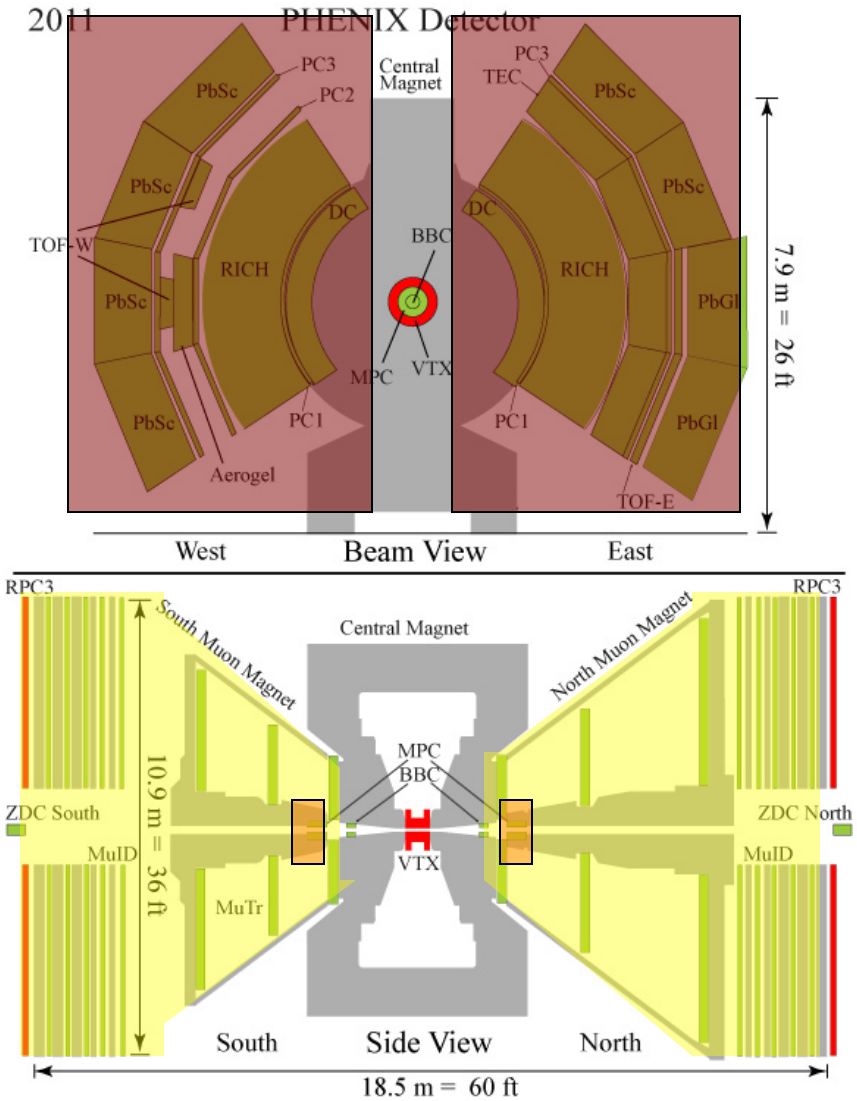
Current and Near-term Transverse Spin Measurements at PHENIX

John Koster
for the PHENIX collaboration
RIKEN BNL Research Center
RHIC AGS Users' Meeting
2011/06/20

PHENIX Detector at RHIC

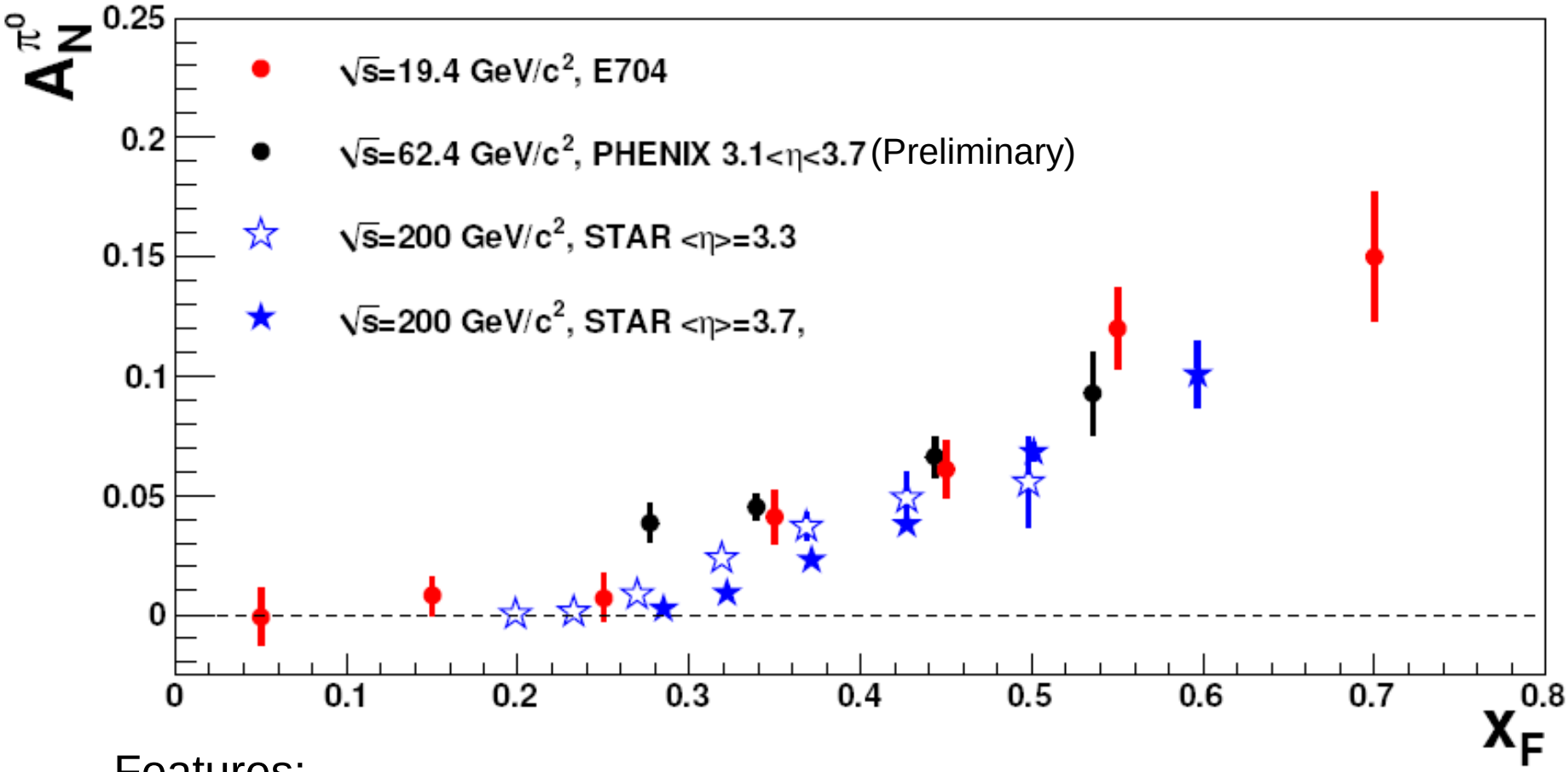


Central Arms $|\eta| < 0.35$
- Identified charged hadrons
- π^0, η
- Direct Photon
- J/Ψ
- Heavy Flavor

Muon Arms $1.2 < |\eta| < 2.4$
- J/Ψ
- Unidentified charged hadrons
- Heavy Flavor

MPC $3.1 < |\eta| < 3.9$
- π^0, η

Single Transverse Spin Asymmetries in pp Collisions



Features:

- Forward non-zero asymmetries.
- Asymmetries consistent over an order of magnitude in sqrt(s).
- Several theoretical frameworks to explain the results.

Transverse Spin Effects in p↑p Collisions

Graphic from Zhongbo Kang

(III) Higher-twist effects

Twist-3 quark-gluon/gluon-gluon correlators

Expectation: at large p_T, $A_N \sim 1/p_T$

So far, fall-off with p_T has not been observed!

