Transverse Spin Physics With the PHENIX Detector at RHIC

Yousef I. Makdisi

Brookhaven National Laboratory

For

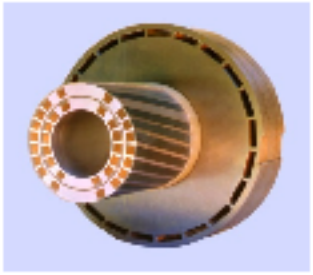
The PHENIX Collaboration

BROOKHAVEN NATIONAL LABORATORY

Outline

- The RHIC Spin Physics program and the PHENIX detector
- Transverse asymmetries near $X_F = 0$ ↓ then and now ↓
- Transverse Asymmetries at Large X_F
- Transverse asymmetries in heavy flavor production
- Upgrades and future physics reach
- Transverse Asymmetries at high X_T is this within reach?
- Summary and outlook

BROOKHAVEN
NATIONAL LABORATORY



Absolute Polarimeter (H jet)

RHIC pC Polarimeters

BRAHMS(p)

Siberian Snakes

PHENIX ($\vec{p}$)

Spin flipper

STAR ($\vec{p}$)

Spin Rotators
(longitudinal polarization)

Spin Rotators
(longitudinal polarization)

Solenoid Partial Siberian Snake

LINAC

BOOSTER

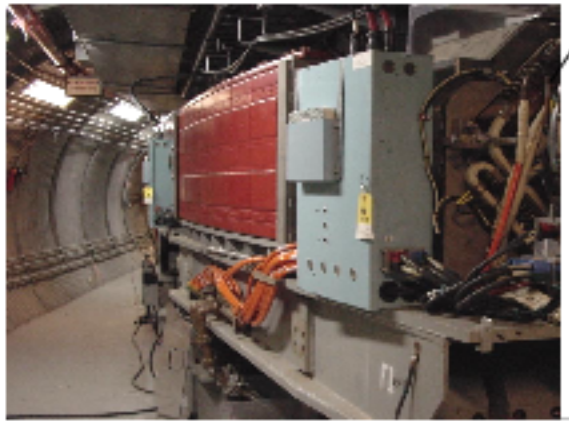
Pol. H⁻ Source

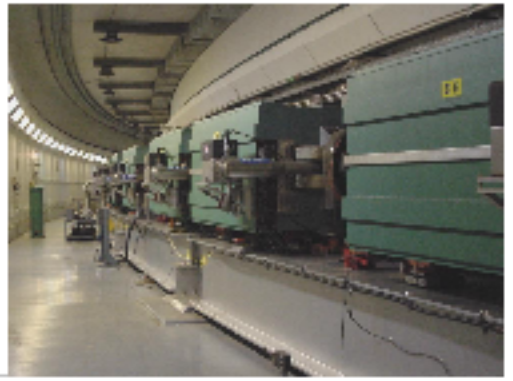
200 MeV Polarimeter

AGS

Helical Partial
Siberian Snake

AGS Polarimeters





Machine performance:
Transverse spin running at PHENIX

Year	√s [GeV]	Recorded L	Pol [%]	FOM (P^2L)
2001 (Run-2)	200	.15 pb^{-1}	15	3.4 nb^{-1}
2005 (Run-5)	200	.16 pb^{-1}	47	38 nb^{-1}
2006 (Run-6)	200	2.7 pb^{-1}	51	700 nb^{-1}
2006 (Run-6)	62.4	.02 pb^{-1}	48	4.6 nb^{-1}
2008 (Run-8)	200	5.2 pb^{-1}	46	1100 nb^{-1}

The PHENIX detector

High rate capability to measure rare probes, limited acceptance.

2 central spectrometers

- Track charged particles and Calorimeters

$|\eta| < 0.35$

$90^\circ + 90^\circ$ azimuth

2 forward muon spectrometers

- Identify and track muons

$1.2 < |\eta| < 2.4$

2π azimuth

2 forward calorimeters

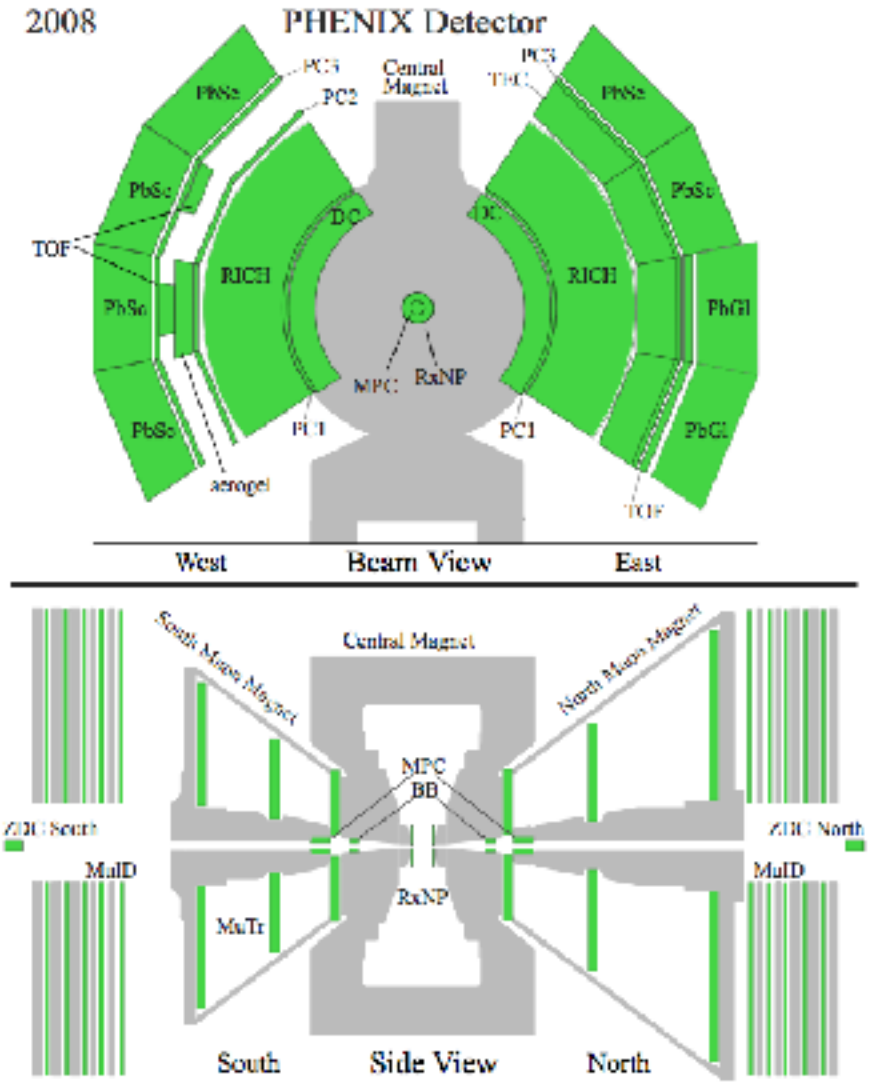
- Measure forward pions

$3.1 < |\eta| < 3.7$

2π azimuth

Relative Luminosity

- Beam-Beam Counter (BBC)
- Zero-Degree Calorimeter (ZDC)



