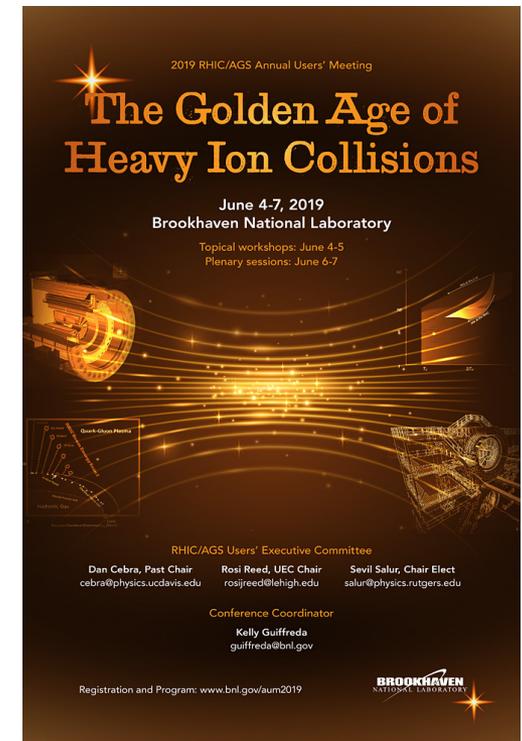


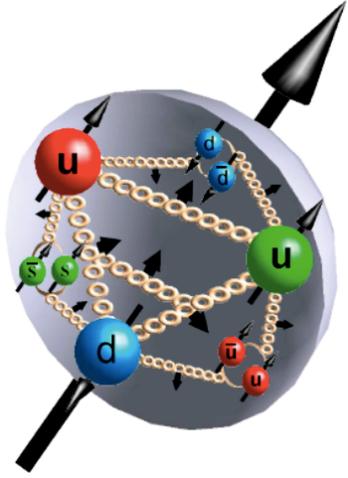
# STAR Gluon Spin Results

Amilkar Quintero  
For the STAR collaboration  
4 June 2019

1. Motivation
2. RHIC and STAR experiment
3. Correlation Measurements
4. Reaching lower  $x$  values
5. Previous STAR results
6. Impact on latest global fit
7. Status of latest measurements
8. Low  $x$  with forward  $\pi^0$
9. Summary



# Motivation



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

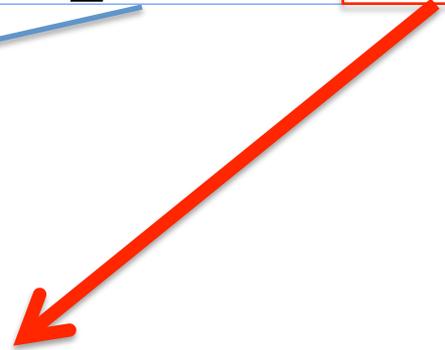
The proton spin sum rule:

$$\langle S_p \rangle = \frac{1}{2} = \frac{1}{2} \Delta\Sigma + \Delta G + L_q + L_g$$

Polarized DIS results  $\Delta\Sigma \approx 0.3$

Poorly constrained

Jinlong Zhang  
4 June @ 9:00



**What is the contribution of gluon polarization ( $\Delta G$ ) to the spin of the proton?**

# Motivation

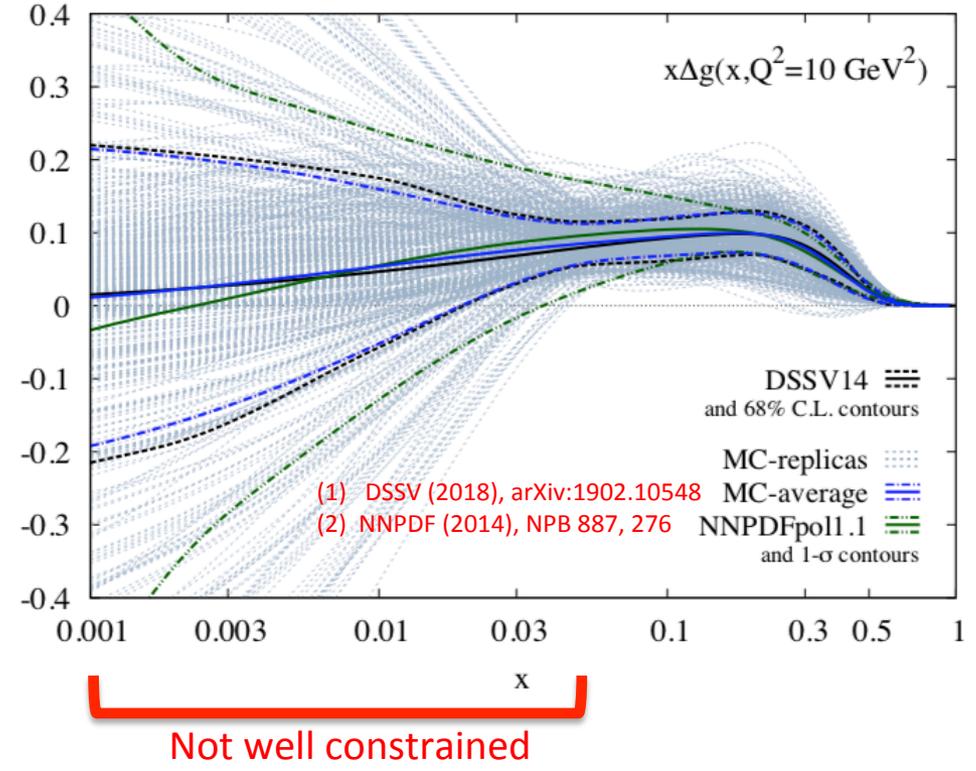
- Gluon polarization can be measured using longitudinal double-spin asymmetry ( $A_{LL}$ ) of jets in proton collisions.
- For most RHIC kinematics,  $gg$  and  $qg$  scattering dominate.



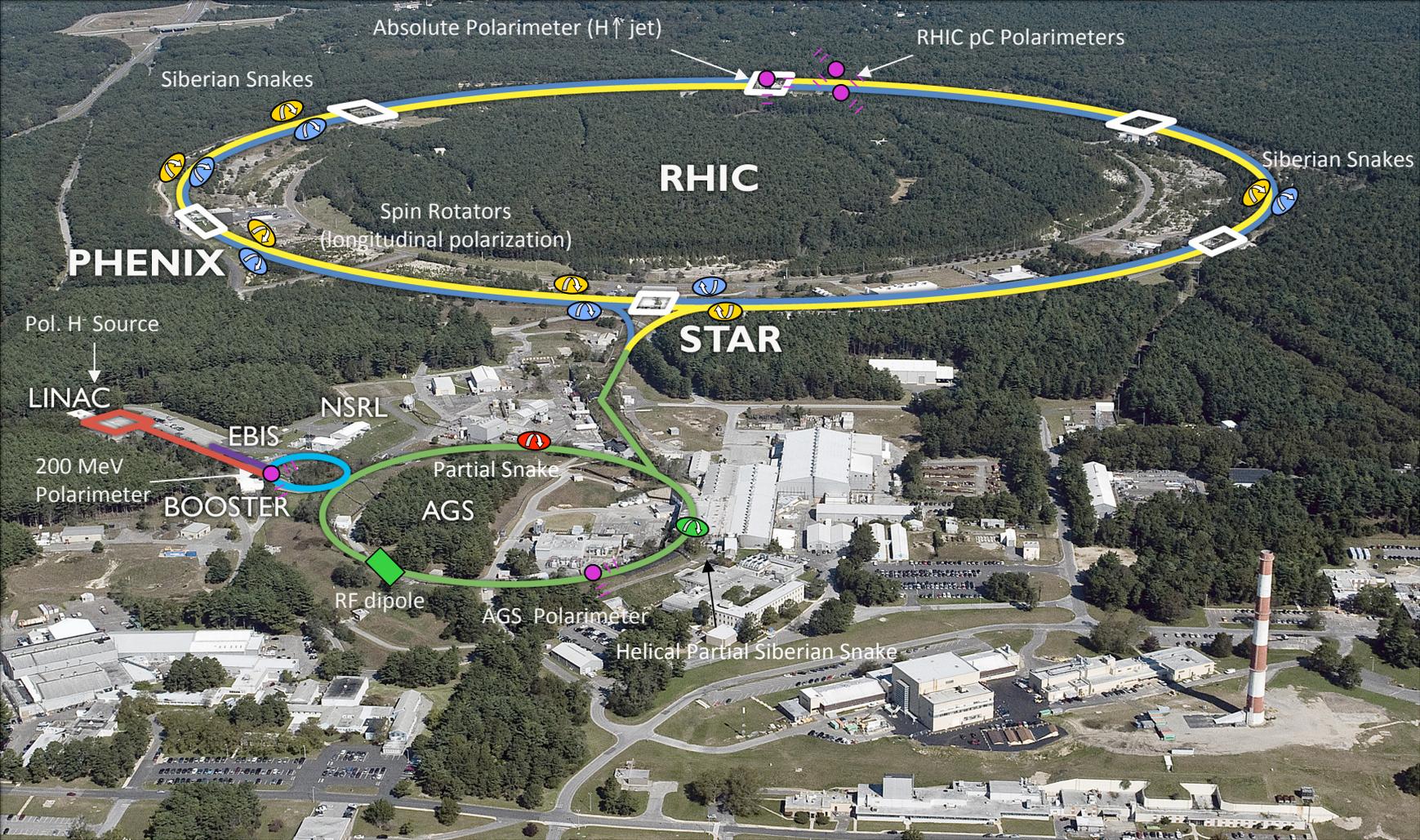
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$

