52nd International Symposium on Multiparticle Dynamics
(ISMD 2023)

Direct photon cross section and double-helicity asymmetry measurement at PHENIX

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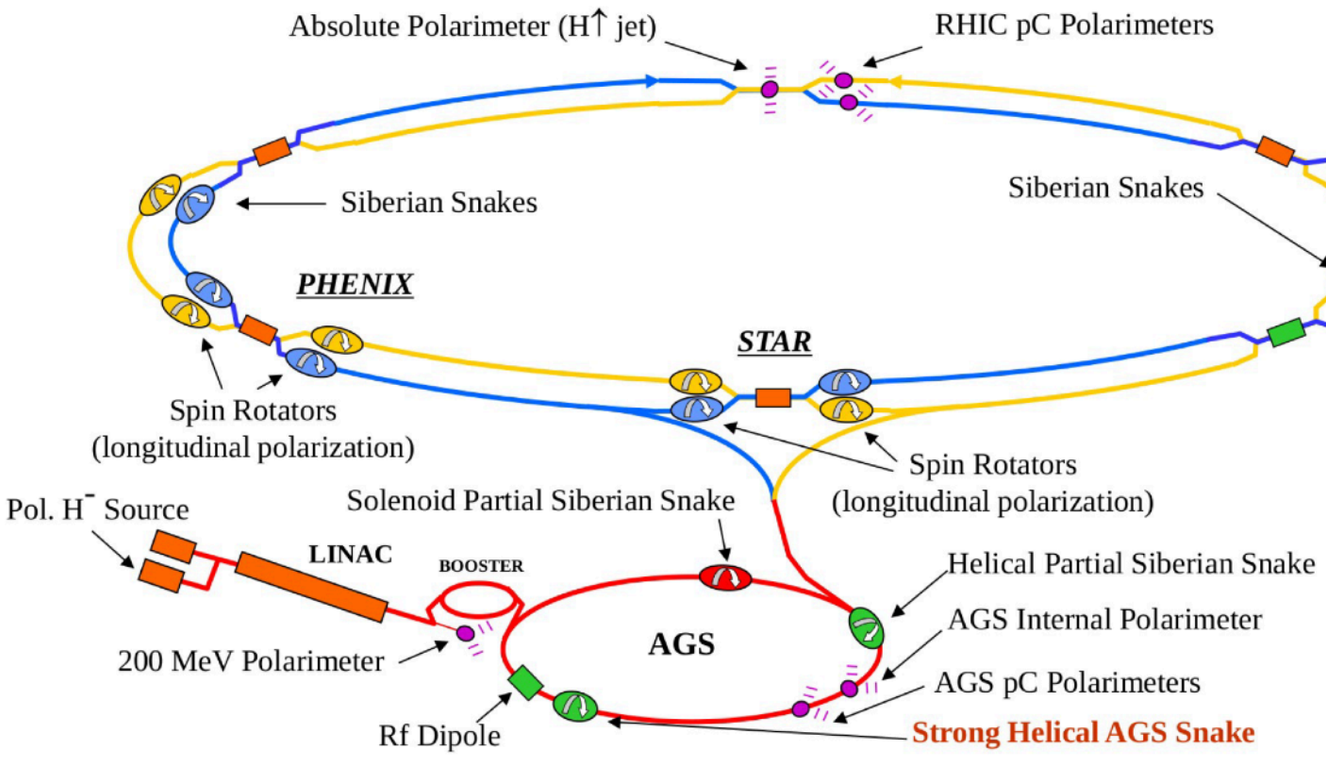
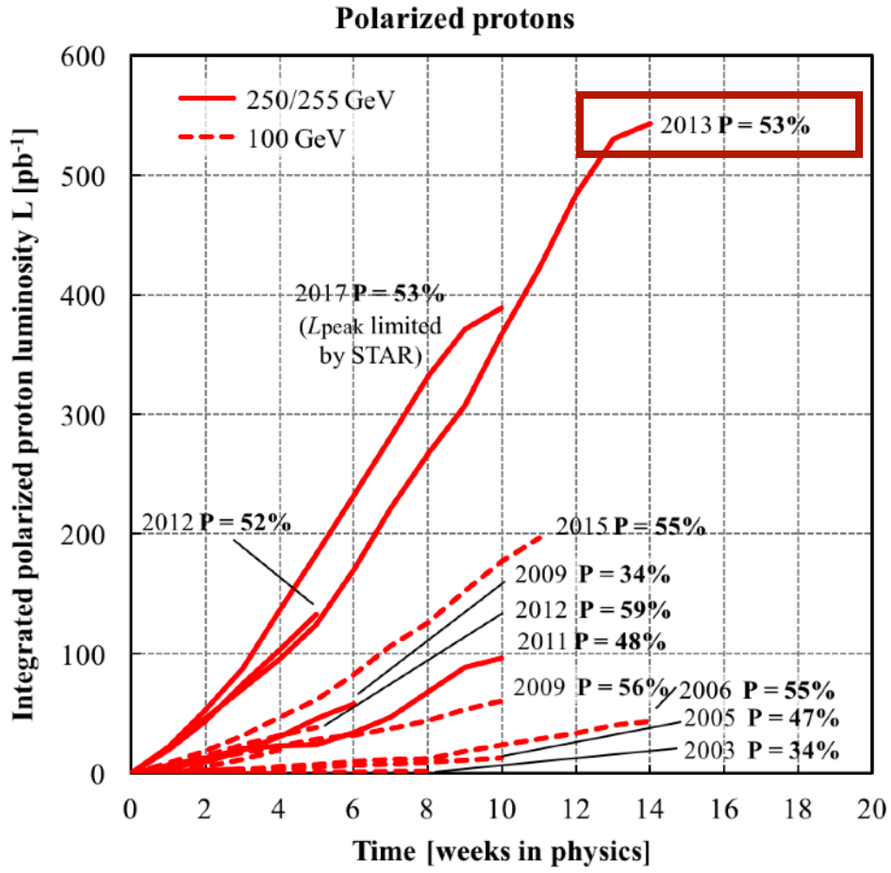
for the PHENIX collaboration

