Recent results on nucleon spin structure study at RHIC

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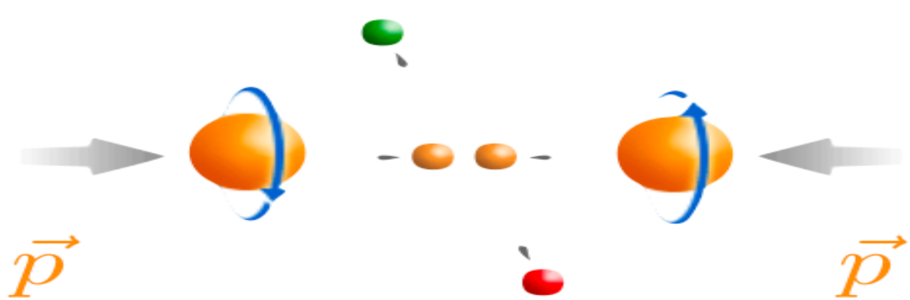
Hadron 2018, Weihai

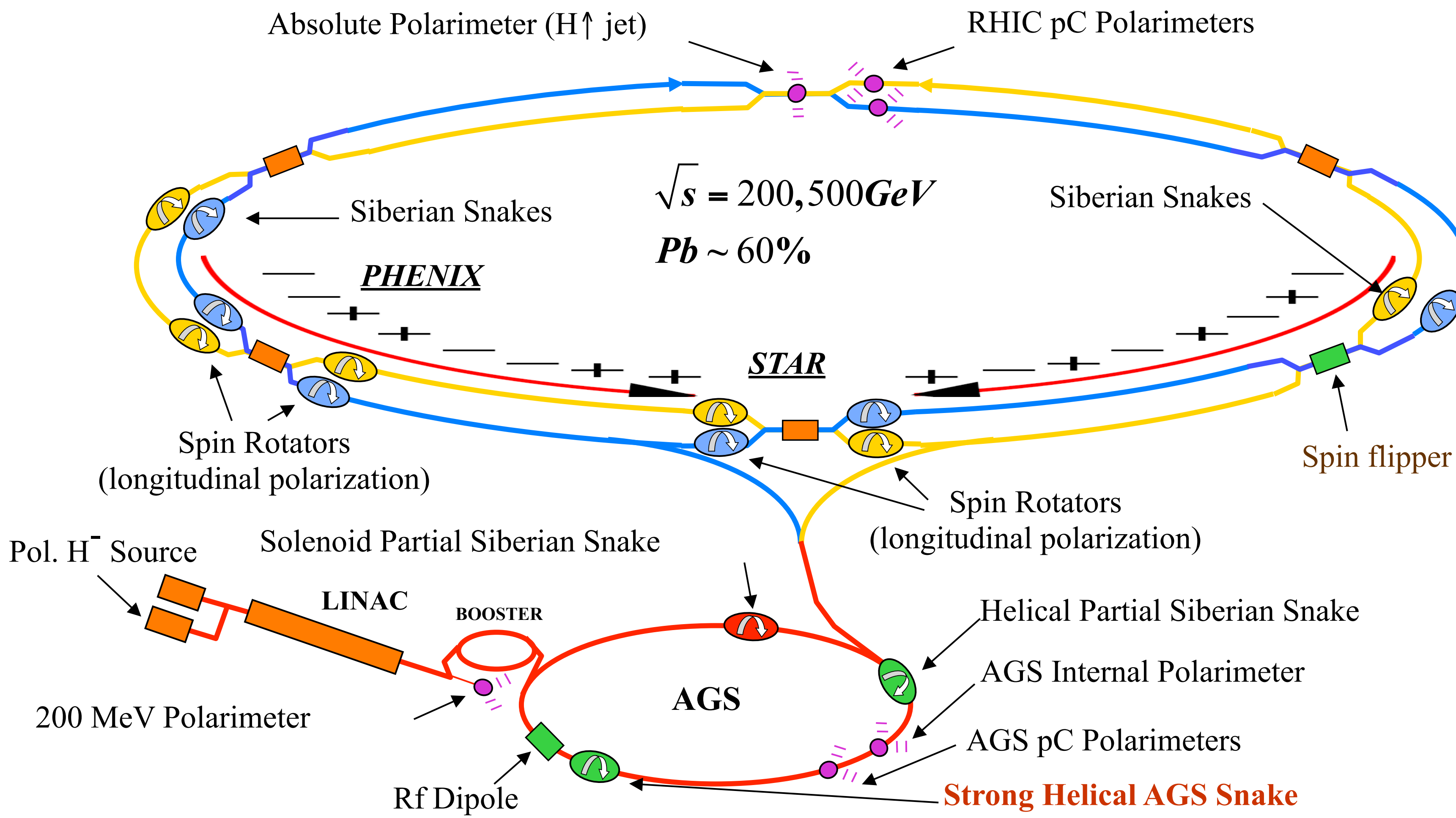
July 28, 2018



Outline:

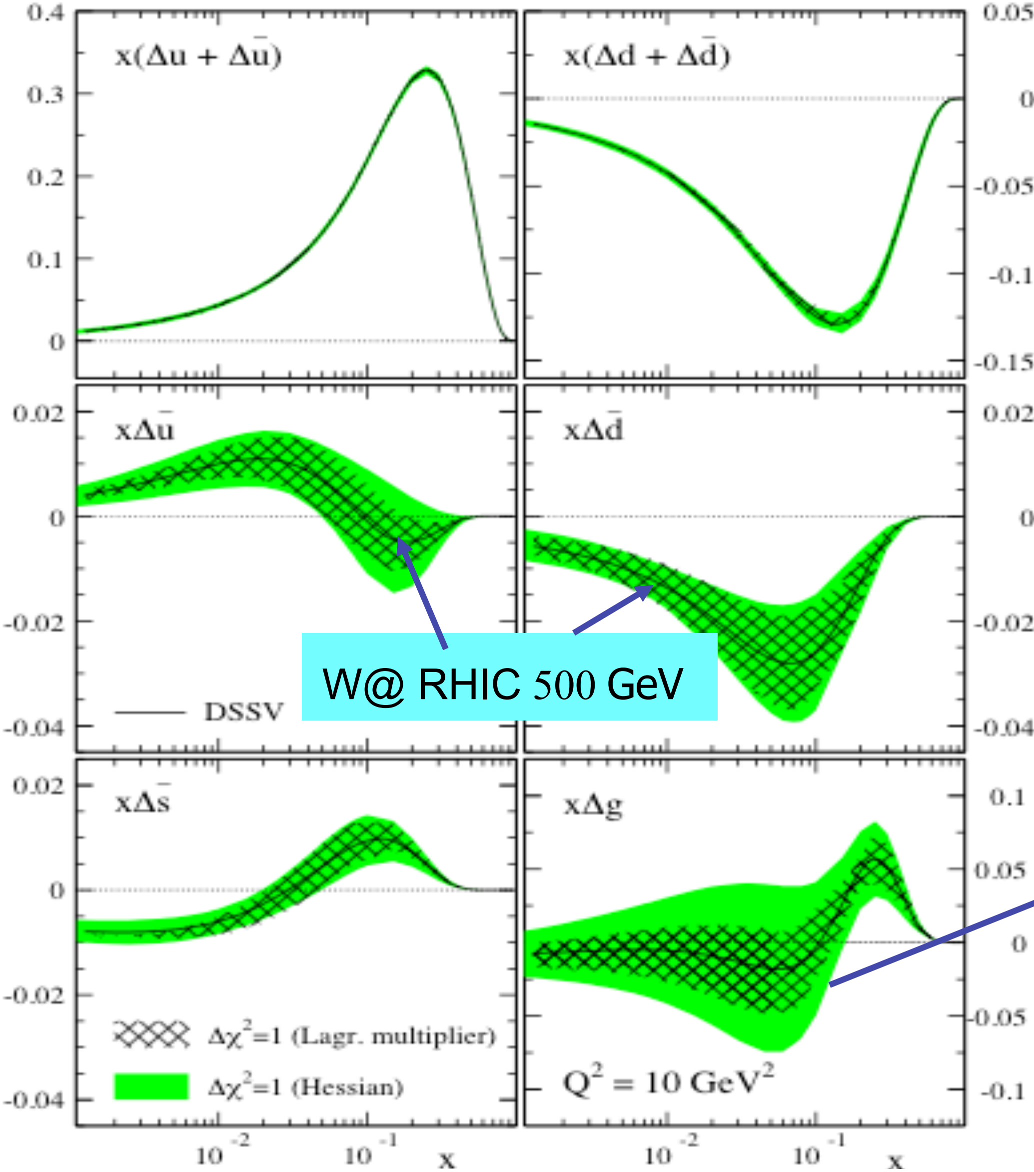
- Experimental aspects: RHIC
- Recent spin highlights:
  - ✓ Gluon polarization (Jet production, π^0): gluon polarization Δg
  - ✓ Quark/Anti-quark polarization (W/Z production): sea quark Δq
  - ✓ Transverse spin asymmetry (W/Z production): Sivers function
  - ✓ Transverse spin asymmetry (Hadron production): Collins & IFF
- Upgrade plans for spin physics in 2021+ at RHIC
- Summary

RHIC- 1st polarized proton-proton collider



- World's only polarized hadron-hadron collider
- Polarization direction changes from bunch to bunch
- Spin rotators provide choice of spin orientation

Δq(x), Δg(x)- global analysis of data



- Spin sum rule (longitudinal):

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \langle L_{q,g} \rangle$$

Quark spin, (~30%) -DIS

Gluon spin, Poorly known, RHIC

Orbital Angular Momenta Little known

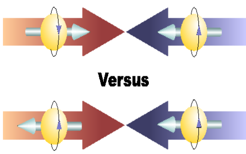
RHIC (jet, π^0, photon) 200 GeV, 500 GeV

D. De Florian, R. Sassot, M. Stratmann, W. Vogelsang, PRD80(2009)

Accessing Δg(x) in pp collision

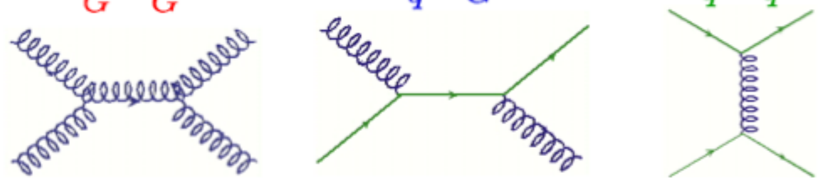
- Longitudinal spin asymmetry:

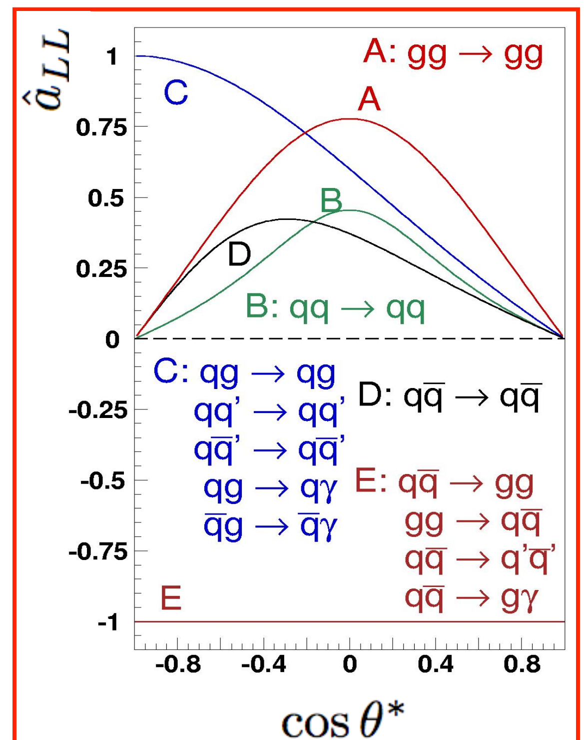
$$\Delta f_1 \qquad \Delta f_2 \qquad \hat{a}_{LL} = \frac{d\Delta\hat{\sigma}}{d\hat{\sigma}} \qquad D_f^{\pi}$$



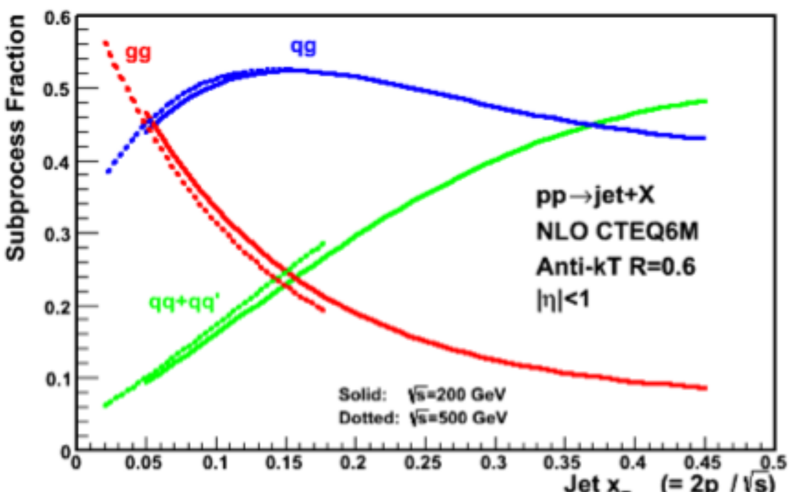
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{\sum_{f_1,f_2} \Delta f_1 \otimes \Delta f_2 \otimes d\hat{\sigma}^{f_1 f_2 \to fX} \cdot \hat{a}_{LL}^{f_1 f_2 \to fX} \otimes D_f^{\pi}}{\sum_{f_1,f_2} f_1 \otimes f_2 \otimes d\hat{\sigma}^{f_1 f_2 \to fX} \otimes D_f^{\pi}}$$

$$\frac{\Delta G}{G}\frac{\Delta G}{G} \qquad \frac{\Delta q}{q}\frac{\Delta G}{G} \qquad \frac{\Delta q}{q}\frac{\Delta q}{q}$$





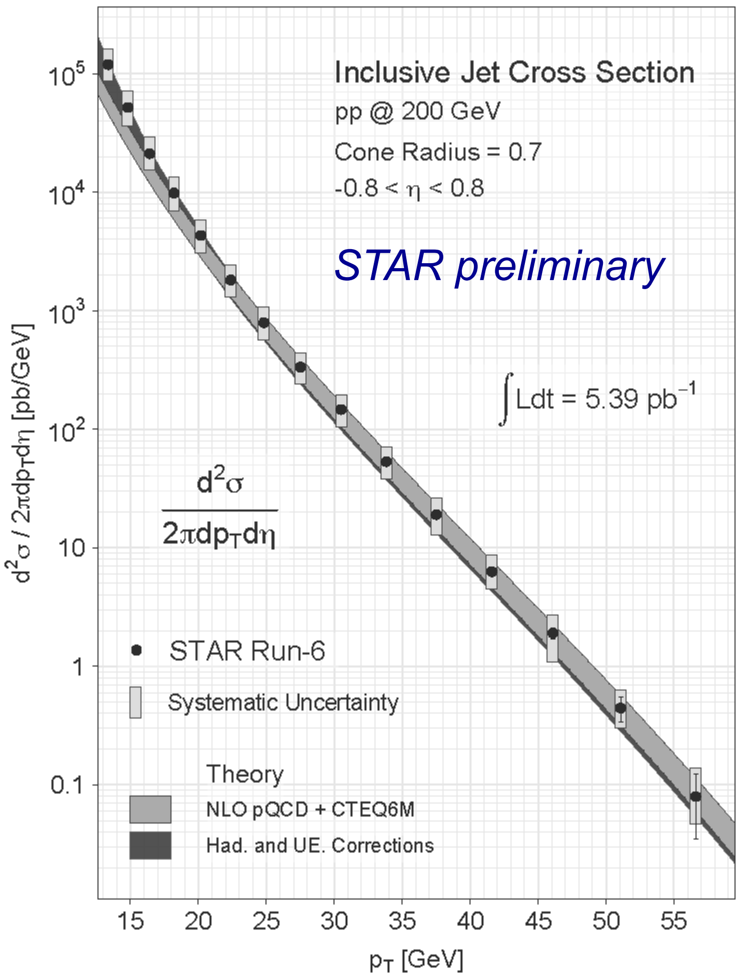
- Partonic fraction for jet/π^0 production:



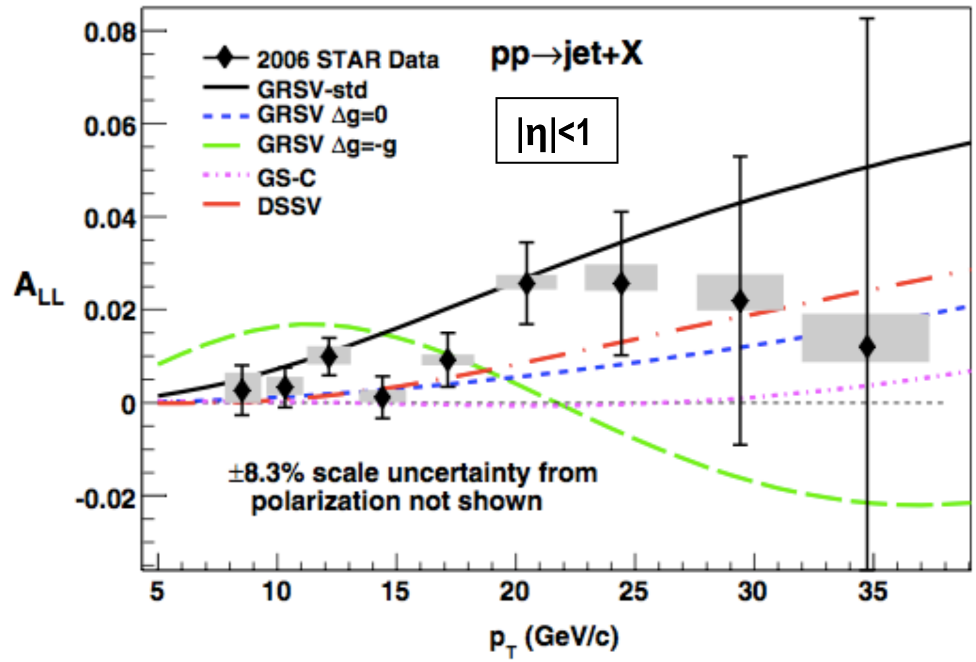
Mukherjee and Vogelsang, PRD.86.094009

STAR Run6 results on jet x-section and A_{LL}

- Cross section well described by NLO pQCD+Hadronization



STAR, PRD86, 32006(2012)



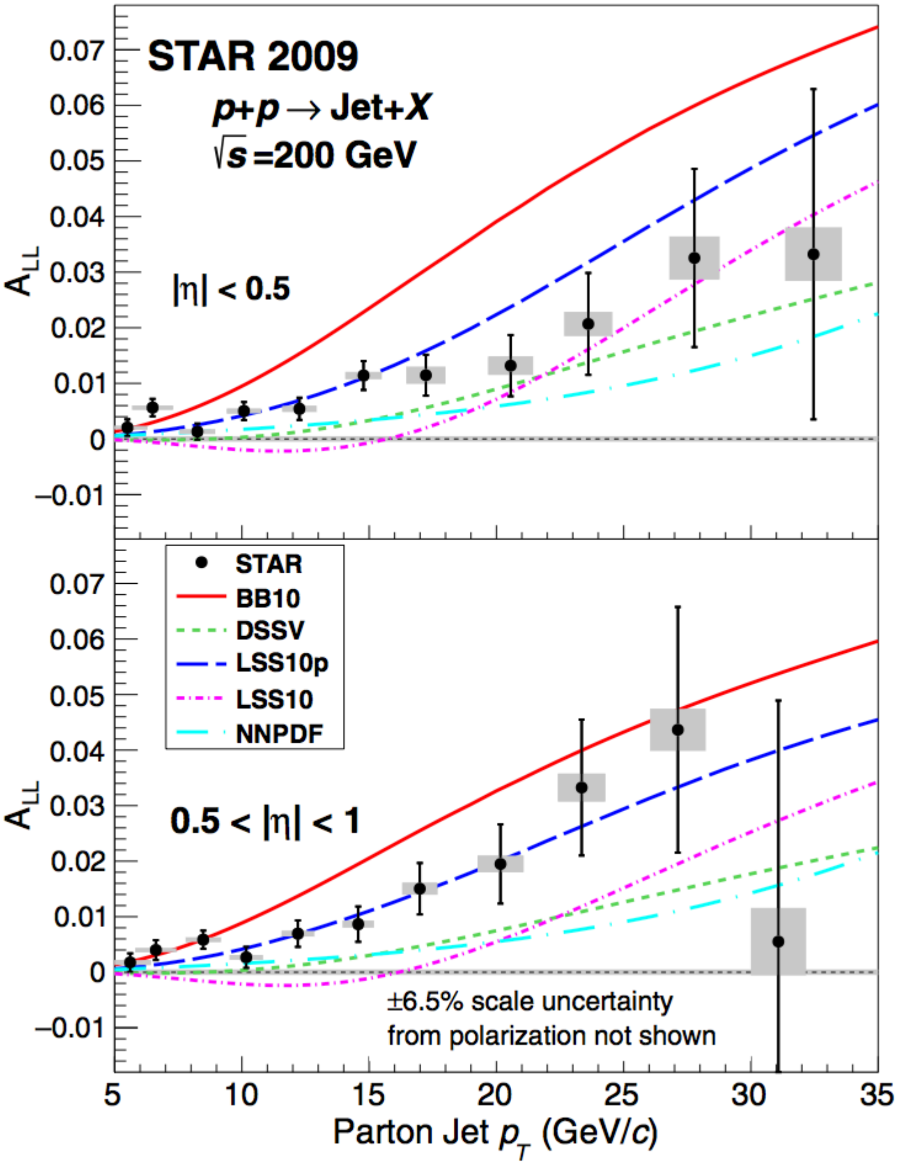
- STAR run6 data rule out several previous models of gluon polarization, and included in the DSSV global analysis together with PHENIX π^0 results.

$$\int_{0.05}^{0.2} \Delta g(x)dx = 0.005 \pm^{0.129}_{0.164}$$ at $Q^2 = 10 GeV^2$

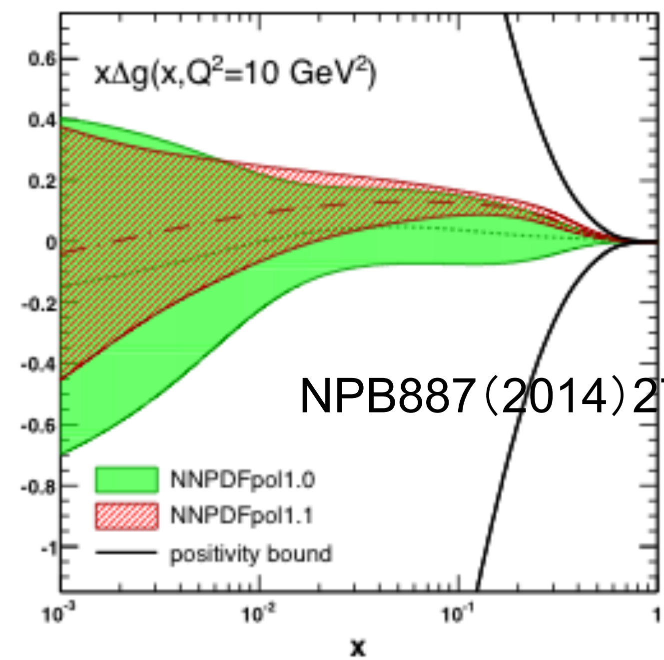
-arXiv:1304.0079

STAR inclusive jet A_{LL} from run9

STAR, Phys. Rev. Lett. 115(2015) 92002



- 2009 STAR data is a factor of 4 more precise than 2006.
- The A_{LL} asymmetry is small, but clearly non-zero !
- Impact of STAR data in NNPDF:

