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Longitudinal Double Spin Asymmetries with π^0 - Jet Correlations in Polarized Proton Collisions at $\sqrt{s}$ = 510 GeV at STAR

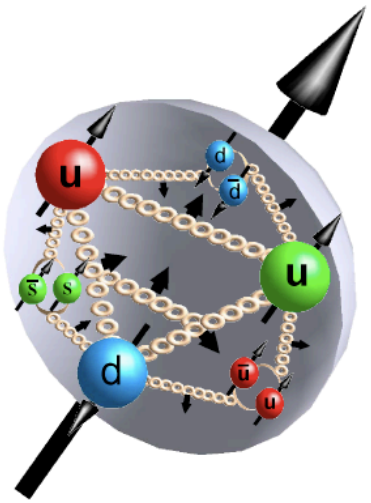
Yaping Wang (for the STAR Collaboration)

Central China Normal University

Outline

- Introduction
- STAR experiment at RHIC
- π^0 - Jet double spin asymmetry (A_{LL}) measurements at STAR
  - Analysis methodology
  - π^0 – Jet A_{LL} analysis status
- Conclusion and Outlook

Introduction – Proton Spin Puzzle



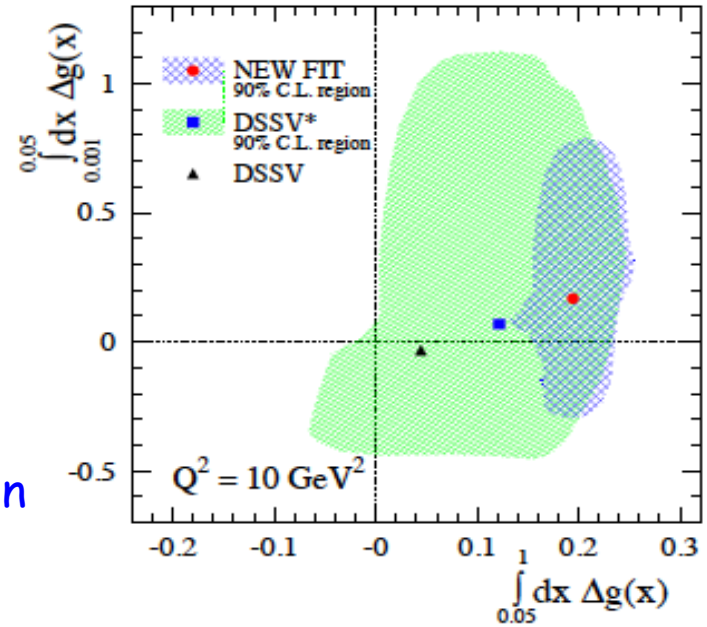
The observed spin of the proton can be decomposed into contributions from the intrinsic quark and gluon spin and orbital angular momentum.

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

DIS RHIC DVCS

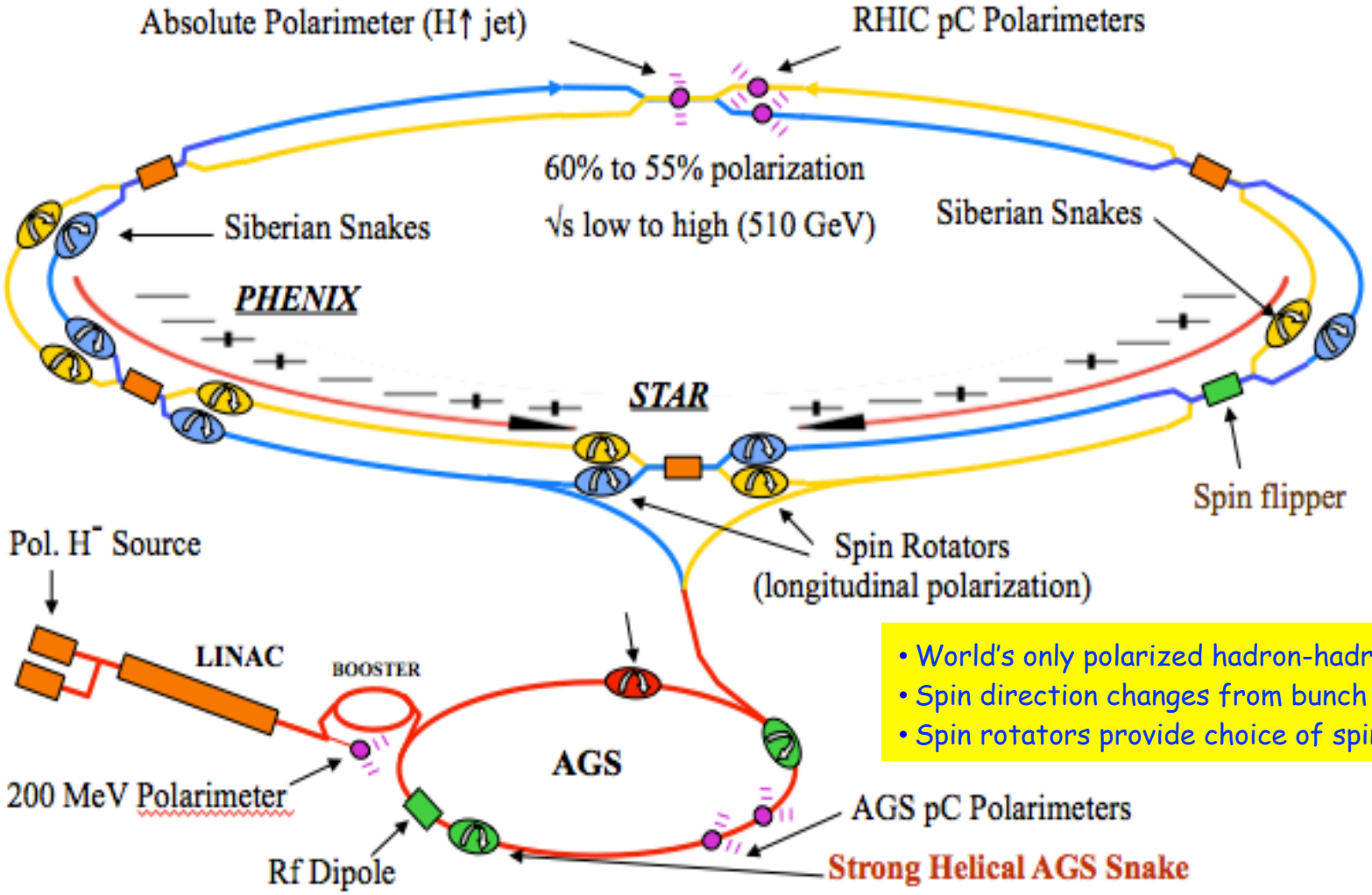
- DIS data measure the integral of quark polarization well to be around ~ 30%
- Both DSSV and NNPDF, with 2009 RHIC results integrated in the fits, find evidence for positive gluon polarization:
  - DSSV: $0.19^{+0.06}_{-0.05}$ at 90% c.l. for $x > 0.05$
- Uncertainties on integral of gluon polarization over low x region are still sizeable

