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Spin'16

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)

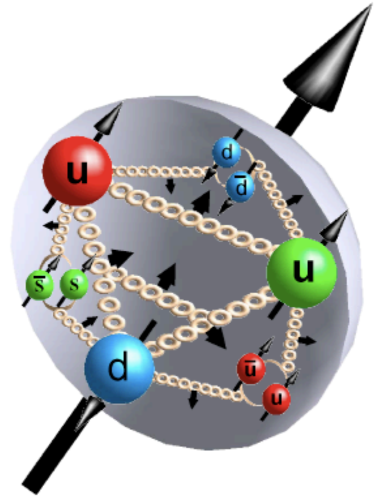
Central China Normal University

Outline

Spin'16

- 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



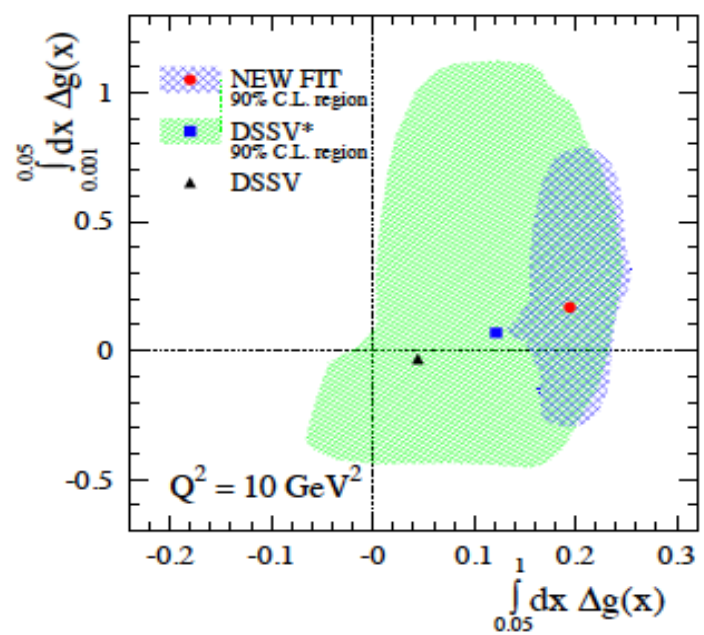
The observed spin of the proton can be decomposed into contributions from the intrinsic quark and gluon spin and orbital angular momentum.

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

unique measurement at RHIC

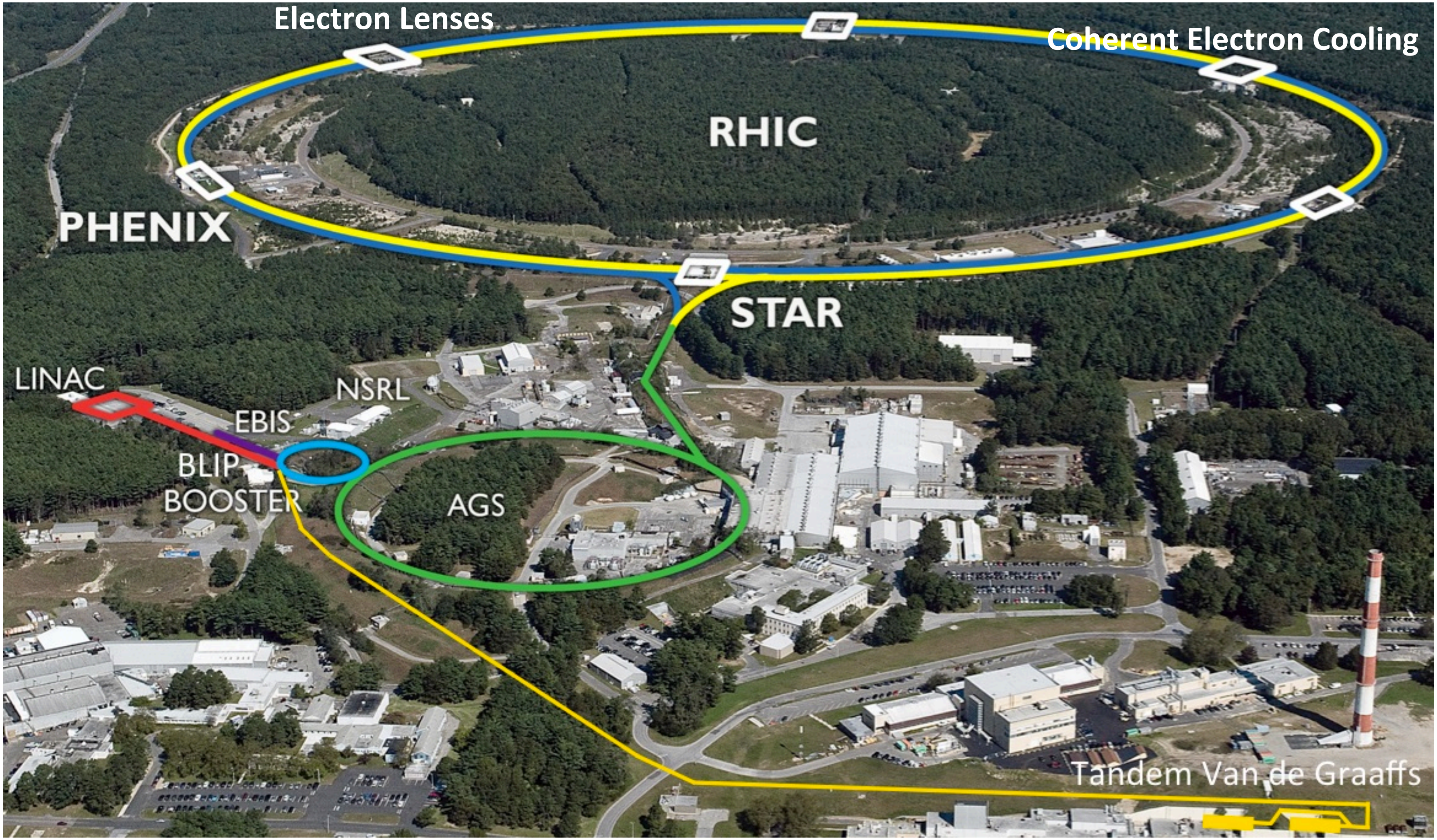
- DIS data measure the integral of quark polarization well to be around ~ 30%
- Both DSSV and NNPDF, with 2009 RHIC results integrated in the fits, find evidence for positive gluon polarization:
  - DSSV: $0.19^{+0.06}_{-0.05}$ at 90% c.l. for x > 0.05
- Uncertainties on integral over low x region are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