(I) Transversity quark distributions and Collins fragmentation function

Correlation between proton & quark spin + spin dependant fragmentation function

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

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

(II) Sivers quark-distribution

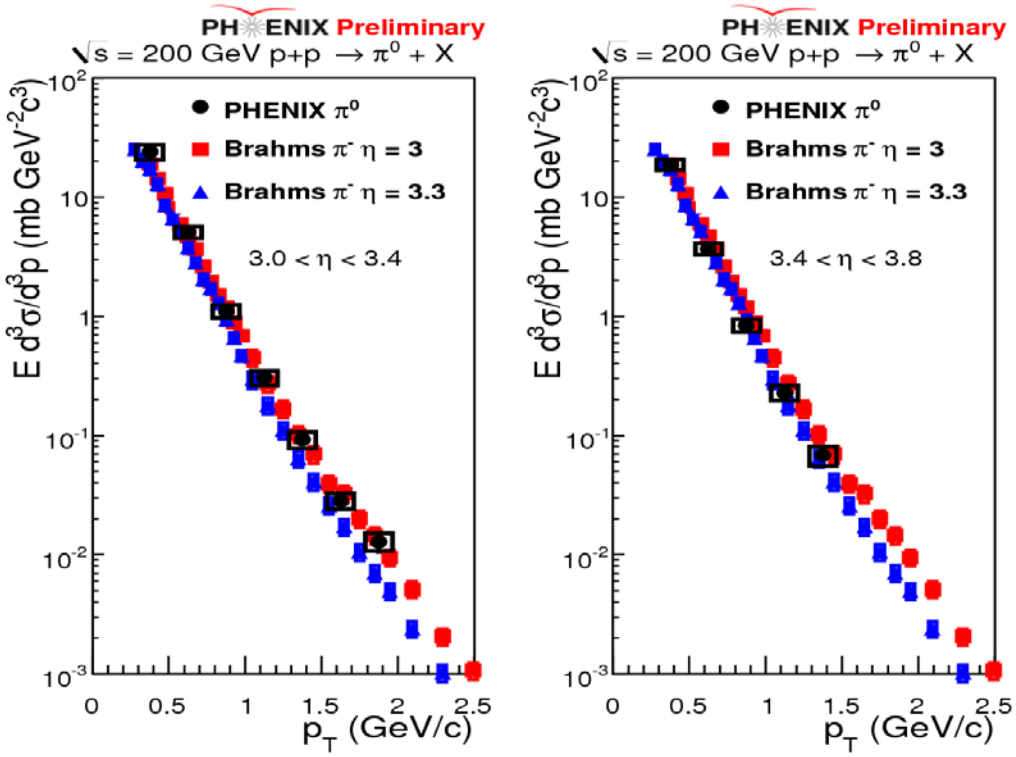
Correlation between proton-spin and transverse quark momentum

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

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

Neutral Pion Cross-Sections Experiment vs pQCD

New PHENIX Result with Forward Neutral Pions at √s=200 GeV



Close agreement with charged pions from BRAHMS.

PHENIX Measurement Strategy

1. A_N Measurements
   - Sensitive to combinations of all three effects
   - At forward and mid rapidity
2. Sivers Measurements
   - Heavy flavor
   - Back to back hadrons
3. Transversity Measurements
   - Interference Fragmentation Function
   - Collins in Jets

2012+2013 Runs are projected to produce 33 pb^{-1} at 60% polarization. Projected error bars are interspersed throughout the talk.

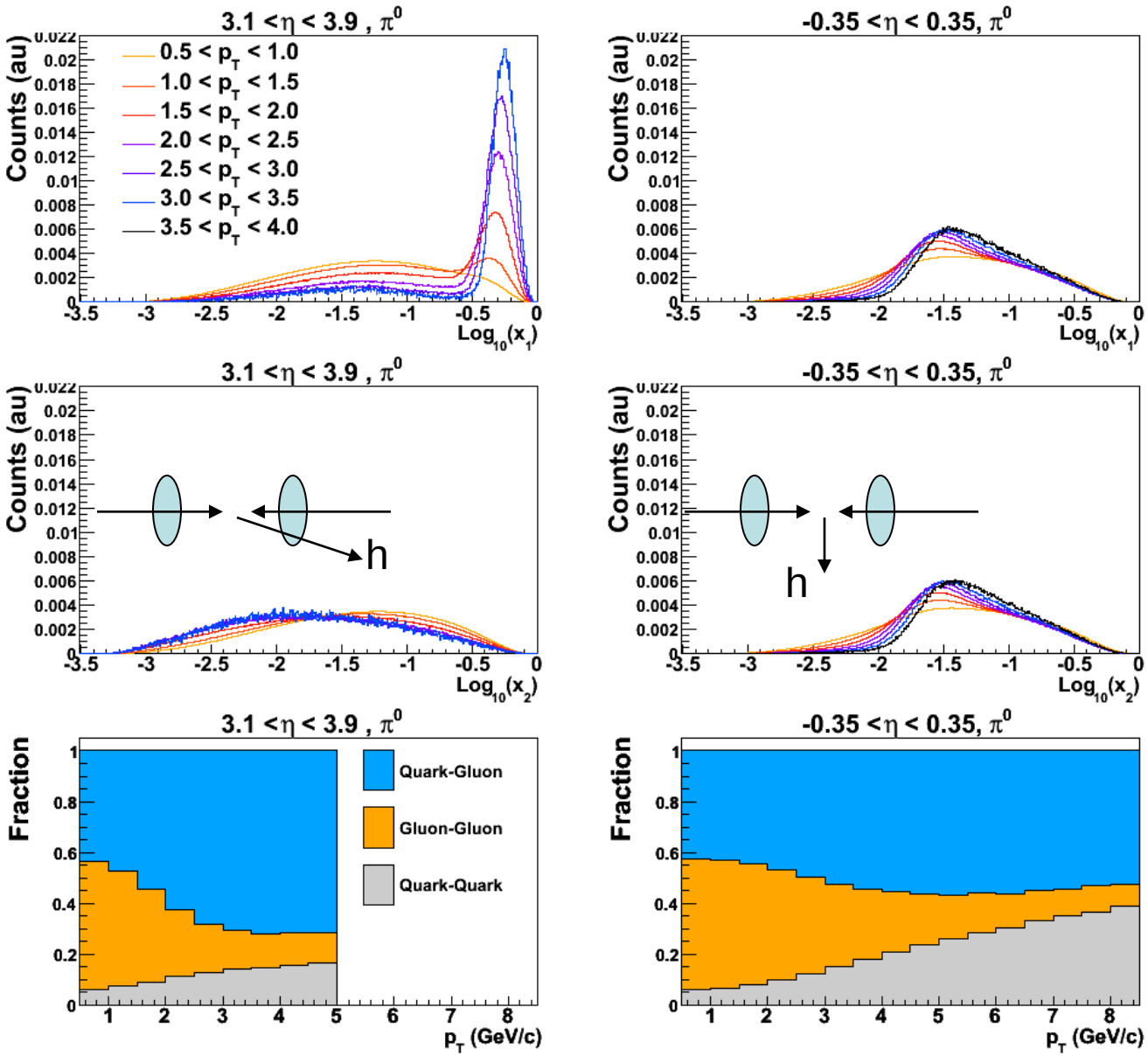
Underlying Event Kinematics of p-p Scattering at √s=200 GeV

- Estimated with Pythia simulation package
- Mid-rapidity:

Low p_T dominated by gluon gluon scattering

- Forward-rapidity

High-x + Low-x scattering



(i) Muon Piston Calorimeter A_N

Photon merging effects prevent two-photon π^0 analysis for E>20 GeV (p_T>2 GeV/c)

