

# PHENIX Forward Transverse Spin Measurements

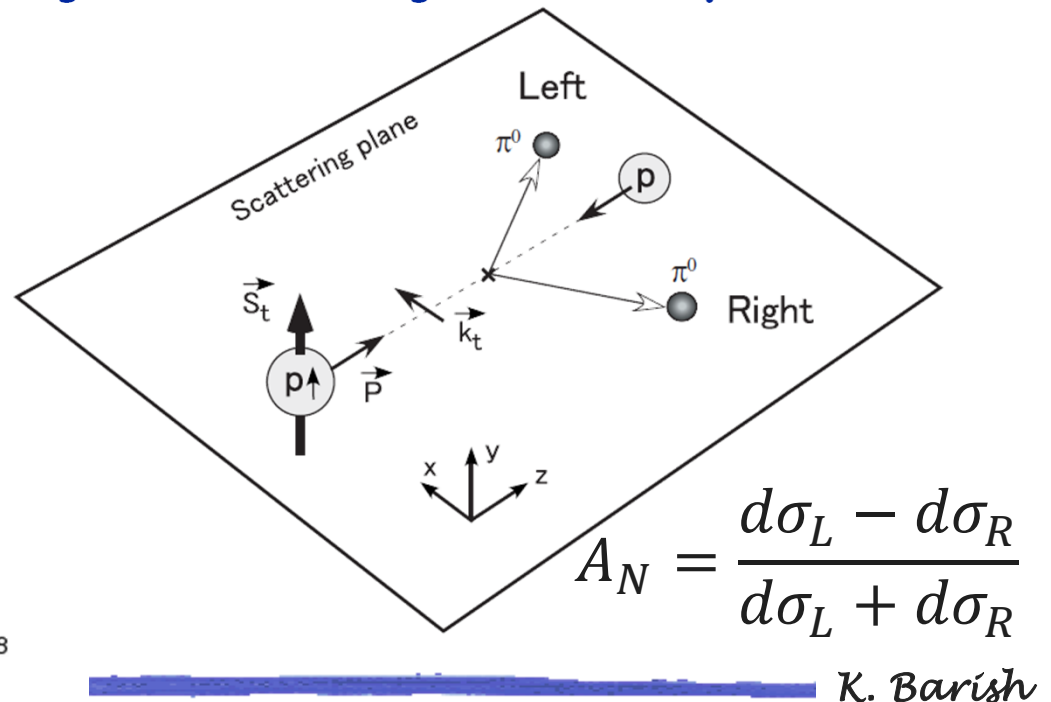
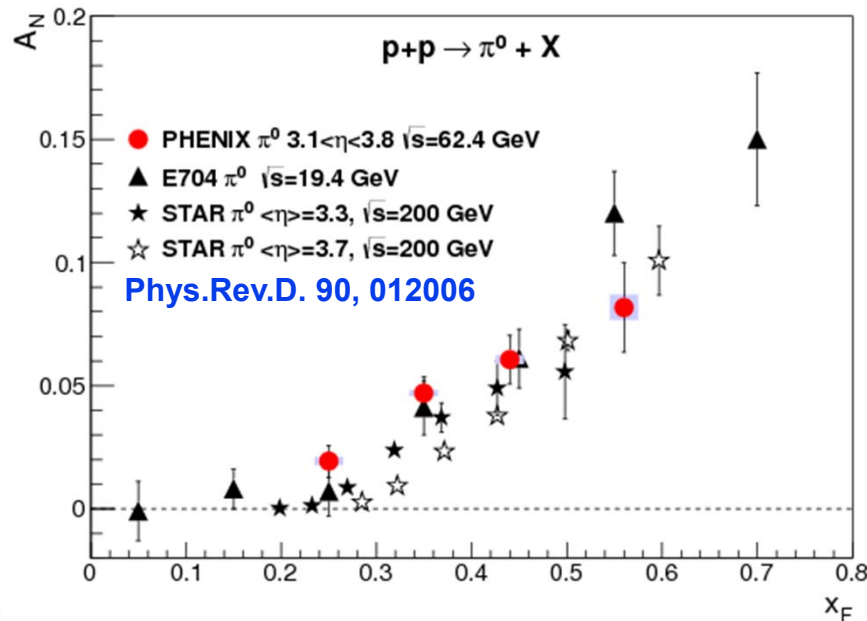
Kenneth N. Barish  
for the  
PHENIX Collaboration



XXIII. International Workshop on Deep-  
Inelastic Scattering and Related Subjects  
Dallas, Texas April 27-May 1, 2015

# Transverse Spin Asymmetries

- The persistence of large transverse asymmetries at RHIC energies, where collinear pQCD describes the cross-sections well, was a surprise.
- The transverse structure of the nucleon is largely unknown
- Large transverse asymmetries carry potential information about QCD dynamics beyond 1-D picture



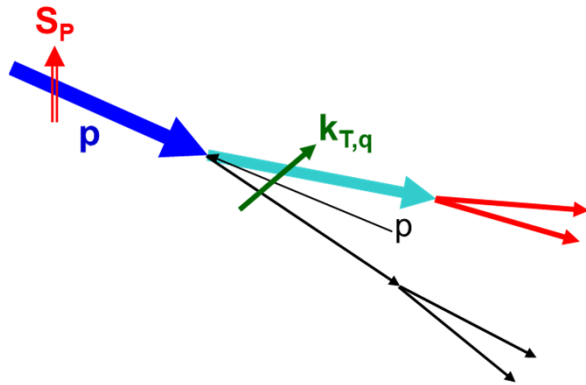
# Transverse Spin Asymmetry Sources

## (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)

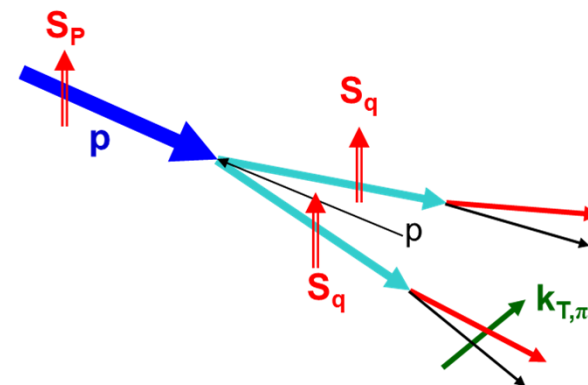
Twist-3 quark-gluon/gluon-gluon correlators in polarized hadron.

## (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



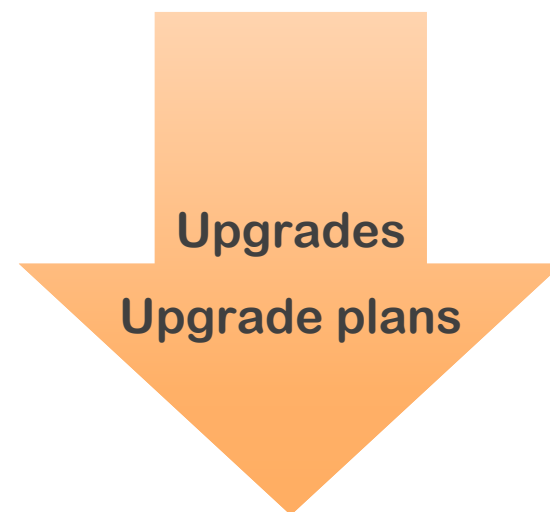
J. C. Collins, Nucl. Phys. **B396**, 161 (1993)

Twist-3 quark-gluon fragmentation function.

# Transverse Spin Measurements

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- **Inclusive  $A_N$  (central/forward)**
  - Central  $\pi^0, \eta$
  - Forward  $\pi^0, \eta, \mu, J/\psi$
- Photon  $A_N$  (MPC-EX)
- Jet correlations/structure, DY (fsPHENIX)



# The PHENIX Detector

## Central Arms

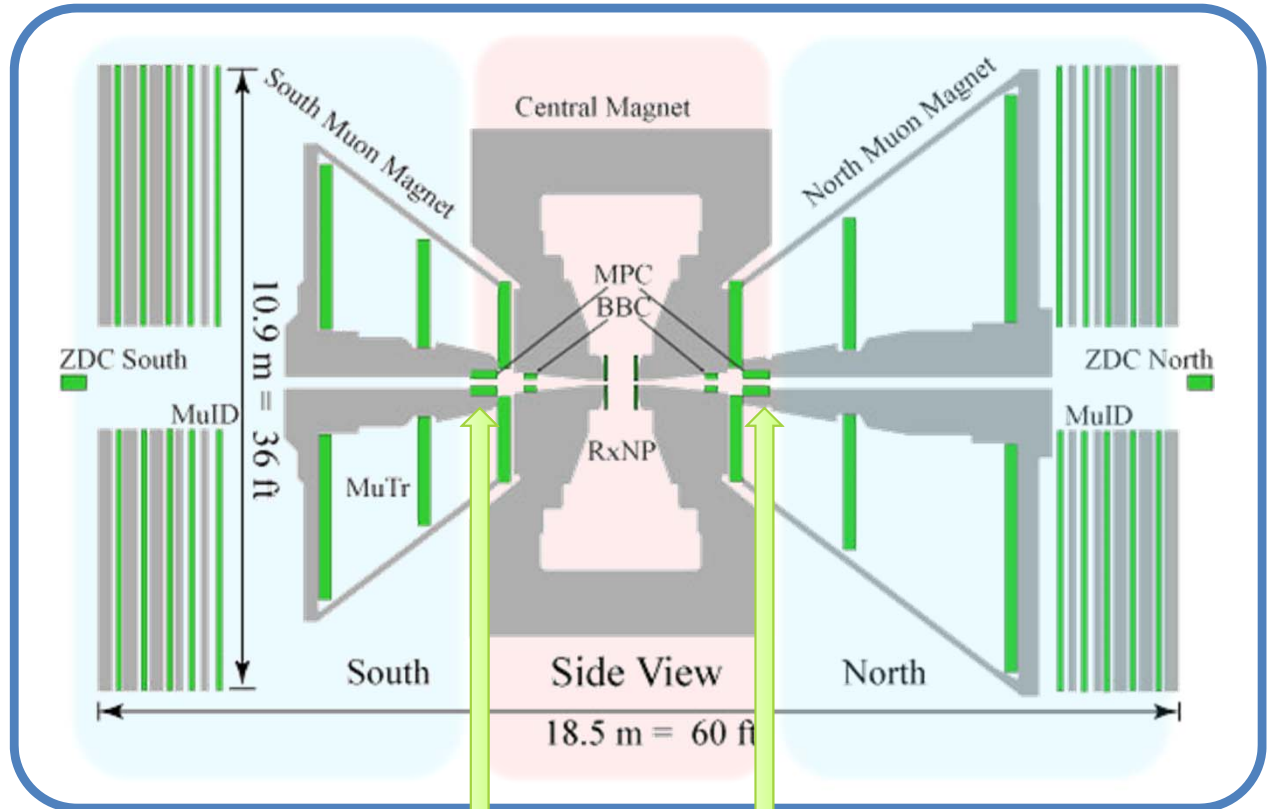
$$|\eta| < 0.35$$

- ❖ charged hadrons
- ❖  $\pi^0, \eta$
- ❖ direct photon
- ❖  $J/\psi$
- ❖ heavy flavor

