Constraining the Polarized Gluon Distribution Function of the Proton with Recent STAR Measurements

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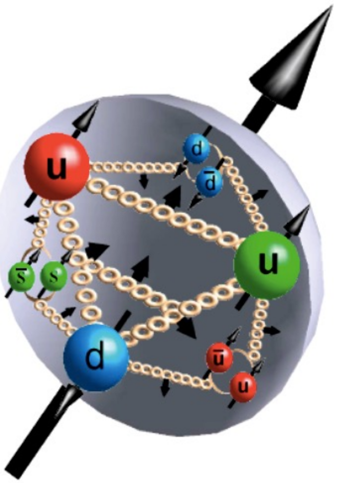
Proton Spin Composition

Jaffe-Manohar Spin Sum Rule: $S = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$

R.L. Jaffe, A. Manohar, Nucl. Phys. B 337, 509 (1990)

The spin of the proton is composed of the spin of the quarks and antiquarks, the spin of the gluons, and the orbital angular momentum of the quarks and gluons

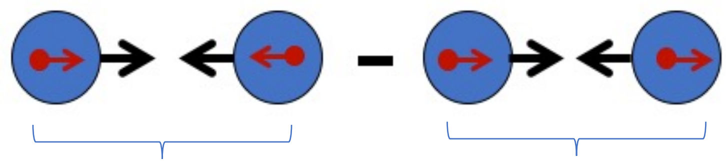
Quark Spin Contribution: $\Delta\Sigma = \int (\Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s})dx$



Gluon Spin Contribution: $\Delta G = \int \Delta g(x)dx$

Gluon Polarization & Longitudinal Double-Spin Asymmetry

- Polarized gluon distribution function can be constrained by measuring the longitudinal double-spin asymmetry of jets (A_{LL}) in polarized proton-proton collisions



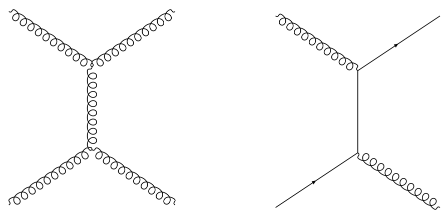
σ^{++} σ^{+-}

$$A_{LL} = \frac{\Delta\sigma}{\sigma} = \frac{(\sigma^{++} + \sigma^{--}) - (\sigma^{+-} + \sigma^{-+})}{(\sigma^{++} + \sigma^{--}) + (\sigma^{+-} + \sigma^{-+})}$$

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$

Subprocess Sensitivity

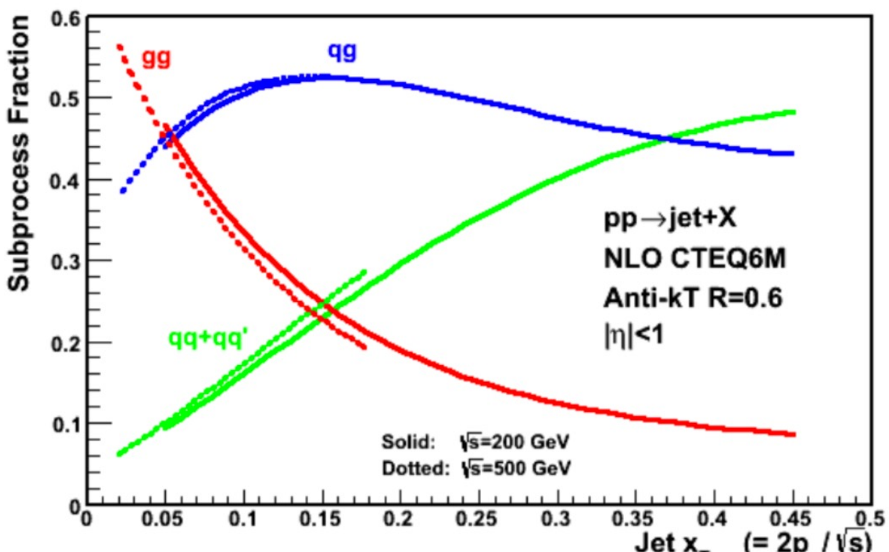
- STAR observables are dominantly sensitive to qg and gg scattering



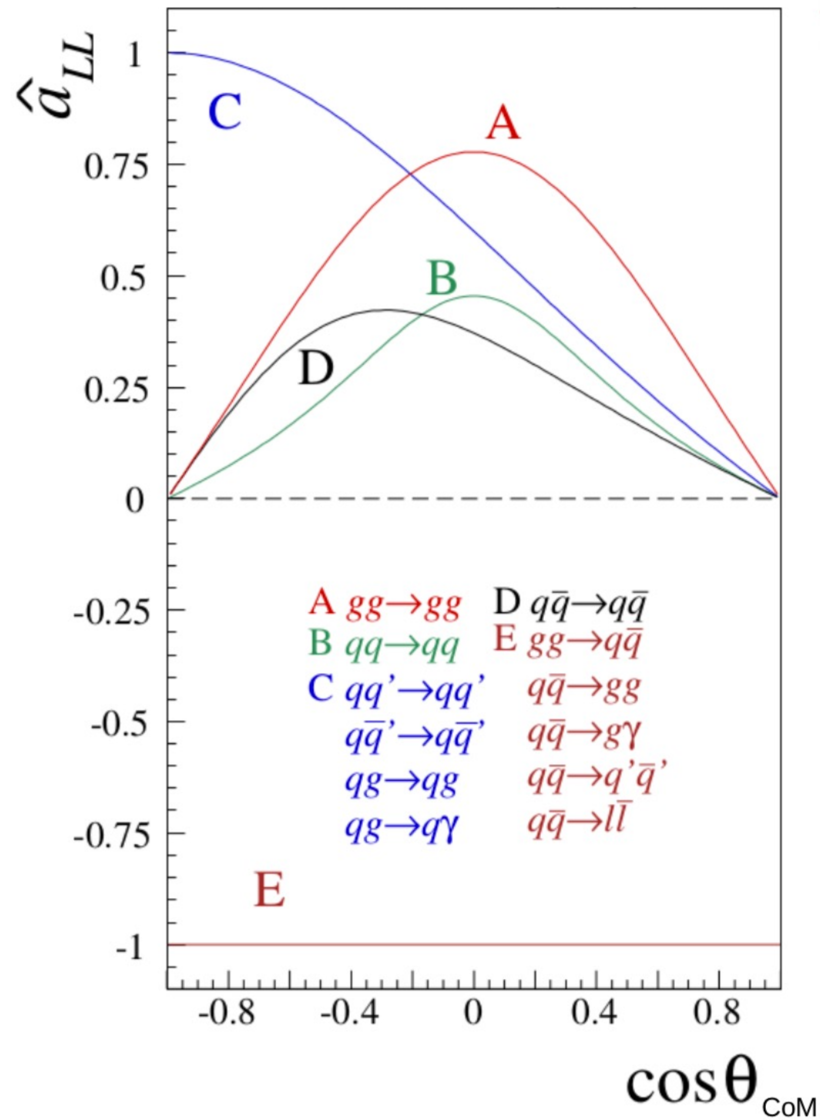
- Because of this sensitivity, A_{LL} allows access to $\Delta g(x)$