BROOKHAVEN NATIONAL LABORATORY

Measurement of transverse single spin asymmetries

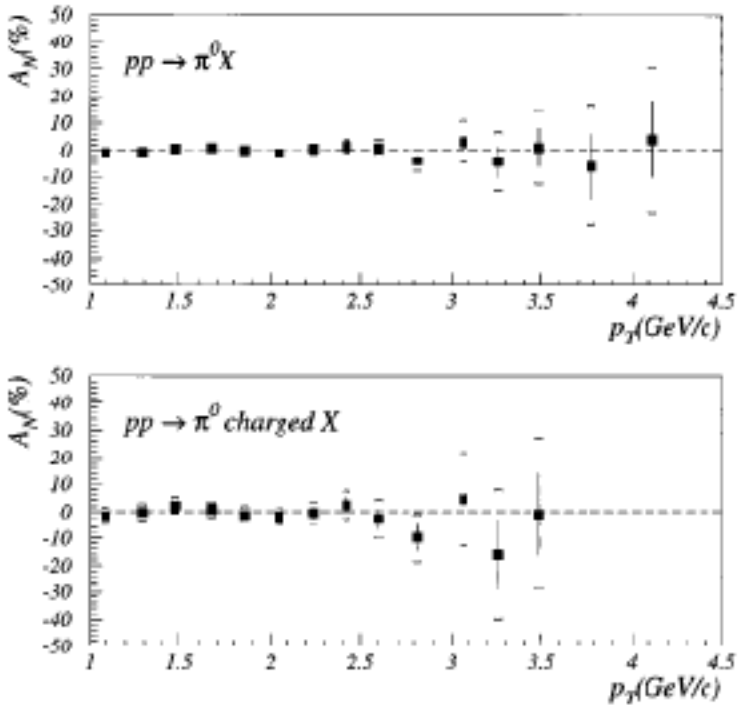
Look at left-right asymmetries relative to one transversely polarized proton beam

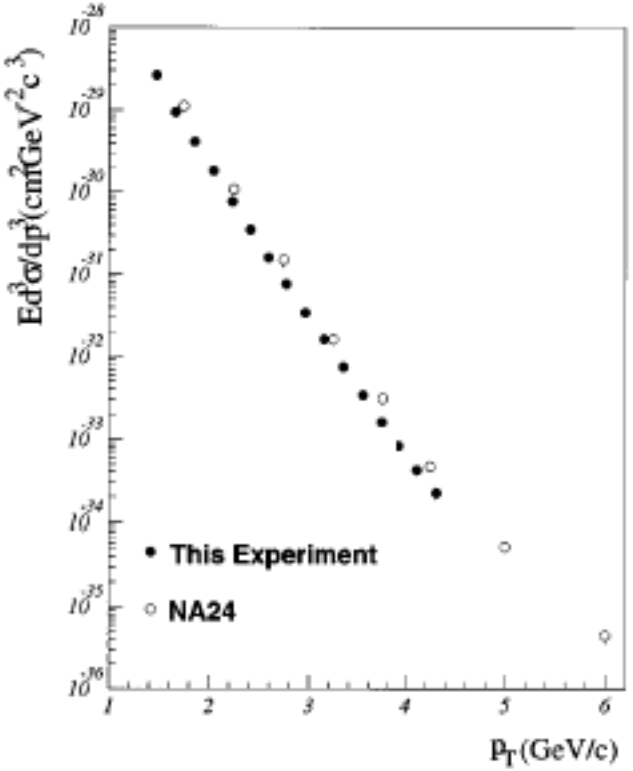
$$A_N^{Left} = \frac{1}{P}\frac{N^{\uparrow} - RN^{\downarrow}}{N^{\uparrow} + RN^{\downarrow}}, R = \frac{L^{\uparrow}}{L^{\downarrow}}$$

To cancel acceptance and luminosity effects use so-called square root formula

$$A_N = \frac{1}{P}\frac{\sqrt{N_{left}^{\uparrow} \cdot N_{right}^{\downarrow}} - \sqrt{N_{left}^{\downarrow} \cdot N_{right}^{\uparrow}}}{\sqrt{N_{left}^{\uparrow} \cdot N_{right}^{\downarrow}} + \sqrt{N_{left}^{\downarrow} \cdot N_{right}^{\uparrow}}}$$

At $X_F = 0$ Inclusive π^0 Asymmetry (E704)





D.L. Adams *et al.* PRD53:4747-4755,1996

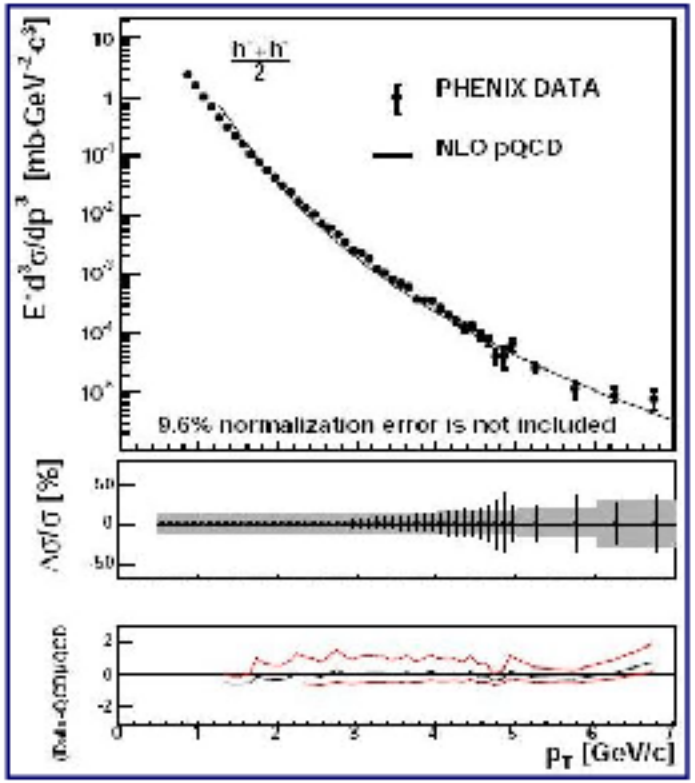
$\sqrt{s} = 20$ GeV are we in the partonic regime?
No asymmetry is observed in π^0 production

BROOKHAVEN
NATIONAL LABORATORY

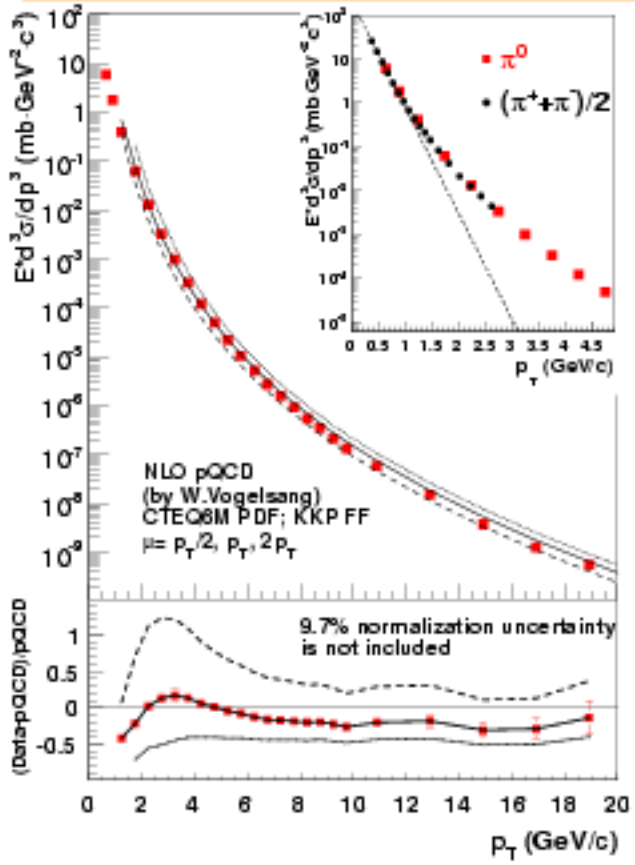
π^0 and h^+/h^- Cross Sections at $\sqrt{s}$ = 200 GeV at Midrapidity

PHENIX

$h^{\pm}$: PRL95, 202001 (2005)



π^0: PRD76, 051106 (2007)



