Talk information

- A PHENIX contribution talk at Pan-Pacific Spin 2013, Oct 28-31, Ji'nan China. Time slot: 20 minutes (15+5), plan to show ~15 slides total, with backup slides.
- Main points to cover
  - Transverse spin results from PHENIX, preliminary and recently published results.
  - Near term transverse spin physics plan, run-2015 p+p and p+A.
  - Longer term plan, ePHENIX at eRHIC, and forward sPHENIX for transverse pp and p+A.
- Slides based on:
  - Yuji Goto: Spin-2012 talk on forward neutron SSA.
  - Oleg: J/psi SSA results from Run-2012 200 GeV data.
  - Michey and John K. et al.: MPC pi0 SSA paper.
  - Other SSA preliminary slides.
  - X. Jiang: MPC-EX prompt photon SSA, p+A pi0 SSA slides for Run-2015.
  - Jin Huang: DNP talk on ePHENIC detectors.
  - Cesar L. da Silva and Jin Huang: DNP talk on the fsPHENIX detector design.
  - X. Jiang: PHENIX Oct. core week discussion slides on fsPHENIX transverse spin.

Transverse Spin Physics with the PHENIX Experiment at RHIC

Xiaodong Jiang
Los Alamos National Laboratory
(For the PHENIX Collaboration)
Pan-Pacific Spin 2013, Ji'nan, China.

- Transverse spin physics updated results.
- Upcoming p+p and p+A runs (Run-2015) with near-term upgrades.
- Planned ePHENIX upgrades for eRHIC, and forward sPHENIX for p+p and p+A physics.

Introduction: single-spin asymmetry in $p\,p^{\uparrow} \rightarrow \pi X$

E704 √s =20 GeV.

PLB 264 (1991) 462.

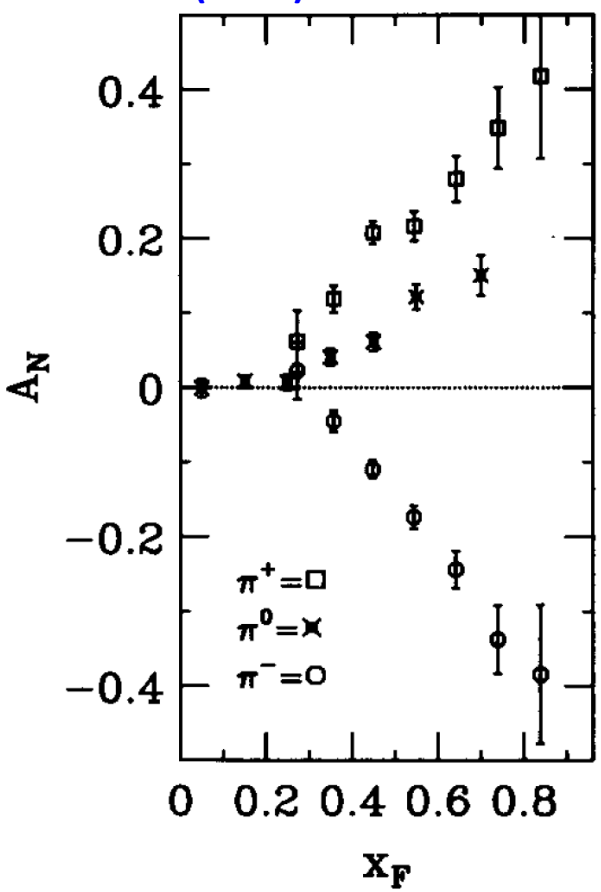
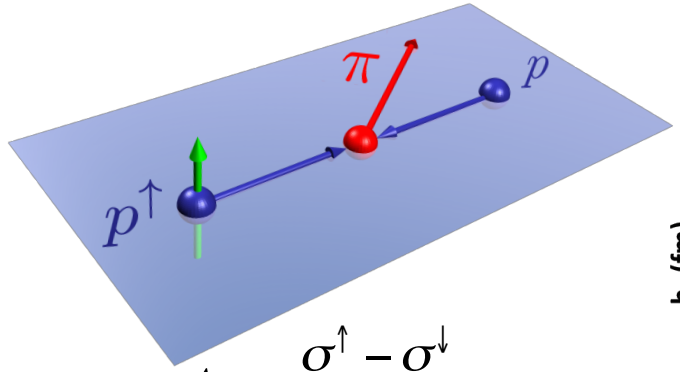


Fig. 4. A_N versus x_F for π^+, π^- and π^0 data.



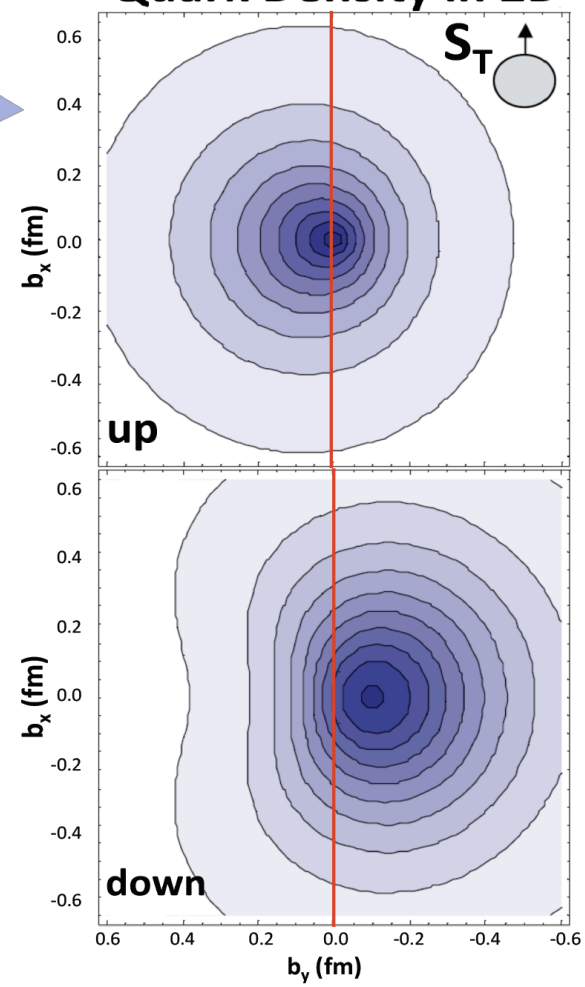
$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

π^+ $(u\bar{d})$ favors left

π^- $(d\bar{u})$ favors right

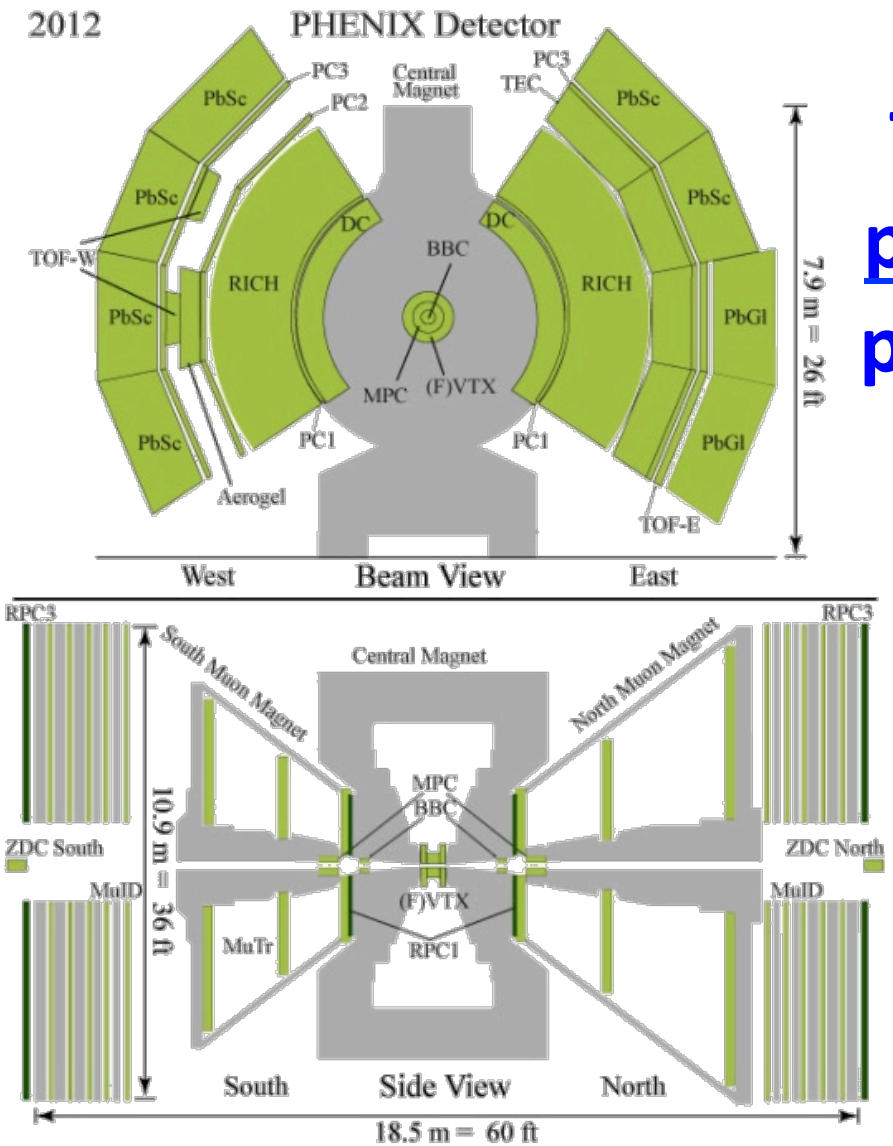
One possible explanation (Sivers effect): quark transvers motion generates a left-right bias.

Quark Density in 2D



Lattice QCD PRL98:222001,2007.

Quarks in a transversely polarized nucleon can tell left-right, up-quarks favor left, down-quarks favor right.



Transverse spin physics: p↑+p@62.4 and 200 GeV p↑+A@200 GeV in future

PHENIX updated results of SSA:

- Very forward neutron
- Forward π^0 and single-cluster-hit
- Forward J/psi
- (Forward single-muon)
- (di-hadron correlation)

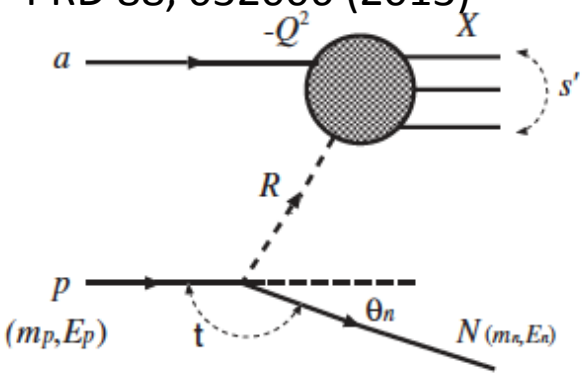
$-0.35 < \eta < 0.35, \Delta\varphi = 2 \times {}^{\pi}/_{2}$: tracking and EM-cal