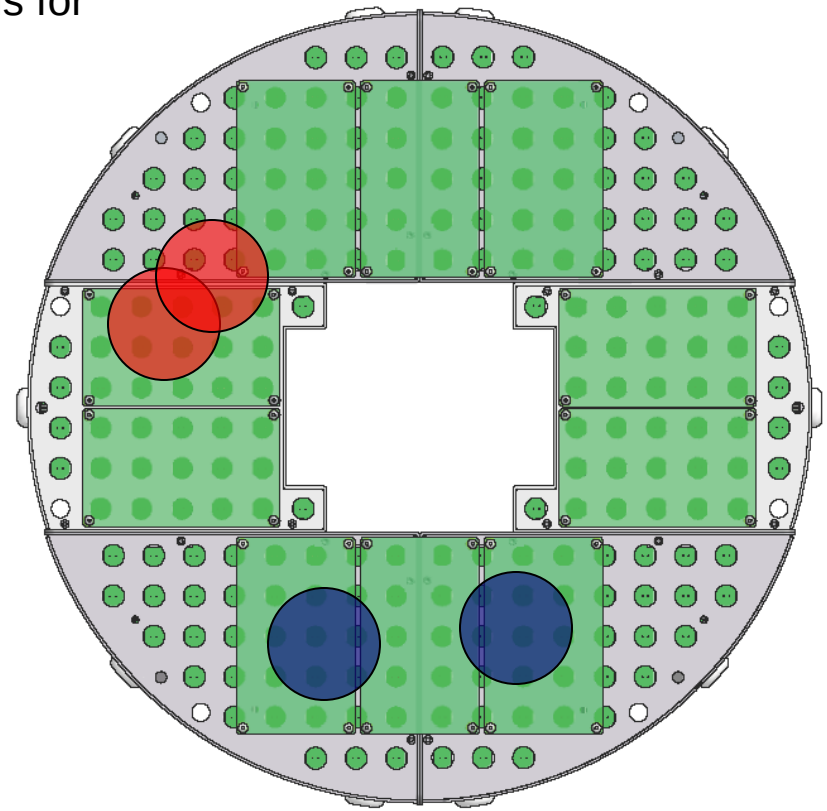
62 GeV

20 GeV → 0.65 x_F:Two-photon π^0 analysis

200 GeV

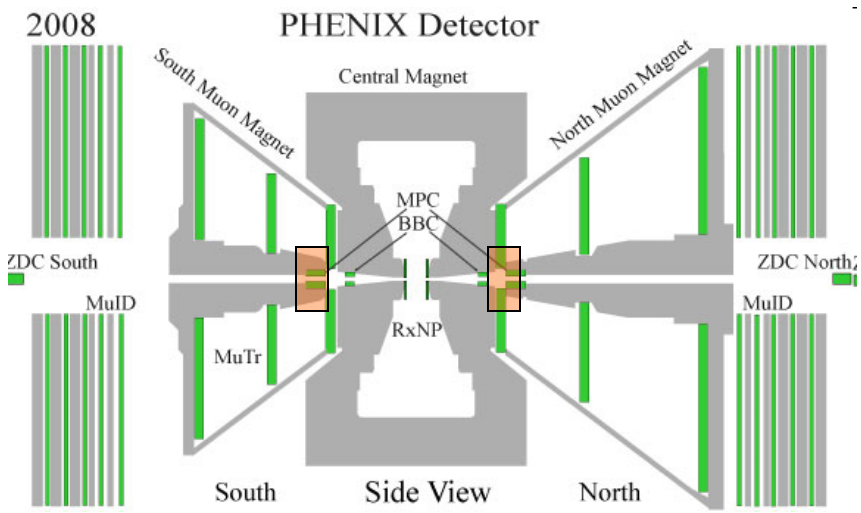
20 GeV → 0.20 x_F : "Single clusters". Yields dominated by π^0's but also get contributions from:

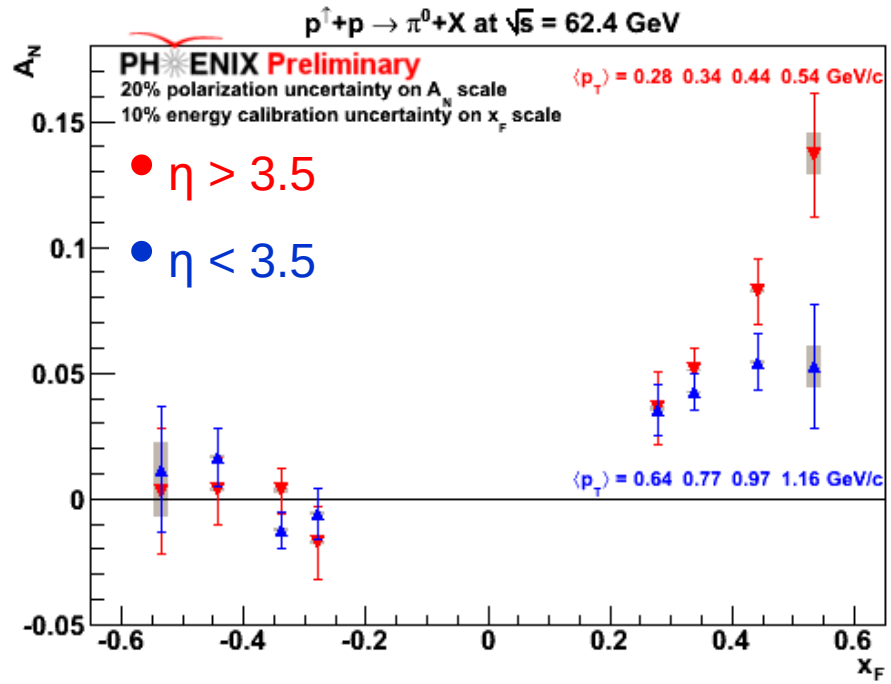
- **Electromagnetic**
  - Direct photons
  - Decay photons (η, etc)
  - Estimated using Pythia (TuneA)
- **Hadronic: ($\pi^{+/-}$, $K^{+/-}$, etc.)**
  - Estimated with Pythia+GEANT. Initial estimate is <10% contamination in lowest energy bin with decreasing fraction as deposited energy increases
  - Qualitatively consistent with expected detector behavior



Decay photon impact positions for low and high energy π^0's

(i) Forward SSA A_N π^0 in MPC at $\sqrt{s}$=62 GeV

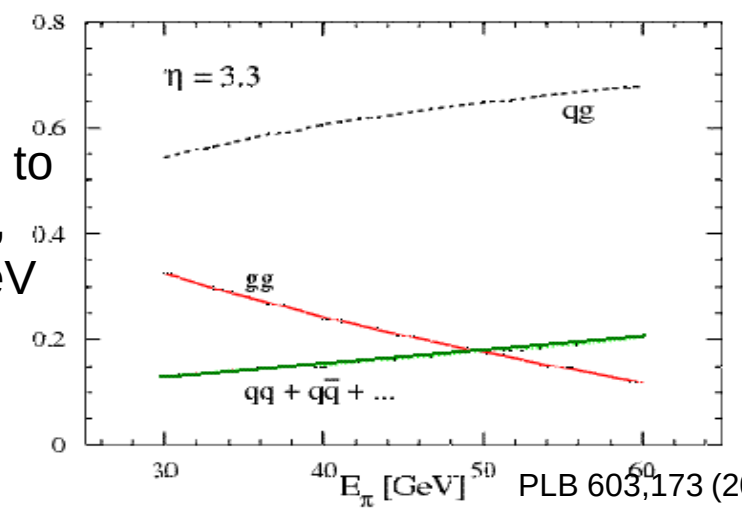




PHENIX π^0 results available for $\sqrt{s}$=62 GeV

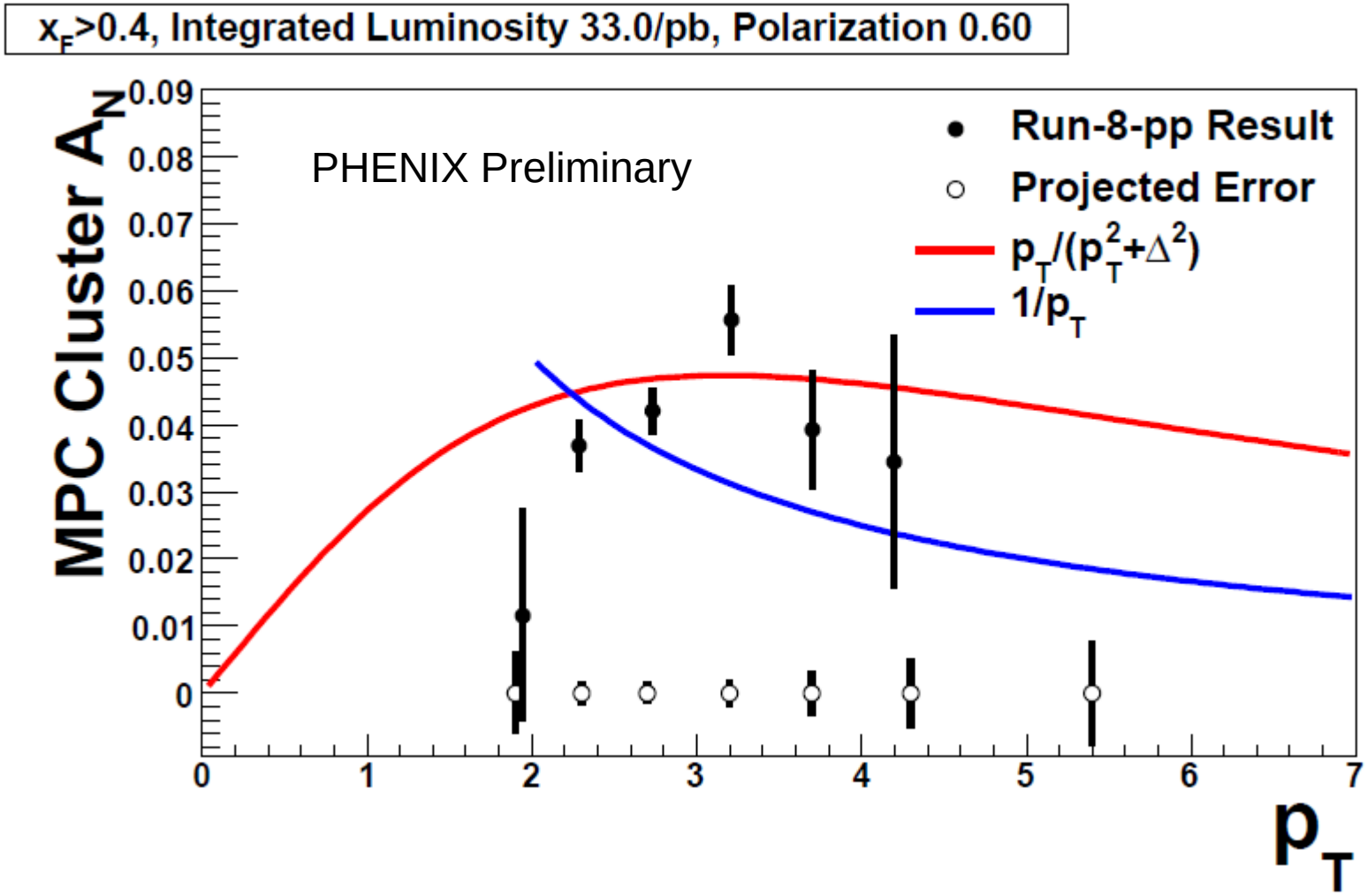
- Production dominated by quark-gluon
- Similar x_F scaling to higher and lower center of masses
- Asymmetries could enter a global analysis on transverse spin asymmetries

