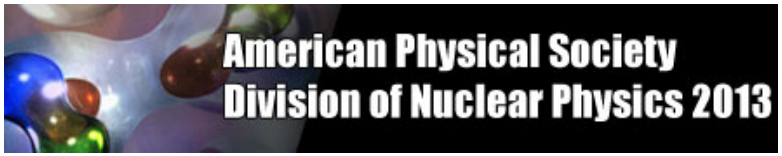
Transverse Single-spin Asymmetries from $p^{\uparrow} + p \longrightarrow jet + X$ and $p^{\uparrow} + p \longrightarrow jet + \pi^{\pm} + X$ in the Central Pseudorapidity Range and $\sqrt{s} = 500$ GeV at STAR

James L. Drachenberg

For the STAR Collaboration



October 24, 2013

OUTLINE

- Introduction
- Event Selection
- Analysis Description
- Systematic Uncertainties
- Preliminary Results
- Conclusions

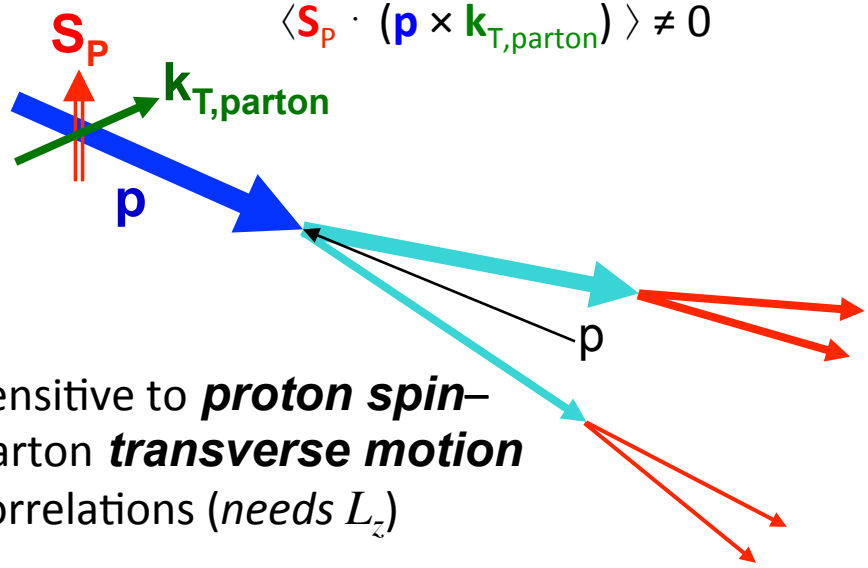
STAR

Valparaiso University

Sensitivity to Orbital Motion and Transversity?

Sivers mechanism: asymmetry in the forward jet or γ *production*

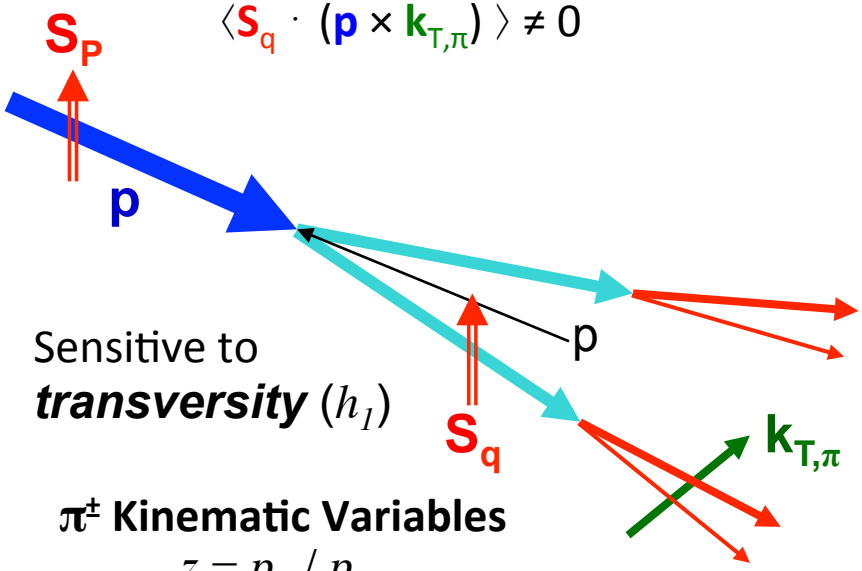
$\langle S_P \cdot (p \times k_{T,parton}) \rangle \neq 0$



Sensitive to ***proton spin–*** parton ***transverse motion*** correlations (*needs* L_z)

Collins mechanism: asymmetry in the forward jet *fragmentation*

$\langle S_q \cdot (p \times k_{T,\pi}) \rangle \neq 0$



Sensitive to ***transversity*** (h_1)

$\pi^{\pm}$ Kinematic Variables

$z = p_\pi / p_{jet}$

$j_T\,(k_{T,\pi}) = \pi\, p_T$ relative to jet axis

Separate Sivers and Collins:

Go beyond inclusive production - *e.g. Jets, correlations, direct photons*

Sivers ~ $\sin(\phi_S)$

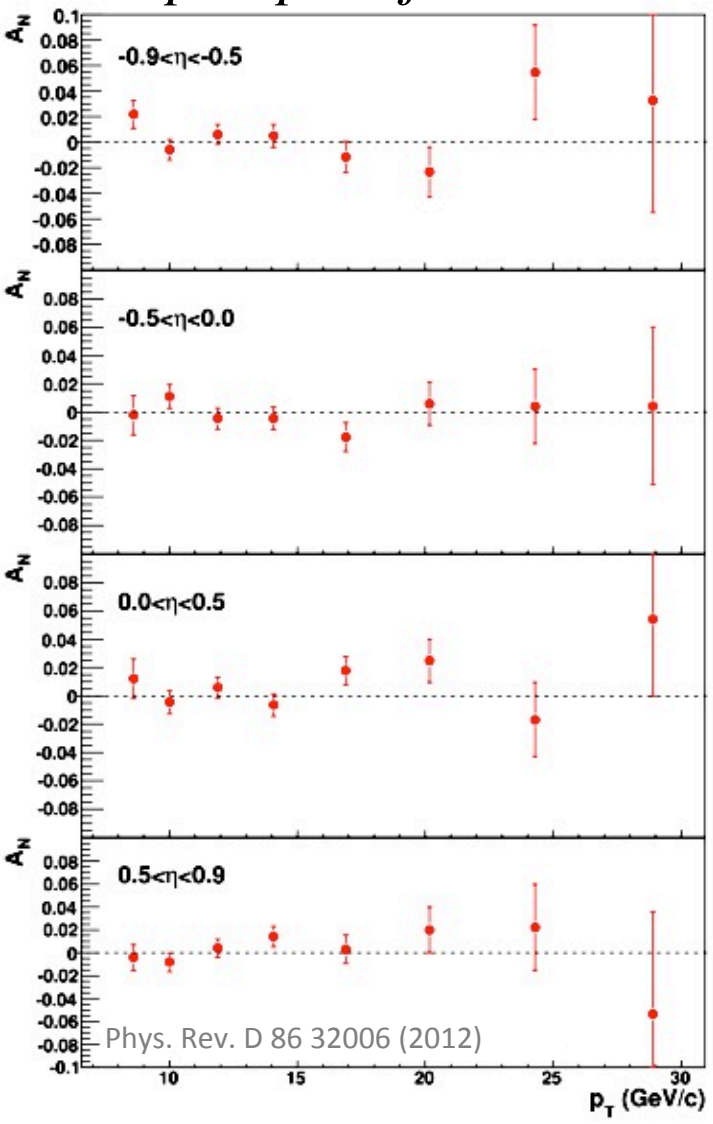
ϕ_S—*angle between spin and event plane*

