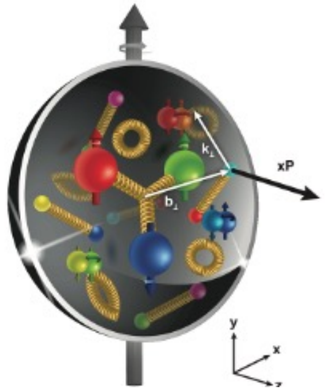


EIC Physics in PHENIX

Devon Loomis

PHENIX

RHIC AGS User Meeting 2025

THE UNIVERSITY OF MICHIGAN
ARTES · SCIENTIA · VERITAS
1817

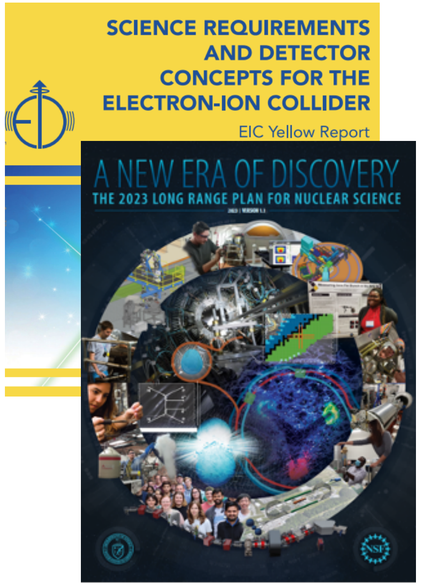
Science Pillars

EIC Physics in PHENIX

EIC **PHENIX**

Science Pillars

EIC Physics in PHENIX



EIC

Proton spin content

PHENIX

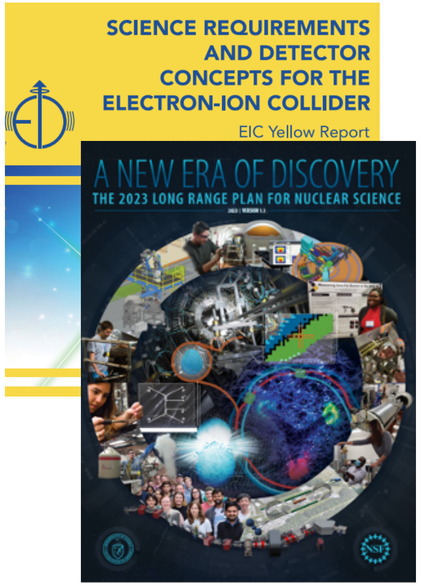
PHENIX Beam Use Proposal
for RHIC Runs 4-8

The PHENIX Collaboration

Are gluons polarized in the proton?

Science Pillars

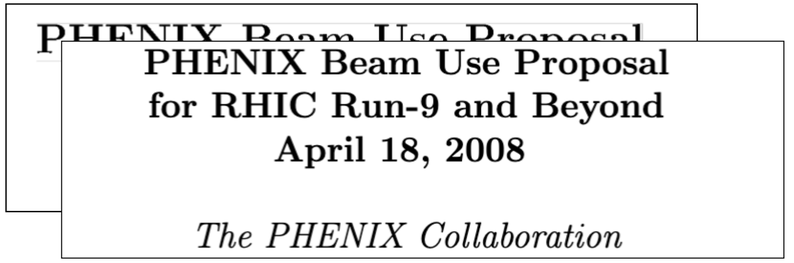
EIC Physics in PHENIX



EIC

Proton spin content

PHENIX

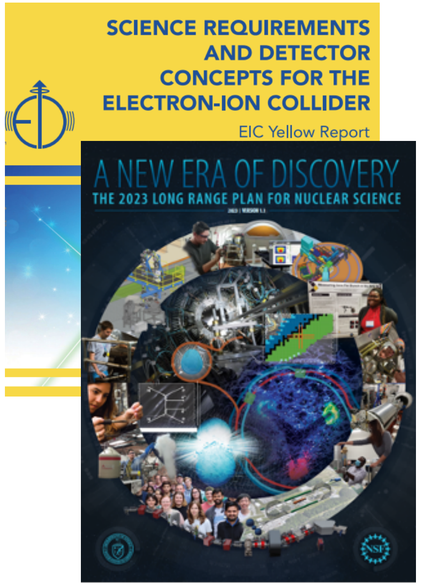


Are gluons polarized in the proton?

Are sea quarks polarized in the proton?

Science Pillars

EIC Physics in PHENIX



EIC

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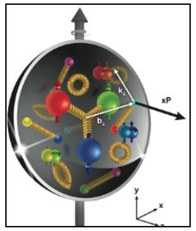
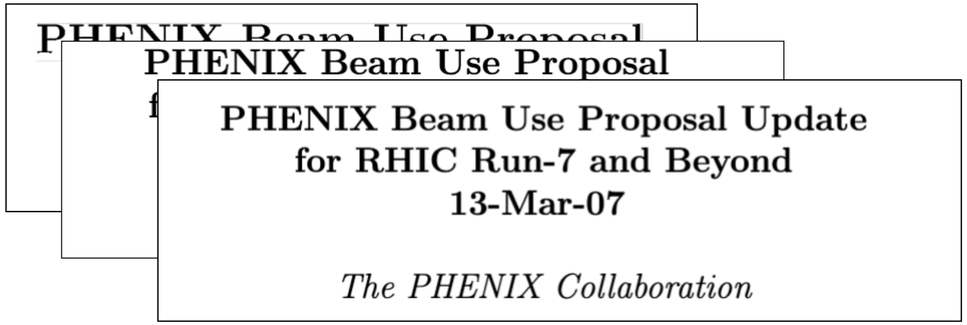


TMD PDFs, FFs

PHENIX



Are gluons polarized in the proton?

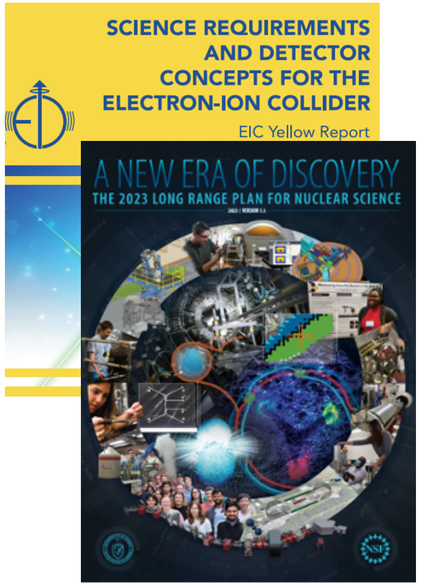
Are sea quarks polarized in the proton?

Are there parton correlations in the proton?

Are there parton correlations in fragmentation?

Science Pillars

EIC Physics in PHENIX



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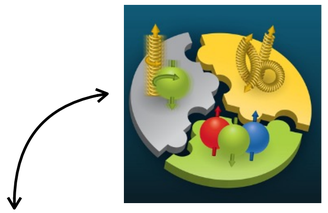
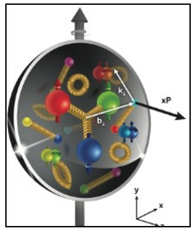
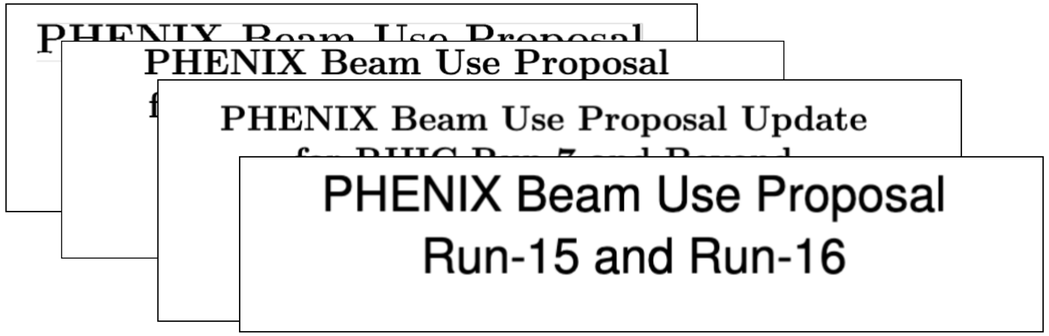


Nuclear matter effects



TMD PDFs, FFs

PHENIX



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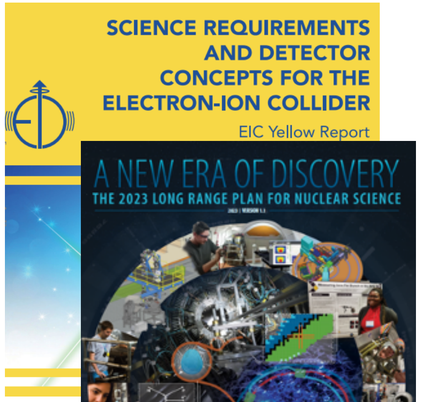
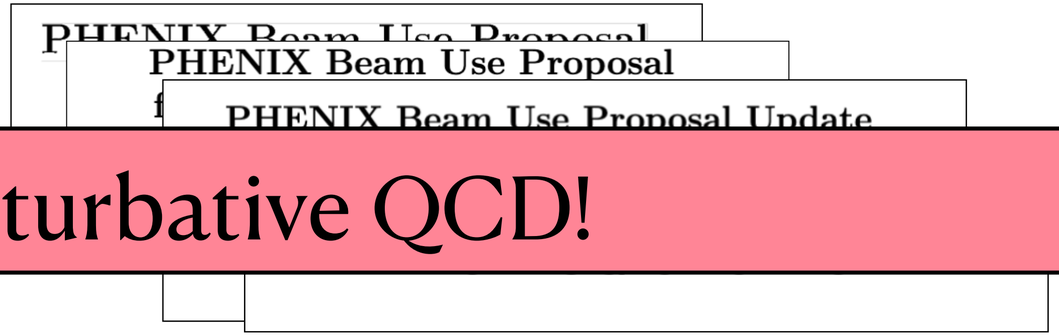
Science Pillars

EIC Physics in PHENIX



EIC

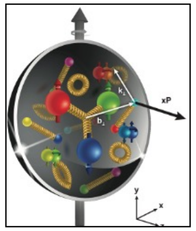
PHENIX



Proton spin content

Exploring nonperturbative QCD!

Nuclear matter effects



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Are gluons polarized in the proton?

