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

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For the STAR collaboration

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STAR

DIS 2019 TORINO 8-12 April

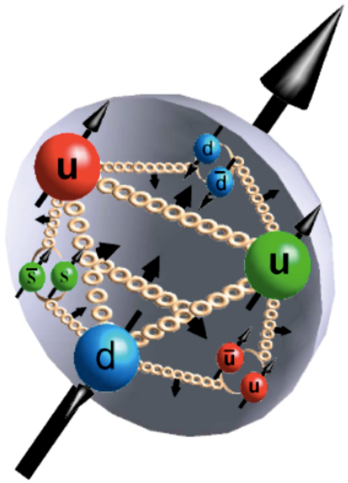
Proton Spin Composition

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

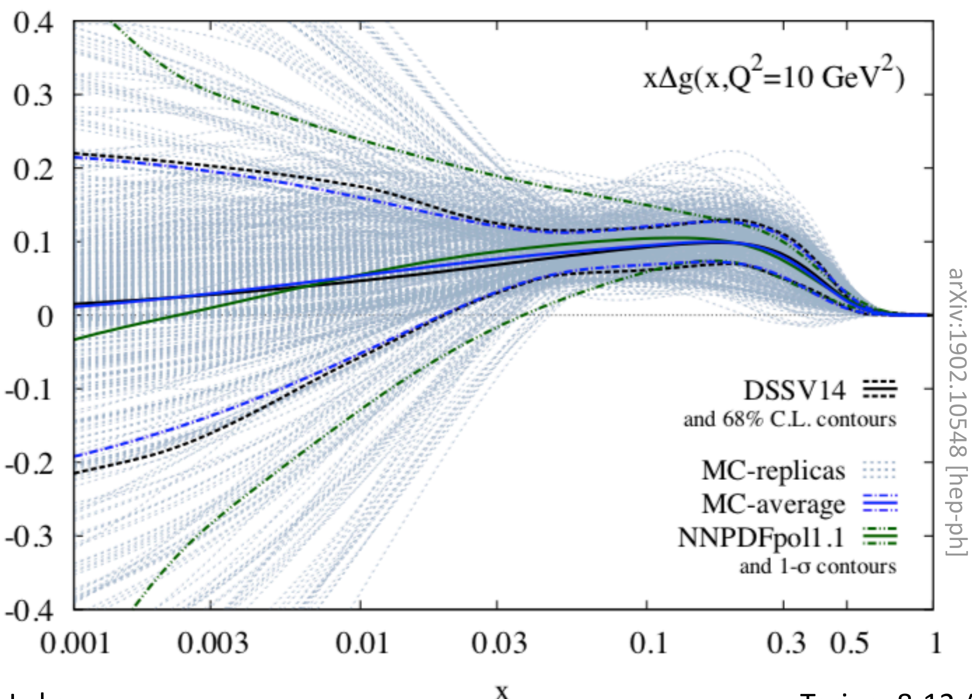


Gluon Spin Contribution: $\Delta G = \int \Delta g(x)dx$

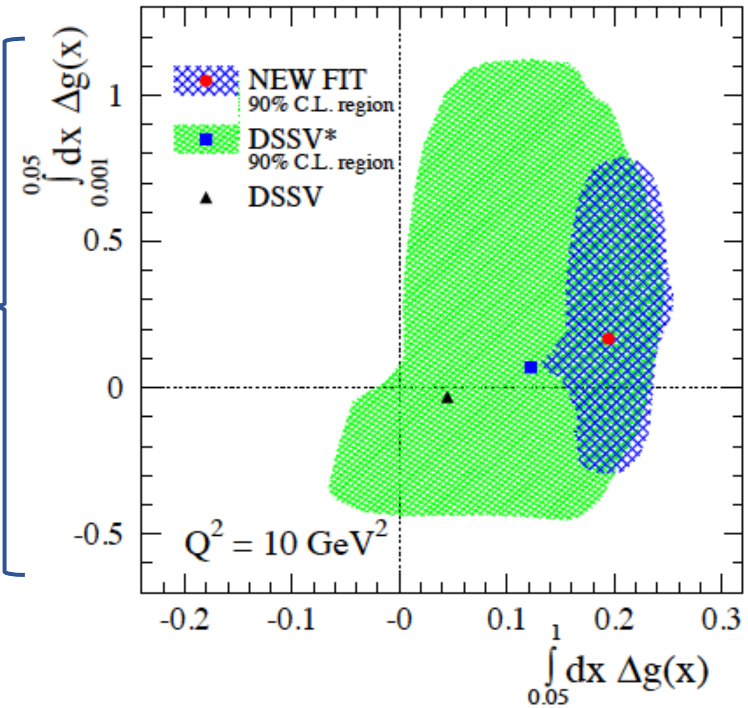
Gluon Polarization & Longitudinal Double-Spin Asymmetry