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$

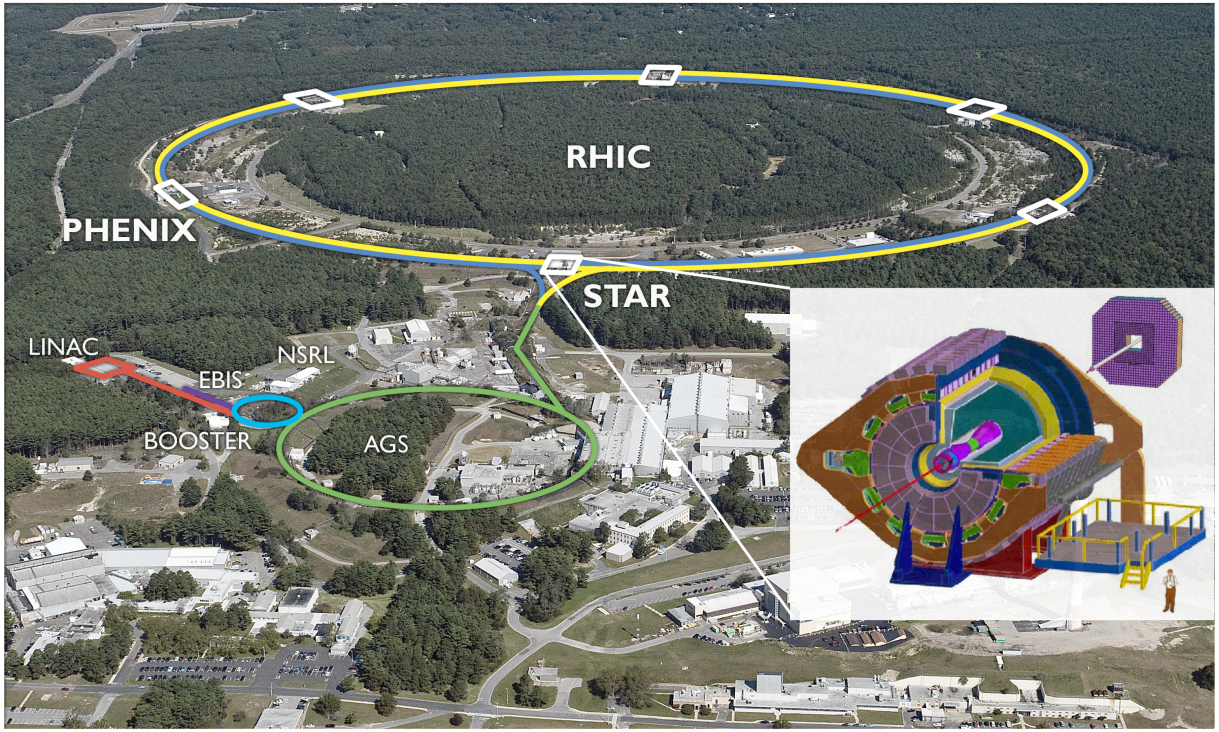
RHIC Spin Program – arXiv:1501.01220



Bunce, et al. Ann. Rev. Nucl. Part. Sci. 50 (2000) 525-575



RHIC/STAR



- The Relativistic Heavy Ion Collider (RHIC) is capable of colliding polarized protons
  - Polarization: ~60%
  - Center-of-mass energies of 200 GeV and 510 GeV

- The Solenoidal Tracker at RHIC (STAR) experiment is used for these analyses
  - Tracking provided by a time projection chamber
  - Barrel and endcap electromagnetic calorimeters for energy measurement and triggering
  - Jets are reconstructed using the anti-k_T algorithm

Jet and Dijet Results from STAR

Midrapidity ($|\eta| < 1.0$)

- Jets at 200 GeV in 2009

  Phys.Rev.Lett. 115 (2015) 092002
- Jets at 510 GeV in 2012

  Phys.Rev. D100 (2019) 052005
- Jets at 510 GeV in 2013

  (STAR Preliminary)

  [in preparation for publication]
- Jets at 200 GeV in 2015 *

  Phys.Rev. D103 (2021) 091103

- Dijets at 200 GeV in 2009

  Phys.Rev. D95 (2017) 071103
- Dijets at 510 GeV in 2012

  Phys.Rev. D100 (2019) 052005
- Dijets at 510 GeV in 2013

  (STAR Preliminary)

  [in preparation for publication]
- Dijets at 200 GeV in 2015 *

  Phys.Rev. D103 (2021) 091103

Intermediate Rapidity ($0.8 < \eta < 2.0$)

* New this year

- Dijets at 200 GeV in 2009

  Phys.Rev. D98 (2018) 032011
- Dijets at 510 GeV in 2012

  (STAR Preliminary)

- Dijets at 510 GeV in 2013

  (STAR Preliminary)
- Dijets at 200 GeV in 2015

  (Work in Progress)

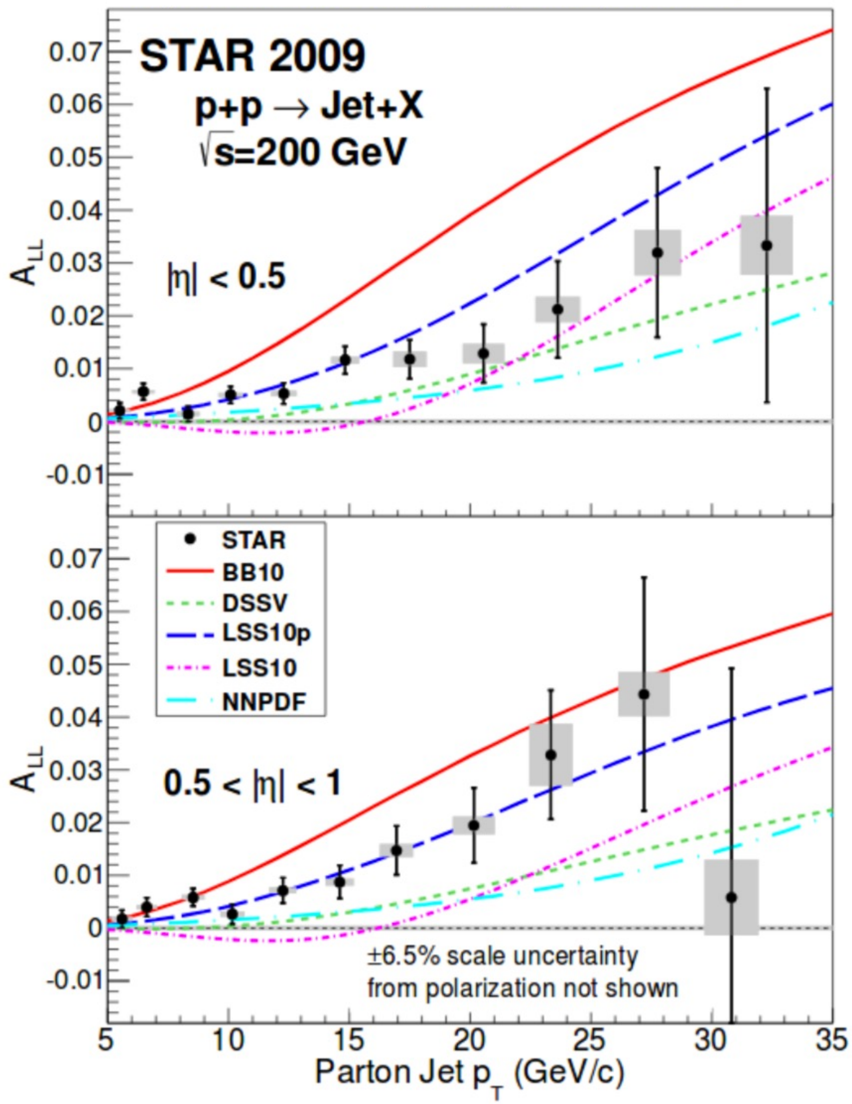
Longitudinal Double-Spin Asymmetry

$$A_{LL} = \frac{1}{P_1 P_2} \cdot \frac{(N_{++} + N_{--}) - R_3 (N_{+-} + N_{-+})}{(N_{++} + N_{--}) + R_3 (N_{+-} + N_{-+})}$$

- N_{++} , N_{--} - Yield of jets/dijets when helicities are the same sign
- N_{+-} , N_{-+} - Yield of jets/dijets when helicities are of opposite signs
- P_1 , P_2 - Polarization of beam 1, 2
- $R_3 = \frac{(L_{++} + L_{--})}{(L_{+-} + L_{-+})}$ - Relative luminosity