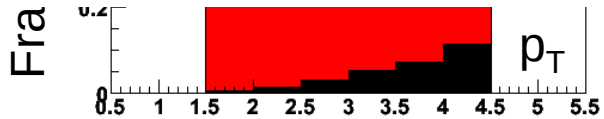
Process contribution to π^0, η=3.3, $\sqrt{s}$=200 GeV



PLB 603,173 (2004)

(i) Forward SSA A_N Cluster in MPC at √s=200 GeV





(i) Mid-rapidity, $|y|<0.38$, A_N π^0, η Analysis

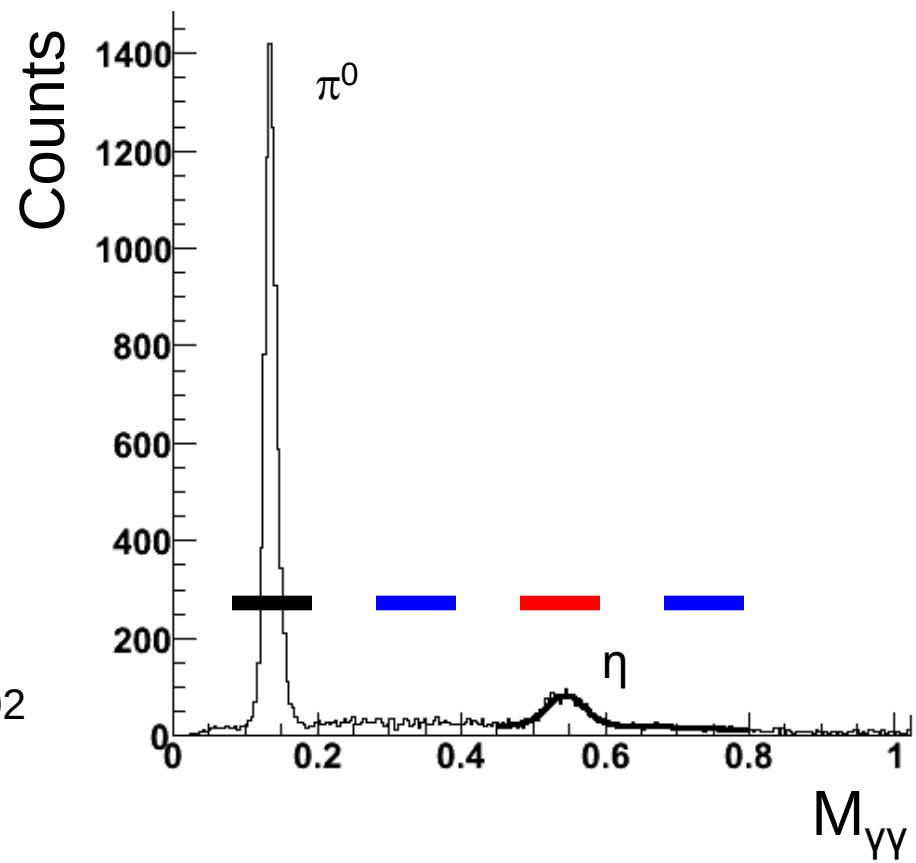
Similar analysis to existing PHENIX A_{LL}

1. Measure A_N in mass window of:
   - π^0 (Signal+Background)
   - η (Signal+Background)
   - **Background**
2. Determine background fractions (r)
3. $$A_N^{Signal} = \frac{A_N^{Signal+Background} - rA_N^{Background}}{1-r}$$

Asymmetries binned in p_T for:

- inclusive selection
- with $x_F > 0.01$, $x_F < -0.01$

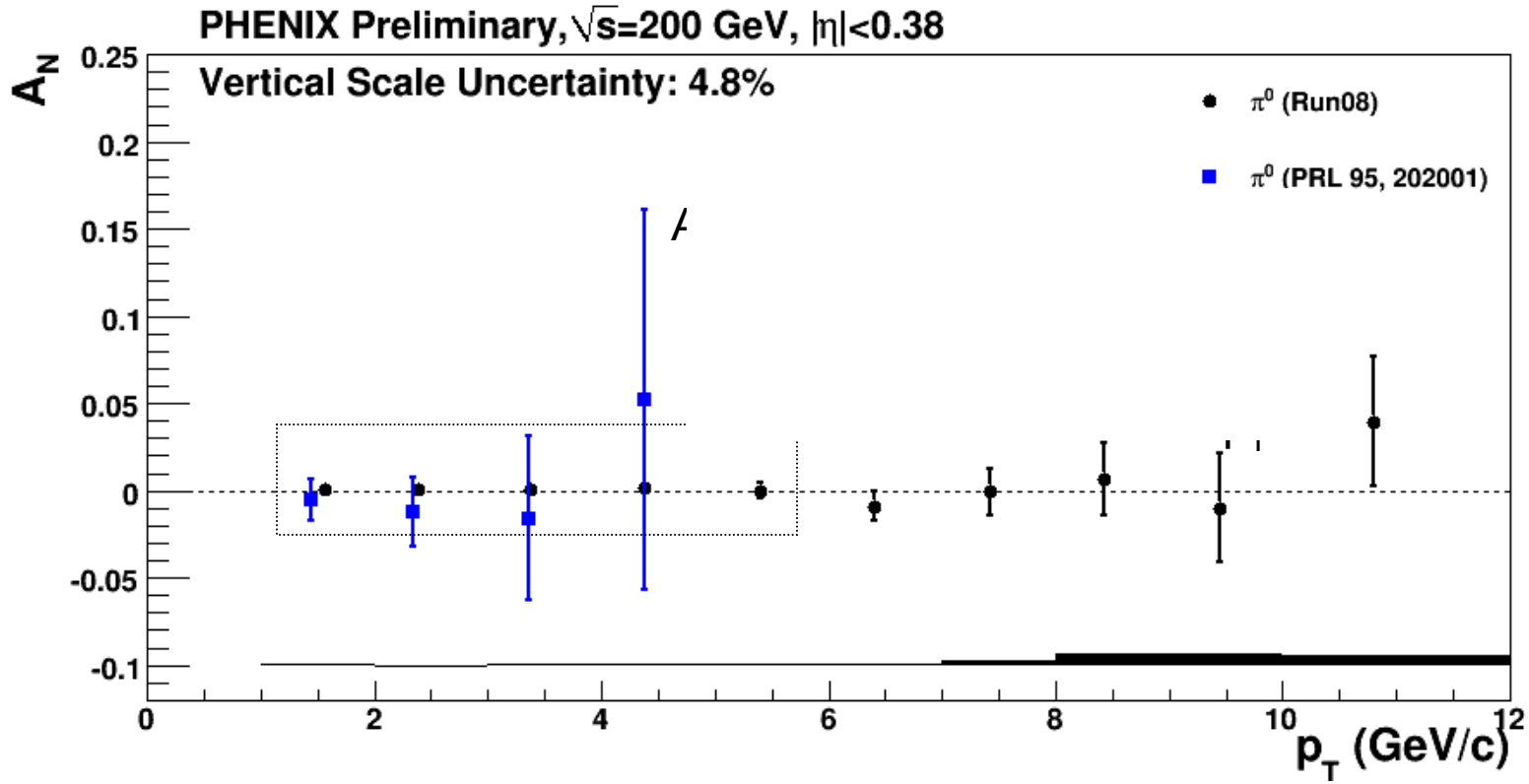
Previous π^0 A_N measurement done with 2002 dataset.



