The Future of RHIC Spin

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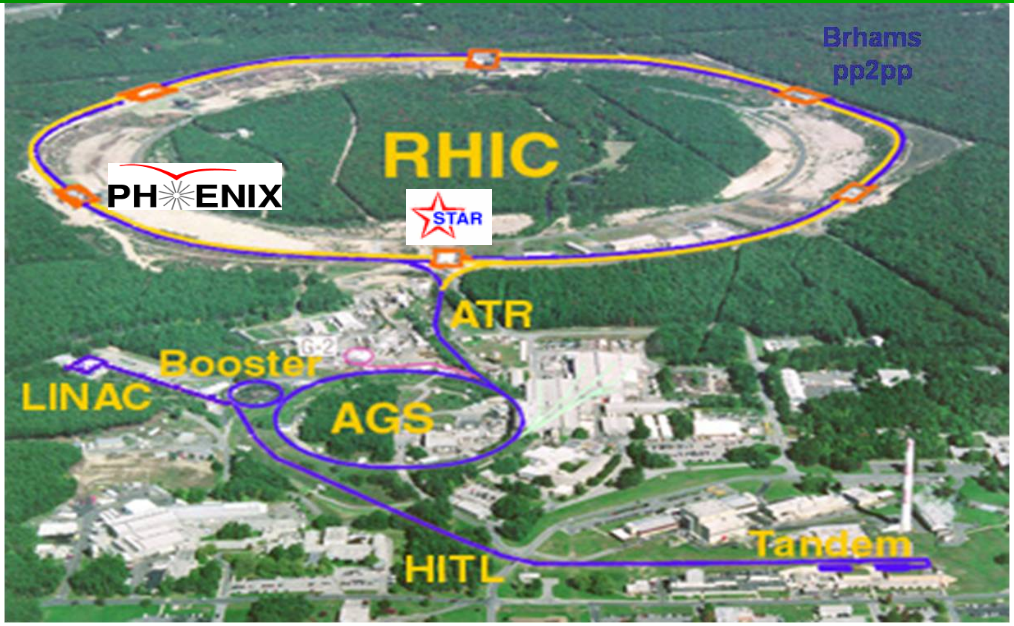
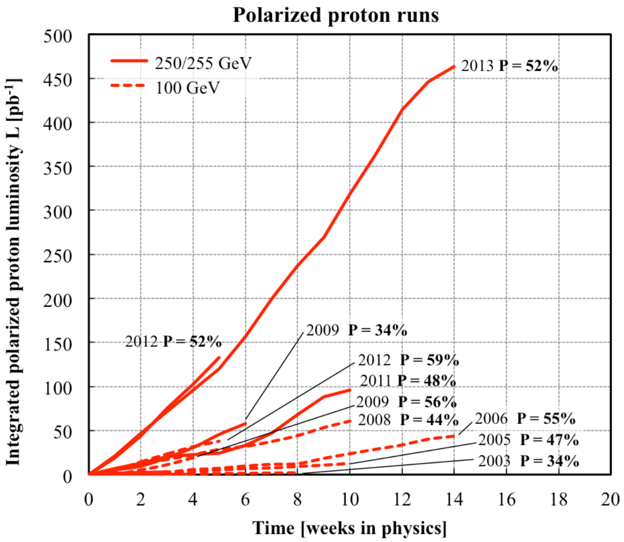
Outline

- Quick Overview of RHIC
- Helicity Structure
  - What we've learned
  - What's next
- Transverse Spin physics
  - Understanding large forward asymmetries
  - Near term plans
  - Longer term detector upgrade plans
- Transverse Spin as a tool to understand QCD
  - Saturation effects in polarized p+A:
  - Factorization:
    - Drell Yan, W

RHIC



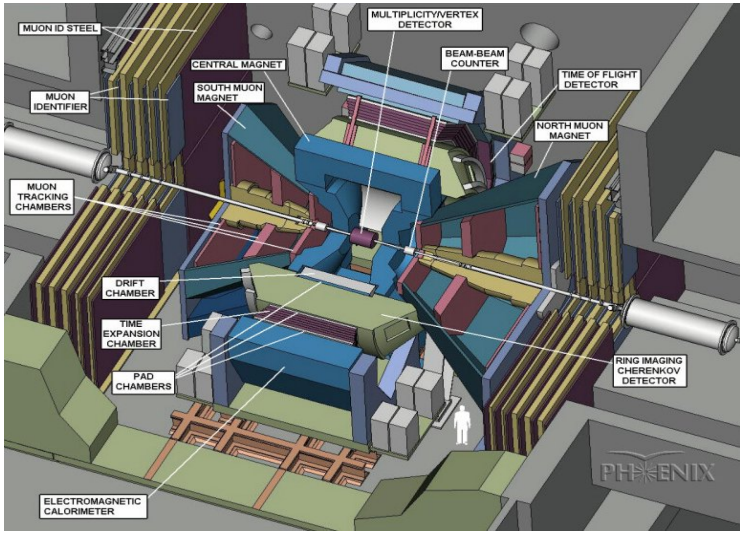


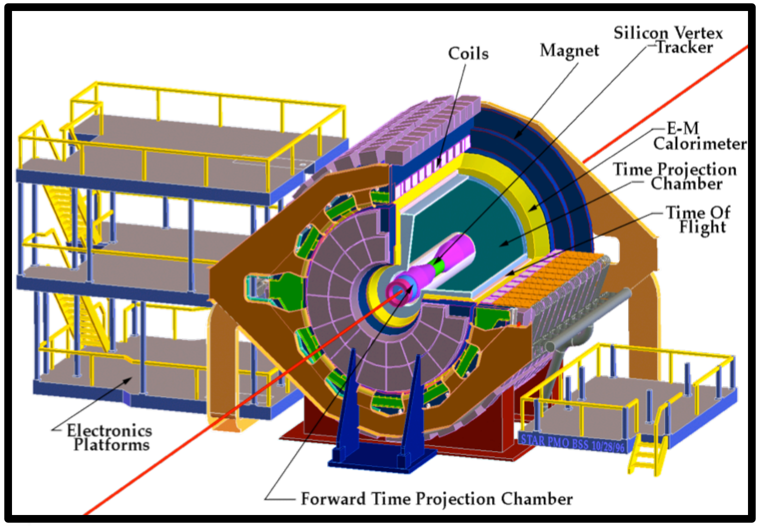
- √s=62.4-500(510) GeV
- Experiments choose Transverse or Longitudinal polarization
- Achieved 60% (55%) polarization at √s=200 (500) GeV

Experiments

PHENIX

- High rate capability
- Limited acceptance
- High p_T photon trigger
- Forward muon arms





STAR

- Large acceptance
- Azimuthal symmetry
- Jet patch trigger
- Forward EMcal

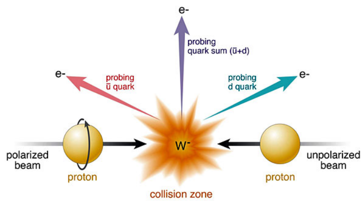
RHIC Spin Program

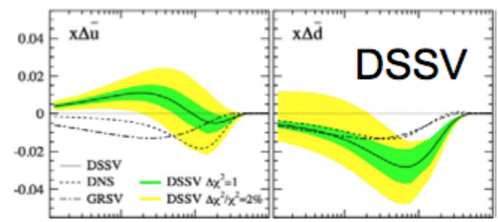
Three Main Programs:

- Gluon Helicity

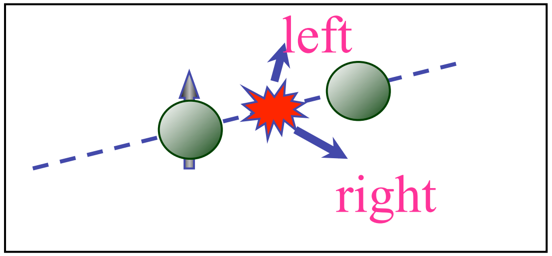
$$S_p = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

- Flavor-separated Sea Quark Helicity



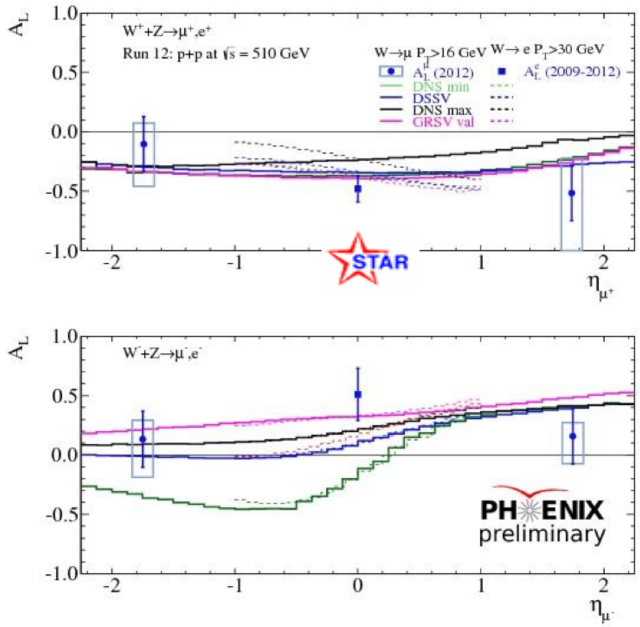


- Transverse Spin Phenomena

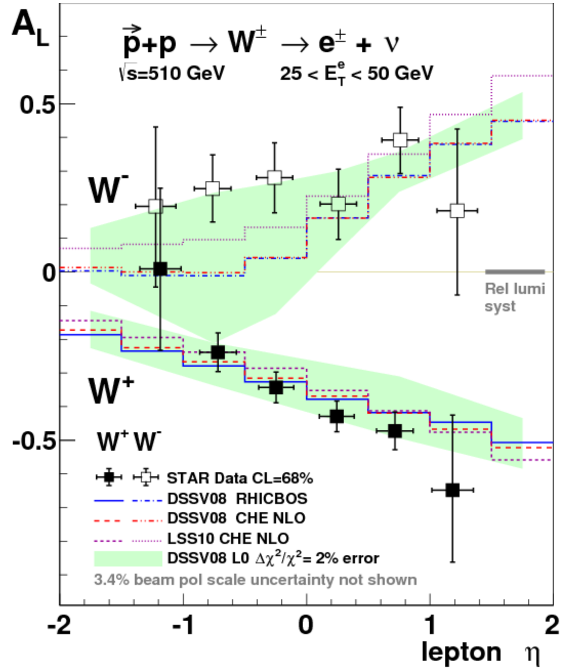


Helicity Program

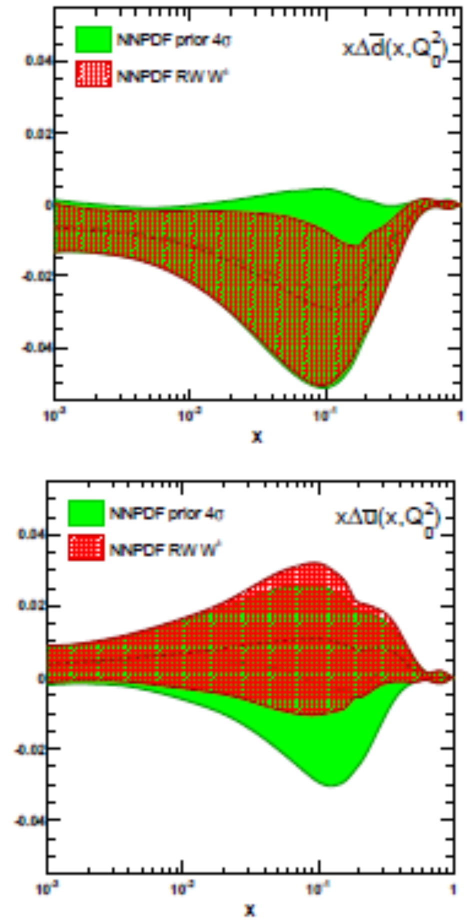
Sea Quark Polarization ($\Delta\bar{u}$, $\Delta\bar{d}$)