RHIC Spin Program

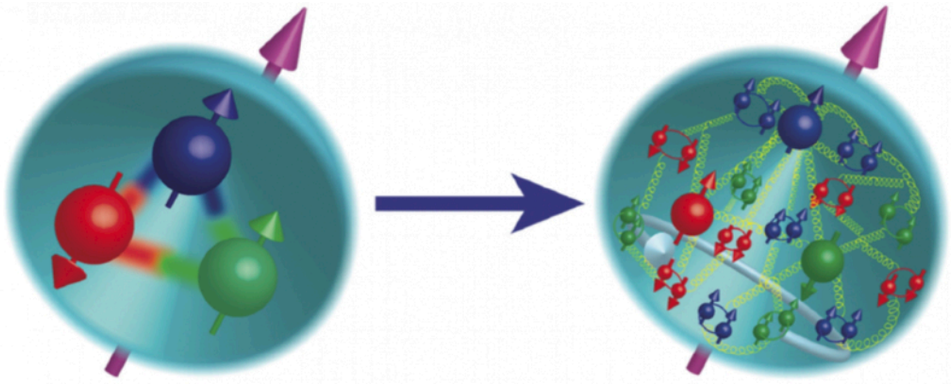




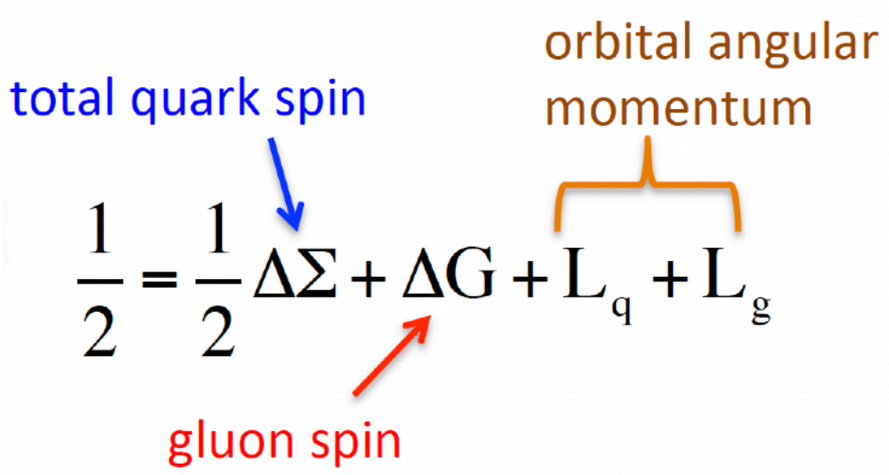
- **How do gluons contribute to the proton spin?**
- **What is the landscape of the polarized sea in the nucleon?**
- **What do transverse spin phenomena teach us about proton structure?**

Proton spin decomposition

Proton Spin Decomposition



1980s Now



- **(Quark + antiquark) spin contribution**

$$\frac{1}{2}\int dx(\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s})$$

~30%. Well constrained by polarized DIS

- **Gluon spin contribution**

$$\Delta G = \int dx \Delta g(x)$$

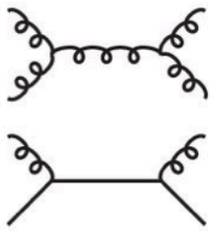
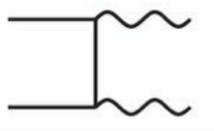
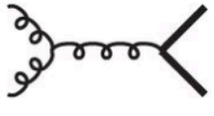
Start to understand better with RHIC p+p data

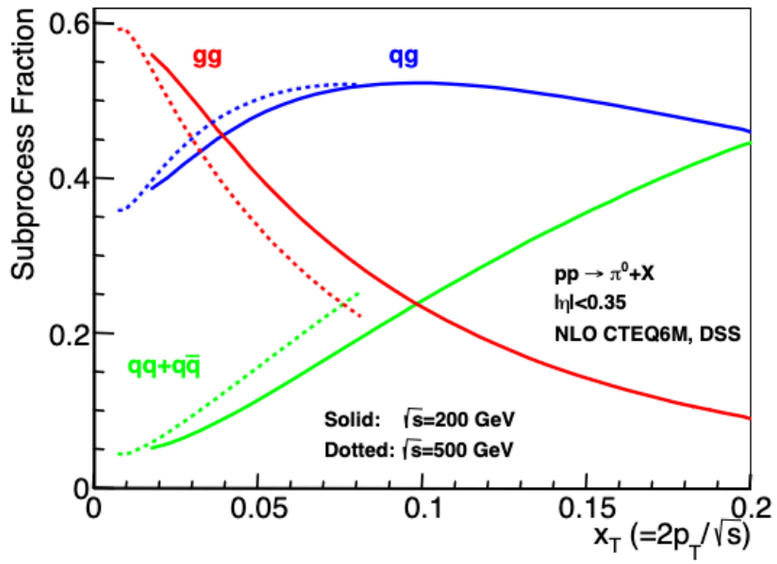
- **Quark and gluon orbital angular momentum**

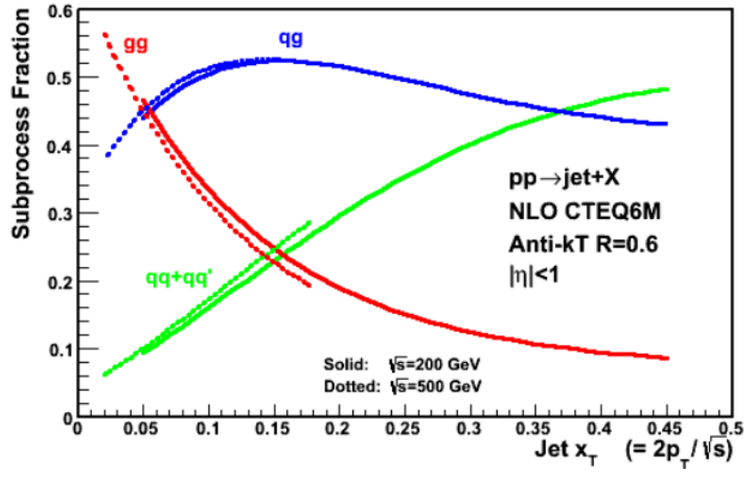
Very little known, need to know 3D structure

