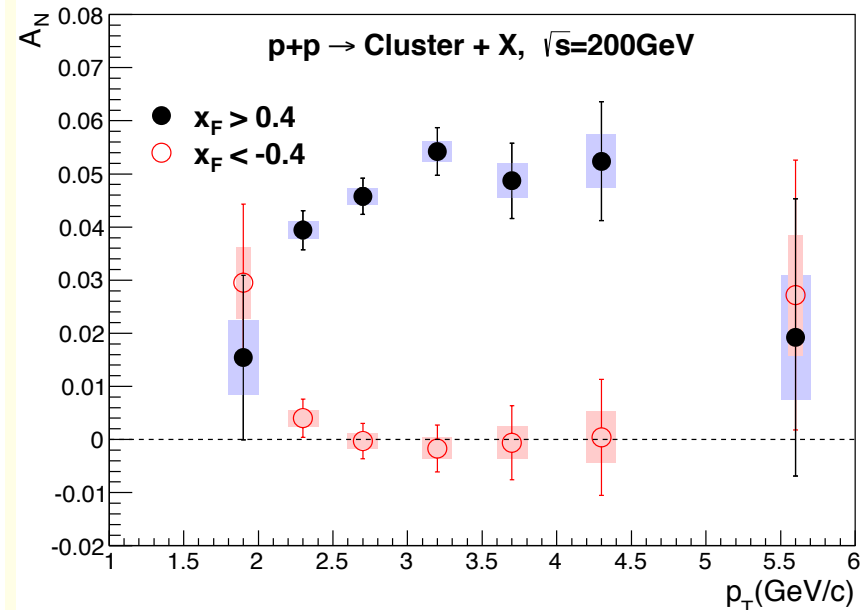
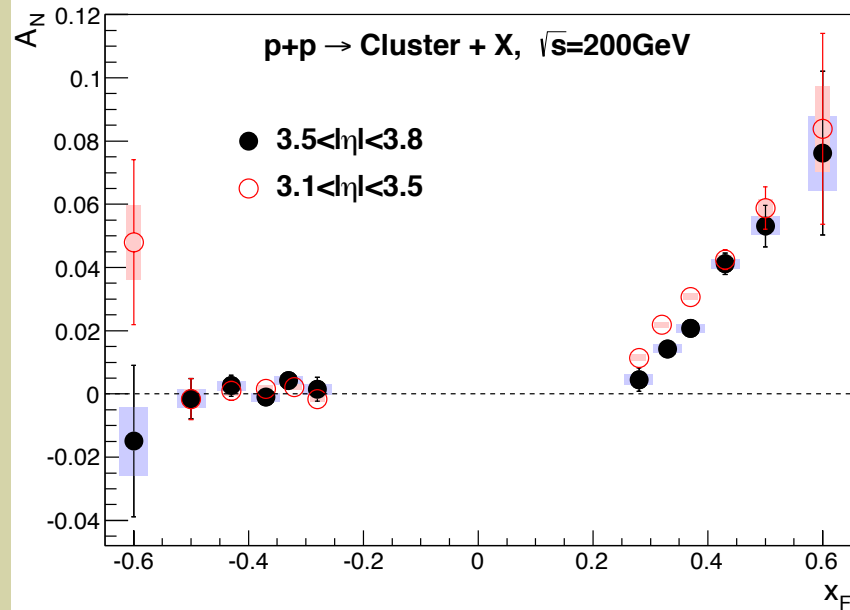
$$u \rightarrow \pi^0 / d \rightarrow \pi^0 : 75 / 25$$