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

**DSSV<sup>(1)</sup> :  $0.126 \pm 0.023$  ( $0.1 < x$ )**  
**NNPDF<sup>(2)</sup>:  $0.17 \pm 0.06$  ( $0.05 < x < 0.2$ )**



# Relativistic Heavy Ion Collider



# Polarized proton runs at RHIC

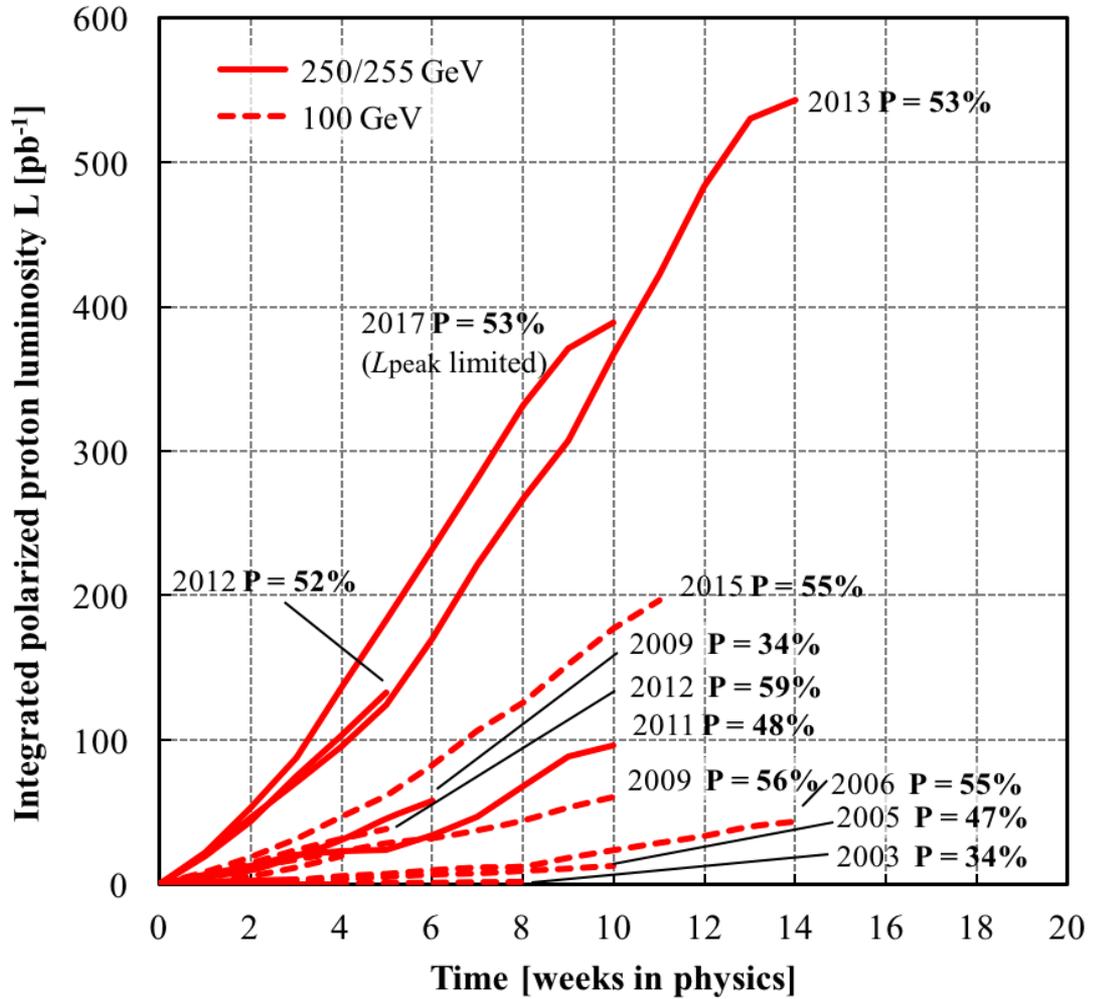
## Longitudinally polarized runs

Year	$\sqrt{s}$ (GeV)
2009	200
2012	510
2013	510
2015	200

## Experimentally

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

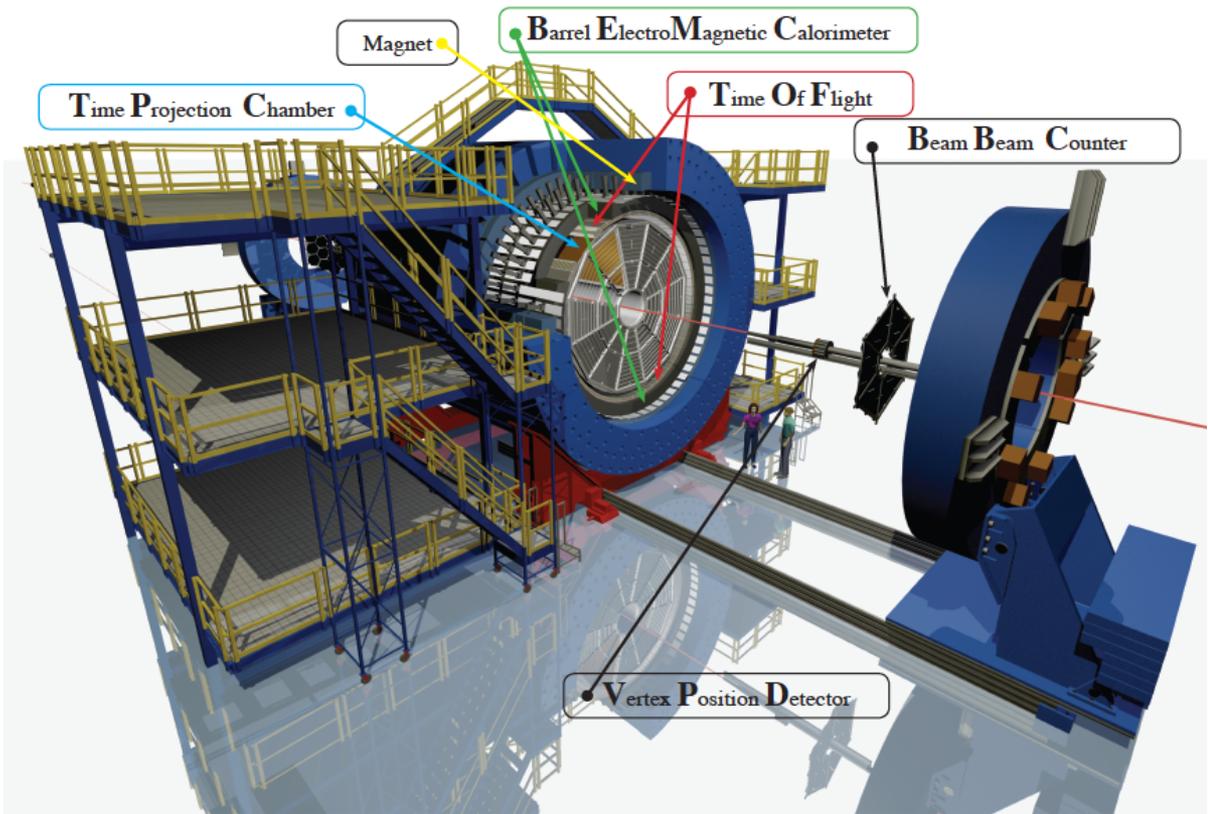
$$N = \sigma L, R = \frac{L^{++}}{L^{+-}}$$



