STAR Gluon Spin Results

Amilkar Quintero
For the STAR collaboration
4 June 2019

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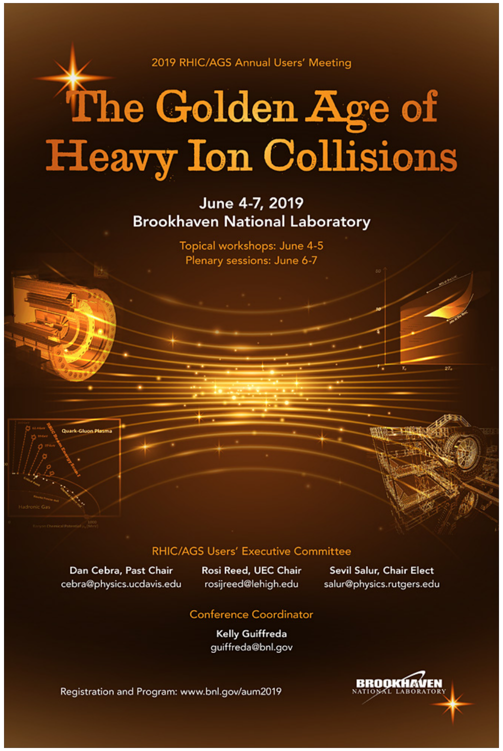
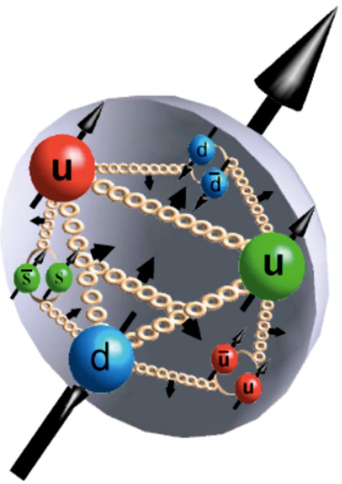


Motivation



Measure the individual contribution of quarks, antiquarks and gluons, to the spin of the proton.

The proton spin sum rule:

$$< S_p >= \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

Polarized DIS results **ΔΣ ≈ 0.3**

Jinlong Zhang
4 June @ 9:00

Poorly constrained

What is the contribution of gluon polarization (ΔG) to the spin of the proton?

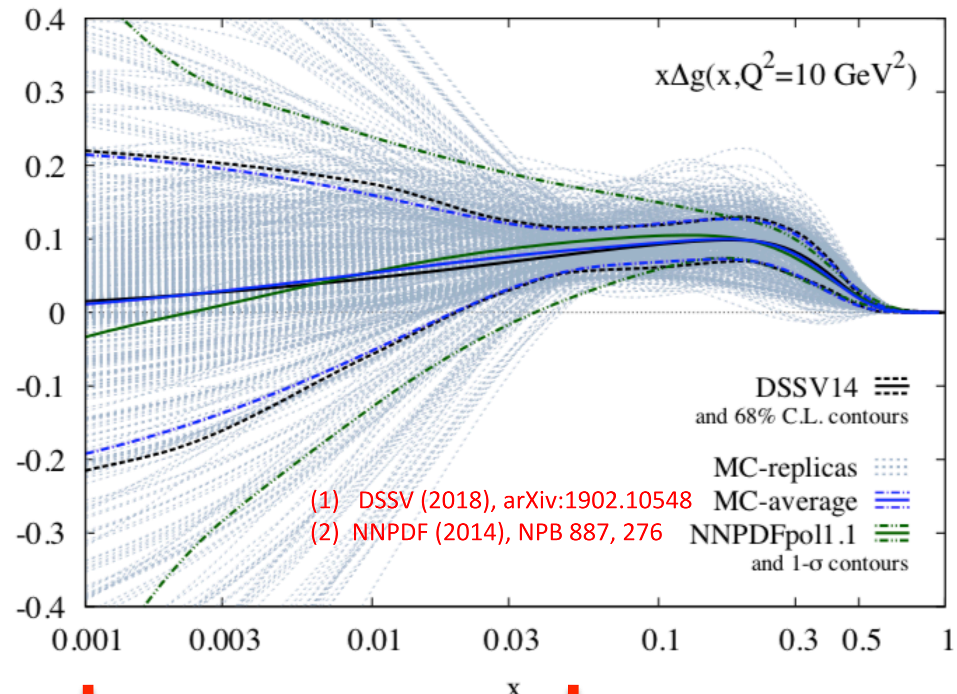
Motivation

- Gluon polarization can be measured using longitudinal double-spin asymmetry (A_{LL}) of jets in proton collisions.
- For most RHIC kinematics, *gg* and *qg* scattering dominate.

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

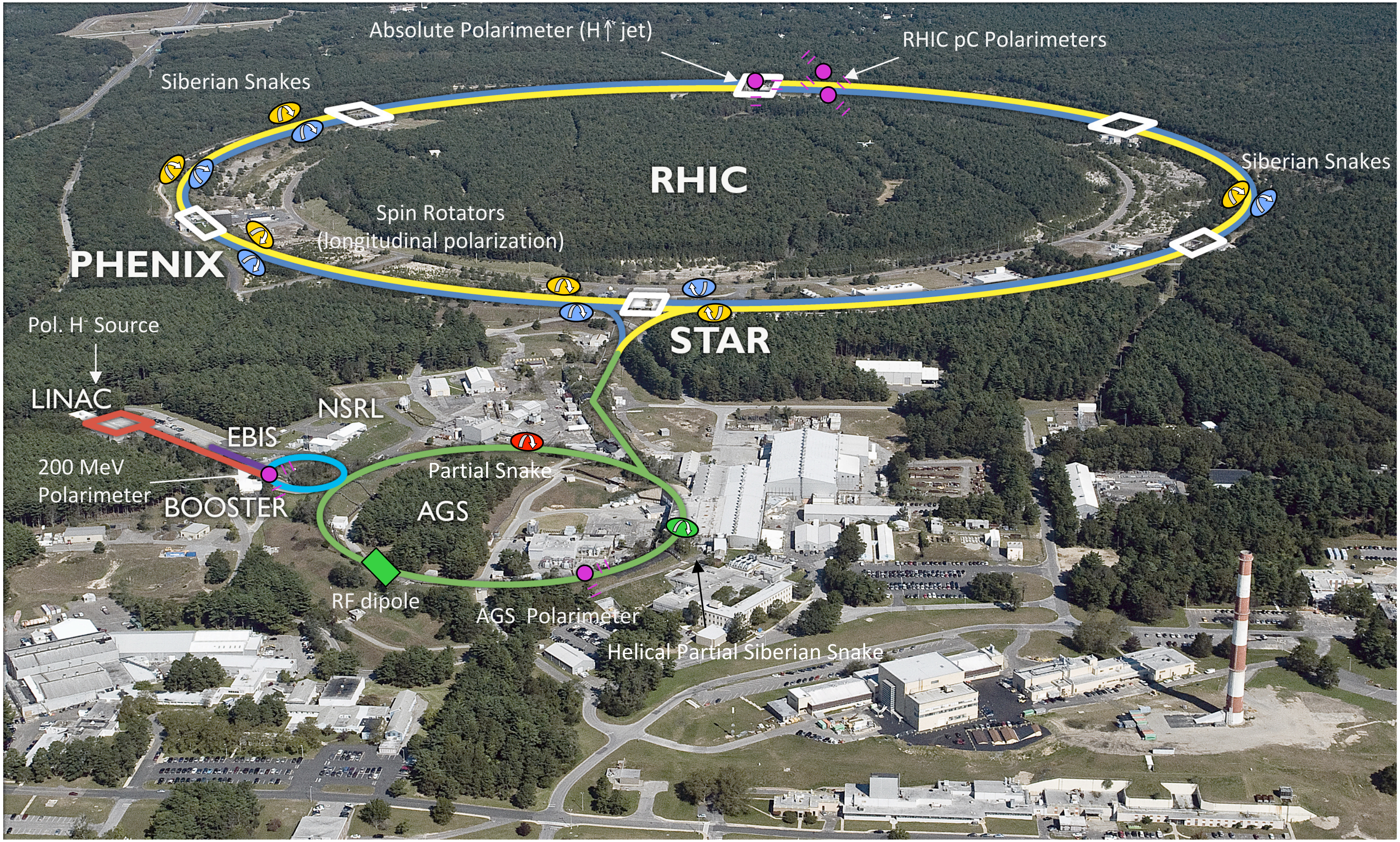
$$\Delta G = \int dx \Delta g(x)$$

DSSV[1] : 0.126 ± 0.023 (0.1 < x)
NNPDF[2]: 0.17 ± 0.06 (0.05 < x < 0.2)



