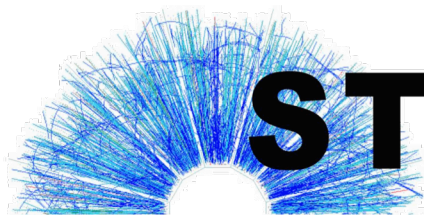# Longitudinal Double-Spin Asymmetry for Inclusive and Di-Jet Production in Polarized Proton Collisions at $\sqrt{s} = 200$ GeV

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For the STAR collaboration

30 October 2020

Proton Spin Composition

Jaffe-Manohar Spin Sum Rule:
Nucl. Phys. B 337, 509 (1990)

$$S = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

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: $\Delta\Sigma = \int \left(\Delta u + \Delta d + \Delta s + \Delta \bar{u} + \Delta \bar{d} + \Delta \bar{s} \right) dx$
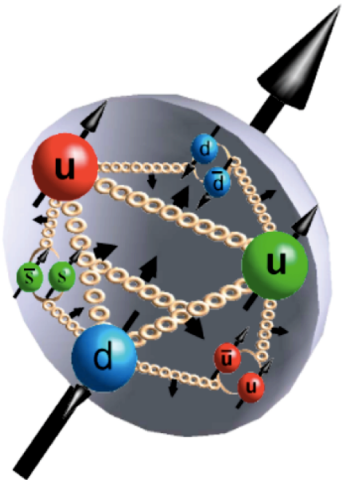
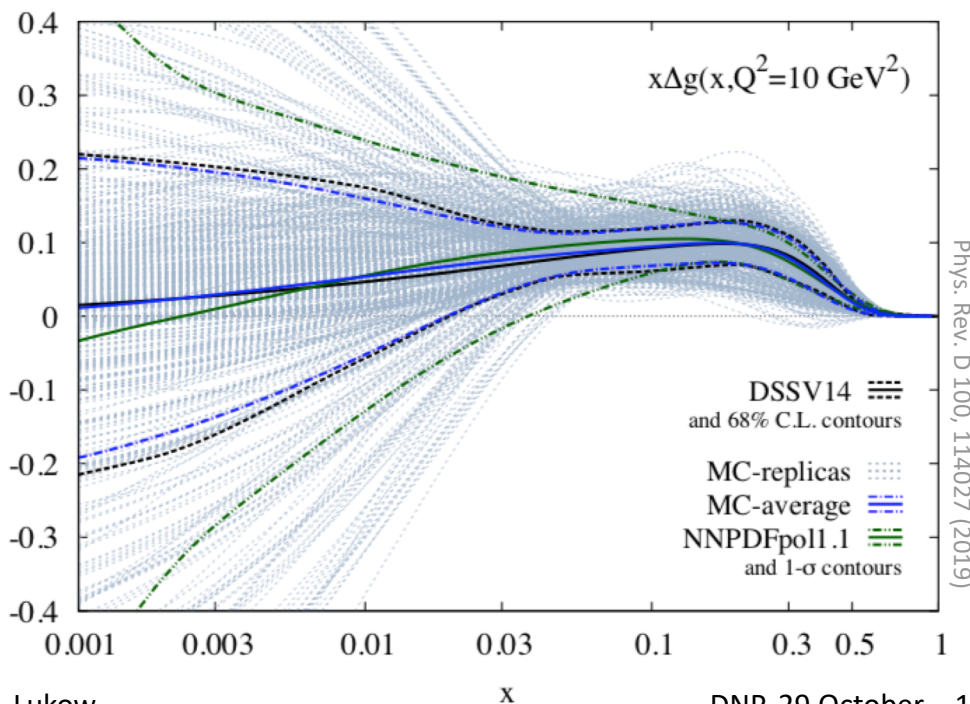Gluon Spin Contribution: $\Delta G = \int \Delta g(x) dx$

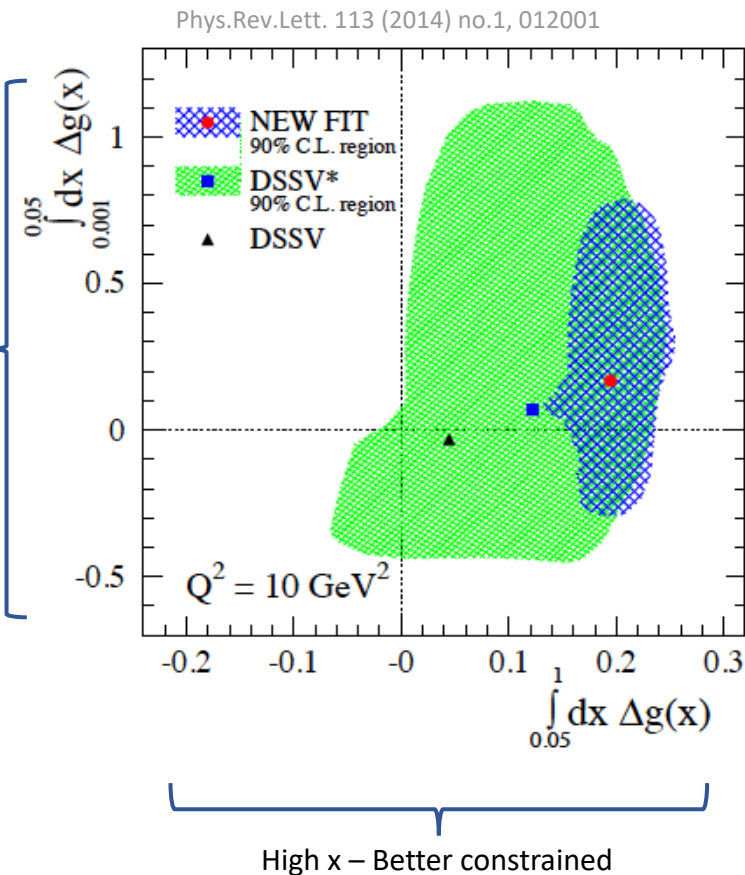# Gluon Polarization & Longitudinal Double-Spin Asymmetry