Exploring gluon polarization at RHIC

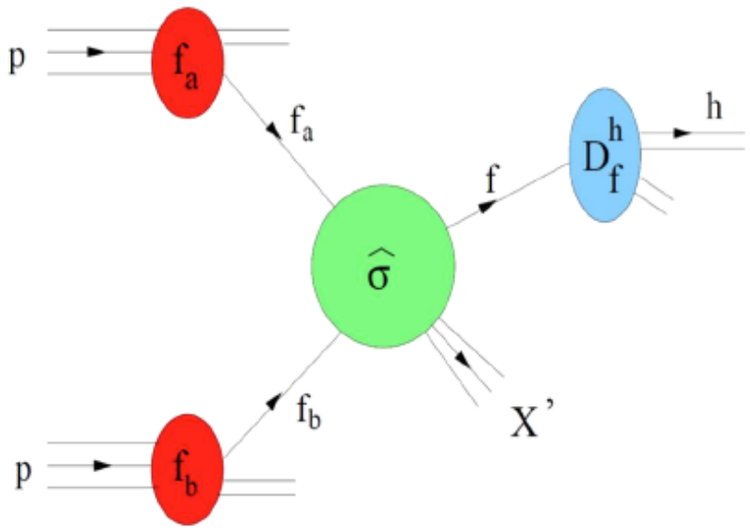
- **Access gluons at LO**
- **gg and qg dominant at RHIC kenematics**

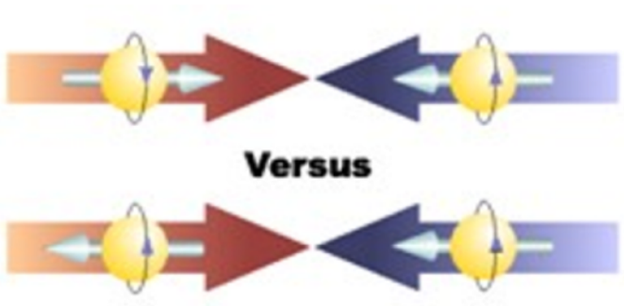
Reaction	Dom. partonic process	probes	LO Feynman diagram
$\vec{p}\vec{p} \to \pi + X$	$\vec{g}\vec{g} \to gg$ $\vec{q}\vec{g} \to qg$	Δg	
$\vec{p}\vec{p} \to \text{jet(s)} + X$	$\vec{g}\vec{g} \to gg$ $\vec{q}\vec{g} \to qg$	Δg	(as above)
$\vec{p}\vec{p} \to \gamma + X$ $\vec{p}\vec{p} \to \gamma + \text{jet} + X$	$\vec{q}\vec{g} \to \gamma q$ $\vec{q}\vec{g} \to \gamma q$	Δg Δg	
$\vec{p}\vec{p} \to \gamma\gamma + X$	$\vec{q}\vec{\bar{q}} \to \gamma\gamma$	$\Delta q, \Delta\bar{q}$	
$\vec{p}\vec{p} \to DX, BX$	$\vec{g}\vec{g} \to c\bar{c}, b\bar{b}$	Δg	





Exploring gluon polarization at RHIC





Longitudinally polarized protons

- **Double-helicity asymmetry:**

Polarized PDFs

Parton-level hard scattering cross section calculable in pQCD

$$A_{LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \propto \frac{\sum_{a,b,c=q,\bar{q},g} \Delta f_a \otimes \Delta f_b \otimes d\hat{\sigma}^{f_a f_b \to f_c X} \otimes D_{f_c}^{\pi^0}}{\sum_{a,b,c=q,\bar{q},g} f_a \otimes f_b \otimes d\hat{\sigma}^{f_a f_b \to f_c X} \otimes D_{f_c}^{\pi^0}}$$

What's measured

Unpolarized PDFs

Fragmentation functions from e+e- scattering

- Experimentally:

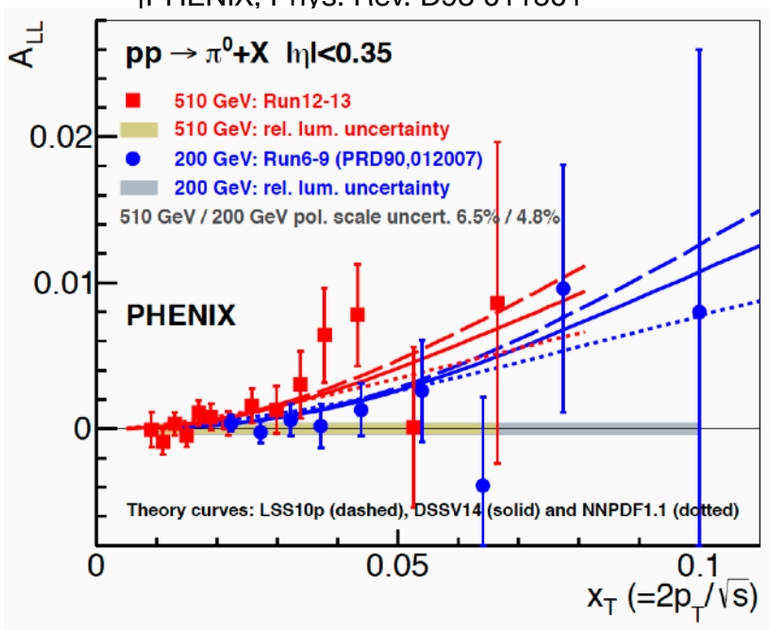
$$A_{LL} = \frac{1}{P_B P_Y} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}$$