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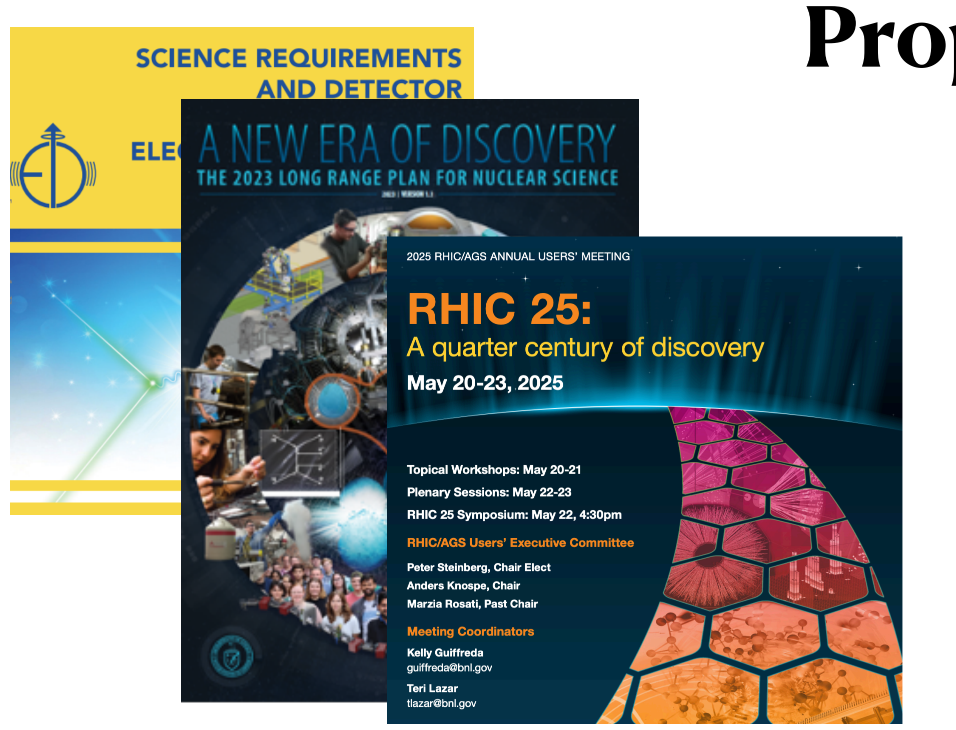
Project Timeline in Context

ePIC

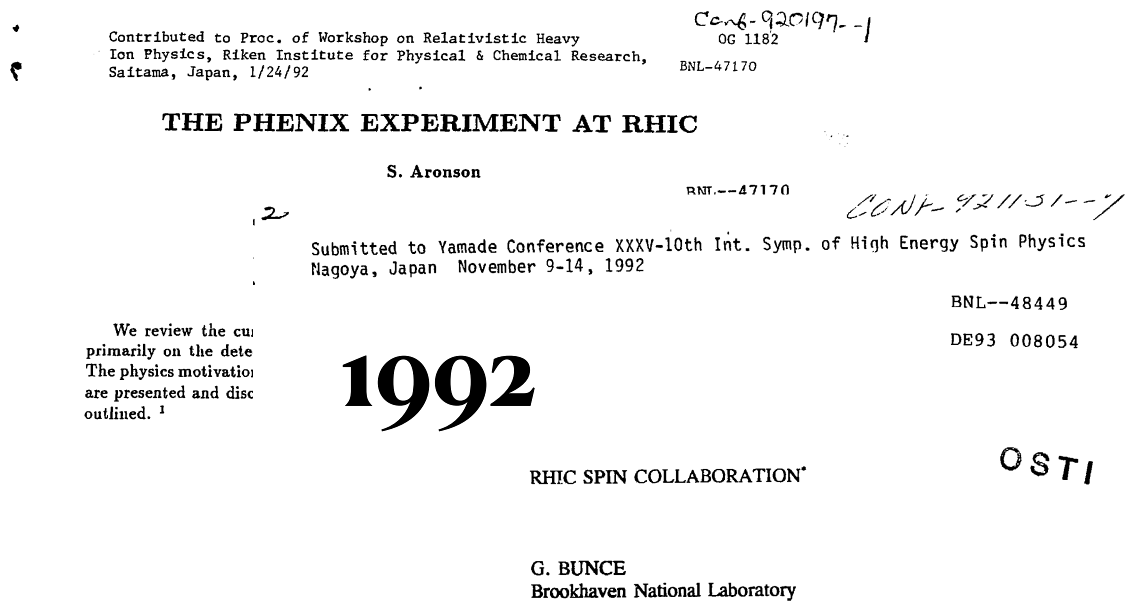
Proposed plan



Year 1	Year 2	Year 3	Year 4	Year 5	...
First EIC eA collisions	First EIC eD collisions	First EIC $ep^{\uparrow}$ collisions	First EIC $e\vec{p}$ collisions	First EIC electron on polarized He^3	Polarized electrons

PHENIX

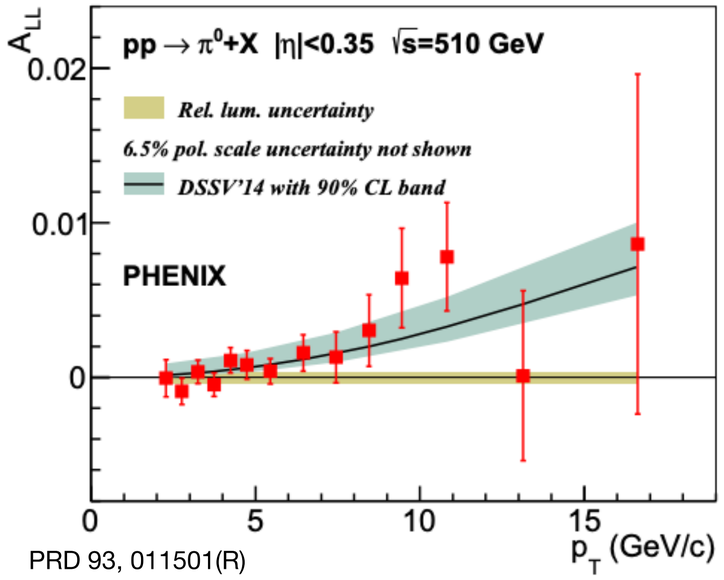
2000	2002	2003	... 2013	2015	... 2025
First RHIC AuAu collisions	First PHENIX transverse spin results	First PHENIX longitudinal spin results	Flagship high lumi longitudinal spin run	Transversely polarized p+A collisions	Analysis continues



Gluon polarization

PHENIX A_{LL} measurements

- High priority from outset of PHENIX collaboration
- Precise π^0 A_{LL} from Run 13: significant **nonzero** gluon polarization!



PRD 93, 011501(R)

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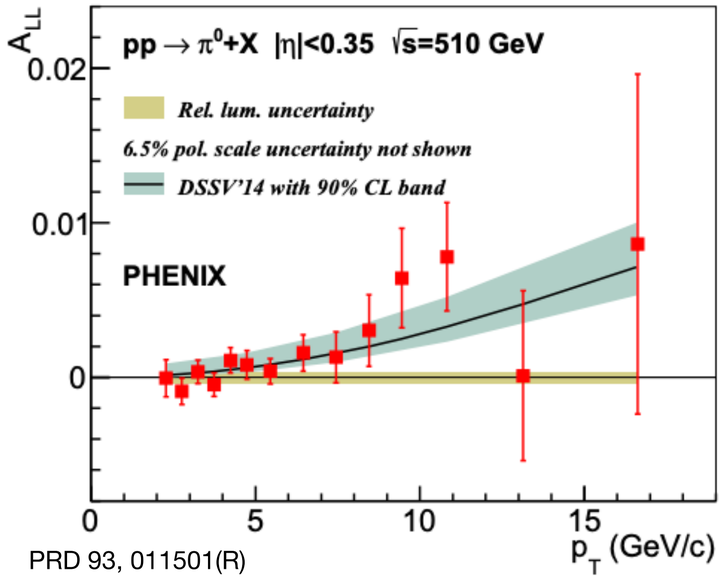
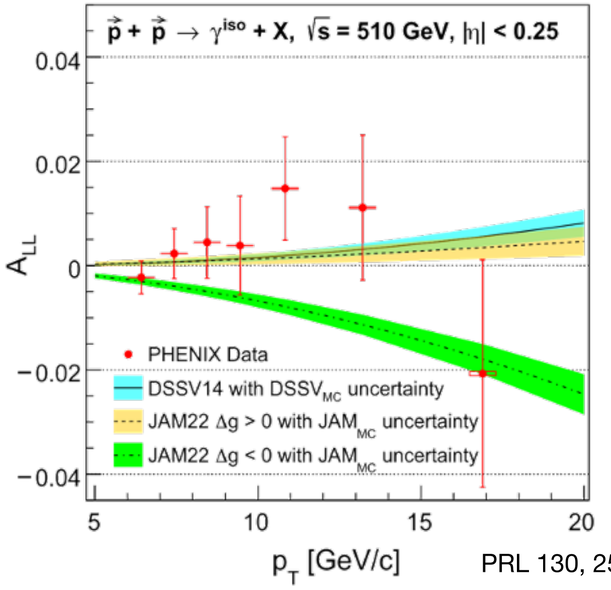


PRD 93, 011501(R)



PRL 130, 251901 (2023)

