Gluon polarization measurements from longitudinally polarized proton-proton collisions at STAR

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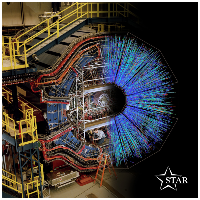
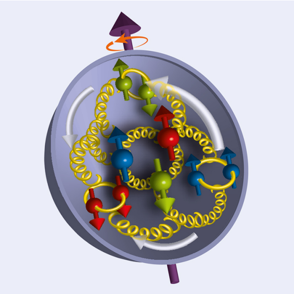


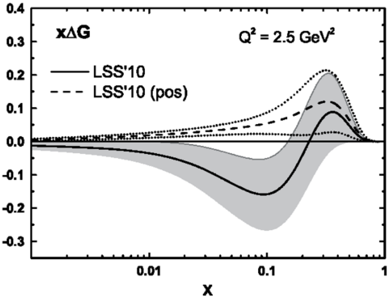
- Proton spin sum rule:

$$S_z = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{q,g}$$



- $\Delta\Sigma$: ~ 0.3 constrained by DIS and SIDIS
- ΔG: poorly constrained by DIS and SIDIS
- $L_{q,g}$: unconstrained

Leader et al, PRD 82, 114018



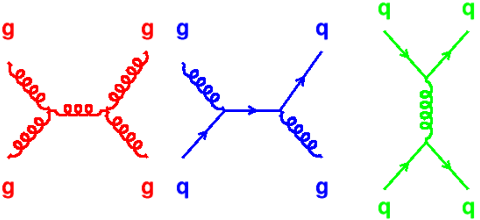
- With fit to DIS and SIDIS data,
  $\Delta G = -0.34 \pm 0.46$
  $\Delta G = 0.32 \pm 0.19$ for pos

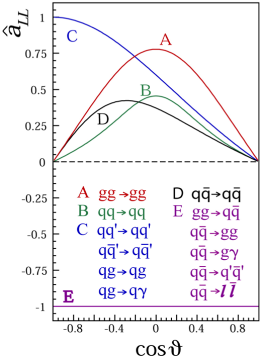
Leader et al, PRD 82, 114018

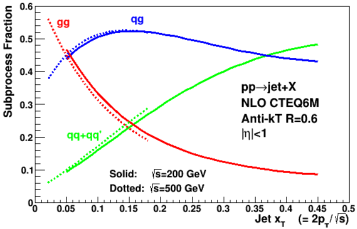
Exploring Gluon Polarization at RHIC

- In longitudinally polarized *pp* collisions, define longitudinal double-spin asymmetry A_{LL} as:

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \sim \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$





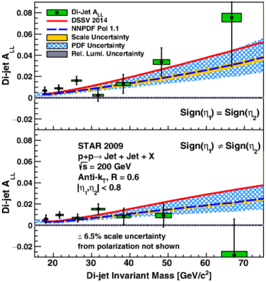


- *gg* and *qg* dominate jet production + large $\hat{a}_{LL}$ → **making A_{LL} for jets sensitive to gluon polarization**
- Experimentally, $P_{B(Y)}$: beam polarizations, and R: relative luminosity

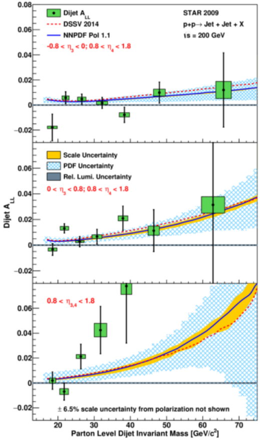
$$A_{LL} = \frac{1}{P_B P_Y} \frac{N_{++} - R \times N_{+-}}{N_{++} + R \times N_{+-}}$$

Impact of Recent STAR Dijet Results

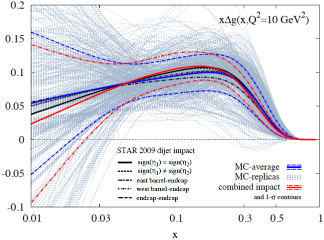
- Recent STAR dijet A_{LL} results at $\sqrt{s} = 200$ GeV: both jets in $|\eta| < 0.8$, or at least one jet in $0.8 < \eta < 1.8$



