



Stony Brook University



Measurement of Direct Photon Cross Section and Double Helicity
Asymmetry at $\sqrt{s} = 510$ GeV in $\vec{p} + \vec{p}$ Collisions at PHENIX

UCLA

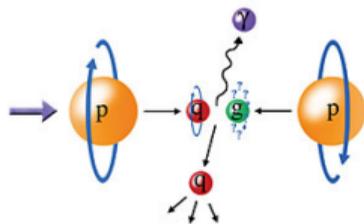
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UCLA & Stony Brook University

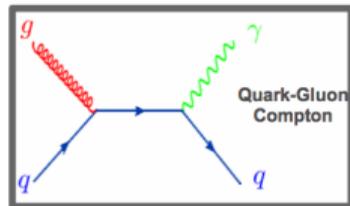
**XXIX International Workshop on
Deep-Inelastic Scattering and Related Subjects**

May 4, 2022

Direct photon as the “golden” channel



$$A_{LL}^{pp \rightarrow \gamma X} \sim \frac{\Delta q(x_q)}{q(x_q)} \cdot \frac{\Delta g(x_g)}{g(x_g)} \cdot a_{LL}^{qg \rightarrow \gamma q}$$



- $A_{LL} = \frac{\Delta\sigma}{\sigma} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$

- Little fragmentation contributions.

- “Golden” channel.

- Linear in Δg : probe the sign of gluon spin.

Challenges in the direct photon measurement:

- Low statistics.

- π^0 decay photon merging at high p_T in the EMCal detector.

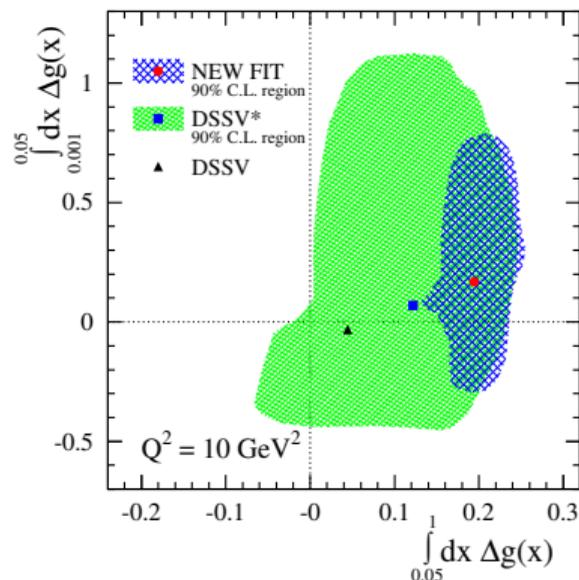
Advantages at PHENIX with RHIC running period of year 2013:

- The largest integrated luminosity (155 pb^{-1}) in $\vec{p} + \vec{p}$

- EMCal with fine granularity to separate π^0 decay photons up to p_T of 12 GeV/c, and a shower profile analysis extends the γ/π^0 discrimination to beyond 20 GeV/c.