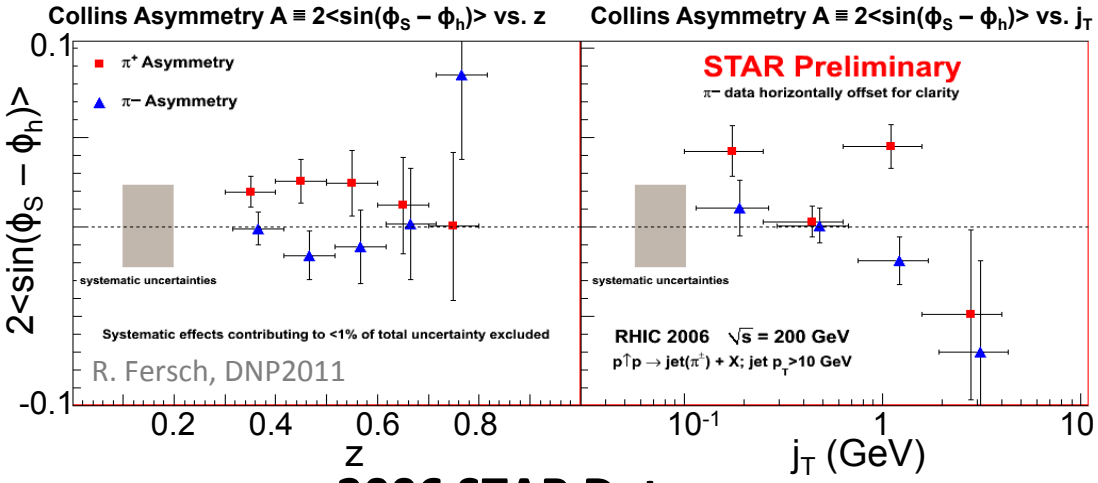
Collins ~ $\sin(\phi_S - \phi_h)$

ϕ_h—*angle of hadron around jet axis*

STAR Transverse Jet Asymmetries at Central Pseudorapidity

$$p^{\uparrow} + p \rightarrow jet + X$$





2006 STAR Data

transverse single-spin asymmetries for inclusive jet production at central pseudorapidity and √s = 200 GeV

$A_{UT}^{\sin(\phi_S)}$: consistent with zero

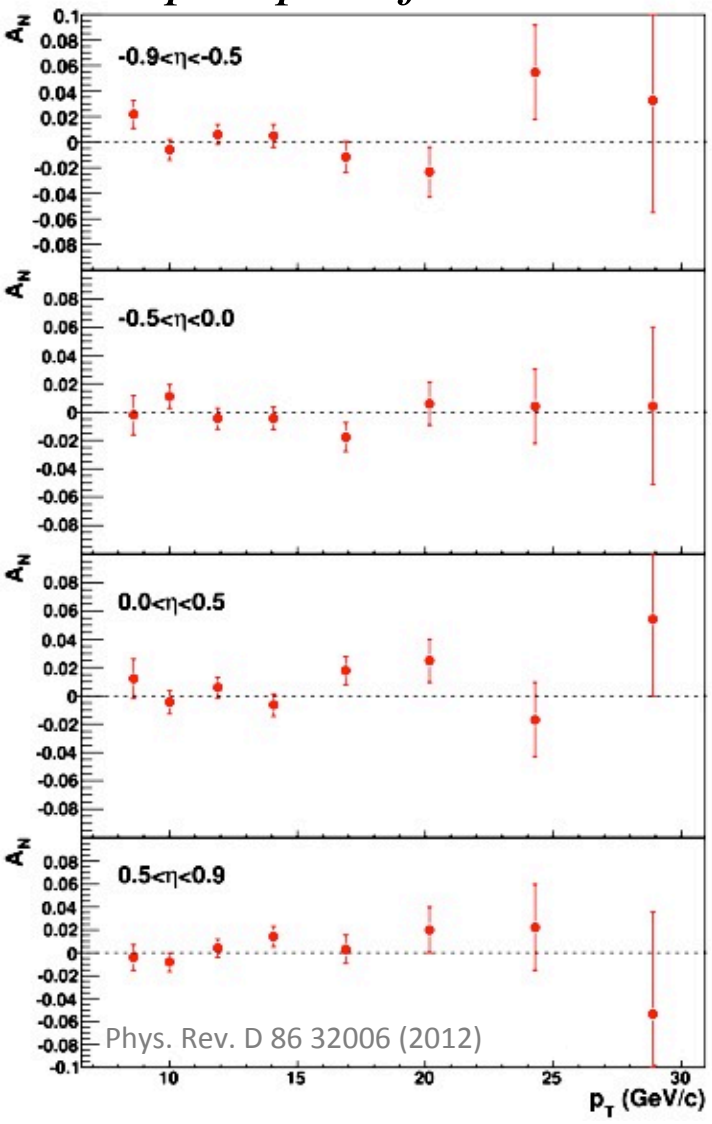
$A_{UT}^{\sin(\phi_S-\phi_h)}$: hints of non-zero asymmetry with charge-sign dependence

Similarly, di-jet and π^0 A_N at central psuedorapidity and 200 GeV consistent with zero

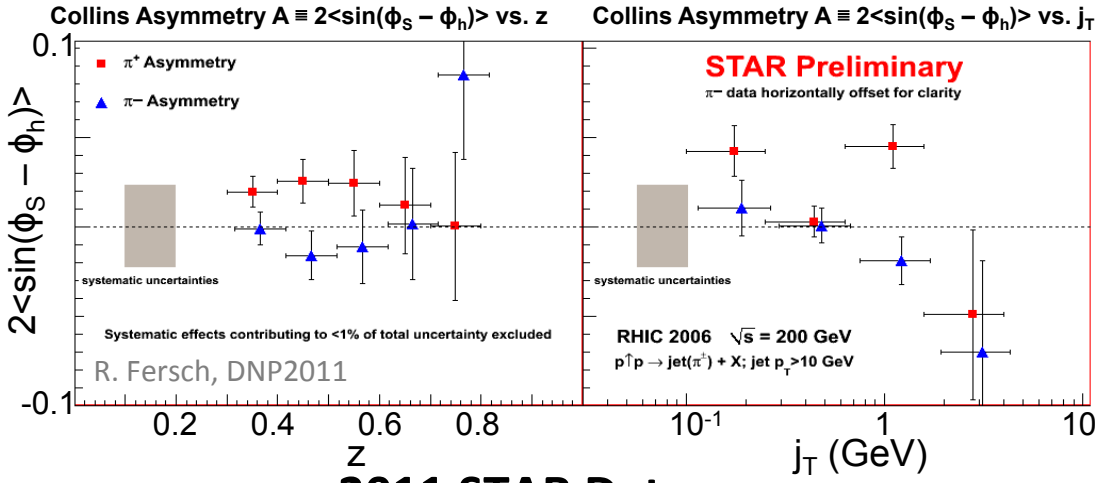
PRL 99, 142003; PRL 95, 202001; J. Koster, Ph.D. Dissertation

STAR Transverse Jet Asymmetries at Central Pseudorapidity

$$p^{\uparrow} + p \rightarrow jet + X$$



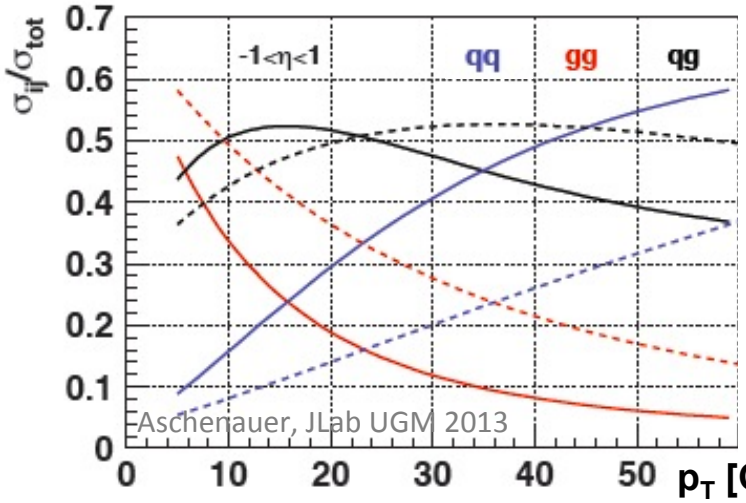
Phys. Rev. D 86 32006 (2012)



R. Fersch, DNP2011

2011 STAR Data

→ first measurements of **central pseudorapidity inclusive jet asymmetries at $\sqrt{s} = 500$ GeV**



Aschenauer, JLab UGM 2013

Inclusive Jet Production
- 200 GeV: Solid line
- 500 GeV: Dashed line

→ ***Increased sensitivity to gluonic subprocesses***

Moments of Jet Asymmetries at 500 GeV

Various contributions to polarized jet+π cross section (TMD approach)

$$d\sigma(\phi_S,\phi_h) - d\sigma(\phi_S+\pi,\phi_h) \sim d\Delta\sigma_0 \sin\phi_S$$
$$+d\Delta\sigma_1^- \sin(\phi_S-\phi_h) + d\Delta\sigma_1^+ \sin(\phi_S+\phi_h)$$
$$+d\Delta\sigma_2^- \sin(\phi_S-2\phi_h) + d\Delta\sigma_2^+ \sin(\phi_S+2\phi_h)$$

Phys. Rev. D 83, 034021 (2011)

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Phys. Rev. D 83, 034021 (2011)

Negligible under ***maximized*** scenario!