$$u \rightarrow \pi^- / d \rightarrow \pi^- : 50 / 50$$

Sivers



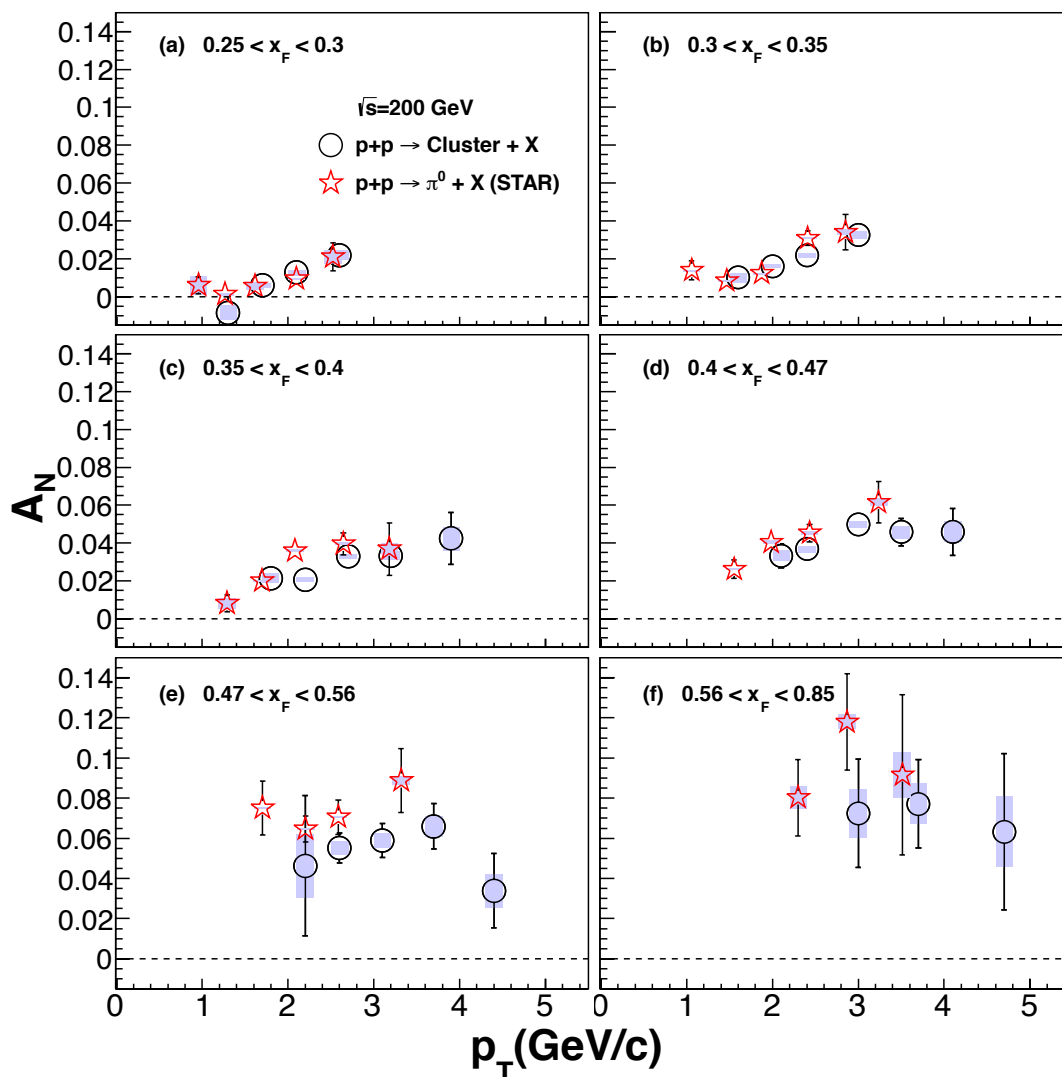
Forward A_N for EM Cluster at $\sqrt{s} = 200$ GeV



A significant asymmetries observed at forward rapidity, but not at backward rapidity

A significant decrease of the asymmetry as expected from higher twist calculations is not conclusive.