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

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

$x\Delta g(x, Q^2 = 10 \text{ GeV}^2)$

DSSV14 and 68% C.L. contours

MC-replicas
MC-average
NNPDFpol1.1 and 1-σ contours

Phys. Rev. D 100, 114027 (2019)

Low x –
Poorly
constrained

NEW FIT 90% C.L. region

DSSV* 90% C.L. region

DSSV

$Q^2 = 10 \text{ GeV}^2$

High x – Better constrained

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

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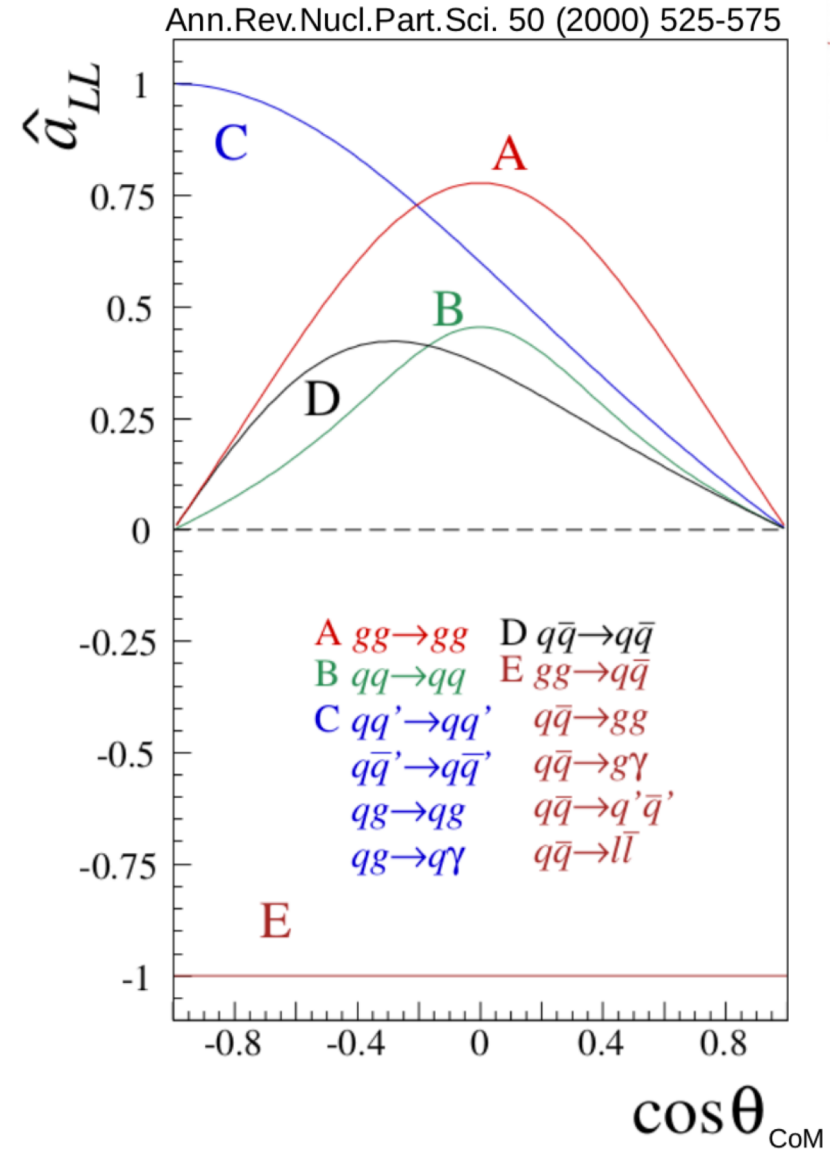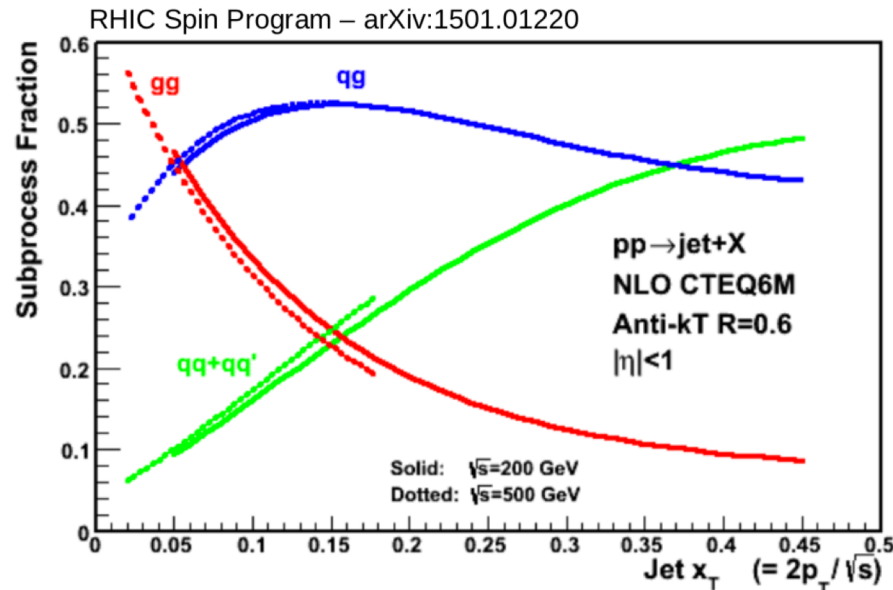
Subprocess Sensitivity

