TEMPLE UNIVERSITY®

Cold QCD Highlights from STAR

Nick Lukow for the STAR Collaboration

RHIC/AGS Annual Users Meeting

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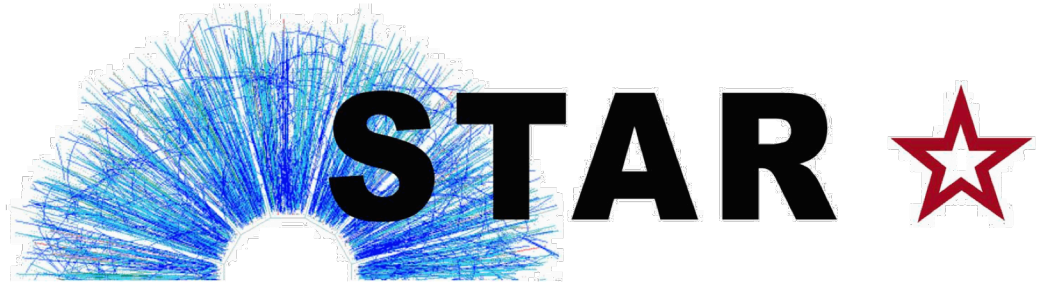

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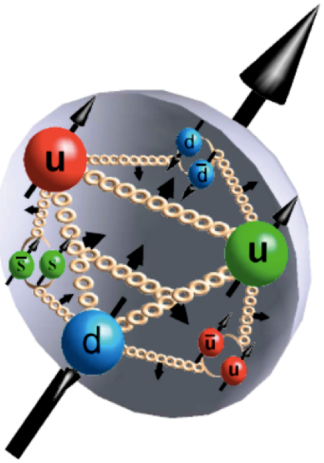
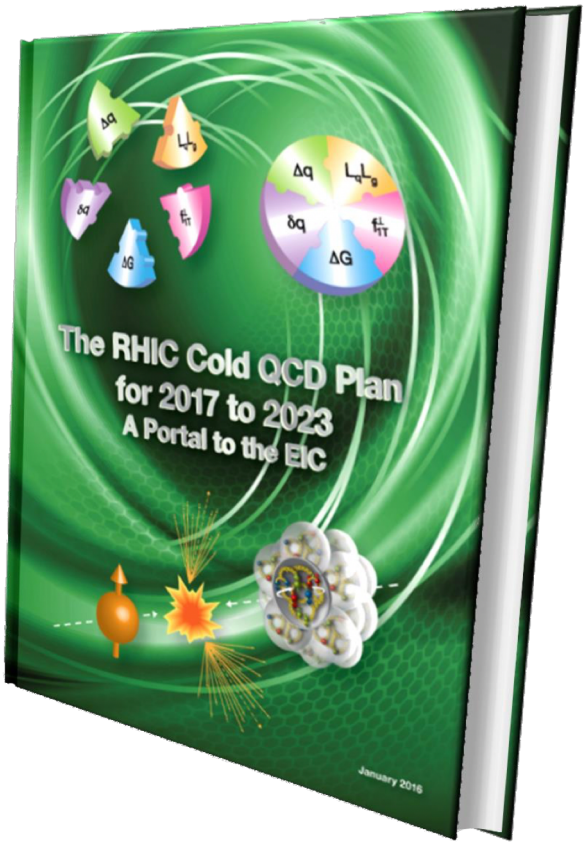
Introduction

The goal of the RHIC Cold QCD program is to address several overarching questions:

- "What is the nature of the spin of the proton?"
- "How can we describe the multidimensional landscape of nucleons and nuclei?"
- "What is the nature of the initial state in nuclear collisions?"