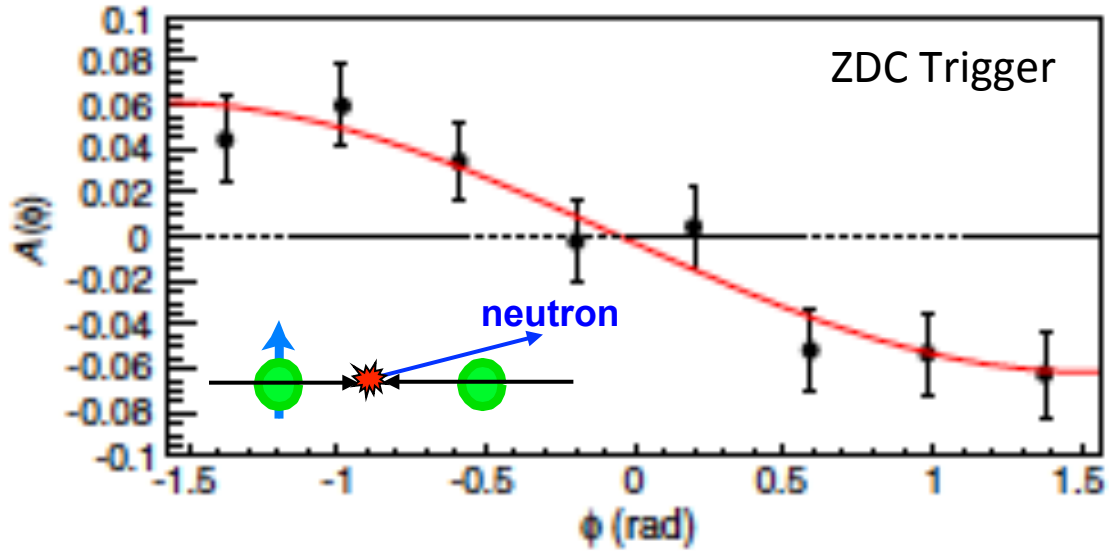
$1.2 < |\eta| < 2.4, \Delta\varphi = 2\pi$: tracking and μ-ID

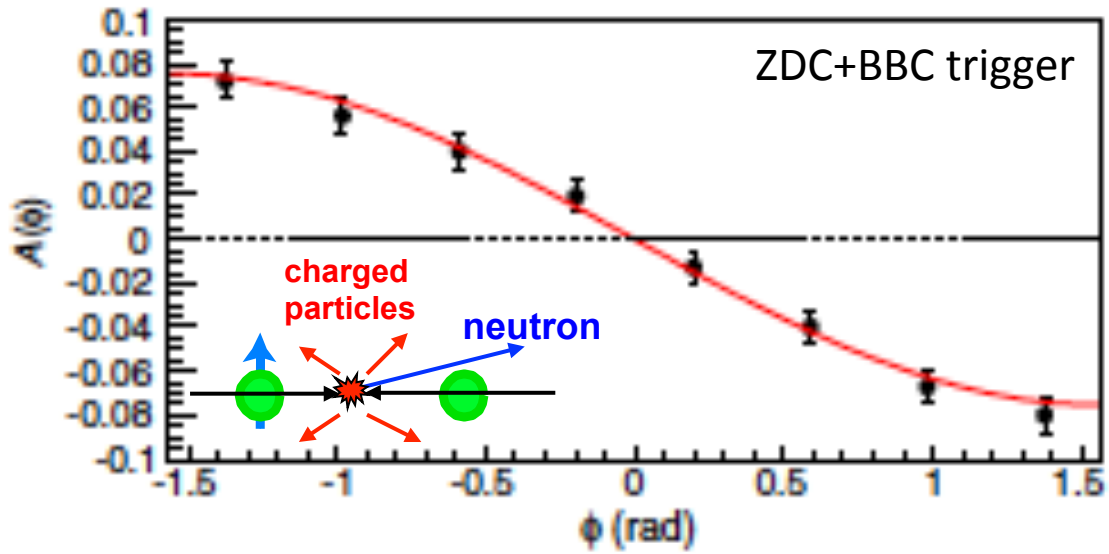
$3.1 < |\eta| < 3.9, \Delta\varphi = 2\pi$: EM-cal

SSA of Very Forward Neutron Production in p+p@ 200 GeV

PRD 88, 032006 (2013)

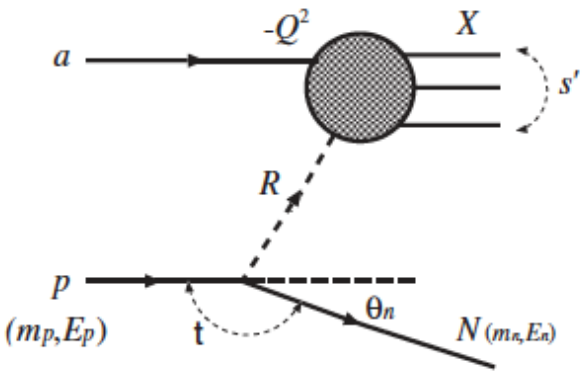


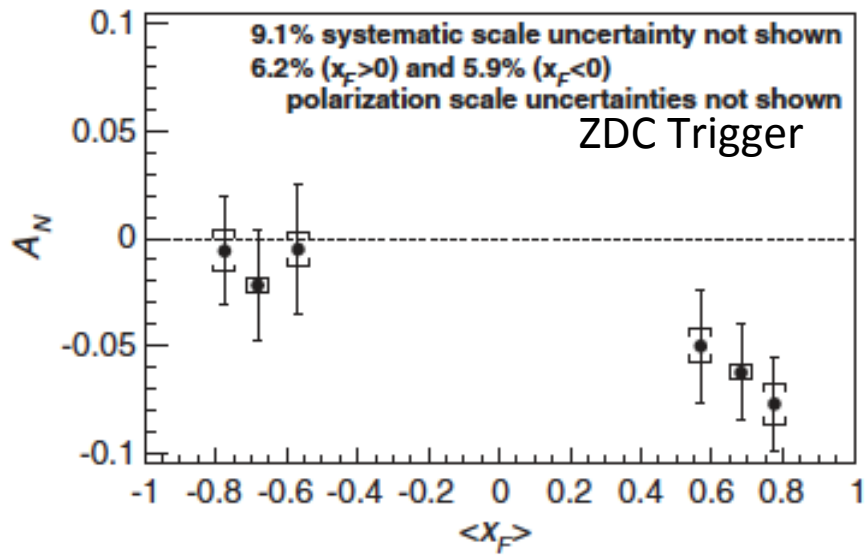




SSA of Very Forward Neutron Production in p+p@ 200 GeV

PRD 88, 032006 (2013)

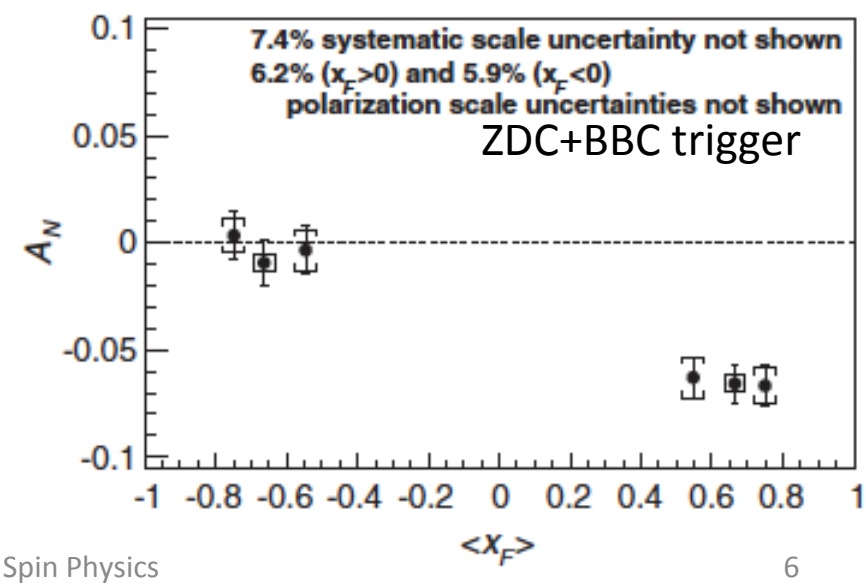




Interference between spin-flip and non-flip with a phase difference

$$A_N \approx \frac{2\,\mathrm{Im}\left(fg^*\right)}{|f|^2 + |g|^2}$$

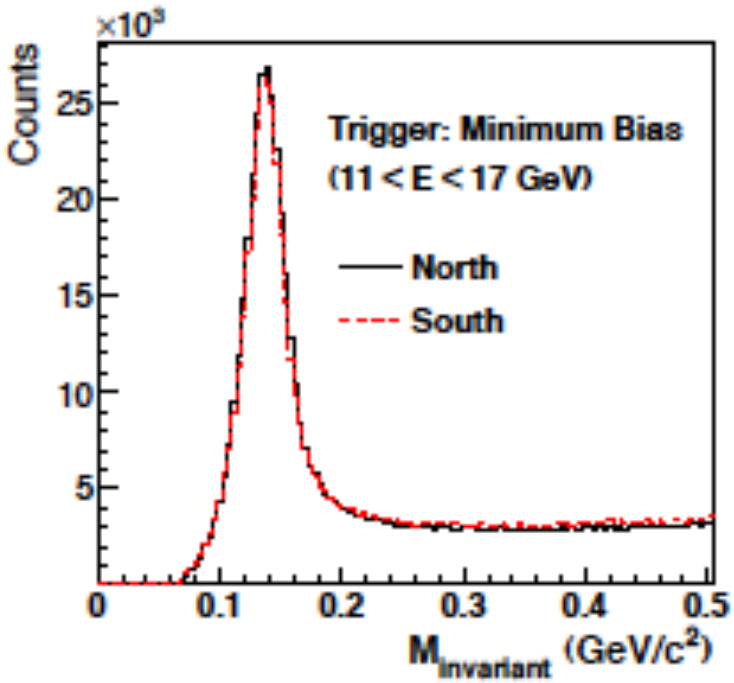
f : spin non-flip amplitude
g : spin flip amplitude



Interference with other Reggeons
Kopeliovich, Potashnikova, Schmidt, Soffer:
Phys. Rev. D 84 (2011) 114012.

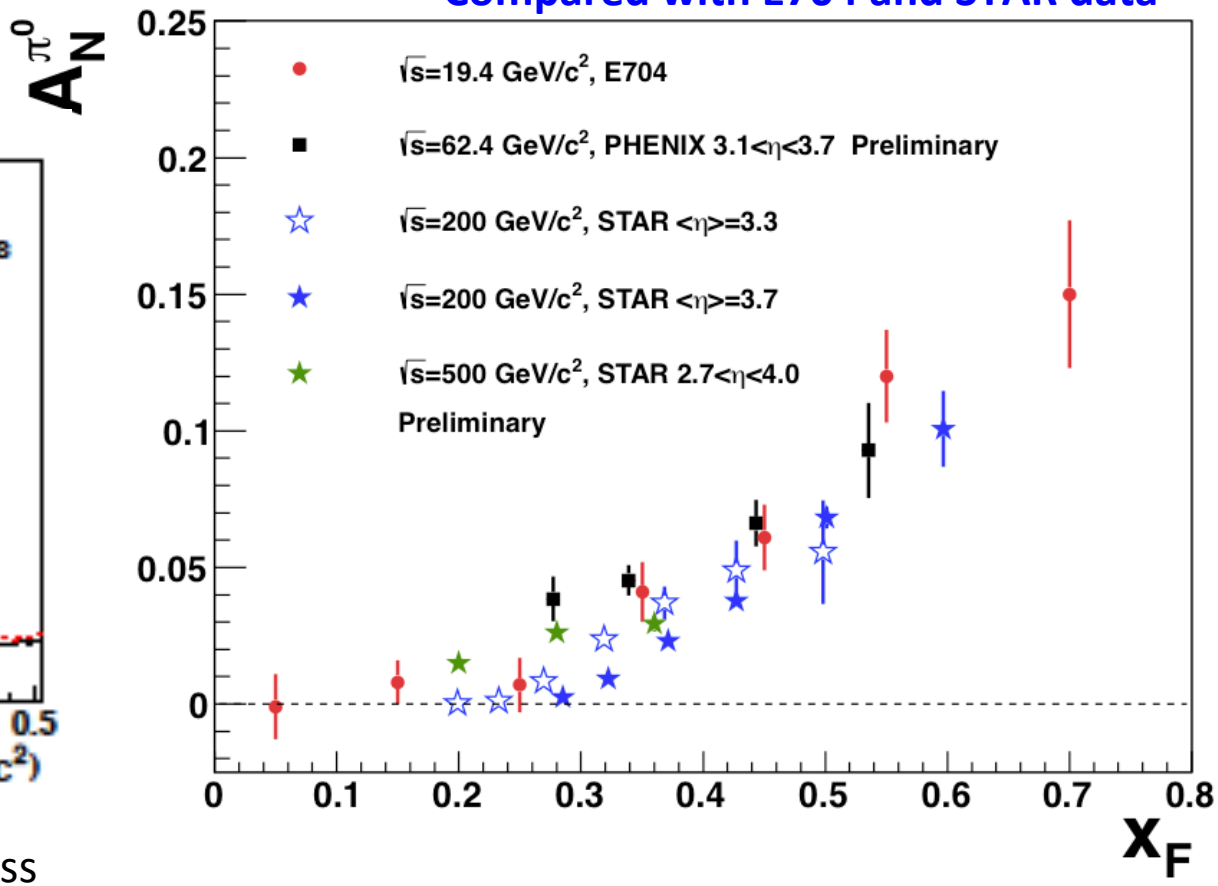
SSA of π^0 @62.4 GeV

(J. Koster, Ph.D. thesis. UIUC)