- 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

Ann.Rev.Nucl.Part.Sci. 50 (2000) 525-575

$pp \rightarrow jet+X$
NLO CTEQ6M
Anti-kT R=0.6
$|\eta|<1$

Solid: $\sqrt{s}$=200 GeV
Dotted: $\sqrt{s}$=500 GeV

A $gg \rightarrow gg$ D $q\bar{q} \rightarrow q\bar{q}$
B $qq \rightarrow qq$ E $gg \rightarrow q\bar{q}$
C $qq' \rightarrow qq'$ $q\bar{q} \rightarrow gg$
  $q\bar{q}' \rightarrow q\bar{q}'$ $q\bar{q} \rightarrow g\gamma$
  $qg \rightarrow qg$ $q\bar{q} \rightarrow q'\bar{q}'$
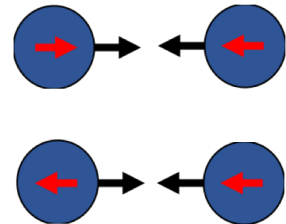 $qg \rightarrow q\gamma$ $q\bar{q} \rightarrow l\bar{l}$
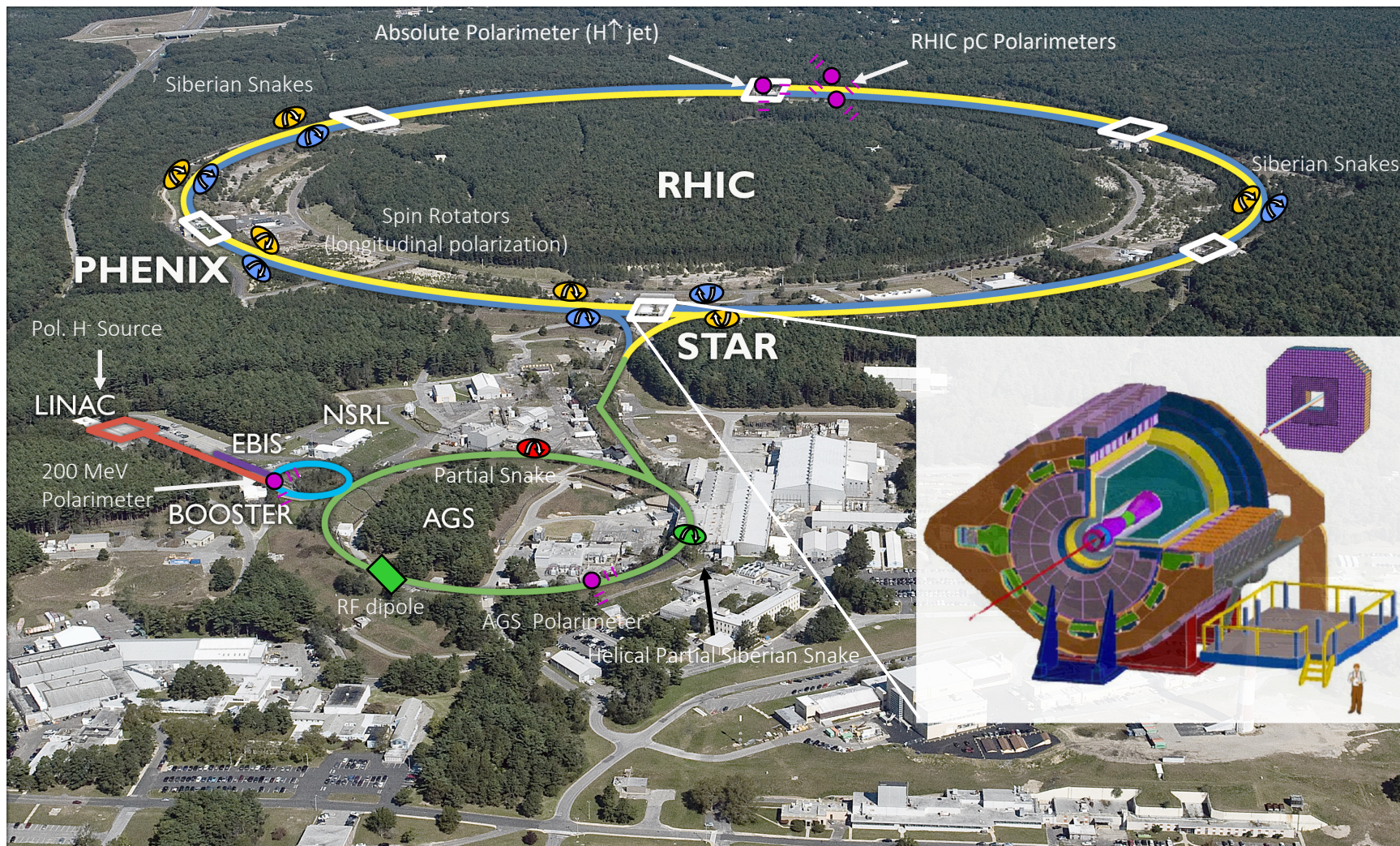
Longitudinal Double-Spin Asymmetry