PRL 113 072301



arXiv:1406.5539

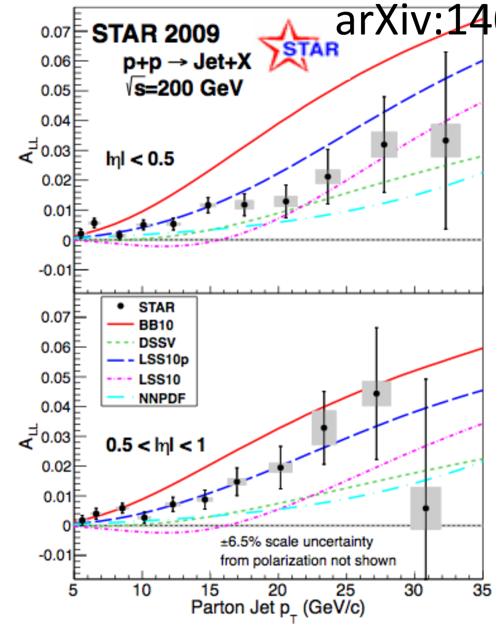


- Unique access to sea quarks through weak interactions
- Complimentary approach with SIDIS
- Huge 2013 data set will further constrain sea quark helicities

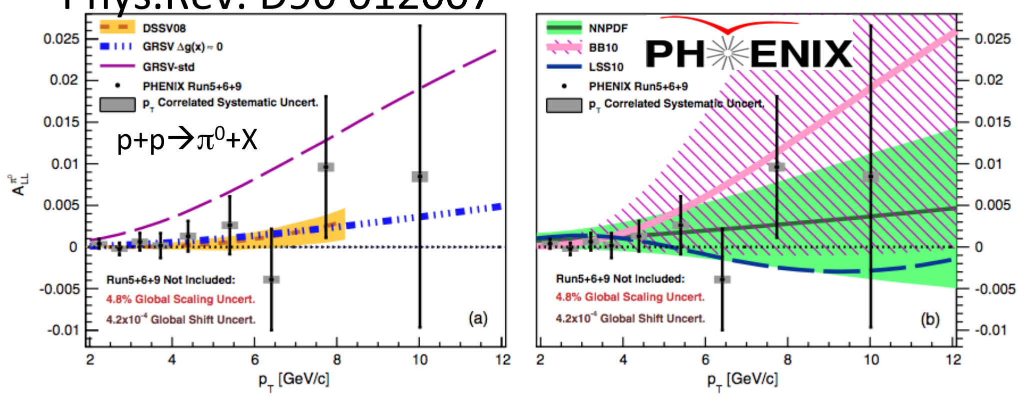
Gluon Polarization (ΔG)

$$A_{LL} = \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}} \qquad R = \frac{L_{++}}{L_{+-}}$$

arXiv:1405.5134

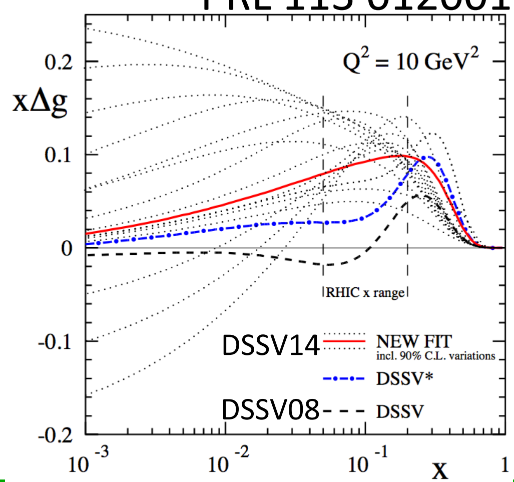


Phys.Rev. D90 012007



- 2009 results indicate positive asymmetries.
- Used in global analyses
- positive ΔG, similar to quark contribution

PRL 113 012001



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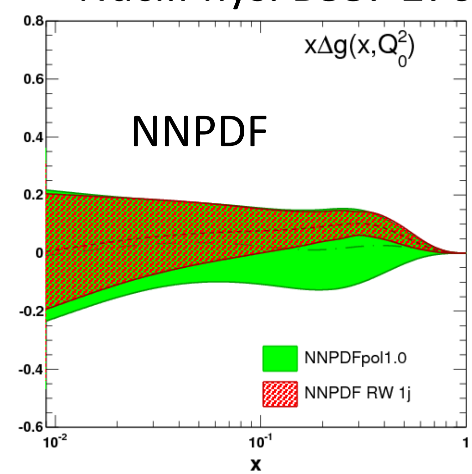
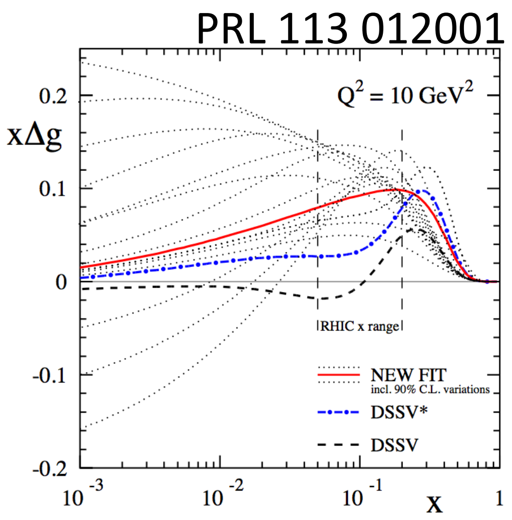
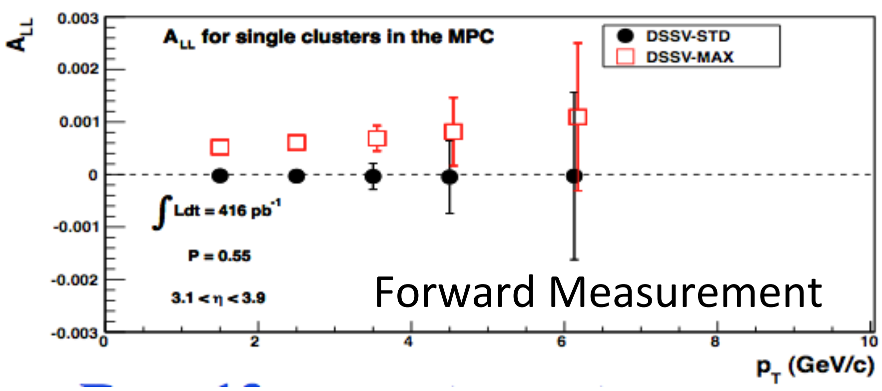
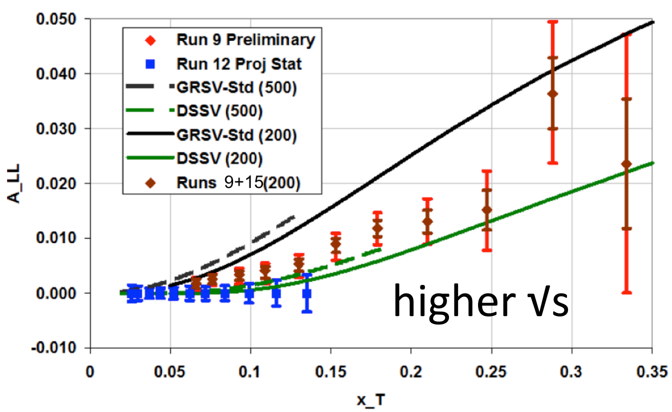


Gluon Polarization (ΔG)



- Large uncertainty at low x
  - RHIC can get to lower x two ways:
    - higher √s (510 GeV)
    - forward measurements
- Additional data at √s=200 GeV in 2015

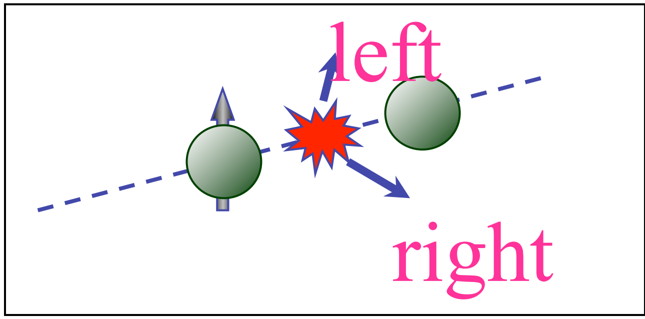


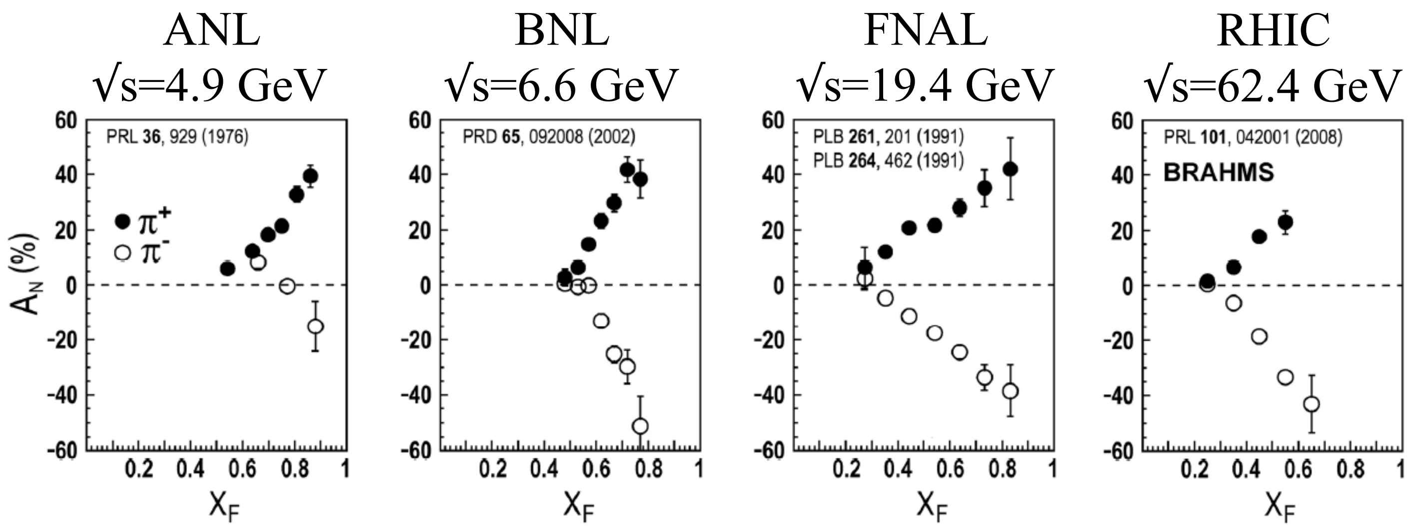


Transverse Spin Physics

Transverse Spin Conundrum

- Very large asymmetries seen over wide range in scattering energy
- Survive up to √s = 500 GeV