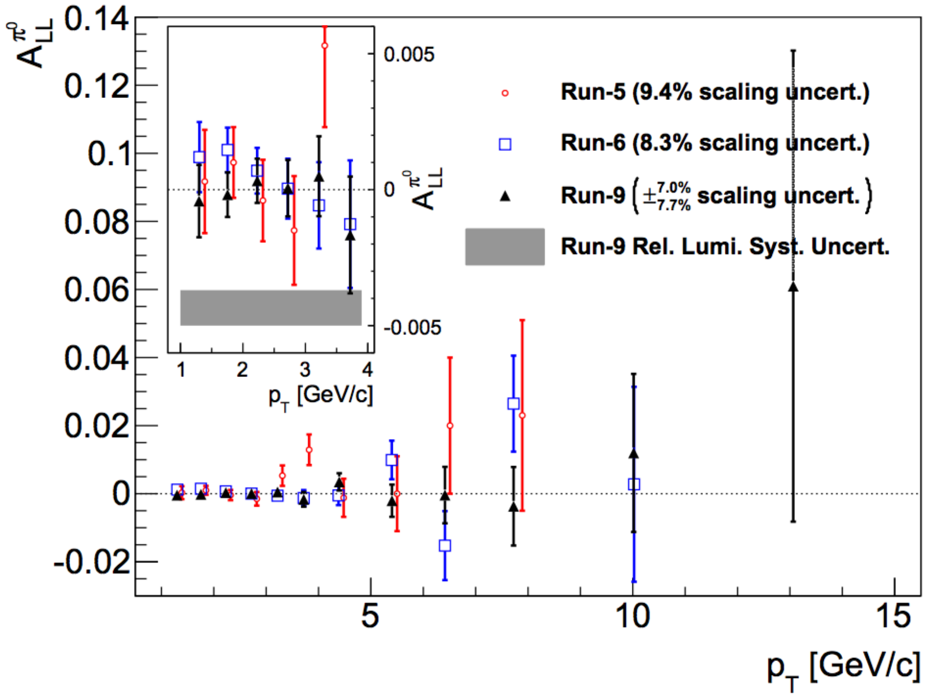


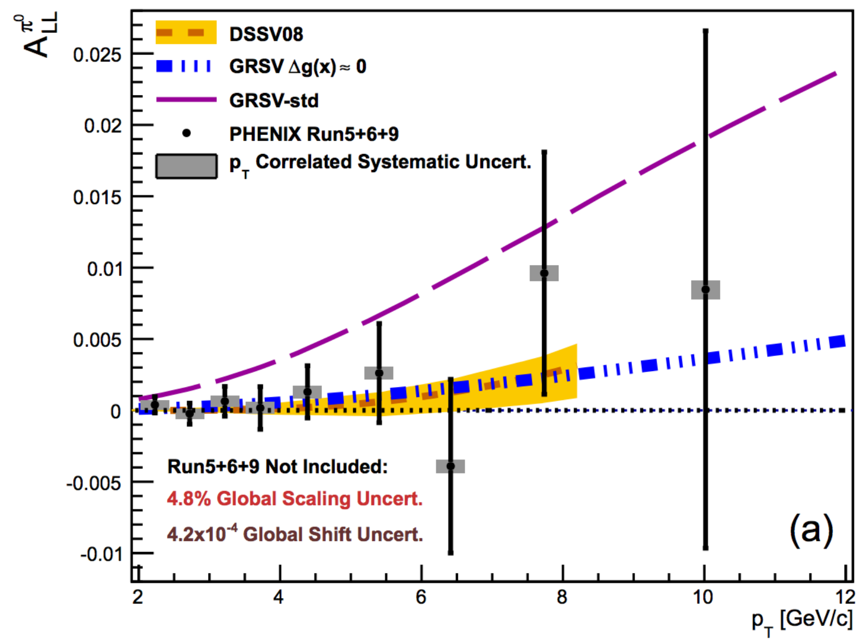
NPB887（2014）276

$$\int_{0.05}^{0.2} \Delta g(x,Q^2=10GeV^2)dx = 0.17 \pm 0.06$$

PHENIX results on π^0 A_{LL}

PHENIX-Phys. ReV. D 90, 12007(2014) [arXiv:1402.6296]

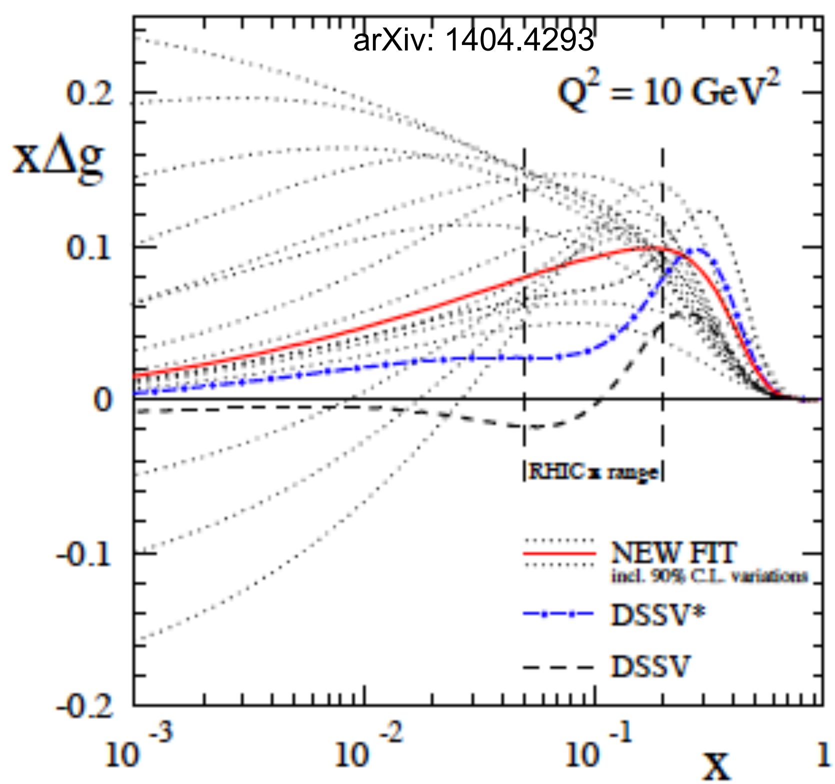


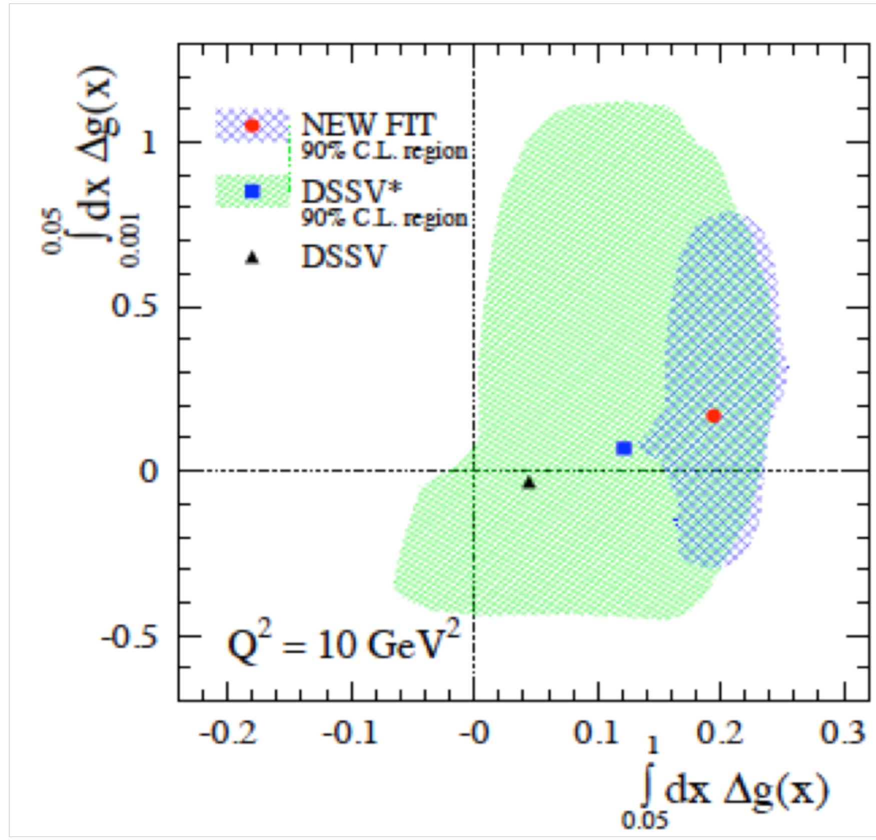


- ➢ High precision measurement at mid-rapidity
- ➢ Results are consistent with zero within uncertainty

DSSV global analysis including both STAR & PHENIX data
-Observation of gluon polarization

DSSV, PRL113,12001(2014)





DSSV: arXiv:0904.3821
DSSV*: DSSV + all new (SI)DIS
DSSV: DSSV* & RHIC 2009

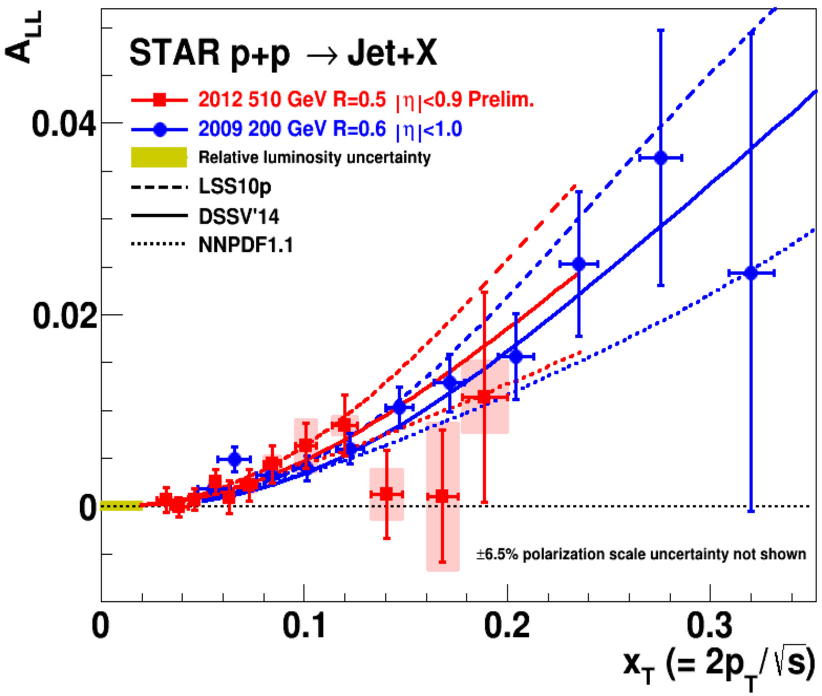
$$\int_{0.05}^{1.0} dx\Delta g \sim 0.2 \pm^{0.06}_{0.07} @\ 10\ \mathrm{GeV}^2$$

To further constrain $\Delta g(x)$, need to go to lower x

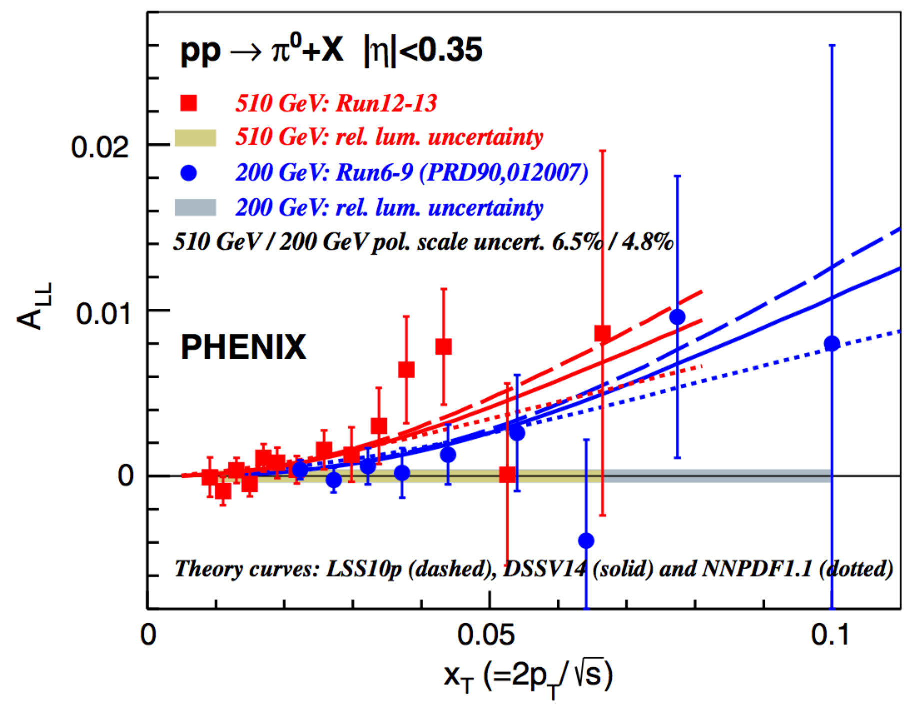
-> higher energy, forward di-jets

New A_{LL} results at 500 GeV

- *Can we further improve our knowledge on $\Delta g(x)$? Yes!*



- STAR jet A_{LL} at 510 GeV, which access small x region, consistent with 200GeV data.

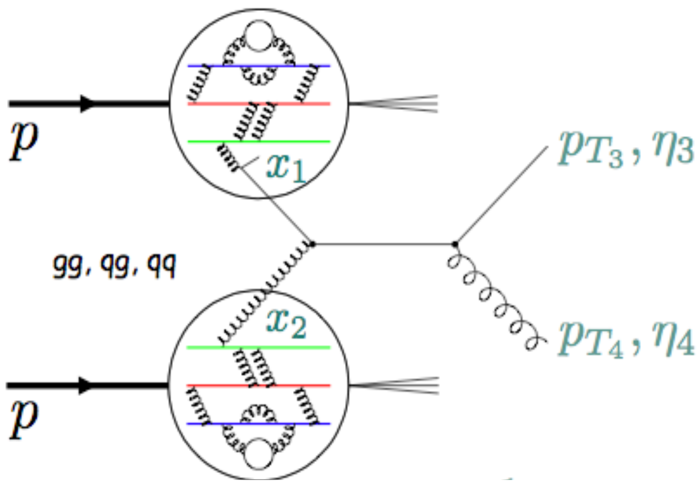


PHENIX, PRD 93, 011501 (2016)

- PHENIX π^0 A_{LL} at 510 GeV, which access small x region

Correlation measurements with partonic kinematics

- Access to partonic kinematics through di-jet production



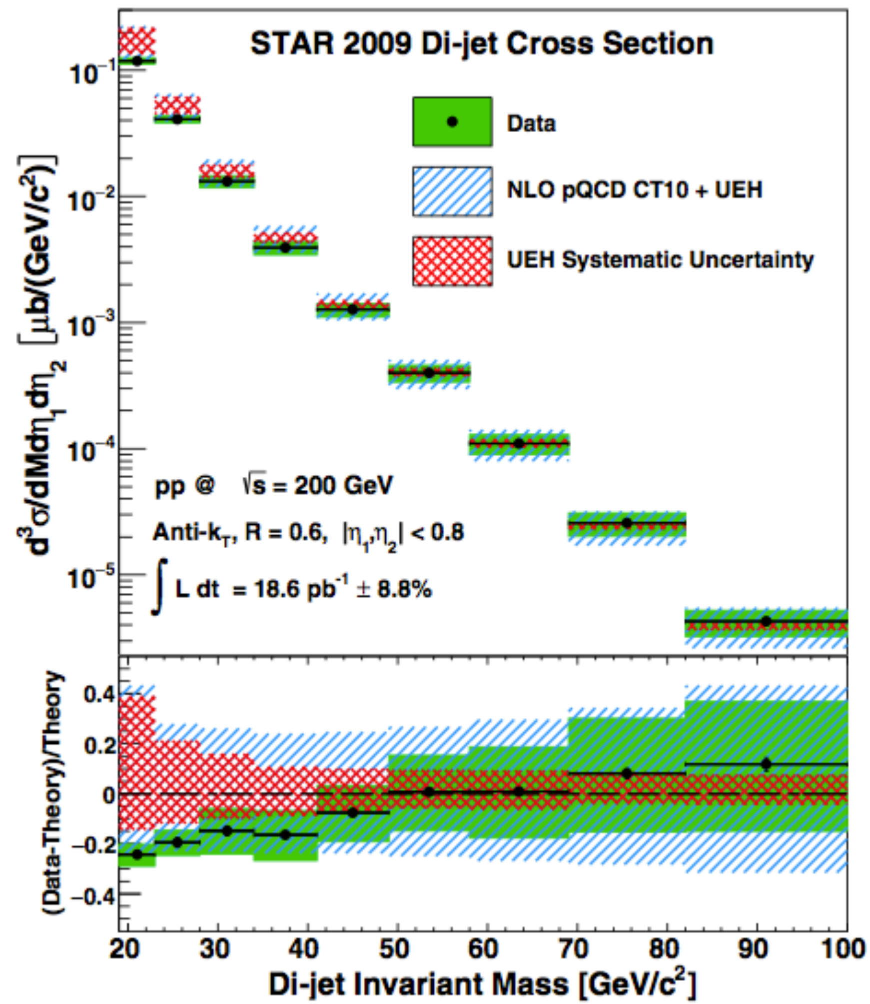
$$x_1 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{\eta_3} + p_{T4}e^{\eta_4}\right)$$

$$x_2 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{-\eta_3} + p_{T4}e^{-\eta_4}\right)$$

$$M = \sqrt{x_1 x_2 s}$$

$$\eta_3 + \eta_4 = \ln\frac{x_1}{x_2}$$

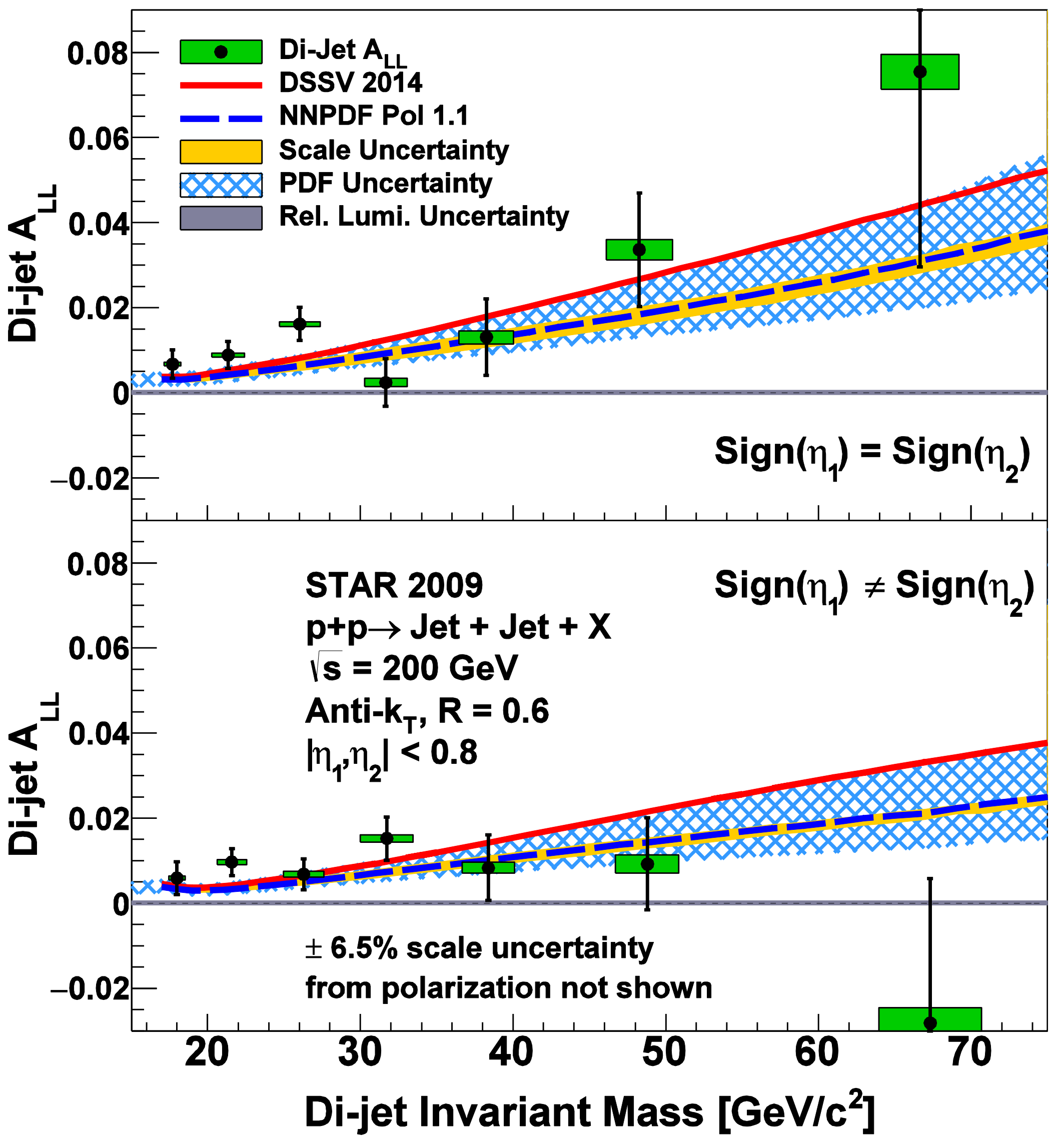
$$|\cos\theta^*| = \tanh\left|\frac{\eta_3 - \eta_4}{2}\right|$$

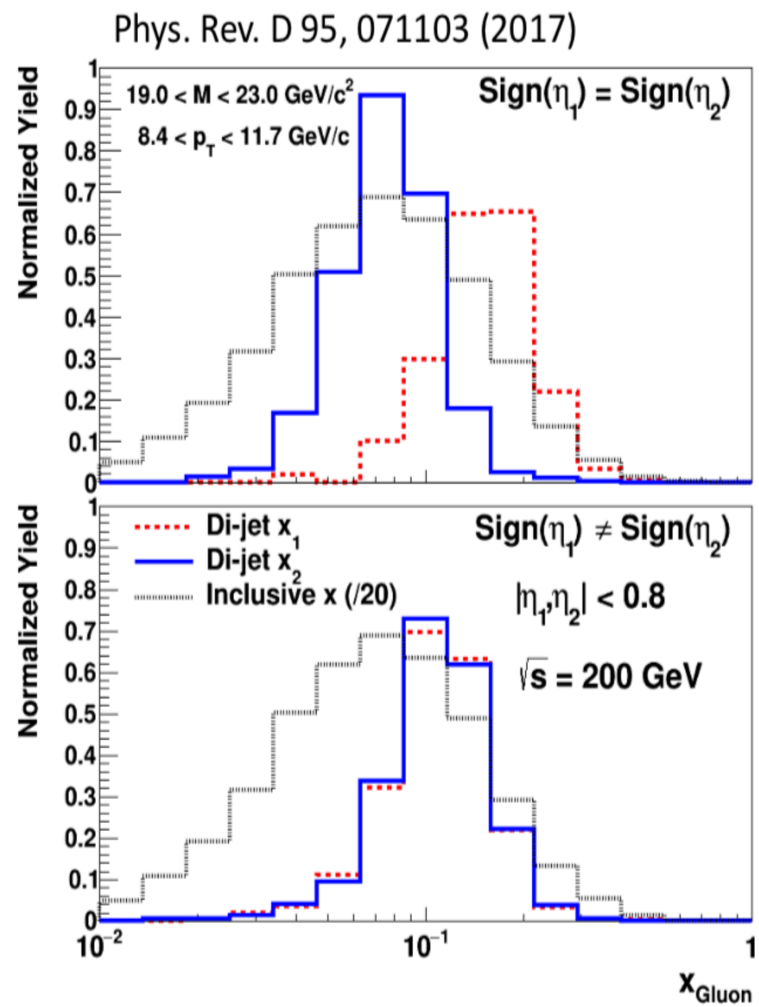


STAR, Phys. Rev. D95,071103(2017)