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

- 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

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

  (STAR Preliminary)
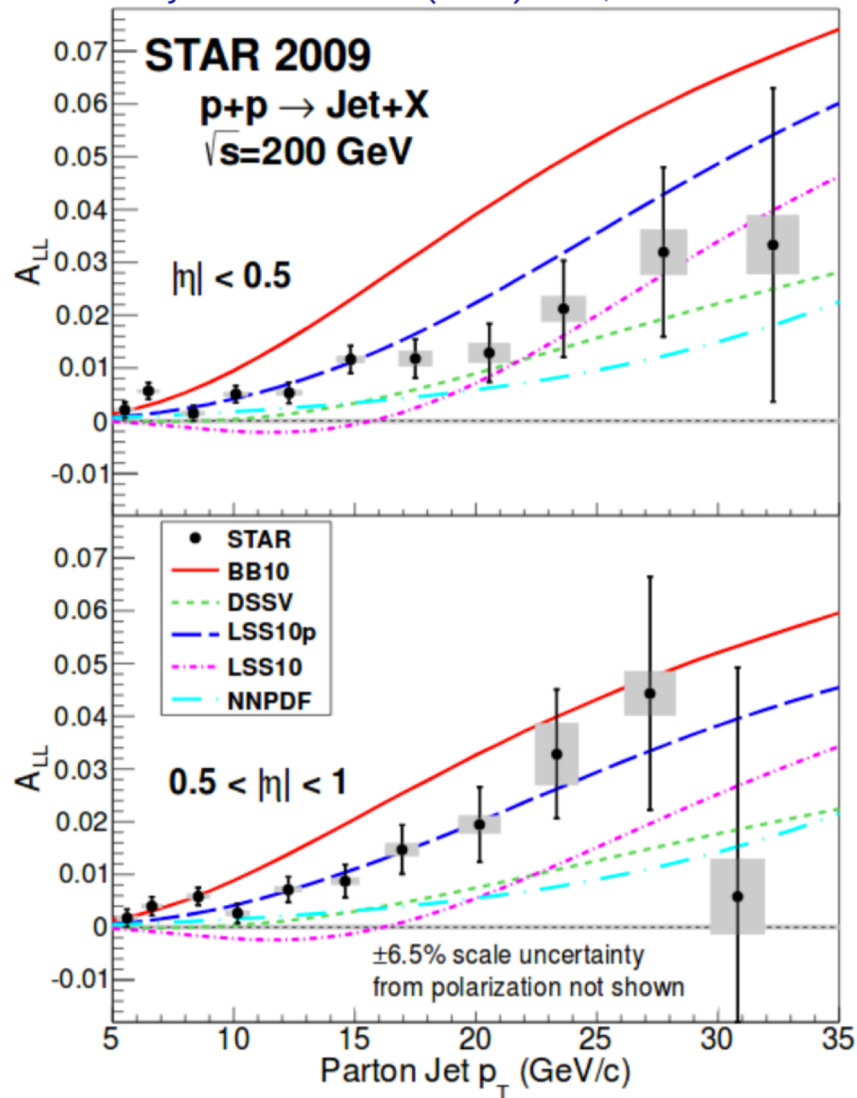
- Dijets at 200 GeV in 2015

  (STAR Preliminary)

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

  (Preliminary)

- Dijets at 510 GeV in 2013

  (Work in Progress)

Central Jets at 200 GeV in 2009

Phys.Rev.Lett. 115 (2015) no.9, 092002

STAR 2009
p+p → Jet+X
$\sqrt{s}$=200 GeV
$|\eta| < 0.5$

$0.5 < |\eta| < 1$

- STAR
- BB10
- DSSV
- LSS10p
- LSS10
- NNPDF

±6.5% scale uncertainty
from polarization not shown

- 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
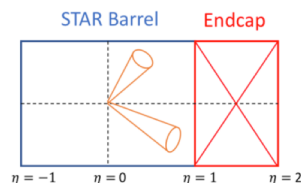
Phys.Rev. D95 (2017) no.7, 071103
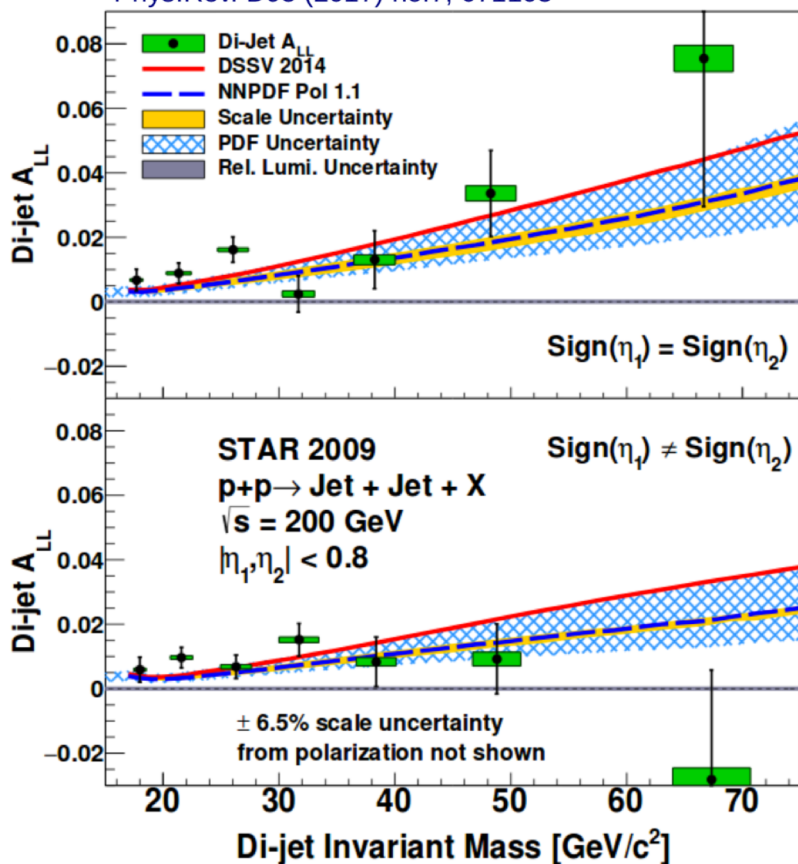
- Dijets probe a narrower region in *x*
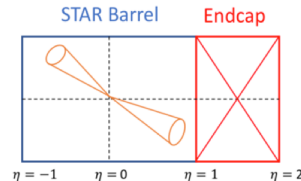
- Plotted vs dijet invariant mass:

$$M = \sqrt{sx_1x_2}$$
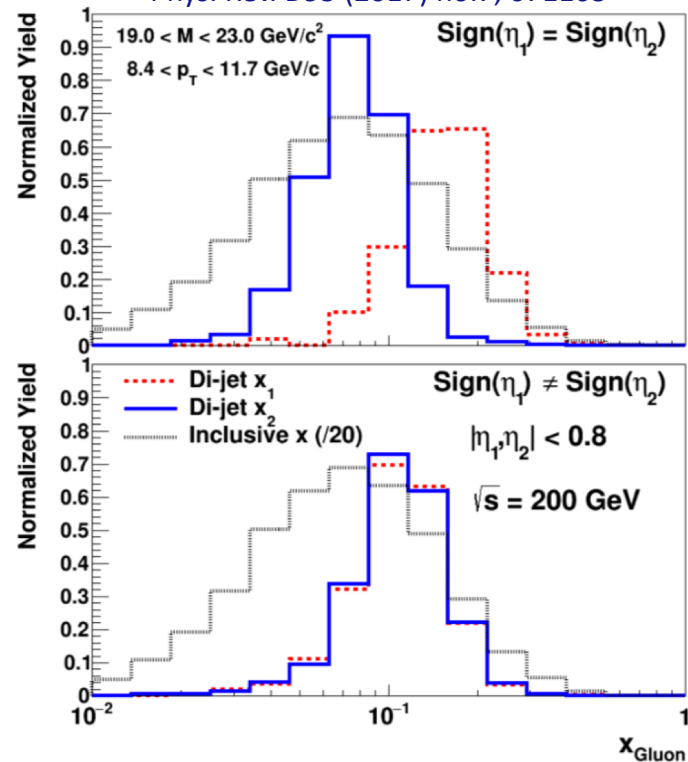
- Two topologies shown sample different x ranges:

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

- Sign(η_1) = Sign(η_2)

- Sign(η_1) ≠ Sign(η_2)

Intermediate Dijets at 200 GeV in 2009

Phys.Rev. D98 (2018) no.3, 032011
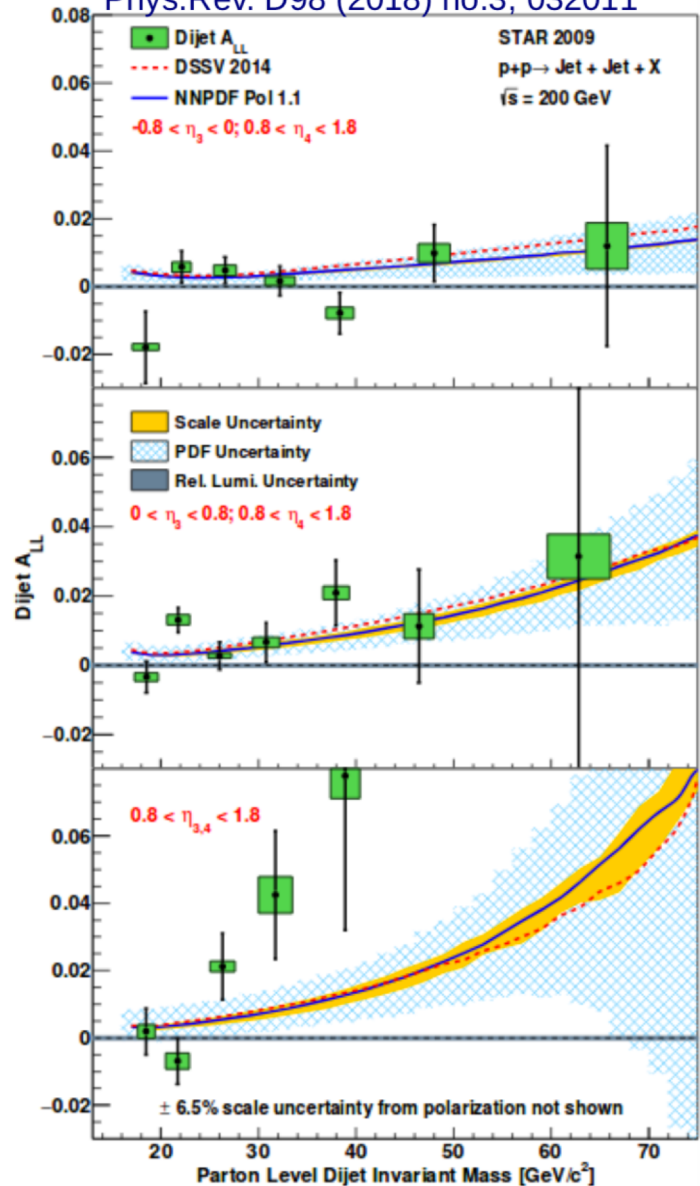
- By extending to intermediate rapidity, dijets can probe an even lower region in x