Midrapidity Jets at 200 GeV in 2009

STAR, Phys. Rev. Lett. 115 (2015), 092002

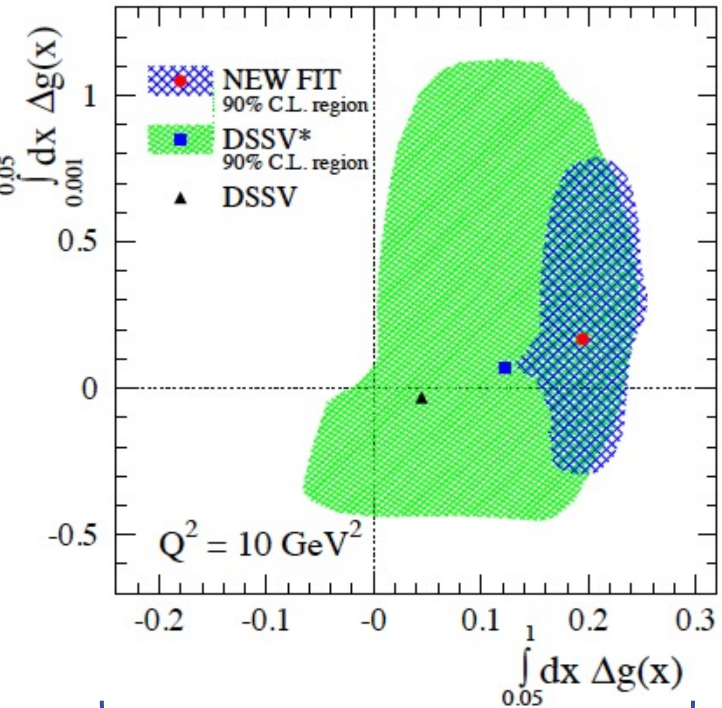


- Jet p_T is corrected to the parton-level which doesn't include underlying event or beam remnants
- These results provided a significant increase in statistical precision compared to earlier measurements made in 2006
- These results show systematically larger A_{LL} than the DSSV 2008 global fit
- These results strongly suggest a positive gluon polarization value after inclusion in DSSV14 and NNPDF1.1 fits

Gluon Polarization & Longitudinal Double-Spin Asymmetry

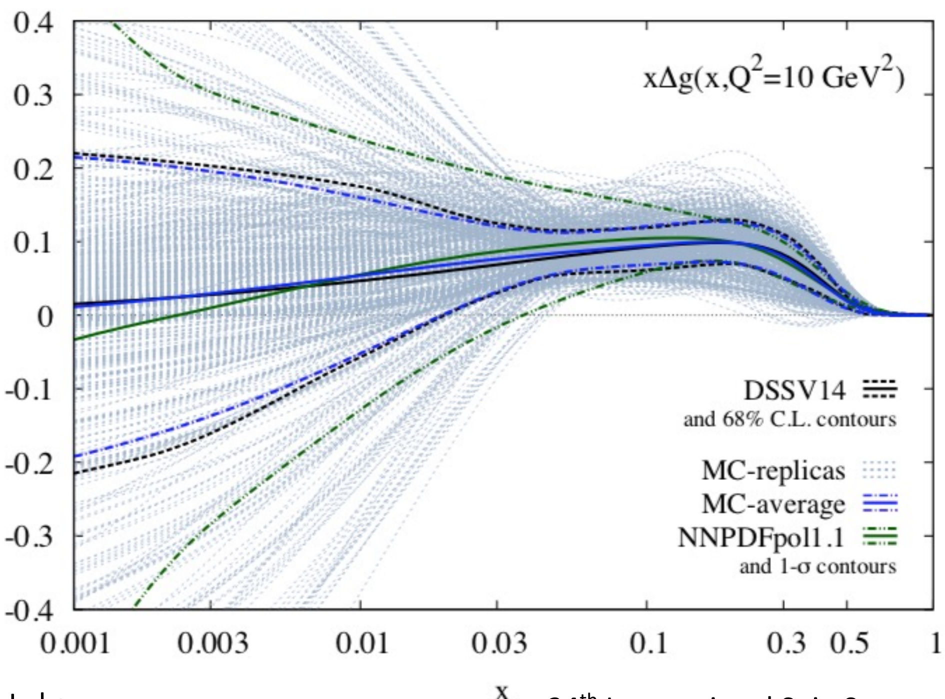
- The results of the midrapidity jets asymmetry at 200 GeV using the 2009 data provided the first strong evidence of a non-zero gluon polarization for $x > 0.05$

de Florian, et al. Phys. Rev. Lett. 113 (2014) 012001



Low x – Poorly constrained

High x – well constrained



de Florian, et al. Phys. Rev. D100 (2019) 114027

DSSV: $\int_{0.1}^{1} \Delta g(x)dx = 0.126 \pm 0.023$

de Florian, et al. Phys. Rev. D100 (2019) 114027

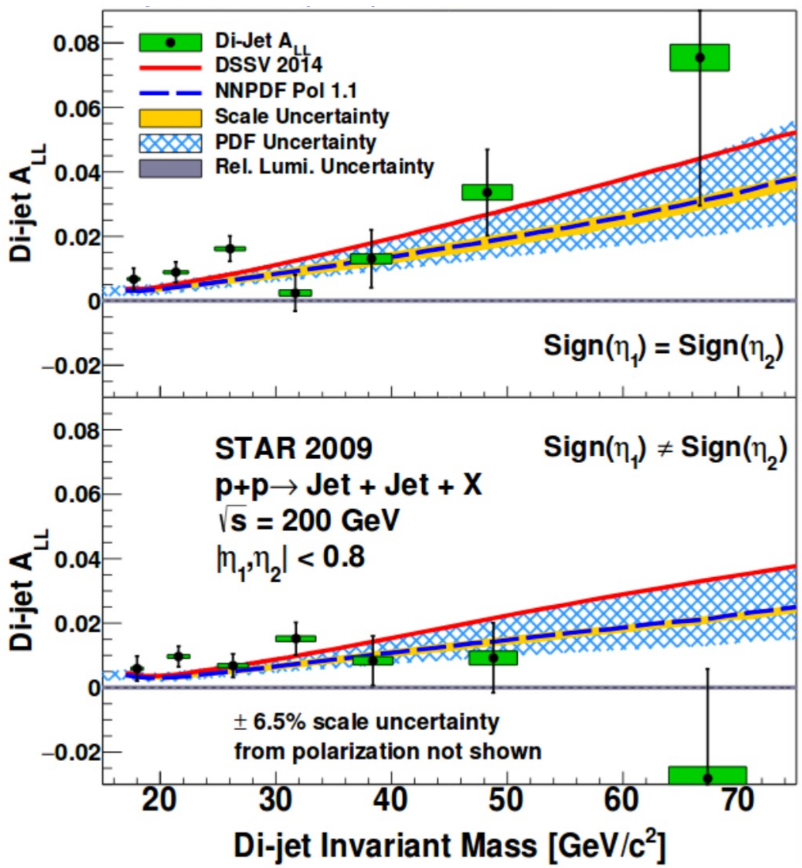
NNPDF: $\int_{0.05}^{0.2} \Delta g(x)dx = 0.17 \pm 0.06$

Nocera, et al. Nucl. Phys. B 887, 276 (2014)

Midrapidity Dijets at 200 GeV in 2009

- Dijets probe a narrower region in x which helps constrain the functional form of $\Delta g(x)$

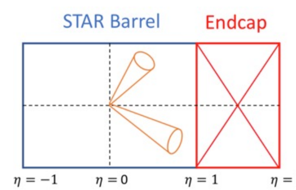
STAR, Phys. Rev. D95 (2017) 071103



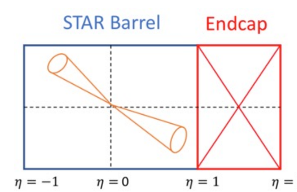
- A_{LL} plotted as a function of dijet invariant mass:

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

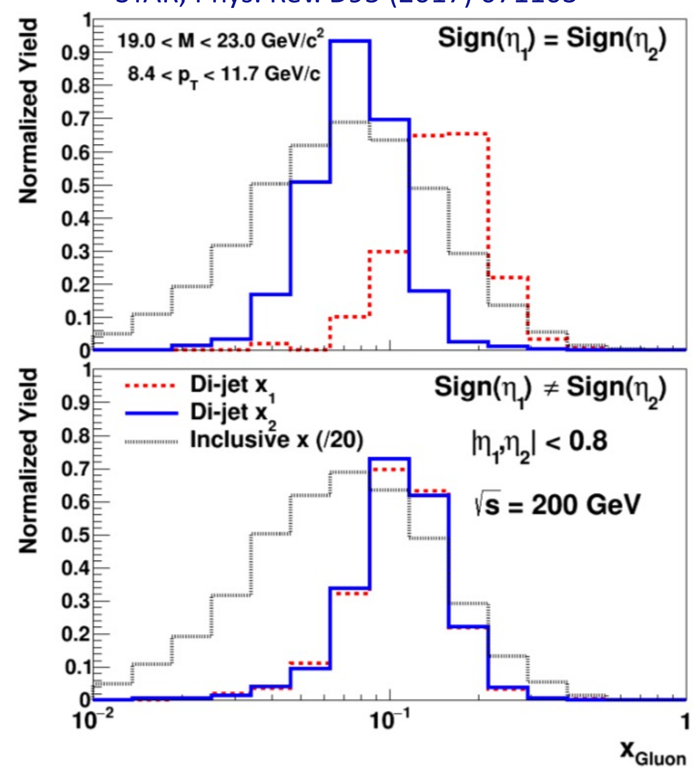
- Two topologies shown sample different x ranges:
  - Sign(η_1) = Sign(η_2)



  - Sign(η_1) ≠ Sign(η_2)

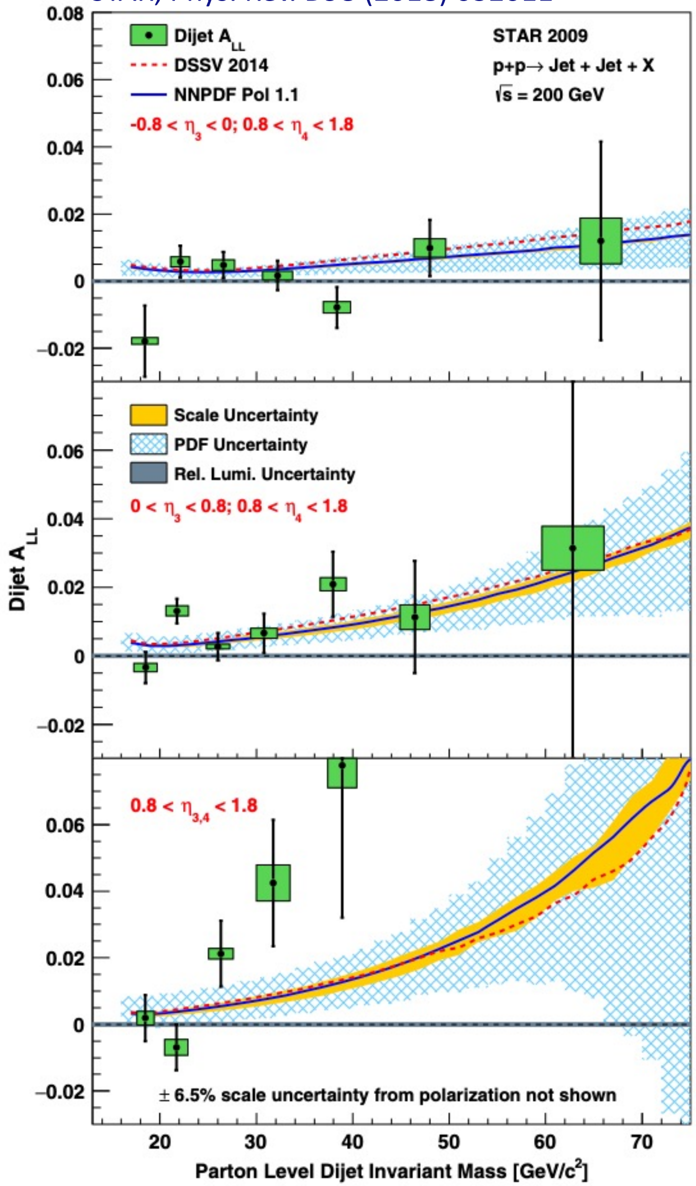


STAR, Phys. Rev. D95 (2017) 071103

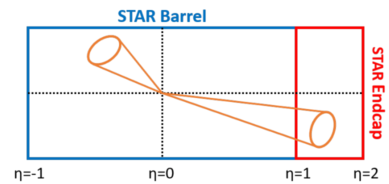


Intermediate Rapidity Dijets at 200 GeV in 2009

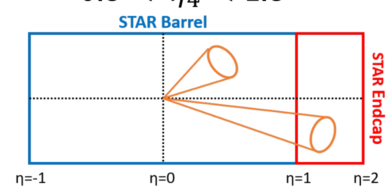
STAR, Phys. Rev. D98 (2018) 032011



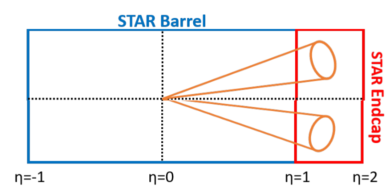
- By extending to intermediate rapidity, dijets can probe lower *x*
- Three topologies shown sample different *x* ranges:
  - $-0.8 < \eta_3 < 0$
    $0.8 < \eta_4 < 1.8$



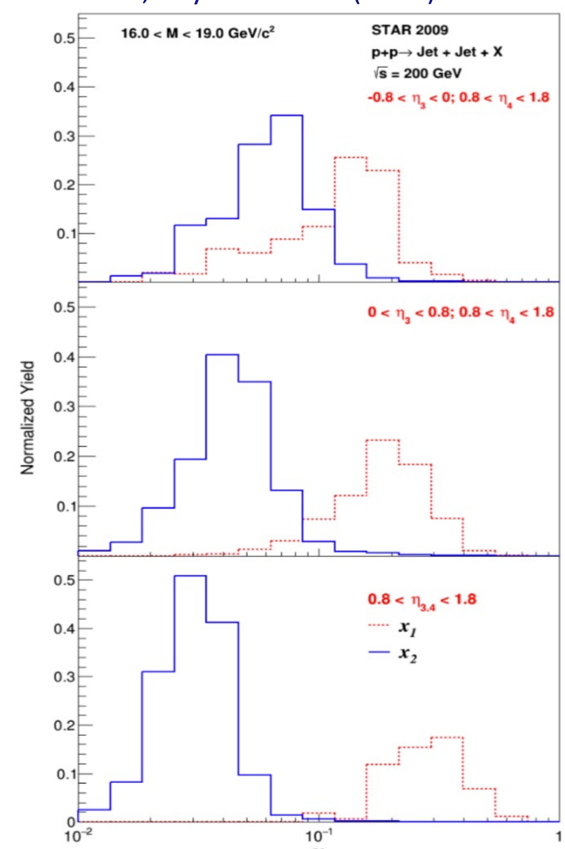
  - $0 < \eta_3 < 0.8$
    $0.8 < \eta_4 < 1.8$