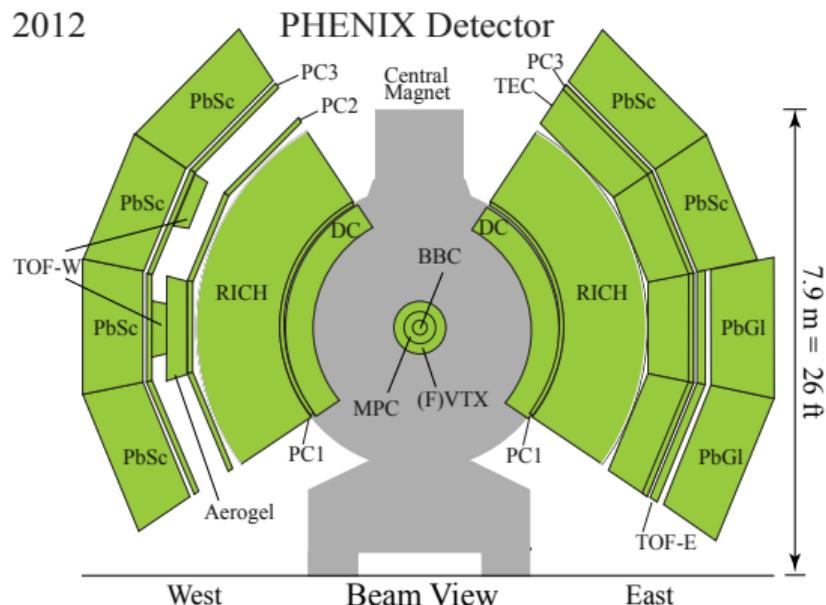
From A_{LL} to Δg

- Existing RHIC data mainly probe $0.05 < x_g < 0.2$
- PHENIX $\pi^0 A_{LL}$ at 510 GeV confirms a nonzero Δg and extend x_g to 0.01
- STAR jet data clearly imply a polarization of gluons in this range.
- This will be the first direct photon A_{LL} result to be published [arXiv: 2202.08158]
- Our results will add independent constraints on the Δg



PRL 113, 012001 (2014)

- Pseudorapidity $|\eta| < 0.35$
- Azimuthal angle ϕ : π radians coverage.
- Electromagnetic Calorimeter (EMCal):
 - ▶ primary detector for photons.
- EMCal trigger:
 - ▶ Select high energy photons.
- Drift Chamber (DC):
 - ▶ Measure charged particle momenta.
 - ▶ Charge veto criteria.



Direct photon signal extraction

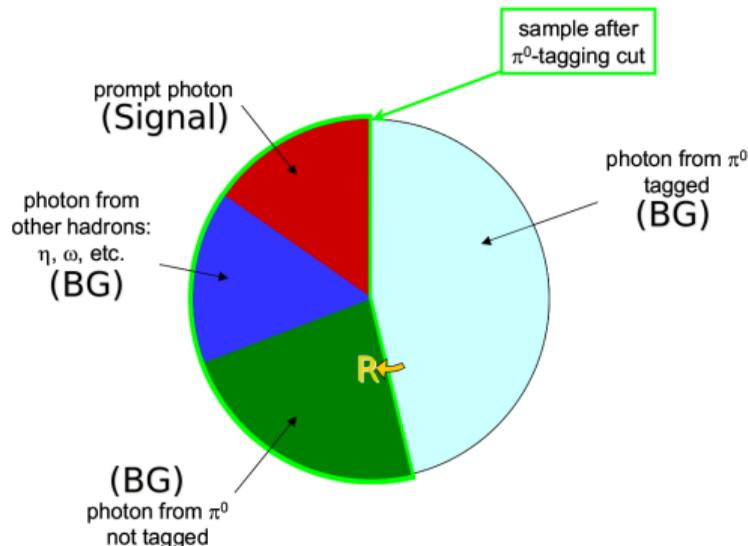
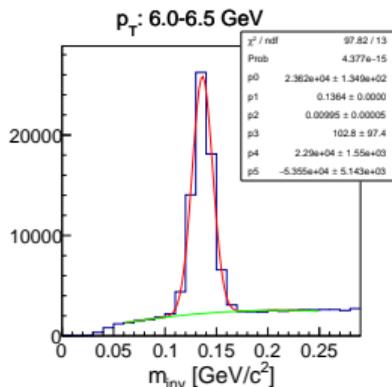


Source of direct photon:

- Compton scattering: $g + q \rightarrow \gamma + q$
- Annihilation: $q + \bar{q} \rightarrow \gamma + g$
- Parton fragmentation to photon.
- Quark bremsstrahlung.