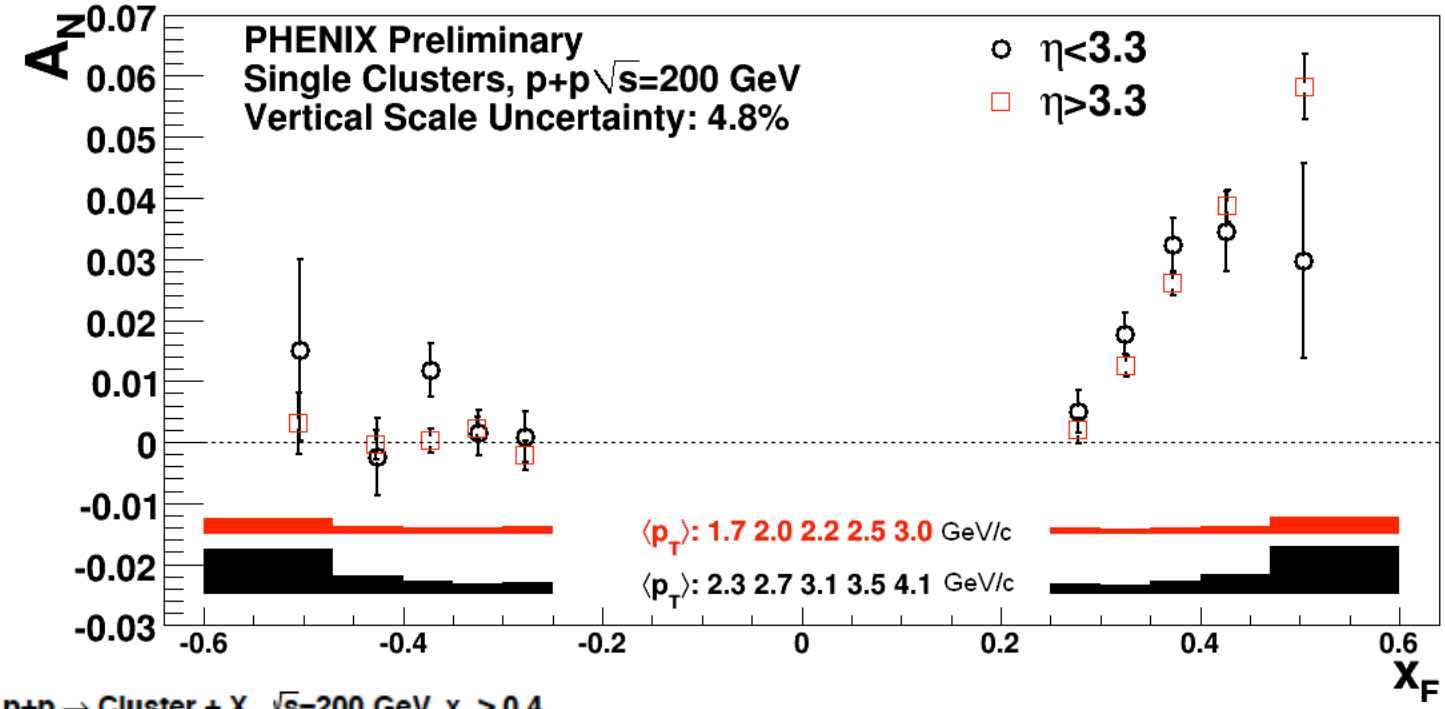


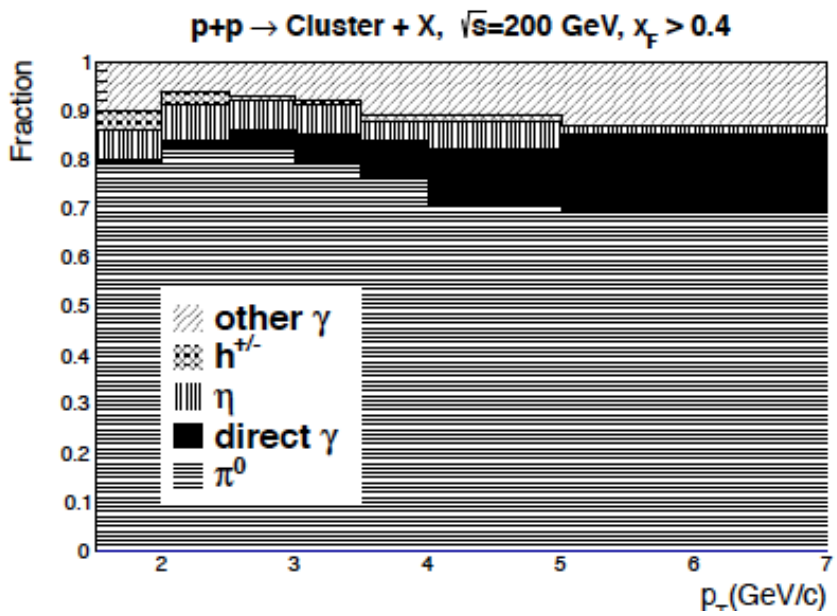
two-cluster-hits invariant mass

Compared with E704 and STAR data



Single-Cluster A_N in MPC





Single-cluster mostly from un-resolved π^0

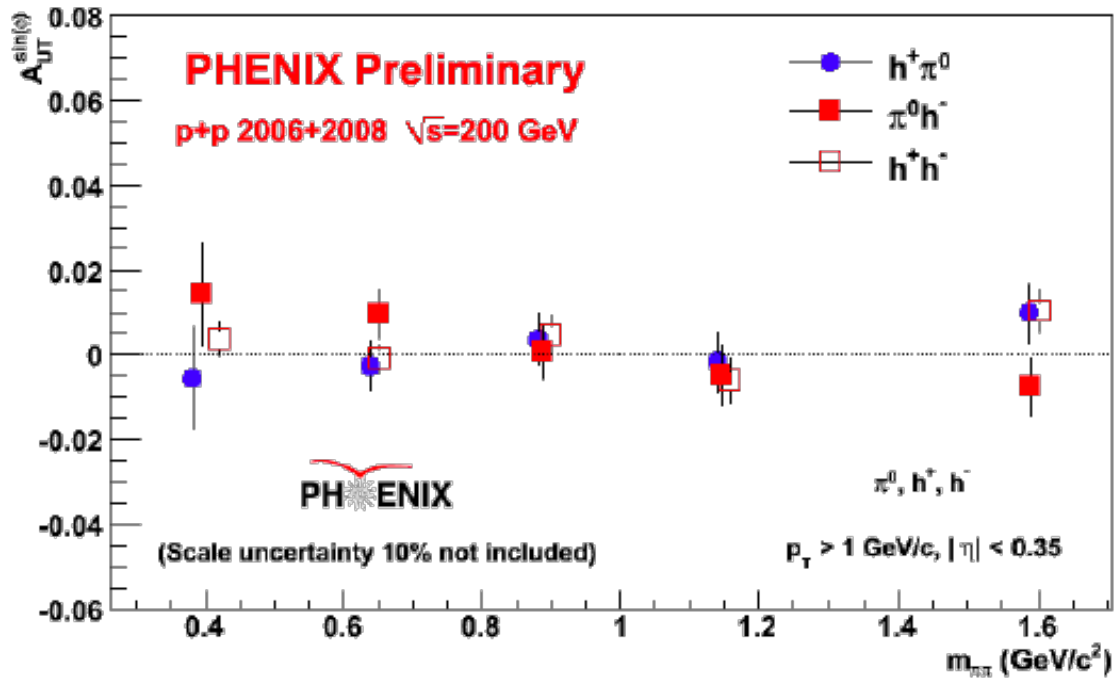
simulation

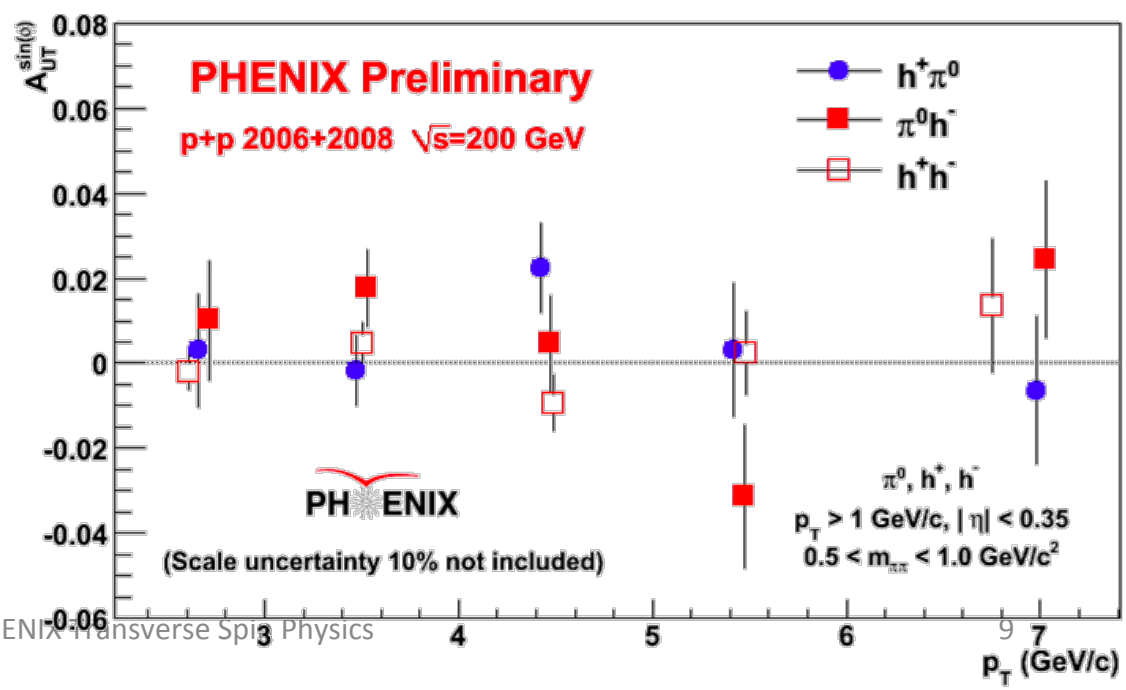
Di-hadron Correlated SSA

PHENIX 2006/2008 data
(R. Yang, Ph.D. Thesis, UIUC)

(transversity)⊙(2hadron-IFF)

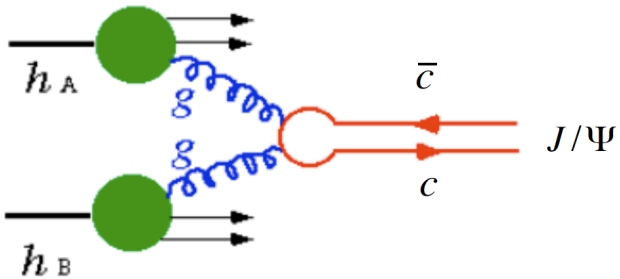
Chiral-Odd: 2h-Interference Frag. Func.

