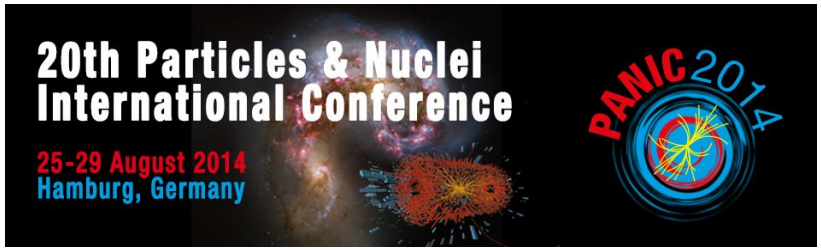
Constraining Transversity and Nucleon Transverse-polarization Structure Through Polarized-proton Collisions at *STAR*

James L. Drachenberg
Valparaiso University
for the STAR Collaboration



August 25, 2014

OUTLINE

- Introduction
- RHIC and the STAR detector
- Jets and Di-hadrons at $\sqrt{s} = 200$ GeV
- Jets at $\sqrt{s} = 500$ GeV
- Summary

STAR

Valparaiso University

A Challenge from Transverse Single-spin Asymmetries

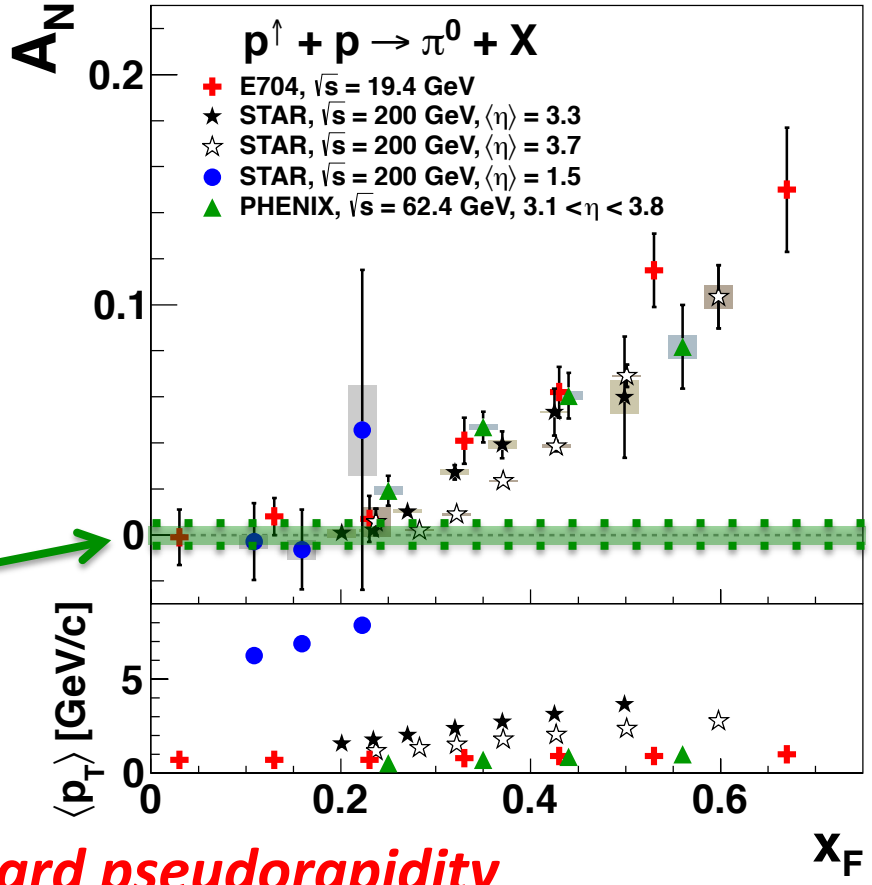
$$A_{UT} = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

$d\sigma^{\uparrow(\downarrow)}$ – cross section for ***leftward*** scattering when beam polarization is spin-**up**(down)

(*Also commonly expressed as* A_N)

Collinear pQCD at leading twist predicts very small A_{UT}

Kane, Pumplin, Repko, PRL 41, 1689 (1978)



PLB 261, 201 (1991)
PRL 101, 222001 (2008)
PRD 89, 012001 (2014)
arXiv:1312.1995v1

Sizeable A_{UT} at forward pseudorapidity across a large range of $\sqrt{s}$

Measurements at RHIC in region where NLO pQCD cross-section provides a reasonable description of the data

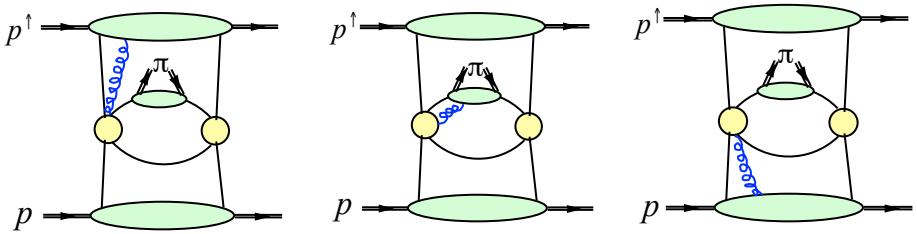
→ Go beyond collinear pQCD at leading twist

→ Insight into transverse polarization structure?

Formalisms for Transverse Single-spin Asymmetries

Transverse Momentum Dependent (TMD) PDFs and FFs

Collinear Twist-3 PDFs and FFs



Y. Koike, RSC Discussion (2004)

Non-zero asymmetry from multi-parton correlation functions

e.g. Qiu and Sterman, PRL 67, 2264 (1991); PRD 59, 014004 (1998)

Correlators closely related to k_T moments of TMDs

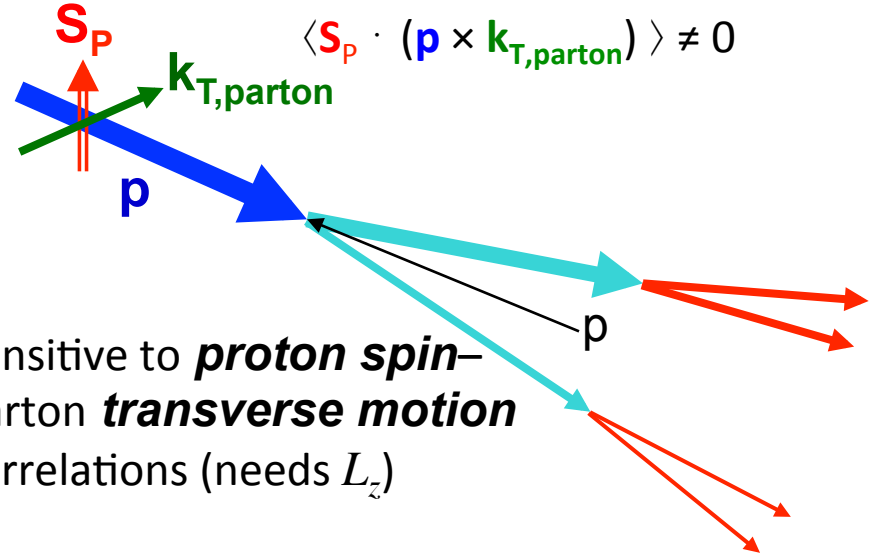
Boer, Mulders, Pijlman, NPB 667, 201 (2003)

Formalisms for Transverse Single-spin Asymmetries

Transverse Momentum Dependent (TMD) PDFs and FFs

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

D. Sivers, PRD 41, 83 (1990); 43, 261 (1991)

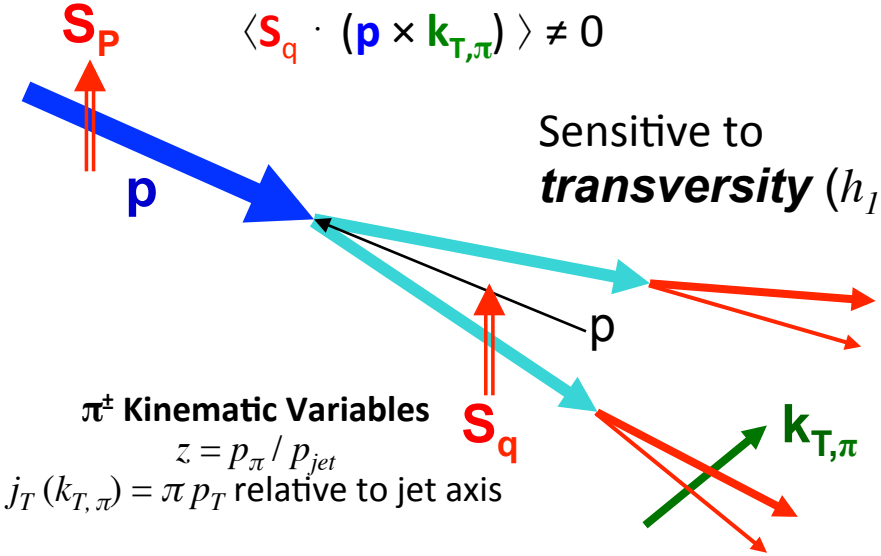


$\langle S_P \cdot (p \times k_{T,parton}) \rangle \neq 0$

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

Collins mechanism: asymmetry in the forward jet *fragmentation*

J. Collins, NP B396, 161 (1993)



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

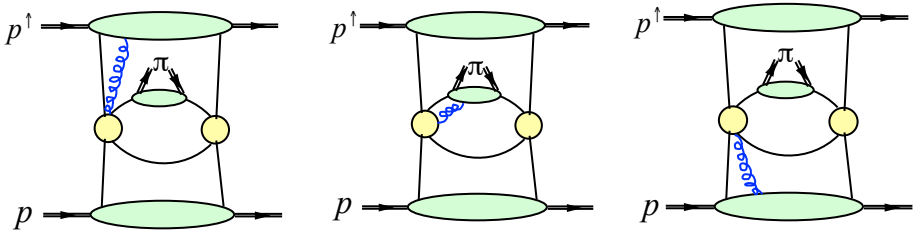
Sensitive to ***transversity*** (h_1)