DSSV, PRL 113, 012001



RHIC – Polarized Proton+Proton Collider

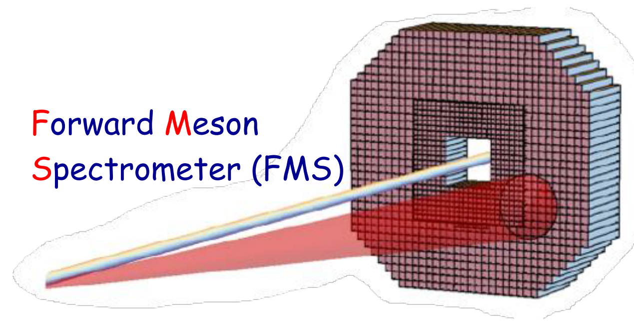
The Relativistic Heavy Ion Collider (RHIC), the world's first polarized hadron collider, is designed to collide many particle species energies.

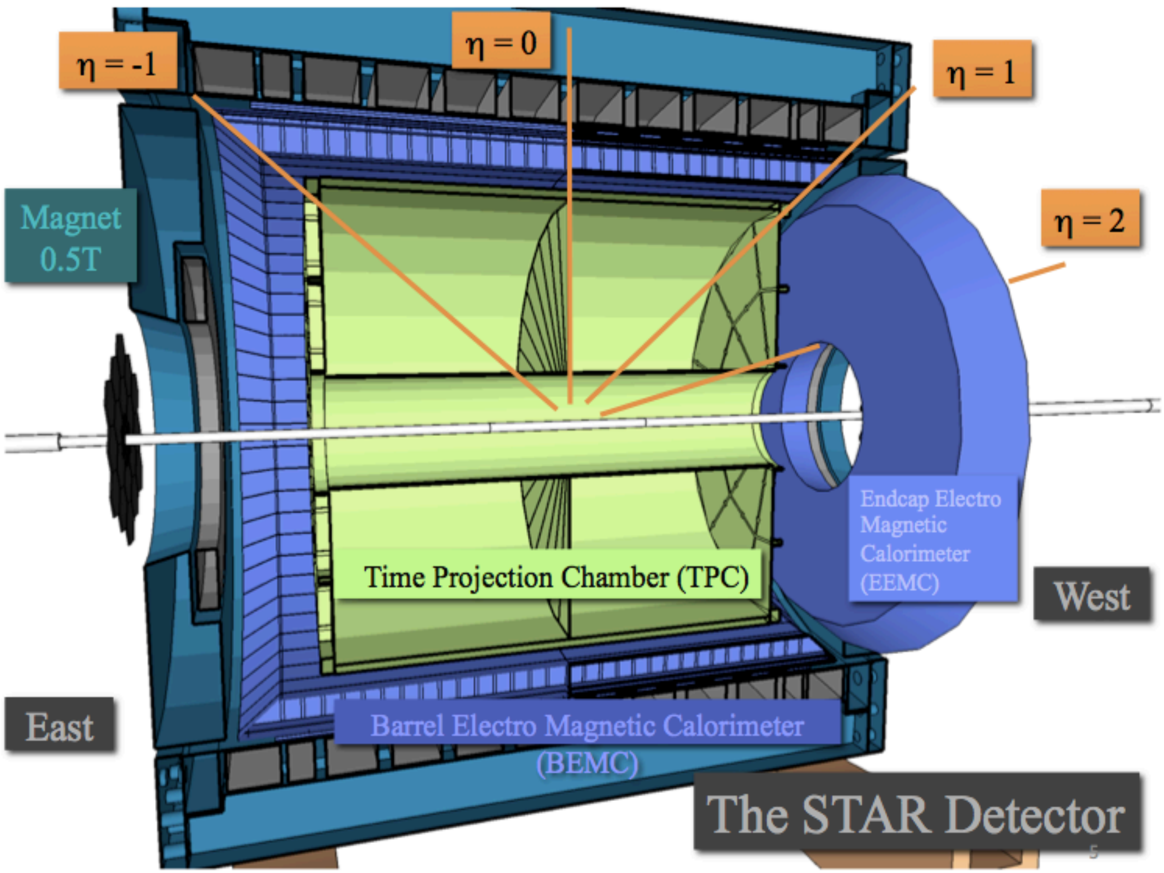


STAR Experiment at RHIC – STAR Detector

The polarized p+p program at Solenoidal Tracker at RHIC (STAR):

- Study proton intrinsic properties
- QCD
- Forward program





Detectors used for gluon polarization study:

- Time Projection Chamber
  $|\eta| < 1.1,\ 0 \leq \varphi < 2\pi$
- Barrel EM Calorimeter
  $|\eta| < 1,\ 0 \leq \varphi < 2\pi$
- Endcap EM Calorimeter
  $1.08 < \eta < 2,\ 0 \leq \varphi < 2\pi$
- FMS
  $2.5 < \eta < 4,\ 0 \leq \varphi < 2\pi$