- Plotted vs dijet invariant mass

- Three topologies shown sample different x ranges:

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

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

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

Phys. Rev. D98 (2018) no.3, 032011

Central Jets at 200 GeV in 2015
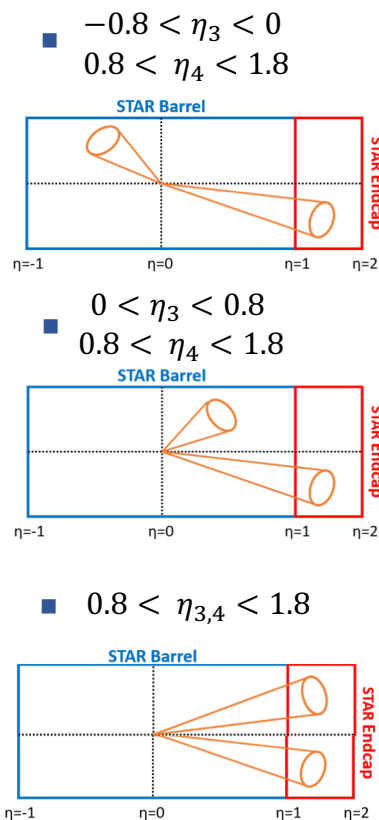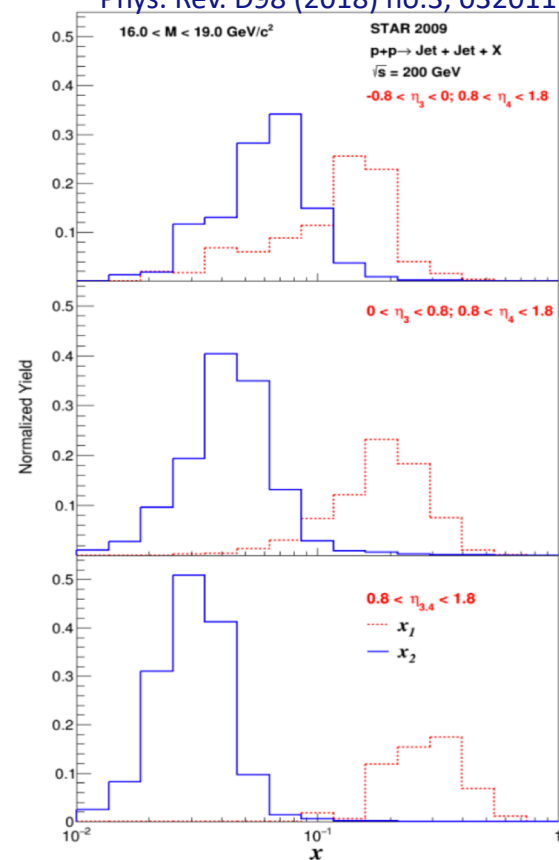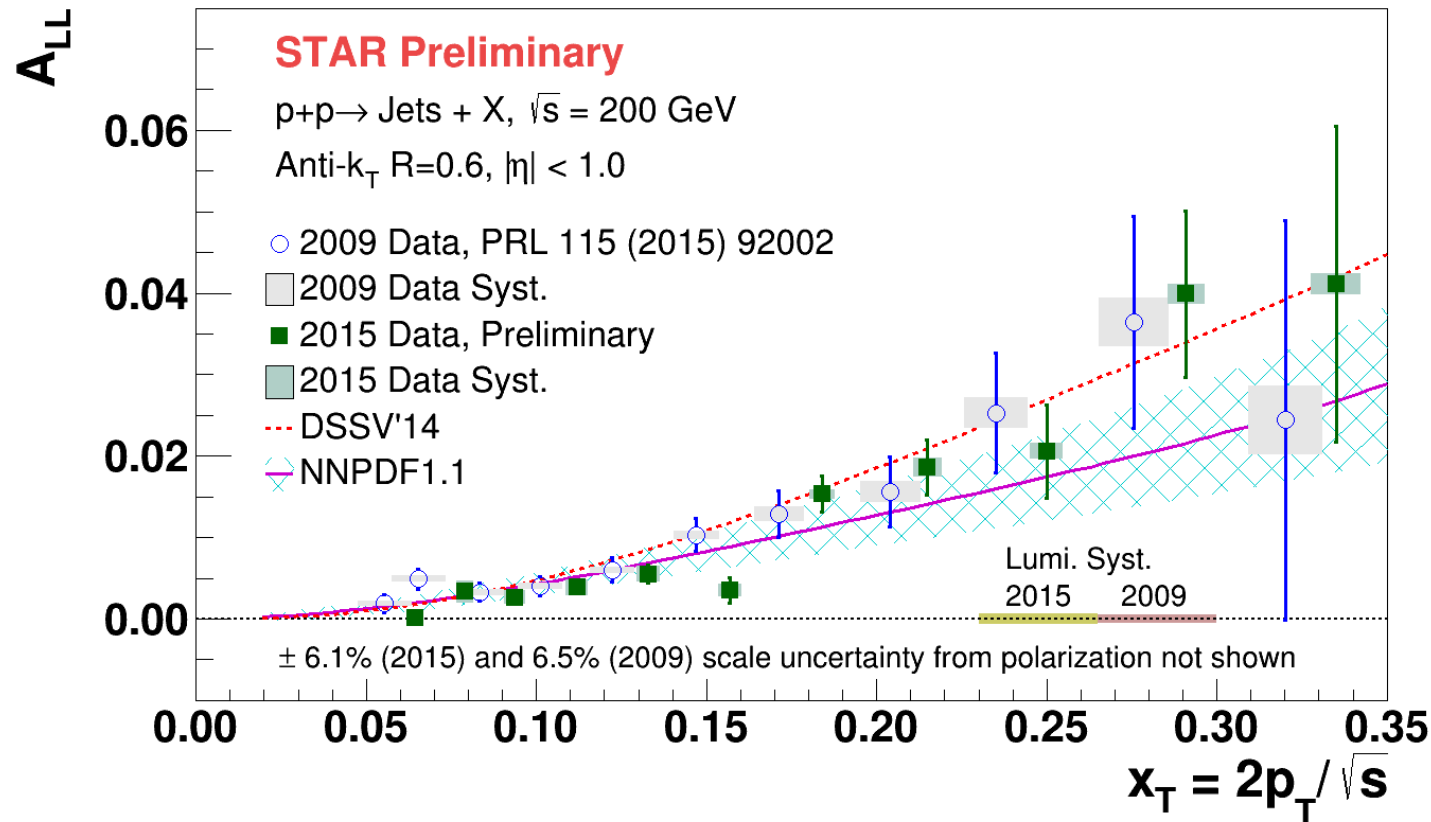