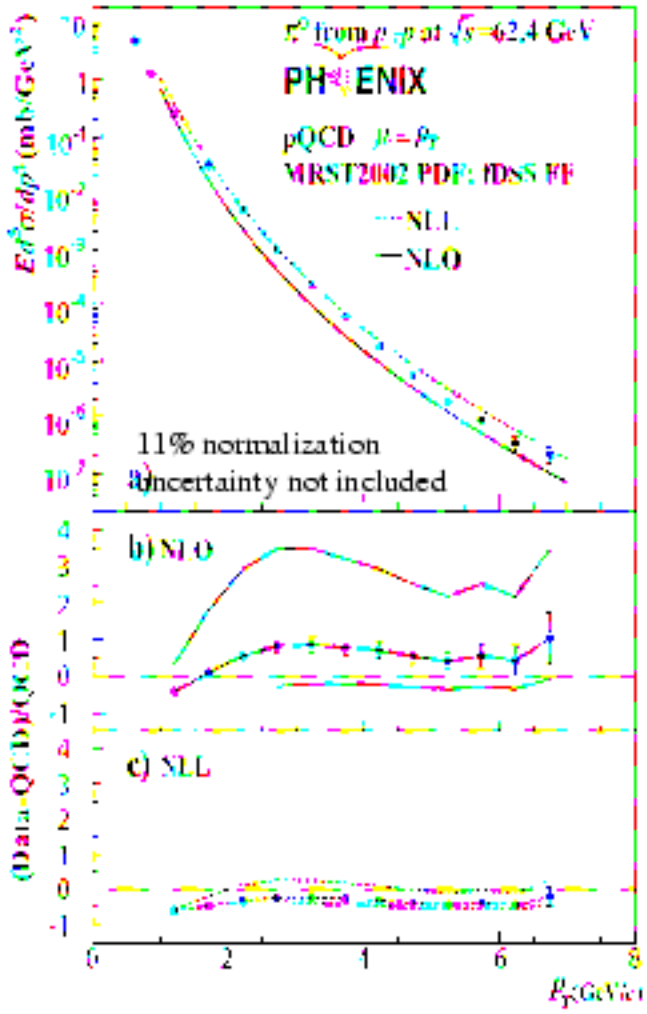
- Results consistent with pQCD calculations and favors a larger gluon-to-pion FF (KKP)
- *Provides confidence to use NLO pQCD analysis to extract spin dependent pdfs. via hadronic channels*

BROOKHAVEN NATIONAL LABORATORY

$\sqrt{s}$ = 62.4 GeV Midrapidity pions

Bazilevsky

PHENIX



Comparisons to NLO and NLL pQCD calculations using $\mu=p_T$ shown.

Unlike at 200 GeV, scale choice of $\mu=p_T$ underpredicts the data.

Threshold logarithm effects still relevant at this intermediate energy?

But—overall, pretty good agreement!

Data points from arXiv:0801.4555, Accepted by PRL

BROOKHAVEN NATIONAL LABORATORY

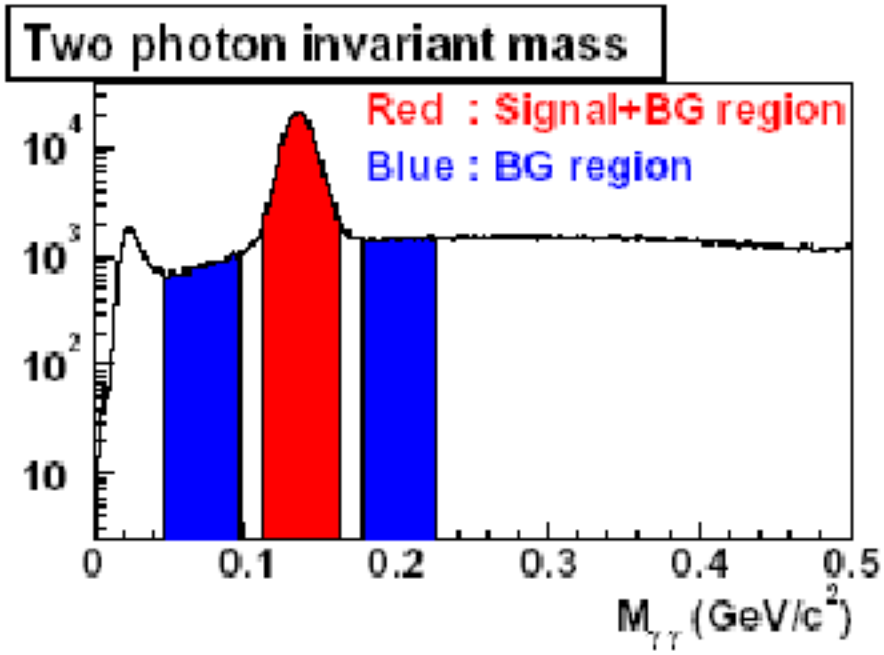
Inclusive pions analysis

C. Aidala

•Calculate asymmetry of (signal + background 50 Mev around the peak) in the π^0 mass window

• Calculate the asymmetry of two different background regions
• Subtract the asymmetries

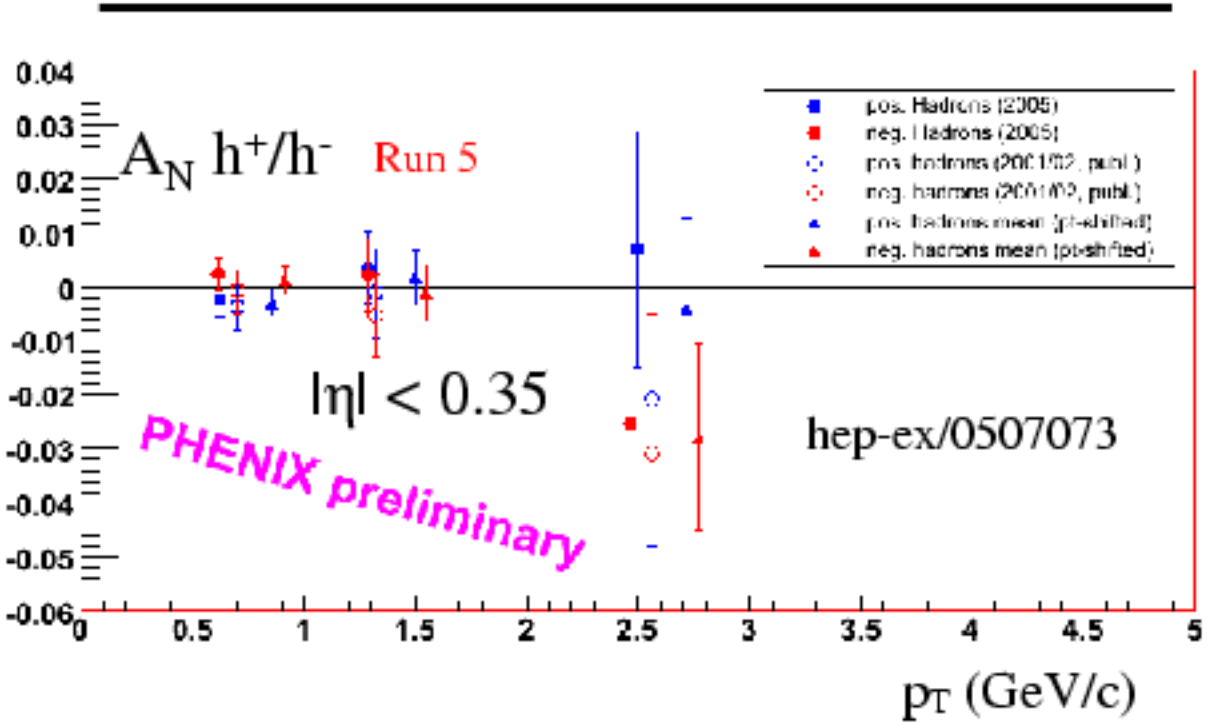
$$A_N^{\pi^0} = \frac{A_N^{\pi^0+bkg} - rA_N^{bkg}}{1-r}$$

