Transverse Spin Physics at PHENIX

Douglas Fields
(University of New Mexico)
For the PHENIX Collaboration

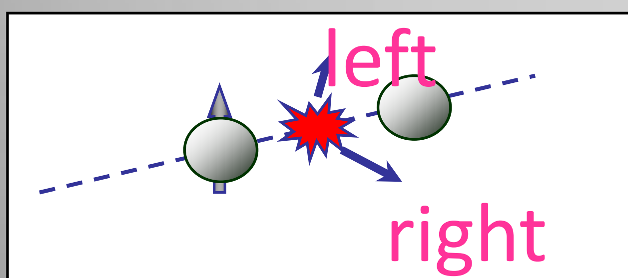
Motivation for Spin

- The proton has a rather complicated structure.
- Spin is a useful handle to dissect the proton.
- DIS experiments found that quarks carry ~30% of proton spin.
- Not surprising, after all:
  - Relativistic effects
  - Pion cloud
  - OGE interactions
  - All convert quark spin to quark orbital angular momentum.

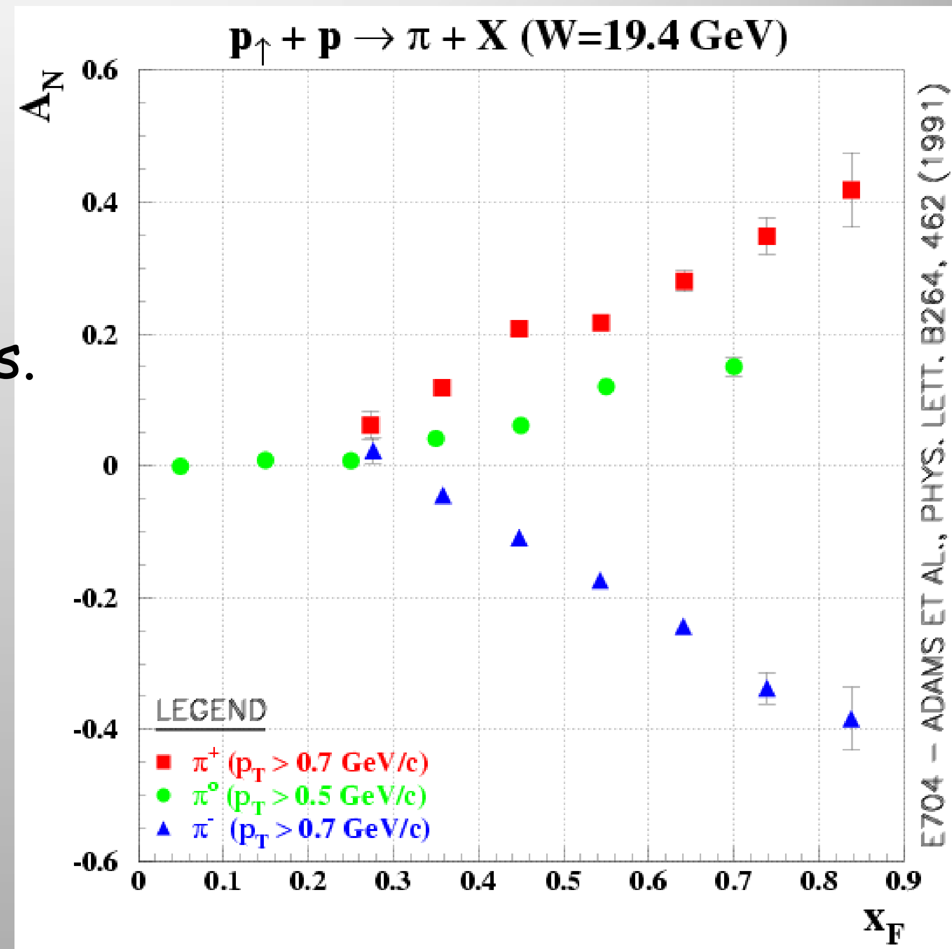
Myhrera & Thomas arXiv:0709.4067v1
Thomas arXiv:0803.2775v1

Motivation for Transverse Spin

- Transverse spin effects were supposed to be small in the high energy limit…
- But, large asymmetries were seen in the early 90's.

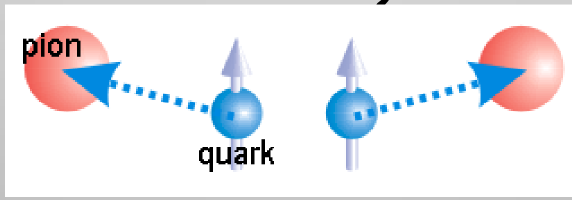


$$A_N \propto \frac{1}{P} \frac{N^{\uparrow}_{left} - N^{\uparrow}_{right}}{N^{\uparrow}_{left} + N^{\uparrow}_{right}}$$

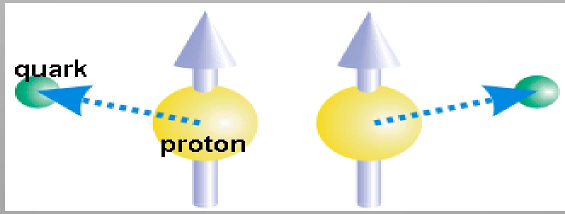


Transversity vs. Orbital Angular Momentum

- Two ways to get to the transverse spin structure:
  - Measure the transverse spin (transversity usually in conjunction with Collins).

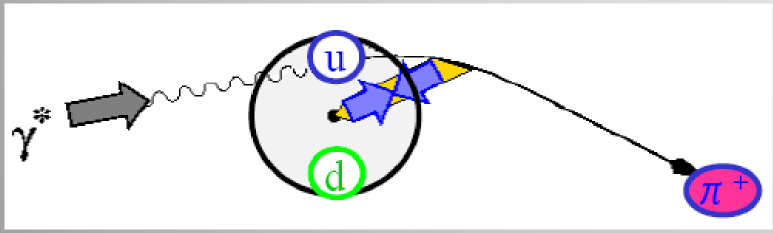


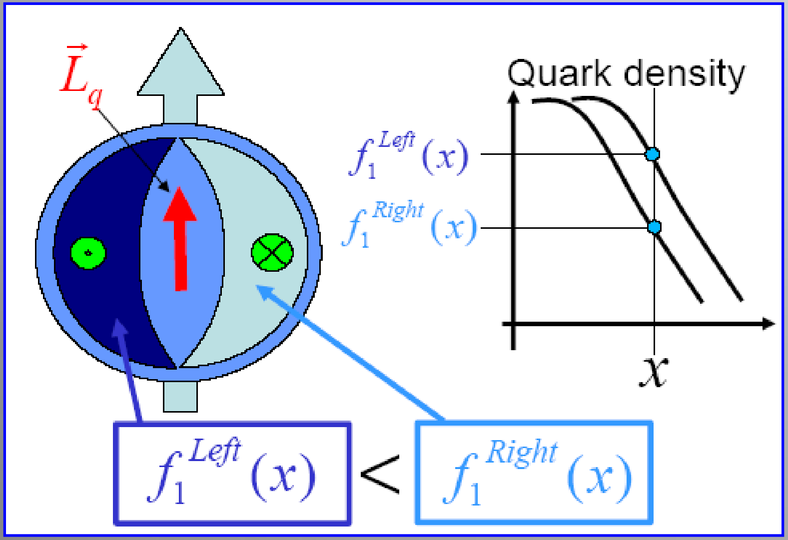
  - Measure observables linked to orbital angular momentum (Sivers, k_T asymmetry).

