Recent Spin Results from STAR

James L. Drachenberg
Valparaiso University
for the STAR Collaboration

Lake Louise  Winter Institute
Fundamental Interactions in Particle Physics, Alberta, Canada

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OUTLINE

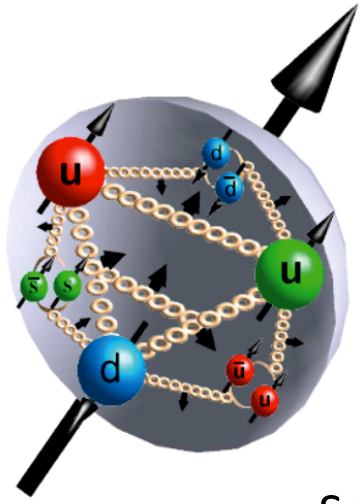
- Introduction
- RHIC and the STAR detector
- Jets and Di-hadrons at $\sqrt{s} = 200$ GeV
- Jets at $\sqrt{s} = 500$ GeV
- Summary

STAR

Valparaiso University

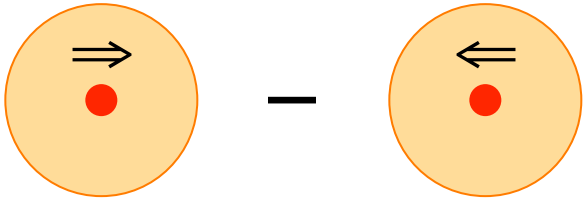
Contributions to Proton Spin Structure

Consider proton moving right



Proton spin-polarization ⇒

$\Delta q(x)$
$\Delta g(x)$



coming into focus:

$$\int_{0.05}^{0.2} \Delta g(x)\,dx = 0.1 \pm^{0.06}_{0.07}$$

arXiv:nucl-ex/1304.0079

Polarized DIS: ~ 0.3

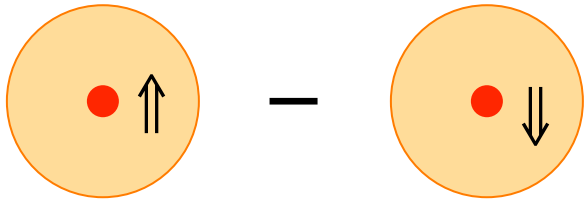
Spin sum rule: $\left\langle S_z^p \right\rangle = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \left\langle L_z \right\rangle$

poorly constrained

STAR spin program:
Exploring less-constrained components of the proton

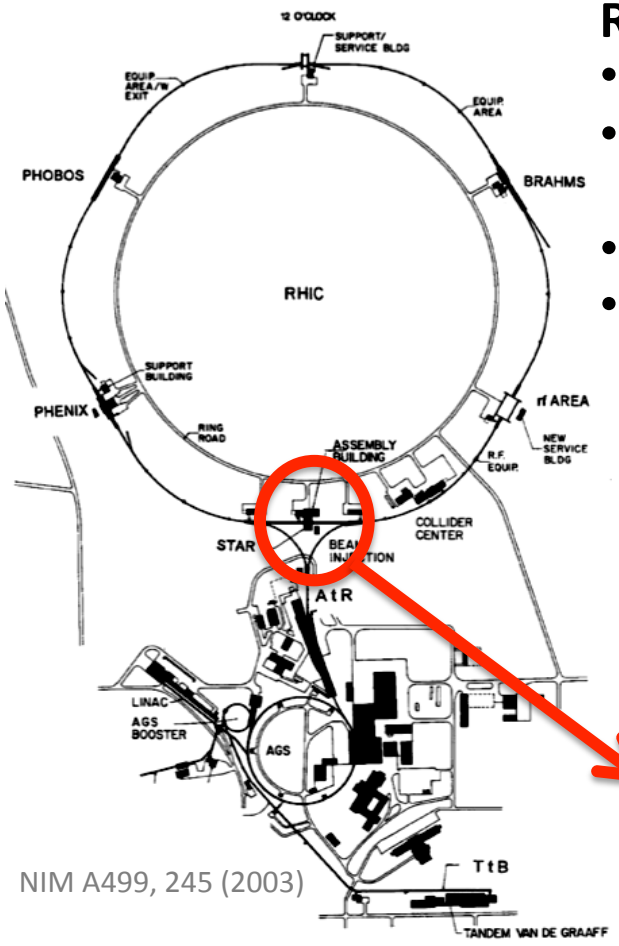
Proton spin-polarization ⇑

$h_1(x)$



Transversity – data over limited kinematic range: $x_{Bj} \leq 0.3$

Solenoidal Tracker at RHIC

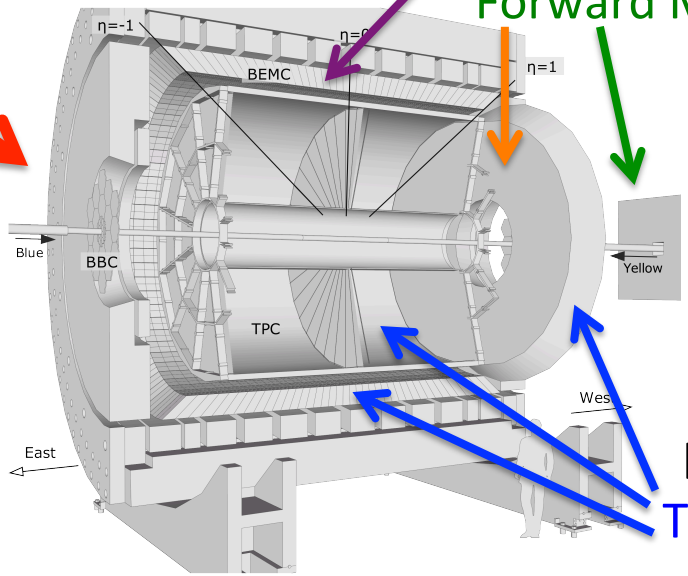


NIM A499, 245 (2003)

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

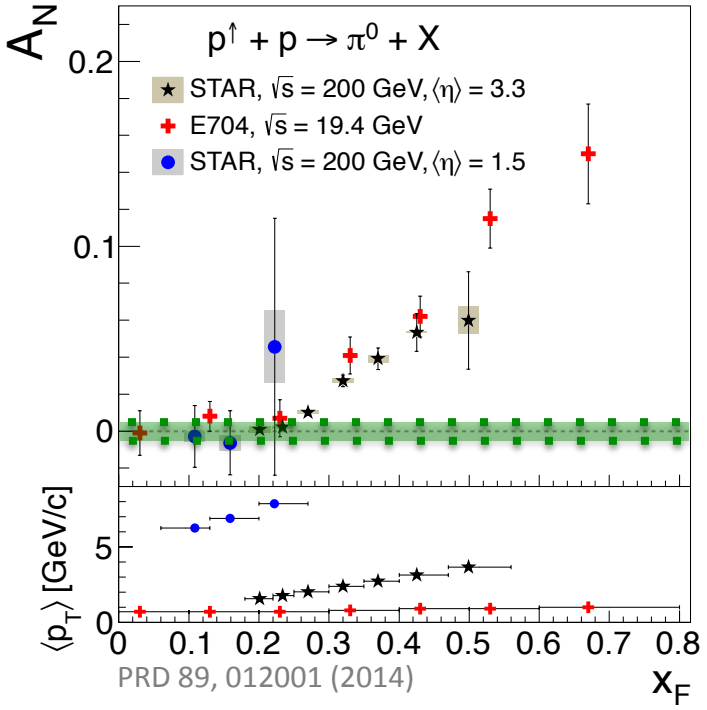
Transverse Single-spin Asymmetries from Inclusive Hadrons

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

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

Collinear pQCD at leading twist predicts very small A_N

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



PRD 89, 012001 (2014)

Sizeable A_N at forward pseudorapidity measured across a large range of $\sqrt{s}$

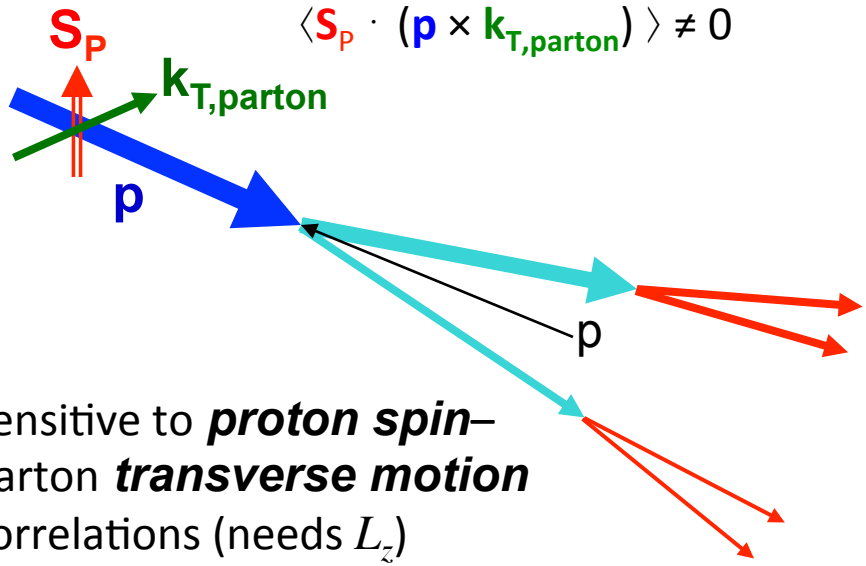
Measurements at RHIC in region where NLO pQCD cross-section provides a reasonable description of the data

→ Go beyond collinear pQCD at leading twist

Mechanisms for Transverse Single-spin Asymmetries

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

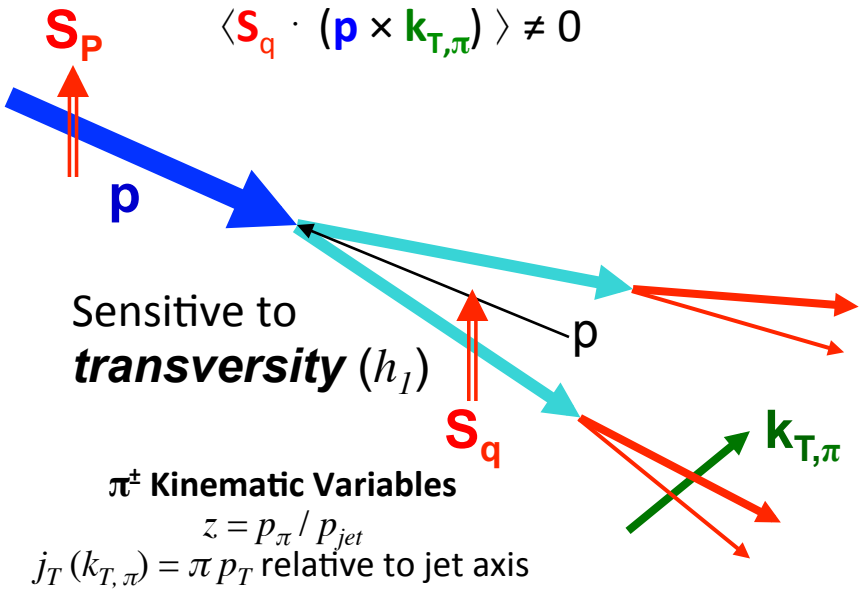
D. Sivers, PRD 41, 83 (1990); 43, 261 (1991)



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

Collins mechanism: asymmetry in the forward jet *fragmentation*

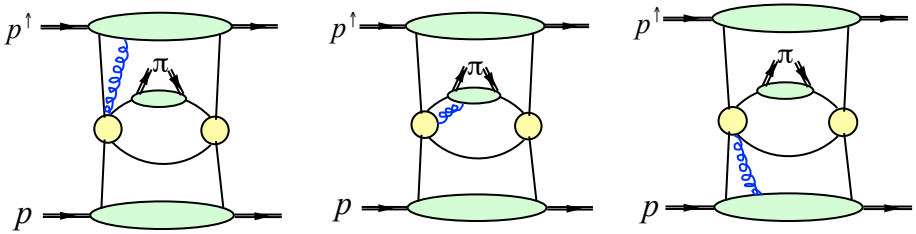
J. Collins, NP B396, 161 (1993)



$\pi^{\pm}$ Kinematic Variables

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

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



Y. Koike, RSC Discussion (2004)

Twist-3 mechanism: 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 TMD's

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

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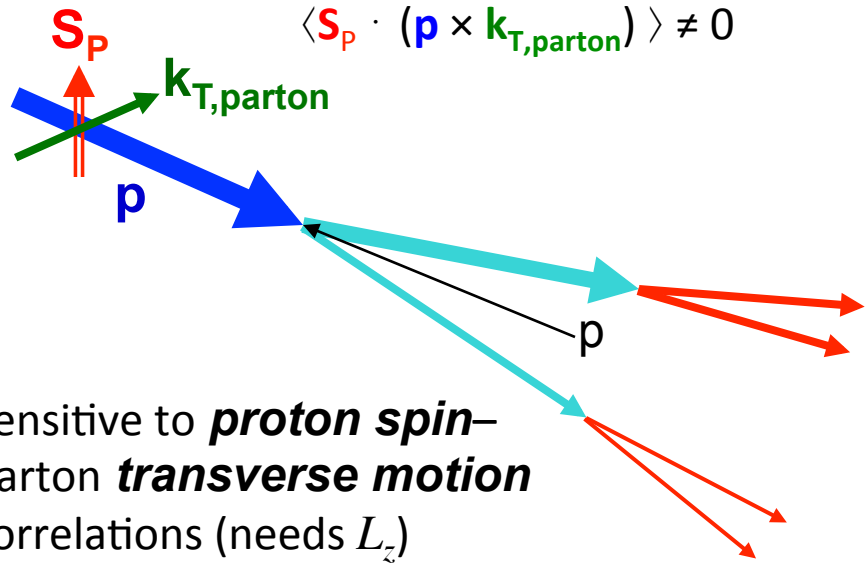

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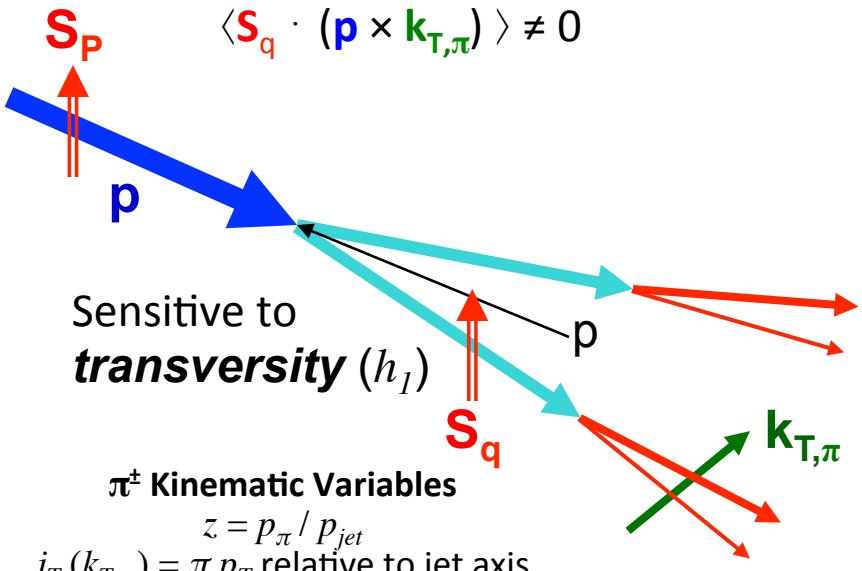

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Inclusive hadron asymmetries:

Unable to islolate contributions

Sivers, Collins, twist-3 ~ $\sin(\phi_S)$

ϕ_S—*angle between spin and event plane*

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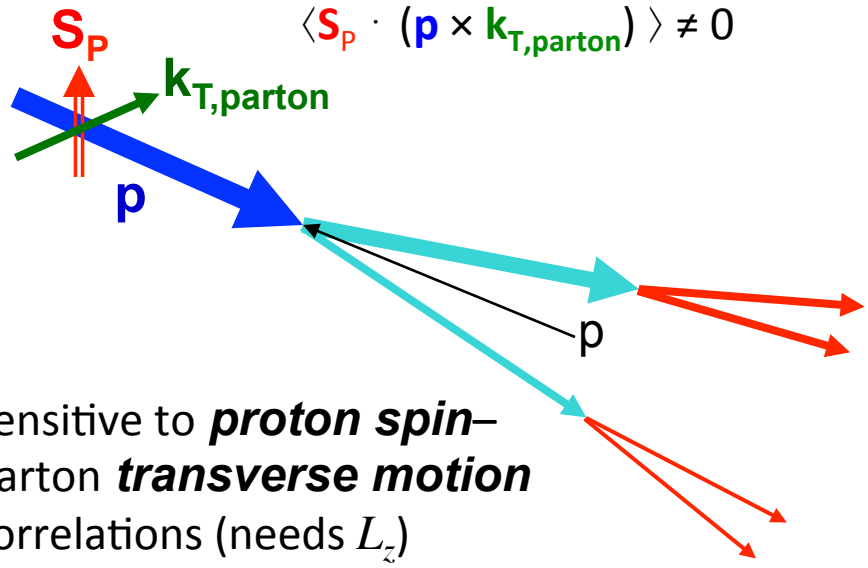

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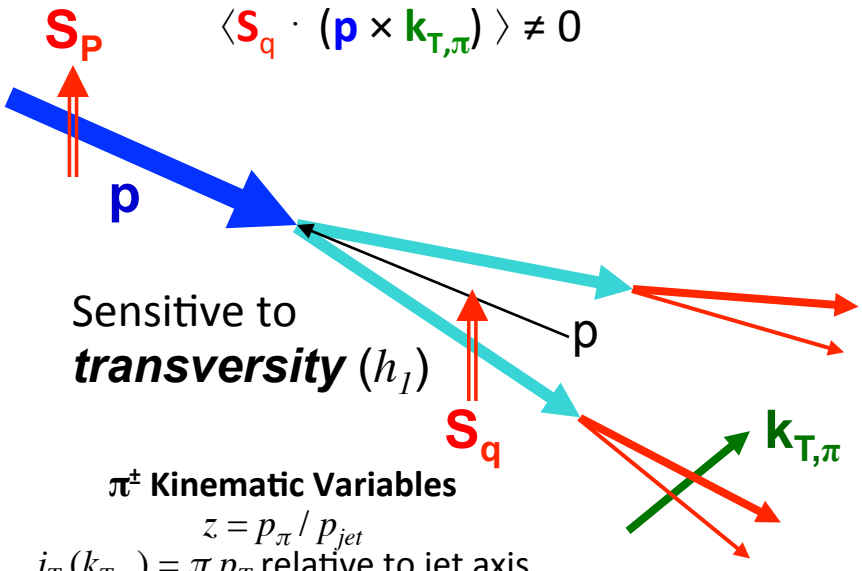

$\pi^{\pm}$ Kinematic Variables

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

Separate Sivers and Collins:

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

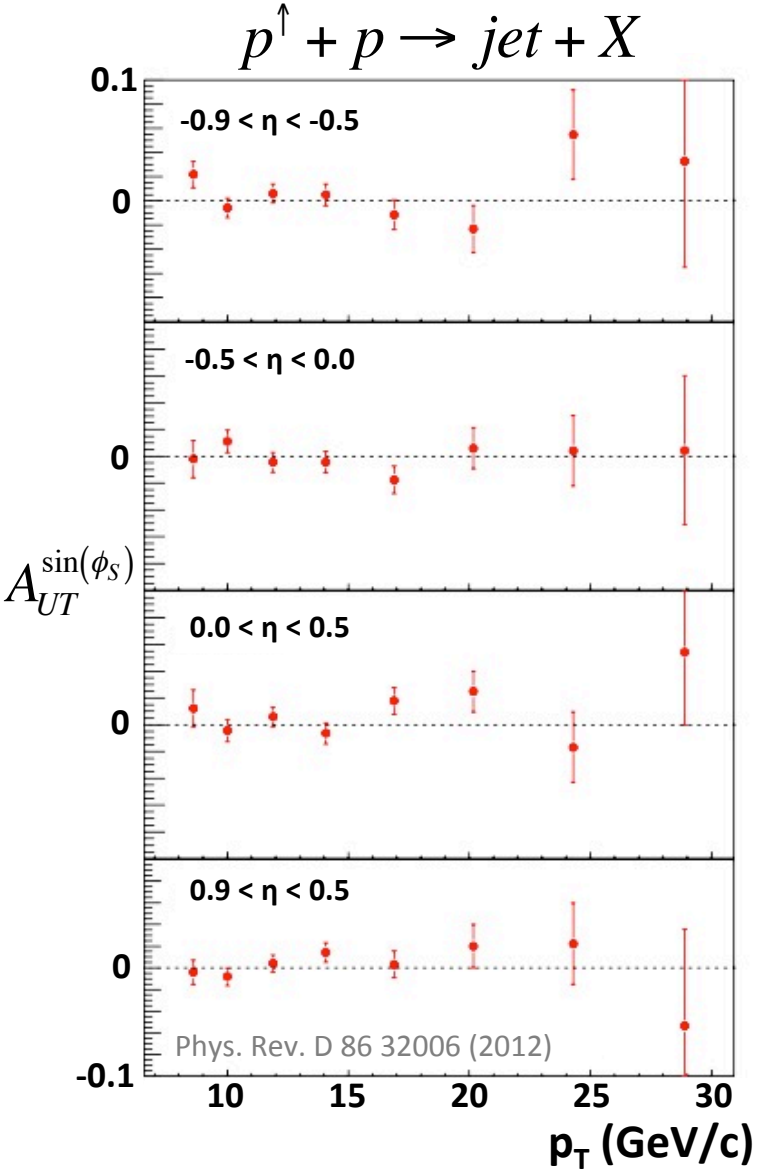
Sivers ~ $\sin(\phi_S)$

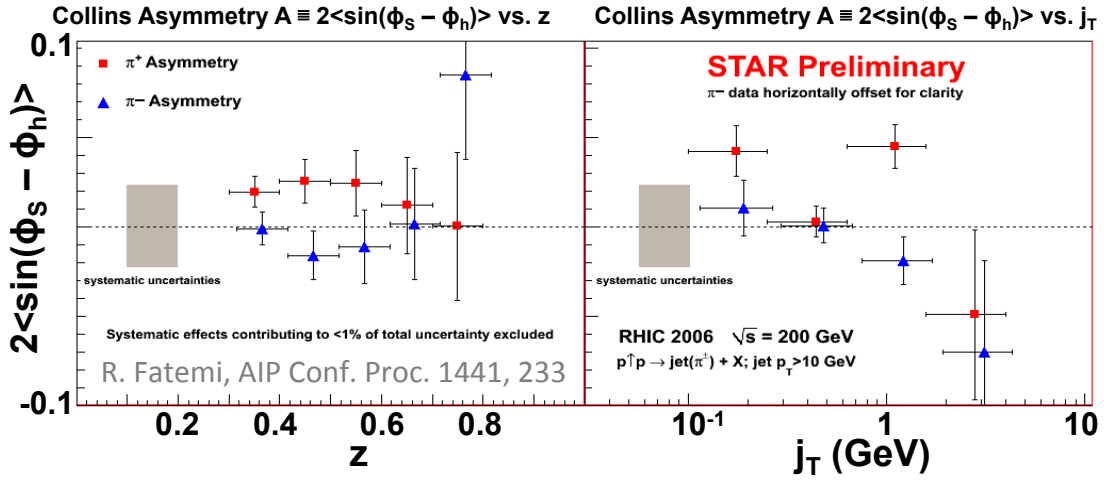
ϕ_S—*angle between spin and event plane*