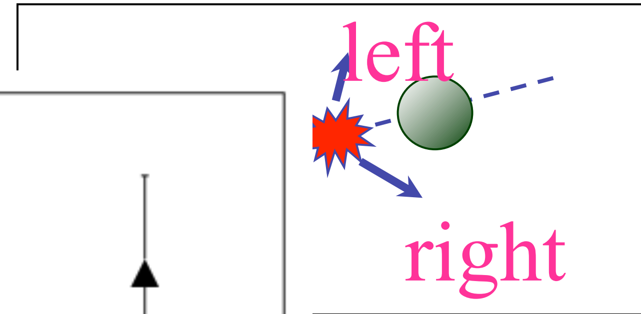


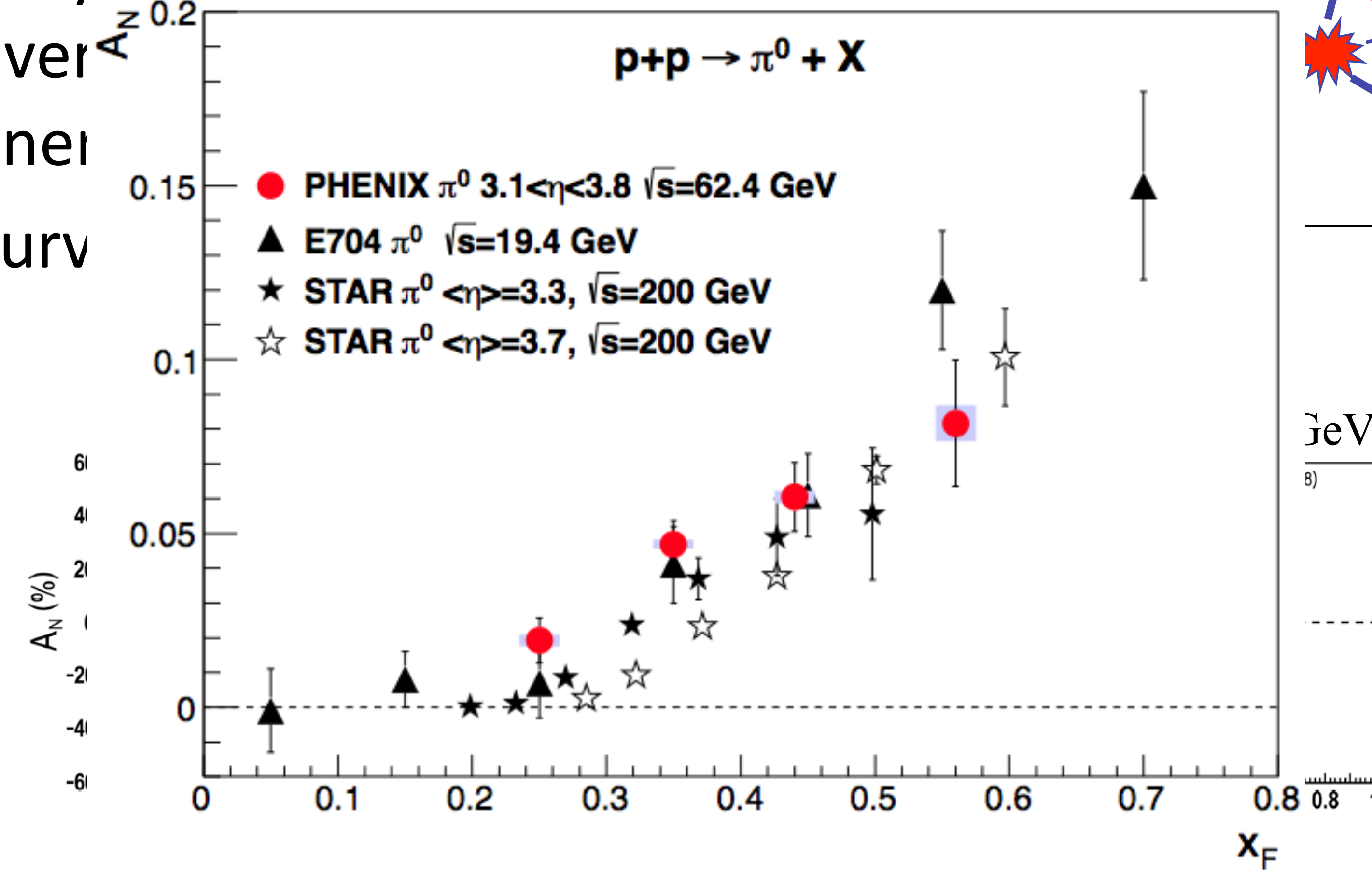


$$x_F = 2 p_{long} / \sqrt{s}$$

Transverse Spin Conundrum

- Very large asymmetries seen over ener
- Surv

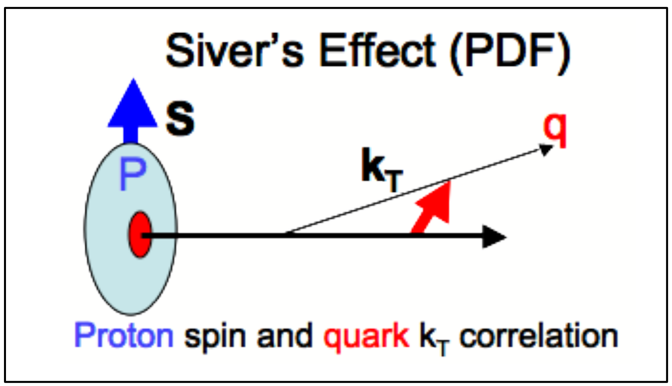


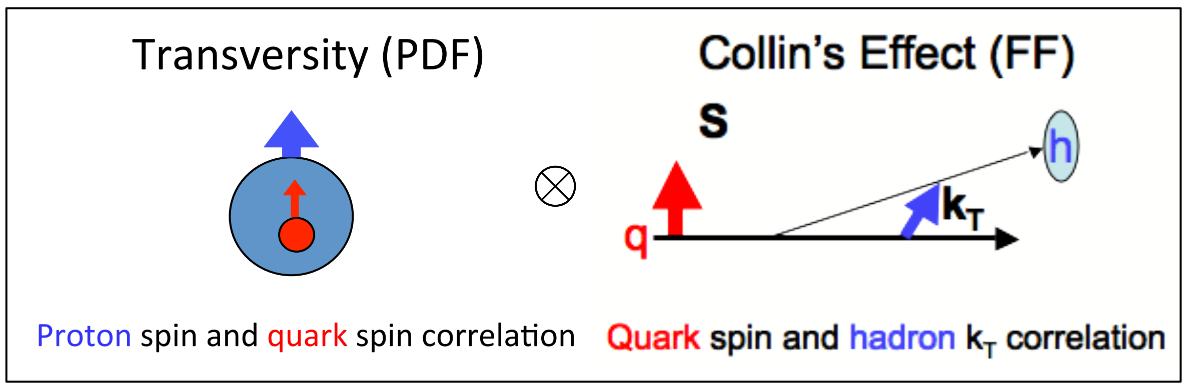


$$x_F = 2p_{long} / \sqrt{s}$$

But what is the cause?

- Some possibilities:
  - Transverse Momentum Dependent (TMD) effect (and there twist three counterparts)
    - Sivers: Initial state effect with quark k_T correlated with proton spin
    - Transversity $\otimes$ Collins: Correlation between quark and proton spin, coupled with pin dependent fragmentation function

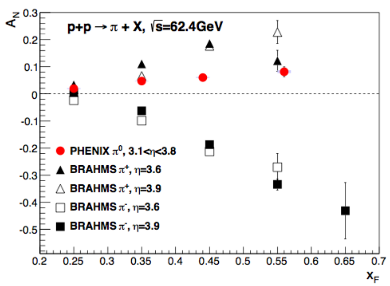


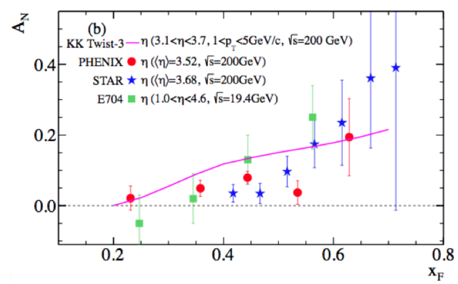


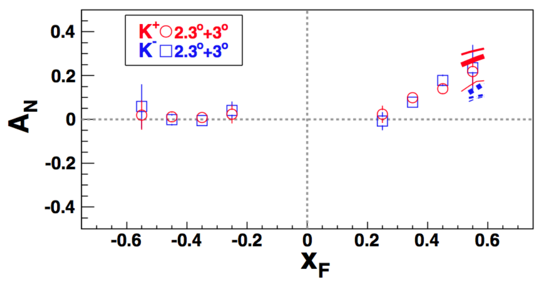
  - Something else, like diffractive physics.

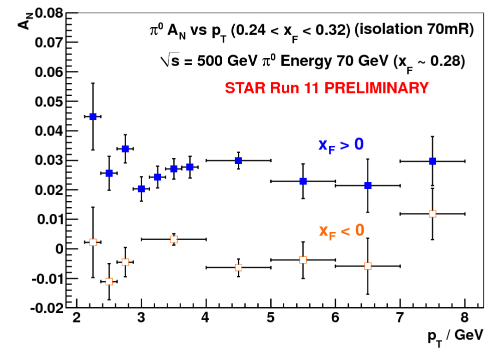
Results

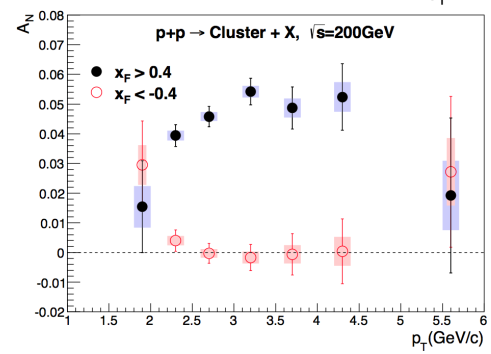
- RHIC has measured many single hadron transverse spin asymmetries