# 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  $\pi^0$  at  $2.5 \leq \eta \leq 4.2$ .
- Relative luminosity calculated with the Vertex Position Detector (VPD) and the Zero Degree Calorimeter (ZDC).

## Solenoidal Tracker At RHIC



# Correlation Measurements with Di-jets

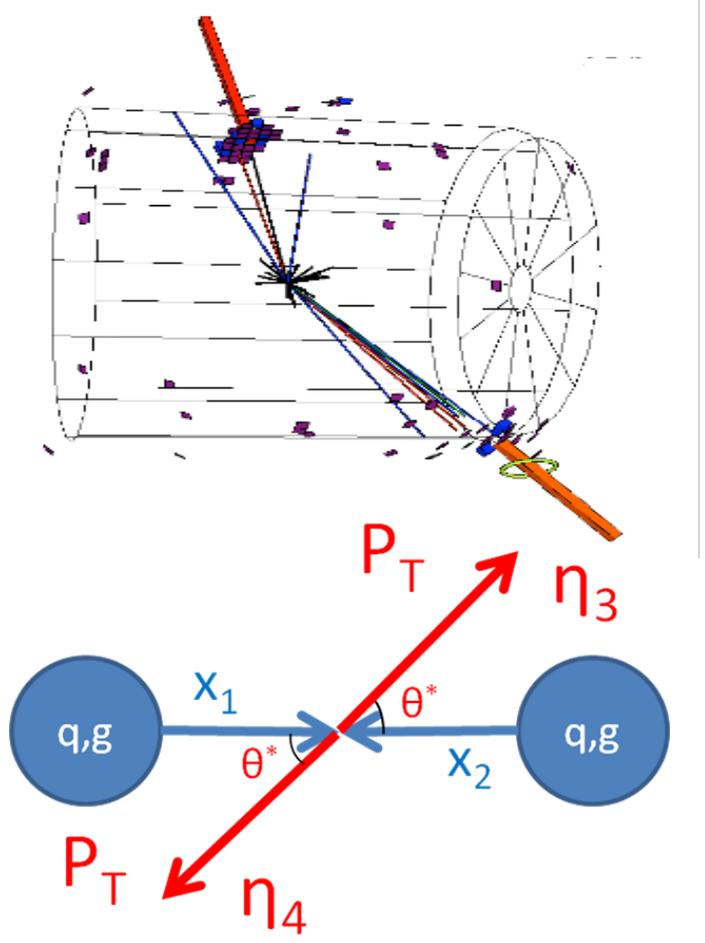
$$x_1 = \frac{1}{\sqrt{s}} (p_{T3} e^{\eta_3} + p_{T4} e^{\eta_4})$$

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

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

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

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



Better constrain the functional form of  $\Delta g$

# Reaching lower x values

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

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

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

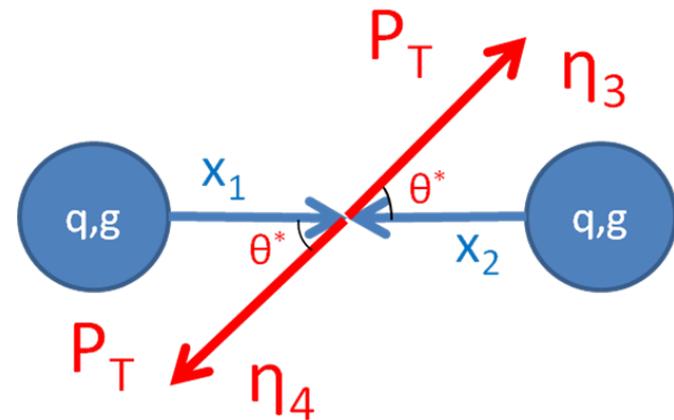
$$\eta_3 + \eta_4 = \ln \frac{x_1}{x_2}$$

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

Higher center of mass energy

$\sqrt{s} = 200 \text{ GeV} \rightarrow x > 0.05$

$\sqrt{s} = 510 \text{ GeV} \rightarrow x > 0.02$



# Reaching lower x values

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

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

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

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

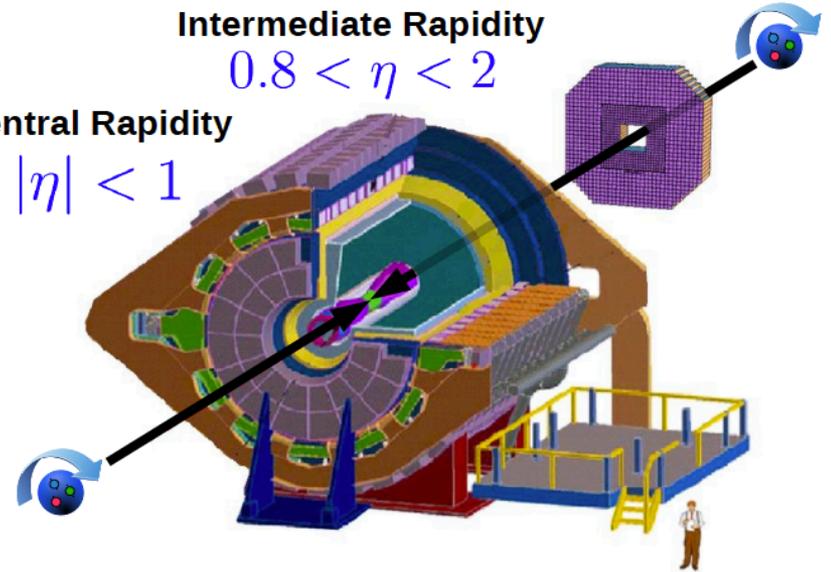
$$|\cos \theta^*| = \tanh \left| \frac{\eta_3 - \eta_4}{2} \right|$$