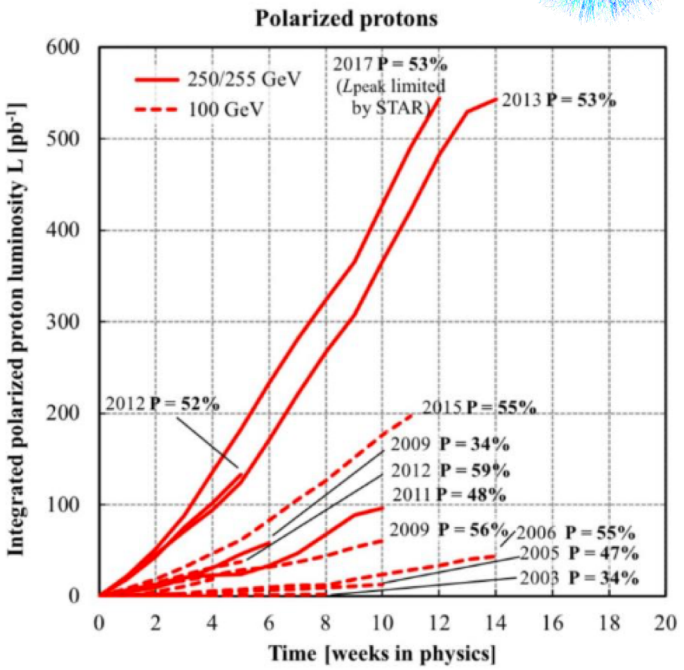


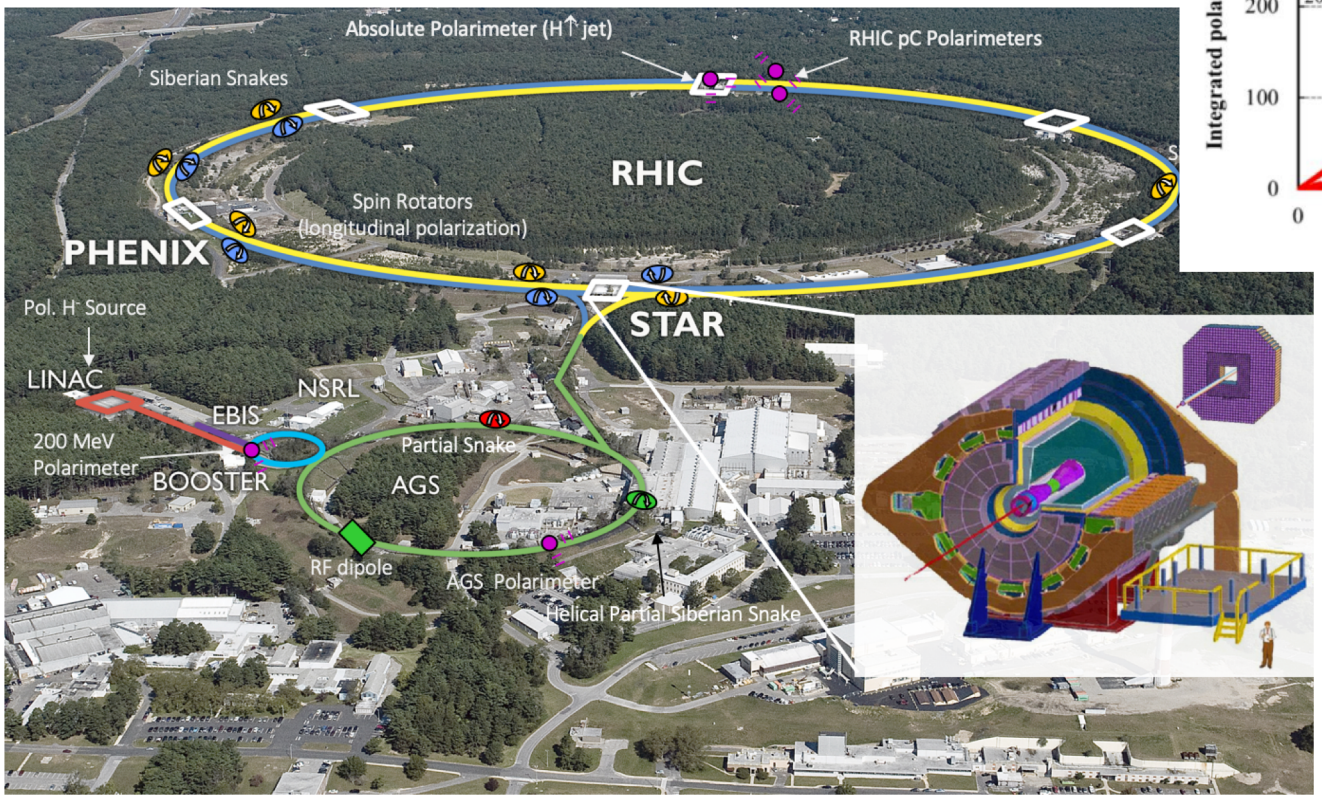


arxiv: 1602.03922

Polarized Proton Runs at RHIC

- Run 2017 is the latest polarized pp run
  - $\sqrt{s} = 510$ GeV
  - Peak luminosity limited to optimize the recorded statistics and detector performance





Overview

Longitudinal polarization:

- Inclusive jet and dijet A_{LL}

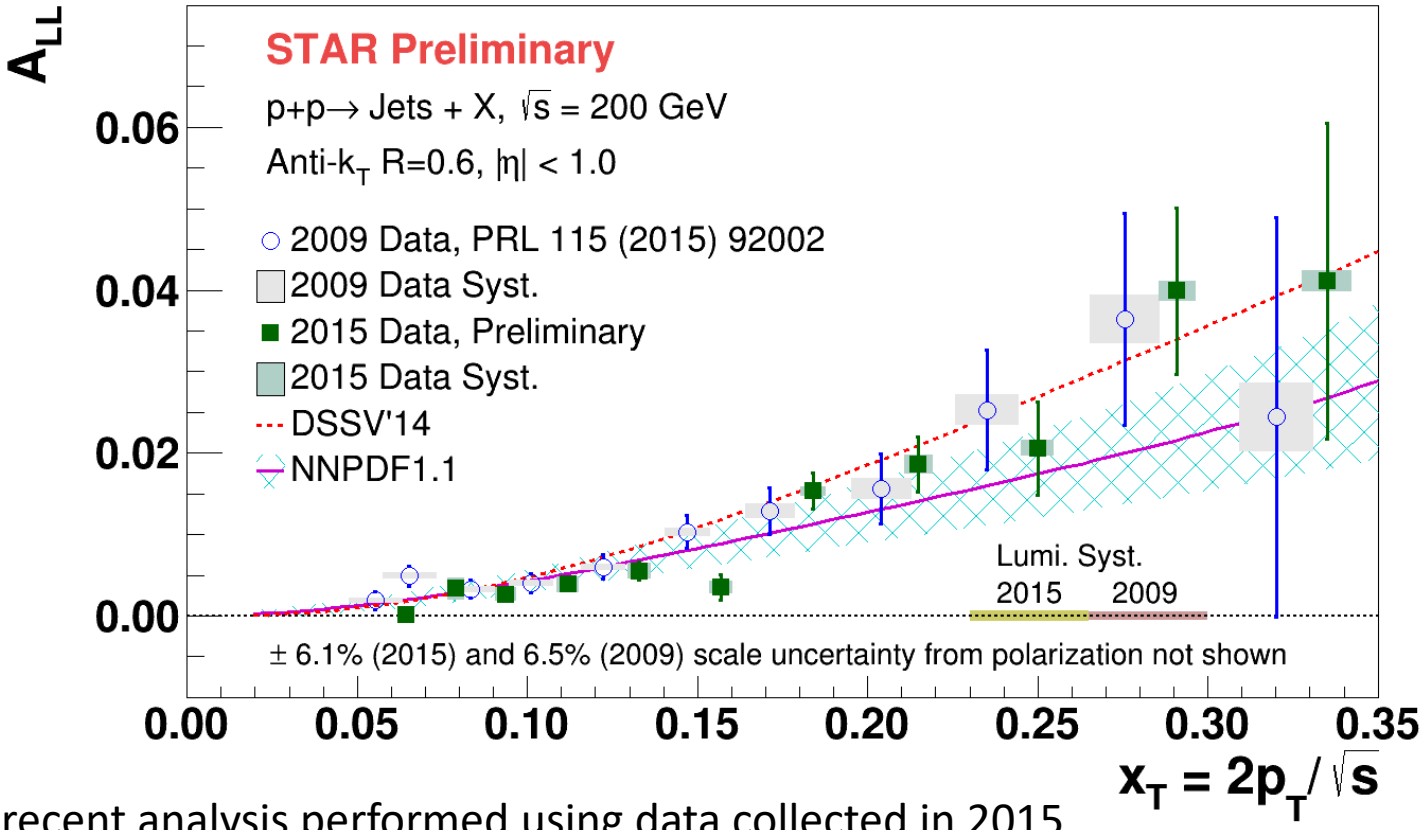
Transverse polarization:

- Collins asymmetry for charged pions within a jet
- Dijet Sivers asymmetry
- Transverse single spin asymmetries for π^0

Unpolarized:

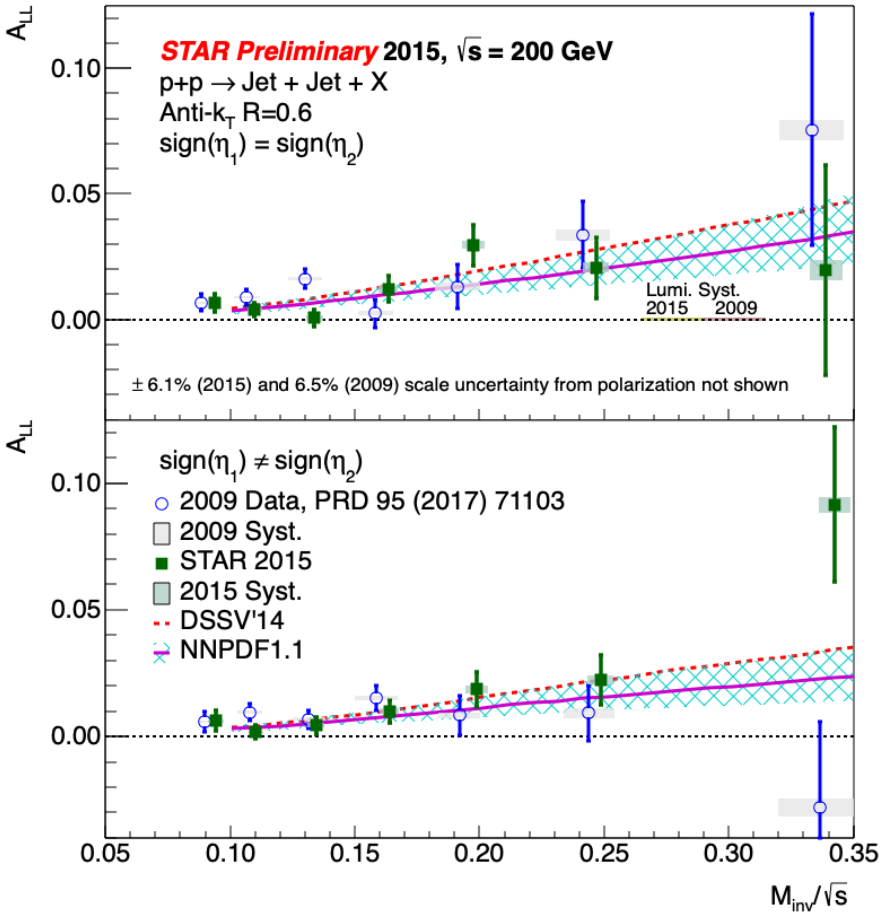
- Azimuthal correlation of forward di-pions
- W^+/W^- cross section ratio
- Z^0 differential cross section