DSSV, PRL 113, 012001



RHIC – Polarized Proton+Proton Collider

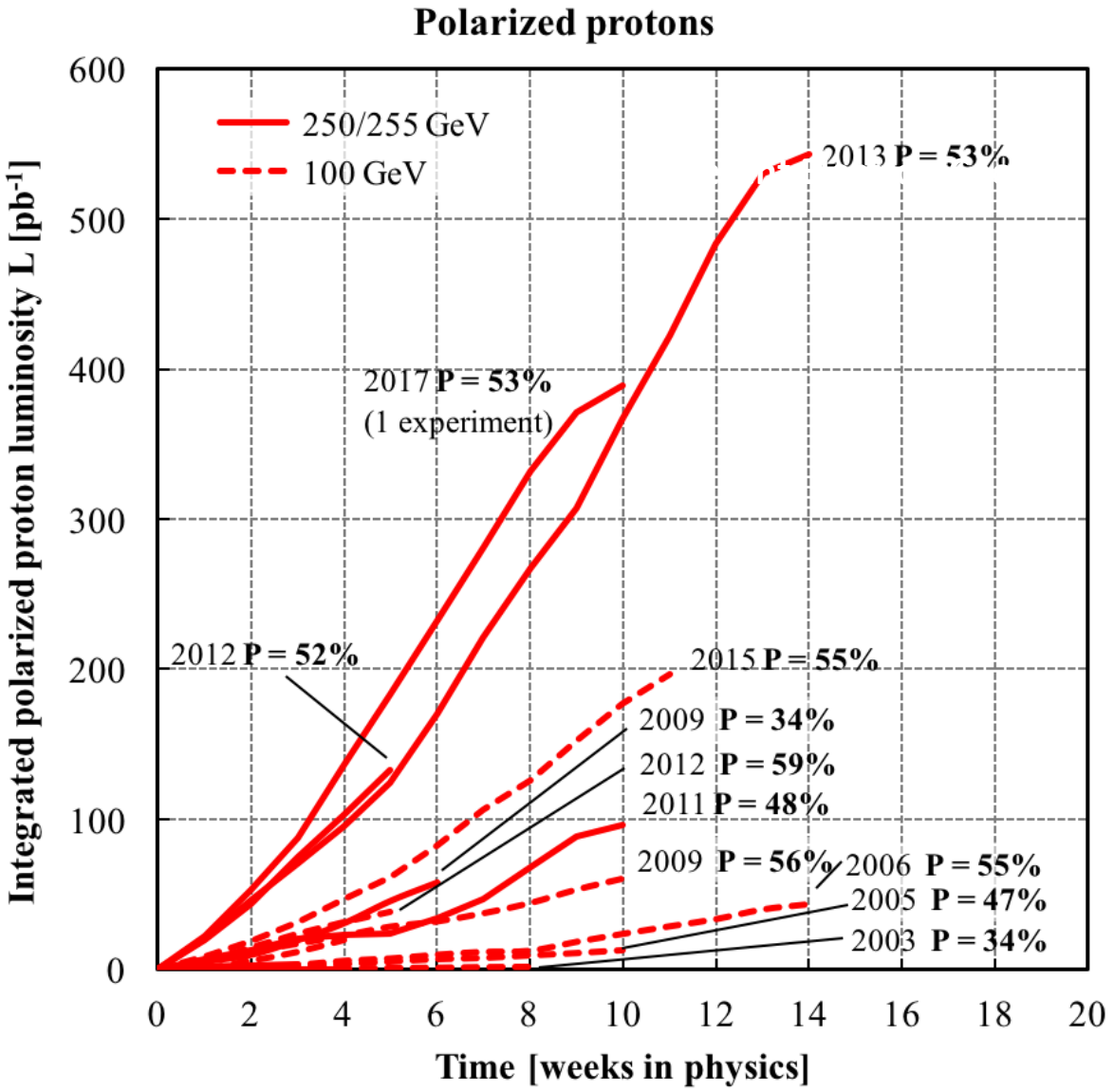
The Relativistic Heavy Ion Collider (RHIC), the world's first and only polarized hadron collider, is designed to collide many particle species at different energies.



- World's only polarized hadron-hadron collider
- Spin direction changes from bunch to bunch
- Spin rotators provide choice of spin orientation

RHIC – Performance with Proton+Proton Collisions

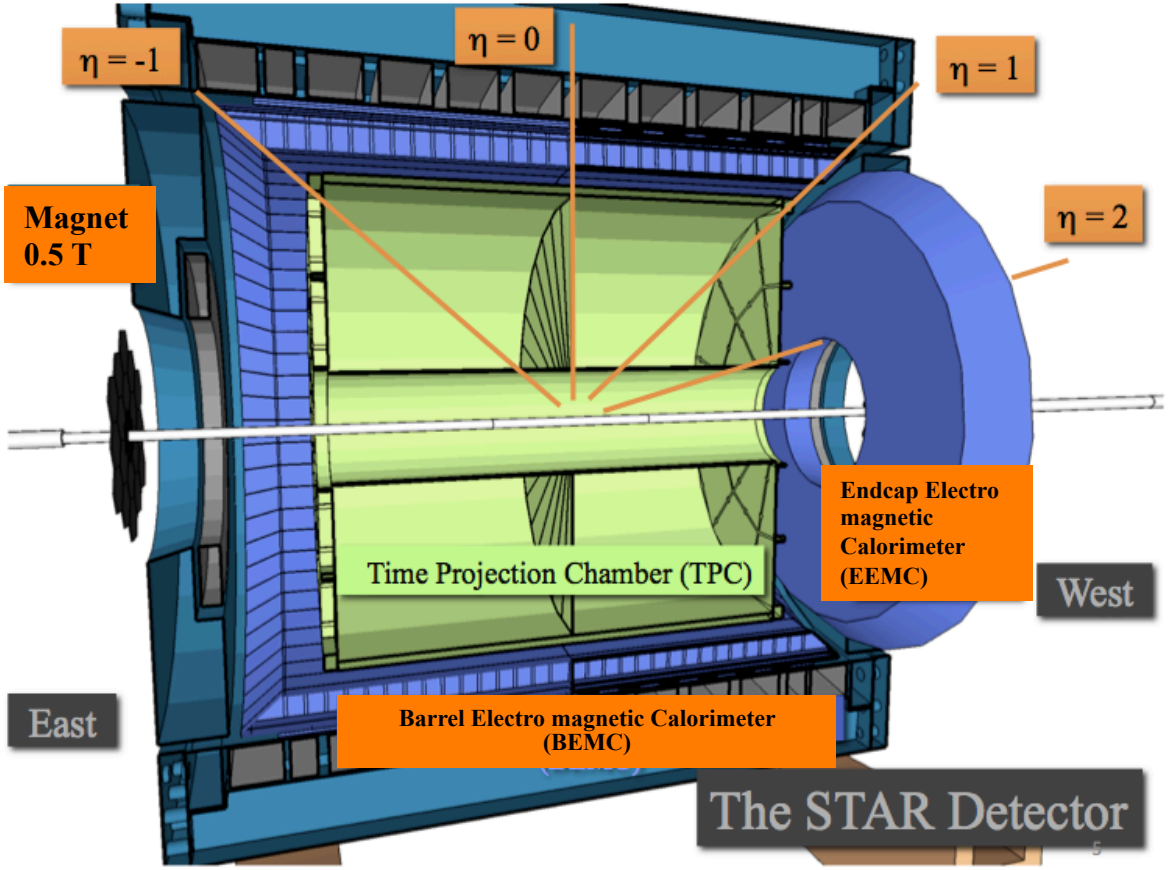
- Long runs with long. Polarization at 200 GeV in 2005, 2006, 2009, 2015.
- Collisions at 500/510 GeV with long. Pol. in 2009, 2012 and 2013.
- Long runs with trans. pol. in 2006, 2008, 2012 at 200GeV and 2011
  2017 at 500 GeV

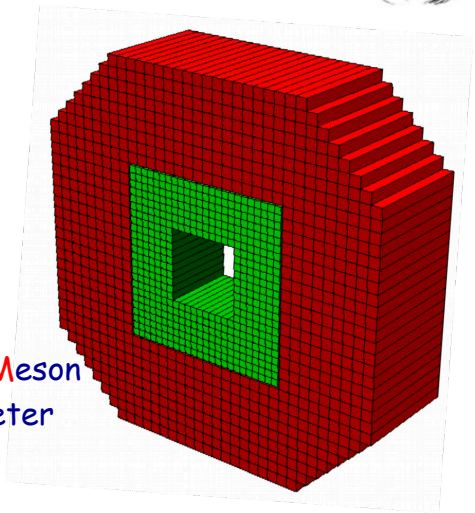


STAR Experiment at RHIC – STAR Detector

The spin program at Solenoidal Tracker at RHIC (STAR):