## Muon Arms

$$1.2 < |\eta| < 2.4$$

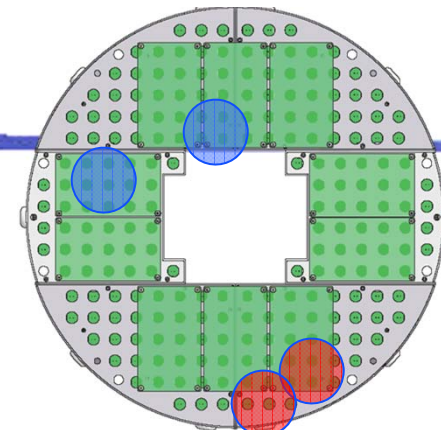
- ❖  $J/\psi$
- ❖ charged hadrons
- ❖ heavy flavor



MPC  $3.1 < |\eta| < 3.9$

- ❖  $\pi^0, \eta$

# MPC detectors



tower size  $2.25^2 \text{ cm}^2$   
220 cm from vertex

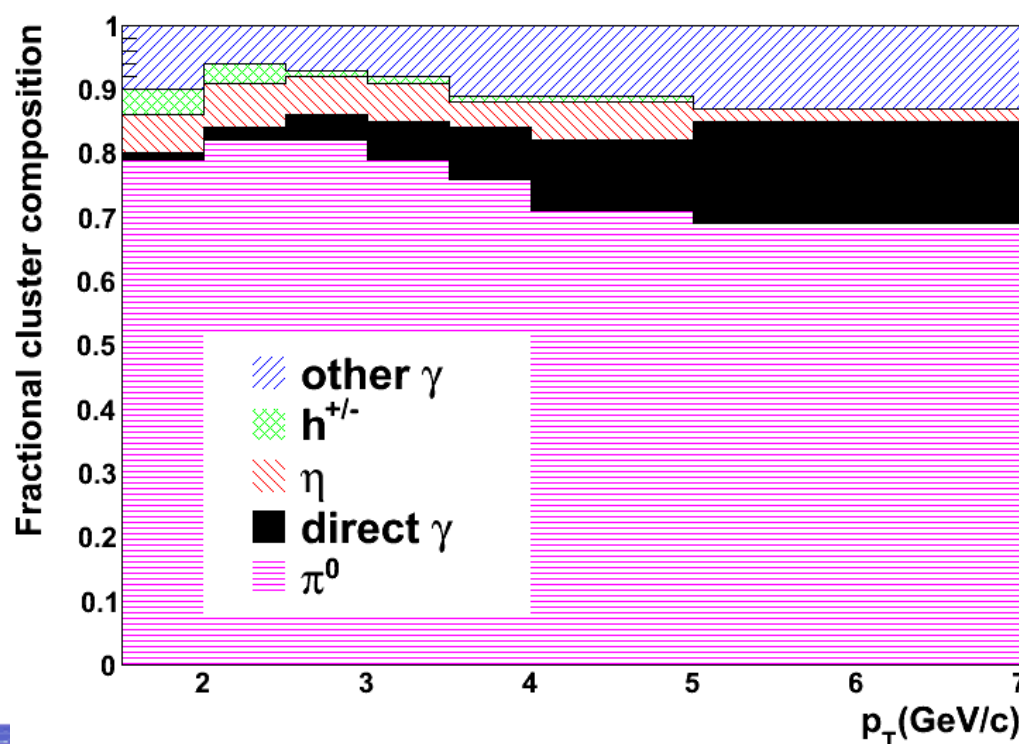
- **Lead-tungstate EMCal ( $3.1 < |\eta| < 3.8$ )**
  - » Enables measurements of forward  $\pi^0$  and  $\eta$  mesons

- **Photon merging effects significant for  $E > 20 \text{ GeV}$  ( $p_T > 2 \text{ GeV/c}$ )**

- » For  $\sqrt{s} = 62 \text{ GeV}$ ,  $20 \text{ GeV} \rightarrow 0.65 x_F \Rightarrow$  two photon  $\pi^0$  analysis
- » For  $\sqrt{s} = 200 \text{ GeV}$ ,  $20 \text{ GeV} \rightarrow 0.20 x_F \Rightarrow$  “Single clusters”

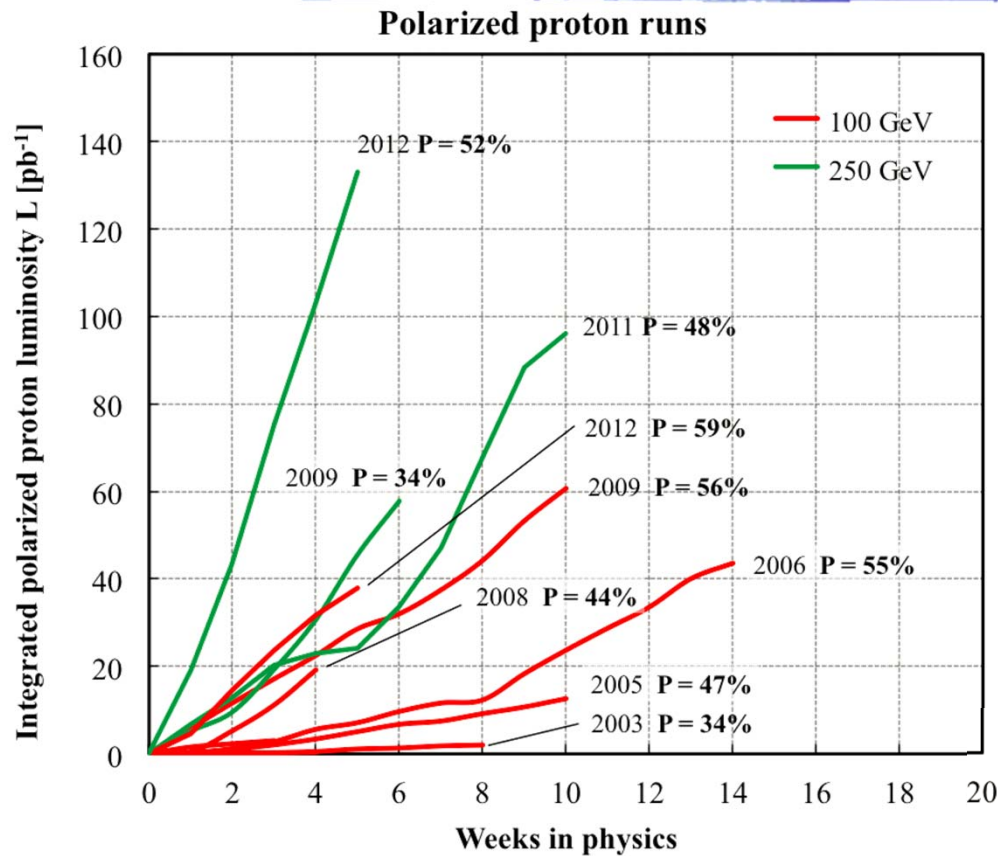
- **Single Clusters**

- »  $\pi^0$ 's are dominant source.
- » With increasing  $p_T$ , there is a sizable increase in contributions from direct and other photons.



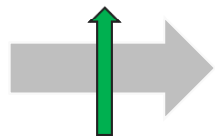


# Polarized Protons at RHIC-PHENIX



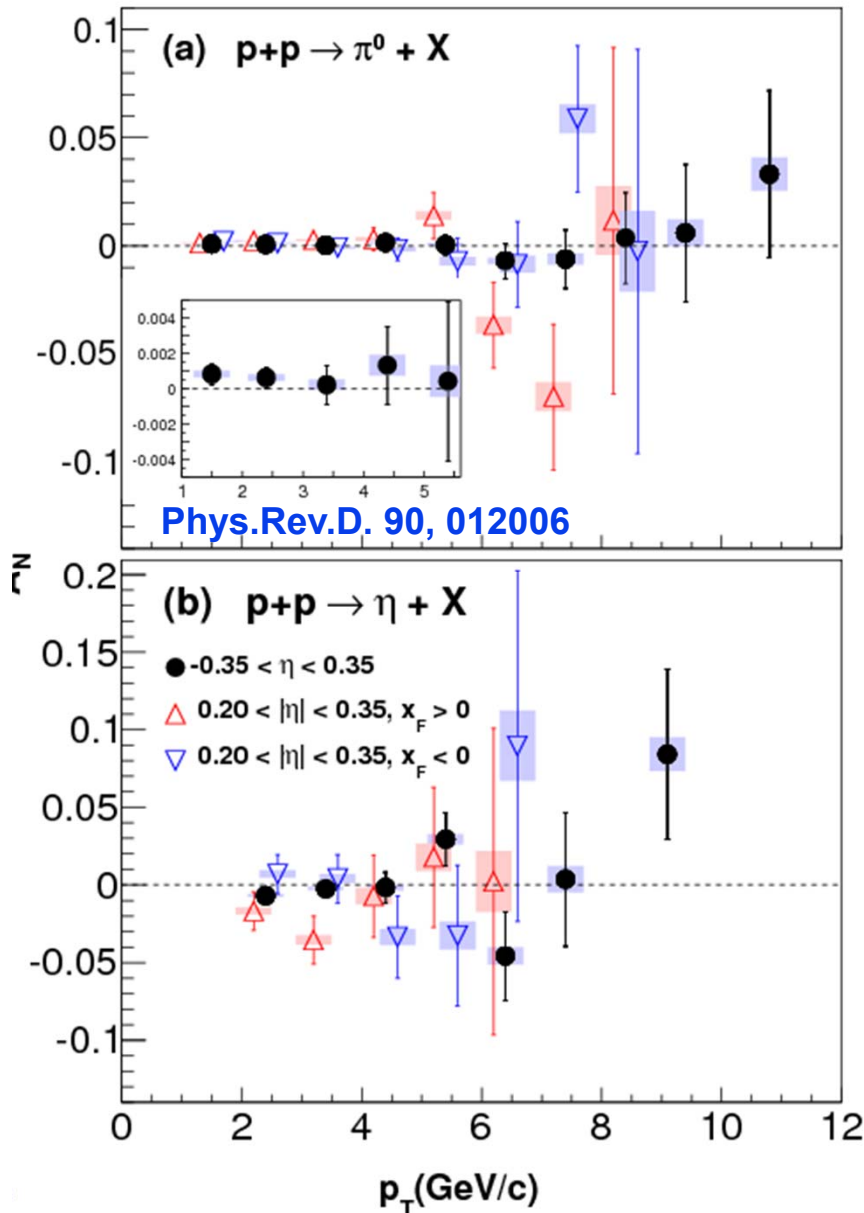
## Transverse Data

Year	$\sqrt{s}$ (GeV)	$L$ ( $\text{pb}^{-1}$ )	P	FoM ( $P^2L$ )
2006	62.4	0.02	48%	0.0046
2006	200	2.7	51%	0.7
2008	200	5.2	46%	1.1
2012	200	9.2	58%	3.1

