Longitudinal Double-Spin Asymmetry for Inclusive and Di-Jet Production in Polarized Proton Collisions at $\sqrt{s} = 200$ GeV

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For the STAR collaboration

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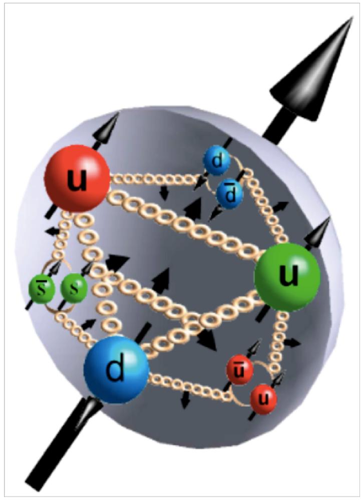
Proton Spin Composition

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

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

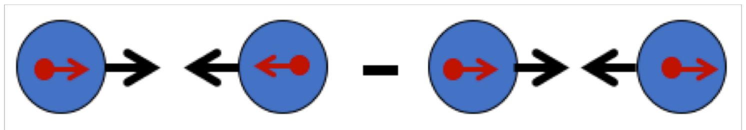
Quark Spin Contribution: $\Delta\Sigma = \int (\Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s}) dx$



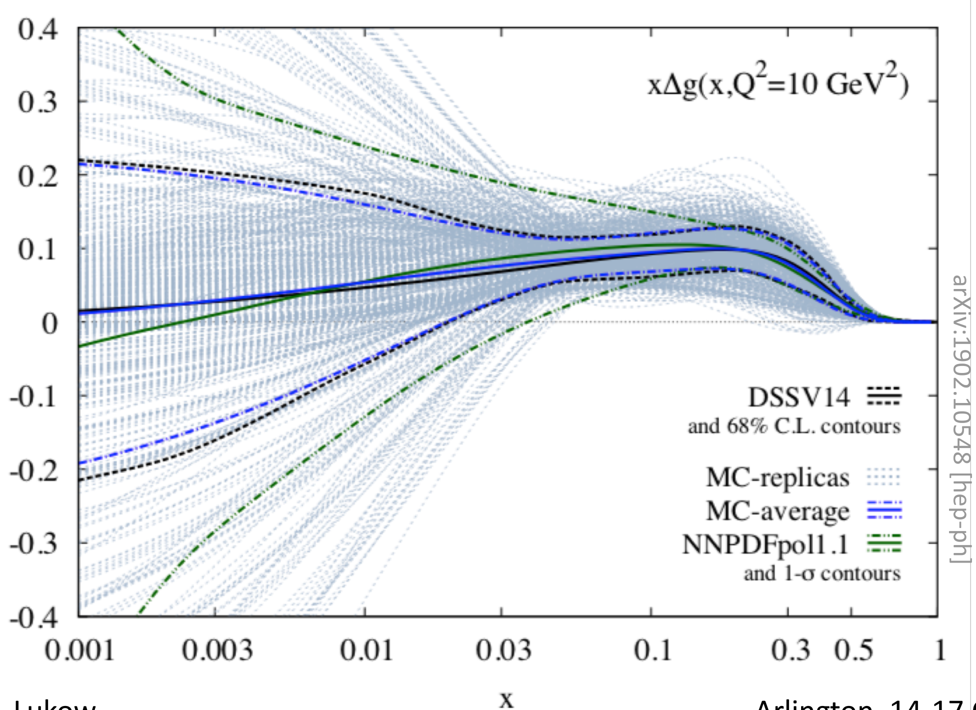
Gluon Spin Contribution: $\Delta G = \int \Delta g(x) dx$

Gluon Polarization & Longitudinal Double-Spin Asymmetry

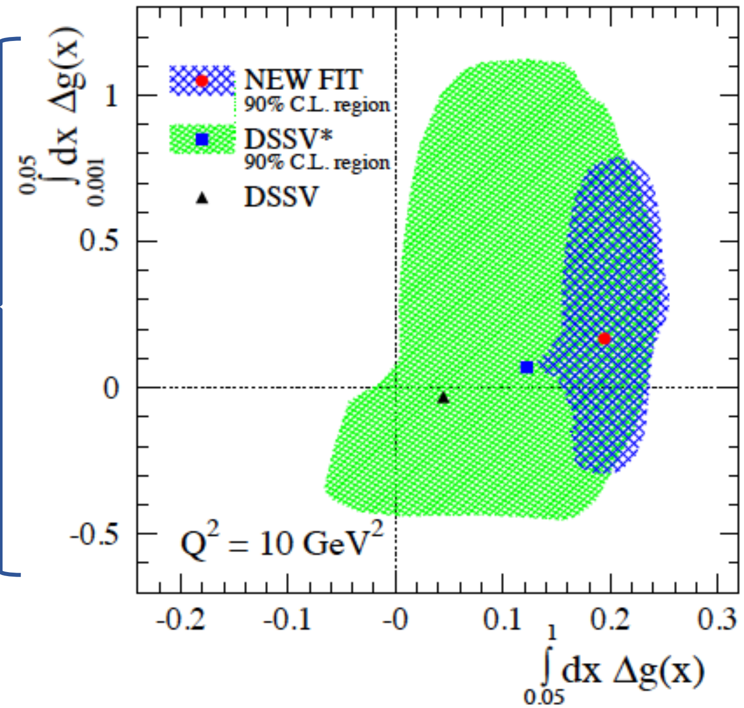
- Polarized gluon distribution function can be constrained by measuring the longitudinal double-spin asymmetry of jets (A_{LL})