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

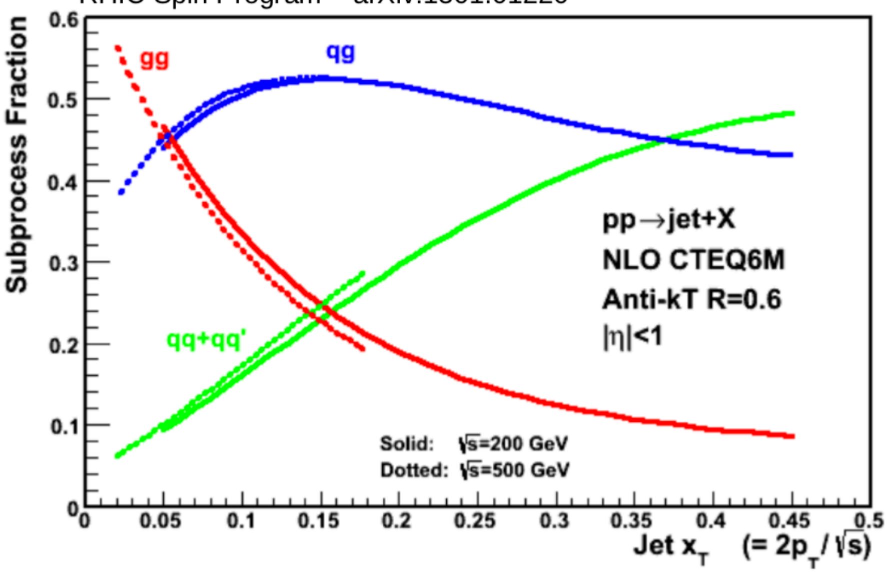
Nucl. Phys. B 887, 276 (2014)

Subprocess Sensitivity

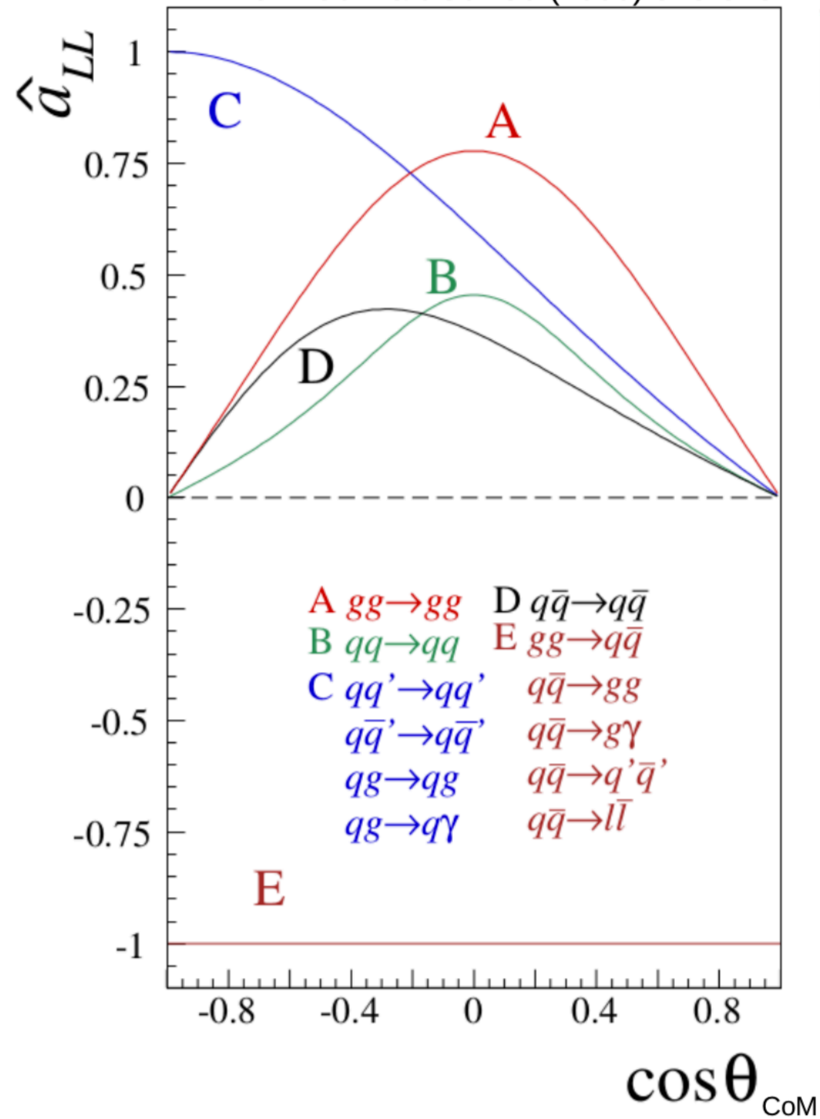
- STAR observables are dominantly sensitive to qg and gg scattering.
- Because of this sensitivity, A_{LL} allows access to $\Delta g(x)$