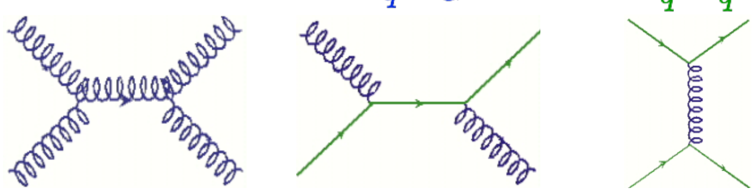
Exploring gluon Polarization at RHIC

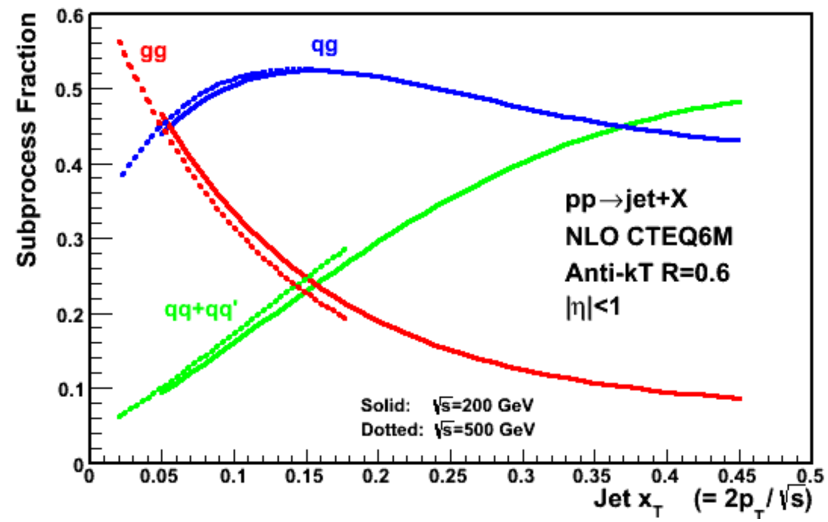
Measure Longitudinal double spin asymmetries (A_{LL}):

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

Δf: polarized parton distribution functions;
$D^h{}_f$: fragmentation functions.

$\frac{\Delta G}{G}\frac{\Delta G}{G}$ $\quad$ $\frac{\Delta q}{q}\frac{\Delta G}{G}$ $\quad$ $\frac{\Delta q}{q}\frac{\Delta q}{q}$





Sensitive probes:

- inclusive jets
- neutral pions (π^0)
- correlations (di-jets, h-jet, …)

For most RHIC kinematics, gg and qg dominate, making A_{LL} for jets sensitive to gluon polarization.

Exploring gluon Polarization at RHIC

Longitudinally polarized p+p collisions at 200 GeV and 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 at 200/510 GeV

- Inclusive π^0

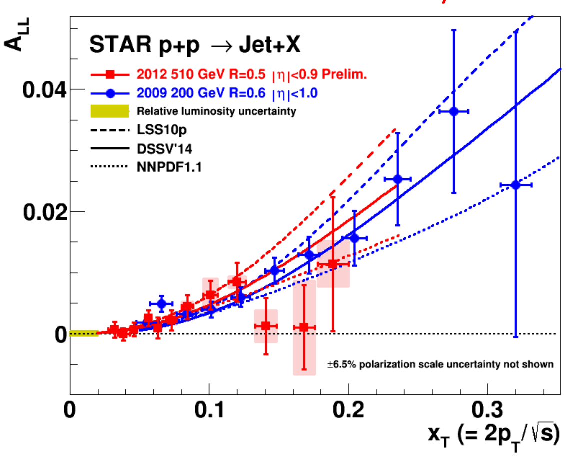
  x down to ~ 0.02 for forward π^0 $0.8 < \eta < 2.0$ at 200/510 GeV

- Di-jet

  Correlation unfolds x_1, x_2 at the leading order

Run 2009: PRL 115, 092002

Run 2012: STAR Preliminary



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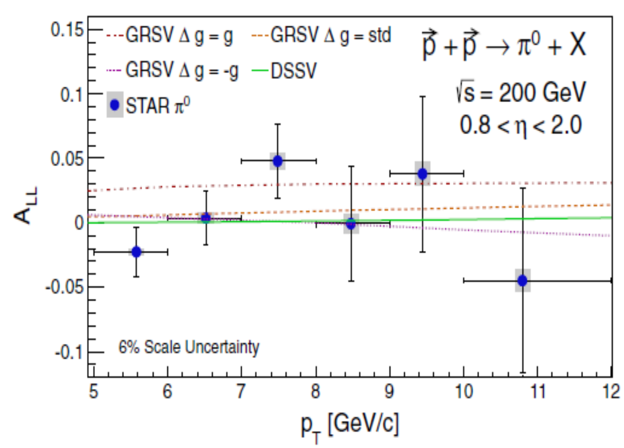
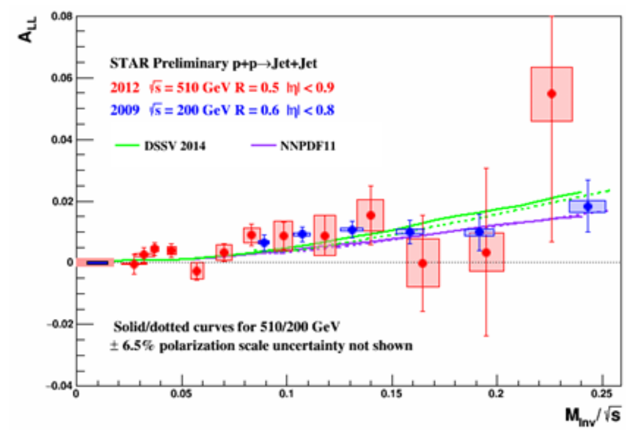