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



Phys.Rev.Lett. 113 (2014) no.1, 012001



Low x – Poorly constrained

High x – well constrained

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

arXiv:1902.10548 [hep-ph]

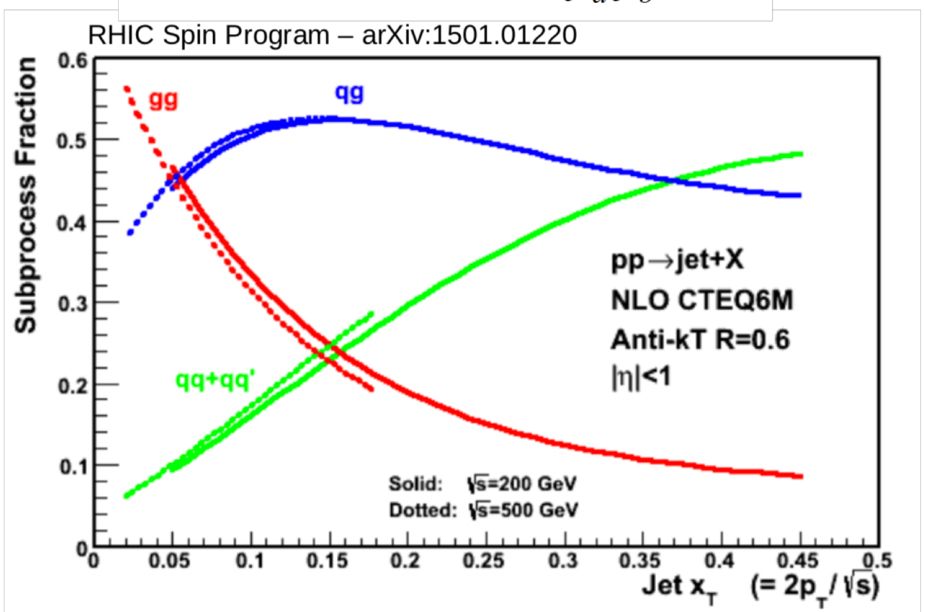
NNPDF: $\int_{0.05}^{0.2} \Delta g(x) dx = 0.17 \pm 0.06$

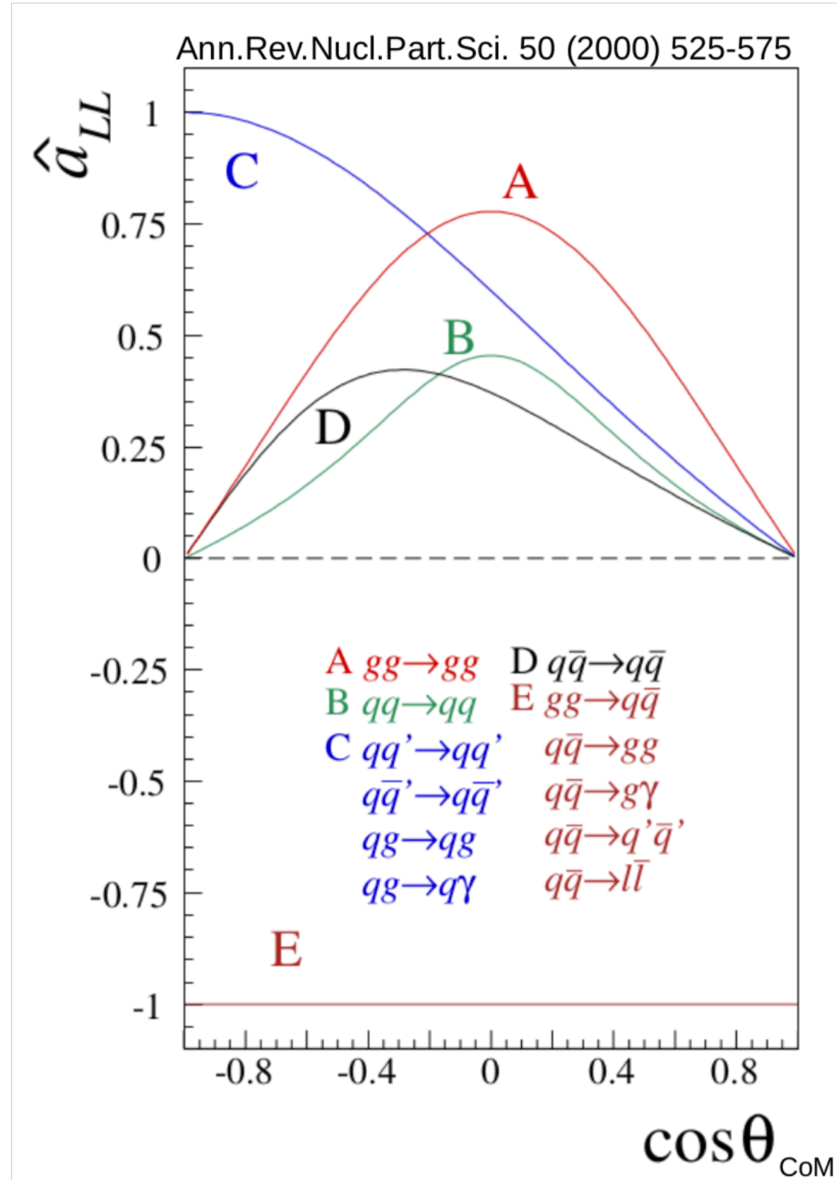
Nucl. Phys. B 887, 276 (2014)