$P_{B(Y)}$: Proton beam polarization

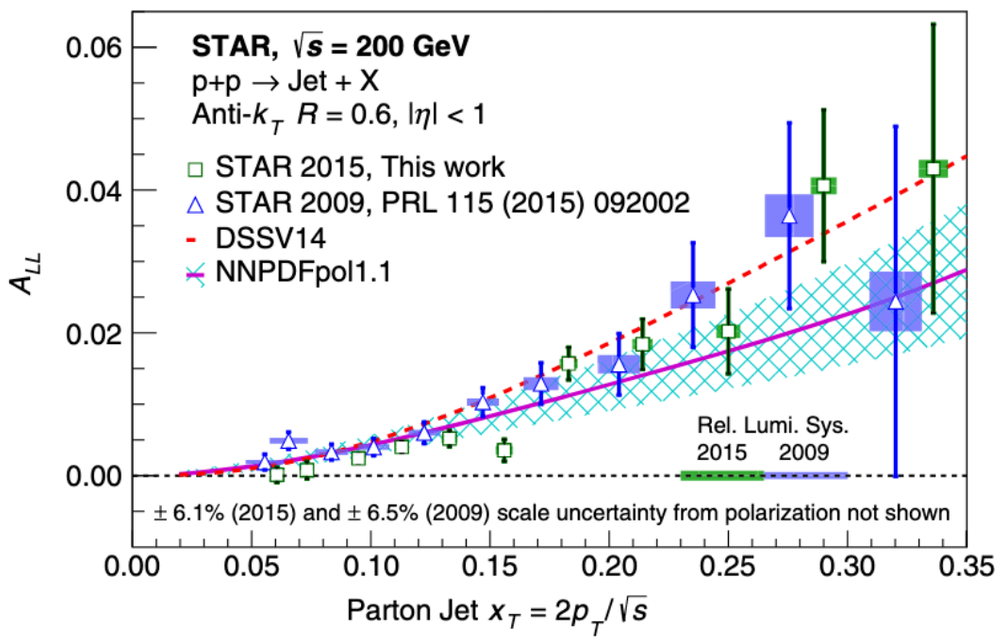
R: Relative luminosity L_{++}/L_{+-}

Exploring gluon polarization at RHIC

[PHENIX, Phys. Rev. D93 011501



[STAR, Phys. Rev. D 103, L091103 (2021)]

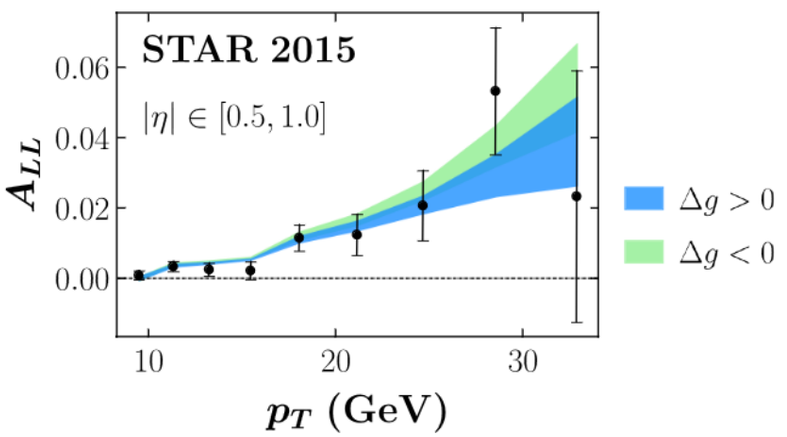


- Two workhorse measurements: π^0 and jets
- First experimental evidence of **non-zero gluon contribution to the proton spin** at $x > 0.05$:

$$\int_{0.05}^{1} dx\Delta g(x) = 0.2^{+0.06}_{-0.07}(Q^2 = 10GeV^2)$$

DSSV14: Phys. Rev. Lett. 113 (2014) 012001
(included 2009 200 GeV data only)

- Confirmed non-zero gluon polarization at 510 GeV
- Mixed gg and qg contributions: Recent analysis by JAM collaboration showed that existing data cannot rule out negative Δg scenario [JAM, Phys. Rev. D 105, 074022 (2022)]