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

ϕ_h—*angle of hadron around jet axis*

STAR Transverse Asymmetries from Jet Production





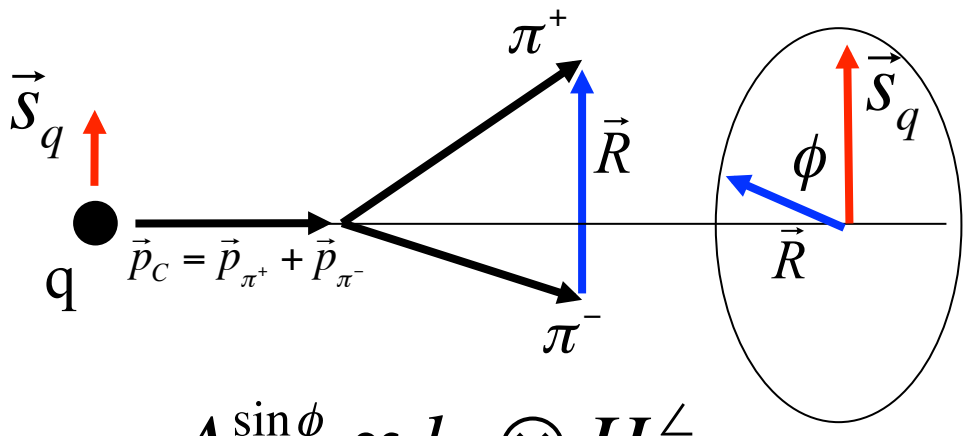
STAR measured transverse single-spin asymmetries for inclusive jet production at central pseudorapidity and $\sqrt{s} = 200$ GeV (2006)

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

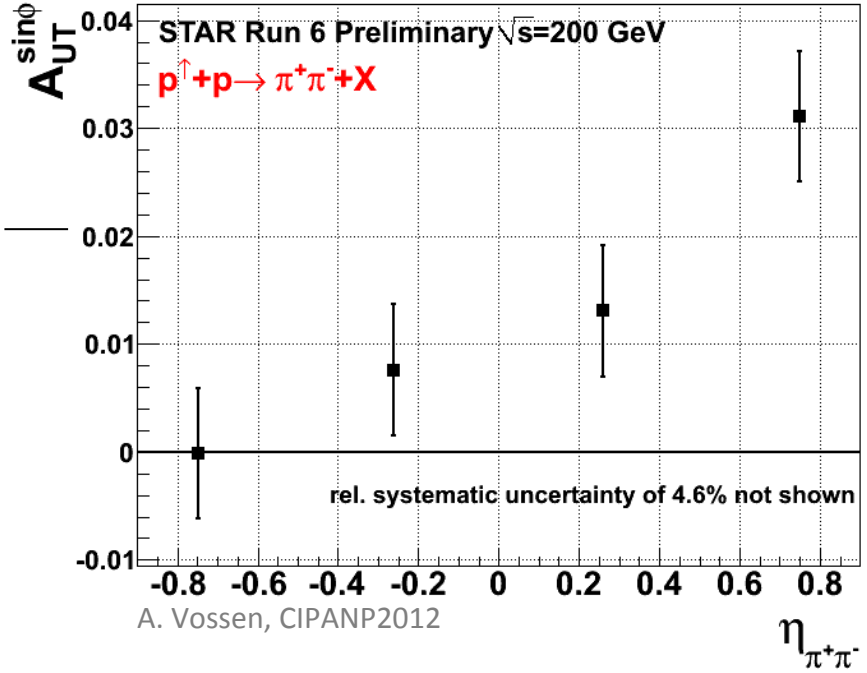
STAR Transverse Asymmetries from Di-hadrons



$$A_{UT}^{\sin\phi} \propto h_1 \otimes H_1^{\angle}$$

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

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



A. Vossen, CIPANP2012

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

Sign of ***non-zero di-hadron asymmetries*** for charged pions at central pseudorapidity

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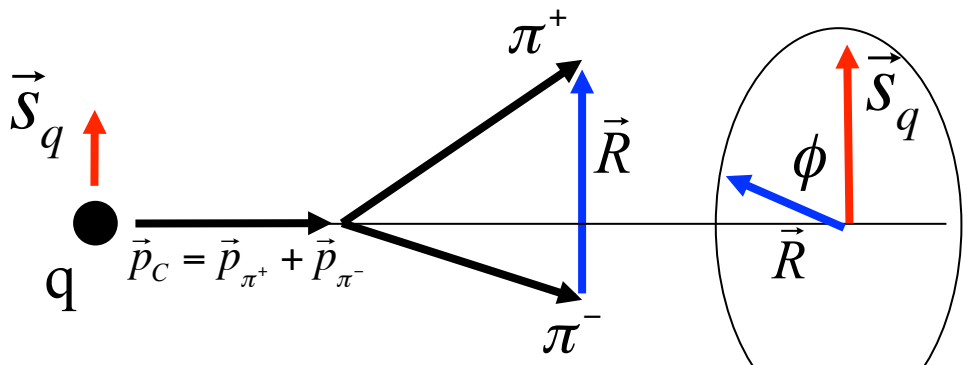

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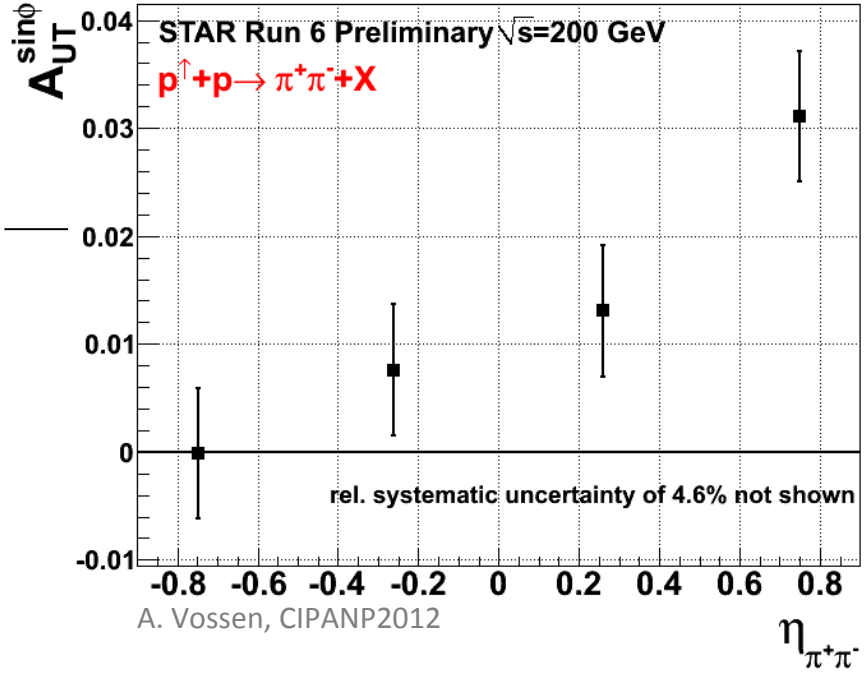

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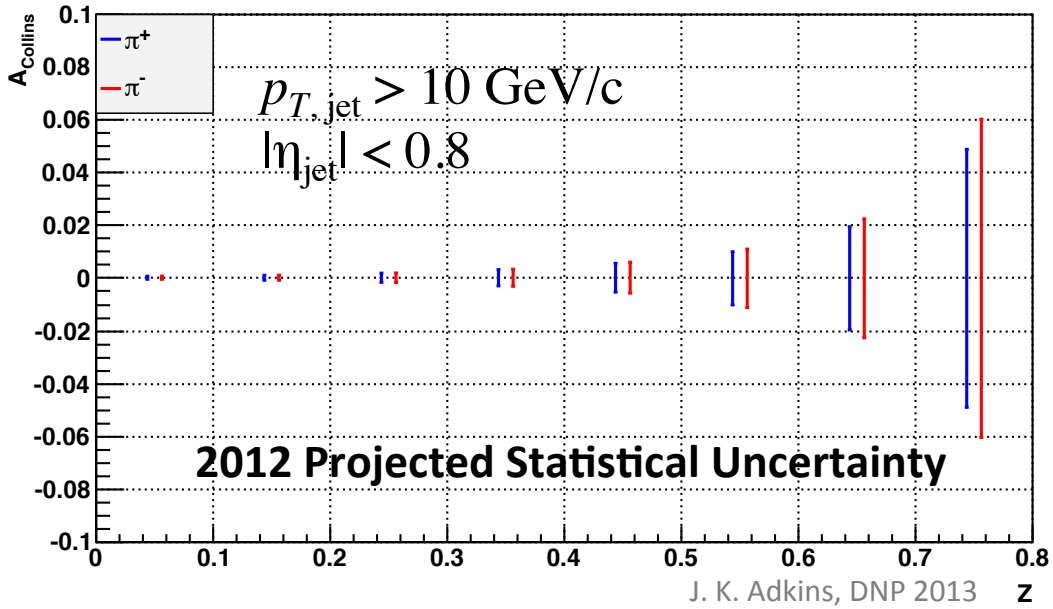
Non-zero Collins + Di-hadron Asymemtries

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

STAR Transverse Asymmetries from Jet Production

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

analysis well underway



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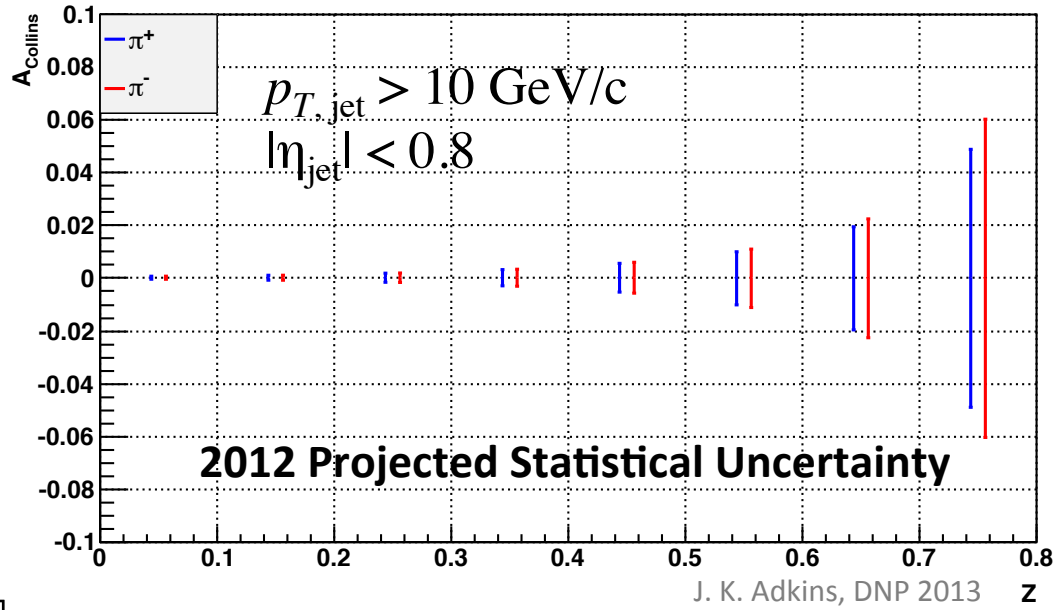
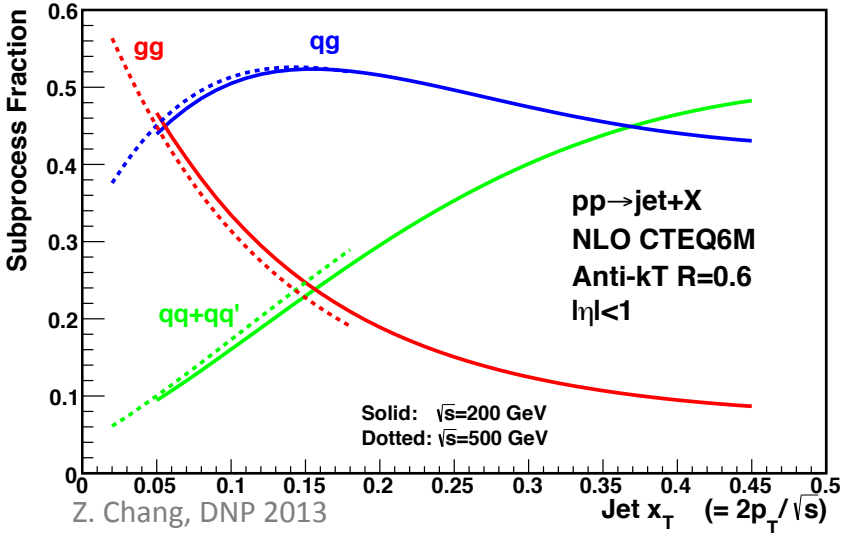


J. K. Adkins, DNP 2013



Z. Chang, DNP 2013

2011 STAR data provide opportunity for first measurements of **central pseudorapidity inclusive jet asymmetries at** $\sqrt{s} = 500$ **GeV**

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

Moments of Jet Asymmetries at 500 GeV

Various contributions to polarized $jet+\pi$ 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);
arXiv:1307.4880

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Negligible under ***maximized*** scenario!

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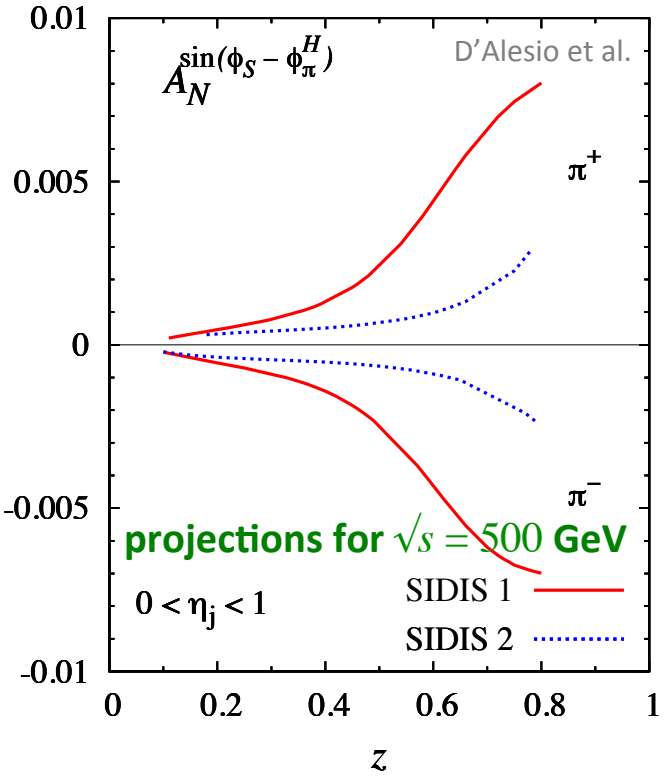

Phys. Rev. D 83, 034021 (2011);
arXiv:1307.4880

Possible non-zero contributions,

expected to be quite small

e.g. Phys. Rev. Lett 99, 142003 (2007);
Phys. Rev. D 86, 032006 (2012);
Phys. Lett. B 720, 161 (2013)

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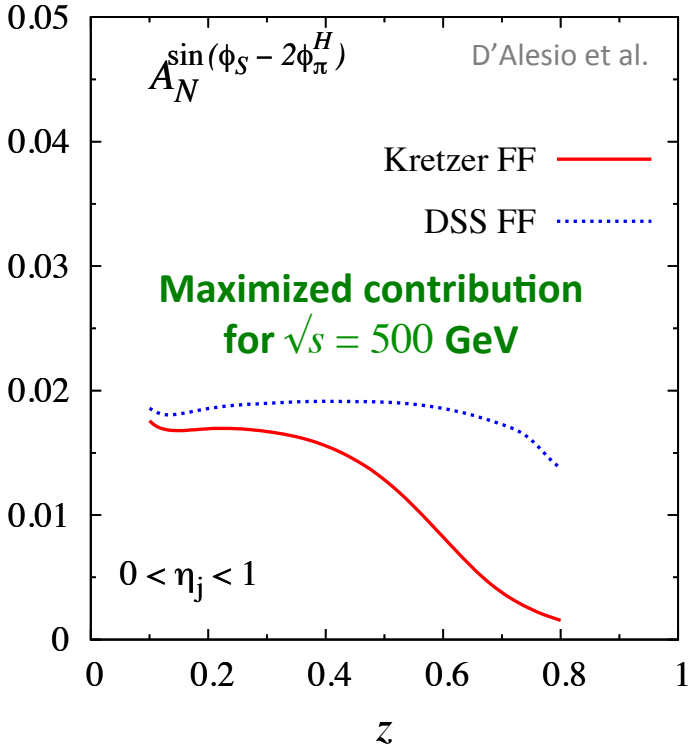


"Collins-like" asymmetry:

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)

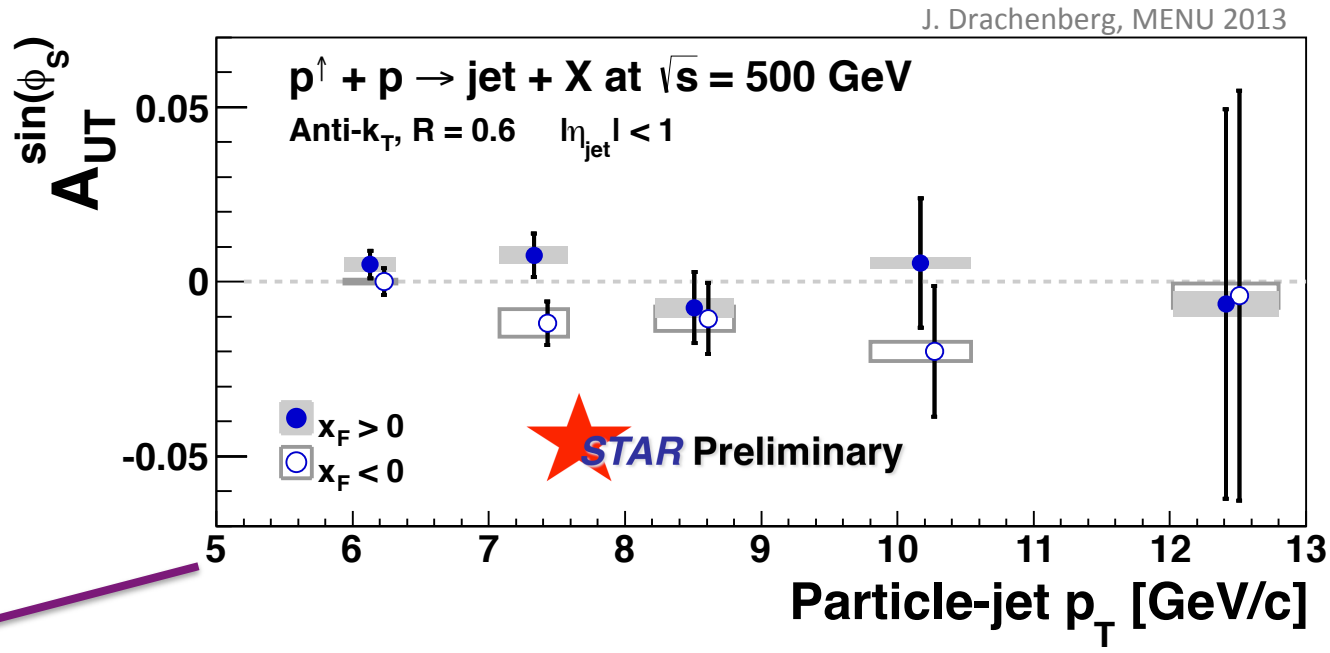
Sivers Asymmetries at 500 GeV

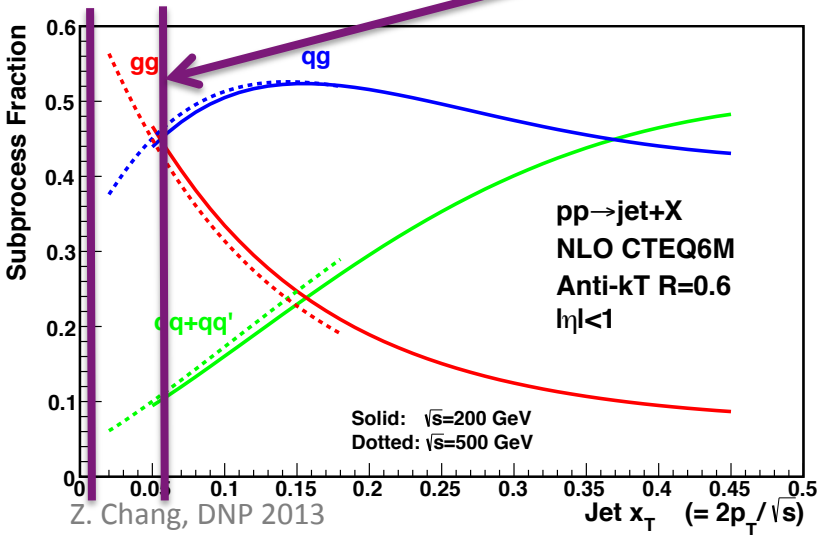
Asymmetries shown as function of particle-jet p_T