Subprocess Sensitivity

- STAR observables are dominantly sensitive to qg and gg scattering.
- Because of this sensitivity, A_{LL} allows access to $\Delta g(x)$

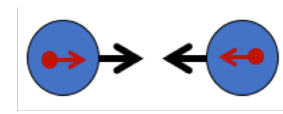
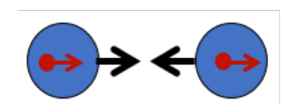
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$



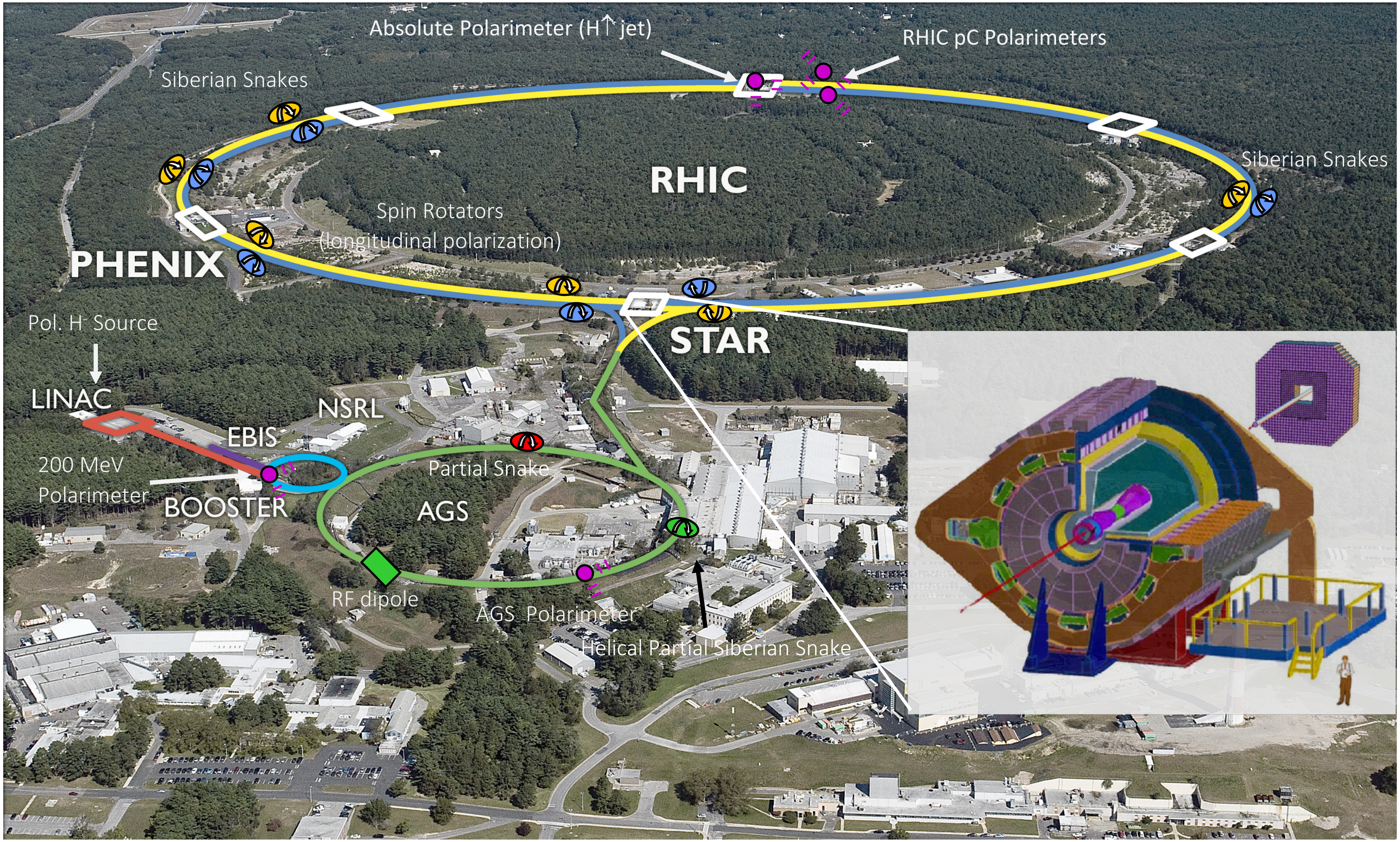


Longitudinal Double-Spin Asymmetry

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

- N_{++} - Yield of jets/dijets when helicities are the same sign 
- N_{+-} - Yield of jets/dijets when helicities are opposite sign 
- $P_{1,2}$ - Polarization of Beam 1,2
- $\left(\frac{L_{++}}{L_{+-}}\right)$ - Relative Luminosity