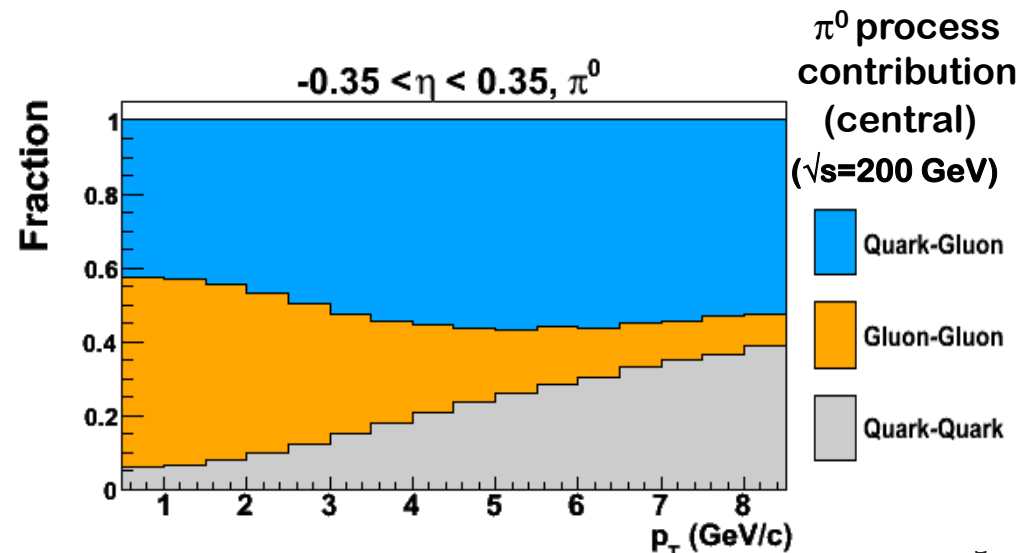


# $A_N$ : mid-rapidity $\pi^0$ and $\eta$

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



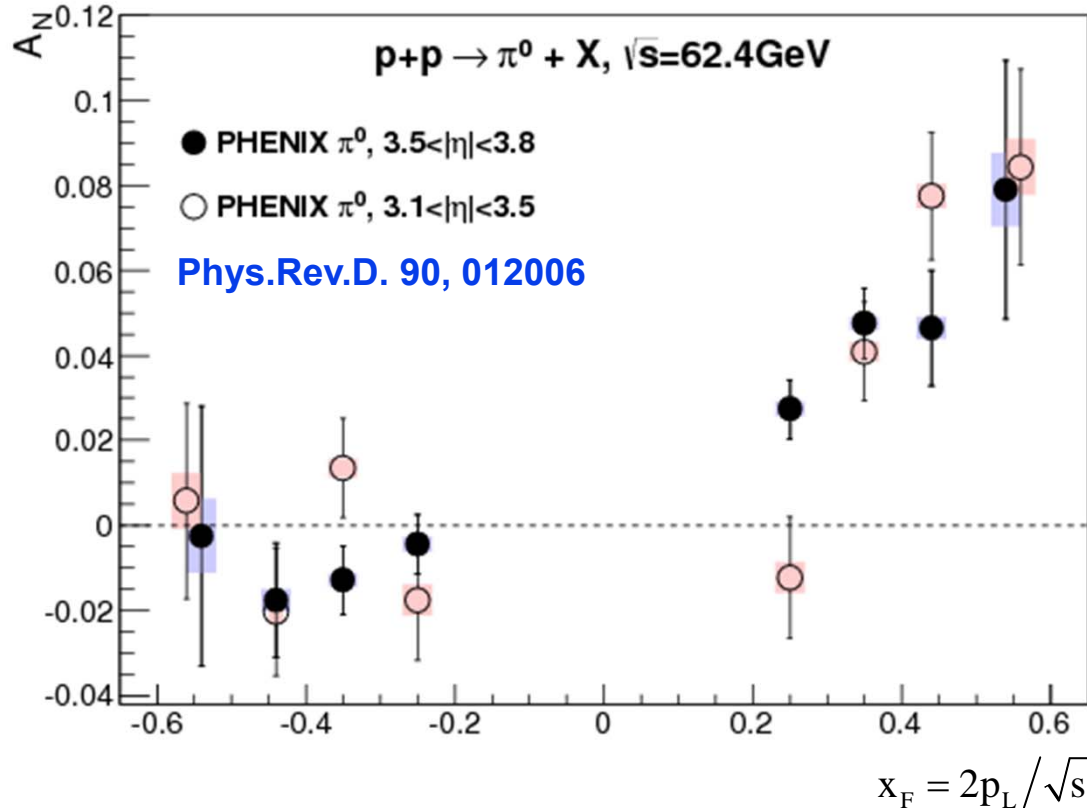
- $\pi^0$  asymmetries consistent with zero observed over a wide  $p_T$  range
- Exceed precision of previous publication (Phys. Rev. D 74, 094011) by a factor of 20 and extends  $p_T$  range.
- Constrains gluon Sivers
- $\eta$  asymmetries are also consistent with zero.



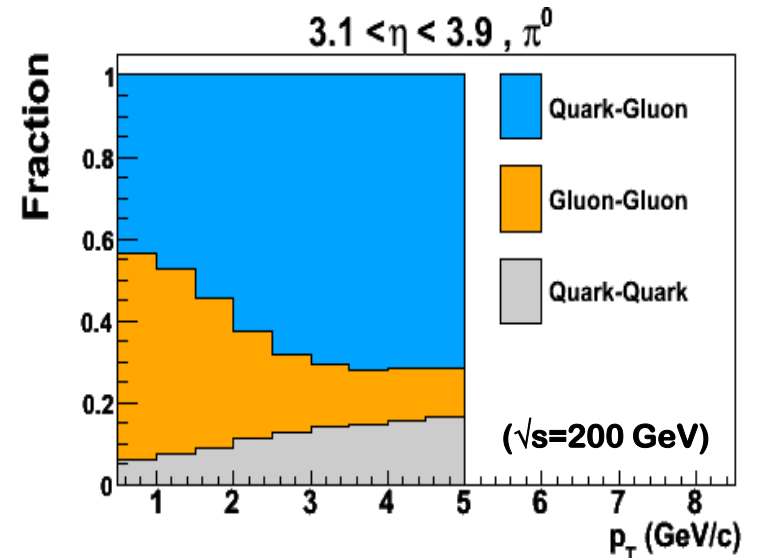
K. Barish



# Forward $\pi^0$ $A_N$ (62.4 GeV)

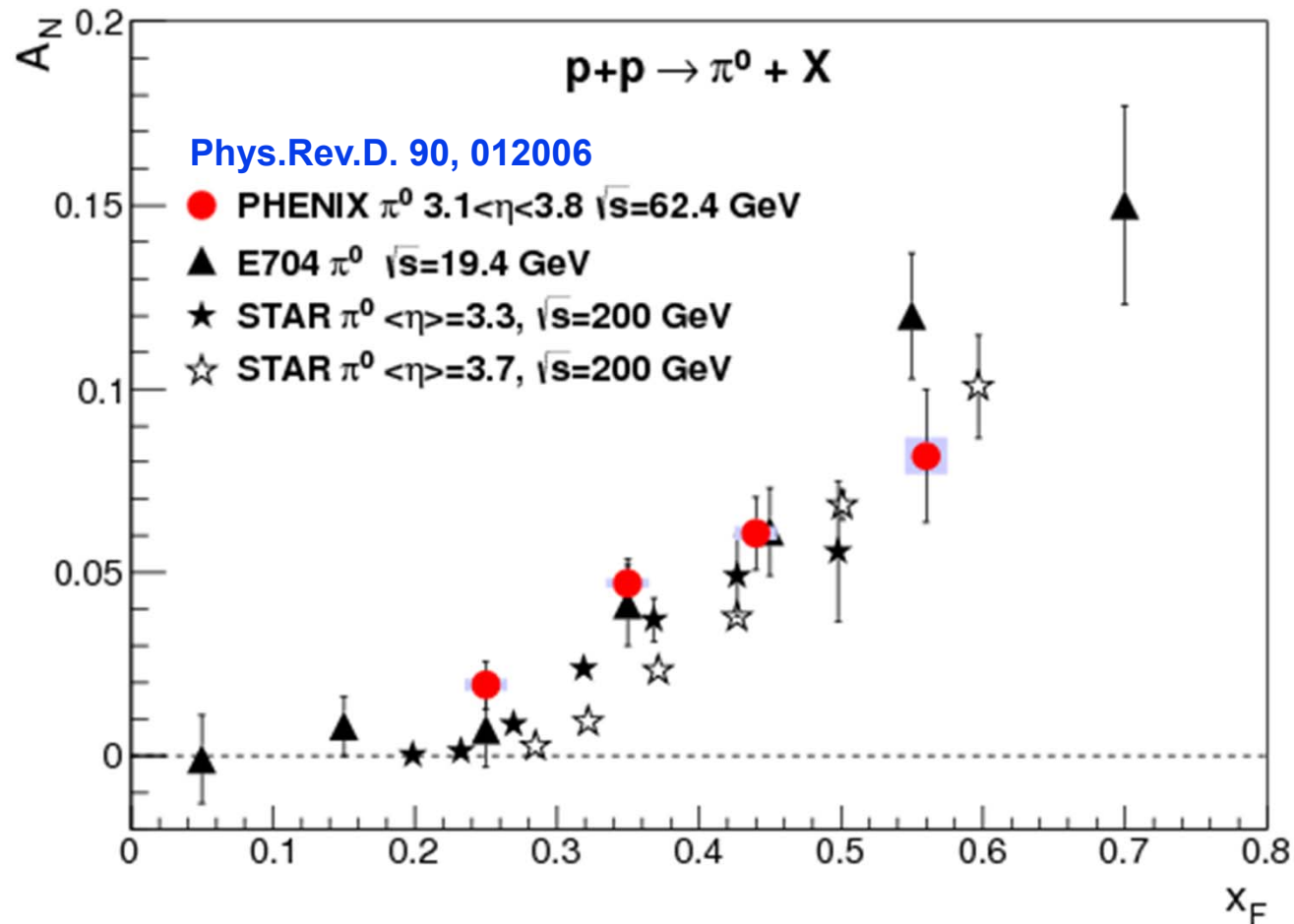


$\pi^0$  process contribution  
in PHENIX forward arms



- Significant asymmetries for  $x_F > 0$  (~ linear for  $x_F > 0.2$ )
- $A_N$  consistent with zero for  $x_F < 0$
- Quark-gluon is the dominant partonic component.