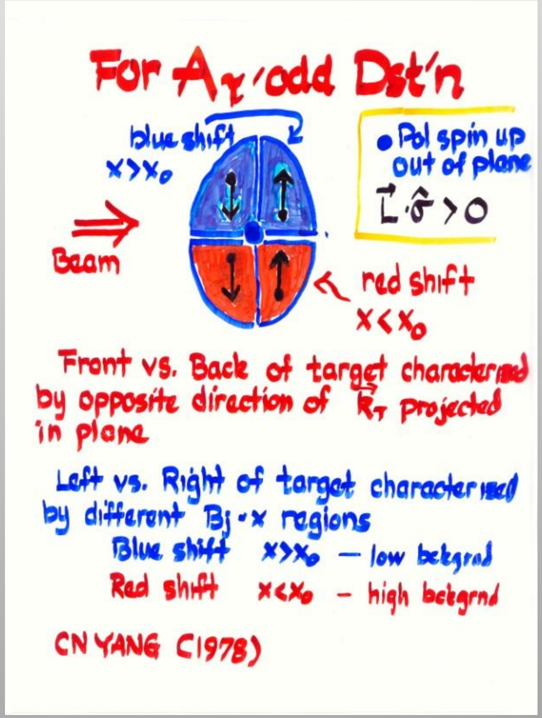


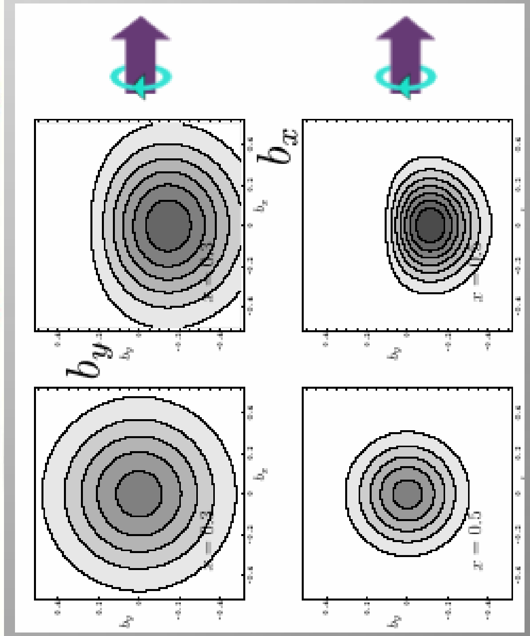
Observables sensitive to Orbital Angular Momentum