(i) Results for mid-rapidity π^0 A_N

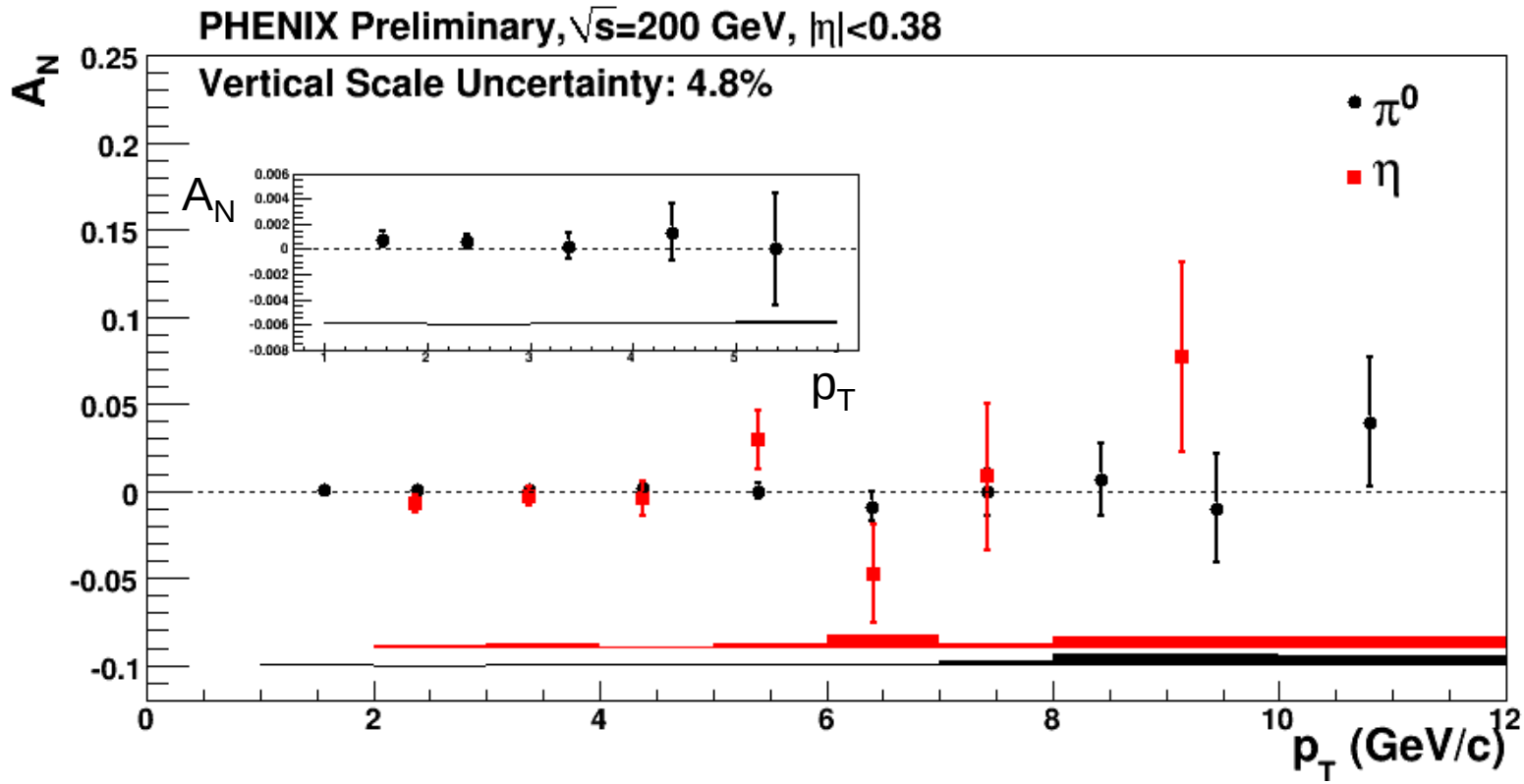
2002 Published Result

2008 Preliminary Result



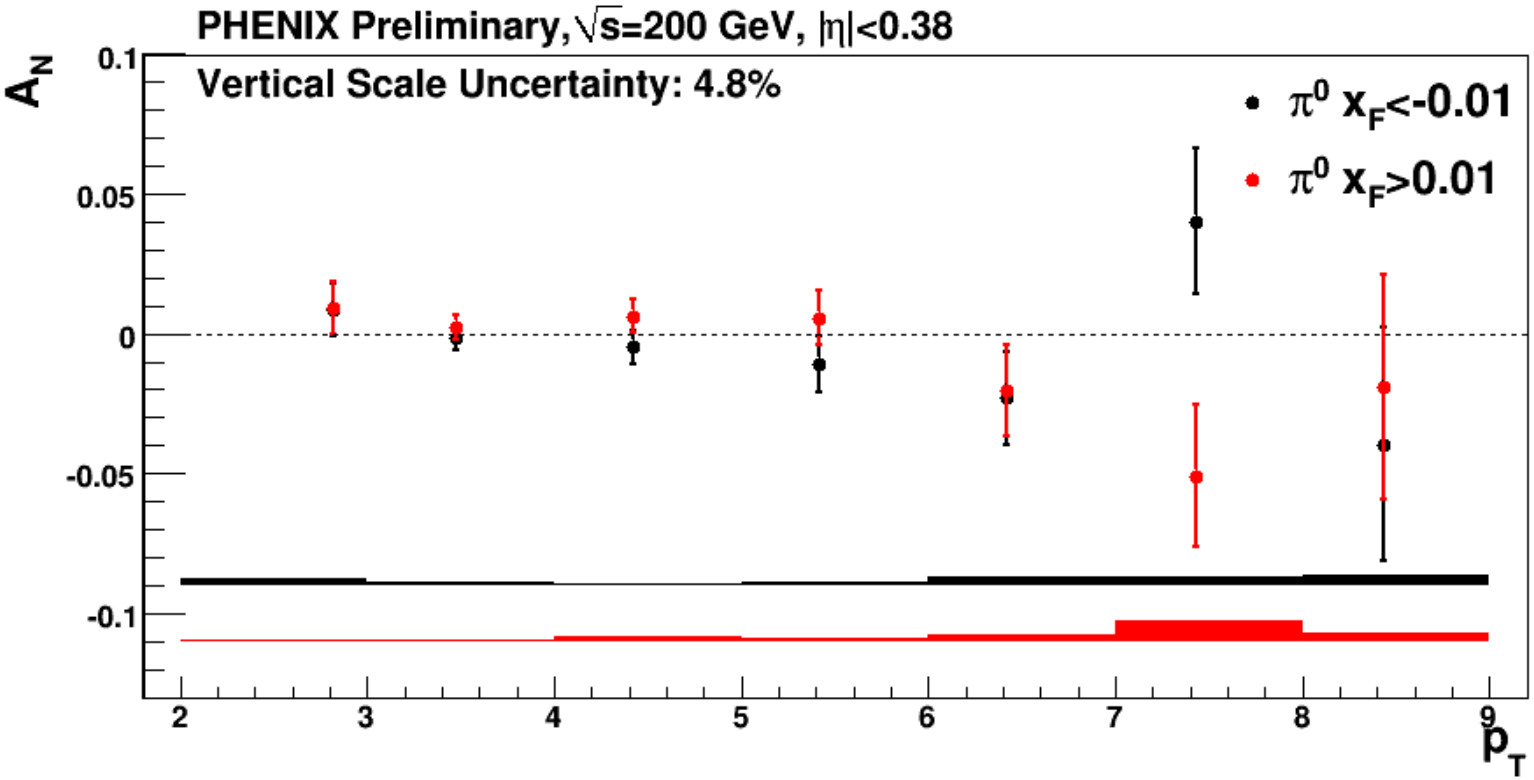
- Previous result shown to be sensitive to gluon Sivers function.
- New result will be published with 20x smaller error bars.