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

J. Drachenberg, MENU 2013





Z. Chang, DNP 2013

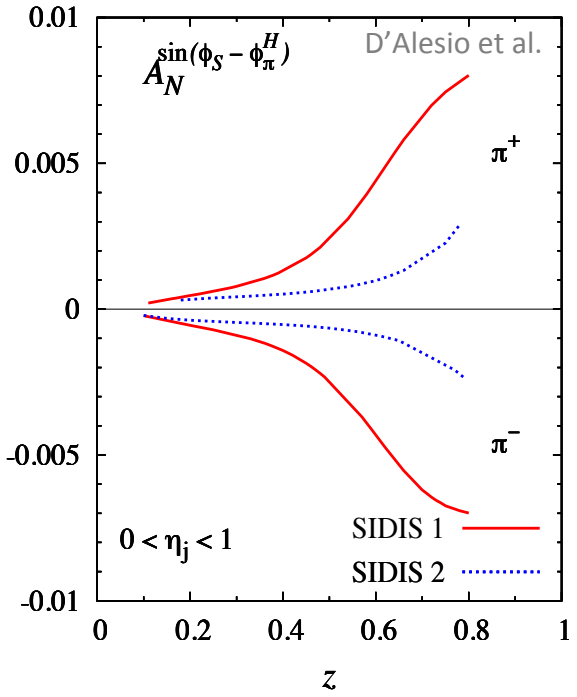
No sign of sizable azimuthal asymmetry in jet production at $\sqrt{s} = 500$ GeV

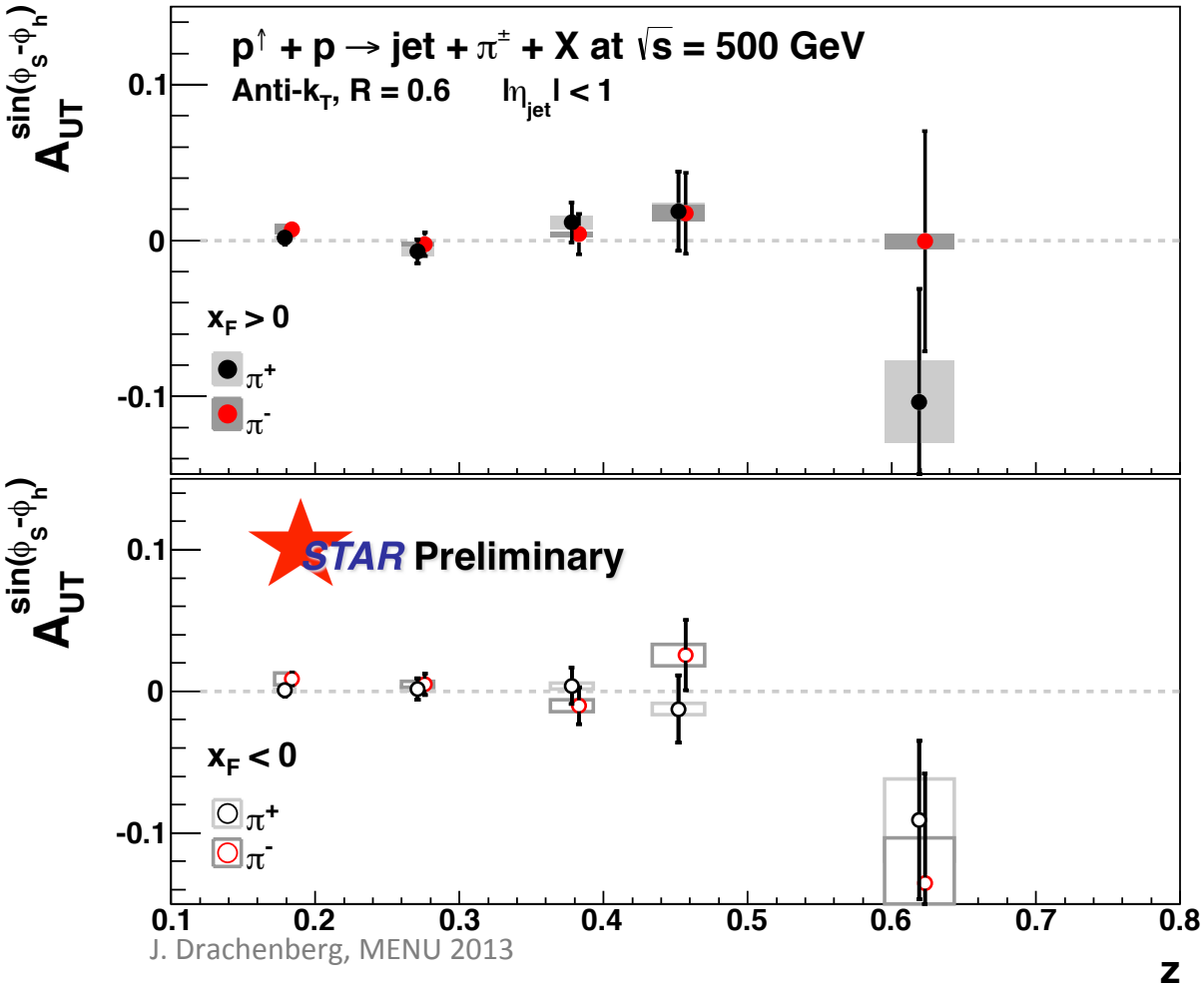
- *Consistent with expectation from measurements at $\sqrt{s} = 200$ GeV*
- *Consistent with theory predictions*

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

Collins Asymmetries at 500 GeV

Increased gluonic subprocesses at $\sqrt{s} = 500$ GeV lead to expectation of ***small Collins asymmetry*** until larger z

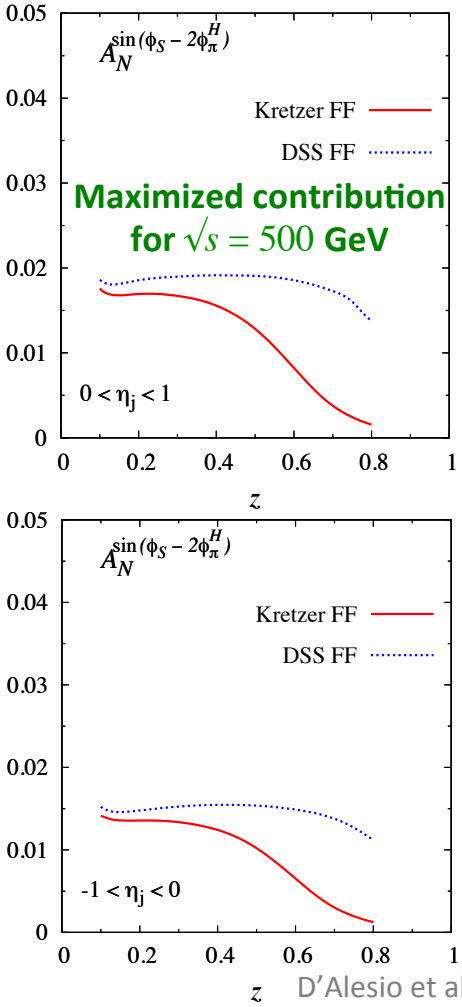




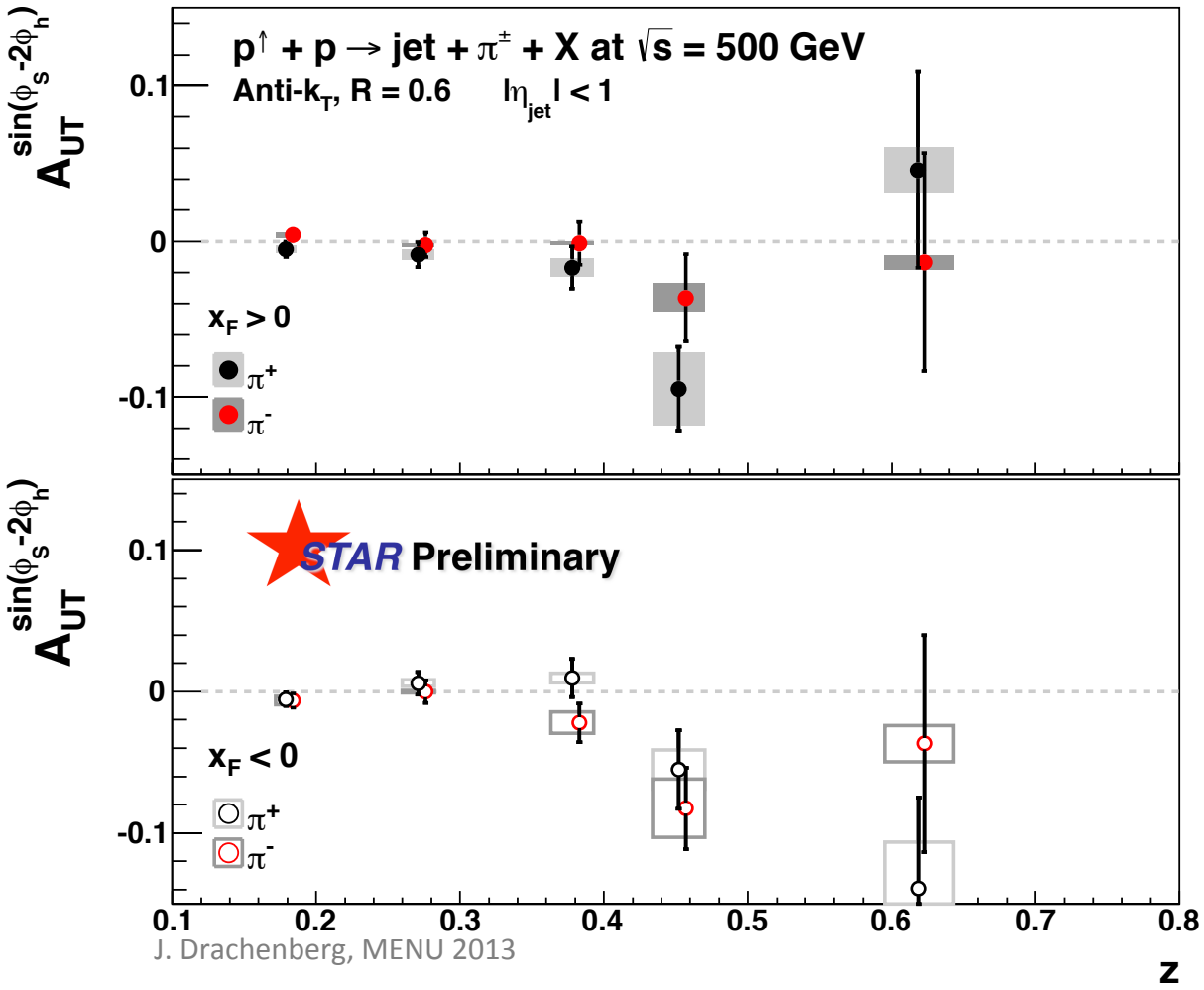
J. Drachenberg, MENU 2013

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

Collins-like Asymmetries at 500 GeV



D'Alesio et al.



J. Drachenberg, MENU 2013

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

Until now, Collins-like asymmetries completely unconstrained

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

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  - ***First signs of transversity at RHIC*** through inclusive jet and di-hadron asymmetries

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- Active program in proton helicity structure: ΔG, $\Delta \bar{u}$, etc.
- Transversity and transverse-polarization phenomena
  - ***First signs of transversity at RHIC*** through inclusive jet and di-hadron asymmetries
  - First investigation of transverse single-spin asymmetries in inclusive jets at central pseudorapidity and $\sqrt{s} = 500$ GeV
    - ***First ever measurement of "Collins-like" effect from linearly polarized gluons***
    - Stage set for analysis of A_{UT}-moment evolution from 200 GeV to 500 GeV

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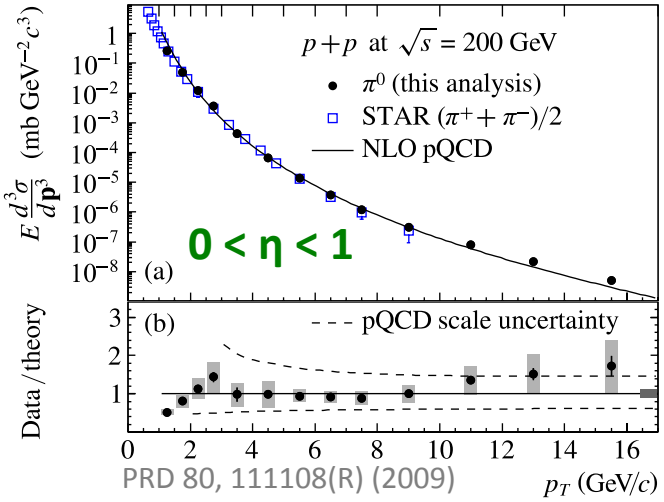
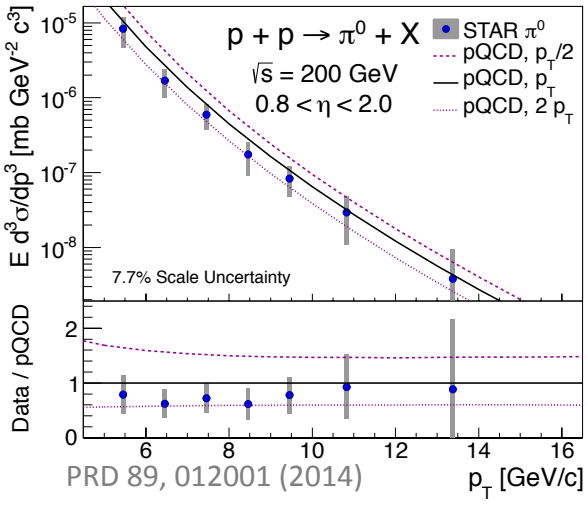
  - ***First signs of transversity at RHIC*** through inclusive jet and di-hadron asymmetries
  - First investigation of transverse single-spin asymmetries in inclusive jets at central pseudorapidity and $\sqrt{s} = 500$ GeV
    - ***First ever measurement of "Collins-like" effect from linearly polarized gluons***
    - Stage set for analysis of A_{UT}-moment evolution from 200 GeV to 500 GeV
  - Analyses underway of Collins and IFF from 2012 run
    → ***higher statistical precision and reduced systematics***

Back-up Slides

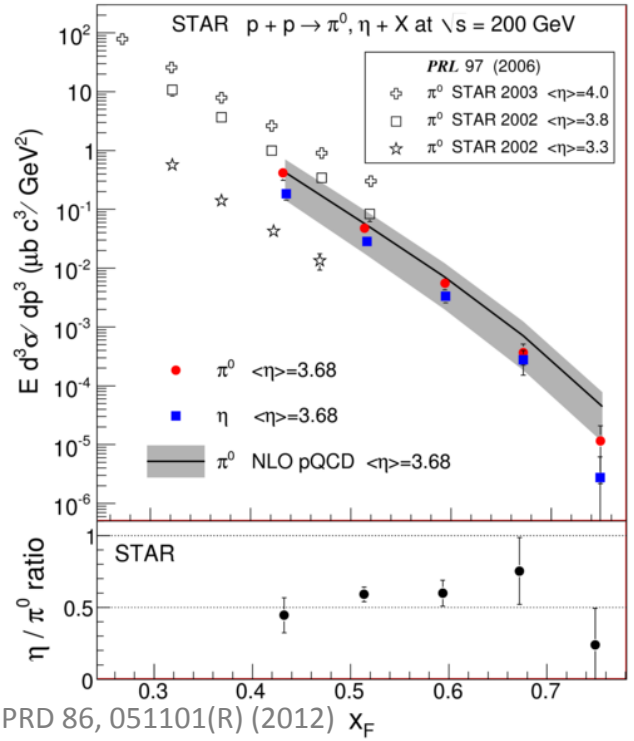
Inclusive Hadron Production at STAR



PRD 80, 111108(R) (2009)



PRD 89, 012001 (2014)



PRD 86, 051101(R) (2012)

Inclusive π^0 production at $\sqrt{s} = 200$ GeV measured over three ranges of pseudorapidity at STAR

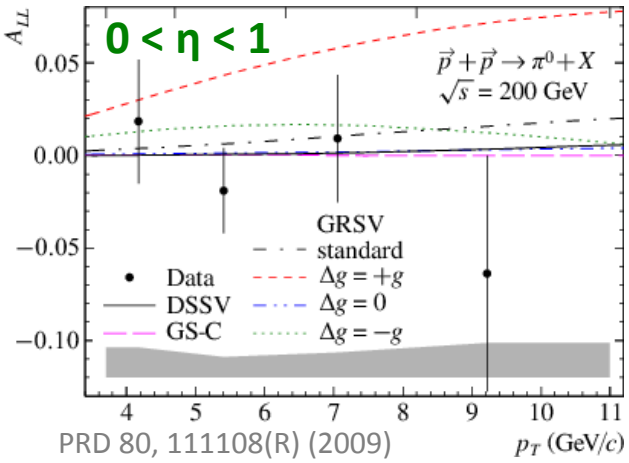
All in agreement with NLO pQCD predictions (DSS Frag. Func.)

→ **Important benchmark for asymmetry studies**

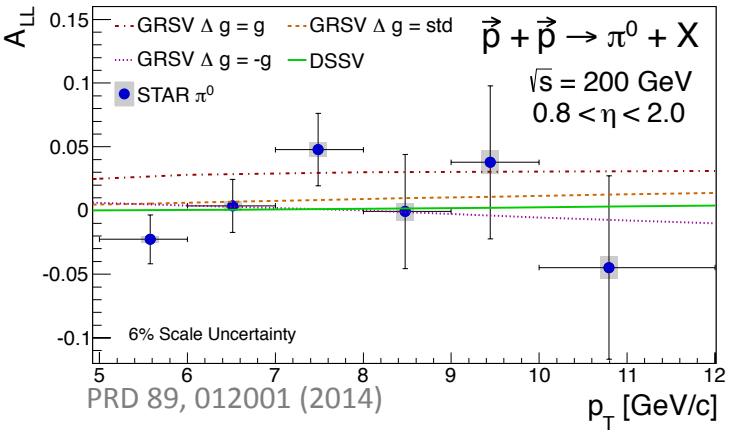
(*Inclusive jet cross section at 200 GeV also found in agreement with NLO pQCD*)

PRL 97, 252001 (2006)

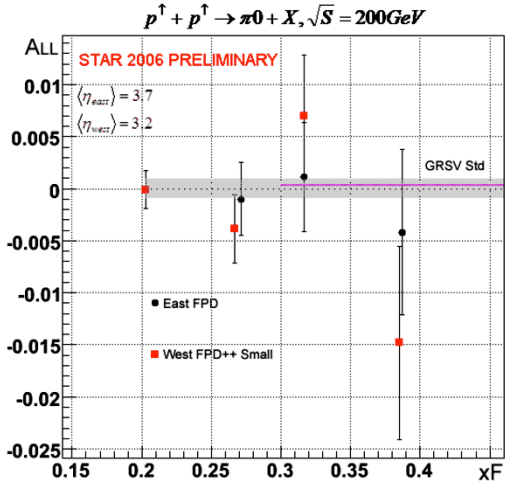
Probing Gluon Polarization with Inclusive Hadrons



PRD 80, 111108(R) (2009)



PRD 89, 012001 (2014)

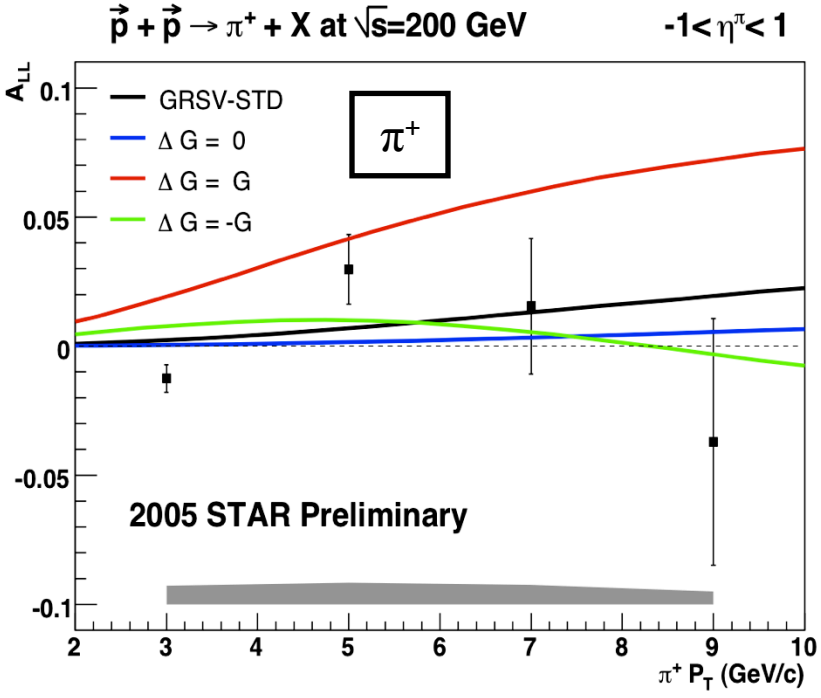


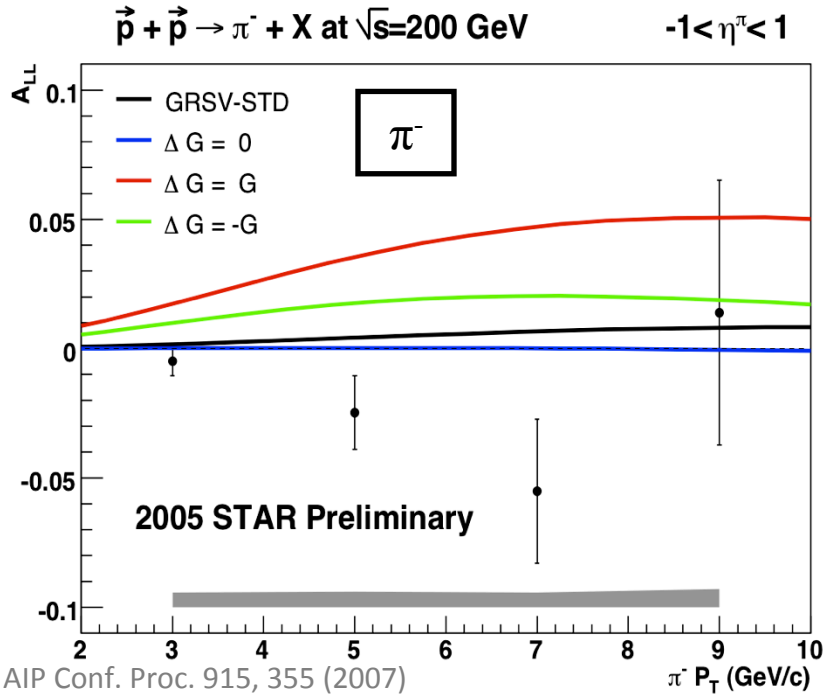
S. Wissink, Spin 2008

A_{LL} for Inclusive π^0 production at $\sqrt{s} = 200$ GeV measured over three ranges of pseudorapidity at STAR