# Forward $\pi^0$ $A_N$ $\sqrt{s}$ dependence

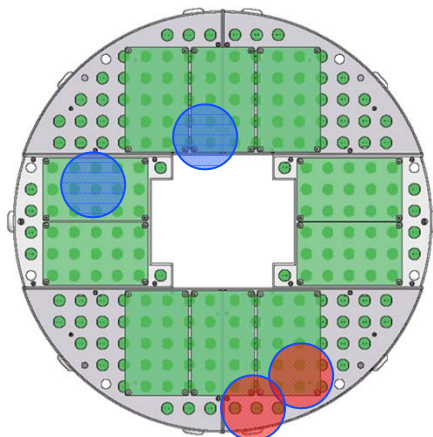


- Sizable forward non-zero asymmetries
- No dependence on  $\sqrt{s}$  apparent from 19.6 GeV to 200 GeV
- Note: slight differences in pseudorapidity and/or  $p_T$

# Forward $A_N$ for EM Clusters

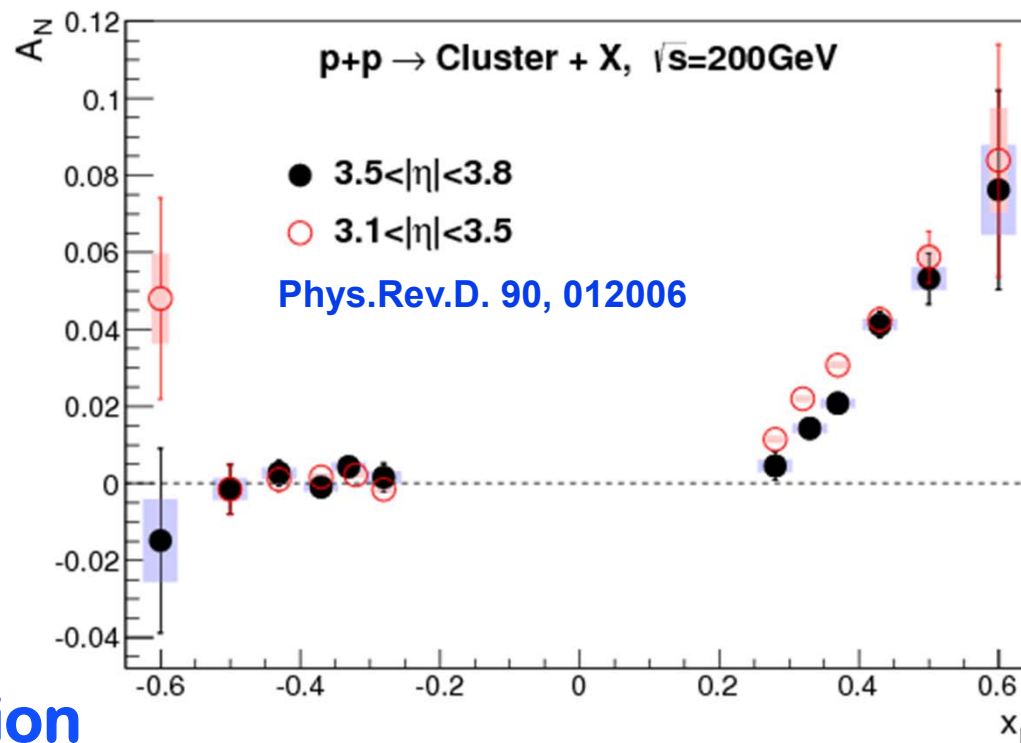
## MPC

tower size  $2.25^\circ \text{ cm}^2$   
220 cm from vertex

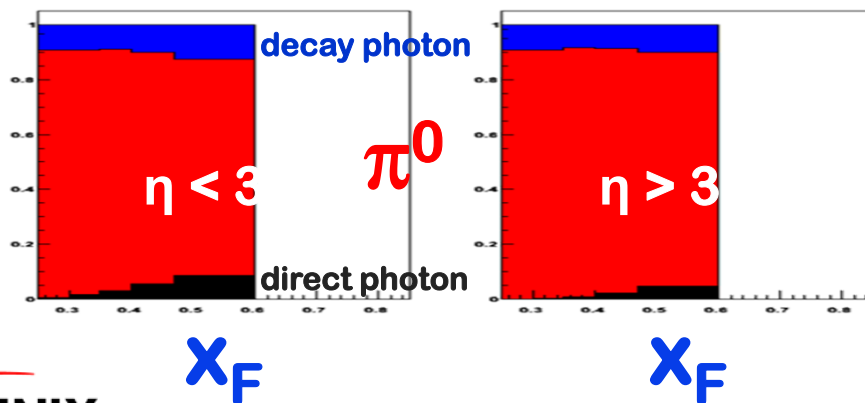


Decay photon impact positions  
for low and high energy  $\pi^0$ 's.

$\sqrt{s} = 200 \text{ GeV}$

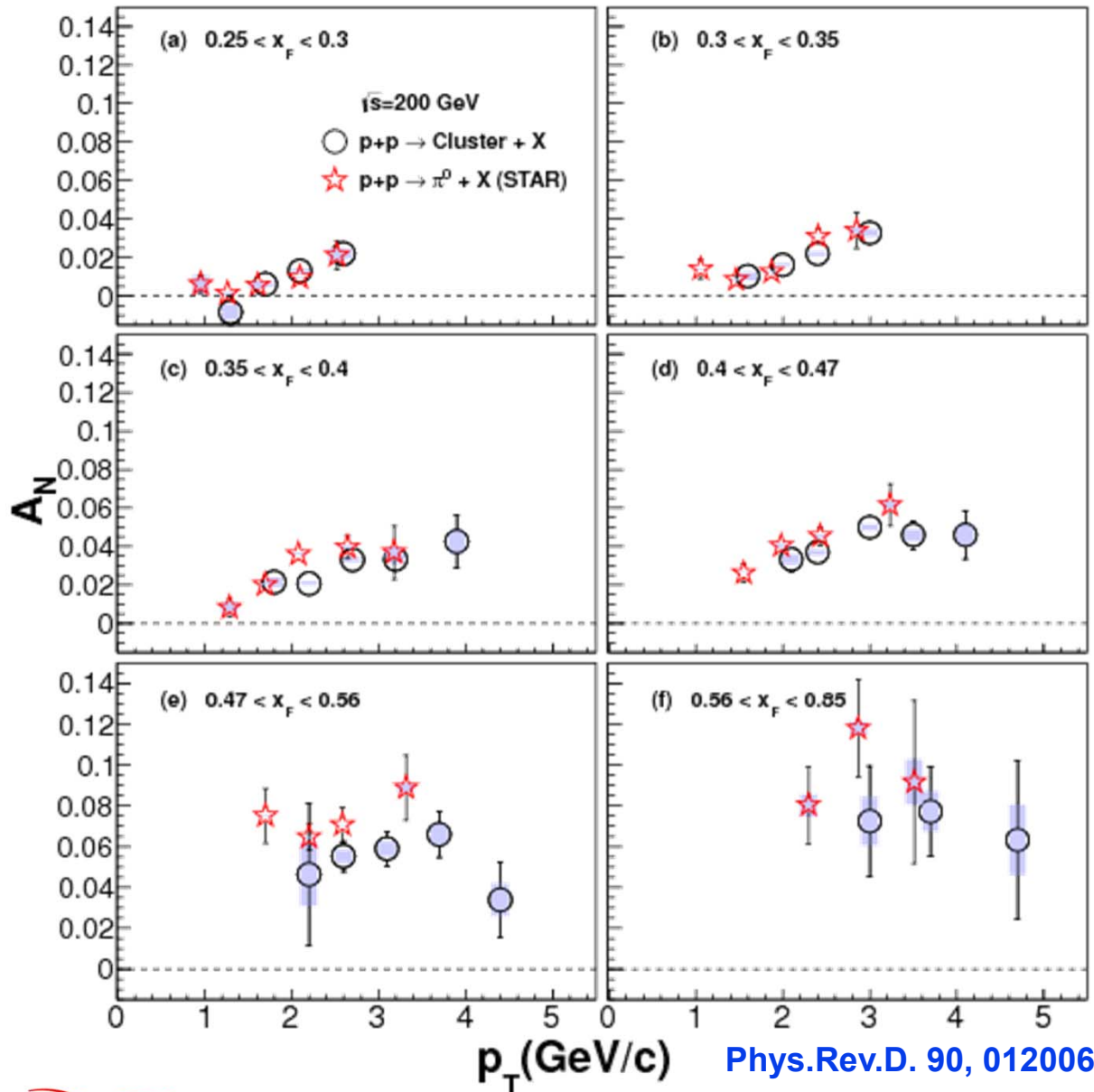


## EM Cluster contribution

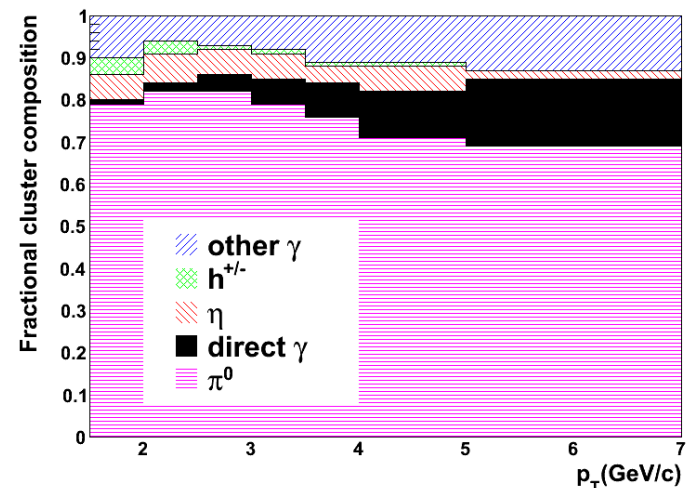


Magnitude of forward  
asymmetries similar to  
E704 (19.4 GeV/c<sup>2</sup>) and  
STAR at (200GeV/c<sup>2</sup>)