Source of direct photon background:

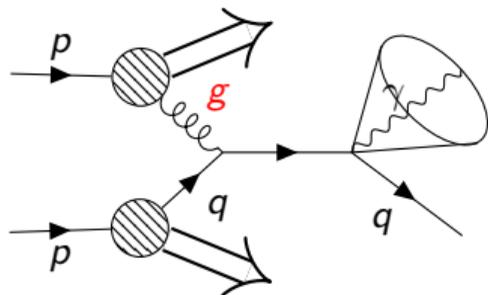
- Decay photons from mesons (π^0 , η , ω , η').



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.

Identifying direct photon through isolation

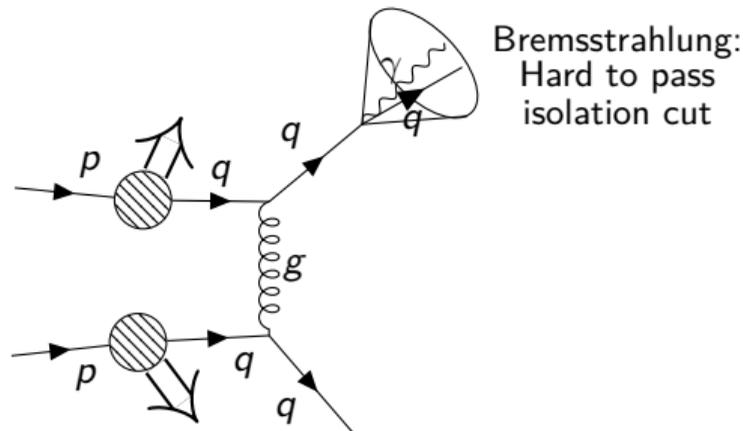
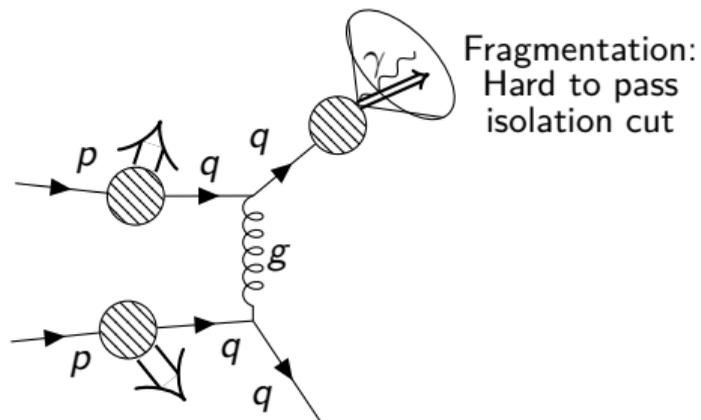


$$r_{\text{cone}} = \sqrt{(\delta\eta)^2 + (\delta\phi)^2} = 0.5$$

Isolation cut requirement:

$$\sum E_{\text{in cone}} < 0.1 E_\gamma$$

Quark-gluon Compton scattering: Easy to pass isolation cut



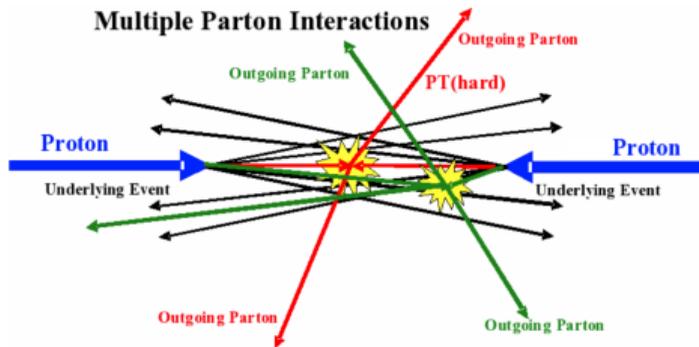
POWHEG + PYTHIA8 for xsec

- Parton shower (PS) in PYTHIA8: leading log; no interference.
- Matrix element (ME) at NLO in POWHEG: with interference.
- NLO output (ME) of POWHEG as input (PS) of PYTHIA8.
- Overlapping between ME and PS is vetoed in PYTHIA8.