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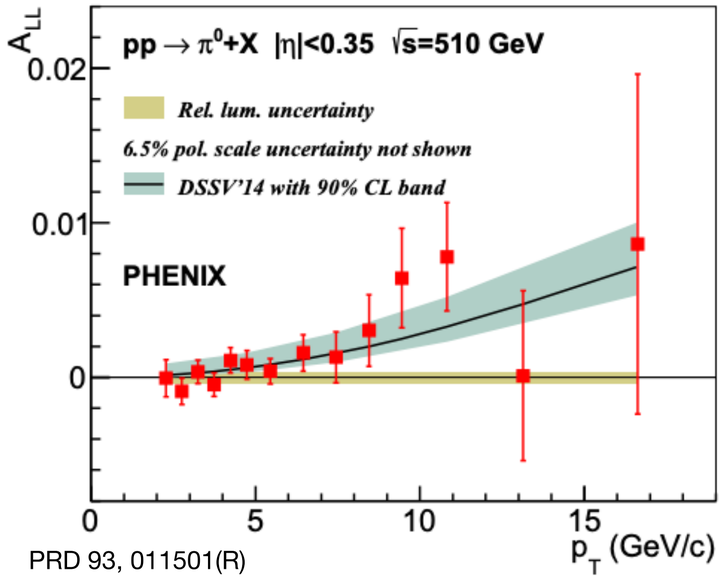
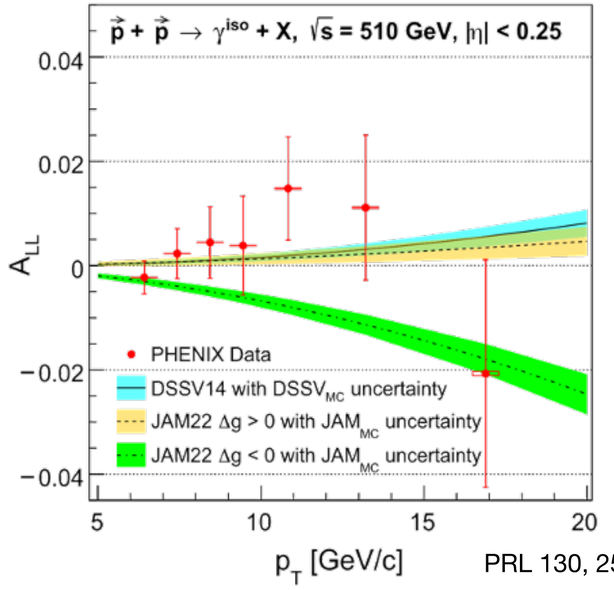
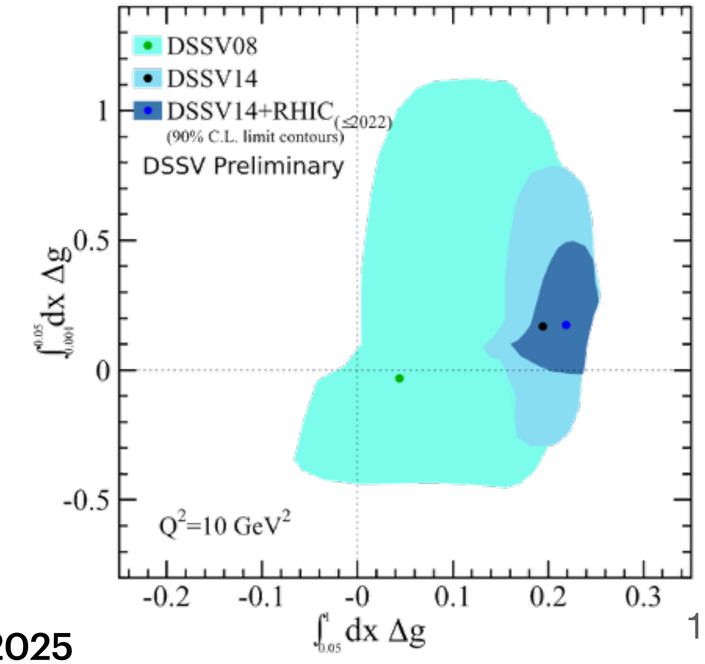


PRD 93, 011501(R)



PRL 130, 251901 (2023)

arxiv:2302.00605



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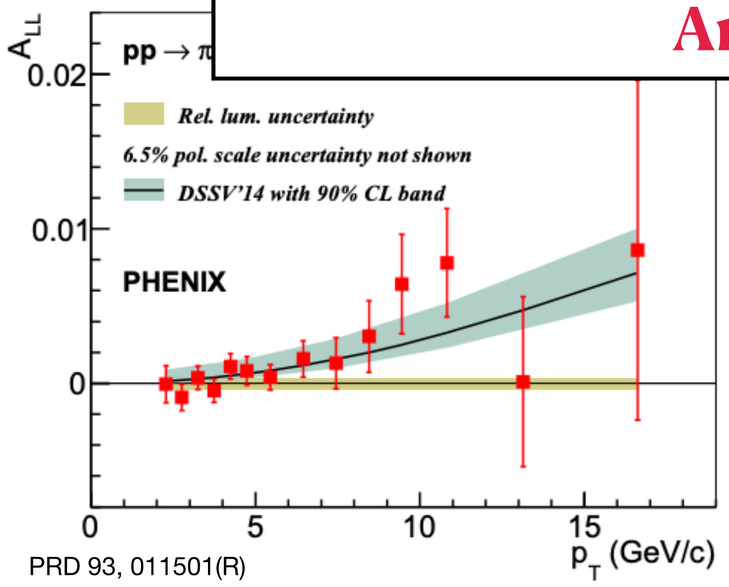

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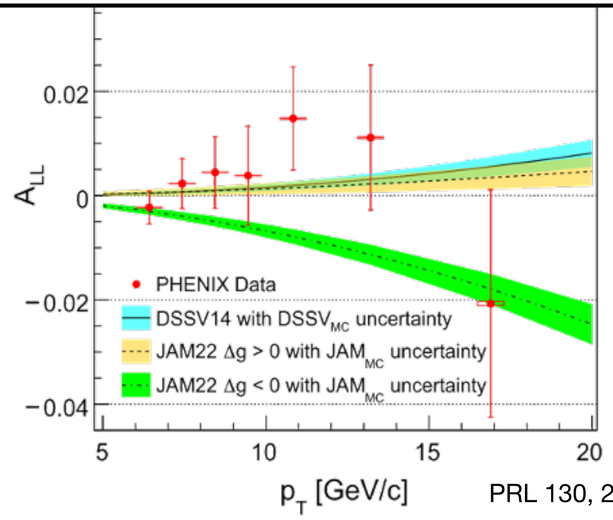

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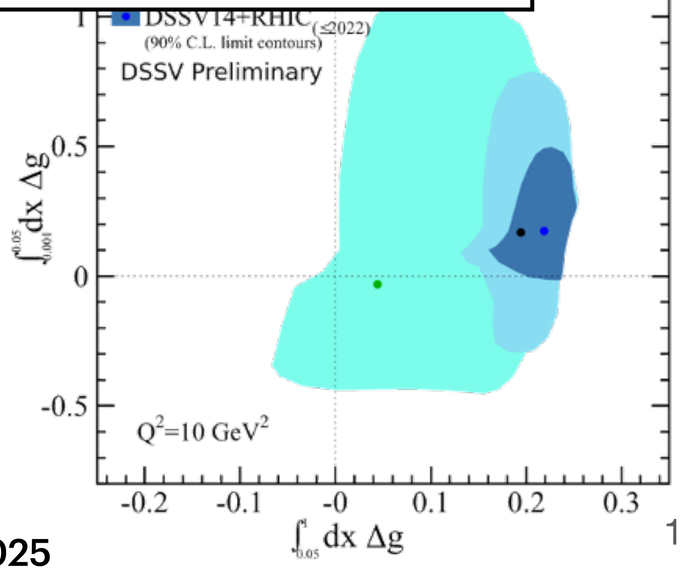
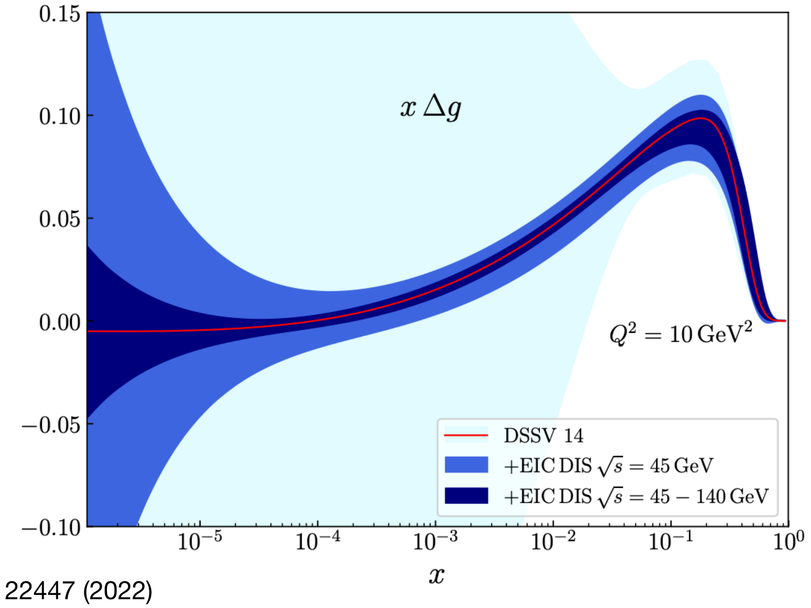


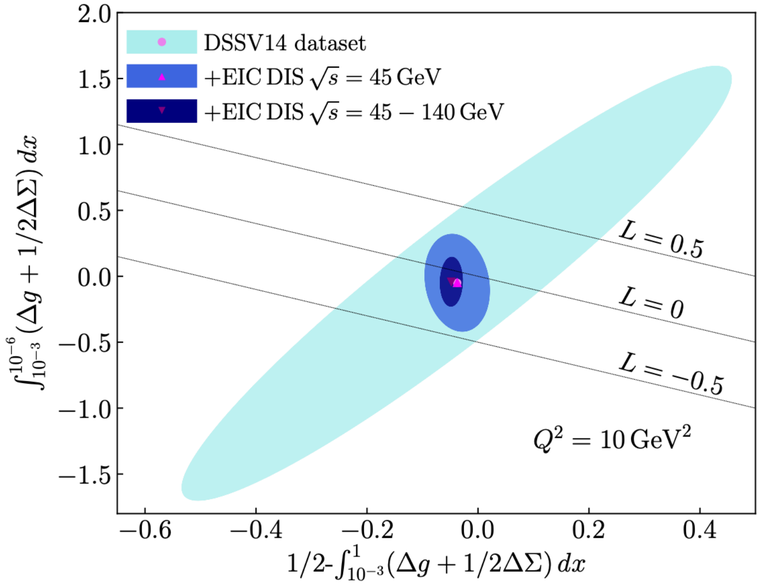
arxiv:2302.00605

Gluon polarization

Where EIC comes in

- DIS scaling violations in g_1 provide low-x sensitivity to ΔG
- Also probed with heavy flavor A_{LL}
- Strong constraints on ΔG and $\Delta\Sigma \rightarrow$ indirect constraint on parton OAM



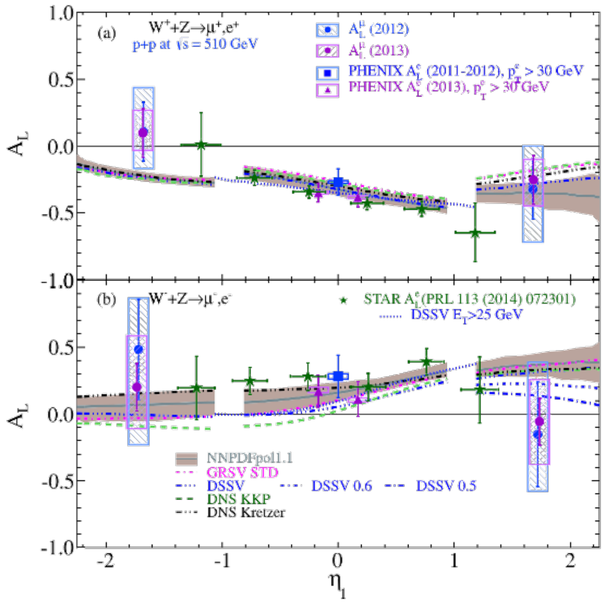


Nucl. Phys. A. 1026, 122447 (2022)

