

Recent Highlights from the PHENIX Cold-QCD Physics Program 2021 (Spin Workshop)



Benard Mulilo for the PHENIX Collaboration

Korea University

RIKEN

University of Zambia

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Recent Highlights from the PHENIX Cold-QCD Physics Program (Spin Workshop)

Transverse single spin asymmetry, A_N (TSSA) and longitudinal double spin asymmetry (A_{LL}) of various particle species.

A_N of:

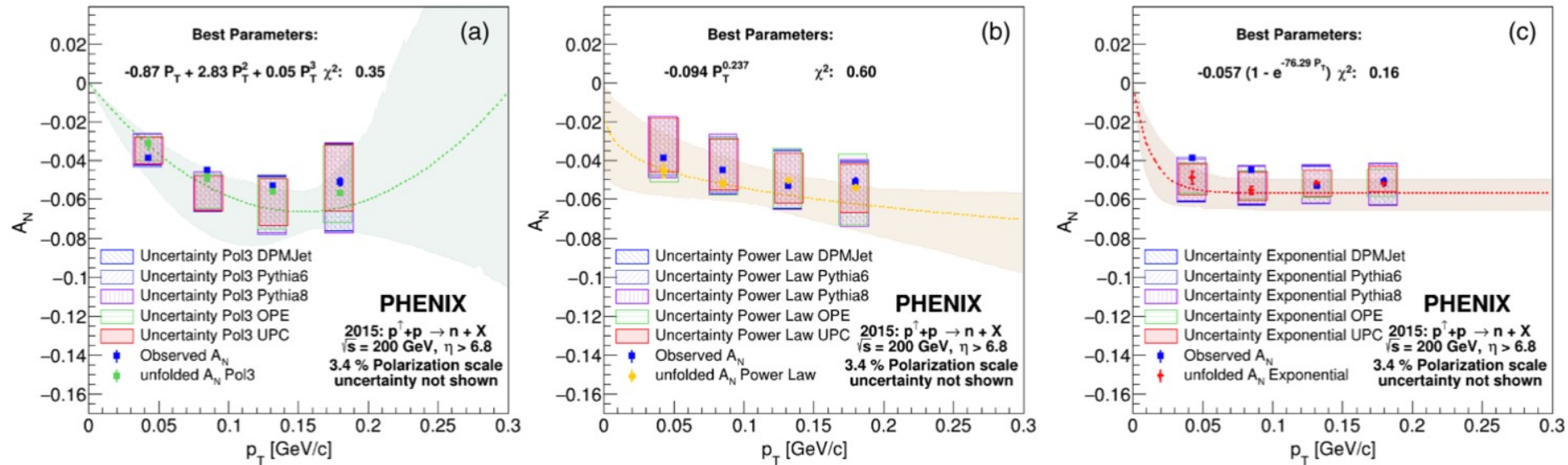
- ❑ Neutrons ($p^\uparrow + p$, $\sqrt{s} = 200 \text{ GeV}$, $|\eta| > 6.8$)
- ❑ Neutral pions ($p^\uparrow + p$, $\sqrt{s} = 200 \text{ GeV}$, $|\eta| < 0.35$)
- ❑ Eta mesons ($p^\uparrow + p$, $\sqrt{s} = 200 \text{ GeV}$, $|\eta| < 0.35$)
- ❑ Isolated direct photons ($p^\uparrow + p$, $\sqrt{s} = 200 \text{ GeV}$, $|\eta| < 0.35$)
- ❑ Heavy flavor electrons ($p^\uparrow + p$, $\sqrt{s} = 200 \text{ GeV}$, $|\eta| < 0.35$)
- ❑ Charged pion ($p^\uparrow + p$, $\sqrt{s} = 200 \text{ GeV}$, $|\eta| < 0.35$)

A_{LL} from:

- ❑ Direct photon ($\vec{p} + \vec{p}$, $\sqrt{s} = 510 \text{ GeV}$, $|\eta| < 0.25$)
- ❑ Jet ($\vec{p} + \vec{p}$ collisions)
- ❑ Charged pion ($\vec{p} + \vec{p}$ collisions)

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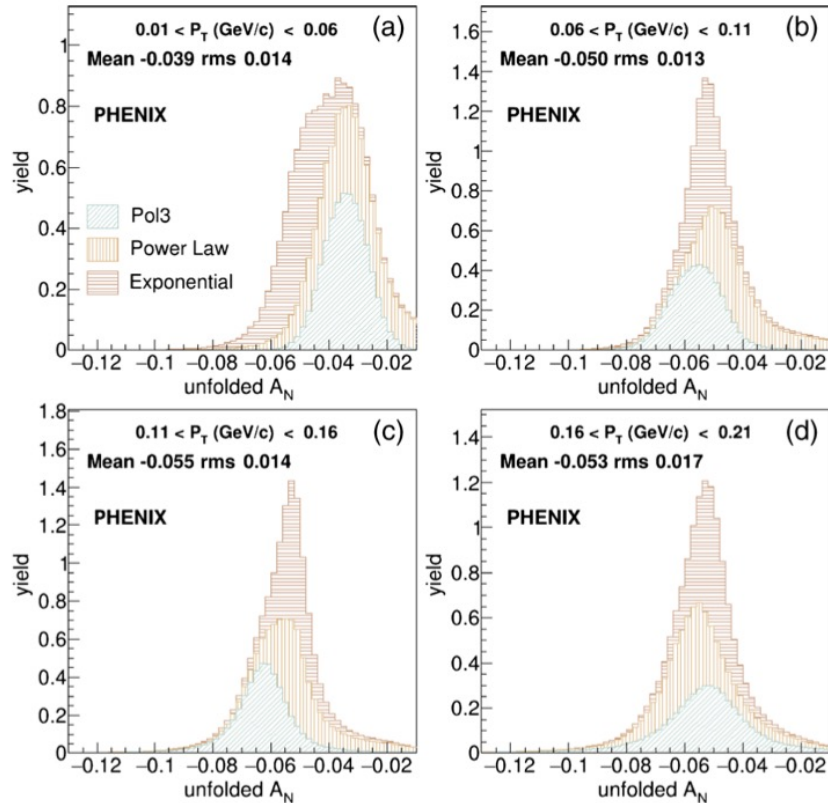
Transverse momentum dependent forward neutron single spin asymmetries in transversely polarized $p + p$ collisions at $\sqrt{s} = 200$ GeV. (<https://doi.org/10.1103/PhysRevD.103.032007>)



True asymmetry parameterizations as a function of transverse momentum for (a) a 3rd order polynomial dependence, (b) a power law dependence and (c) an exponential dependence.

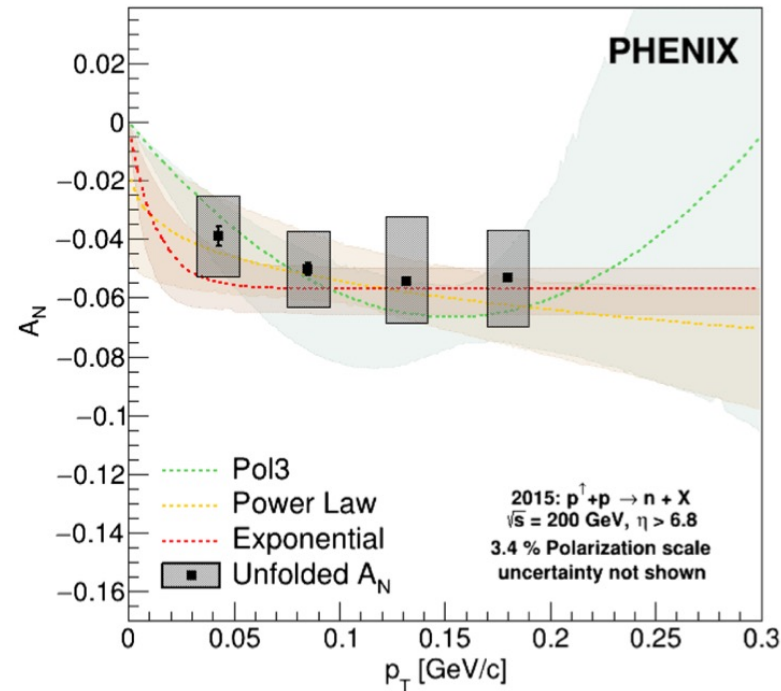
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Relative likelihood distributions of unfolded A_N for each p_T bin for all sets of parameters of each functional form weighted by the inverse of its χ^2 .