Di-jets A_{LL} at 200 GeV at STAR

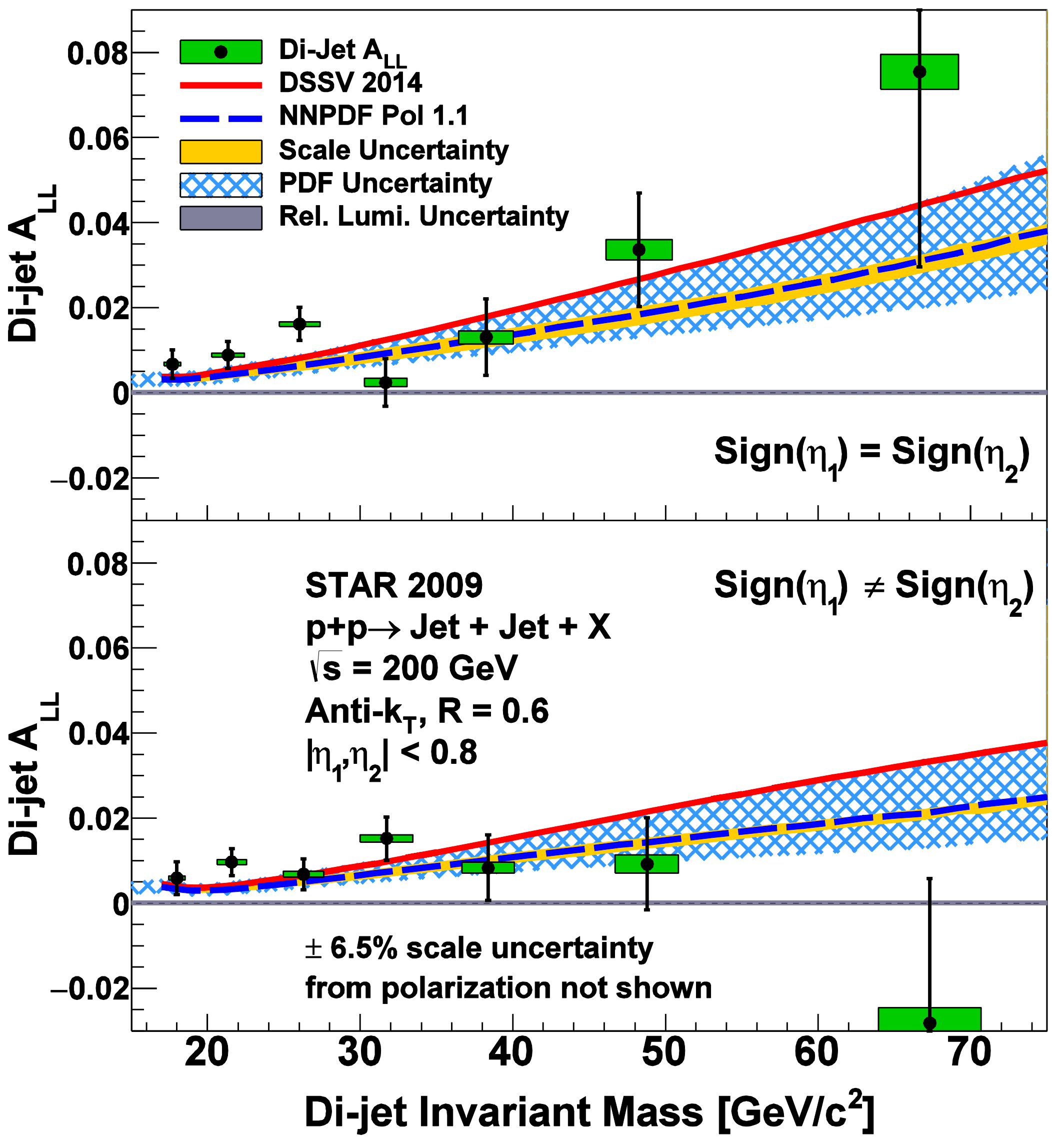
STAR, Phys. Rev. D95,071103(2017)





Di-jets A_{LL} at 200 GeV at STAR

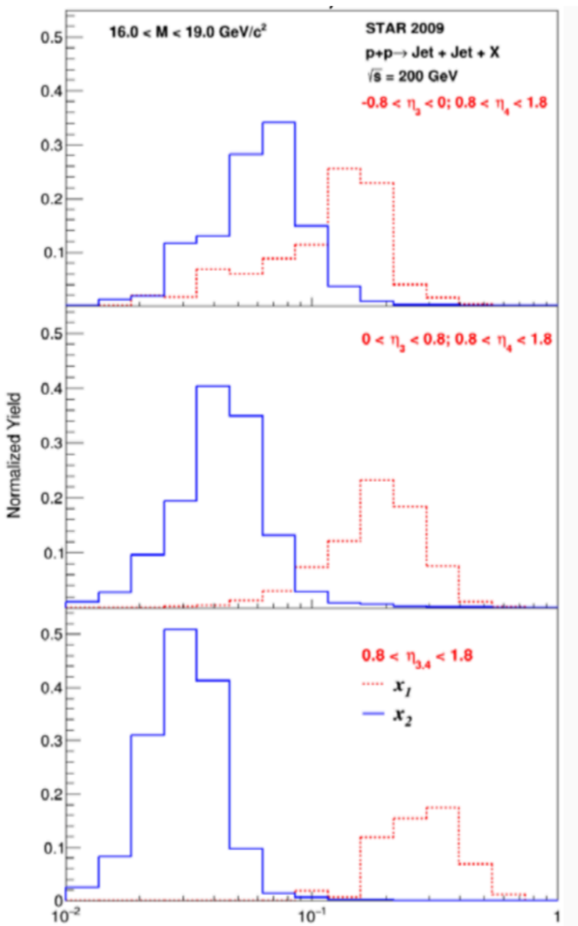
STAR, Phys. Rev. D95,071103(2017)

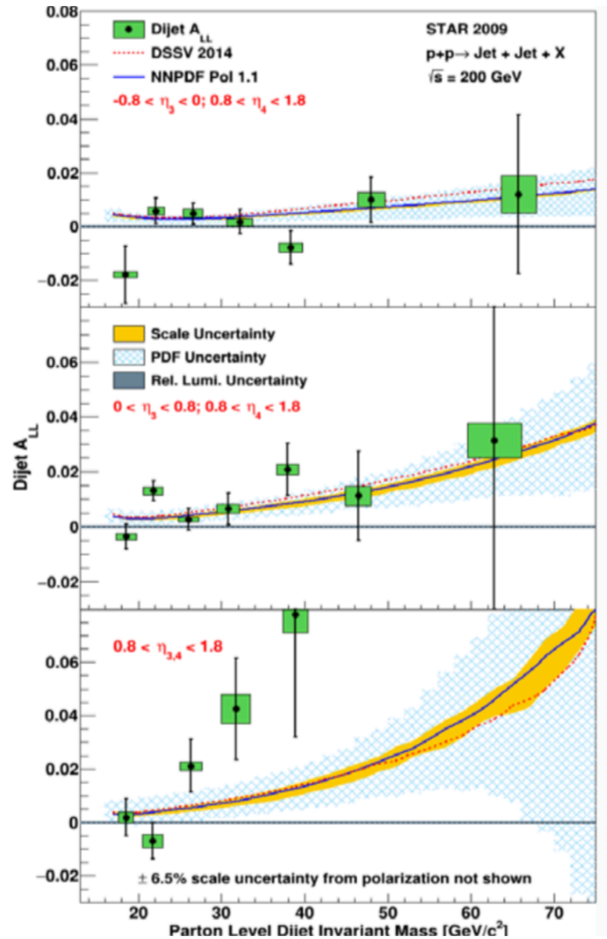


- Mid-rapidity di-jet A_{LL} for two topologies, allowing for constraints on the shape of $\Delta g(x)$
- Compared to expectations from DSSV14 and NNPDFpol1.1 polarized PDFs, both containing 2009 inclusive jet results
- Systematic bands from PDF and scale uncertainties shown for NNPDFpol1.1 curve

Intermediate Pseudorapidity Di-jet: STAR

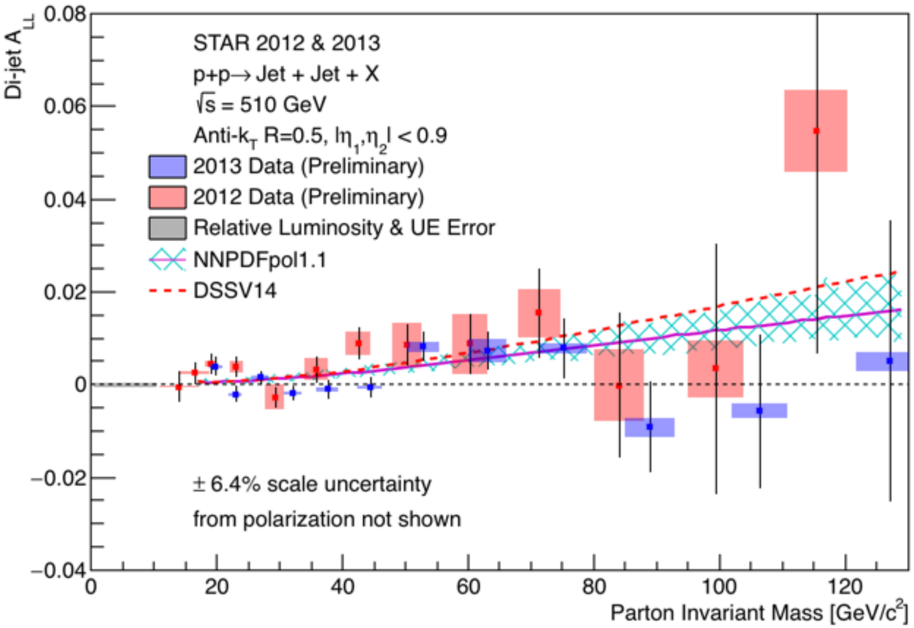
arXiv: 1805.09742, to appear in PRD





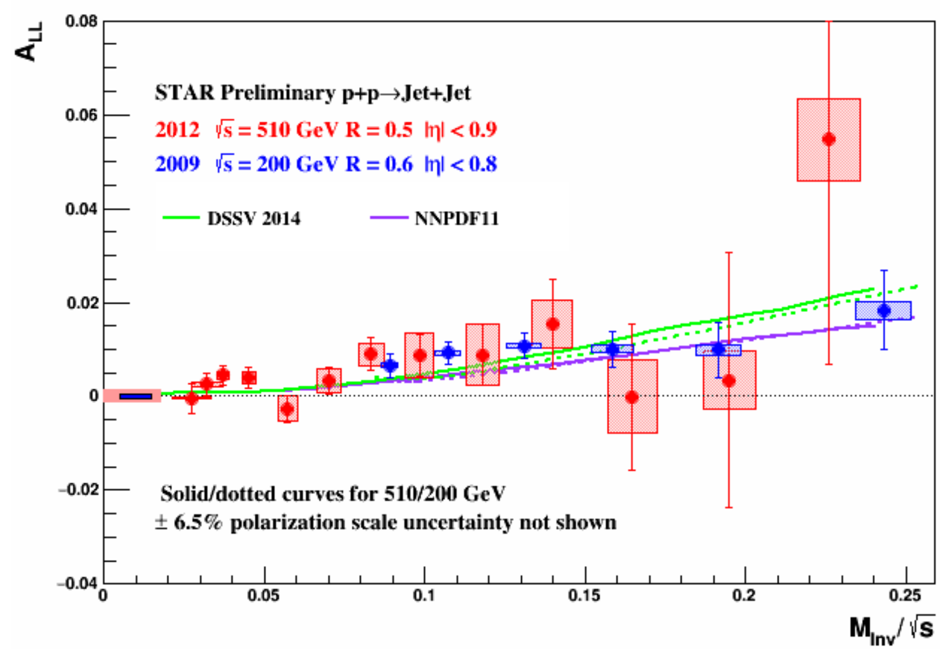
- Di-jet A_{LL} shown for two Barrel-Endcap topologies
- New results are compared to DSSV14 and NNPDFpol1.1 expectations
- The dijet data will more tightly constrain gluon spin at lower momentum fraction

Di-jets A_{LL} at 500 GeV at STAR

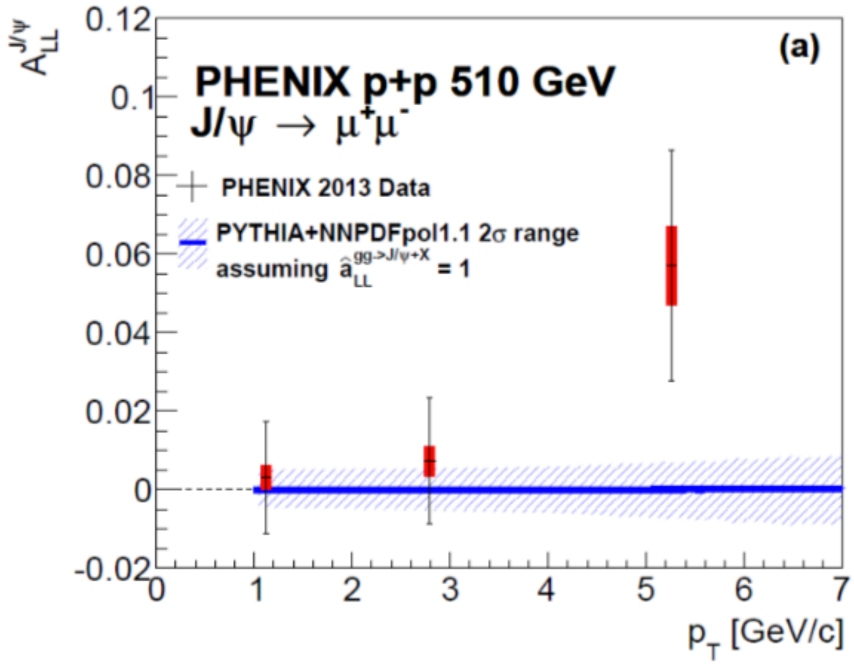


- Preliminary results for run 13, Run 12 ready for final release at STAR
- Good agreement between Run 12 and Run 13

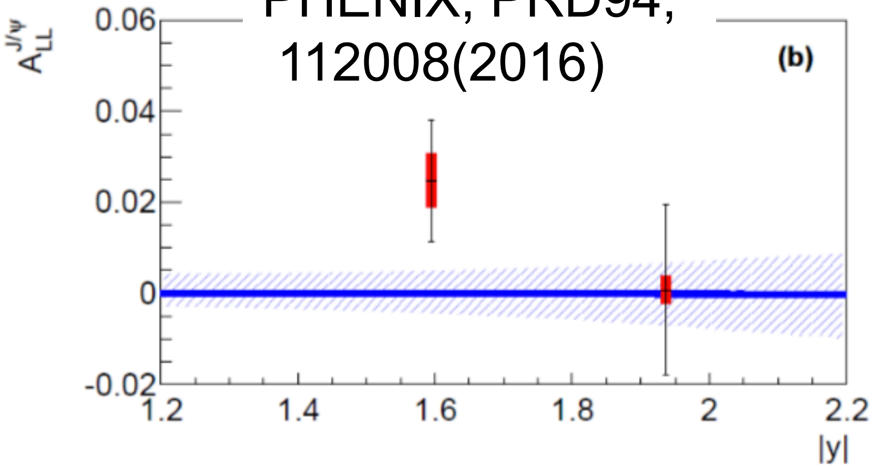
- Comparison of 500 and 200 GeV di-jets results, plotted vs. $M_{inv}/\sqrt{s}$
- 510GeV data extend to lower $M_{inv}/\sqrt{s}$



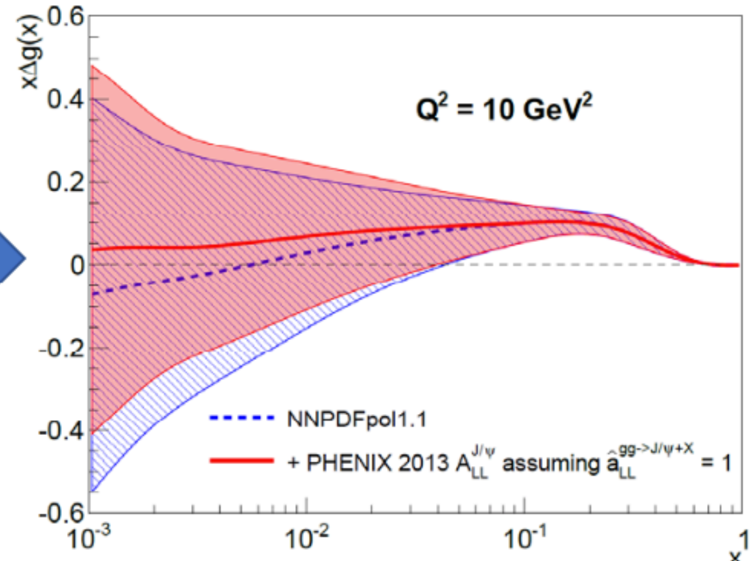
Forward J/psi A_{LL} at PHENIX



PHENIX, PRD94, 112008(2016)

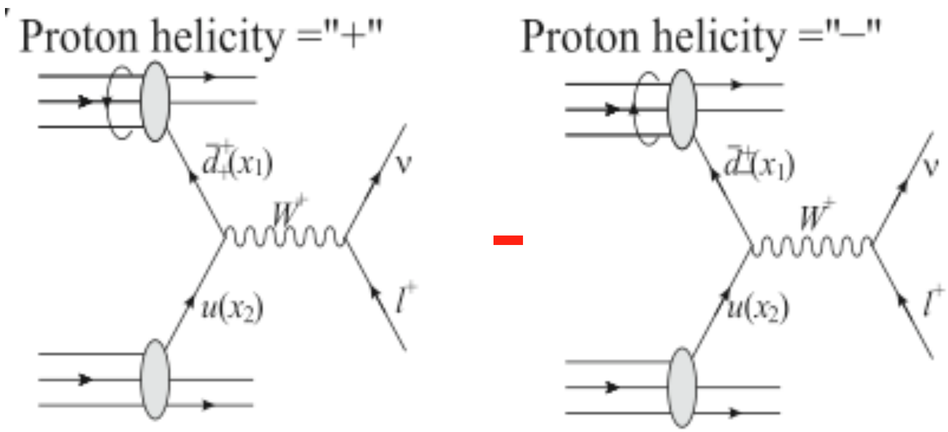


J/Ψ A_{LL} measurements in the forward region ($1.2 < |\eta| < 2.2$) offer a new way to access Δg via heavy-quark production, and allow access gluons down to x values of ~ 0.002



Probing sea quark polarization via W production

- Quark polarimetry with W-bosons:



$$\propto \Delta\bar{d}(x)u(x)$$

W-detection through high energy lepton

- Spin asymmetry measurements:

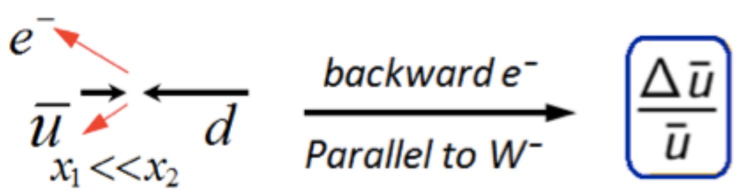
$$A_L^{W^+} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = \frac{-\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)} = \begin{cases} -\dfrac{\Delta u(x_1)}{u(x_1)}, \; y_{W^+} >> 0 \\ \dfrac{\Delta\bar{d}(x_1)}{\bar{d}(x_1)}, \; y_{W^+} << 0 \end{cases}$$

$$A_L^{W^-} = \begin{cases} -\dfrac{\Delta d(x_1)}{d(x_1)}, \quad y_{W^-} >> 0 \\ \dfrac{\Delta\bar{u}(x_1)}{\bar{u}(x_1)}, \quad y_{W^-} << 0 \end{cases}$$

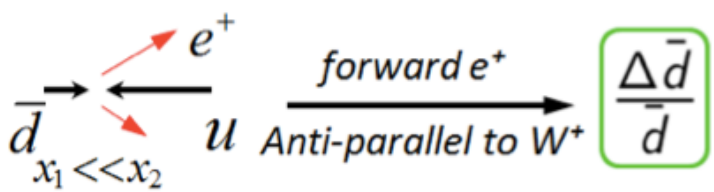
Expectation of W A_L at RHIC

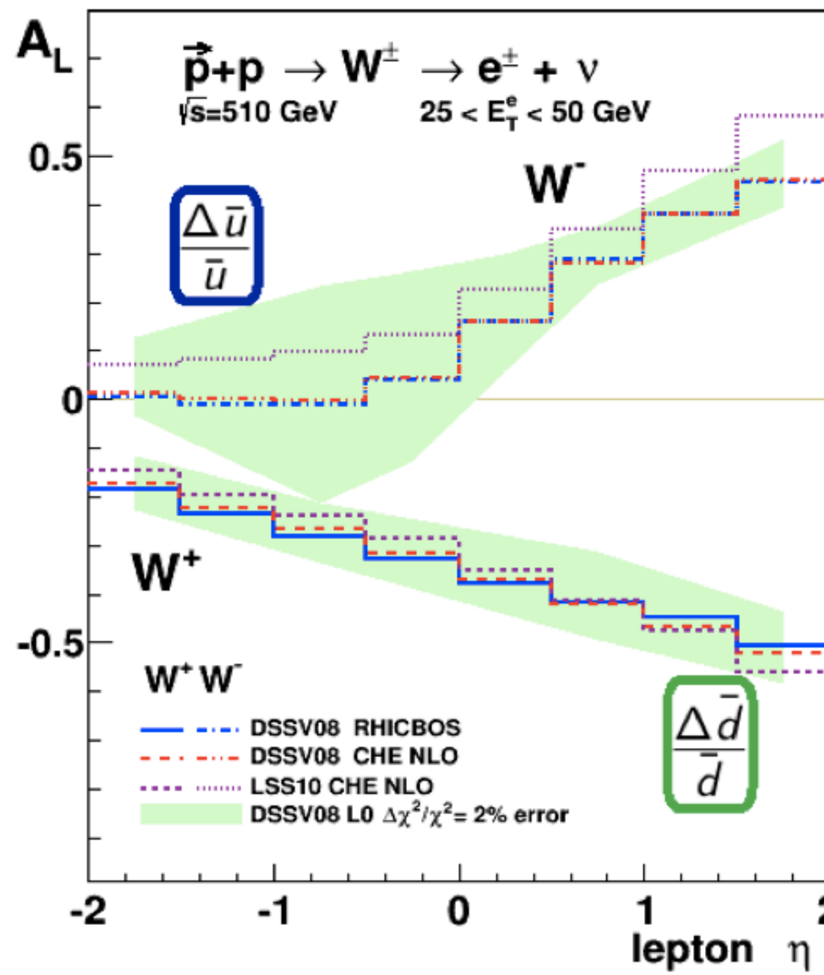
- Large parity-violating asymmetries expected.
- Simplified interpretation at forward and backward rapidity:

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



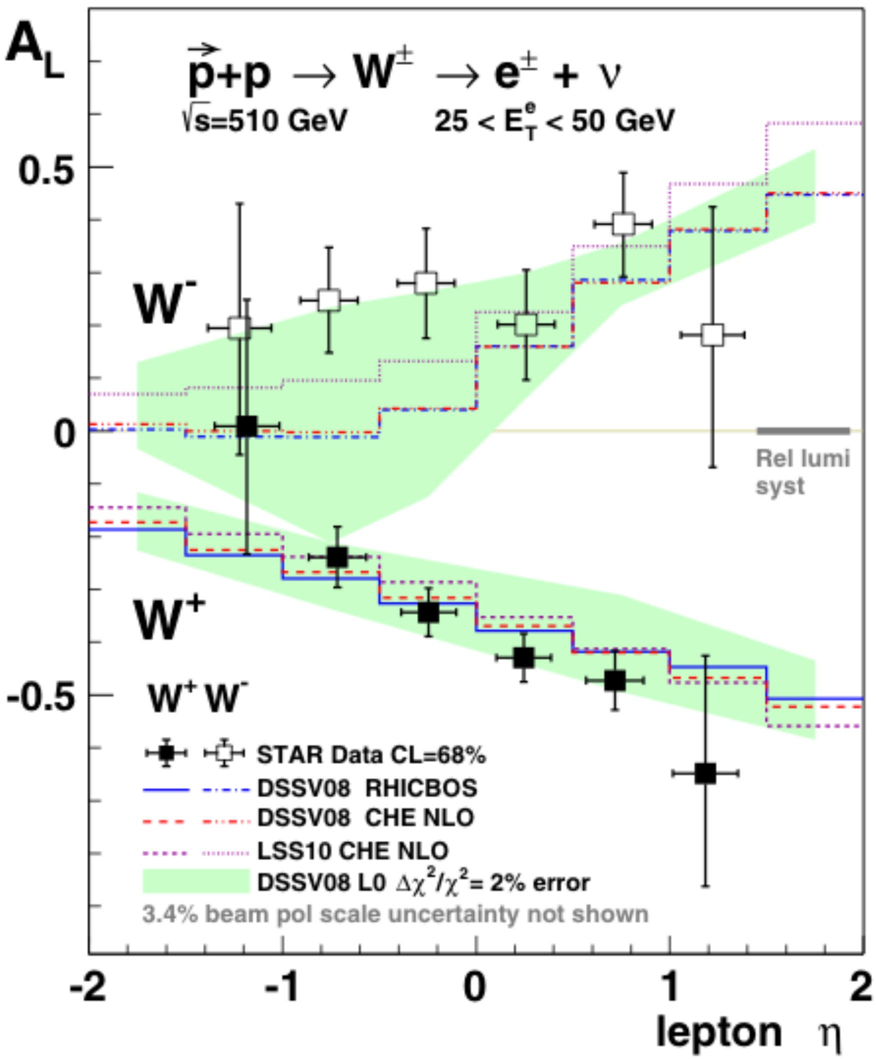
$$A_L^{W^+} \propto \frac{-\Delta u(x_1)\bar{d}(x_2)+\Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2)+\bar{d}(x_1)u(x_2)}$$





STAR mid-rapidity W A_L –2011+2012

- First multiple-eta-bin A_L results from 2011+2012 data:

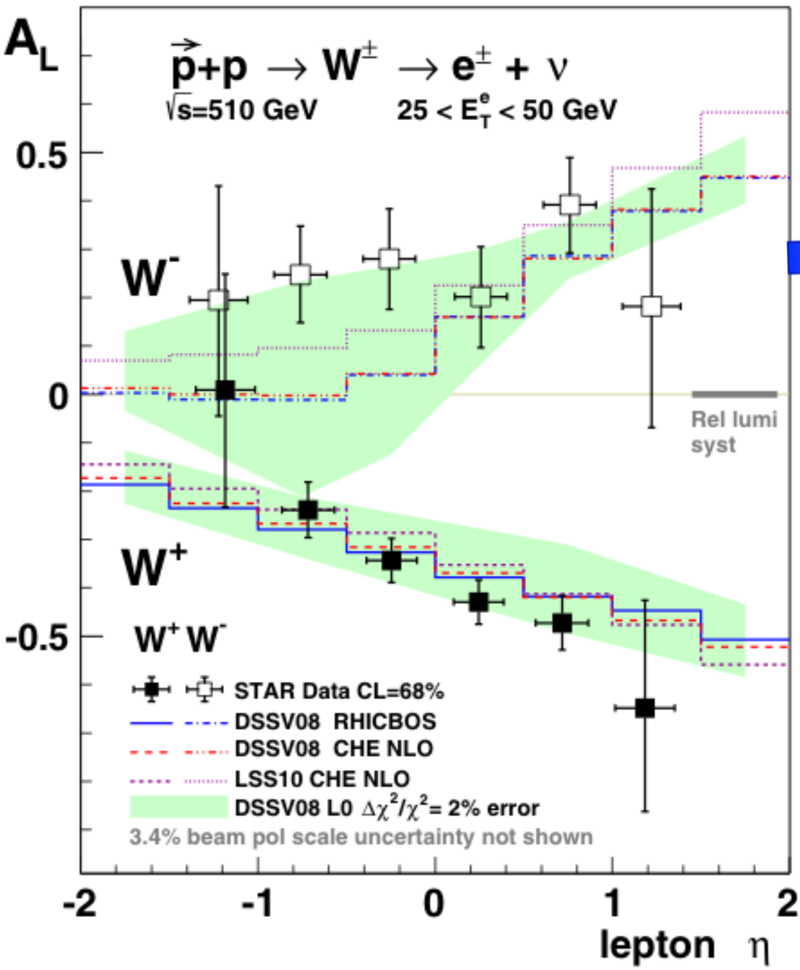


- A_L of W^- shows indication that data are larger than the DSSV predictions
- A_L of W^+ is consistent with theoretical predictions with DSSV pdf.
- Indication of symmetry breaking of polarized sea.

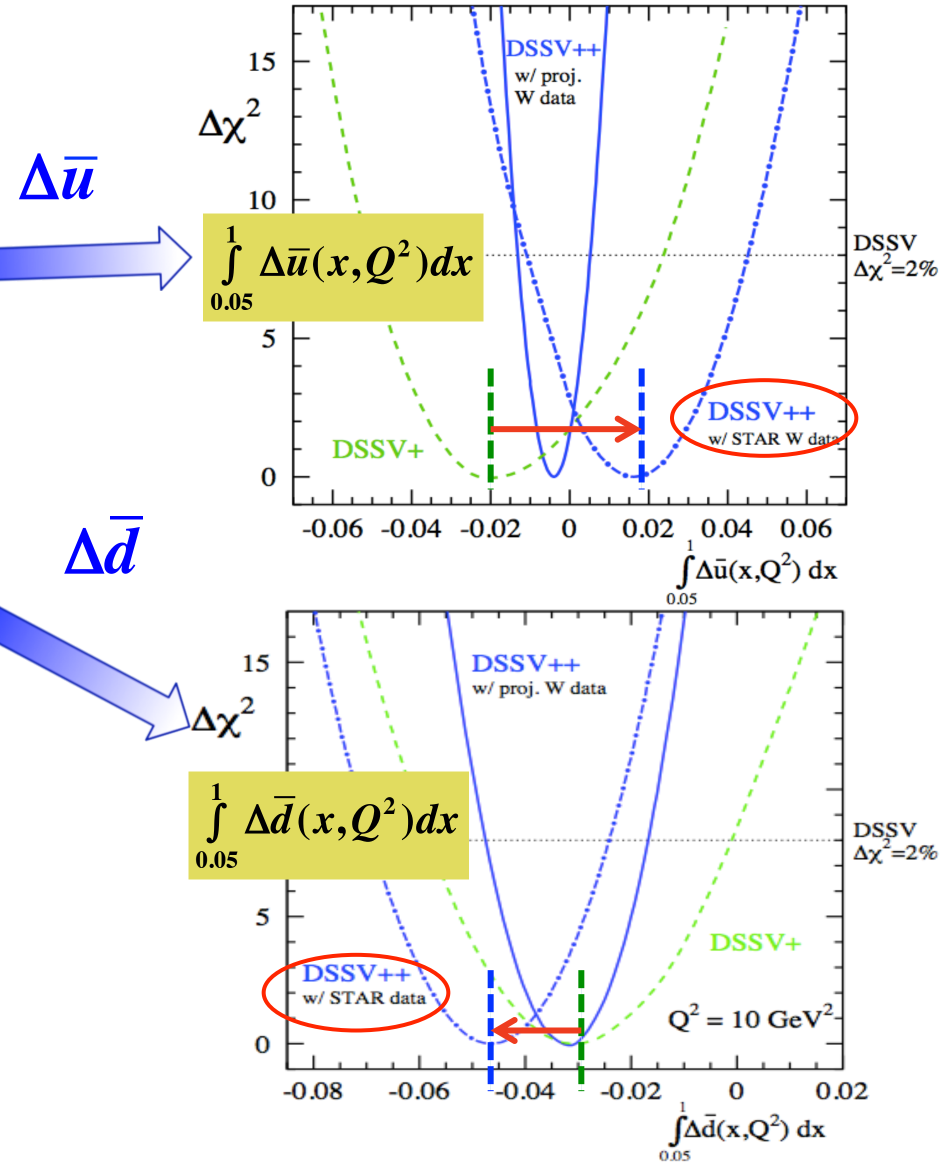
STAR, PRL113(2014)72301

Global Analysis with STAR W A_L 2012

STAR, PRL113(2014)72301



arXiv:1304.0079



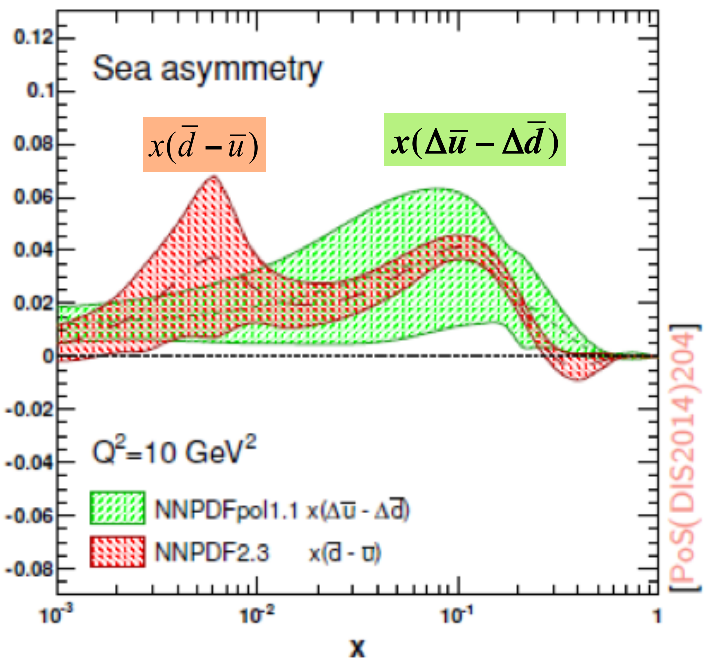
STAR 2012 W results provide significant constraints on $\Delta\bar{u}, \Delta\bar{d}$.

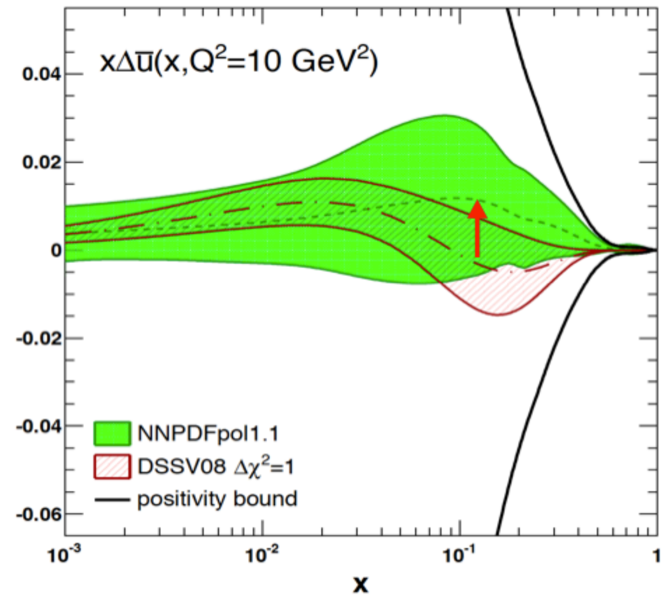
Global Analysis with STAR W A_L results

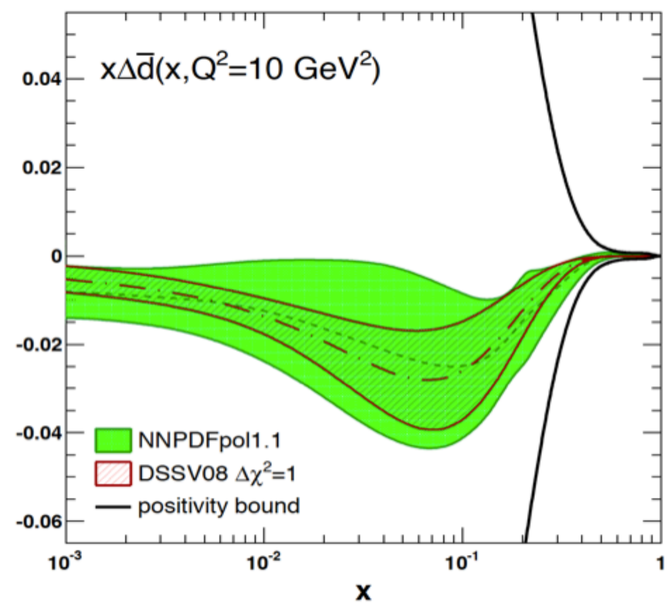
- Big impact seen in NNPDFpol1.1 global analysis after including STAR A_L data.

NNPDF1.1, Nucl.Phys. B887,276 (2014)

- Polarized sea asymmetry:

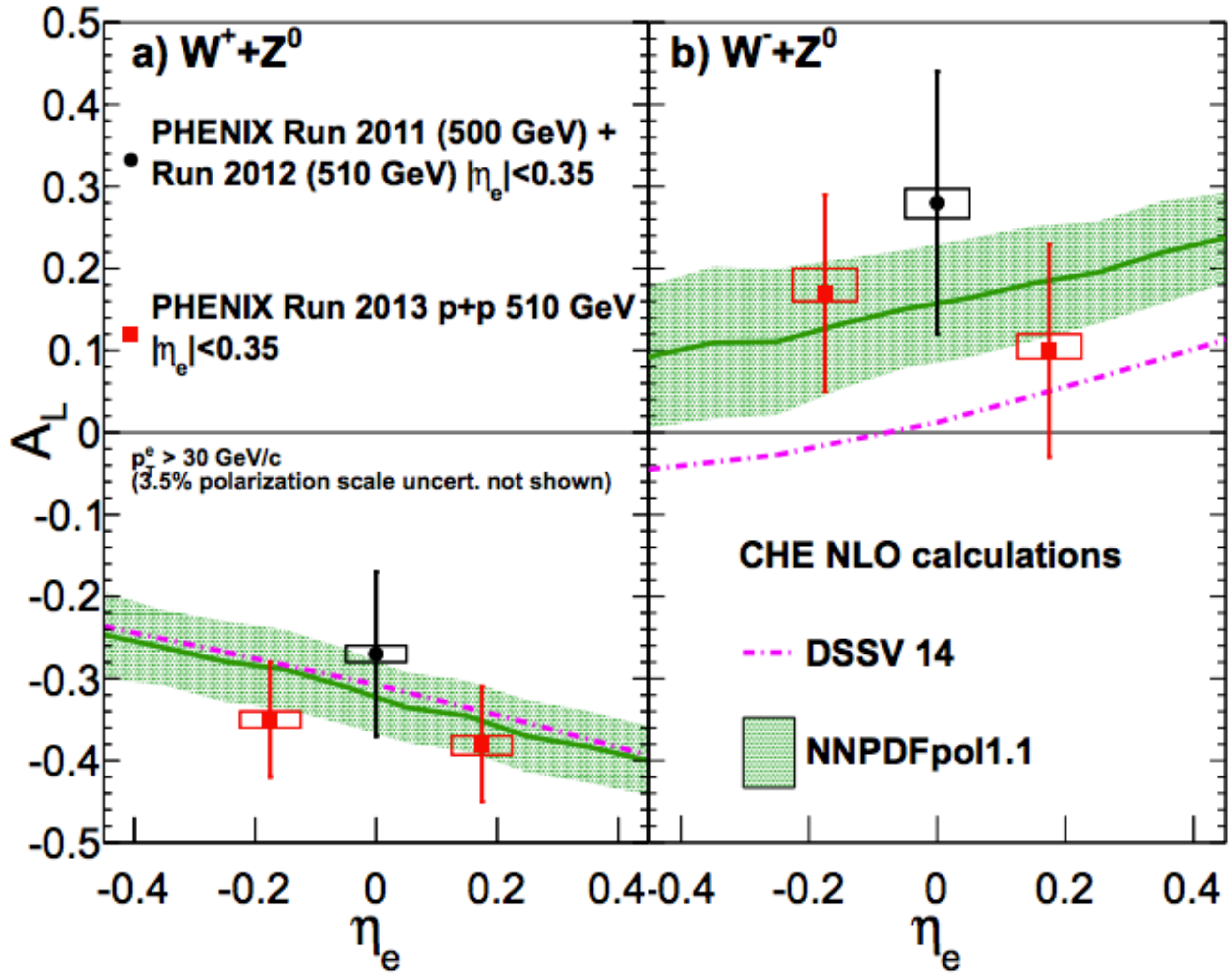






PHENIX mid-rapidity W A_L –more data

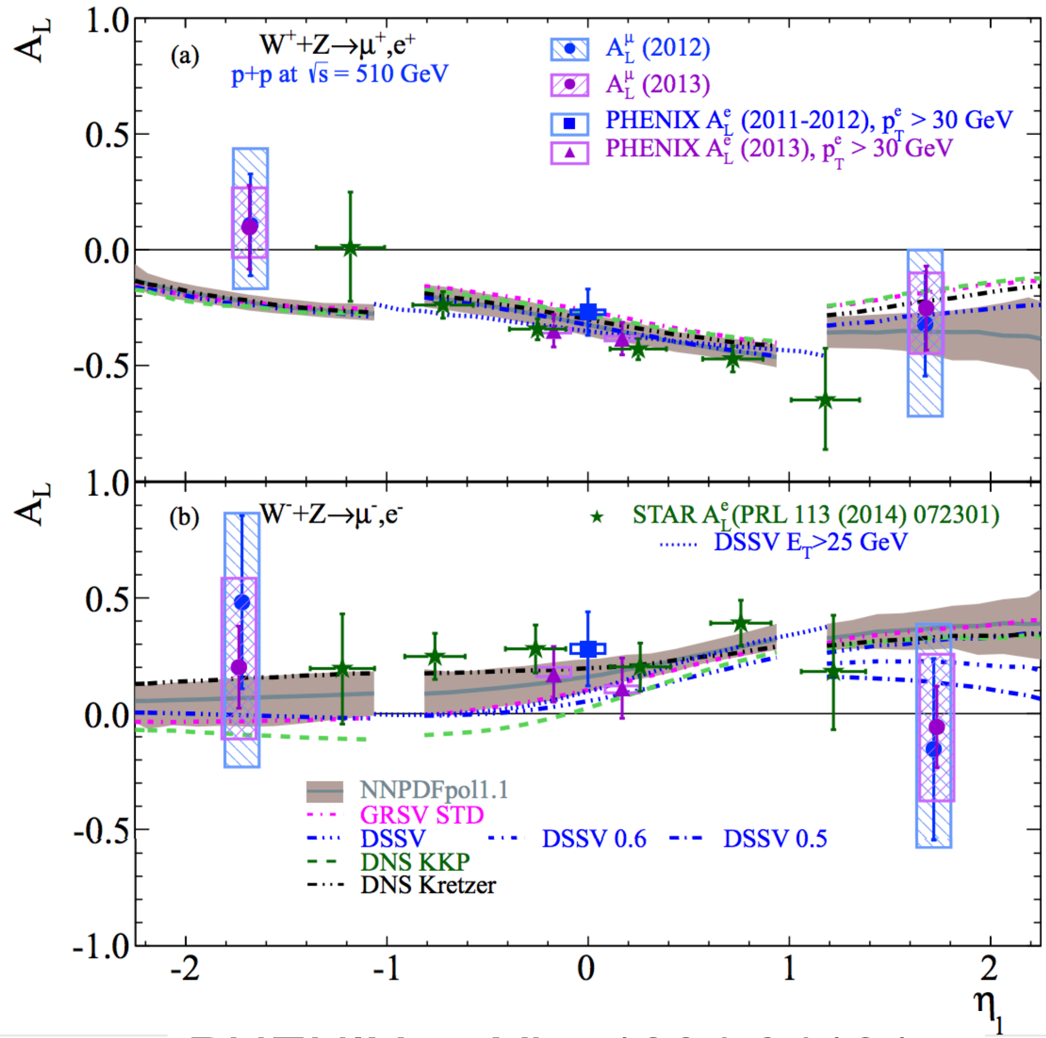
- PHENIX mid-rapidity A_L results from run 2011-2013:



PHENIX, PRD 93, 51103 (2016)

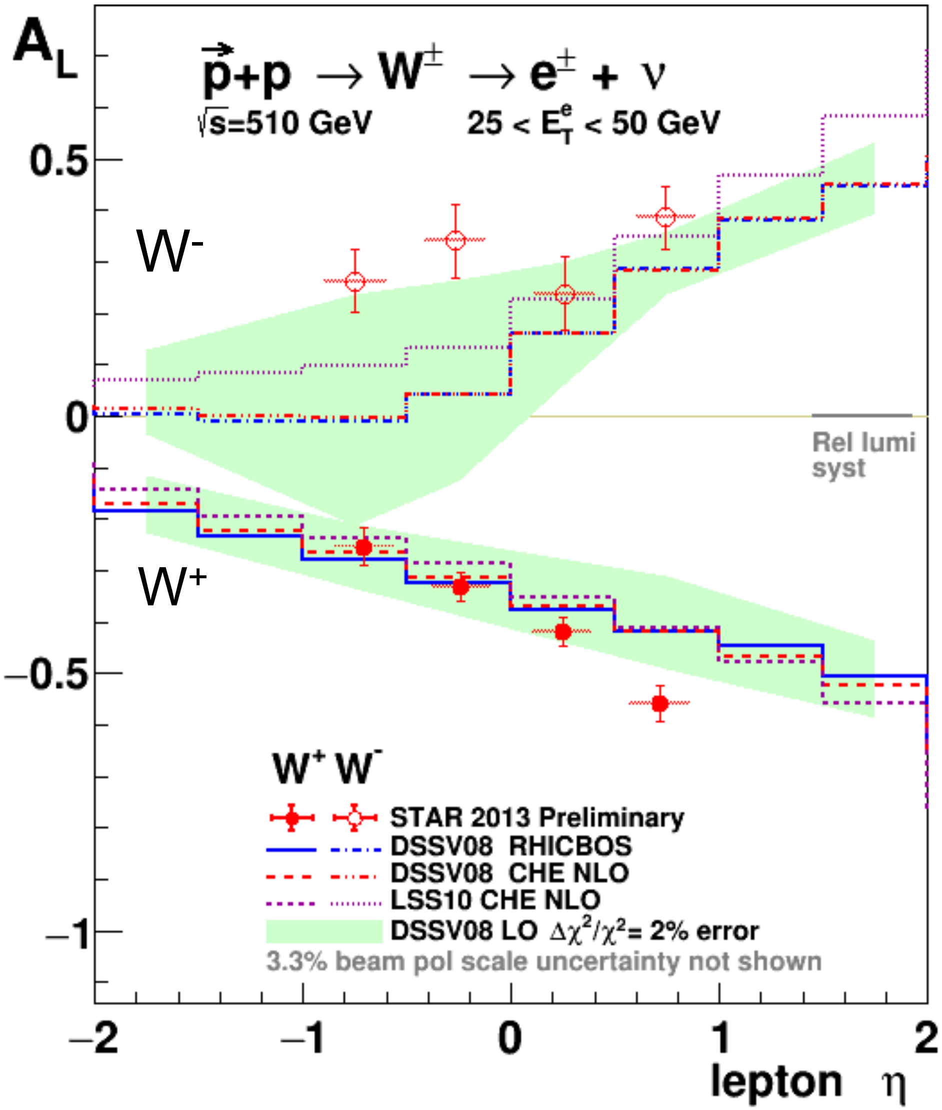
W A_L results in the forward region at PHENIX