$$\frac{d\sigma_{ME}}{dx_1 dx_2} \sim \left| \begin{array}{c} \text{Diagram 1} \\ + \\ \text{Diagram 2} \end{array} \right|^2$$

$$\frac{d\sigma_{PS}}{dx_1 dx_2} \sim \left| \begin{array}{c} \text{Diagram 1} \\ + \\ \text{Diagram 2} \end{array} \right|^2$$

The diagrams show two Feynman diagrams for each case. In the top case, the diagrams are summed before squaring. In the bottom case, each diagram is squared and then summed.



- Multiparton interactions (MPI) in PYTHIA8:

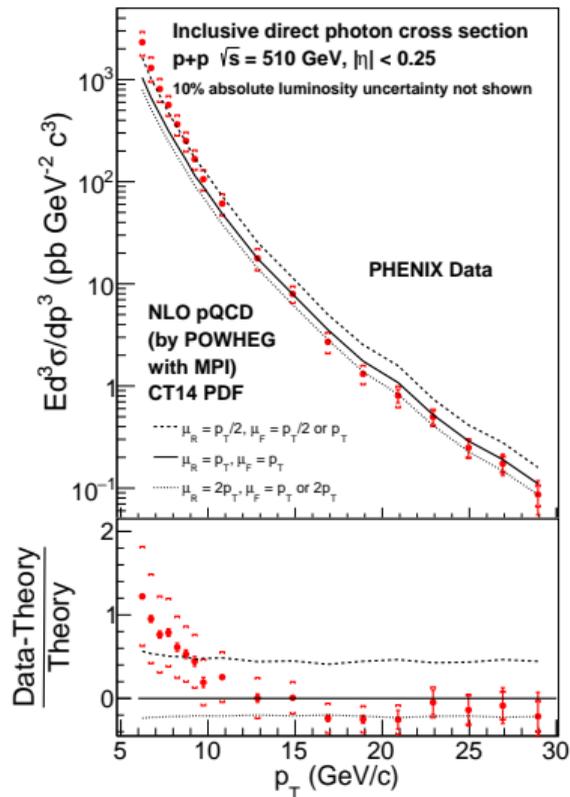
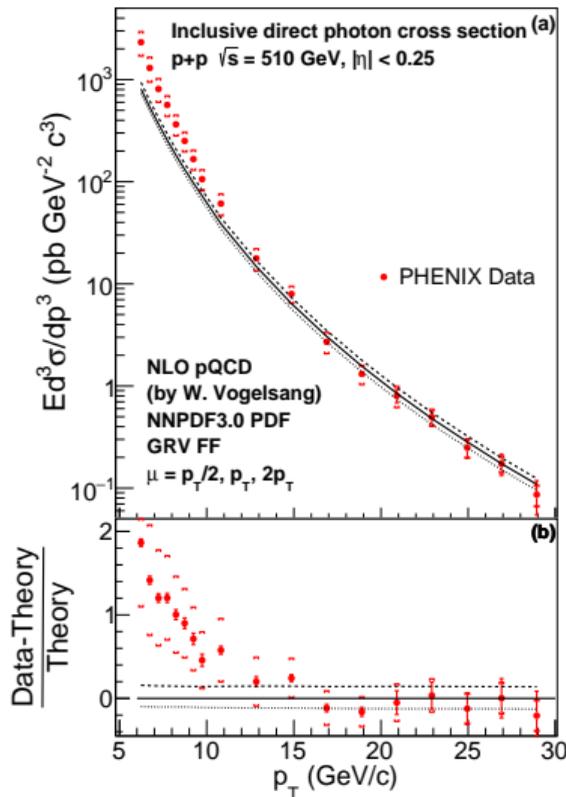
$$\frac{d\mathcal{P}_{MPI}}{dp_{\perp}} = \frac{1}{\sigma_{ND}} \frac{d\sigma_{2 \rightarrow 2}}{dp_{\perp}} \exp \left(- \int_{p_{\perp}}^{p_{\perp}+1} \frac{1}{\sigma_{ND}} \frac{d\sigma_{2 \rightarrow 2}}{dp'_{\perp}} dp'_{\perp} \right)$$

- $\sigma_{ND} \simeq \sigma_{BBC}$ is the nondiffractive xsec.