# Comparison of clusters with STAR $\pi^0$

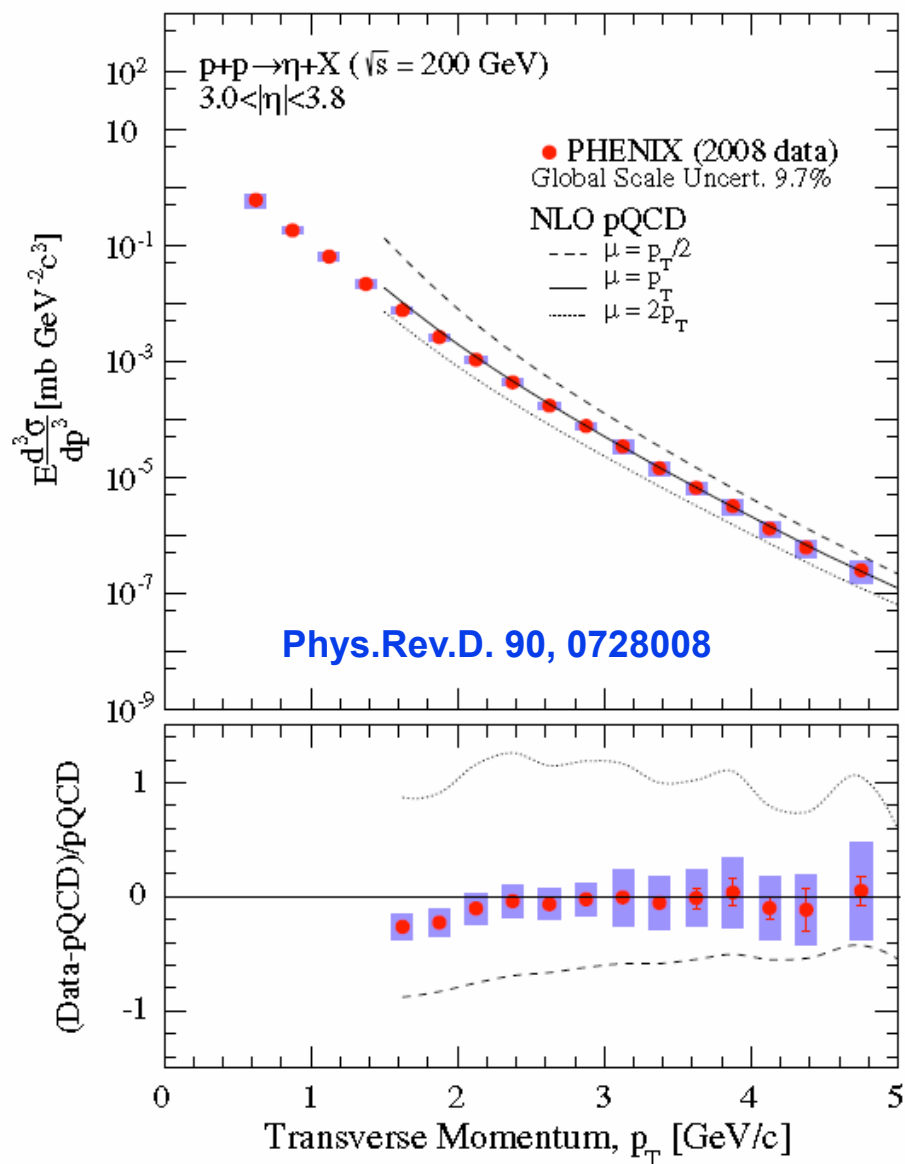


- Good agreement for  $x_F < 0.4$ .
- For  $x_F > 0.4$ , statistically limited, but there is a possible difference between clusters and  $\pi^0$ 's, leaving room a direct photon contribution.

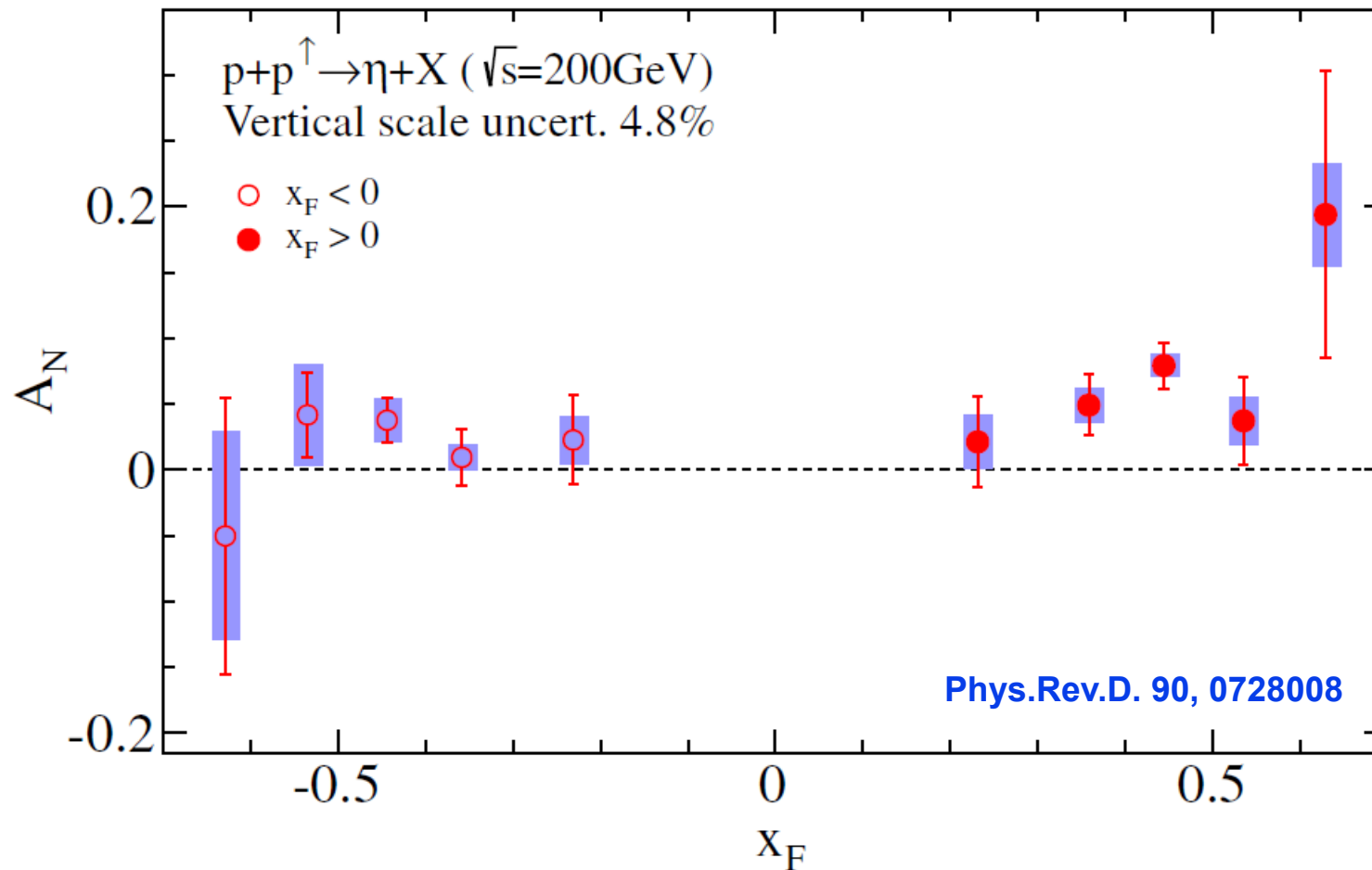


# Forward $\eta$ cross-section

- Consistent with pQCD calculations at a scale of  $\mu=p_T$  consistent with data.
- Can be used to improve constraints on  $\eta$  fragmentation functions.
- pQCD calculations by M. Stratmann (pp $\rightarrow$ hx +  $\eta$  FF)  
PhysRev.D.67, 054005(2003),  
Phys.Rev.D83, 034002 (2011)
- Comparison of  $\pi$ ,  $\eta$ , and K may provide info about initial vs final spin-momentum correlations as well as possible isospin, strangeness, and mass effects



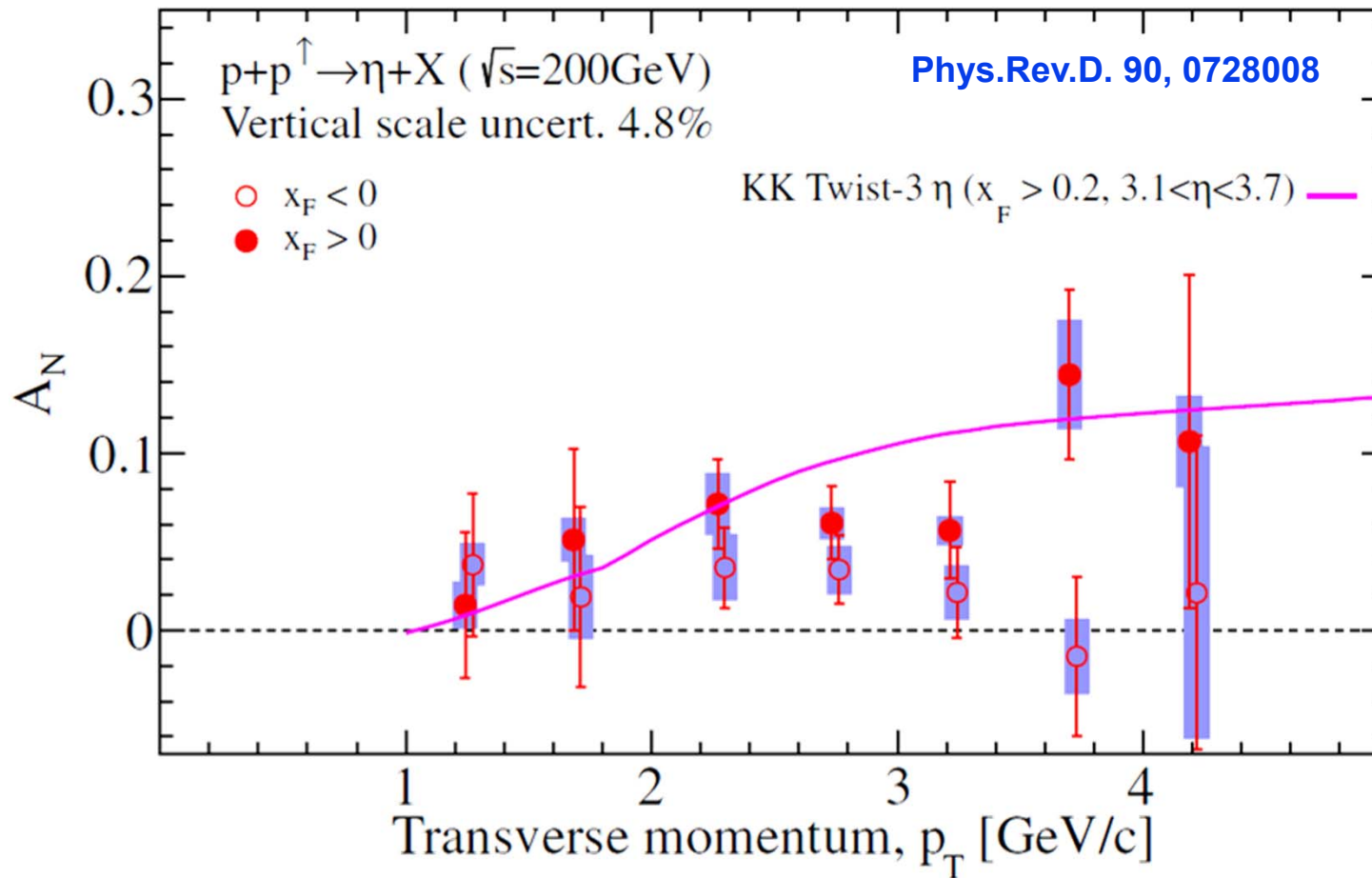
# Forward $A_N(\eta)$ $x_F$ dependence



- Rising  $A_N$  ranging from 2% to 20% for positive (forward)  $x_F$
- Consistent with flat & zero ( $1.7\sigma$ ) at negative (backward)  $x_F$

