Recent PHENIX Efforts on Probing the Gluon Polarization in the Proton

Haiwang Yu

(New Mexico State University)

for PHENIX Collaboration

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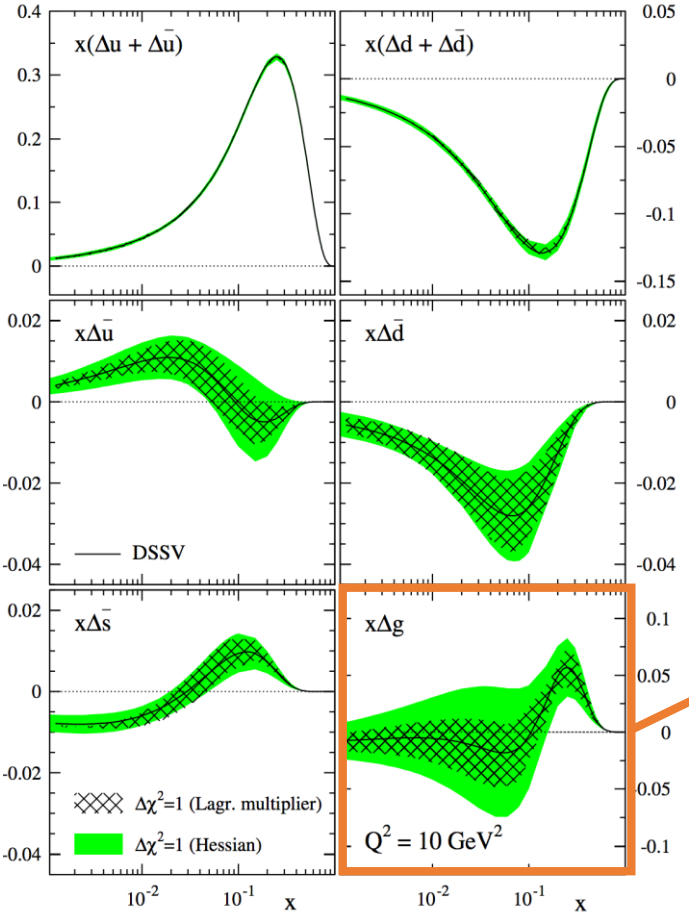
U.S. DEPARTMENT OF ENERGY | Office of Science

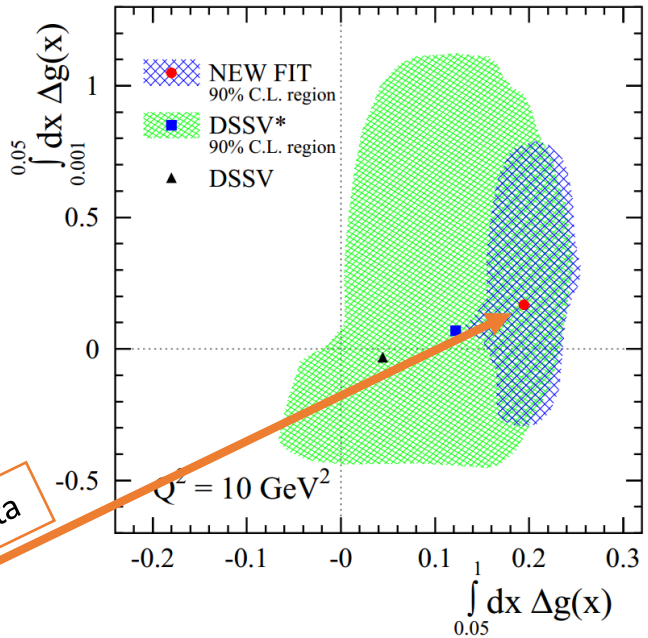
Current Knowledge on Gluon Polarization

DSSV NLO Global Fit*
PRD80. 034030 (2009)



*Including DIS, SIDIS data and RHIC data before 2006.

Phys. Rev. Lett. 113, 012001 (2014)



RHIC 2009 π^0 and Jet data

- Quark polarization was relatively well constrained by DIS, SIDIS experiments.
  - Sea quark polarization not so well known.

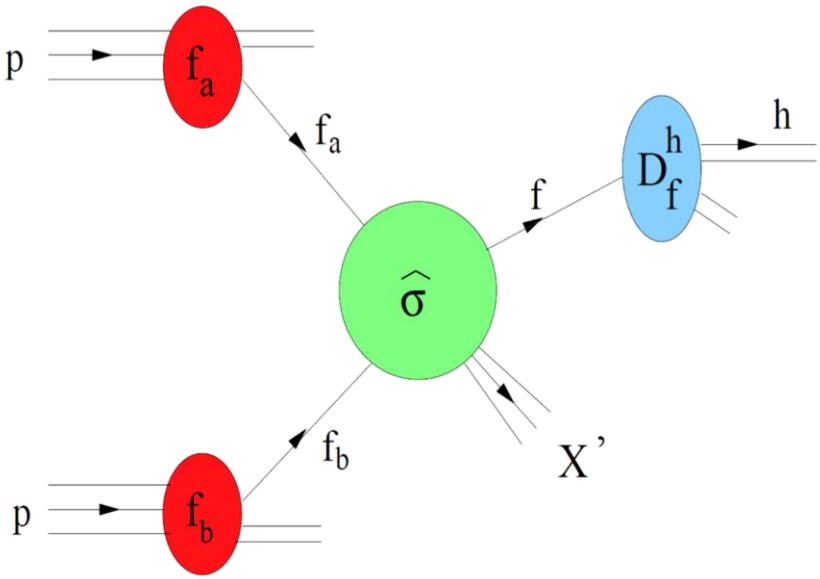
S. Park's Talk

- The Gluon polarization was poorly constrained.

Gluon Polarization and Double Helicity Asymmetries (A_{LL})

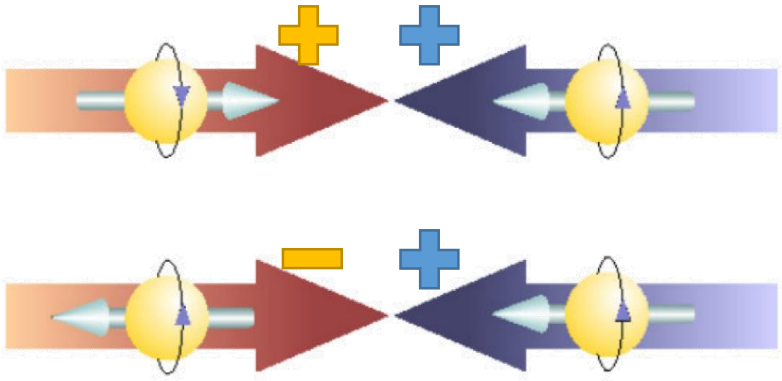
Theoretically:

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{\sum_{a,b,c=q,\bar{q},g} \Delta f_a \otimes \Delta f_b \otimes \Delta\hat{\sigma} \otimes D_{h/c}}{\sum_{a,b,c=q,\bar{q},g} f_a \otimes f_b \otimes \hat{\sigma} \otimes D_{h/c}}$$



Experimentally:

$$A_{LL} = \frac{1}{P_B P_Y} \frac{N^{++} - R\,N^{+-}}{N^{++} + RN^{+-}}$$

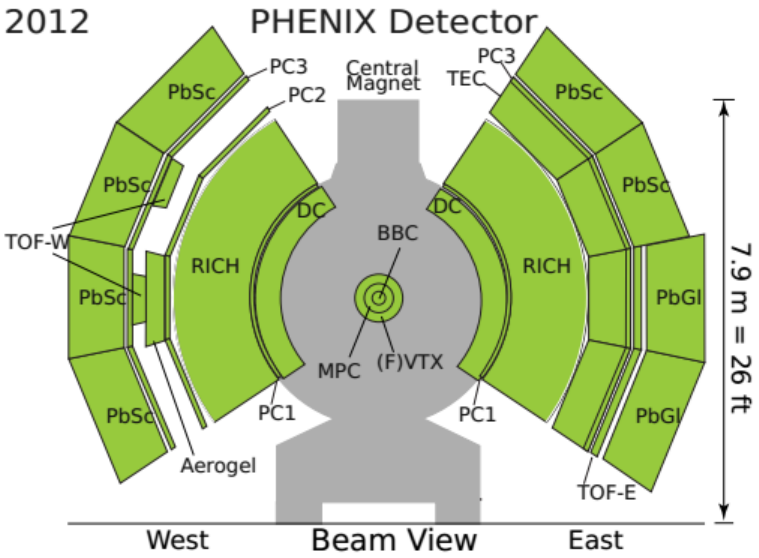


Where $P_{B,Y}$ is the polarization of Blue (Yellow) beam.
And R is the relative luminosity:

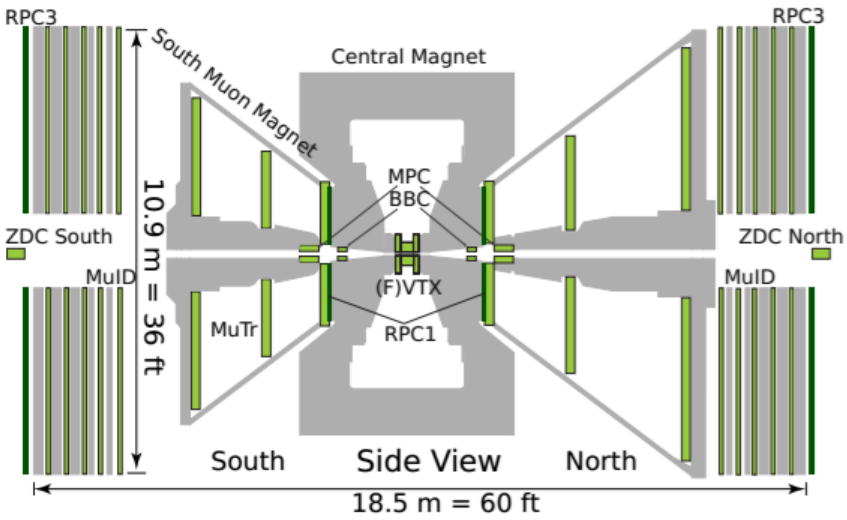
$$R = \frac{L^{++}}{L^{+-}}$$

PHENIX

PHENIX Central Arm



Forward Muon Spectrometer

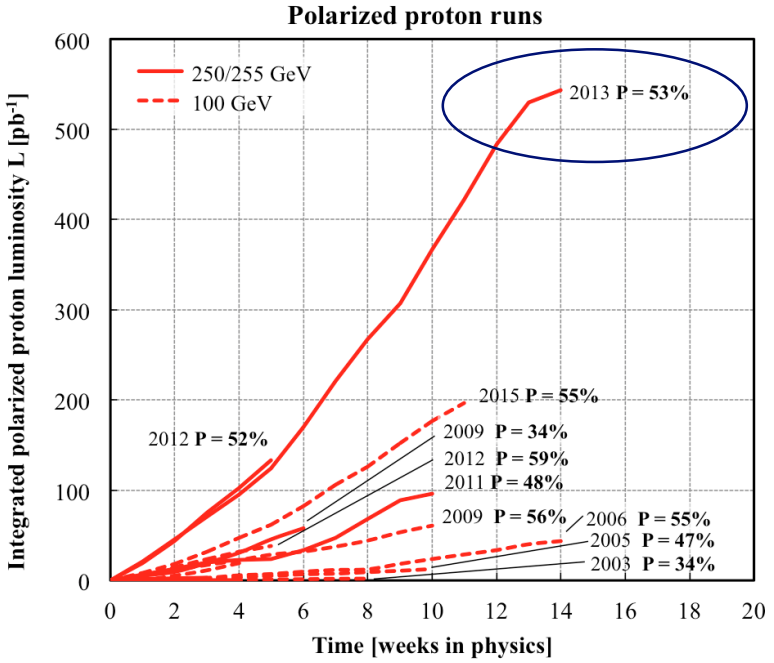


- Energy measured in EM Calorimeter (PbSc + PbGl)
- Momentum/Tracking in Drift Chamber (DC) + Silicon Barrel (VTX)
- PID with Ring Imaging Cherenkov Counter (RICH)
- $|\eta| < 0.35$, $\Delta\phi = 2 \times \frac{\pi}{2}$

- Silicon strip tracking and vertexing (FVTX)
- Momentum measured in cathode strip tracking chambers (MuTr)
- $\mu^{\pm}$ ID from Iarocci tubes interleaved with steel absorbers (MuID)
- $1.2 < |\eta| < 2.2$, $\Delta\phi = 2\pi$
- Muon Piston Calorimeter (MPC) 3.1 < $|\eta|$ <3.9

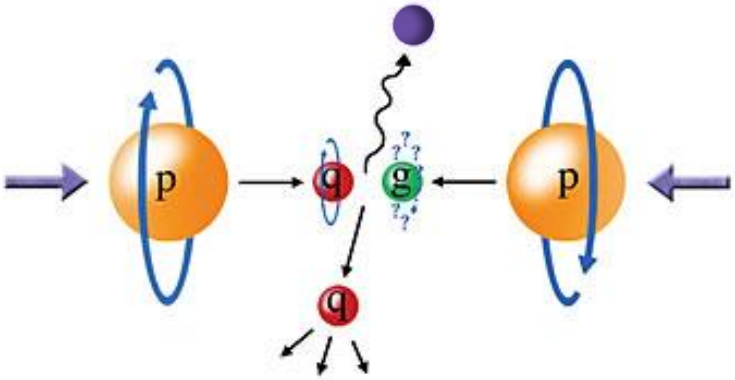
Recent PHENIX Measurements Sensitive to Gluon Polarizations

- Finalized Analyses:
  - 2012, 2013 510 GeV π^0 A_{LL} at central rapidity
    - Phys. Rev. D 93, 011501(R) – Published 7 January 2016
  - 2013 510 GeV J/ψ A_{LL} at forward rapidity
    - arXiv:1606.01815 – Submitted to PRD, June 2016



- Ongoing analyses:
  - Central:
    - 2013 charged pion A_{LL} → T. Moon's Talk
    - 2013 direct photon A_{LL}
    - 2013 *Jet* A_{LL} → M. Patel's Poster
    - 2009, 2011 di-π^0 A_{LL}
  - Forward:
    - 2011, 2013 500, 510 GeV π^0 A_{LL}

π^0 A_{LL} and Gluon Polarization



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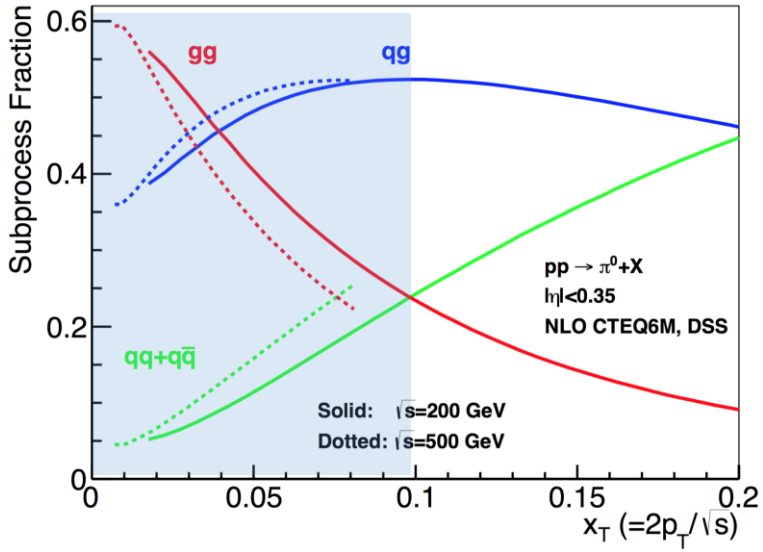


$$A_{LL} = \frac{d\Delta\sigma}{d\sigma} \approx a_{gg}\Delta g\Delta g + a_{qg}\Delta q\Delta g$$

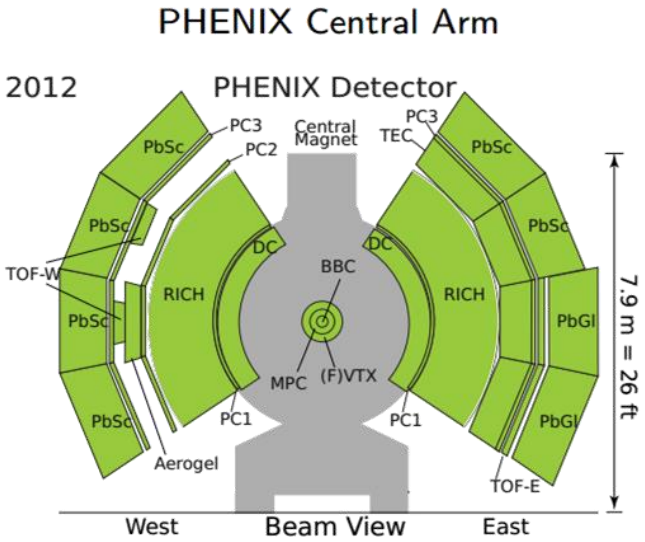
π^0 A_{LL} measurement procedure

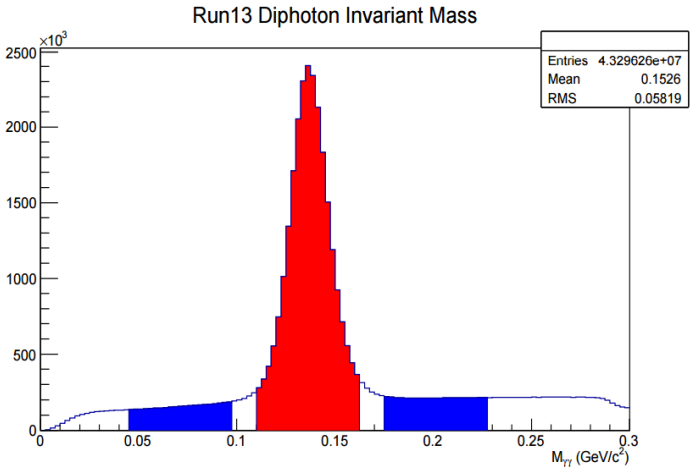
- Reconstruct π^0 peak with γ pair in Electromagnetic Calorimeter at PHENIX (PbSc and PbGl).

- Workhorse channel at PHENIX:
  - large cross section
  - finely segmented EMCal:
    - $\Delta\eta$:0.01, 0.008, $\Delta\phi$: 0.01, 0.008 for PbSc and PBGl
  - high p_T photon trigger.