Neutron A_N as a function of the true transverse momentum.

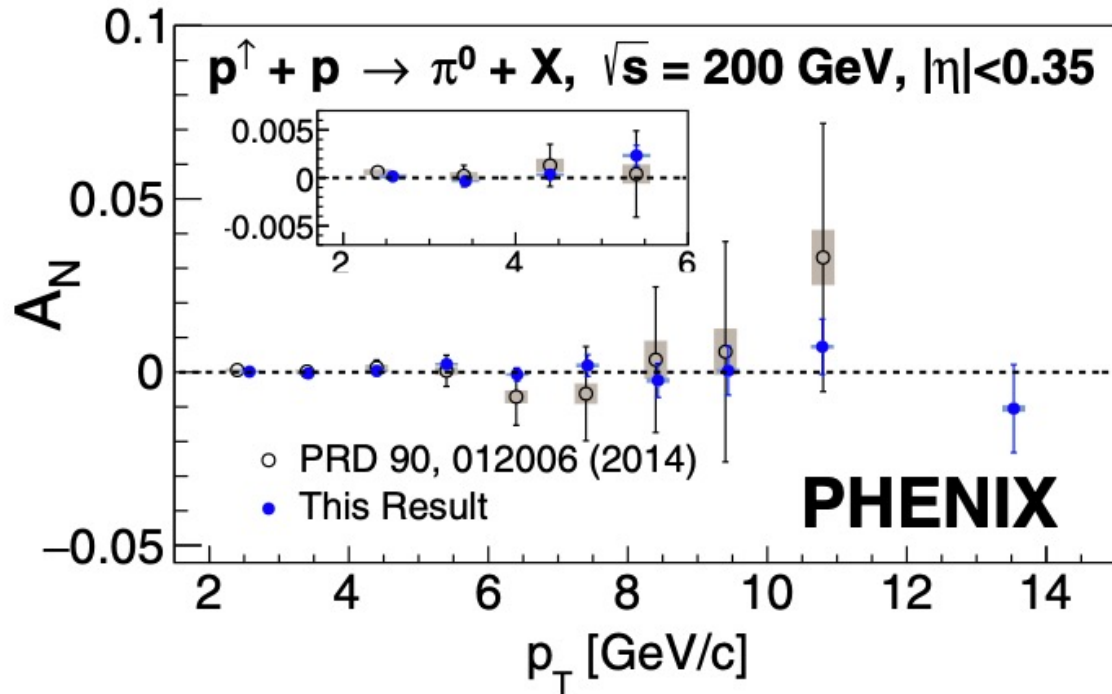


- A_N rapidly increases and eventually levels off at high p_T . Trend not in accordance with a linear p_T dependence in *Regge theory* calculations [PRD84, 114012 \(2011\)](#). Further probe is done in pA and detector correlation studies.
- [Preliminary results for pA and detector correlation studies upcoming.](#)

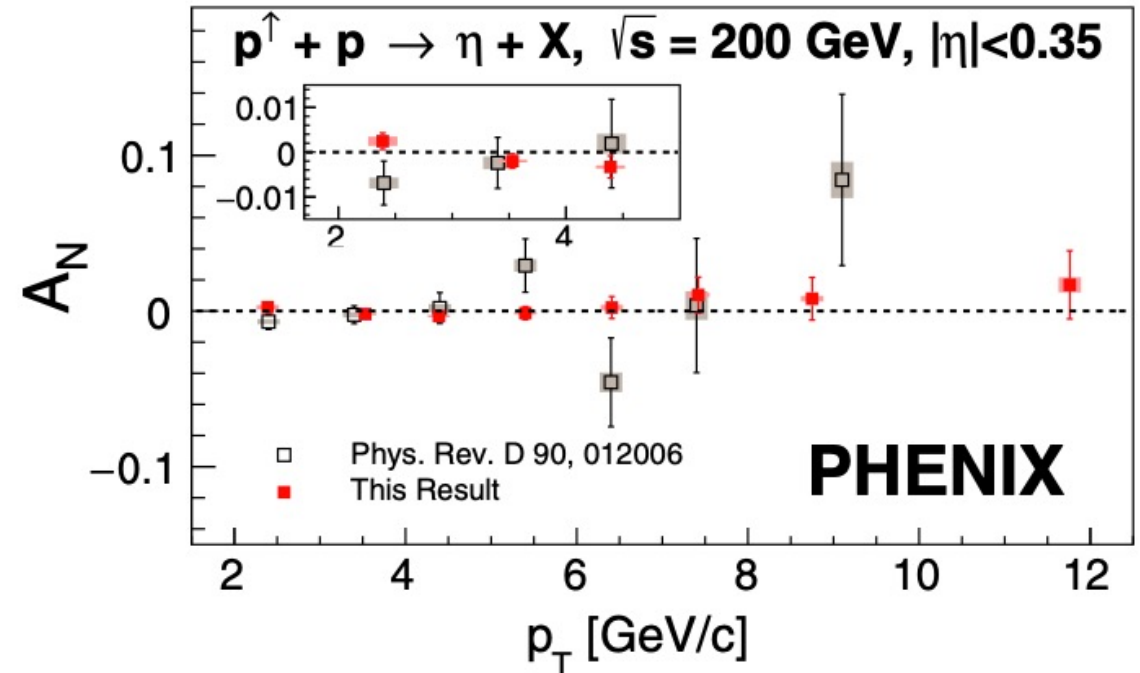
Recent Highlights from the PHENIX Cold-QCD Physics Program (Spin Workshop)

Transverse single-spin asymmetries of midrapidity π^0 and η mesons in polarized $p + p$ collisions at $\sqrt{s} = 200$ GeV.

<https://doi.org/10.1103/PhysRevD.103.052009>



TSSA of π^0 measured at $|\eta| < 0.35$ in $p^\uparrow + p$ collisions at $\sqrt{s} = 200$ GeV.

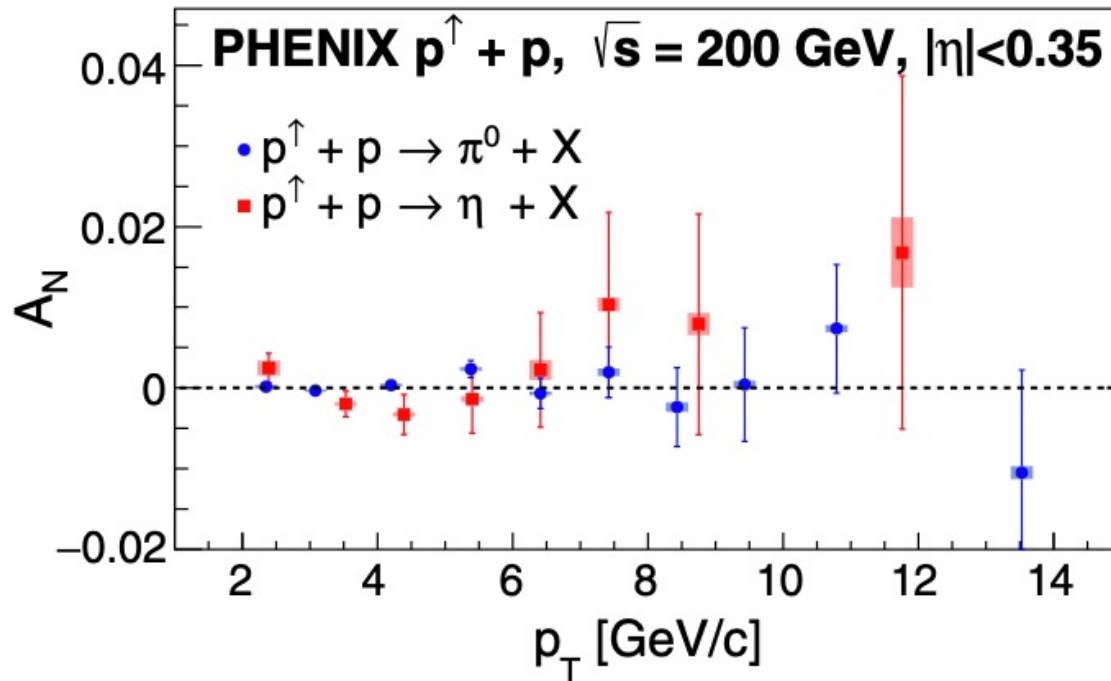


TSSA of η mesons measured at $|\eta| < 0.35$ in $p^\uparrow + p$ collisions at $\sqrt{s} = 200$ GeV.