(i) Mid-rapidity π^0 and η A_N



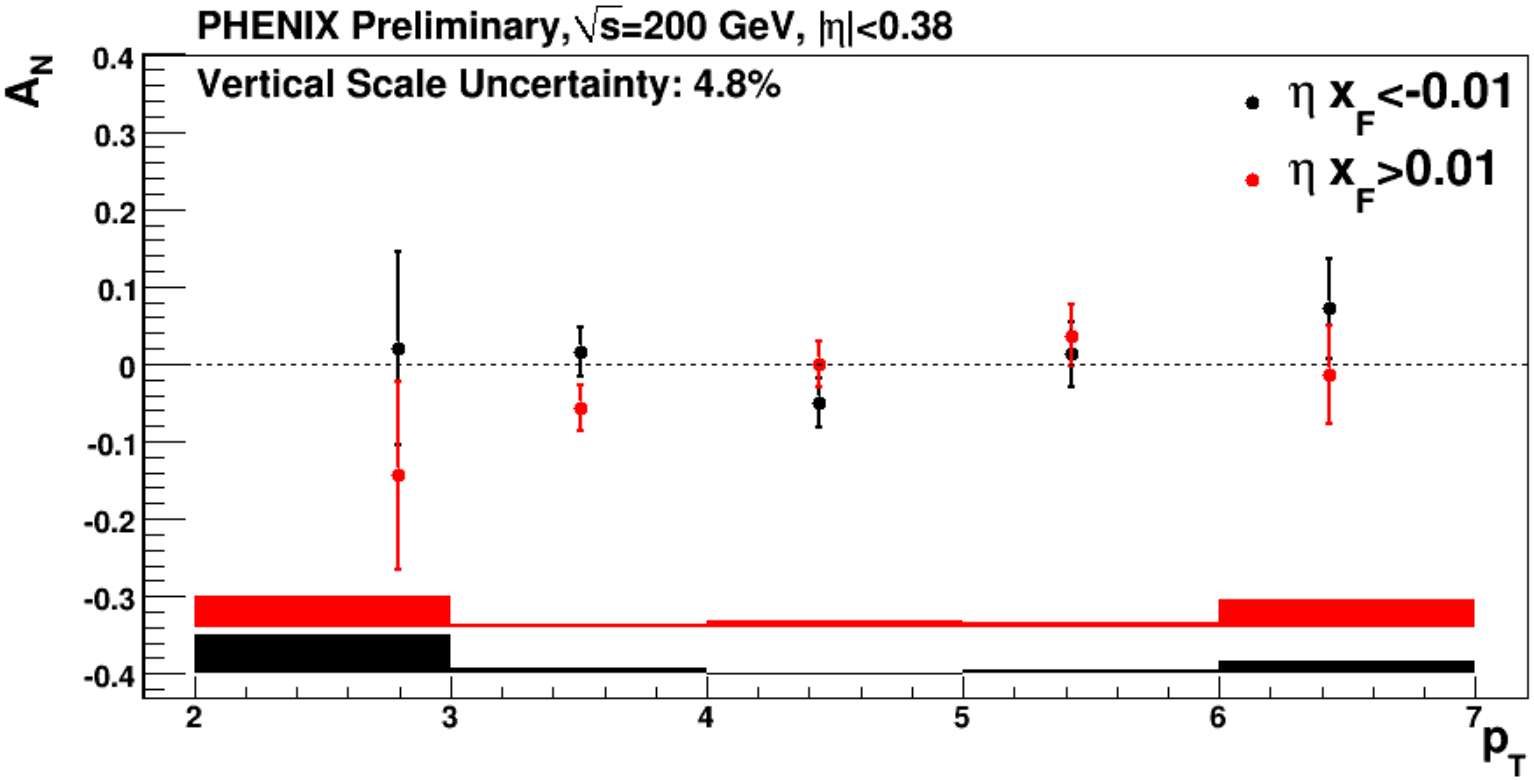
- A_N consistent with zero

(i) Mid-rapidity π^0 A_N $|x_F|>0.01$



- A_N consistent with zero

(i) Mid-rapidity η A_N $|x_F|>0.01$



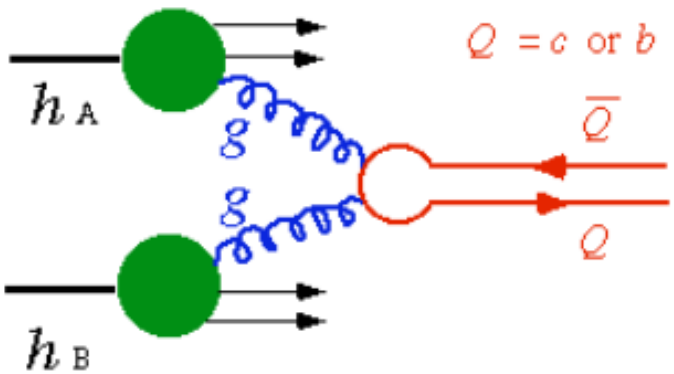
- A_N consistent with zero

1. A_N Measurements
   - Sensitive to combinations of all three effects
   - At forward and mid rapidity
2. Sivers Measurements
   - Heavy flavor
   - Back to back hadrons
3. Transversity Measurements
   - Interference Fragmentation Function
   - Collins in Jets

(ii) Constraints on Sivers Function: Heavy Flavor

D meson A_N

- Production dominated by gluon-gluon fusion at RHIC energy

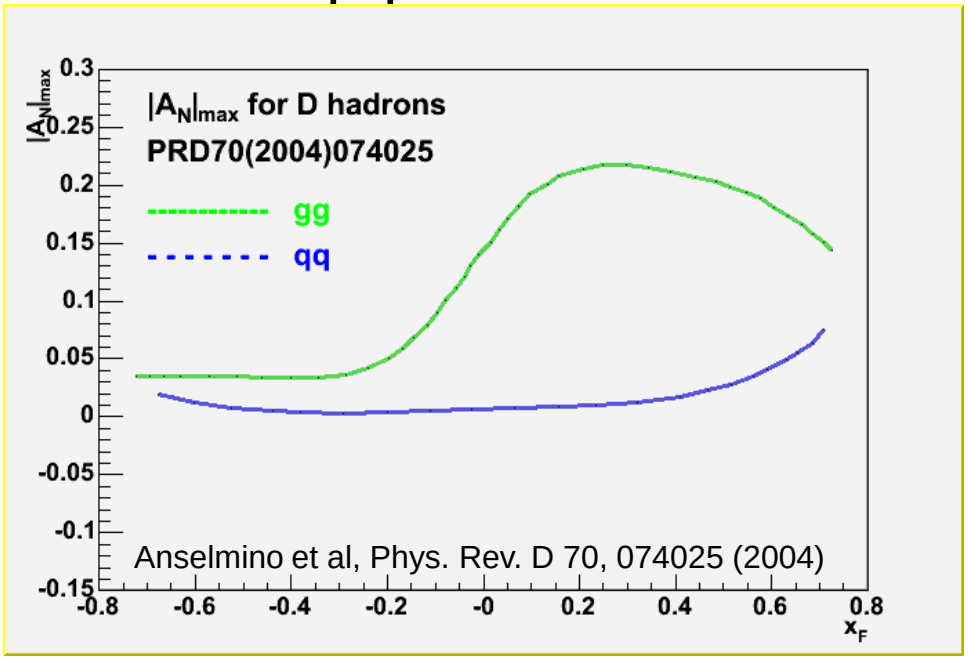


- Gluon transversity zero
→Asymmetry cannot originate from Transversity x Collins

- Sensitive to gluon Sivers effect

Theoretical prediction:

$p^{\uparrow}p \rightarrow DX$

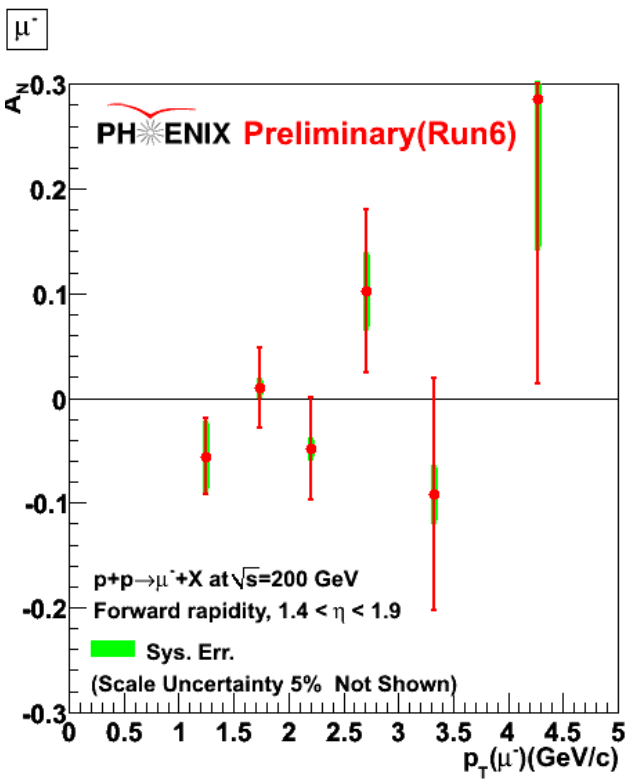


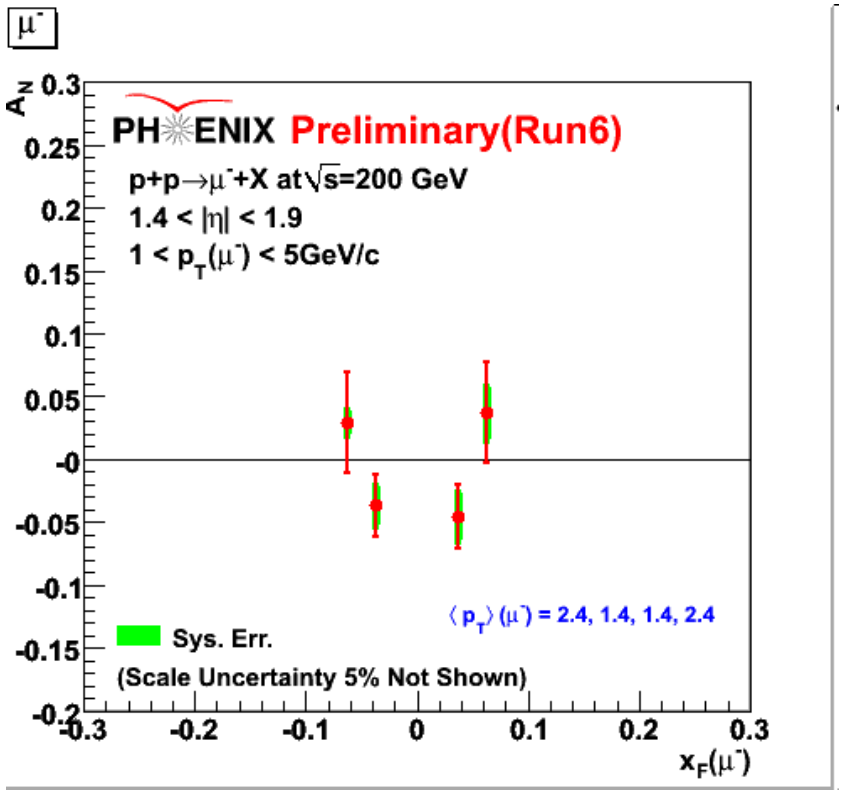
Gluon Sivers=Max
Quark Sivers=0
Gluon Sivers=0
Quark Sivers=Max