Sea quark polarization

Single spin asymmetries of W^{+-} at RHIC

- Longitudinal *single* spin asymmetries in maximally parity violating $u\bar{d} \rightarrow W^{+} \rightarrow e^{+} + \nu_{e}$ provide flavor separated access to $\Delta\bar{u}$, $\Delta\bar{d}$



PRD 98, 032007 (2018)

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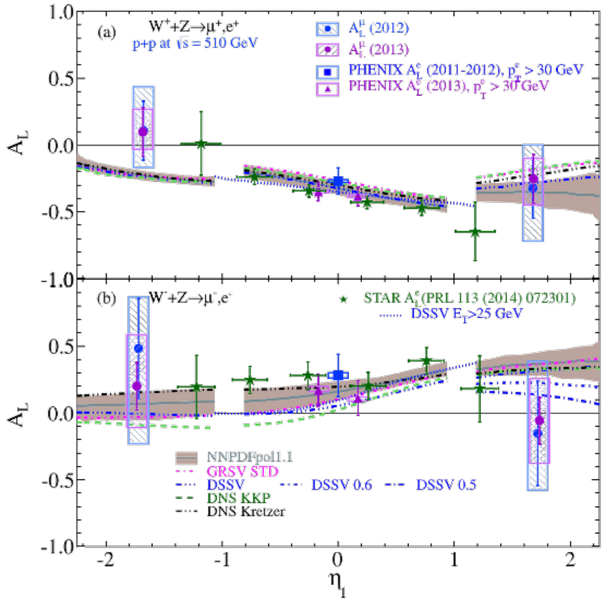
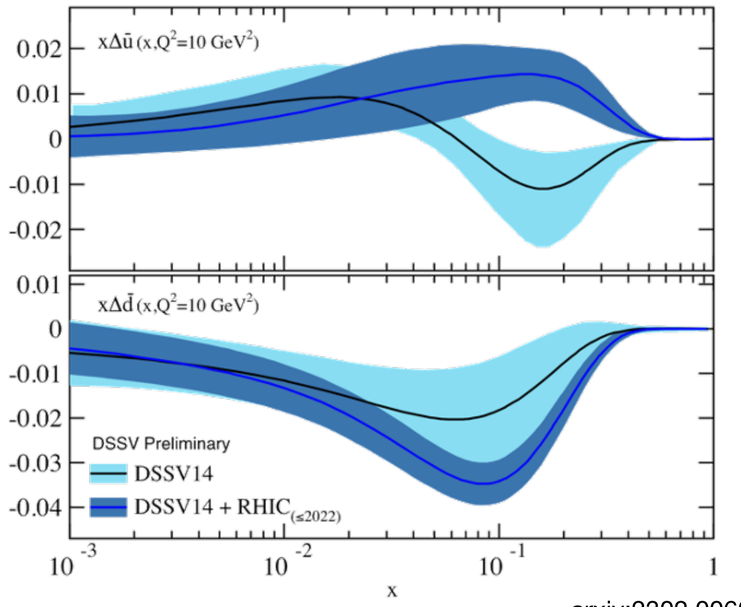


PRD 98, 032007 (2018)



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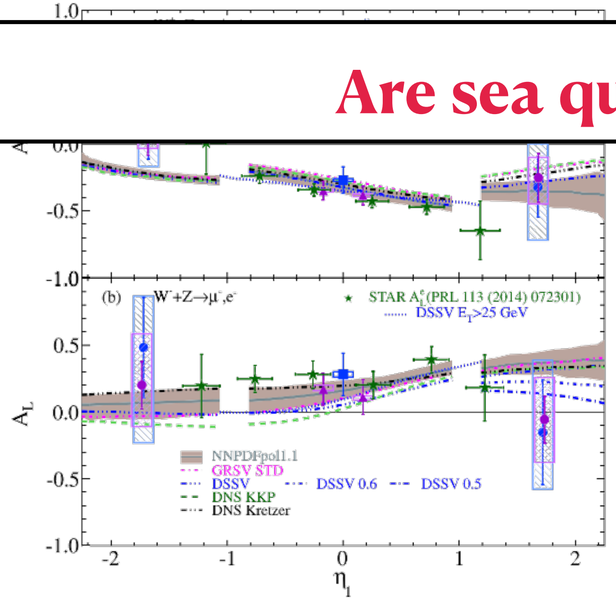
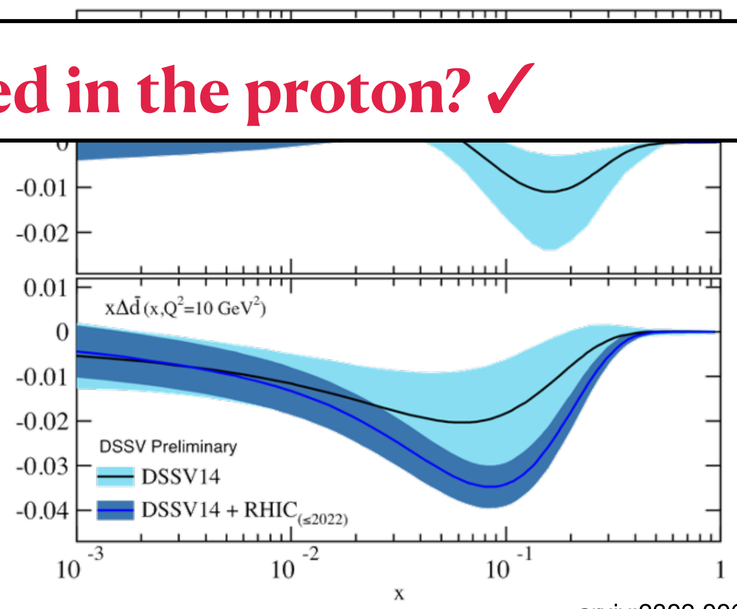
Are sea quarks polarized in the proton? ✓



PRD 98, 032007 (2018)

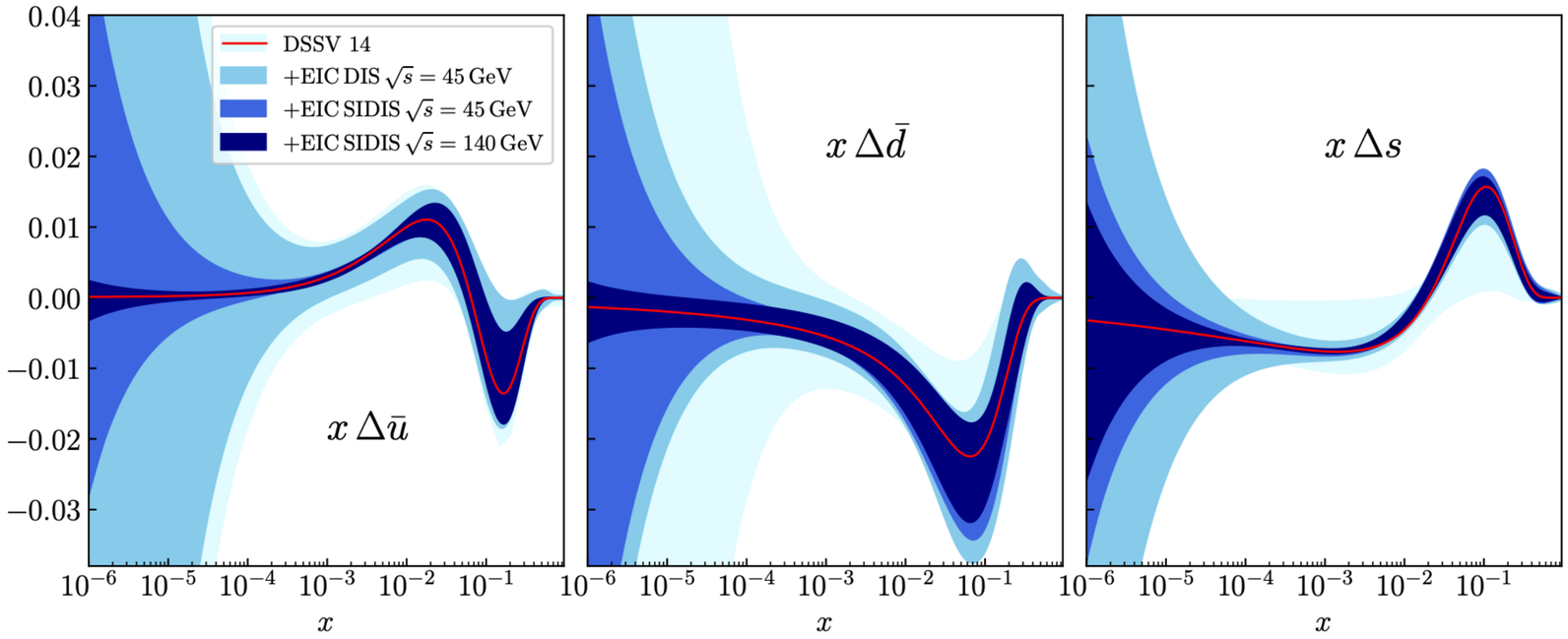


arxiv:2302.00605

Sea quark polarization

EIC impact

- SIDIS with pions and kaons provide precise determinations of flavor separated $\bar{u}$, $\bar{d}$ + ***strange quark*** helicities with unparalleled reach to low-x



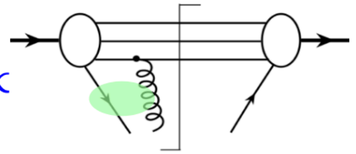
Nucl. Phys. A. 1026, 122447 (2022)

Transverse spin physics

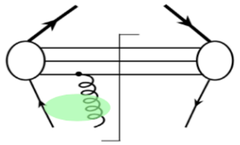
Powerful probes of multiparton correlators at PHENIX

- PHENIX has explored a wide range of transverse single spin asymmetry measurements of single-inclusive high-p_T observables
- Factorized in terms of higher-twist multiparton correlators (**related by k_T moments to polarized TMD PDFs, FFs**)
- Different observables → different correlators e.g. heavy flavor A_N for initial state trigluon correlator

$$\Delta\sigma(s_T) \propto T^{(3)}(x,x) \otimes \hat{\sigma}_T \otimes D(z) + \delta q(x) \otimes \hat{\sigma}_D \otimes D^{(3)}(z,z) + \ldots$$