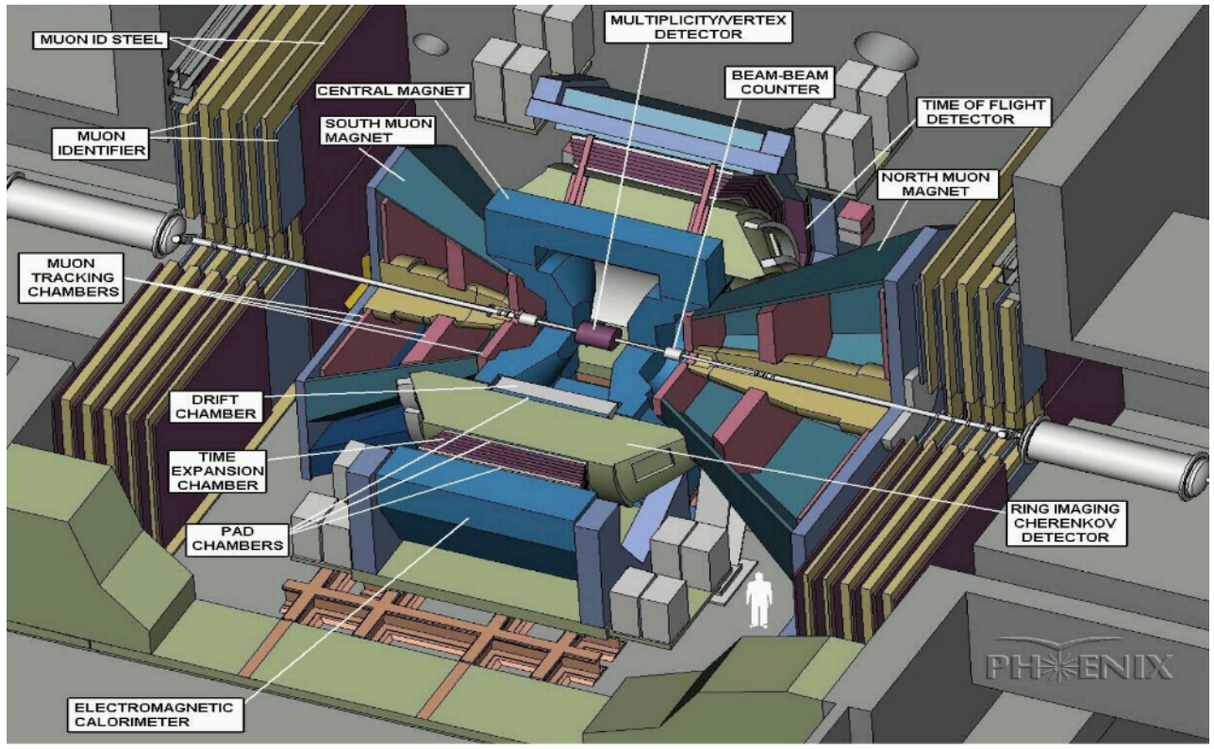


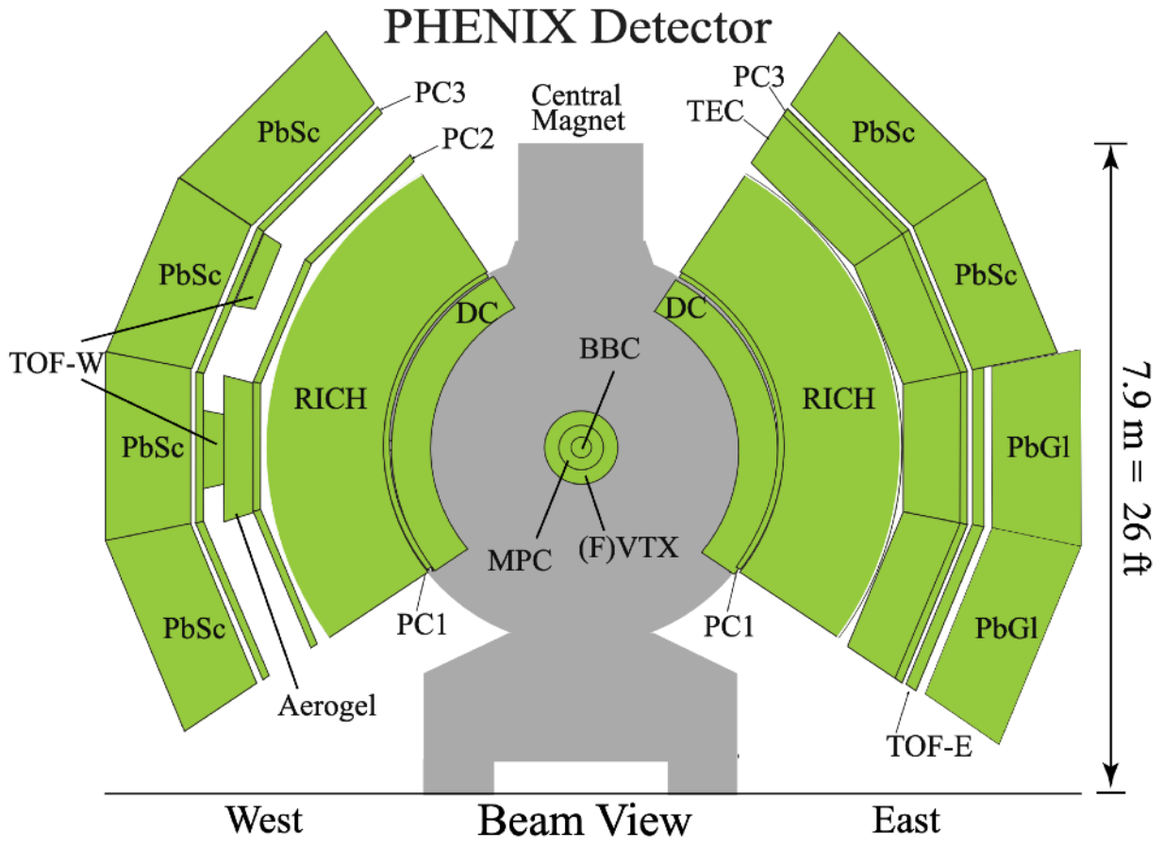
Direct photon measurements in $\vec{p}+\vec{p}$

- Theoretically clean interpretation: only sensitive to initial partonic hard process and doesn't involve strong interaction
- Direct photons are produced dominantly by quark-gluon Compton scattering at RHIC
  - linearly sensitive to gluon helicity distribution
- Proposed as a golden channel to study the gluon spin (RHIC Spin Proposal, 1992)
- Also:
  - Unpolarized cross section: test NLO pQCD applicability, constraint unpolarized gluon distribution
  - Transversely polarized p+p collisions: direct photon single spin asymmetry A_N. Constraint the trigluon correlation function.

    [PHENIX, Phys. Rev. Lett. 127, 162001 (2021)]