$\pi^{\pm}$ Kinematic Variables

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

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

Collinear Twist-3 PDFs and FFs



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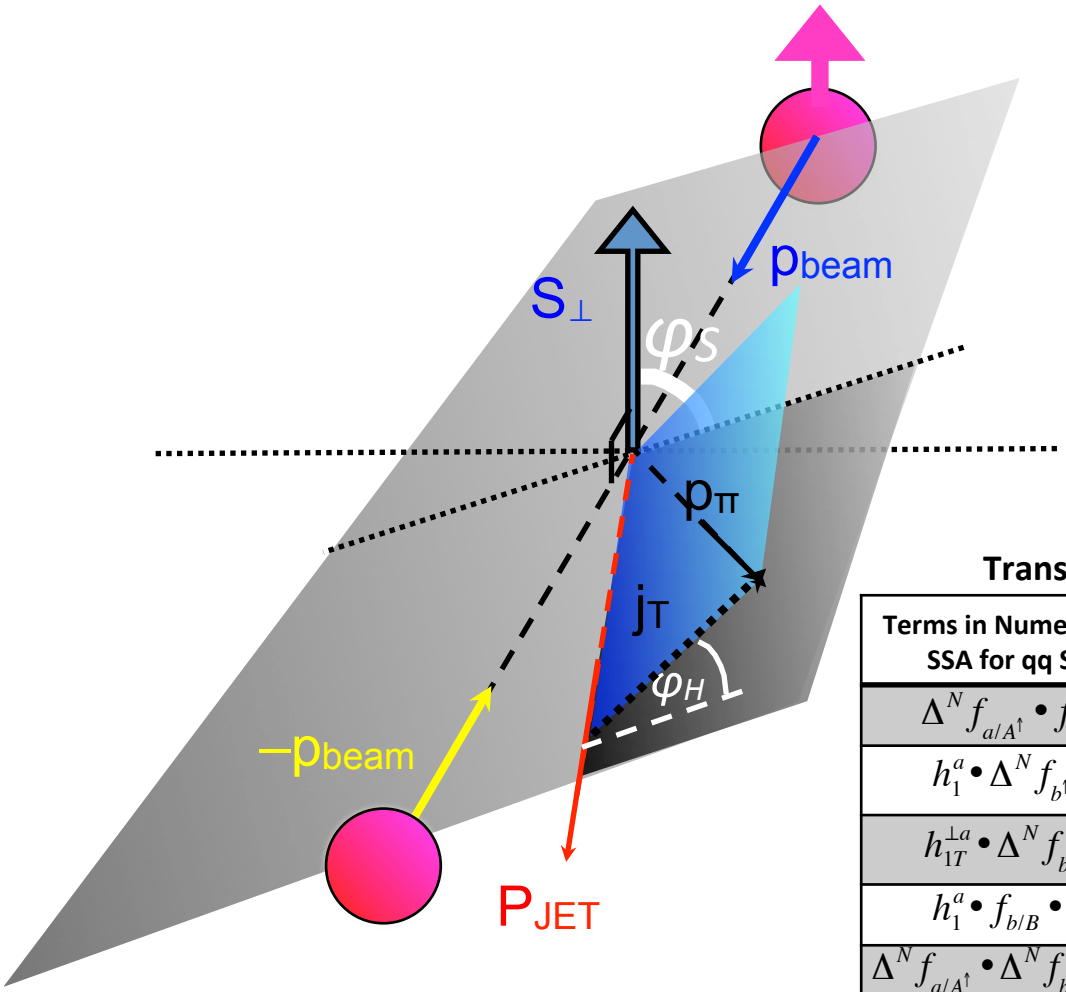
Transverse Asymmetries from Jet Production



Anselmino et al., PRD 73, 014020 (2006)
F. Yuan, PRL 100, 032003 (2008)
D'Alesio et al., PRD 83, 034021 (2011)

Asymmetry modulations sensitive to various contributions (often involving *transversely polarized quarks* or *linearly polarized gluons*)

A_{UT} – Transverse single-spin asymmetry (also written A_N)

Transverse Momentum Dependent (TMD) Approach

Terms in Numerator of TMD SSA for qq Scattering	English Names	Modulation
$\Delta^N f_{a/A^\uparrow} \bullet f_{b/B} \bullet D_{\pi/q}$	Sivers • PDF • FF	$\sin\left(\phi_{S_A}\right)$
$h_1^a \bullet \Delta^N f_{b^\uparrow/B} \bullet D_{\pi/q}$	Transversity • Boer-Mulders • FF	$\sin\left(\phi_{S_A}\right)$
$h_{1T}^{\perp a} \bullet \Delta^N f_{b^\uparrow/B} \bullet D_{\pi/q}$	Pretzelocity • Boer-Mulders • FF	$\sin\left(\phi_{S_A}\right)$
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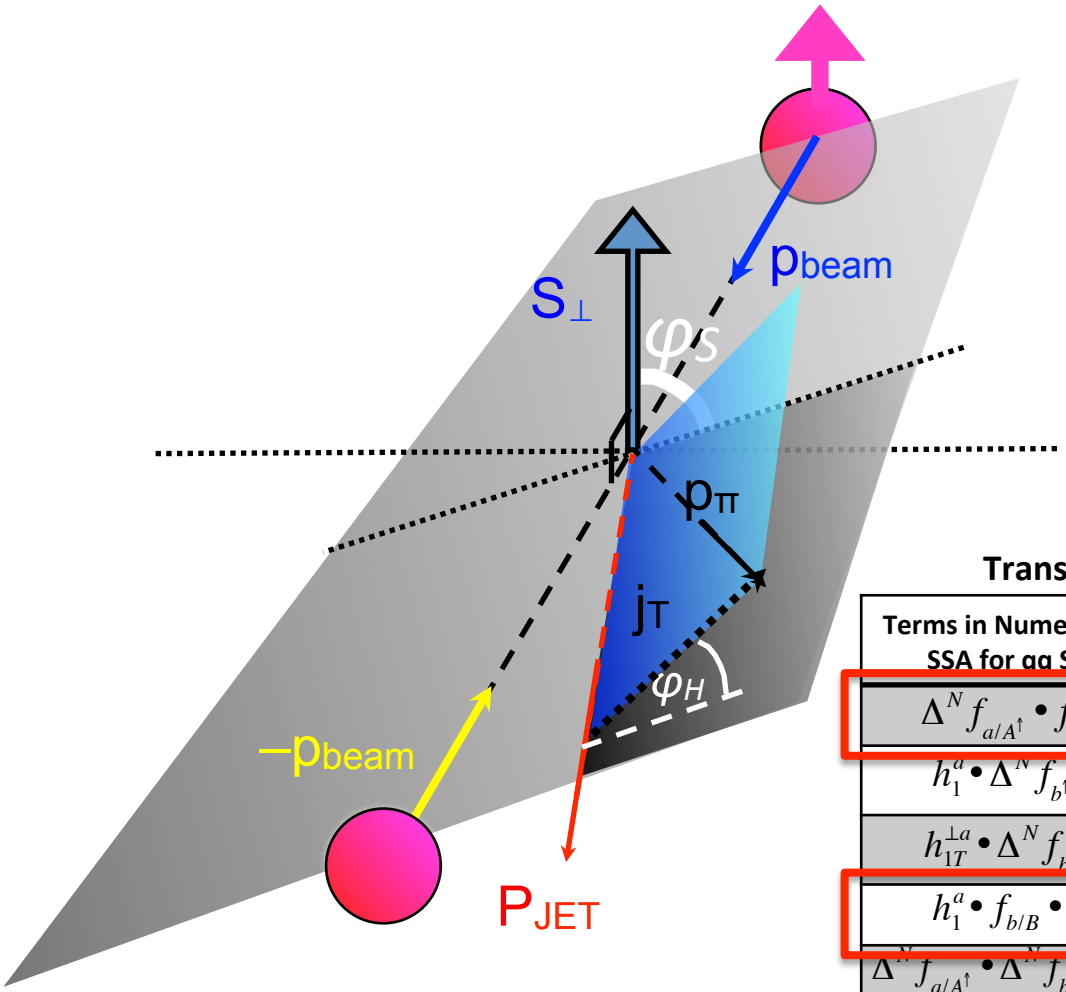

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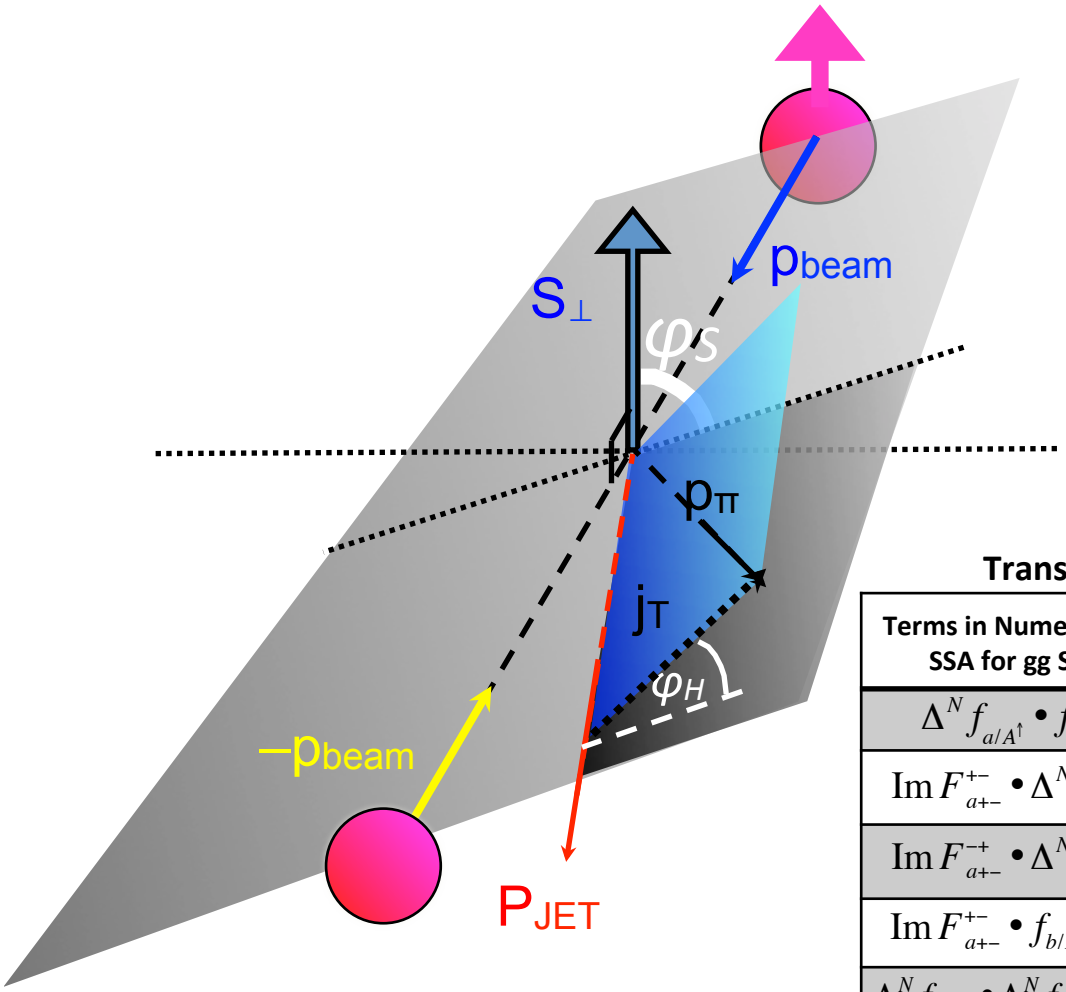