- Complementary to STAR jet measurements
- Expect A_{LL} to decrease with increasing pseudorapididty
- Current statistics dominated by 2005/2006 datasets
- Higher-statistics datasets under investigation

STAR Longitudinal Asymmetries from Inclusive Hadrons

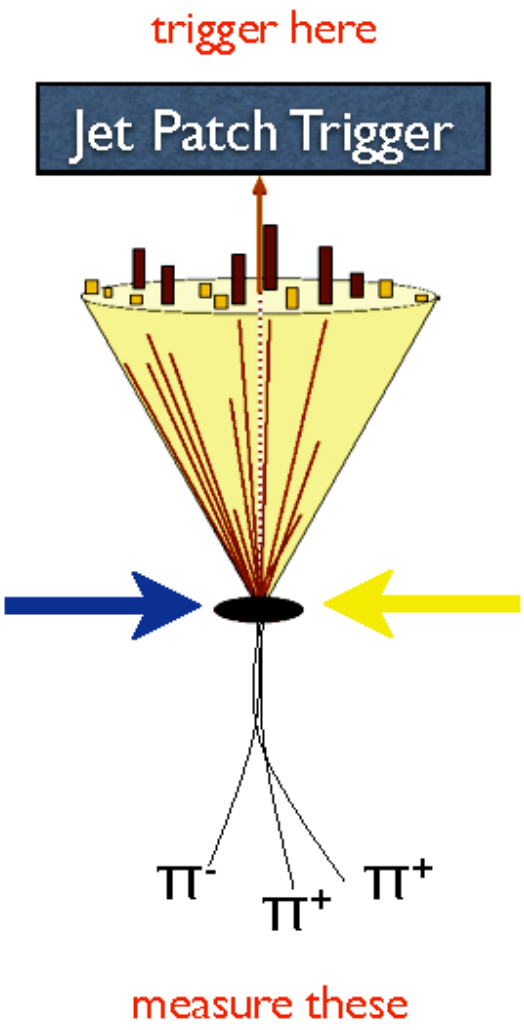


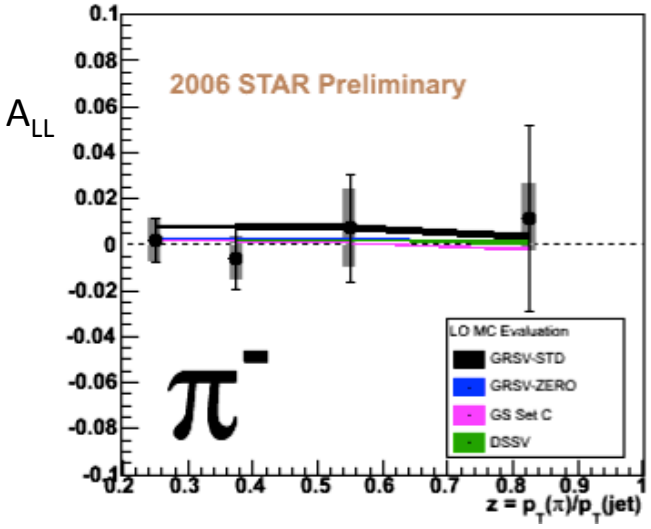


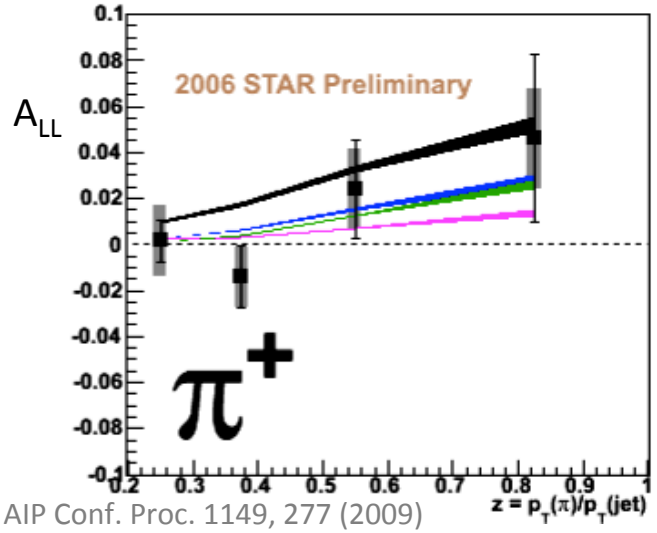
AIP Conf. Proc. 915, 355 (2007)

- STAR measured A_{LL} for inclusive charged pions during 2005
- $A_{LL}(\pi^{+}) - A_{LL}(\pi^{-})$ is sensitive to the sign of ΔG
- **Difficult to trigger on charged pions**
- Used the E/M calorimeter jet patch trigger as a surrogate
  → **significant trigger bias** (*dominates syst. error band*)

STAR Longitudinal Asymmetries from ~~Inclusive~~ Hadrons





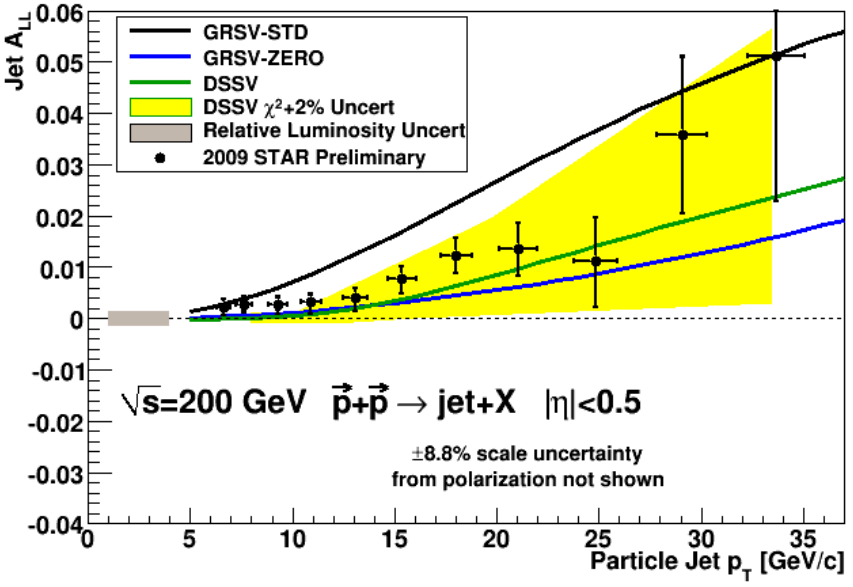


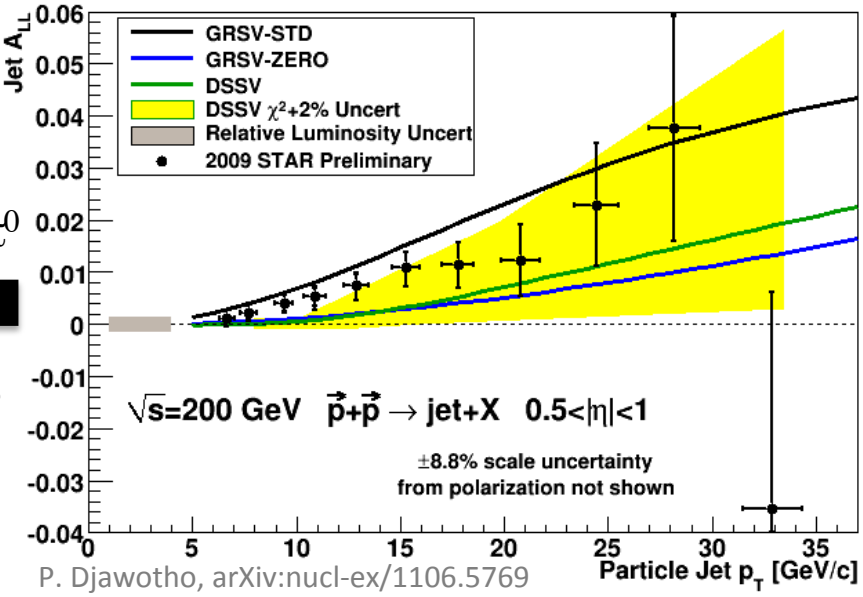
AIP Conf. Proc. 1149, 277 (2009)

- Making lemons into lemonade
  → *Beat the trigger bias by using it*
- Trigger and reconstruct a jet, then look for a charged pion on the opposite side
- Correlation measurement significantly increases the sensitivity of $A_{LL}(\pi^+)$

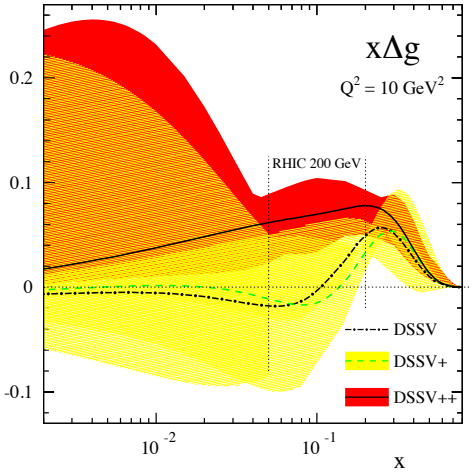
Probing Gluon Polarization with Inclusive Jets

- 2009 A_{LL} → two pseudorapidity ranges
- **Forward jets (0.5 < η < 1):**
  - Larger fraction of q-g scattering with
    - Higher *x* quarks that are more polarized
    - Lower *x* gluons that are less polarized
  - Larger |cos(θ*)| → reduced $\hat{a}_{LL}$
- A_{LL} falls between the predictions from **DSSV** and **GRSV-STD**
- First experimental evidence of **non-zero Δg(x)** in range 0.05 ≤ x ≤ 0.2





P. Djawotho, arXiv:nucl-ex/1106.5769



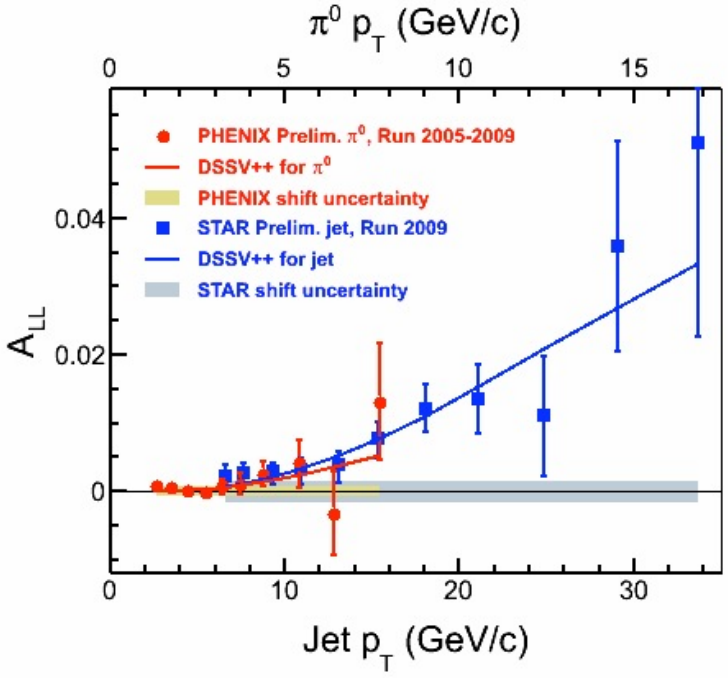
2009 STAR Jets + PHENIX π^0

$$\int_{0.05}^{0.20} \Delta g(x)\,dx = 0.10^{+0.06}_{-0.07}$$

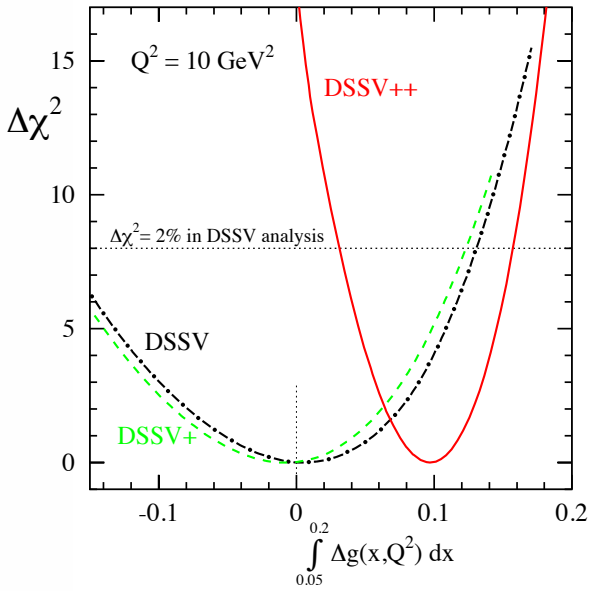
with $Q^2 = 10\ \mathrm{GeV}^2$

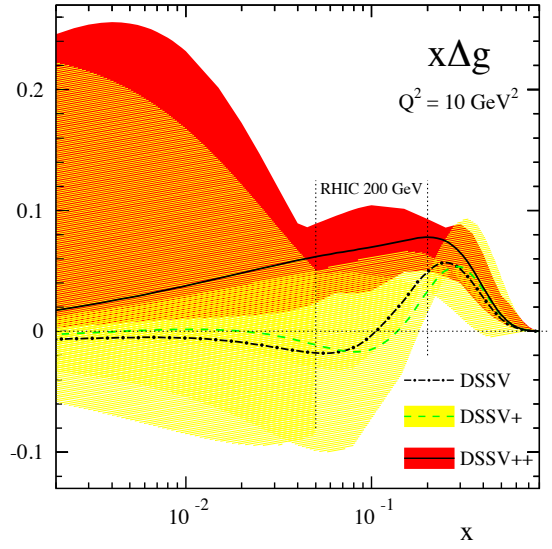
arXiv:nucl-ex/1304.0079

Global analysis with 2009 RHIC data



arXiv:nucl-ex/1304.0079





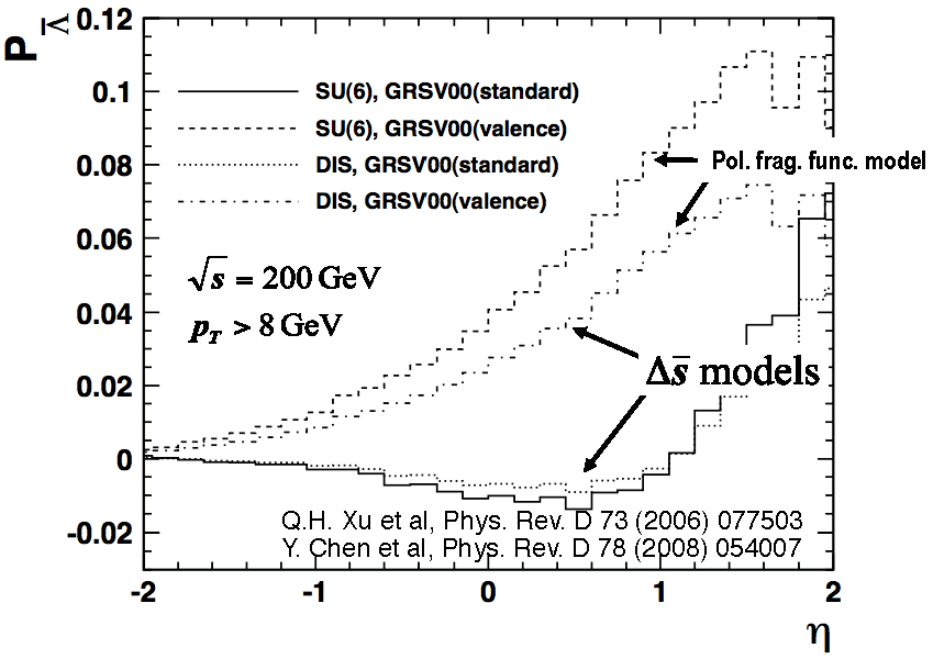
- **DSSV++** is a preliminary global analysis from the DSSV group that includes the 2009 RHIC A_{LL} data (STAR inclusive jets and PHENIX π⁰'s)

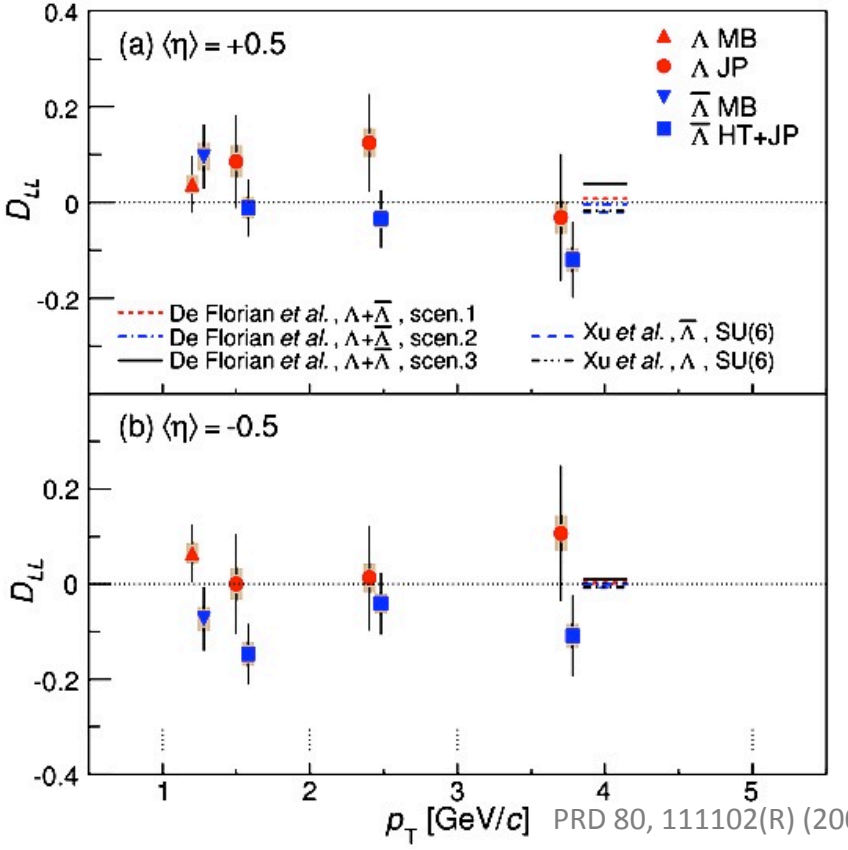
$$\int_{0.05}^{0.20} \Delta g(x, Q^2 = 10\ \mathrm{GeV}^2)\,dx = 0.10^{+0.06}_{-0.07}$$

- First experimental evidence of **non-zero Δg(x)** in range 0.05 ≤ x ≤ 0.2

Probing Strange Quark Polarization with Hyperons

$$D_{LL}^{\Lambda} \equiv \frac{\sigma_{p^+p\to\Lambda^+X} - \sigma_{p^+p\to\Lambda^-X}}{\sigma_{p^+p\to\Lambda^+X} + \sigma_{p^+p\to\Lambda^-X}} = P_{\Lambda}^{+}$$





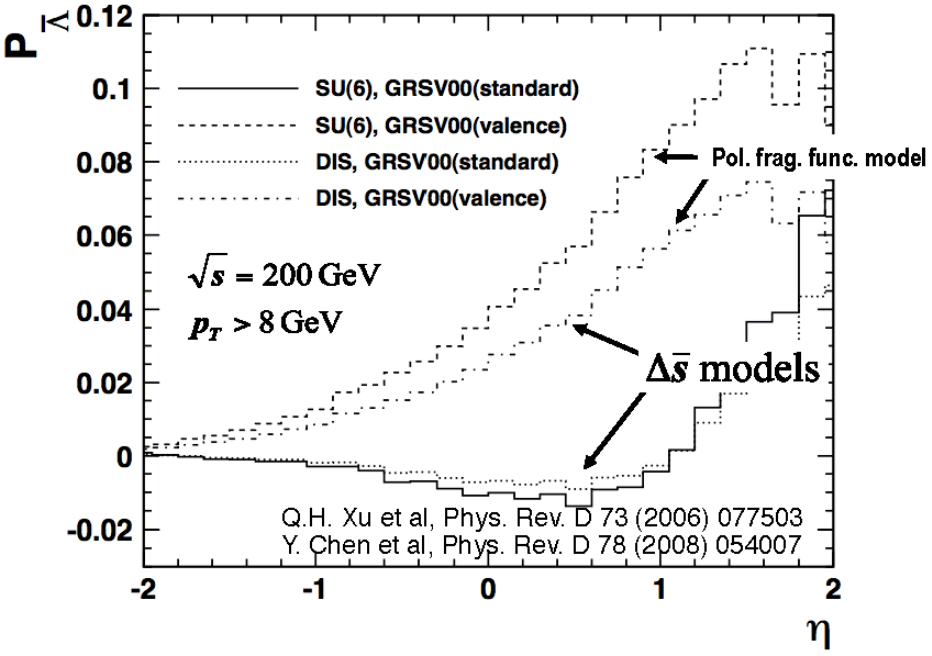
PRD 80, 111102(R) (2009)