Inclusive Jet A_{LL} at $\sqrt{s} = 200$ GeV

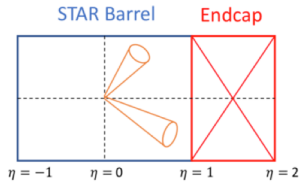


- Most recent analysis performed using data collected in 2015
- Longitudinal double-spin asymmetry of jets, A_{LL}, is useful in constraining the polarized gluon distribution function, $\Delta G(x, Q^2)$
- The figure-of-merit for the 2015 data set is twice as large as that for the 2009 data set
- Will significantly reduce uncertainty on gluon polarization for $x > 0.05$ once included in global fits

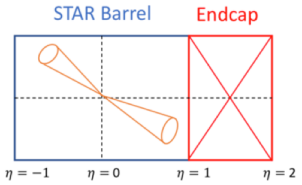
Central Dijet A_{LL} at $\sqrt{s} = 200$ GeV



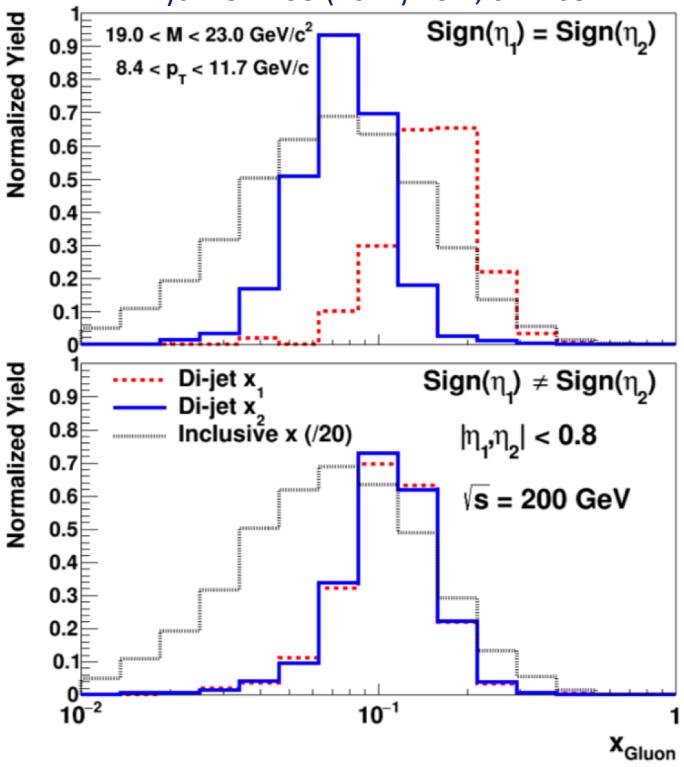
- $\text{Sign}(\eta_1) = \text{Sign}(\eta_2)$



- $\text{Sign}(\eta_1) \neq \text{Sign}(\eta_2)$

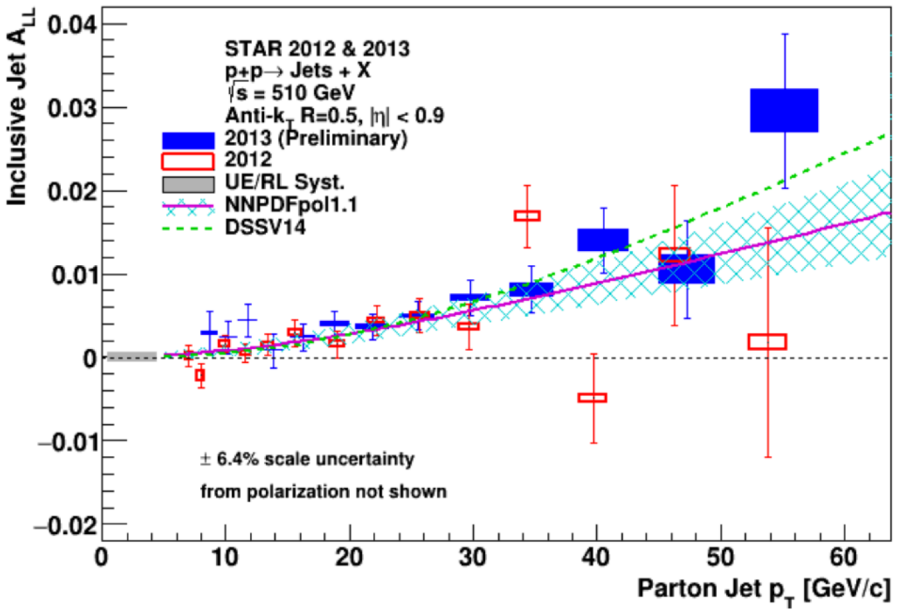


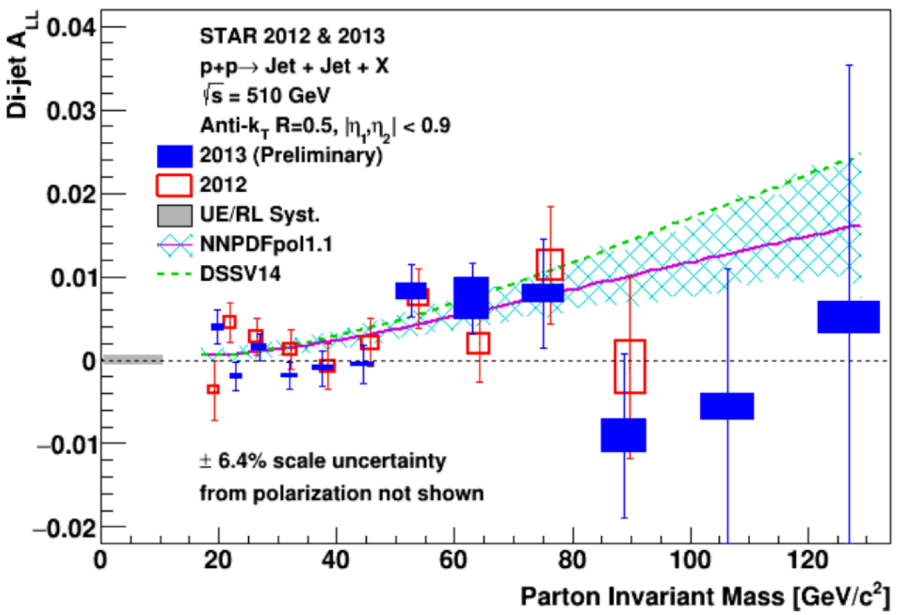
Phys. Rev. D95 (2017) no.7, 071103



- New preliminary result from an analysis performed using data collected in 2015
- Dijets can provide further constraints by probing narrower regions in x