Not well constrained

Relativistic Heavy Ion Collider



Polarized proton runs at RHIC

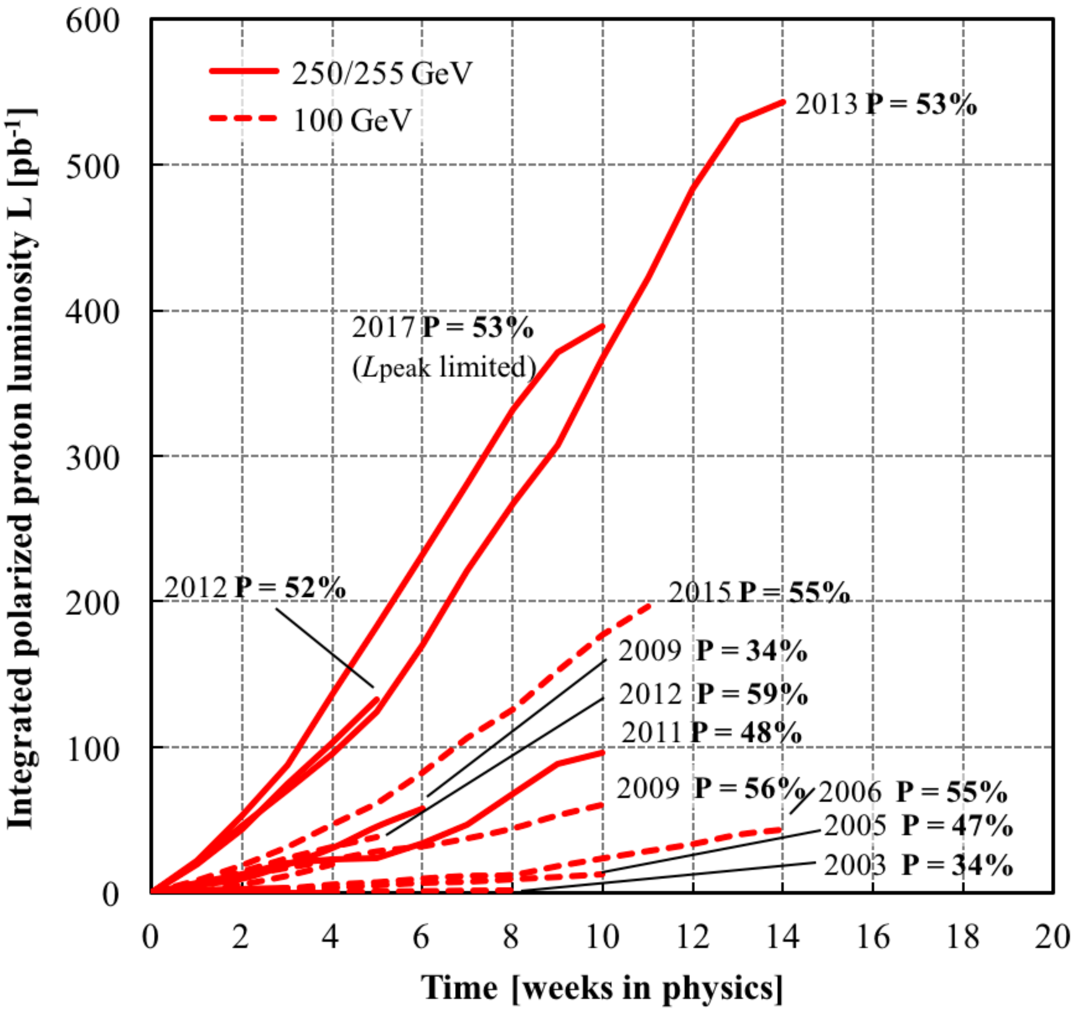
Longitudinally polarized runs

Year	√s (GeV)
2009	200
2012	510
2013	510
2015	200

Experimentally

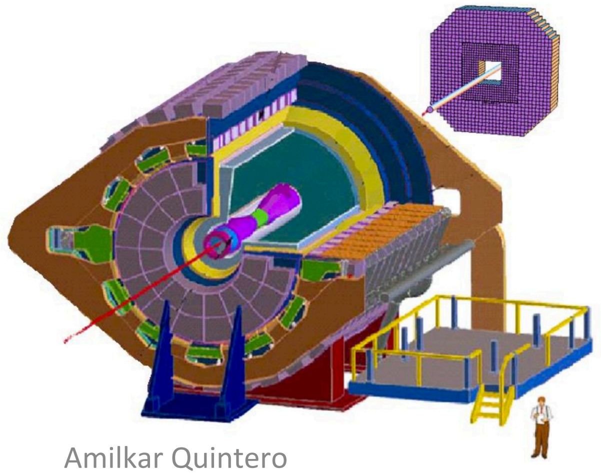
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{1}{P_1 P_2} \frac{N^{++} - RN^{+-}}{N^{++} + RN^{+-}}$$

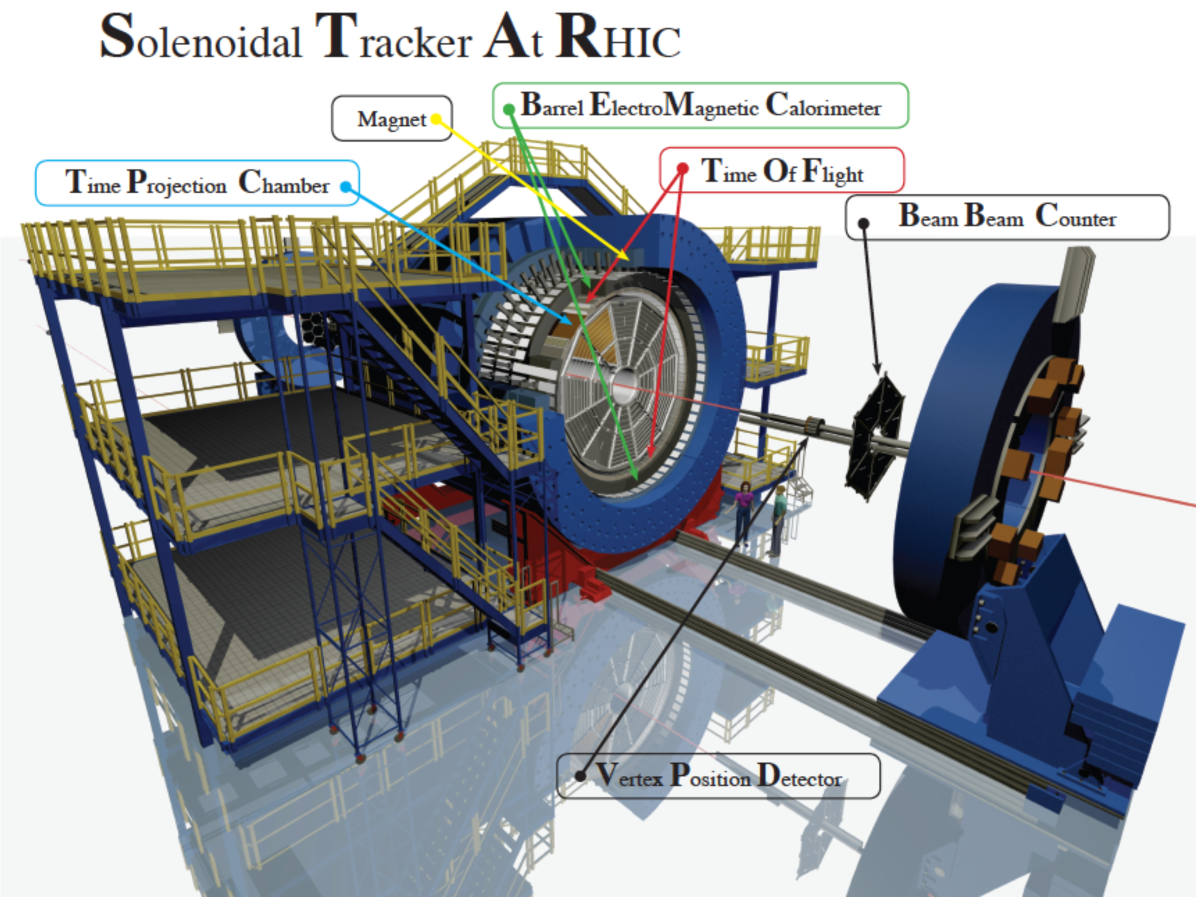
$$N = \sigma L, R = \frac{L^{++}}{L^{+-}}$$



STAR Experiment

- The main tracking device is a Time Projection Chamber (TPC) at $|\eta| \leq 1.3$.
- Electromagnetic calorimeters ($-1 \leq \eta \leq 2$) are used to trigger high momentum particles and measure neutral component of jets.
- Forward Meson Spectrometer (FMS) is a lead-glass EM calorimeter to detect π^0 at $2.5 \leq \eta \leq 4.2$.
- Relative luminosity calculated with the Vertex Position Detector (VPD) and the Zero Degree Calorimeter (ZDC).