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

RHIC Spin Program – arXiv:1501.01220



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

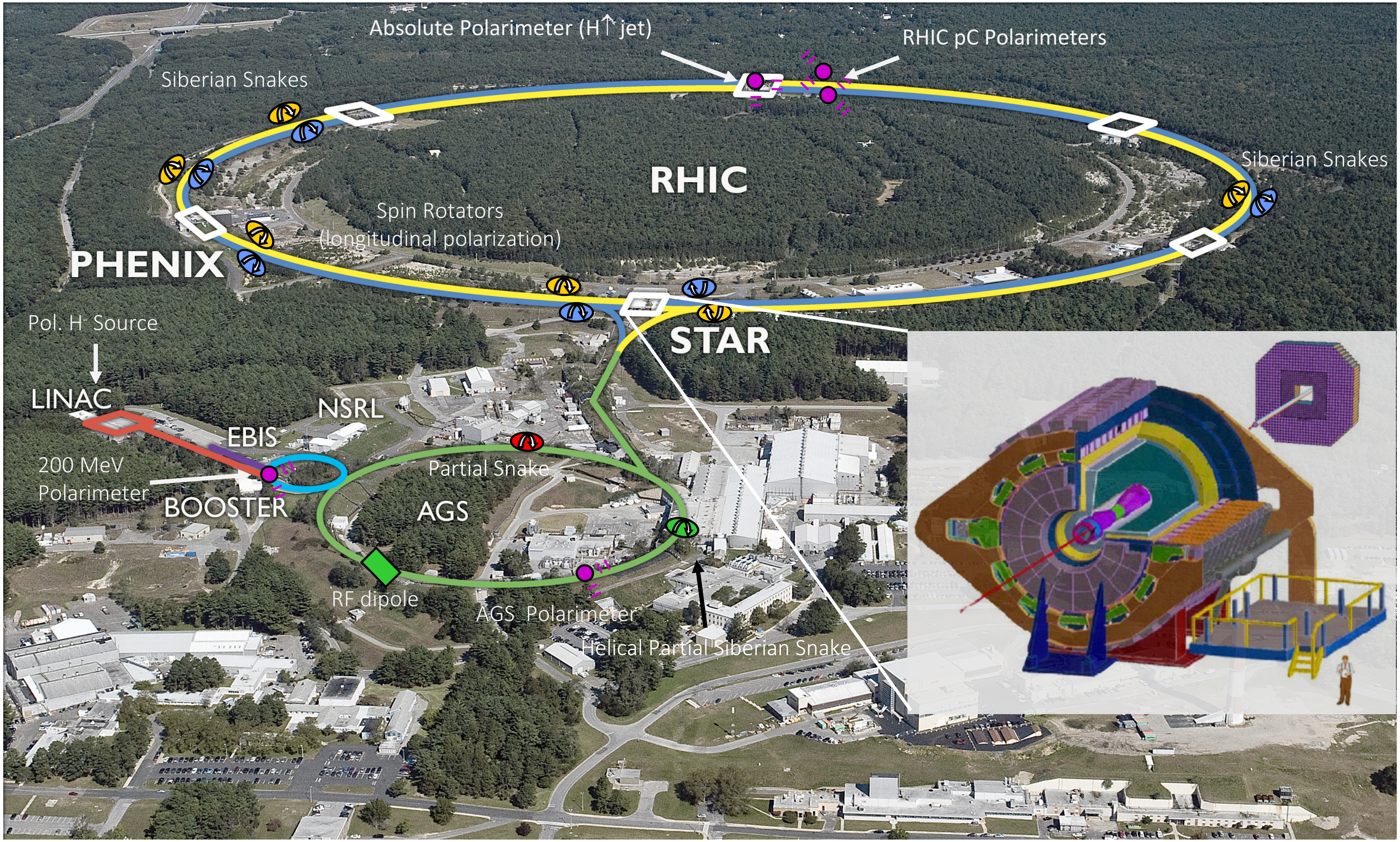


Longitudinal Double-Spin Asymmetry

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

- 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

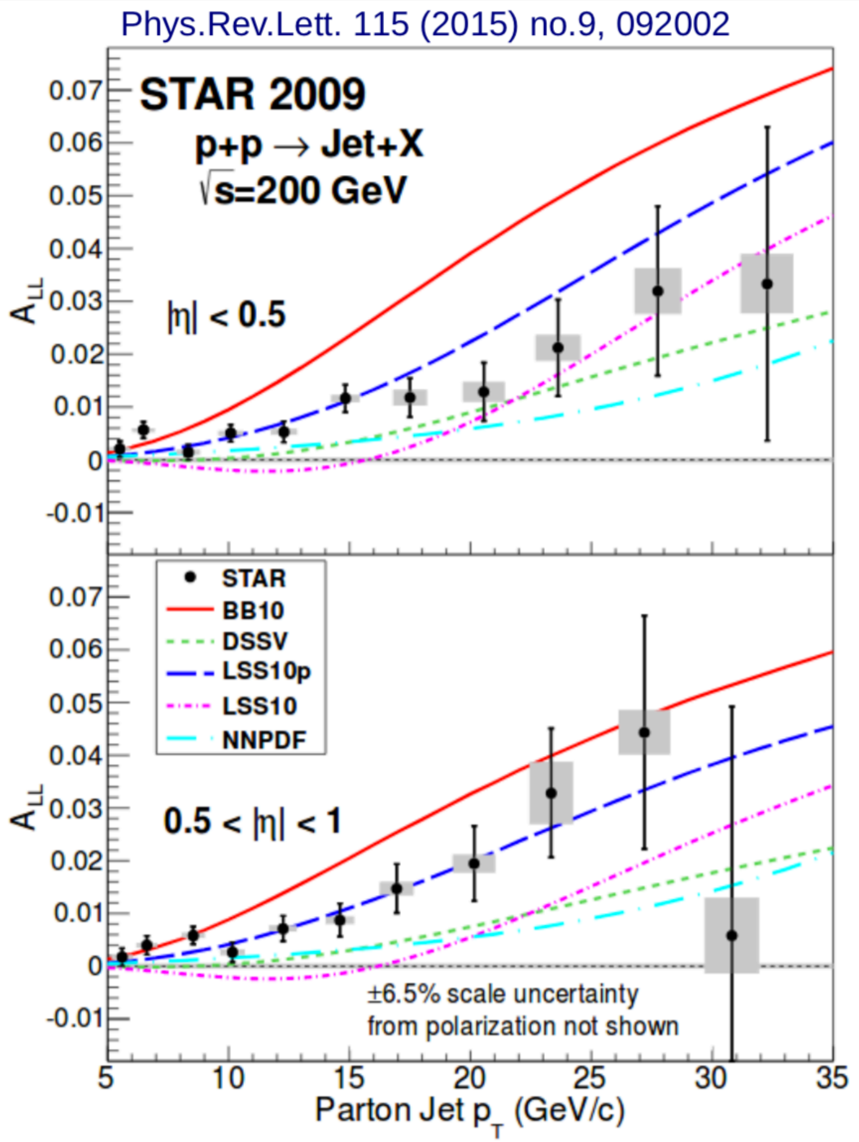
Central Rapidity ($|\eta| < 1.0$)