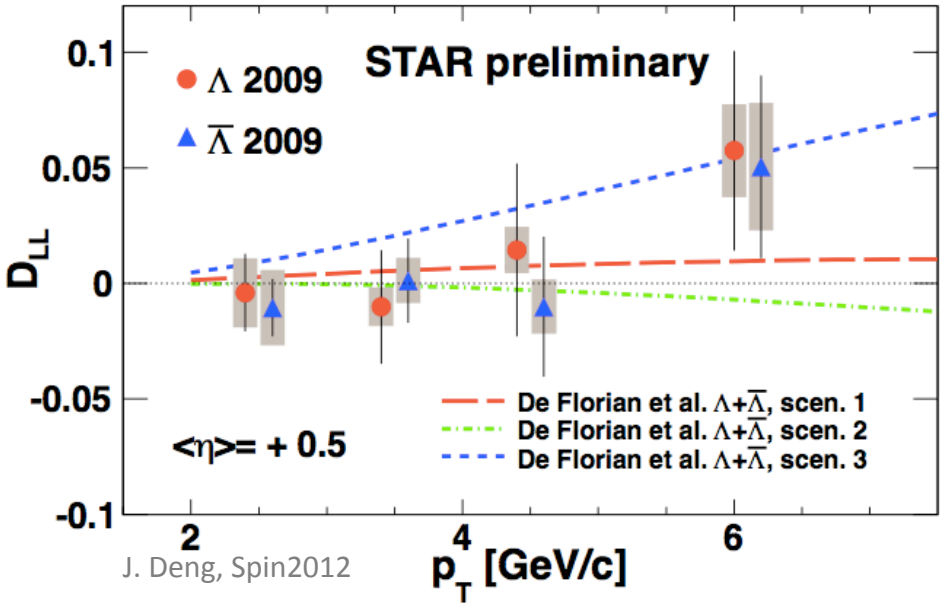
Outgoing $\bar{\Lambda}$ polarization is particularly sensitive to $\Delta\bar{s}$

Proof of principle measurement with 2005 data

Probing Strange Quark Polarization with Hyperons

$$D_{LL}^{\Lambda} \equiv \frac{\sigma_{p^+p\to\Lambda^+X} - \sigma_{p^+p\to\Lambda^-X}}{\sigma_{p^+p\to\Lambda^+X} + \sigma_{p^+p\to\Lambda^-X}} = P_{\Lambda}^{+}$$





Outgoing $\bar{\Lambda}$ polarization is particularly sensitive to $\Delta\bar{s}$

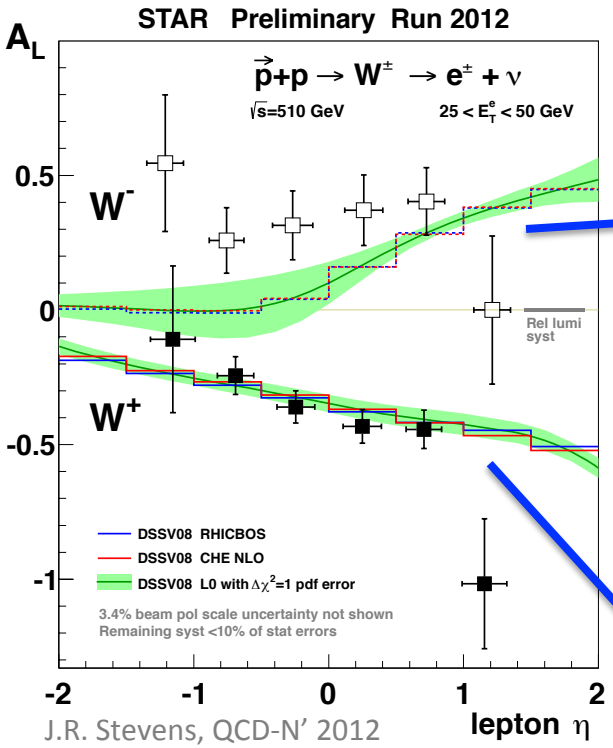
Proof of principle measurement with 2005 data

Higher statistics (factor~4-5) with higher p_T in 2009 data

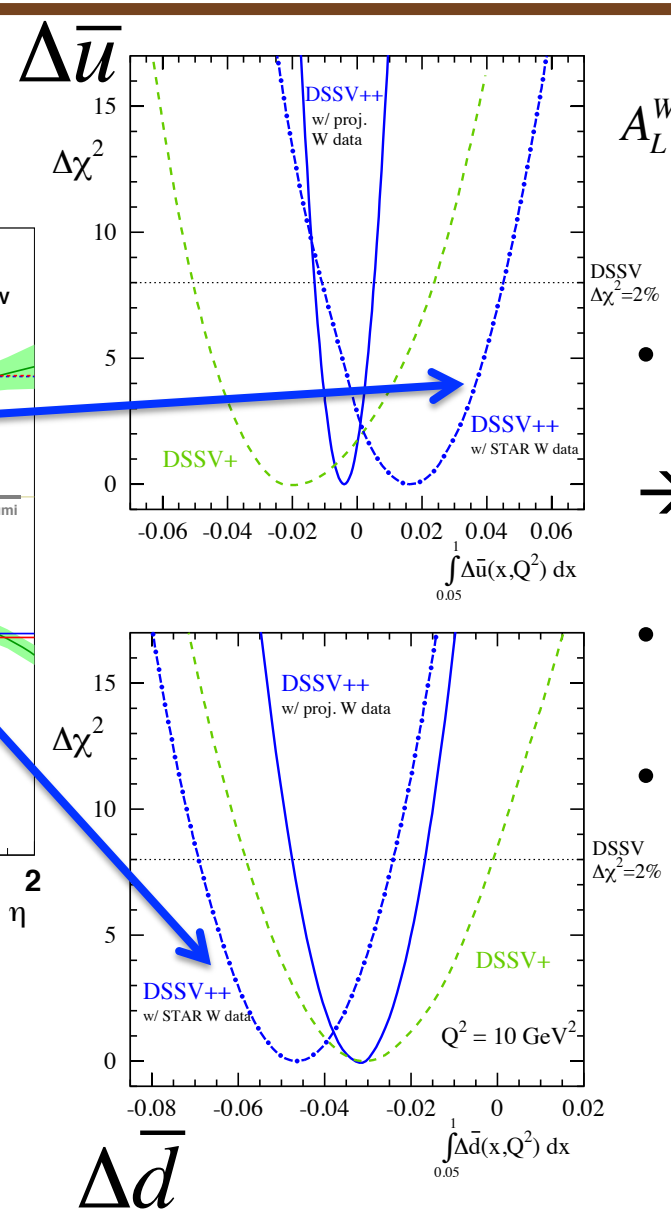
2013 data provide opportunity for even higher precision

Probing Sea Quark Polarization with W±

arXiv:nucl-ex/1304.0079



J.R. Stevens, QCD-N' 2012



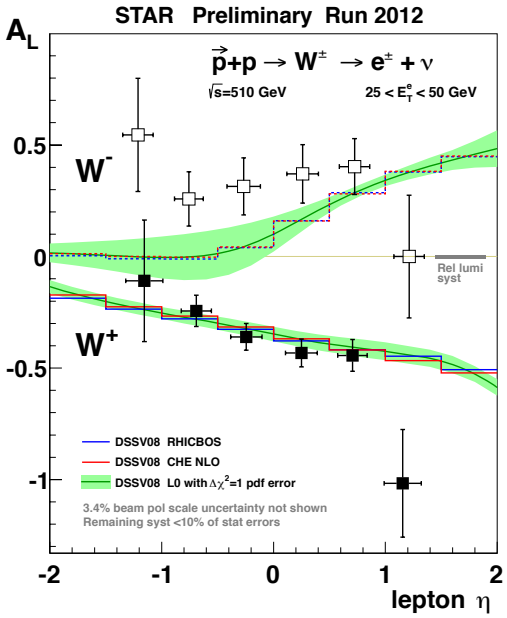
$$A_L^{W^-} \sim \frac{\Delta\bar{u}(x_1)d(x_2) - \Delta d(x_1)\bar{u}(x_2)}{\bar{u}(x_1)d(x_2) + d(x_1)\bar{u}(x_2)}$$

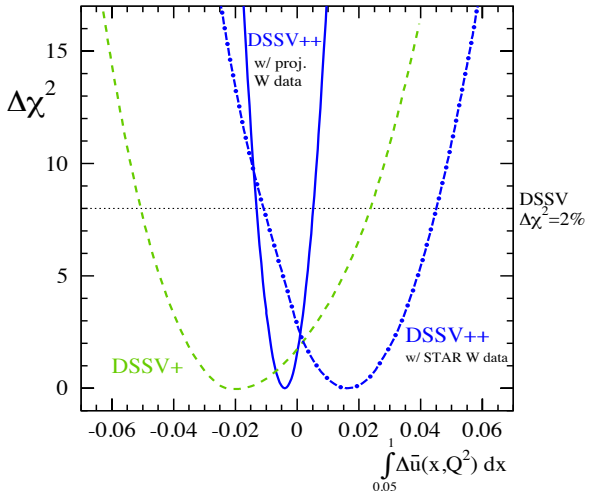
- $A_L(W^-)$ – ***systematically larger than DSSV***

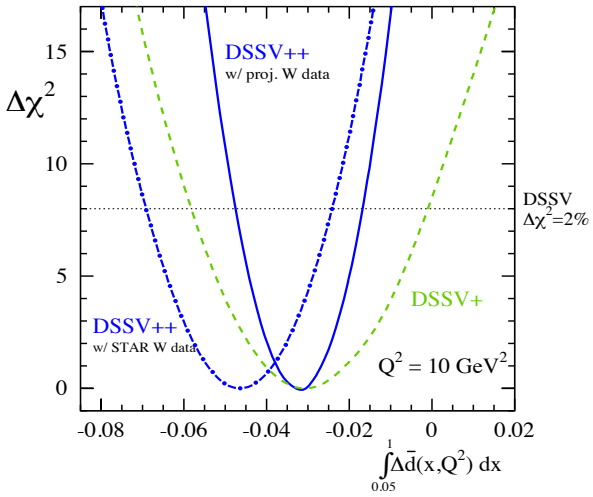
→ Enhancement at $\eta < 0$ sensitive to $\Delta\bar{u}$

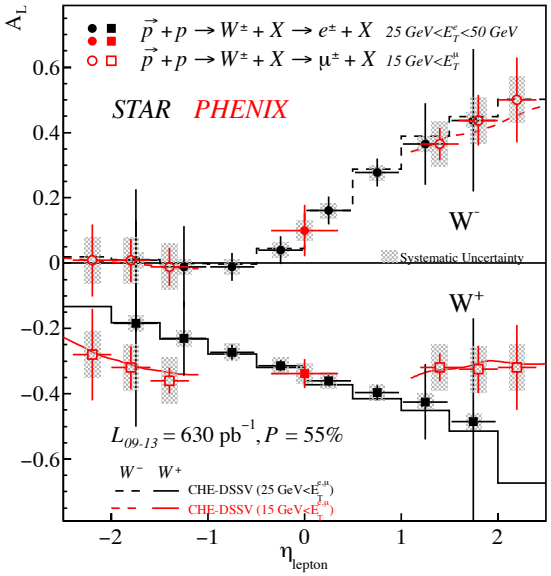
- $A_L(W^+)$ – ***consistent with DSSV***
- Systematics well under control for $|\eta_e| < 1.4$

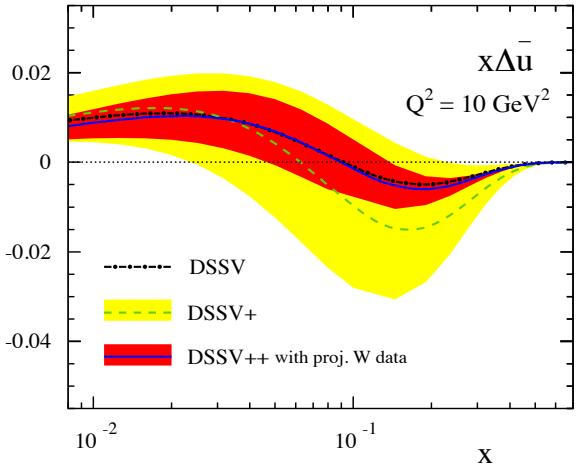
Probing Sea Quark Polarization with W±

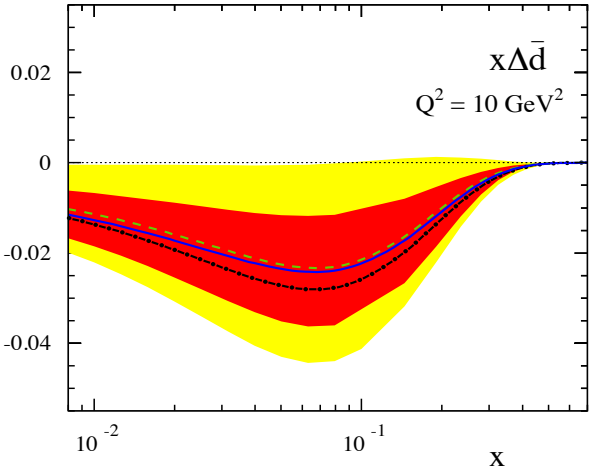




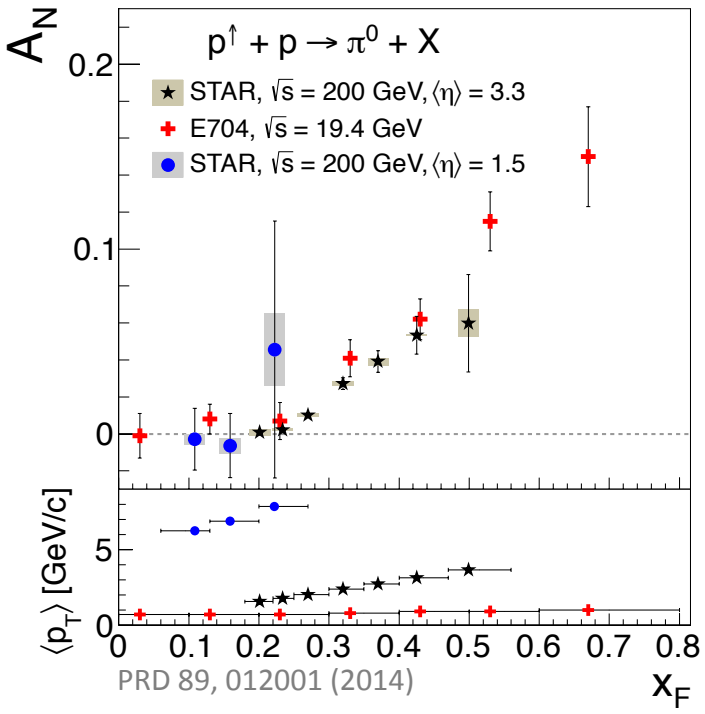


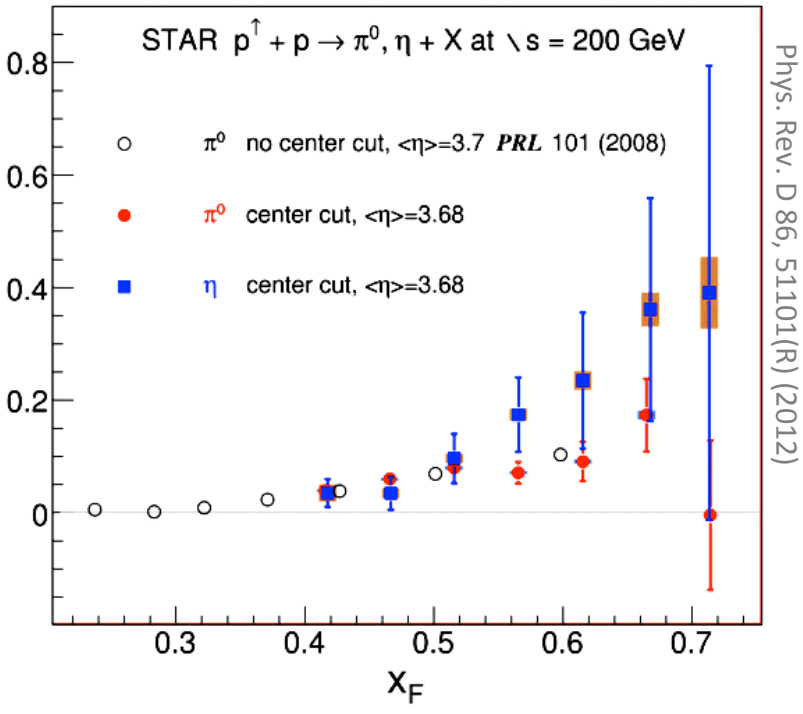






STAR Transverse Asymmetries from Inclusive Hadrons





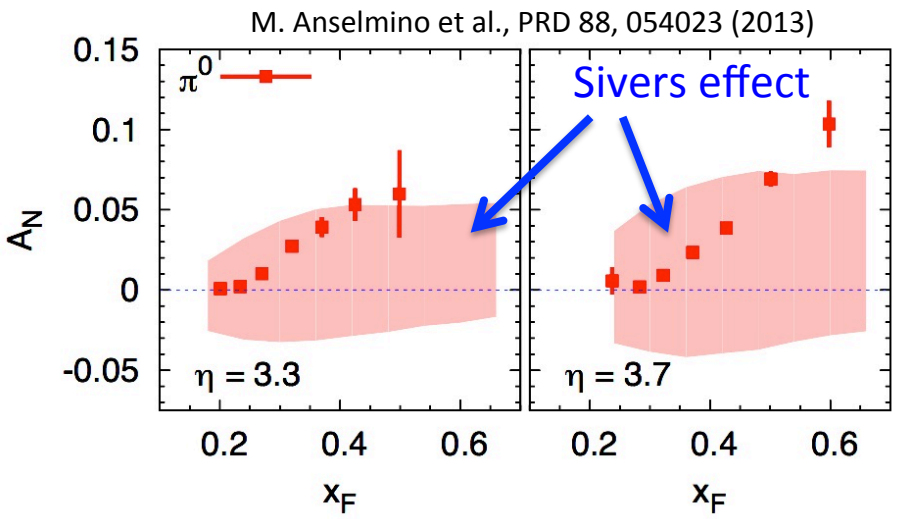
STAR has measured sizeable transverse single-spin asymmetries for forward π^0 and η production

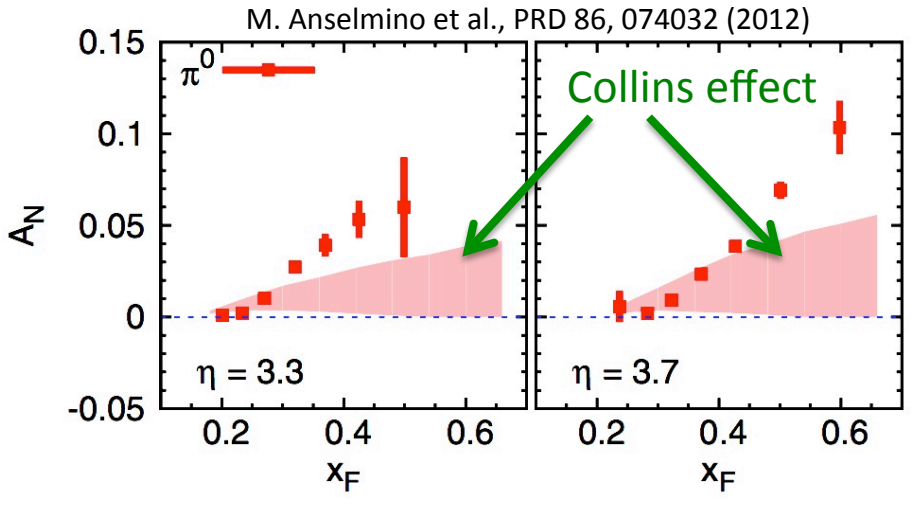
At high-x_F, η asymmetry may be larger than that of π^0

Asymmetries at intermediate pseudorapidity consistent with zero

Above results mostly from 2006 (6.8 pb^{-1} at 55% polarization)

STAR Transverse Asymmetries from Inclusive Hadrons





STAR data from PRL 101, 222001 (2008)

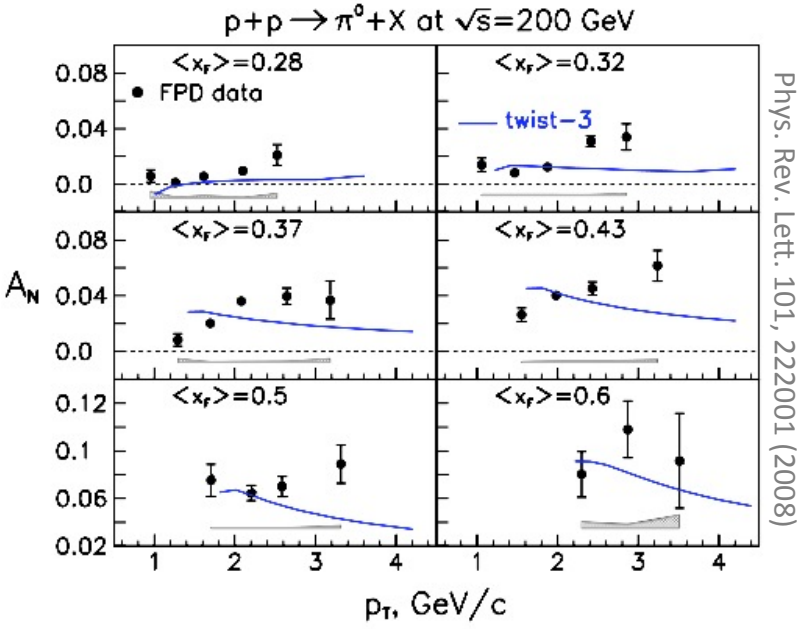
Current models based on fits to SIDIS and e^+e^-:

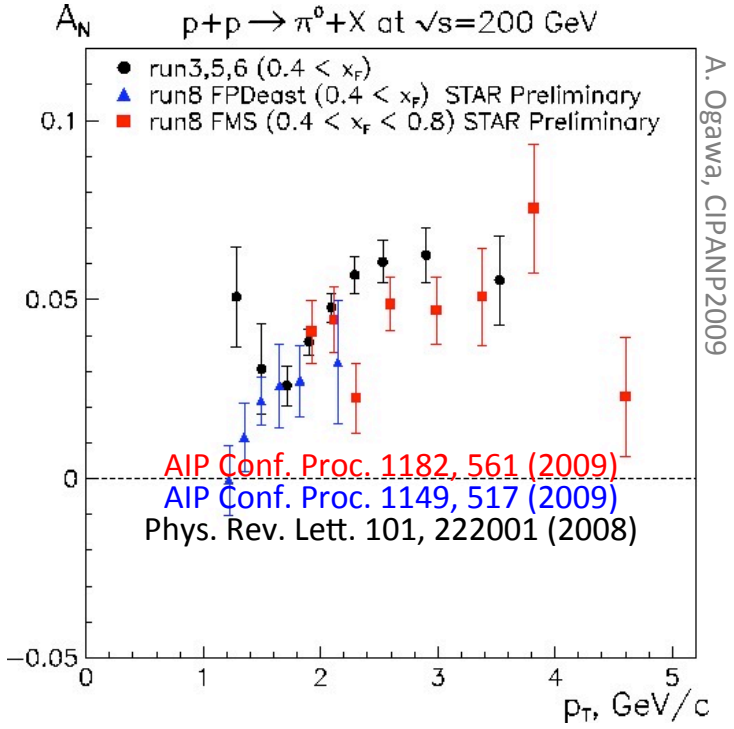
- *"The Collins effect…is not sufficient for the medium-large x_F range of STAR data, $x_F \gtrsim 0.3$"*
- *"…the Sivers effect alone might in principle be able to explain…almost the full amount of STAR π^0 data on A_N"*

Theoretical questions remain about applicability to p+p data of Sivers extractions from SIDIS

(*e.g. Kang et al., PRD 83, 094001 (2011)*)

STAR Transverse Asymmetries from Inclusive Hadrons

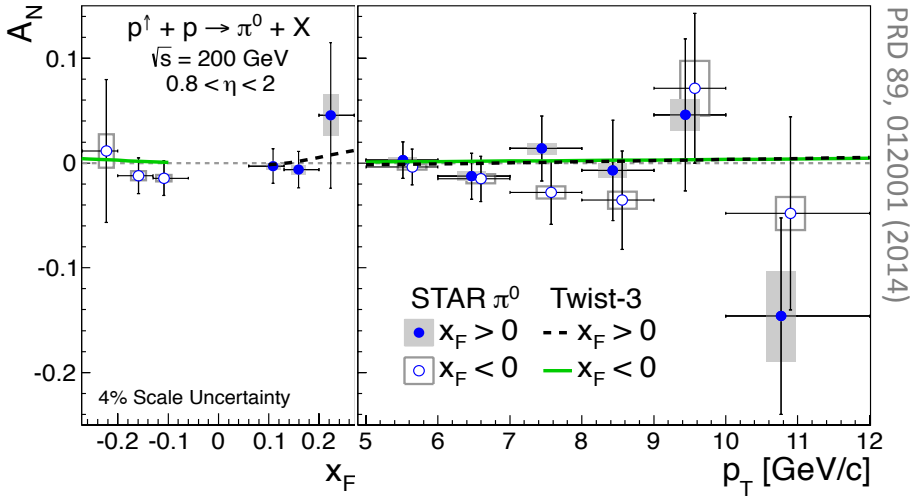




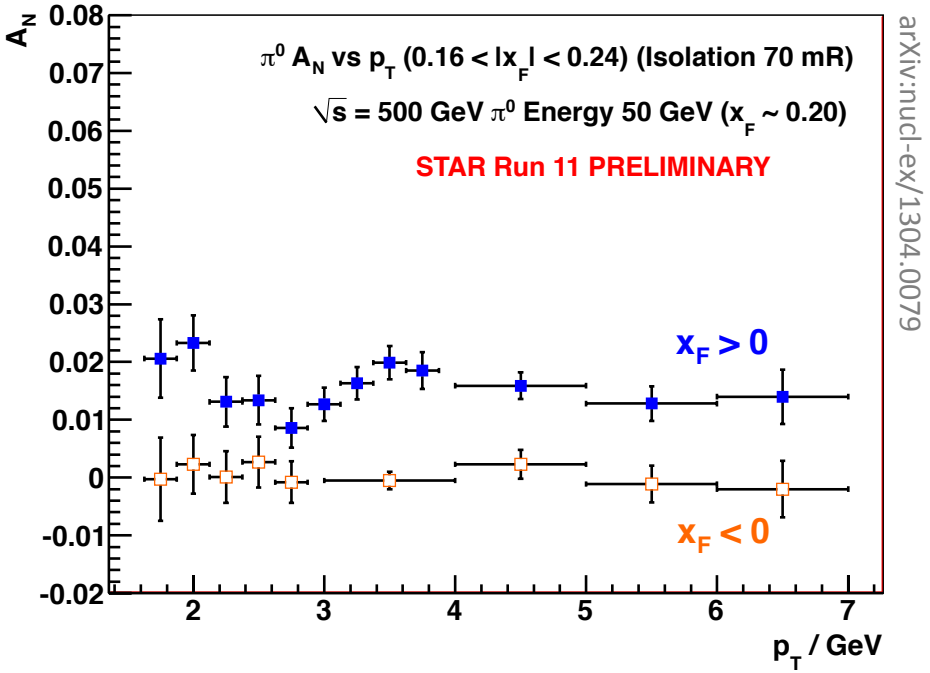
Despite expectation of $1/p_T$ scaling,
STAR data from 2003 to 2008 show

no sign of $1/p_T$ fall-off out to $p_T \sim 5$ GeV/c

STAR Transverse Asymmetries from Inclusive Hadrons



PRD 89, 012001 (2014)



arXiv:nucl-ex/1304.0079

Asymmetries at intermediate pseudorapidity at $\sqrt{s} = 200$ GeV:

consistent with zero for $5 < p_T < 12$ GeV/c

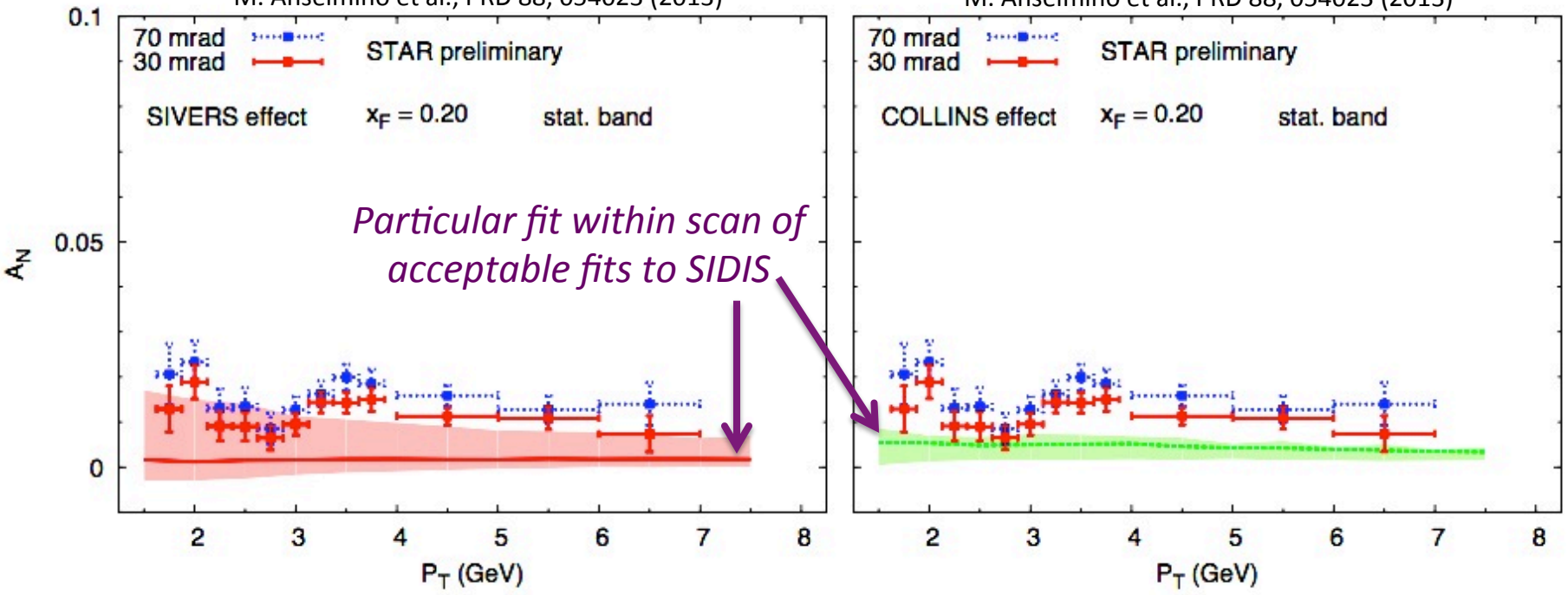
STAR data from 2011 at $\sqrt{s} = 500$ GeV:

no sign of $1/p_T$ fall-off out to $p_T \sim 10$ GeV/c

(*consistent across multiple x_F-bins*)

STAR Transverse Asymmetries from Inclusive Hadrons

M. Anselmino et al., PRD 88, 054023 (2013)



Particular fit within scan of acceptable fits to SIDIS

M. Anselmino et al., PRD 88, 054023 (2013)

Recent models based on SIDIS fits suggest flat p_T-dependence for **Sivers effect** out to $p_T \sim 7$ GeV/c but at

lower magnitude than data

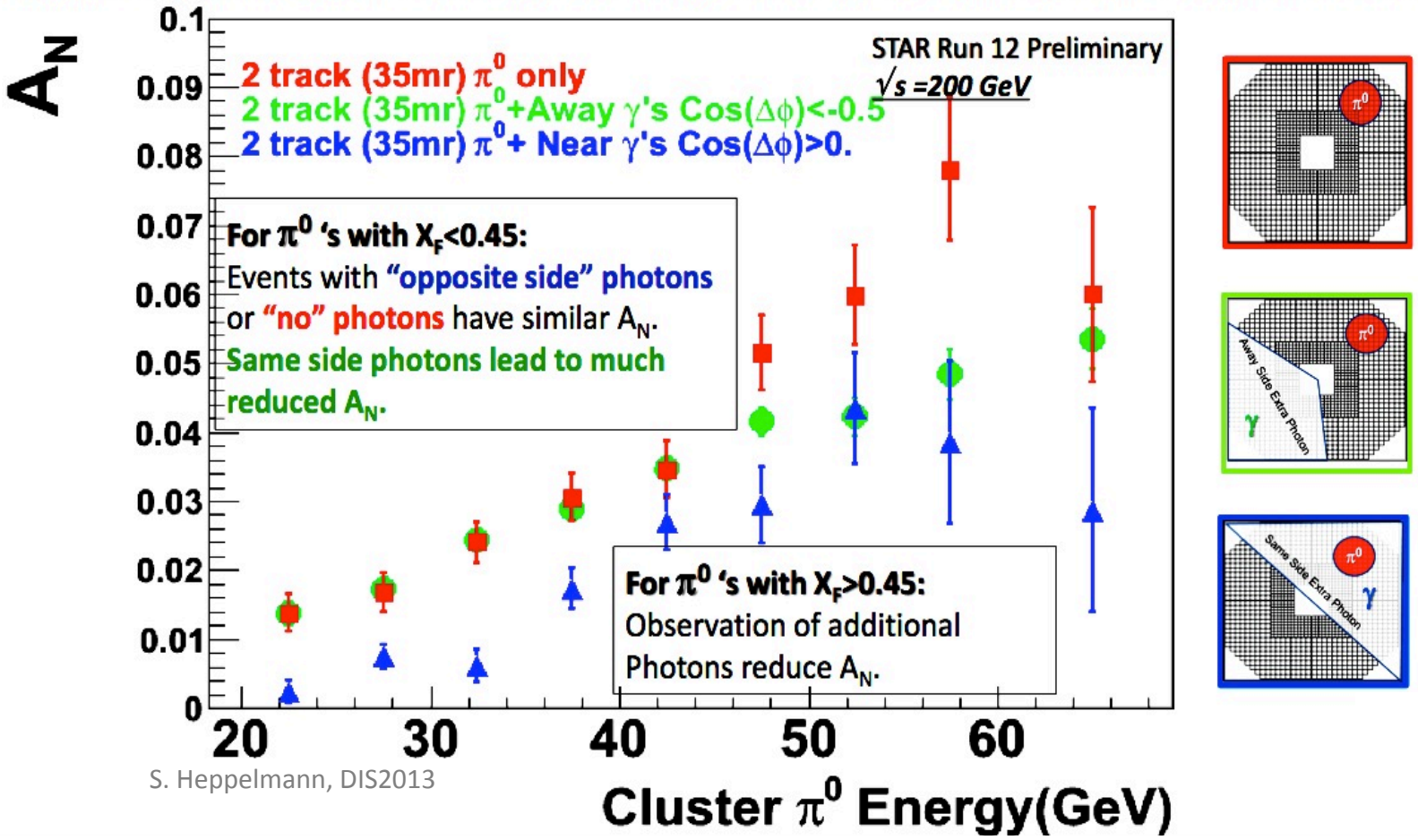
Similar behavior for **Collins effect** in some parameterizations

→ ***possible hint of Collins+Sivers effect?***

Twist-3 models also see flat p_T dependence out to $p_T \sim 15$ GeV/c

e.g. Kanazawa and Koike, PRD 83, 114024 (2011)

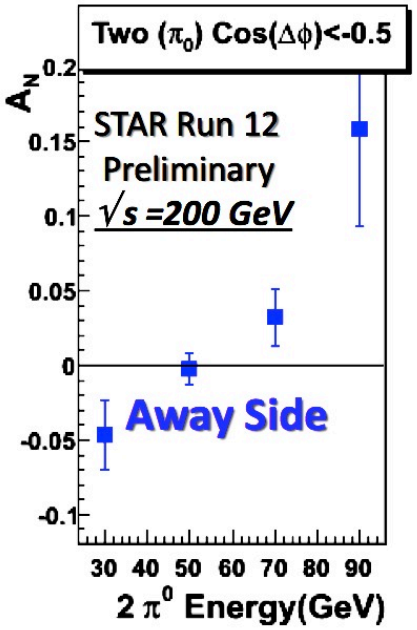
STAR Transverse Asymmetries from Inclusive Hadrons

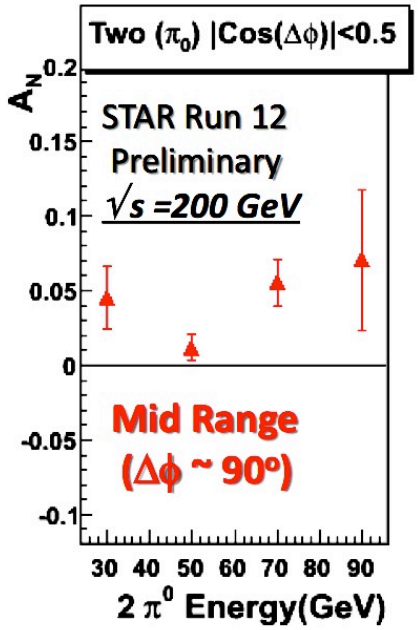


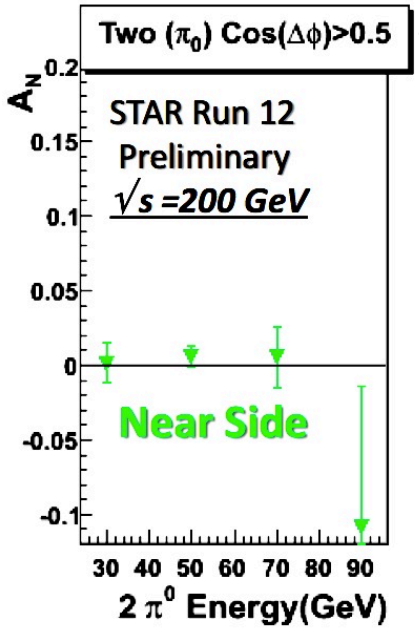
S. Heppelmann, DIS2013

Recent data from 2012 suggest that asymmetries for pions with additional near-side energy deposit have *lower asymmetries than those of more isolated pions*

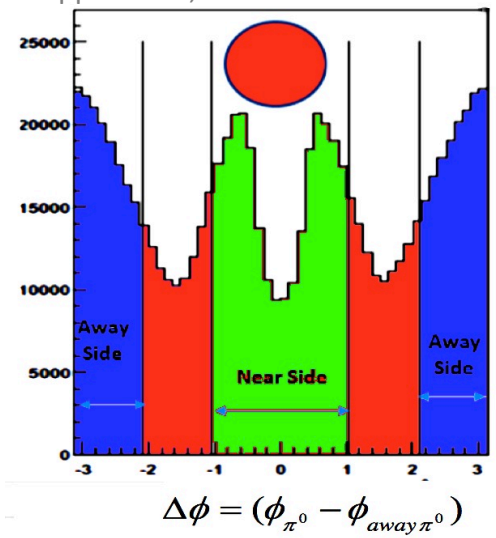
STAR Transverse Asymmetries from Inclusive Hadrons







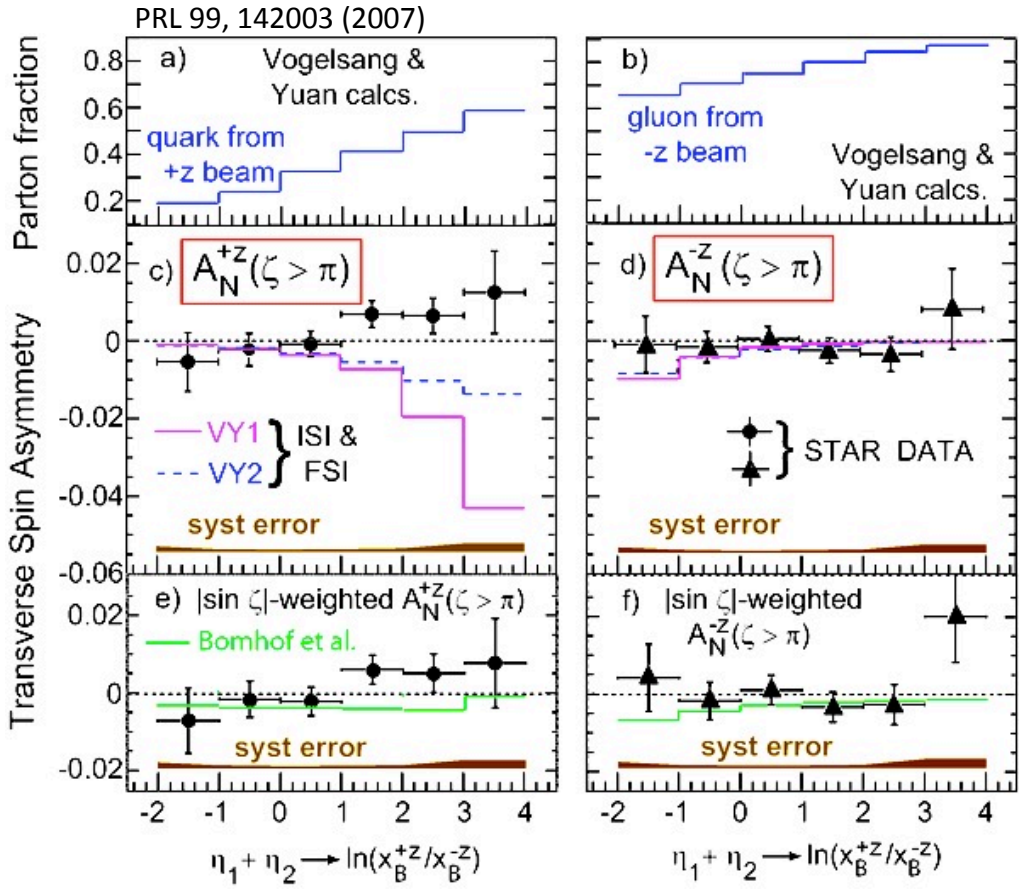
S. Heppelmann, DIS2013



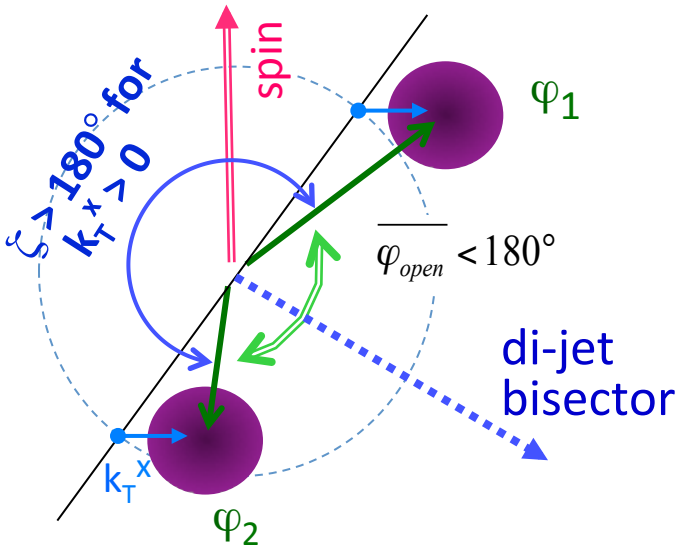
STAR data from 2012 at $\sqrt{s} = 200$ GeV:
asymmetries for pions with additional near-side pion have
lower asymmetries than those with away-side or mid-range pion