STAR, PRD 95, 071103(R)



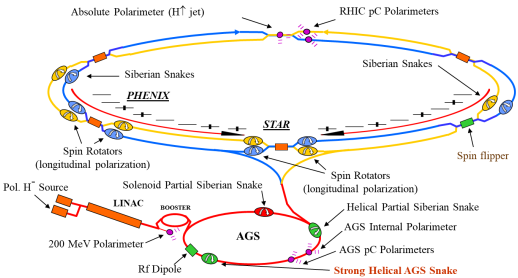
STAR, PRD 98, 032011



Florian et al., arXiv:1902.10548 [hep-ph]

- The DSSV study shows: $\int_{0.01}^{1} \Delta g(x, Q^2 = 10GeV^2) = 0.296 \pm 0.108$

Florian et al., arXiv:1902.10548 [hep-ph]

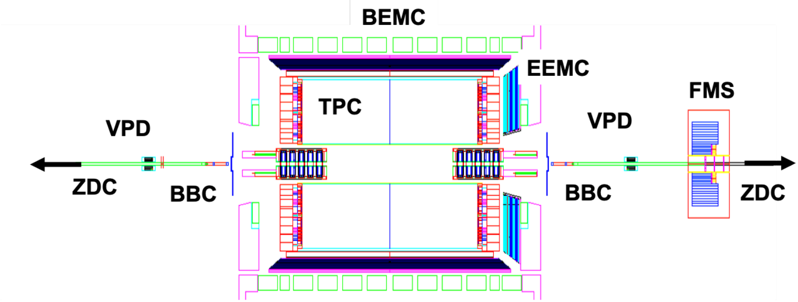


- Tracking with TPC: $|\eta| < 1.3$
- EM energy and triggering with:

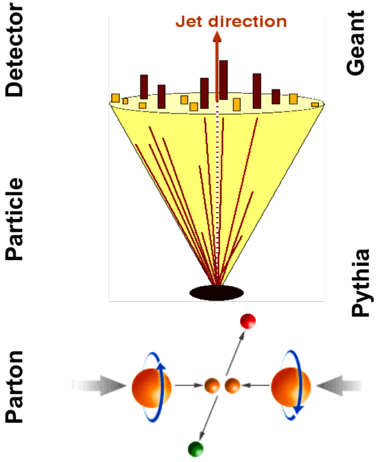
  BEMC: $-1.0 < \eta < 1.0$

  EEMC: $1.0 < \eta < 2.0$

  FMS: $2.65 < \eta < 3.9$



Jet Reconstructions



- Dataset: pp at $\sqrt{s} = 510$ GeV
- Inputs: charged tracks + electro-magnetic towers
- Algorithm: anti-k_T algorithm with $R = 0.5$
- Systematics study: PYTHIA + GEANT + Zero-bias events as embedding sample
  - Data-driven modified PYTHIA Perugia Tune
  - Correct jet p_T and dijet M_{inv} from measured detector jets to PYTHIA parton jets
  - Trigger bias and reconstruction uncertainty

Monte Carlo Tune Study

- Tuning based on matching between PYTHIA simulation and previous STAR charged $\pi^{\pm}$ spectrum measurements STAR, PLB 637, 161 and STAR, PRL 108, 072302
- Default Perugia 2012 tune except a smaller $p_{T,0}$ scale parameter ($P_{90} = 0.213$ default 0.24)