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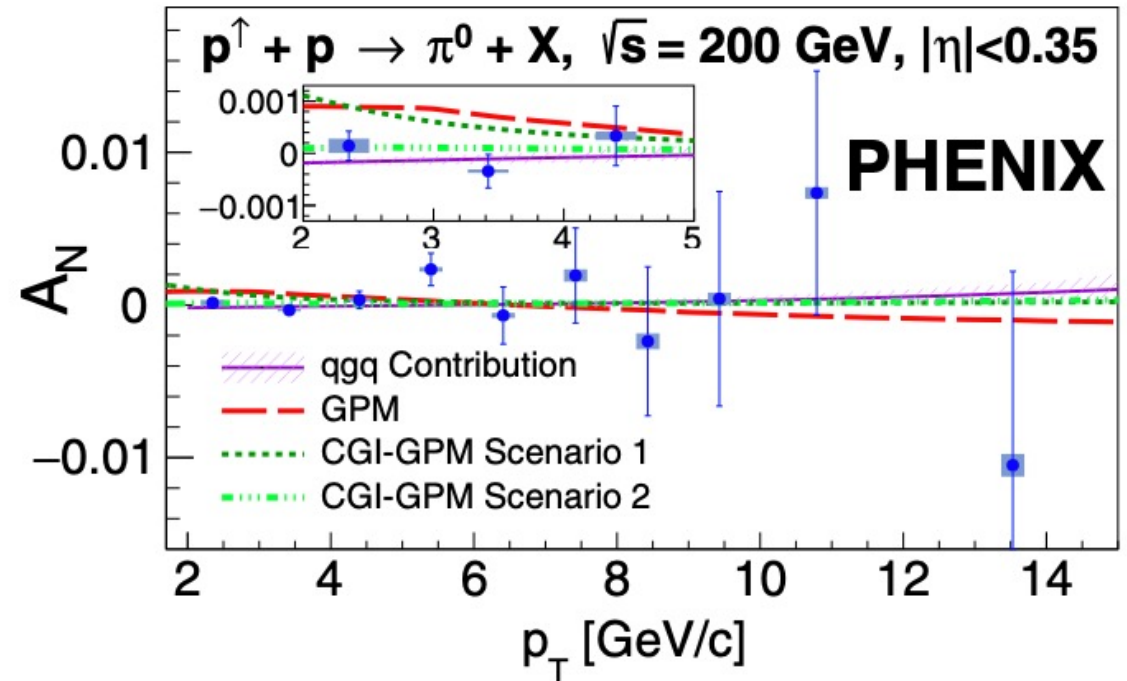
Transverse single-spin asymmetries of midrapidity π^0 and η mesons in polarized $p + p$ collisions at $\sqrt{s} = 200$ GeV.

(<https://doi.org/10.1103/PhysRevD.103.052009>)



TSSA comparison of π^0 and η mesons measured at $|\eta| < 0.35$ in $p^\uparrow + p$ collisions at $\sqrt{s} = 200$ GeV.

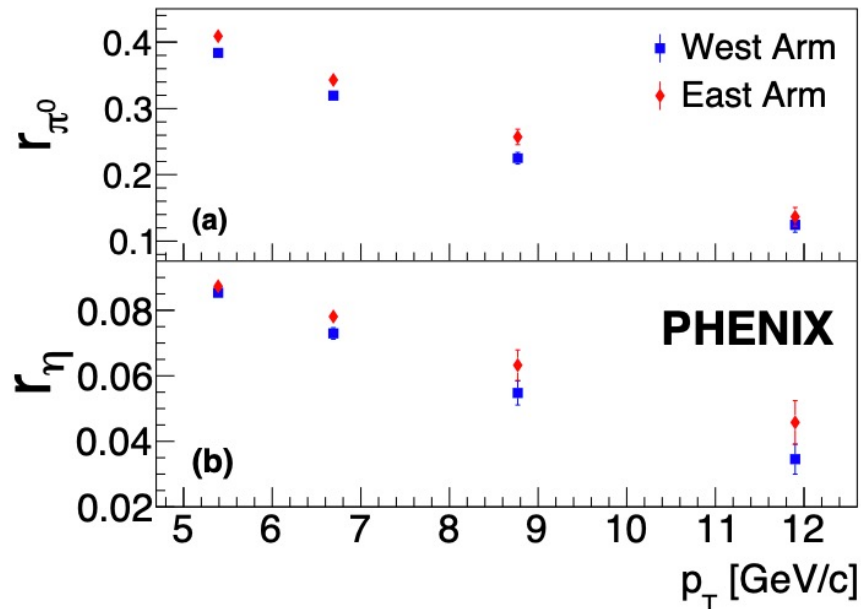
π^0 and η meson asymmetries are consistent with zero \rightarrow no contribution from strange quarks, isospin or even hadron mass. Larger A_N contribution is from gluon dynamics at midrapidity.



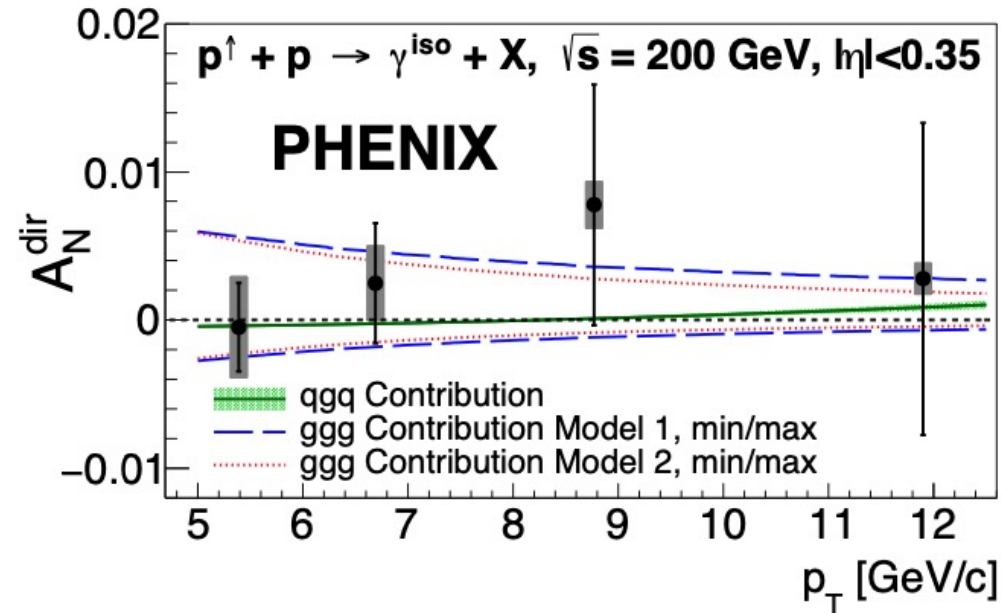
TSSA of π^0 result plotted with theory in collinear twist-3 and TMD framework predictions.