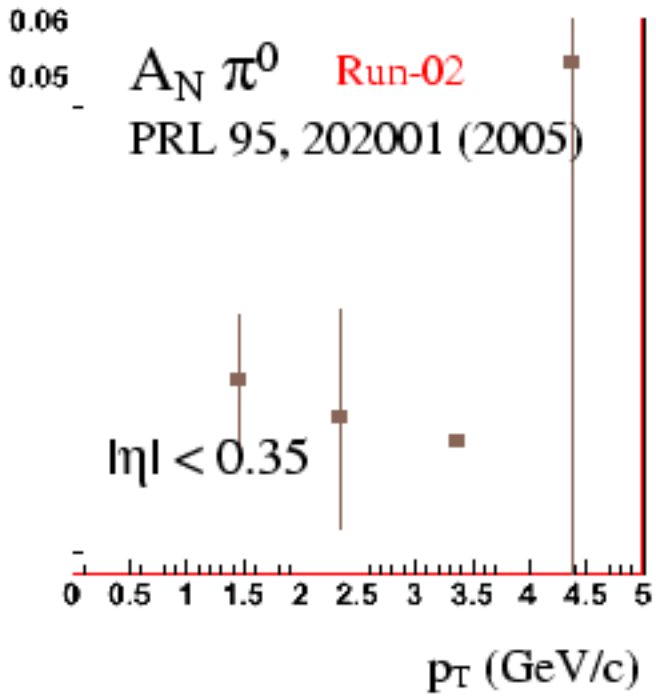


BROOKHAVEN NATIONAL LABORATORY

A_N at Midrapidity for π^0 and h+/- at $\sqrt{s}$ =200 GeV

PHENIX



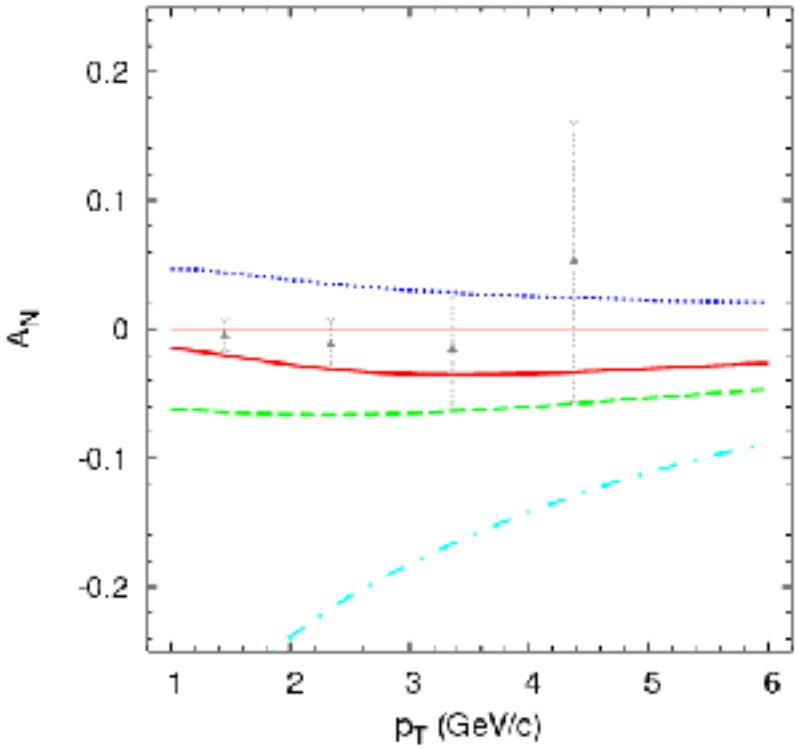


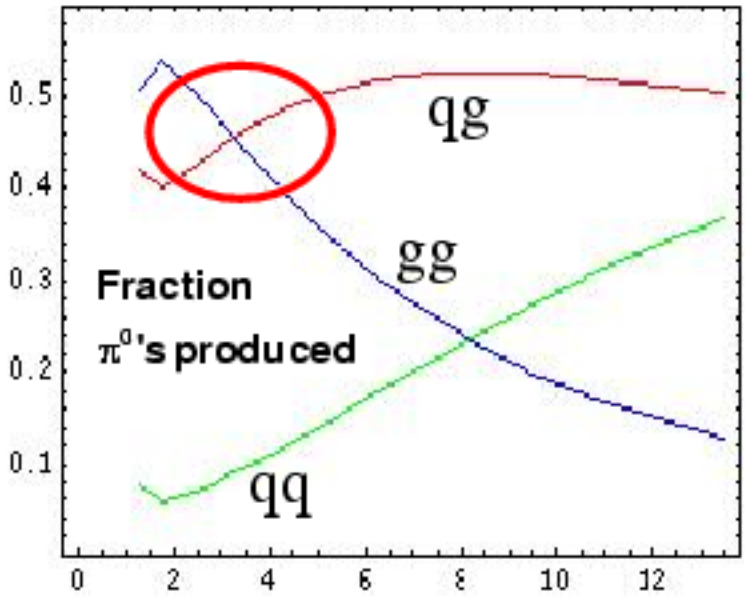
- A_N is zero within 1%
- Constrains Sivers function for gluons (Anselmino et al., PRD74, 094011 (2006)
- π^0 Run 6 & 8 data ~ 500x statistics being analyzed (D. Kleinjan , UCR)

No active analysis of charged data beyond Run 5

BROOKHAVEN NATIONAL LABORATORY

A_N in inclusive pi zero production





sensitive to g-g and g-q interactions

Anselmino et al., PRD74, 094011 (2006)

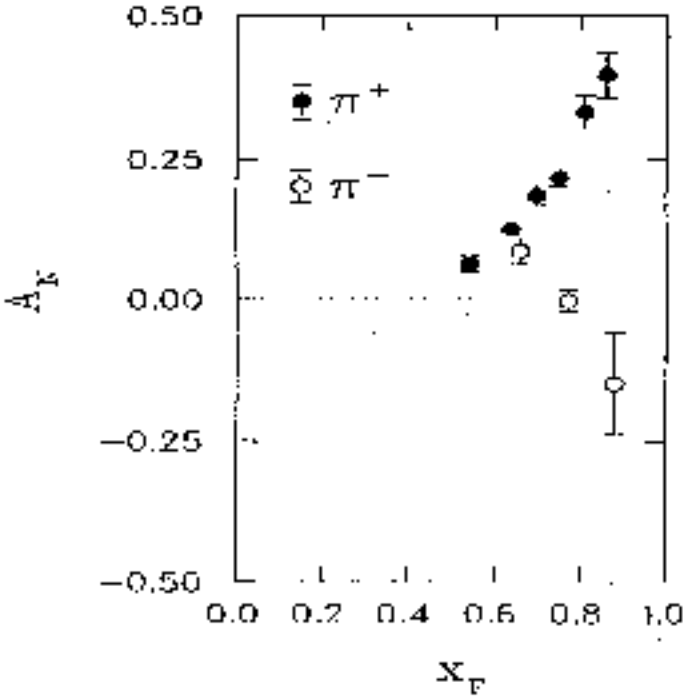
LO QCD Transverse Momentum Dependent parton scattering calculations

- Thin Red: valence u and d Sivers alone
- Cyan: Gluon Sivers Function at positivity bound, no sea quark Sivers
- Thick Red: Gluon Sivers parameterized to be 1 sigma from PHENIX π^0 A_N, no sea quark Sivers
- Blue: valence + sea quark Sivers at positivity bound
- Green: Gluon Sivers function and valence + sea quark at positivity bound → the largest gluon Sivers function compatible with our data