- 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
  (STAR Preliminary) [*Publication in preparation*]
- Dijets at 510 GeV in 2012
  (STAR Preliminary) [*Publication in preparation*]
- 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)

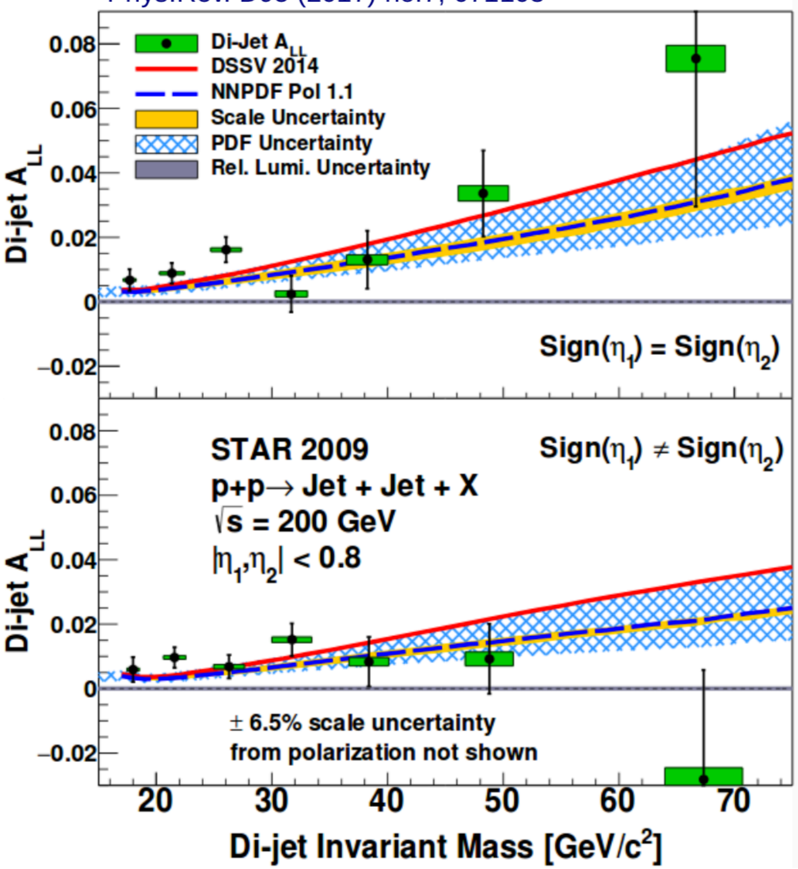
Central Jets at 200 GeV in 2009



- 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

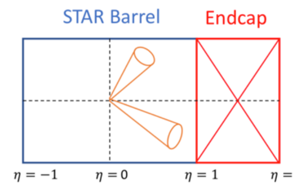
Phys.Rev. D95 (2017) no.7, 071103



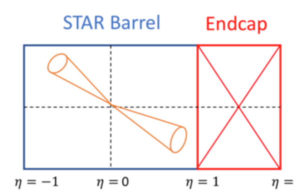
- Dijets probe a narrower region in *x*
- Plotted vs dijet invariant mass:

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

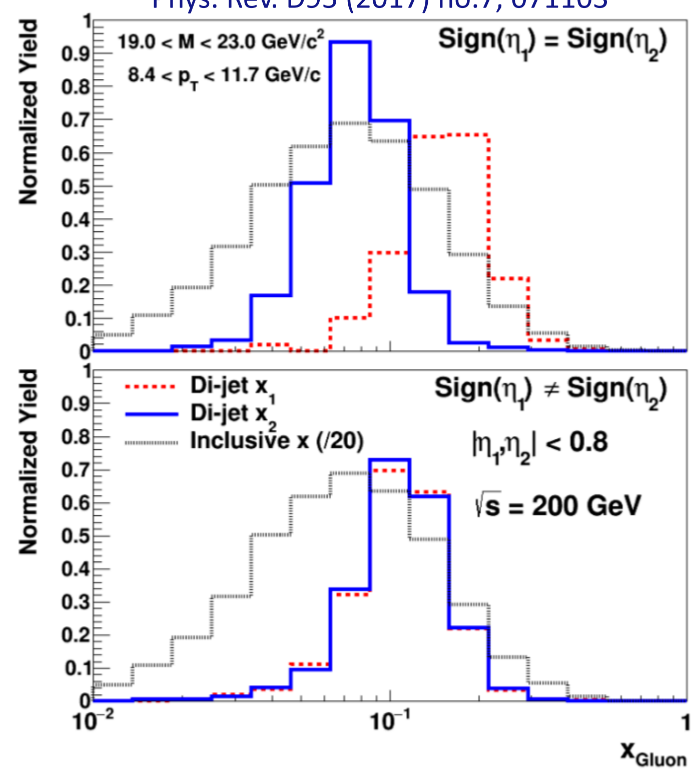
- Two topologies shown sample different x ranges:
  - Sign(η_1) = Sign(η_2)



  - Sign(η_1) ≠ Sign(η_2)