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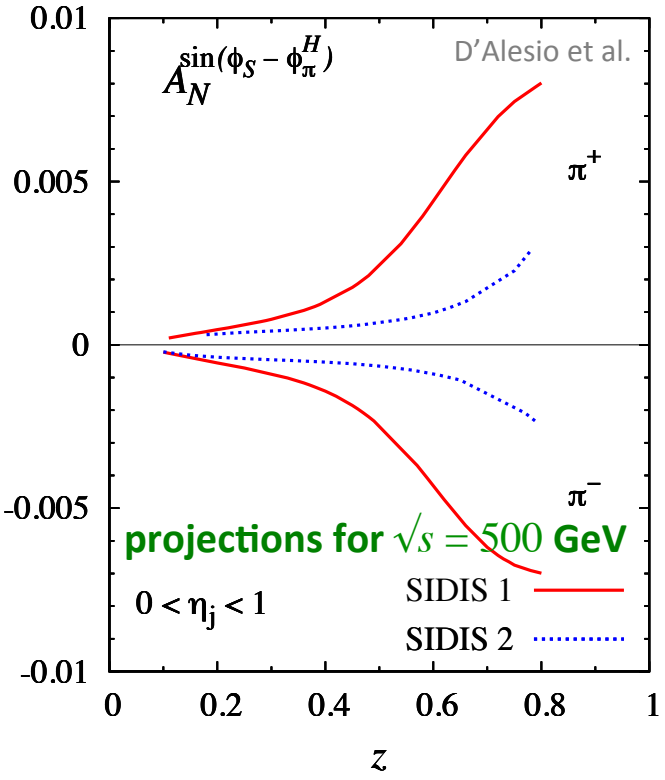
Phys. Rev. D 83, 034021 (2011)



Possible non-zero contributions,

expected to be quite small

e.g. Phys. Rev. Lett. 95, 202001 (2005);
Phys. Rev. Lett 99, 142003 (2007);
Phys. Rev. D 86, 032006 (2012);
Phys. Lett. B 720, 161 (2013);
J. Koster, Ph.D. Dissertation

Moments of Jet Asymmetries at 500 GeV

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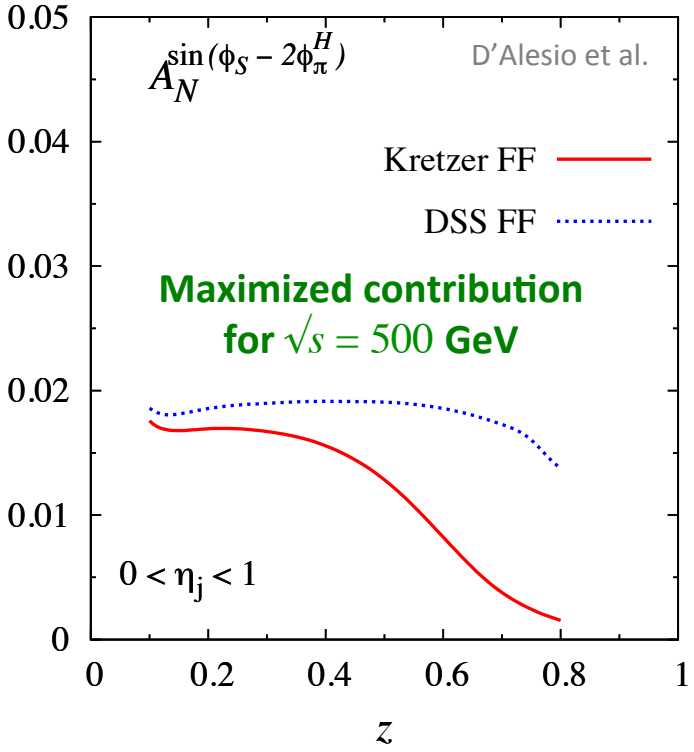
Phys. Rev. D 83, 034021 (2011)



"Collins-like" asymmetry:

Sensitive to linearly polarized gluons

Completely unconstrained!

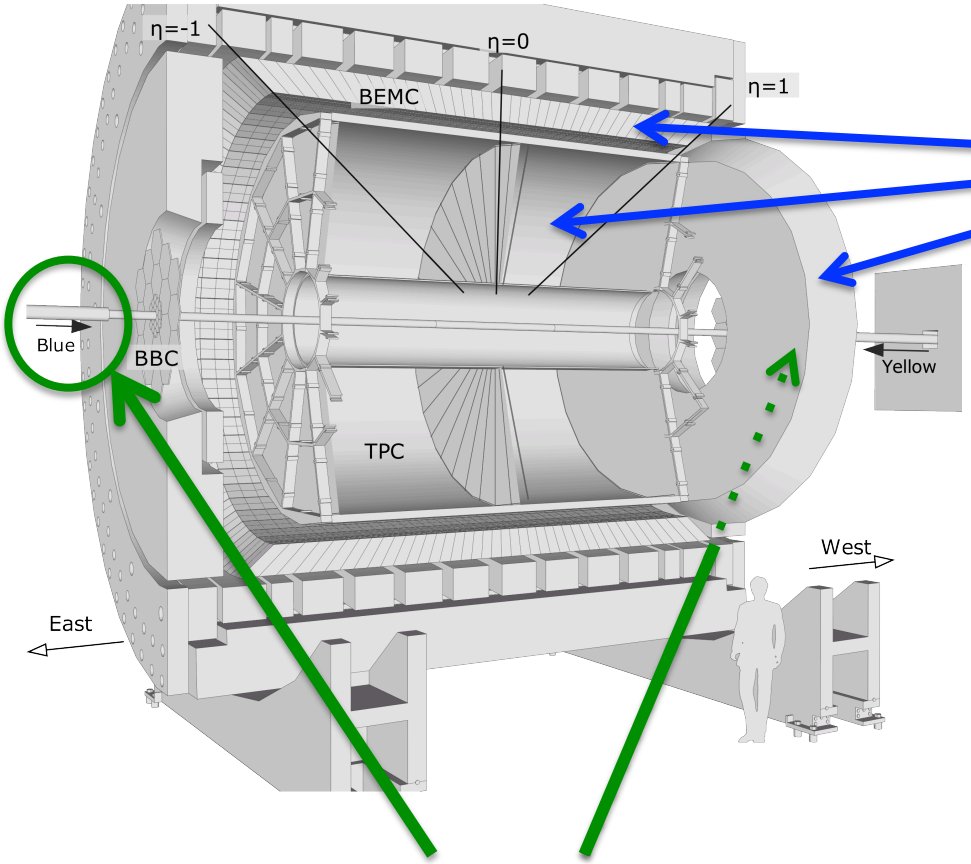
Gluon helicity density matrix

$$\rho = \frac{1}{2}\begin{pmatrix} 1+P_{circ} & -P_{lin}e^{-2i\phi} \\ -P_{lin}e^{2i\phi} & 1-P_{circ} \end{pmatrix}$$

Off-diagonal terms related to linear polarization in (xy) plane at angle ϕ to x-axis

Phys Rev. D 73, 014020 (2006)