Correlation Measurements with Di-jets

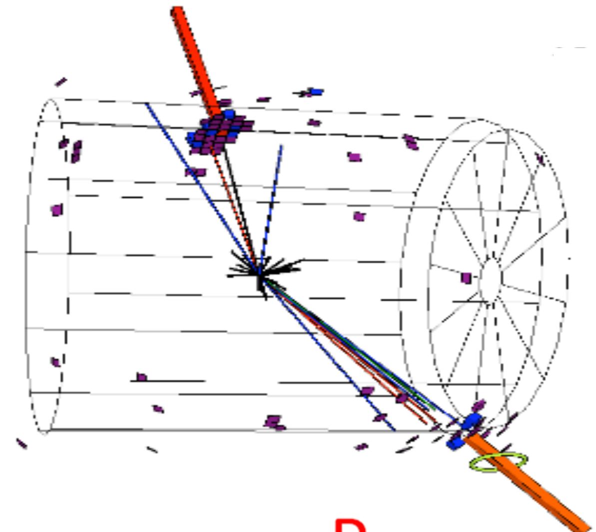
$$x_1 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{\eta_3} + p_{T4}e^{\eta_4}\right)$$

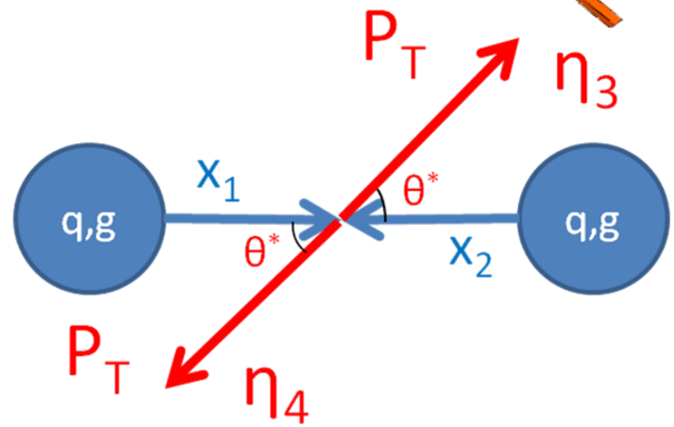
$$x_2 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{-\eta_3} + p_{T4}e^{-\eta_4}\right)$$

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

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

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





Better constrain the functional form of Δg

Reaching lower x values

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

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

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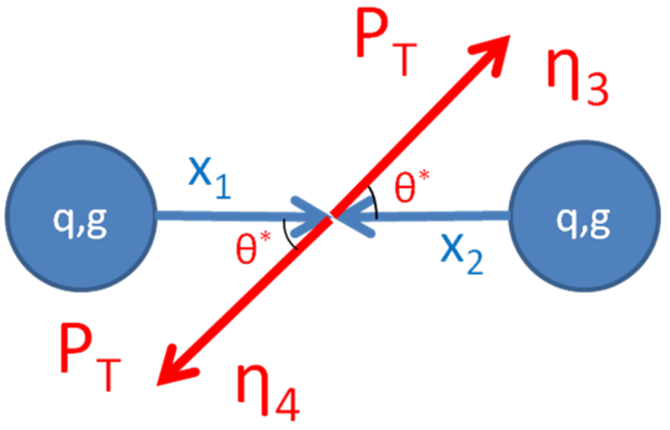
Higher center of mass energy

$\sqrt{s}$ = 200 GeV ➔ x > 0.05
$\sqrt{s}$ = 510 GeV ➔ x > 0.02



Reaching lower x values

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

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

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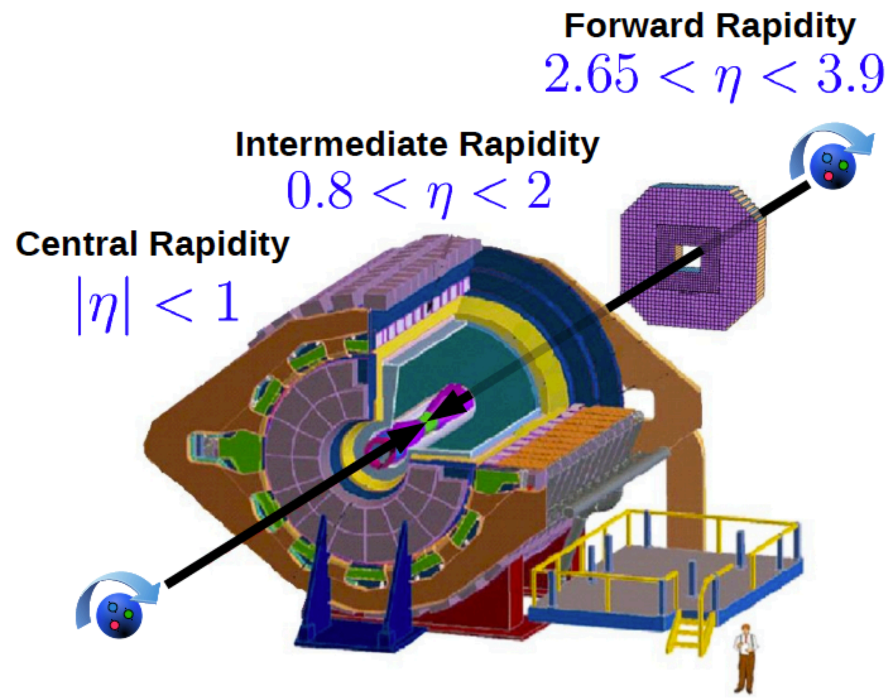
Forward jets indicates a collision of a high x parton with a much lower x parton.



Previous STAR Results

Data from the 2009 RHIC run at 200 GeV

- Jets:

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

- Di-jets:

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

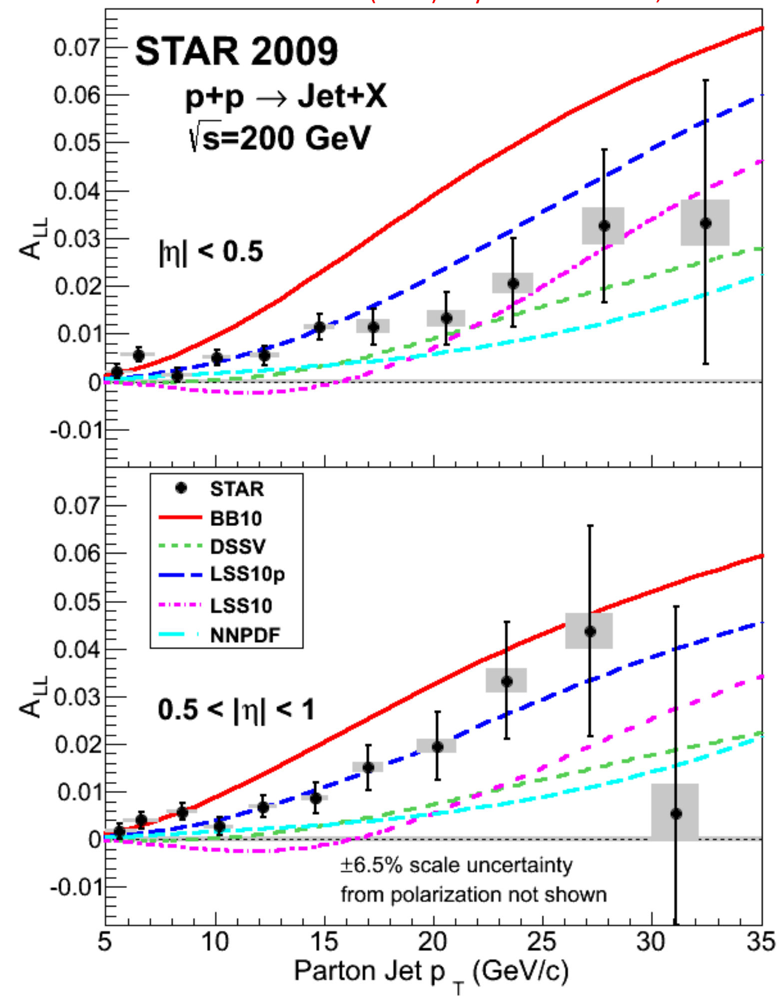
- Intermediate Di-jets:

  Phys.Rev. D98 (2018) no.3, 032001

Inclusive Jets at √s=200 GeV in 2009

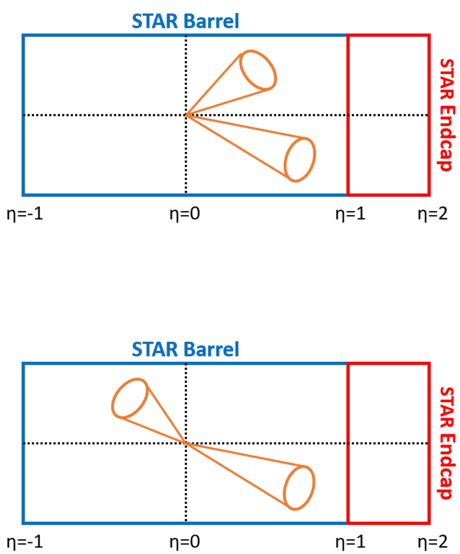
- Increase statistical precision compared to earlier STAR measurements in 2006.
- Provided the first evidence of non-zero gluon polarization at x > 0.05
- Results were systematically above the DSSV 2008 global fit.
- These results strongly suggest a positive gluon polarization value after inclusion in DSSV14 and NNPDF1.1 fits.

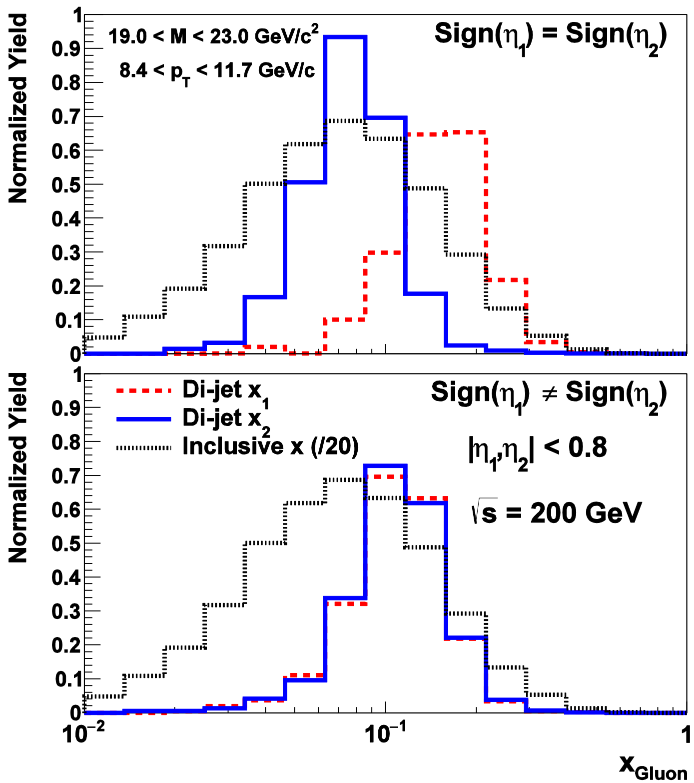
STAR coll. (2014) Phys. Rev. Lett. 115, 092002

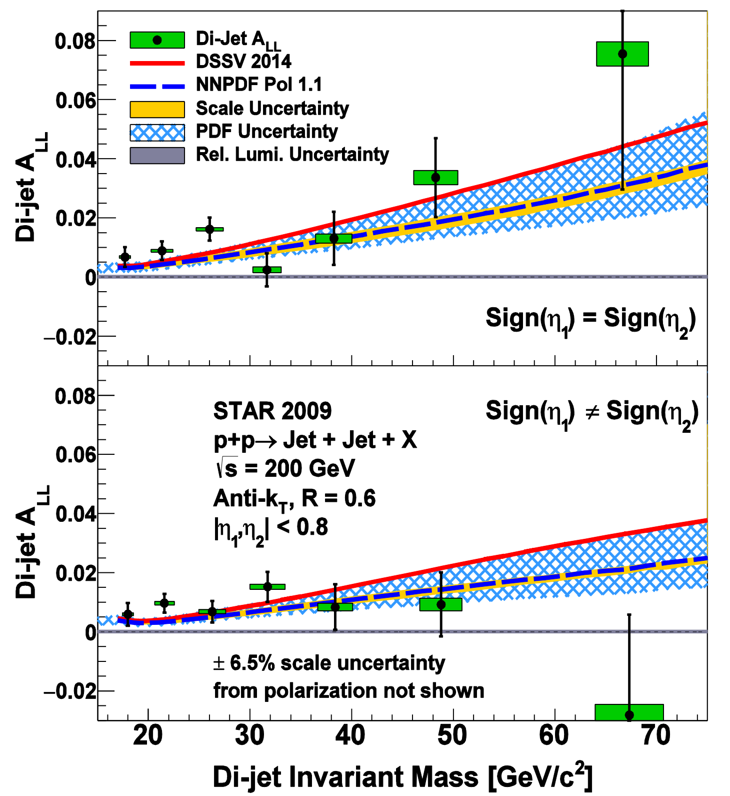


Di-jets at √s=200 GeV in 2009

STAR coll. (2017) Phys. Rev. D 95, 071103(R)