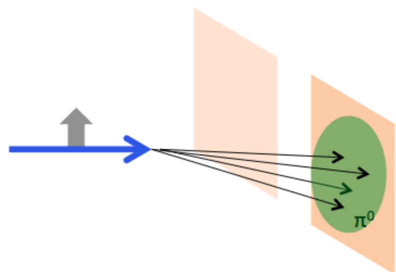


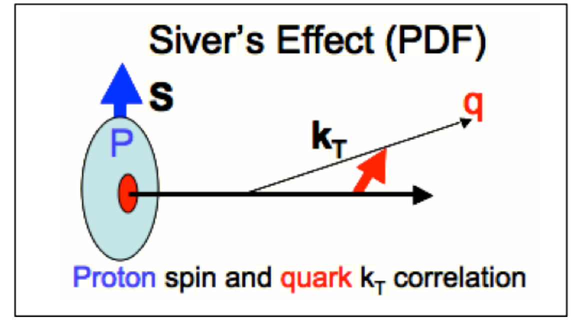


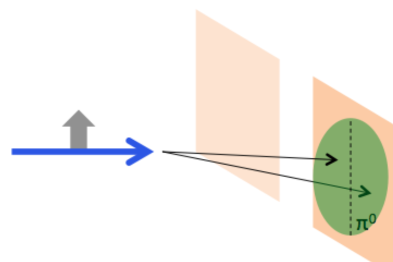
- To understand the mechanism generating these asymmetries, we must move beyond single hadrons

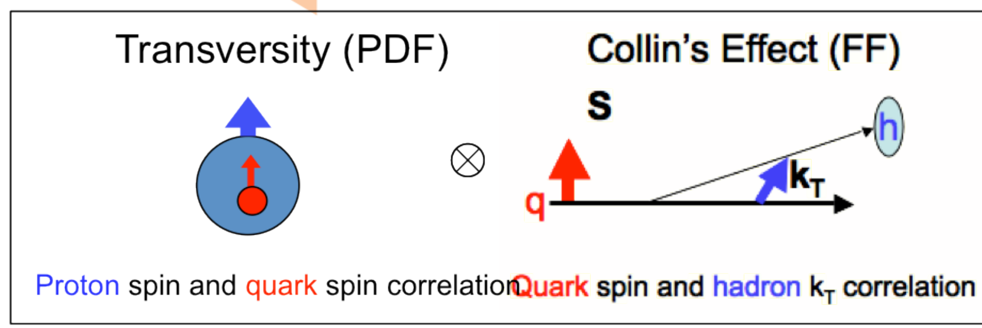
The problem with hadrons

- Hadron asymmetries could be caused by
  - asymmetries in the parent Jet, like for Sivers
  - asymmetries within a parent Jet, like for Collins
- Therefore, event level information, like jet structure is needed to separate the two



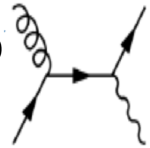


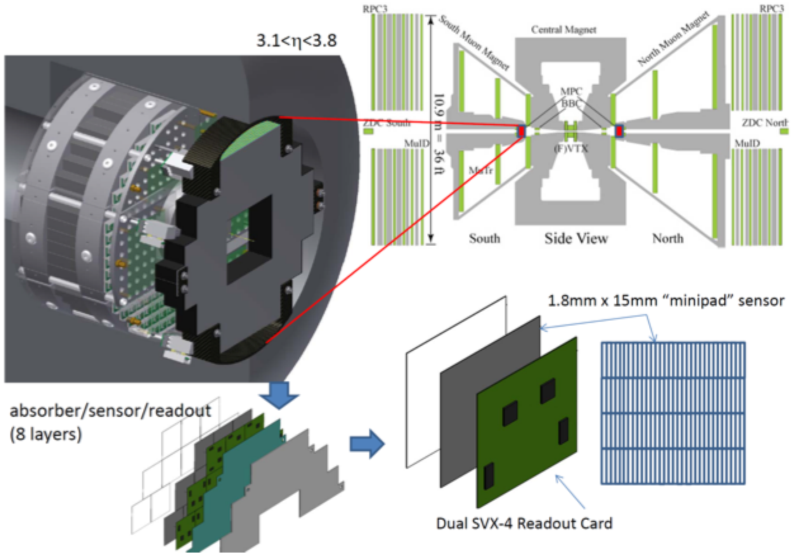


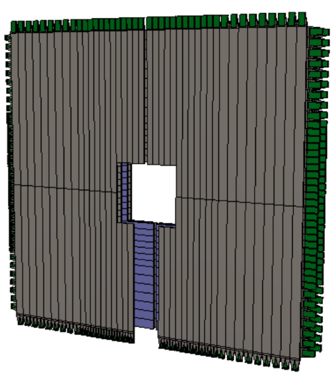


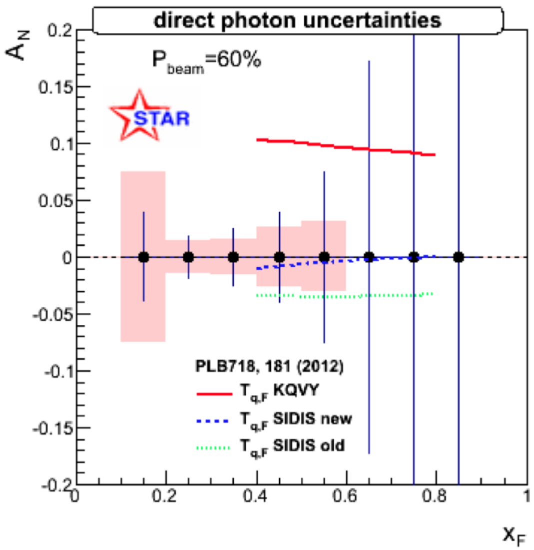
Solution 1: Look at direct photons

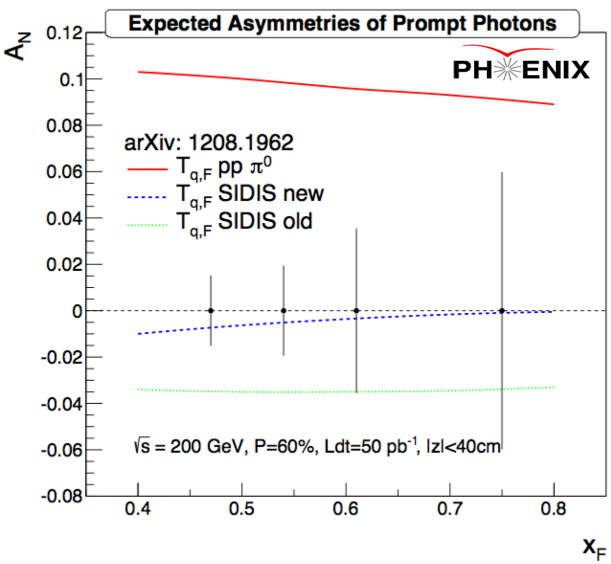
- Direct Photon is sensitive to Siver's
  - small contribution from fragmentation photons
- PHENIX and STAR installing preshowers for forward calorimetry
- 2015 run will allow for test of Siver's type asymmetry source





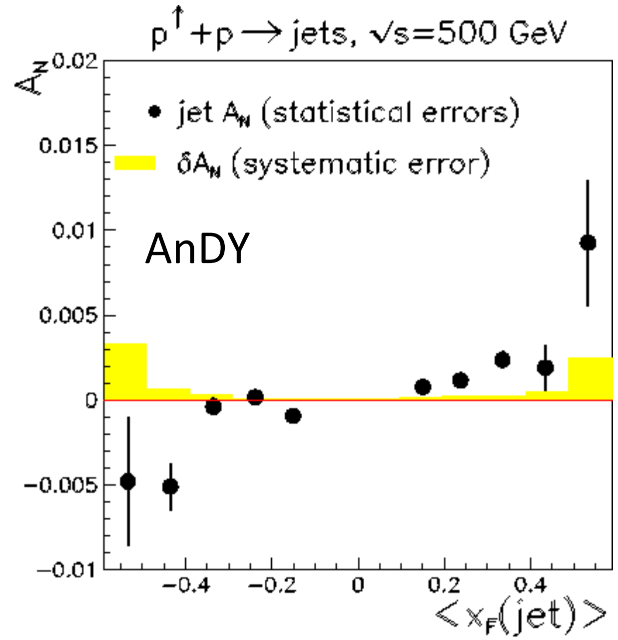


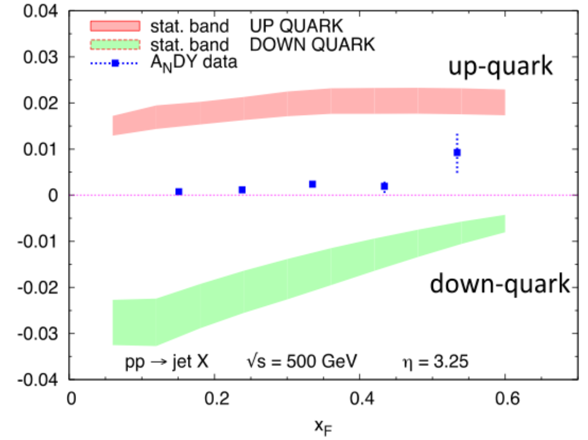




Solution 2: Look at Jets

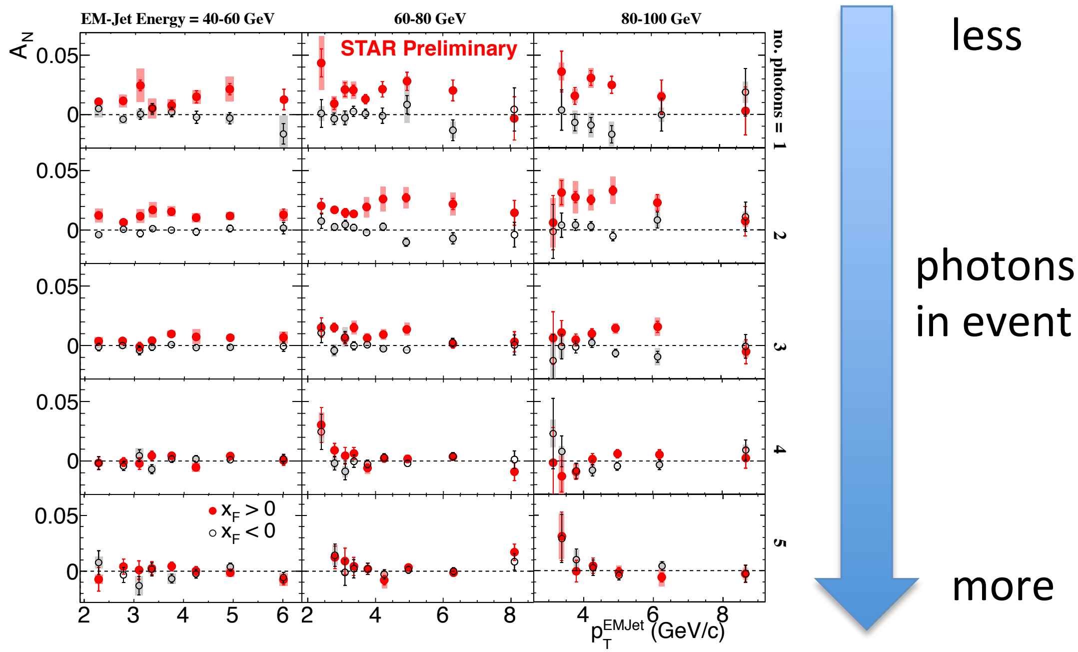
- If we can look at jet containing hadrons, can start to separate effects
- Measurements by AnDY found small jet asymmetries
  - possible that Siver's effect for up and down quarks cancel





Forward π^0 and jetlike events

- STAR has looked at how the measured A_N for π^0 depend on other activity in the forward calorimeter, i.e. proxy for jet
- Find that with more activity, asymmetries are reduced