(ii) Constraints on Sivers Function: Heavy Flavor

PHENIX: no reconstruction of D meson
Exploratory measurements of A_N for single muons
Dominated by charm production in current kinematic range

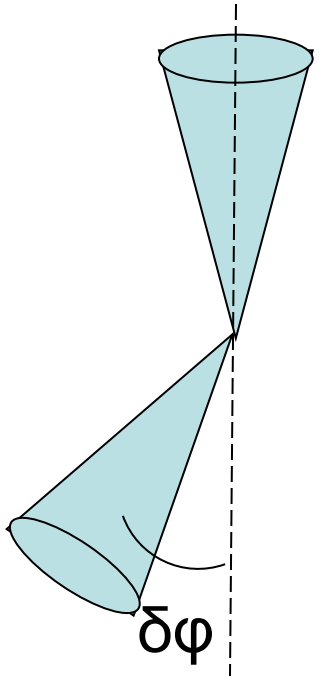
- Predicted asymmetry smeared by decay kinematics
- Measurements will be enhanced significantly by the inclusion of precision tracking: VTX (installed) and FVTX (to be installed for next run).

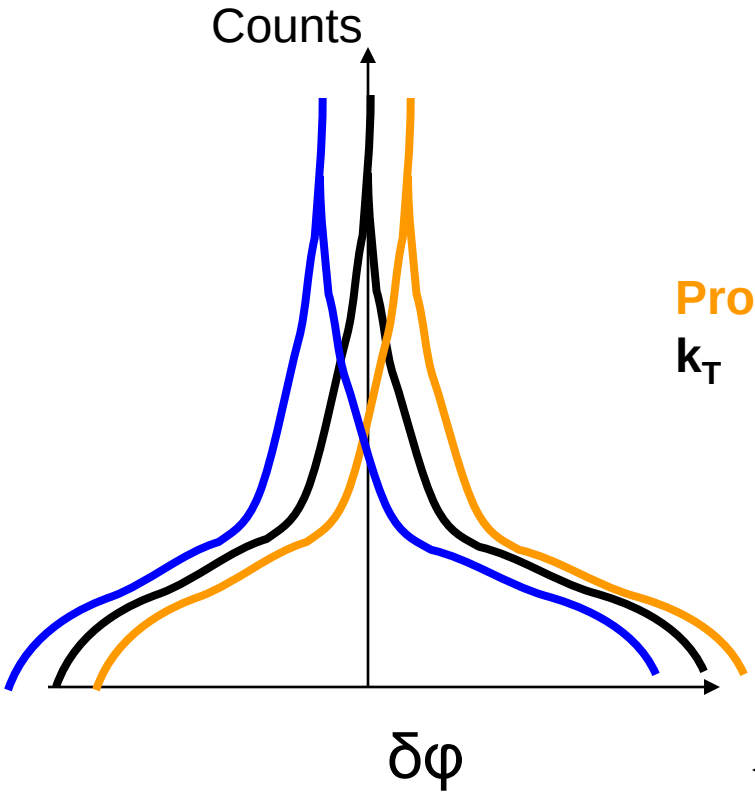


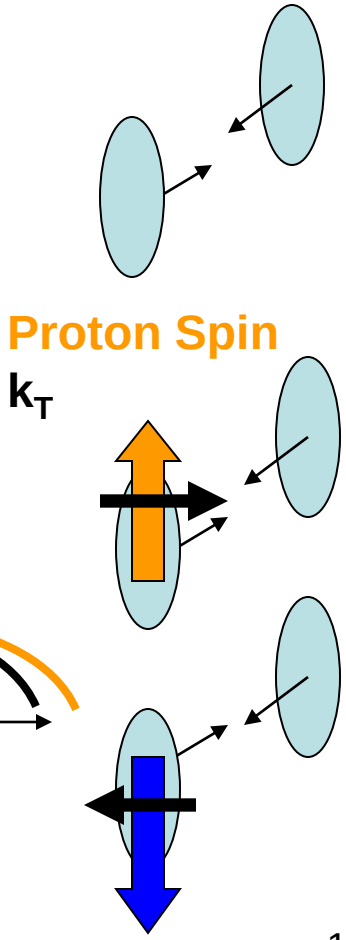


(ii) Constraints on Sivers Function: DiJet Production

Azimuthal distribution of Di-Jet production in pp
Suggested in: Boer, Vogelsang, Phys. Rev. D 69, 094025





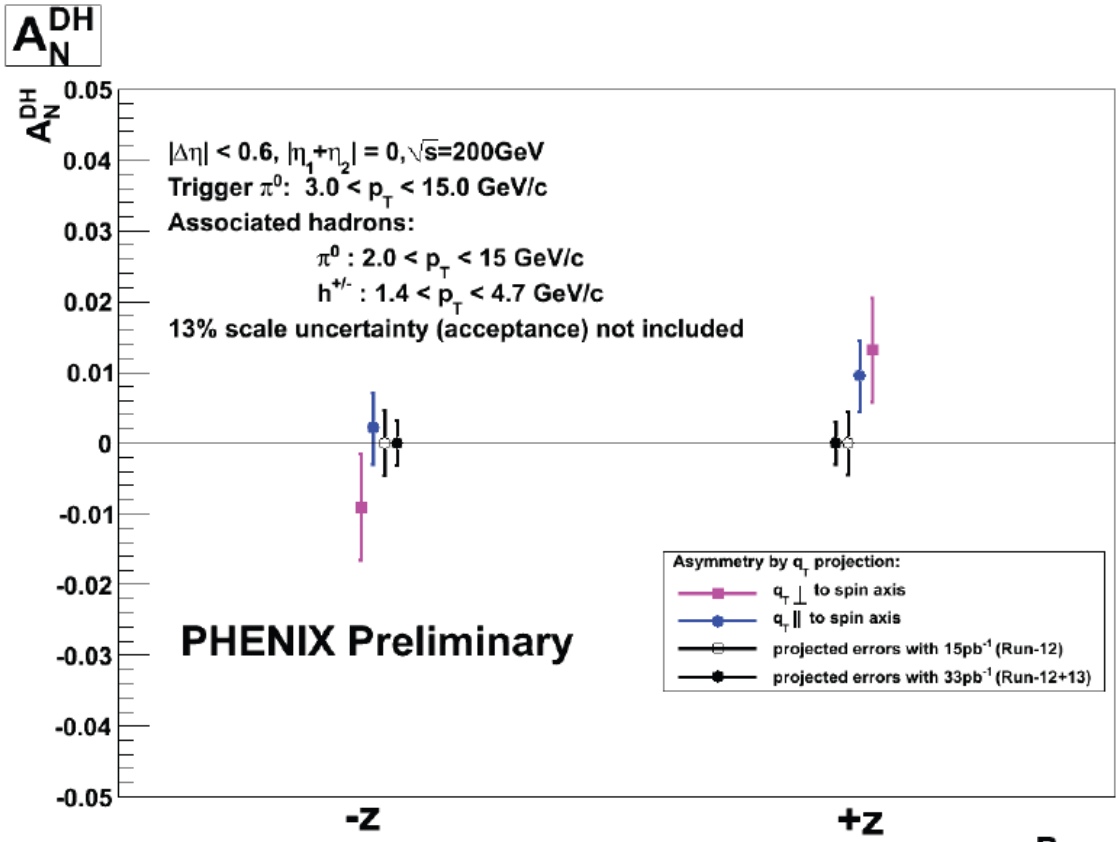


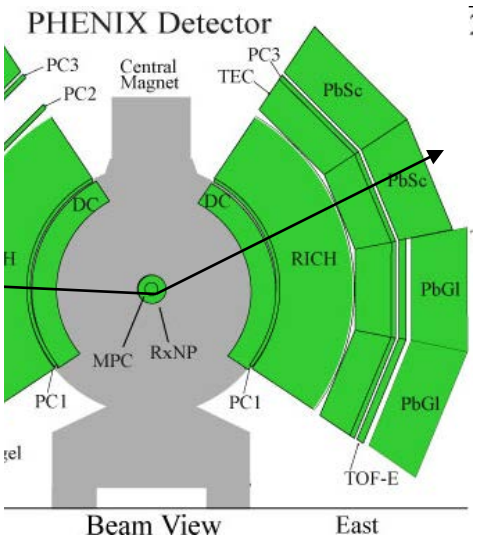
Beam is in and out of page
Look at back-to-back jet opening angles

Sensitive to Sivers function only!