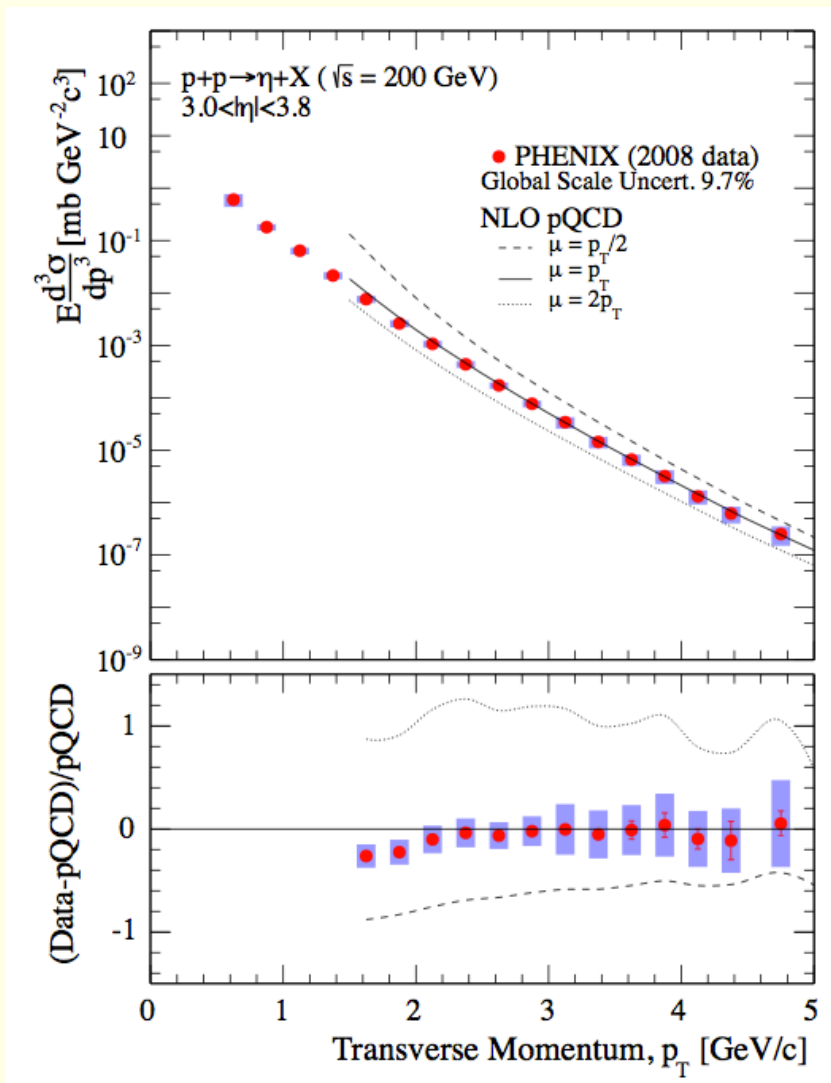
Comparison of Cluster with STAR π^0



□ $x_F < 0.4$
 Good agreement

□ $x_F > 0.4$
 Statistically limited, but
 there is a possible
 difference between
 clusters and π^0 's, leaving
 room for some direct
 photon contribution.

Forward η Cross Section at $\sqrt{s} = 200$ GeV

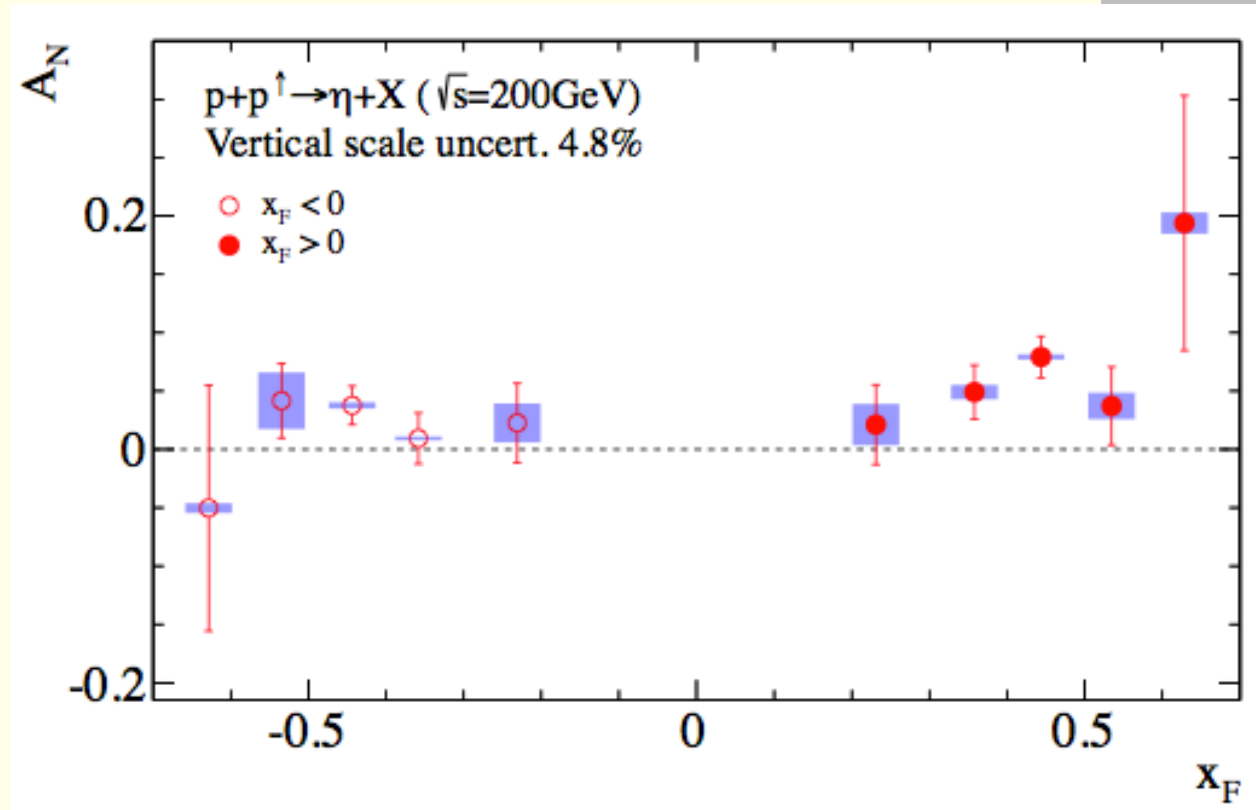


PHENIX collaboration, arxiv:1406.3541

$p_T > 2$ GeV/c: the NLO pQCD calculation is in a very good agreement with the measured cross section.