Inclusive xsec at 510 GeV



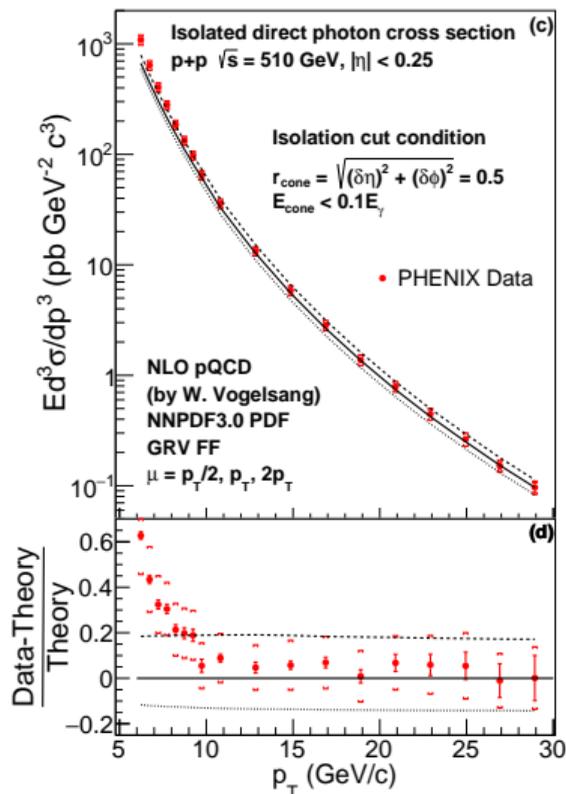
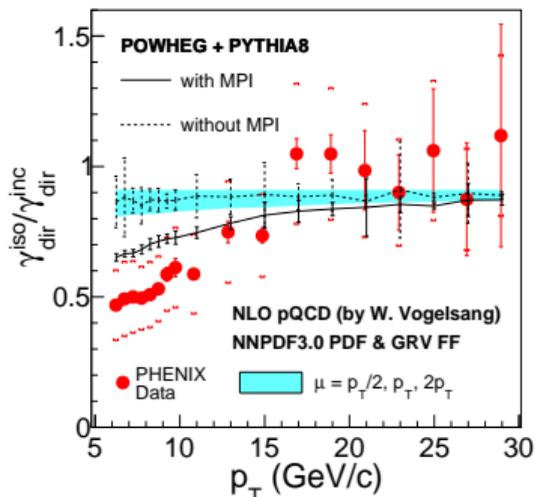
- arXiv: 2202.08158
- NLO pQCD underestimates the data by a factor of ~ 3 at low p_T .
- POWHEG + PYTHIY8 with MPI and parton shower gives better description of data.



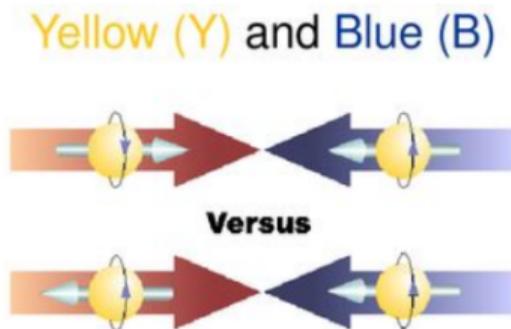
Isolated xsec at 510 GeV



- arXiv: 2202.08158
- Cross section consistent with NLO pQCD.
- MPI is important to explain the data/theory discrepancy at low p_T .
- Constrain unpolarized gluon density function.