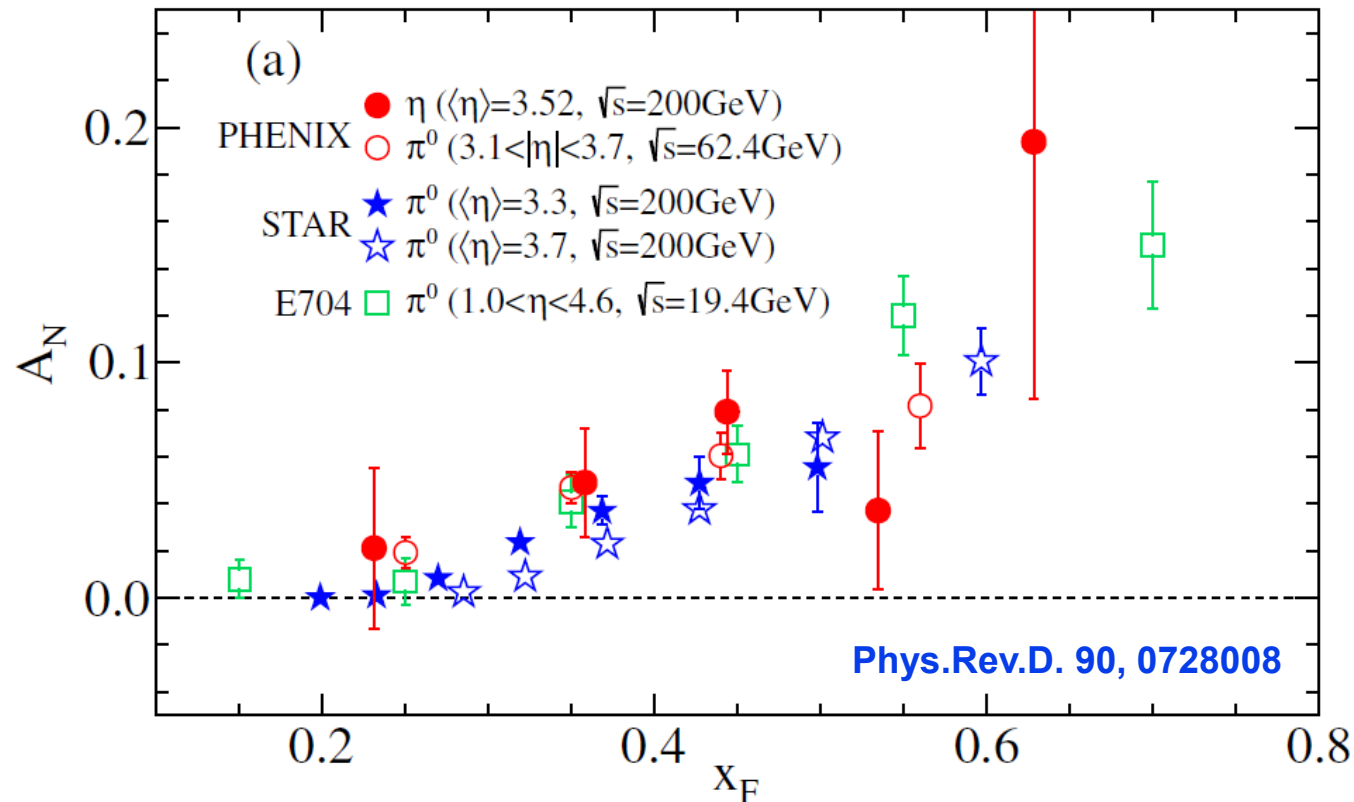


# Forward $A_N(\eta)$ $p_T$ dependence



- $x_F > 0.2$ : Non-zero asymmetry is seen  $\langle A_N \rangle = 0.061 \pm 0.012$ .
- $x_F < -0.2$ : Consistent with zero within  $1.7\sigma$

# Comparison with $\pi^0$ meson results

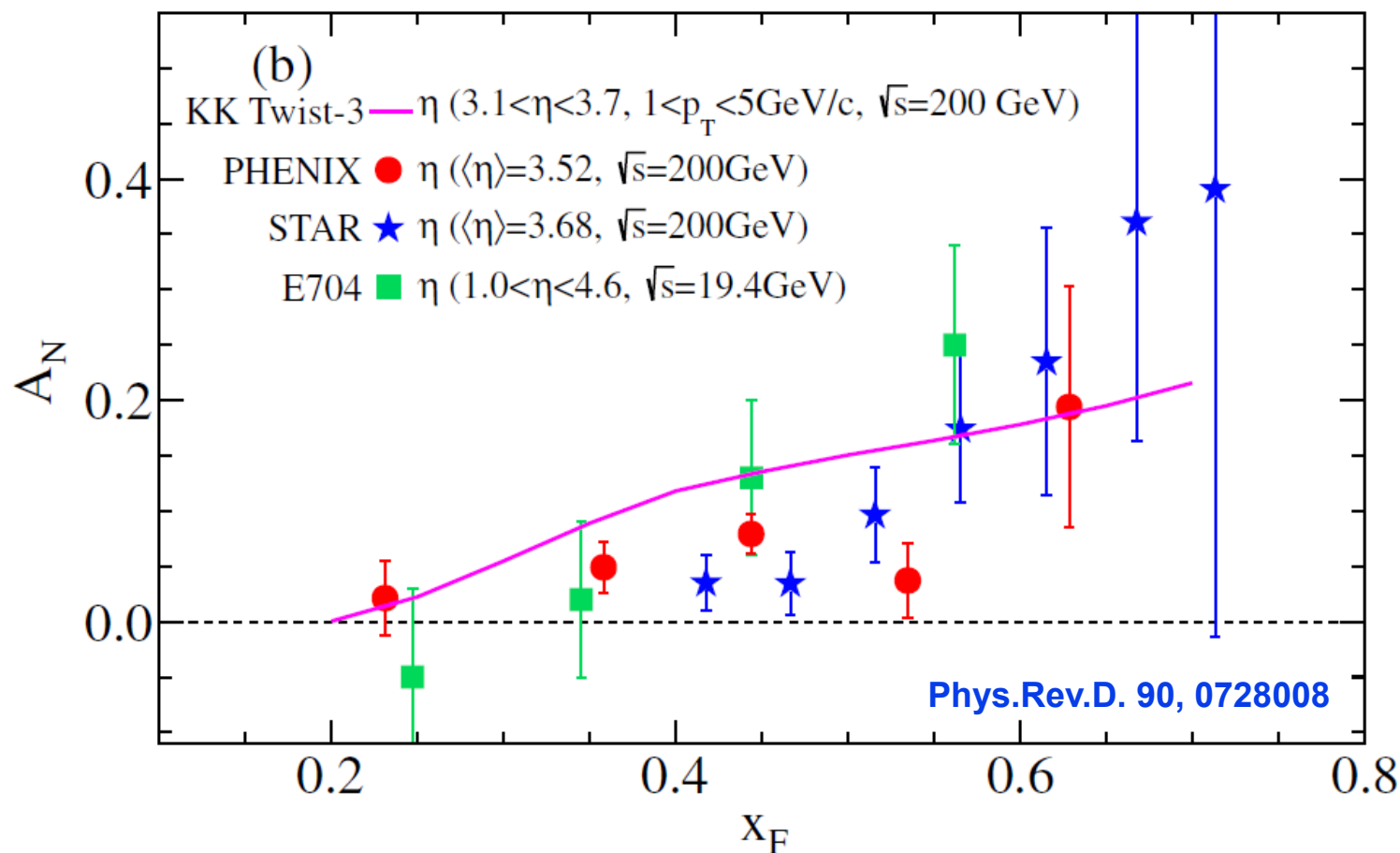


Similar to previous  $A_N(\pi^0)$  results despite

- » Differences in isospin, mass, and strangeness
- » Potentially different polarized fragmentation functions

⇒ Initial state spin momentum correlations could play a role or a common spin-momentum correlation is present in the fragmentation of the  $\pi^0$  and  $\eta$  mesons.

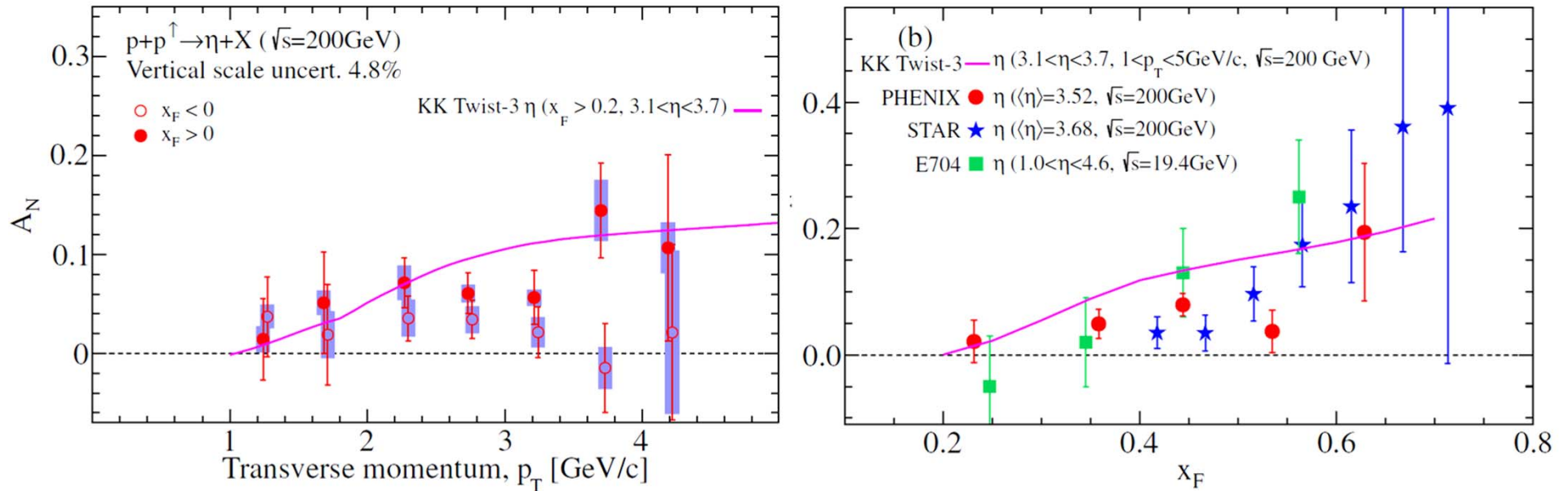
# Comparison with $\eta$ meson results



For  $x_F > 0.55$  STAR  $A_N(\eta)$  may be larger, but consistent within uncertainty.