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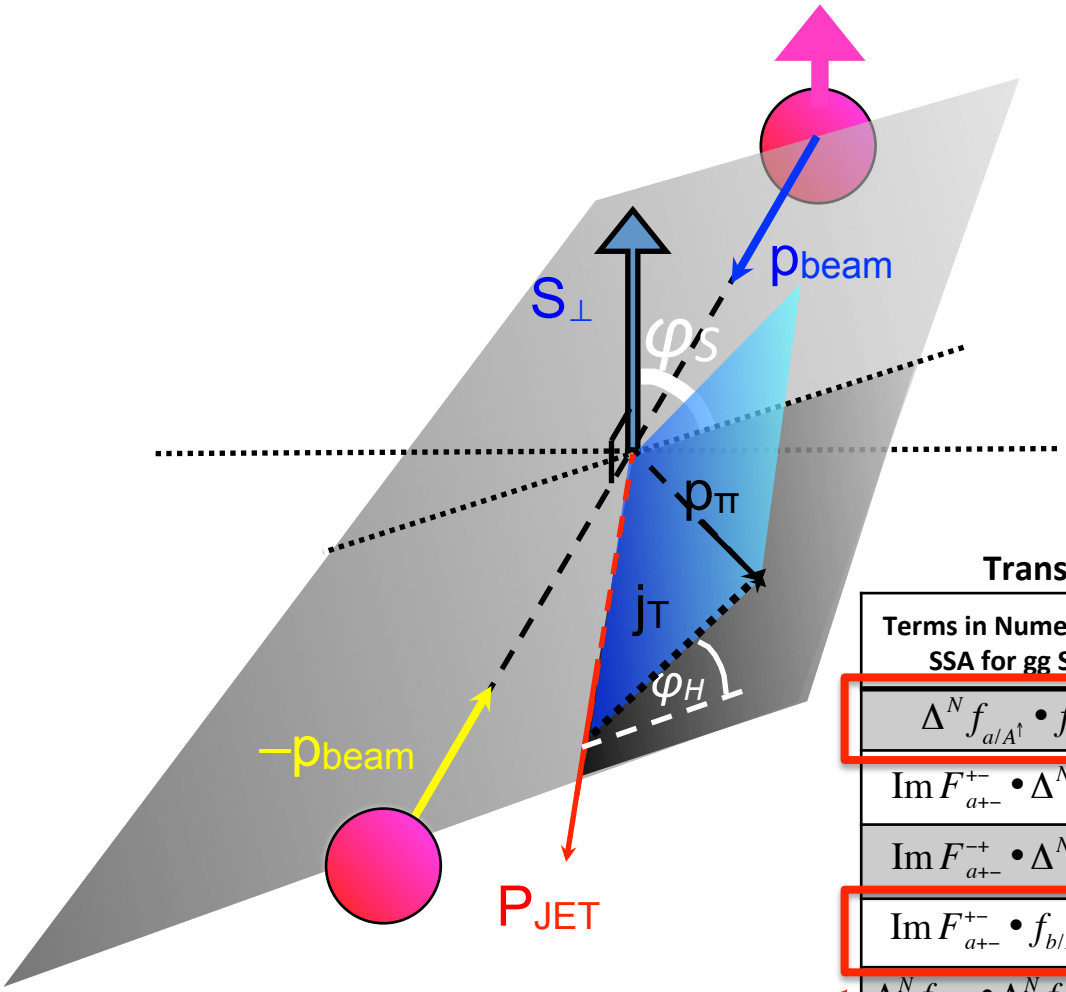

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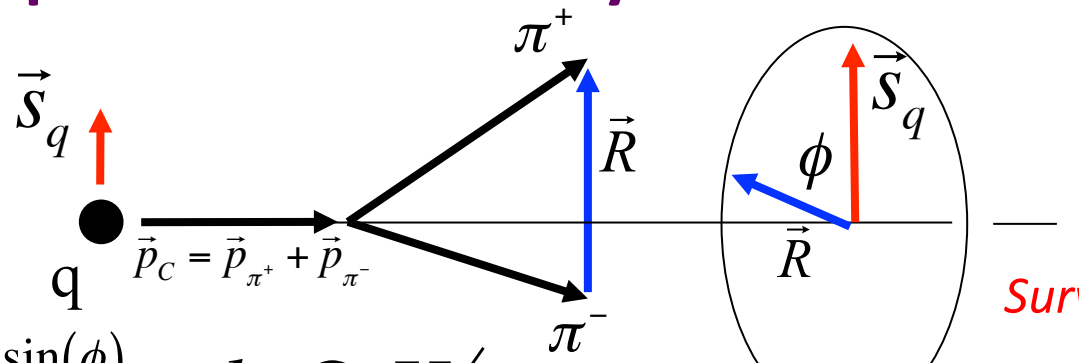
F. Yuan, PRL 100, 032003 (2008)
D'Alesio et al., PRD 83, 034021 (2011)

UNCONSTRAINED!

Transverse Asymmetries from Di-hadrons

Another path to transversity: Di-hadron Asymmetries



Survives in collinear framework

$$A_{UT}^{\sin(\phi)} \propto h_1 \otimes H_1^{\sphericalangle}$$

ϕ: Angle between polarization vector and di-hadron plane

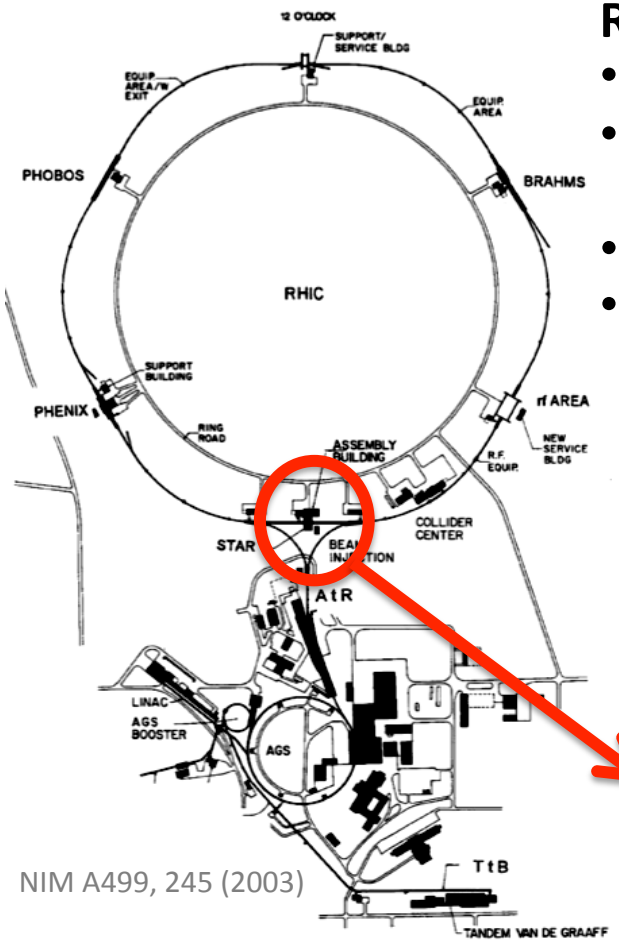
$H_1^{\sphericalangle}$ —"Interference Fragmentation Function"

e.g. Bacchetta and Radici, PRD 70, 094032 (2004)

Studying both jet+hadron and di-hadron asymmetries over range of collision energy:

- ***Extend kinematic reach*** beyond existing measurements
- ***Probe evolution*** of transversity and TMDs
- ***Probe open theoretical questions***, e.g. TMD factorization-breaking and universality

Solenoidal Tracker at RHIC

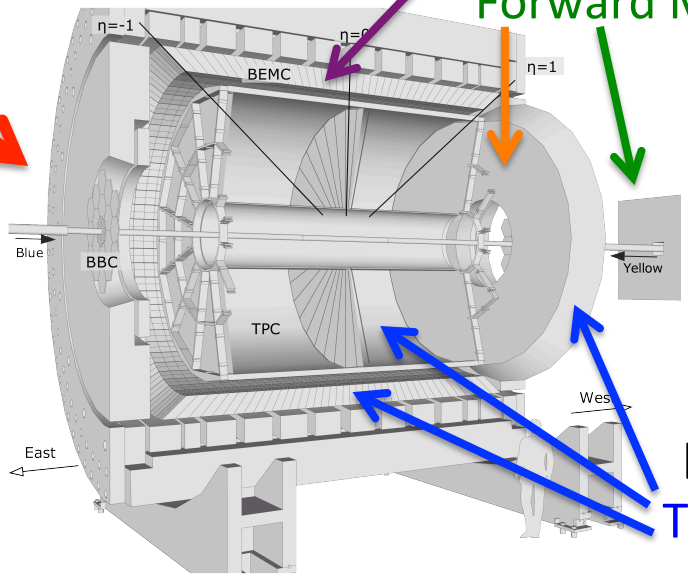


NIM A499, 245 (2003)

RHIC as Spin Collider

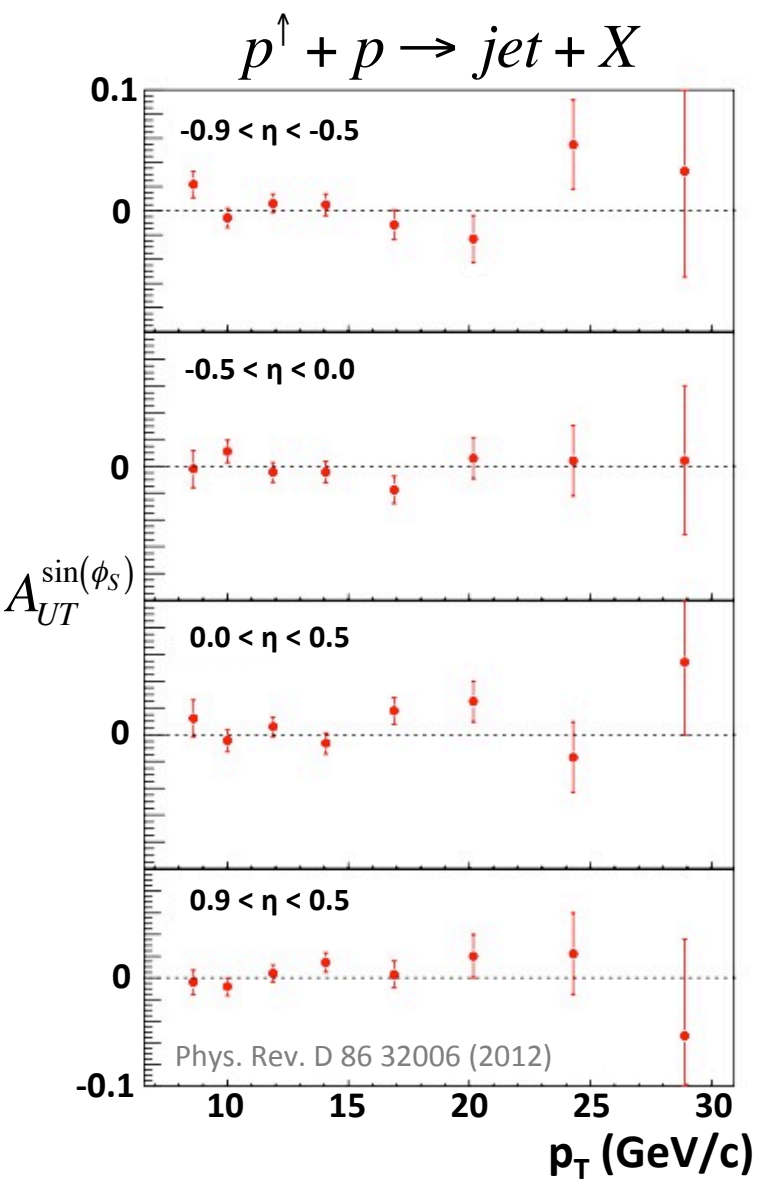
- "Siberian Snakes" → mitigate depolarization resonances
- Spin rotators provide choice of spin orientation *independent of experiment*
- Spin direction varies bucket-to-bucket (9.4 MHz)
- Spin pattern varies fill-to-fill