STAR Preliminary

p+p→ Jets + X, $\sqrt{s}$ = 200 GeV

Anti-k_T R=0.6, $|\eta|$ < 1.0

○ 2009 Data, PRL 115 (2015) 92002
☐ 2009 Data Syst.
■ 2015 Data, Preliminary
☐ 2015 Data Syst.
--- DSSV'14
✕ NNPDF1.1

Lumi. Syst.
2015   2009

± 6.1% (2015) and 6.5% (2009) scale uncertainty from polarization not shown

$x_T = 2p_T/\sqrt{s}$
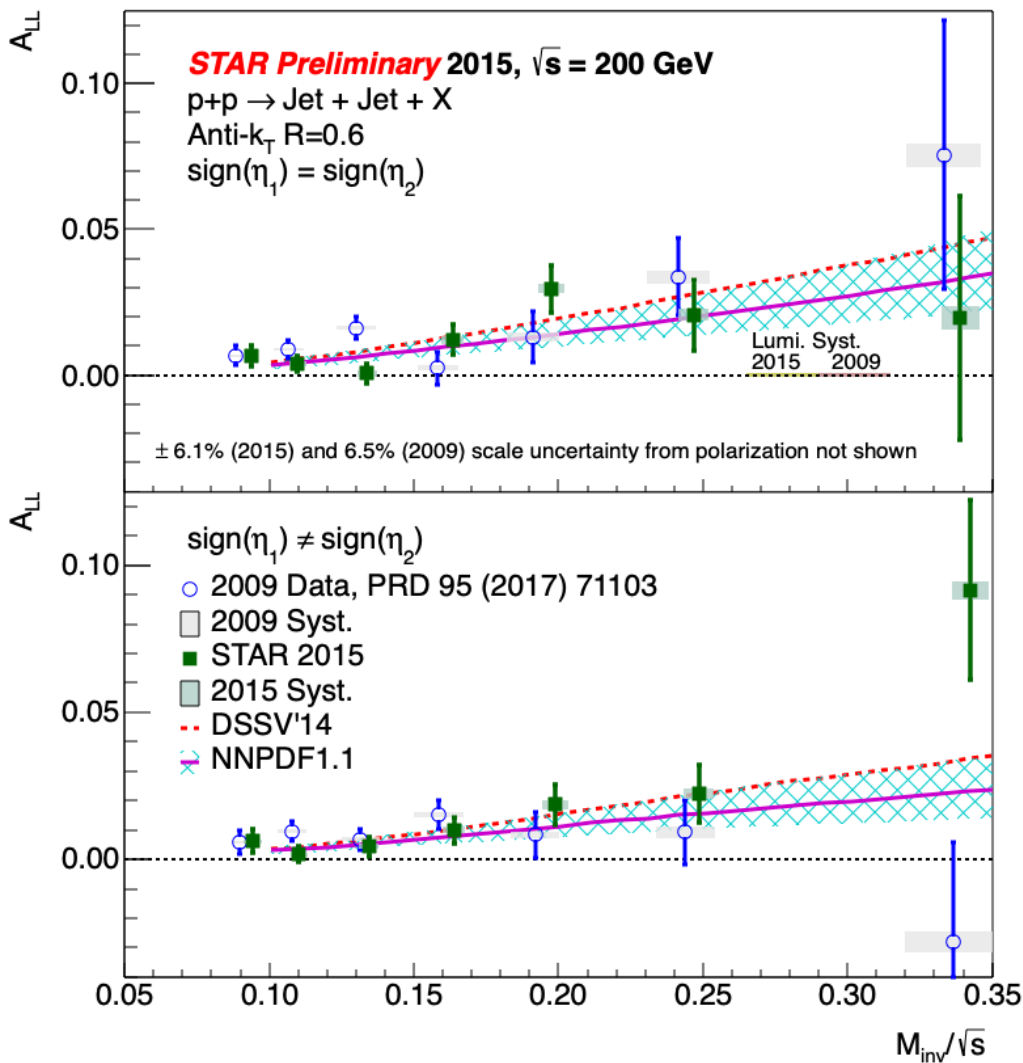
- Most recent central jet analysis performed using data collected in 2015