RHIC/STAR



Absolute Polarimeter (H↑ jet)
RHIC pC Polarimeters
Siberian Snakes
Siberian Snakes
RHIC
Spin Rotators
(longitudinal polarization)
PHENIX
STAR
Pol. H⁻ Source
LINAC
NSRL
EBIS
200 MeV
Polarimeter
BOOSTER
Partial Snake
AGS
RF dipole
AGS Polarimeter
Helical Partial Siberian Snake

Jet and Dijet Results from STAR

Central Rapidity ($|\eta| < 1.0$)

- Jets at 200 GeV in 2009

  Phys.Rev.Lett. 115 (2015) no.9, 092002
- Dijets at 200 GeV in 2009

  Phys.Rev. D95 (2017) no.7, 071103
- Jets at 510 GeV in 2012

  Phys.Rev. D100 (2019) no.5, 052005
- Dijets at 510 GeV in 2012

  Phys.Rev. D100 (2019) no.5, 052005
- Jets at 510 GeV in 2013

  (STAR Preliminary)
- Dijets at 510 GeV in 2013

  (STAR Preliminary)
- Jets at 200 GeV in 2015

  (Work in Progress)
- Dijets at 200 GeV in 2015

  (Work in Progress)

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

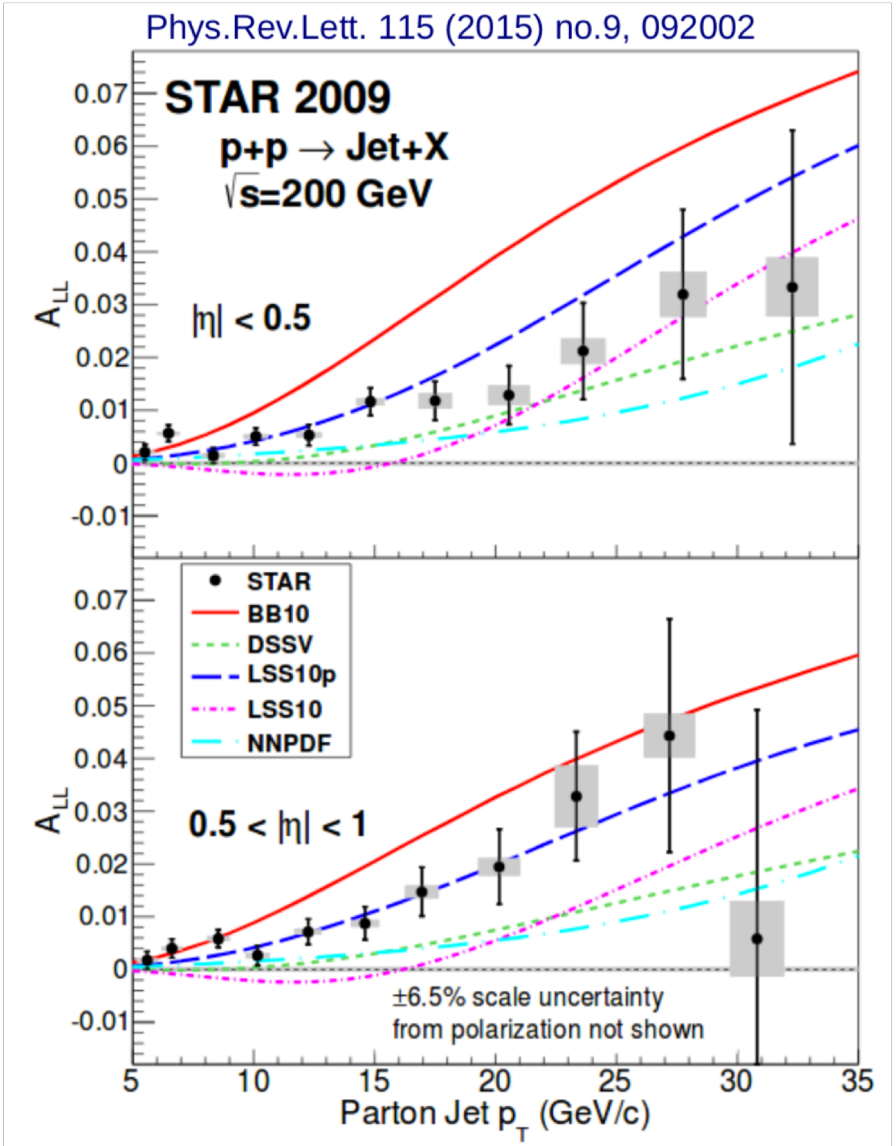
- Dijets at 200 GeV in 2009

  Phys.Rev. D98 (2018) no.3, 032011
- Dijets at 510 GeV in 2012

  (Work in Progress)
- Dijets at 510 GeV in 2013

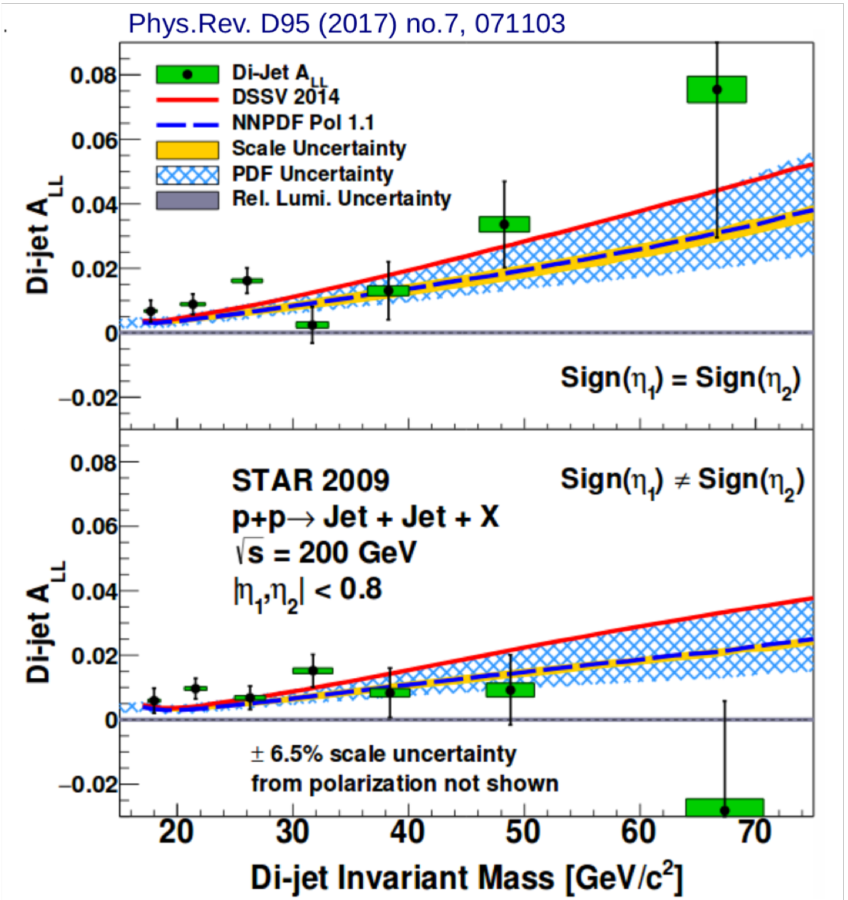
  (Work in Progress)

Central Jets at 200 GeV in 2009



- 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

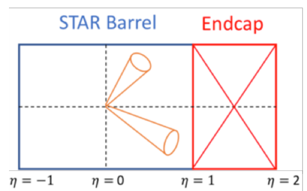
Central Dijets at 200 GeV in 2009



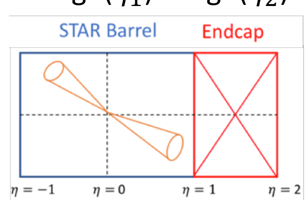
- Dijets probe a narrower region in *x*
- Plotted vs dijet invariant mass:

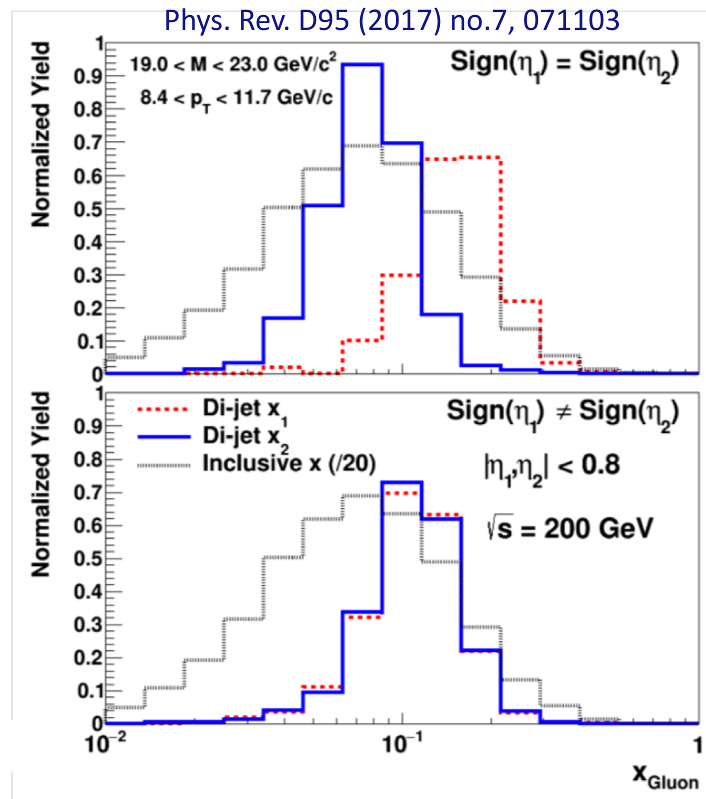
$$M = \sqrt{s x_1 x_2}$$

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

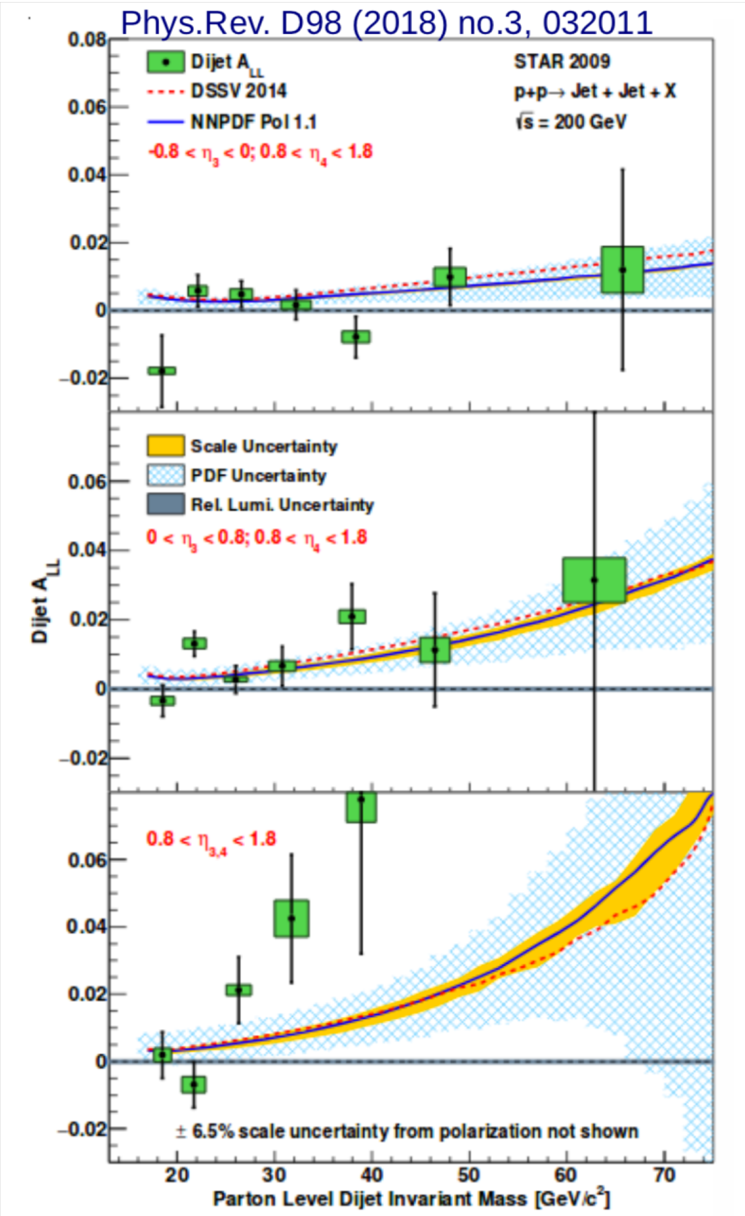


  - Sign(η_1) ≠ Sign(η_2)

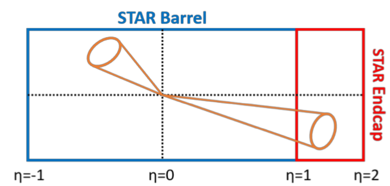




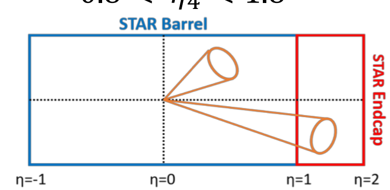
Intermediate Dijets at 200 GeV in 2009



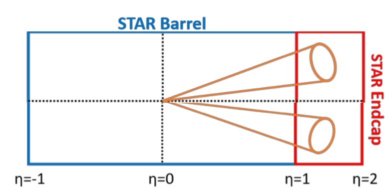
- By extending to intermediate rapidity, dijets can probe an even lower region in *x*
- Plotted vs dijet invariant mass
- Three topologies shown sample different x ranges:
  - $-0.8 < \eta_3 < 0$
 $0.8 < \eta_4 < 1.8$