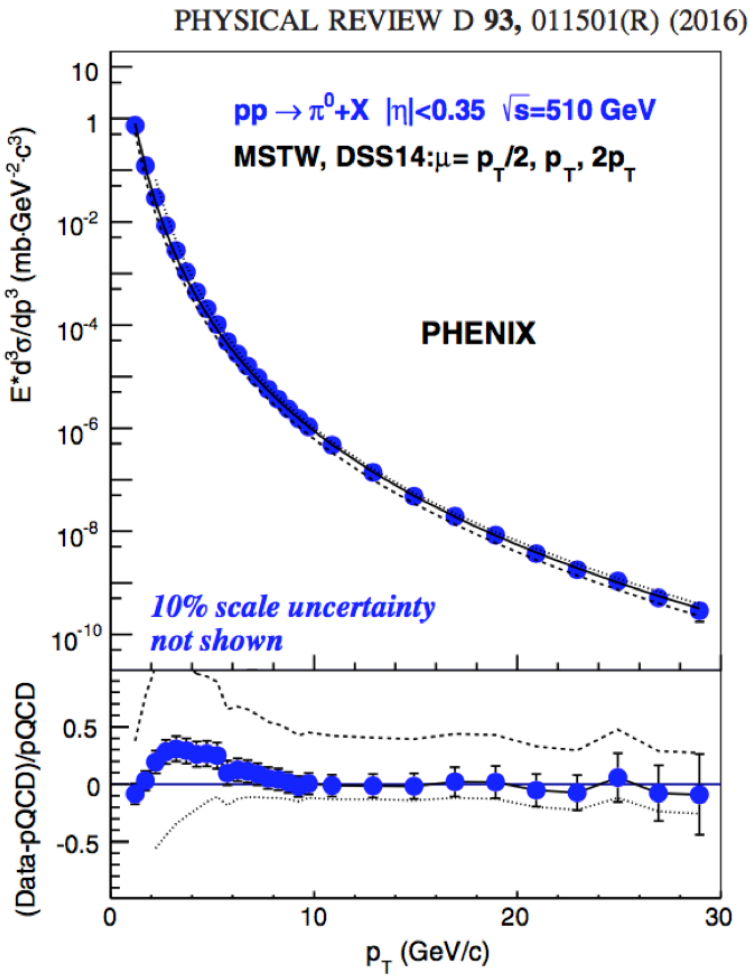
- Inclusive asymmetry and side band background asymmetry:

$$A_{LL}^{\pi^0} = \frac{A_{LL}^{(\pi^0+BG)} - rA_{LL}^{BG}}{1-r}$$





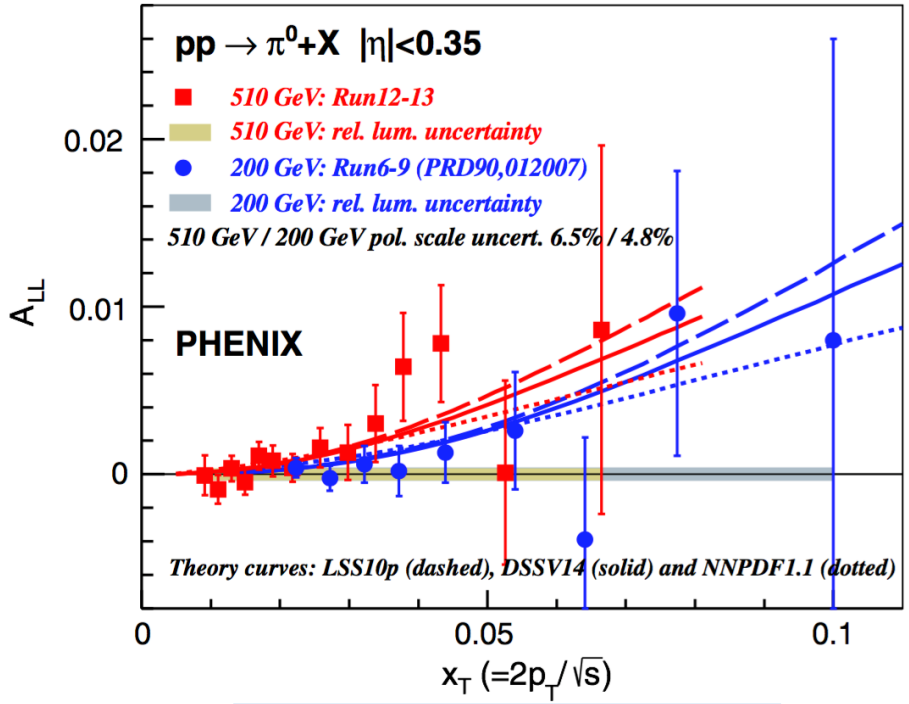
π^0 Cross Section at 510 GeV



- Cross section results are given for $0.5 < p_T < 30$ GeV/c.
- The cross section is well described by NLO perturbative QCD.

π^0 A_{LL} results at central rapidity ($|\eta|$<0.35)

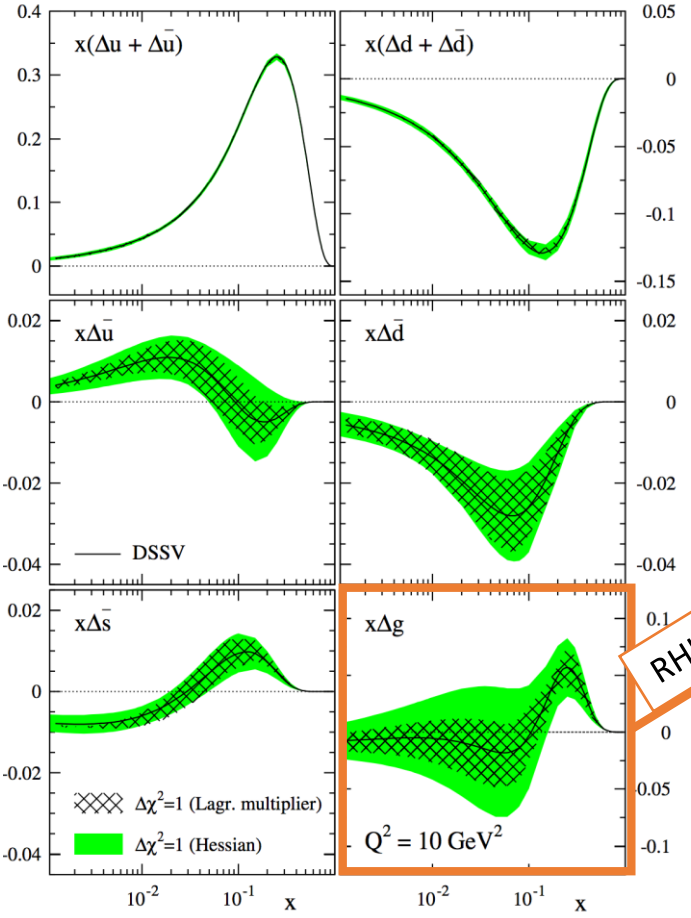
- 200 GeV results published in Phys. Rev. D 90, 012007 (2014)
- 510 GeV results recently published Phys. Rev. D 93, 011501(R) (2016).
  - The results follows positive trend with p_T and $\sqrt{s}$ as predicted by NLO pQCD.
  - Additional constrains on gluon polarization and extended Bjorken x coverage down to ~0.01.



PRD 93, 011501(R) (2016)

Further improve the knowledge of Δg

PRD80. 034030 (2009)



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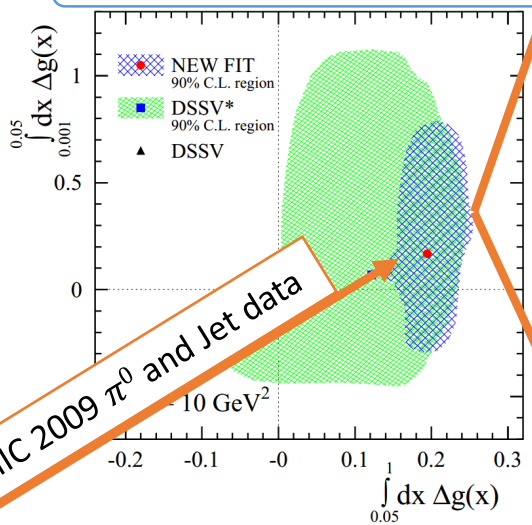
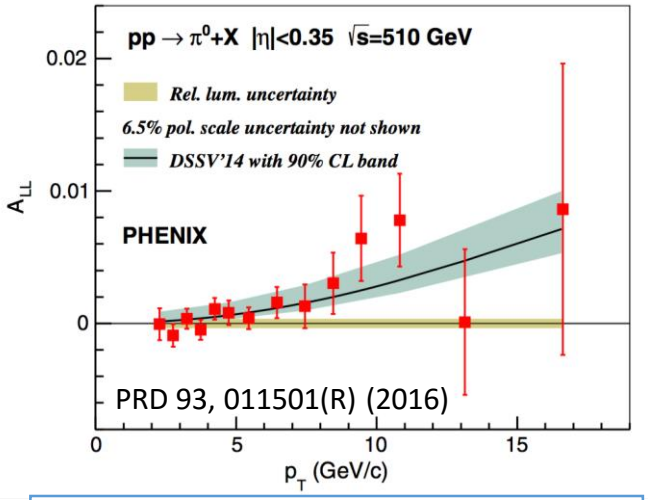
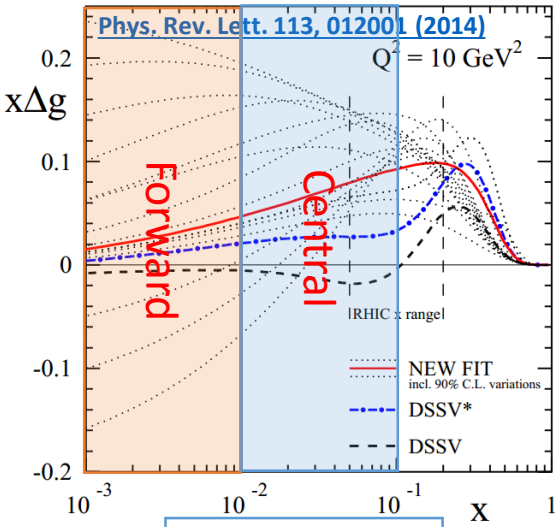