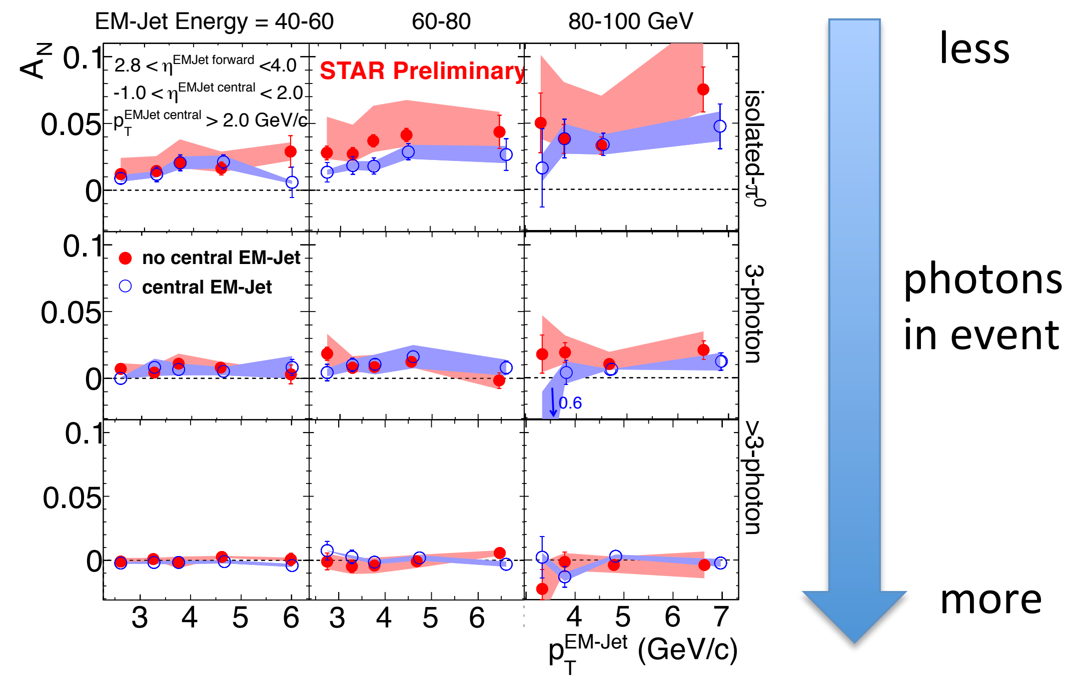


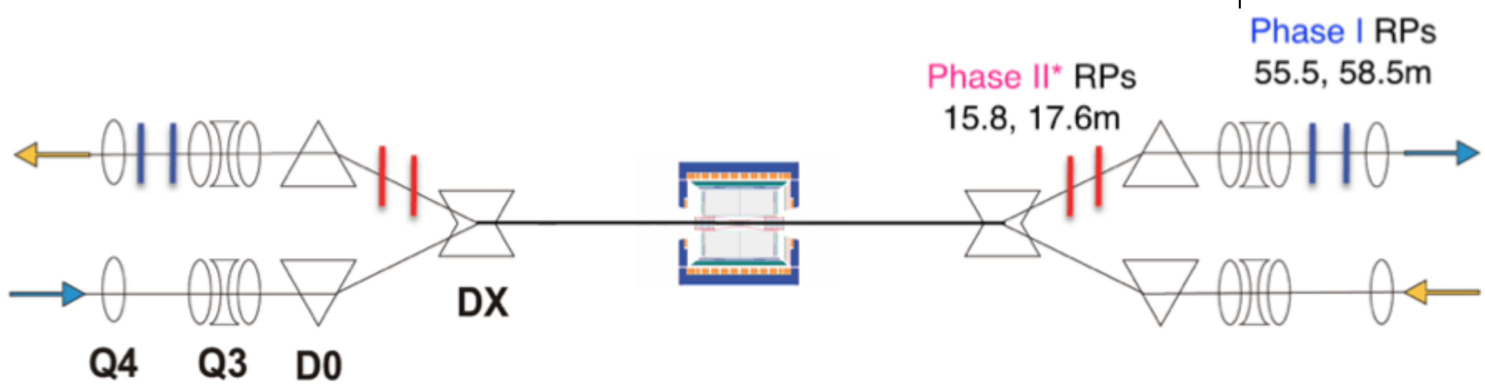
Why?

- z dependence? could be Collin's
- Some suggestions that could be effect of diffractive physics

Study diffractive events

- For 2015 run, STAR will have installed Roman Pots.
- Will allow tagging of diffractive events, testing the idea that diffractive processes could be the source of large hadron A_N.



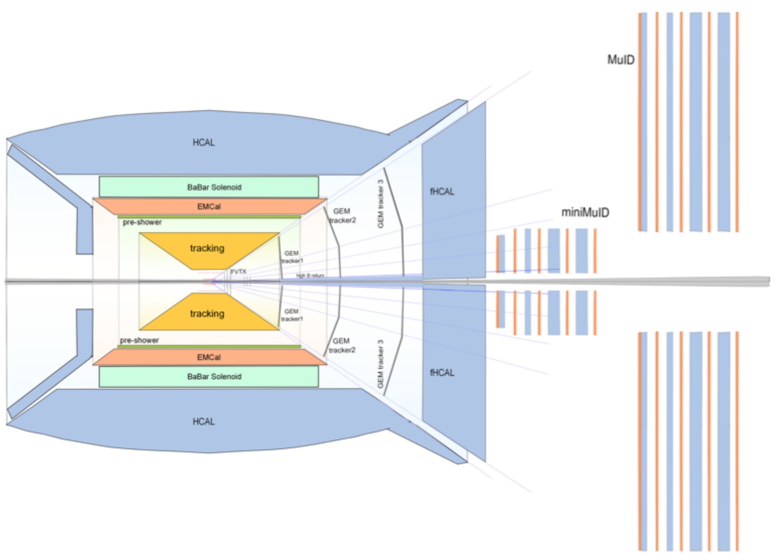


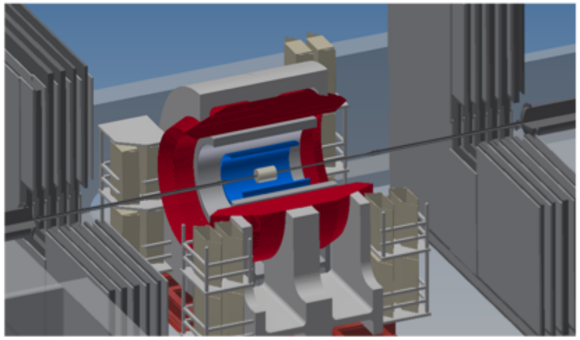
Limitations of current detectors

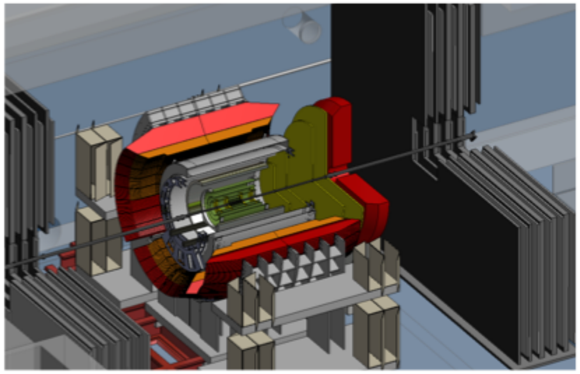
- Both PHENIX and STAR forward detectors for measuring hadrons are limited to EM Calorimeters
  - This limits how well we can distinguish Sivers from Collins effects
- For real jet measurements, need at a minimum hadronic calorimetry and/or tracking in the forward direction
- Both STAR and PHENIX plan long term upgrades to allow forward jet measurements at the start of the next decade.

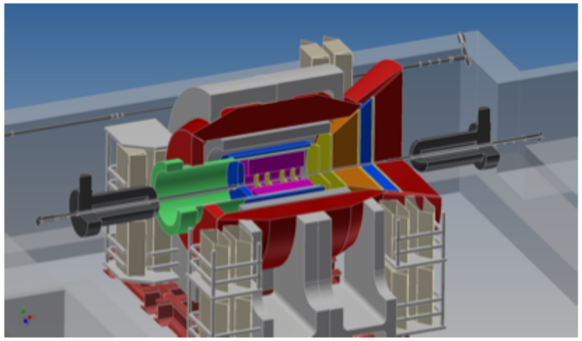
Forward sPHENIX

- PHENIX is planning an significant upgrade (sPHENIX) which will use the BABAR magnet and wider calorimetry coverage
- This will open up the forward direction, allowing for a forward spectrometer to be added
- Such a spectrometer could form the basis for and EIC detector at eRHIC