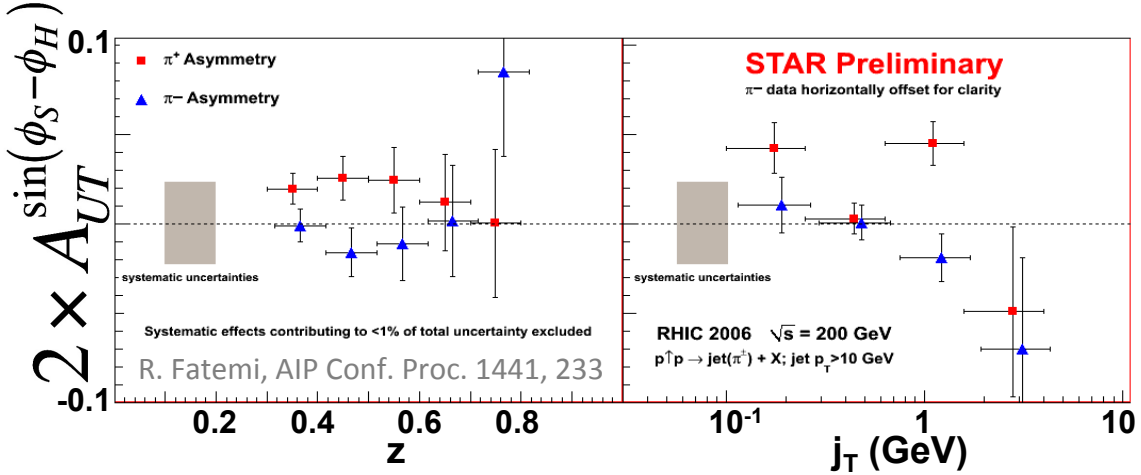
Inclusive hadron measurements:
Barrel E/M Calorimeter (BEMC),
Endcap E/M Calorimeter (EEMC),
Forward Meson Spectrometer (FMS)
FPD (east) not shown



Jet, di-hadron, W, and hyperon measurements:
TPC + Barrel + Endcap EMC

STAR Transverse Asymmetries from Jet Production





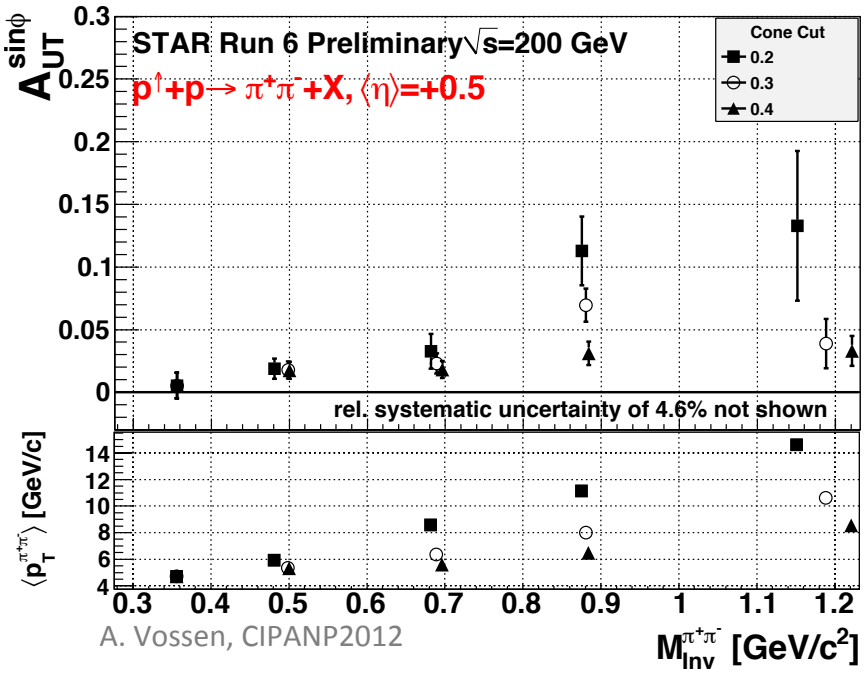
STAR measured transverse single-spin asymmetries for inclusive jet production at central pseudorapidity and $\sqrt{s} = 200$ GeV (2006)

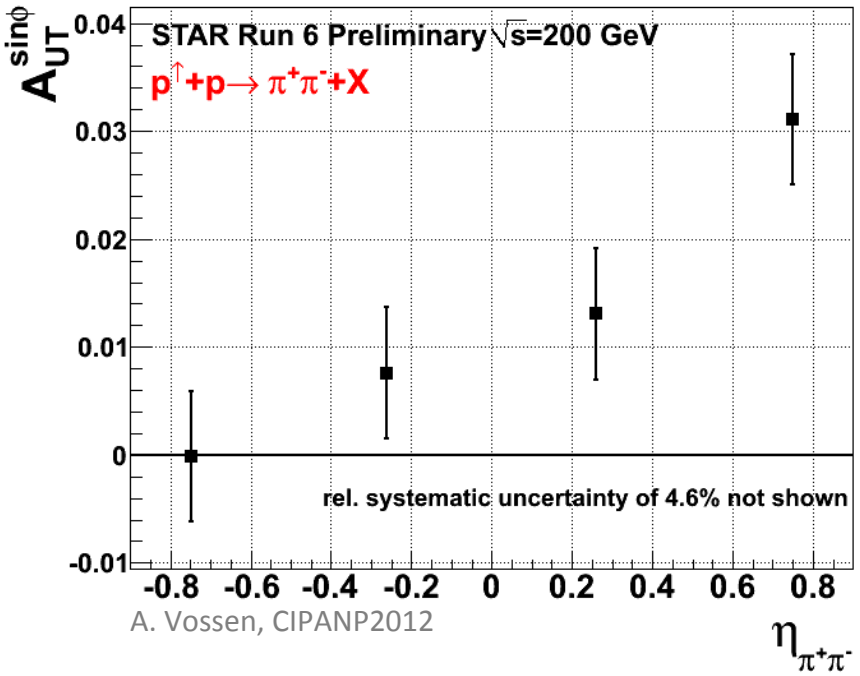
$A_{UT}^{\sin(\phi_S)}$: consistent with zero

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

Similarly, di-jet at central psuedorapidity and 200 GeV consistent with zero
PRL 99, 142003

STAR Transverse Asymmetries from Di-hadrons





STAR data from 2006 at $\sqrt{s} = 200$ GeV:

Significant non-zero di-hadron asymmetries

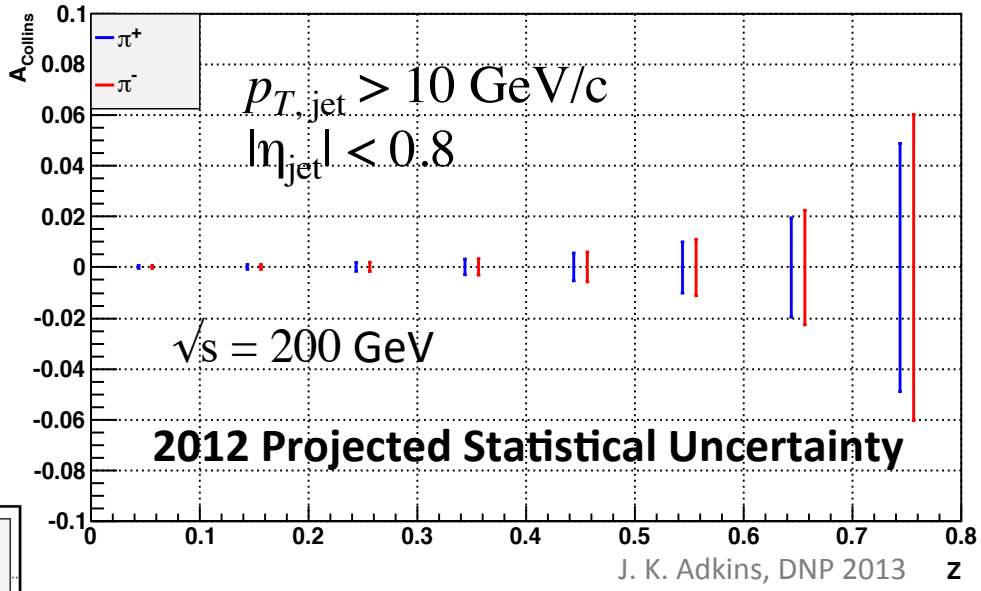
for charged pions at central pseudorapidity

Non-zero Collins + Di-hadron Asymmetries

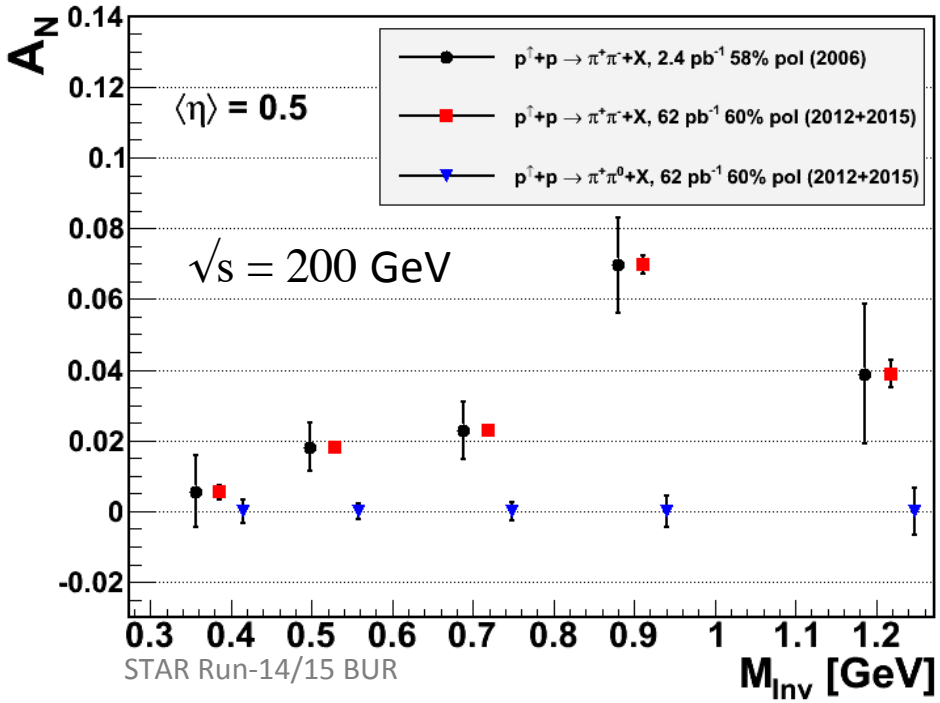
→ ***Access to transversity in p+p!***

STAR Transverse Asymmetries from Recent Data

2012 STAR data provide opportunity for ***higher precision*** *and* ***greatly reduced systematic uncertainties*** *at* $\sqrt{s} = 200$ *GeV* ***analyses well underway***



J. K. Adkins, DNP 2013



STAR Run-14/15 BUR

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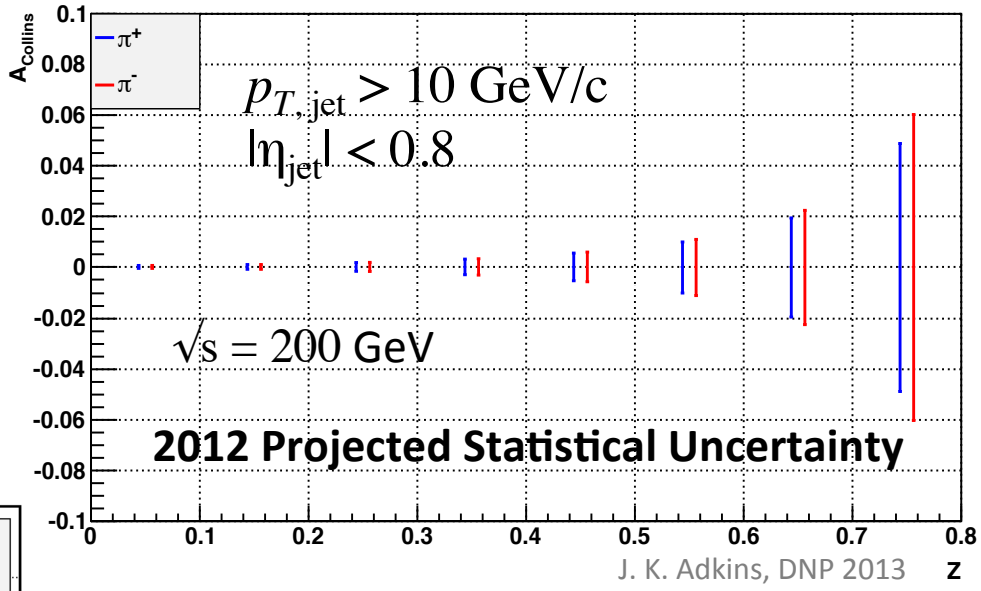
STAY TUNED FOR SPIN-2014!!!