Solenoidal Tracker at RHIC

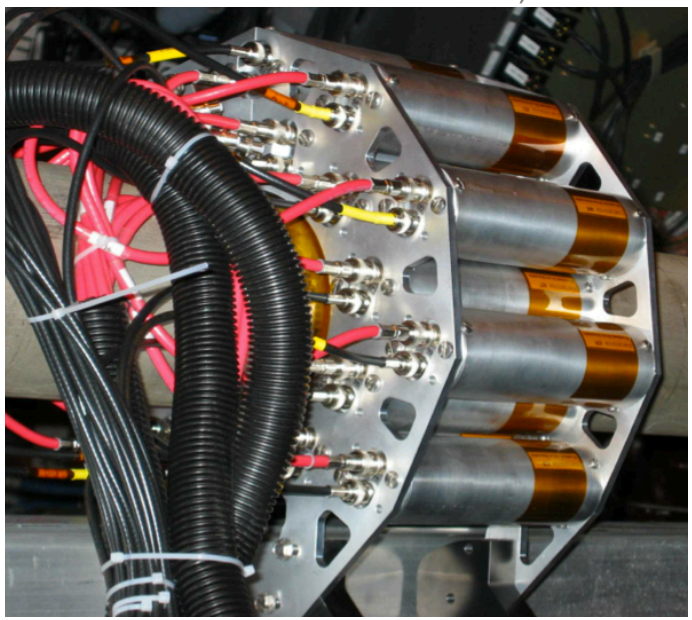


Jet reconstruction utilizes

TPC + Barrel + Endcap EMC

- Anti-k_T algorithm, R = 0.6
- $N_{hits,\ track} > 12$
- Track association with event vertex
- Minimum track $p_T > 0.2$ GeV/c
- Minimum tower energy > 0.2 GeV

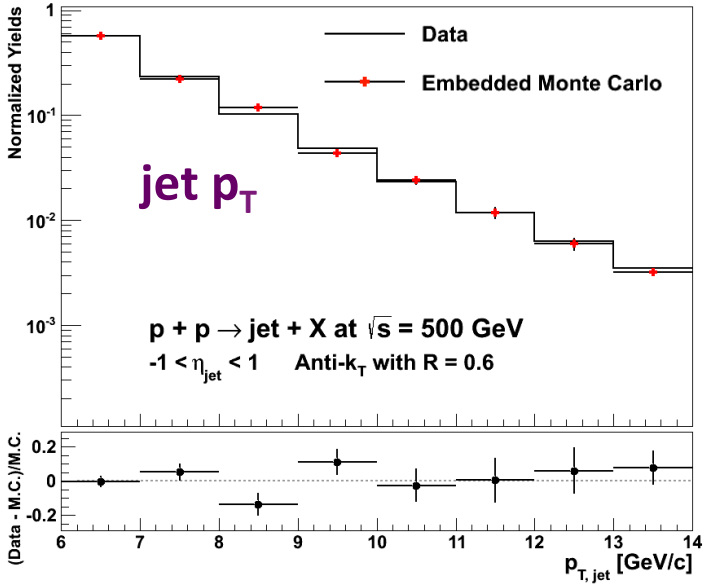
J. Zhou, M.S. Thesis



Minbias Trigger: coincidence in vertex position detector (VPD)

- Pb+plastic scintillator with PMT readout
- 570 cm from interaction point
- $4.24 < |\eta| < 5.1,\ \eta = -\ln\left[\tan\left(\theta/2\right)\right]$

Studies with Embedded Monte Carlo



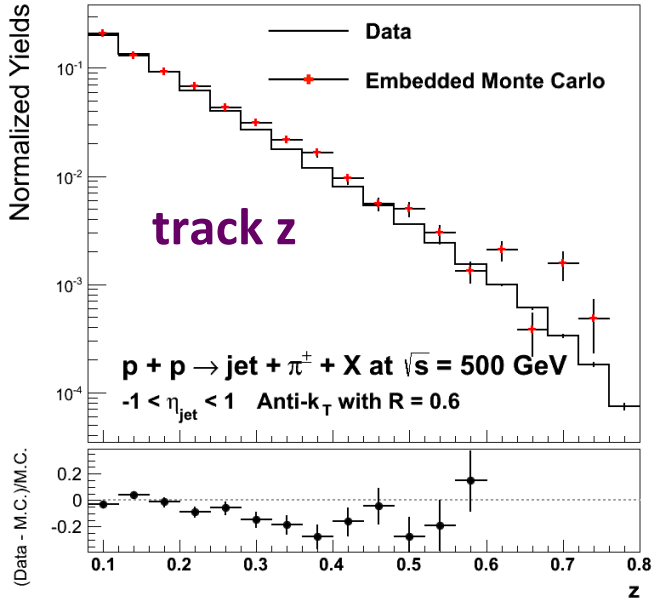
Systematic shifts in reconstructed kinematic variables and azimuthal resolutions evaluated by comparing to Monte Carlo embedded in real zero-bias data

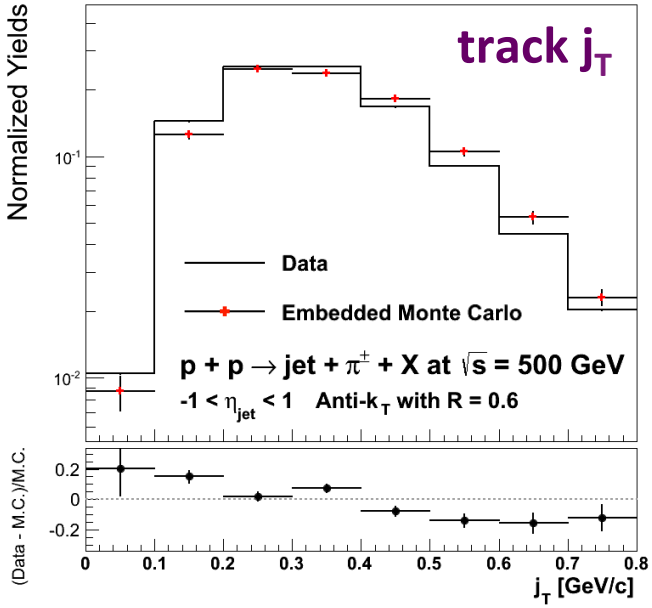
simulate effects of real, out-of-time pile-up

Detector-level jets matched both to ***parton and particle jets*** with matched event vertex

Kinematic shifts evaluated at particle level

Corresponding parton-jet p_T ~0.6-1.4 GeV/c lower





Sources of Systematic Uncertainty

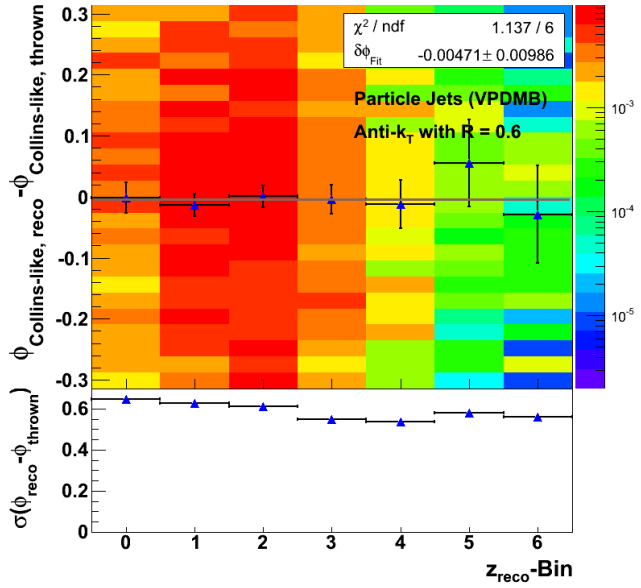
Dominant systematic uncertainty from reconstructed jets unassociated with parton jets

→ *Take difference between measured A_{UT} and A_{UT} assuming dilution*

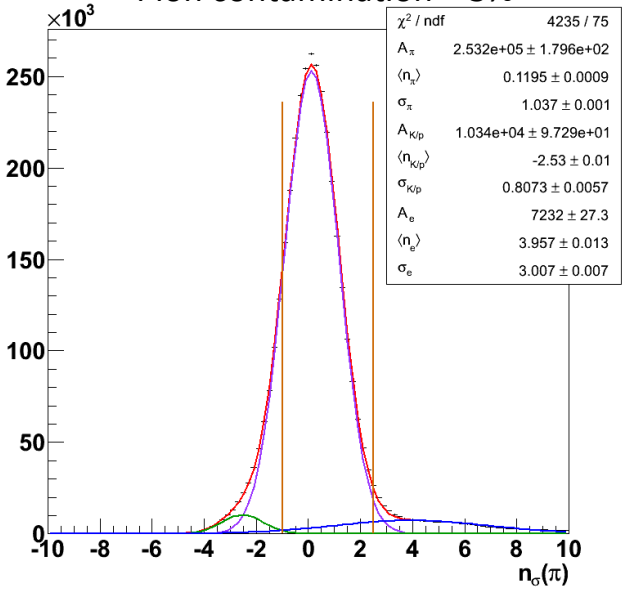
Further systematic uncertainties:

- Resolution of relevant azimuthal angles
  → ***corrected as dilution to measured asymmetry***
- "leak-through" of other moments of A_{UT}
- Pion contamination from K/p and $e^{\pm}$ (< 3%)
- Polarization uncertainty (correlated vertical scale uncertainty, σ(P)/P = 5.6%)

Angular resolution corrected as dilution



Pion contamination < 3%

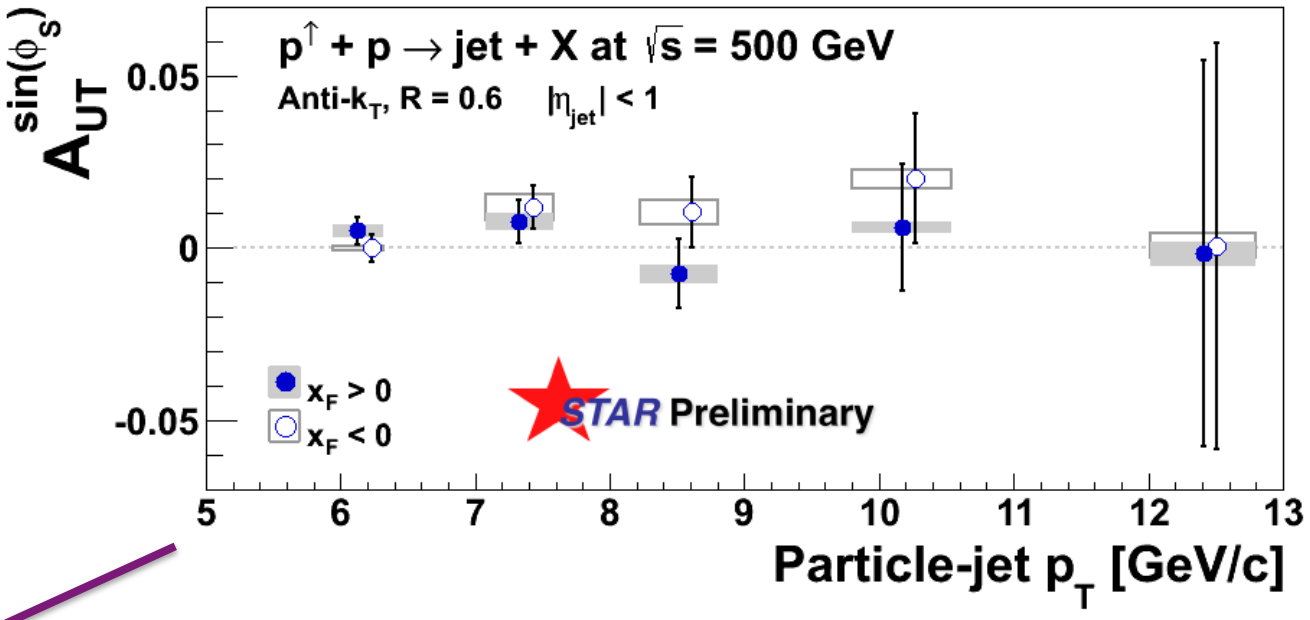


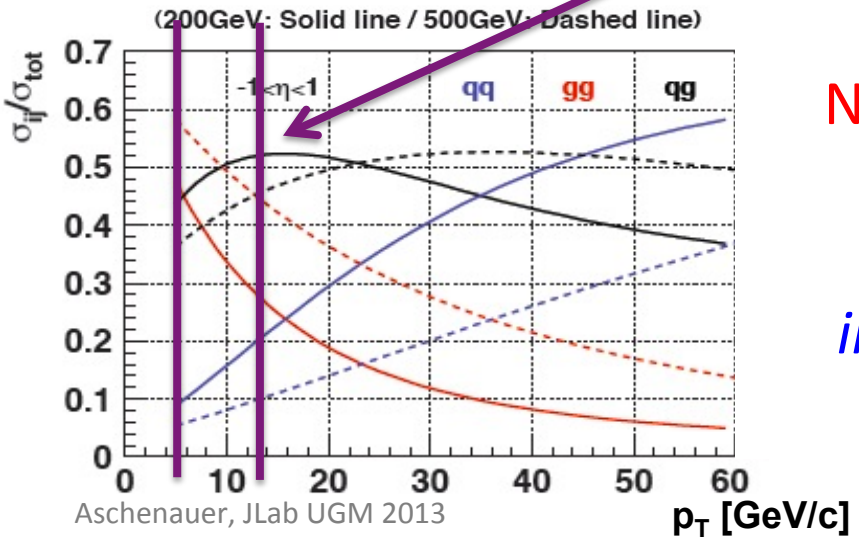
Sivers Asymmetries

Asymmetries shown as function of particle-jet p_T

Corresponding parton-jet p_T lower by 0.6-1.4 GeV/c

Horizontal errors include uncertainties from statistics, calorimeter gains, efficiencies, track momentum, and tracking efficiency





Aschenauer, JLab UGM 2013

No sign of sizable azimuthal asymmetry in jet production at $\sqrt{s} = 500$ GeV

Consistent with expectation from inclusive jets, di-jets, and neutral pions at $\sqrt{s} = 200$ GeV

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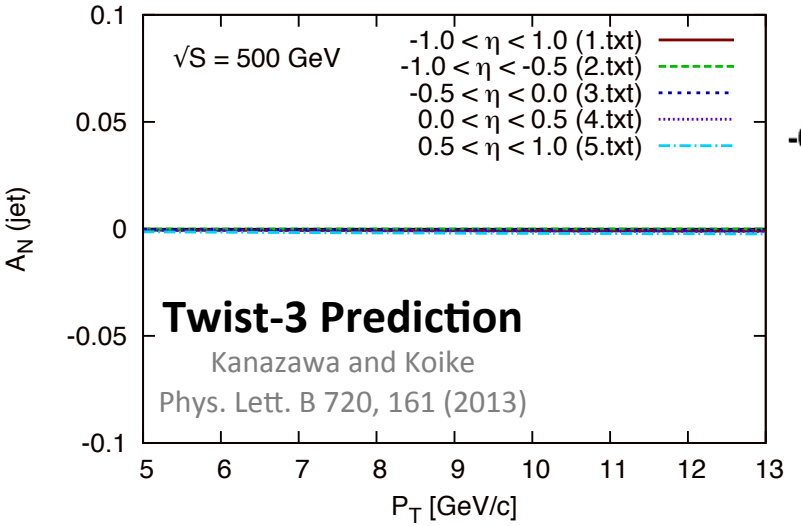
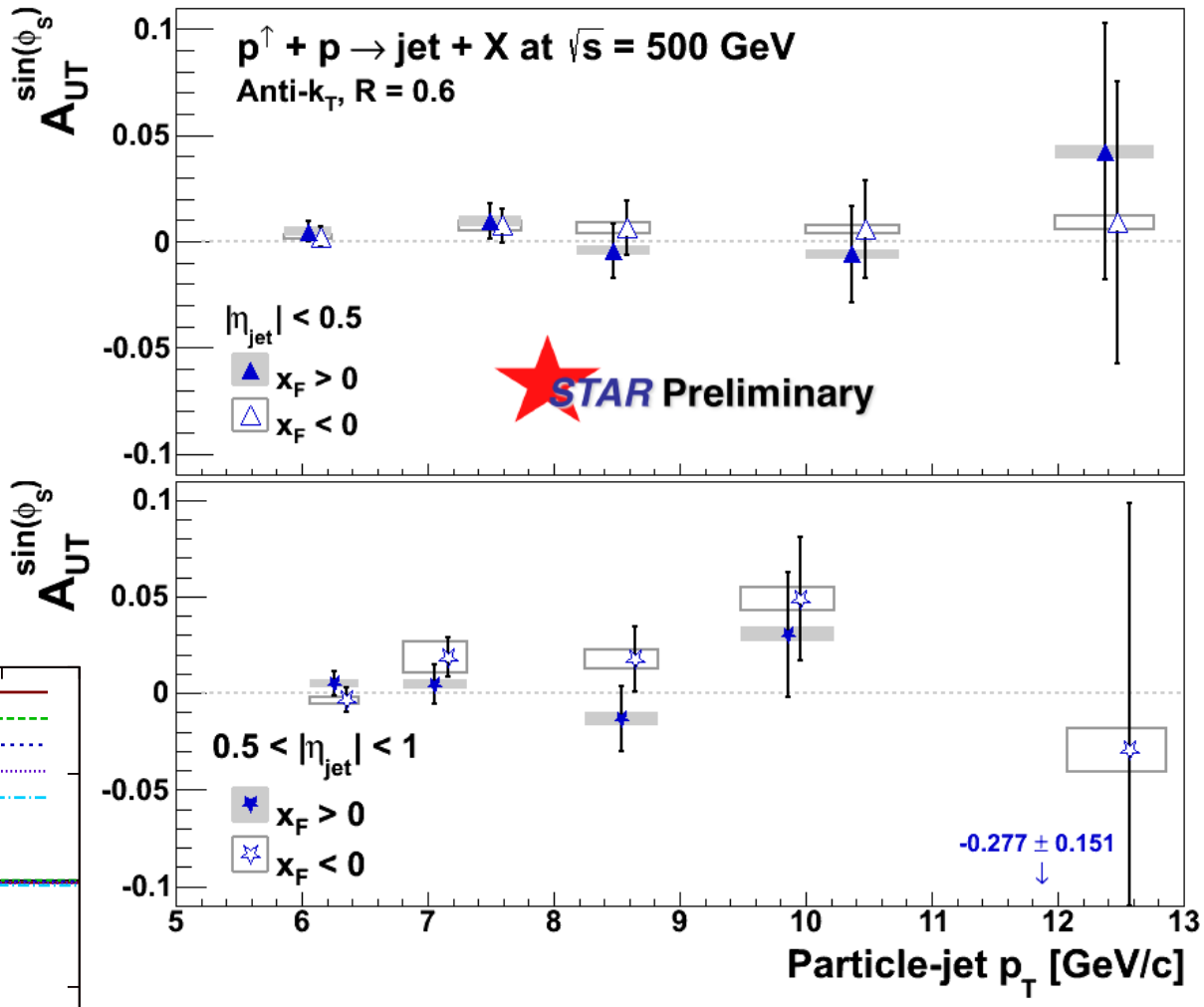