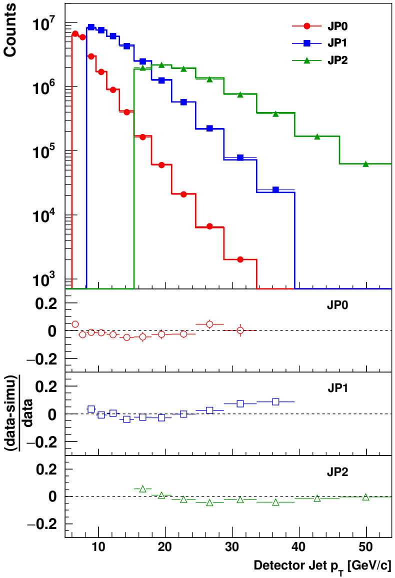
$$\sigma \sim \frac{1}{(p_T^2 + p_{T,0}^2)^2}$$

$$p_{T,0} = p_{T,ref} \times \left(\frac{\sqrt{s}}{\sqrt{s_{ref}}}\right)^{P_{90}}$$

- Reduce multiple parton interaction contribution
- Jet spectrum comparison for three jet patch triggers, JP0, JP1 and JP2

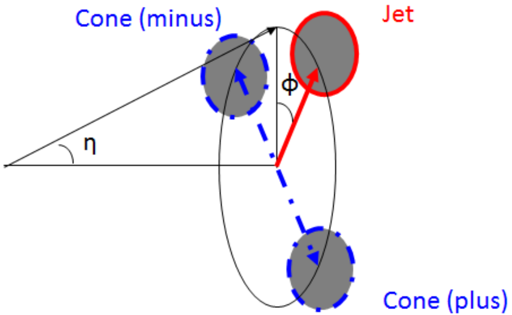
Markers: data and lines: simulation

STAR, arXiv:1906.02740 [hep-ex]



Underlying Event Correction to Jet Transverse Energy

- Two off-axis cones centered at $\pm\frac{\pi}{2}$ away in ϕ and the same η relative to a given jet are used to estimate underlying event for that jet, ALICE, PRD 91, 112012

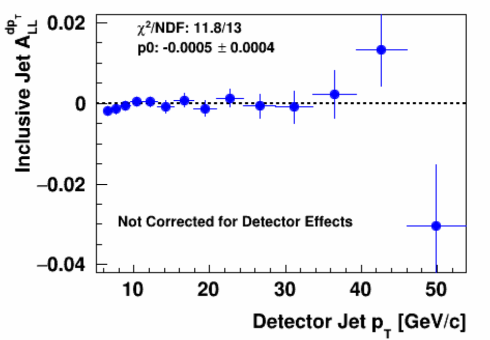


- The underlying event correction on jet transverse momentum: $dp_T = \frac{1}{2}(\rho_{plus} + \rho_{minus}) \times A_{jet}$
- Scan η dependence of underlying events
- Allow to study the underlying event contribution to jet A_{LL}

Effects of Underlying Events on Measured Jet A_{LL}

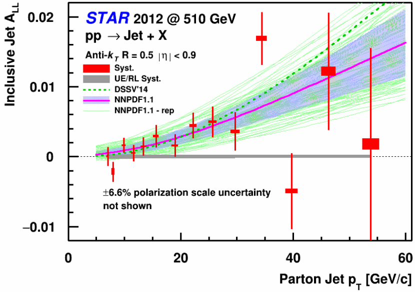
- Define underlying event correction dp_T asymmetry:

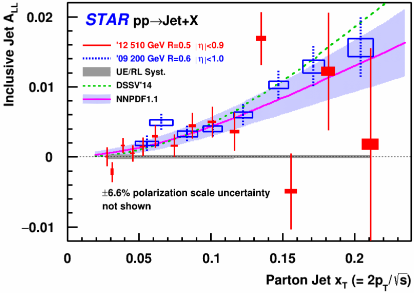
$$A_{LL}^{dp_T} = \frac{1}{P_A P_B} \frac{< dp_T >^{++} - < dp_T >^{+-}}{< dp_T >^{++} + < dp_T >^{+-}}$$