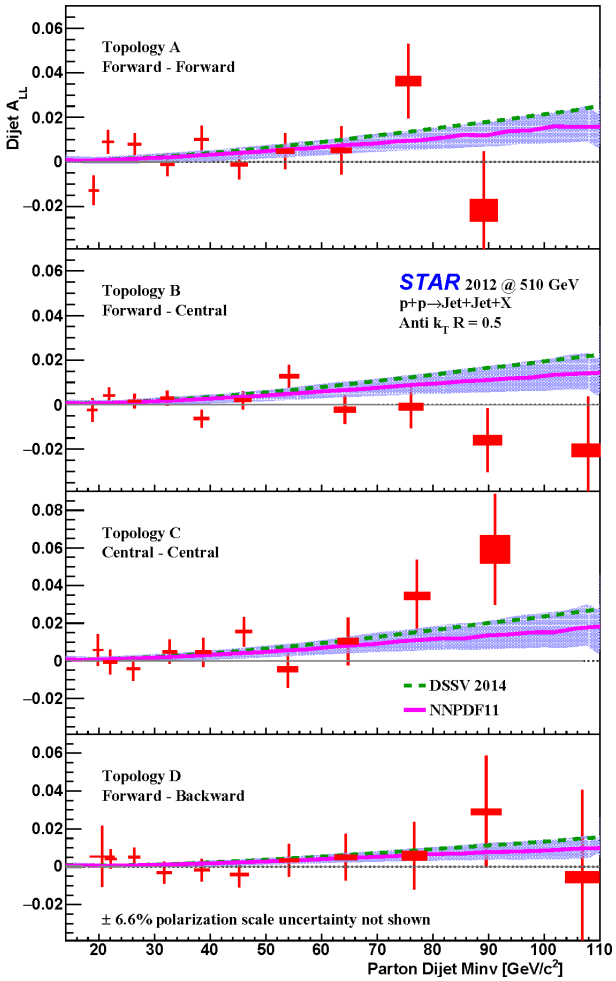
Jet and Dijet A_{LL} at $\sqrt{s} = 510$ GeV

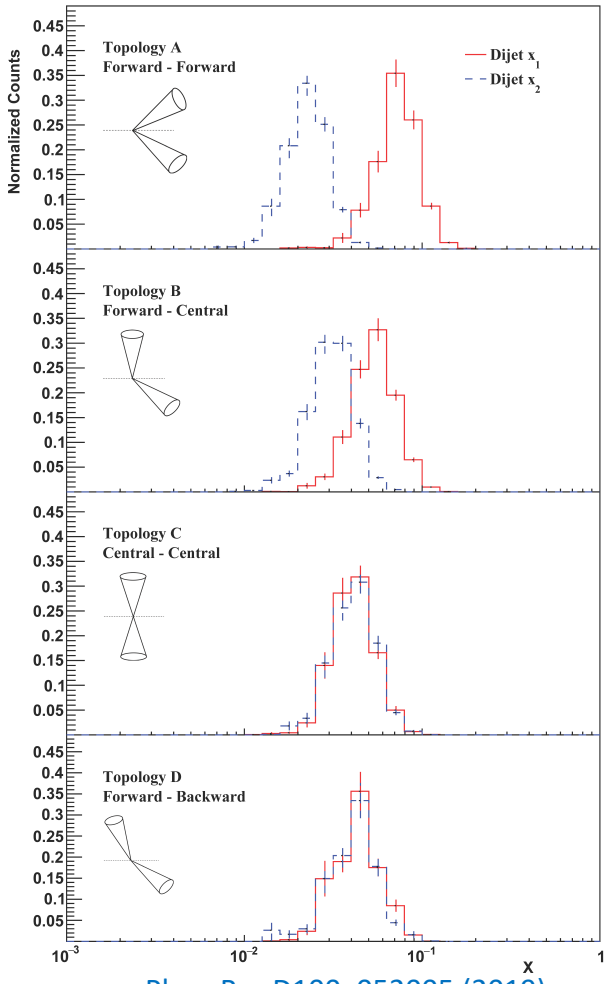




- Higher center-of-mass energy provides sensitivity to gluons at lower x
- Inclusive jet and dijet analysis of 2012 data has been published
  - Results for dijet A_{LL} were reported for 4 different dijet topologies (next slide)
- Analysis of data collected in 2013 is being finalized

Central Dijet A_{LL} at $\sqrt{s} = 510$ GeV





Phys. Rev.D100, 052005 (2019)