No Collins-type effects

(ii) Constraints on Sivers Function: DiHadron Production





pi0

lysis possible in different
ns of rapidity

P_{Beam}	3.7	-2.0	-0.35	1.4	3.1
η_{max}	-3.1	-1.4	+0.35	2.0	3.9

- Asymmetry consistent with zero

Works in progress…

1. A_N Measurements
   - Sensitive to combinations of all three effects
   - At forward and mid rapidity
2. Sivers Measurements
   - Heavy flavor
   - Back to back hadrons
3. Transversity Measurements
   - Interference Fragmentation Function
     Already covered in Anselm Vossen's talk
   - Collins in Jets

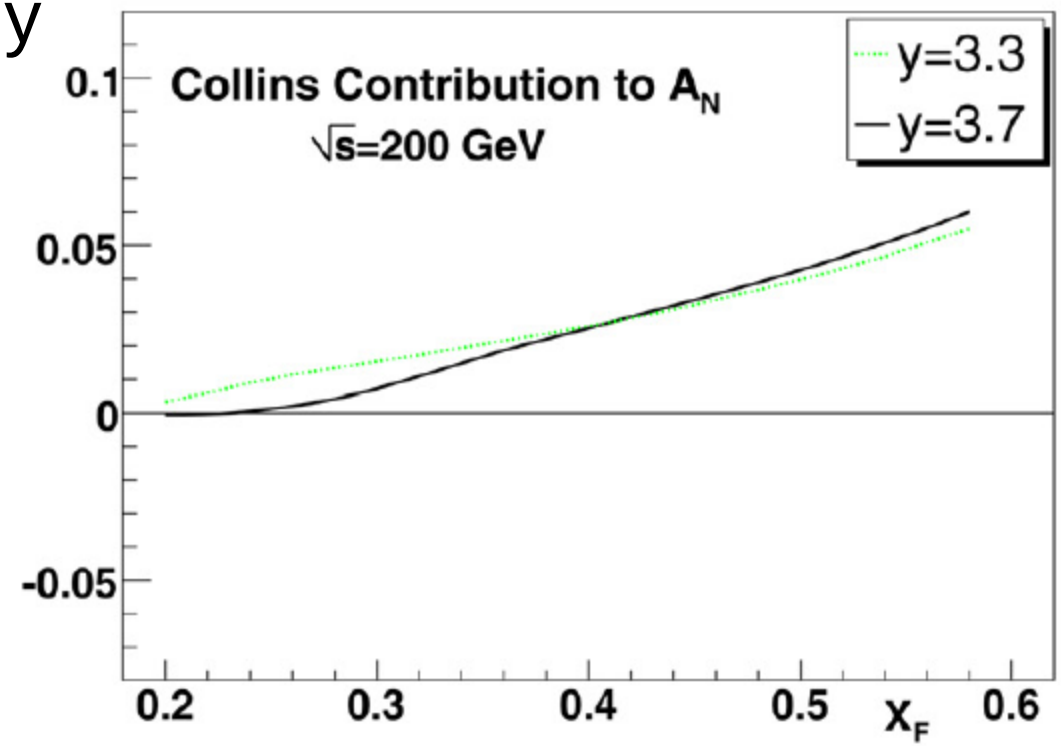
(iii) Collins Jet+Hadron Measurements

- Measurement originally proposed in:
  F. Yuan, PLB 666 (2008) 44-47
- Measure:

  $p(P_A,S)+p(P_B) \rightarrow jet(P_j) \rightarrow H(P_H)+X$

  Define two angles:
  φ_S proton spin direction
  φ_H hadron angle around jet axis

  Measure: azimuthal modulation of $\sin(\varphi_H - \varphi_S)$



Model dependent calculations show that Collins effect can produce large forward single spin asymmetries.

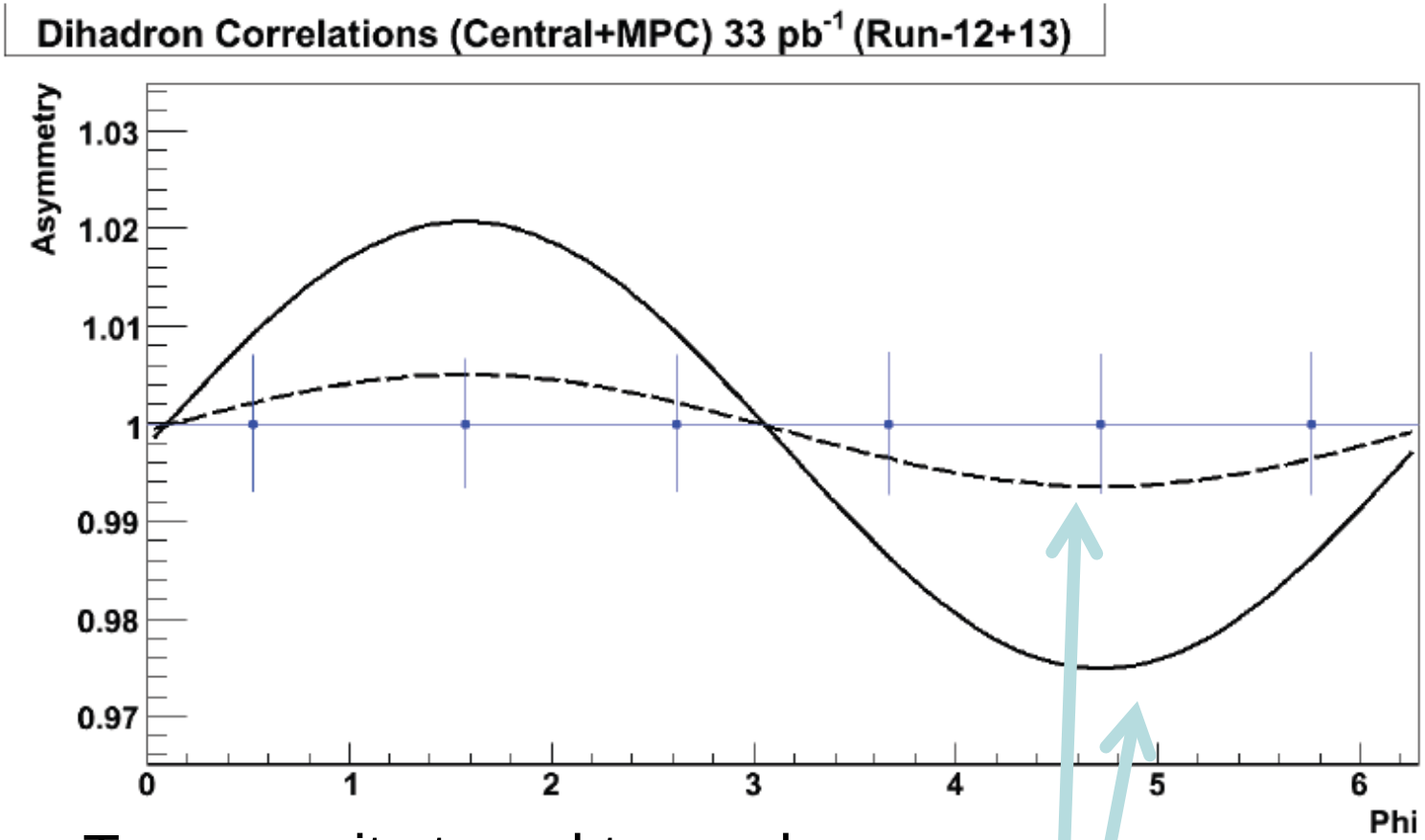
Planned measurement:

- Measure near-side jet axis using PHENIX central arm.
  - Central arm recently upgraded with large acceptance silicon tracker (| η |<1.2)
- Measure away side neutral pion in forward region using MPC.

Projected asymmetries:

- Added transverse spin processes in Pythia to predict the asymmetries for various transversity distributions.
- Collins function taken from analysis of SIDIS+BELLE data.

(iii) Predicted Collins Asymmetries



Transversity tuned to produce:

25% of PHENIX forward A_N

100% of PHENIX forward A_N

Summary

PHENIX has exciting measurements for the near-term of RHIC running.
(Exciting long term opportunities covered in other talks!)

- Figure of merit (P^2L):
  on disk: 2.3 pb^{-1}
  projected: 11.9 pb^{-1}

Planned Measurements

- Inclusive A_N asymmetries
  - High p_T results at forward rapidity.
  - Precision results at mid rapidity for both π^0 and η mesons
- Sivers asymmetries
  - Di-hadron correlations at mid rapidity
  - Heavy flavor asymmetries
    Results will be significantly enhanced by precision tracking upgrades.
- Collins asymmetries
  - Interference Fragmentation Function asymmetry at mid rapidity (covered in Anselm's talk)
  - Jet+Hadron Collins measurement.