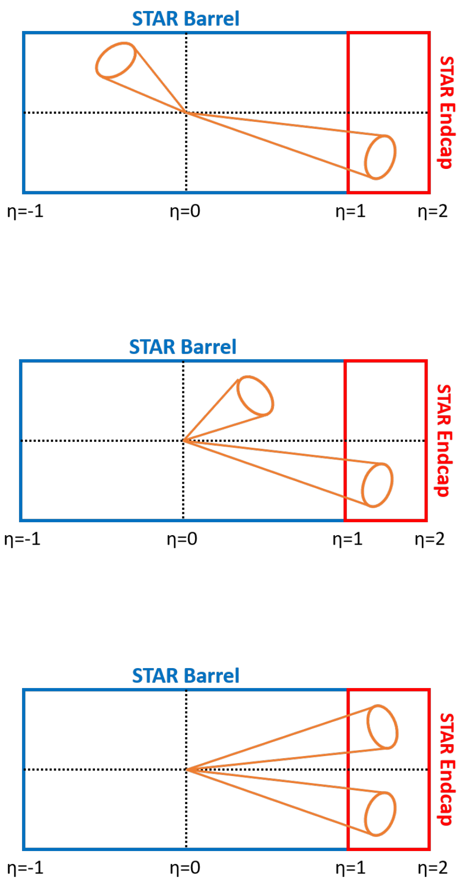


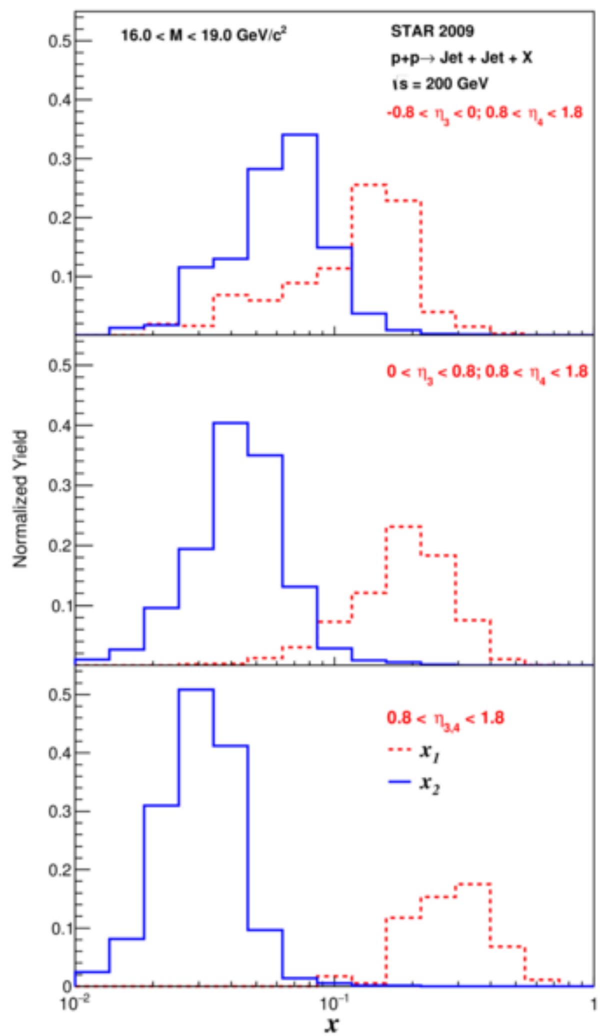




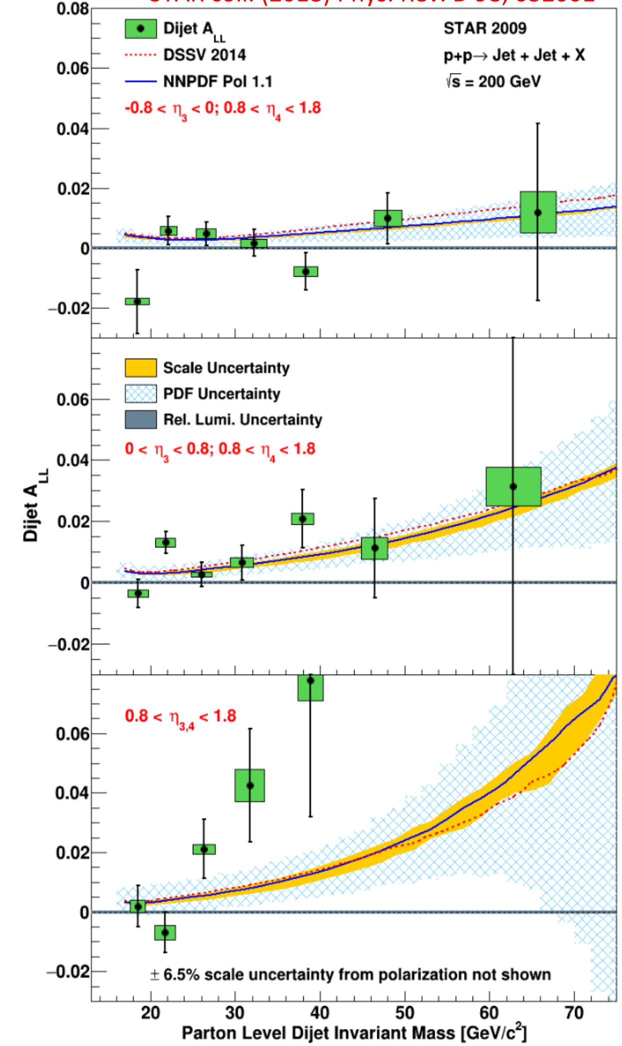
- Di-jets measurements allows to probe a narrower x region.
- Results are consistent with 2014 global fits.

Intermediate Di-jets at √s=200 GeV in 2009





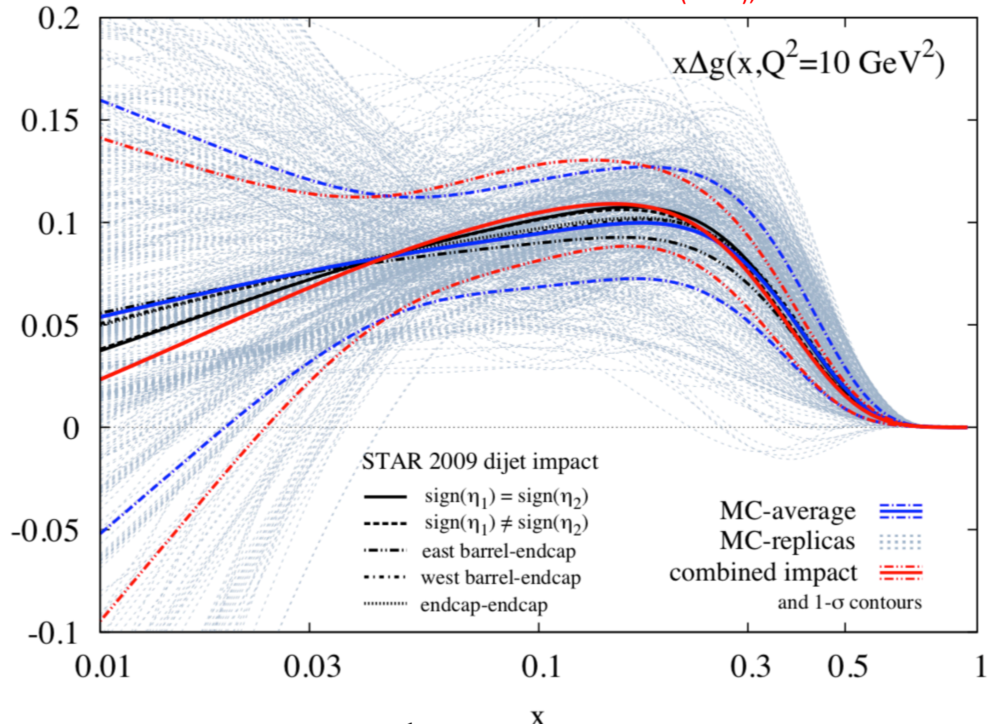
STAR coll. (2018) Phys. Rev. D 98, 032001



Impact to latest global fit

- All STAR results from RHIC run 2009 at 200 GeV, where included in the latest DSSV MC sampling analysis.
- Moderate increase in the gluon polarization value in the range 0.05 $\lesssim x \lesssim$ 0.2.
- Reduction in the uncertainty after the reweighting.
- Still no data included for x < 0.05, therefore large dispersion of the MC-replicas in this region.

DSSV (2018), arXiv:1902.10548



Before reweighting: $\int_{0.1}^{1} \Delta g(x)\,dx = 0.133 \pm 0.035$

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

Status of Latest Measurement

- Jets and di-jets in 2012 at 510 GeV:

  Soon to be published

- Jets and di-jets in 2013 at 510 GeV:

  Preliminary

- Intermediate di-jets for 2012 and 2013 at 510 GeV:

  In progress

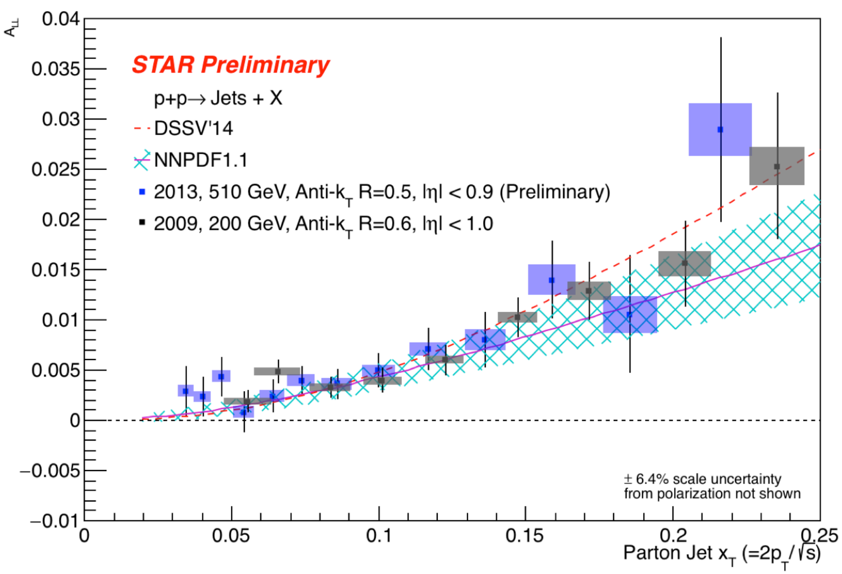
- Jets and di-jets in 2015 at 200 GeV:

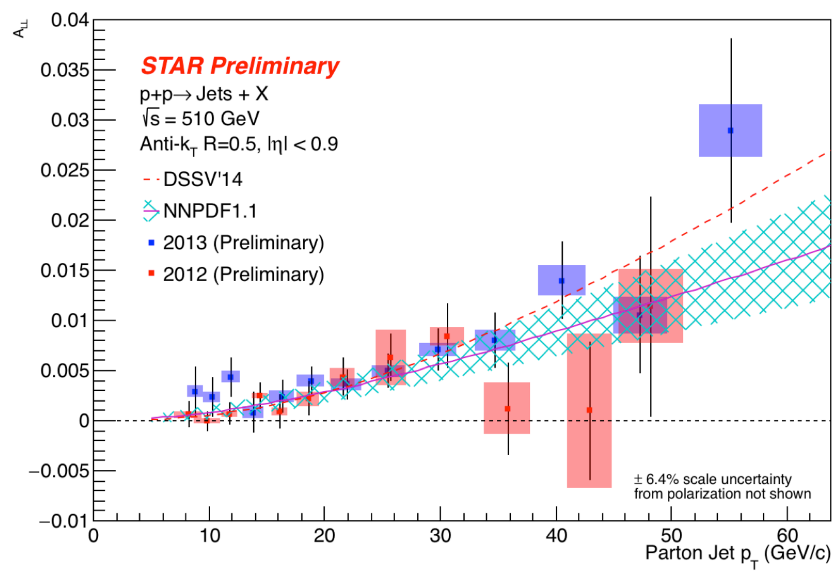
  In progress

AQ Poster

Nick Lukow Poster

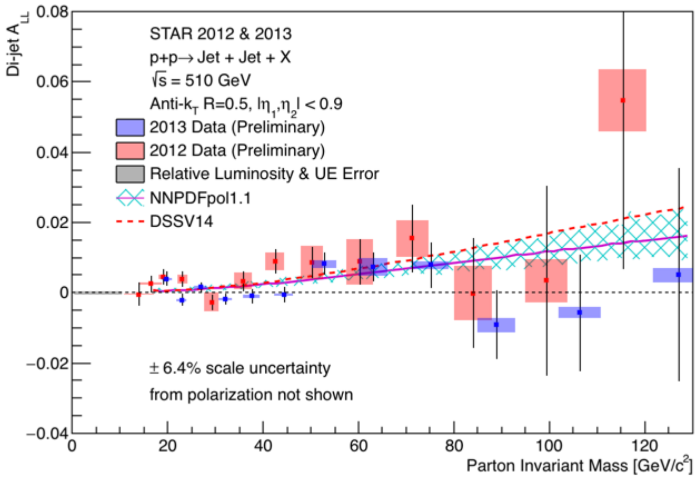
Inclusive Jets Preliminary Results

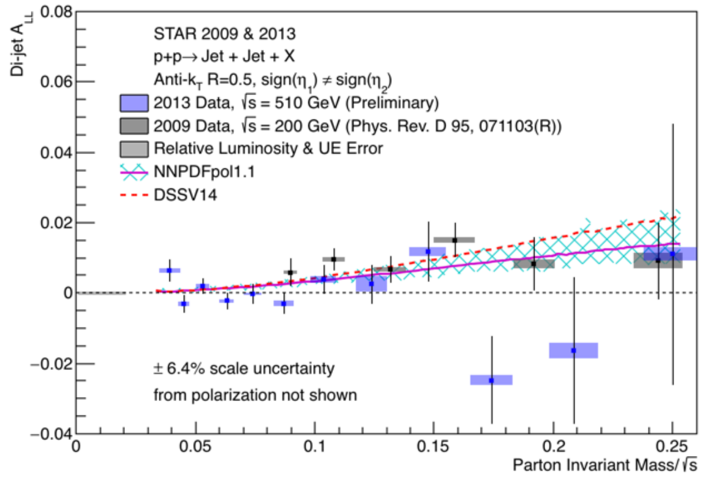




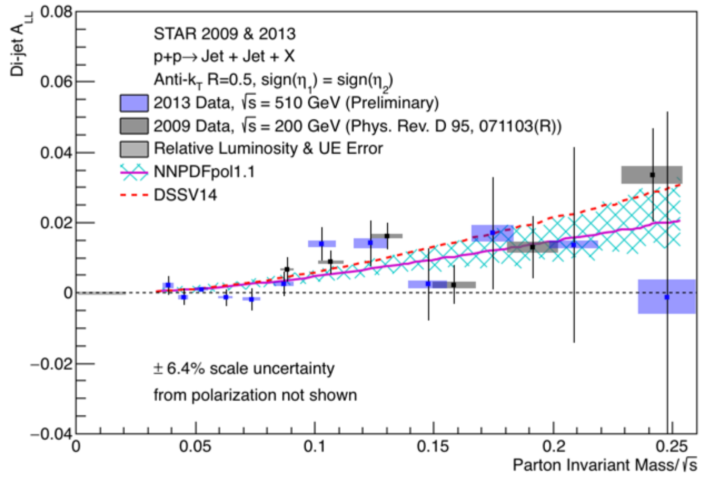
- Run 2009 (200 GeV), Run 2012 and the Run 2013 (510 GeV) A_{LL} measurements show good agreement in x overlap region.
- The full data sample of Run 2013 (510 GeV) is already processed and simulation is being produced to finalize systematic uncertainty studies for final result.

Di-jets Preliminary Results

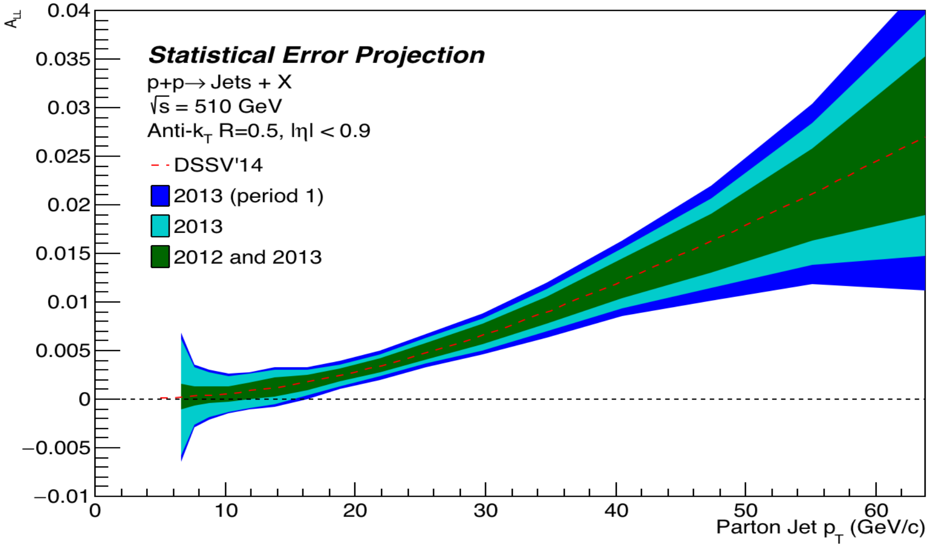


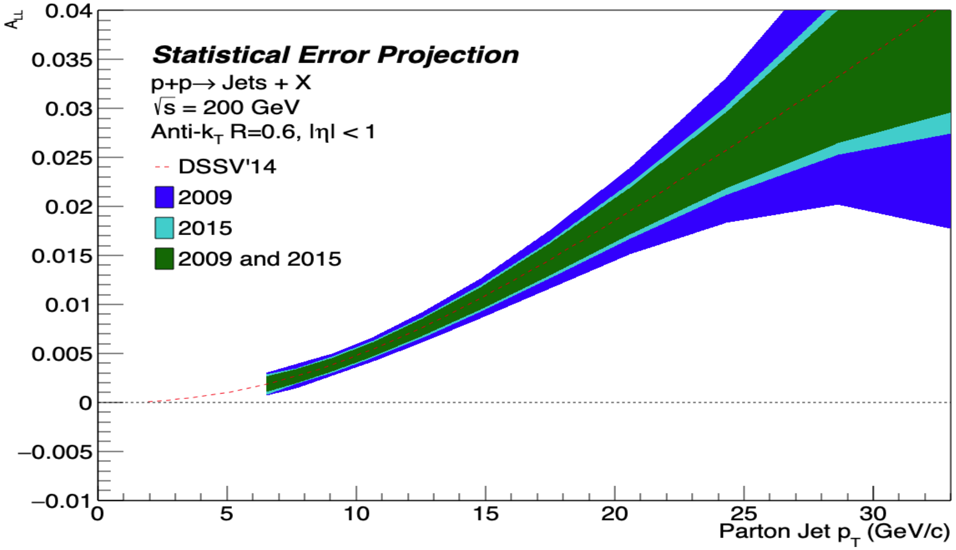


- Preliminary di-jet asymmetries results for 2009, 2012 and 2013 are in agreement.
- Reduced statistical and systematic uncertainties for 2013 compared to 2012.
- Preliminary results are in agreement with 2009 results in the overlap region.