  - $0.8 < \eta_{3,4} < 1.8$

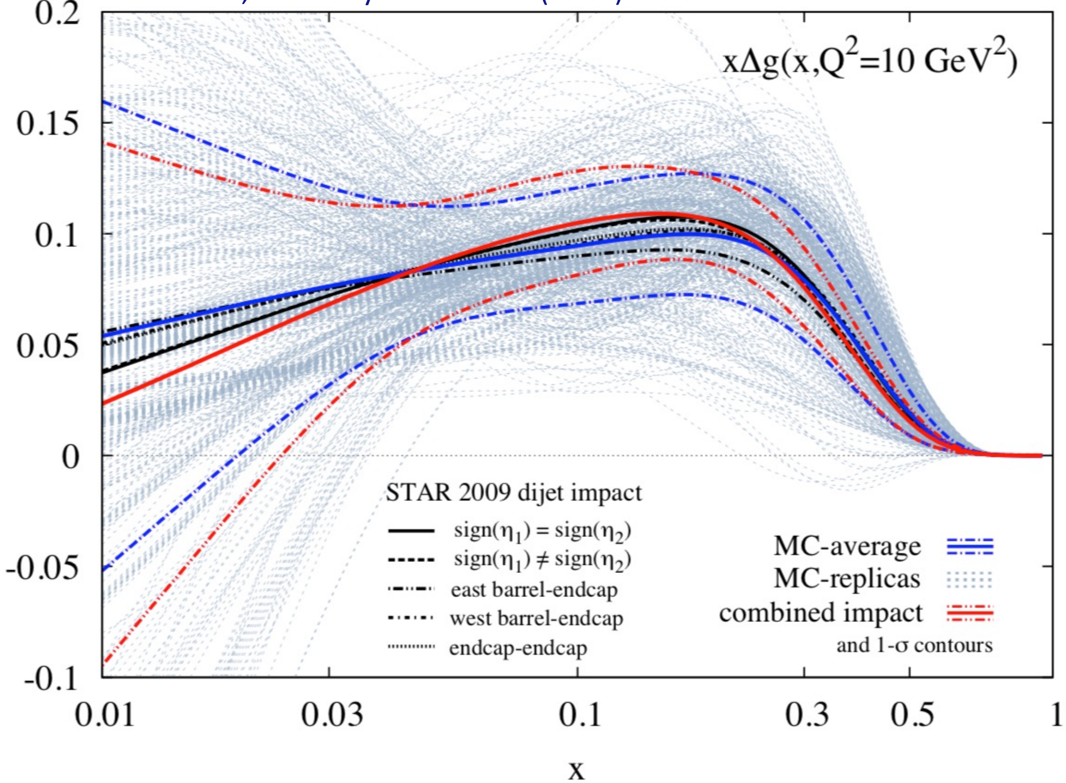


STAR, Phys. Rev. D98 (2018) 032011



Impact of 2009 Dijet Results

de Florian, et al. Phys. Rev. D100 (2019) 114027



- 2009 dijet results were included in a DSSV Monte Carlo sampling analysis
- The results before the 2009 dijet results are included via a reweighting technique are shown in blue
- The results after including the 2009 dijet results are shown in red
- Moderate increase in the gluon polarization in the range $0.05 \lesssim x \lesssim 0.2$

Before reweighting

$$\int_{0.1}^{1} \Delta g(x)dx = .133 \pm 0.035$$

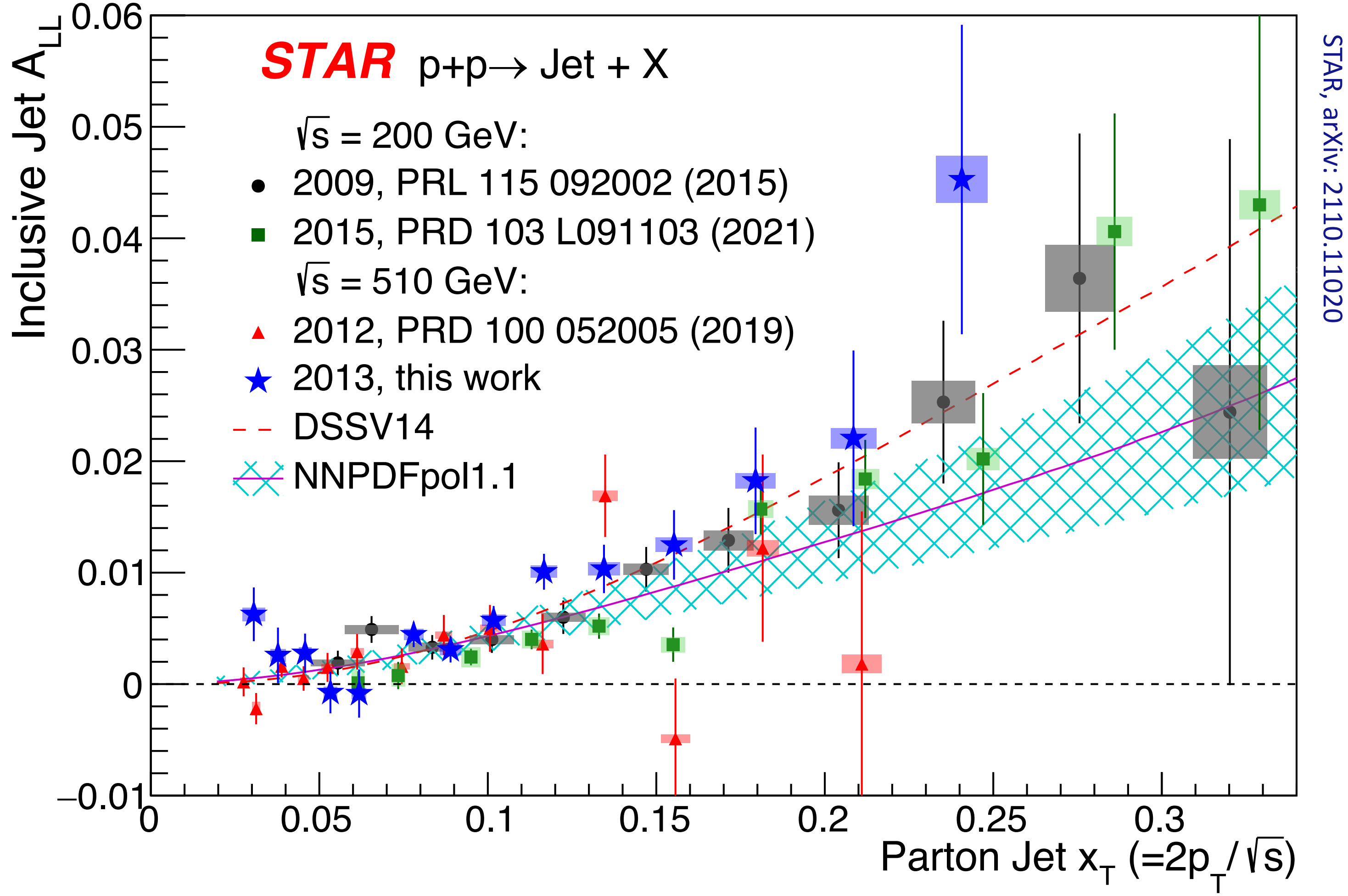
$$\int_{0.01}^{1} \Delta g(x)dx = .309 \pm 0.109$$