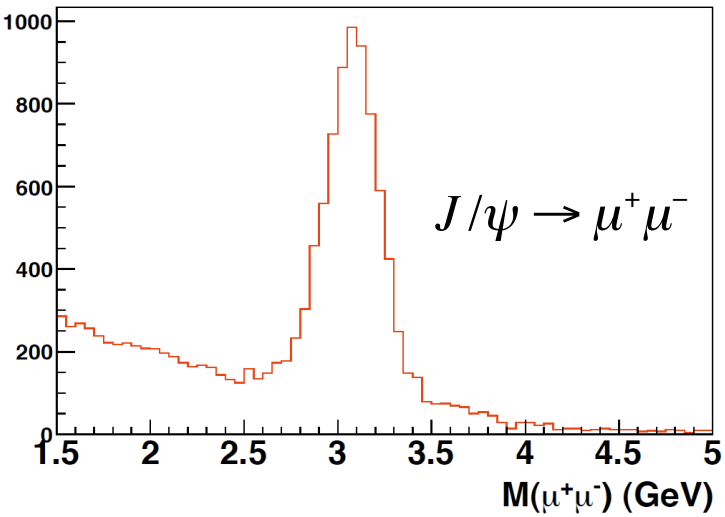


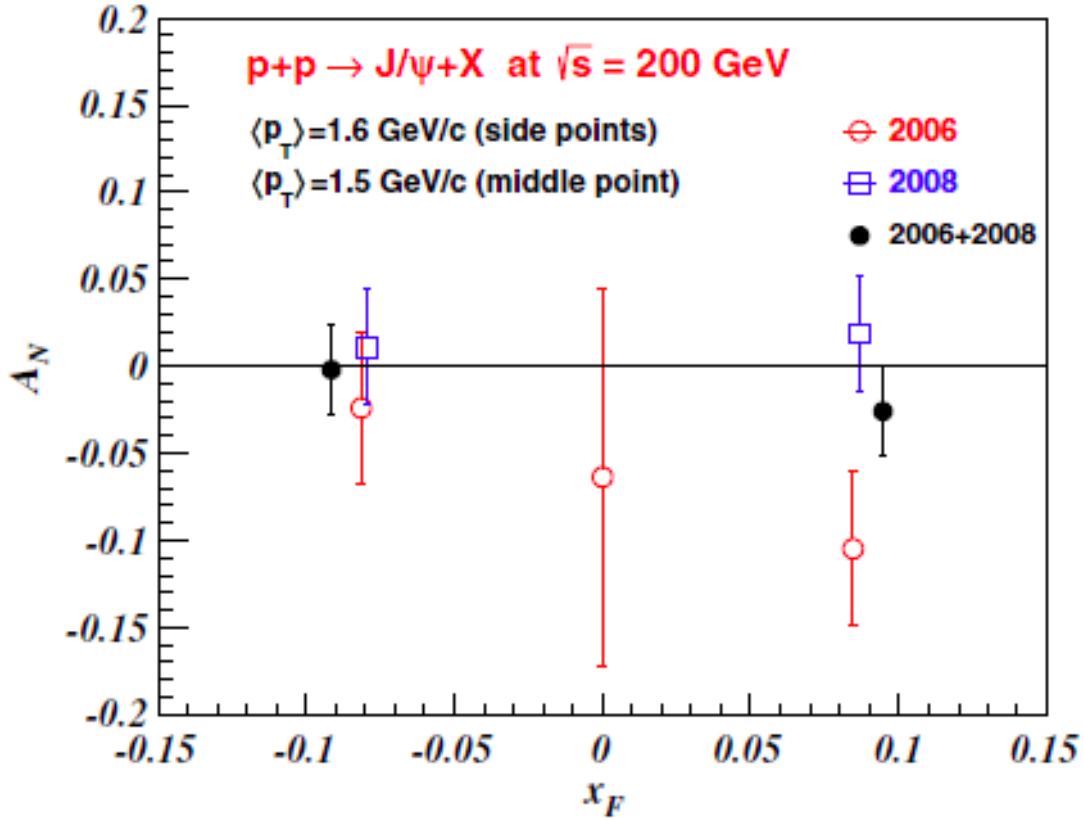


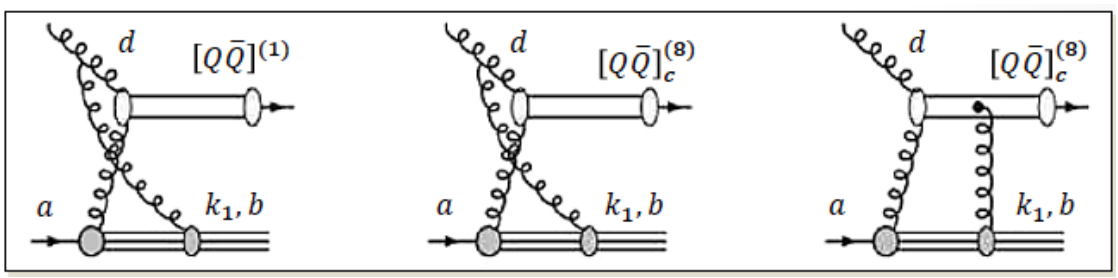
Single spin asymmetry in: $p^{\uparrow} + p \rightarrow J/\psi + X$

PRD 86, 099904 (E), 2012



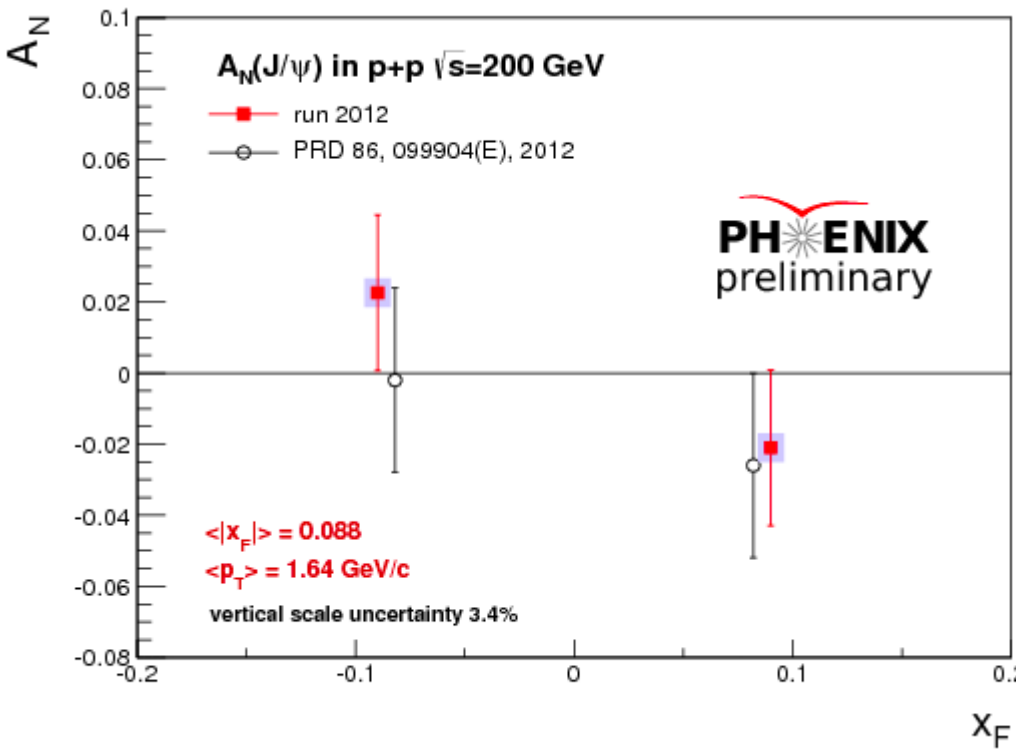


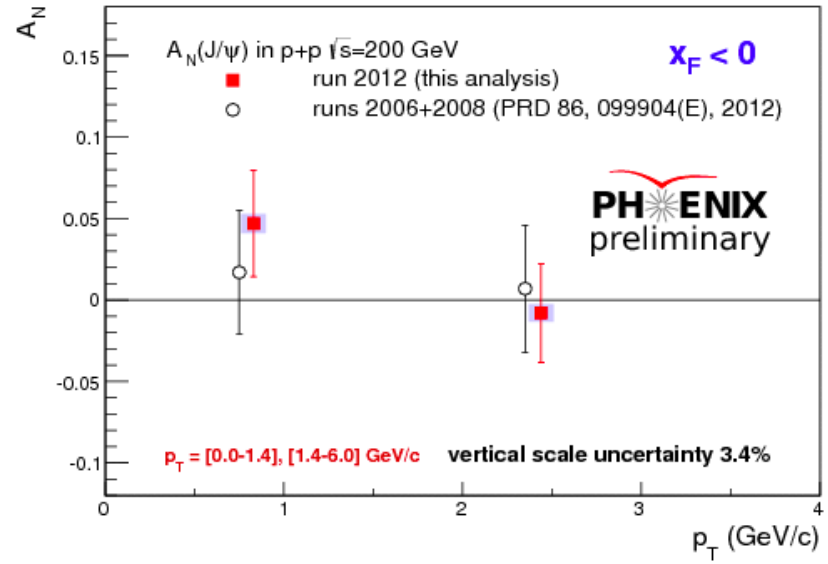


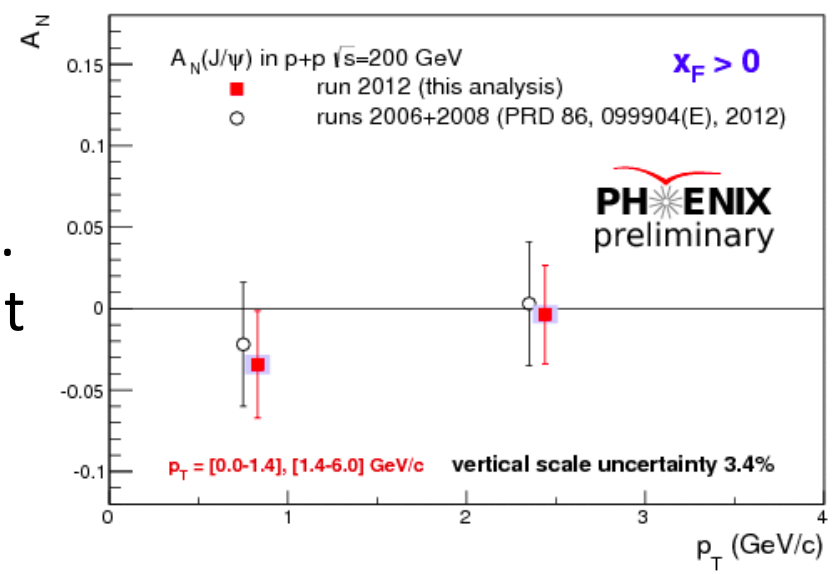


Only Color-Singlet generate SSA. Color-Octet produces zero SSA due to cancelations. PRD78, 014024, 2008.