- Sivers function



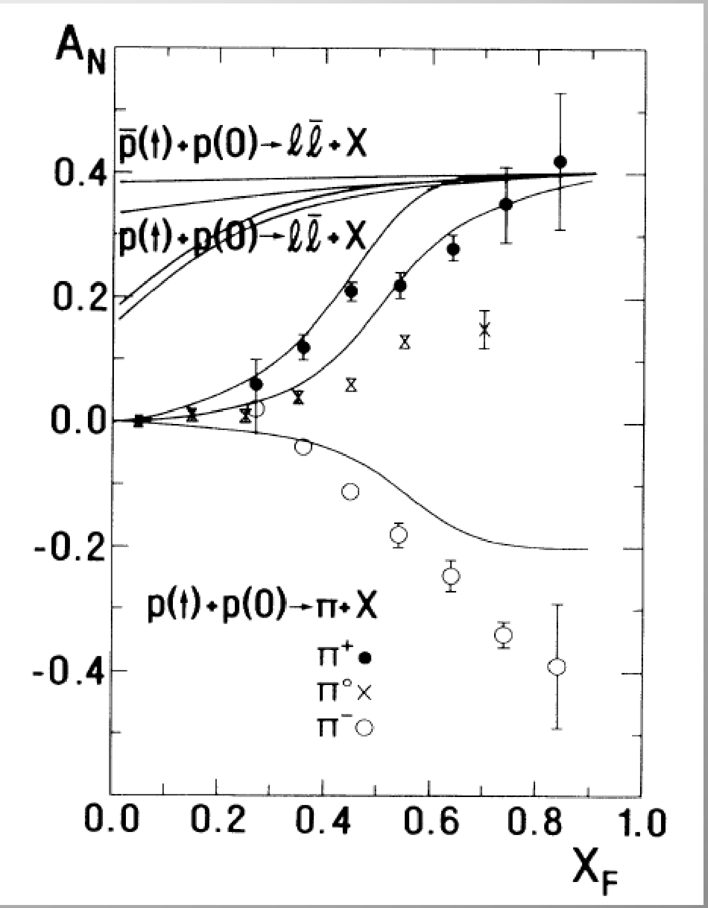




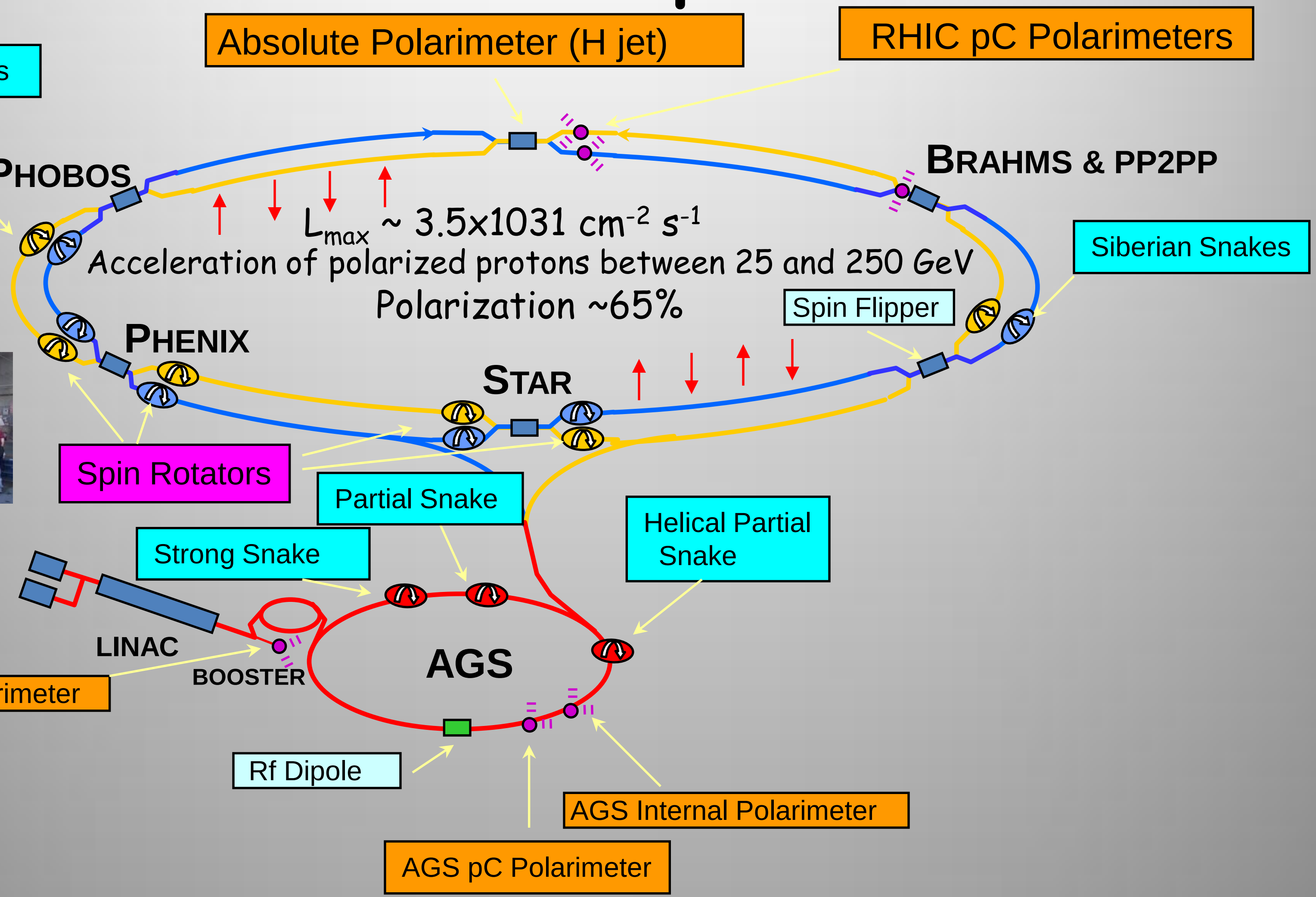


Observables sensitive to Orbital Angular Momentum

- There is a long history of trying to explain SSA's with orbital motion.
  - C.Boros, et al., PRL 70 p1751 (1993).
  - q-qbar annihilation of orbiting valence quarks.



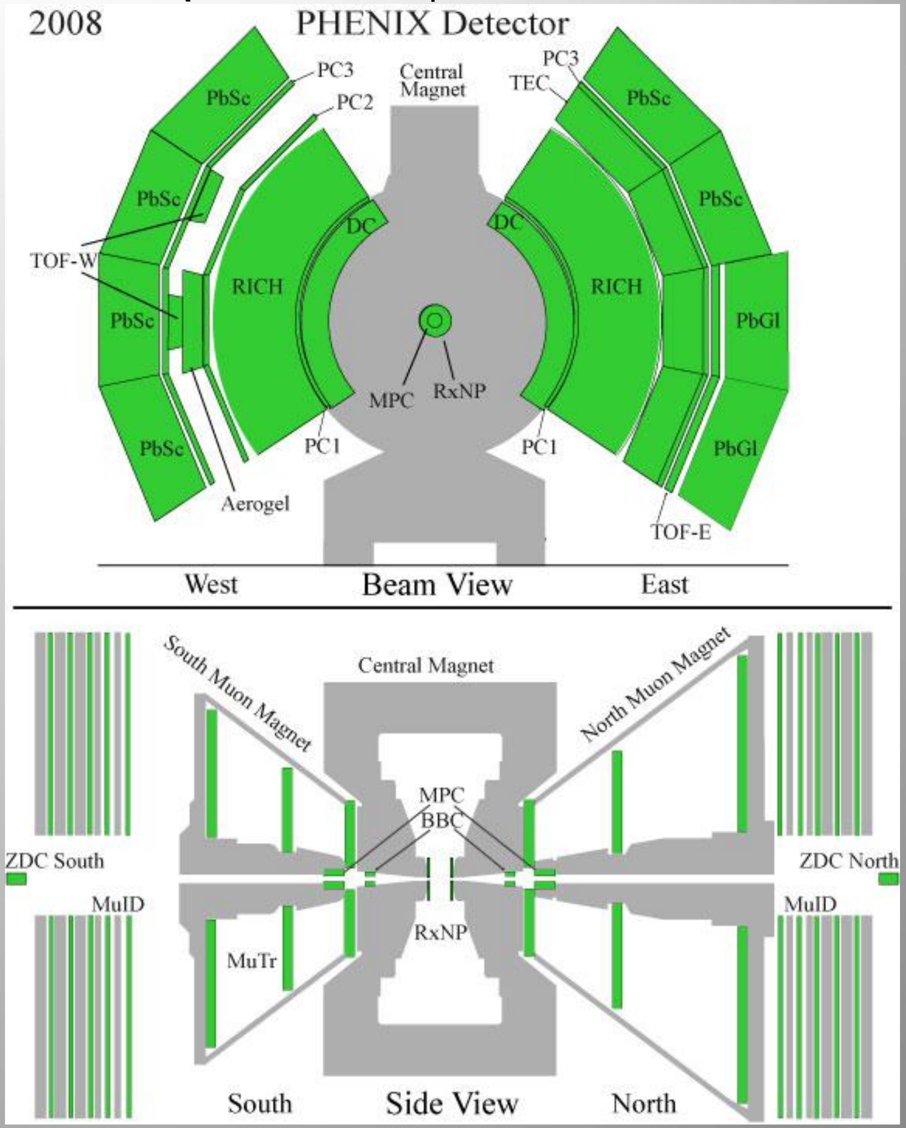
RHIC Spin


Siberian Snakes
Absolute Polarimeter (H jet)
RHIC pC Polarimeters
PHOBOS
BRAHMS & PP2PP
L_{max} ~ 3.5x1031 cm^{-2} s^{-1}
Acceleration of polarized protons between 25 and 250 GeV
Polarization ~65%
Siberian Snakes
Spin Flipper
PHENIX
STAR
Spin Rotators
Partial Snake
Helical Partial Snake
Strong Snake
LINAC
BOOSTER
AGS
200 MeV Polarimeter
Rf Dipole
AGS Internal Polarimeter
AGS pC Polarimeter