- $W \to \mu\ A_L$ in Run 13 pp 510 GeV at forward region



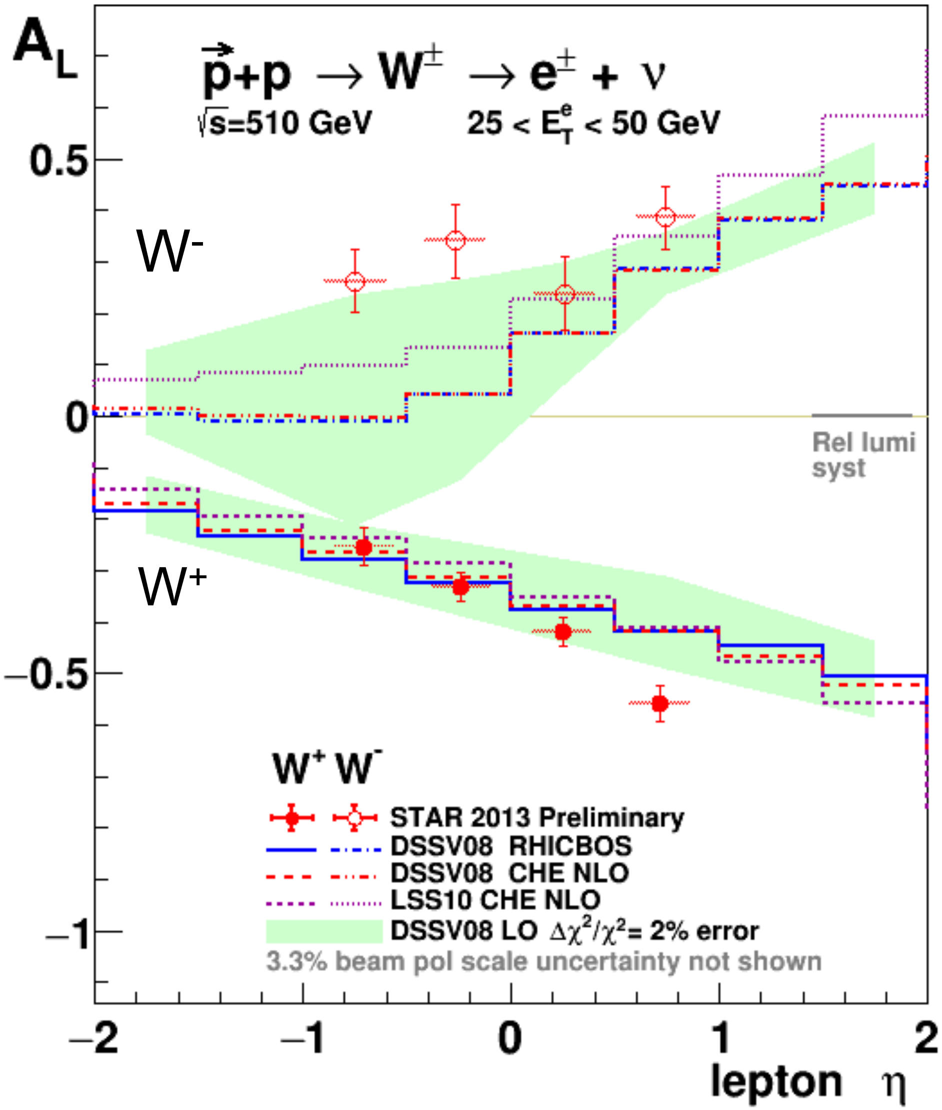
PHENIX, arXiv: 1804.04181

W A_L results – STAR 2013

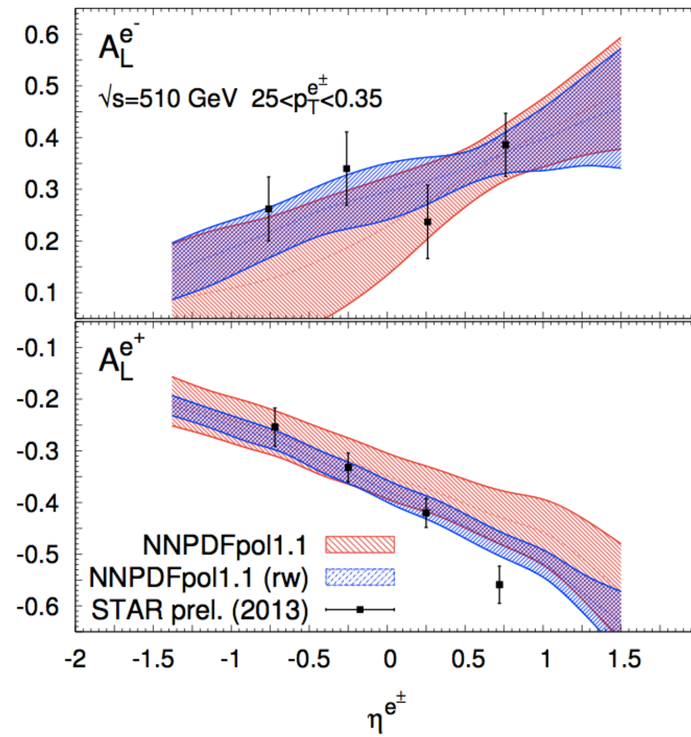


- STAR 2013 W A_L results:
  - Jinlong Zhang @ INPC 2016
  - Devika Gunarathne@ SPIN2016

W A_L results – STAR 2013

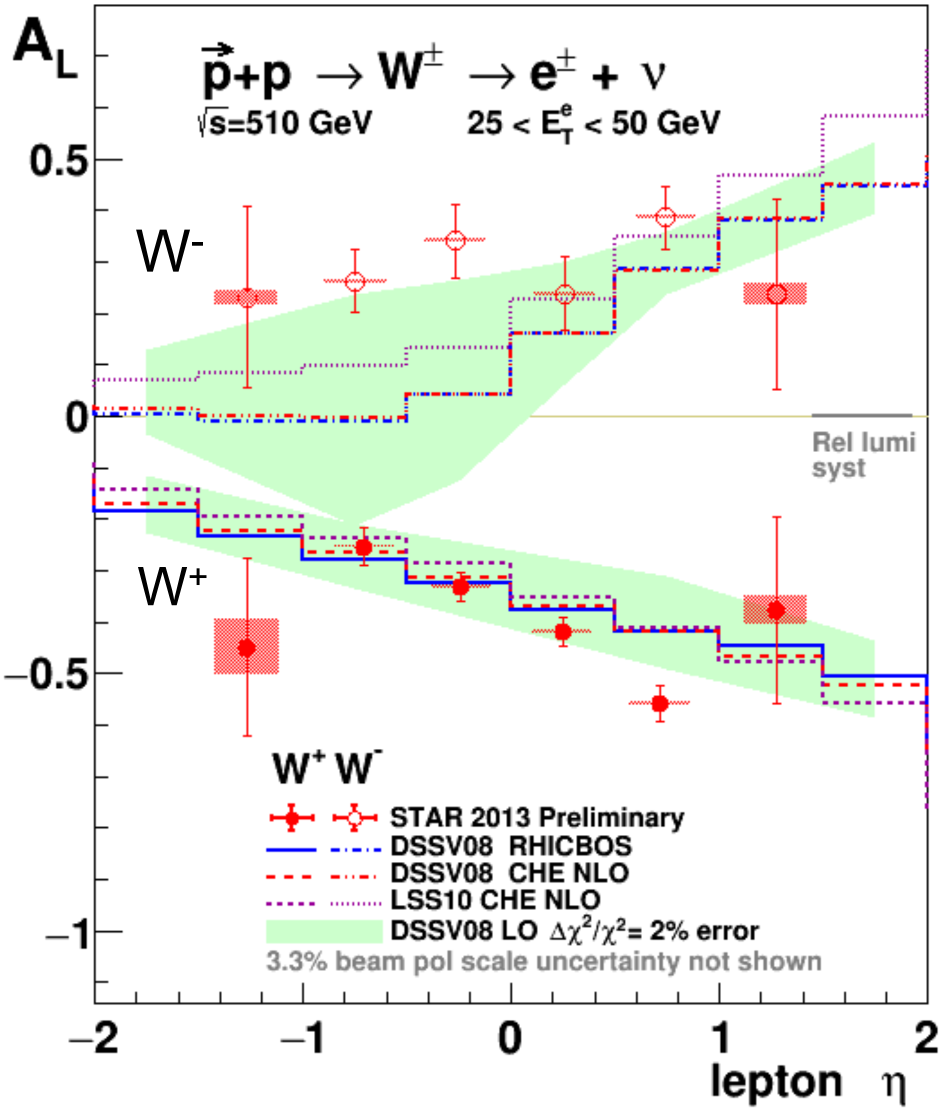


- STAR 2013 W A_L results:
  - Jinlong Zhang @ INPC 2016
  - Devika Gunarathne@ SPIN2016
- Impact in reweighting NNPDFpol1.1



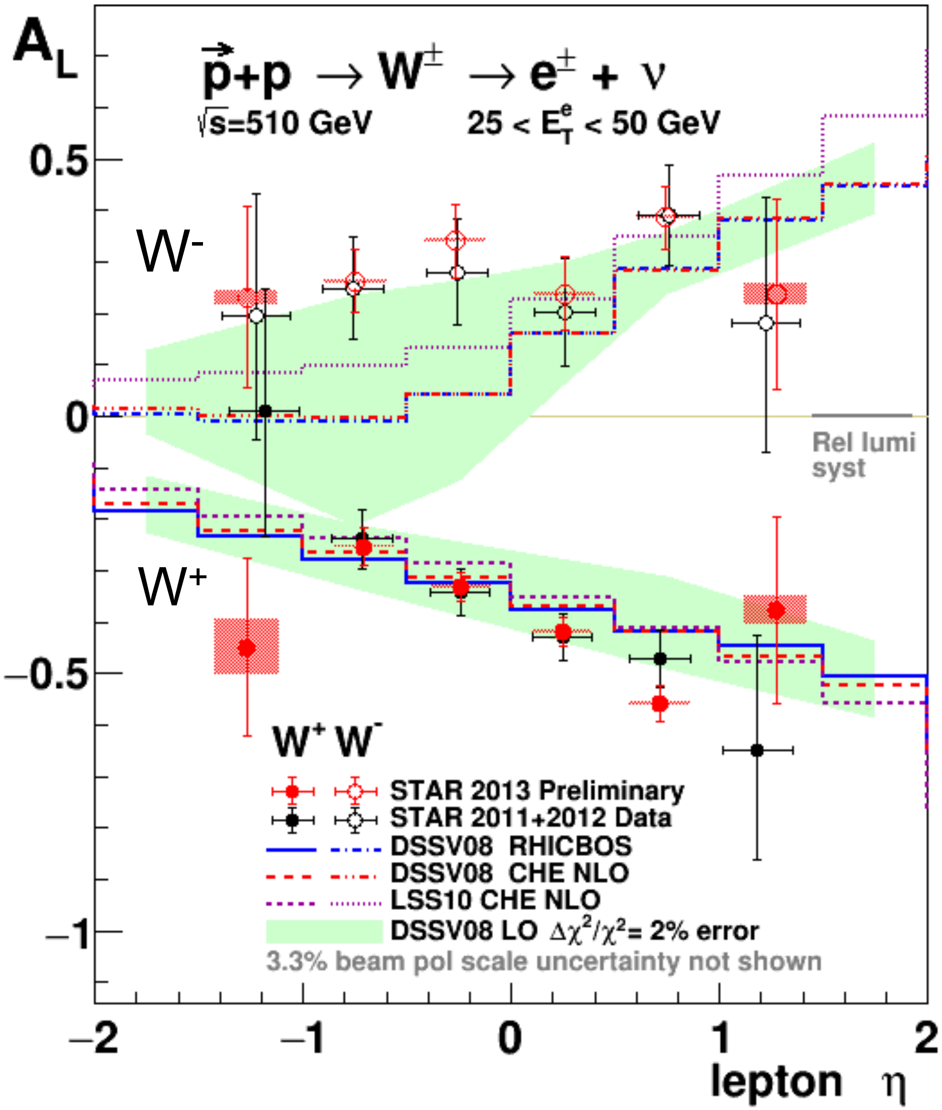
E. Nocera, arXiv:1702.05077

W A_L results – STAR 2013



- New preliminary A_L results at near-forward rapidity !
- STAR 2013 results are the most precise measurements of W A_L so far.

W A_L results – STAR 2013



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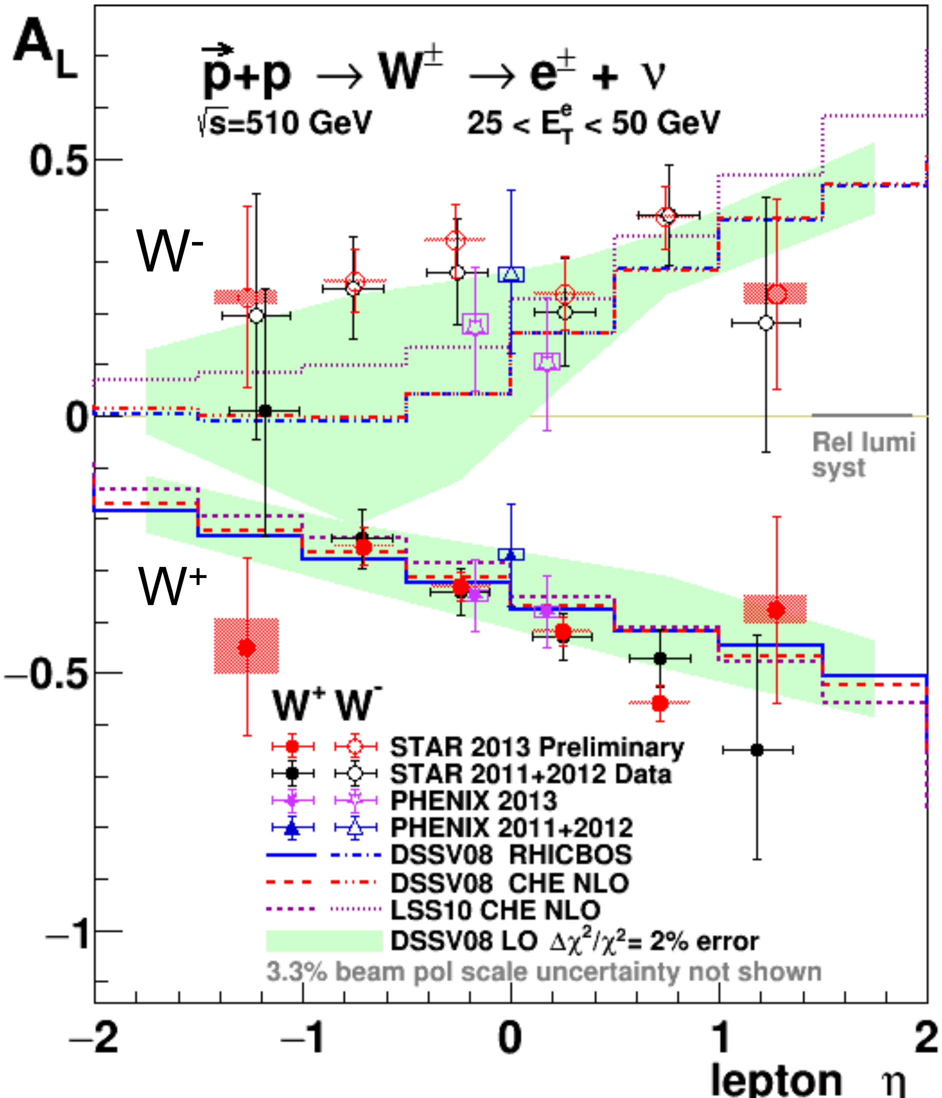
- STAR 2013 results are the most precise measurements of W A_L so far.
- Consistent with 2011+2012 published results, with 40% uncertainty reduced.
- Further confirmed the preference of positive $\Delta\bar{u}$.
- Can provide further constraints for $\Delta\bar{u}$, $\Delta\bar{d}$.

W A_L results – STAR 2013



- STAR, PRL113,072301(2014)
- PHENIX, PRD93,051103(2016)

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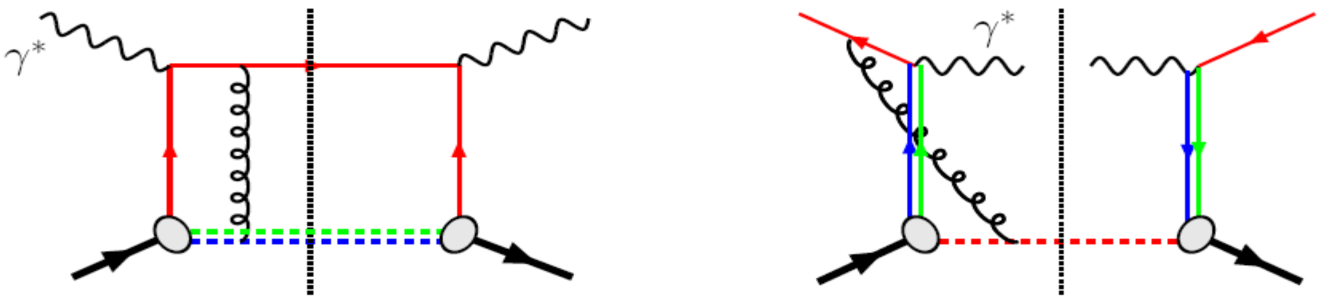
- Can provide further constraints for $\Delta\bar{u}$, $\Delta\bar{d}$.

Transverse Single spin asymmetry (A_N) of W boson

- Sivers sign change in DIS and DY/W/Z process:

DIS: γq scattering
attractive FSI

pp: $q/\bar{q}$ annihilation
repulsive ISI



Sivers_{DIS} = - Sivers (DY or W or Z)

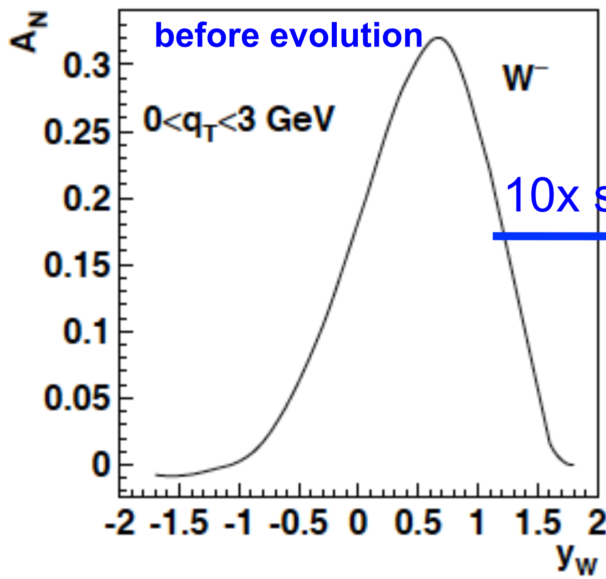
-Critical test for our understanding of TMD's and TMD factorization

- Active experimental programs at COMPASS (DY) and RHIC (W production)
- **Advantages of weak boson production**
  - Low background
  - High Q^2-scale (~ W/Z boson mass)

STAR goal: *measure sign change and pin down TMD-evolution by measuring A_N for all the processes:* $W^{\pm}$, Z^0, DY

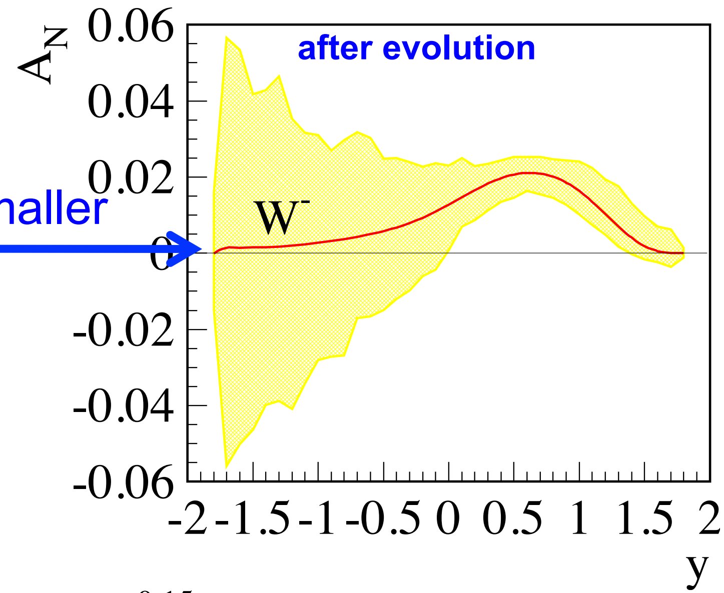
The effects from TMD evolution on Sivers A_N

Z.-B. Kang & J.-W. Qiu, PRL103, 172001(2009)

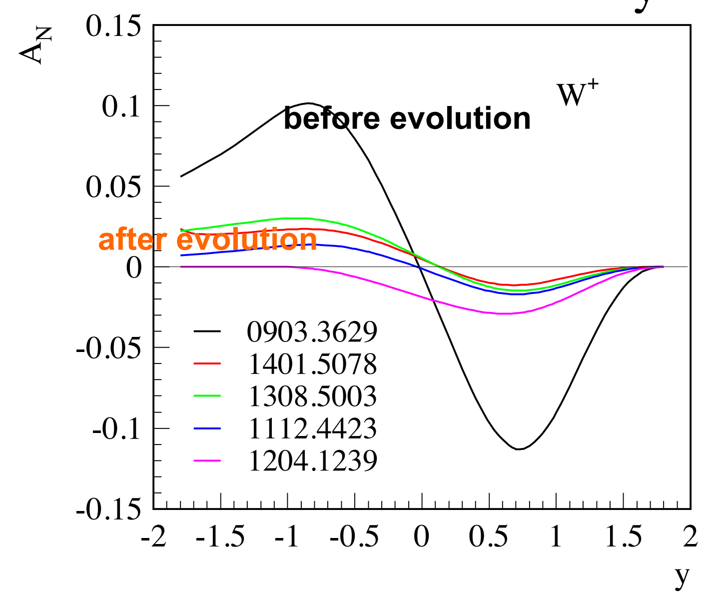


10x smaller

M. Echevarria et al, PRD89, arXiv:1401.5078



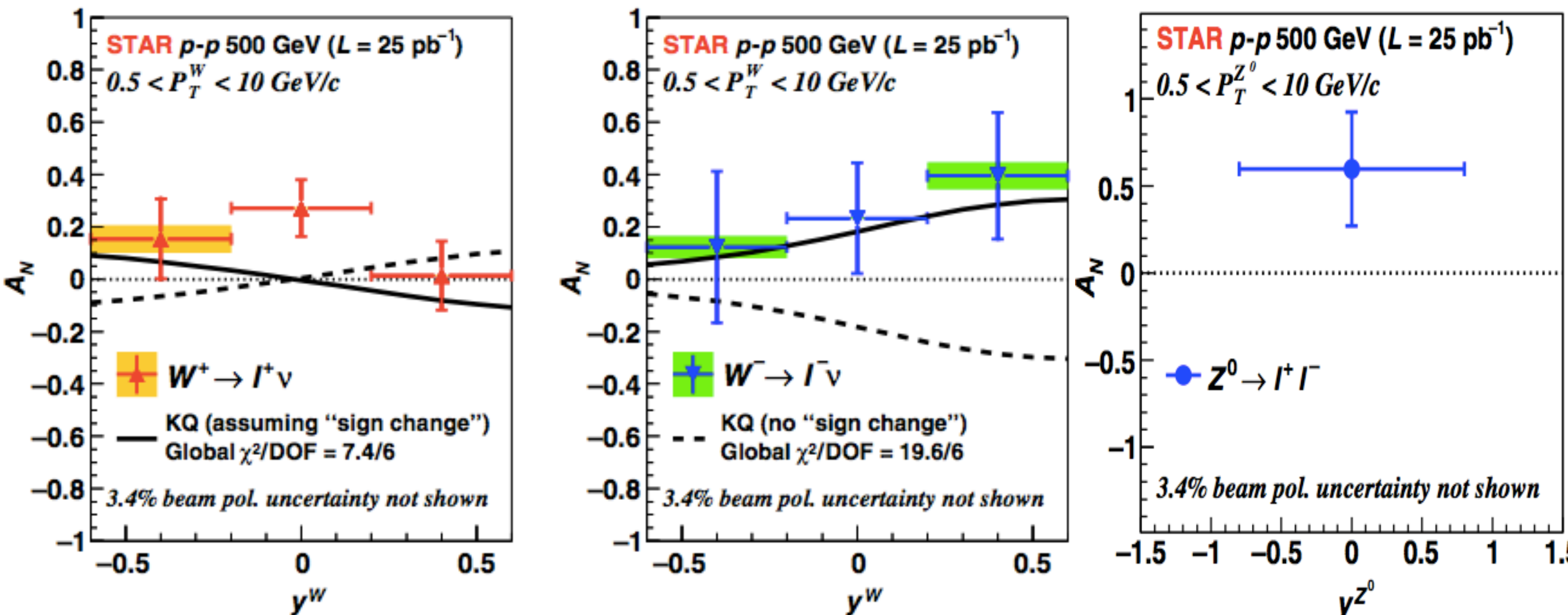
Very strong TMD evolution effects size of the asymmetry, still under discussion in theory community.