- Gluon polarization (π^0/Jet production): $\Delta g(x)$
- Quark/Anti-quark polarization (W/Z production): $\Delta q(x)$
- Transverse spin dynamics (W/Z production): Sivers function





Forward Meson Spectrometer (FMS)

Detectors used for gluon polarization study:

- Time Projection Chamber
  $|\eta| < 1.1, 0 \le \varphi < 2\pi$
- Barrel EM Calorimeter
  $|\eta| < 1, 0 \le \varphi < 2\pi$
- Endcap EM Calorimeter
  $1.08 < \eta < 2, 0 \le \varphi < 2\pi$
- Forward Meson Spectrometer
  $2.5 < \eta < 4, 0 \le \varphi < 2\pi$

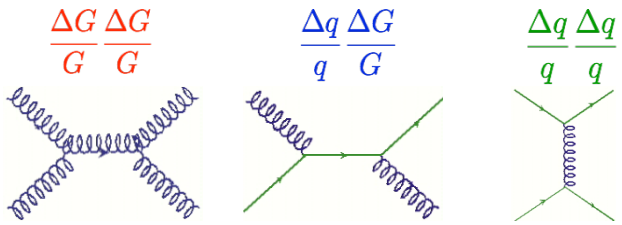
Exploring gluon Polarization at RHIC

Measure Longitudinal double spin asymmetries (A_{LL}):

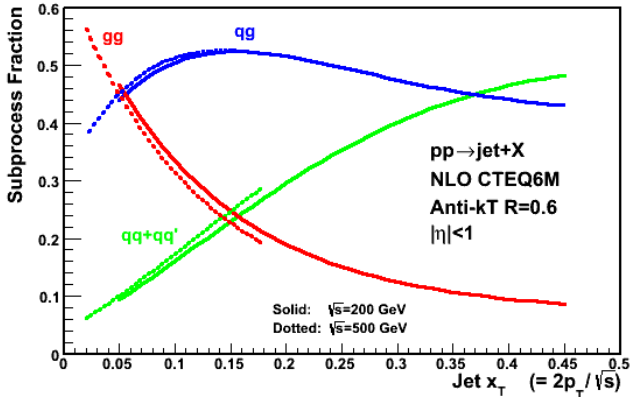
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{\sum_{f_1,f_2} \Delta f_1 \otimes \Delta f_2 \otimes d\hat{\sigma}^{f_1 f_2 \to fX} \cdot \hat{a}_{LL}^{f_1 f_2 \to fX} \otimes D_f^{\pi}}{\sum_{f_1,f_2} f_1 \otimes f_2 \otimes d\hat{\sigma}^{f_1 f_2 \to fX} \otimes D_f^{\pi}}$$

Δf_i: polarized parton distribution functions;

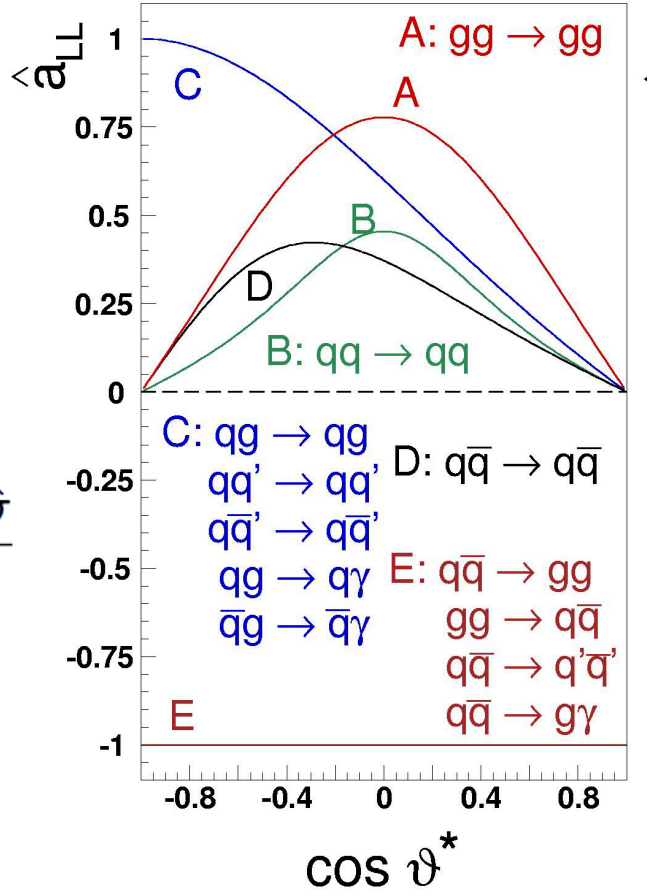
D^{π}_f: fragmentation functions.



Partonic fraction for jet production



$$\hat{a}_{LL} = \frac{d\Delta\hat{\sigma}}{d\hat{\sigma}}$$



Mukherjee and Vogelsang, PRD.86.094009

Exploring gluon Polarization at RHIC

Longitudinally polarized p+p collisions at 200 GeV and 500/510 GeV allow both cross section and double spin asymmetry A_{LL} measurements at STAR on:

- Inclusive Jet

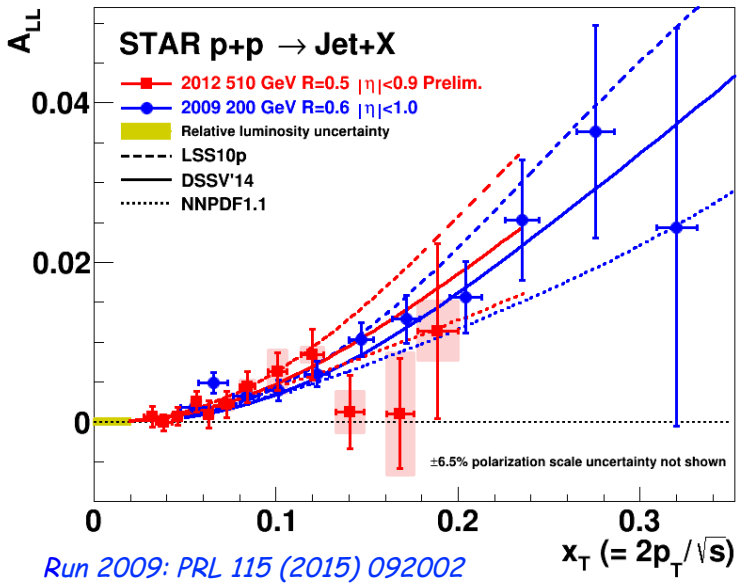
  x down to ~ 0.05 for jets in the mid-rapidity