PHENIX

- Tracking:
  - Drift Chamber, Pad Chambers
- Electromagnetic Calorimeter (PbSc or PbGl) with fine granularity (10x10 mrad)
- RICH
  - EMCal-RICH Trigger
  - e/h separation p<5 GeV
  - π ID 5<p<16 GeV
- TOF
  - 85 ps resolution
  - π/k separation for pT<2.8 GeV/c,
  - Proton ID for pT<5 GeV/c
  - With Aerogel, separation up to pT ~8GeV/c
- TEC
  - e/h separation for pT< GeV/c,
- Muon arms
  - Muon identification and tracking
- Beam-Beam counter (BBC)
  - Charged particles $3.0 < |\eta| < 3.9$
  - Minimum Bias Trigger, Luminosity
  - Event vertex and time t_0
- Zero Degree Calorimeter (ZDC)
  - Neutral particles in 2mrad cone around beam axis
  - Event vertex and time
  - Local polarimetry
  - Independent luminosity measurement

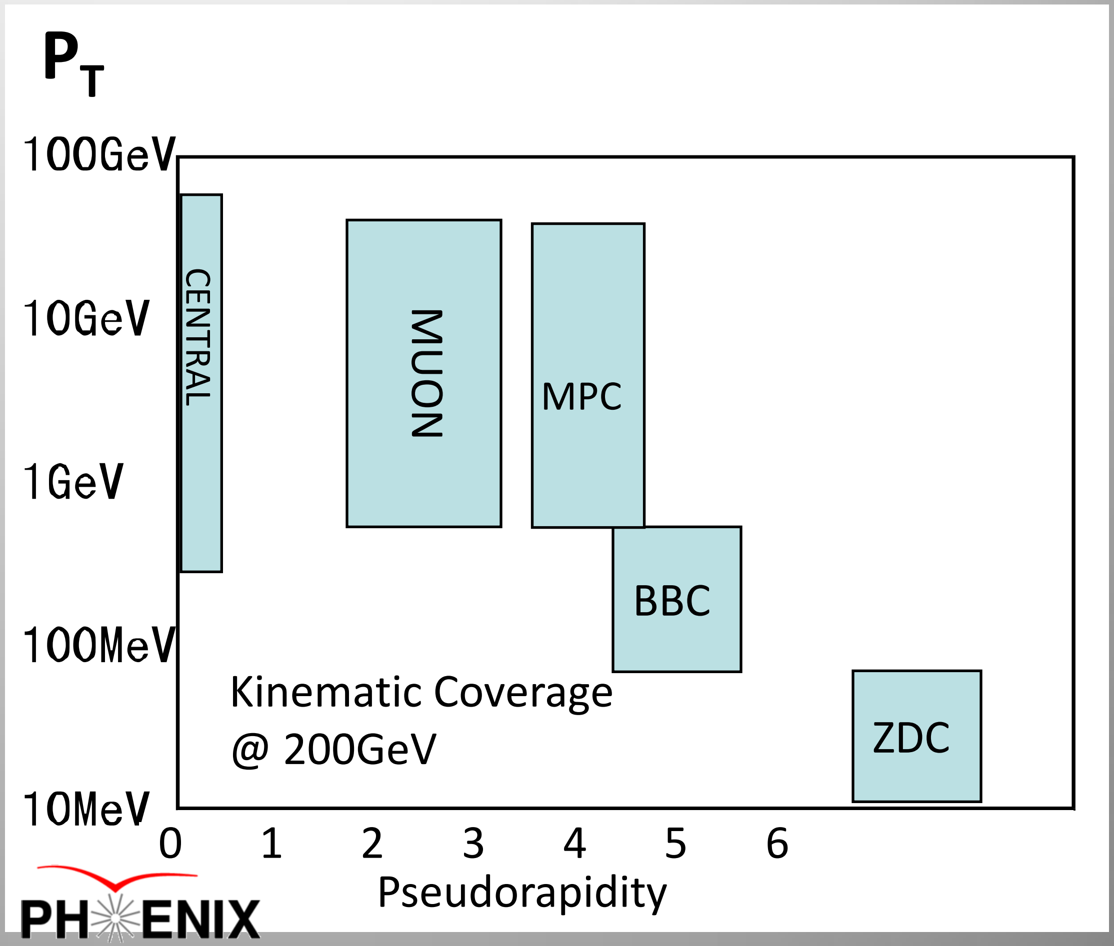
$|\eta| < 0.35, \phi = 2 \times \pi/2$



$(\sim 1.1 < |\eta| < 2.4)$