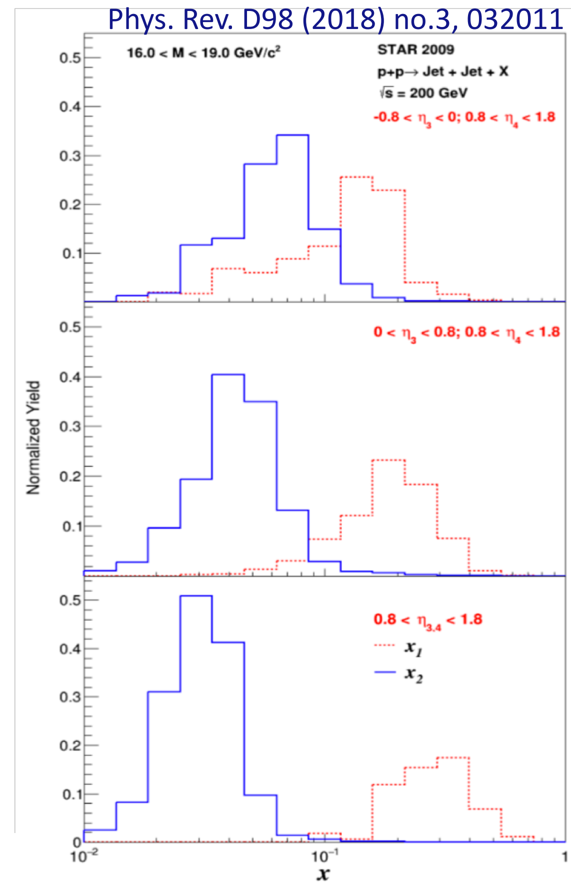


  - $0 < \eta_3 < 0.8$
 $0.8 < \eta_4 < 1.8$



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

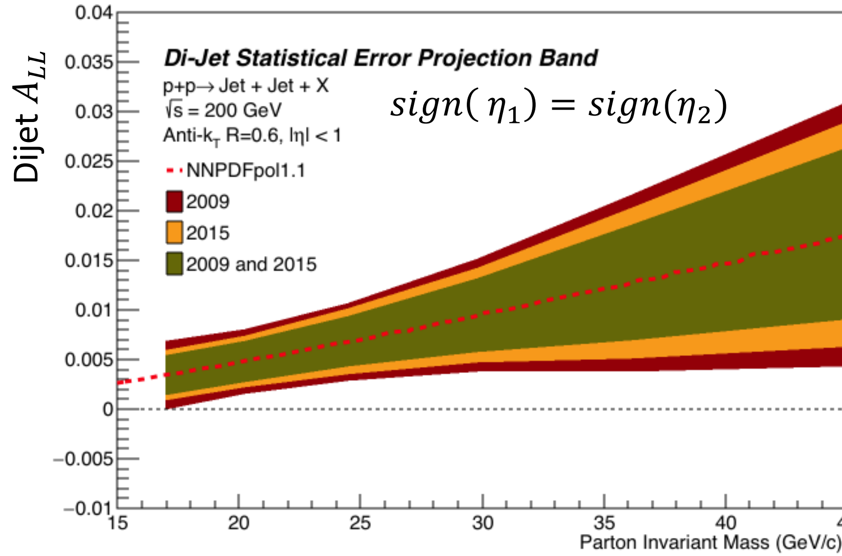


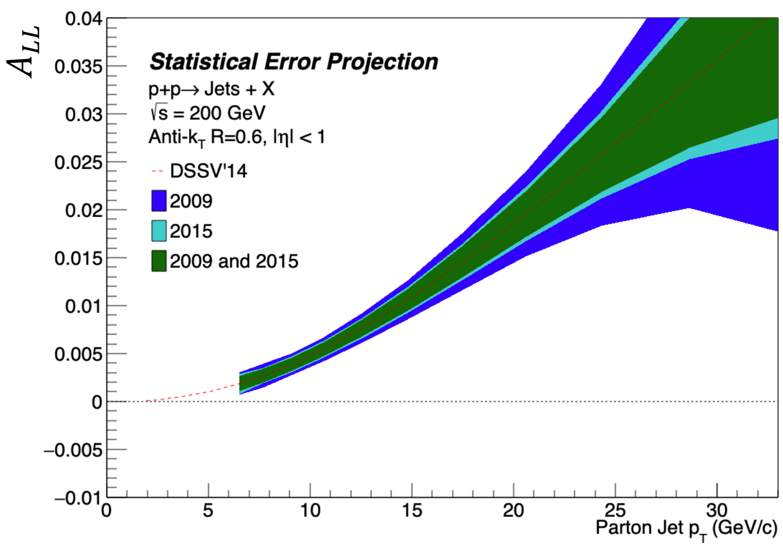


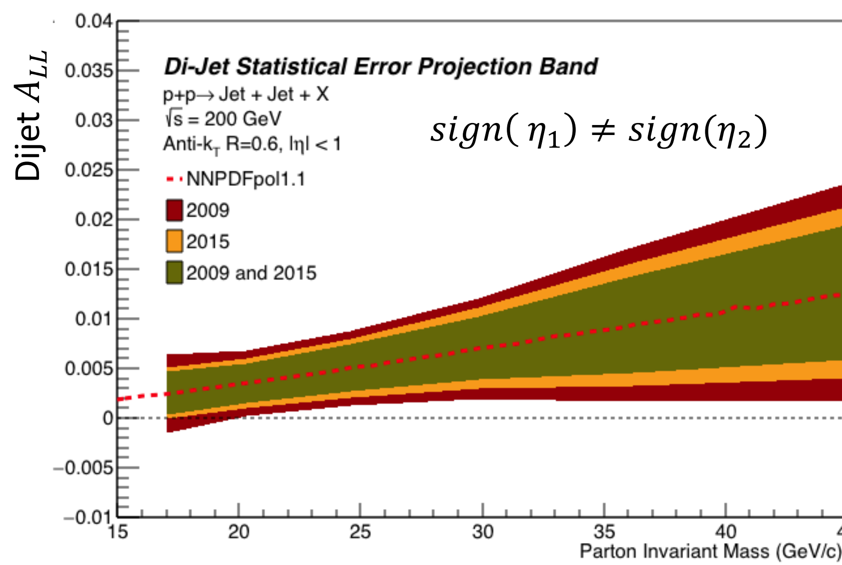
Central Jets and Dijets at 200 GeV in 2015