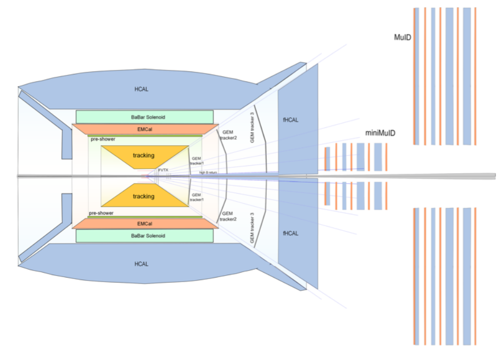


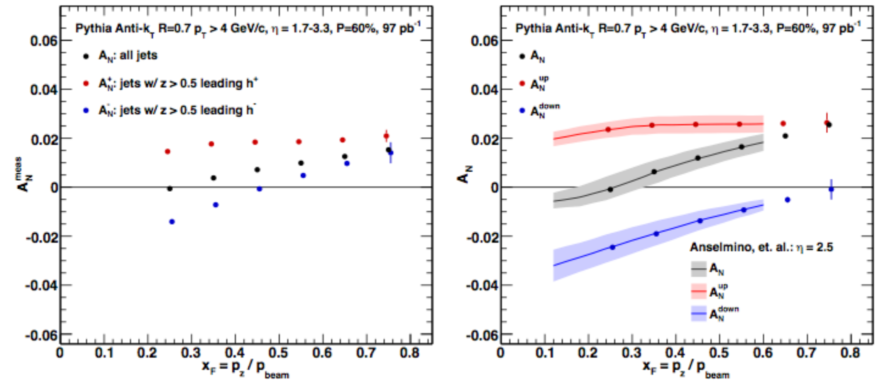


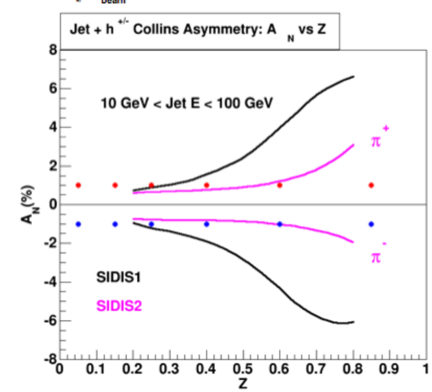


Forward sPHENIX

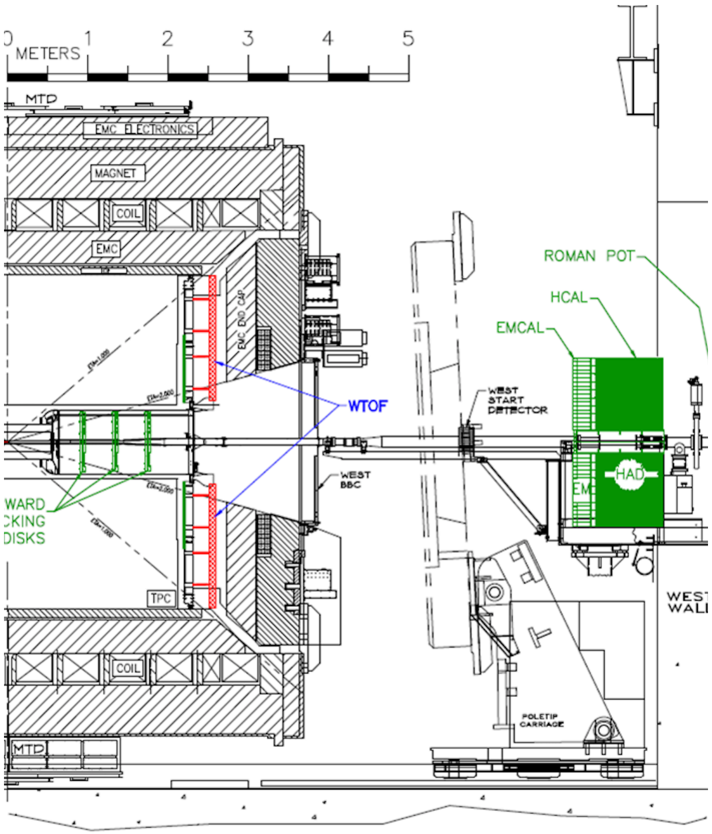
- Tag hadron charge with tracking
- Determine z with hadronic calorimeter
- Separation of jets by leading hadron can isolate jets from up and down quarks, testing whether Sivers generate hadron A_N
- Can also look at Collins asymmetry of hadrons in jets







STAR Forward Upgrades



Part of a coordinated upgrade path that can lead to an EIC detector.

ECal:

- Tungsten-Powder-Scintillating-fiber
- 2.3 cm Moliere Radius, Tower-size: 2.5x2.5x17 cm^3, 23 X_o

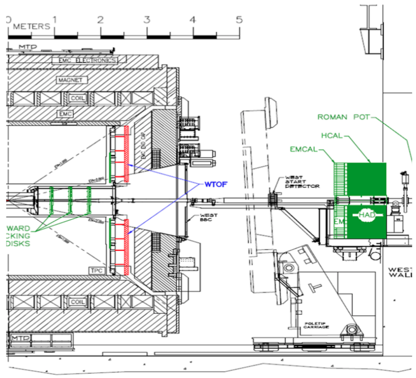
HCal:

- Lead and Scintillator tiles, Tower size of 10x10x81 cm^3
- 4 interaction length

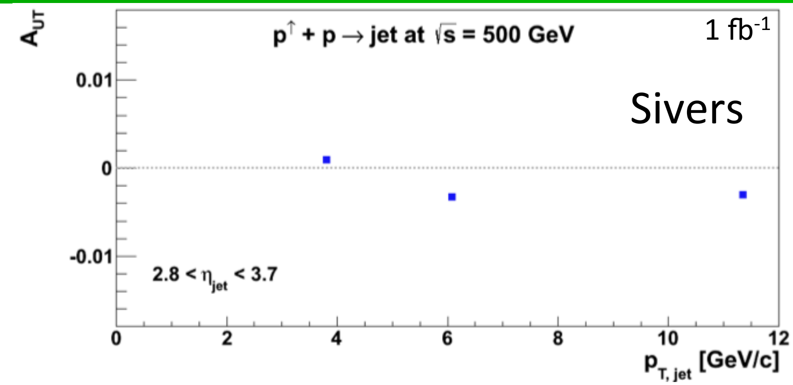
Tracking:

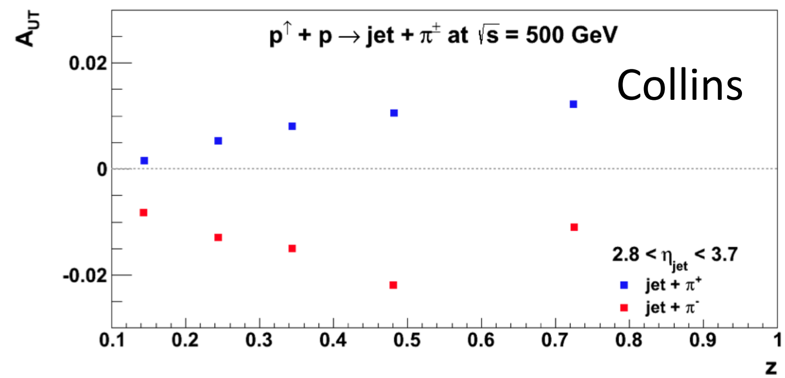
- Silicon mini-strip detector 3-4 disks at z ~70 to 140 cm
- Each disk has wedges covering full 2π range in ϕ
- and 2.5-4 in η (other options still under study)

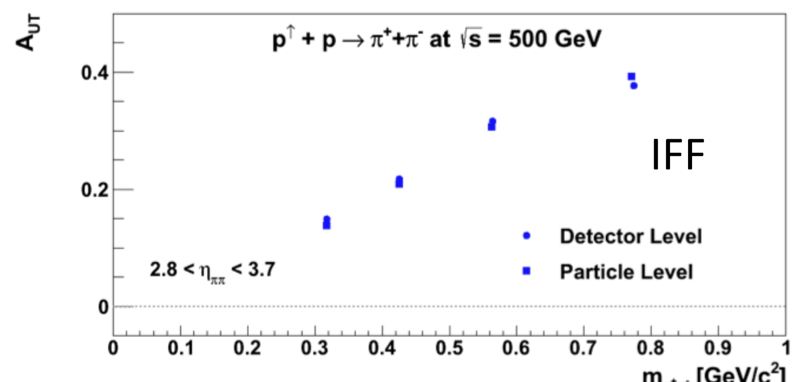
STAR Forward Upgrade



- Upgrade allows very precise measurements of
  - Forward jets for Sivers
  - Hadrons in jets for Collins
  - Hadron pairs for Interference fragmentation functions (IFF)
    - allow access to transversity

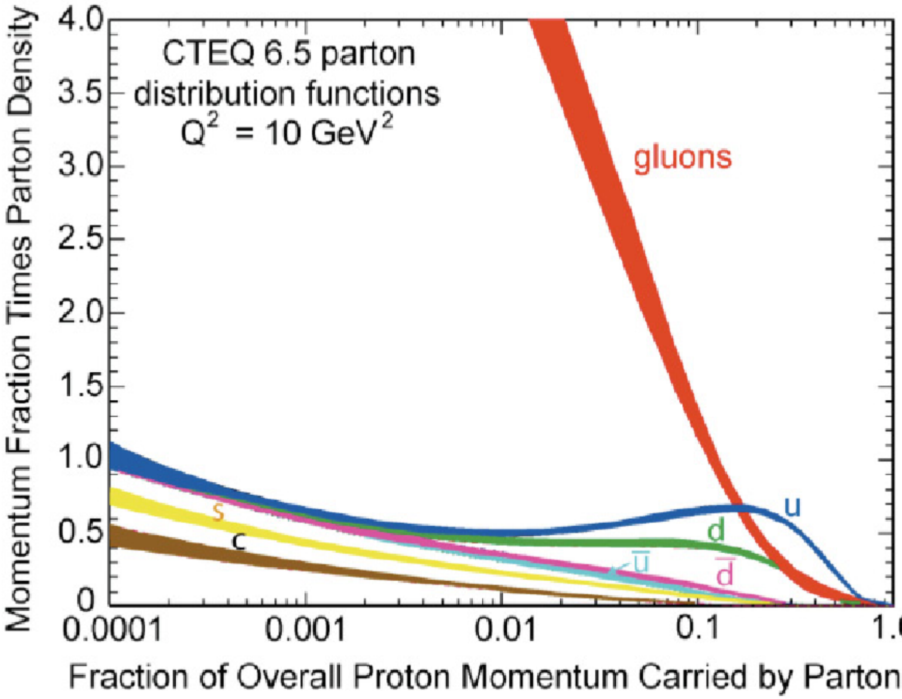




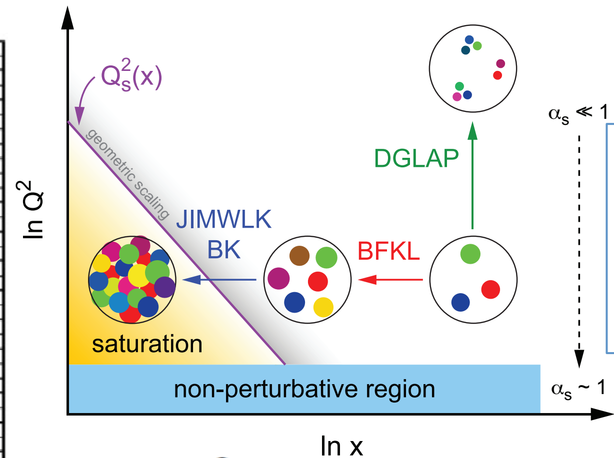


Transverse Spin Asymmetries as a Tool

Saturation



(x)

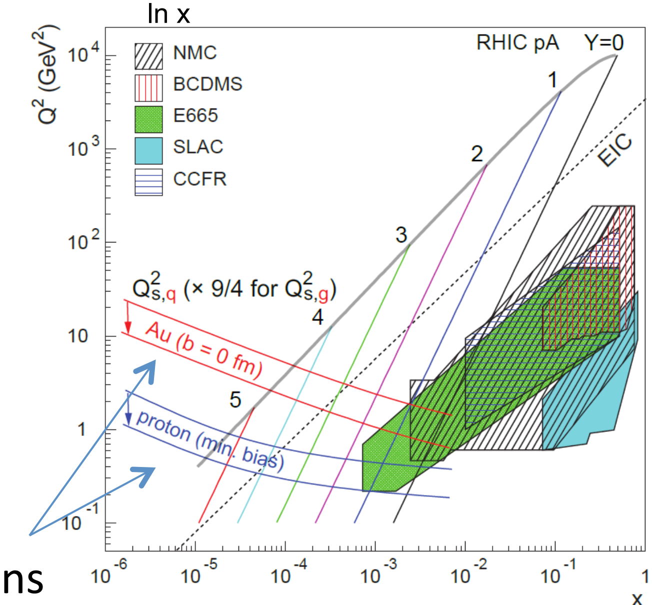


The gluon density grows to the point where recombination tames the growth of the gluon distribution at small x.

The nucleus is an *amplifier* of high gluon densities.