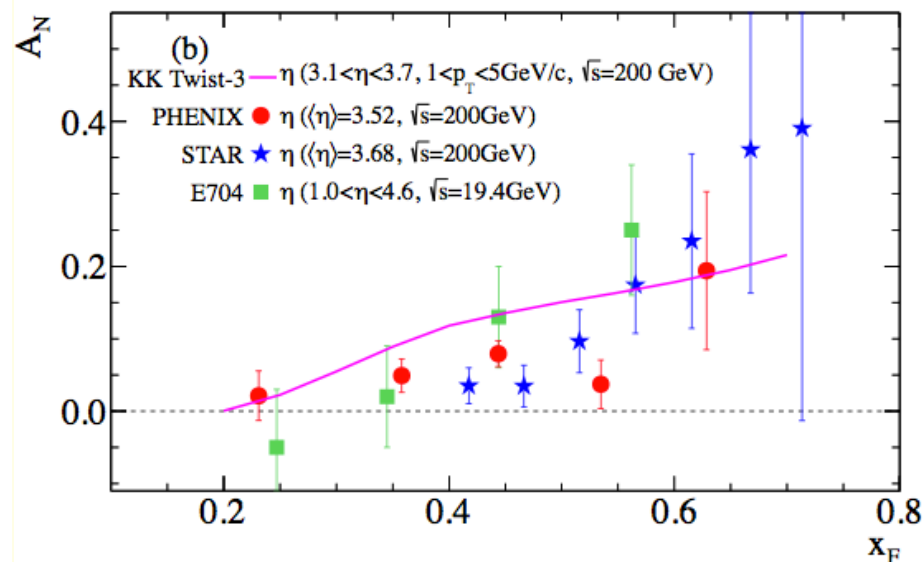
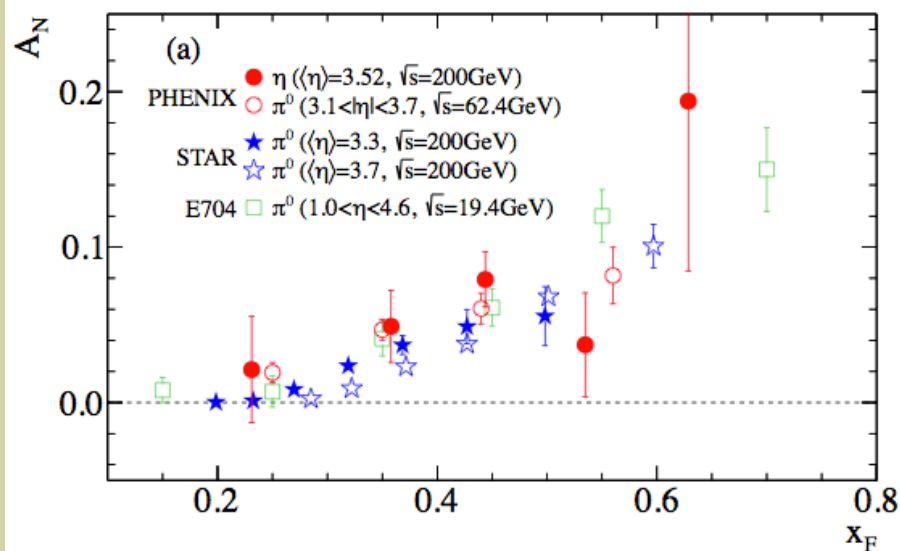
$p_T < 2$ GeV/c: the agreement between NLO pQCD and data is less clear, but well within the factorization uncertainty