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

**Forward Rapidity**  
 $2.65 < \eta < 3.9$

**Intermediate Rapidity**  
 $0.8 < \eta < 2$

**Central Rapidity**  
 $|\eta| < 1$



# Previous STAR Results

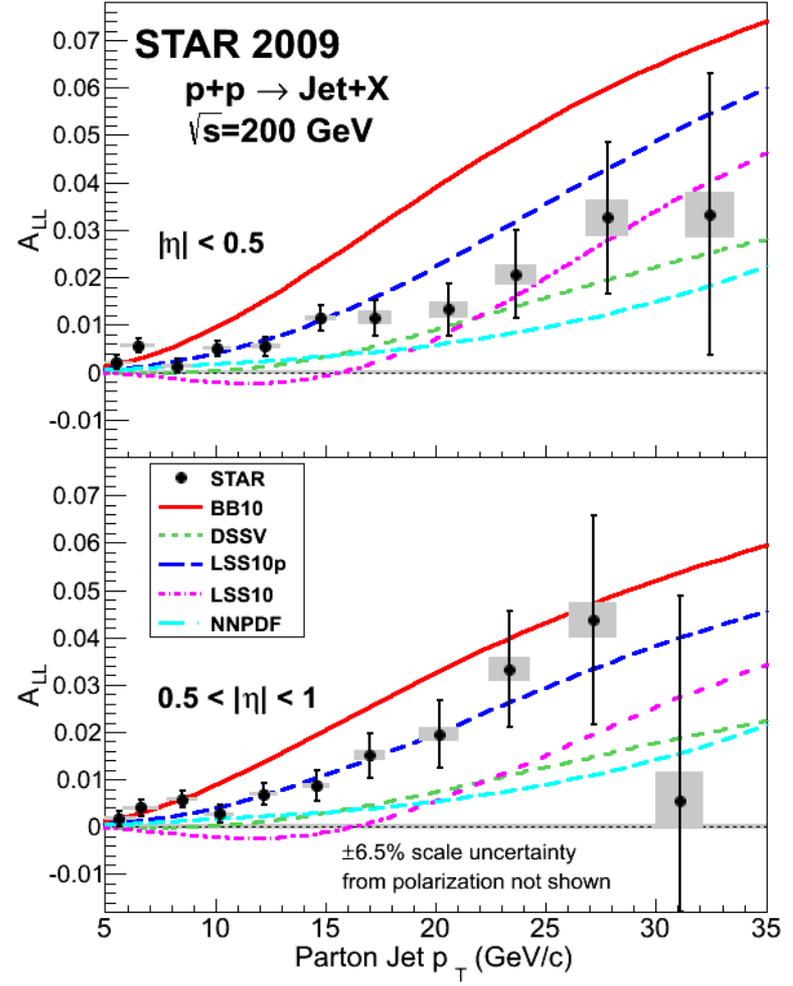
## Data from the 2009 RHIC run at 200 GeV

- 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 $\sqrt{s}=200$ GeV in 2009

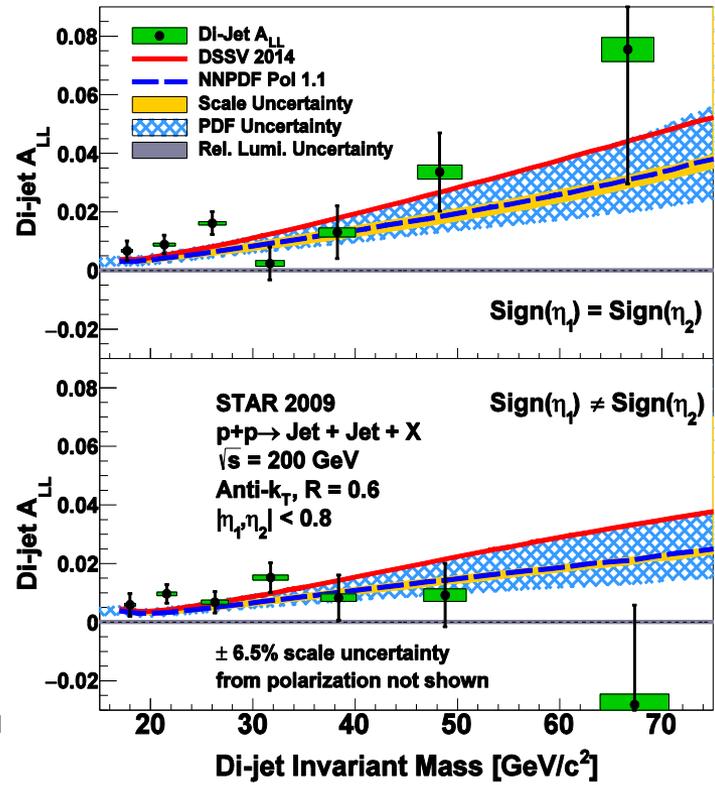
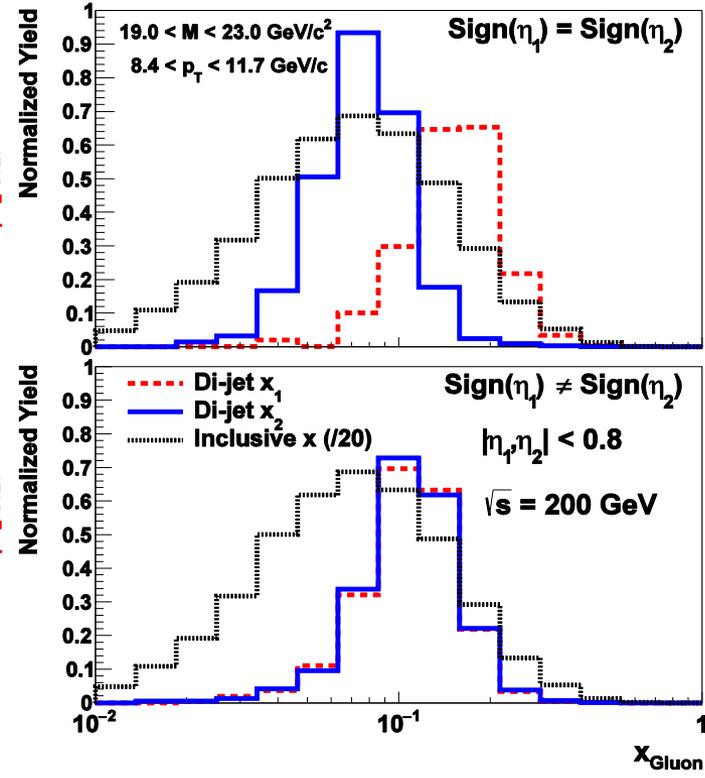
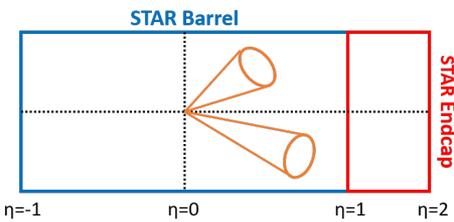
- Increase statistical precision compared to earlier STAR measurements in 2006.
- Provided the first evidence of non-zero gluon polarization at  $x > 0.05$
- Results were systematically above the DSSV 2008 global fit.
- These results strongly suggest a positive gluon polarization value after inclusion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