Double helicity asymmetry A_{LL}



$$A_{LL} = \frac{\Delta\sigma}{\sigma} = \frac{\sigma_{++} + \sigma_{--} - \sigma_{+-} - \sigma_{-+}}{\sigma_{++} + \sigma_{--} + \sigma_{+-} + \sigma_{-+}}$$

$$= \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}, \quad R = \frac{L_{++}}{L_{+-}}$$

$$A_{LL}^{\text{dir}} = \frac{A_{LL}^{\text{total}} - r_{\pi^0} A_{LL}^{\pi^0} - r_h A_{LL}^h}{1 - r_{\pi^0} - r_h}$$

Measured in a run-by-run basis

Separated for 4 spin patterns

Separated for even and odd crossings

4 spin patterns \times 2 crossings = 8 groups

Crossing: 0 1 2 3 4 5 6 7

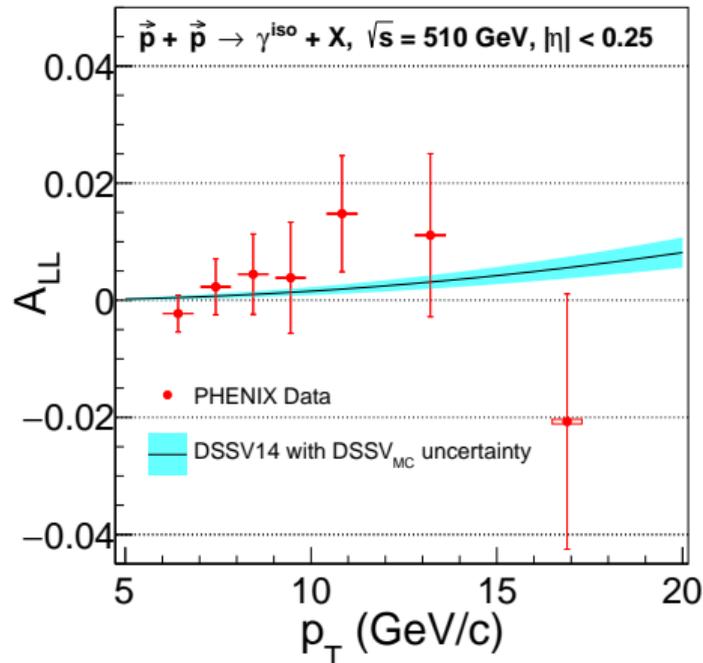
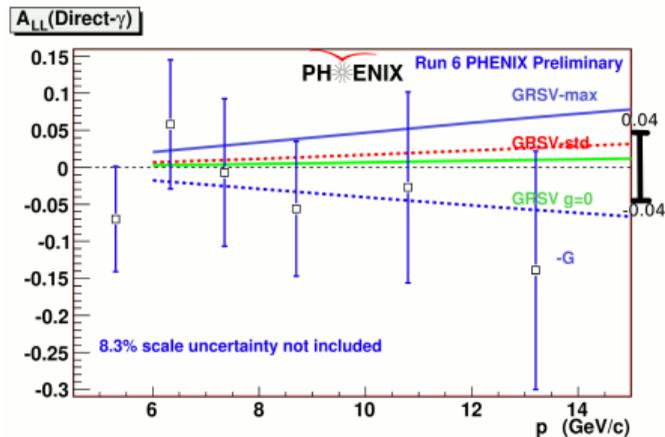
Blue: + + - - + + - -

Yellow: + + + + - - - -

Direct photon A_{LL} [arXiv: 2202.08158]



- Consistent with NLO DSSV14.
- Will be the first published direct photon A_{LL}
- Constrain polarized gluon density function Δg
- Much smaller uncertainty compared with the previous preliminary at 200 GeV.