J/psi SSA in p+p: Run2012





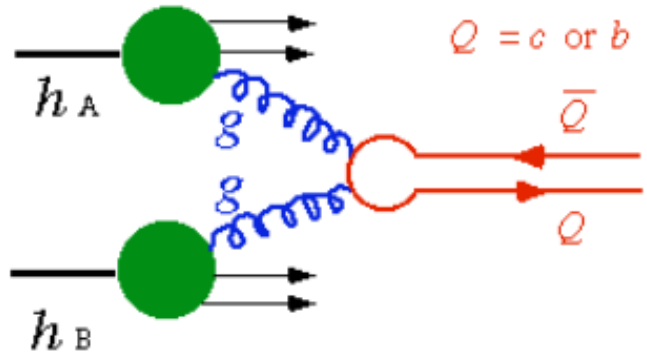


- Observed A_N are consistent with zero.
- Measured asymmetries are consistent between data sets.

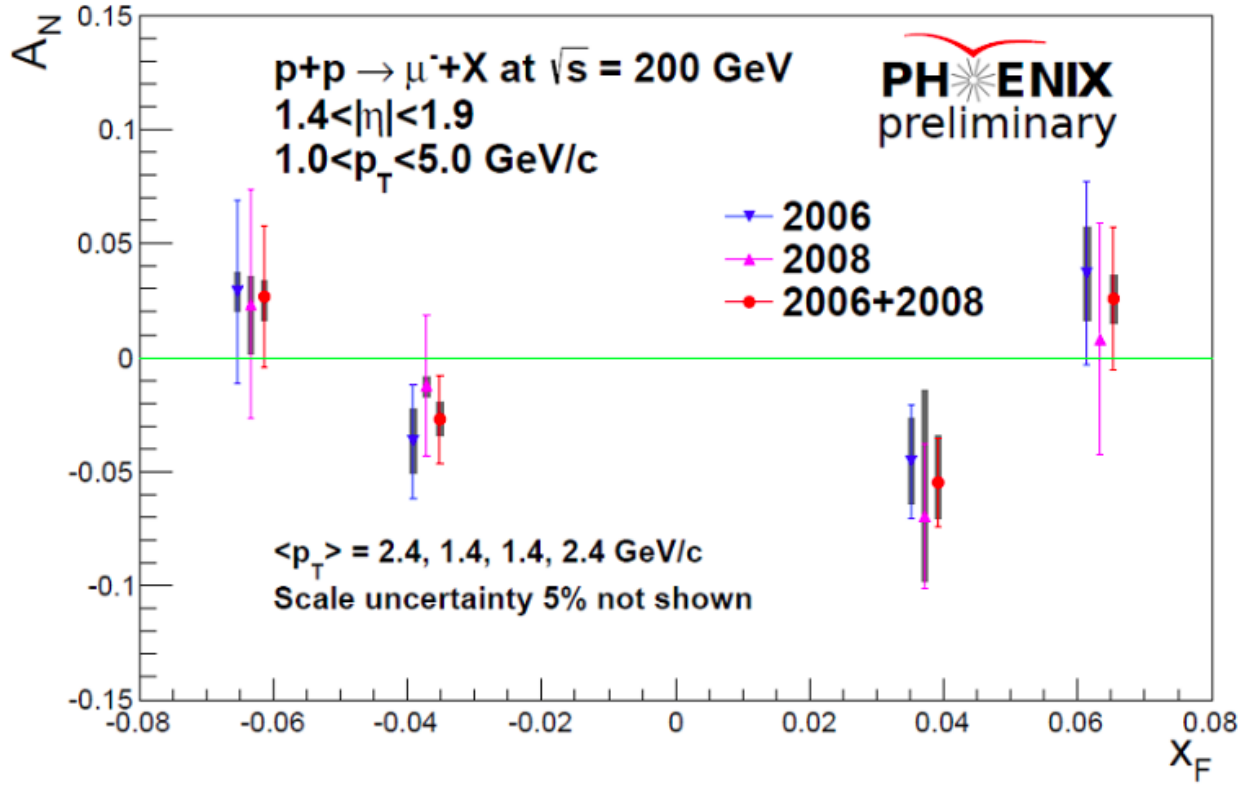
Open charm SSA to probe gluon Sivers distribution

Single-muon SSA from D meson decay:

- Production dominated by gluon-gluon fusion
- Sensitive to gluon Sivers distribution



A new Forward Silicon Vertex Detector (FVTX) will help in rejection hadronic decay background in Run-2015



Kang, Qiu, Yuan, Vogelsang, Phys. Rev. D 78,114013(2008)

PHENIX Transverse Spin Near-Term Plan: p↑+p and p↑+A in Run-2015

from PHENIX beam use proposal, May 2013:

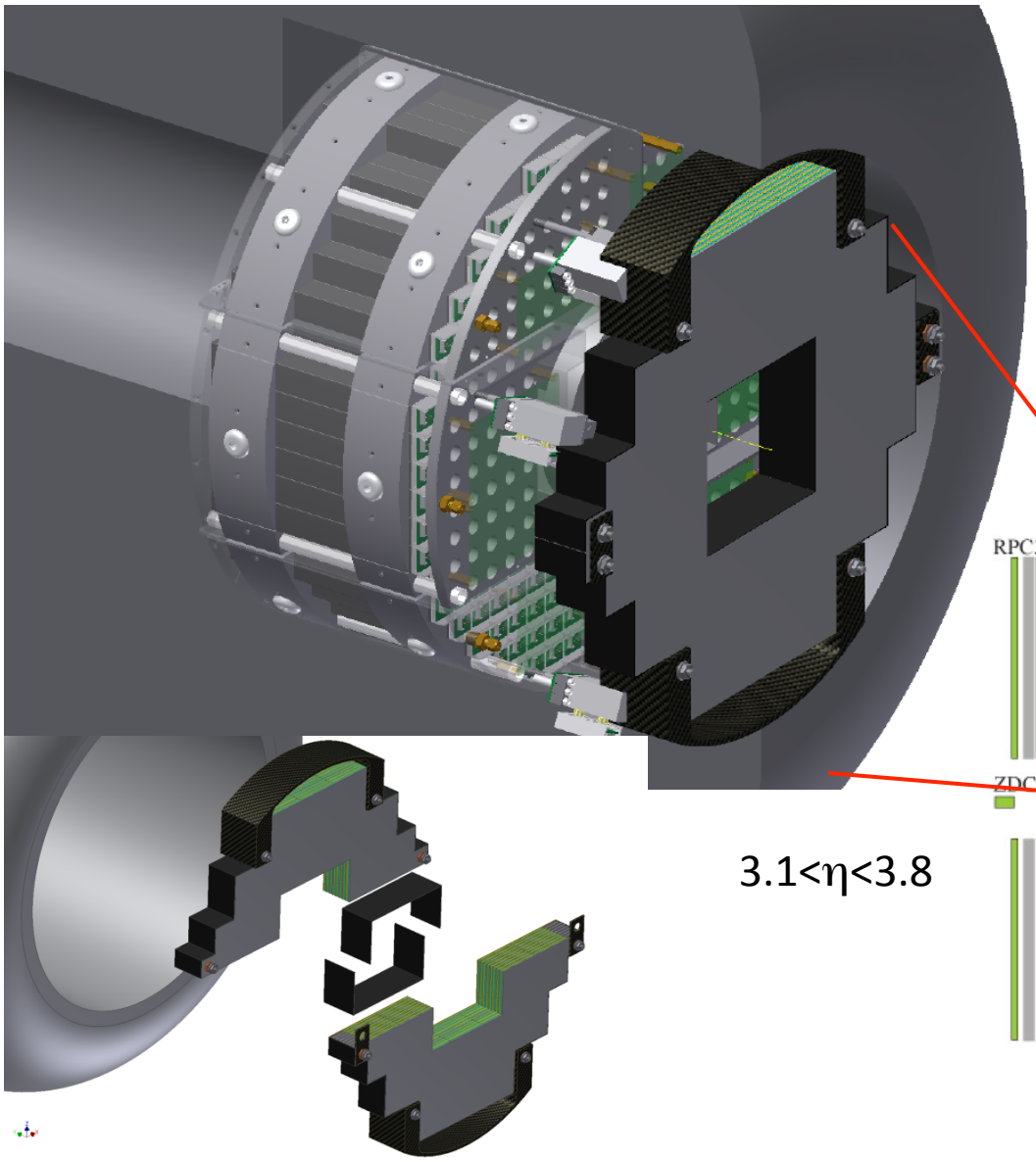
Run-15 Proposal (22 cryo-weeks)

- $p+p$ @ 200 GeV with transverse polarization for 9 weeks [Physics driven goal is 50 pb^{-1} recorded within $|z| < 40$ cm and $\langle \mathcal{P} \rangle = 60\%$]
- $p+Au$ @ 200 GeV with transverse polarization of the proton for 4 weeks [Physics driven goal is 150 nb^{-1} sampled within $|z| < 40$ cm and $\langle \mathcal{P} \rangle = 60\%$]
- Geometry studies with $d+Au$ @ 200 GeV and ^3He+Au @ 200 GeV for 1 week each [Physics driven goal is recording 1 billion minimum bias events for each]
- $p+Si$, $p+Cu$ @ 200 GeV for 2 weeks each [Physics driven goal is 450 nb^{-1} and 225 nb^{-1}, respectively, sampled within $|z| < 40$ cm and $\langle \mathcal{P} \rangle = 60\%$]

Detector upgrades for Run-2015:

- **Forward Silicon Vertex Tracker (Completed)**
- **MPC-EX Detector Upgrade (on-going)**

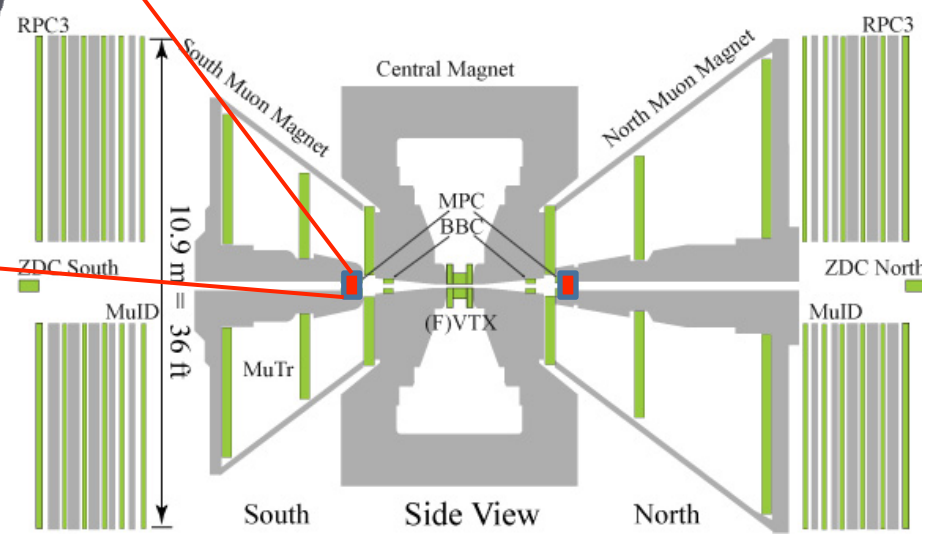
MPC-EX Detector Upgrade at Very Forward Angle



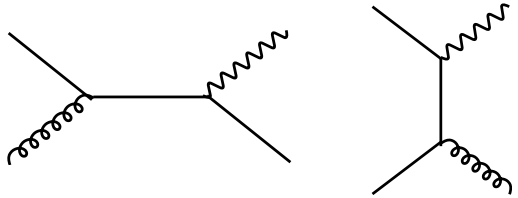
A combined charged particle tracker and EM preshower detector – dual gain readout allows sensitivity to MIPs and full energy EM showers.