- Data taken in 2015 is currently being analyzed in the same manner as the 2009 central jets/dijets except it will include an off-axis cone underlying event correction technique introduced in the 2012 analyses

- The 2015 data sample represents a large increase in sample size compared to the 2009 results, which will further reduce statistical uncertainties







Summary

$\sqrt{s}$ (GeV)	RHIC Run	Central Jets ($\|\eta\| < 1.0$)	Central Dijets ($\|\eta\| < 1.0$)	Intermediate 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	Work in Progress x > 0.05	Work in Progress x > 0.05	
510	2012	Published x > 0.02	Published x > 0.02	Work in Progress x > 0.004
510	2013	Preliminary x > 0.02	Preliminary x > 0.02	Work in Progress x > 0.004

See Carl Gagliardi's presentation next for more information on analyses of STAR 2012 data and other recent STAR gluon polarization measurements

Backup

Dijet Correlation Measurements

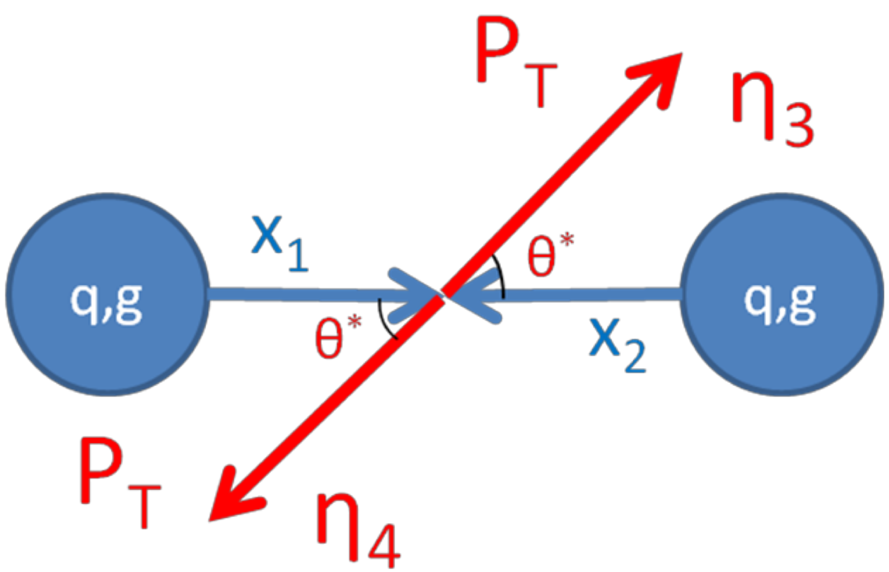
$$x_1 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{\eta_3} + p_{T4}e^{\eta_4}\right)$$

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

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

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

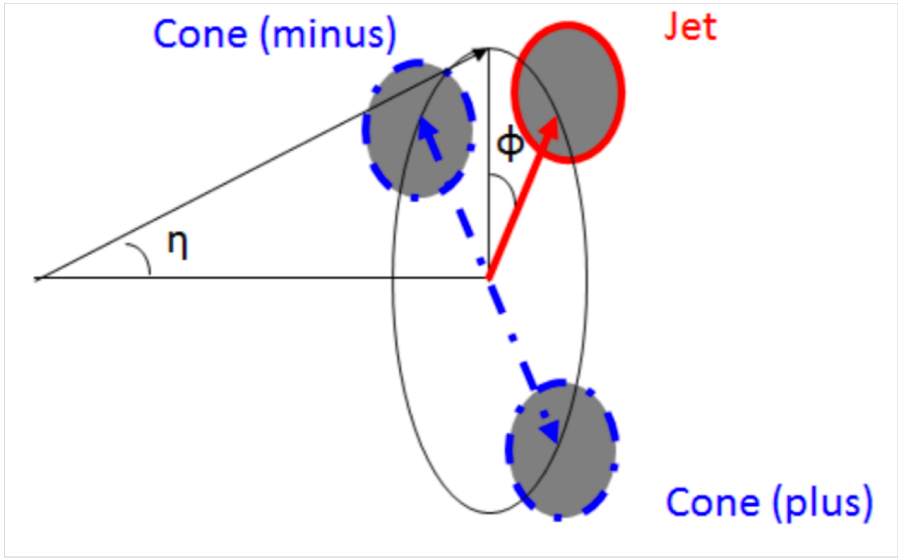
$$\left|\cos\theta^*\right| = \tanh\left|\frac{\eta_3 - \eta_4}{2}\right|$$



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.

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

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