- Inclusive π^0

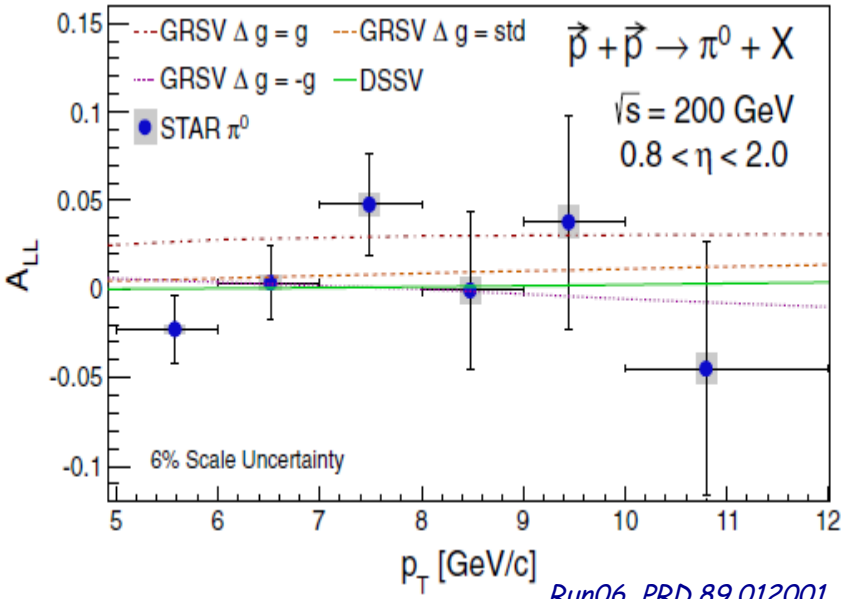
  x down to ~ 0.02 for forward π^0 $0.8 < \eta < 2.0$

- Di-jet

  x down to ~ 0.02 , correlation unfolds x_1, x_2 at the leading order



Run 2009: PRL 115 (2015) 092002
Run 2012: STAR Preliminary



Run06, PRD.89.012001

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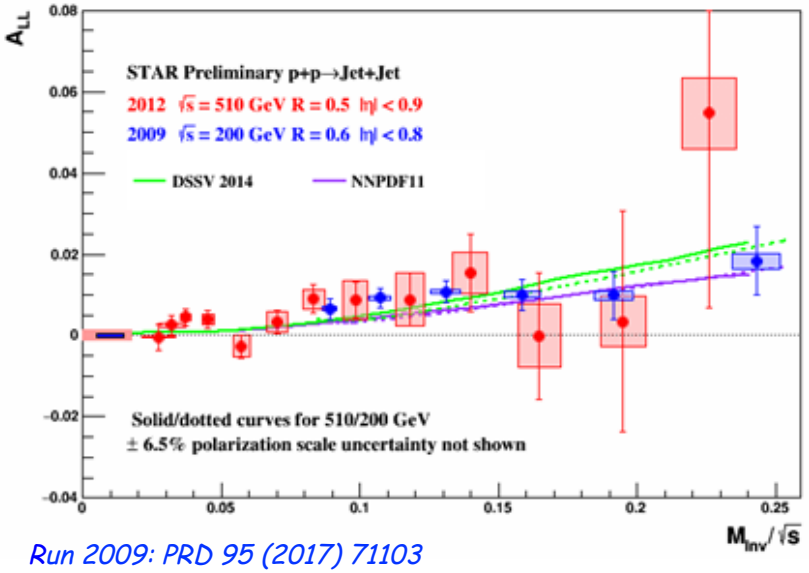

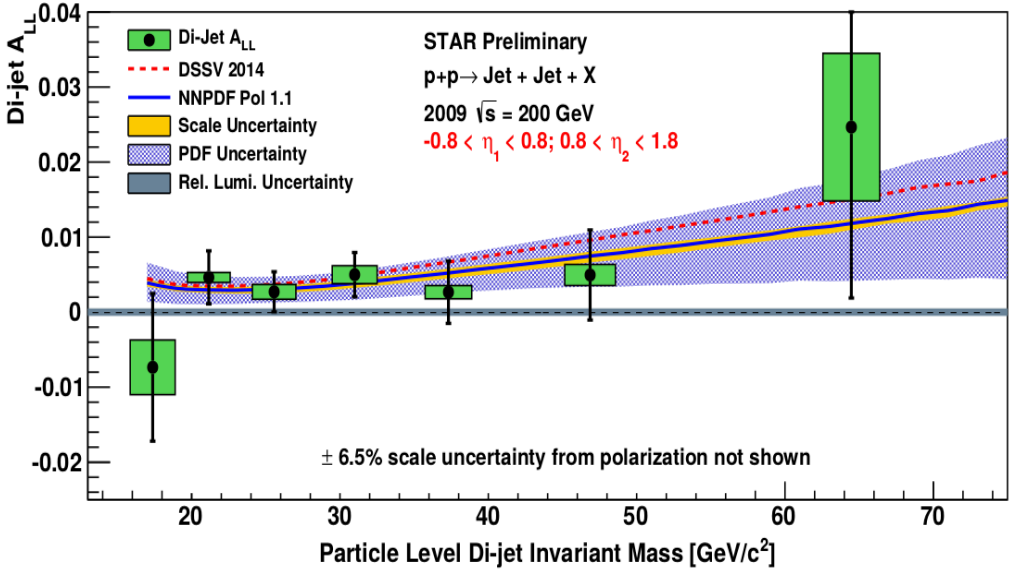

Run 2009: PRD 95 (2017) 71103
Run 2012: STAR Preliminary

Exploring gluon Polarization at RHIC

Longitudinally polarized p+p collisions at 200 GeV and 500/510 GeV allow both cross section and double spin asymmetry A_{LL} measurements at STAR on:

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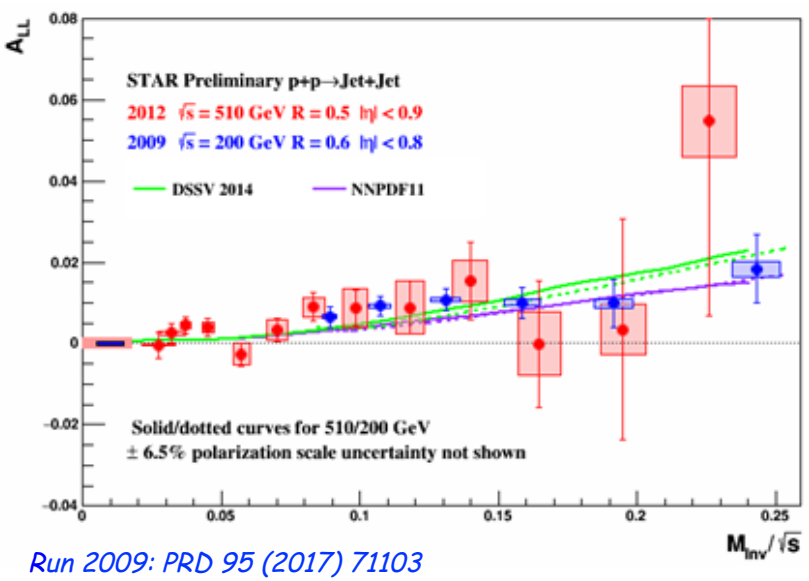
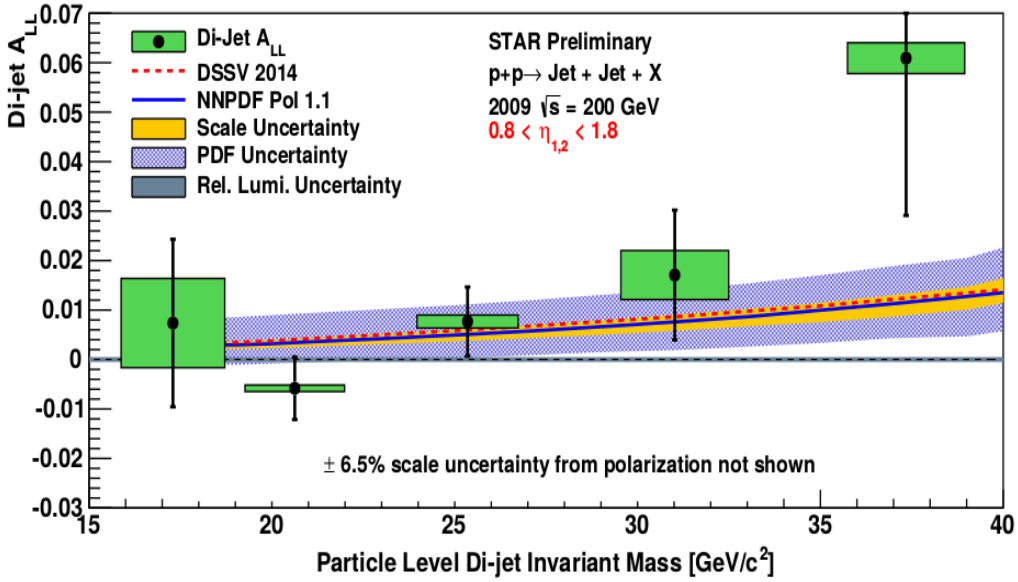
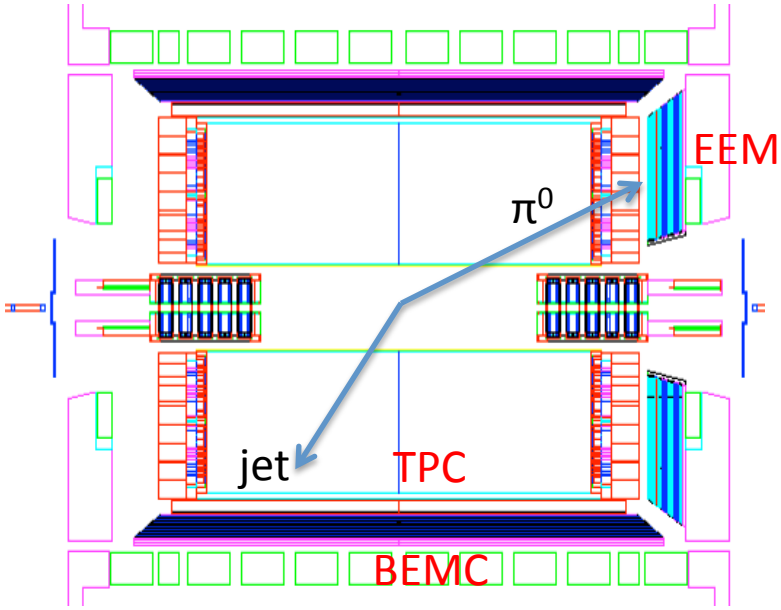