RHIC 2009 π^0 and Jet data

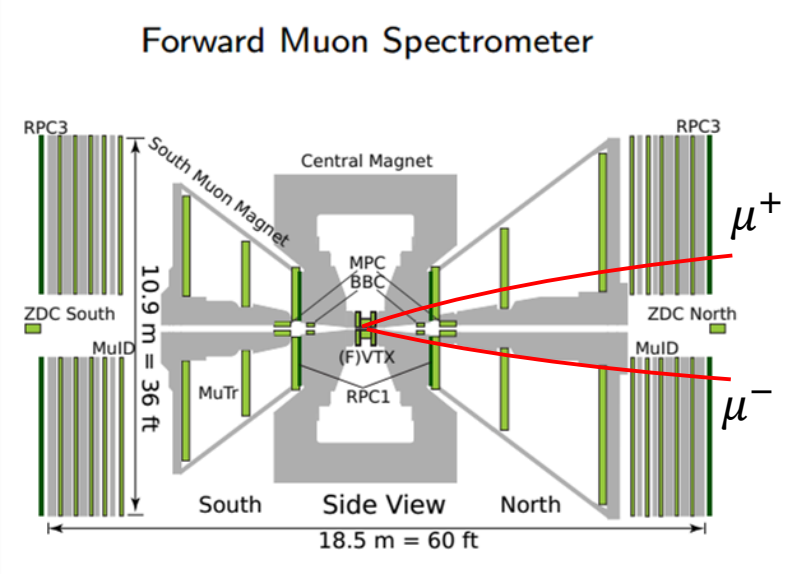


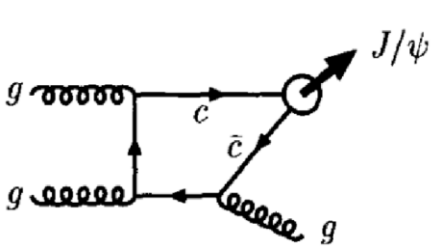
More data at central rapidity.

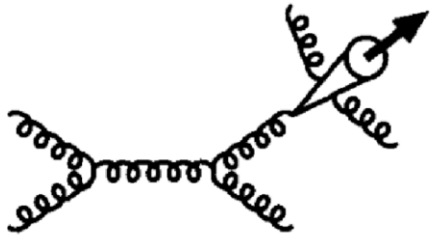


Go forward!

J/ψ production at RHIC



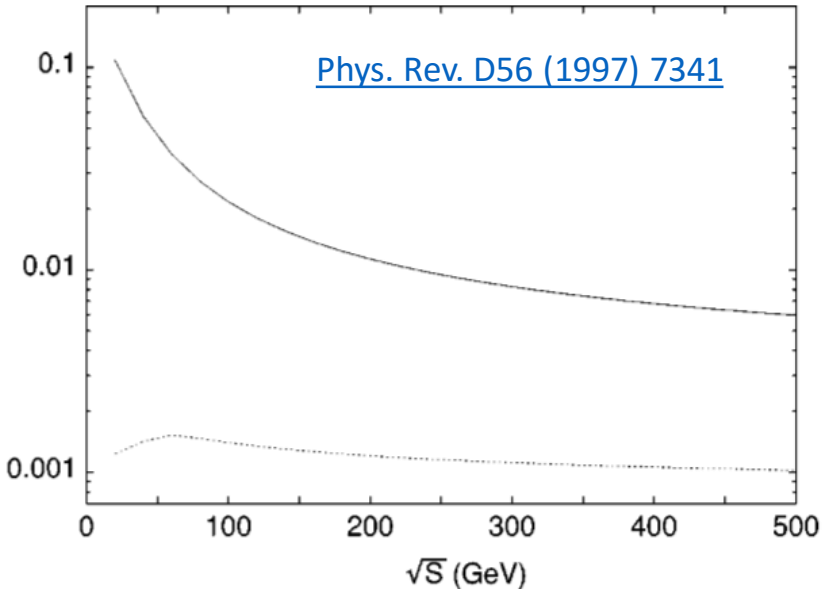




At RHIC energies J/ψ production is dominated by gluon-gluon fusion.

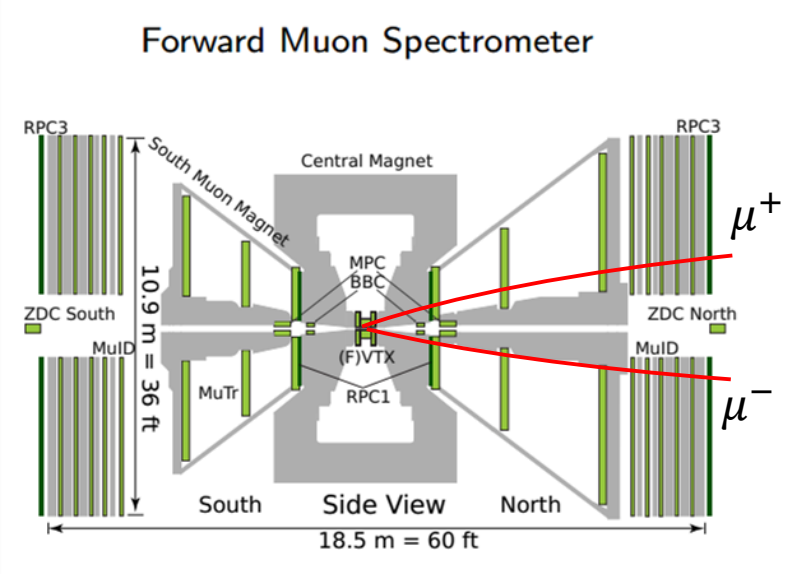
The A_{LL} for J/ψ can be written (LO):

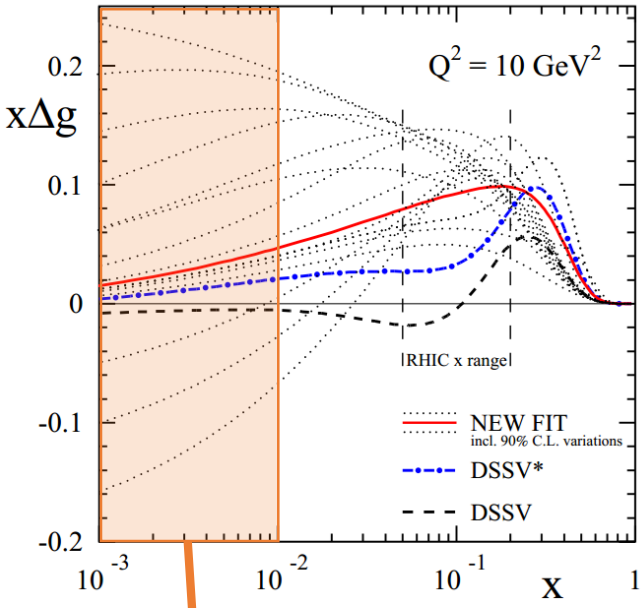
$$A_{LL} = \frac{\Delta\sigma}{\sigma} = \hat{a}^{gg\to J/\psi}\frac{\Delta g(x1)}{g(x1)}\frac{\Delta g(x2)}{g(x2)}$$