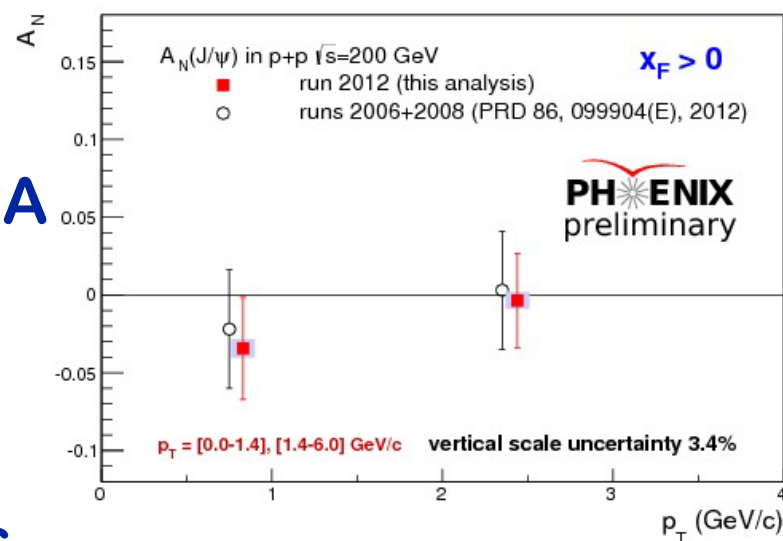
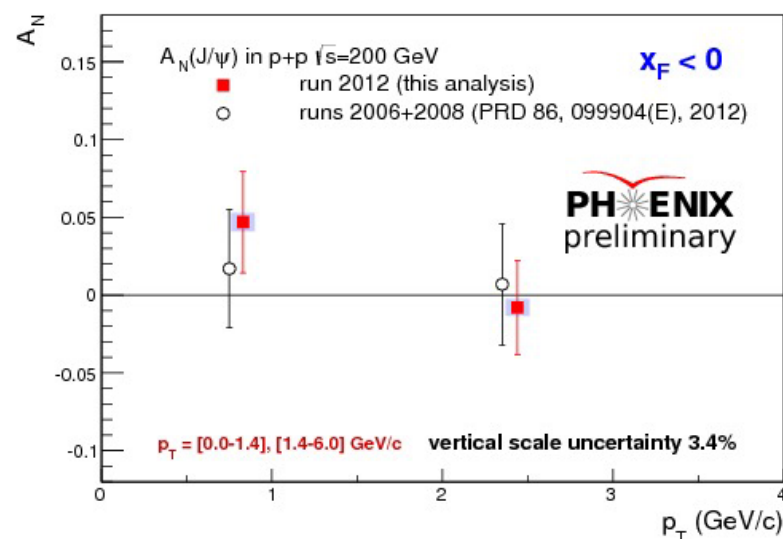
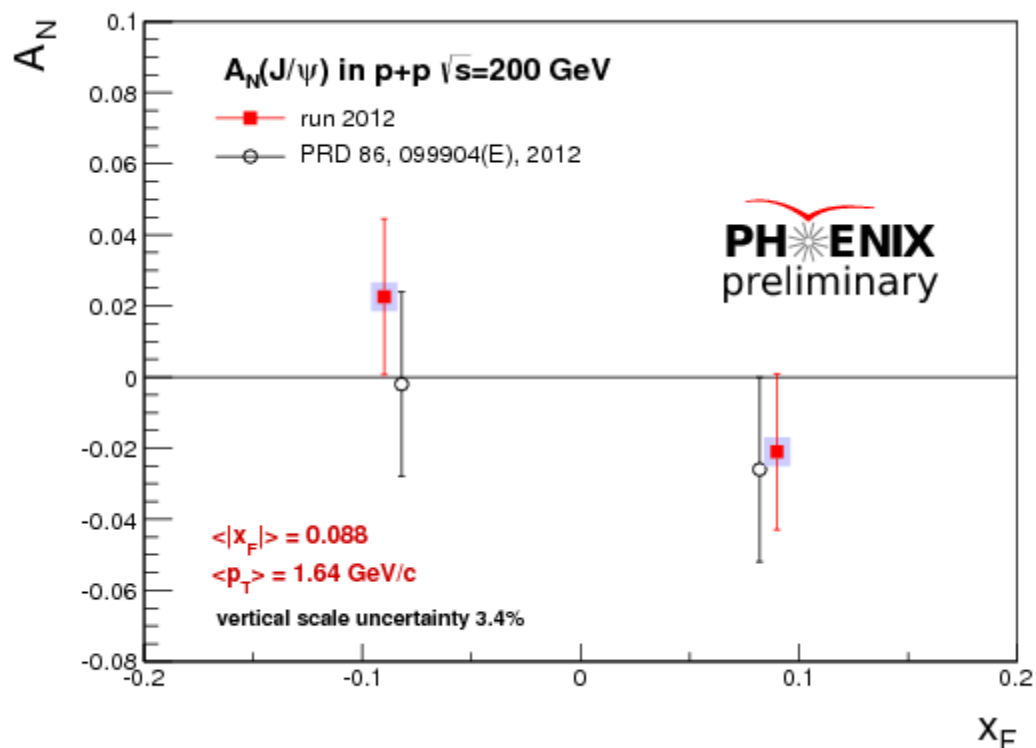
# Comparison with twist-3 calculations

Phys.Rev.D. 90, 0728008



- Measurement consistent with this particular calculation at low and high  $p_T$  and  $x_F$ , but consistency with mid  $x_F$  and  $p_T$  not clear.
- Theoretical uncertainties uncertain. Development of theoretical framework underway (e.g. Pitonyak and Y. Koike, ArXiv: 1404.1033)
- With higher statistics data, a double differential measurement of  $A_N$  if  $x_F$  and  $p_T$  could provide a more stringent test of models.

# $A_N$ Forward $J/\psi$ at 200GeV (Run 12)

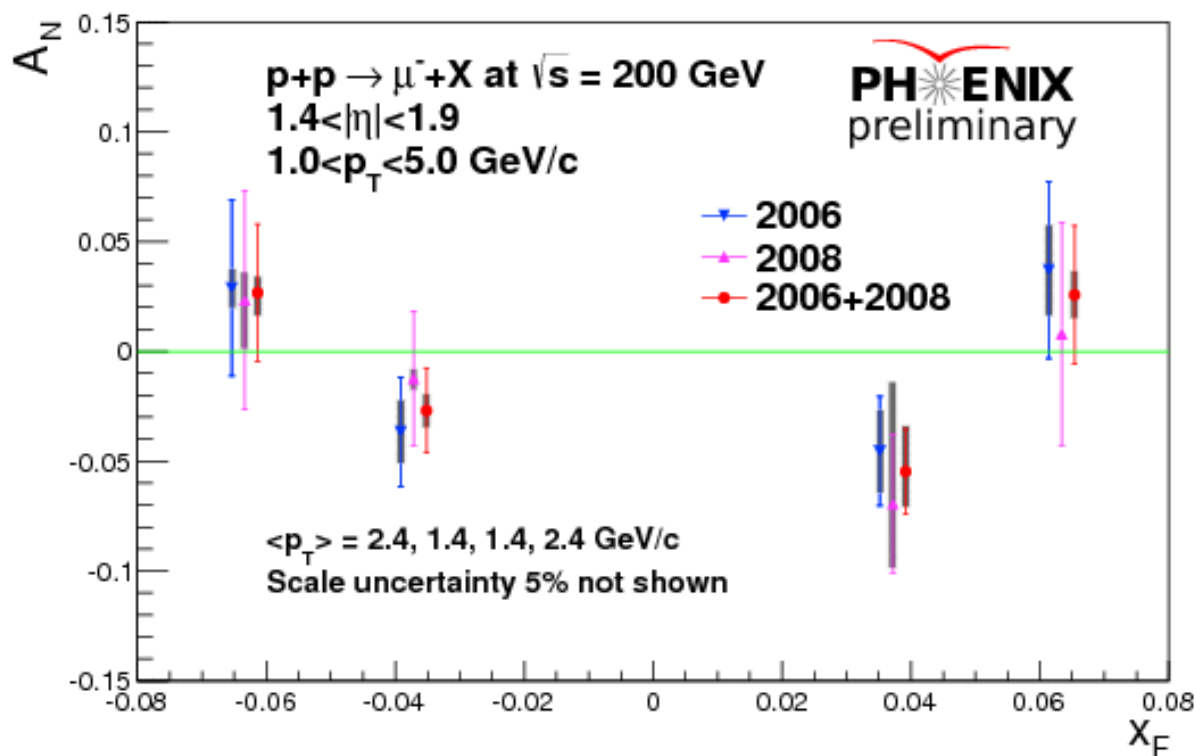


- Only color single generates SSA  
 $\Rightarrow$  sensitive to production mechanism.
- $A_N$  is consistent with zero.
- Precession limited by statistics.