$0.3 < |\eta_{1,2}| < 0.9$
$\eta_1 \cdot \eta_2 > 0$

$|\eta_{1,2}| < 0.3$
$0.3 < |\eta_{2,1}| < 0.9$

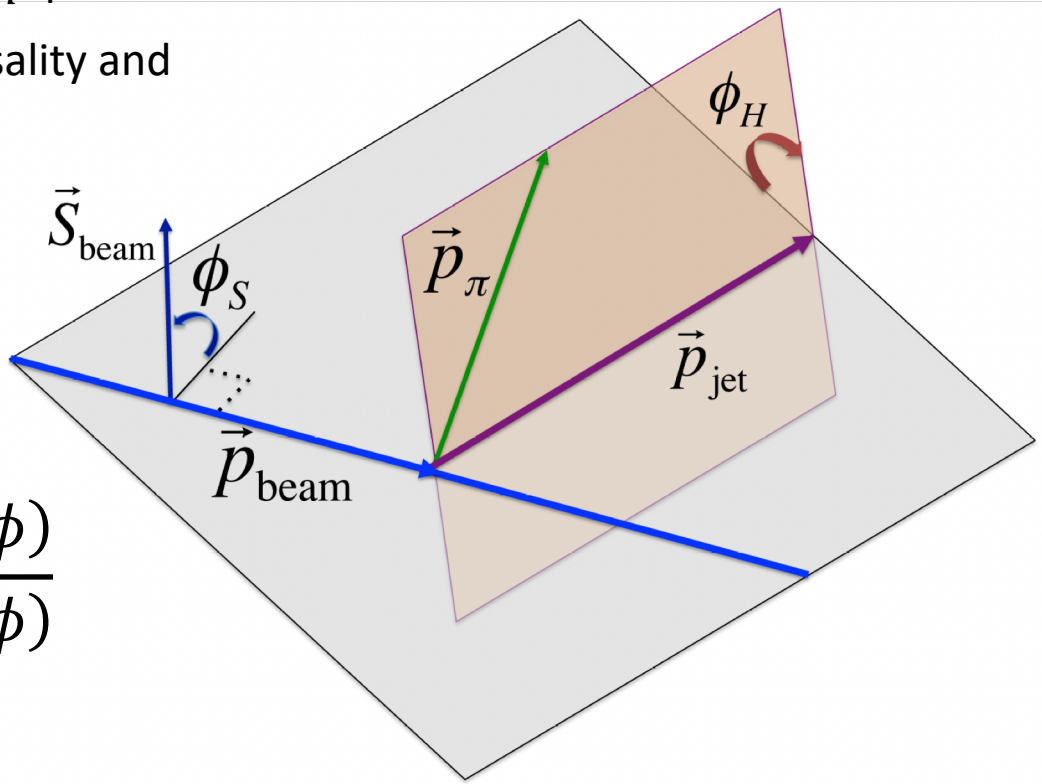
$|\eta_{1,2}| < 0.3$

$0.3 < |\eta_{1,2}| < 0.9$
$\eta_1 \cdot \eta_2 < 0$

- Dijet analysis of 2012 data categorized the dijets in four distinct topologies

Collins Asymmetry at $\sqrt{s} = 200$ GeV

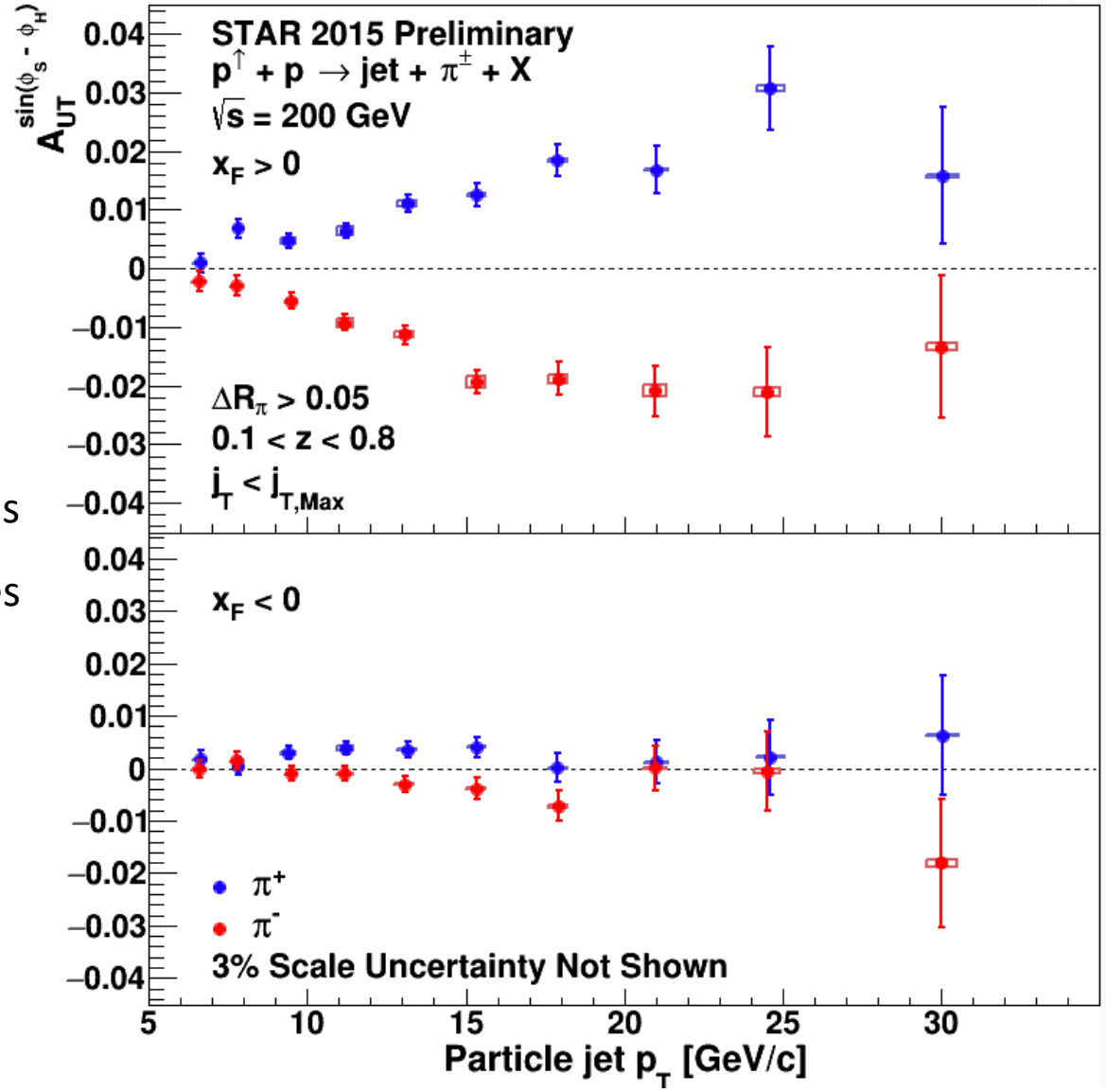
- Collins fragmentation function is coupled to the quark transversity distribution
- This leads to azimuthal modulations of charged hadron yields around the jet axis
- Collins fragmentation function in $p + p$ probes fundamental questions about factorization, universality and the evolution of TMDs



$$A_{UT}^{\sin(\phi)} \sin(\phi) = \frac{\sigma^{\uparrow}(\phi) - \sigma^{\downarrow}(\phi)}{\sigma^{\uparrow}(\phi) + \sigma^{\downarrow}(\phi)}$$

Collins Asymmetry at $\sqrt{s} = 200$ GeV

- Analysis performed with data collected in 2015
- Results for the Collins asymmetry of charged pions and kaons were determined, as well as Collins-like asymmetries
- Results are consistent with previous measurements using 2012 data, but with smaller statistical uncertainties

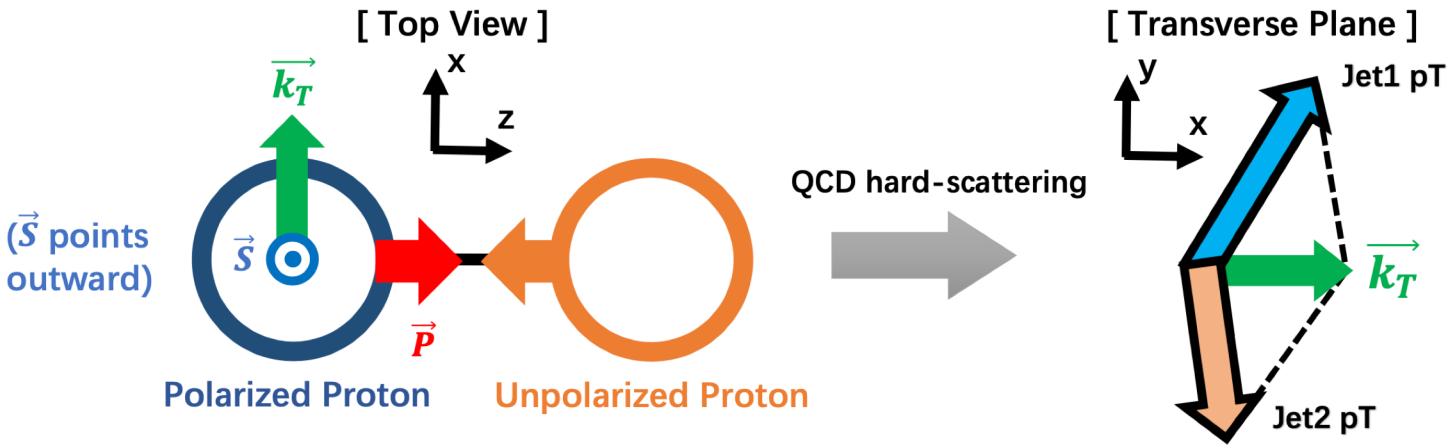


Dijet Sivers Asymmetry at $\sqrt{s} = 200$ GeV

$$\langle \vec{S}_{proton} \cdot (\vec{P}_{proton} \times \vec{k}_T) \rangle \neq 0$$