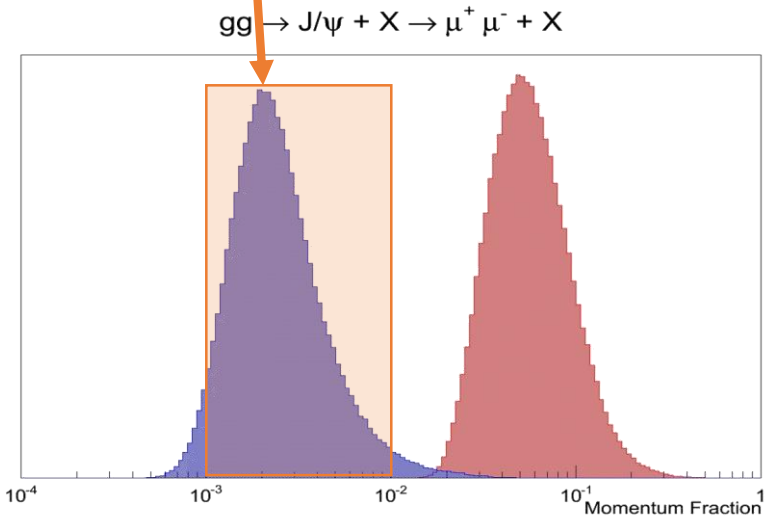


$q\bar{q}$ to gg ratios of unpolarized (solid) and polarized (dashed) processes

J/ψ production at RHIC







from Pythia simulation

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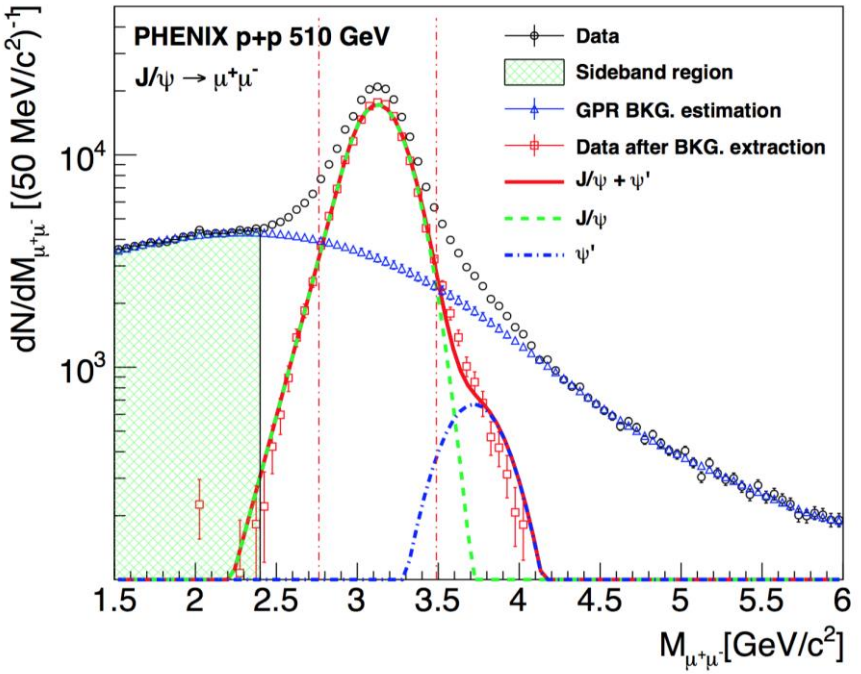
J/ψ A_{LL} Measurement Procedure

Outline

- Analyze south and north arm separately, and divide data from each arm into 3 p_T bins. So 6 subsets total.
- Fit each subsets for 2σ J/ψ mass window and background fraction "r".
  - CB shape for J/ψ, Gaussian for ψ'
  - Gaussian Process Regression (GPR) for background shape
- Sideband region is defined as $M_{\mu\mu} \in [1.5GeV, 2.5GeV]$
- Calculate $A_{LL}^{incl.}$ in the 2σ J/ψ mass window
- Estimate the background asymmetry from a sideband

$$A_{LL}^{J/\psi} = \frac{A_{LL}^{incl.} - r * A_{LL}^{BKG.}}{1 - r}$$

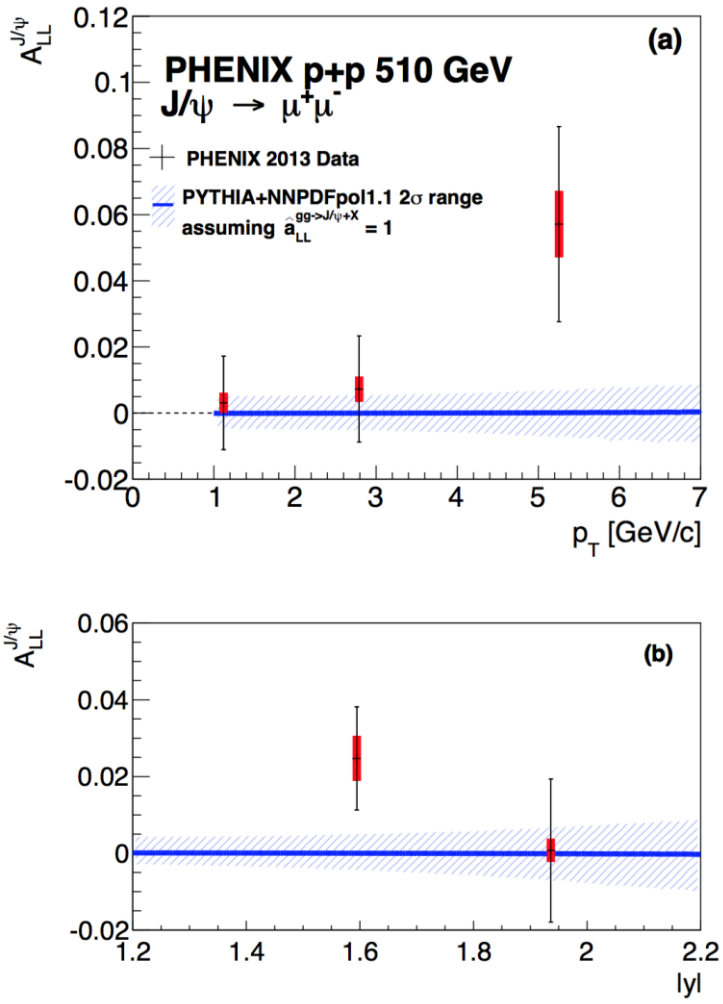
$$\Delta A_{LL}^{J/\psi} = \frac{\sqrt{(\Delta A_{LL}^{incl.})^2 + r^2 * (\Delta A_{LL}^{BKG.})^2}}{1 - r}$$



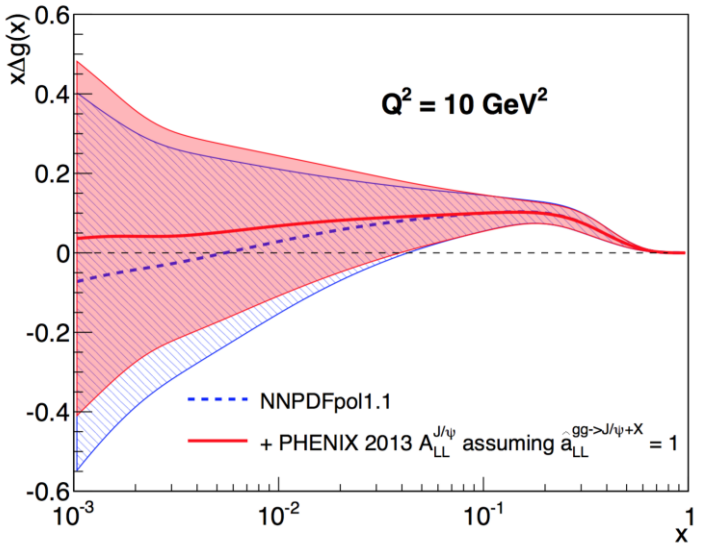
Gaussian Process Regression (GPR) background fraction extraction

J/ψ A_{LL} at Forward Rapidity Results

Submitted to PRD. [arXiv:1606.01815]



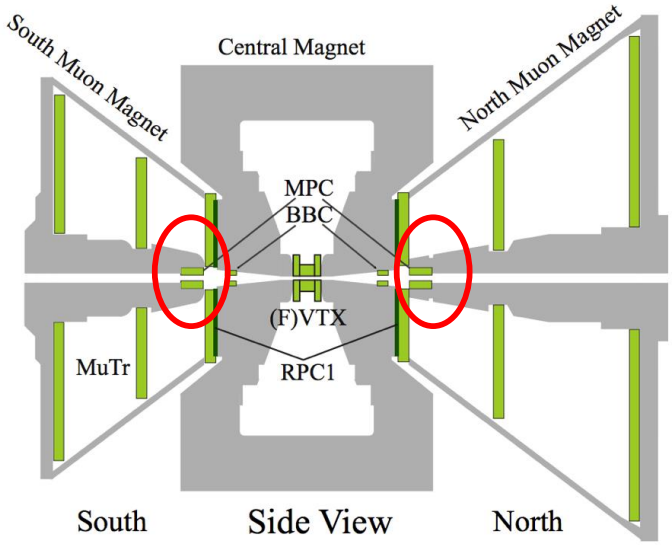
NNPDFpol 1.1: Nucl. 616 Phys. B 887, 276 (2014).
Re-weighting method: Nucl. Phys. B 849, 112 (2011)



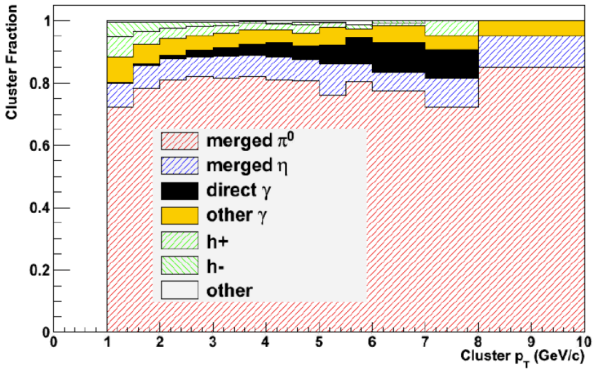
- Currently the constraining power on gluon polarization limited by large production mechanism uncertainty.
- Favors positive gluon polarization under assumption that $\hat{a}^{gg\to J/\psi} = 1$. We are looking forward to future experimental and theoretical progress to pin down the $\hat{a}^{gg\to J/\psi}$.
- Universality test of the helicity-dependent gluon densities and QCD factorizations.