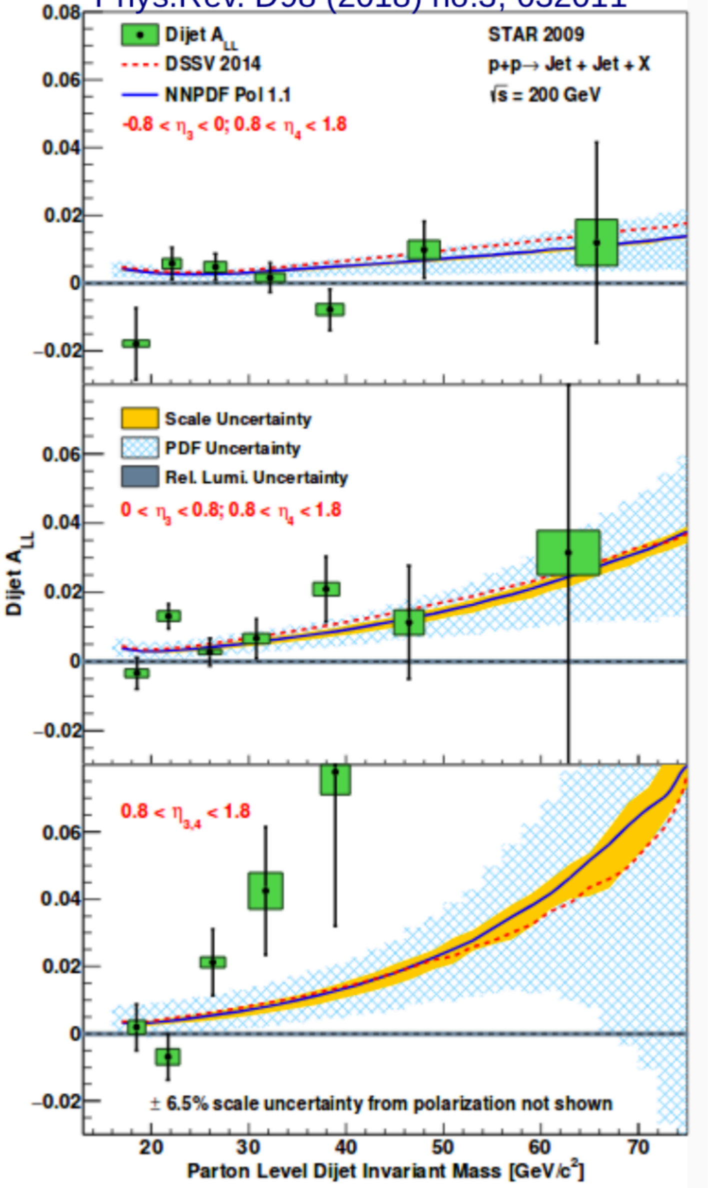


Phys. Rev. D95 (2017) no.7, 071103

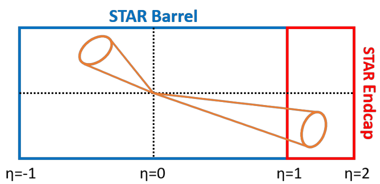


Intermediate Dijets at 200 GeV in 2009

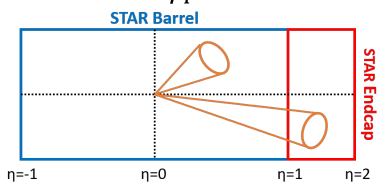
Phys.Rev. D98 (2018) no.3, 032011



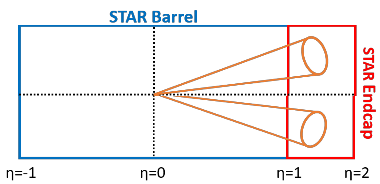
- By extending to intermediate rapidity, dijets can probe an even lower region in *x*
- Plotted vs dijet invariant mass
- Three topologies shown sample different x ranges:
  - $-0.8 < \eta_3 < 0$, $0.8 < \eta_4 < 1.8$



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



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



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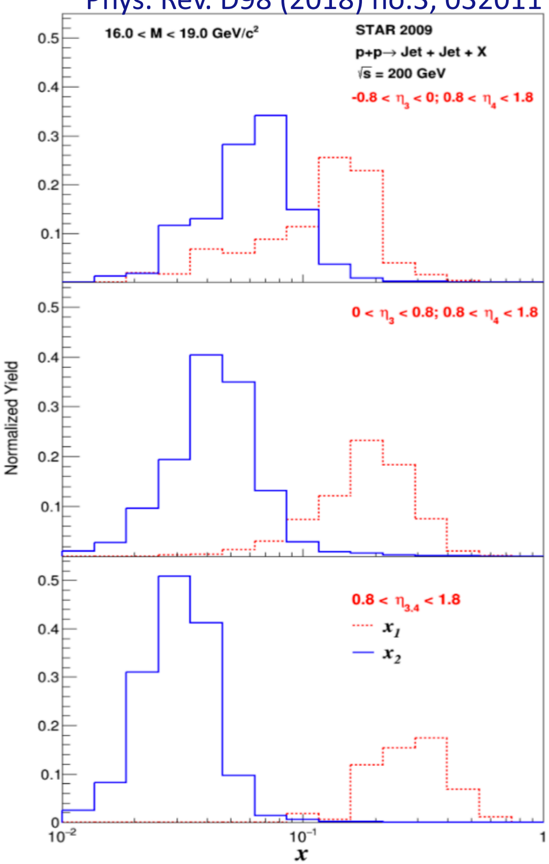
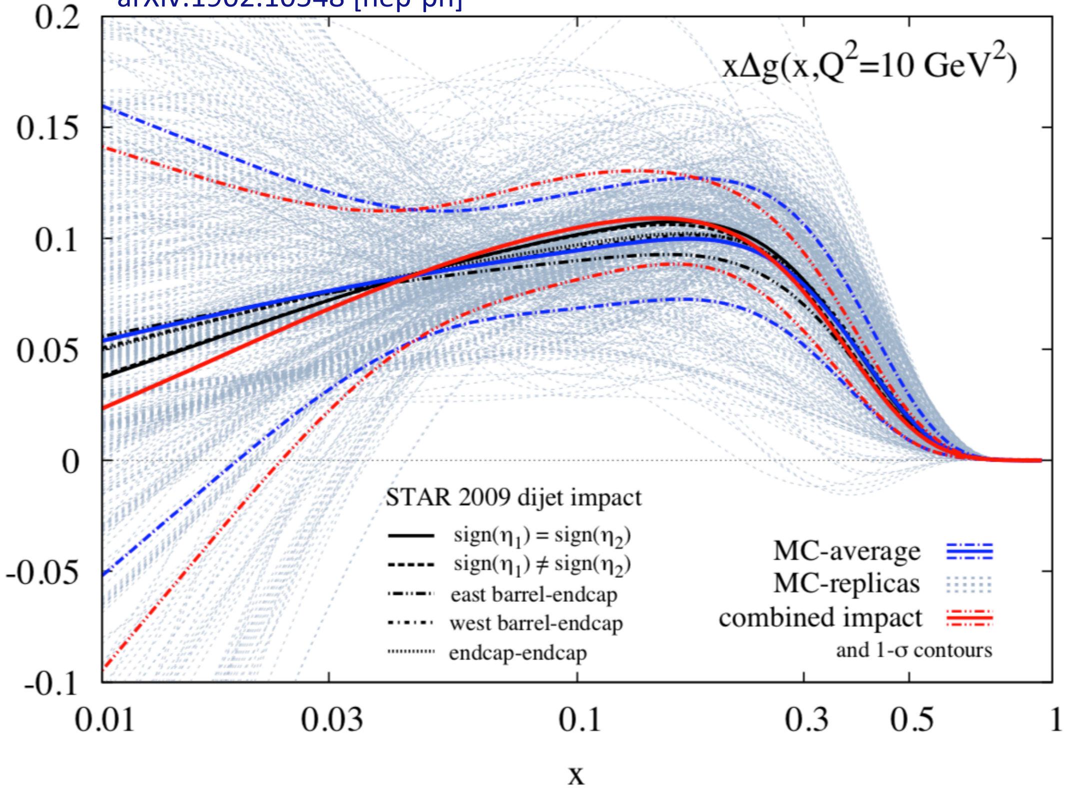