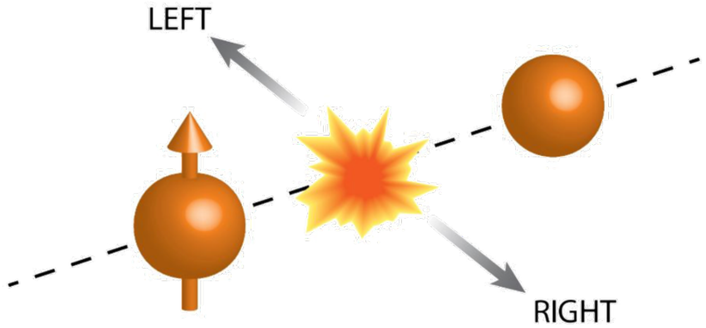
$T^{(3)}(x,x) \propto$ 

Qiu, Sterman, 1991, …

$D^{(3)}(z,z) \propto$ 

Kang, Yuan, Zhou, 2010

J. Qiu



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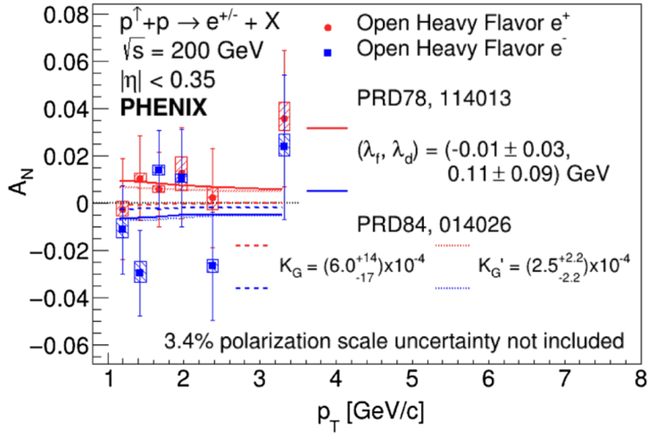
Open heavy flavor (trigluon initial state)



First constraints on trigluon parameters λ, K_G

PRD 107, 052012 (2023)

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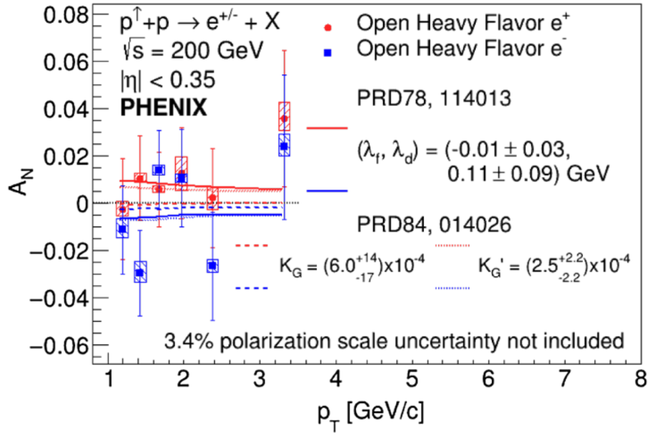

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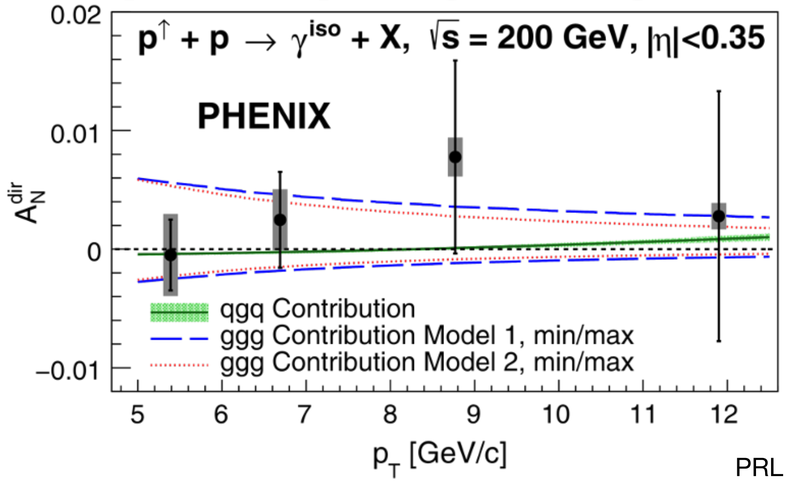
PRD 107, 052012 (2023)

Direct photon (quark-gluon/trigluon initial state)



50x statistical improvement on previous E704 result

PLB 345, 569 (1995)

PRL 127, 162001 (2021)

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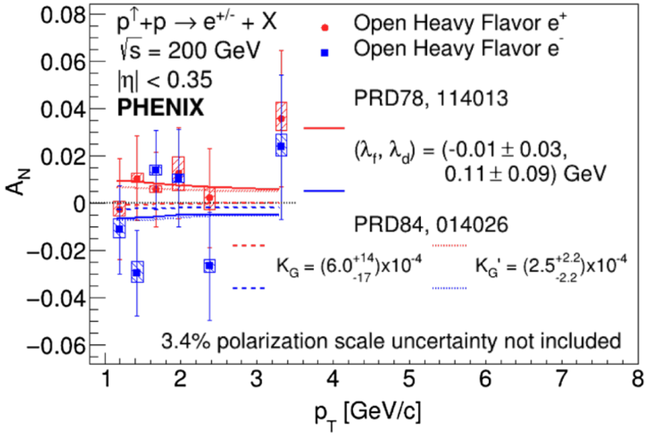

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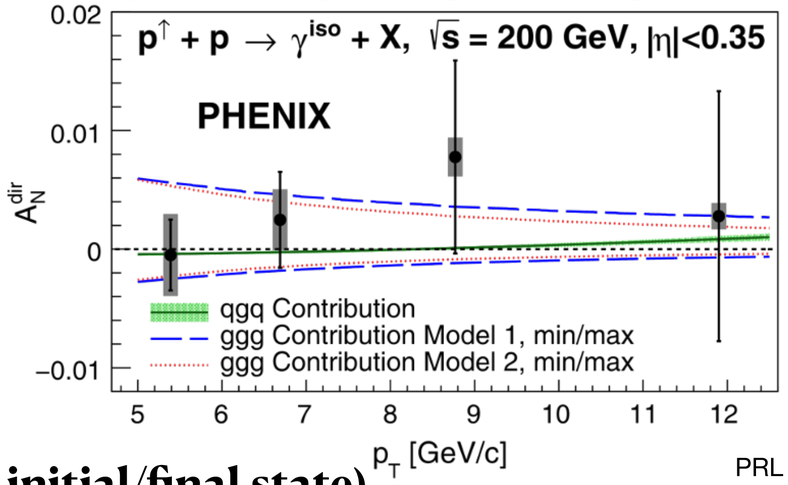

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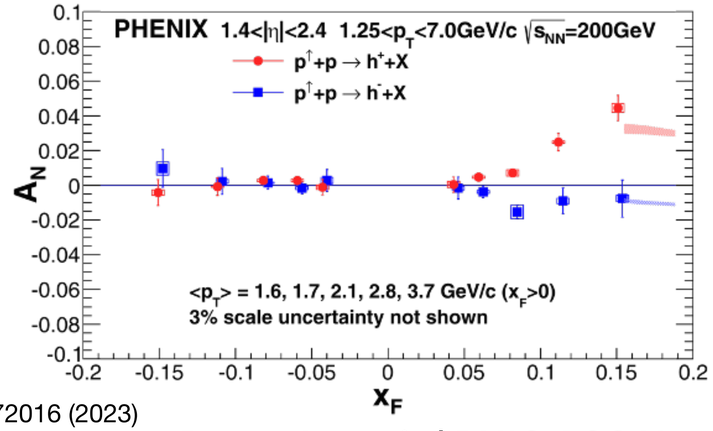
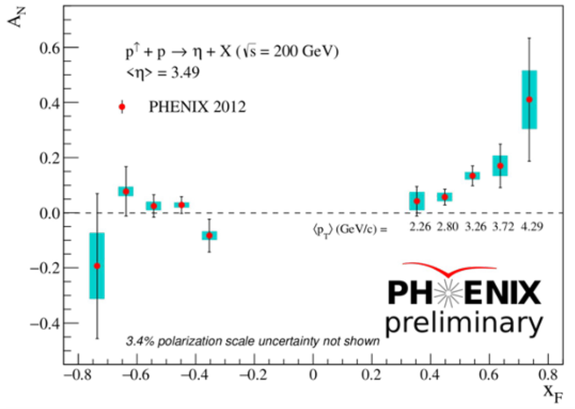
PLB 345, 569 (1995)

PRL 127, 162001 (2021)

Forward hadron (quark-gluon initial/final state)





Indications of large contribution from final state Collins-like qgq correlator

PRD 108, 072016 (2023)

Transverse spin physics

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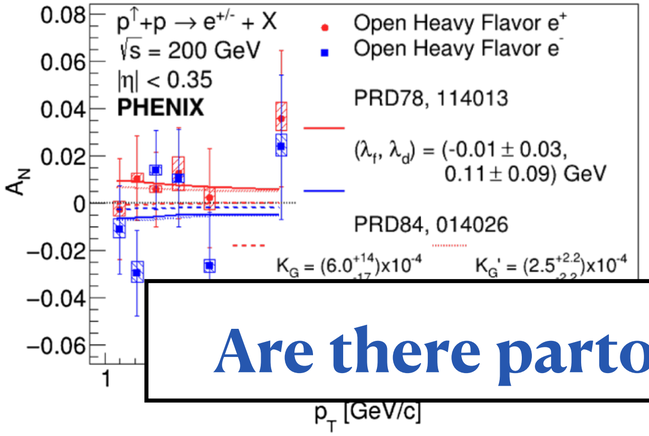

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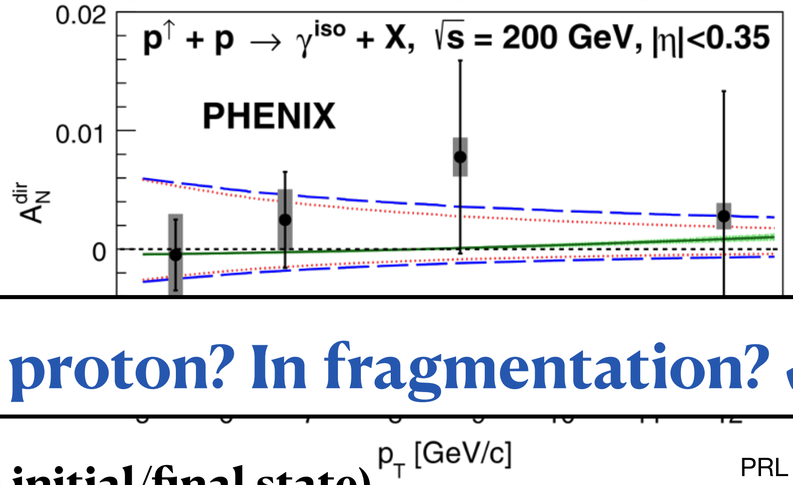