Run 2009: PRD 95 (2017) 71103
Run 2012: STAR Preliminary

π^0 - Jet A_{LL} measurements at STAR

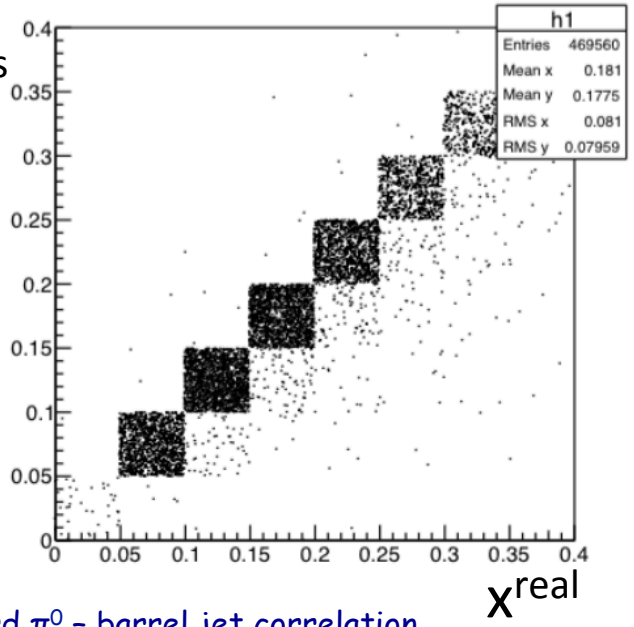
Channel: Using a jet in the mid-rapidity region correlated with an opposite-side neutral pion in the forward rapidity region 1.08 < η < 2.0 in the STAR EEMC provides a new tool to access the Δg(x) distribution at Bjorken-x down to 0.01.



$$x_1 = \frac{p_T^{jet}}{\sqrt{s}}(e^{\eta_{jet}} + e^{\eta_{\pi^0}}),$$

$$x_2 = \frac{p_T^{jet}}{\sqrt{s}}(e^{-\eta_{jet}} + e^{-\eta_{\pi^0}}),$$

$$\sqrt{\hat{s}} = \sqrt{x_1 x_2 s}.$$



Forward π^0 – barrel jet correlation using Daniel's NLO model calculation for this work

- Compared to inclusive jet measurements, this π^0 – jet channel also allows to constrain the initial parton kinematics, such as x_1, x_2 and $\sqrt{\hat{s}}$.
- Theoretical description of hadron-jet A_{LL} by next-to-leading order (NLO) model calculation: Daniel de Florian, PRD **79** (2009) 114014.

π^0 - Jet A_{LL} measurements at STAR

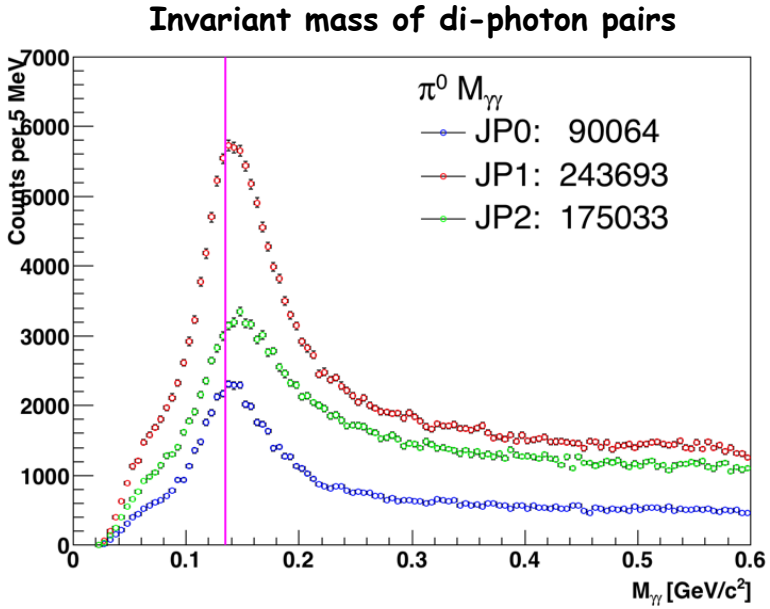
Analysis cuts for Run12 pp 510 GeV data:

π^0 reconstruction:

- π^0 p_T: > 4.0 GeV/c
- π^0 mass: (0, 0.6)
- π^0 physics eta: (1.086, 2.0)

π^0 – jet pairing:

✧ $|\Delta\varphi|$ > 2.0 (back-to-back)



Jet reconstruction:

- Anti k_T alogorithm, R=0.6
- Leading jet with p_T > 8.0 GeV/c
- Jet physics eta: (-0.9, 0.9)
- Jet points to a jet patch (JP) trigger
- Contribution from the calorimeters to the total jet energy (R_t) was required to be less than 0.95
- Sum track p_T > 0.5 GeV/c