Projections

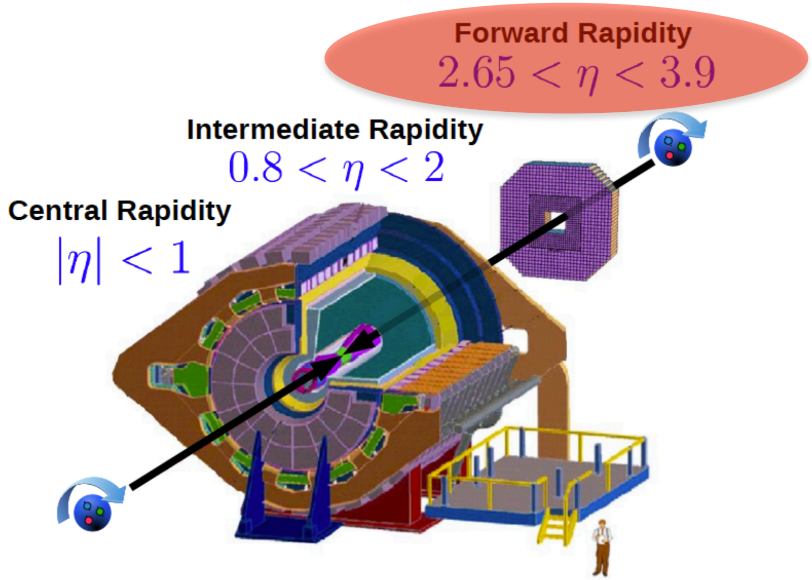




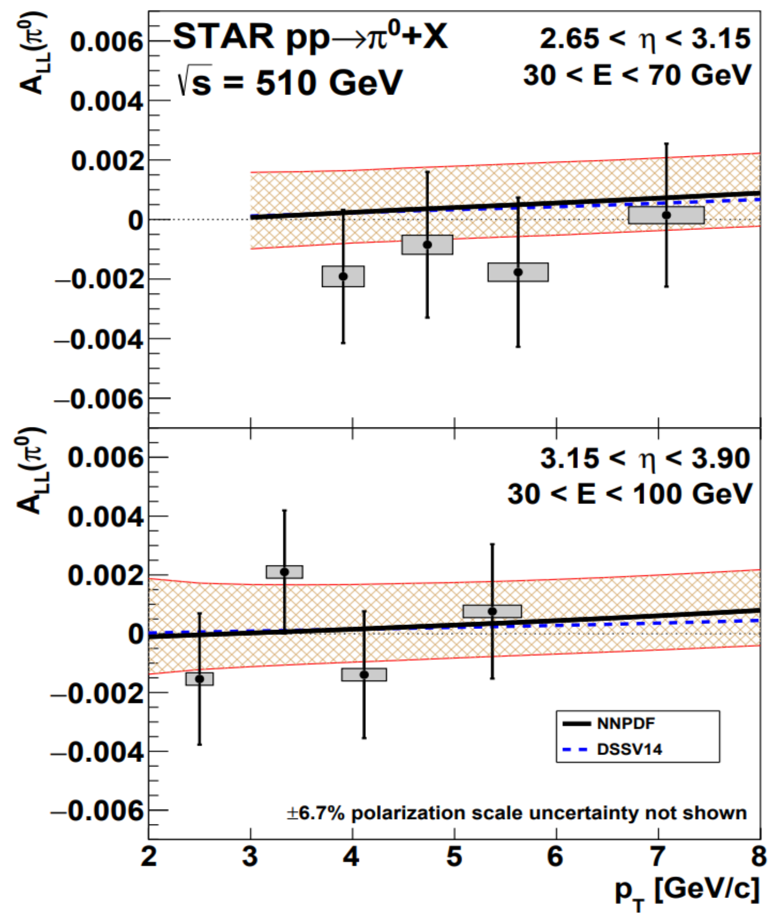
- The combined data from Runs 2012 and 2013 should provide statistics to reduce the uncertainty at lower partonic momentum fraction.
- The additional 200 GeV data taken during 2015, will consolidate previous measurements in 2009 (reduce uncertainties by a factor of ~1.6).

Forward π^0 analysis

- Reaching the lowest x values at STAR.
- Control of the systematics is critical for this precision measurement .
- First direct constraints for x < 0.01



STAR coll. (2018) Phys. Rev. D 98, 032013



Summary

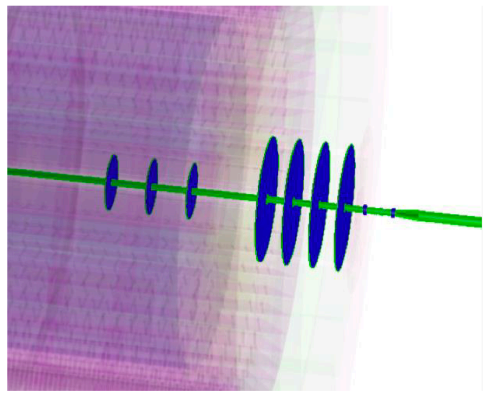
$\sqrt{s}$	Run	Central Jets $\|\eta\| < 1$	Central Di-jets $\|\eta\| < 1$	Intermediate Di-jets $0.8 < \eta < 1.8$
200	2009	Published $x > 0.05$	Published $x > 0.05$	Published $x > 0.01$
200	2015	In Progress $x > 0.05$	In Progress $x > 0.05$	
510	2012	Submitted $x > 0.02$	Submitted $x > 0.02$	In Progress $x > 0.004$
510	2013	Preliminary $x > 0.02$	Preliminary $x > 0.02$	In Progress $x > 0.004$

- The measurements obtained with the 2009 data is being included in global fits.
- These high precision measurements motivate the natural step to move to the STAR forward upgrade, in order to access even lower x values.

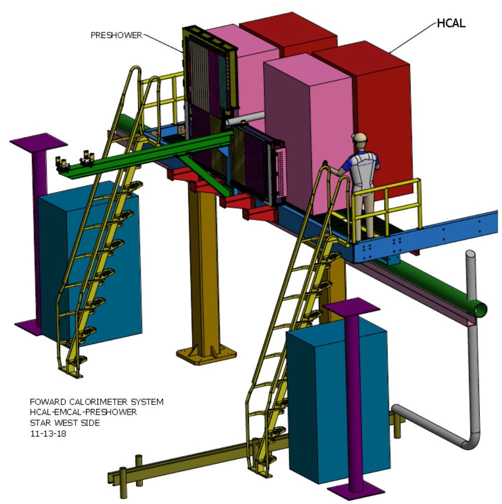
STAR Forward Upgrade

Upgrade in 2021 to 2.5 < η < 4

- 3 Silicon microstrip disks
- 4 small Thin Gap Chambers



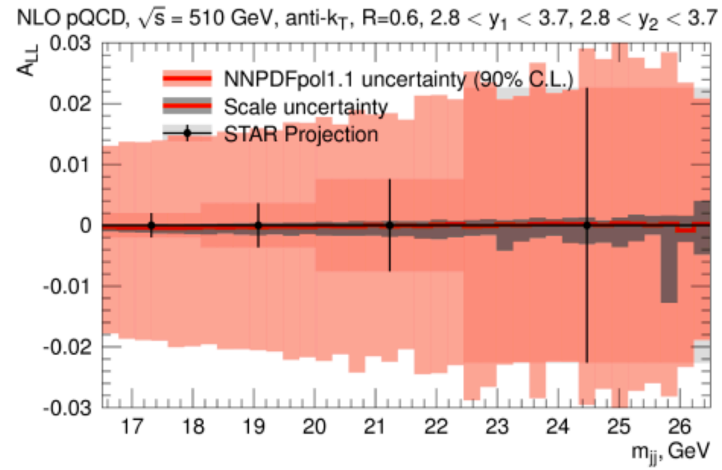
- EM calorimeter
- Had. calorimeter
- Pre-shower: Scintillator