After reweighting

$$\int_{0.1}^{1} \Delta g(x)dx = .126 \pm 0.023$$

$$\int_{0.01}^{1} \Delta g(x)dx = .296 \pm 0.108$$

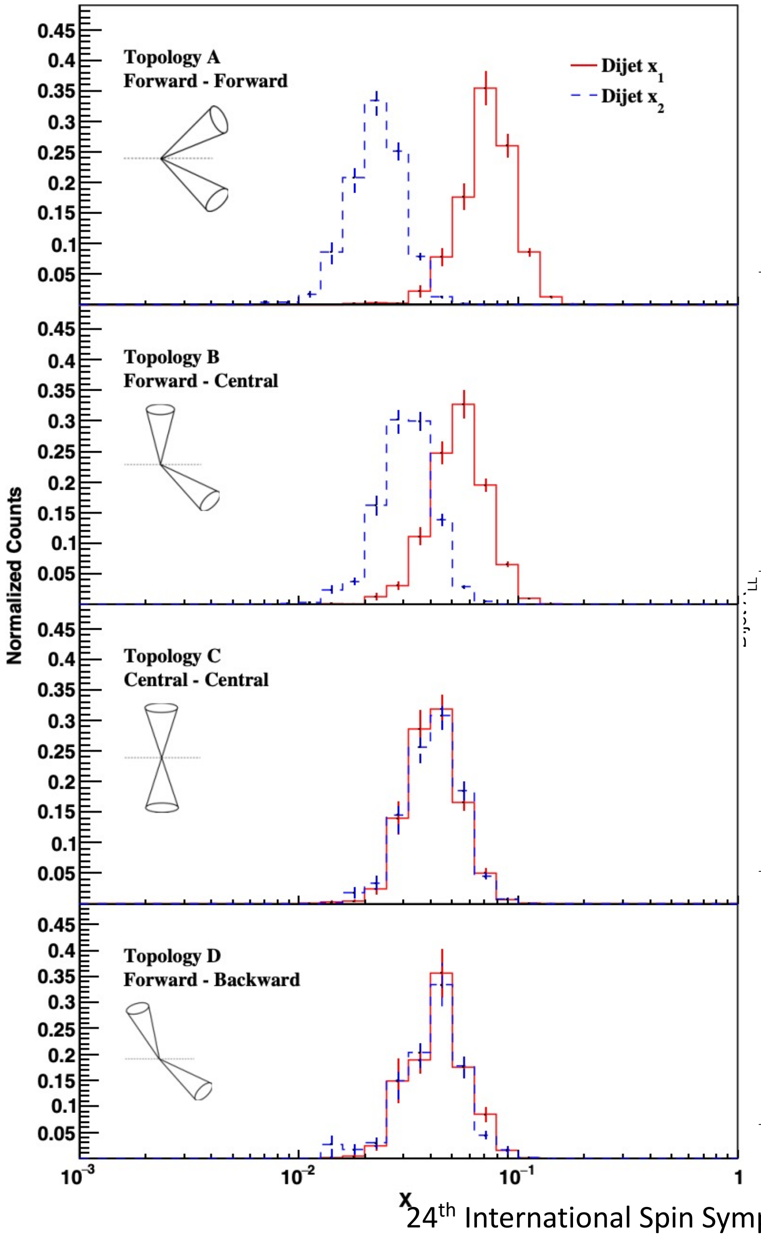
Midrapidity Jets at 510 GeV in 2012 & 2013



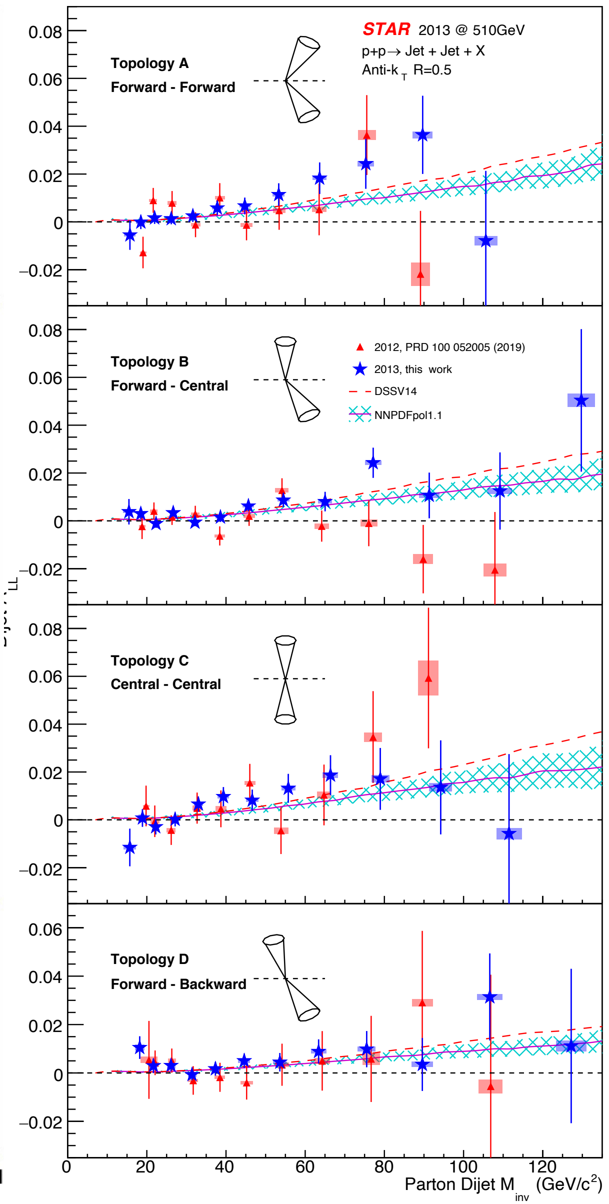
- Increasing the center-of-mass energy provides sensitivity to lower values of *x*
- STAR collected data corresponding to an integrated luminosity of 82 pb^{-1} in 2012 and 250 pb^{-1} in 2013

Midrapidity Dijets at 510 GeV in 2012 & 2013

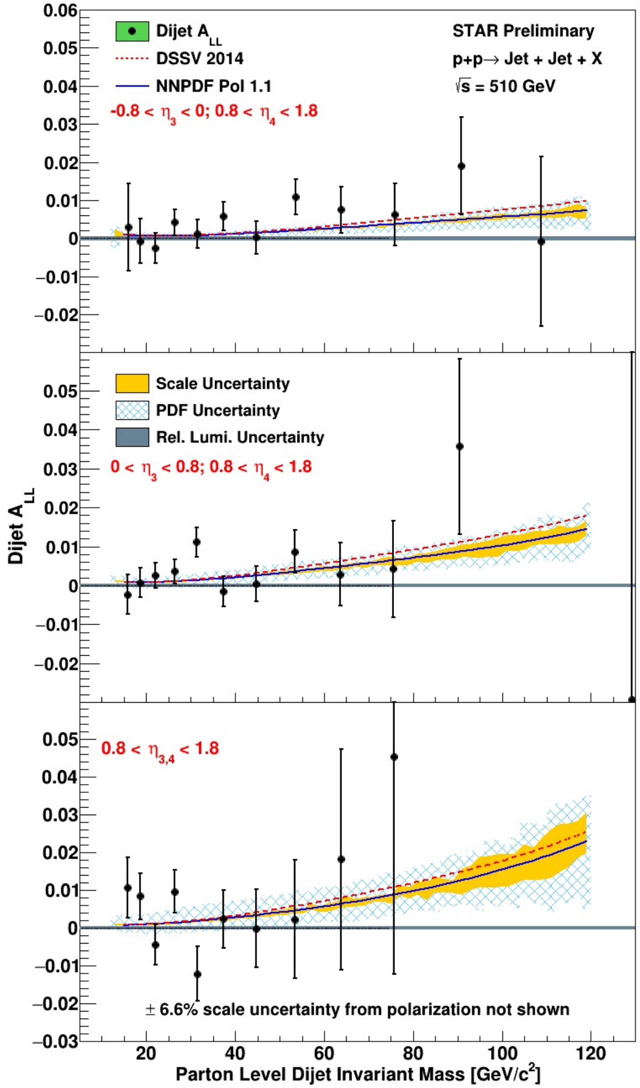
STAR, Phys. Rev. D100 (2019) 52005



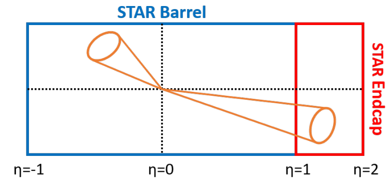
STAR, arXiv:2110.11020



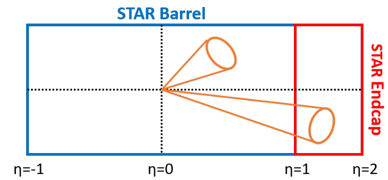
Intermediate Rapidity Dijets at 510 GeV in 2012 & 2013