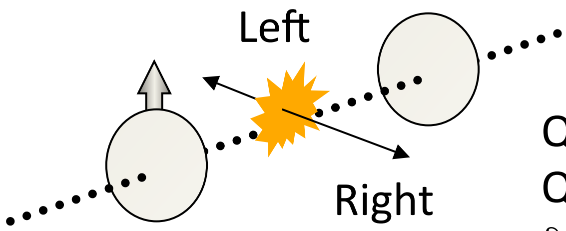
$$\left(Q_S^A\right)^2 \approx cQ_0^2\left(\frac{A}{x}\right)^{1/3}$$

gluons



Polarized p+A Collisions at RHIC

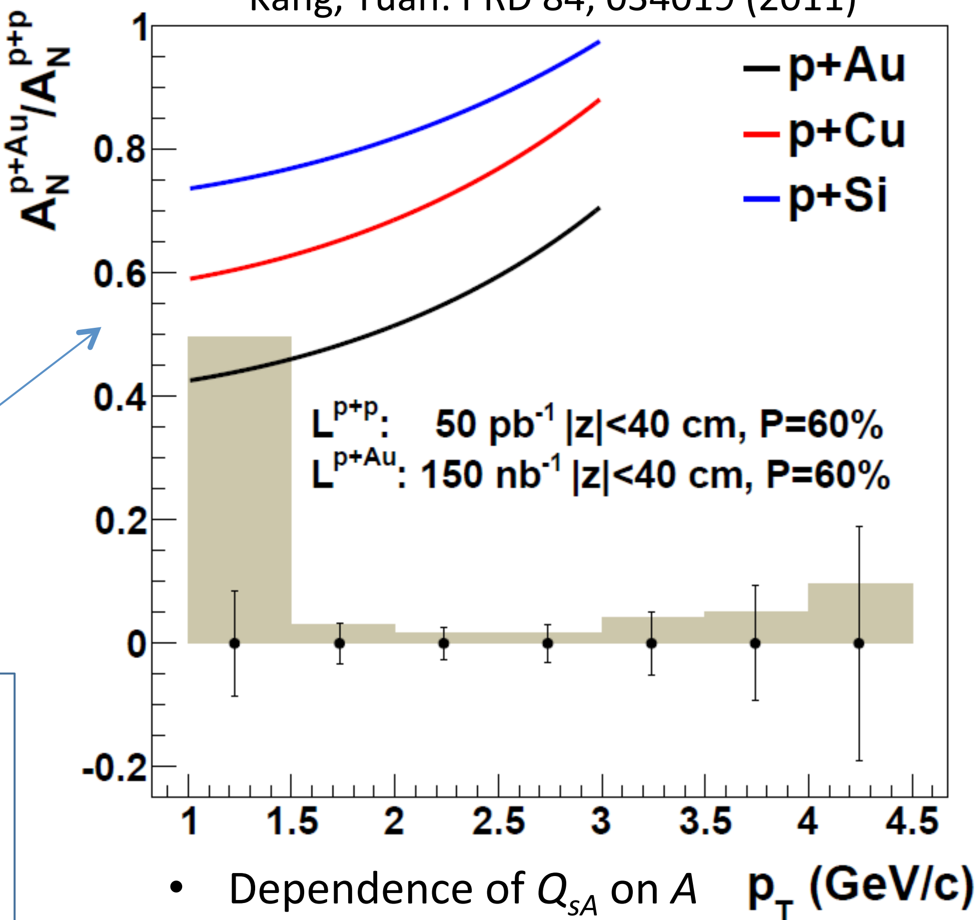
$$A_N = \frac{1}{P}\frac{\sigma_L^\pi - \sigma_R^\pi}{\sigma_L^\pi + \sigma_R^\pi}$$



$Q_{sp}^2 = (1.0\ \mathrm{GeV})^2$
$Q_{sA}^2 = (2.5\ \mathrm{GeV})^2$
$\delta = 0.16\ \mathrm{GeV}$

$$\left.\frac{A_N^{pA\to h}}{A_N^{pp\to h}}\right|_{P_{h\perp}^2 \ll Q_{sA}^2} \approx \frac{Q_{sp}^2}{Q_{sA}^2}\, e^{P_{h\perp}^2 \delta^2 / Q_{sp}^2}$$

Y. Kovchegov & M.D. Sievert: PRD 86, 034028 (2012)
Kang, Yuan: PRD 84, 034019 (2011)



Single spin asymmetries can act as a probe of the saturation scale – the p+p reference will also be better understood with new instruments.

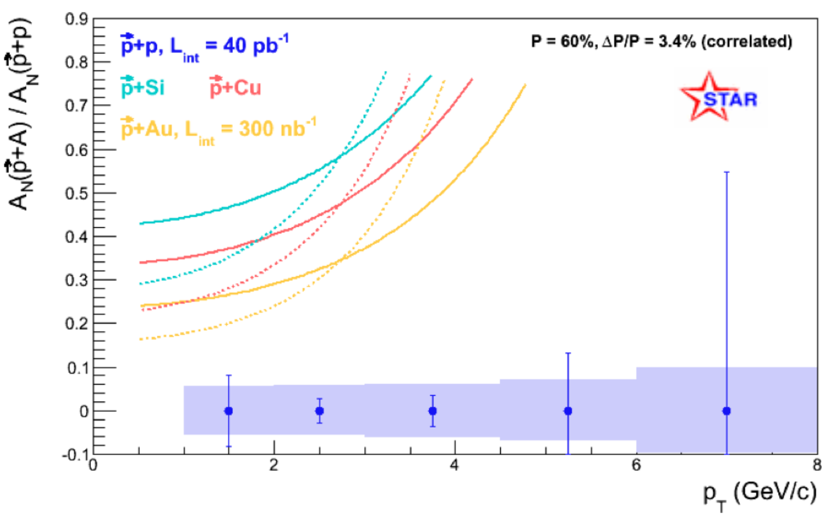
A unique capability of RHIC!

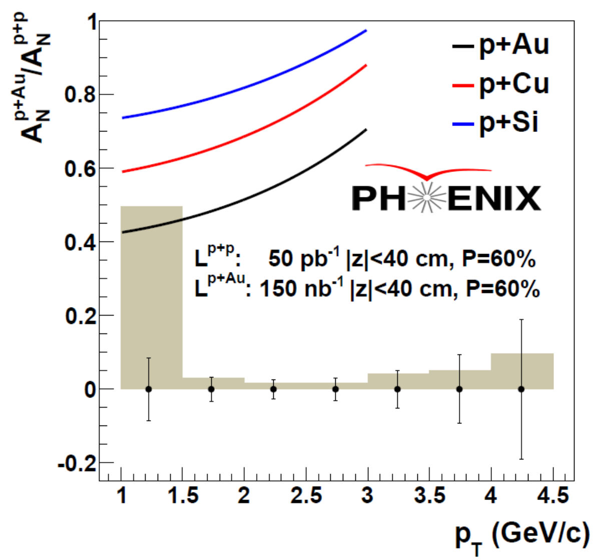
- Dependence of Q_{sA} on A
- Combined with other measurements this can estimate Q_{sp}

Plan for 2015 RHIC Run

First p+A Run at RHIC

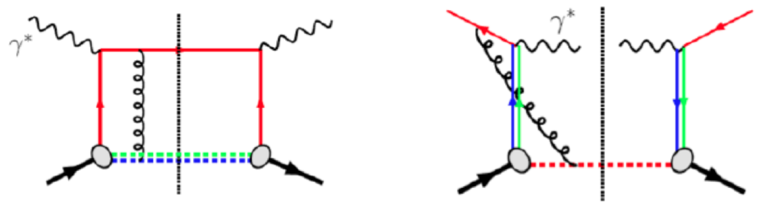
1. 5 weeks of p+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV with transverse polarization of the proton
2. 2 weeks of p+Al collisions at $\sqrt{s_{NN}}$ = 200 GeV with transverse polarization of the proton

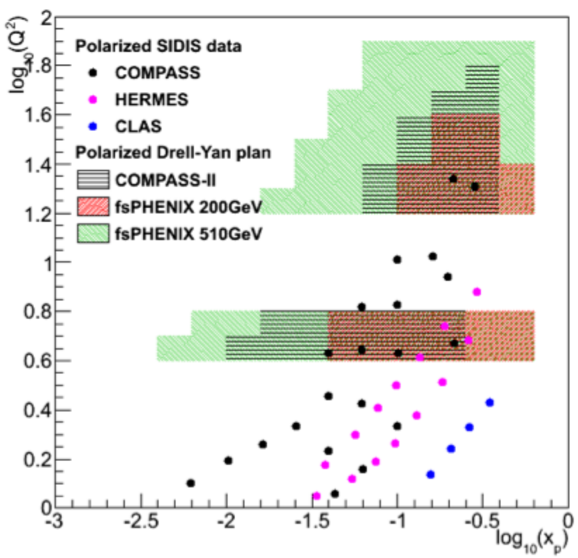


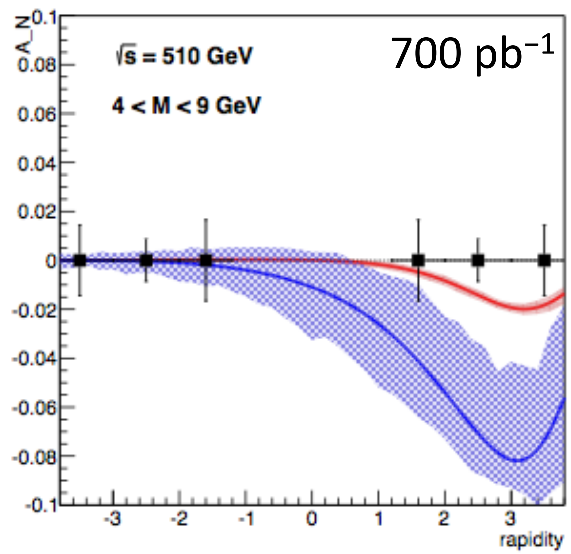


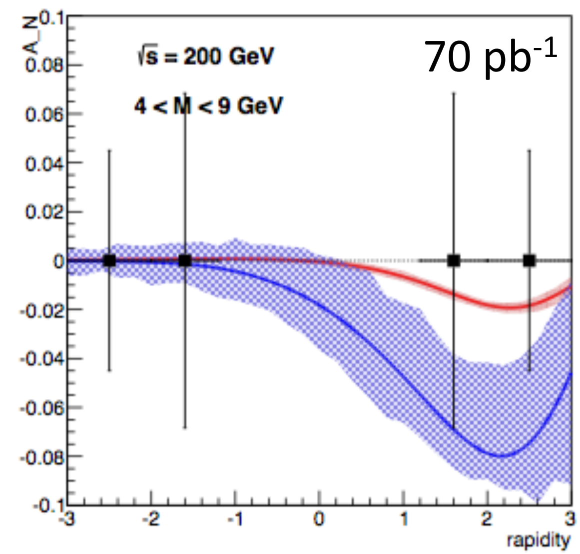
Testing Factorization in TMDs

- TMD factorization predicts the sign of the Sivers effect is flipped between SIDIS and Drell Yan
  - Due to difference in the color interaction between the proton remnant and the initial (Drell-Yan) or final (SIDIS) state hadron.