Strong dependence on y_W,
-> need fully reconstruction of W kinematics!

First W, Z A_N results at 500 GeV from STAR

- Data: STAR 2011 transverse run @ 500 GeV, integrated luminosity ~25 pb^{-1}
- First A_N for $W^{\pm}$ and Z results : $A_N \equiv \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$

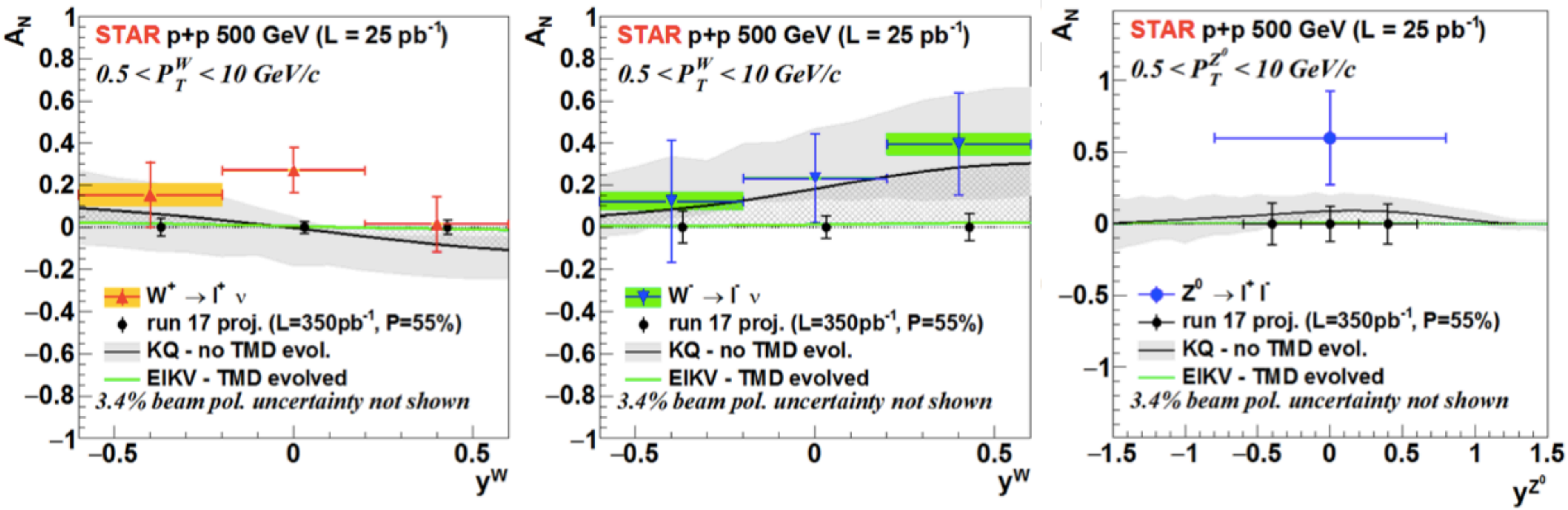


STAR, Phys. Rev. Lett. 116 (2016)132301

- Sivers sign-change scenario preferred over no-sign change scenario.
- Precision measurements from run 17, x14 times in integrated luminosity!

Coming measurements of W/Z A_N at STAR

- STAR collected ~400 pb^{-1} transverse pp in 2017:



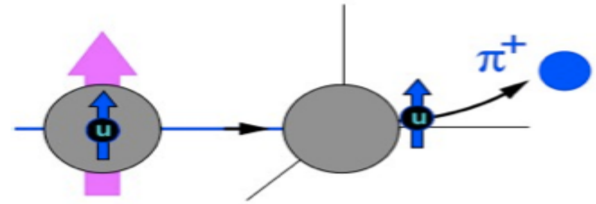
Goal:

✓ Constrain TMD evolution sea-quark Sivers function

✓ Test sign-change if TMD-evolution suppression factor ~5 or less

Mid-rapidity hadron-jet correlations (Collins)

- Study proton transversity through its coupling to Collins function:



$$A_{UT} \propto h_1(x) \otimes H_1^{\perp}(z, j_T)$$

- Collins asymmetries:

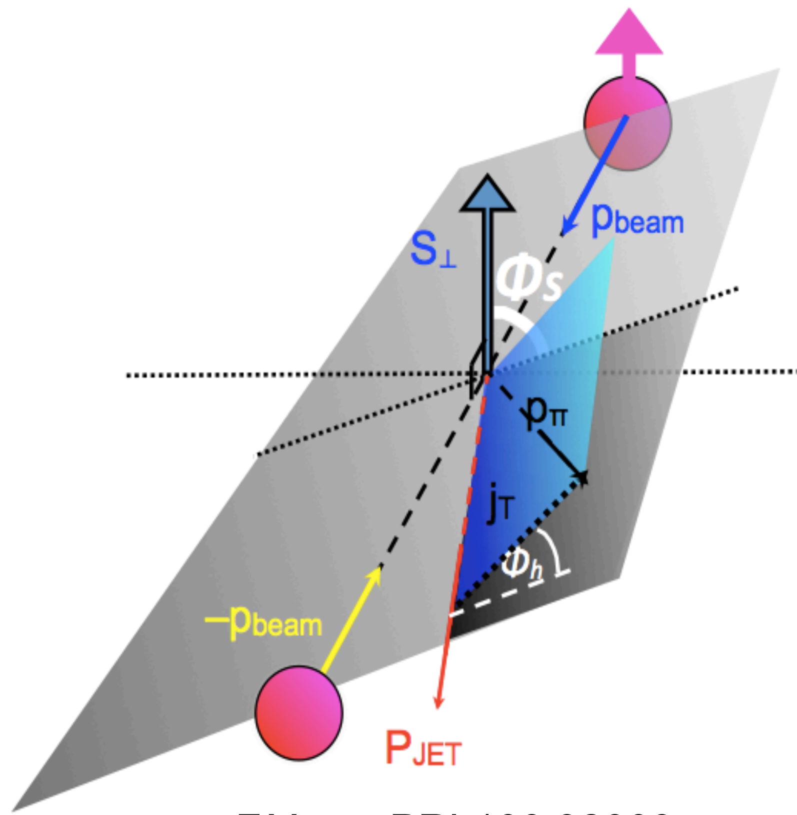
Collins angle: $\Phi_c=\Phi_s-\Phi_h$

Collins modulation: $\sin(\Phi_s-\Phi_h)$

j_T : transverse momentum in jet

Φ_s: azimuthal angle of beam spin

Φ_h: azimuthal angle of hadron

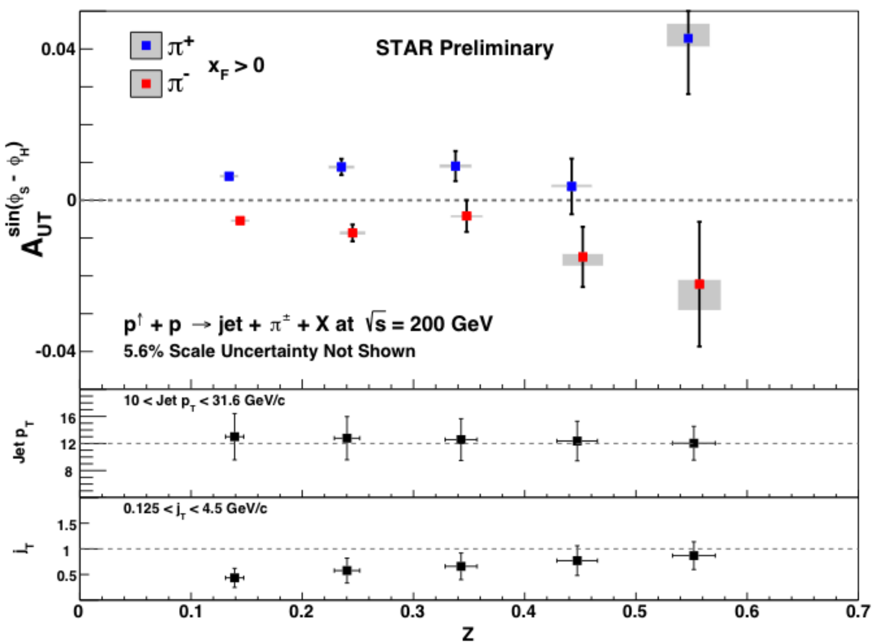


-F.Yuan, PRL100,32003

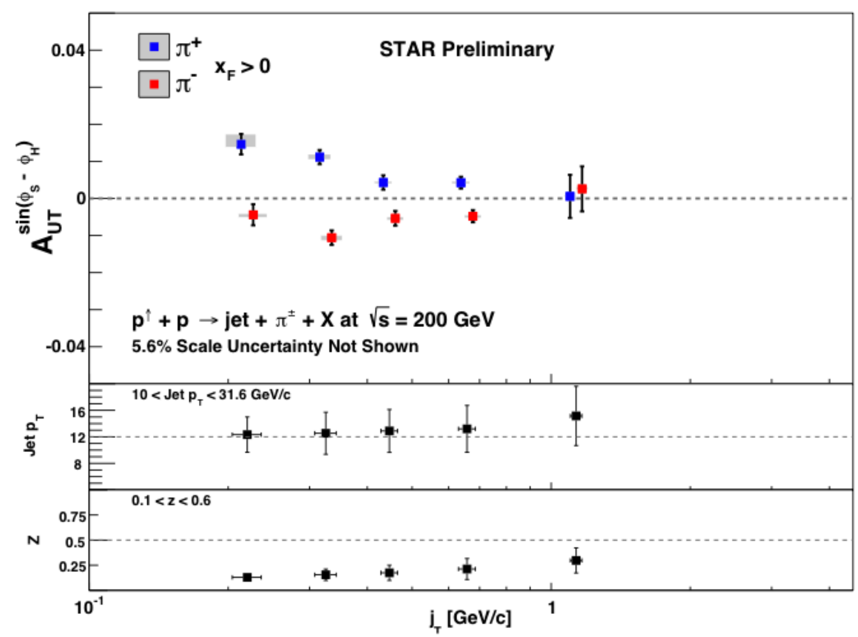
Mid-rapidity hadron-jet correlations (Collins)

- Non-zero Collins asymmetries observed from run2012 200 GeV

A_{UT} vs. z for $x_F > 0$



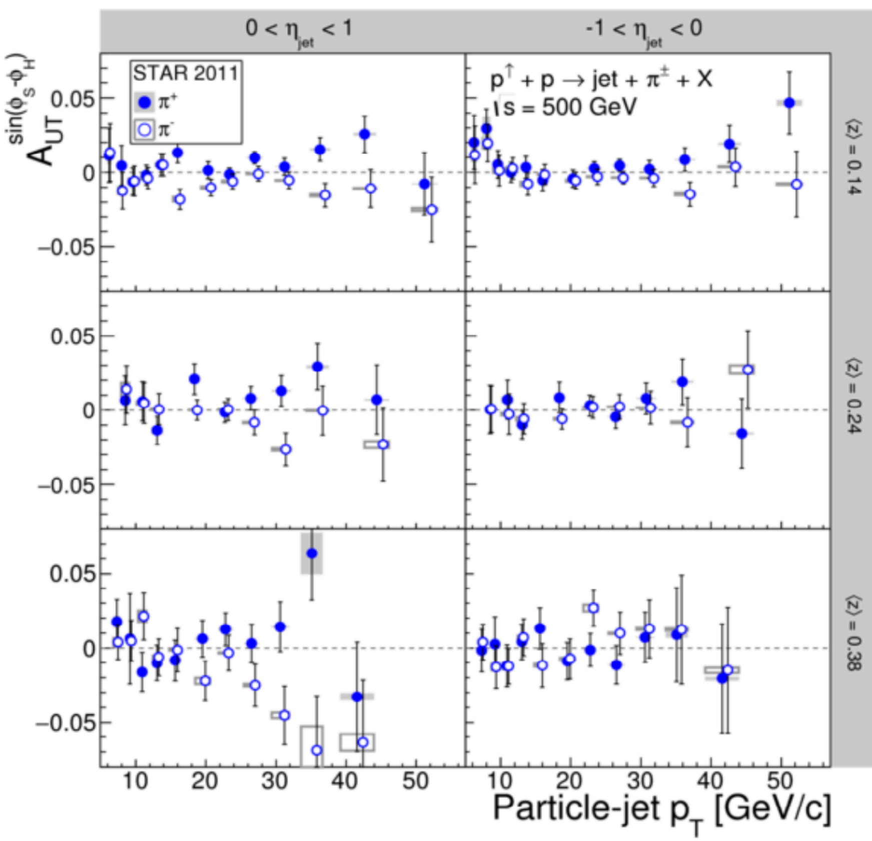
A_{UT} vs. j_T for $x_F > 0$

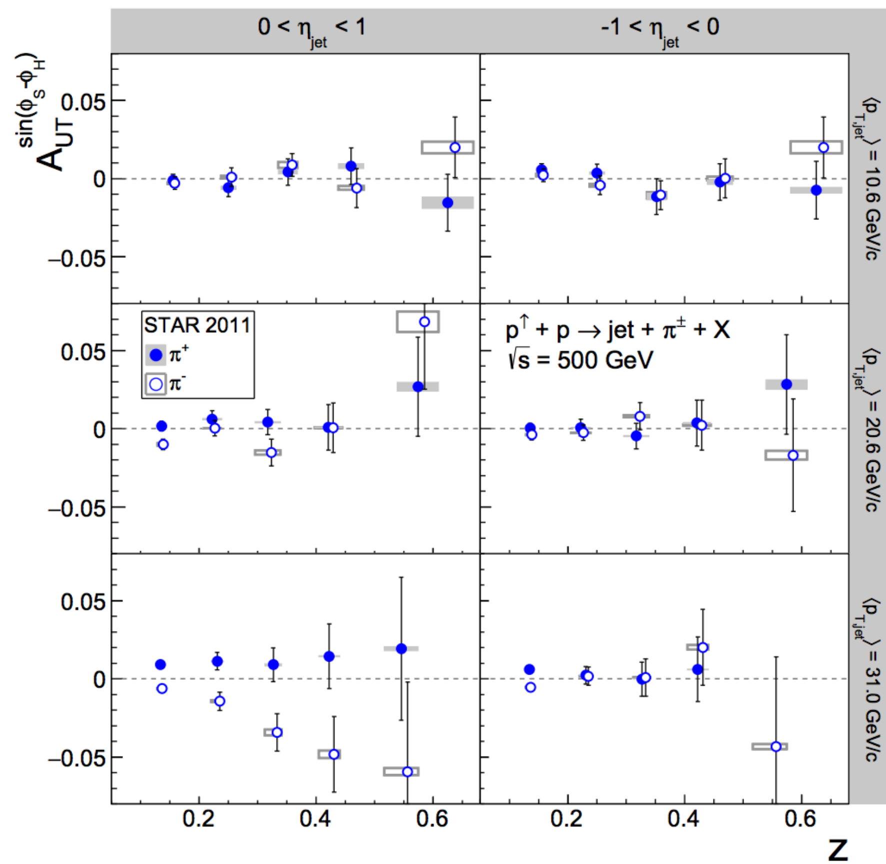


2012 data, 20 pb^{-1} at 200 GeV, Pb=61%, anti-k_T jet algorithm, R = 0.7

Collins asymmetries at 500 GeV

- New results on Collins asymmetries at 500 GeV (run11):

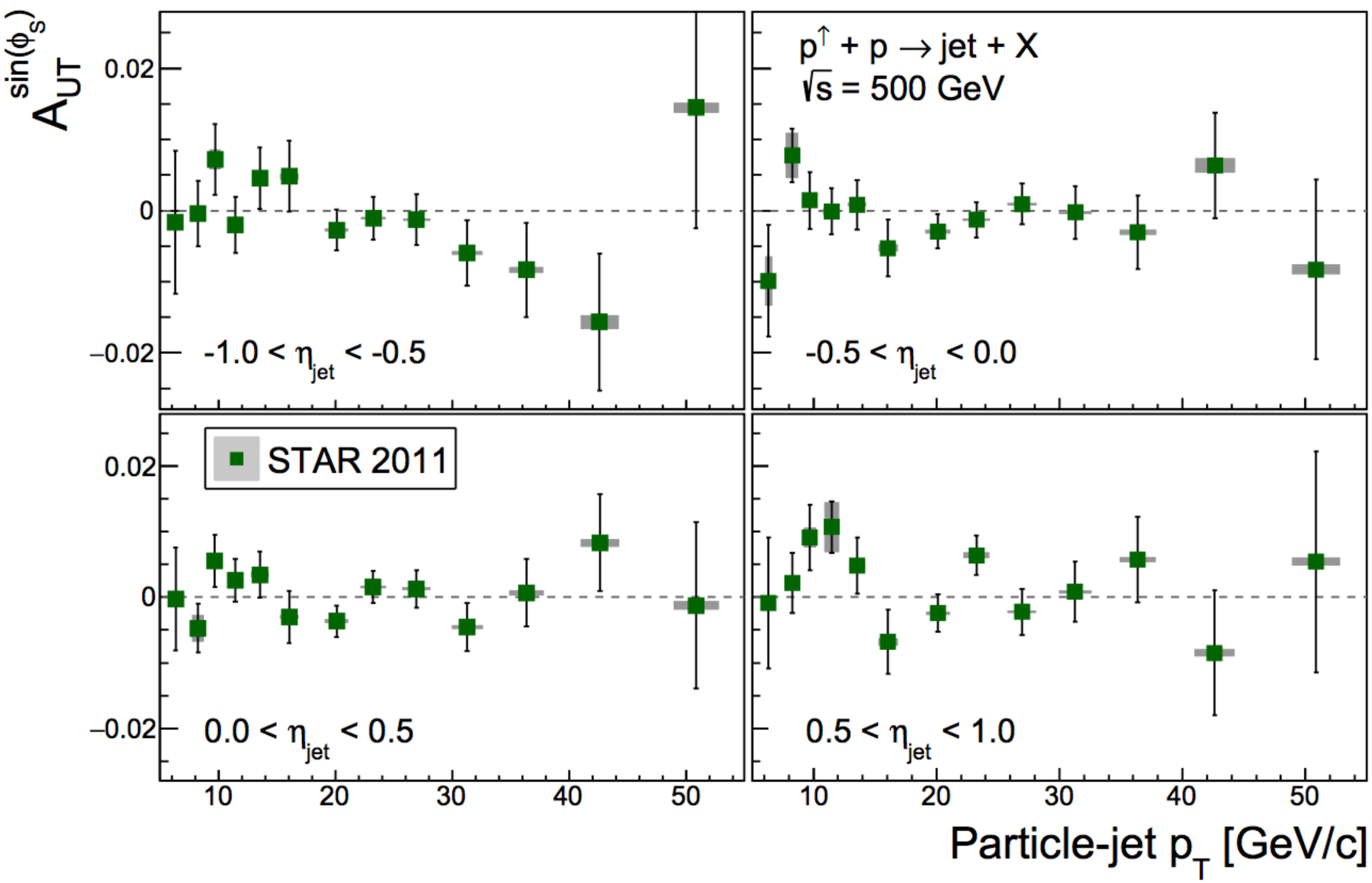




STAR, Phys. Rev. D **97** (2018)32004

Sivers asymmetries- jet SSA

- New results on jet spin asymmetries at 500 GeV (Run 11):



STAR, Phys. Rev. D **97** (2018)32004

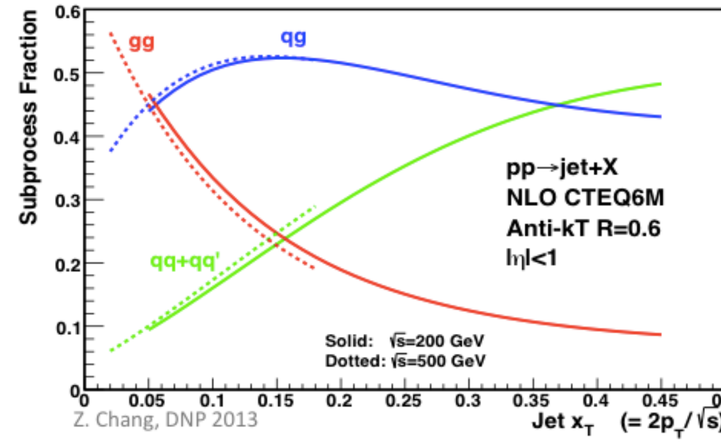
Collins-like Asymmetries at 500 GeV

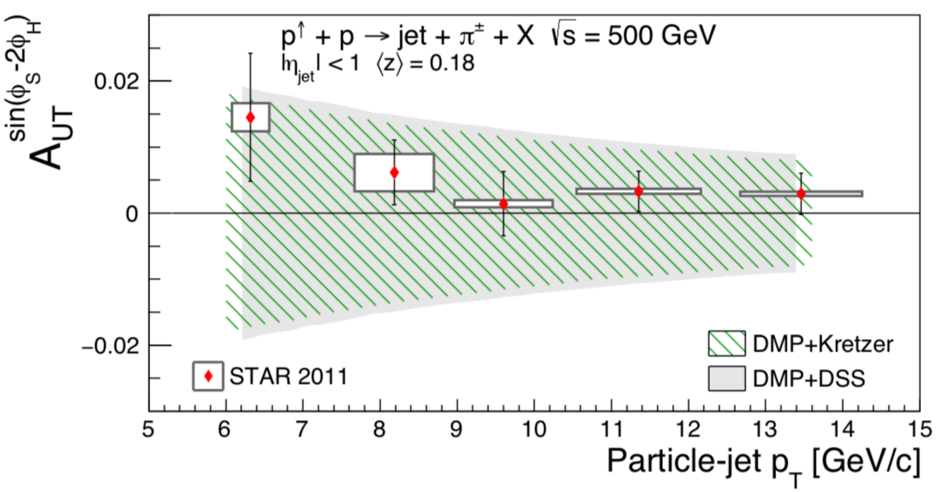
- Collins-like asymmetry $A_{UT}^{\sin(\phi_s - 2\phi_H)}$, provide sensitivity to gluon linear polarization.