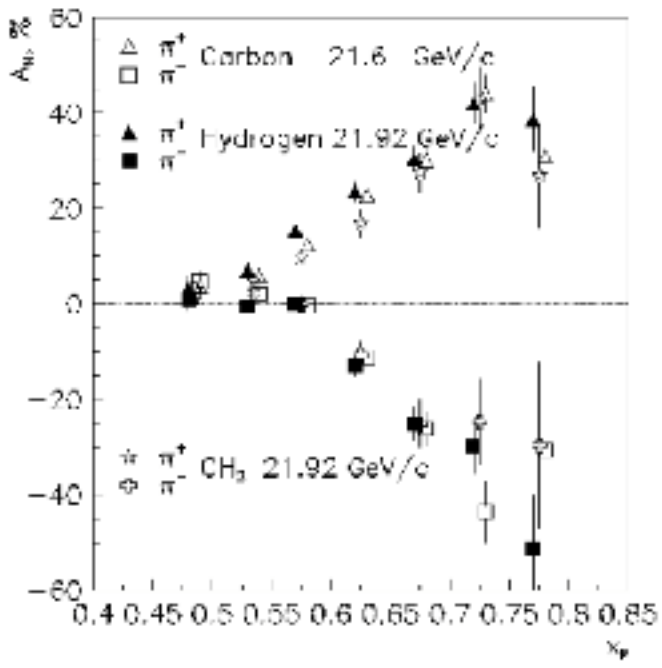
BROOKHAVEN NATIONAL LABORATORY

At large X_F: A_N in pion production (Pre-RHIC)

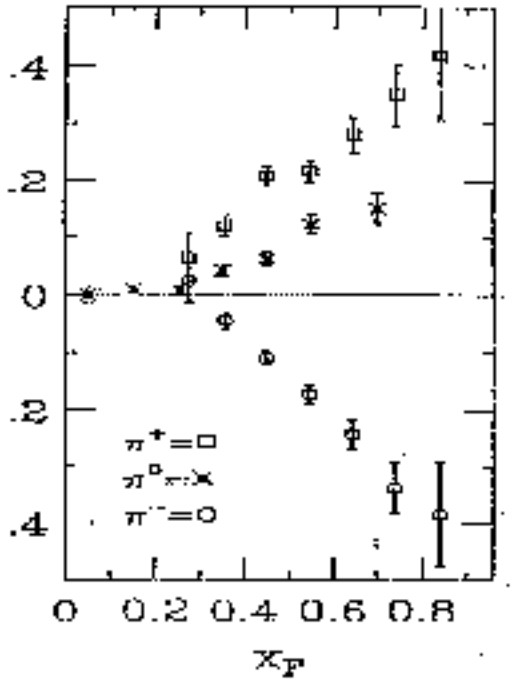
Beam Energy → ZGS (12 GeV) AGS (22 GeV) FNAL (200 GeV)



Phys. Rev. D18, 3939 (1978)
Points re-plotted vs. X_F



Phys.Rev.D65:092008,2002



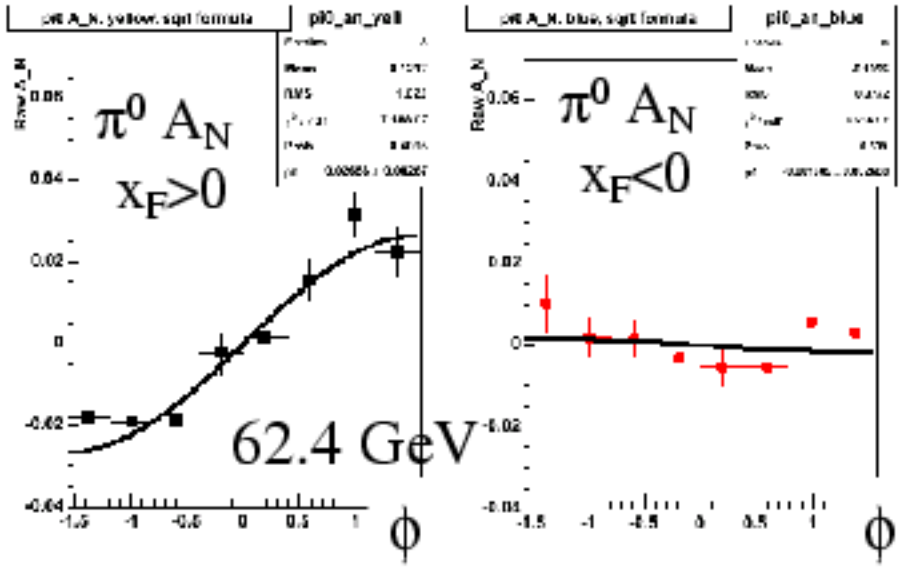
Phys. Lett. B261(1991)201
Phys. Lett. B264(1991)462

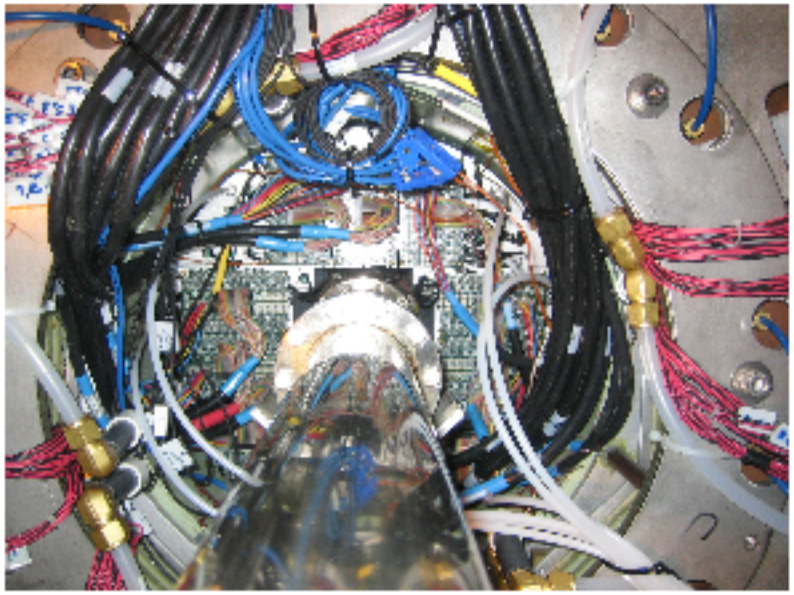
BROOKHAVEN NATIONAL LABORATORY

Large asymmetry in pion production
Asymmetry persists to high energy
No asymmetry in proton production at the AGS (not shown)

Forward coverage at PHENIX

- Muon Piston Calorimeter (MPC): $PbWO_4$ calorimeter
- Full azimuth $3.1 < |\eta| < 3.7$
  - Region of large observed asymmetries
- Single arm commissioned in Run-6 and data at 62 GeV
- Both arms took data in Run-8 200 times the FOM Analysis is ongoing.
- STAR and BRAHMS have measured sizable asymmetries.