- π^0 rejection (direct photons)
- π^0 reconstruction out to >80GeV
- Charged track identification

$3.1<\eta<3.8$



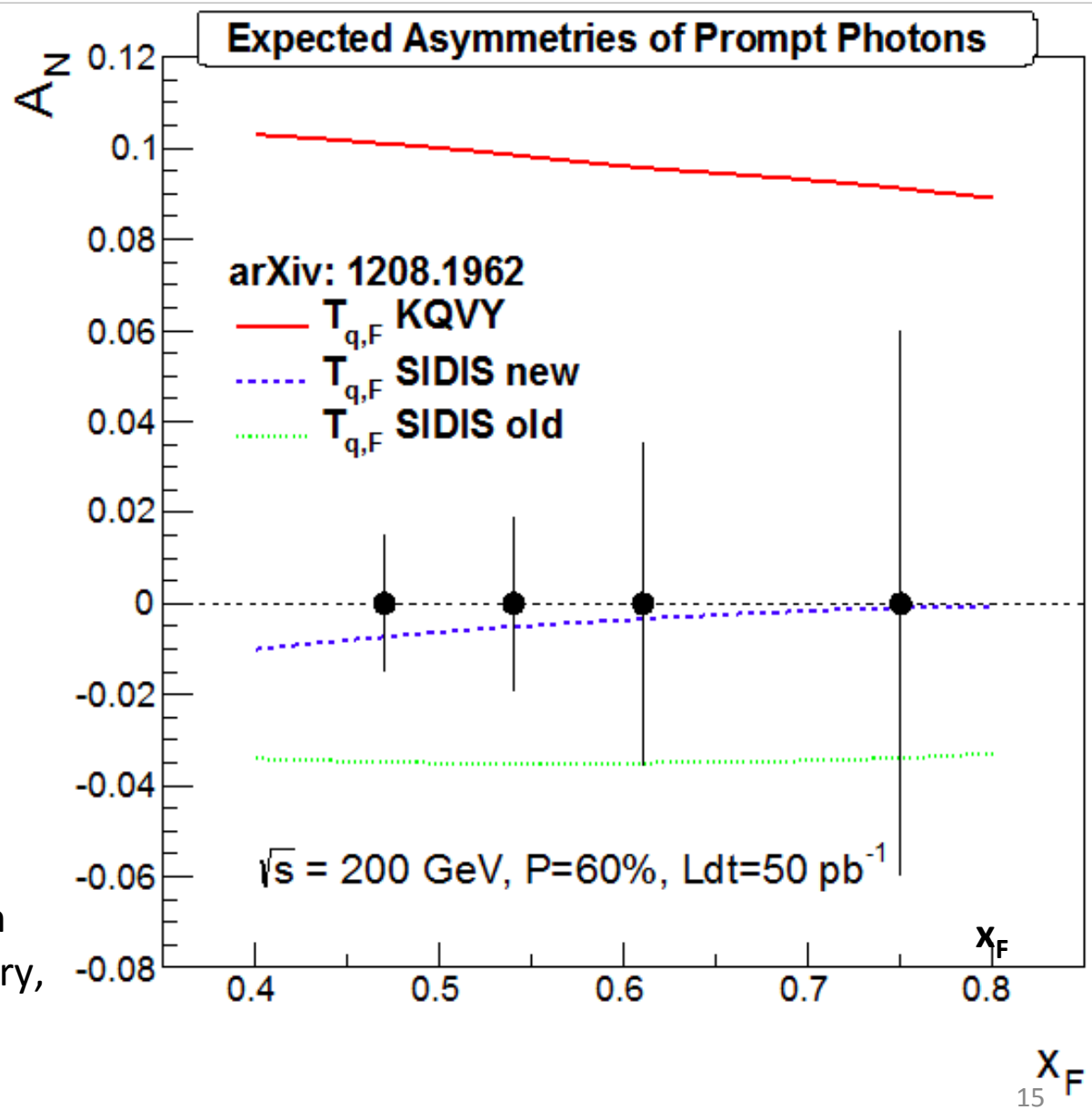
Projected for Run-2015: Prompt Photon A_N (x_F>0)



Sensitive to up-quark Sivers.

Help to resolve Sivers function "sign mismatch" issue.
Twist-3 quark-gluon correlation functions (KQVY) disagree with Sivers function moments extracted from SIDIS

Projected error bars assume statistical errors, subtraction of π^0 and η photon asymmetry, and 60% polarization



p↑+A : Single-Spin Asymmetry to probe gluon saturation effects in nuclei

- The possibility of polarized proton and ion collision opens a new territory beyond pA@LHC.
  - it also allows not only measure the source of transverse asymmetry

$$\frac{A_N^{pA\to h}}{A_N^{pp\to h}}\Big|_{P_{h\perp}\ll Q_s^2} \approx \frac{Q_{sp}^2}{Q_{sA}^2} e^{\frac{P_{h\perp}^2\delta^2}{Q_{sp}^4}} \qquad \frac{A_N^{pA\to h}}{A_N^{pp\to h}}\Big|_{P_{h\perp}\gg Q_s^2} \approx 1$$

Kang, et al,

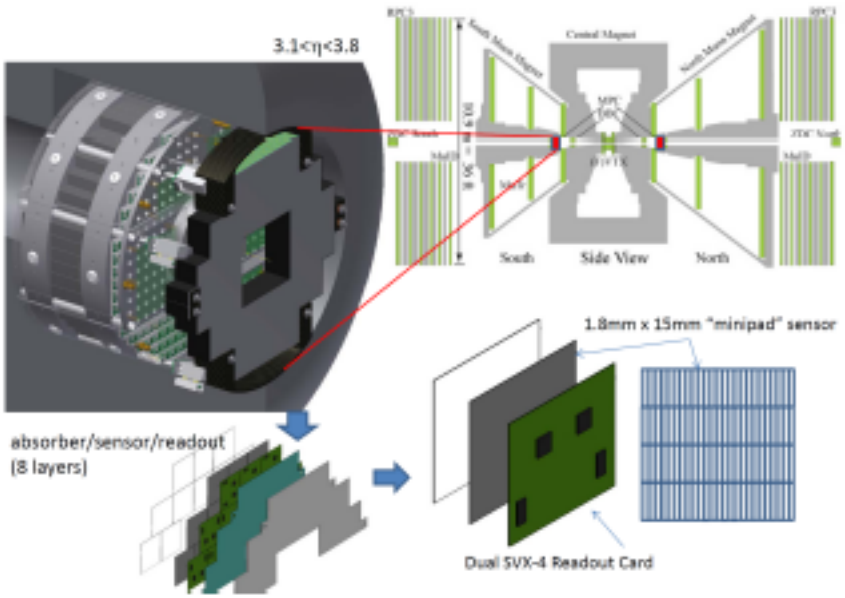
  - provides additional sensitive observable for the saturation physics study

PHENIX Beam Use Proposal for Run-2015 p+A

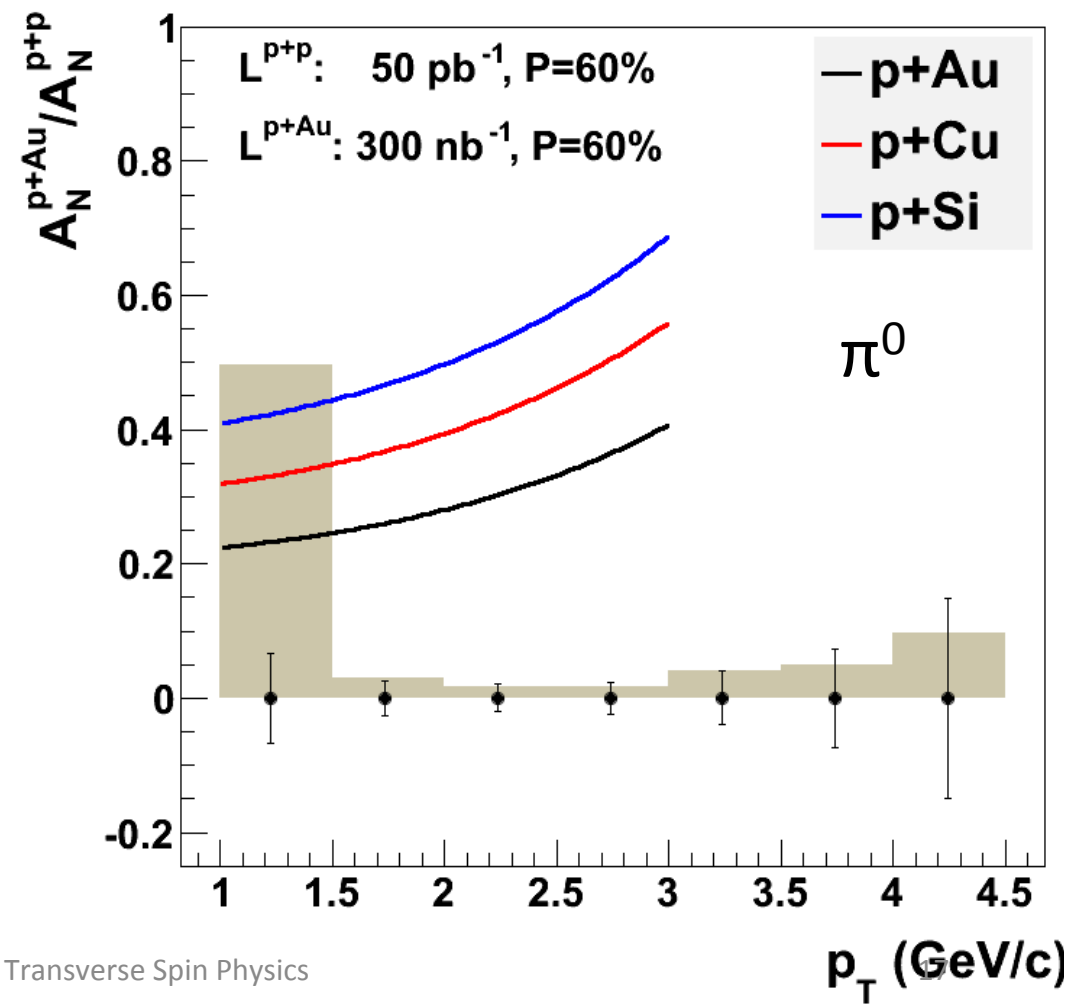
Single-Spin Asymmetry of forward π^0 through MPC-EX calorimeter

Ratios of SSA p+A vs p+p

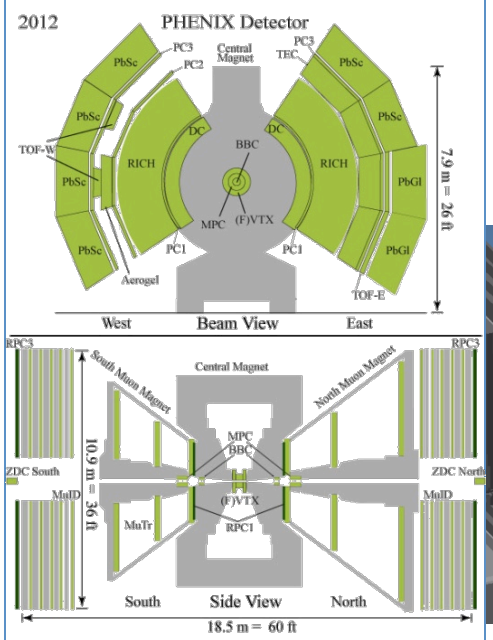
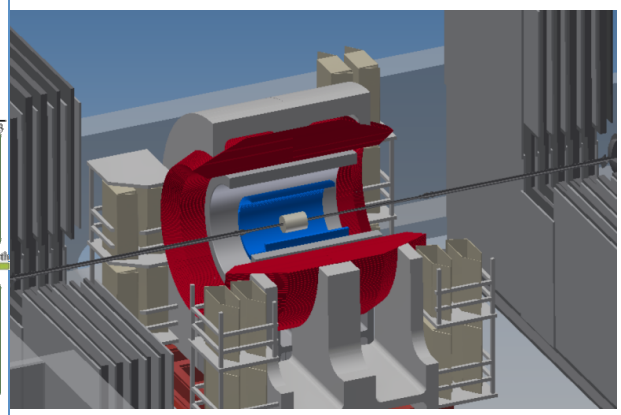
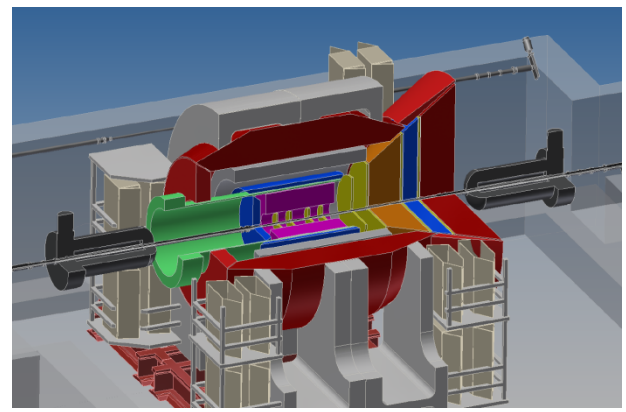
$$\frac{A_N^{pA\to h}}{A_N^{pp\to h}}\Big|_{P_{h\perp}\ll Q_s^2} \approx \frac{Q_{sp}^2}{Q_{sA}^2} e^{\frac{P_{h\perp}^2 \delta^2}{Q_{sp}^4}} \qquad \frac{A_N^{pA\to h}}{A_N^{pp\to h}}\Big|_{P_{h\perp}\gg Q_s^2} \approx 1$$