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



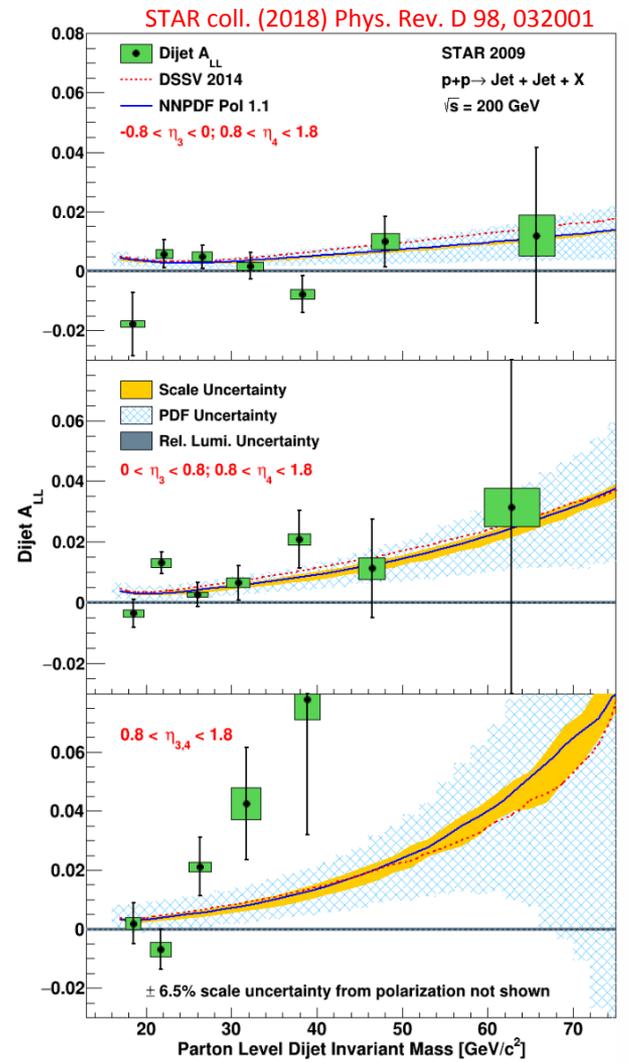
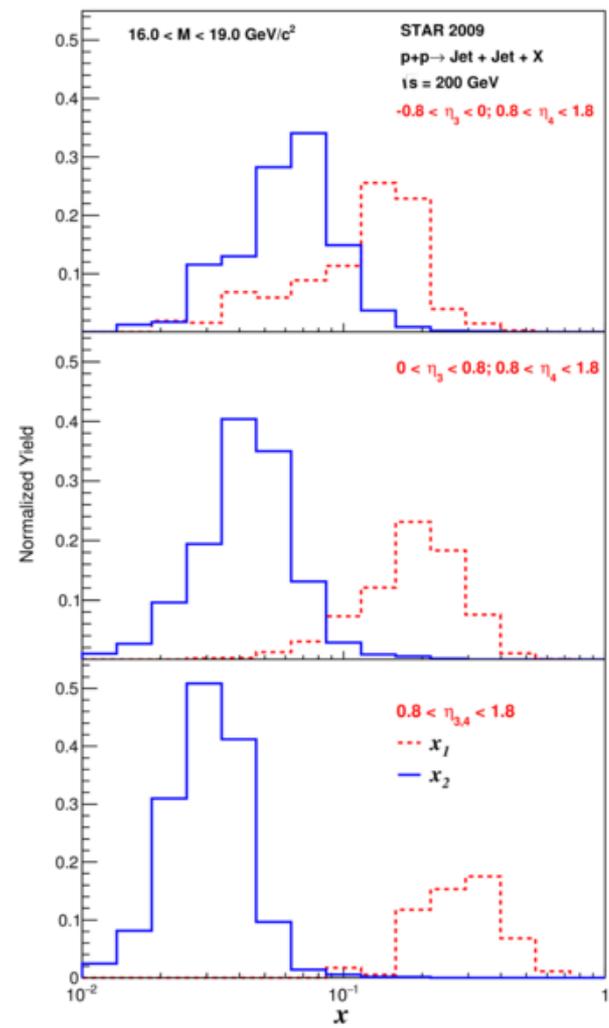
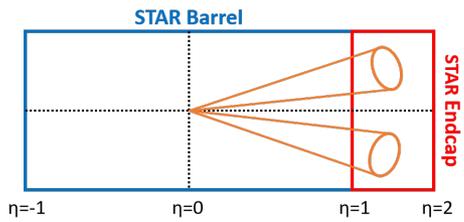
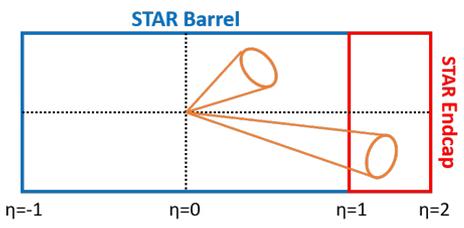
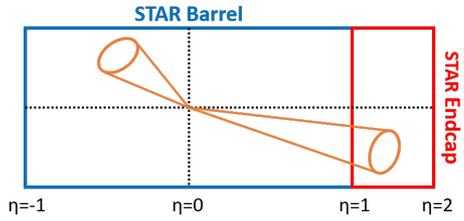
# Di-jets at $\sqrt{s}=200$ GeV in 2009

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



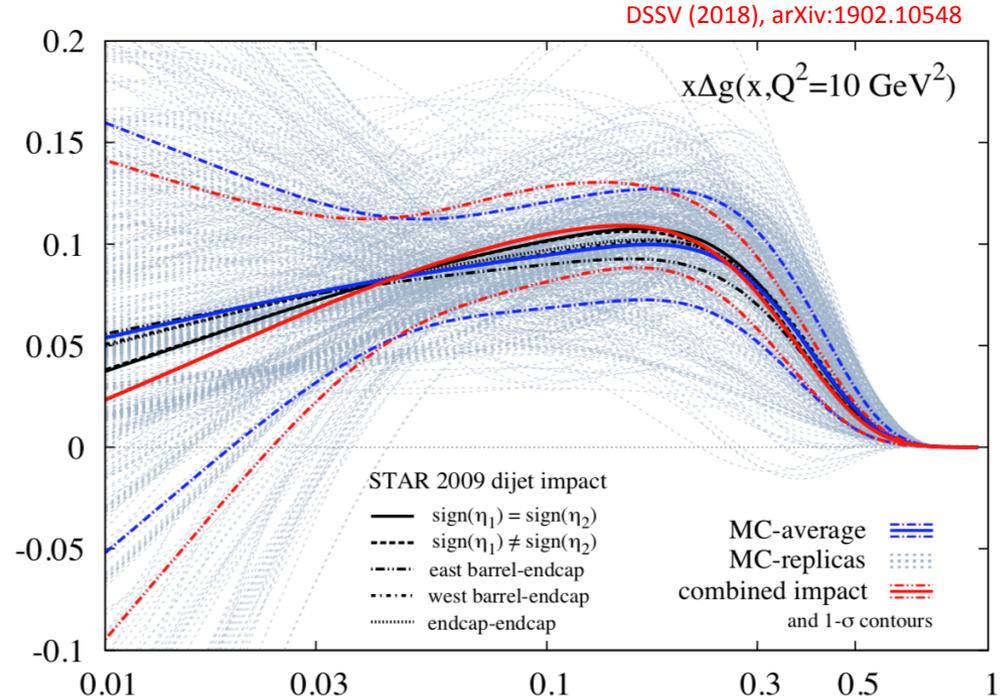
- Di-jets measurements allows to probe a narrower x region.
- Results are consistent with 2014 global fits.

# Intermediate Di-jets at $\sqrt{s}=200$ GeV in 2009



# 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.



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

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

# 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

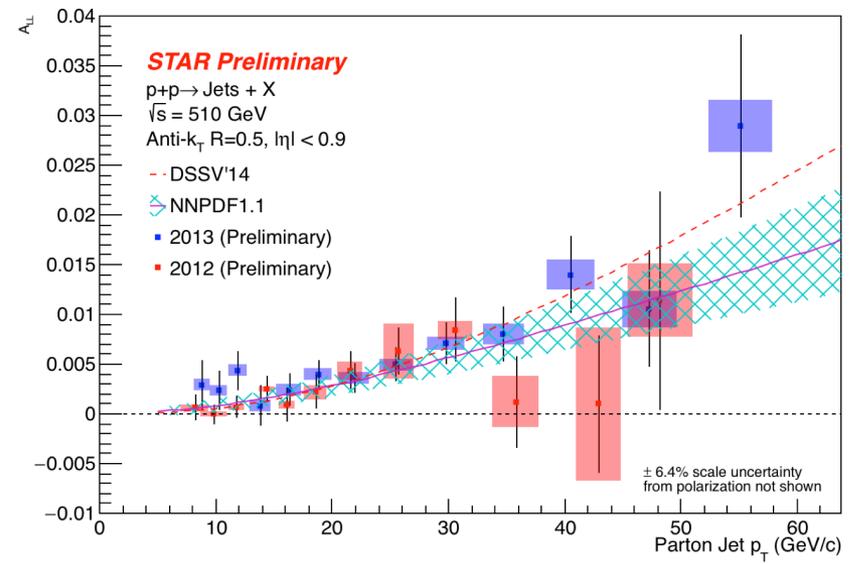
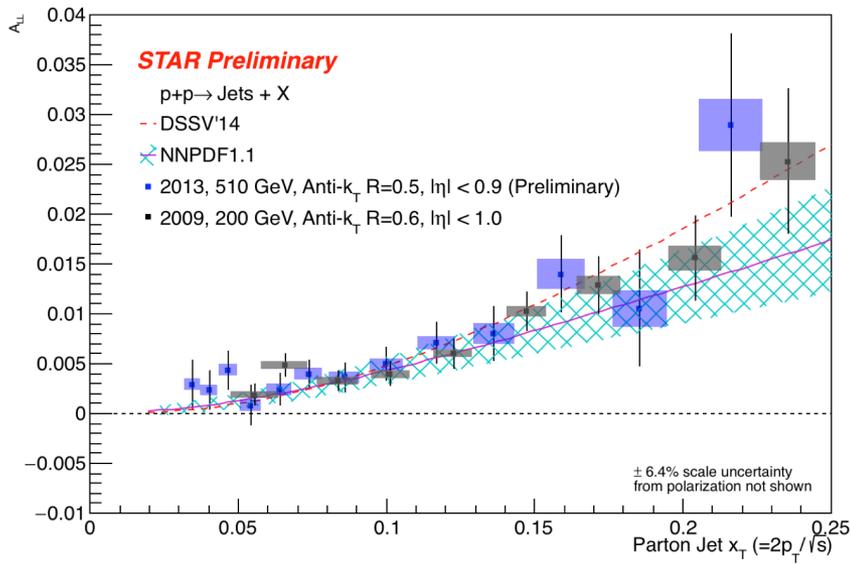
- Jets and di-jets in 2015 at 200 GeV:

In progress

AQ  
Poster

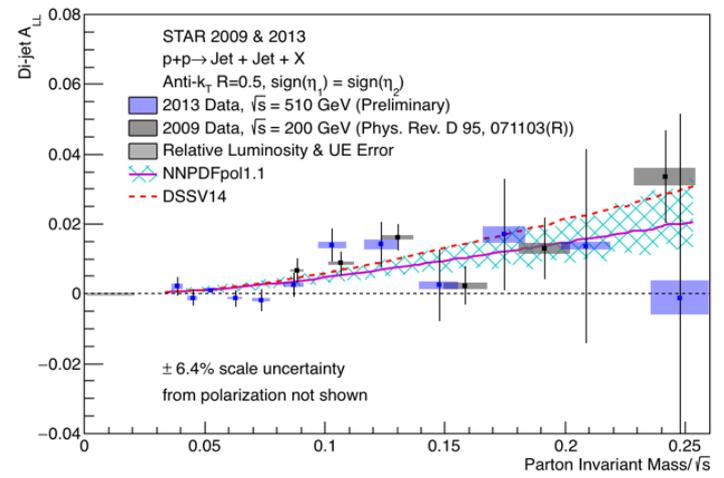
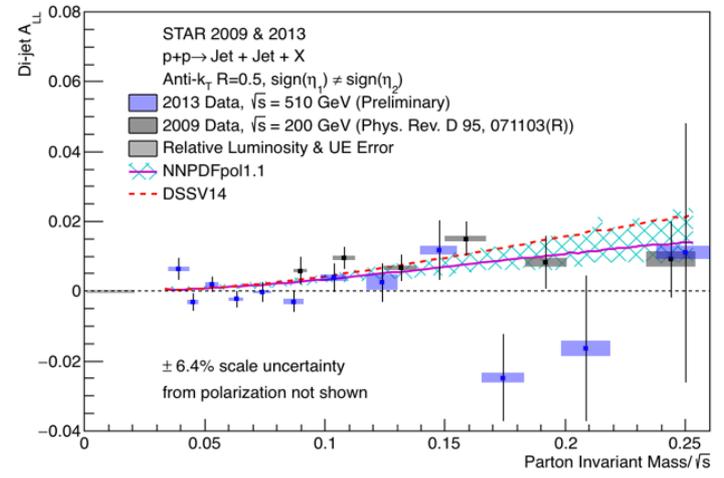
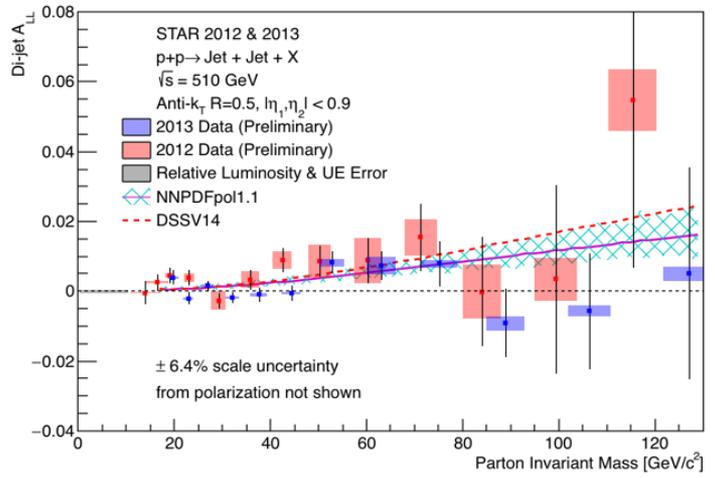
Nick Lukow  
Poster

# Inclusive Jets Preliminary Results



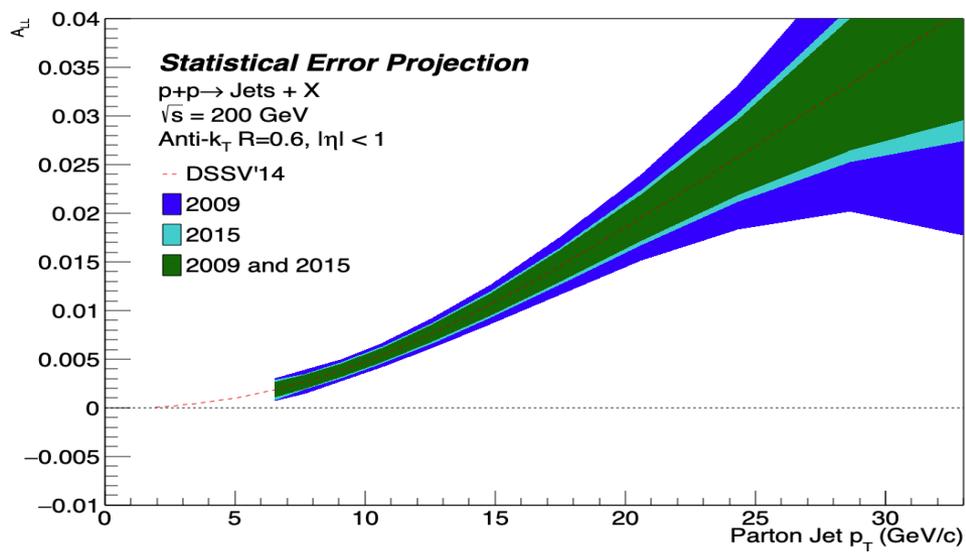
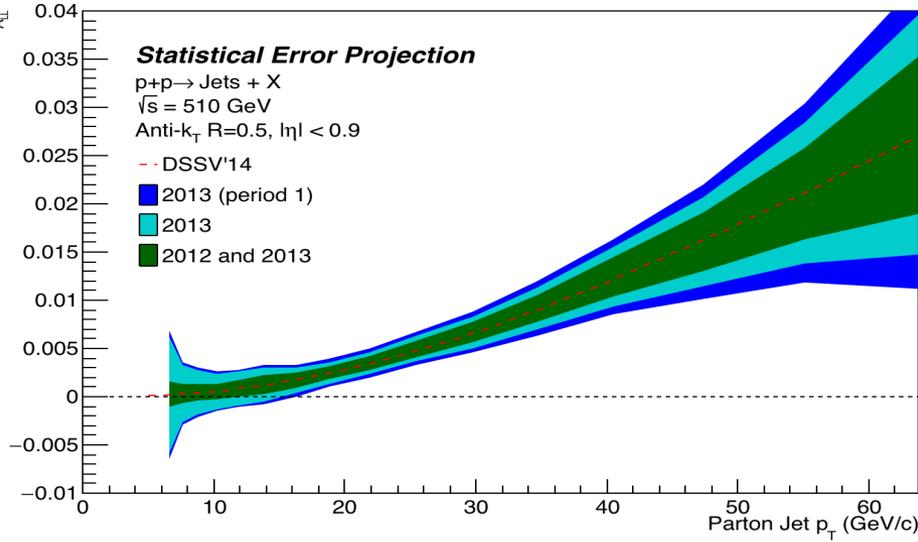
- Run 2009 (200 GeV), Run 2012 and the Run 2013 (510 GeV)  $A_{LL}$  measurements show good agreement in x overlap region.
- The full data sample of Run 2013 (510 GeV) is already processed and simulation is being produced to finalize systematic uncertainty studies for final result.