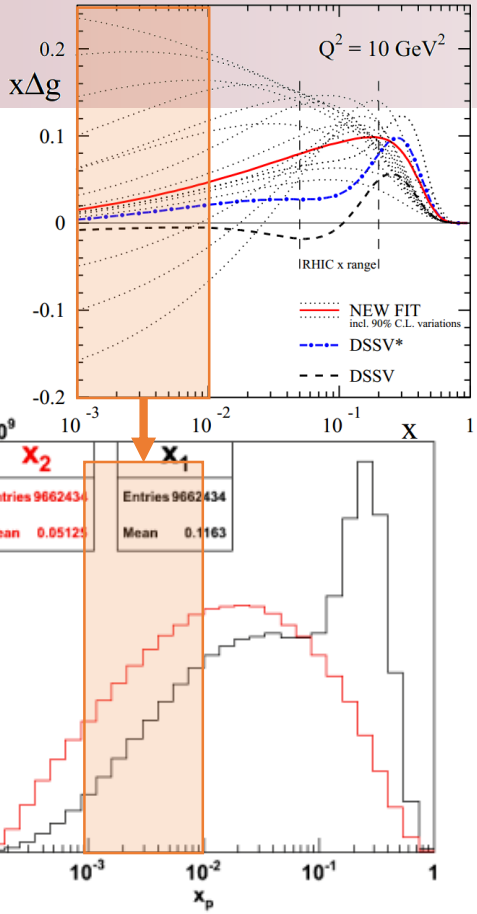
Ongoing Forward π^0 A_{LL} Analyses

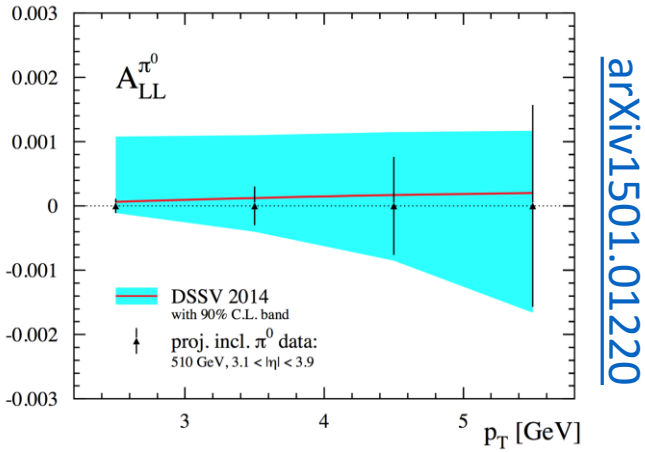
- Muon Piston Calorimeter (MPC) 3.1 < $|\eta|$ <3.9
- 2011 MPC cluster ALL result is finalized. 2013 data analysis underway.
- Could extend the constraints on Δg down to x ~ 10^{-3}.



MPC Clusters Fraction from Pythia simulation at 500 GeV



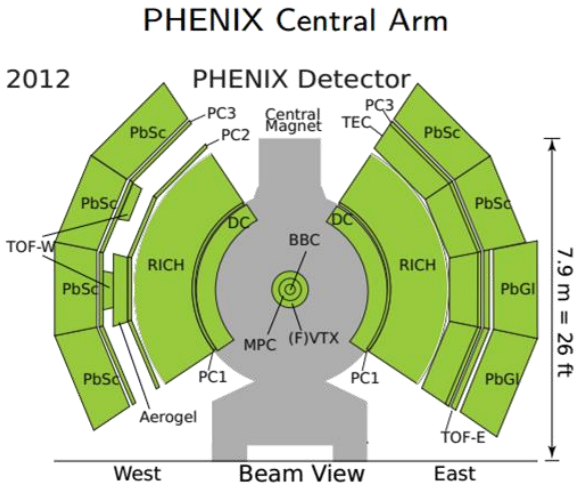




arXiv1501.01220

Charged Pion A_{LL}

T. Moon's Talk

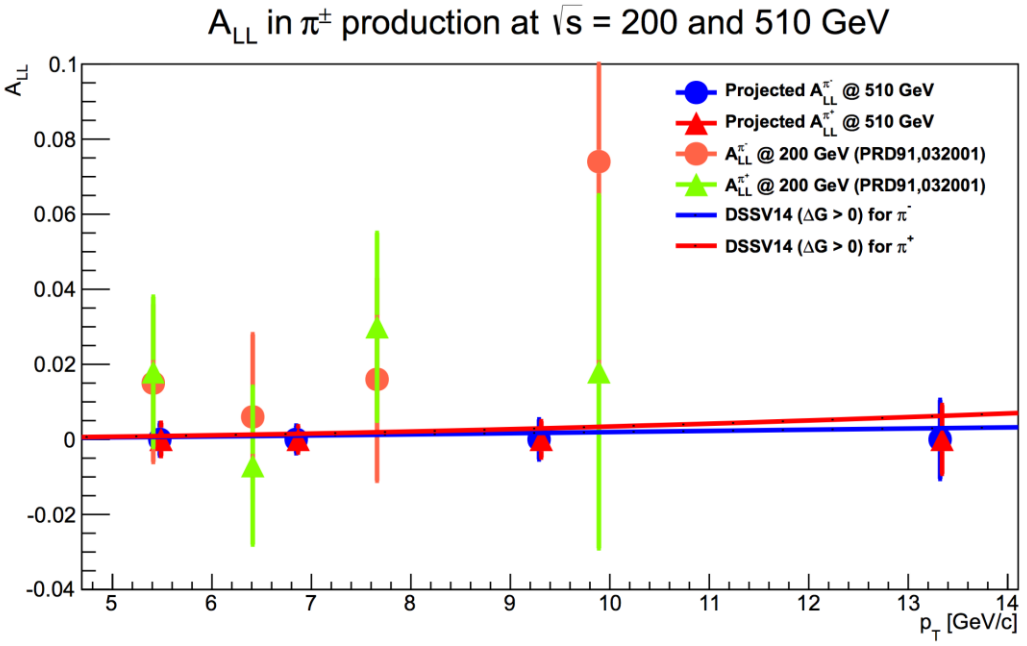


- Charged Pion A_{LL} Analysis on-going with PHENIX 2013 data.
- Complementary measurement to neutral pion A_{LL} measurements with large statistics.

$$A_{LL}^{\pi^+} \approx a_{gg}\Delta g\Delta g + a_{ug}\Delta u\Delta g$$

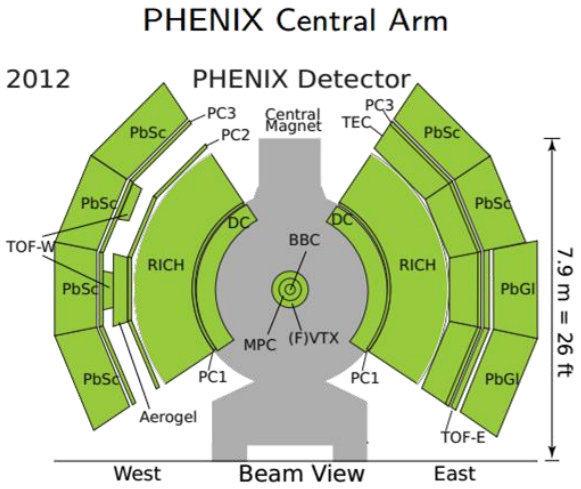
$$A_{LL}^{\pi^-} \approx a_{gg}\Delta g\Delta g + a_{dg}\Delta d\Delta g$$

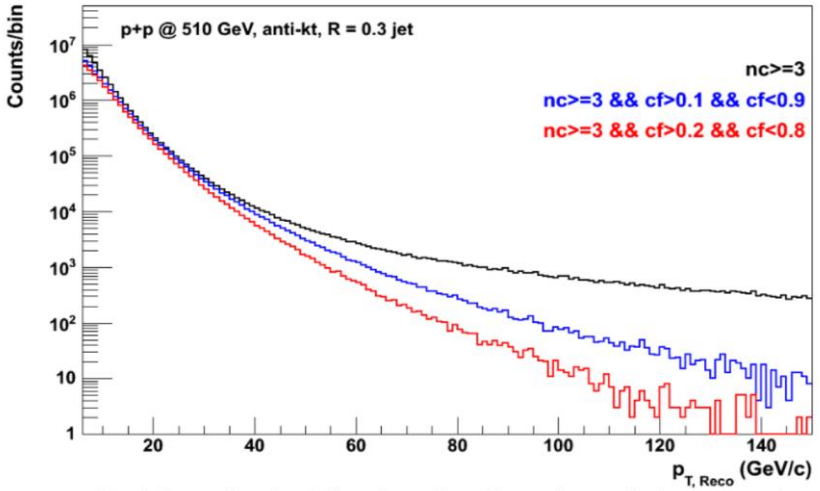
Previous Charged Pion A_{LL} Results and expected statistical precisions for currently on-going analysis based on 2013 PHENIX data.