Gluon helicity density matrix

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

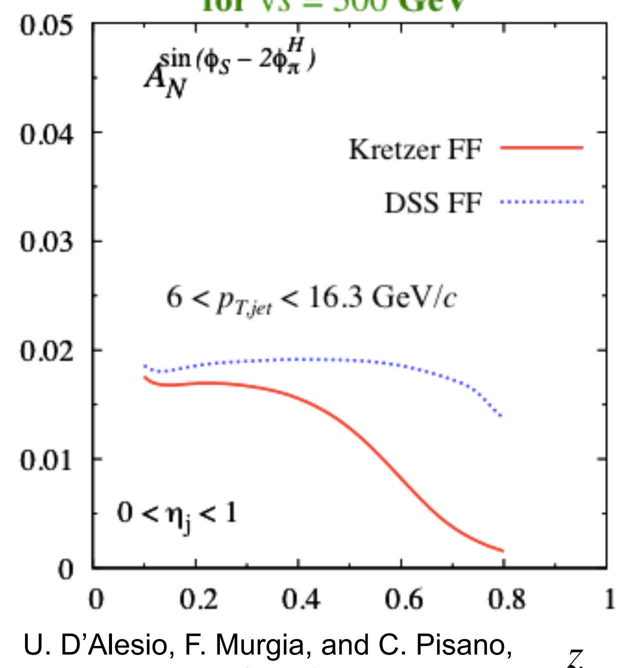
- First measurement on $A_{UT}^{\sin(\phi_s - 2\phi_H)}$





STAR, Phys. Rev. D **97** (2018)32004

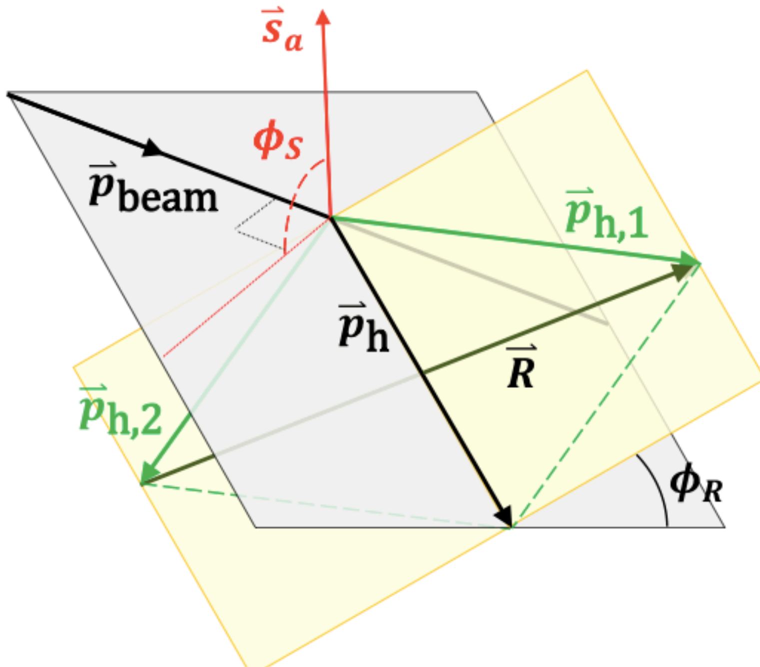
Maximized contribution for $\sqrt{s}$ = 500 GeV



U. D'Alesio, F. Murgia, and C. Pisano, PRD 83, 34021 (2011); 1307.4880

Di-hadron spin asymmetries at STAR

- Di-hadron correlation provides access to IFF& transversity:



$$A_{UT}\sin(\phi_{RS}) = \frac{1}{Pol}\frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

$$A_{UT}^{\sin(\phi_{RS})} \propto h_1 \otimes H_1^{\angle}$$

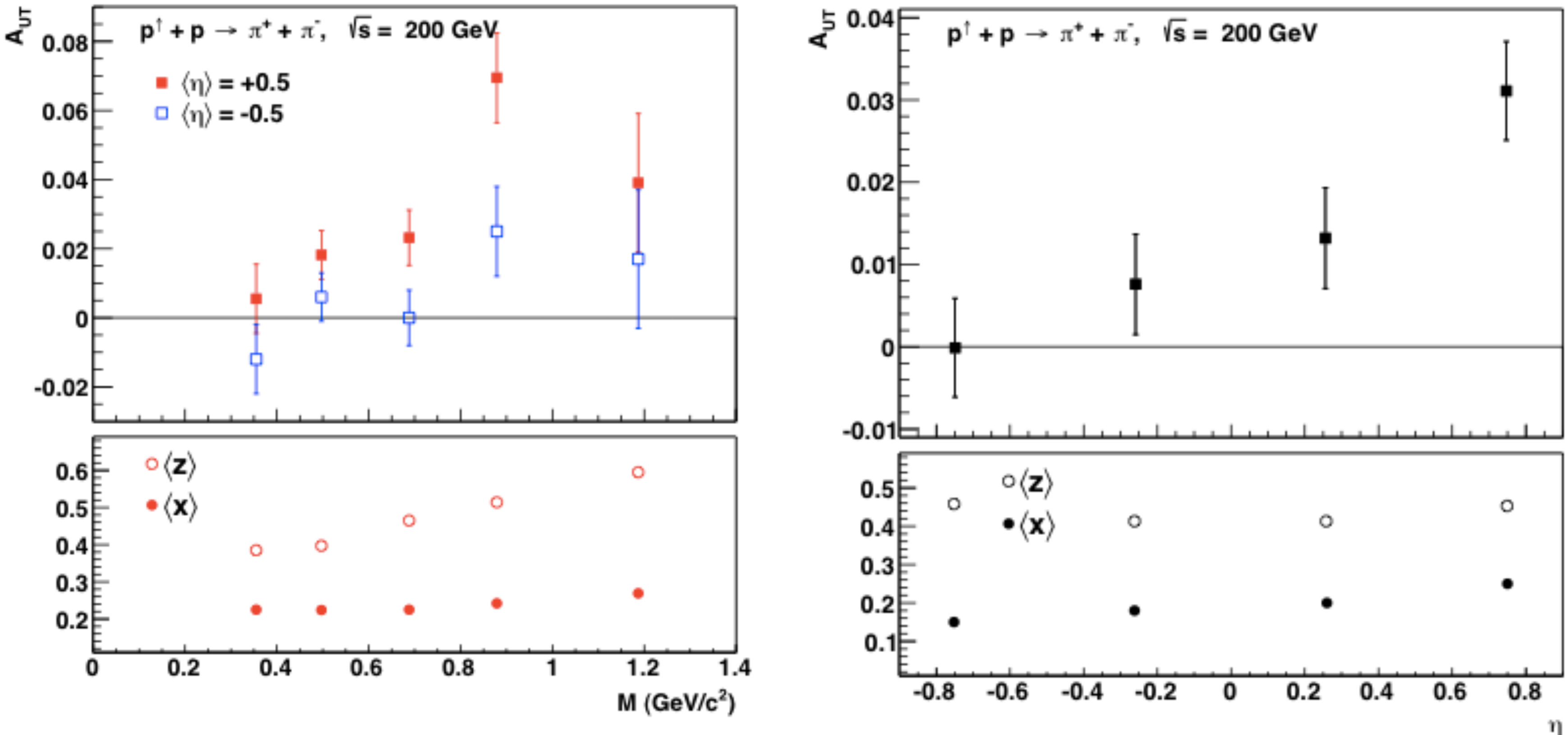
$$\phi_{RS} = \phi_R - \phi_S$$
$$\vec{p}_h = \vec{p}_{h,1} + \vec{p}_{h,2}$$
$$\vec{R}_h = \vec{p}_{h,1} - \vec{p}_{h,2}$$

—"Interference Fragmention Function"

Bacchetta, Radici, Phys.Rev. D70 (2004)

Di-hadron spin asymmetries at STAR

- Significantly non-zero di-hadron asymmetries from run6 data:



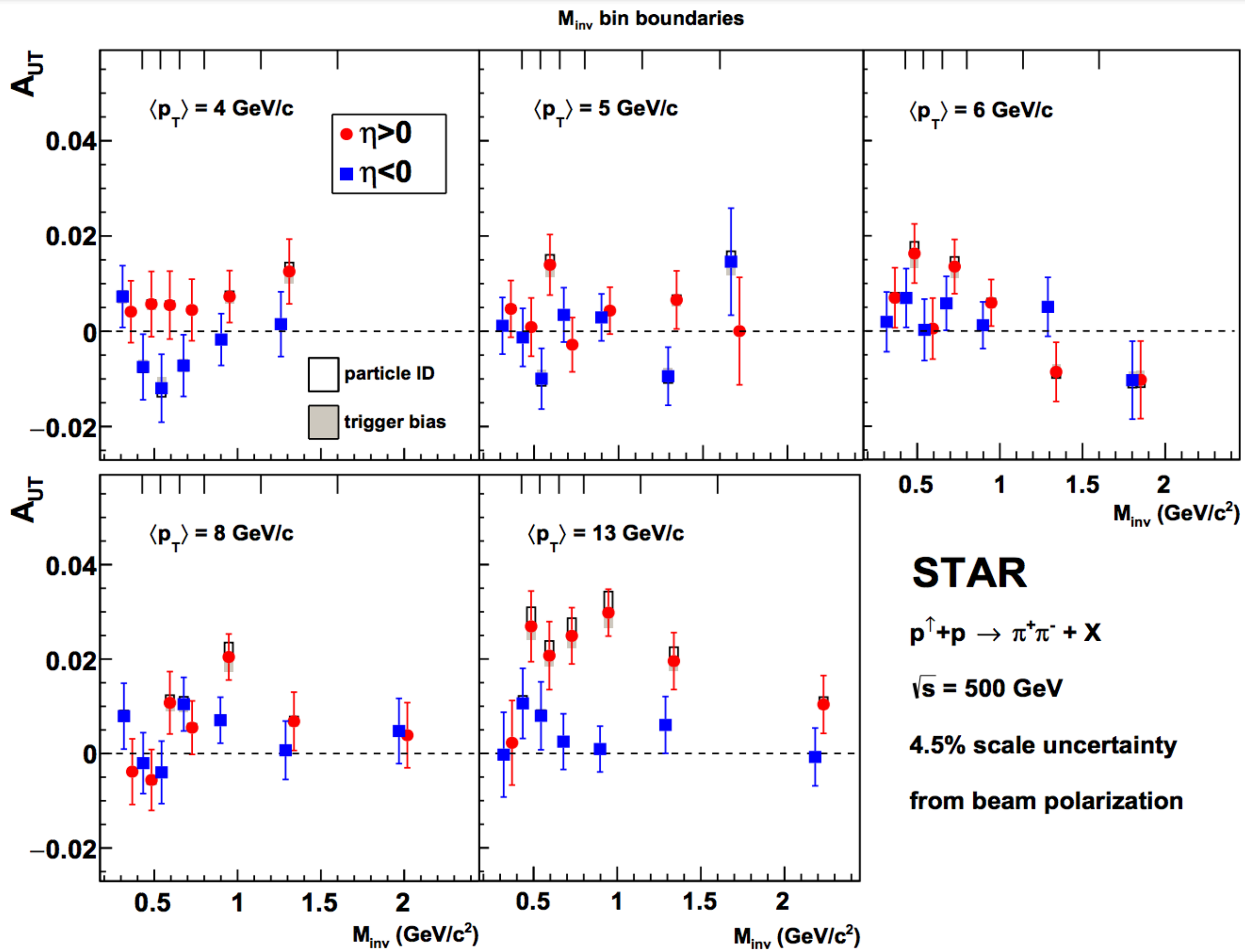
STAR, PRL 115(2015)242501

Sign of non-zero signal for di-hadron transverse single spin asymmetries-> constraints on transversity!

Di-hadron spin asymmetries at STAR

Di-hadron correlation provide access to IFF& transversity:

$$\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}(\Phi_S - \Phi_R) = A_{UT}^{\sin\Phi} \sin(\Phi_S - \Phi_R).$$



STAR, Phys. Lett. B780(2017)332

Future RHIC Spin in 2021+

Year	$\sqrt{s}$ (GeV)	Delivered Luminosity	Scientific Goals	Observable	Required Upgrade
2017	$p^{\uparrow}p$ @ 510	400 pb^{-1} 12 weeks	Sensitive to Sivers effect non-universality through TMDs and Twist-3 $T_{q,F}(x,x)$ Sensitive to sea quark Sivers or ETQS function Evolution in TMD and Twist-3 formalism Transversity, Collins FF, linearly pol. Gluons, Gluon Sivers in Twist-3 First look at GPD Eg	A_N for γ, $W^{\pm}$, Z^0, DY $A_{UT}^{\sin(\phi_s-2\phi_h)}$ $A_{UT}^{\sin(\phi_s-\phi_h)}$ modulations of $h^{\pm}$ in jets, $A_{UT}^{\sin(\phi_s)}$ for jets A_{UT} for J/Ψ in UPC	A_N^{DY}: Postshower to FMS@STAR **None** **None**
2023	$p^{\uparrow}p$ @ 200	300 pb^{-1} 8 weeks	subprocess driving the large A_N at high x_F and η evolution of ETQS fct. properties and nature of the diffractive exchange in p+p collisions.	A_N for charged hadrons and flavor enhanced jets A_N for γ A_N for diffractive events	Yes Forward instrum. **None** **None**
2023	$p^{\uparrow}Au$ @ 200	1.8 pb^{-1} 8 weeks	What is the nature of the initial state and hadronization in nuclear collisions Nuclear dependence of TMDs and nFF Clear signatures for Saturation	R_{pAu} direct photons and DY $A_{UT}^{\sin(\phi_s-\phi_h)}$ modulations of $h^{\pm}$ in jets, nuclear FF Dihadrons, γ-jet, h-jet, diffraction	R_{pAu}(DY):Yes Forward instrum. **None** Yes Forward instrum.
2023	$p^{\uparrow}Al$ @ 200	12.6 pb^{-1} 8 weeks	A-dependence of nPDF, A-dependence of TMDs and nFF A-dependence for Saturation	R_{pAl}: direct photons and DY $A_{UT}^{\sin(\phi_s-\phi_h)}$ modulations of $h^{\pm}$ in jets, nuclear FF Dihadrons, γ-jet, h-jet, diffraction	R_{pAl}(DY): Yes Forward instrum. **None** Yes Forward instrum.
202X	$p^{\uparrow}p$ @ 510	1.1 fb^{-1} 10 weeks	TMDs at low and high x quantitative comparisons of the validity and the limits of factorization and universality in lepton-proton and proton-proton collisions	A_{UT} for Collins observables, i.e. hadron in jet modulations at $\eta > 1$ and mid-rapidity observables as in 2017 run	Yes Forward instrum. **None**
202X	$\vec{p}\vec{p}$@ 510	1.1 fb^{-1} 10 weeks	$\Delta g(x)$ at small x	A_{LL} for jets, di-jets, h/γ-jets at $\eta > 1$	Yes Forward instrum.

Forward detector upgrade required

STAR sPHENIX

EIC detector

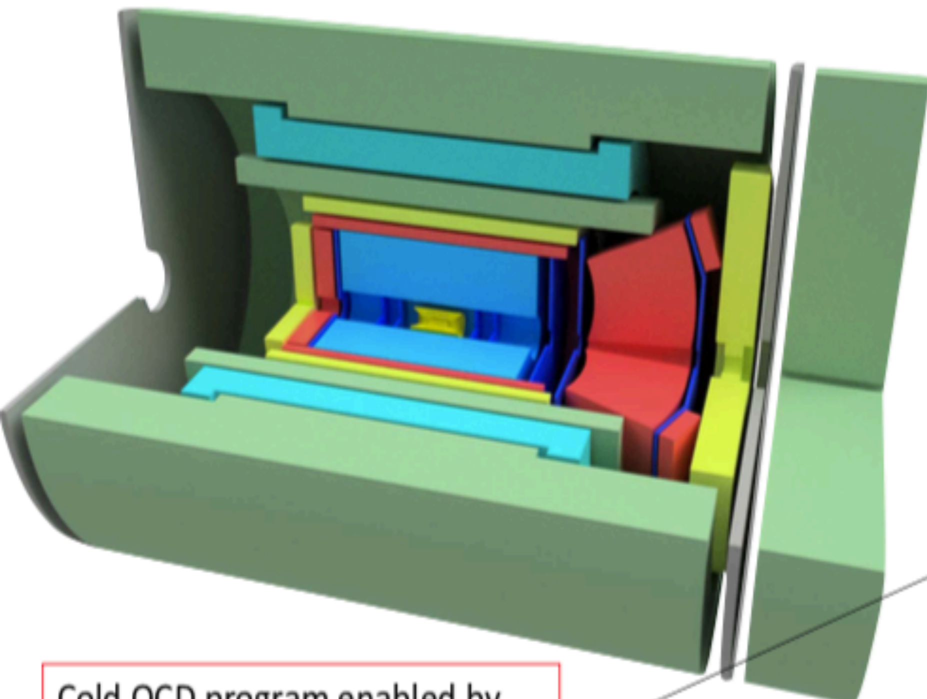
- RHIC is the world's only polarized hadron hadron collider
- Unique physics opportunities in pp and pA

sPHENIX plan

- talk by Gunther Roland

sPHENIX Implementation

A solid foundation for EIC physics – LOI requested by BNL ALD.



- EIC-sPHENIX detector
  - HCal/Flux return
  - Solenoid
  - Extended Central EMCal
  - Central hadron PID
  - TPC
  - MAPS
  - Forward and backward tracking
  - Forward and backward hadron PID
  - Backward crystal EMCal
  - Forward EMCal
  - Forward HCal

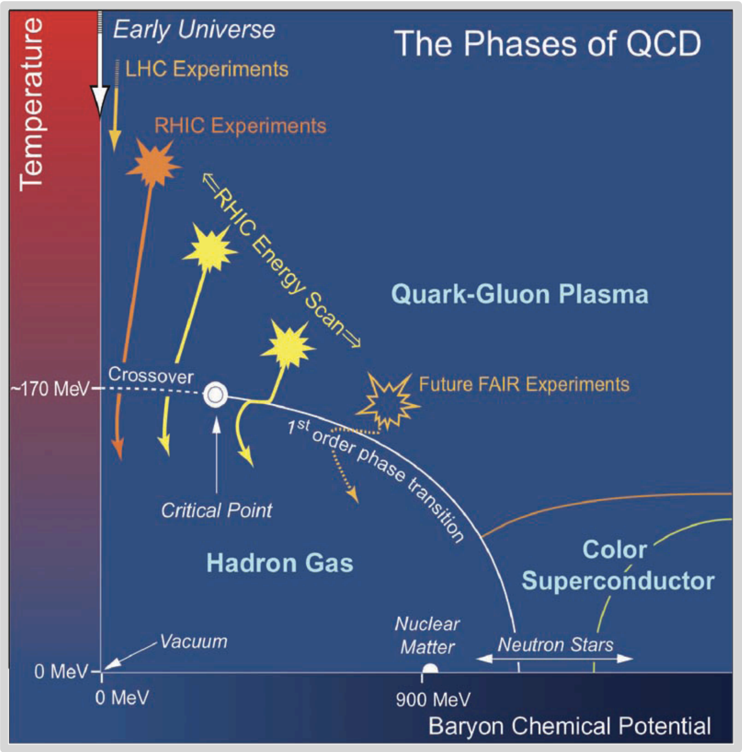
Cold QCD program enabled by early realization of some EIC-sPHENIX detector components!