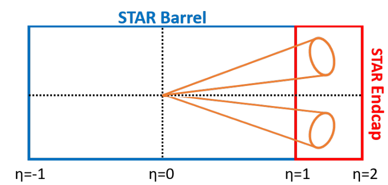
- East Barrel-Endcap

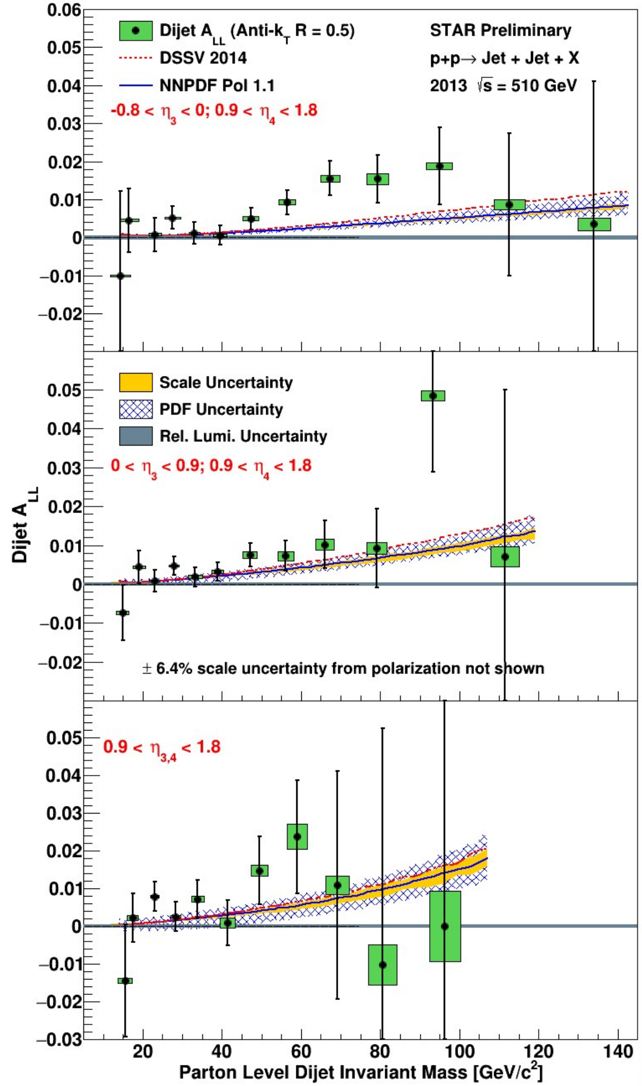


- West Barrel-Endcap



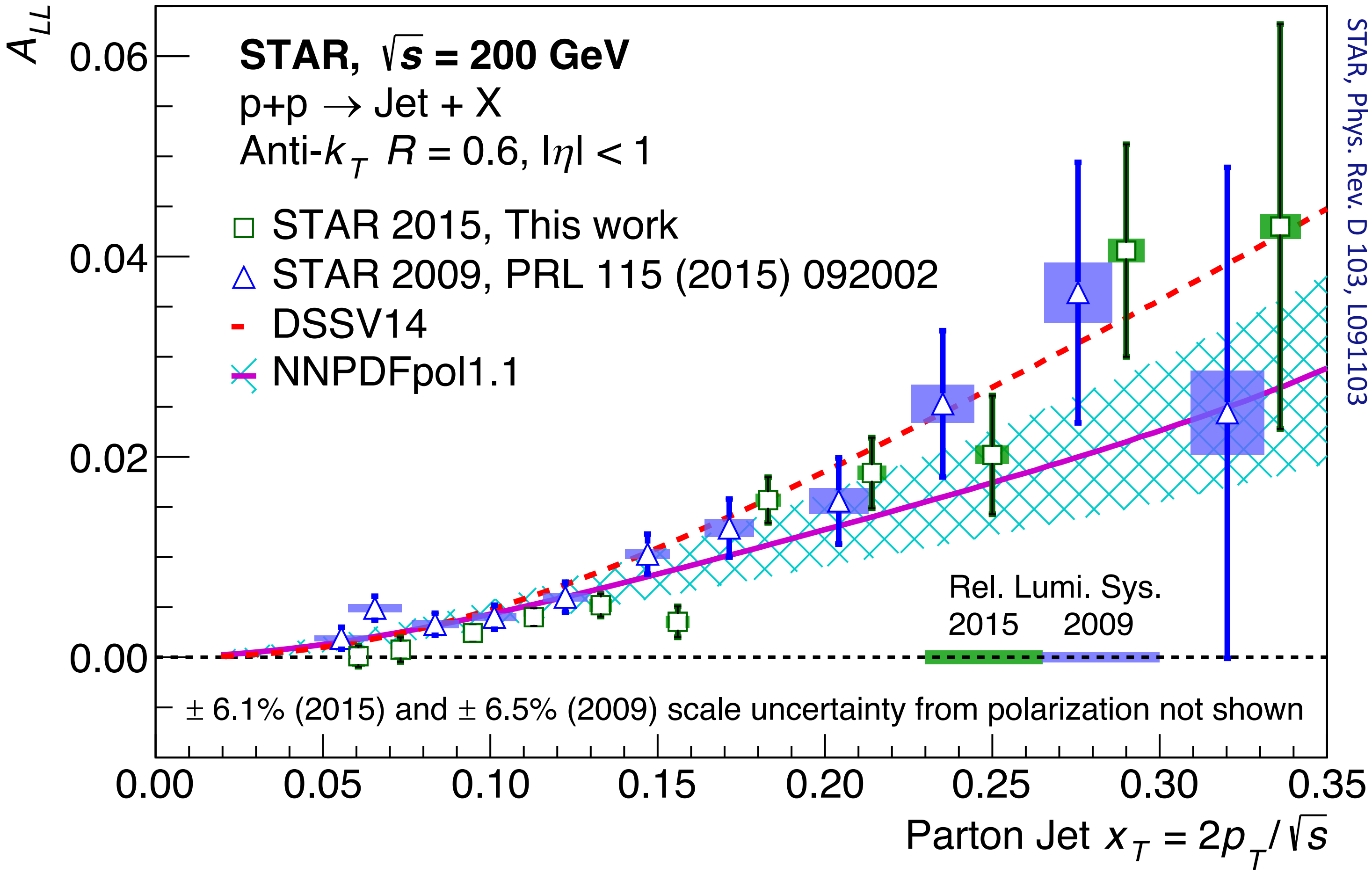
- Endcap-Endcap





- By extending to intermediate rapidity as well as increasing the center-of-mass energy, dijets can probe an even lower region in *x*, down to 0.004