Run 2009: STAR Preliminary

Run 2012: STAR Preliminary



π^0 - Jet A_{LL} measurements at STAR

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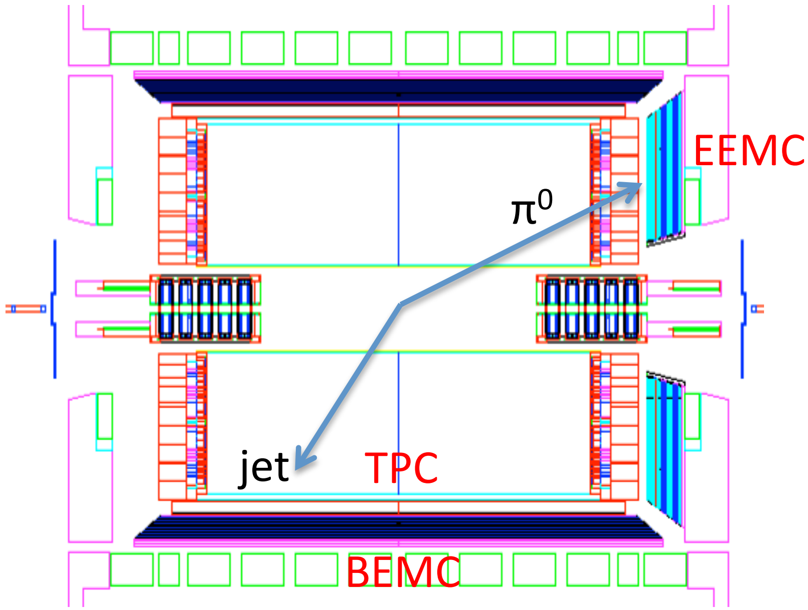
Channel: Using a jet in the mid-rapidity region correlated with an opposite-side neutral pion in the forward rapidity region $1.08 < \eta < 2.0$ in the STAR EEMC provides a new tool to access the $\Delta G(x)$ distribution at Bjorken-x down to 0.01.



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

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

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

- 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

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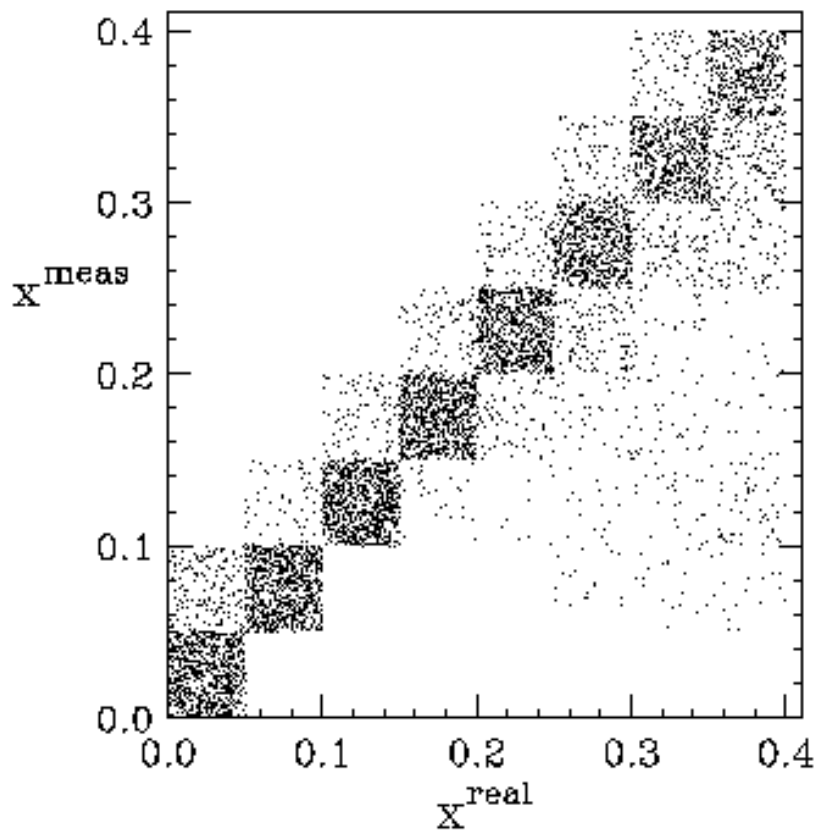
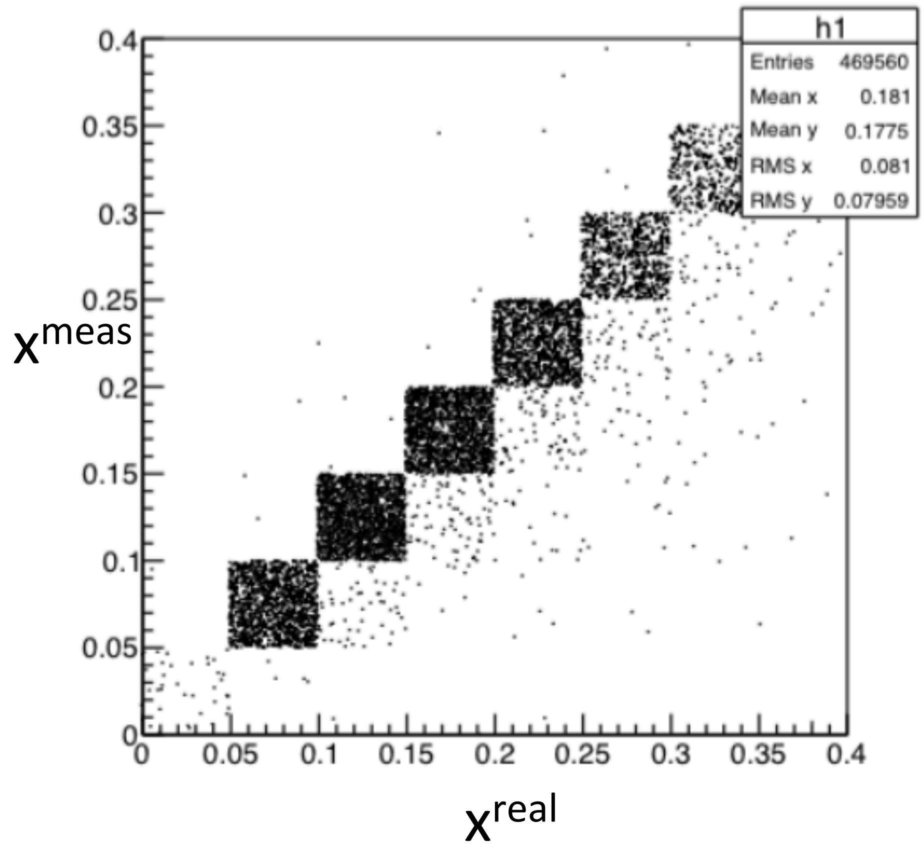
Parton vs. Reconstructed kinematics:



π^+ - jet correlation in mid-rapidity
from Daniel de Florian, PRD **79** (2009) 114014



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

- Find that most of the generated events in the Monte Carlo implementation of the NLO corrections give the same value for the 'real' and 'measured' momentum fractions.