Impact of 2009 Dijet Results

arXiv:1902.10548 [hep-ph]



- 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

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

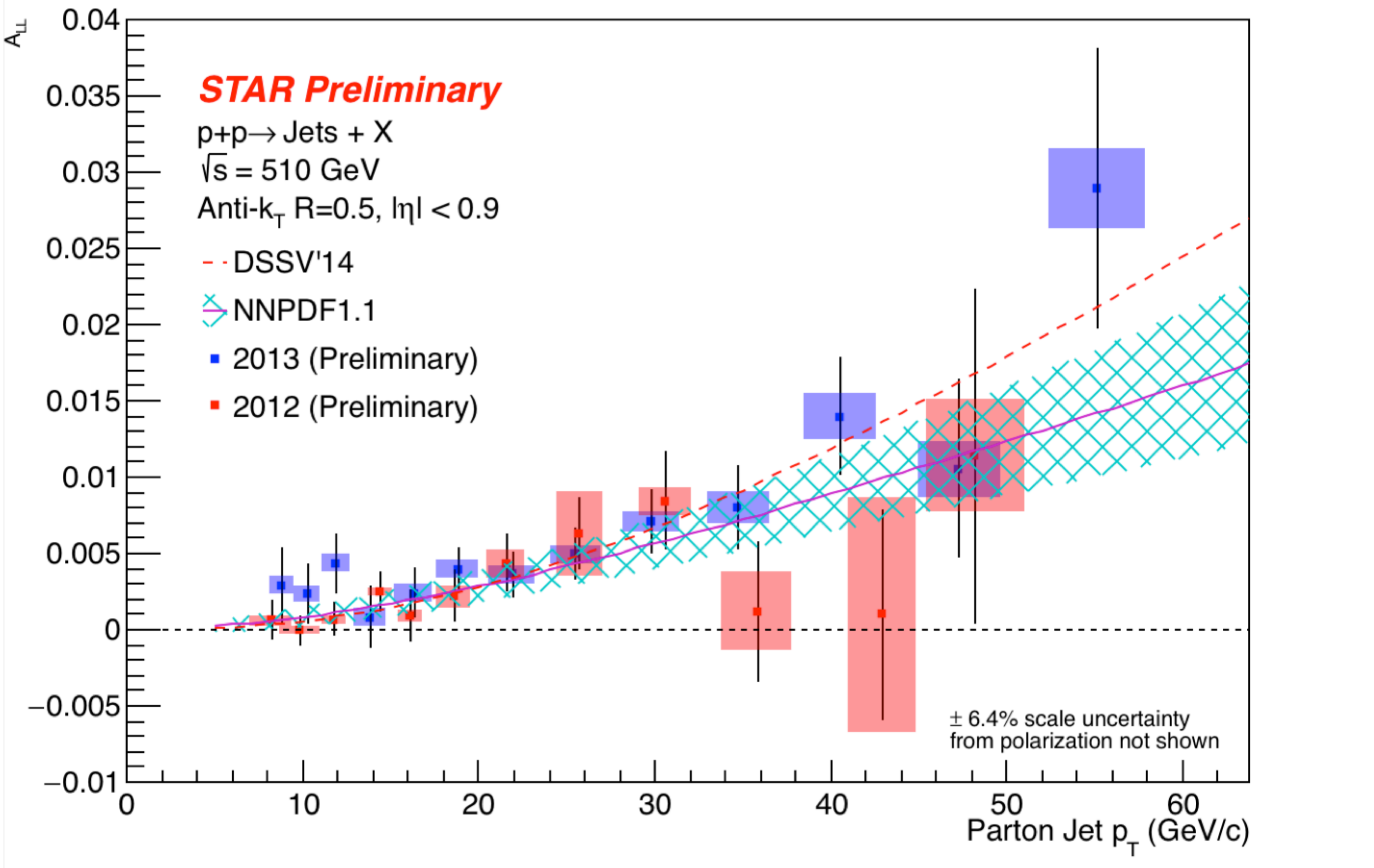
$$\int_{0.01}^{1} \Delta g(x)dx = .309 \pm 0.109$$