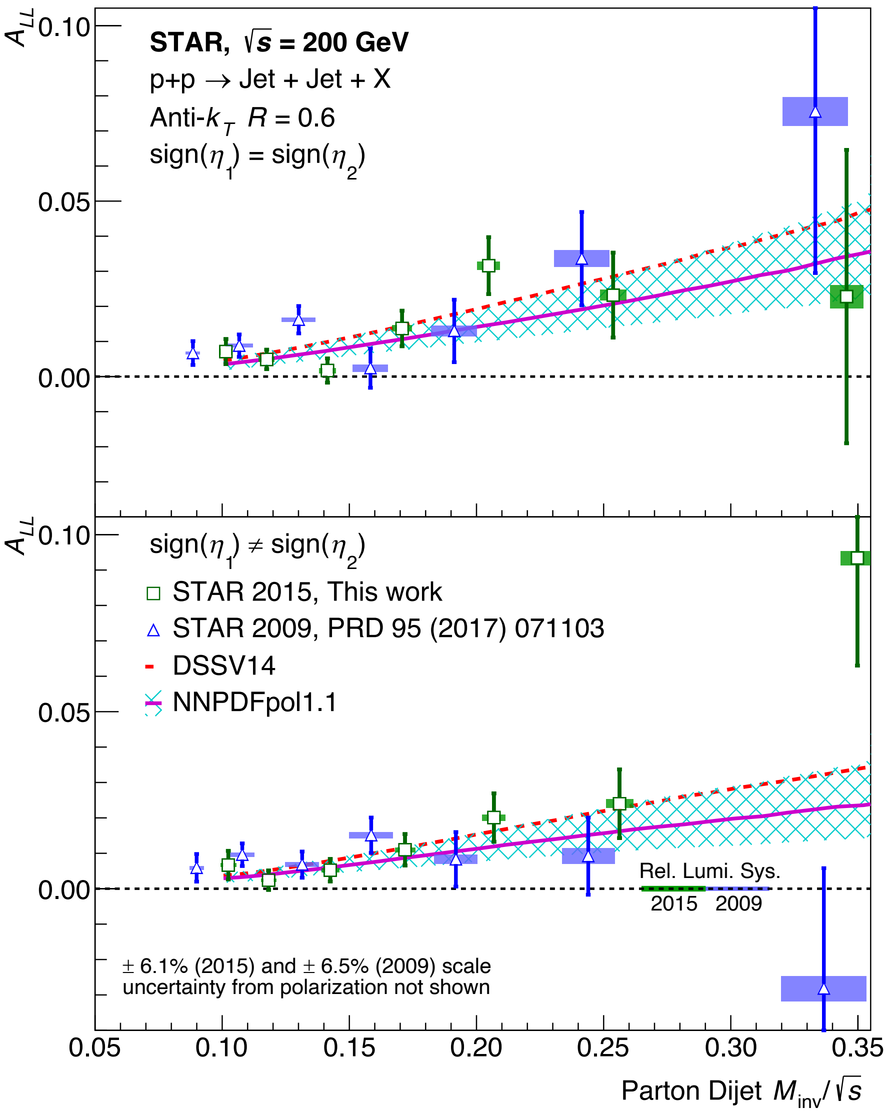
Midrapidity Jets at 200 GeV in 2015



- In 2015 STAR collected data corresponding to an integrated luminosity of 52 pb^{-1}
- Results from the 2015 data are consistent with the results from the 2009 data
- Systematic uncertainties are significantly reduced compared to previous results

Midrapidity Dijets at 200 GeV in 2015

STAR, Phys. Rev. D 103 (2021), L091103



- The results from the 2015 STAR data are consistent with the results from the 2009 data
- Systematic uncertainties are significantly reduced compared to results from the 2009 data

Summary

$\sqrt{s}$ (GeV)	RHIC Run	Midrapidity Jets ($\|\eta\| < 1.0$)	Midrapidity Dijets ($\|\eta\| < 1.0$)	Intermediate Rapidity Dijets ($0.8 < \eta < 2.0$)
200	2006	Published x > 0.05		
200	2009	Published x > 0.05	Published x > 0.05	Published x > 0.01
200	2015	Published x > 0.05	Published x > 0.05	Work in Progress x > 0.01
510	2012	Published x > 0.02	Published x > 0.02	Preliminary x > 0.004
510	2013	Submitted for Publication x > 0.02	Submitted for Publication x > 0.02	Preliminary x > 0.004

- STAR collected a data sample corresponding to an integrated luminosity of 250 pb^{-1} in 2013. The midrapidity jets/dijets final results are submitted for publication
- The inclusion of recently published results in future global analyses will provide further constraints on gluon polarization in the region $0.02 \lesssim x \lesssim 0.5$

Thank You!

Backup Slides

Dijet Correlation Measurements

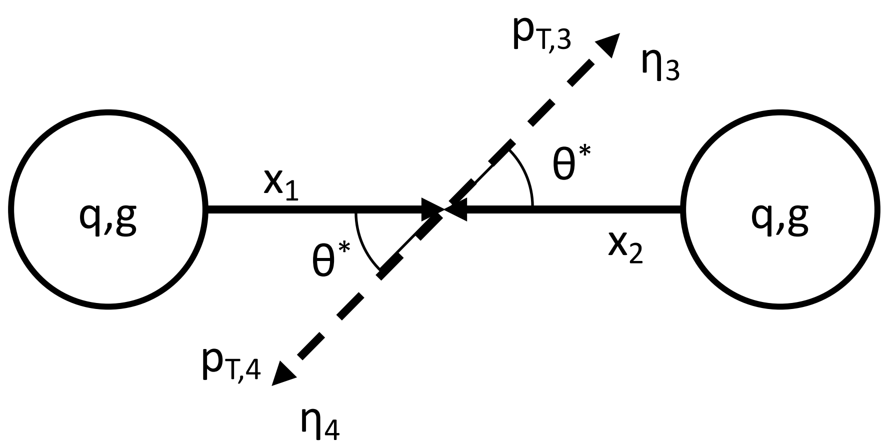
$$x_1 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{\eta_3} + p_{T4}e^{\eta_4}\right)$$

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

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

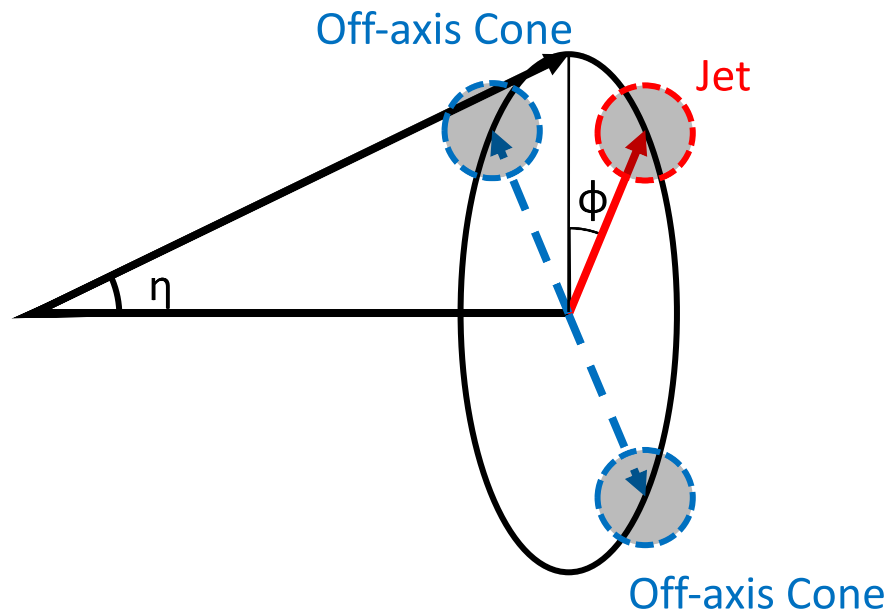
$$\eta_3 + \eta_4 = \ln\frac{x_1}{x_2}$$

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



Underlying Event Subtraction

- Off-axis cones are created at the same η as the reconstructed jet but $\pm\frac{\pi}{2}$ in ϕ
- Then the underlying event density is determined by taking the off axis cone p_T divided by the cone area. The densities of the two cones are then averaged together.
- The correction applied to the reconstructed jet is determined by multiplying the underlying event density by the area of the reconstructed jet. This correction is subtracted from the p_T of the reconstructed jet.



$$\sigma_{UE} = \frac{1}{2}\left(\frac{p_{T,cone(plus)}}{Area_{cone}} + \frac{p_{T,cone(minus)}}{Area_{cone}}\right)$$

$$p_{T,corrected} = p_T - \sigma_{UE} \cdot Area_{Jet}$$