# $A_N$ Forward single muon (200 GeV)

## Single muon $A_N$ from D meson decay

- » Production dominated by gg fusion
- » Probes gluon related correlation functions (initial state)
  - Koike and Yoshida, Phys. Rev. D84 (2011) 014026.
- » Sensitive to gluon Sivers distribution

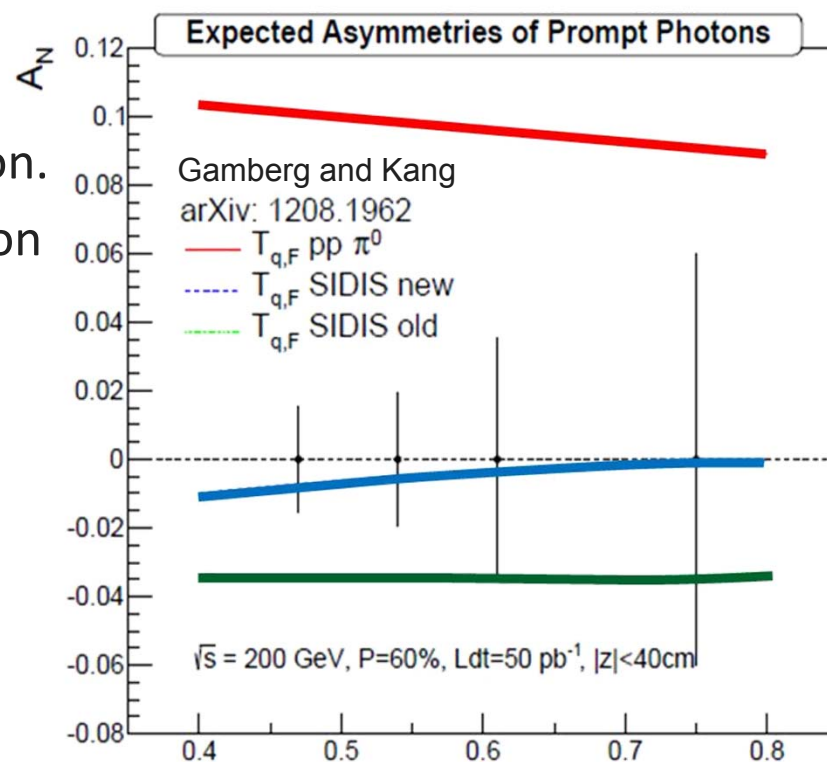
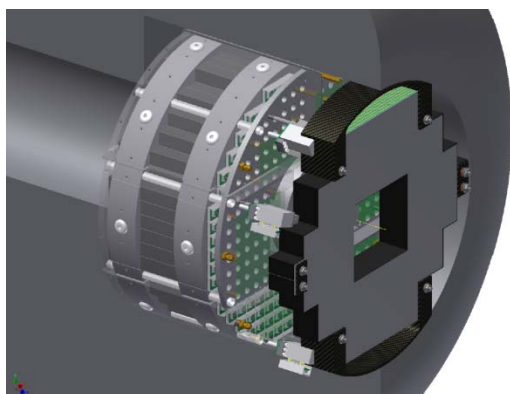


- $A_N$  consistent with zero
- A large 2012 data sample will increase sensitivity.
- A new Forward Silicon Vertex Detector (FVTX) will help in rejecting hadronic decay background in Run 15.



# $A_N$ : forward $\gamma$ (MPC-EX)

- 8 layer Silicon minipad Tungsten sandwich pre-shower in front of lead-tungstate MPC electromagnetic calorimeter ( $3.1 < |\eta| < 3.8$ )
  - Reconstruct and reject  $\pi^0$  mesons  $\Rightarrow$  enhances  $\pi^0/\gamma$  separation (up to  $>80\text{GeV}$ )
- Spin Physics Motivation:
  - Sign mismatch between twist-3 quark gluon distribution functions  $T_{q,F}(x, x)$  extracted from RHIC (assuming no Collins) and moments of the Sivers function from SIDIS measurements.
  - The Collins fragmentation functions in the p+p measurements may be the reason.
  - $A_N$  of prompt photons (free of contribution from the Collins effect) can be used to verify this & check consistency of theory.
- Timescale: Run 15 (p+p run just ended).



# Summary and Outlook

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## ➤ Central rapidity measurements

- $A_N$  for  $\pi^0$  and  $\eta \Rightarrow$  constrain gluon Sivers

## ➤ Forward rapidity measurements

- $A_N$  for  $\pi^0$ , EM Clusters, and  $\eta$  including  $p_T$ ,  $x_F$  dependence
  - Comparison with data at different  $\sqrt{s}$  and charged pions
  - Provides info to constrain Collins, Sivers, and twist-3 effects

## ➤ Upgrades will significantly extend physics capabilities

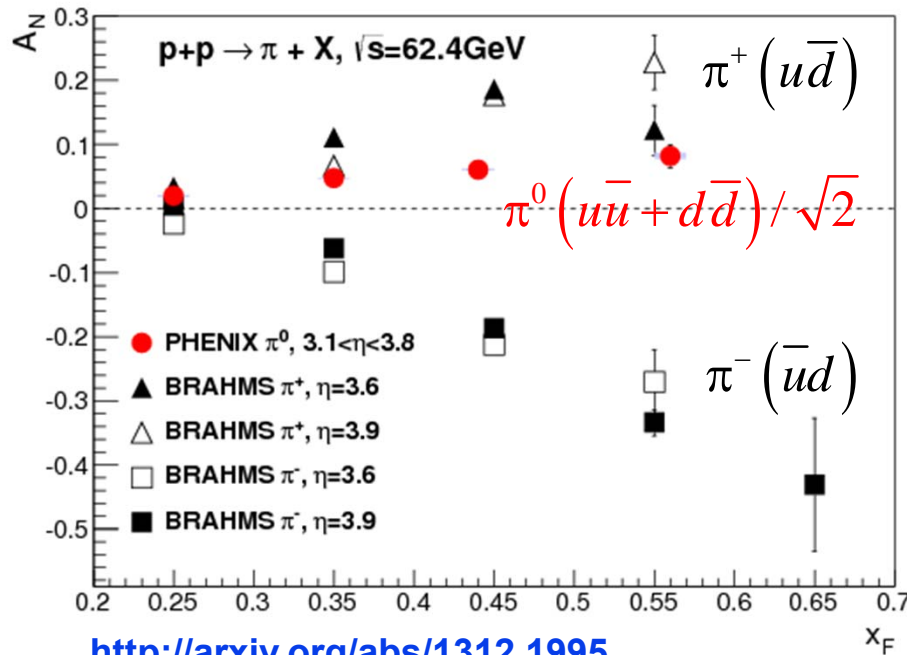
- FVTX will enhance forward heavy-flavor program ( $\mu$ ,  $J/\psi$ )
- MPC-EX will enable forward  $A_N(\gamma)$  measurements
  - Polarized  $p + A$  measurements sensitive to gluon saturation
- Proposed new Forward Spectrometer (fsPHENIX) for jet correlations/structure and Drell-Yan measurements (talk by Nils Feege)
- The fsPHENIX would also be well matched with ePHENIX (talk by Nils Feege).

# Extra slides...

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# Isospin Comparison of pion $A_N$

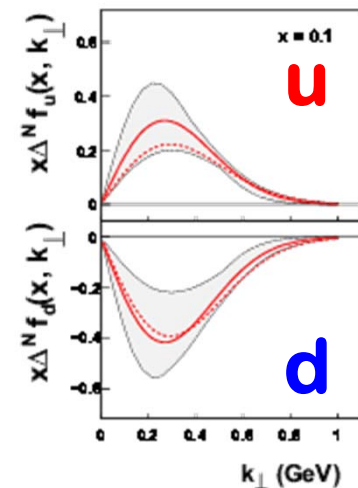
$\sqrt{s} = 62.4 \text{ GeV}$



Quark origins of pions (PYTHIA):

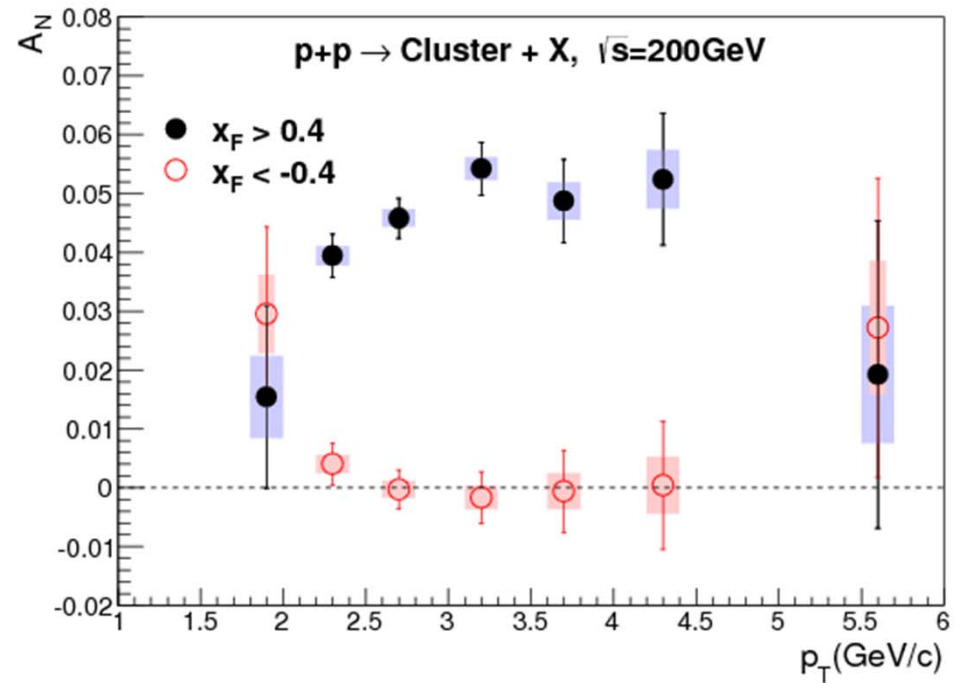
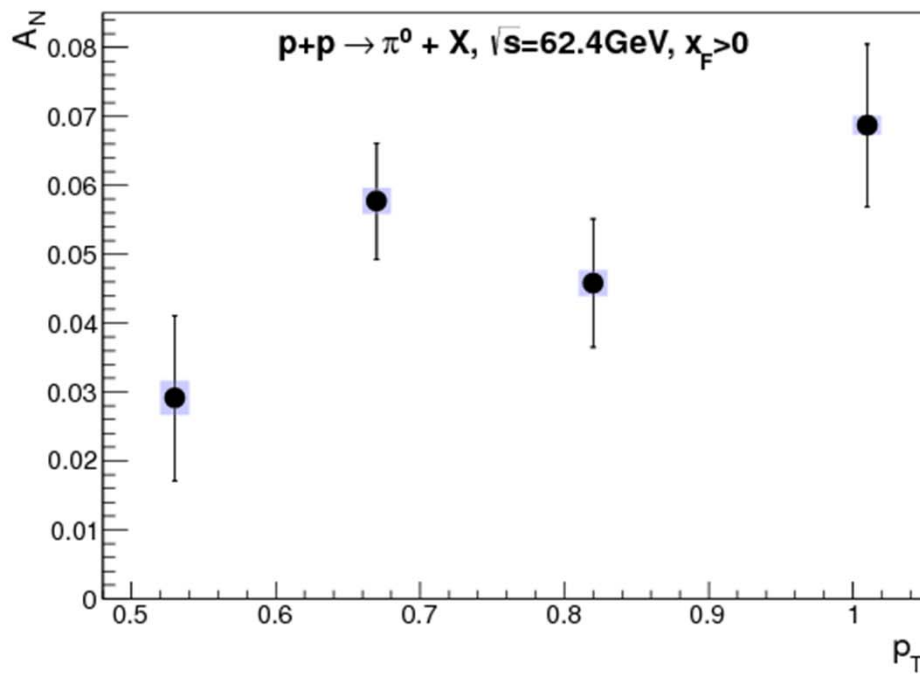
- $u \rightarrow \pi^+ / d \rightarrow \pi^+ : 100 / 0$
- $u \rightarrow \pi^0 / d \rightarrow \pi^0 : 75 / 25$
- $u \rightarrow \pi^- / d \rightarrow \pi^- : 50 / 50$

Sivers



# $A_N$ as a function of $p_T$

Phys.Rev.D. 90, 012006



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