Recent Highlights from the PHENIX Cold-QCD Physics Program (Spin Workshop)

Probing gluon spin-momentum correlations in transversely polarized protons through midrapidity isolated direct photons in $p^\uparrow + p$ collisions at $\sqrt{s} = 200$ GeV (<https://arxiv.org/abs/2102.13585v1>, submitted to PRL)



Background fractional contribution of photons from (a) π^0 and (b) η decays to the isolated photon candidate sample

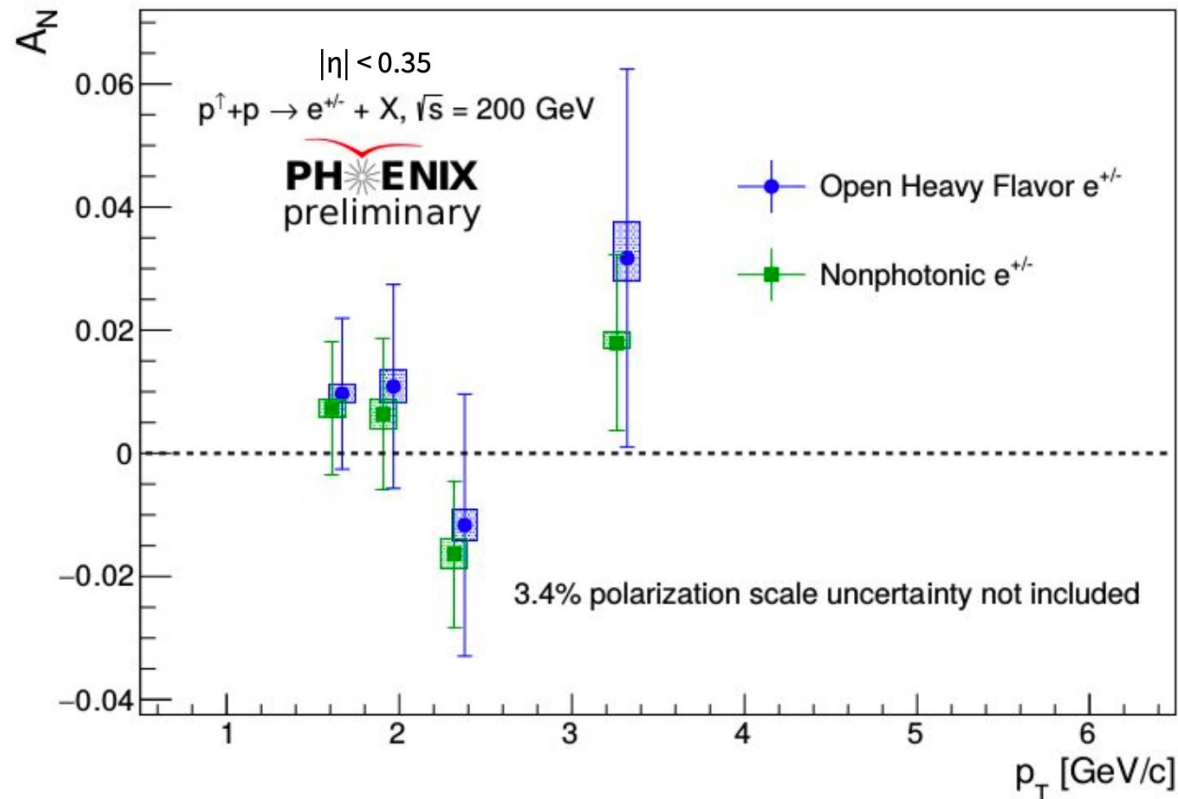


Transverse single-spin asymmetry of isolated direct photons measured at midrapidity $|\eta| < 0.35$ in $p + p$ collisions at $\sqrt{s} = 200$ GeV.

A_N of midrapidity direct photons is consistent with zero. First measurement in ~ 30 years by PHENIX experiment in higher p_T range. Clean probe of proton structure with no contribution from final-state QCD effects, sensitive to gluon dynamics. If included in global analysis of A_N data, will constrain gluon-momentum correlations in p^\uparrow , a vital step toward creating a more 3-D proton structure picture.

Recent Highlights from the PHENIX Cold-QCD Physics Program (Spin Workshop)

Transverse single spin asymmetries of heavy flavor electrons in 200 GeV $p^\uparrow + p$ collisions at midrapidity from PHENIX
(*PHENIX Preliminary, 2021*)



Charge combined open heavy flavor electron A_N .

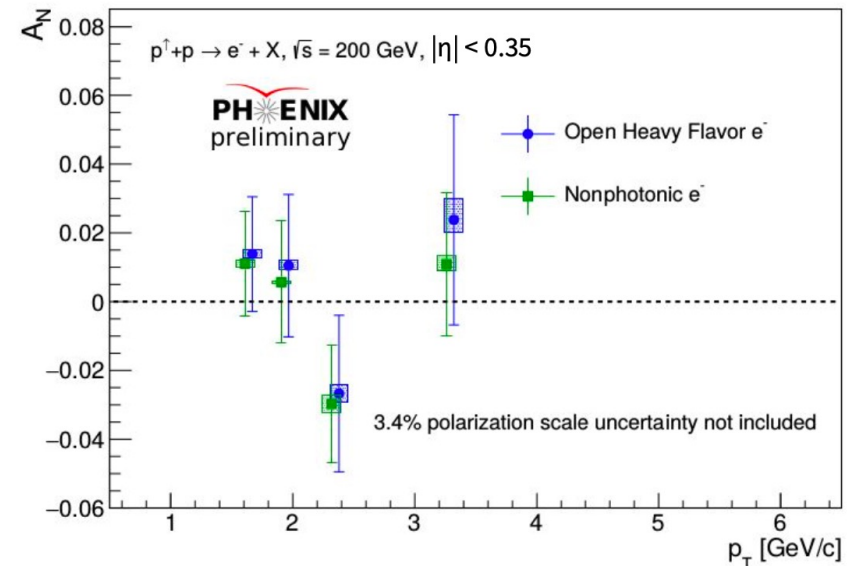
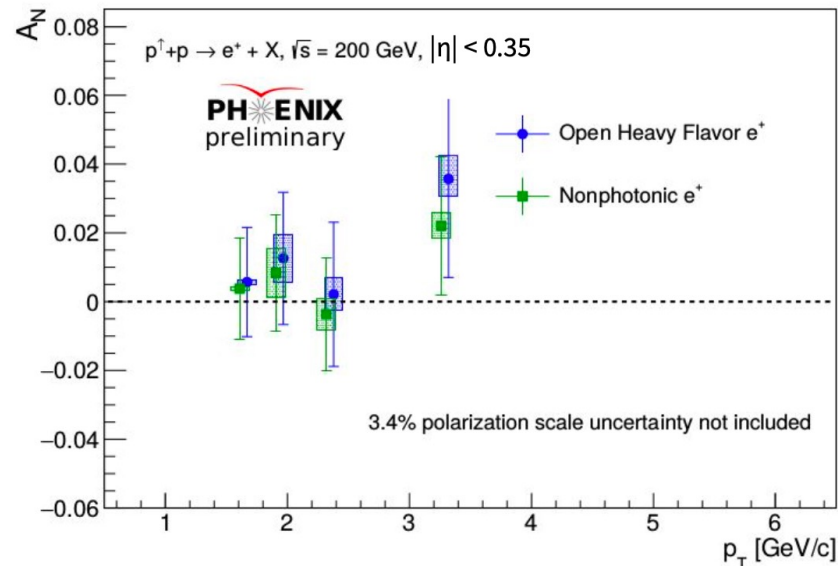
Precise measurement of nonphotonic electron and open heavy flavor TSSA at midrapidity.

Consistent with zero in measured p_T range.