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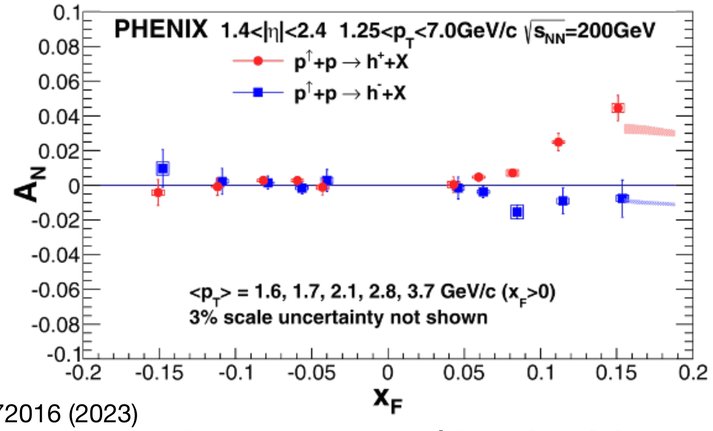
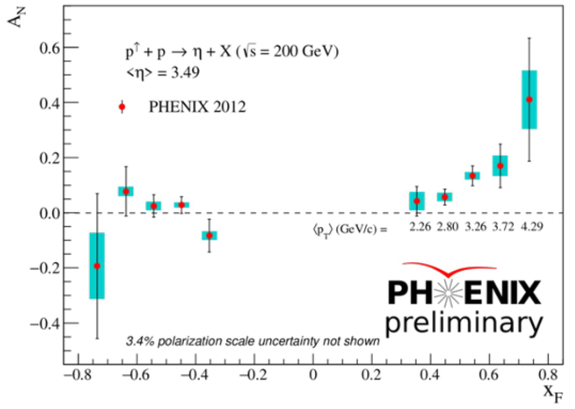
Forward hadron (quark-gluon initial/final state)





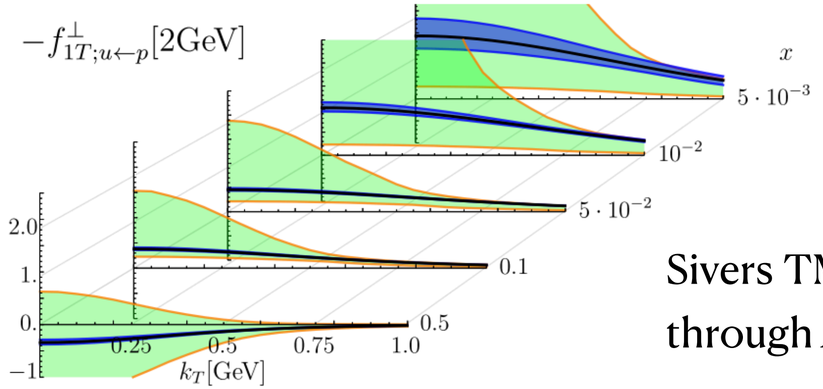
Indications of large contribution from final state Collins-like qgq correlator

PRD 108, 072016 (2023)

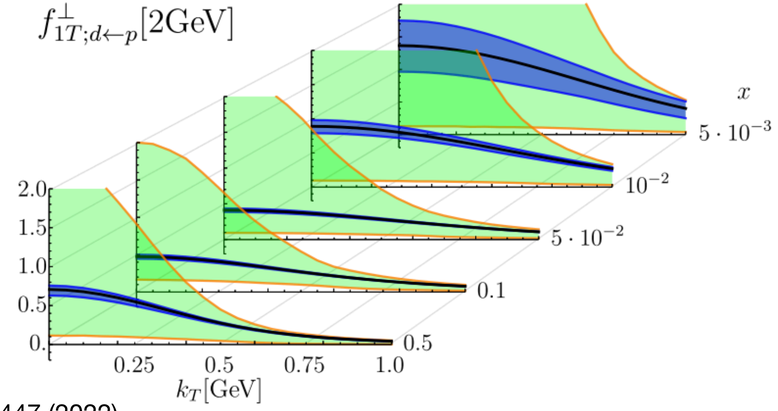
Transverse spin physics

Polarized TMDs at the EIC

- SIDIS factorized in TMD framework → EIC directly sensitive to TMDs in wide x, Q^2 domain



Sivers TMD PDF through $A_{UT}^{\sin(\phi_h-\phi_s)}$



Nucl. Phys. A. 1026, 122447 (2022)

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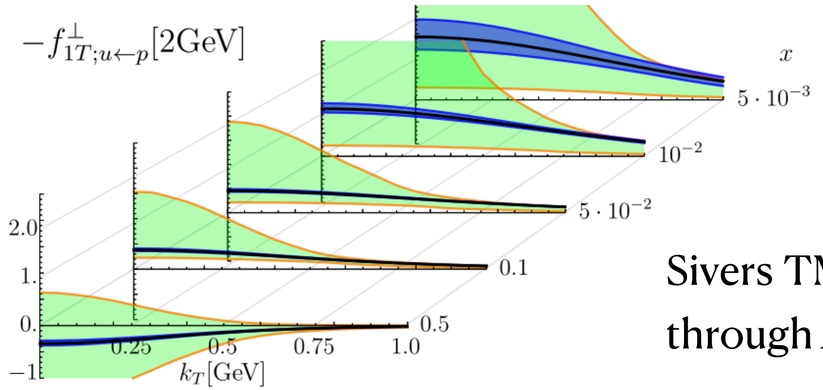

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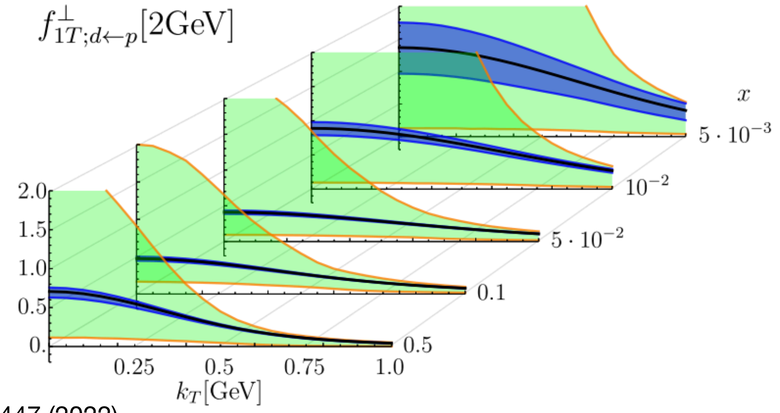
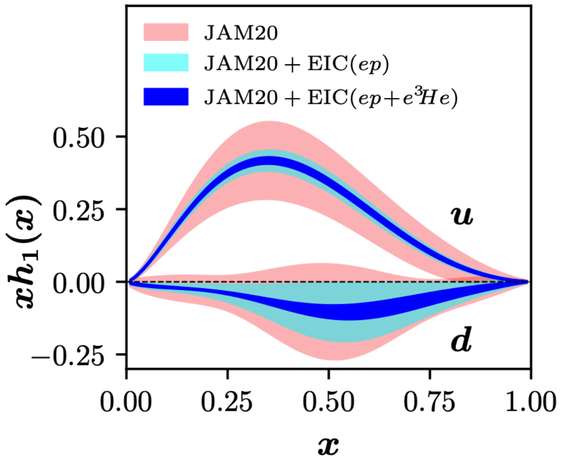
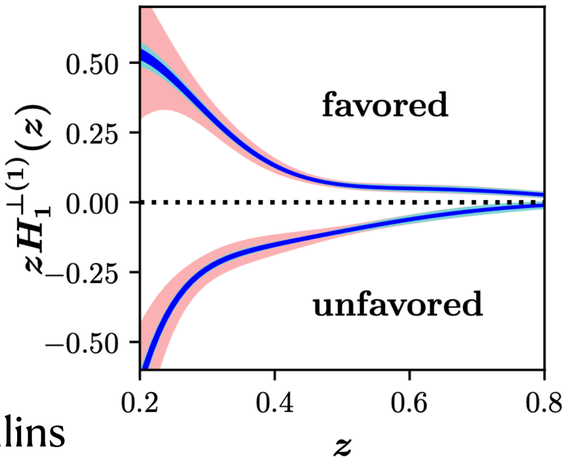




Nucl. Phys. A. 1026, 122447 (2022)



Chiral-odd transversity and Collins TMD FF through $A_{UT}^{\sin(\phi_h+\phi_s)}$

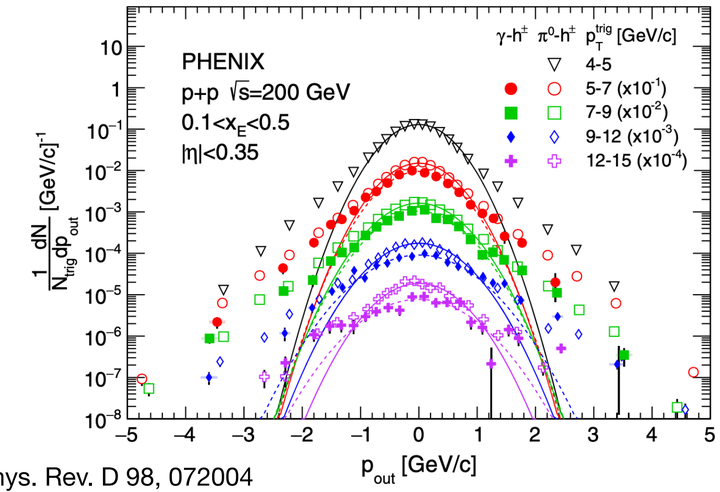
Nucl. Phys. A. 1026, 122447 (2022)

Nuclear effects in cold QCD

An exploration of p+A observables at PHENIX

- PHENIX measured nonperturbative transverse momentum effects with dihadron angular correlations → investigate acoplanar momentum broadening as a function of hard scale
  - Differences in p+p and Drell-Yan predicted due to **TMD factorization breaking**

p+p



Phys. Rev. D 98, 072004

Nonperturbative momentum broadening with hard scale resembles Drell-Yan. More theoretical investigation into TMD factorization needed!