# 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.

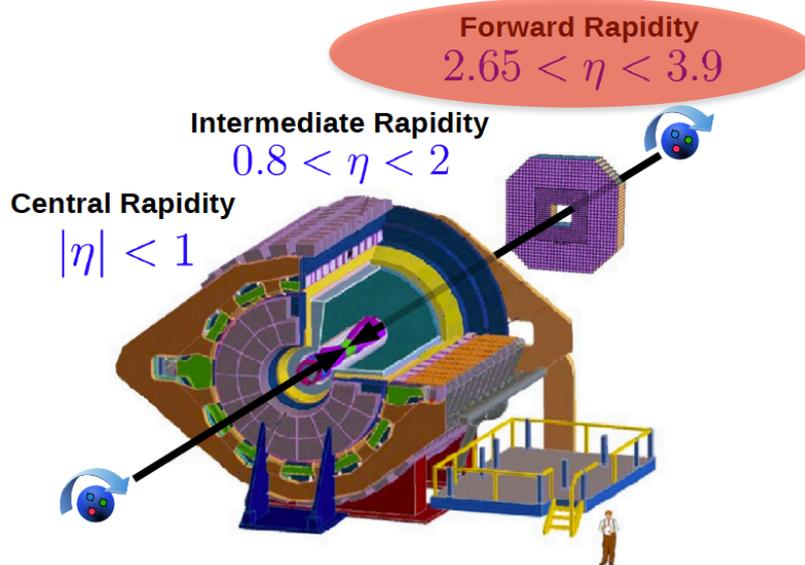
# Projections



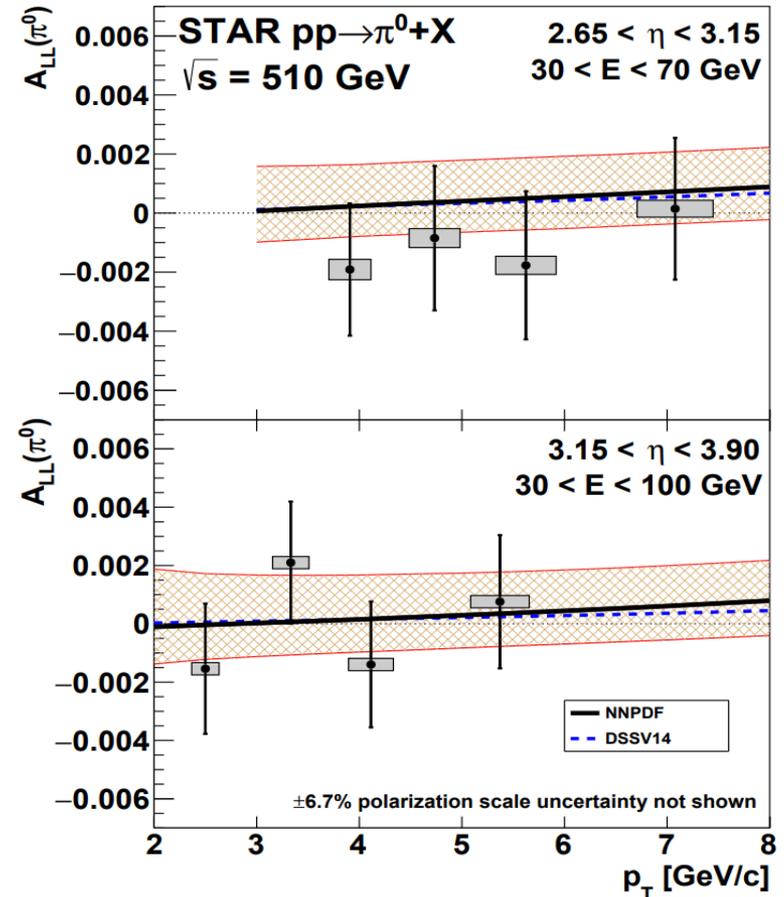
- The combined data from Runs 2012 and 2013 should provide statistics to reduce the uncertainty at lower partonic momentum fraction.
- The additional 200 GeV data taken during 2015, will consolidate previous measurements in 2009 (reduce uncertainties by a factor of  $\sim 1.6$ ).

# Forward $\pi^0$ 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

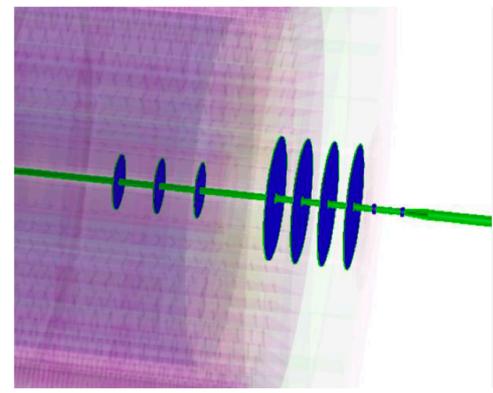
$\sqrt{s}$	Run	Central Jets $ \eta  < 1$	Central Di-jets $ \eta  < 1$	Intermediate Di-jets $0.8 < \eta < 1.8$
200	2009	Published $x > 0.05$	Published $x > 0.05$	Published $x > 0.01$
200	2015	In Progress $x > 0.05$	In Progress $x > 0.05$	
510	2012	Preliminary $x > 0.02$	Preliminary $x > 0.02$	In Progress $x > 0.004$
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  $2.5 < \eta < 4$

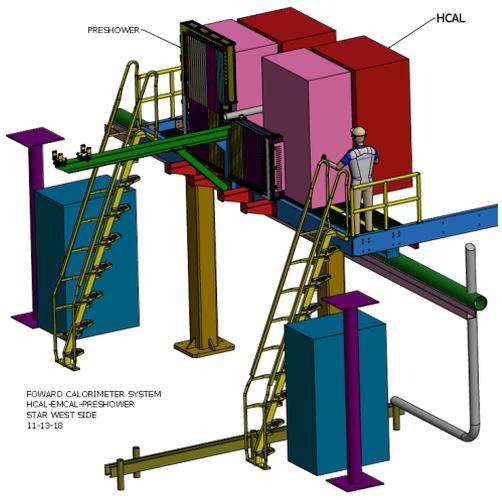
- 3 Silicon microstrip disks
- 4 small Thin Gap Chambers



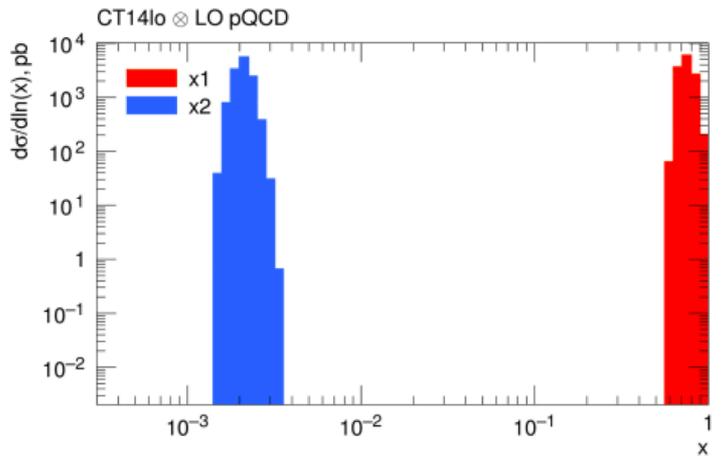
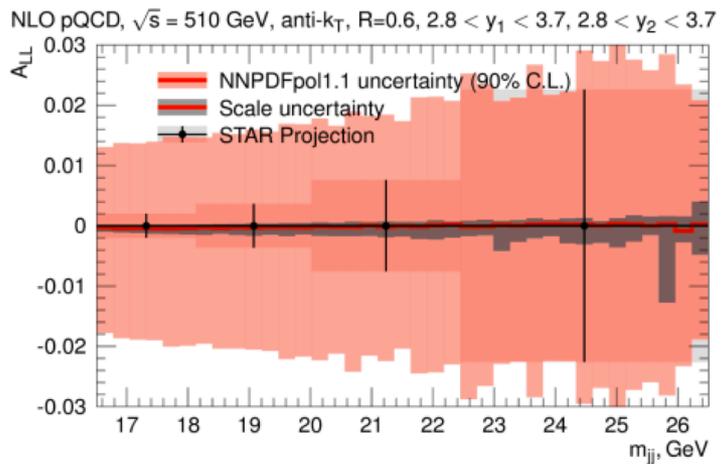
- EM calorimeter
- Had. calorimeter
- Pre-shower: Scintillator