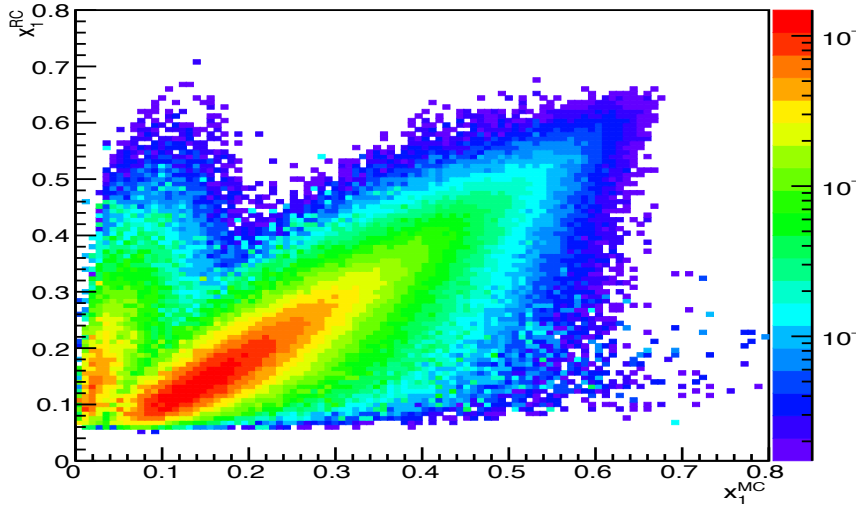
Triggers:

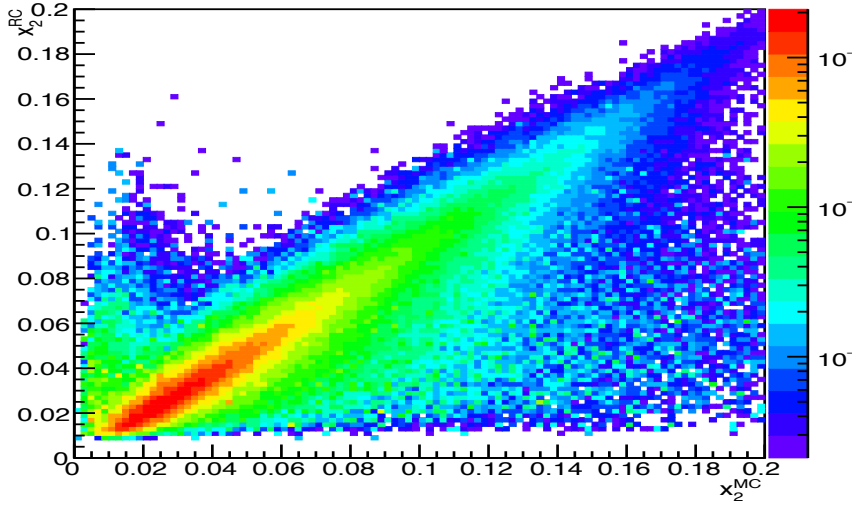
✧ JP triggers (EM calorimeter triggers, and the size of a JP is 1.0×1.0 in η-φ coverage):

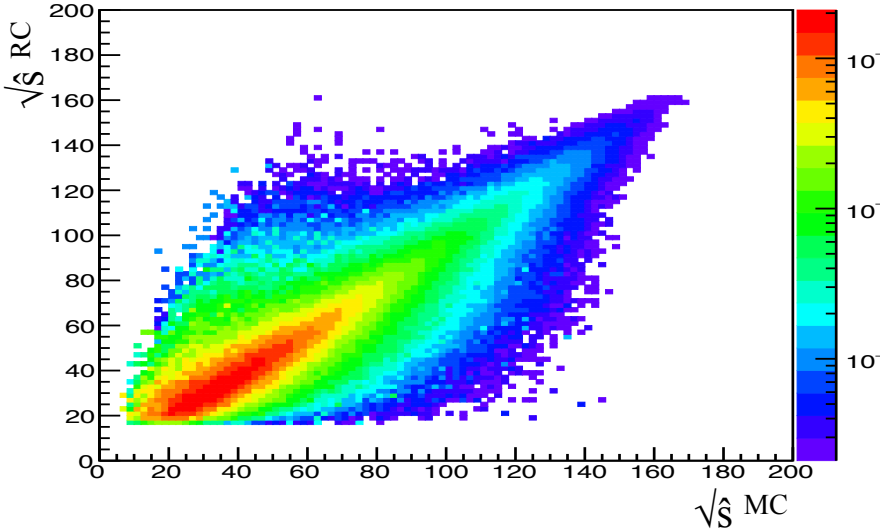
- JP0: jet p_T > 5.4 GeV/c
- JP1: jet p_T > 7.3 GeV/c
- JP2: jet p_T > 14.4 GeV/c

π^0 - Jet A_{LL} measurements at STAR

Pythia simulation:







- The reconstructed x_1, x_2, and $\sqrt{\hat{s}}$ of matched π^0-jet pair show a good linearity with MC (Pythia6426-Perugia0).

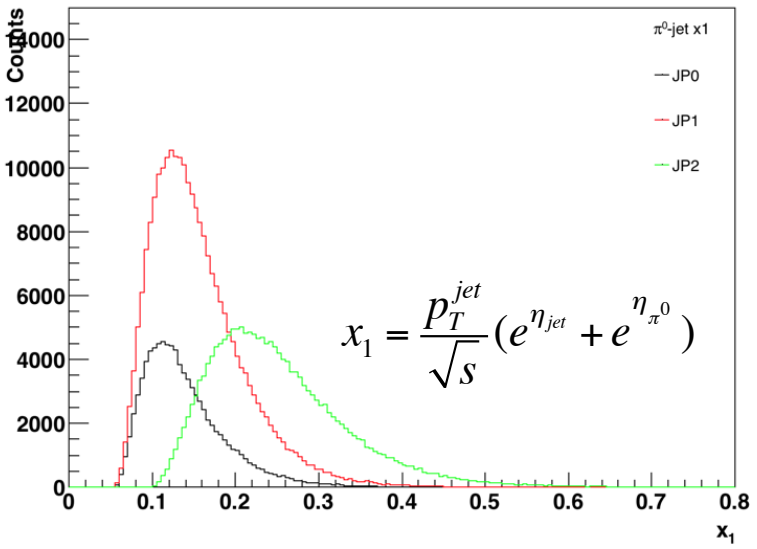
$$x_1 = \frac{p_T^{jet}}{\sqrt{s}}(e^{\eta_{jet}} + e^{\eta_{\pi^0}}),$$

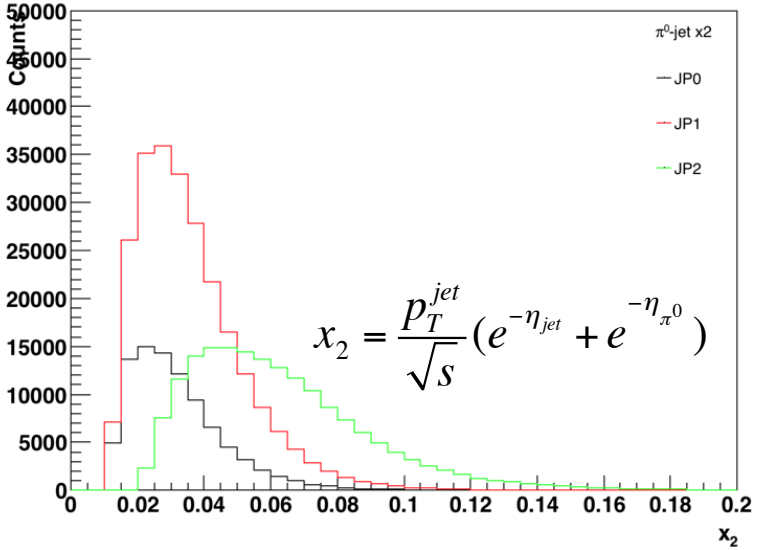
$$x_2 = \frac{p_T^{jet}}{\sqrt{s}}(e^{-\eta_{jet}} + e^{-\eta_{\pi^0}}),$$