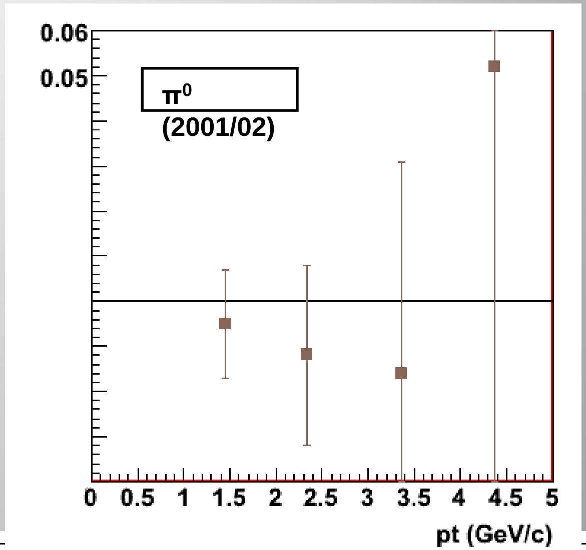
PHENIX Acceptance

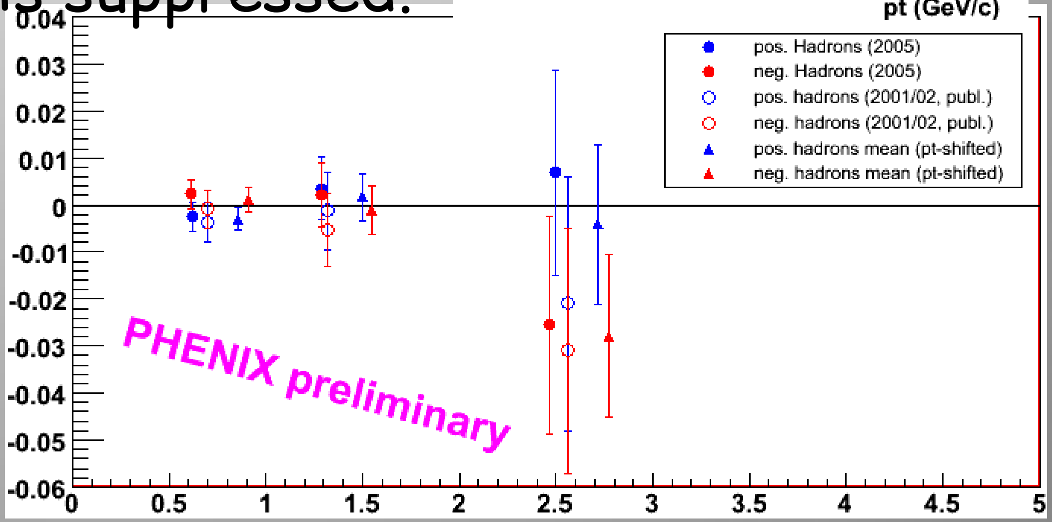
- Slides to follow refer generally to one of the following acceptances of PHENIX.
- Note that the acceptances determine very different kinematics and hence, processes that contribute to a signal.



A_N in Hadrons (Central)

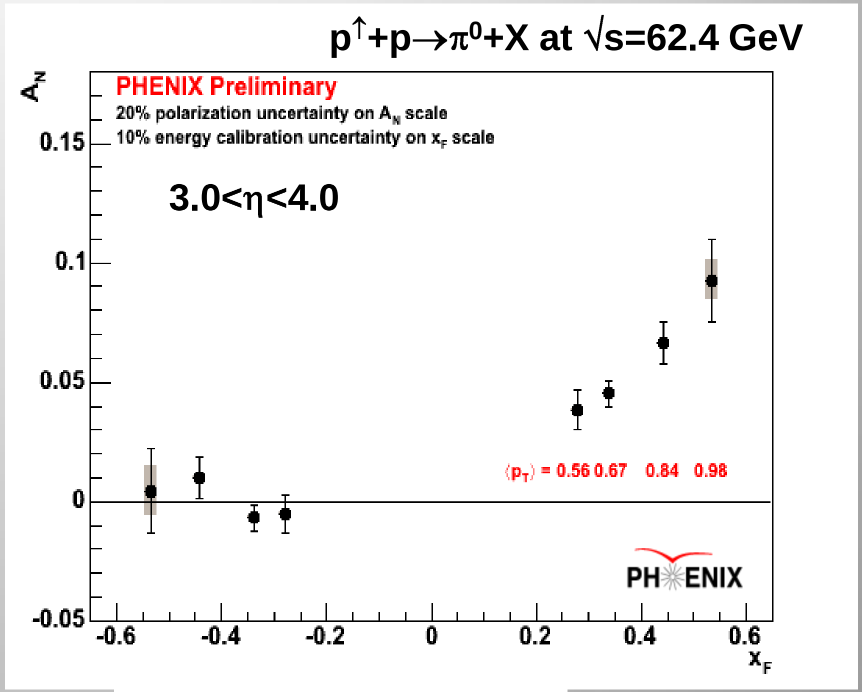
- A_N is 0 within 1% → interesting contrast with forward π
- May provide information on gluon-Sivers effect.
- gg and qg processes are dominant.
- Transversity effect is suppressed.

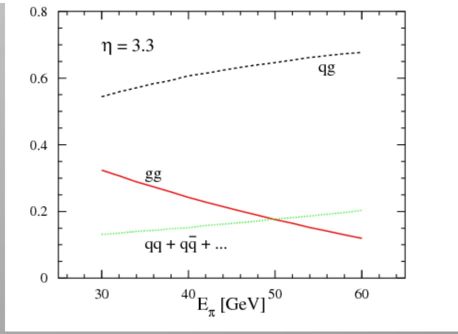




A_N in π^0 (MPC)

- Asymmetry seen in positive x_F, but not in negative x_F.
- Large asymmetries at forward x_F → Valence quark effect?



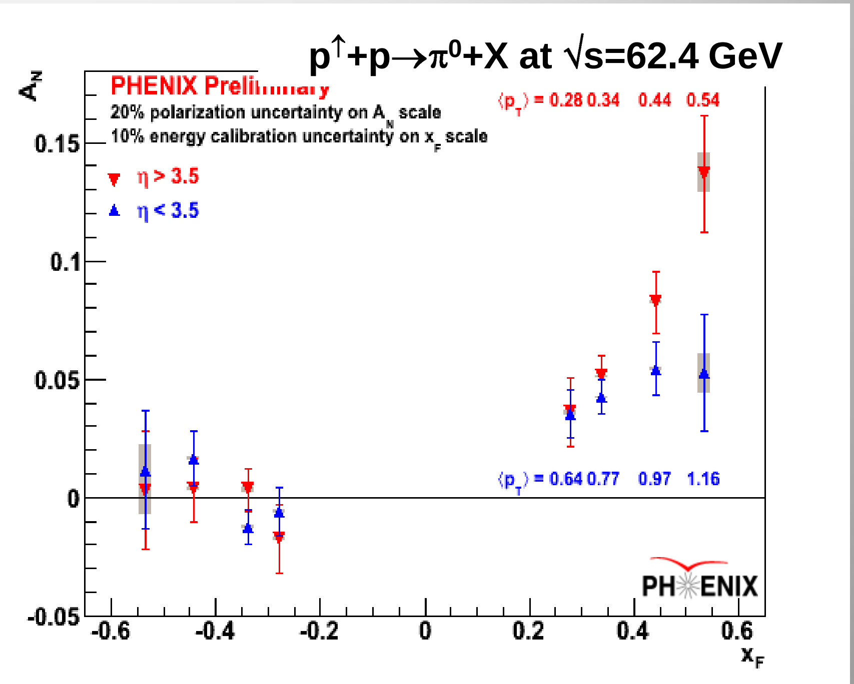


process contribution to π^0, η=3.3, $\sqrt{s}$=200 GeV

PLB **603**,173 (2004)