MPC-EX: forward EM calorimeter

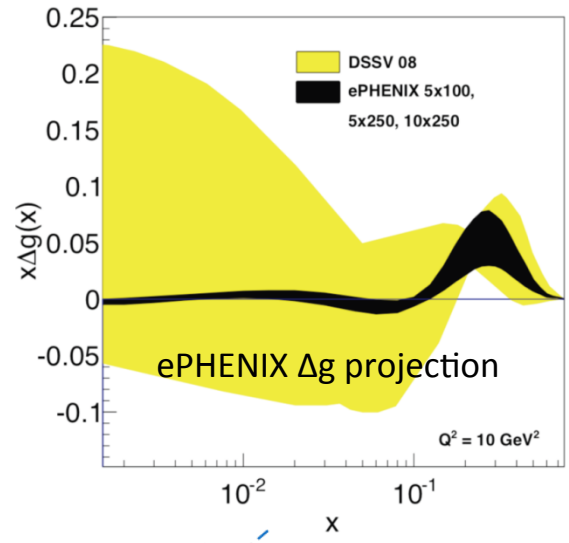


PHENIX Plan of Evolution to eRHIC Era

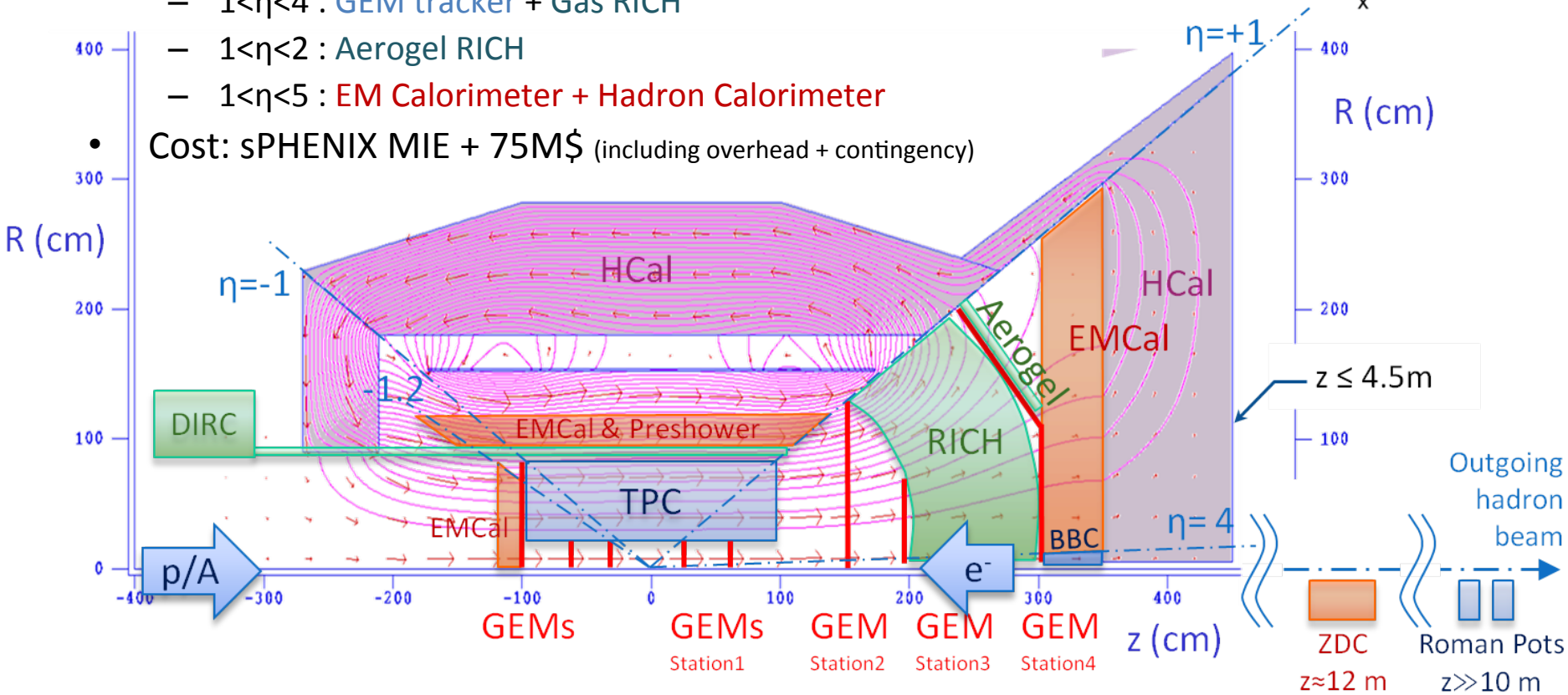
Current PHENIX	sPHENIX	ePHENIX
	Central barrel (and forward detectors) 	

~2000 ~2020 ~2025 Time

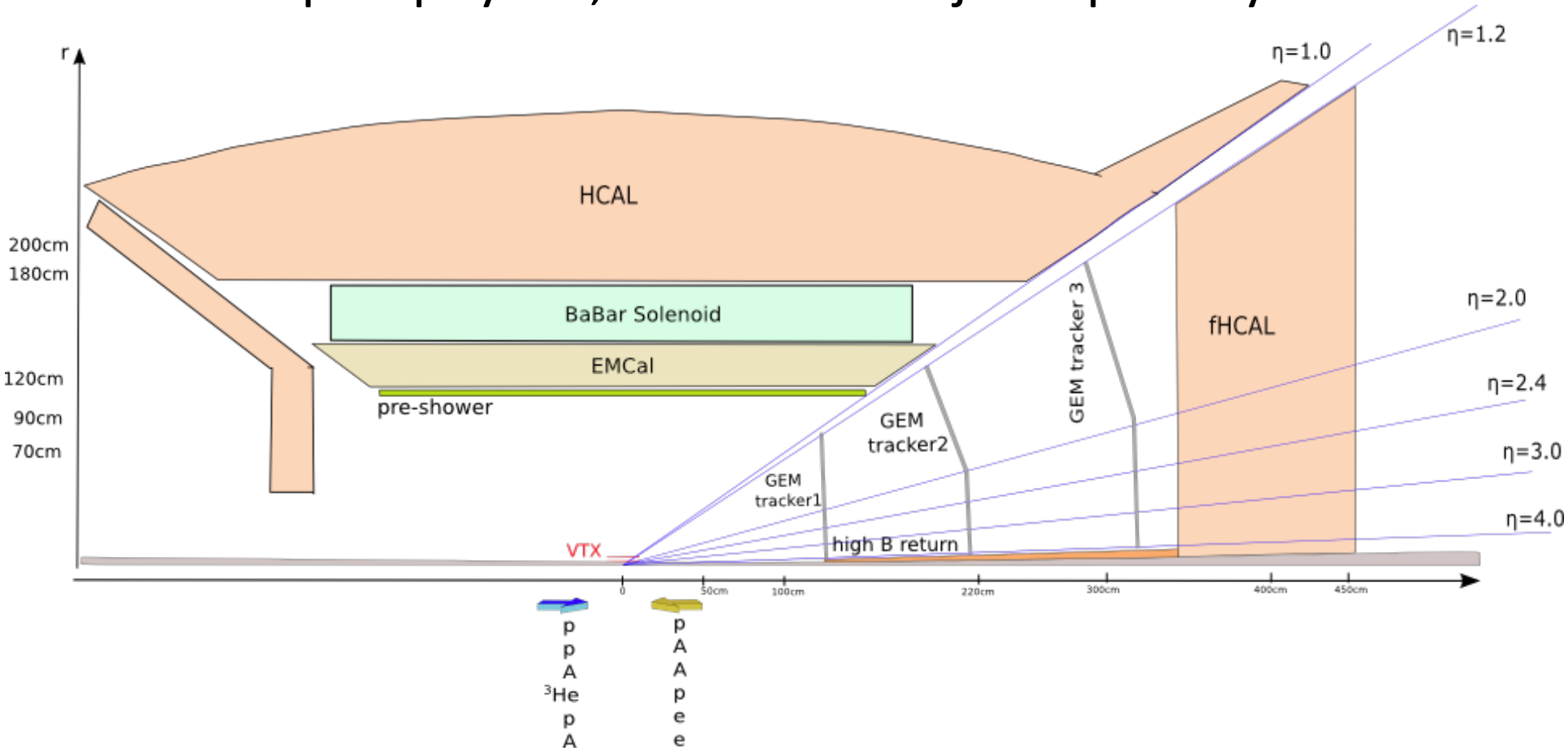
ePHENIX Detector Concept



- -4<η<-1 (e-going) :
  Crystal calorimeter + GEM trackers
- -1<η<+1 (barrel) : sPHENIX + Compact-TPC + DIRC
- +1<η<+4 (h-going) :
  - 1<η<4 : GEM tracker + Gas RICH
  - 1<η<2 : Aerogel RICH
  - 1<η<5 : EM Calorimeter + Hadron Calorimeter
- Cost: sPHENIX MIE + 75M$ (including overhead + contingency)



Stage-I of ePHENIX, if built early, can carry out p+p and p+A physics, with forward jet capability