PHENIX Detector

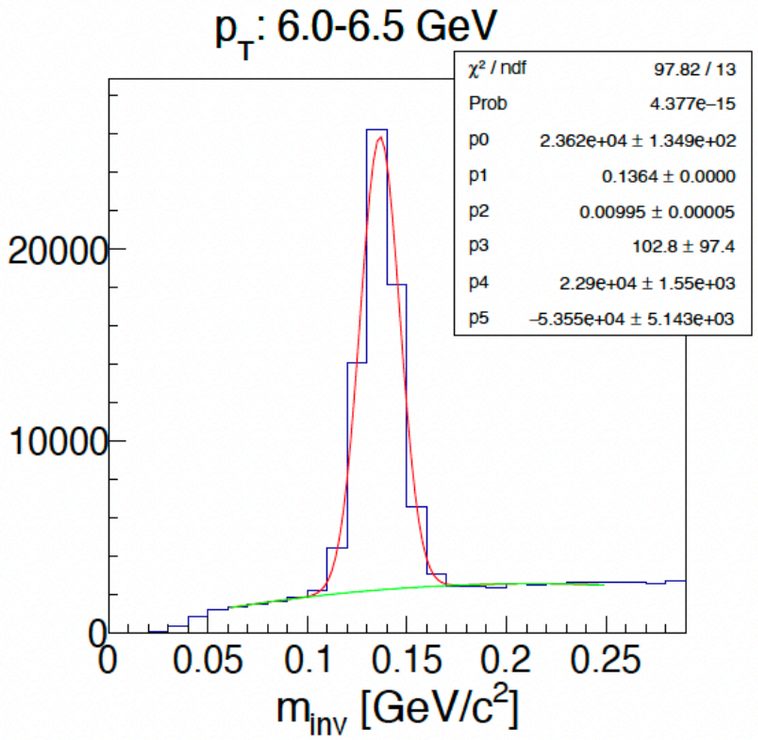


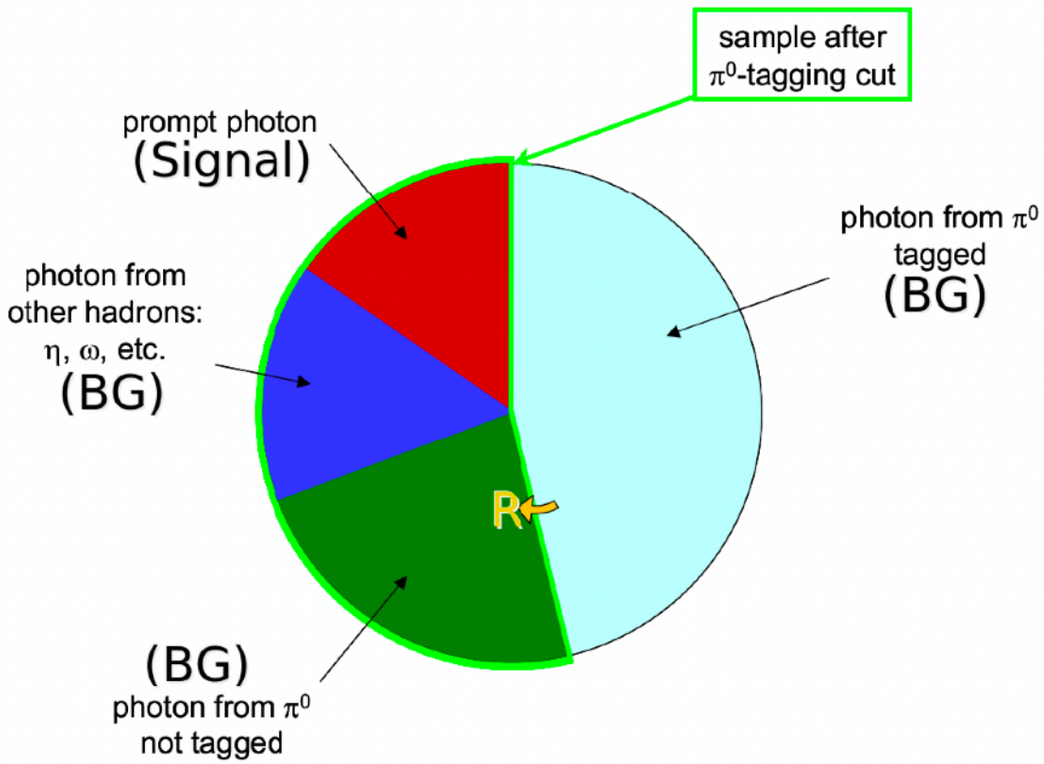


- Central arms: $\Delta\phi = (\pi/2) \times 2,\ |\eta| < 0.35$
  - electrons, photons, $\pi^0, \eta,$ charged hadrons
  - Electromagnetic calorimeter (EMCal): fine granularity PbSc and PbGl detectors
  - Drift chamber (DC): charged particle tracking
- Beam-beam counter (BBC): luminosity monitor, minimum bias trigger

Analysis overview

- Photons detected by EMCal
- Effectively reduced BGs by π^0decay tagging





Yield of direct photon:

- $N_{dir} = N_{total} - (1 + A)(1 + R)N_{\pi^0}$
  - R: π^0 one photon missing ratio.
  - A: Other hadrons' to π^0's photon ratio.

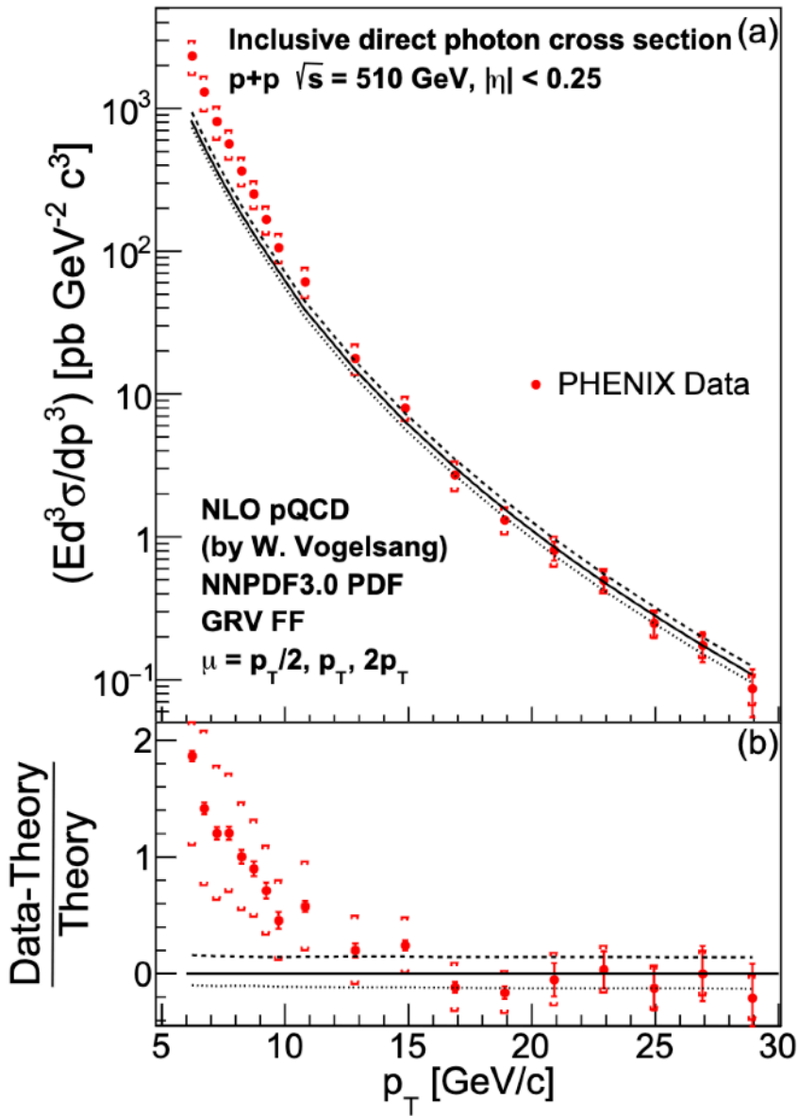
- Isolation cut: reduced the BG contributions from patron fragmentation and hadron decays