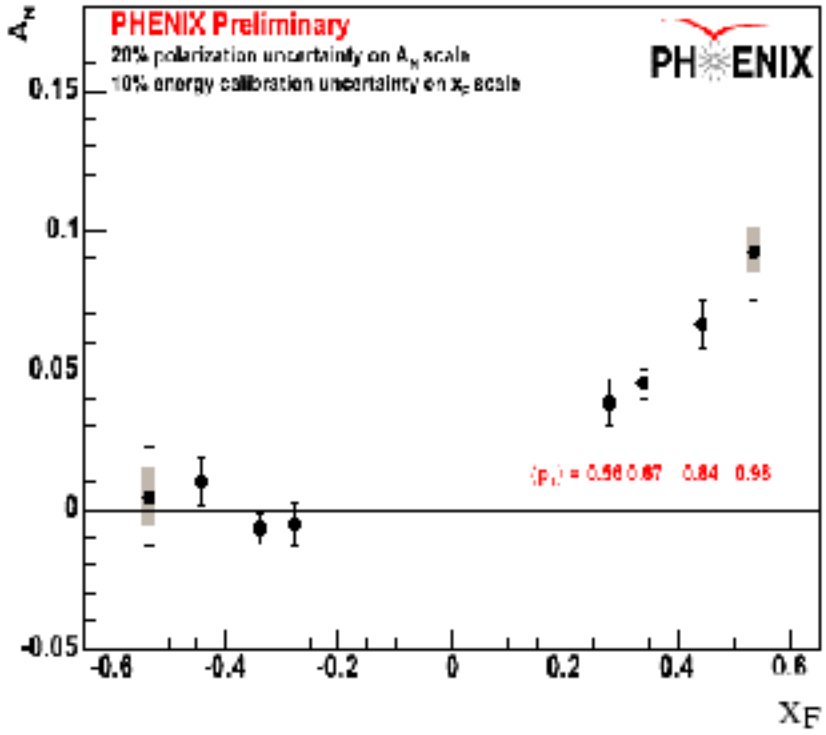


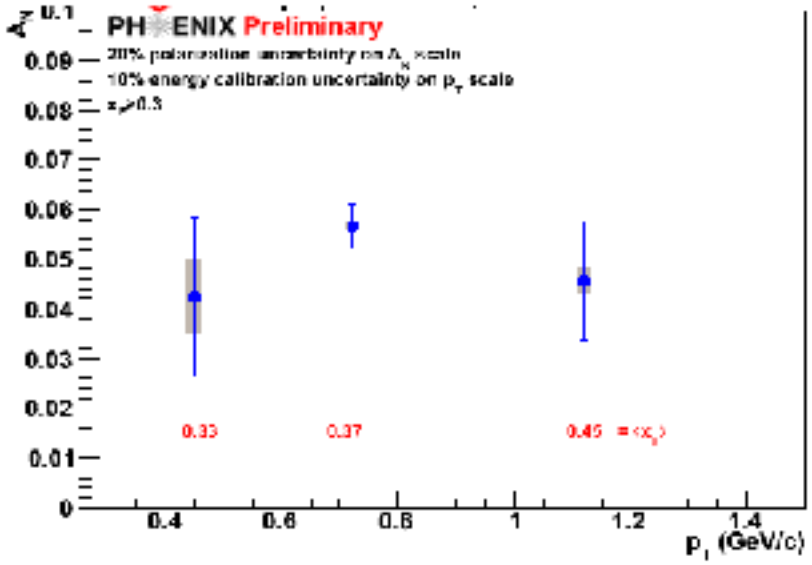


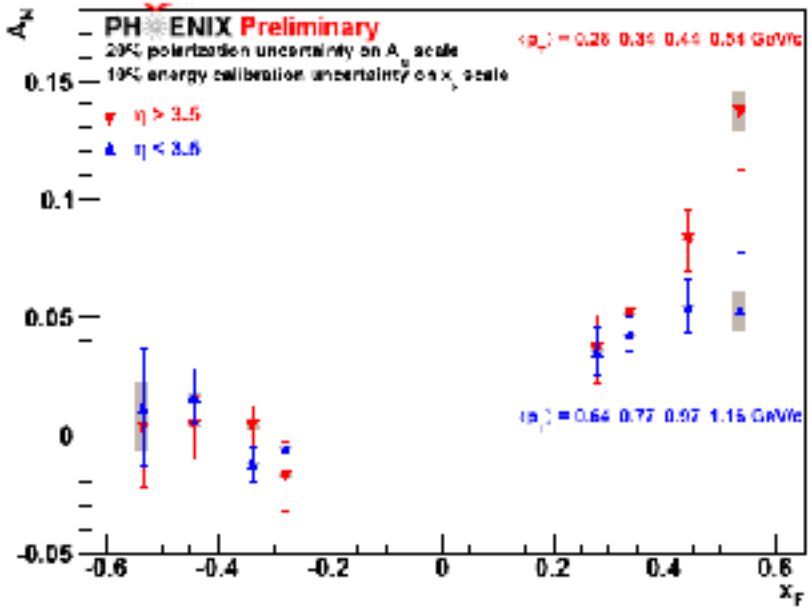
BROOKHAVEN NATIONAL LABORATORY

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

Chiu







Sizable asymmetries
Flat p_T dependence??
Pseuorapidity dependence

BROOKHAVEN NATIONAL LABORATORY

Chiu et al., nucl-ex/0701031

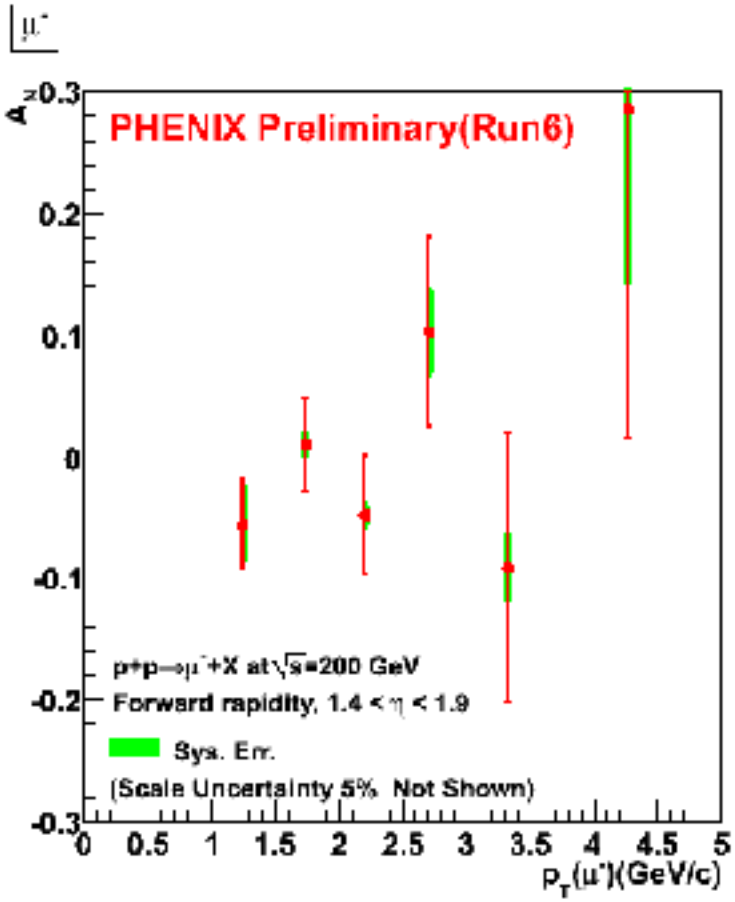
Systematics

- comparison of independent measurement for two polarized beams
  - both beams ("blue" and "yellow") polarized
- comparison of independent measurement for left and right detectors
- comparison of minimum-bias and high-p_T triggered data samples
- store-by-store consistency of asymmetry values
- "bunch shuffling"
  - randomly reassign the polarization direction for each bunch crossing
  - recalculate the asymmetry
  - repeat many times to produce a shuffled asymmetry distribution centered around zero
  - compare width of "shuffled" distribution to statistical error on the physics asymmetry

Heavy Flavor Single Spin Asymmetries

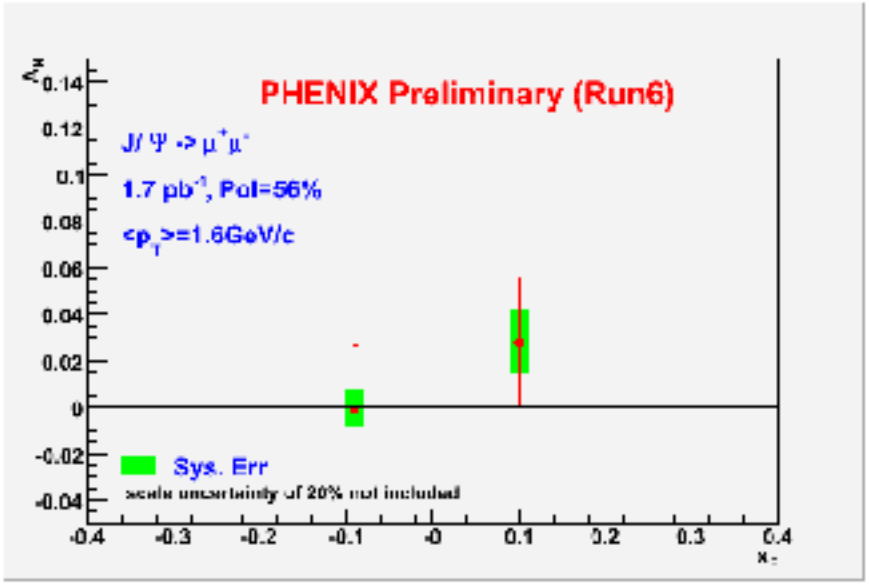
PHENIX

- Open charm single spin asymmetries are sensitive to gluon Sivers function
  Anselmino et al, PRD70, 074025 (2004)
- PHENIX data now available for A_N of prompt muons from heavy flavor decays