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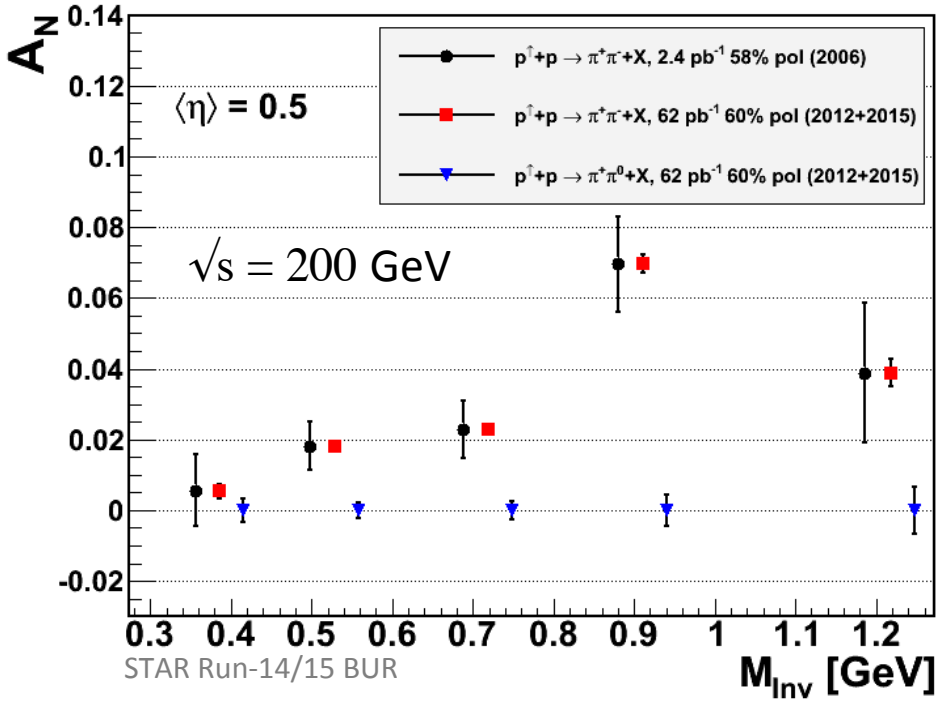

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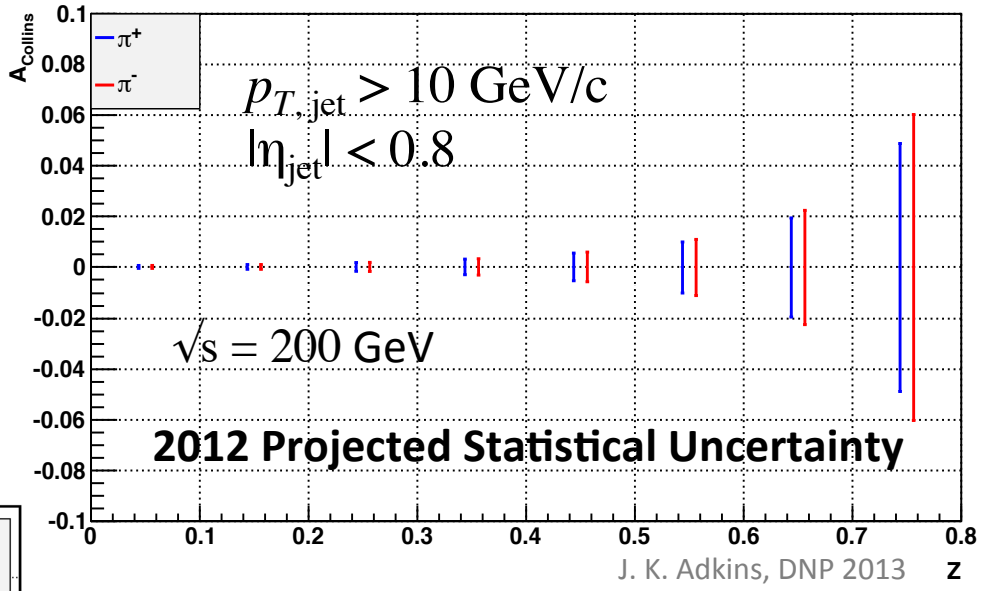

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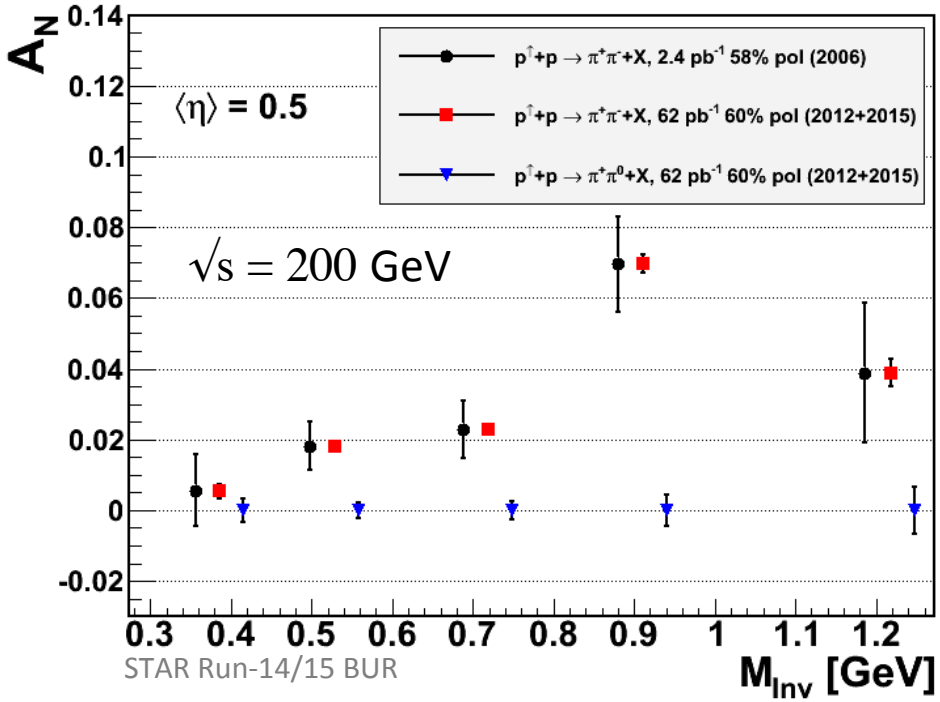

STAR Run-14/15 BUR

2011 STAR Data:

first measurements

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

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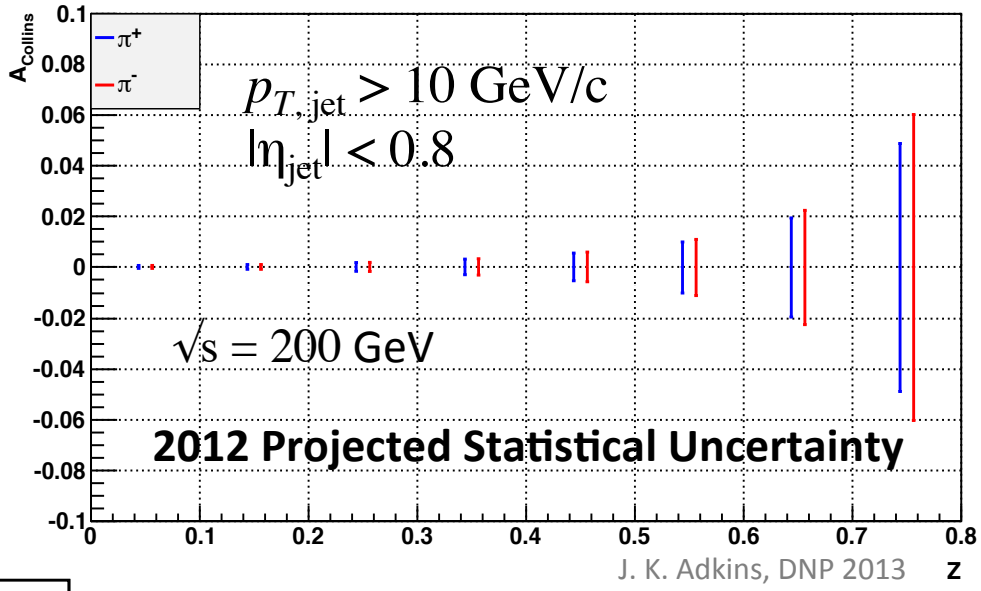

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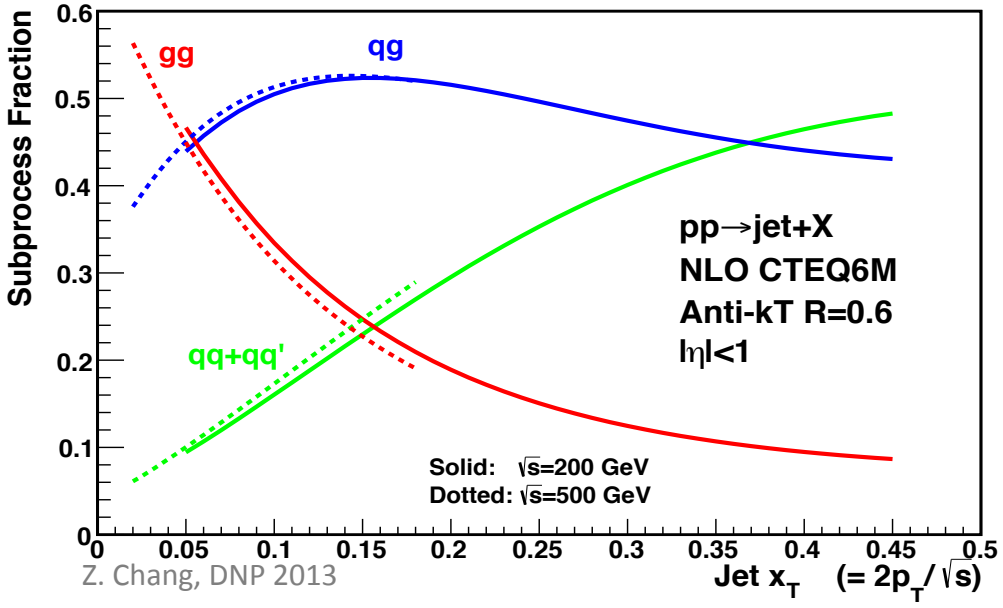