$$r_{cone} = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.5\ rad$$

$$E_{cone} < E_\gamma \cdot 10\,\%$$

Cross section results

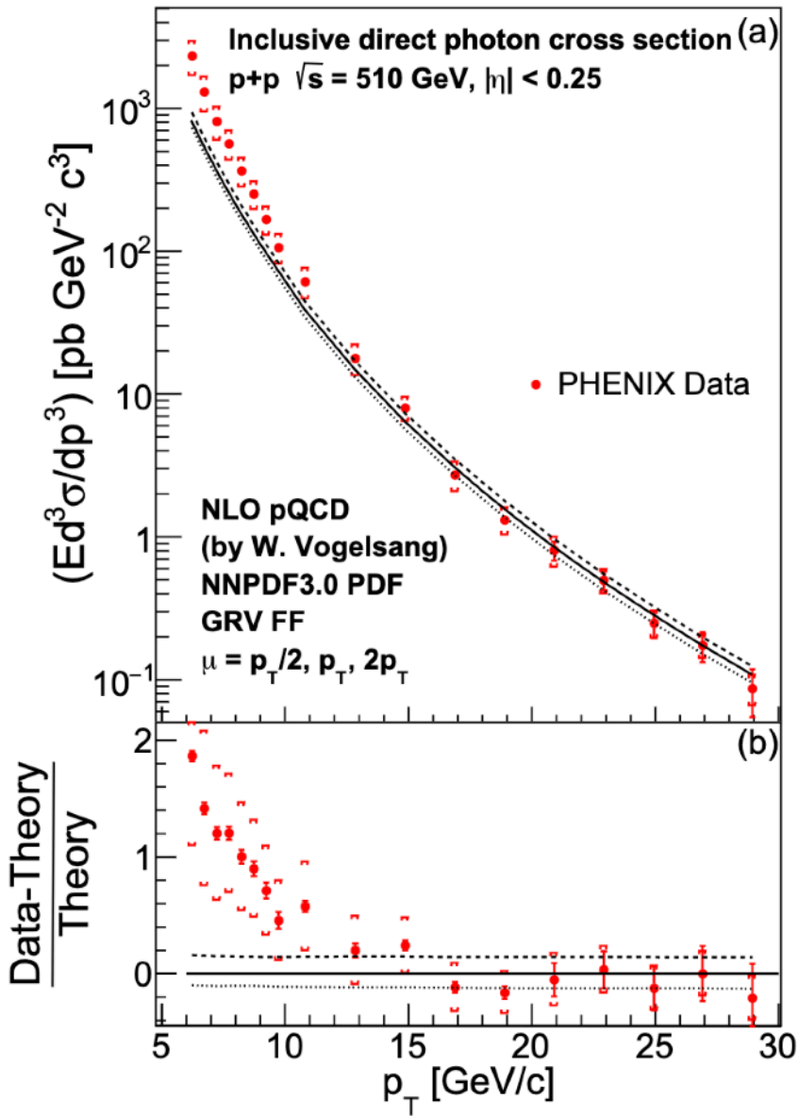
Phys. Rev. Lett. 130, 251901 (2023)