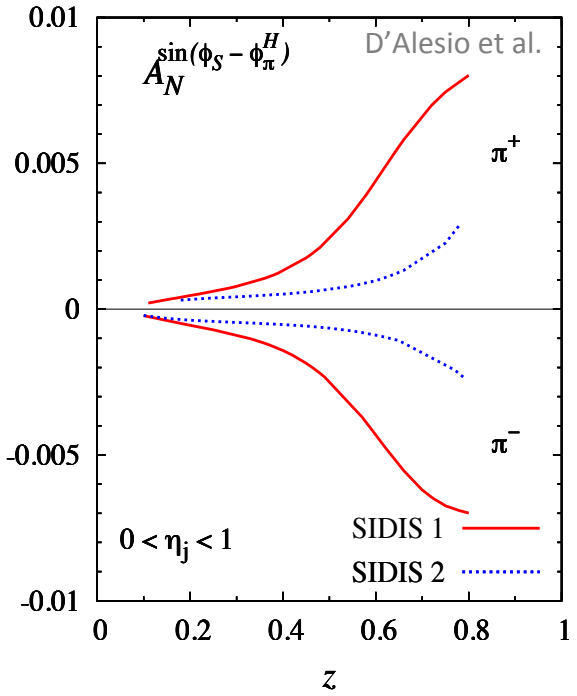


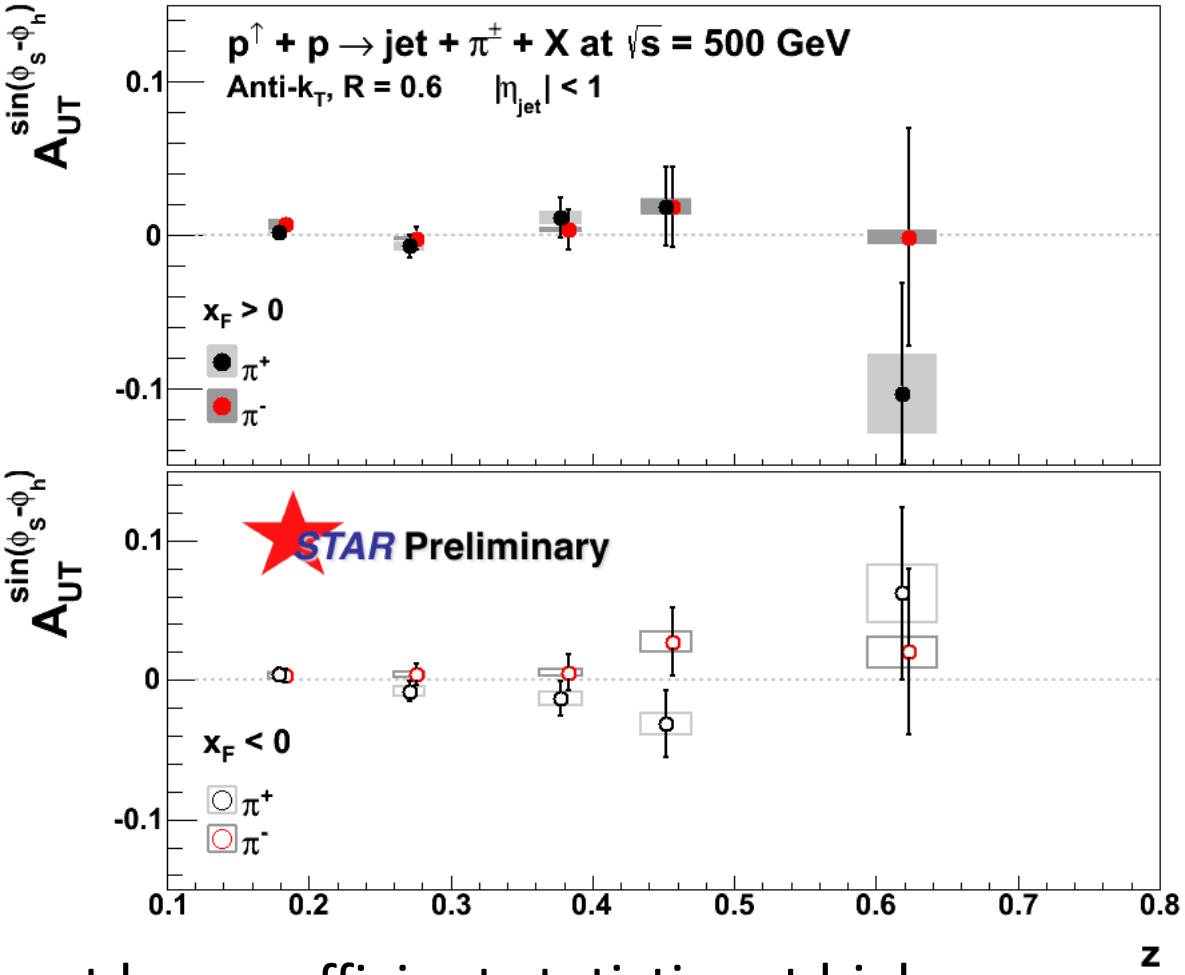
Measured asymmetries shown in η-bins

No sign of sizable asymmetry

Collins Asymmetries

Increased gluonic subprocesses at √s = 500 GeV lead to expectation of ***small Collins asymmetry*** until larger z