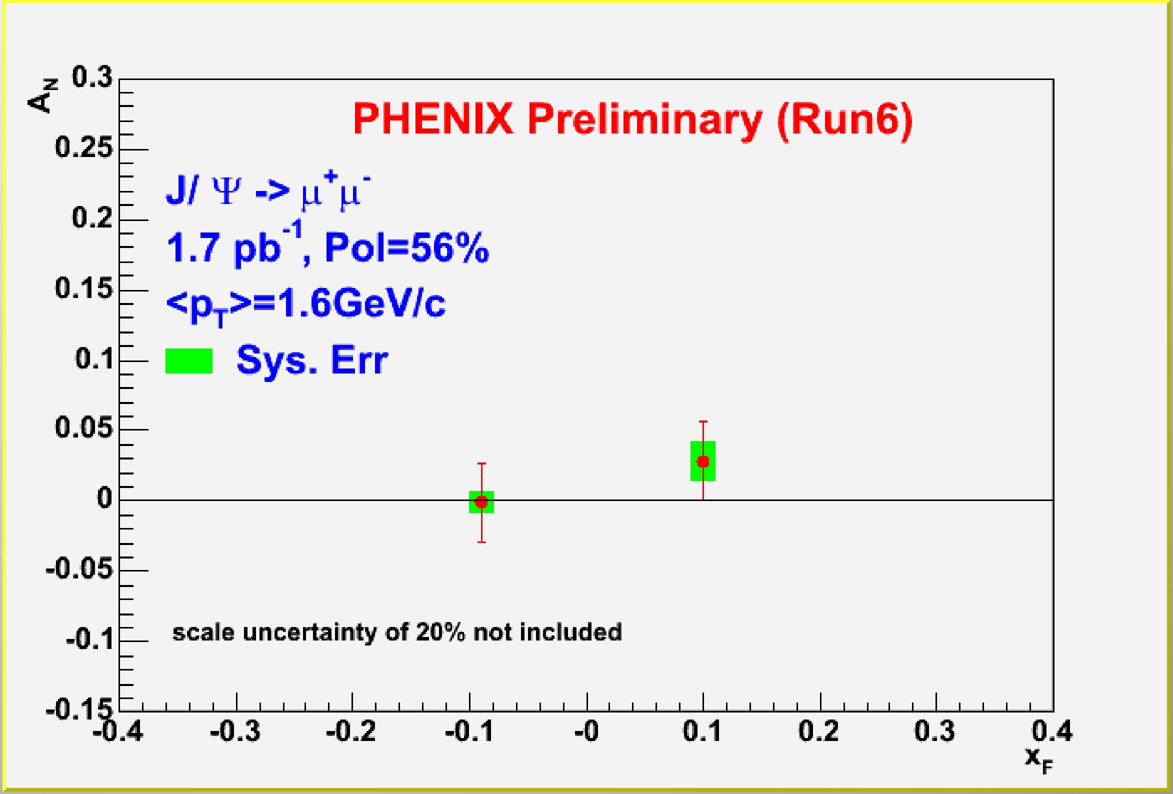
A_N in π^0 (MPC)

- Asymmetry seen in positive x_F, but not in negative x_F.
- Large asymmetries at forward x_F → Valence quark effect?
- x_F, p_T, $\sqrt{s}$, and η dependence provide quantitative tests for theories.
- 4 days of data!



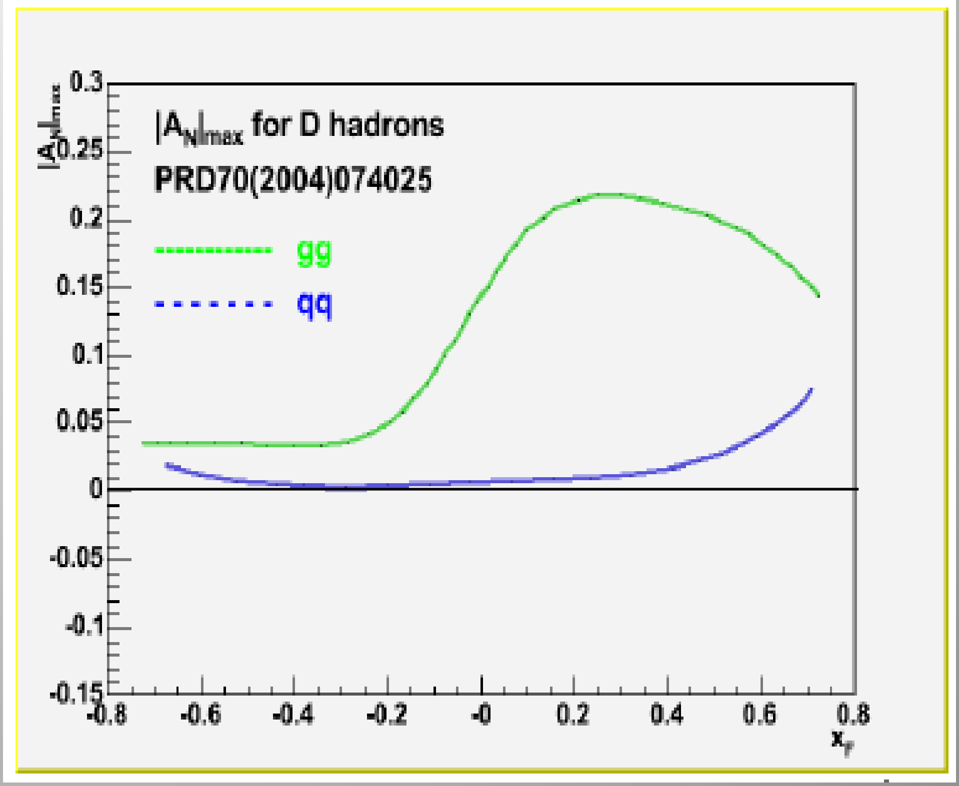
A_N in J/Ψ (Muon Arms)

- Sensitive to gluon Sivers function.