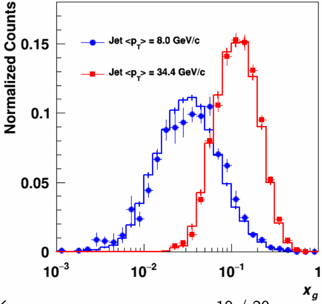
- Underlying event correction dp_T asymmetries are **consistent with zero**, STAR, arXiv:1906.02740 [hep-ex]
- Underlying event contribution to measured jet A_{LL} is estimated to be $\sim 10^{-4}$, assigned as an uncertainty

STAR 510 GeV Inclusive Jet A_{LL} Measurements

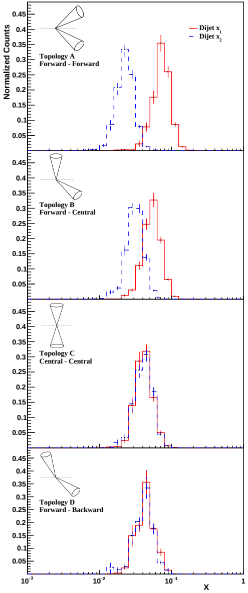


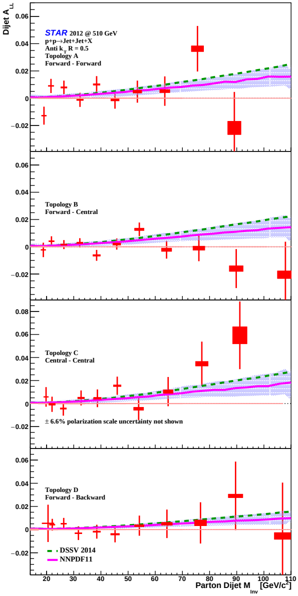


- Much reduced systematic uncertainty than the previous measurements at $\sqrt{s} = 200$ GeV, STAR, arXiv:1906.02740 [hep-ex]
- Agree with recent polarized PDF predictions
- In the overlapping $x_T = \frac{2p_T}{\sqrt{s}}$ region, both results agree well
- Allow to access $\mathbf{x_g}$ as low as **0.015**



STAR 510 GeV Dijet A_{LL} Measurements





- Dijet A_{LL} vs. invariant mass for four η topologies, STAR, arXiv:1906.02740 [hep-ex]

  A/Forward-Forward:
  $0.3 < |\eta_{3,4}| < 0.9$
  $\eta_3 \cdot \eta_4 > 0$

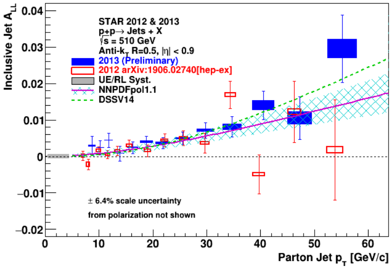
  B/Forward-Central:
  $|\eta_{3,4}| < 0.3$,
  $0.3 < |\eta_{3,4}| < 0.9$

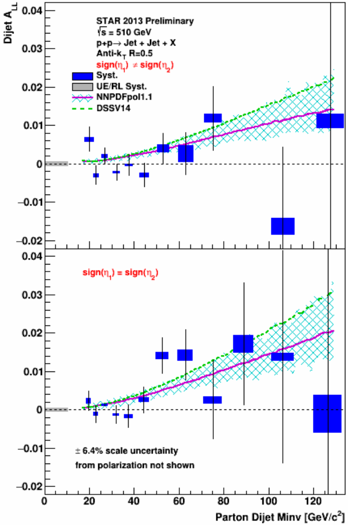
  C/Central-Central:
  $|\eta_{3,4}| < 0.3$

  D/Forward-Backward:
  $0.3 < |\eta_{3,4}| < 0.9$
  $\eta_3 \cdot \eta_4 < 0$
- Topology binning narrows the sampled x_g and the $cos\theta^*$ ranges
- Sampled x_g distributions much narrower than those from inclusive jets