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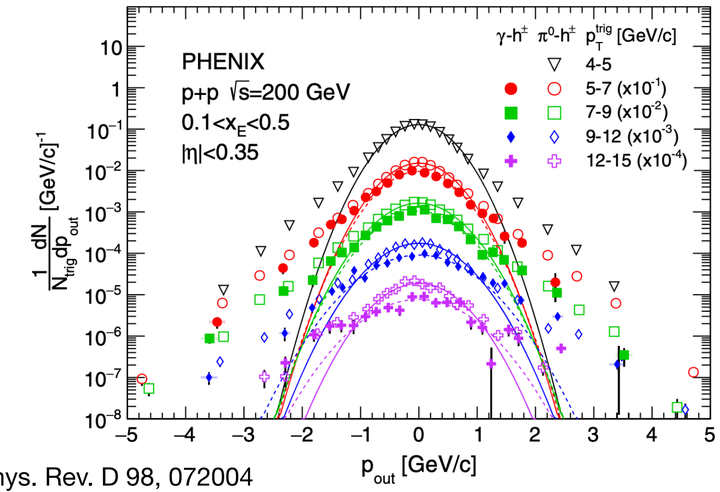
  - Differences in p+p and Drell-Yan predicted due to **TMD factorization breaking**
  - In p+A: Cronin effect? Radiative energy loss within the nucleus?

p+p



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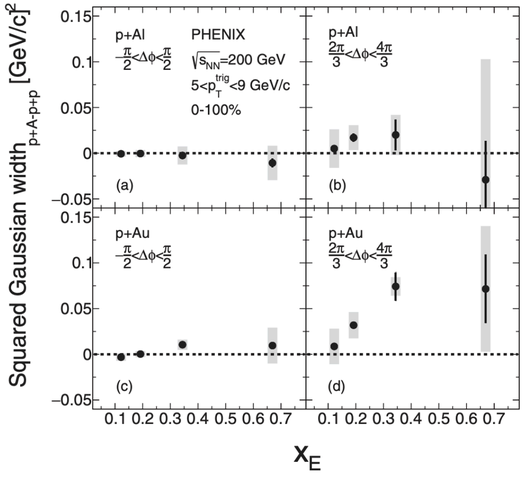
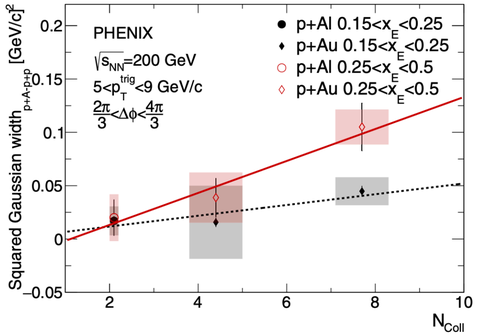


Phys. Rev. C 99, 044912



Dependence of broadening on N_{coll} suggestive of radiative or elastic interactions in remnant

Nuclear effects in cold QCD

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- PHENIX measured single spin asymmetries in transversely polarized p + A collisions
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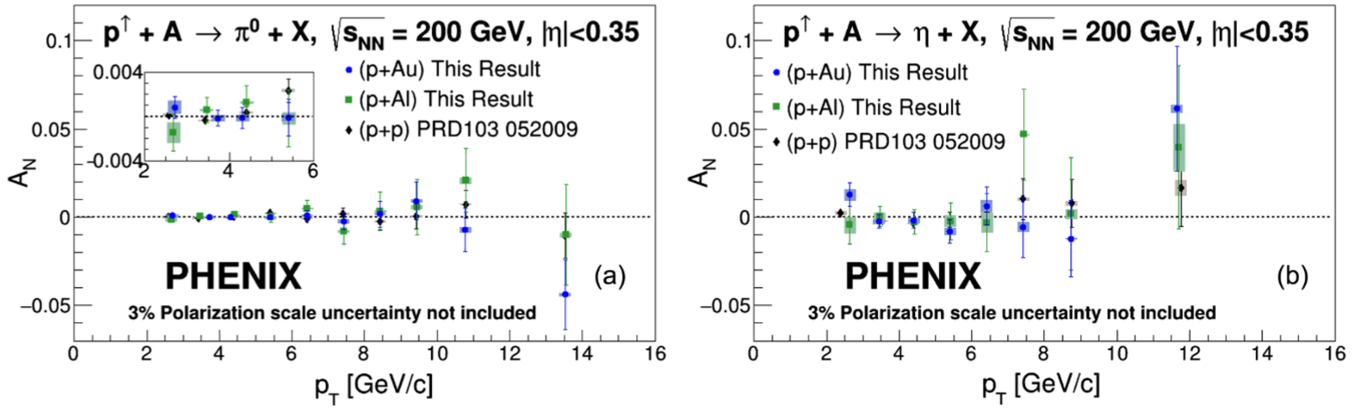
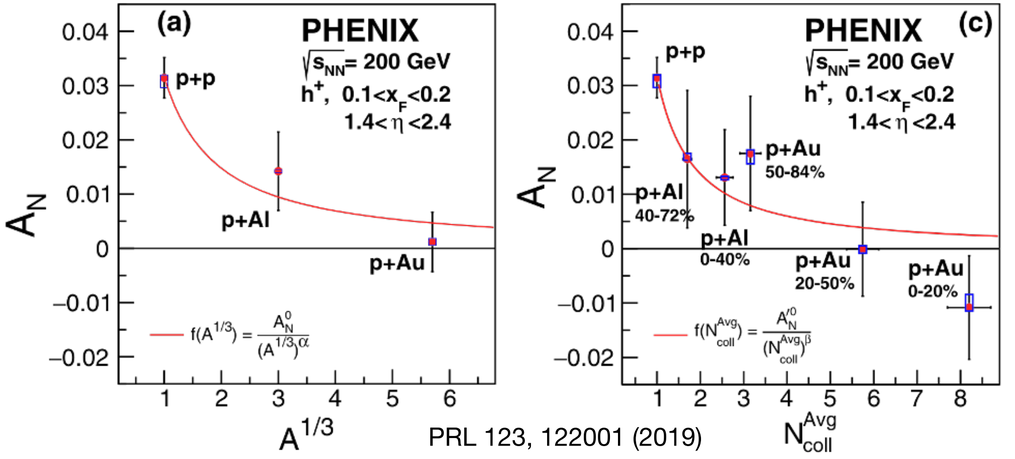
PRD 107, 112004 (2023)



Central rapidity

Forward rapidity



PRL 123, 122001 (2019)

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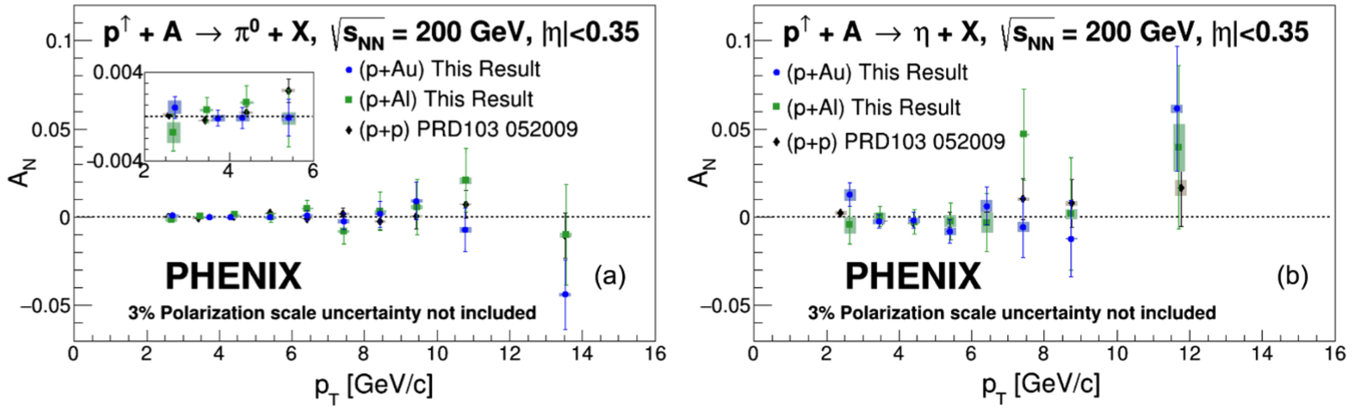
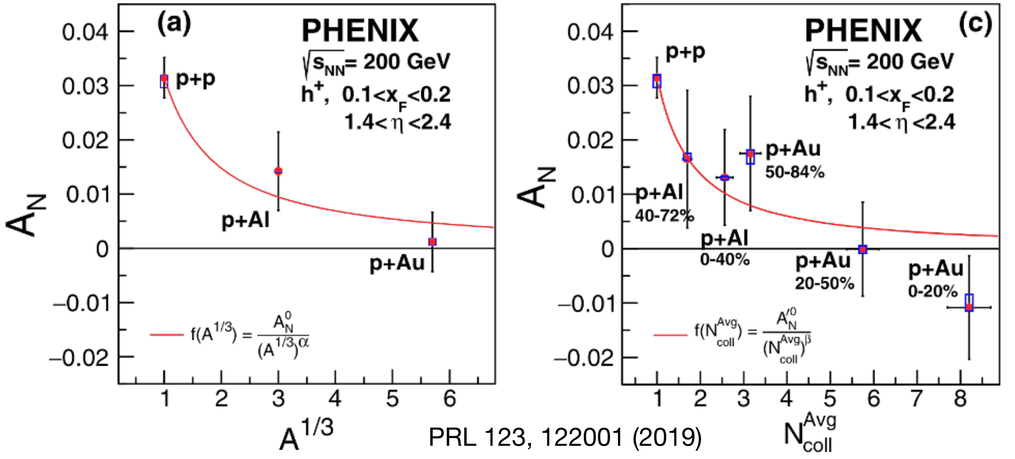
PRD 107, 112004 (2023)



Central rapidity

$A^{-1/3}$ dependence due to gluon saturation? **PRD 84, 034019 (2011)**
Not expected in this regime!