Z. Chang, DNP 2013

2011 STAR Data:

first measurements

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

→ Increased sensitivity to gluonic subprocesses

Inclusive Jet Asymmetries at 500 GeV

Jets corrected to particle-jet p_T

Corresponding parton-jet p_T lower by 0.3-1.2 GeV/c

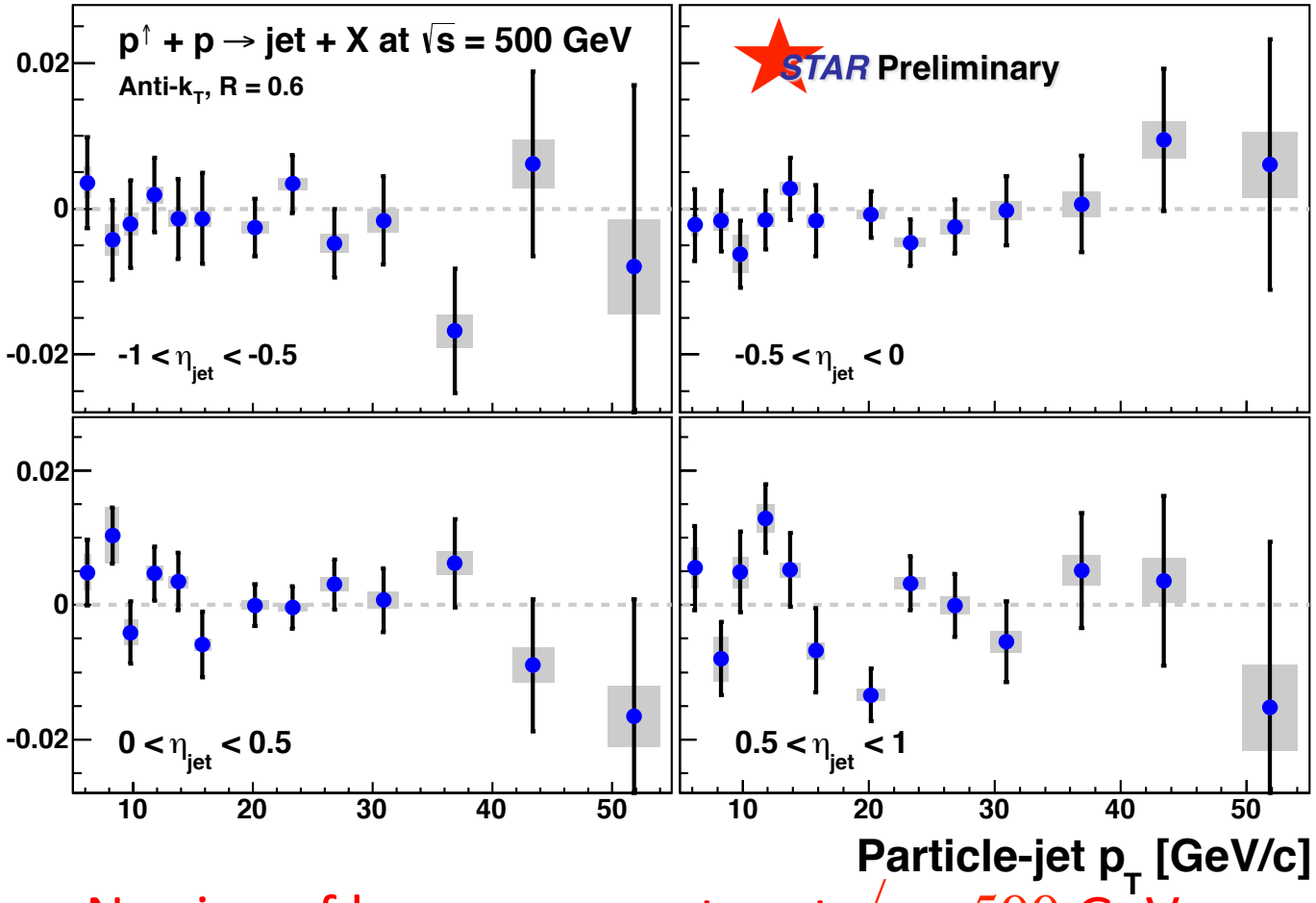
Anti-k_T, R = 0.6

Horizontal Systematics:

- M.C. statistics
- calorimeter gains
- efficiencies
- track momentum
- tracking efficiency

Vertical Systematics:

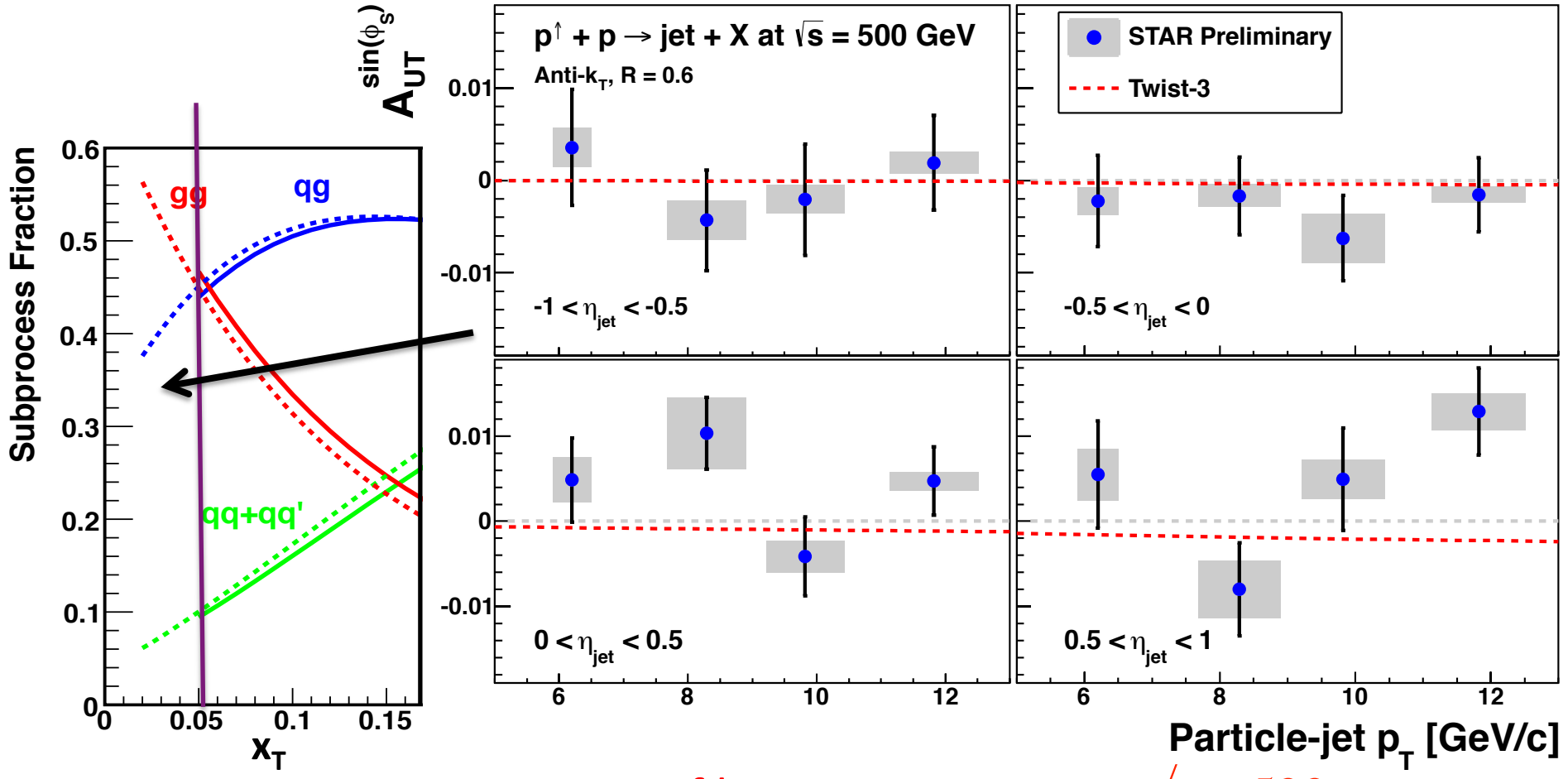
- Parton-jet matching
- Trigger bias
- Acceptance-related distortions



No sign of large asymmetry at $\sqrt{s} = 500$ GeV

- *Consistent with measurements at $\sqrt{s} = 200$ GeV*

Inclusive Jet Asymmetries at 500 GeV

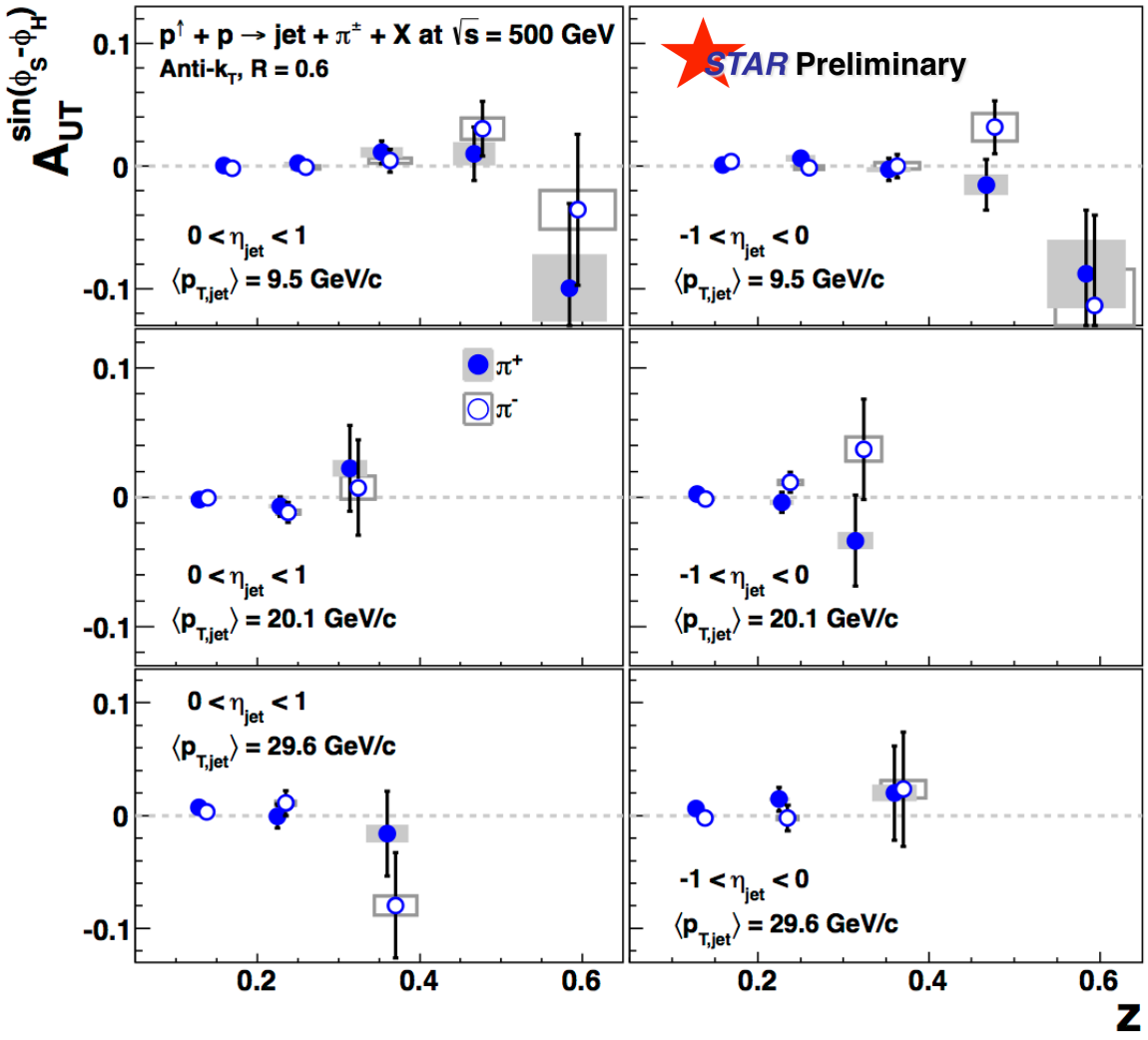


No sign of large asymmetry at $\sqrt{s} = 500$ GeV

- *Consistent with measurements at $\sqrt{s} = 200$ GeV*
- *Enhanced sensitivity to gluonic subprocesses*
- *Theory predictions expect small effects*

e.g., Kanazawa and Koike PLB 720, 161 (2013) shown in red

Collins Asymmetries at 500 GeV



No sign of large Collins asymmetry at current precision in $\sqrt{s} = 500$ GeV jet + hadron production