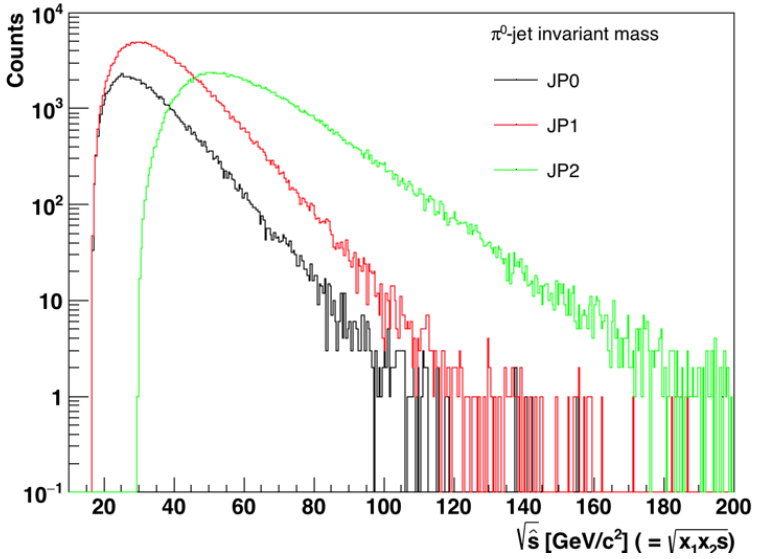
$$\sqrt{\hat{s}} = \sqrt{x_1 x_2 s}.$$

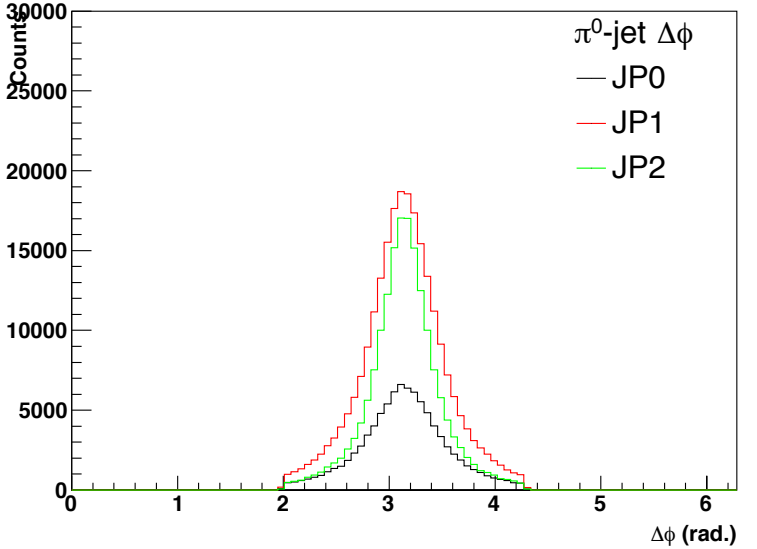
π^0 - Jet A_{LL} measurements at STAR

Reconstructed kinematics from data:



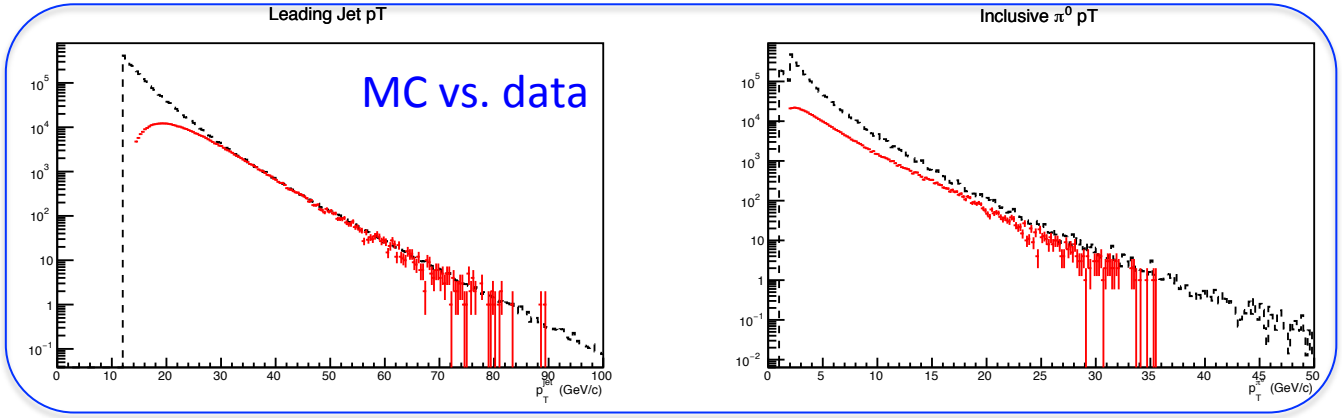


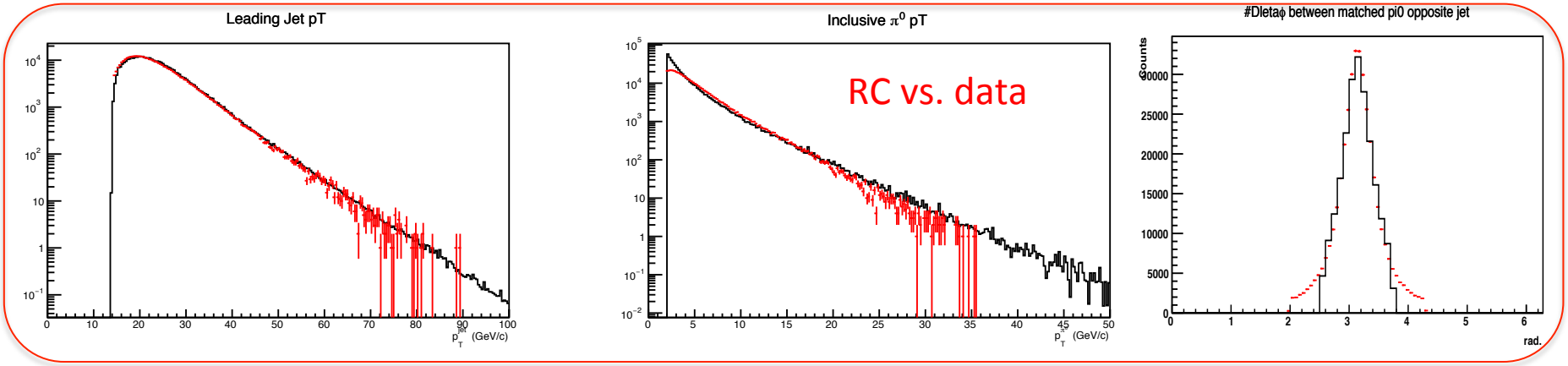




π^0 - Jet A_{LL} measurements at STAR

Pythia simulation VS. data:

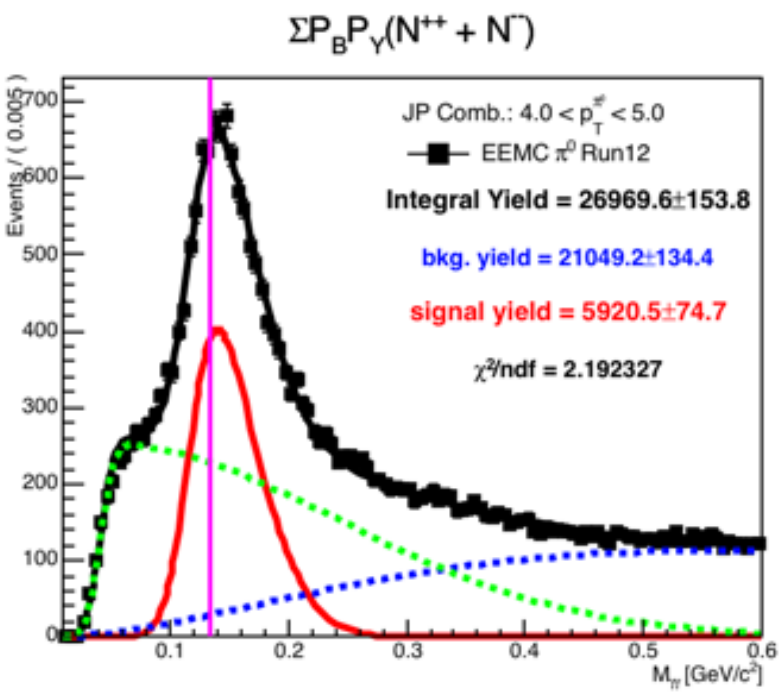




- STAR jet reconstruction efficiency was applied for the reconstructed spectrum (solid black hisogram) in simulation.
- Weighted by the jet reconstruction efficiency, the π^0/jet p_T spectrum and $\Delta\phi$ distribution from simulation are consistent with data.