-J.Lajoie

Looking Forward at STAR beyond 2021

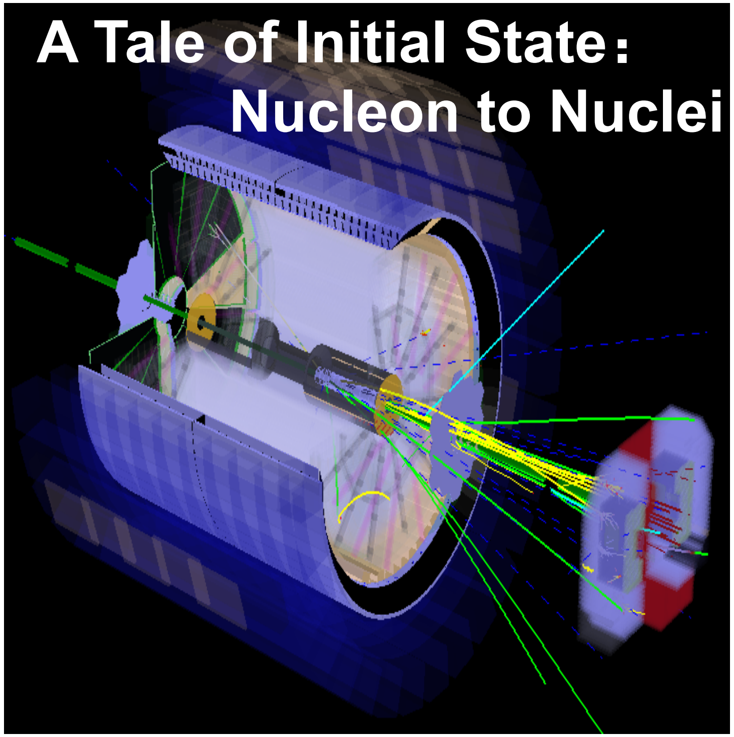
-more on STAR upgrade by Jiangyong

Beam Energy Scan II
2019~2021



iTPC, eToF, EPD

Forward Physics
2021+



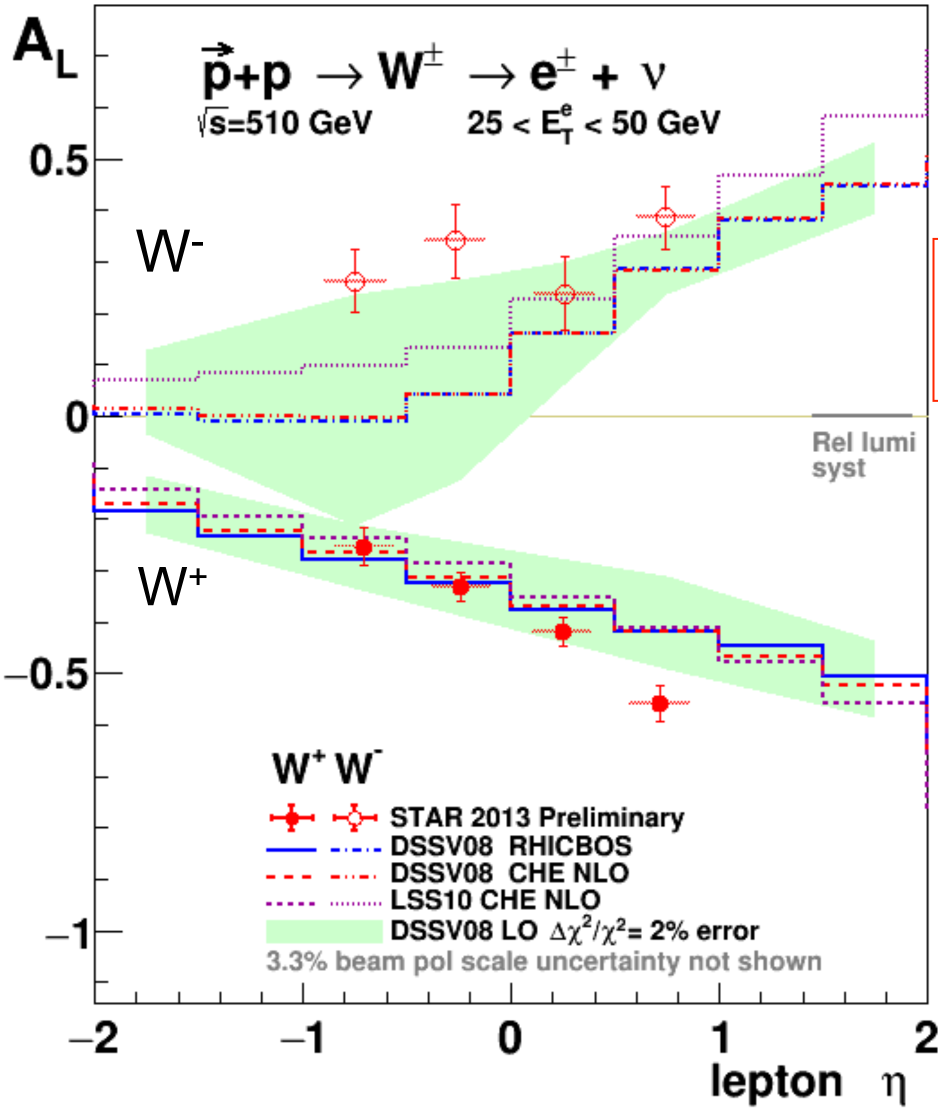
✓ Forward Tracking System
✓ Forward Calorimeter System

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0669

Summary & Outlook

- **Observation of positive gluon polarization from RHIC:**
  - Probes with jets and pion, are providing important constraints on ΔG.
    Global analysis indicates non-zero gluon polarization (0.05<x<0.2).
  - Correlation measurements (di-jet) with access to partonic kinematics
- **Unique probe of sea quark polarization via W production:**
  - RHIC/STAR 2012 results on $W^{\pm}$ A_L provide important constraints on $\Delta\bar{u}, \Delta\bar{d}$.
  - New high precision A_L results for $W^{\pm}$ from RHIC run 13 data!
- **Successful transverse run completed 2017 at 500 GeV**
  - A_N for W,Z at STAR: 1st results obtained, run 17 to study Sivers sign change.
- **Future RHIC spin in 2021^{+} -- Cold QCD plan**
  - Unique physics opportunities in pp and pA, essential to fully realize the scientific promise of the EIC.
  - Forward detectors upgrade required-> evolve into EIC detector.

Impact of 2013 W A_L results



NNPDFpol1.1 reweighting

$\Delta\bar{u}$

$$\langle \Delta\bar{u} \rangle^{[0.01,0.2]} = 0.01 \pm 0.04$$

$$\langle \Delta\bar{u} \rangle^{[0.01,0.2]}_{rw} = 0.02 \pm 0.03$$

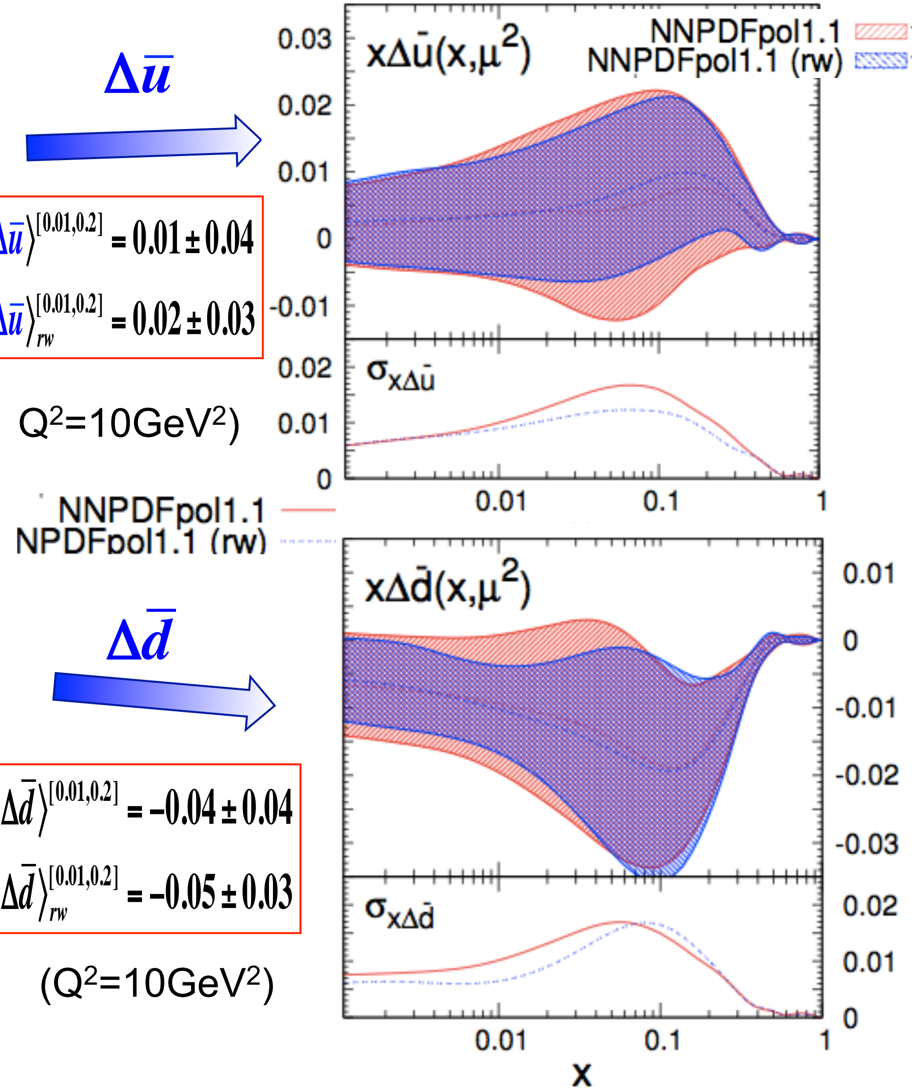
Q^2=10GeV^2)

$\Delta\bar{d}$

$$\langle \Delta\bar{d} \rangle^{[0.01,0.2]} = -0.04 \pm 0.04$$

$$\langle \Delta\bar{d} \rangle^{[0.01,0.2]}_{rw} = -0.05 \pm 0.03$$

(Q^2=10GeV^2)

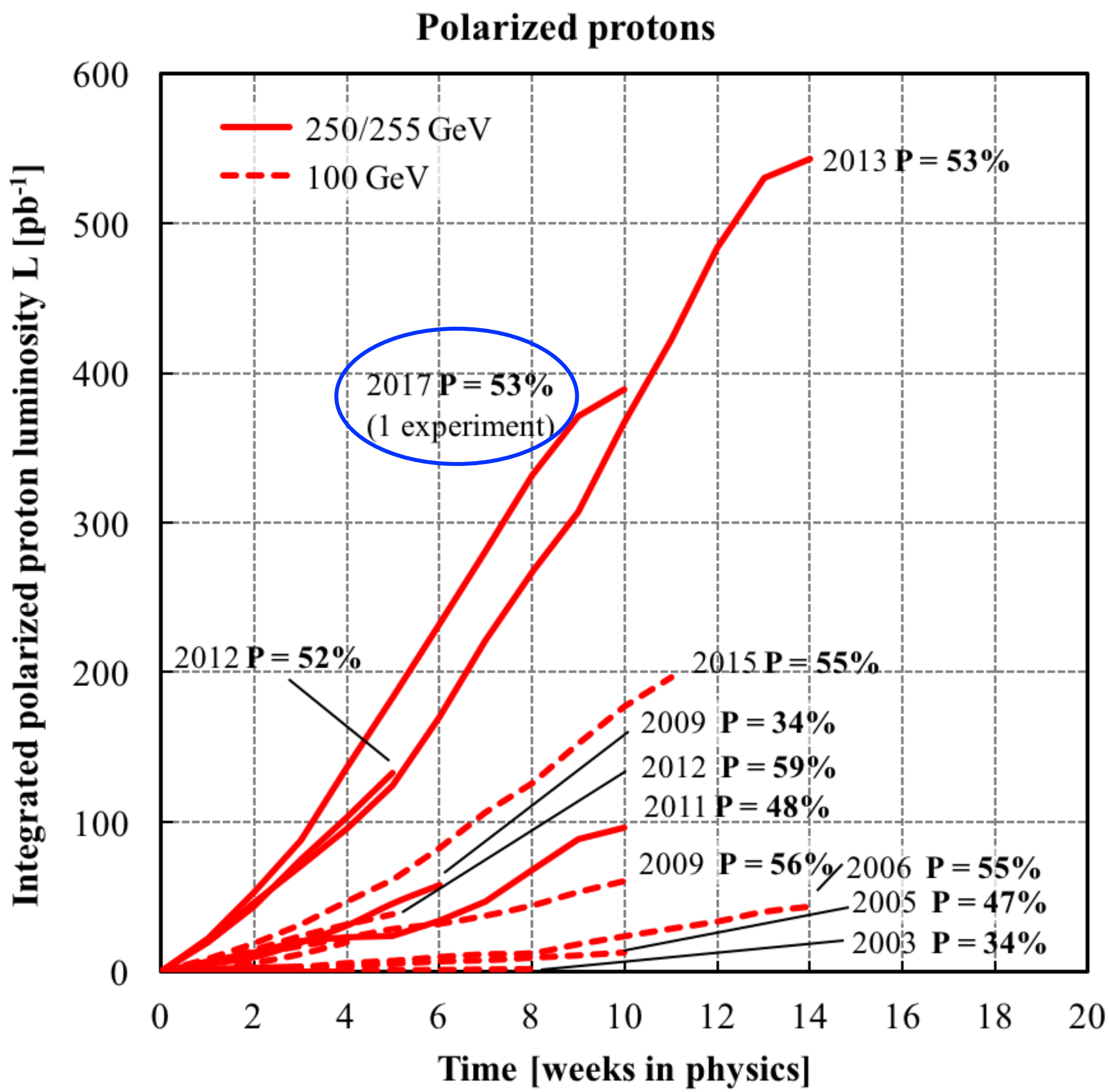


-Provided further constraints for $\Delta\bar{u}$, $\Delta\bar{d}$!

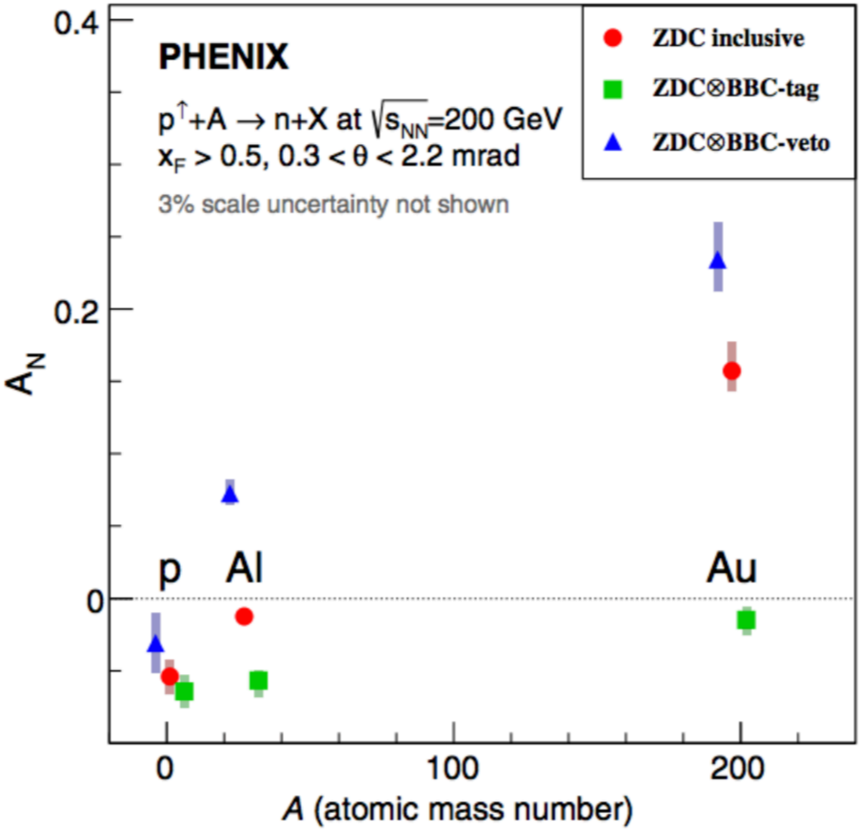
E. Nocera, arXiv:1702.05077

RHIC performance with pp collisions

- Long runs with long. polarization at 200 GeV in 2005, 2006, 2009, 2015.
- Collisions at 500 GeV with long. pol. in 2009, 2012 and 2013.
- Long runs with trans. pol. in 2006, 2008, 2012 at 200GeV and 2011 2017 at 500 GeV.

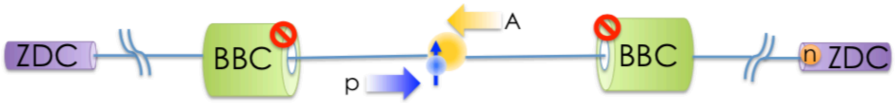


Forward neutron A_N



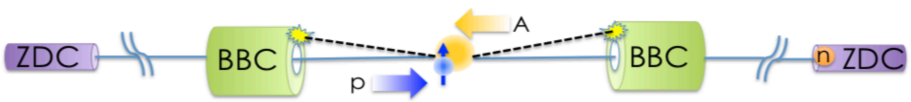
recently published : *Phys.Rev.Lett. 120, 022001 (2018) PHENIX collaboration*

BBC Vetoing



- π^+ boosted toward beam
- enhance EM interactions

BBC Tagging



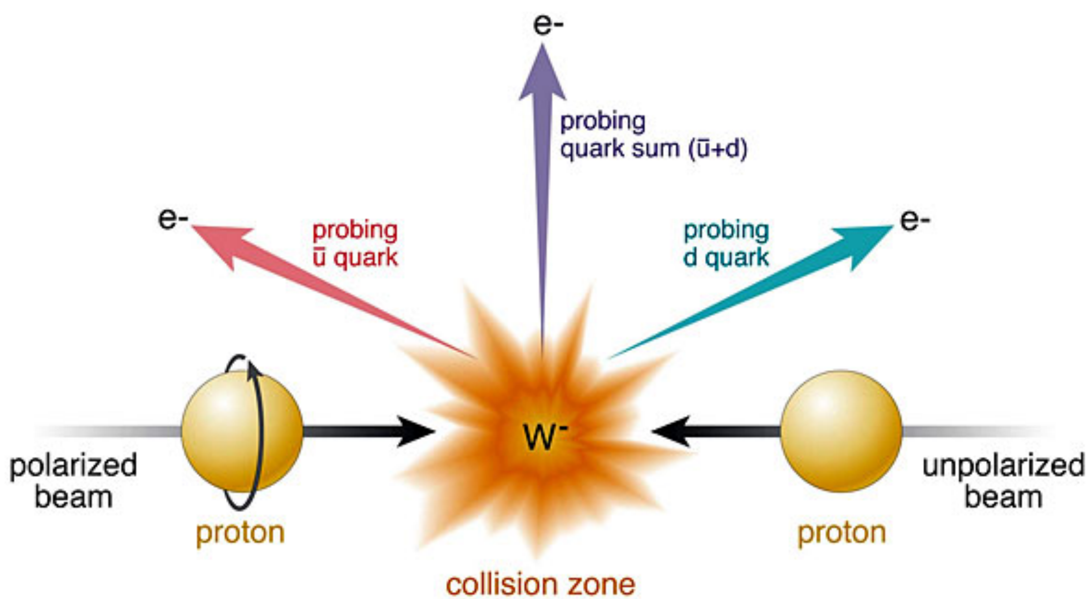
- suppress EM interactions

J.Bok

Probing sea quark polarization via W production

- Ws naturally separate quark flavors
  > backward/forward region probe sea & valence quarks
- Ws are 100% parity-violated
  > select only one helicity of the coupled (anti)quarks
- Ws are clean theoretically
  > no fragmentation function involved
- Complementary to SIDIS: high Q^2, test universality of pdf

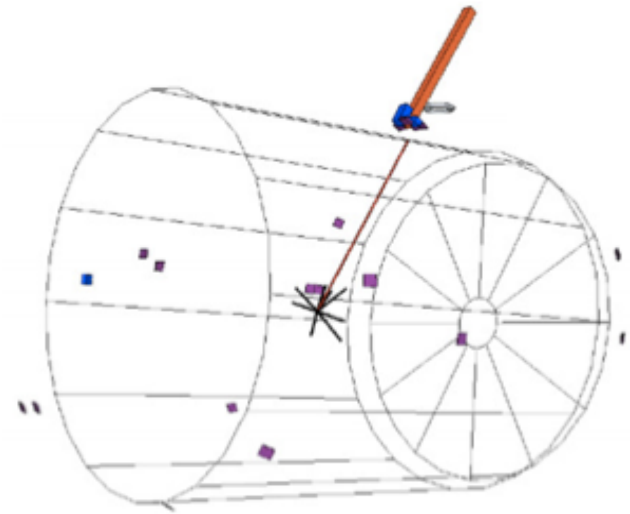
$$A_L^W = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$



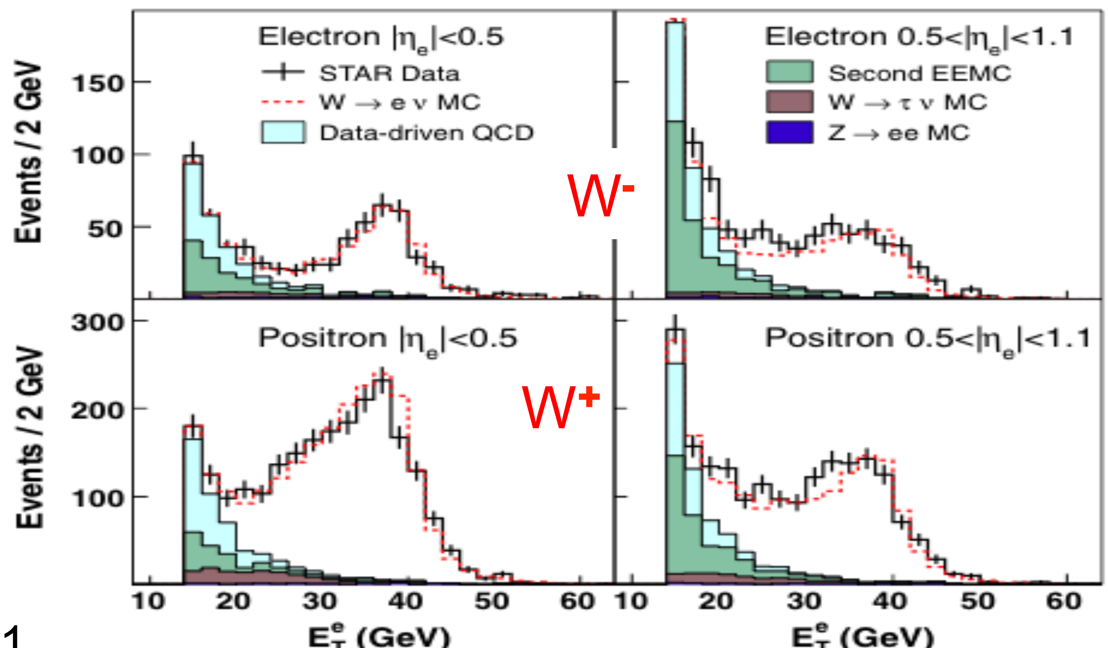
W selection at STAR : Jacobian peak

$W \rightarrow e + \nu$ Candidate Event:

- Isolated track pointing to isolated EM cluster in calorimeter
- Large "missing energy" opposite the electron candidate



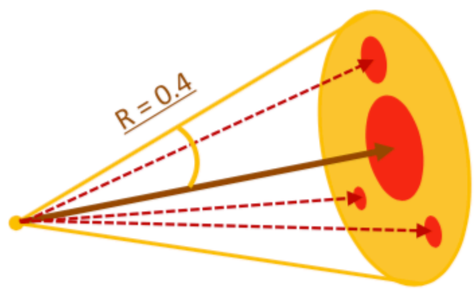
Signal of Jacobian peak with E_T distri. after selection :



STAR, PRL113(2014)72301

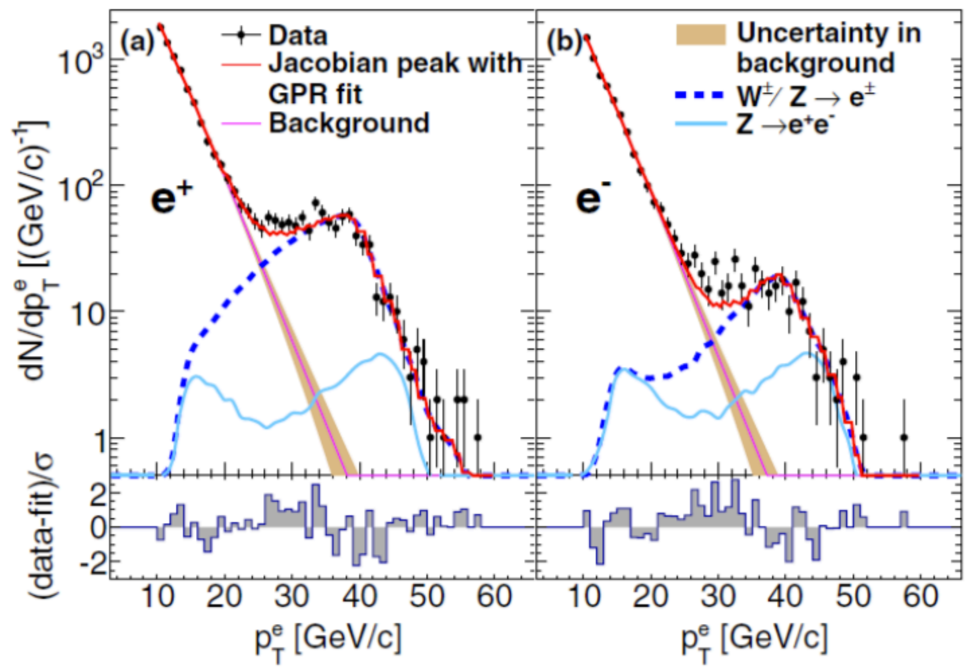
W selection at PHENIX

$W^{\pm} \rightarrow e^{\pm}$ Analysis



$$\frac{E_{cone} - E_{candiate}}{E_{candiate}} < 10\ (\%)$$

PRD93, 051103 (2016)



- Utilize Jacobian peak
  - 1st background suppression by isolation cut, with cone R = 0.4 in η and φ
  - Estimate residual backgrounds in signal region (p_T > 30 GeV) by extrapolating backgrounds in 10 < p_T < 22 (GeV) by using GPR (Gaussian Process Regression)
  - Contribution by Z_0 : 7 % (e+) and 25 % (e-)