- Enhanced gluon sensitivity works against quark-based effects
- High-z statistics limited at high jet p_T

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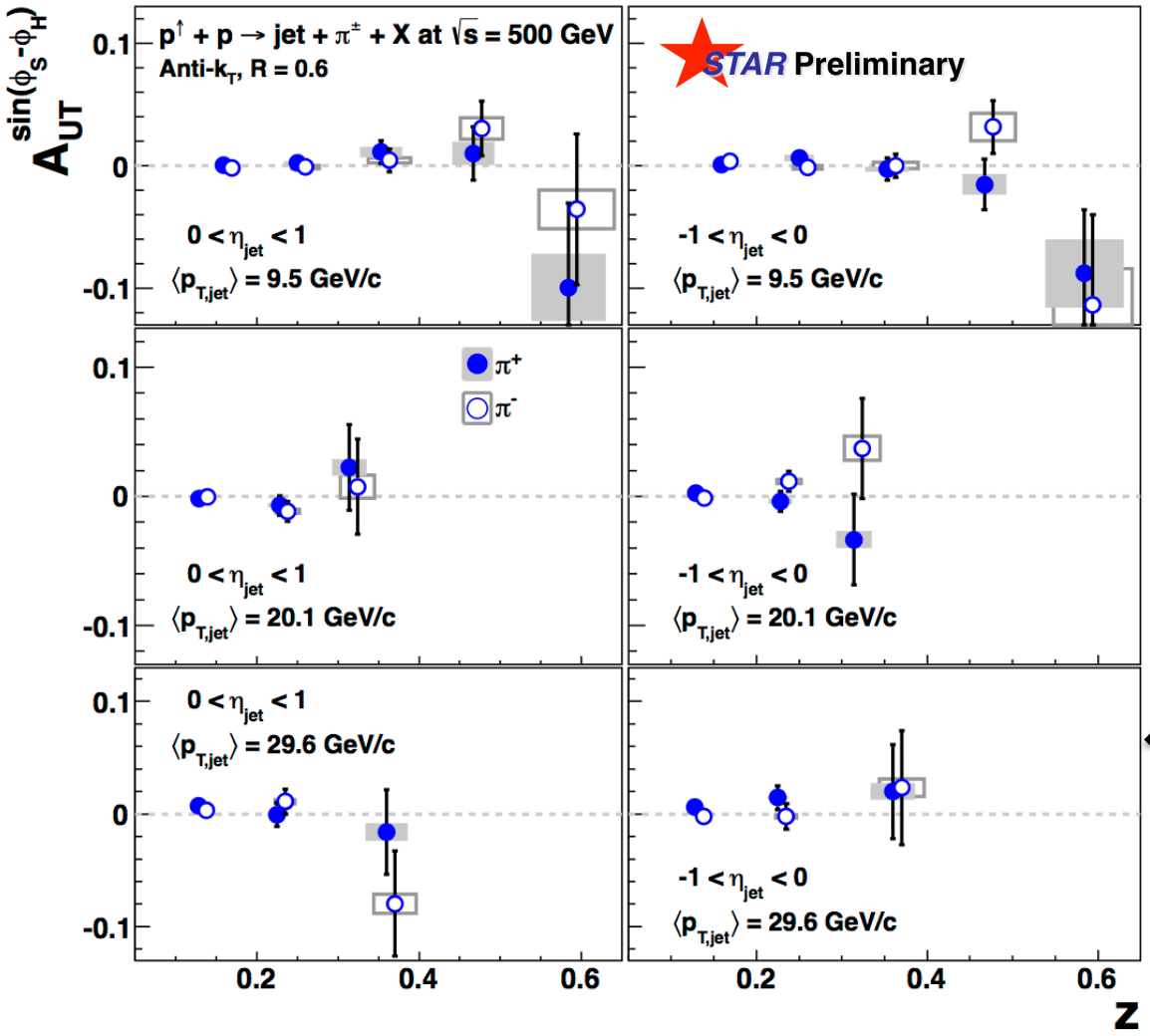
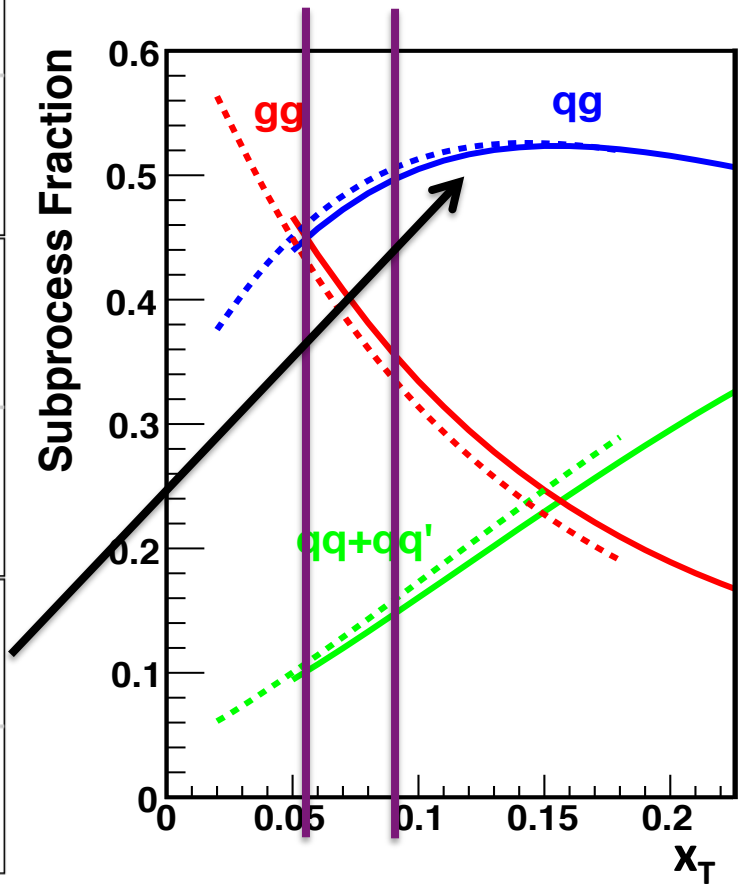
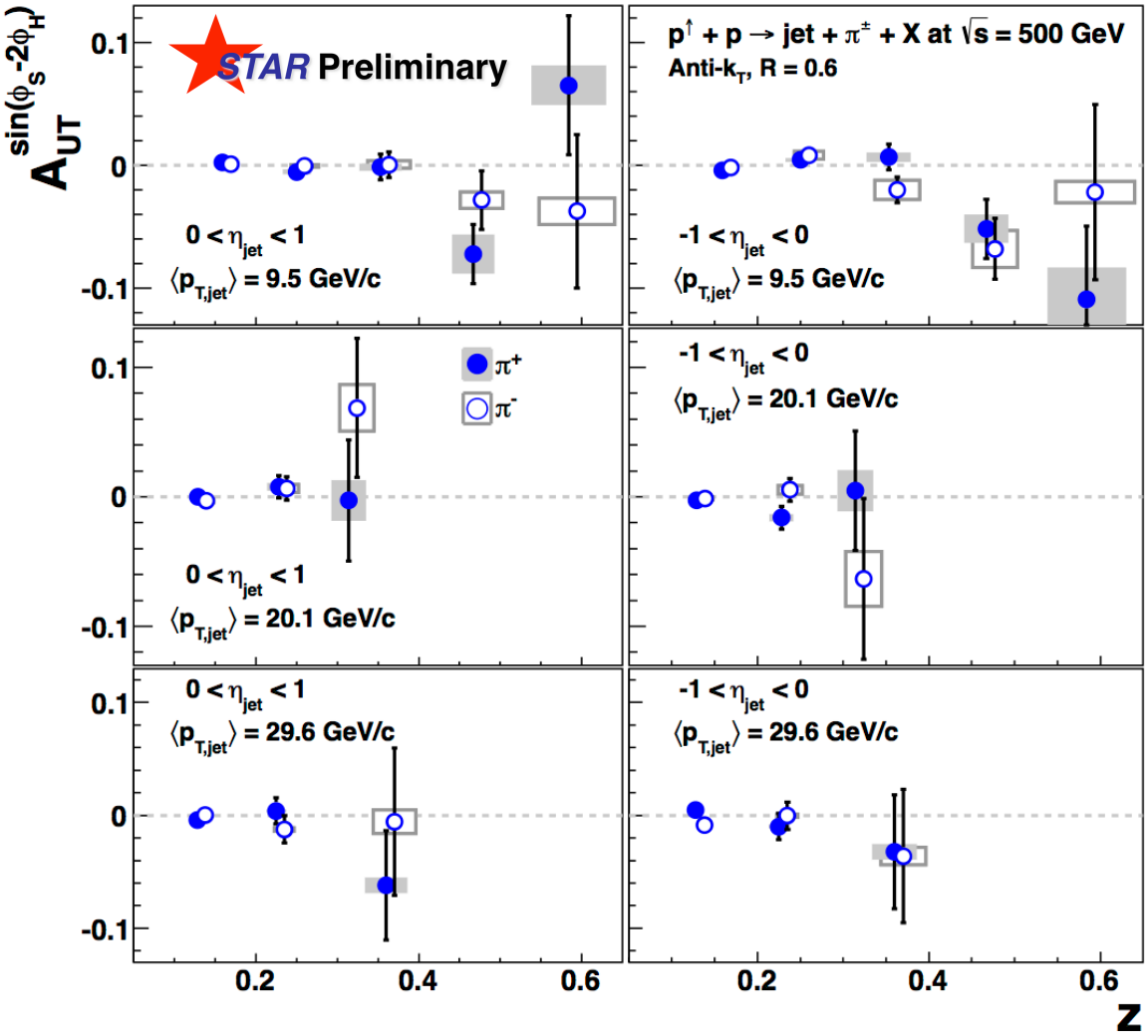




Present data provide opportunity for comparison to IFFs at 500 GeV and Collins asymmetries at overlapping x_T in 200 GeV

Collins-like Asymmetries at 500 GeV



No sign of large Collins-like asymmetry at current precision in $\sqrt{s} = 500$ GeV jet + hadron production

"Collins-like" asymmetry:

Sensitive to

linearly polarized gluons

Completely unconstrained!