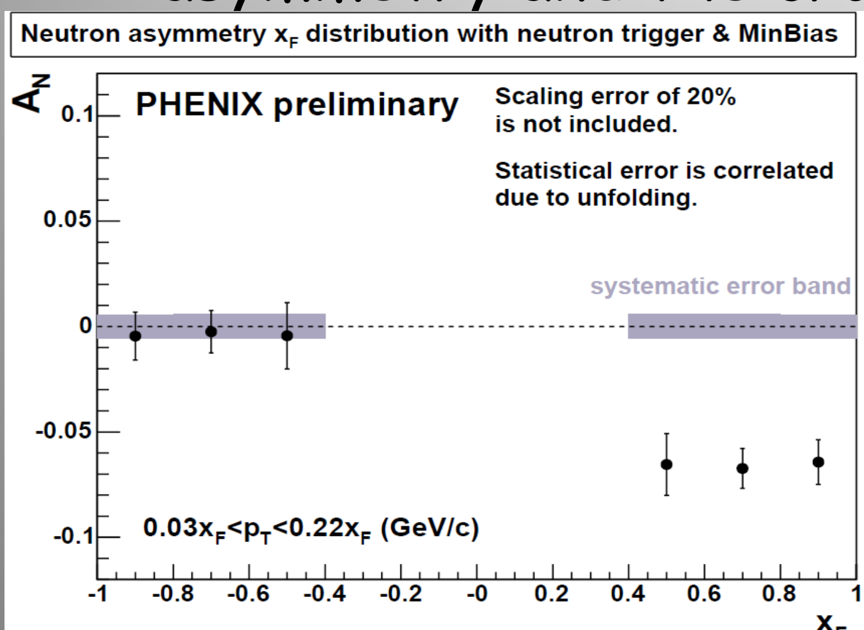
A_N in J/Ψ (Muon Arms)

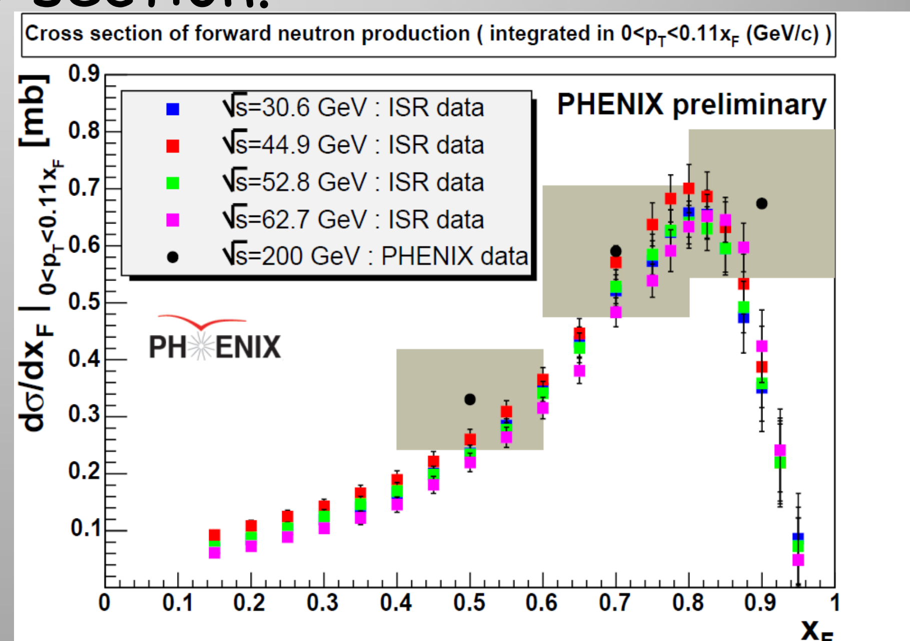
- Sensitive to gluon Sivers function.
- Open charm theory prediction available from Anselmino et al., but…
- J/ψ production mechanism affects asymmetry (Feng Yuan, arXiv:0801.4357v1)



A_N in Neutrons (ZDC)

- Forward neutron asymmetry is used to determine our polarization direction, but also is interesting physics.
- Have examined the xF dependence of the asymmetry and the cross-section.

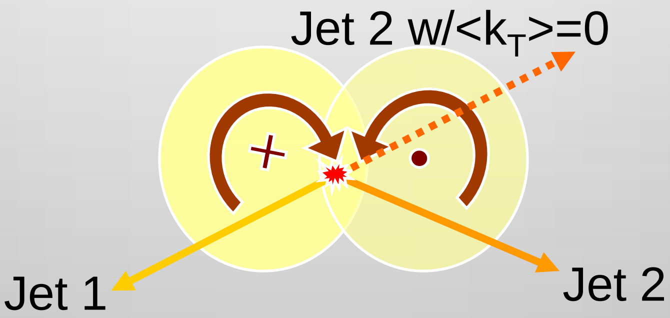


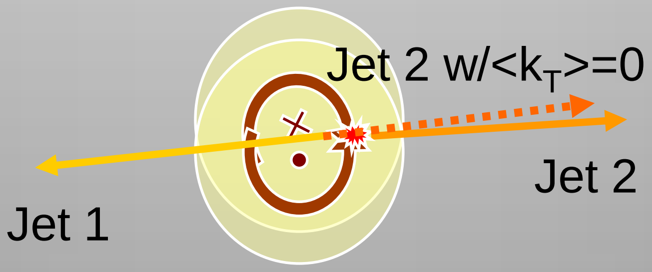


k_T Asymmetry

•×: Beam momenta

- Partonic orbital angular momentum leads to rotation of partons correlated with the proton spin vector
- This leads to different p_T imbalances (p_T-kicks) of jet pairs in semiclassical models
- Can be measured by measuring helicity dependence of $\langle k_T^2 \rangle$





Like helicities

Peripheral Collisions

↓

Larger $\sqrt{\langle k_T^2 \rangle}$

Integrate over b, left with some residual k_T

Central Collisions

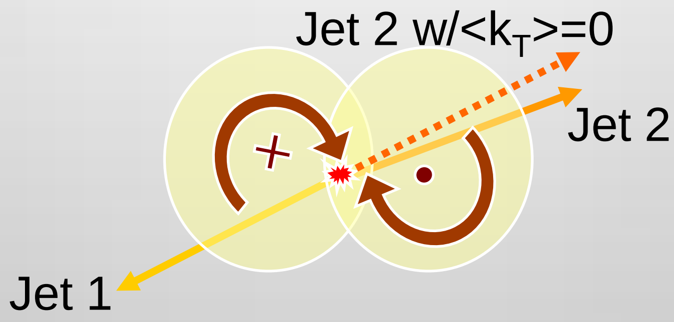
↓

Smaller $\sqrt{\langle k_T^2 \rangle}$

For details on jet see: Phys. Rev. D **74**, 072002 (2006)

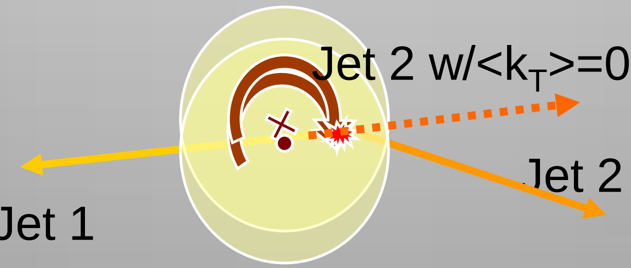
k_T Asymmetry

●×: Beam momenta



- Partonic orbital angular momentum leads to rotation of partons correlated with the proton spin vector
- This leads to different p_T imbalances (p_T-kicks) of jet pairs in semiclassical models
- Can be measured by measuring helicity dependence of $\langle k_T^2 \rangle$