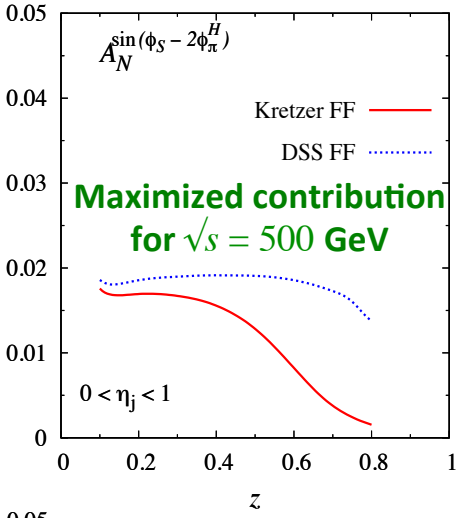




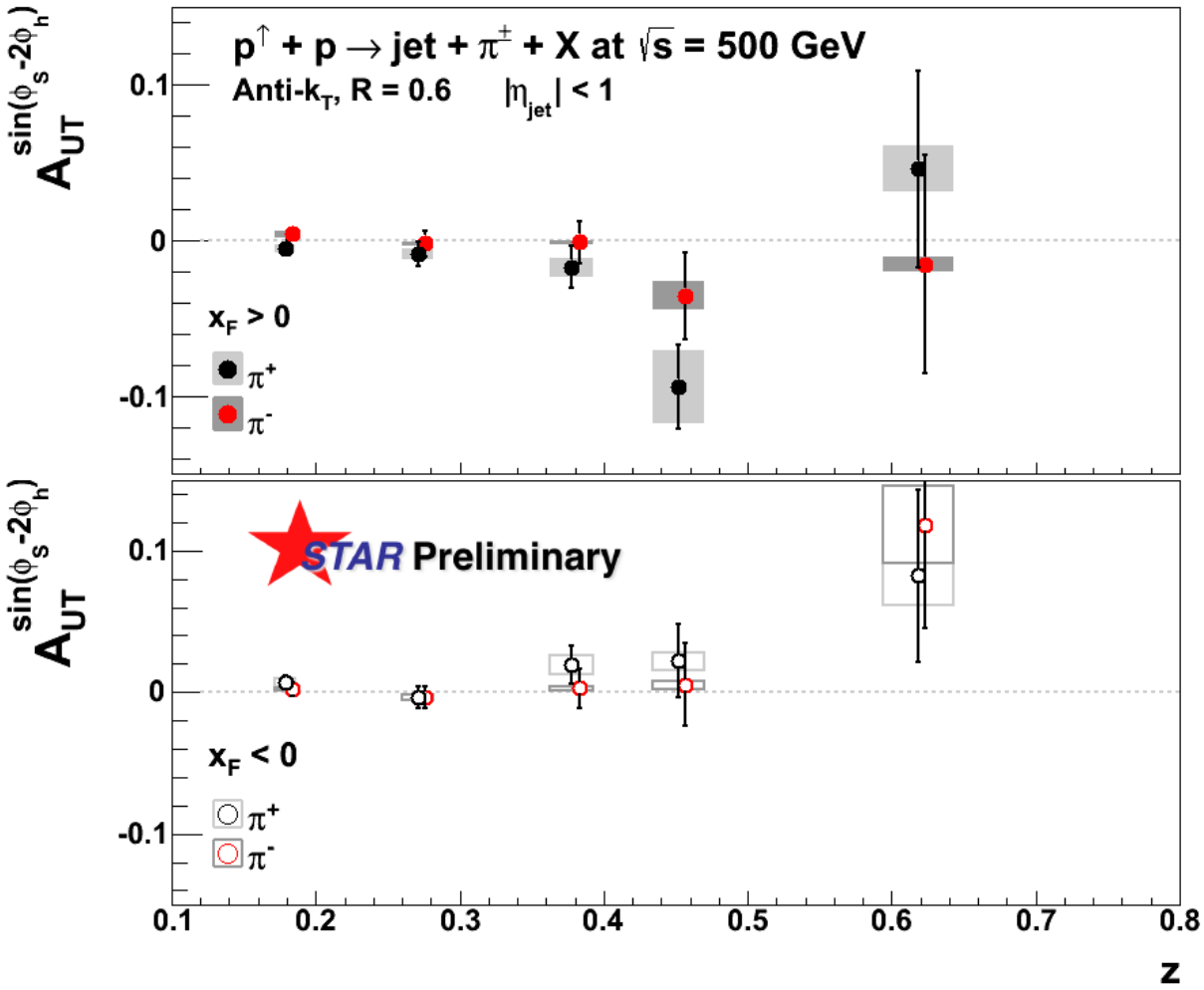
Present data do not have sufficient statistics at high-z to observe Collins asymmetry of order 1%

Similarly small effects observed as a function of j_T and $p_{T,jet}$

Collins-like Asymmetries



D'Alesio et al.

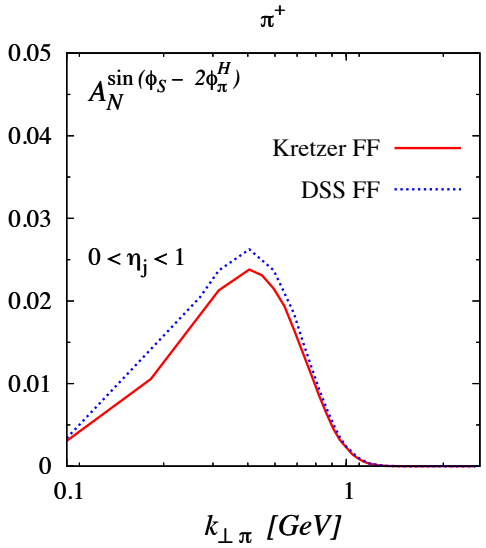


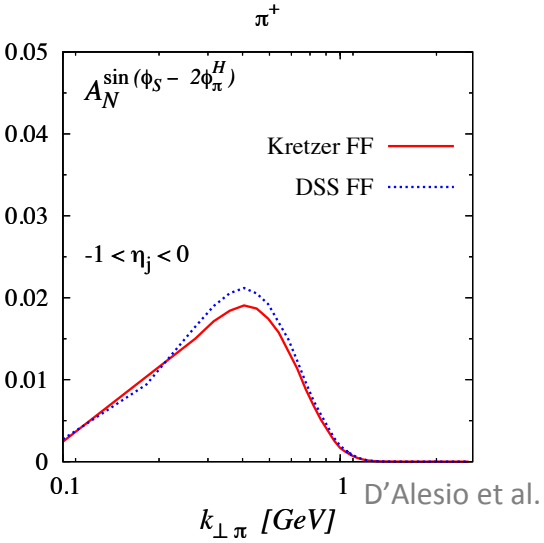
Model predictions shown for "maximized" effect, saturated to positivity bound

Until now, Collins-like asymmetries completely unconstrained

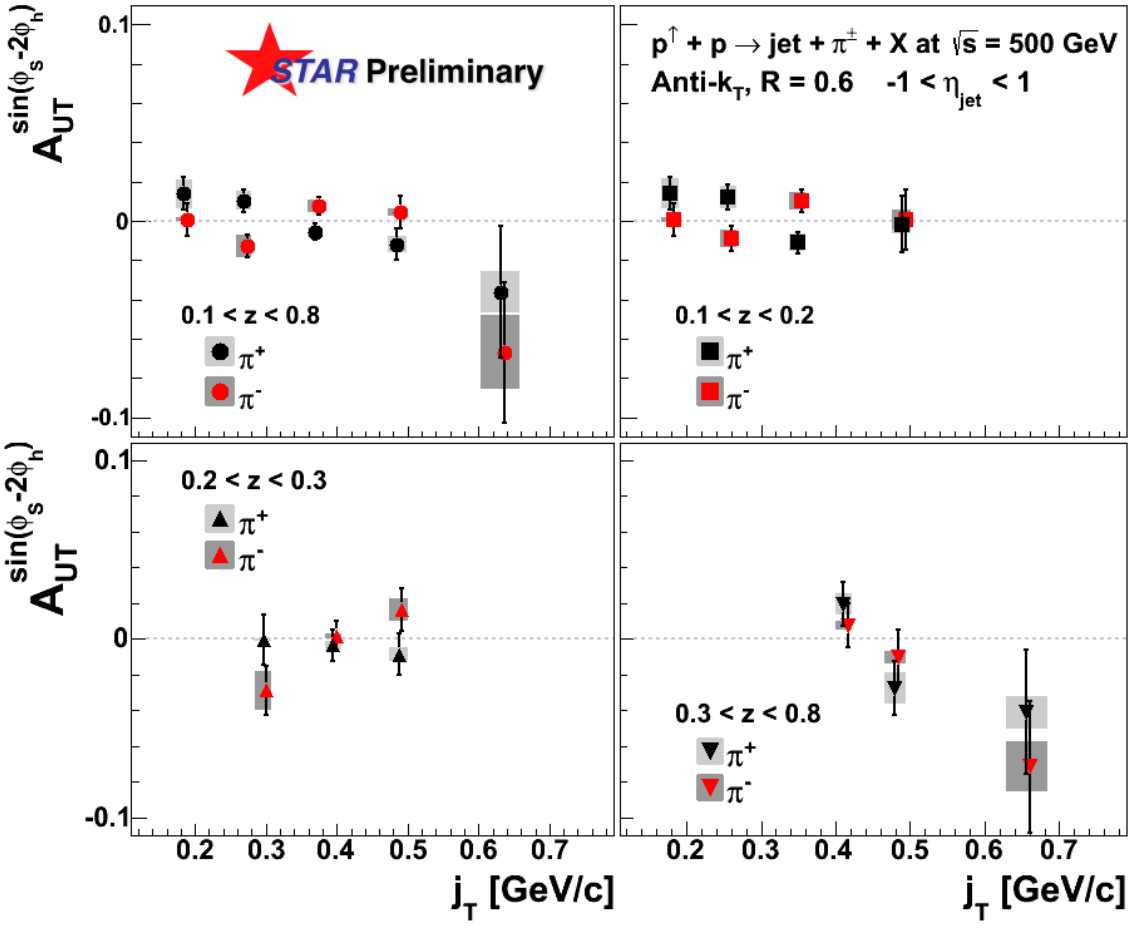
→ ***Sensitive to linearly polarized gluons***