π^0 - Jet A_{LL} measurements at STAR

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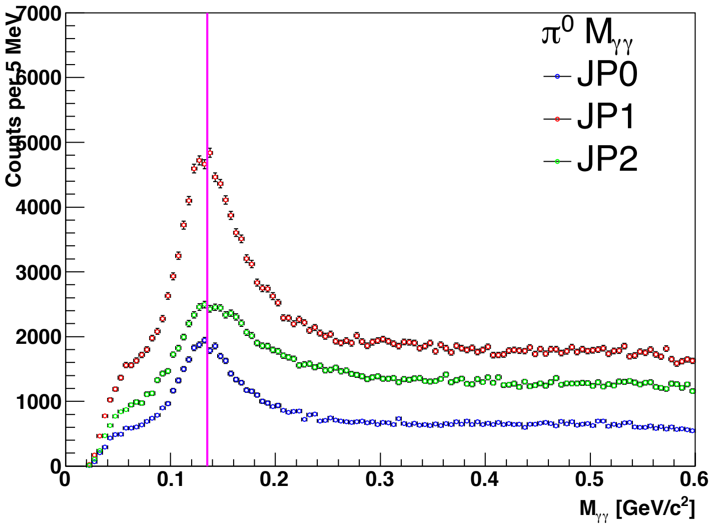
Analysis cuts for Run12 pp 510 GeV data:

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)



Invariant mass of π^0 from π^0-jet pairs

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

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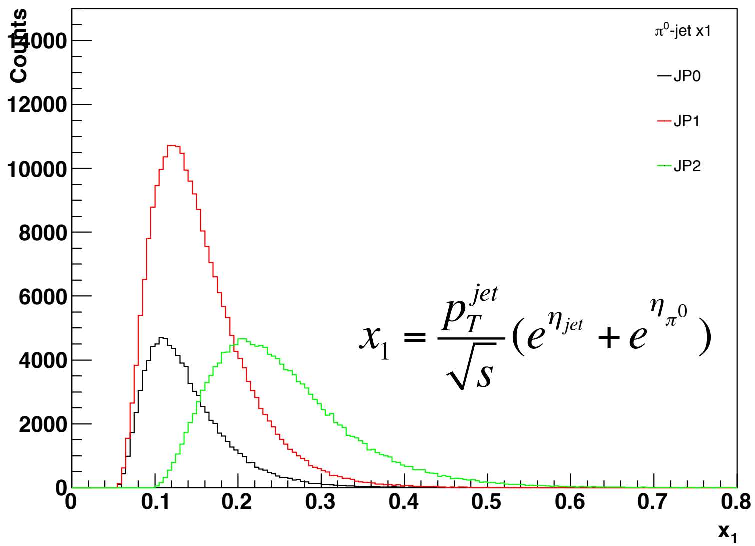
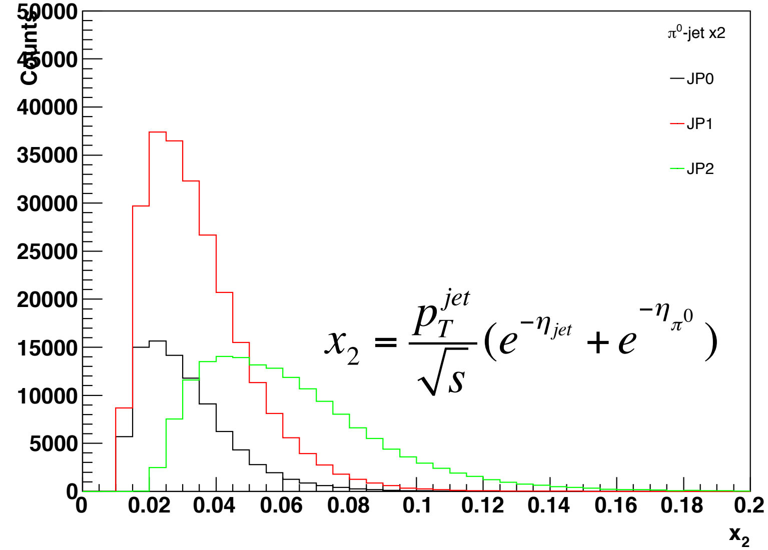
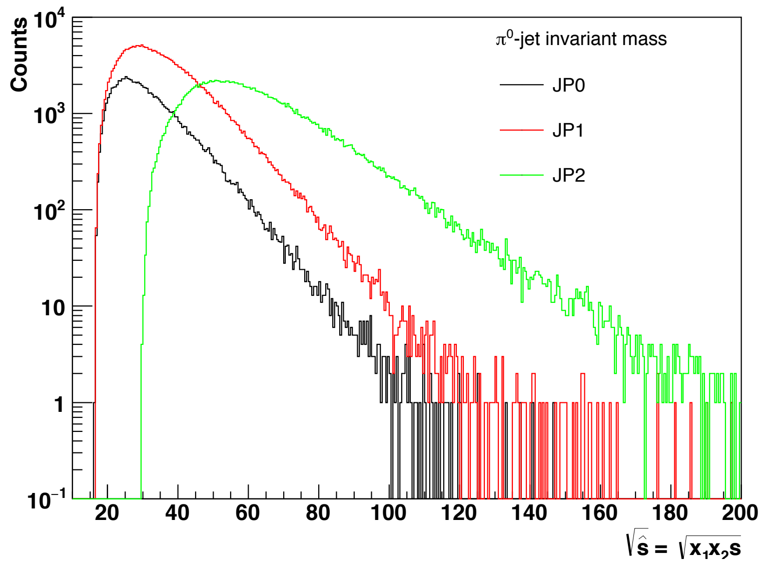
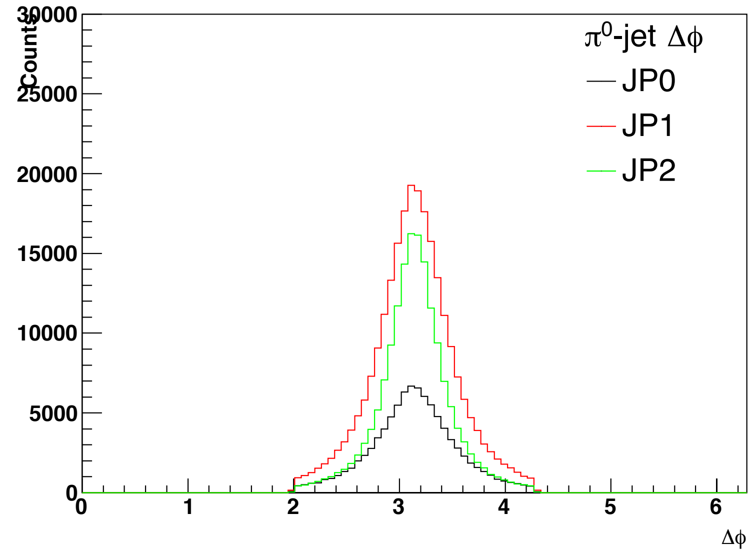
Reconstructed kinematics from data:



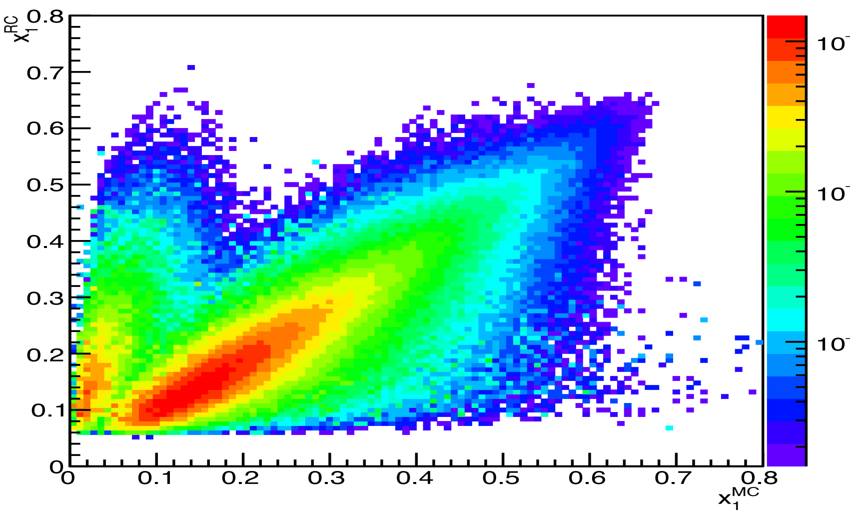


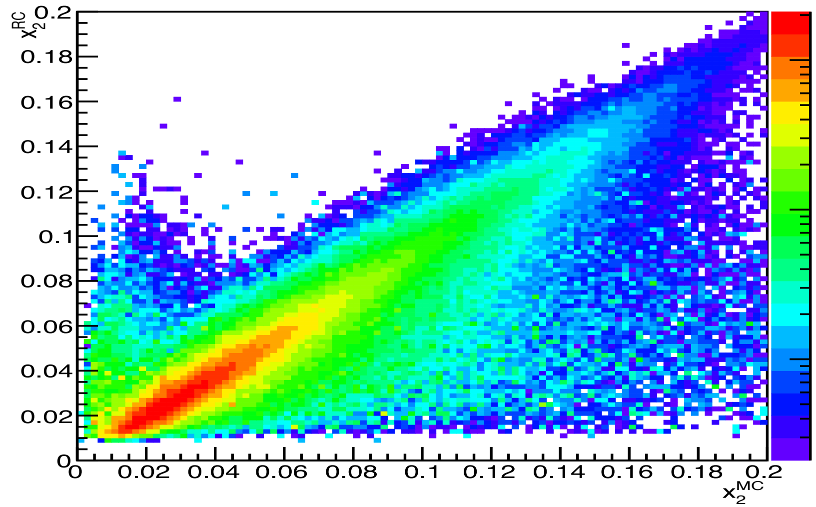


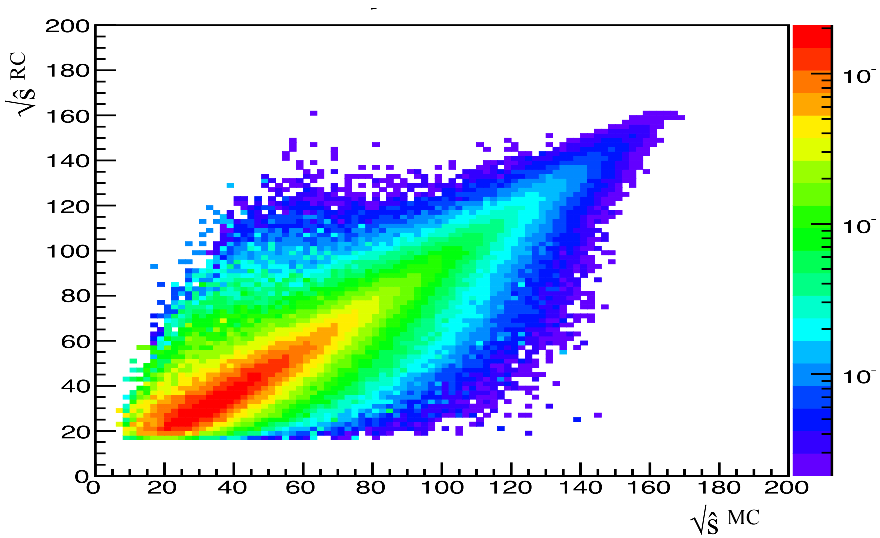


π^0 - Jet A_{LL} measurements at STAR

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).