Forward η A_N at $\sqrt{s} = 200$ GeV



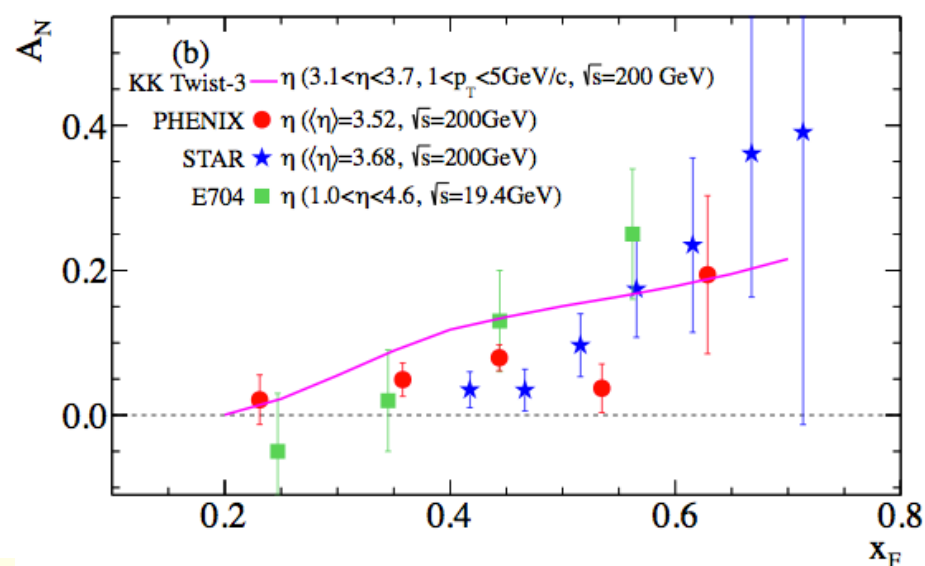
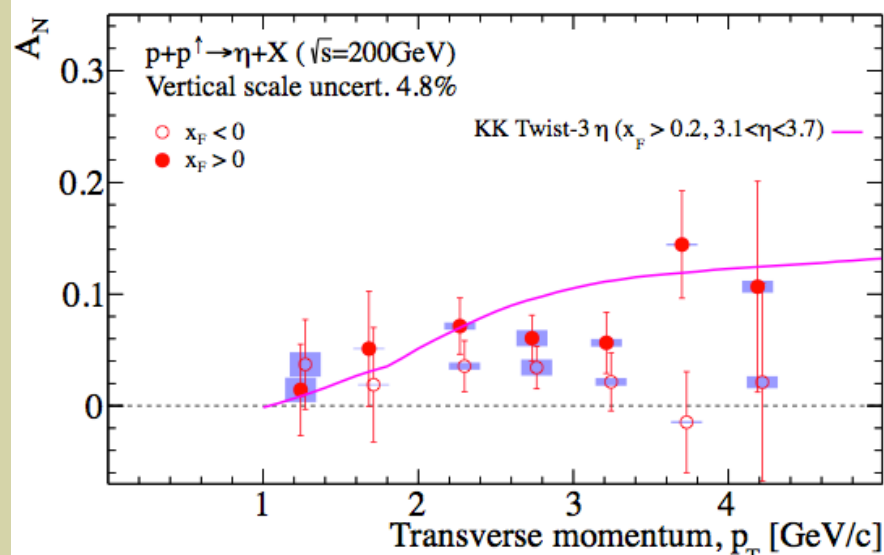
- Forward x_F : non-zero asymmetry from 2-20% over the measured x_F range.
- Backward x_F : A_N is flat and consistent with zero.

Comparison with π_0 meson A_N and other data



- ☐ PHENIX η meson A_N is consistent with π_0 meson A_N
- ☐ PHENIX η meson A_N is consistent with STAR and E704 η meson A_N measurement within uncertainty.

Forward η A_N compare with twist-3



- ❑ PHENIX measurement is consistent with Twist-3 calculation at low, high x_F (p_T), Less agreement at mid x_F (p_T)
- ❑ More developments in theoretical framework are underway.
D. Pitonyak, Y. Koike (ArXiv:1404.1033)

Summary and Outlook

- PHENIX measured A_N for π^0 meson at 62.4 GeV, single and η meson A_N at 200 GeV.
 - Observed non-zero A_N for π^0 , cluster and η meson at forward rapidity. Their magnitude are similar.
 - Single cluster A_N shows possible hint of direct photon A_N at high x_F
 - PHENIX forward π^0 together with BRAHMS charged π A_N suggests origin of A_N can not be explained by Sivers alone, if u and d Sivers from SIDIS holds in $p\uparrow+p \rightarrow \pi + X$.
- PHENIX also measured η meson cross section, it compliments our existing π^0 cross section results.
- Outlook: RHIC will run transverse p + p and p + A in 2015, PHENIX plan to measure direct γ with MPC-EX, it will give us rich understanding of forward SSA. [Talked by X. Jiang, S5, Monday](#)