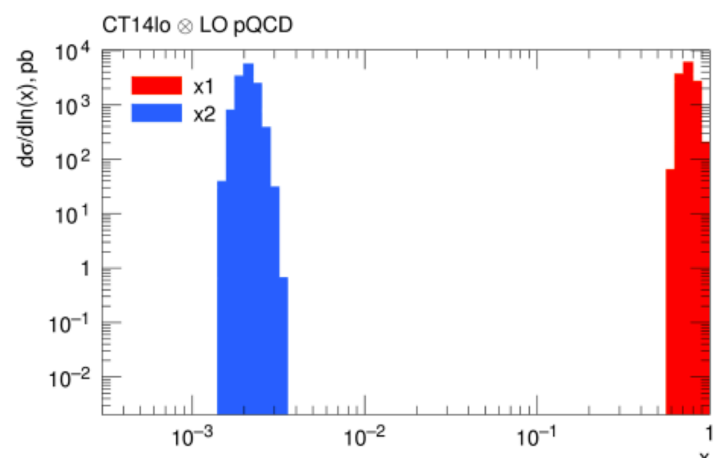


Qian Yang
4 June @ 15:30

D. Brandenburg
7 June @ 10:05

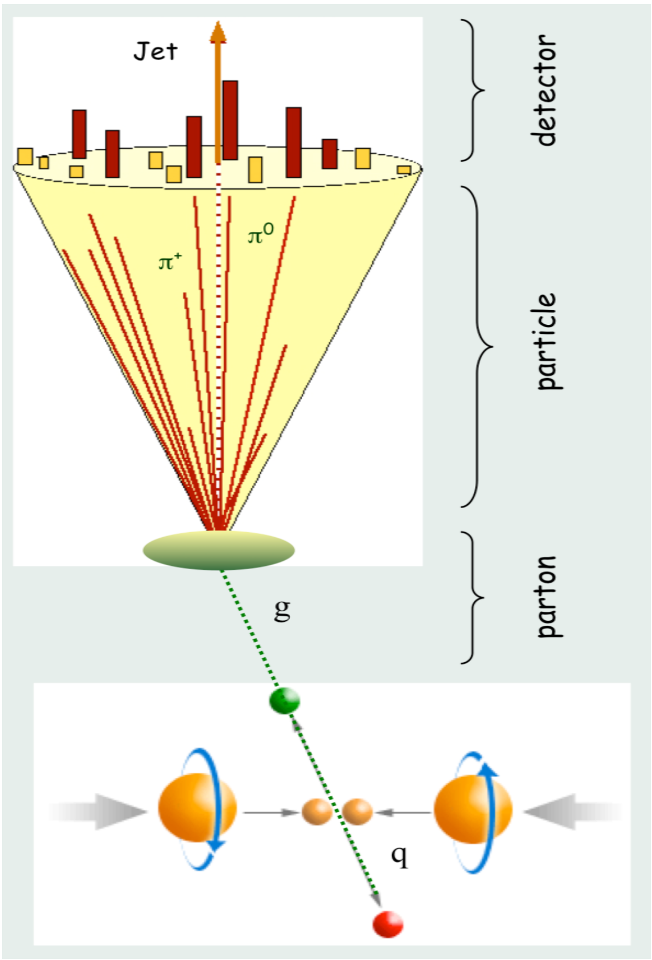
Di-jets A_{LL} at 510 GeV with forward upgrade: x ~ 0.001

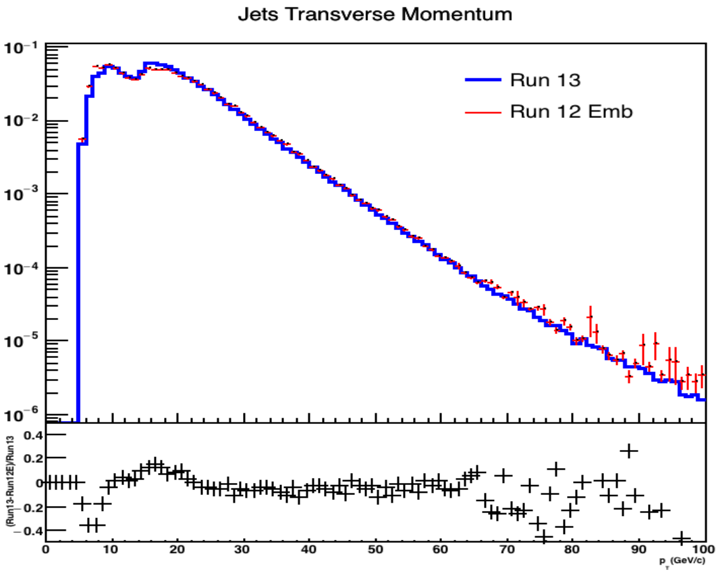




Backup

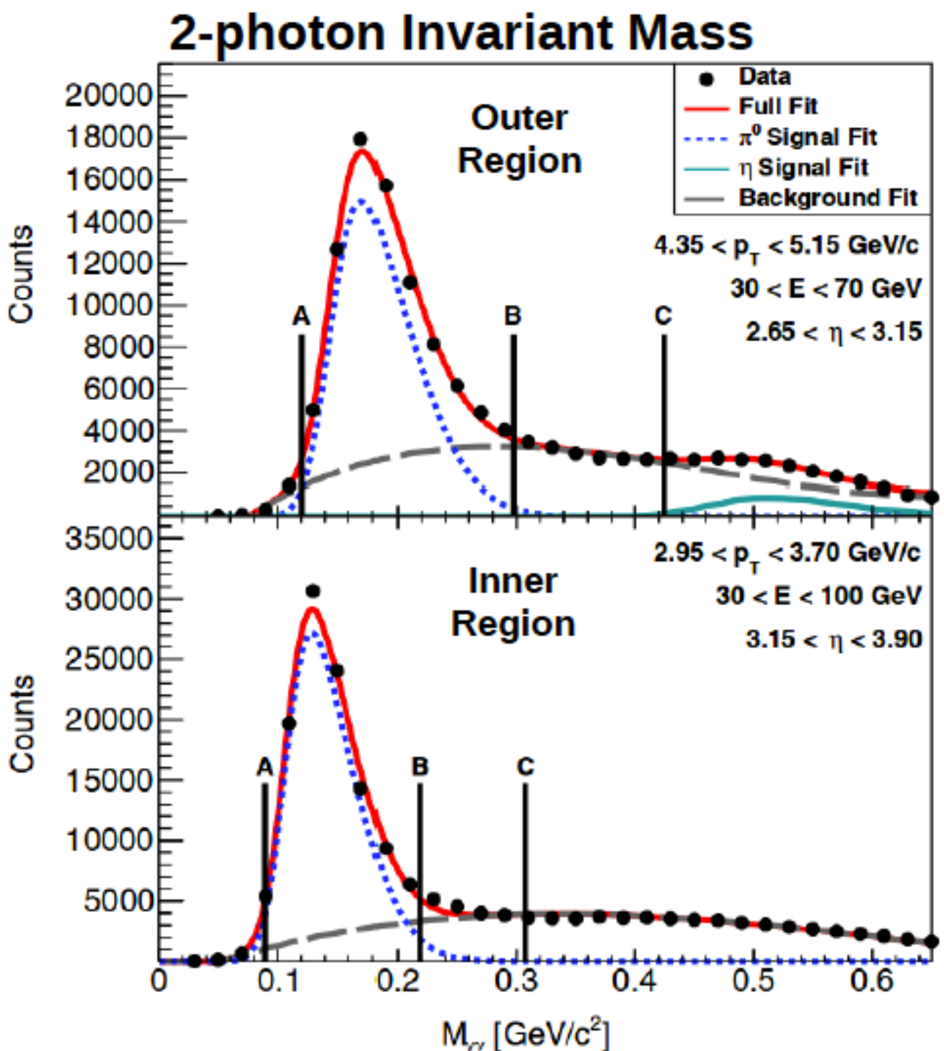
Jet Reconstruction and Simulation





- Jets were reconstructed using the anti-kt jet finding algorithm with R=0.6 for 200 GeV data and R=0.5 for 510 GeV data.
- Embedded simulations (in data) are used to quantify the detector response and estimate systematic uncertainties.
- Embedded simulation sample for the 2012 run agrees with data for the 2013 run (before HFT).

Pion event sample



- Mass Region [AB] – Pions
- Region [BC] – Sideband, for BG
- BG corrections applied to A_{LL}

Full A_{LL} from π^0 mass window

Extracted π^0 Signal A_{LL}

BG A_{LL} from sideband mass window

$$A_{LL}^{\pi^0} = \frac{1}{F} \cdot A_{LL}^{\mathrm{Tot}} - \frac{1-F}{F} \cdot A_{LL}^{\mathrm{BG}}$$

F = π^0 Purity: fraction of events in π^0 mass window which are likely π^0s