Jet A_{LL}

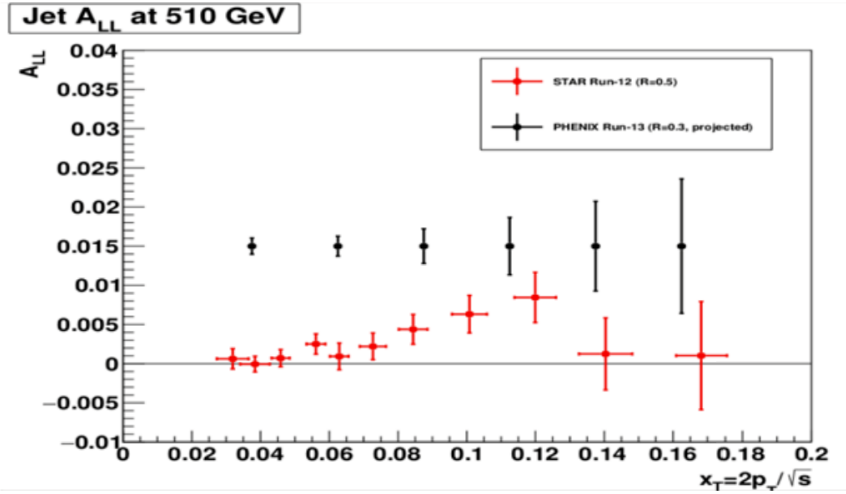
M. Patel's Poster



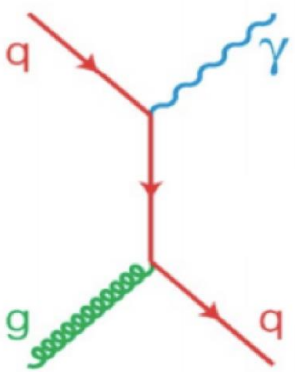


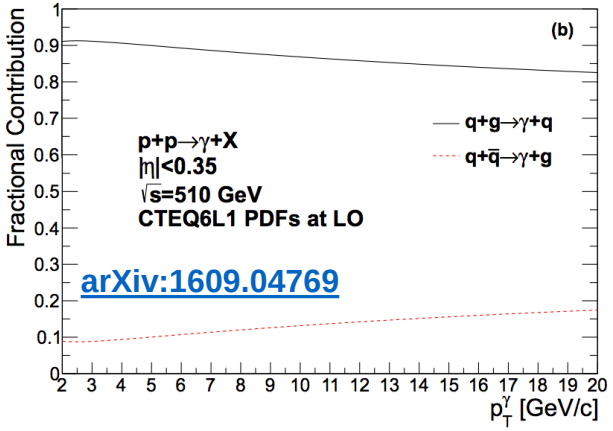
Used Charge fraction (cf) and number of constituents (nc) cuts to reduce high pT background.

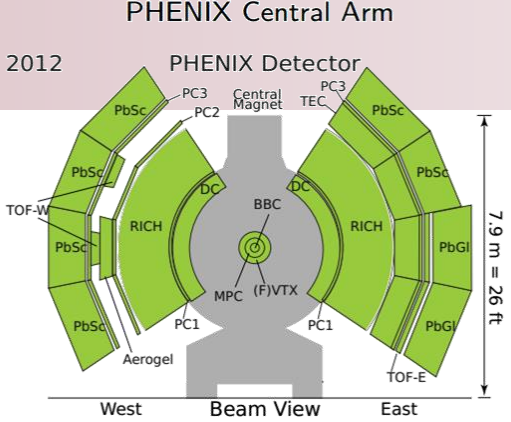
- Jet A_{LL} measurements on-going with PHENIX 2013 data.
- Comparable statistical uncertainty to the STAR 2012 Jet measurement.
- Independent check of STAR data.



Direct Photon A_{LL}

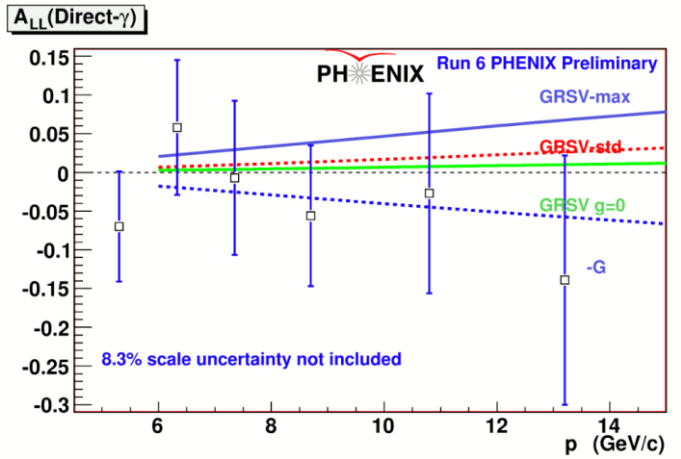


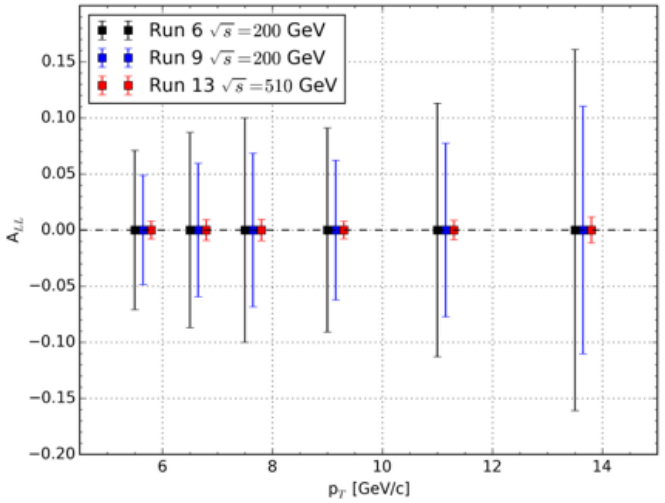




$$A_{LL} = \frac{\Delta g}{g} A_1^p \hat{a}(qg \to \gamma q)$$

- Direct Photon A_{LL} Analysis on-going with PHENIX 2013 data.
- Large statistics.
- Very clean production mechanism.
- No fragmentation function involved.
- Better constrained of the kinematics than π^0 A_{LL}.





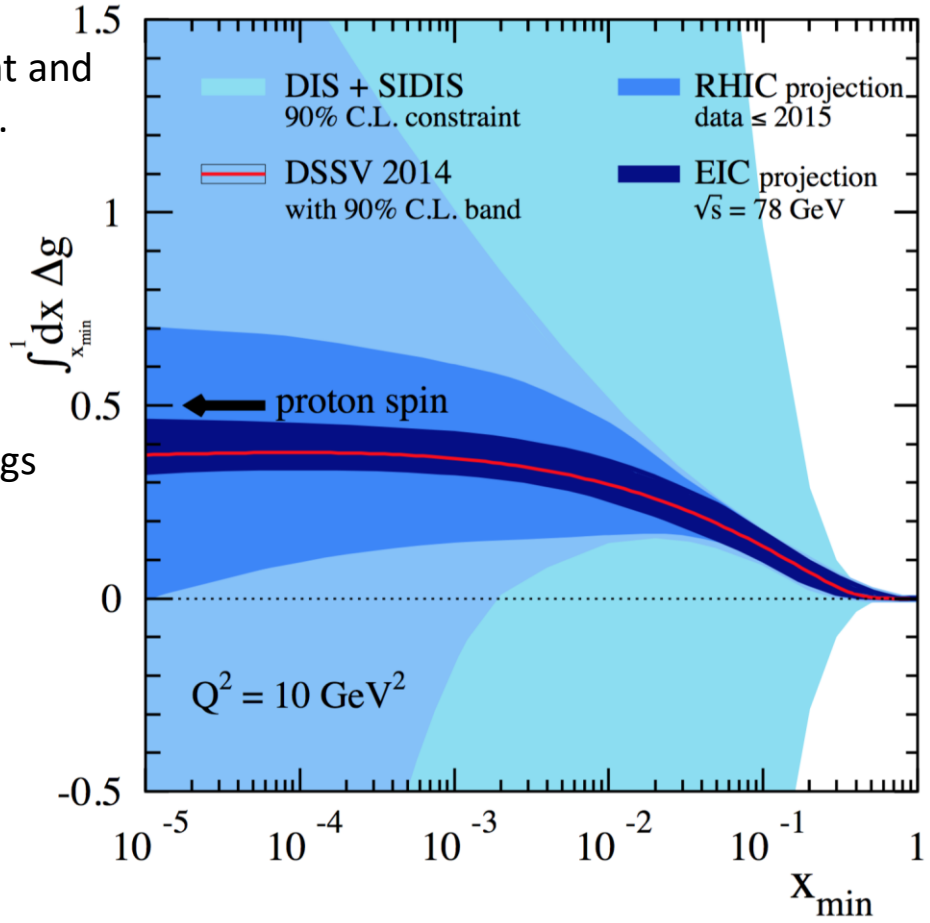
Impact on Gluon Polarization of the RHIC Data

Projection with and without pseudo-data for current and future RHIC measurements up to PHENIX Run-2015.