After reweighting

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

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

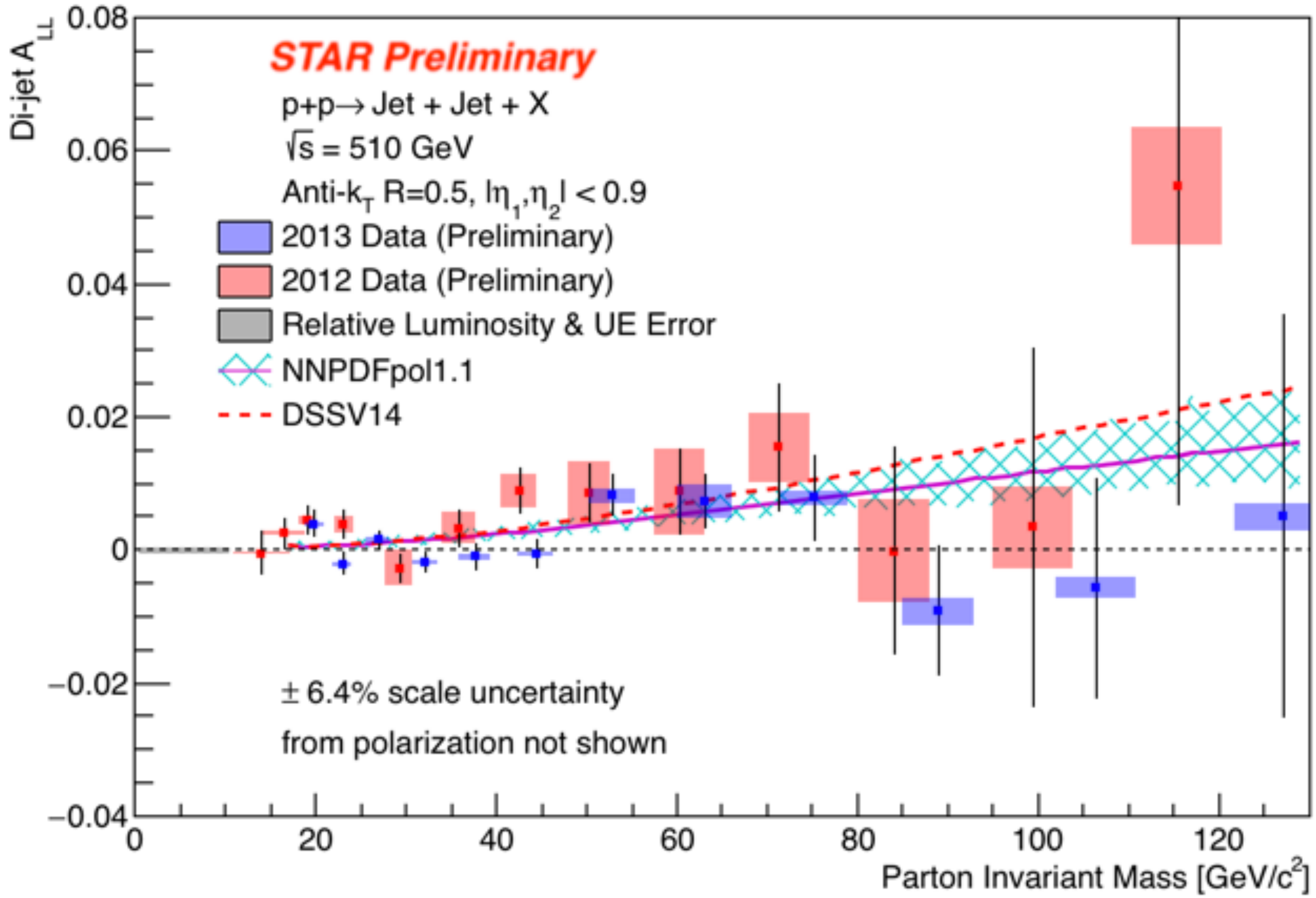
Central Jets at 510 GeV in 2012 & 2013



- Jet p_T is corrected to the parton-level after undergoing off-axis cone underlying event subtraction