π^0 - Jet A_{LL} measurements at STAR

Background subtraction:



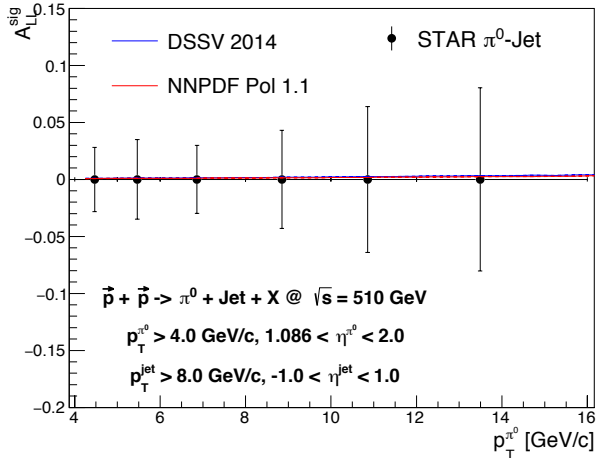
The invariant mass spectrum (weighted by relative luminosities and beam polarizations), are fitted to estimate signal yield for each kinematic variable bin, respectively.

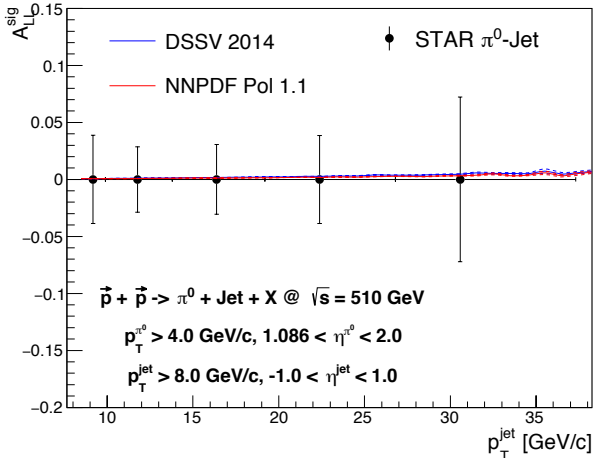
- Signal: A reconstructed photon pair is associated with the π^0 signal
- Conversion background: A reconstructed photon pair is associated with the conversion background
- Other background: Photon pairs that are not identified as signal or conversion background

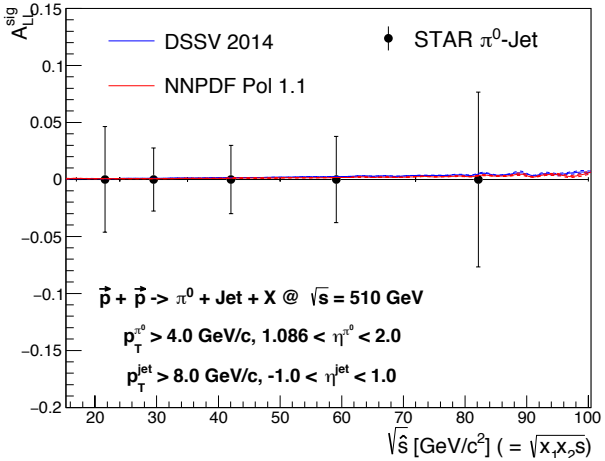
- The raw yield of π^0-jet are well fitted by extended likelihood formalism in RooFit, in which the signal shape was described by skewed Gaussian function
- The shapes of signal and backgrounds are determined by fitting the spectrum summed over spin states
- Signal yield and background yields are estimated as free parameters by fitting over [0., 0.6] GeV/c^2 with the fixed signal and background shapes
- Signal (background) asymmetries, A_{LL}^S (A_{LL}^B), are calculated by the estimated yields

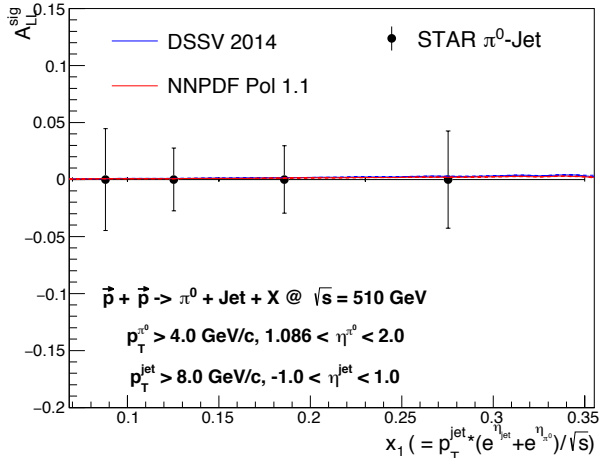
π^0 - Jet A_{LL} measurements at STAR

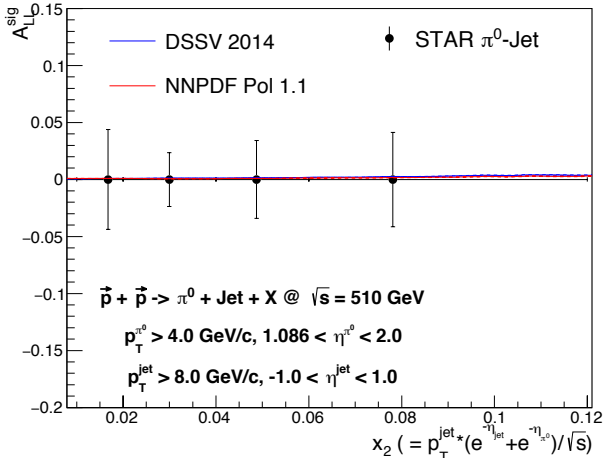
Uncertainty projections of π^0-jet A_{LL}:











$$A_{LL} = \frac{\sum P_Y P_B [(N^{++} + N^{--}) - R_3 (N^{+-} + N^{-+})]}{\sum P_Y^2 P_B^2 [(N^{++} + N^{--}) + R_3 (N^{+-} + N^{-+})]}$$

$$\delta A_{LL} = \frac{\sqrt{\sum P_Y^2 P_B^2 [\delta(N^{++} + N^{--})^2 + R_3^2 \delta(N^{+-} + N^{-+})^2]}}{\sum P_Y^2 P_B^2 [(N^{++} + N^{--}) + R_3 (N^{+-} + N^{-+})]}$$

- Statistics uncertainty projections for π^0-jet A_{LL} in STAR Run12 pp 510 GeV data

➢ Theoretical predictions by NLO model calculations: PRD 79 (2009) 114014.

Conclusion and Outlook

- STAR has been making significant contributions to the gluon polarization program via inclusive jets, inclusive neutral pions and di-jets measurements.

  More results can be found in talk: Adam Gibson, Saturday September 2

- A_{LL} measurements via correlations between forward neutral pion and barrel jet allow to constrain the initial partonic kinematics. Analysis results using this channel is underway.

- More data have been taken by STAR and more precision measurements are expected.

Thanks for your attention!