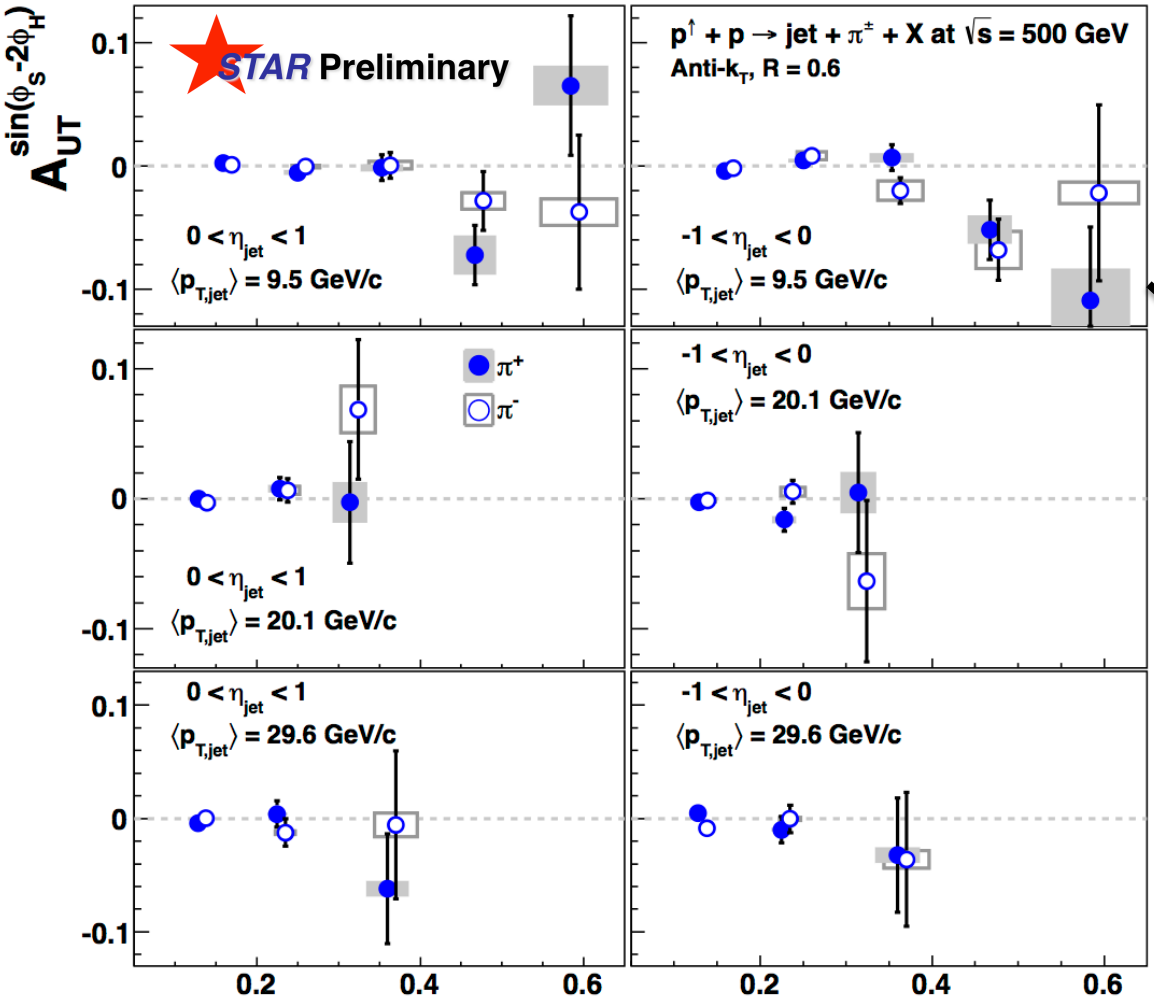
Gluon helicity density matrix

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

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

Phys Rev. D 73, 014020 (2006)

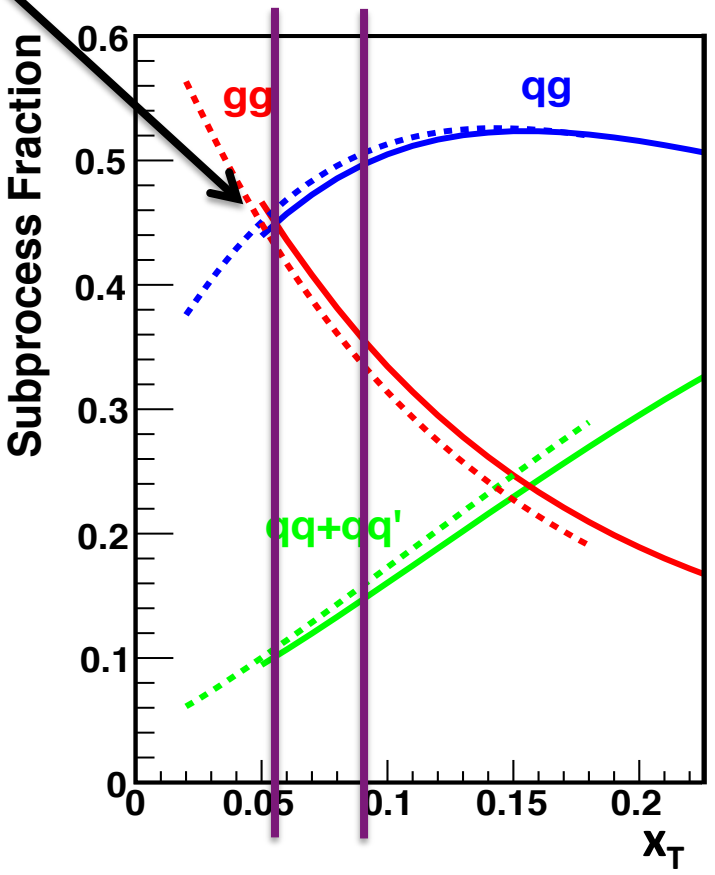
Collins-like Asymmetries at 500 GeV



Data at low jet p_T sit in low-x_T region dominated by gluonic subprocesses

→ **best sensitivity for Collins-like effect**

No sign of large Collins-like asymmetry at current precision in $\sqrt{s} = 500$ GeV jet + hadron production



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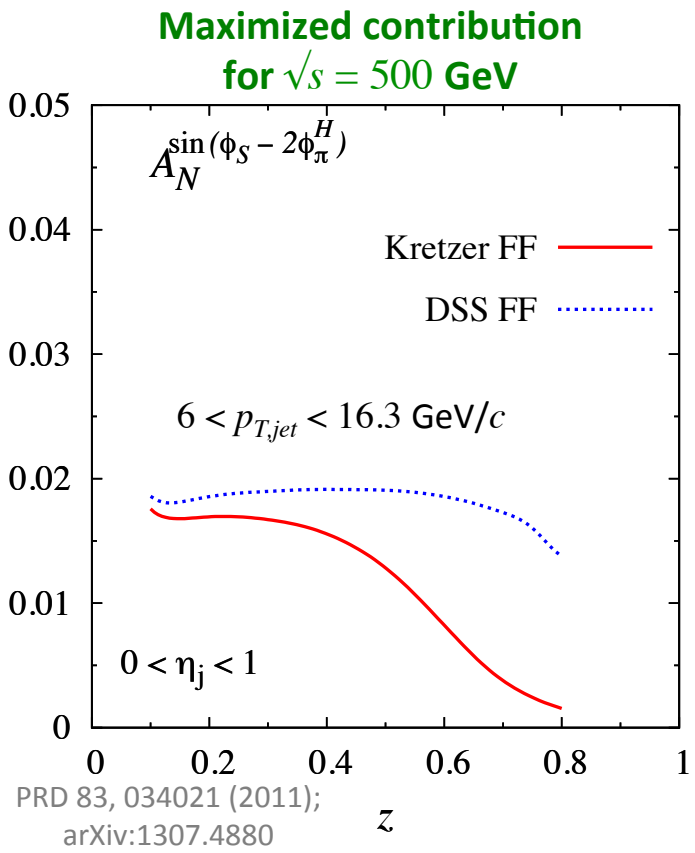
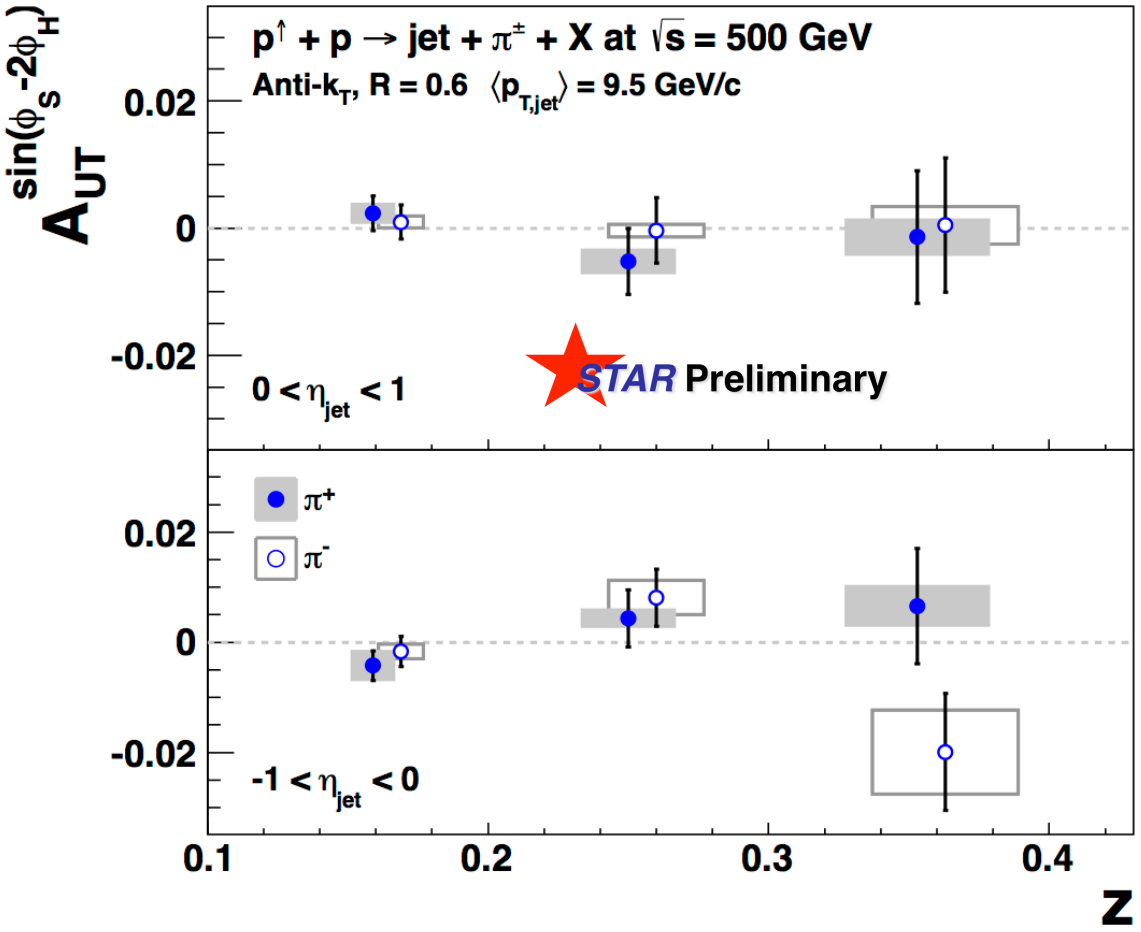


PRD 83, 034021 (2011);
arXiv:1307.4880



Present data sit well below maximized contribution of ~2% at low z

Present data should provide first constraints on Collins-like effect

(sensitive to linearly polarized gluons)

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Stay tuned for more new jet and di-hadron results from STAR at Spin 2014!