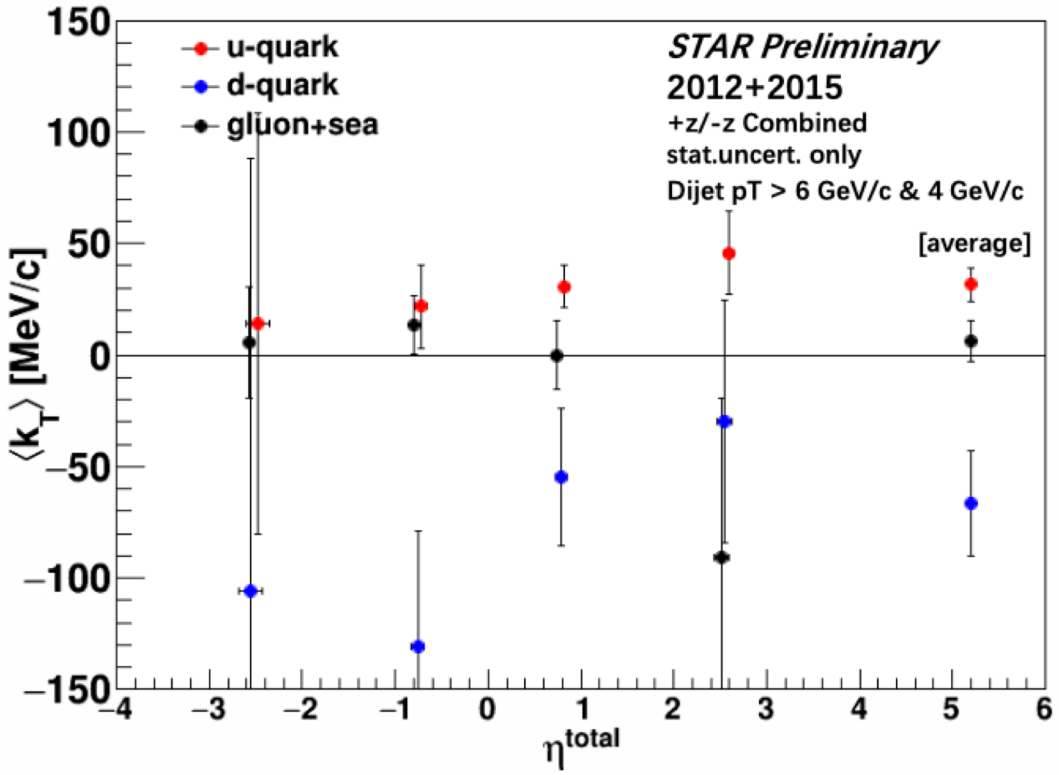
- Sivers effect is a correlation of the initial-state parton transverse momentum with the proton's spin and momentum
- k_T correlations will lead to spin-dependent tilt of the dijet opening angle ζ

$$\Delta\zeta = \frac{\langle\zeta\rangle^{+} - \langle\zeta\rangle^{-}}{P}$$



Dijet Sivers Asymmetry at $\sqrt{s} = 200$ GeV

- Analysis performed with data collected in 2012 and 2015
- Previous analysis using 2006 data showed an asymmetry consistent with 0
- Many improvements with new analysis using 2012+2015 data
  - 33 times larger data set
  - Charge-tagging
- First non-zero Sivers asymmetries in dijet production in polarized pp collisions
- $\Delta\zeta$ is converted to $\langle k_T \rangle$
- $\langle k_T^u \rangle > 0,\ \langle k_T^d \rangle < 0,\ \langle k_T^{g+sea} \rangle \sim 0$



$$\eta^{total} = \eta_1 + \eta_2 \ \propto\ \ln\left(\frac{x_1}{x_2}\right)$$

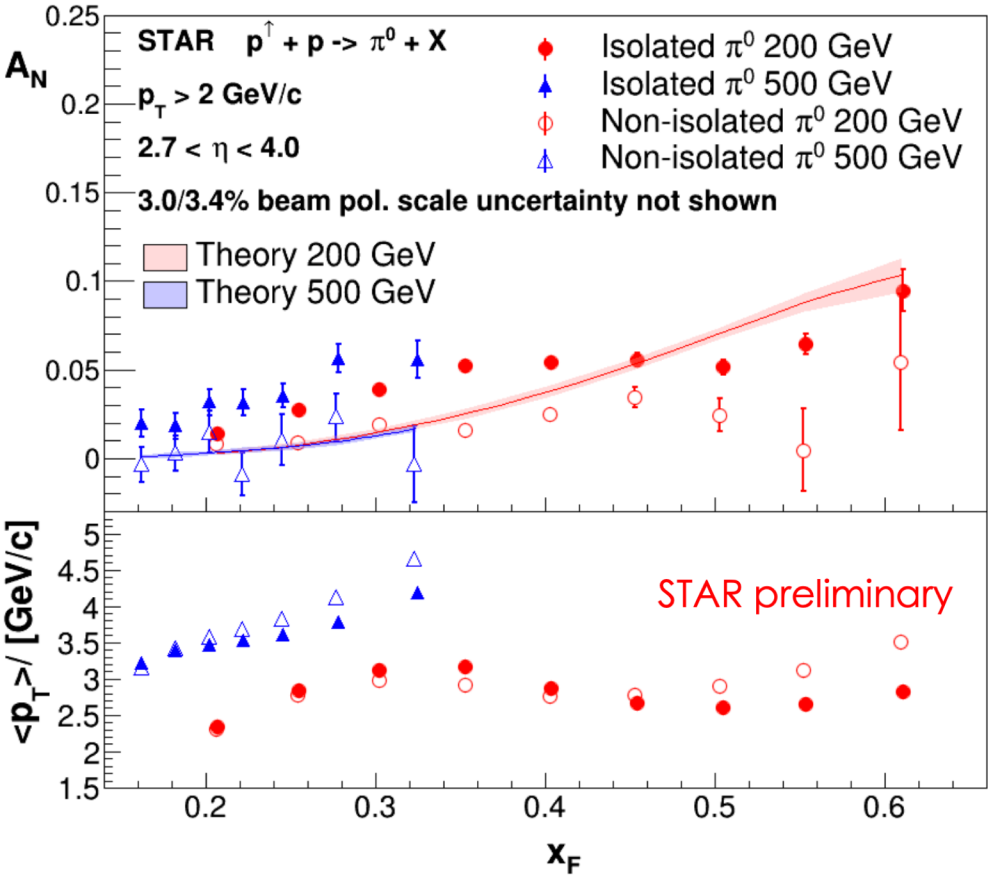
Transverse Single Spin Asymmetries for π^0

- Analysis performed with pp data:
  - $\sqrt{s} = 500$ GeV (2011)
  - $\sqrt{s} = 200$ GeV (2015)