Net p_T kick



Unlike helicities

Peripheral Collisions

↓

Smaller $\sqrt{\langle k_T^2 \rangle}$

Integrate over b, left with different residual k_T

Central Collisions

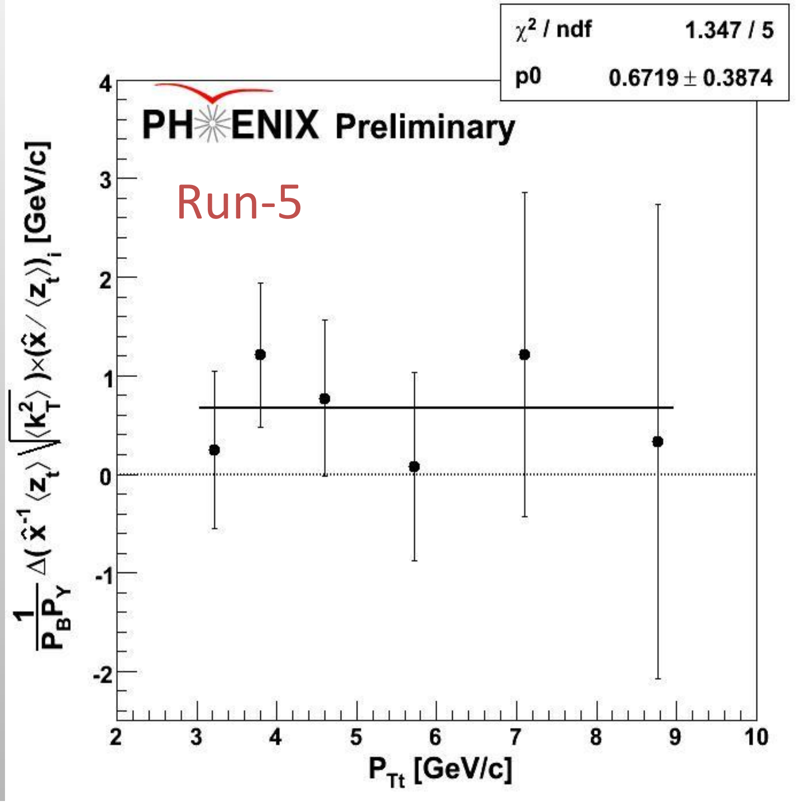
↓

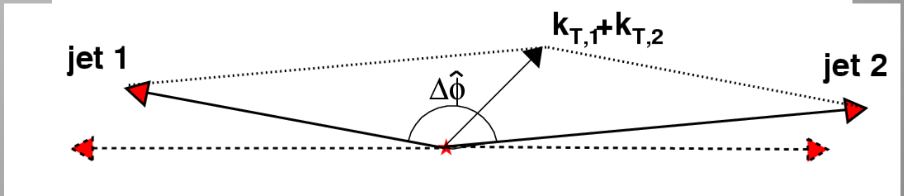
Larger $\sqrt{\langle k_T^2 \rangle}$

For details see: Phys. Rev. D **74**, 072002 (2006)

k_T Asymmetry (Central)

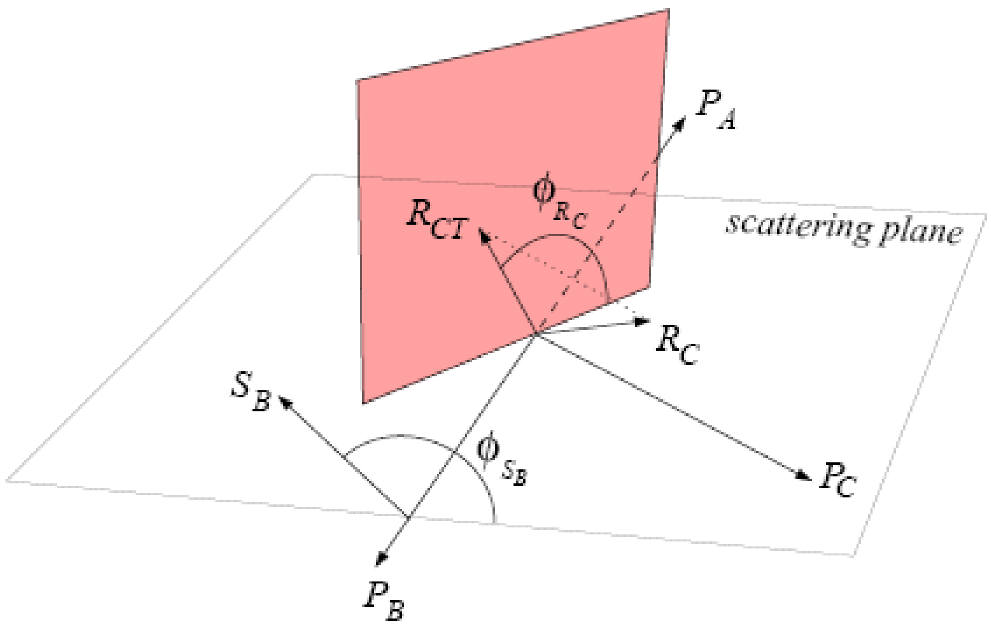
- Spin-correlated transverse momentum (orbital angular momentum) may contribute to jet k_T. (Meng Ta-chung et al., Phys. Rev. D40, 1989)
- Possible helicity dependence.
- Final analysis soon.





Upcoming…

- Sivers via A_N in di-jets in central arm and MPC.
- Transversity via Interference Fragmentation Function analysis.



$\vec{P}_A, \vec{P}_B$: momenta of protons

$\vec{P}_{h1}, \vec{P}_{h2}$: momenta of hadrons

$$\vec{P}_C = \vec{P}_{h1} + \vec{P}_{h2}$$

$$\vec{R}_C = (\vec{P}_{h1} - \vec{P}_{h2})/2$$

$\vec{S}_B$: spin orientation

Summary

- PHENIX is exploring the transverse spin effects at RHIC energies in all accessible kinematic regions.
- A truly "global" analysis of spin asymmetries should include all (not just A_{LL}) effects.
- More data is needed to come to a well-constrained understanding of the interplay between the spin and orbital structure of the nucleon.