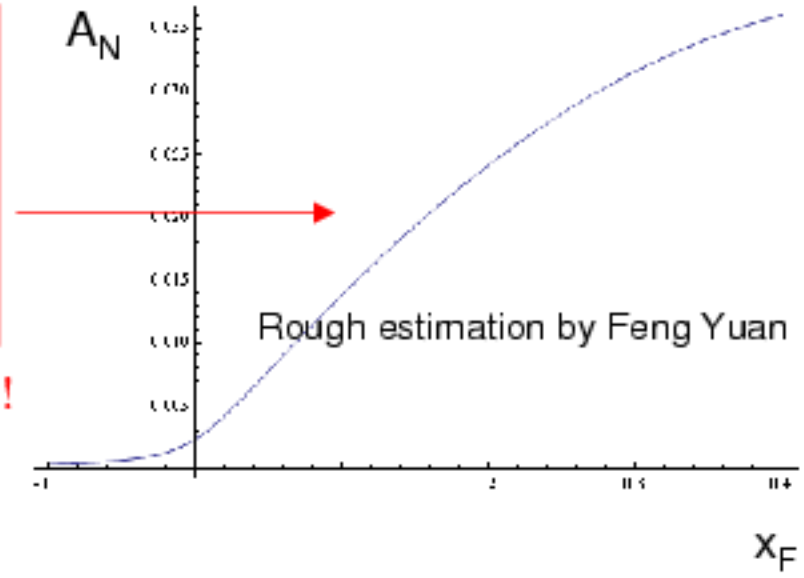
BROOKHAVEN NATIONAL LABORATORY

A_N in Charmonium Production



- J/ψ complicated by unknown production mechanism!
- At RHIC, color-octet dominate the production cross section
- 30%-40% J/Ψ comes from Ψ' and χ_c feed down

F. Yuan, arXiv:0801.4357 [hep-ph]
Assume:
--Gluon Sivers function ~ 0.5 x(1-x) times unpolarized gluon distribution (expect large-x and small-x suppression of the Sivers function as compared to the unpolarized one)



Run 8 has a significantly higher statistical sample !

BROOKHAVEN NATIONAL LABORATORY

Transversity- first look (w/ Interference Fragmentation function

Rhuize Yang

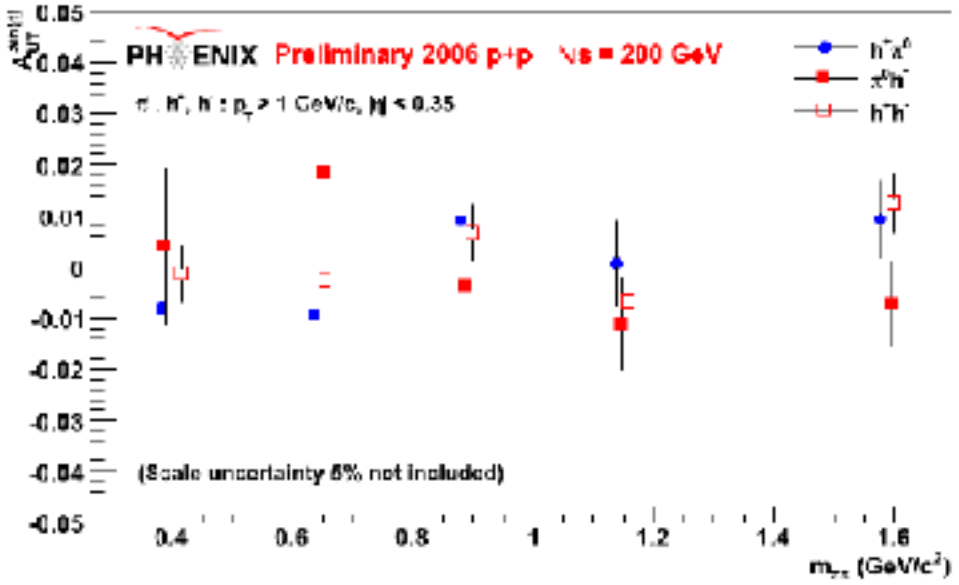
Collins, Heppelmann, Ladinsky,
Nuclear Physics B, 420 (1994) 565

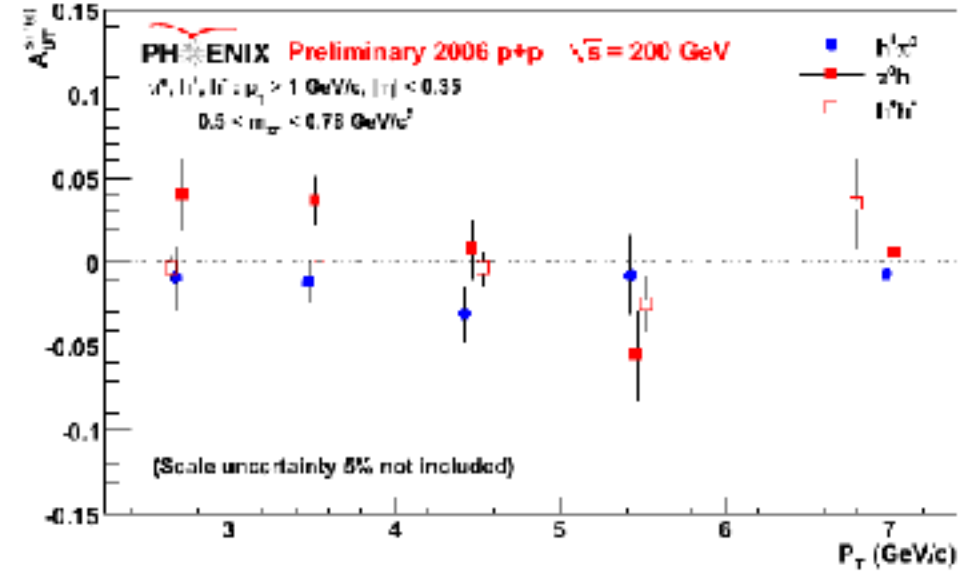
•Find all hadron pairs
(h^+/π^0), (h^-/π^0), (h^+/h^-)
on the same side of the detector

•Assume all hadrons have a pion mass
π^0: $p_T > 1$ GeV/c, h: $1<p_T<4.7$ GeV/c

Calculate the asymmtery and the analyzing power

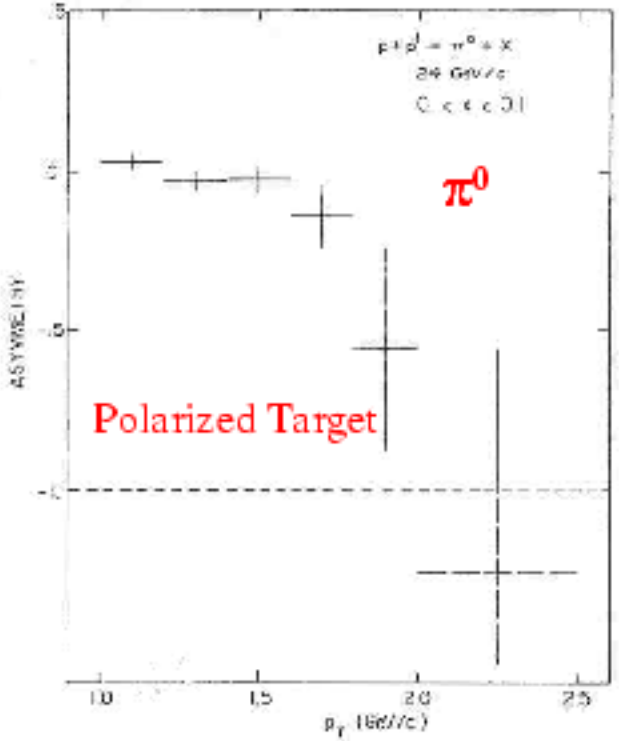
$$A_{UT}(\phi) = \frac{1}{P}\frac{N_{hh}^{\uparrow}(\phi) - RN_{hk}^{\downarrow}(\phi)}{N_{hh}^{\uparrow}(\phi) + RN_{hk}^{\downarrow}(\phi)} = A_{UT}^{\sin\phi}\sin\phi$$