- Results show weak dependence on the center-of-mass energy

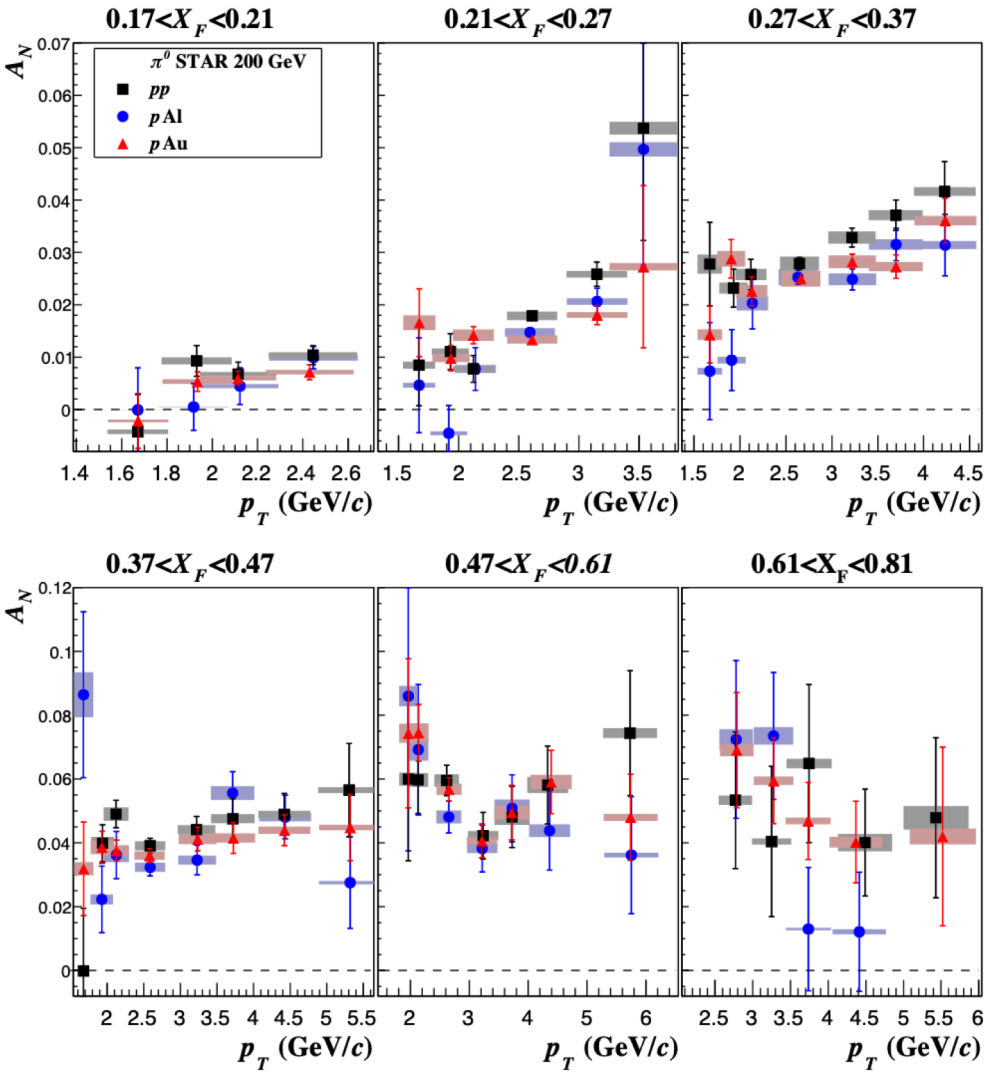
- In addition to the TSSA for (non-) isolated π^0s, the TSSA for EM jets and Collins asymmetry for π^0s within EM jets have been measured

- Isolated π^0s have larger asymmetries than non-isolated π^0s



- This, along with small TSSA for EM jets and small Collins asymmetries for π^0 s within EM jets, suggests there could be a different mechanism other than the Sivers or Collins effects to explain these results

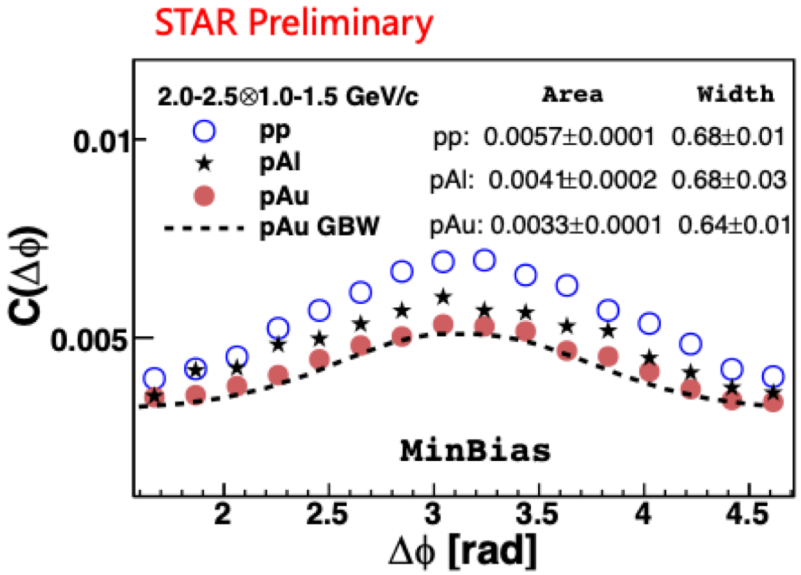
Transverse Single Spin Asymmetries for π^0

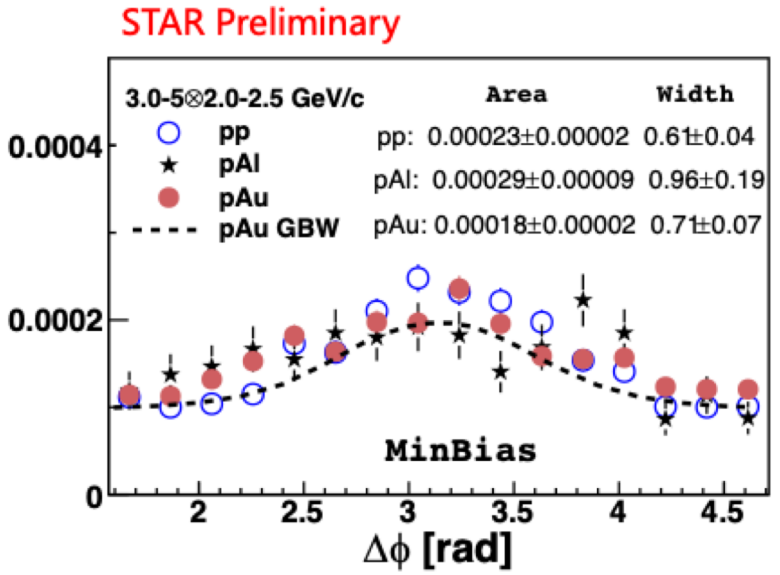


arXiv:XXXX

- Analysis performed with data collected in 2015 at $\sqrt{s_{NN}} = 200$ GeV
- Three different types of collisions:
  - $p^{\uparrow} + p$
  - $p^{\uparrow} + Al$
  - $p^{\uparrow} + Au$
- Asymmetries rise with p_T at low x_F and flatten out at high x_F
- Results are consistent with weak nuclear A dependence