- Includes underlying event subtraction technique first used in the analysis of 2012 data

- Results are consistent with previously published STAR results at $\sqrt{s} = 200$ GeV

- The figure-of-merit for the 2015 data set is twice as large as that for the 2009 data set

Central Dijets at 200 GeV in 2015

STAR Preliminary 2015, $\sqrt{s}$ = 200 GeV
p+p → Jet + Jet + X
Anti-k_T R=0.6
sign(η_1) = sign(η_2)

± 6.1% (2015) and 6.5% (2009) scale uncertainty from polarization not shown

sign(η_1) ≠ sign(η_2)

○ 2009 Data, PRD 95 (2017) 71103
▢ 2009 Syst.
■ STAR 2015
▢ 2015 Syst.
-- DSSV'14
✕ NNPDF1.1

- New preliminary result from an analysis performed using data collected in 2015

- Dijets can provide further constraints by probing narrower regions in x and constraining the functional form of $\Delta g(x)$

- Includes underlying event subtraction technique first used in the analysis of 2012 data

- Results are consistent with previously published STAR results at $\sqrt{s} = 200$ GeV

- This result and the inclusive jet result using 2015 data are currently being prepared for publication

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	Preliminary x > 0.05	Preliminary x > 0.05	
510	2012	Published x > 0.02	Published x > 0.02	Preliminary x > 0.004
510	2013	Preliminary x > 0.02	Preliminary x > 0.02	Work in Progress x > 0.004

- Nearly twice as much data was collected in 2015 as compared to 2009

- Results from data collected in 2015 will provide a significant reduction in the gluon polarization uncertainty for $x > 0.05$

- For details on the first A_{LL} analysis of intermediate-rapidity dijets at $\sqrt{s} = 510$ GeV, see Joe Kwasizur's talk later in this session
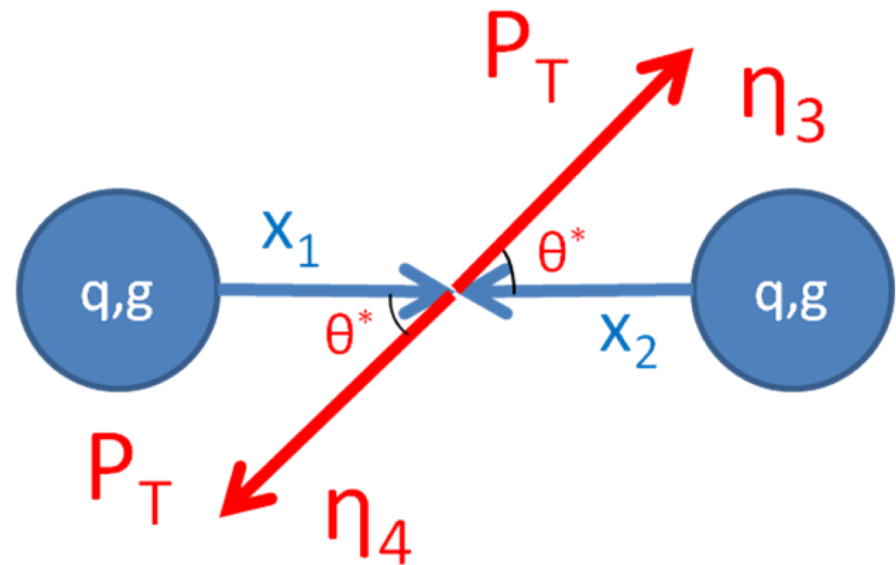
Backup

Dijet Correlation Measurements

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

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

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

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

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

N. Lukow

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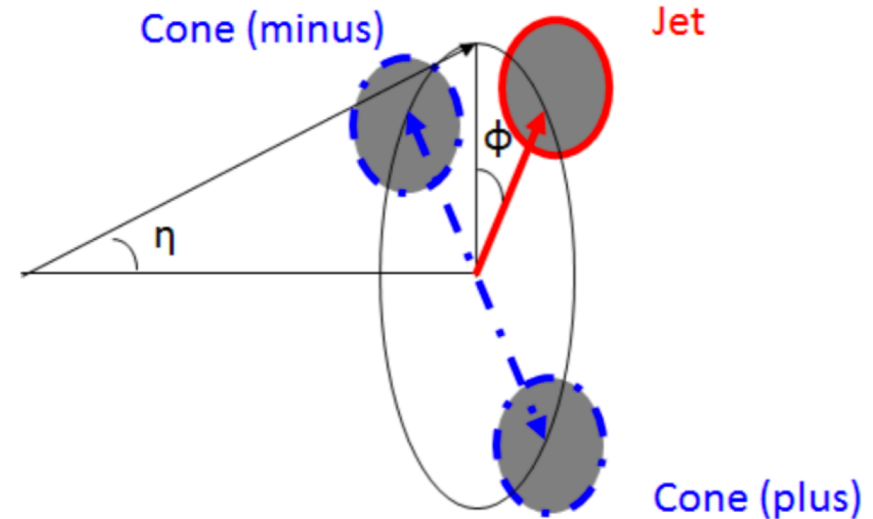
$$\sigma_{UE} = \frac{1}{2}\left(\frac{p_{T,cone(plus)}}{Area_{cone}} + \frac{p_{T,cone(minus)}}{Area_{cone}}\right)$$

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