Recent Highlights from the PHENIX Cold-QCD Physics Program (Spin Workshop)

Transverse single spin asymmetries of heavy flavor electrons in 200 GeV $p^\uparrow + p$ collisions at midrapidity from PHENIX
(PHENIX Preliminary, 2021)

Charge separated open heavy flavor electron A_N

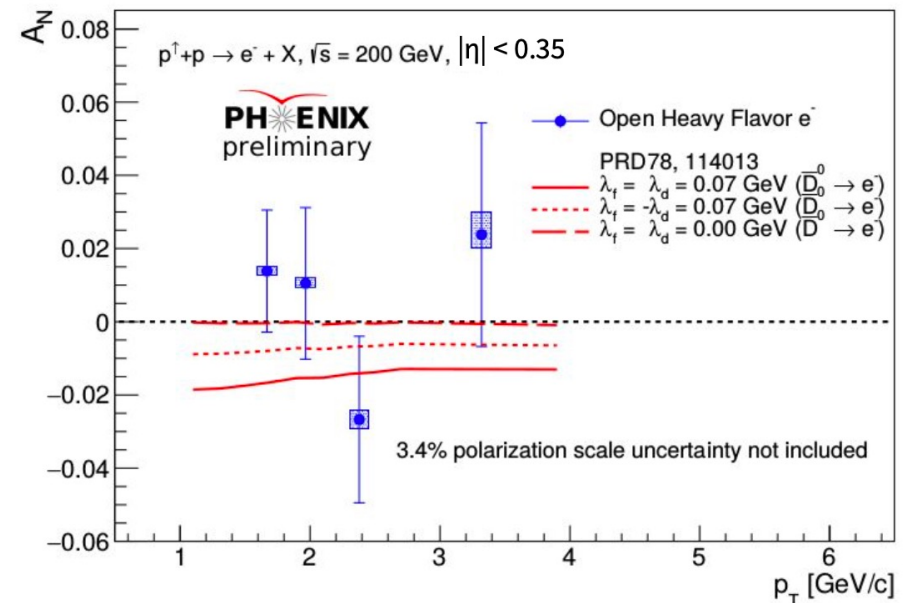
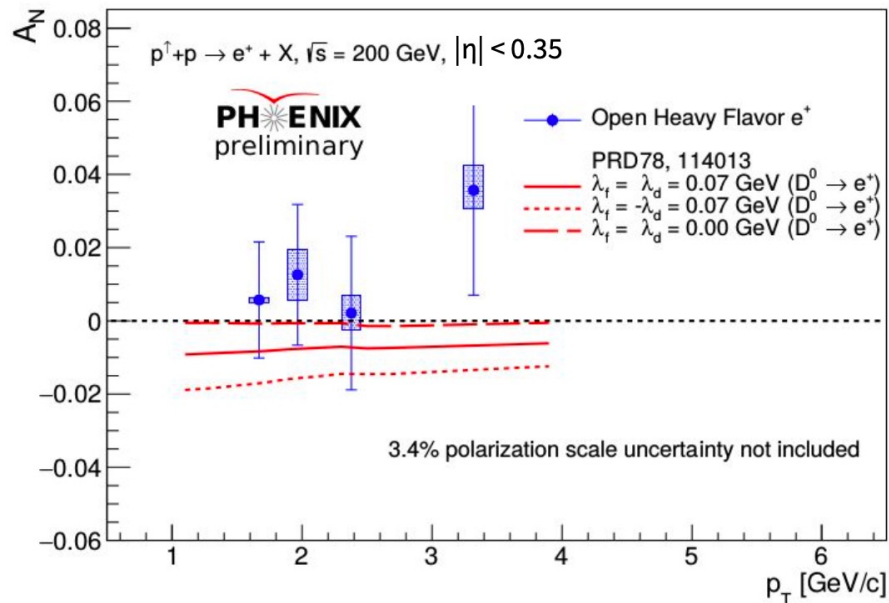


In the measured p_T range, the charge separated A_N results are also consistent with zero.

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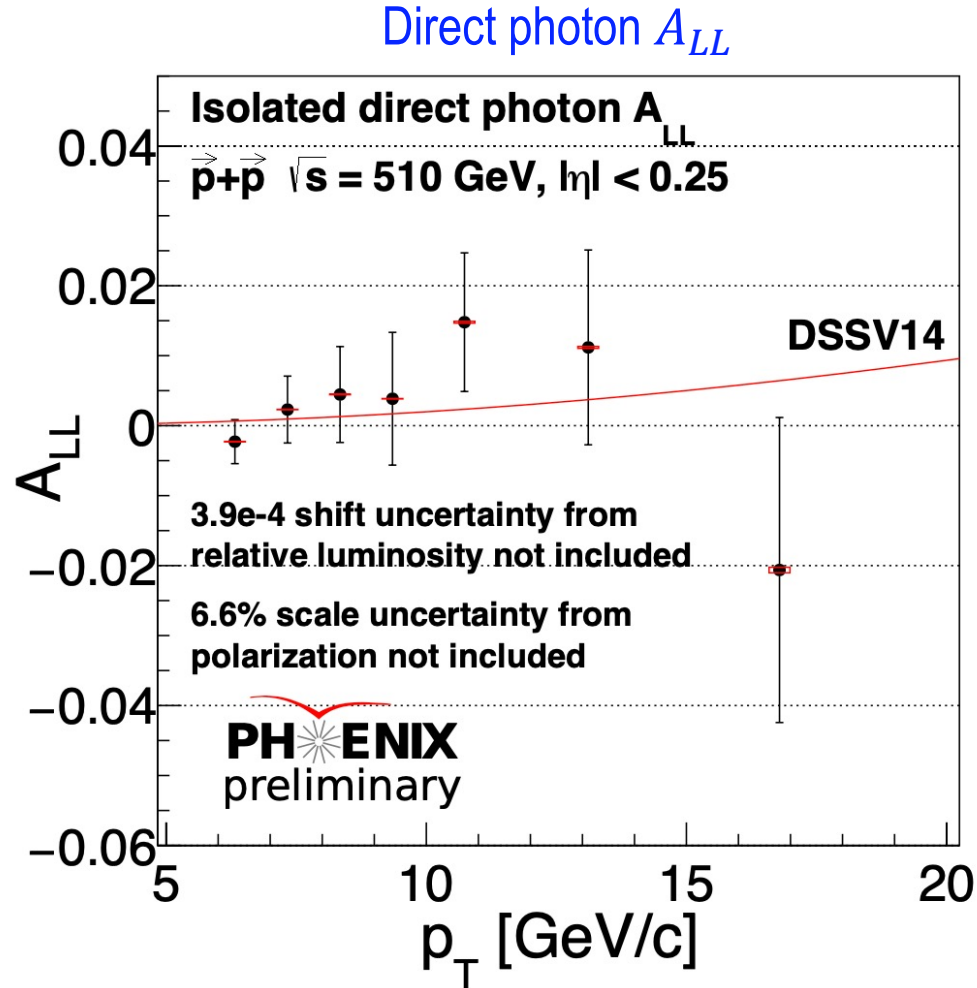
Charge separated open heavy flavor electron A_N



- ❑ Red curves indicate $D^0 \rightarrow e^\pm$ contributions as calculated in **PRD78, 114013**.
- ❑ Ordering of curves is different for charge separated $A_N \rightarrow$ sensitivity to constrain λ parameters.
- ❑ λ parameters correspond to normalizations of ggg correlators w.r.t. to unpolarized gluon PDF.