Qian Yang  
4 June @ 15:30

D. Brandenburg  
7 June @ 10:05

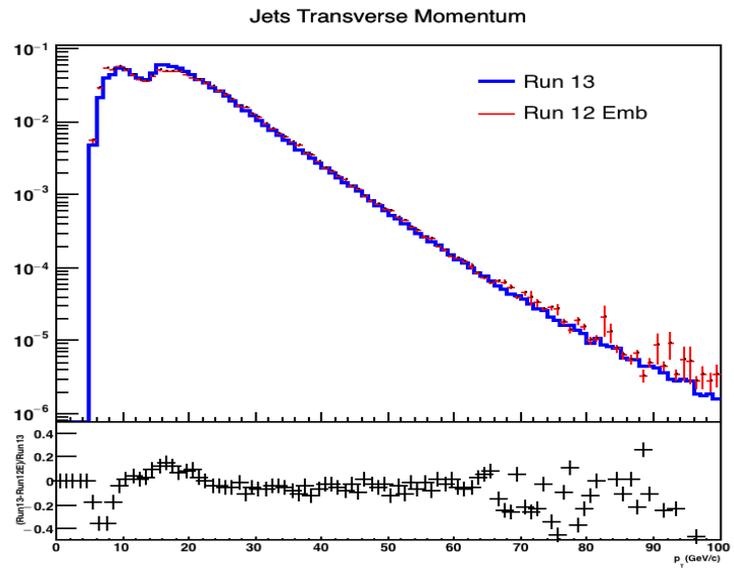
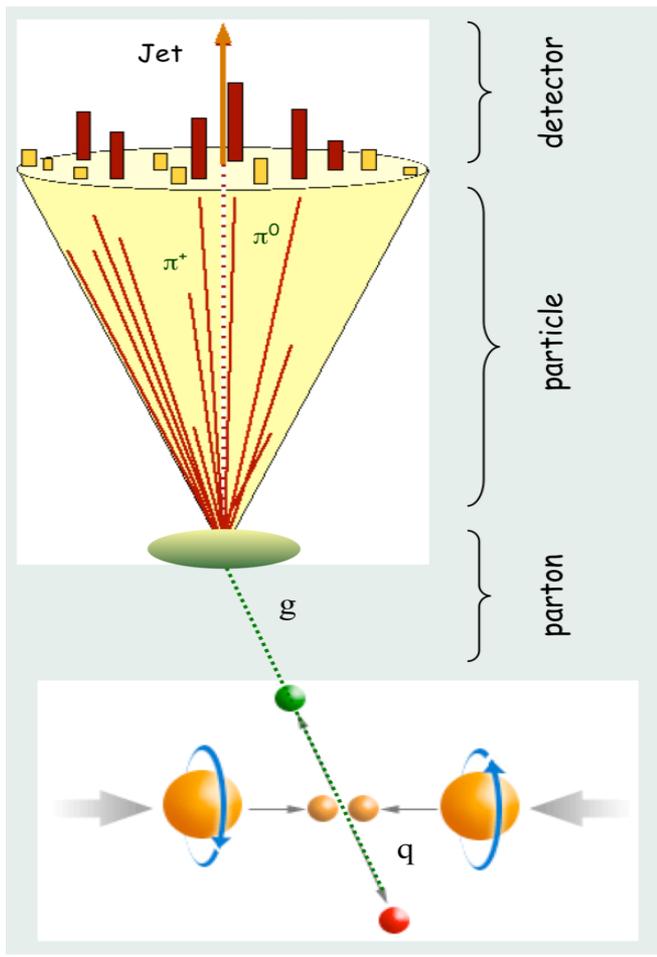


Di-jets  $A_{LL}$  at 510 GeV with forward upgrade:  $x \sim 0.001$



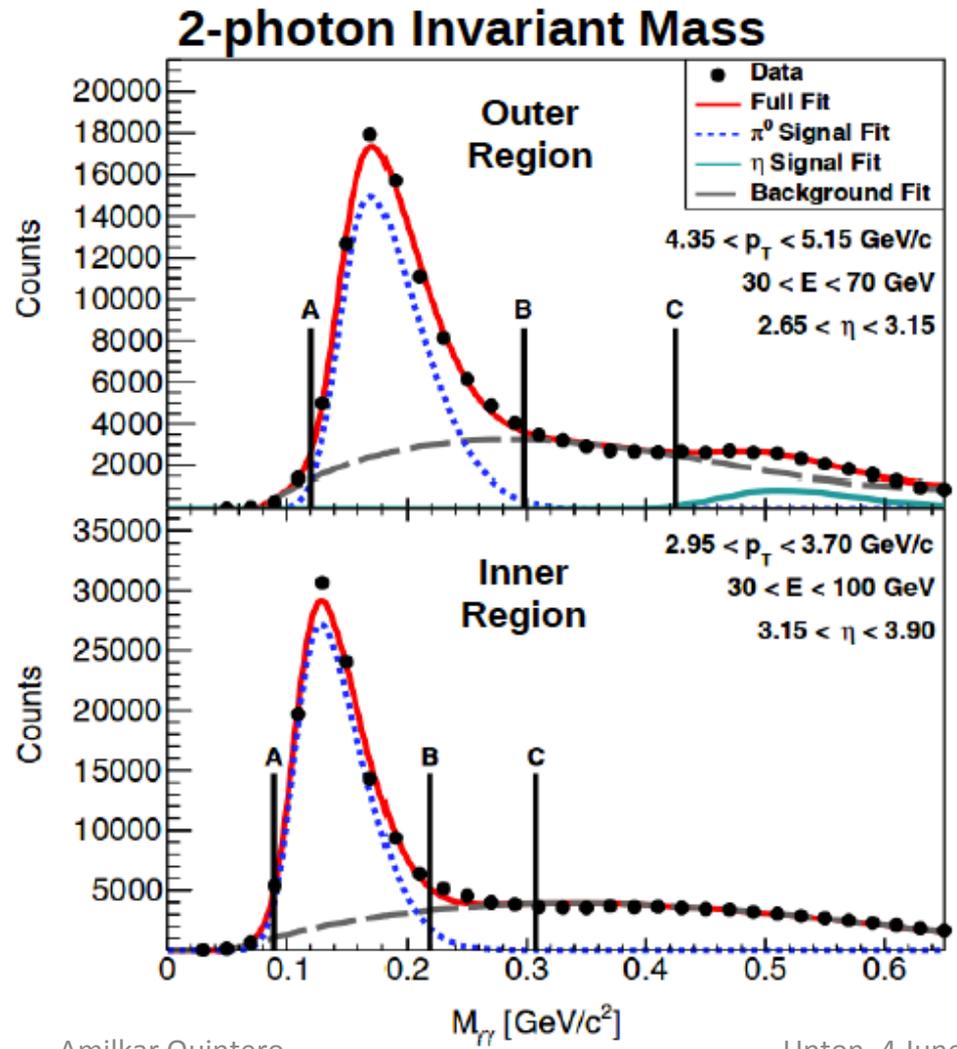
# Backup

# 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  $A_{LL}$