→ *In both* $\sqrt{s} = 200$ *and* 500 *GeV*
isolated pions show higher asymmetry than jet-like pions
Forward neutral-energy jet analysis of 2011 ongoing (M. Mondal, GHP2013)

STAR Transverse Asymmetries at Central Pseudorapidity



Sivers effect in di-jet production



- Spin-dependent sideways boost to di-jets
- Measure di-jet opening angle as function of proton spin
- *Requires parton orbital angular momentum*

Observed di-jet asymmetries much smaller than observed at SIDIS

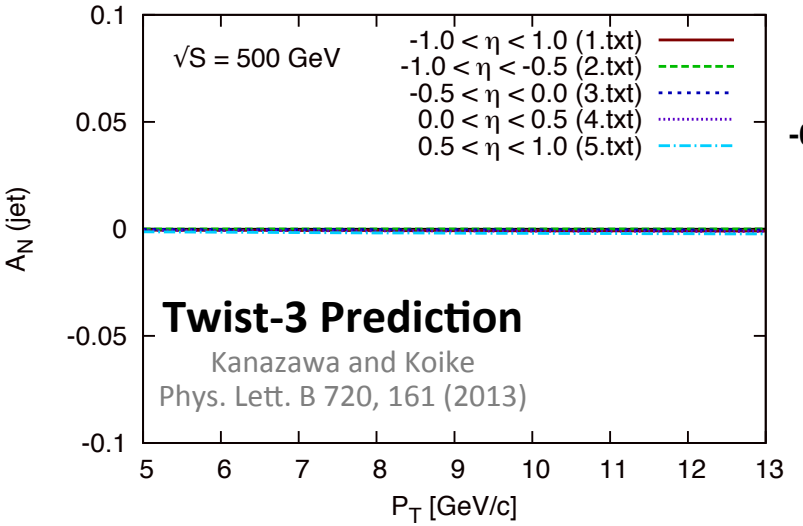
→ ***Cancellation of initial vs. final state interactions, u vs. d quark effects, and small gluon Sivers effect?***

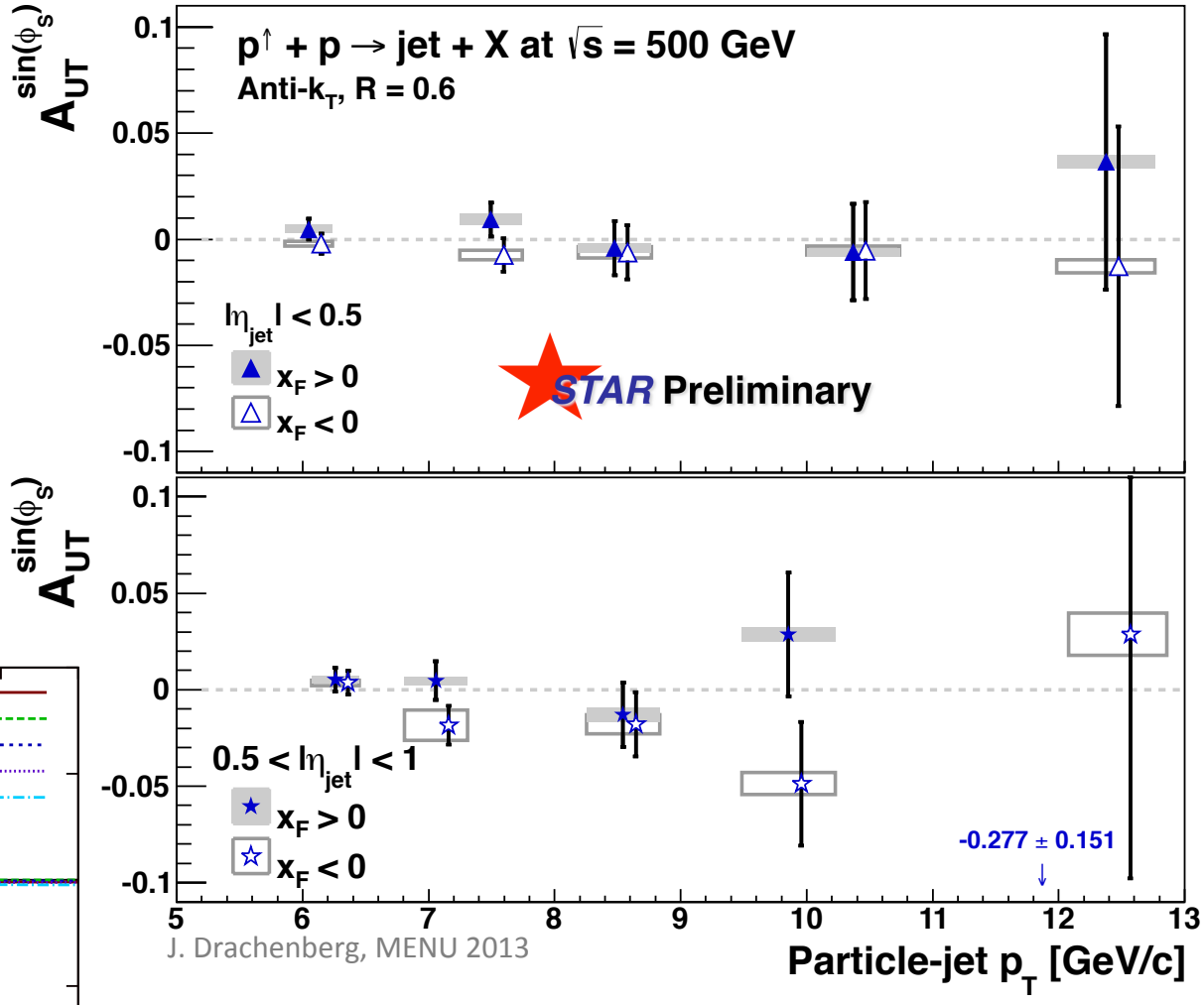
Sivers Asymmetries at 500 GeV

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

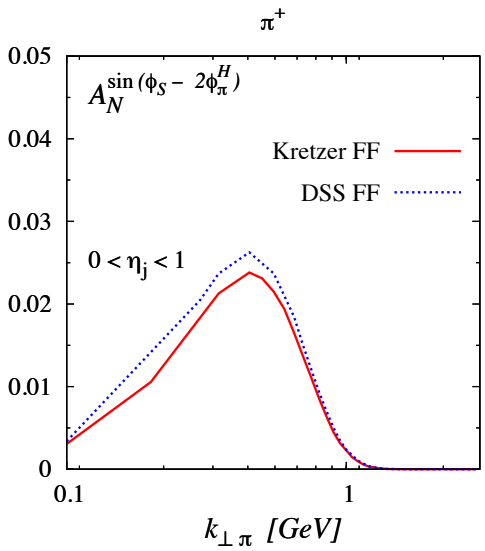


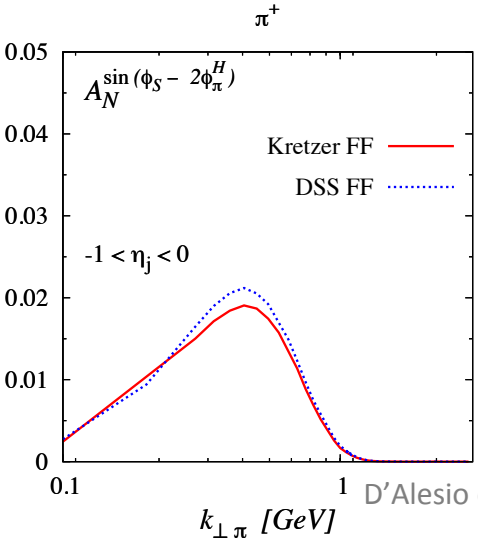


Measured asymmetries shown in η-bins

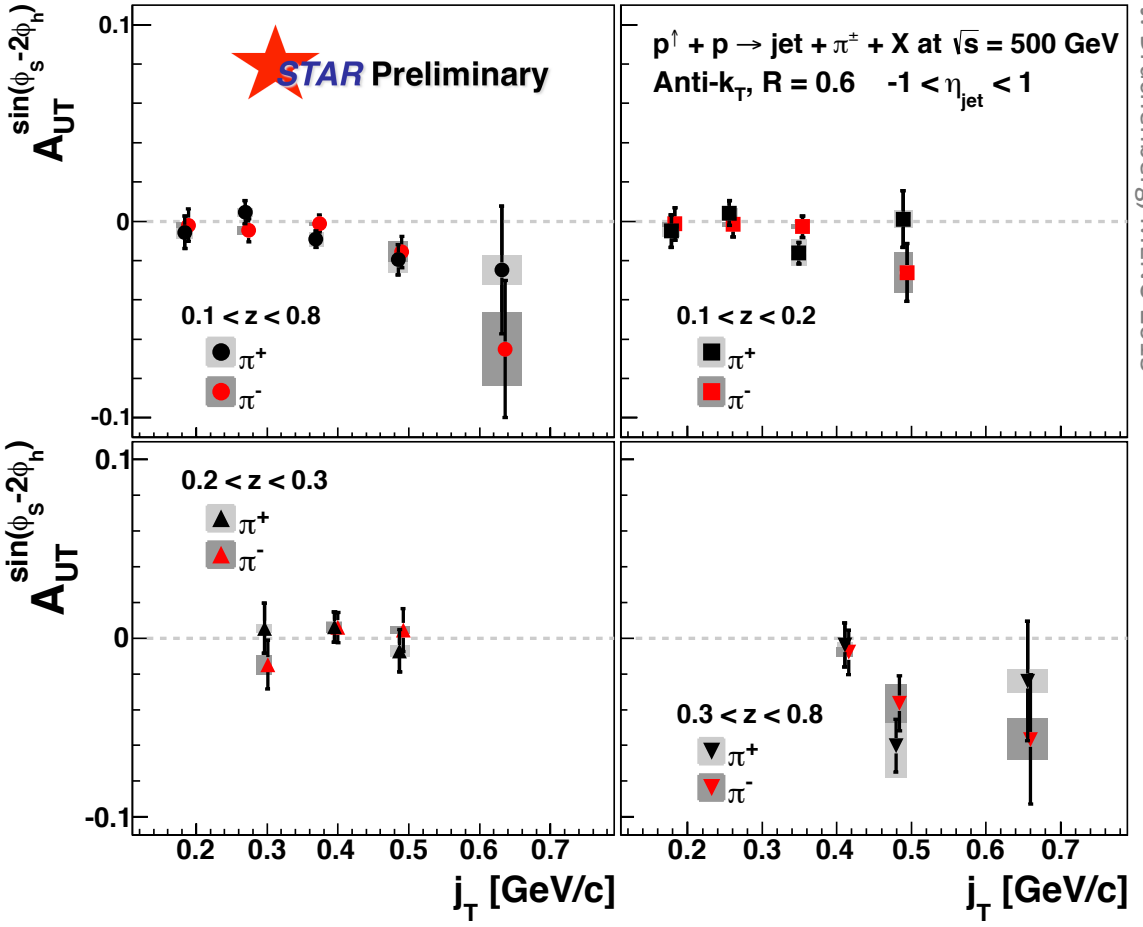
No sign of sizable asymmetry

Collins-like Asymmetries at 500 GeV





D'Alesio et al.

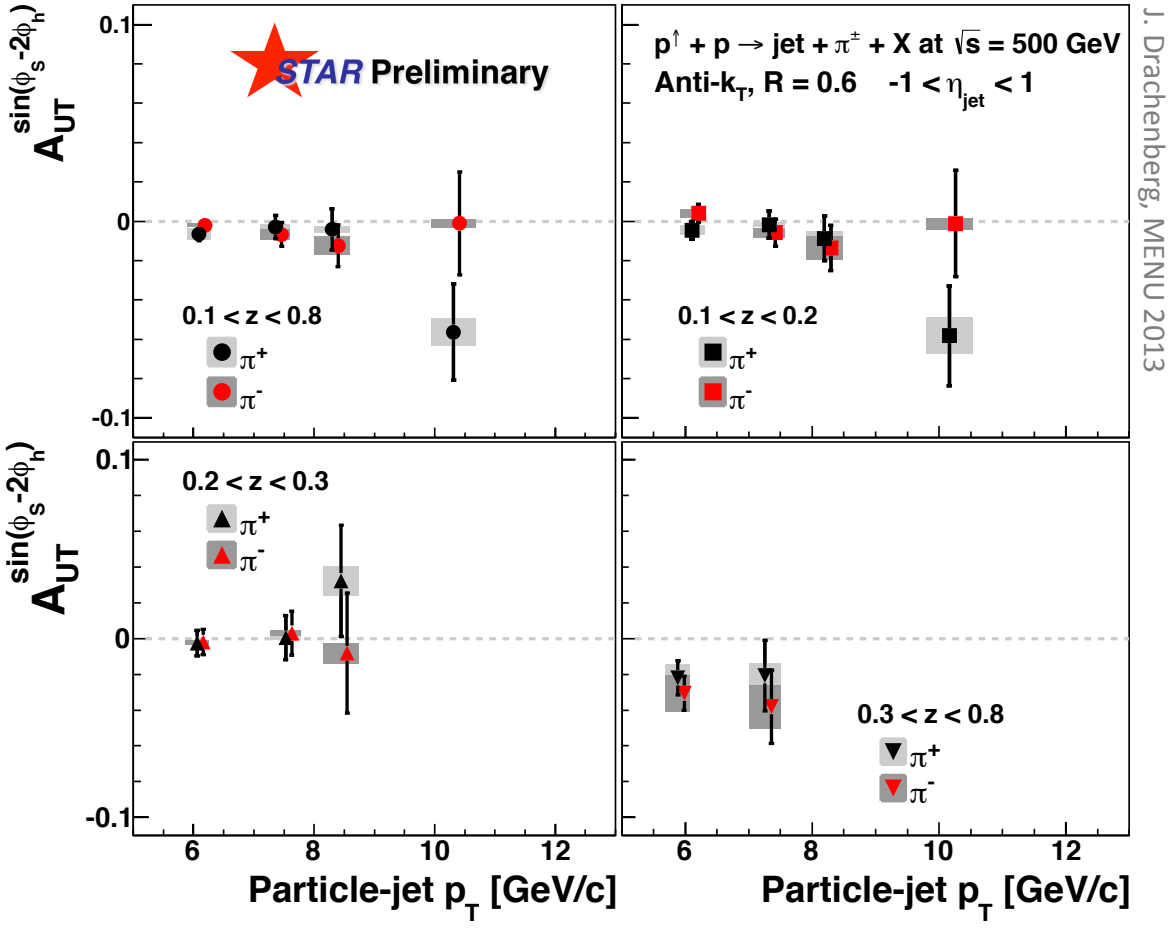


J. Drachenberg, MENU 2013

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

Consistently below 2% maximum from model

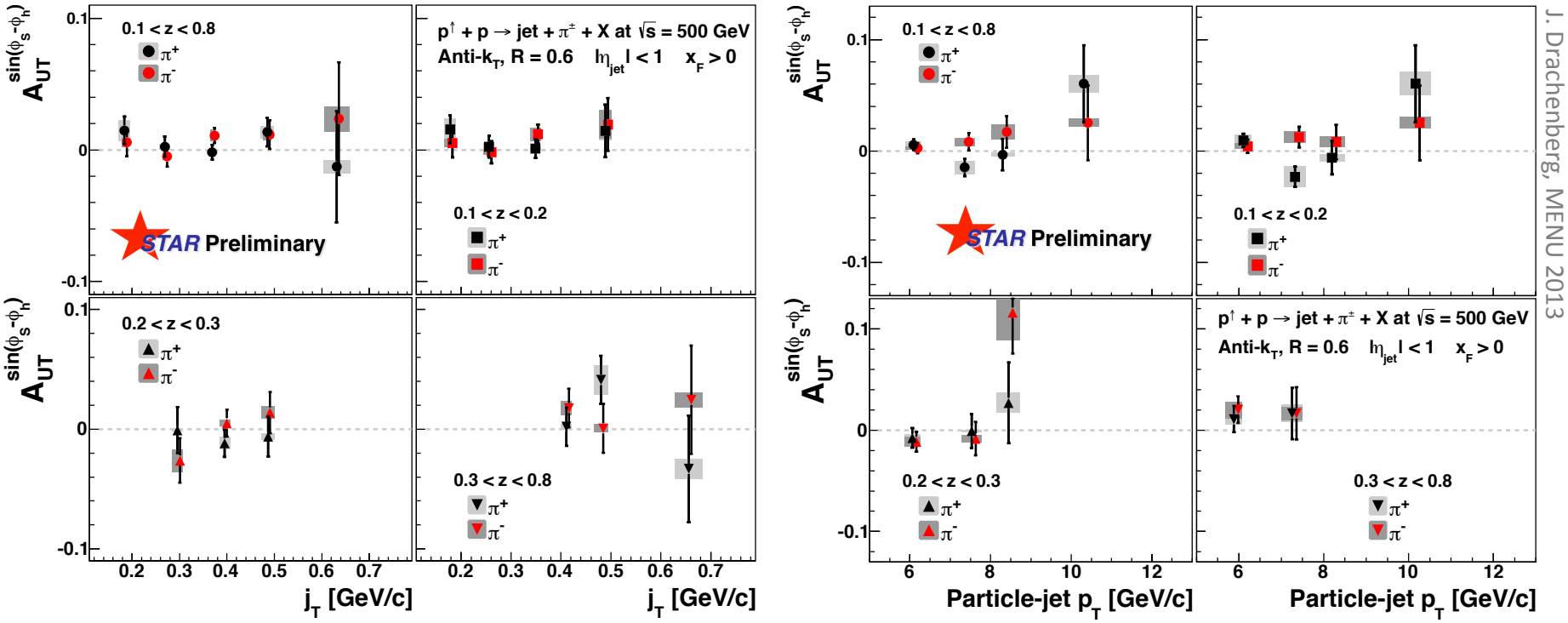
Collins-like Asymmetries at 500 GeV



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

Measured asymmetries shown for $-1 < \eta < 1$ in z-bins

Collins Asymmetries



J. Drachenberg, MENU 2013

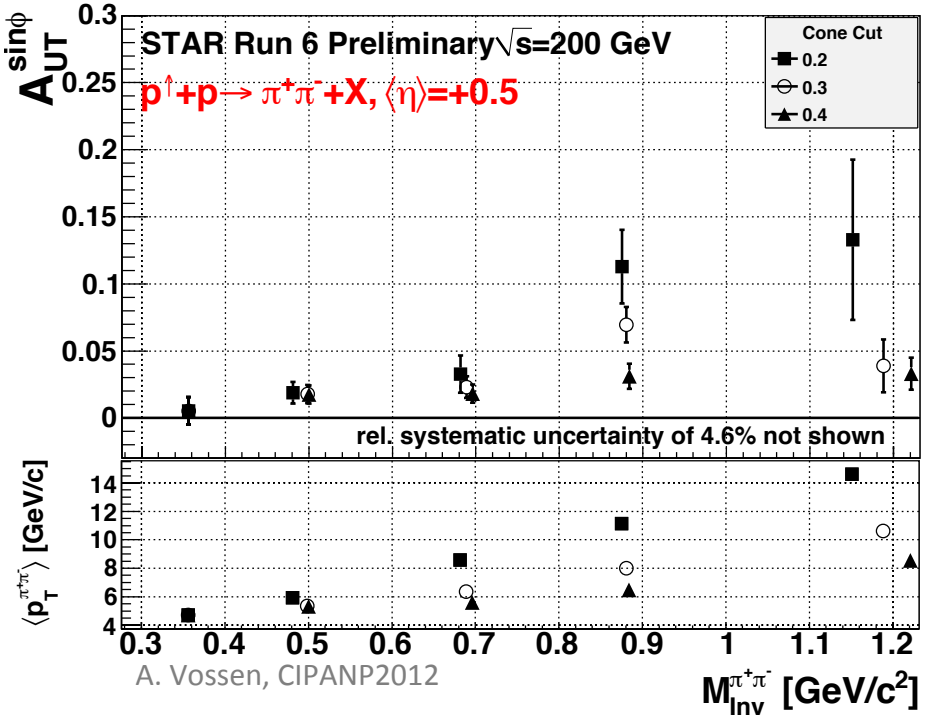
Present model predictions expect negligible effects for A_{UT} vs. j_T integrated over $z > 0.1$

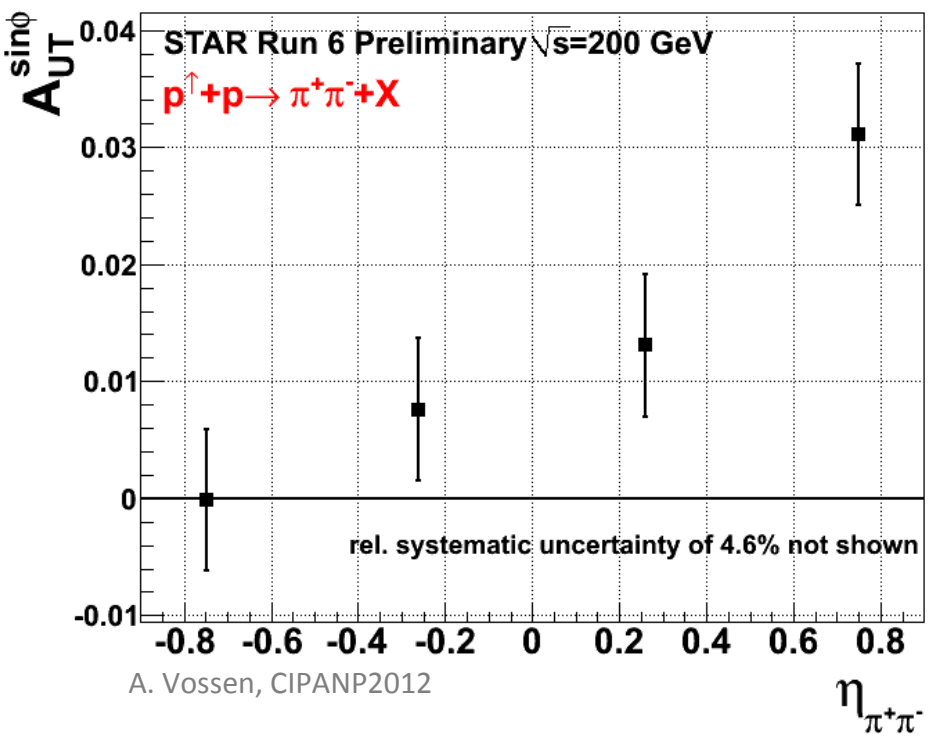
Measured asymmetries shown for $x_F > 0$ (i.e. $0 < \eta_{jet} < 1$) in z-bins