Collins-like Asymmetries





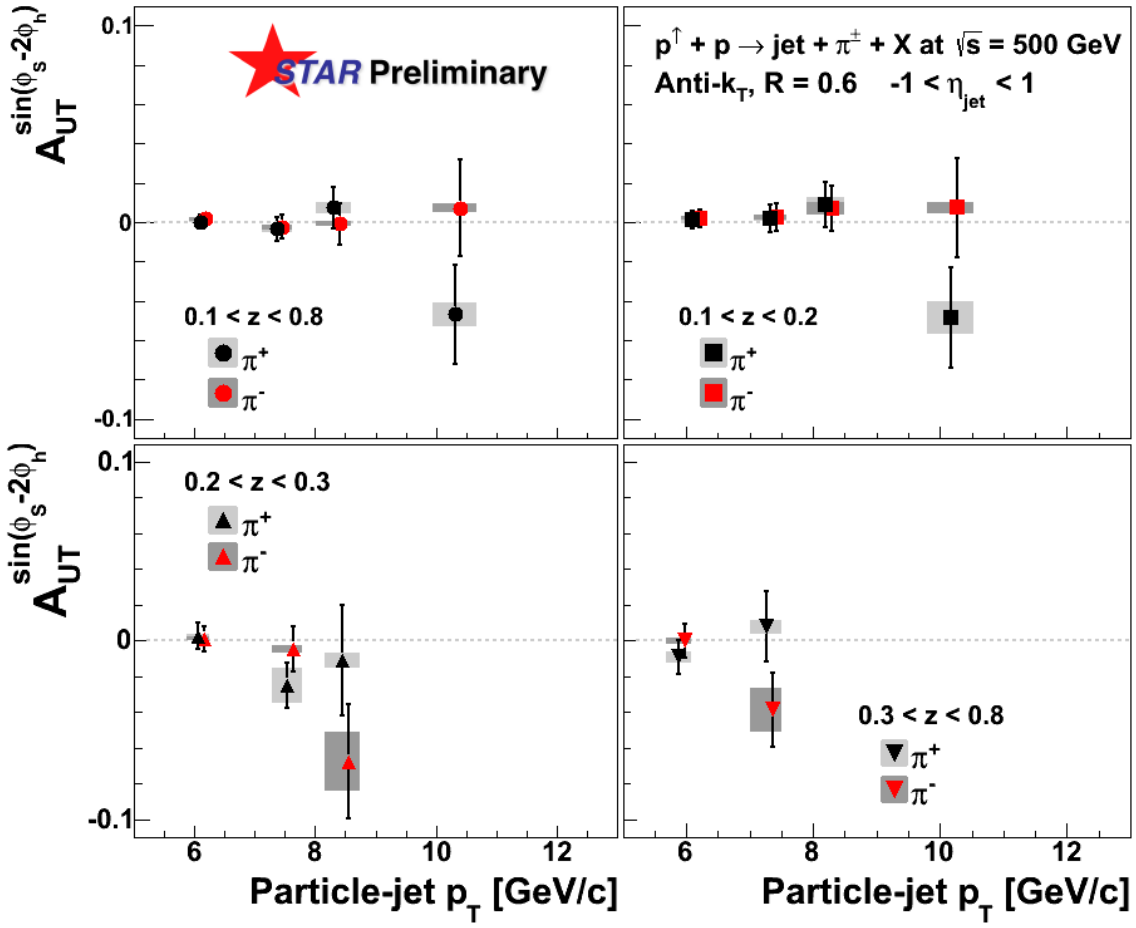
D'Alesio et al.



Measured asymmetries shown for -1 < η < 1 in z-bins

Consistently below 2% maximum from model

Collins-like Asymmetries



Similarly, no large effect observed as a function of jet p_T

Measured asymmetries shown for -1 < η < 1 in z-bins

Summary

- **STAR data from 2011 provide *first measurements* of transverse spin asymmetries for jet production at central pseudorapidity and $\sqrt{s} = 500$ GeV**

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- No observation of large asymmetry from gluon Sivers effect, consistent with expectations from previous measurements of jet and π^0 asymmetries at $\sqrt{s} = 200$ GeV

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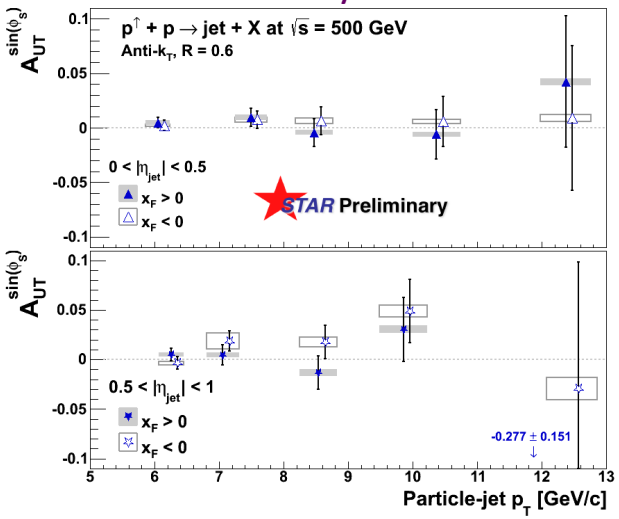
- No observation of large asymmetry from Collins effect, consistent with expectations from decreased quark subprocesses at $\sqrt{s} = 500$ GeV
- **First measurements of Collins-like asymmetries *will help place constraints on model predictions* beyond maximal projections from positivity bounds**

Looking Forward

- Additional data from 2011 jet-patch triggers will allow **much greater precision** for higher jet p_T (above 7 GeV/c)
- High precision measurements from 2012 at $\sqrt{s} = 200$ GeV will allow greater sensitivity to effects from quark subprocesses

STAR Preliminary Results at $\sqrt{s} = 500$ GeV

Sivers Asymmetries



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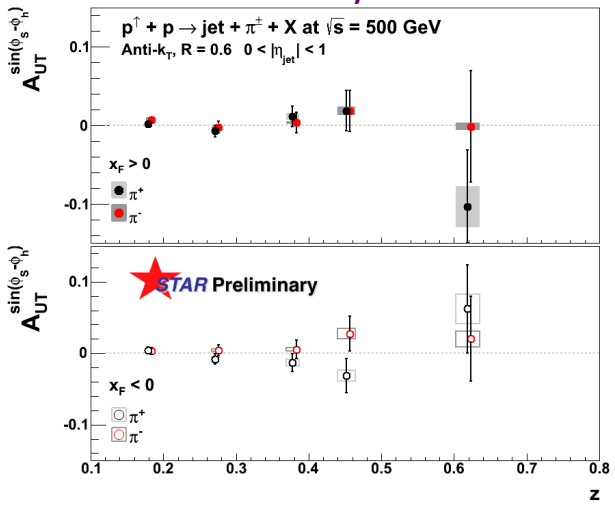

Collins-like Asymmetries