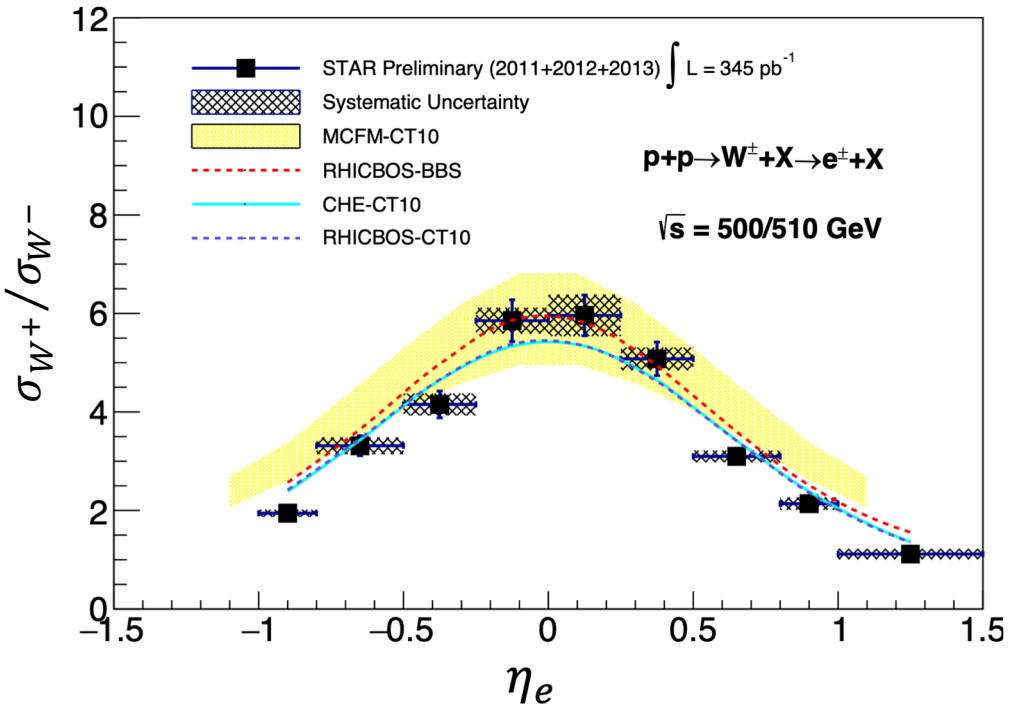
Azimuthal Correlations of Di-Pions

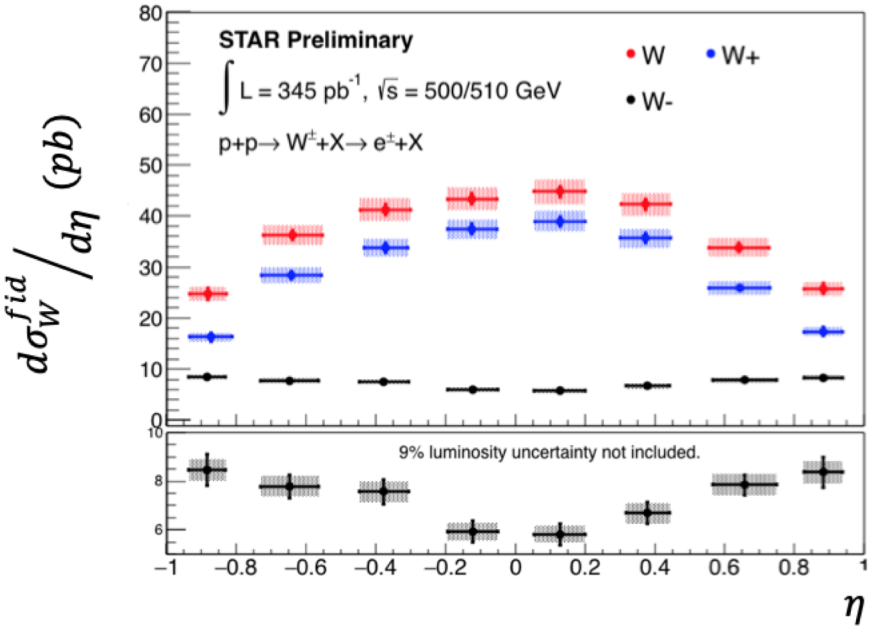




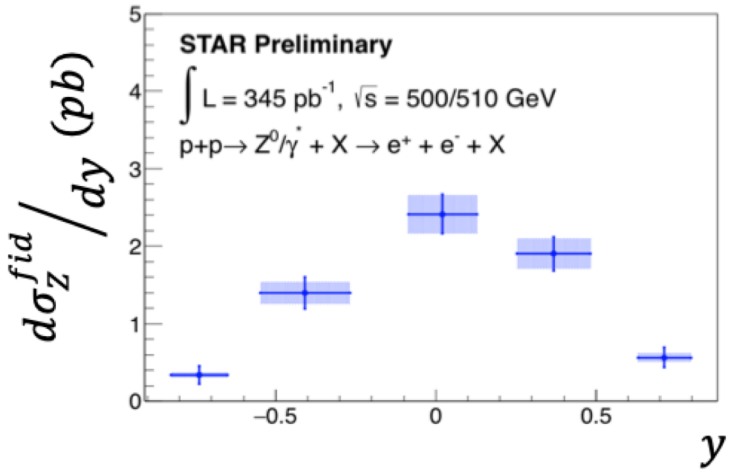
- Analysis performed with data collected in 2015 at $\sqrt{s_{NN}} = 200$ GeV
- Three different types of collisions:
  - $p + p$
  - $p + Al$
  - $p + Au$
- Correlations measured as a function of event activity
  - Suppression is enhanced with higher event activity
- Azimuthal correlations of forward di-pions ($2.5 < \eta < 4$) help probe gluon dynamics at low-x

W^+/W^- Cross Section Ratio at $\sqrt{s} = 510$ GeV

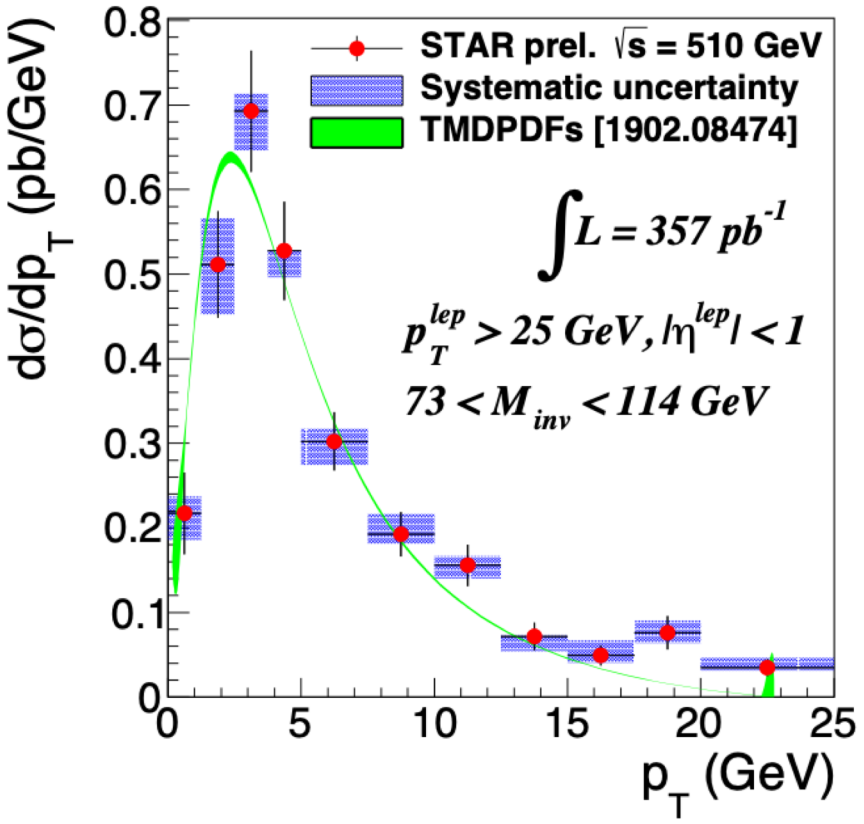




- Analysis performed with data collected in 2011, 2012, and 2013
- W^+/W^- cross section ratio is sensitive to $\bar{d}/\bar{u}$ sea quark ratio in the range $0.06 < x < 0.4$



Z^0 Differential Cross Section at $\sqrt{s} = 510$ GeV



- Analysis performed with data collected in 2011, 2012, and 2013
- Useful input for global fits of TMD parton distribution functions
- STAR kinematic range ($0.1 < x < 0.3$) is complementary to LHC and Tevatron data

Summary and Conclusions

- Results from analyses using longitudinally polarized data will further constrain the polarized gluon distribution function
- Results from analyses using transversely polarized data shed light on the transverse spin structure of the proton
- Results from unpolarized studies provide constraints for global analyses for sea quark distributions and TMDs, and reveal non-linear gluon dynamics
- Many of these results will be submitted for publication very soon
- Future plans include more transversely polarized proton collisions at $\sqrt{s} = 510$ GeV which will make use of the upcoming STAR Forward Upgrade
  - For more details on this see Scott Wissink's talk later in this session