No sign of non-zero asymmetry as a function of j_T or jet p_T

Similarly, no sign of positive effect for backward region ($x_F < 0$), as expected

STAR Transverse Asymmetries from Di-hadrons

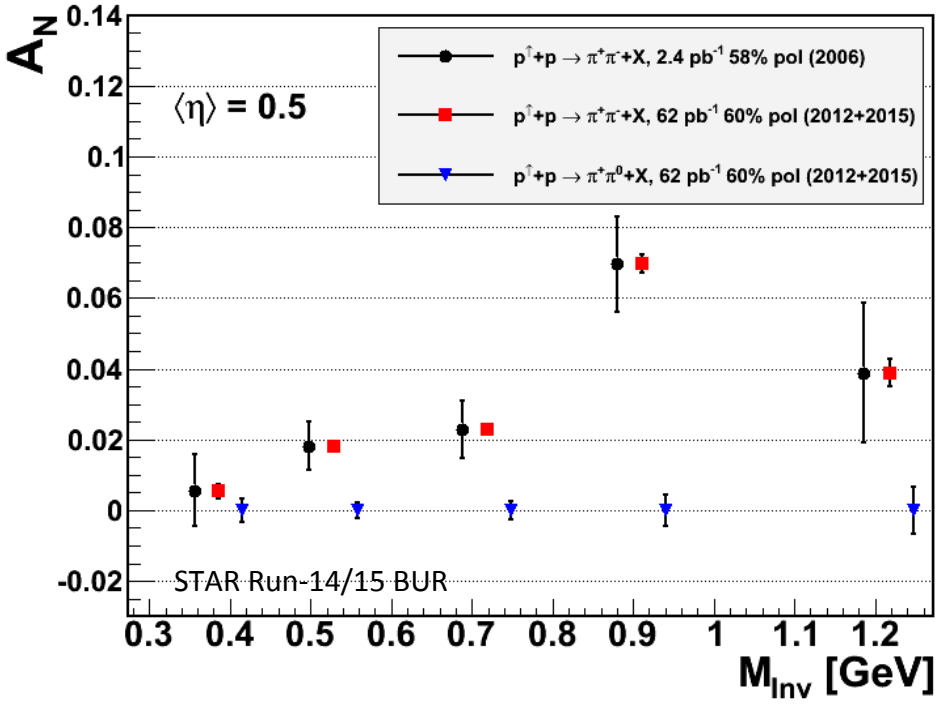


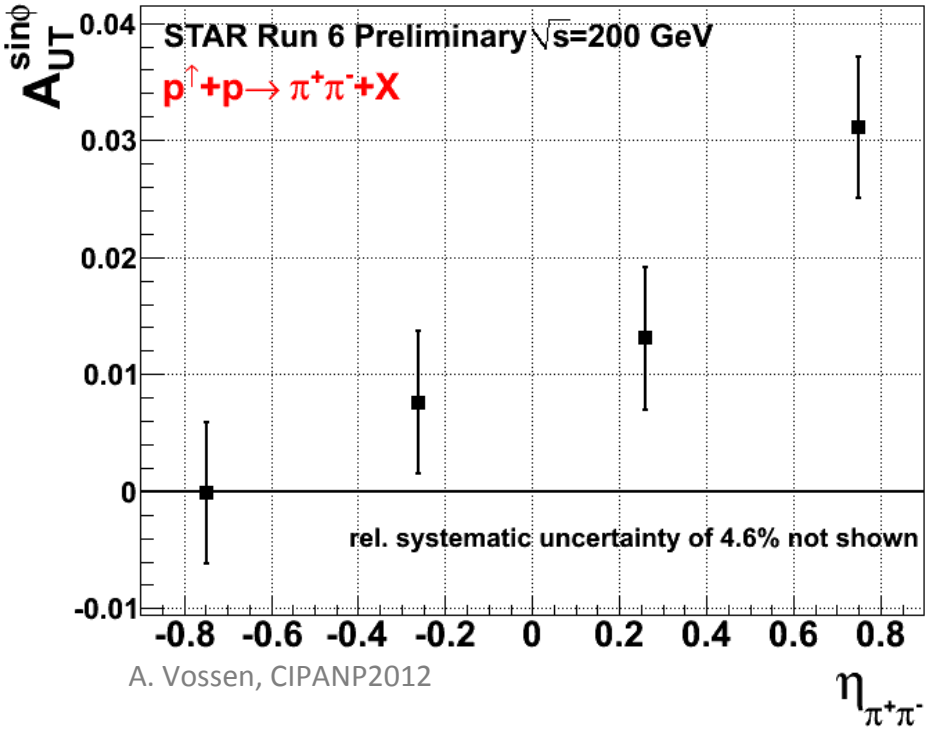


Non-zero signal for di-hadron transverse single-spin asymmetries in 2006 data

→ ***Inform transversity at higher x, Q^2?***

STAR Transverse Asymmetries from Di-hadrons





A. Vossen, CIPANP2012

Non-zero signal for di-hadron transverse single-spin asymmetries in 2006 data

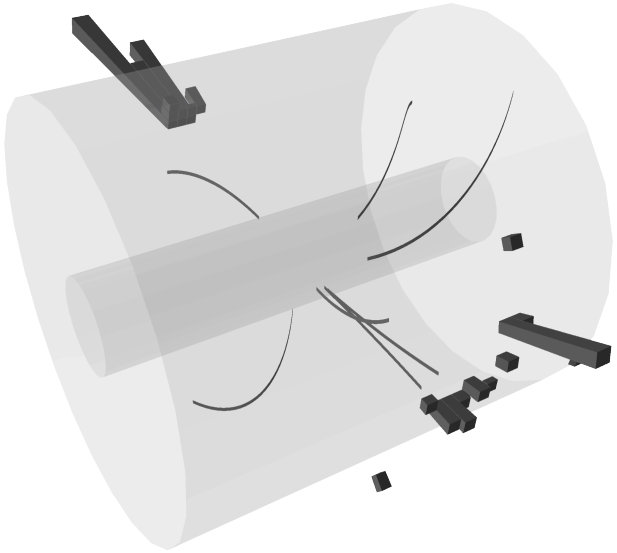
→ ***Inform transversity at higher x, Q^2?***

2012+15: opportunity for much higher precision

Analysis of 2012 data underway

Jet Reconstruction in STAR

STAR Di-jet event at detector-level



e.g. Anti-k_T algorithm (2011 results)

JHEP 0804, 063 (2008)

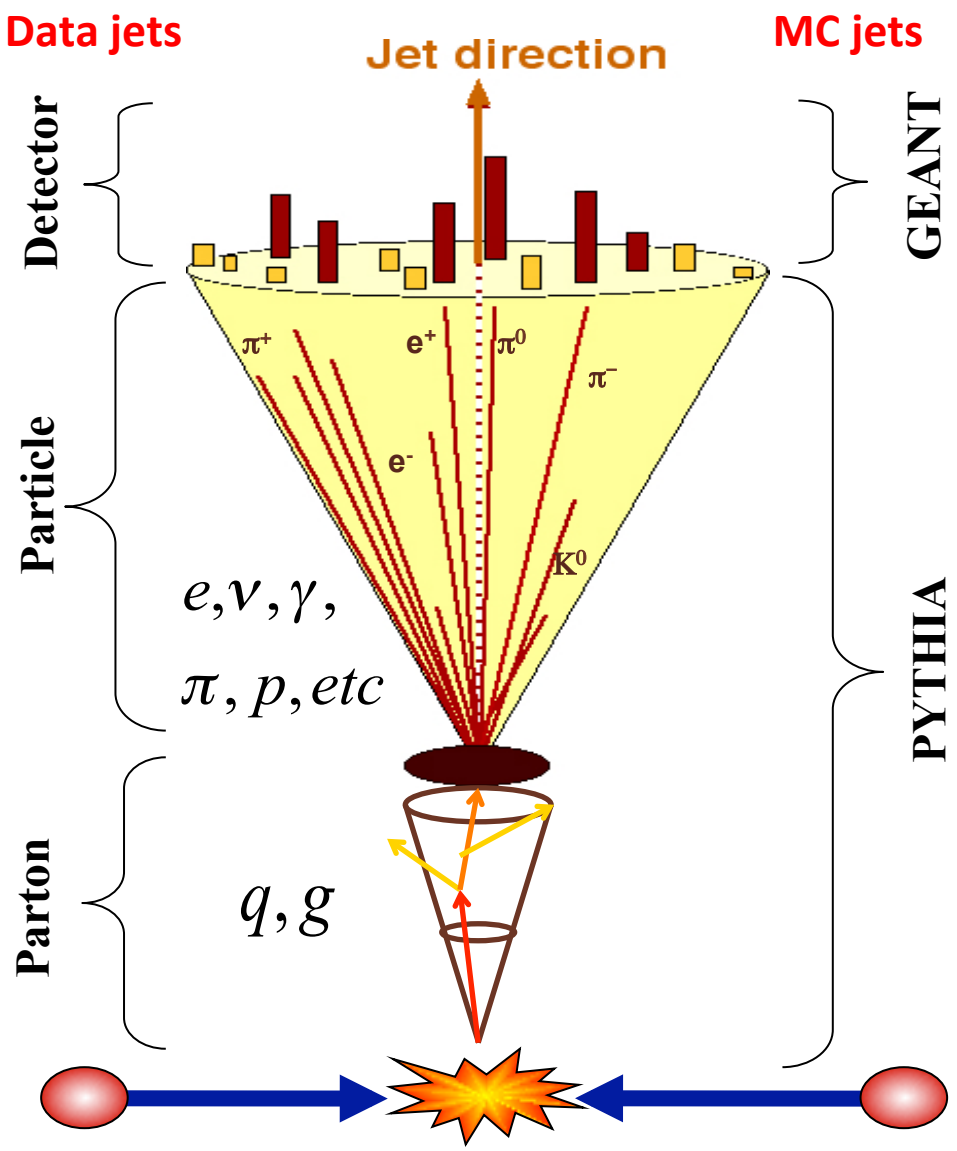
Radius parameter R = 0.6

Use **PYTHIA** + **GEANT** to quantify detector response

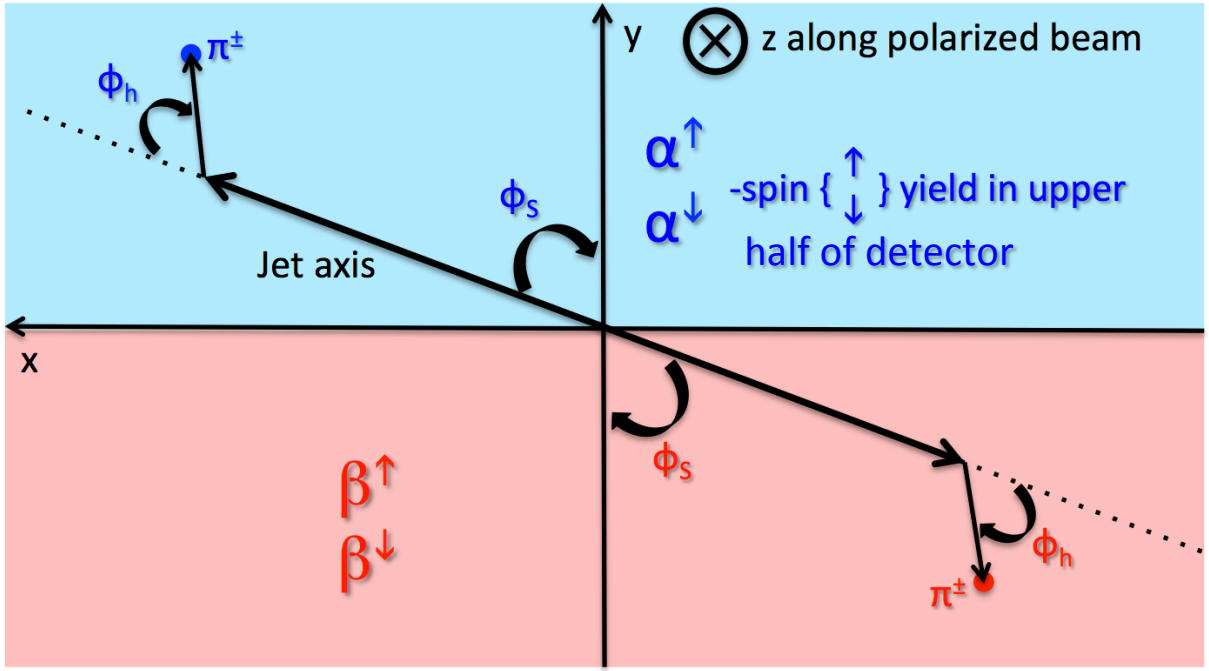
$\pi^{\pm}$ Kinematic Variables

z – π momentum / jet momentum

j_T – π p_T relative to jet axis



Asymmetry Measurements

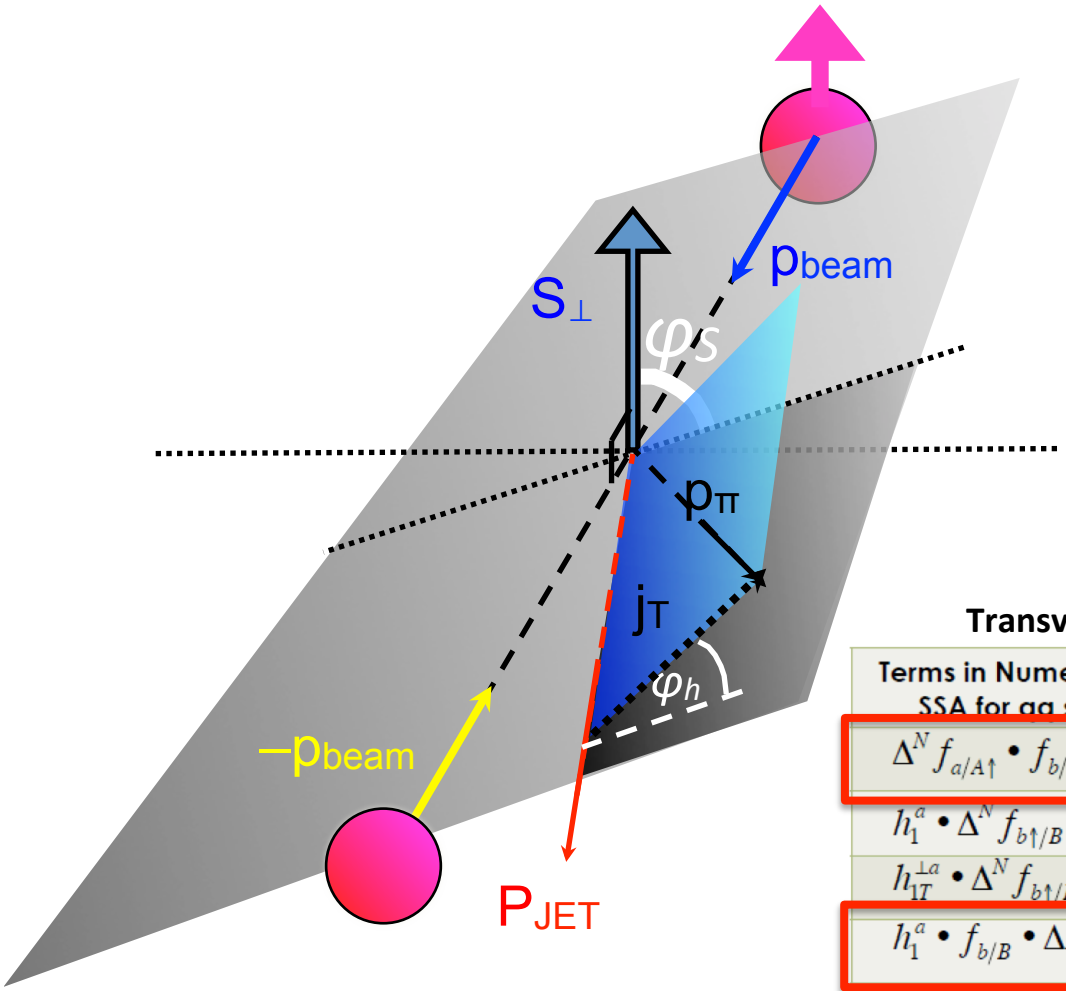


α and β yields are functions of $\left\{ \begin{array}{c} \Delta\phi = \phi_S - \phi_h \\ \phi_S \end{array} \right\}$ integrated over $\left\{ \begin{array}{c} \phi_S \\ \Delta\phi \end{array} \right\}$

$$\varepsilon = \frac{1}{P} \frac{\sqrt{\alpha^{\uparrow}\beta^{\downarrow}} - \sqrt{\alpha^{\downarrow}\beta^{\downarrow}}}{\sqrt{\alpha^{\uparrow}\beta^{\downarrow}} + \sqrt{\alpha^{\downarrow}\beta^{\downarrow}}}$$

For uniform acceptance: $\varepsilon \left\{ \begin{array}{c} \Delta\phi \\ \phi_S \end{array} \right\} = \left\{ \begin{array}{c} A_{Collins} \sin(\Delta\phi) \\ A_{Sivers} \sin(\phi_S) \end{array} \right\}$

Transverse Asymmetries from Jet Production



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

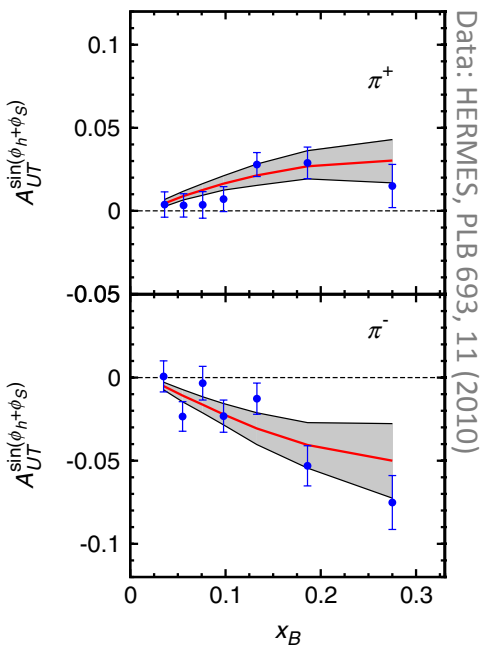
Asymmetry moments sensitive to various contributions (analogous moments sensitive to gluon scattering)

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

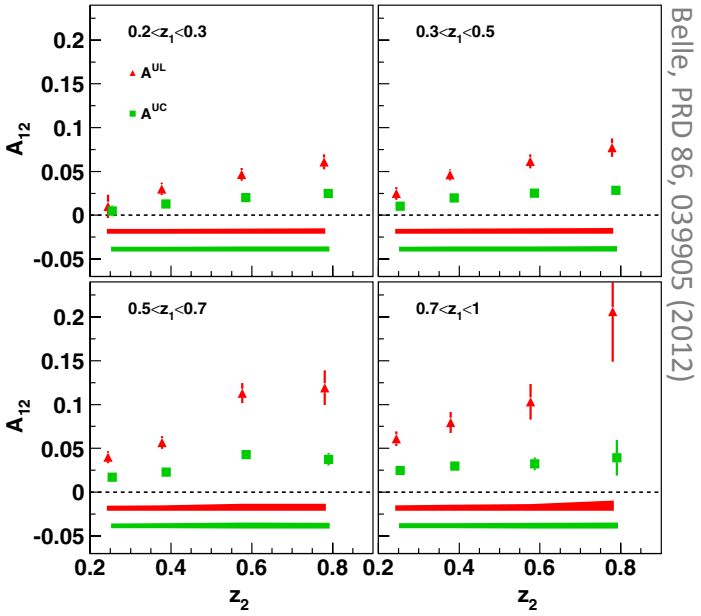
Transverse Momentum Dependent (TMD) Approach

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

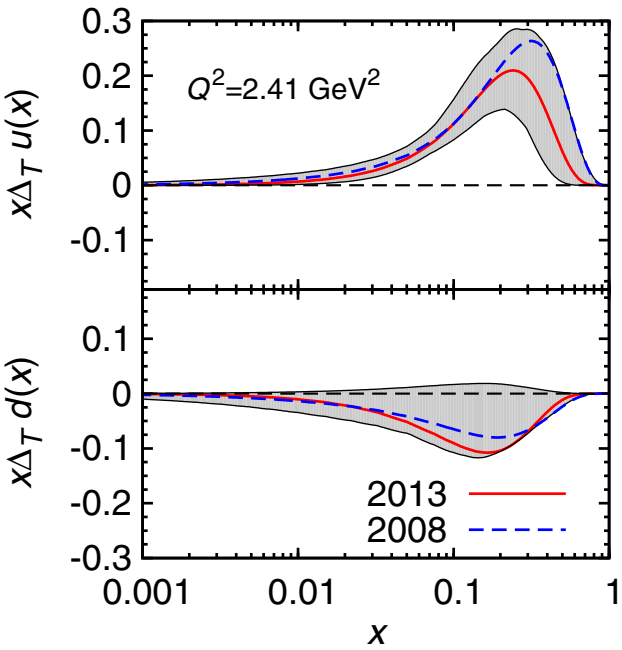
SIDIS Results: Sivers and Collins Asymmetries



Data: HERMES, PLB 693, 11 (2010)



Belle, PRD 86, 039905 (2012)



M. Anselmino et al., PRD 87, 094019 (2013)

Global Analysis

- Factorized functional form for Collins F.F. and transversity
- Simultaneous extraction of Collins F.F. and transversity
  → tune to data from HERMES, COMPASS, and Belle

Opportunities with p+p:

Expanded kinematics? Tests of Q^2? Evolution? Universality?