Recent Highlights from the PHENIX Cold-QCD Physics Program (Spin Workshop)

Longitudinal double helicity asymmetry A_{LL} from direct photon, jet and charged pion production in polarized $\vec{p} + \vec{p}$ collisions (*PHENIX Preliminary, 2021*)



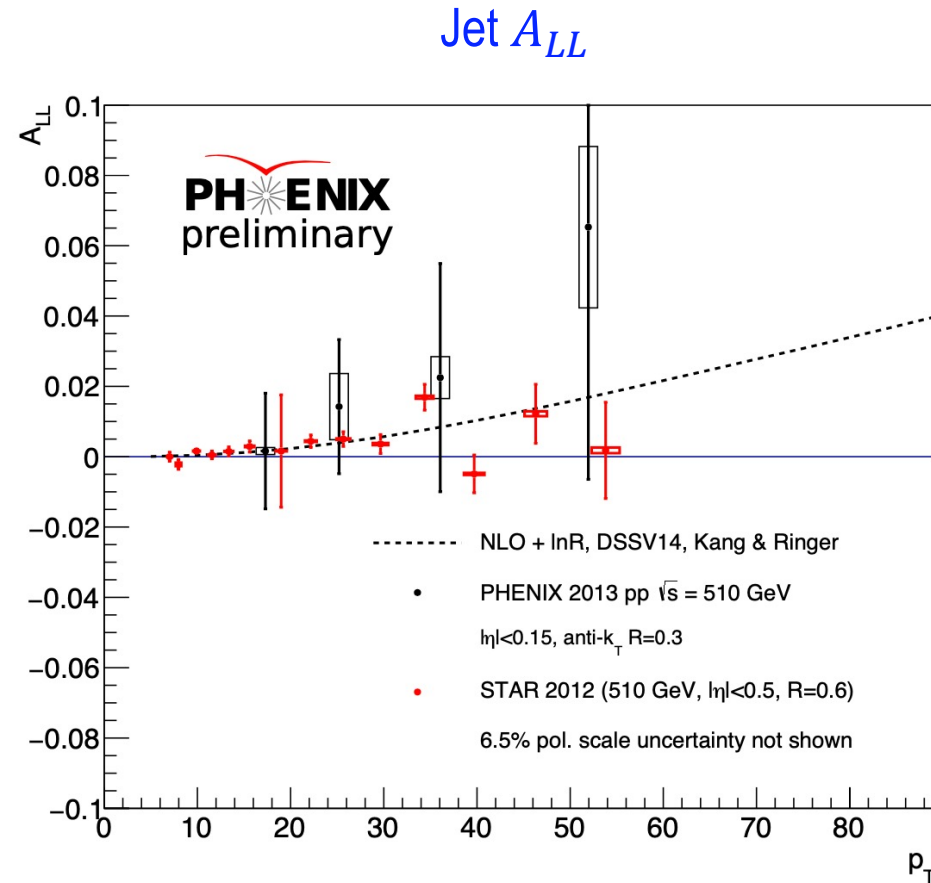
Consistent with DSSV14

Constrain polarized gluon PDF Δg

Will be first published direct photon A_{LL}

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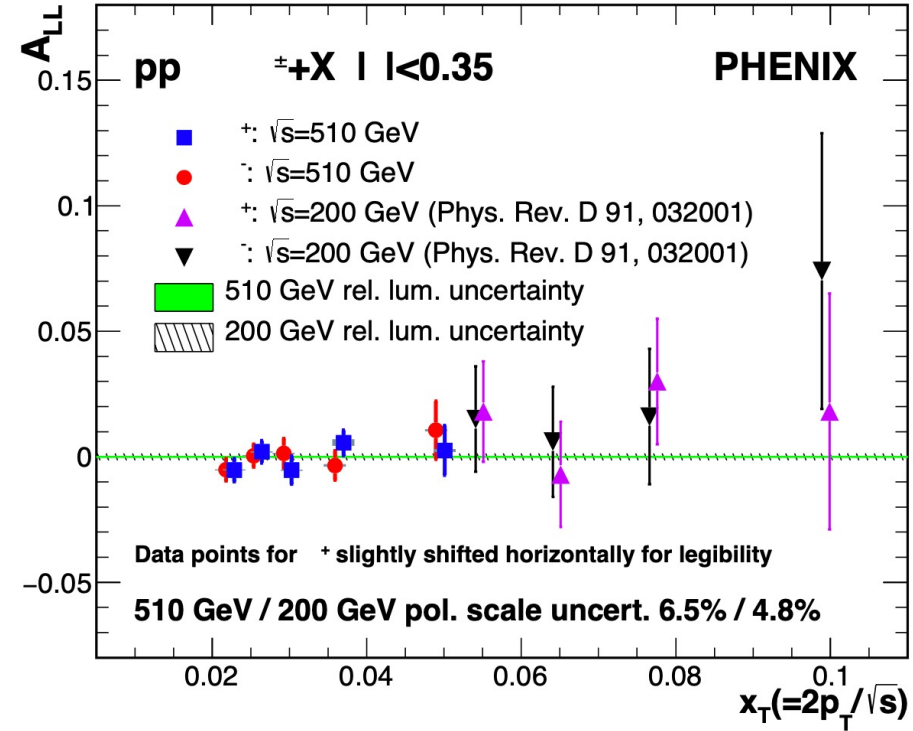
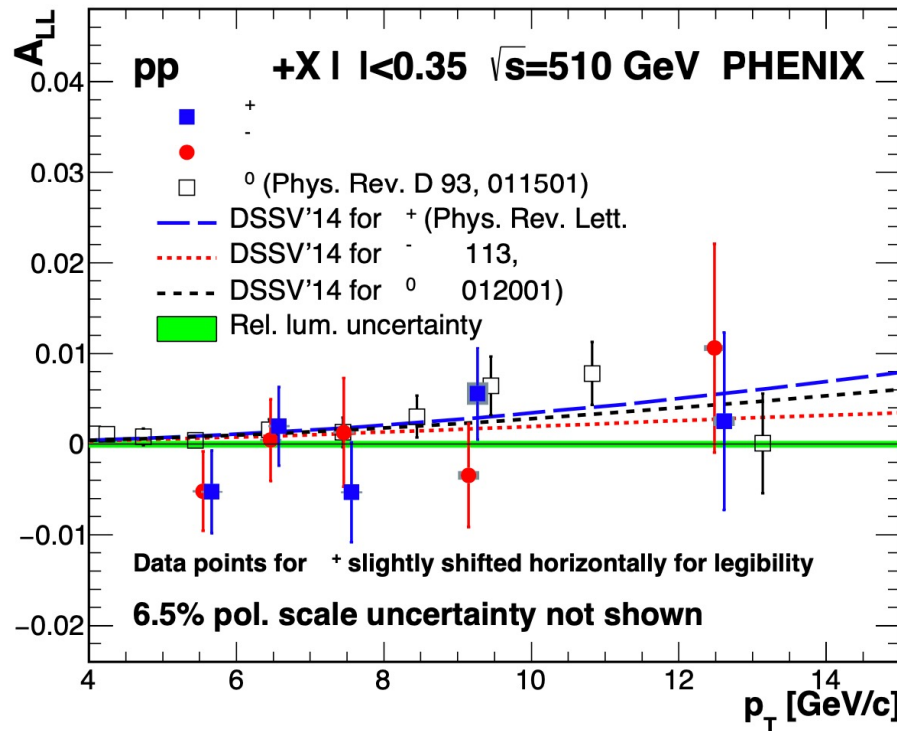
☐ Consistent with DSSV14 at NLO+lnR resummation.

☐ Independent constraint on polarized gluon PDF Δg . Uncertainties are corrected due to the unfolding.