Inclusive and Dijet A_{LL} from STAR 2013 510 GeV Data

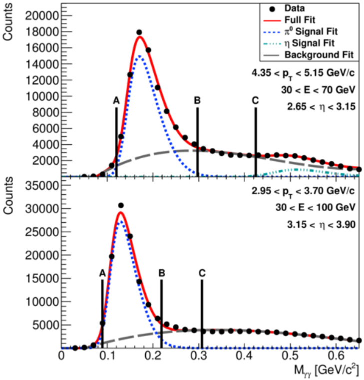
- Preliminary inclusive jet (left) and dijet (right) A_{LL} from STAR 2013 510 GeV data, **Quintero, arXiv:1809.00923 [nucl-ex]**



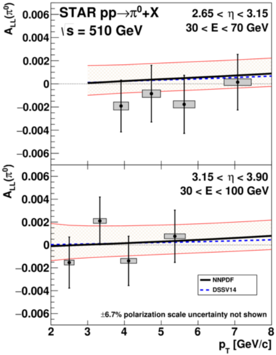


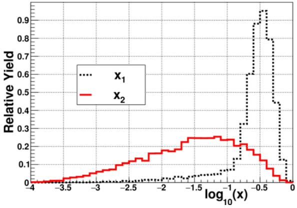
- Same procedure being applied as in 2012 $\sqrt{s} = 510$ GeV data
- The 2012 and 2013 results agree well
- Two η topologies for dijet A_{LL}
- The study of the systematic uncertainty is underway for the final results

STAR 510 GeV Forward π^0 A_{LL}



STAR, PRD 98, 032013



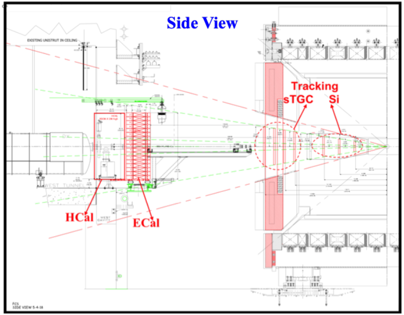


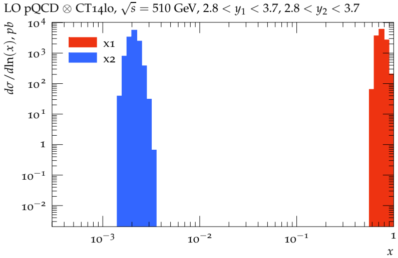
- π^0 reconstructed in STAR FMS
- Measured A_{LL} is small, less than 5×10^{-3}
- Allow to access $x_g \sim 10^{-3}$

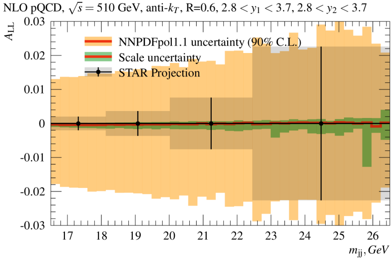
STAR Forward Upgrade

- STAR is planning to install a Forward Calorimeter System (FCS), including an EMCal and a HCal, and a Forwarding Tracking System (FTS) in time for polarized 510 GeV run in 2022
- Dijet measurements with one or both jets in the forward region ($2.8 < \eta < 3.7$) will be one of the highlights of this upgrade
- With both jets in the FCS, it will provide gluon polarization at $x_g \sim 10^{-3}$

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0648







Conclusion

- STAR inclusive jet and dijet double-spin asymmetry measurements are unique to explore gluon polarization in the proton
- The 510 GeV results extend gluon polarization over $x \sim 0.015$ to $x \sim 0.2$, STAR, arXiv:1906.02740 [hep-ex]
  1. Inclusive jets will constrain the magnitude of the gluon polarization
  2. Dijets will constrain the shape of $\Delta g(x)$
- Inclusive jet and dijet A_{LL} are being studied with the 2013 pp data at $\sqrt{s} = 510$ GeV
- The forward upgrade will provide new opportunities to probe low $x \sim 10^{-3}$ gluon polarization where the current polarized PDF studies show large uncertainties

Backup

Longitudinally polarized *pp* Dataset at STAR

- Selected longitudinally polarized *pp* datasets at $\sqrt{s} = 200$ and 510 GeV:

Year	$\sqrt{s}$ (GeV)	Recorded Luminosity (pb^{-1})	B/Y polarization $\langle P \rangle$
2009	200	25	55
2012	**510**	**82**	**50/53**
2013	*510*	*300*	*51/52*
2015	*200*	*52*	*53/57*

- 2009 and **2012** data are in publication
- *2013* and *2015* data are under analysis

Inclusive Jet and Dijet Measurements

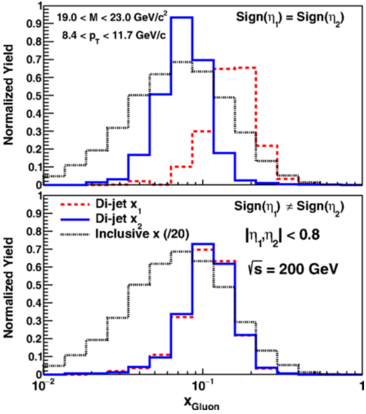
STAR has measured a series of inclusive jet and dijet cross-sections and longitudinal double-spin asymmetry A_{LL}s at $\sqrt{s} = 200$ GeV

- Inclusive jets:
  x_g as low as ~ 0.05 at $\sqrt{s} = 200$ GeV
- Dijets:
  two jet correlation unfolds x_1 and x_2 at the leading order

$$x_1 = \frac{1}{\sqrt{s}}(p_{T,3}e^{\eta_3} + p_{T,4}e^{\eta_4})$$

$$x_2 = \frac{1}{\sqrt{s}}(p_{T,3}e^{-\eta_3} + p_{T,4}e^{-\eta_4})$$

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



- Sampled x_g distributions by inclusive and dijets at $\sqrt{s} = 200$ GeV STAR, PRD 95, 071103(R)

Underlying Event Systematics on Jet A_{LL}

$$\delta A_{LL} = \frac{\int_{p_{T,min}-<dp_T>\times A_{LL}^{dp_T}}^{p_{T,max}-<dp_T>\times A_{LL}^{dp_T}} \frac{d\sigma}{dp_T} dp_T - \int_{p_{T,min}+<dp_T>\times A_{LL}^{dp_T}}^{p_{T,max}+<dp_T>\times A_{LL}^{dp_T}} \frac{d\sigma}{dp_T} dp_T}{\int_{p_{T,min}-<dp_T>\times A_{LL}^{dp_T}}^{p_{T,max}-<dp_T>\times A_{LL}^{dp_T}} \frac{d\sigma}{dp_T} dp_T + \int_{p_{T,min}+<dp_T>\times A_{LL}^{dp_T}}^{p_{T,max}+<dp_T>\times A_{LL}^{dp_T}} \frac{d\sigma}{dp_T} dp_T} \tag{1}$$

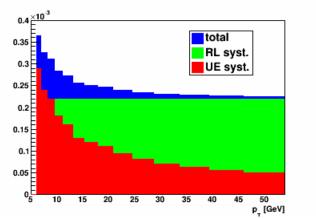


Figure: Underlying event systematic uncertainty on inclusive jet A_{LL} for 2012 510 GeV data compared with systematic uncertainty due to relative luminosity.

STAR Charged $\pi^{\pm}$ Spectrum

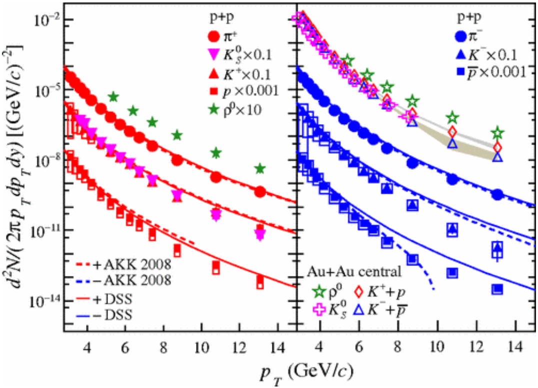


Figure: STAR charged $\pi^{\pm}$ yields. STAR, PRL 108, 072302, 2012