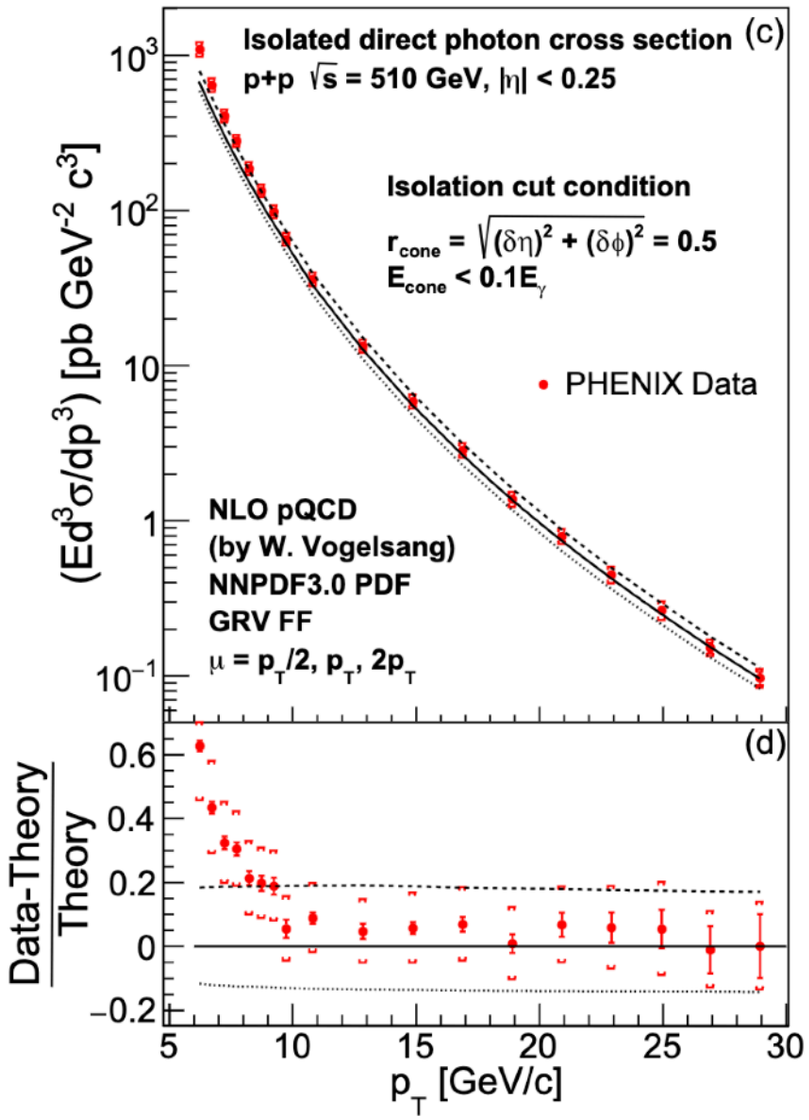


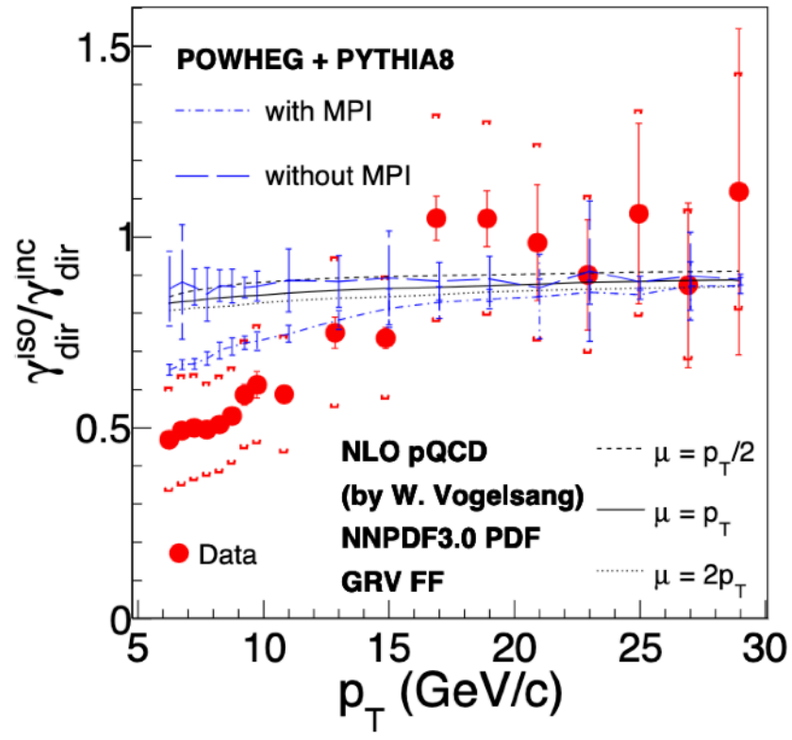
- NLO pQCD calculation underestimates the inclusive cross section data at low pT
- Multiparton interaction and parton shower are important to consider for better describing the data
- With isolation criteria, the calculation consistent with the data.

Cross section results

Phys. Rev. Lett. 130, 251901 (2023)







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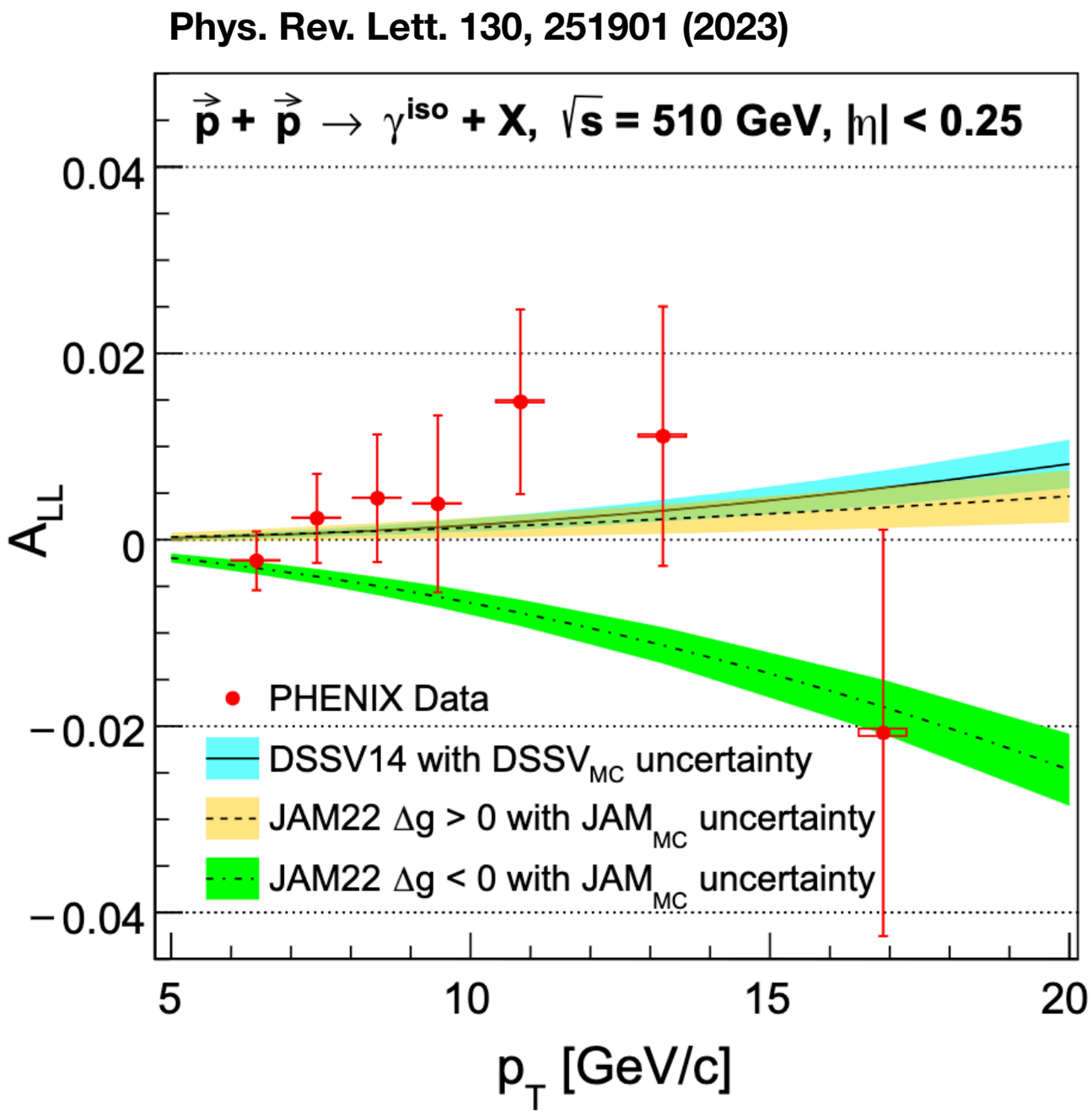
Direct photon A_{LL}



- First published measurement of direct photon A_{LL}
- Compared with two scenarios for gluon spin
- Data consistent with the positive gluon spin contributions and disfavor the negative Δg scenario

Summary

- PHENIX has measured the first direct photon cross section and double-helicity asymmetry at 510 GeV
- Direct photon result provides an important input to improve our understanding of the polarized gluon distribution
  - Theoretically clean interpretation
  - Directly sensitive to the sign of the gluon spin
  - Data consistent with the positive gluon spin contribution