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Longitudinal double helicity asymmetry A_{LL} from direct photon, jet and charged pion production in polarized $\vec{p} + \vec{p}$ collisions (*PHENIX Preliminary, 2021*)

Charged pion A_{LL}



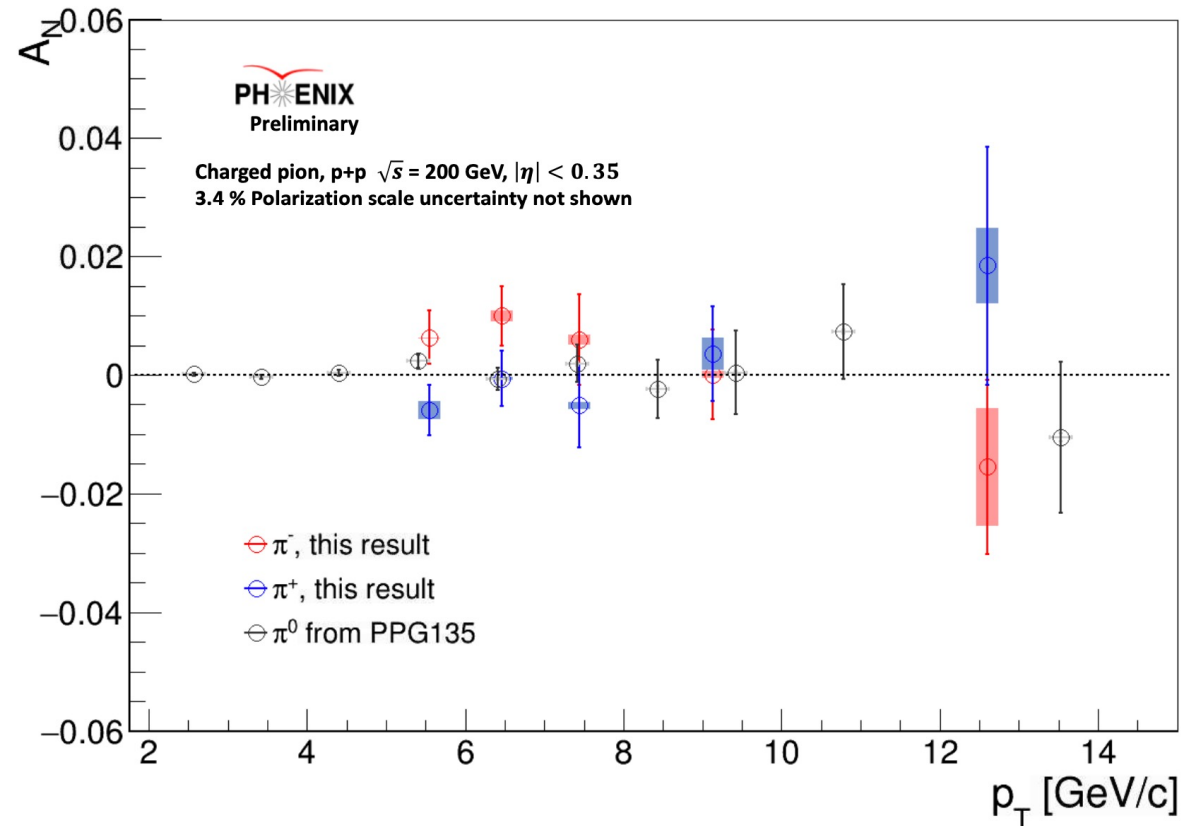
- PRD 102, 032001 (2020)
- Consistent with DSSV14.

- 510 GeV data probe low x range
- Insufficient statistics for π^\pm

Recent Highlights from the PHENIX Cold-QCD Physics Program (Spin Workshop)

Transverse Single Spin Asymmetry via Charged Pion Production in Polarized p + p 200 GeV collisions at Midrapidity
(PHENIX Preliminary, 2021)

TSSA of charged pion in transversely p+p collisions at a center of mass of 200 GeV at midrapidity



A_N of π^\pm is consistent with zero, with a slight indication of differences. Hint \rightarrow possibility of different A_N from up and down quarks.

Summary

- p_T dependent forward neutron A_N in $p^\uparrow + p$ collisions at $\sqrt{s} = 200$ GeV (**Published in PRD**). Overall A_N rapidly increases and levels off at high $p_T \rightarrow$ trend not in accordance with regge theory calculations. Detector correlation and pA studies to give further incite. **Preliminary results upcoming**.
- A_N of midrapidity π^0 and η in polarized $p + p$ collisions at $\sqrt{s} = 200$ GeV (**Published in PRD**). π^0 and η meson A_N 's are consistent with zero implying that there is no contribution from strangeness, isospin or even mass. At midrapidity, larger A_N contribution is from gluon dynamics.
- Probed gluon spin-momentum correlations in p^\uparrow through midrapidity isolated direct photons in $p^\uparrow + p$ collisions at $\sqrt{s} = 200$ GeV (**Submitted to PRL**). A_N of midrapidity direct photons is consistent with zero. Clean probe of proton structure with no contribution from final-state QCD effects.
- TSSA of heavy flavor electrons in $\sqrt{s} = 200$ GeV $p^\uparrow + p$ collisions at midrapidity from PHENIX (**2021 PHENIX Preliminary**). Precise A_N measurement of nonphotonic and open heavy flavor electrons. Both charge combined and separated A_N results are consistent with zero.
- A_{LL} from direct photon, jet and charged pion production in polarized $\vec{p} + \vec{p}$ collisions (**2021 PHENIX Preliminary**). Production of direct photon has little fragmentation contribution. Jet and π^\pm have large statistics, and π^\pm measurement can separate u and d quark contributions.
- A_N via π^\pm production in 200 GeV $p^\uparrow + p$ collisions at Midrapidity (**2021 PHENIX Preliminary**). First A_N measurement of π^\pm at midrapidity. Sensitive to quark flavors. Might help to check if up and down quarks result in different A_N if a complementary probe with improved statistics is used.

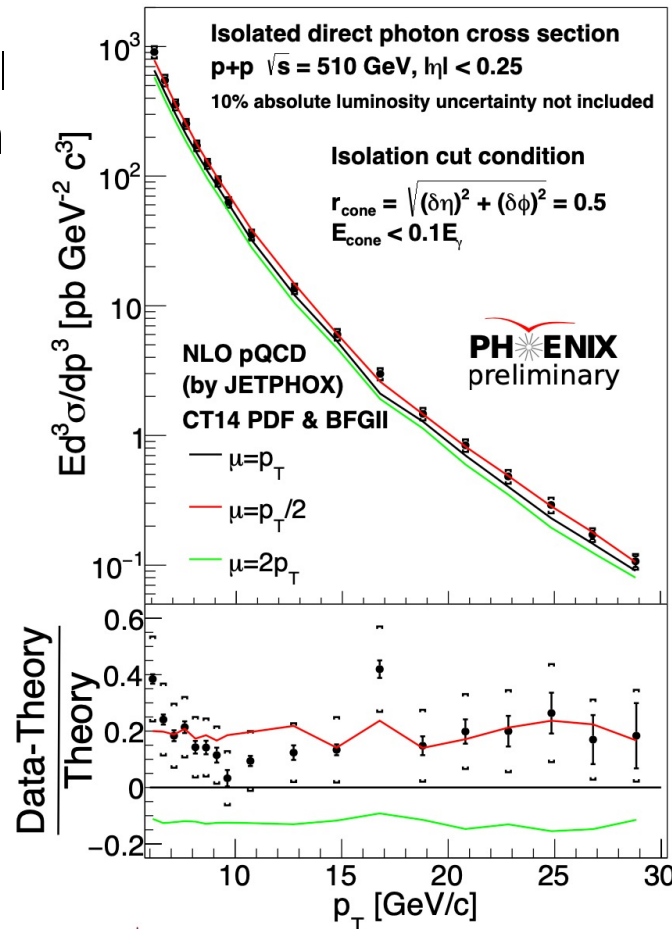
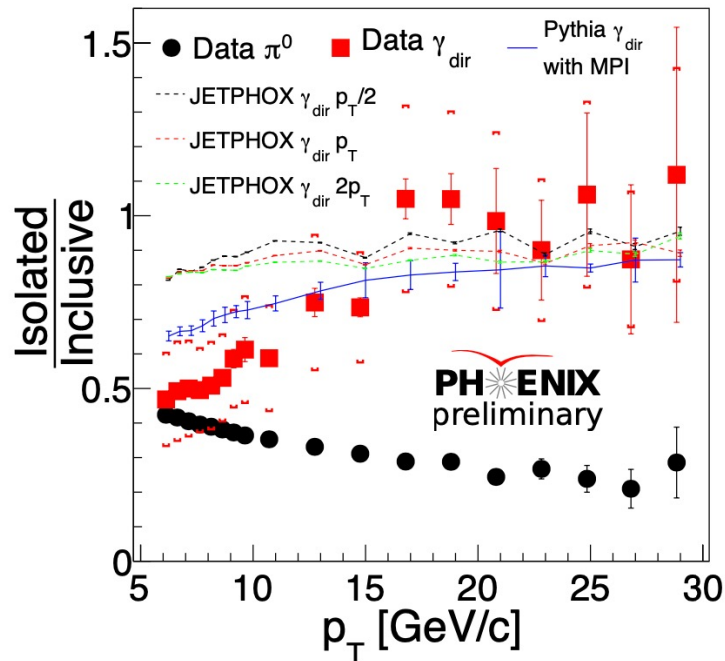
BACKUP