2015 - 2016:

- Published Include in Global fittings
  - 2009 200GeV Central π^0 A_{LL}
- Published/Submitted Not Include in Global fittings
  - 2012, 2013 510GeV Central π^0 A_{LL}
  - 2013 510GeV Forward J/ψ A_{LL}
- Ongoing
  - 2013 510GeV Central $\pi^{\pm}$ A_{LL}
  - 2013 510GeV Central direct photon A_{LL}
  - 2013 *Jet* A_{LL} at central rapidity
  - 2009, 2011 di-π^0 A_{LL}
  - 2011, 2013 500, 510GeV Forward π^0 A_{LL}

arXiv:1602.03922

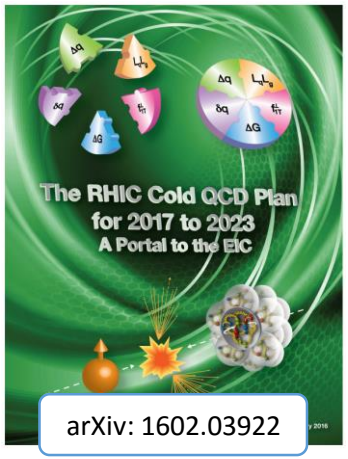


Opportunities at PHENIX IP beyond 2020

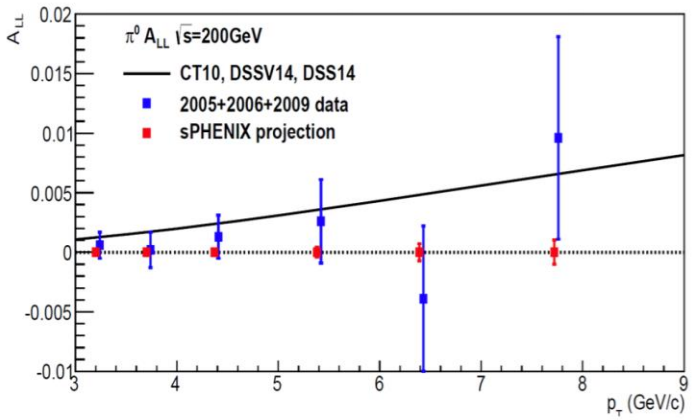
Proposed sPHENIX:

- Tracking, EMCal and HCal covering $-1 < \eta < 1$ and $|\phi| < 2\pi$
- Expecting CD0 soon
- ~ 8 times acceptance of PHENIX EMCal
- ~ 2 time DAQ rate of PHENIX
- Better Jet Energy Scale uncertainty

- Significantly improve the statistical precision of the $\pi^0 A_{LL}$, Jet A_{LL} and Direct Photon A_{LL} measurements.



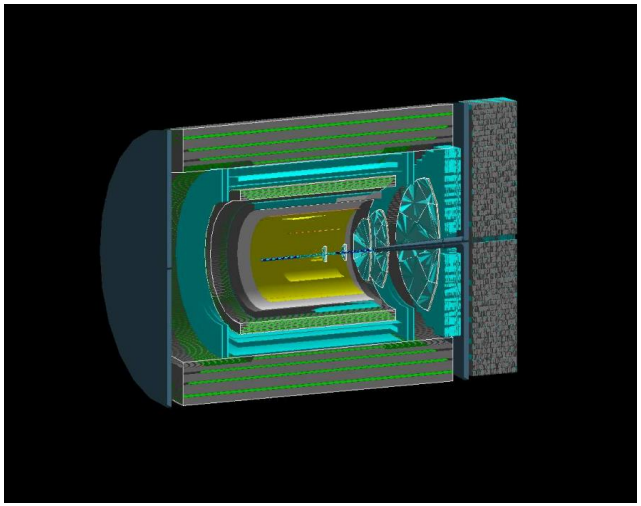
arXiv: 1602.03922



fsPHENIX:

J. Lajoie's Talk

- Forward Spectrometer.
- LOI stage
- Small x: π^0, Jet and Direct Photon



Cold QCD topical group formed recently

Detector at PHENIX IP for EIC

Summary and Outlook

Run12, Run13 π^0 A_{LL} at central rapidity ($|\eta| < 0.35$) published at PRD Rapid Communications.

- Could reduce the global fit uncertainties on $\Delta g(x)$
- Extend the $\Delta g(x)$ constraints down to $x \sim 10^{-2}$.
- We are looking forward to the new global fit including this data.

Run13 J/ψ A_{LL} at forward rapidity submitted to PRD.

- Sensitive to gluon polarization down to $x \sim 2 \times 10^{-3}$.
- Universality check for the QCD factorization of the gluon helicity dependent P.D.F.
- Could improve the gluon polarization precision at smaller x with further knowledge on the production mechanism.

Many analyses also sensitive to Δg are on-going.

Possible opportunities at PHENIX IP for gluon polarization measurement with new detectors beyond 2020.

Backups

RHIC Plan 2017 - 202X

arXiv: 1602.03922

	Year	$\sqrt{s}$ (GeV)	Delivered Luminosity	Scientific Goals	Observable	Required Upgrade
Scheduled RHIC running	2017	$p^{\uparrow}p$ @ 510	400 pb^{-1} 12 weeks	Sensitive to Sivers effect non-universality through TMDs and Twist-3 $T_{q,F}(x,x)$ Sensitive to sea quark Sivers or ETQS function Evolution in TMD and Twist-3 formalism	A_N for γ, $W^{\pm}$, Z^0, DY	A_N^{DY}: Postshower to FMS@STAR
				Transversity, Collins FF, linearly pol. Gluons, Gluon Sivers in Twist-3	$A_{UT}^{\sin(\phi_s-2\phi_h)}$ $A_{UT}^{\sin(\phi_s-\phi_h)}$ modulations of $h^{\pm}$ in jets, $A_{UT}^{\sin(\phi_s)}$ for jets	**None**
				First look at GPD *Eg*	A_{UT} for J/Ψ in UPC	**None**
	2023	$p^{\uparrow}p$ @ 200	300 pb^{-1} 8 weeks	subprocess driving the large A_N at high x_F and η	A_N for charged hadrons and flavor enhanced jets	Yes Forward instrum.
				evolution of ETQS fct. properties and nature of the diffractive exchange in p+p collisions.	A_N for γ A_N for diffractive events	**None** **None**
	2023	$p^{\uparrow}$Au @ 200	1.8 pb^{-1} 8 weeks	What is the nature of the initial sta nuclear collisio		
				Nuclear dependence of T		
				Clear signatures for S		
	2023	$p^{\uparrow}$Al @ 200	12.6 pb^{-1} 8 weeks	A-dependence of		
				A-dependence of TMD		
				A-dependence for Sa		
Potential future running	202X	$p^{\uparrow}p$ @ 510	1.1 fb^{-1} 10 weeks	TMDs at low and		
				quantitative comparisons of the va factorization and universality in lep proton collisio		
	202X	$\vec{p}\vec{p}$@ 510	1.1 fb^{-1} 10 weeks	$\Delta g(x)$ at small		

If the beams are longitudinally polarized at either STAR or sPHENIX during the proposed √s = 200 GeV p+p running in 2023, it would be possible to increase the data sample for the two main channels of the RHIC ΔG program, inclusive mid-rapidity jets and neutral pions, by a factor of 3. With the projected integrated luminosity of 300 pb^{-1} (see Table 1-2) the other channels such as direct photons and charged pions are expected to show sensitivity to a non-zero ΔG for moderate x ($x>0.05$), though with significantly smaller statistical power compared to jets and neutral pions.

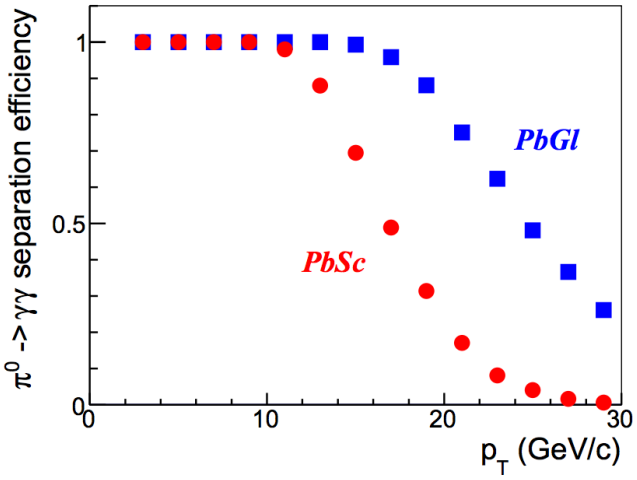
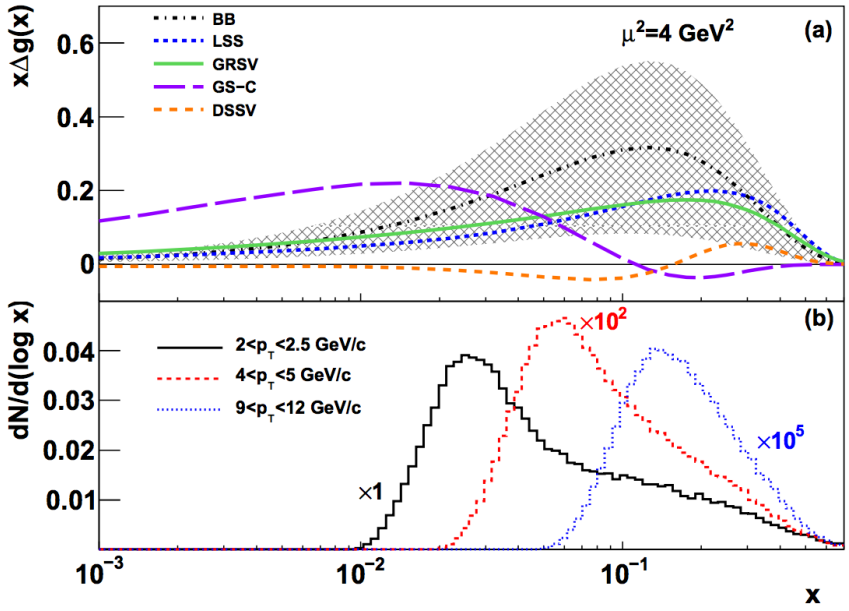


FIG. 1. (color online) The probability for two photons from π^0 decay to be separated by the PHENIX EMCal clustering algorithm vs π^0 p_T; obtained from GEANT [19] simulation for the two-photon energy asymmetry cut $\alpha < 0.8$.

PRD 93, 011501(R) (2016)



arxiv: 0810.0694