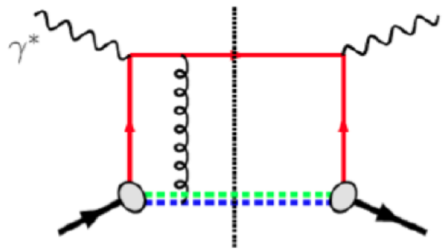


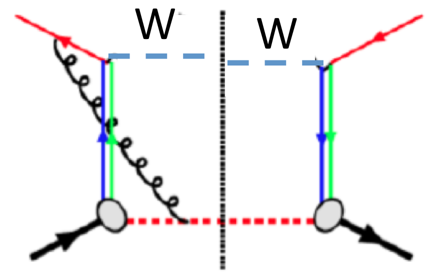




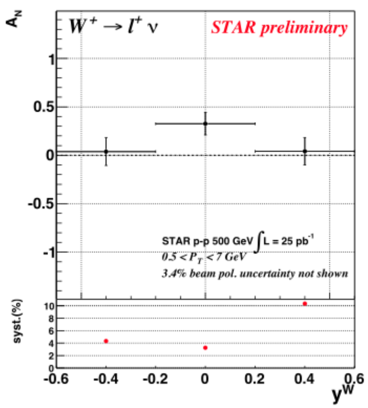
W boson production

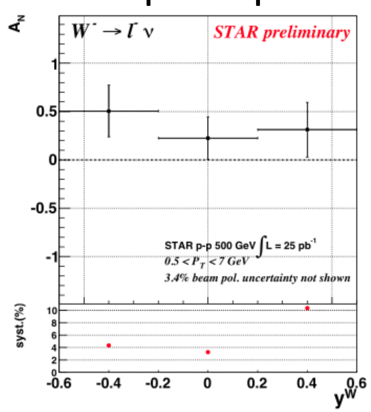
- Similar effect is possible in W-boson production

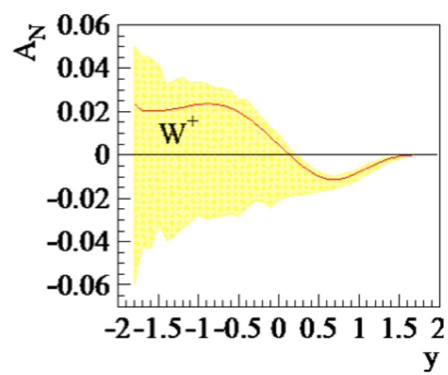


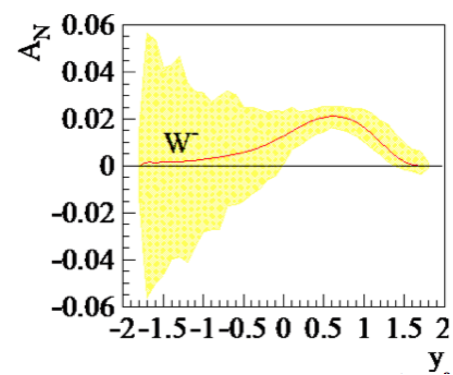


2012: small proof of principle









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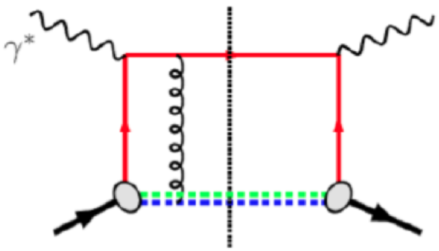
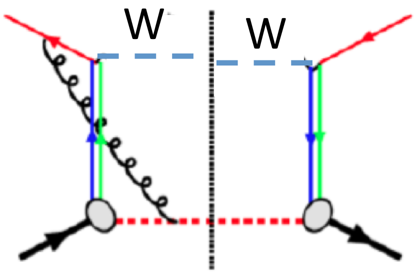
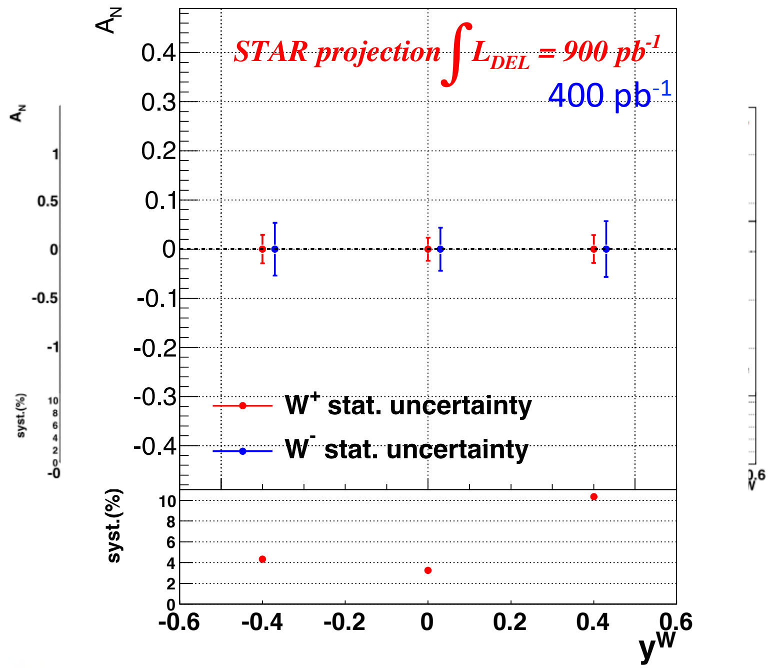
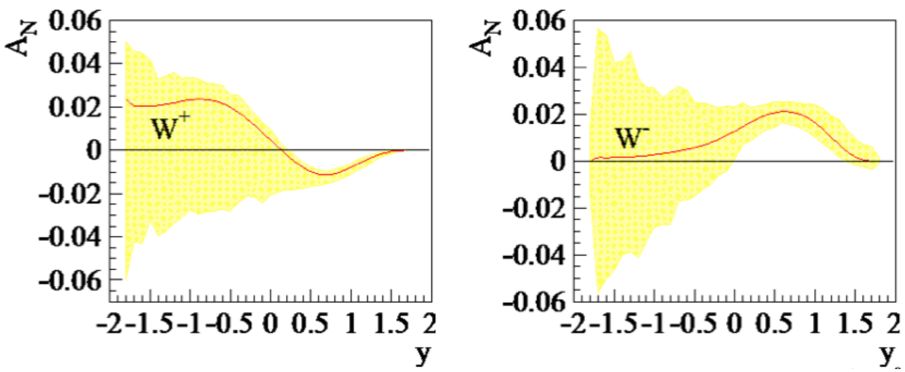








This method to test Sivers sign flip with uniquely available to RHIC

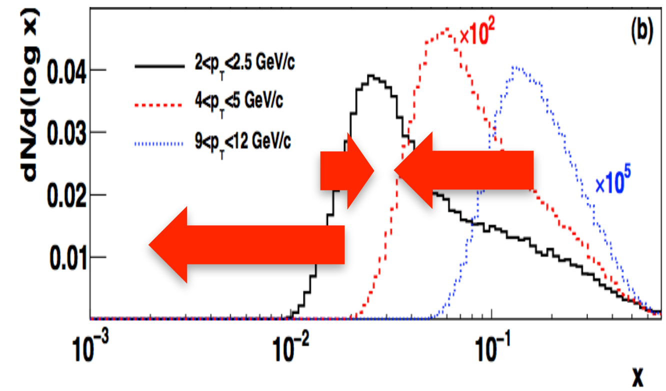
Conclusions

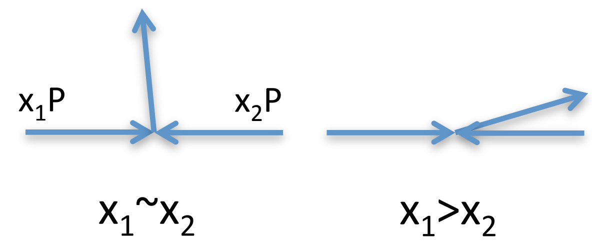
- Over the next several years, RHIC will be used to make measurements that are uniquely available in a flexible polarized hadron collider
- Large transverse spin asymmetries:
  - Asymmetries are quite consistently sizable over very wide range in center of mass energy ($\sqrt{s}$=5-500 GeV)
  - With upgraded forward capabilities, RHIC should allow a final understanding of their source
- Exploring Saturation effects in Nuclei
  - With it's polarized proton and Heavy ion capabilities, RHIC is the only collider in the world that can run polarized p+A
  - Measurements of simple forward hadron asymmetries while varying A can tell us about the saturation scale in Nuclei
- Testing Factorization of TMDs
  - RHIC can extend the reach of Drell-Yan measurements to explore the expected sign flip
  - With transverse spin asymmetry in W production, RHIC can add a second unique test of this sign flip in the next few years

BACKUPS

Limitations of Current Data

- Current mid-rapidity inclusive measurements (π^0, jet, etc.) at $\sqrt{s}$=200 GeV have two draw backs
  - They cover a limited range in x (approx. 0.02<x<0.3)
  - Each p_T bin integrates over a wide range in x
- We can extend x range by
  - Measuring at larger rapidity (low x gluon)
  - Measuring at larger $\sqrt{s}$ (smaller x at same p_T)
- We can more precisely determine x through correlation measurements
- And we can do both





$$x_1 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{\eta_3} + p_{T4}e^{\eta_4}\right)$$

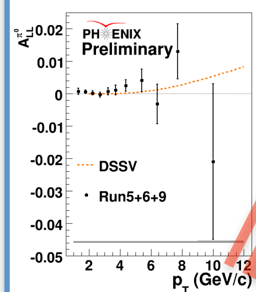
$$x_2 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{-\eta_3} + p_{T4}e^{-\eta_4}\right)$$

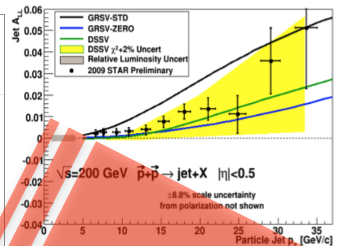
Future plans

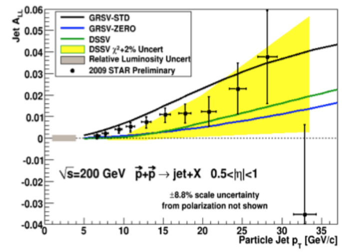
- More precise determination of ΔG(x) over wider range in x

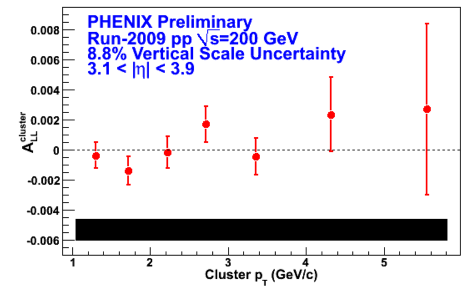
Higher x — Central — Forward — Lower x

Single particle

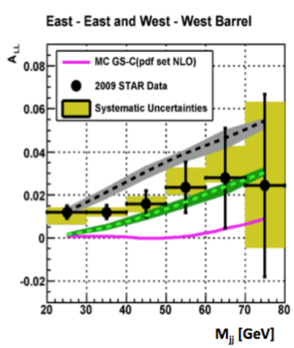


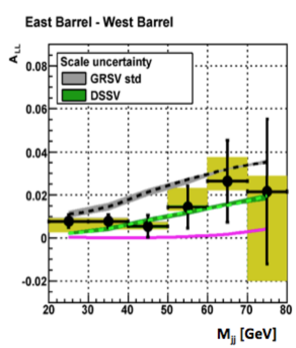






Correlations





Better x determination

Forward-Central correlation measurements at both STAR and PHENIX