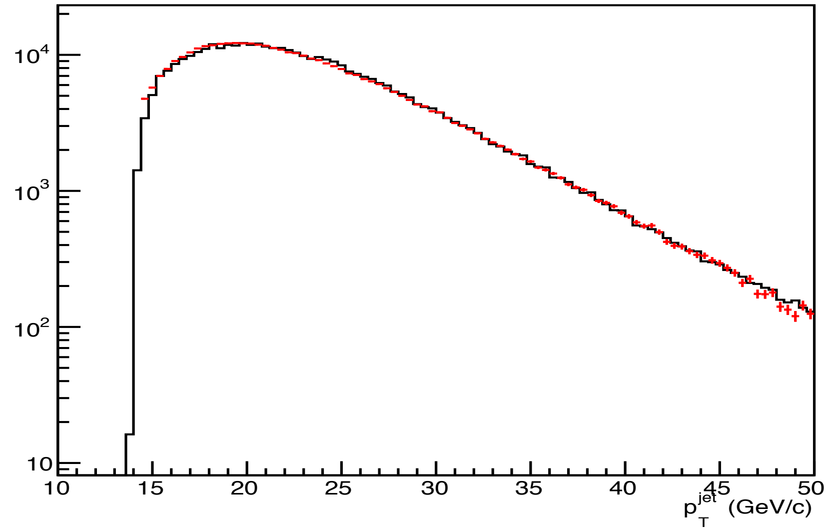
$$x_1 = \frac{p_T^{jet}}{\sqrt{s}}\left(e^{\eta_{jet}} + e^{\eta_{\pi^0}}\right),$$

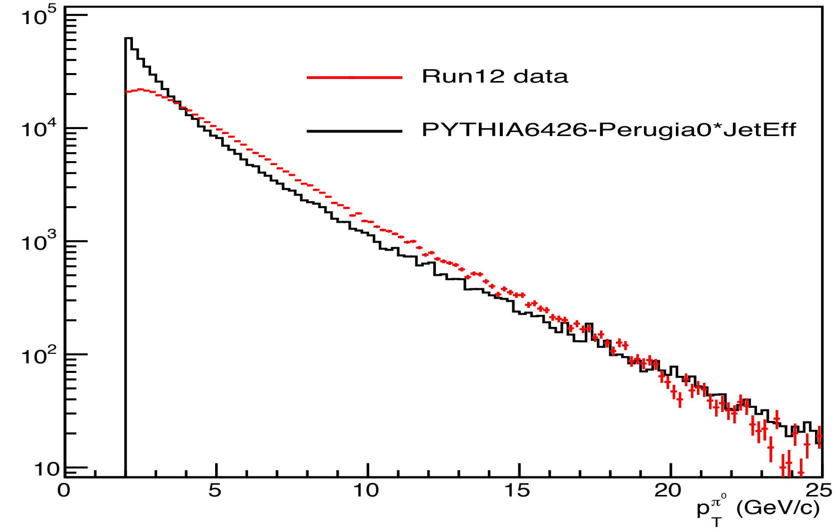
$$x_2 = \frac{p_T^{jet}}{\sqrt{s}}\left(e^{-\eta_{jet}} + e^{-\eta_{\pi^0}}\right),$$

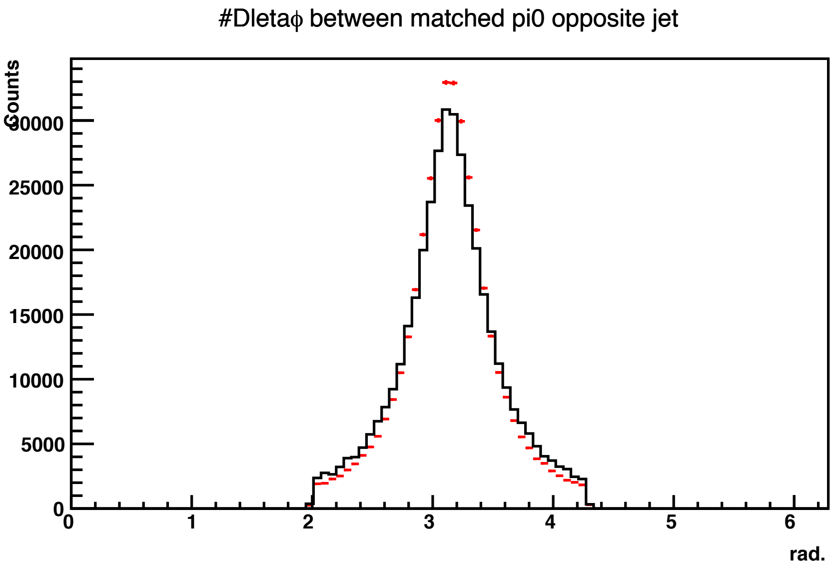
$$\sqrt{\hat{s}} = \sqrt{x_1 x_2 s}.$$

π^0 - Jet A_{LL} measurements at STAR

Pythia simulation VS. data:







- Ratio of leading jet p_T from Run12 data to the leading jet p_T from generator MC was taken as jet reconstruction efficiency.
- Weighted by the jet reconstruction efficiency, the π^0/jet p_T spectrum and $\Delta\phi$ distribution from MC are consistent with data.

π^0 - Jet A_{LL} measurements at STAR

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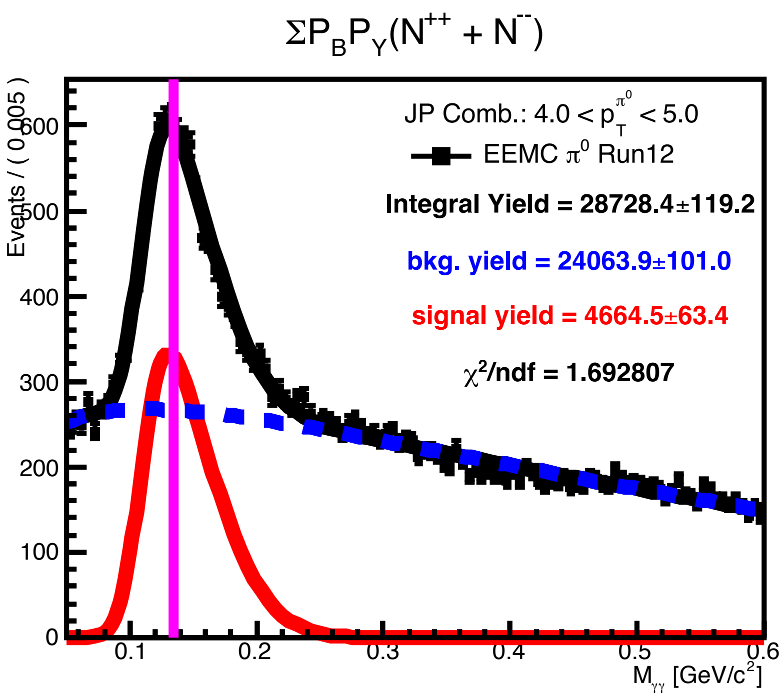
Background subtraction:



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

$$sig(x):\ k \times e^{\frac{-(x-\mu)^2}{2\sigma^2}} \times [1+\mathrm{Erf}(\frac{a(x-\mu)}{\sqrt{2}\sigma})]$$

$$bkg(x):\ A \times x^B \times e^{Cx}$$

$$model(x) = \frac{n_{sig}}{n_{sig}+n_{bkg}} * sig(x) + \frac{n_{bkg}}{n_{sig}+n_{bkg}} * bkg(x)$$

$$n_{raw} * model(x) = n_{sig} * sig(x) + n_{bkg} * bkg(x)$$

- The raw yield (n_{raw})of π^0-jet are well fitted by model(x), in which the signal shape was described by skewed Gaussian function sig(x), and background shape was fitted by Gamma function bkg(x);
- The shapes of sig(x) and bkg(x) were determined by fitting the spectrum summed over spin states.
- Signal yield (n_{sig}) and background yield (n_{bkg}) are estimated as free parameters by fitting over [0.05, 0.6] GeV/c^2 with the fixed sig(x) and bkg(x) shapes.
- Signal (background) asymmetries, A_{LL}^S (A_{LL}^B), are calculated by the estimated normalization n_{sig} (n_{bkg}).

π^0 - Jet A_{LL} measurements at STAR

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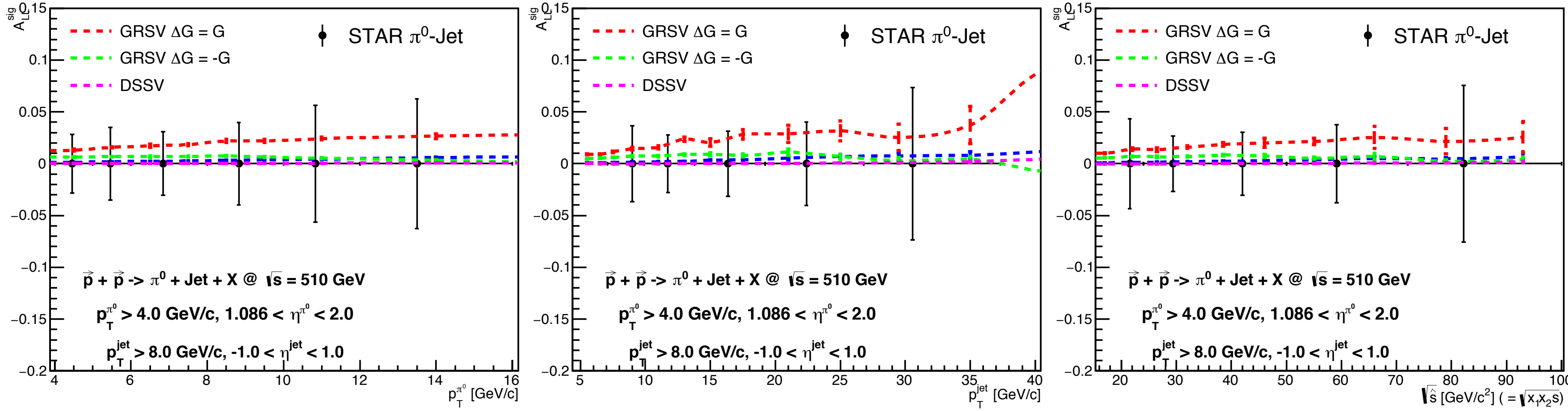
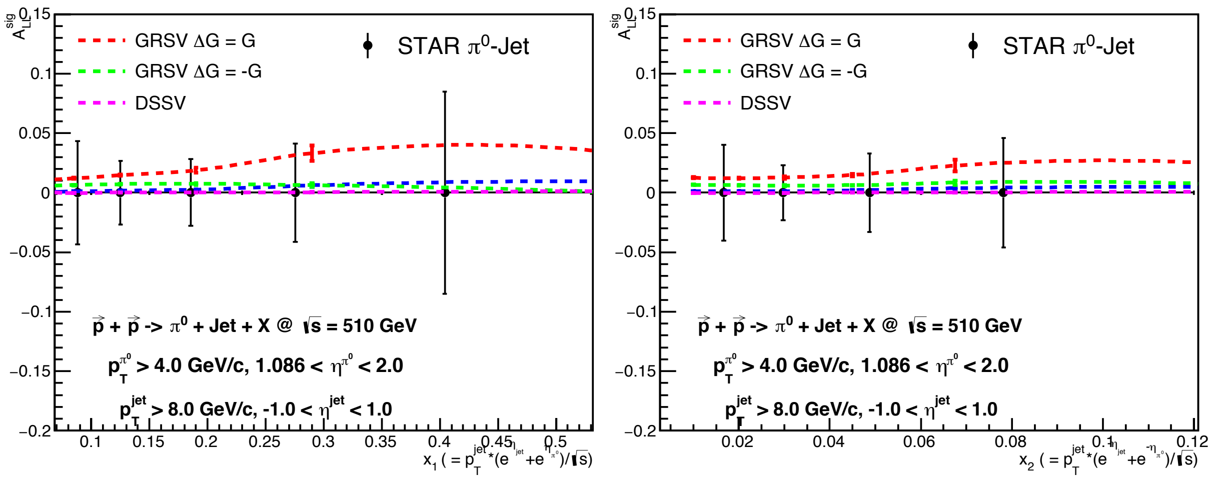
Uncertainty projections of π^0-jet A_{LL}:





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

➢ Theoretical predictions by NLO model calculations: Daniel de Florian, PRD 79 (2009) 114014.

Conclusion

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