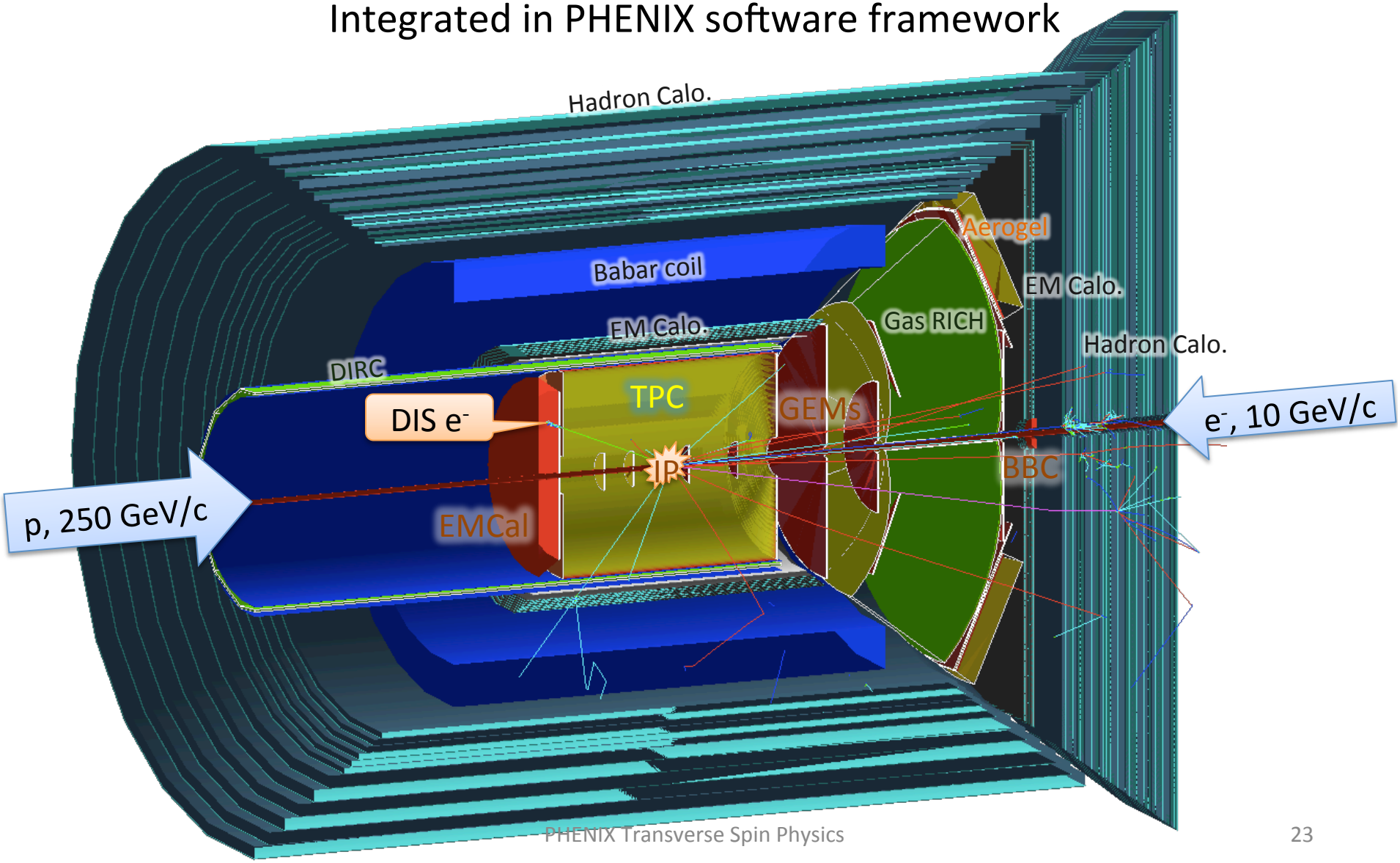
Summary

- PHENIX transverse spin physics results.
- Upcoming p+p and p+A runs (Run-2015) with FVTX and MPC-EX upgrades.
- Planned ePHENIX upgrades for eRHIC
- … and forward sPHENIX for p+p and p+A physics, with forward jet capability.

BACKUP

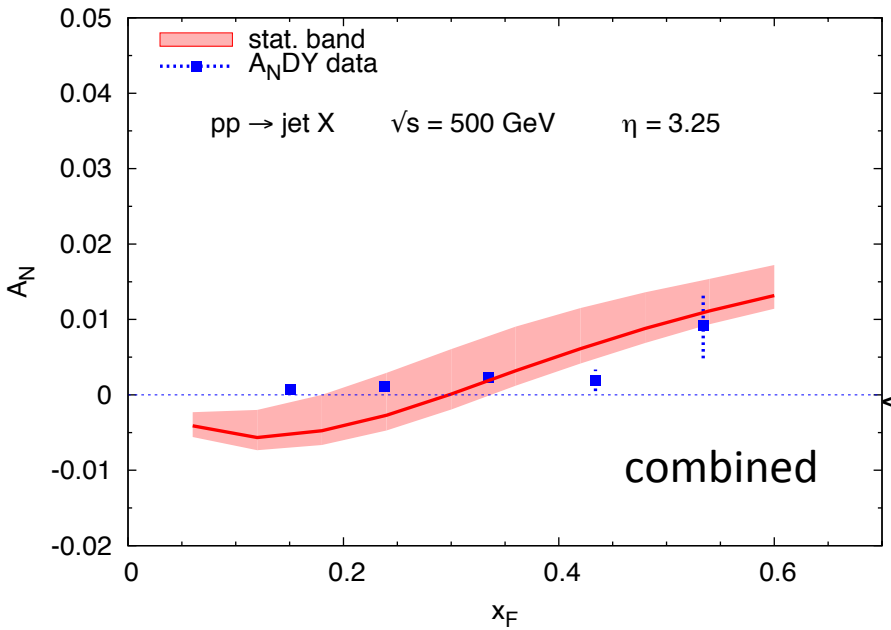
Simulation

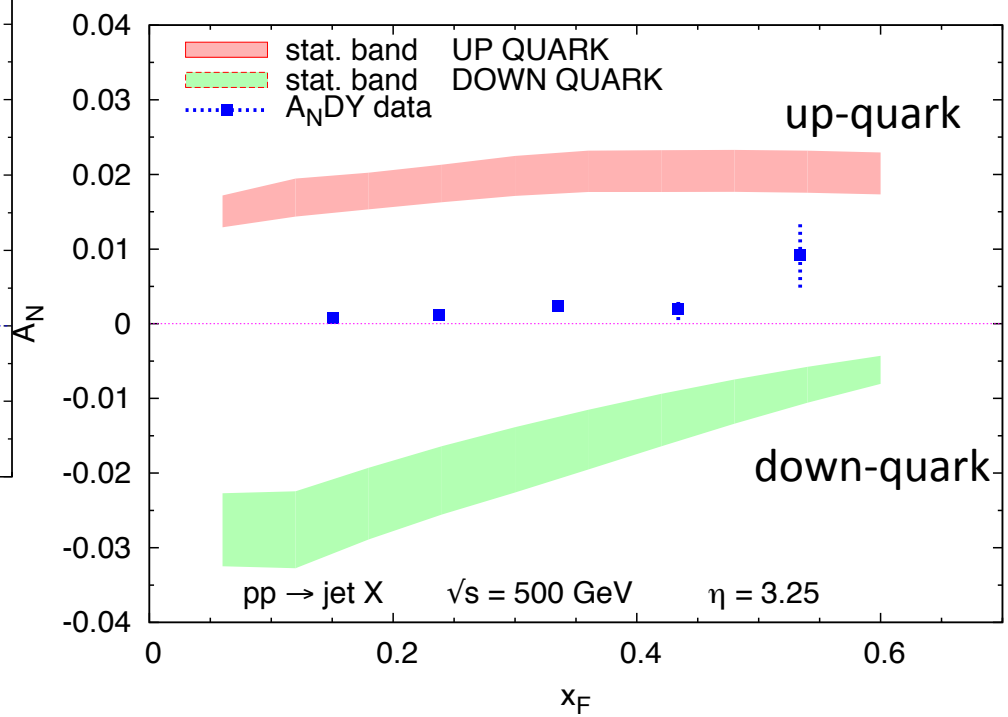
An event display for SIDIS @ $x \approx 5\times10^{-3}$ and $Q^2=10\ (\mathrm{GeV}/c)^2$
Integrated in PHENIX software framework



While not considering "process dependency" of Sivers function…

Directly use Sivers function from SIDIS fit



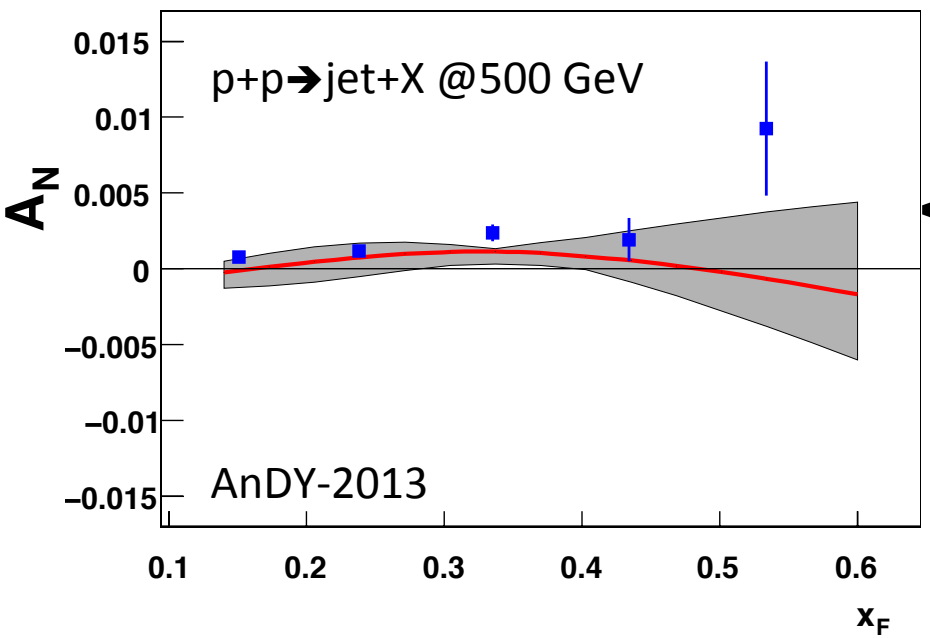


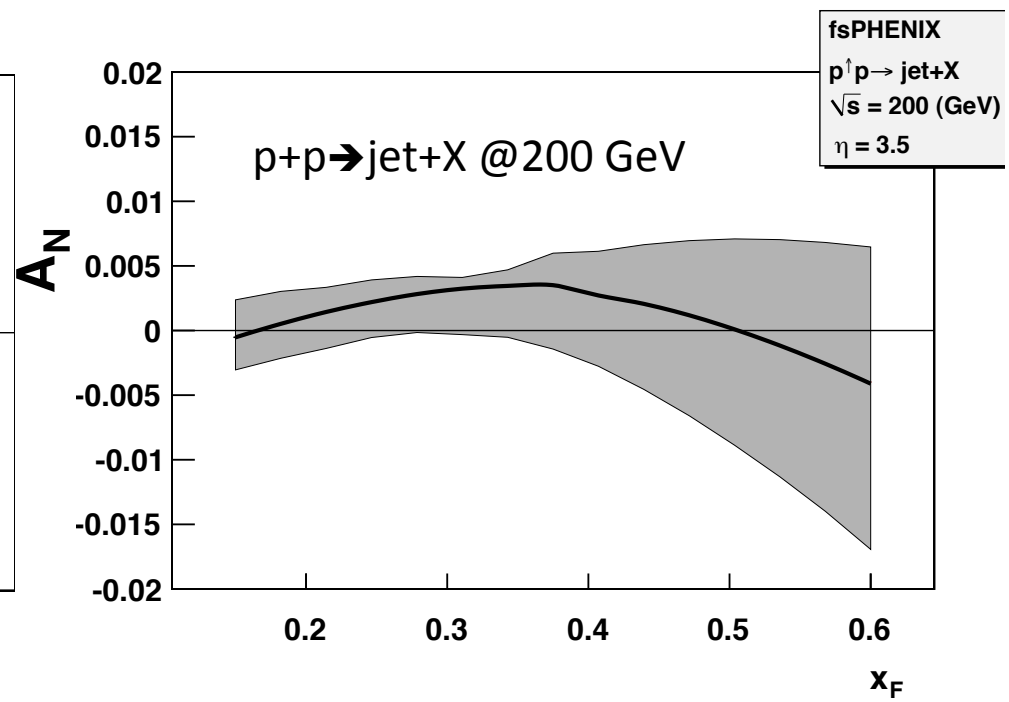
Anselmino et al. updated 2012.

Jet A_N : when considering "process dependency" of Sivers function

Sivers functions in Jet A_N have opposite signs to that of SIDIS. Kang et al. 2013

Second type of theoretical explanation:
Sivers from SIDIS data
Consider process dependency.





up-quark's contribution is negative, down-quark's contribution is positive.