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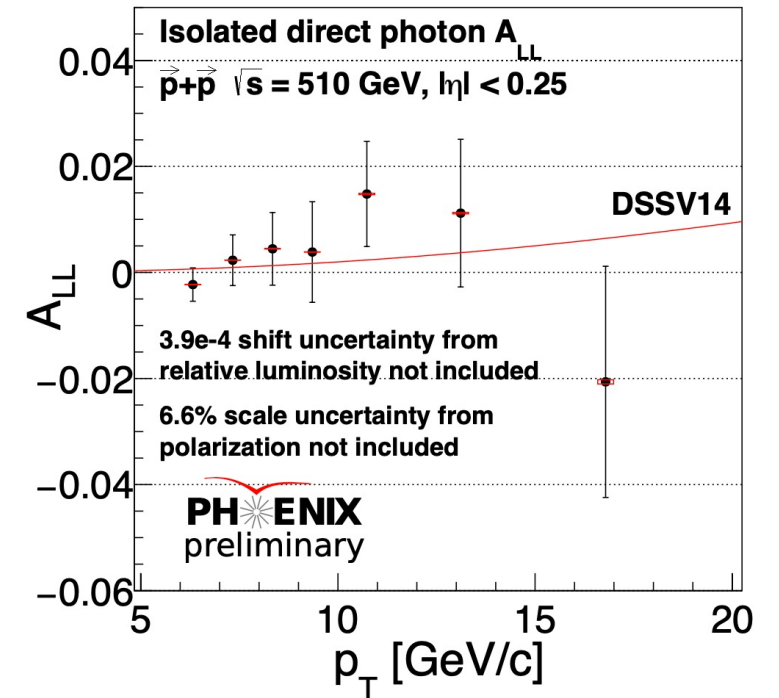
Longitudinal double helicity asymmetry A_{LL} from direct photon, jet and charged pion production in polarized $\vec{p} + \vec{p}$ collisions (*PHENIX Preliminary, 2021*)

Direct photon cross section

- ❑ Pretty consistent with NLO pQCD.
- ❑ Parton shower and MPI are essential for inclusive direct photon production
- ❑ Constrain unpolarized gluon PDF.



Direct photon A_{LL}

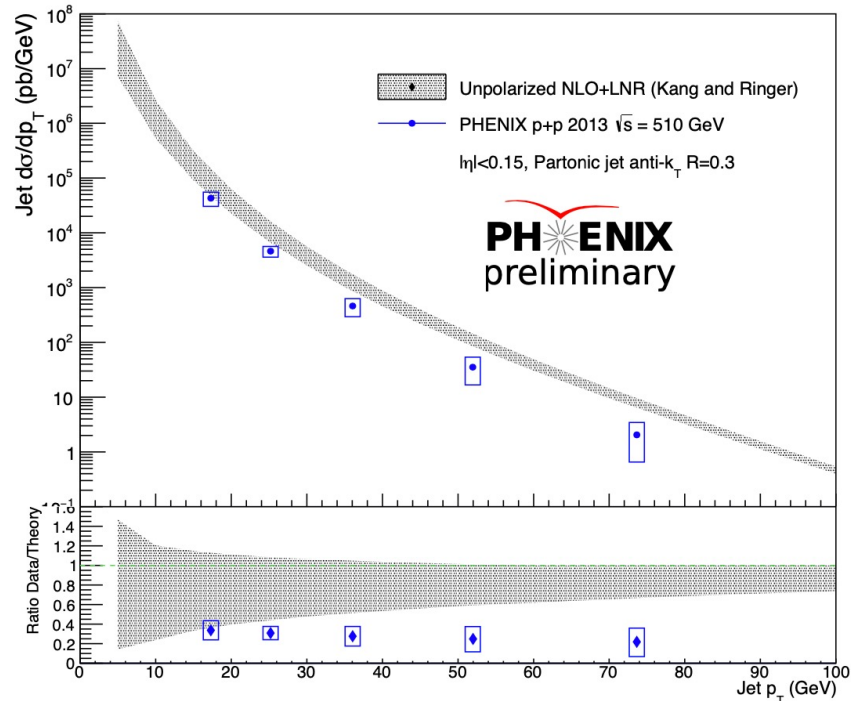


- ❑ Consistent with NLO DSSV14
- ❑ Constrain polarized gluon PDF Δg
- ❑ Will be first published direct photon A_{LL}

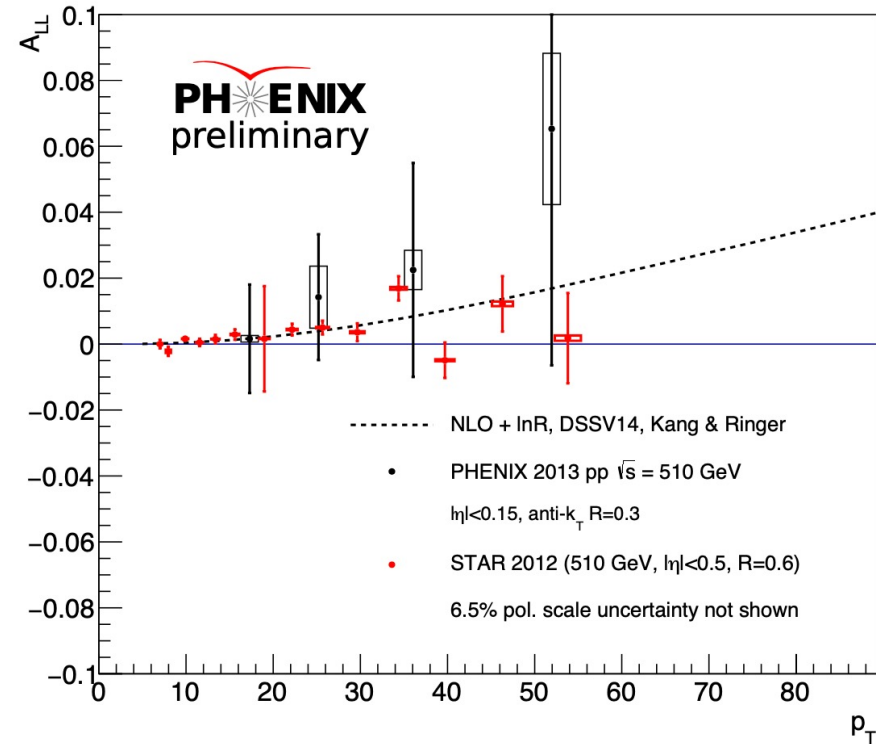
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Jet cross section



Jet A_{LL}



- NLO+ln[®] resummation calculation overestimates data
- Calculation is at partonic level: MPI and parton shower are essential.
- Similar calculation from CMS for small R anti- k_T

- Consistent with DSSV14 at NLO+ln[®] resummation.
- Independent constraint on polarized gluon PDF Δg .
- Uncertainties are corrected due to the unfolding.