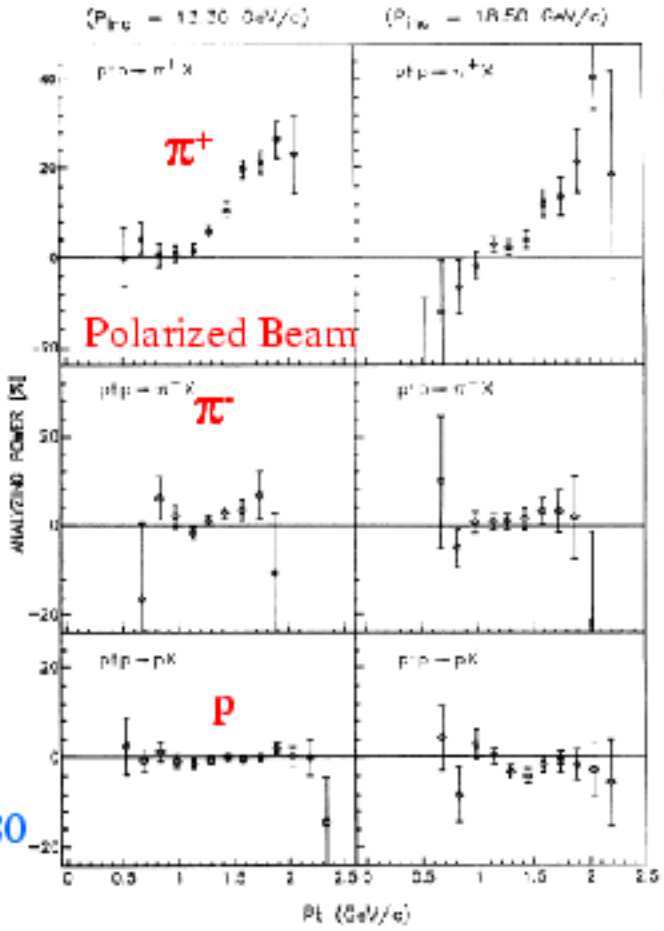


BROOKHAVEN NATIONAL LABORATORY

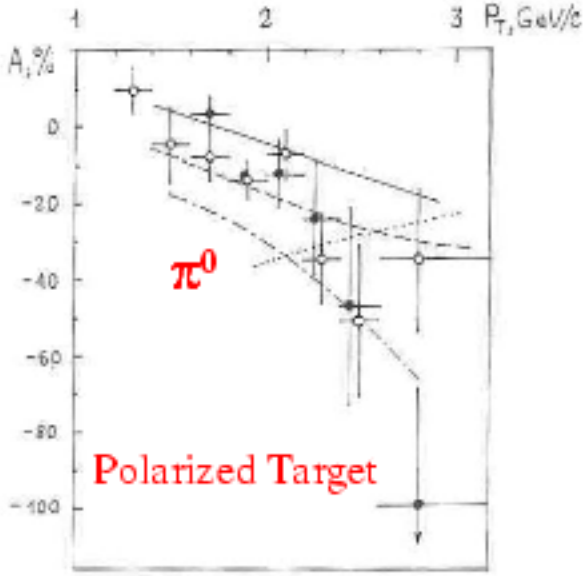
At Large X_T: Asymmetry in inclusive production



J. Antille et al. Phys.Lett.B94:523,1980



S. Saroff et al. PRL64,995,1990



$\pi^- p^\uparrow(d^\uparrow) \rightarrow \pi^0 x$ @ 40 GeV/c
V.D. Apokin et al.,
Phys.Lett.B243:461-464,1990

BROOKHAVEN NATIONAL LABORATORY

Large Asymmetries in π^+ and π^0 production
No asymmetry in π^- and proton production

Can PHENIX Contribute?

- Requires running at lower center of mass energies

- The Heavy Ions search for the Critical Point and transitions call for energy scans from 62 GeV down to well below RHIC injection to $\sqrt{S} = 9$ GeV.

- Take advantage of the baseline pp runs at comparable energies.

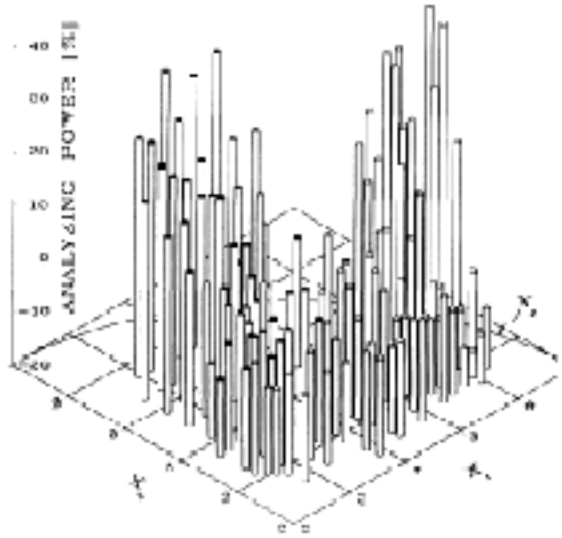
- PHENIX upgrades include:
  - A silicon vertex detector with $-1 < \eta < +1$
  - Additional forward calorimetry $0.9 < \eta < 3$

Will allow us to probe this region more effectively

BROOKHAVEN
NATIONAL LABORATORY

What have we learned so far?

- At large X_F asymmetries persist from low to highest energy measured at RHIC
- At large X_T asymmetry is seen in π^+ and π^0 but not in π^-
- Single Spin asymmetry is zero near $X_F = 0$ (not large X_T)
- Sivers and Collins effects apply at low and high energy
- Are we observing partonic effects:
  - polarized valence quark interactions at large X_F
  - Polarized valence quark interactions at large X_T
  - polarized gluon interaction at $X_F = 0$ and low p_t
  - polarized quark-gluon interactions at higher p_t
- Or possibly an $X_R = \sqrt{(X_F^2 + X_T^2)}$ effect?



S. Saroff et al. PRL64,995,1990

Looking Ahead

Near Term

- Complete analyses of Run6 and Run8
- With the installation of forward calorimetry and VTX

probe the forward region.

Longer Term

- Attempt to measure asymmetries in γ + Jet
  - Requires isolation cuts for prompt photons
- Attempt the Drell Yan measurement using the muon systems
  - Isolation cuts are required to reduce the open charm background
  - Higher luminosities

At issue is the prediction of an attractive final state color charge in SIDIS interactions and a repulsive initial one in DY thus an expected change of sign

Summary

PHENIX is in the midst of a varied and rich program to measure transverse single spin asymmetries in various kinematic regions:

- Midrapity,
- Forward rapidity
- Heavy Quark production
- J/psi production

Longer term

- γ + Jet production
- Drell Yan
- Transversity measurements

The hope is to shed some light on the Sivers and Collins effects. A task for both experiments and theorists.

BROOKHAVEN
NATIONAL LABORATORY