- By increasing center-of-mass energy, lower *x* can be reached

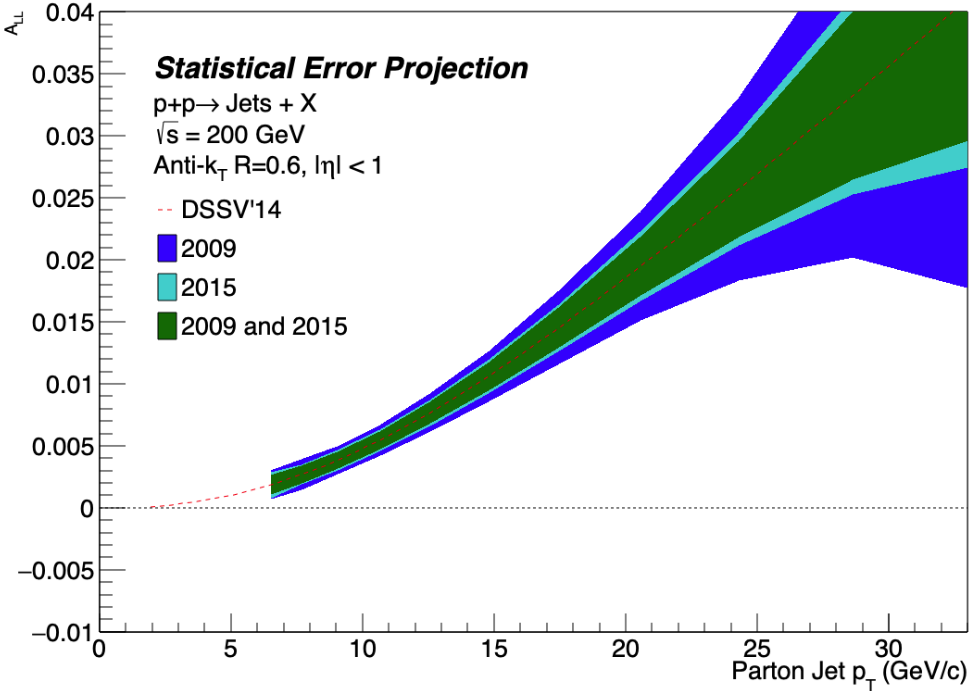
Central Dijets at 510 GeV in 2012 & 2013



- Invariant mass is corrected to the parton-level after undergoing off-axis cone underlying event subtraction
- Plotted vs dijet invariant mass

Central Jets and Dijets at 200 GeV in 2015

- Data taken in 2015 is still being analyzed
- Embedded Monte Carlo sample will be generated for the 2015 data sample in order to apply corrections to the jet/dijet quantities
- Analysis is performed in the same manner as the 2009 central jets/dijets except it will include the 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 ($\lvert\eta\rvert < 1.0$)	Central Dijets ($\lvert\eta\rvert < 1.0$)	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	Preliminary x > 0.02 (publication in preparation)	Preliminary x > 0.02 (publication in preparation)	Work in Progress x > 0.004
510	2013	Preliminary x > 0.02	Preliminary x > 0.02	Work in Progress x > 0.004

- The 2012 central jets/dijets final results will soon be published
- STAR will be undergoing an upgrade to improve particle detection at higher rapidities. See Zhenyu Ye's talk on the STAR Forward Upgrade Program on 11 April.

Backup

Dijet Correlation Measurements

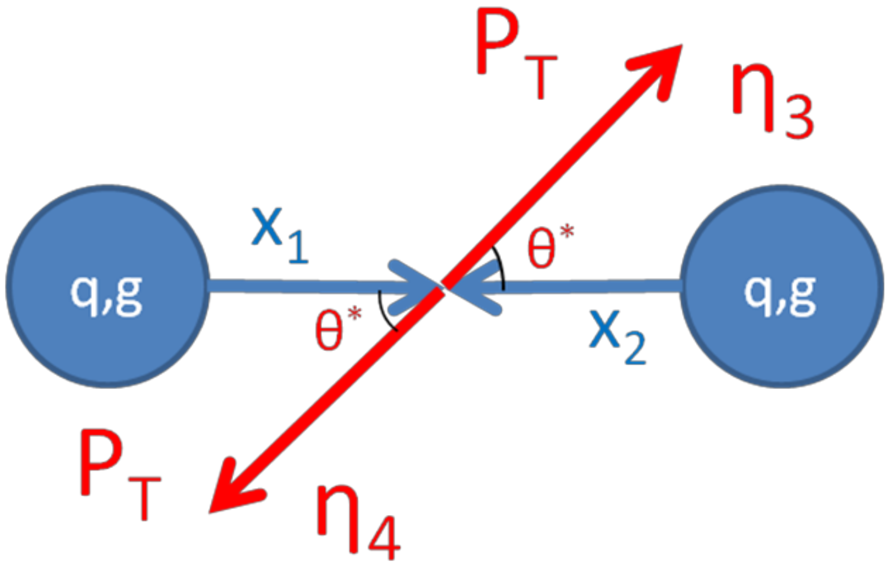
$$x_1 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{\eta_3} + p_{T4}e^{\eta_4}\right)$$

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

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

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

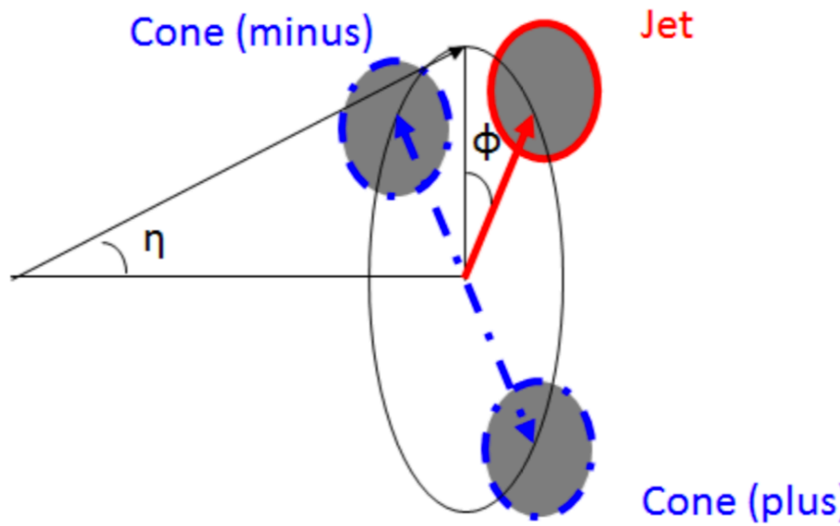
$$\left|\cos\theta^*\right| = \tanh\left|\frac{\eta_3 - \eta_4}{2}\right|$$



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.

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

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