Forward rapidity



PRL 123, 122001 (2019)

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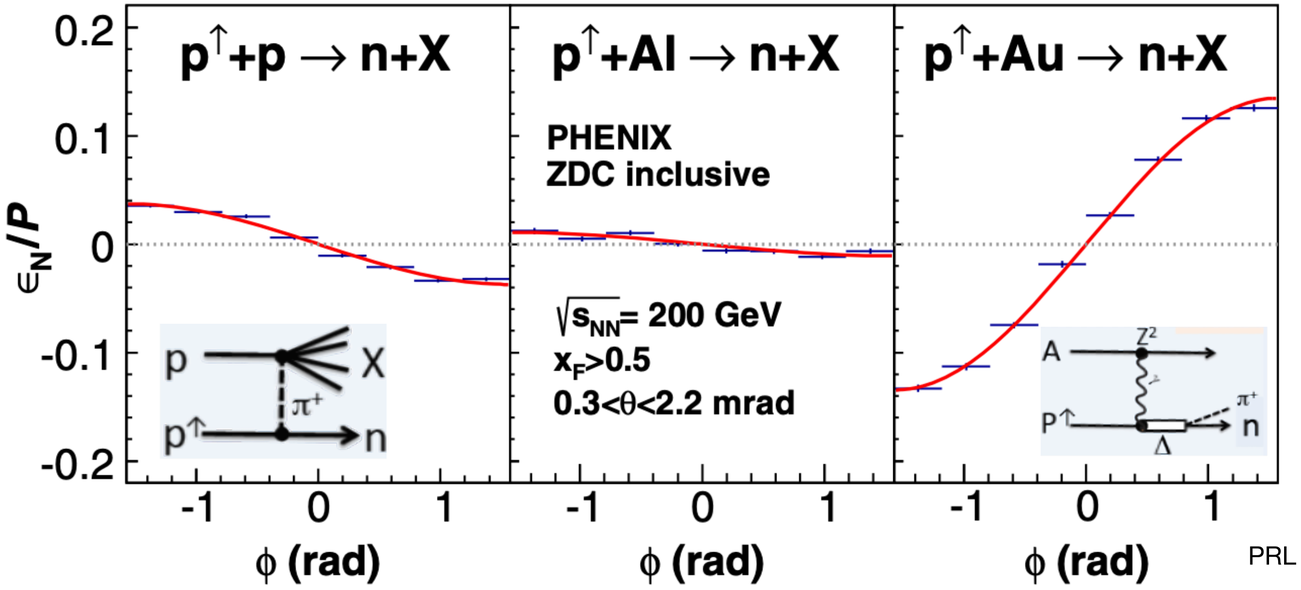

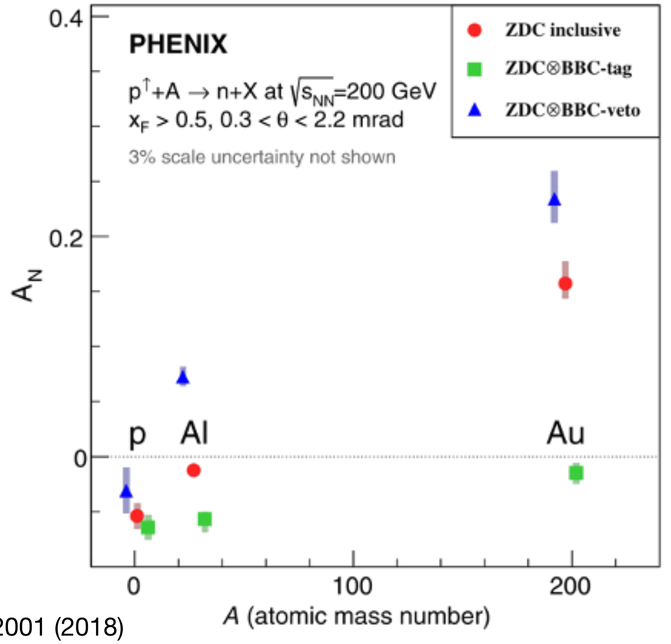

PRL 120, 022001 (2018)

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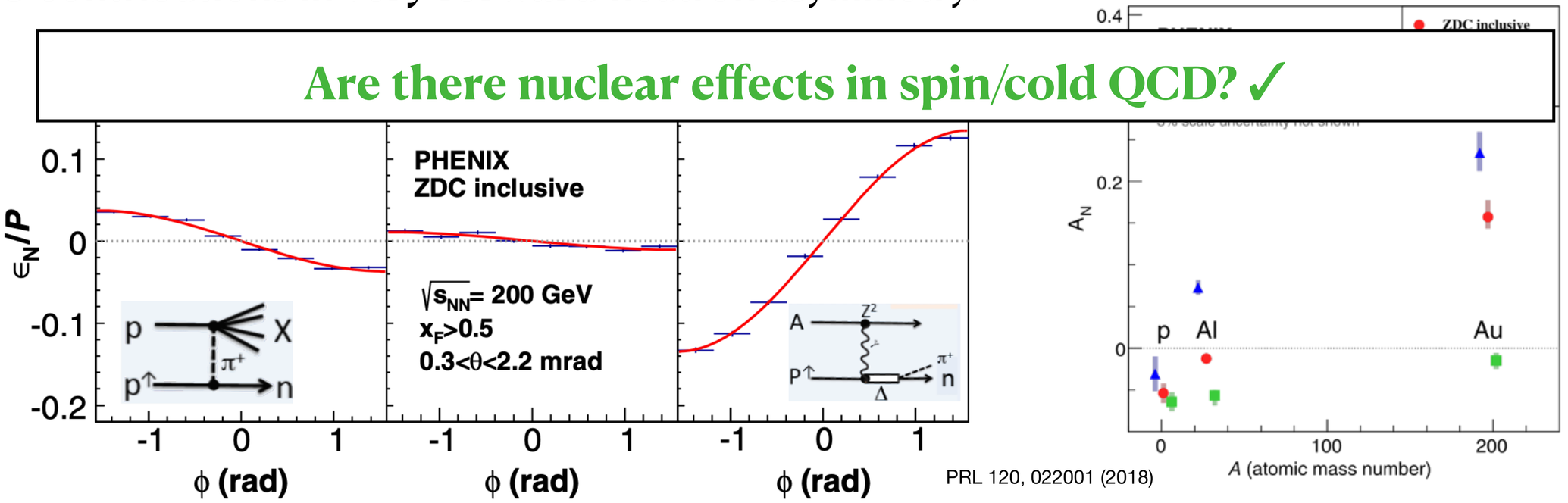
Are there nuclear effects in spin/cold QCD? ✓

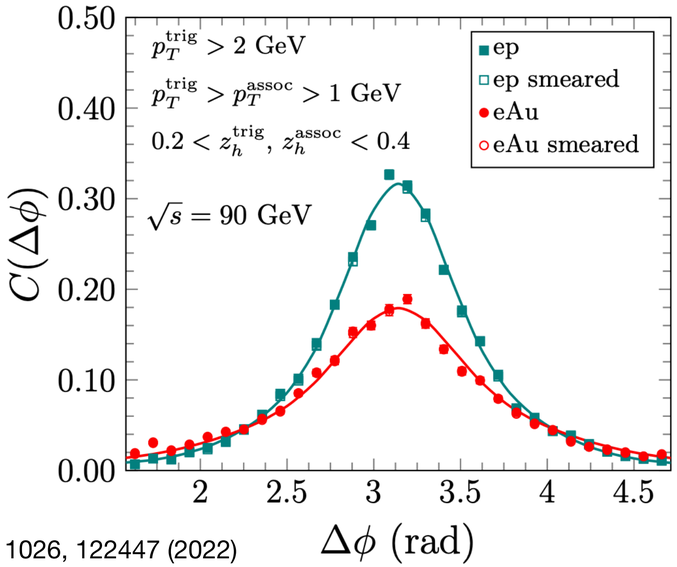


PRL 120, 022001 (2018)

Nuclear effects in cold QCD

EIC observables

- Transverse momentum broadening of back-to-back hadrons in e+A would be signature for onset of **gluon saturation**

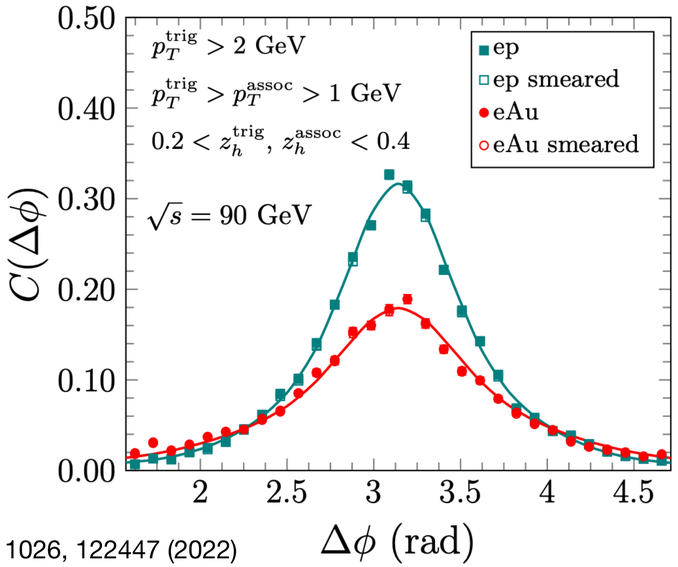


Nucl. Phys. A. 1026, 122447 (2022)

Nuclear effects in cold QCD

EIC observables

- Transverse momentum broadening of back-to-back hadrons in e+A would be signature for onset of **gluon saturation**
- Ratio of single spin asymmetries in e+A to e+p provides sensitivity to higher twist TMDs and their **medium modification**



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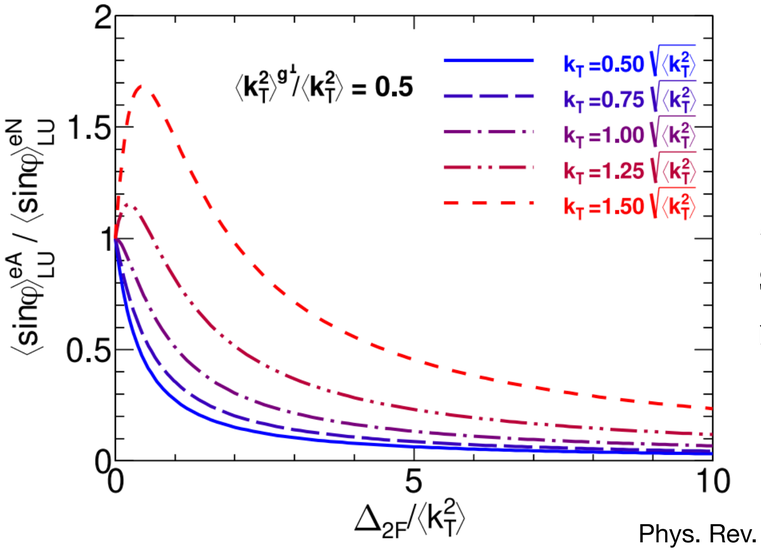

Δ_{2F} - total average squared transverse momentum broadening

Phys. Rev. D 89, 014005

Summary

- PHENIX has had a long, successful cold QCD program that has taught us much about:
  1. The building blocks of proton spin
  2. Multiparton correlations in proton structure and fragmentation
  3. Nuclear effects in cold QCD
- EIC physics will build on these measurements from PHENIX/RHIC and much more!