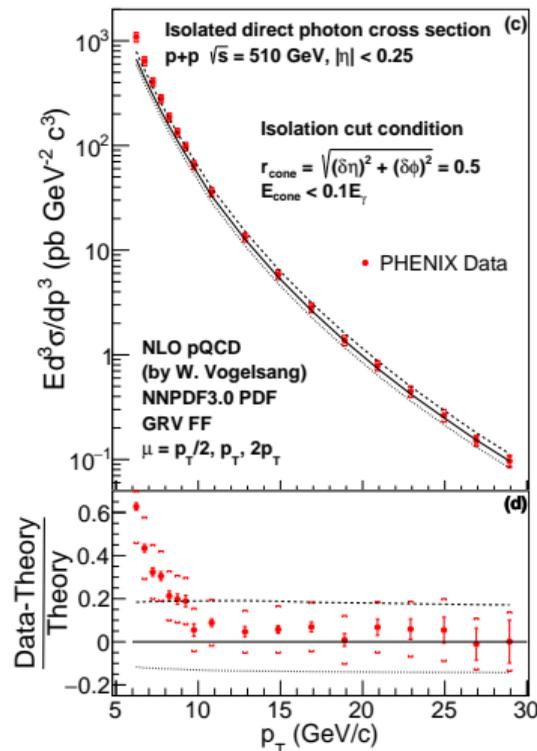
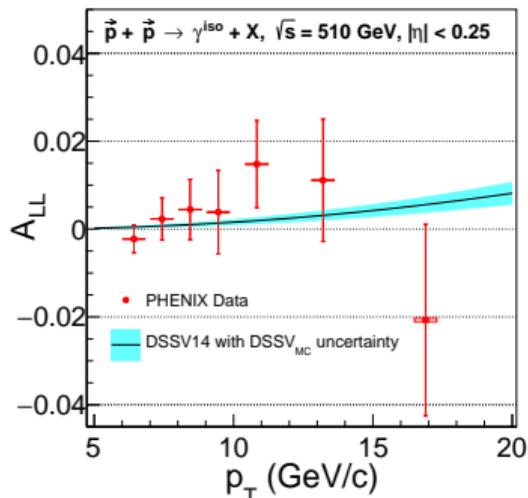


Not published [Bennett, PhD thesis (2009)]

Summary [arXiv: 2202.08158]



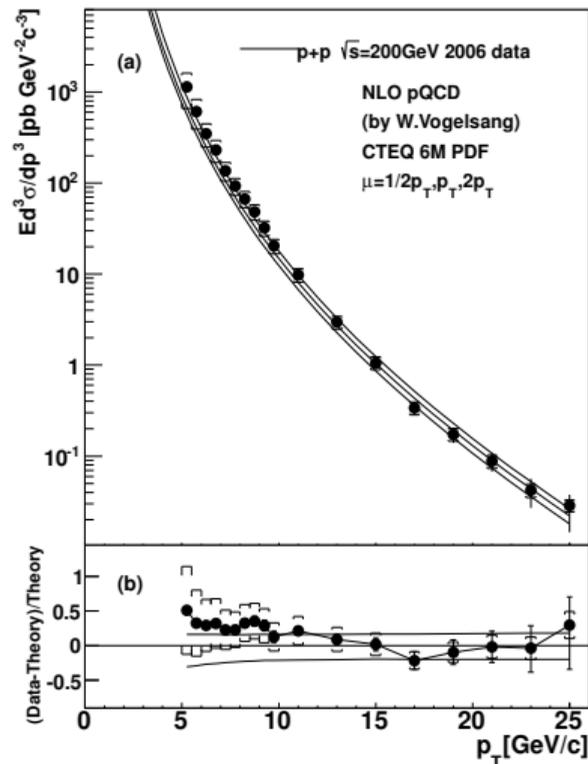
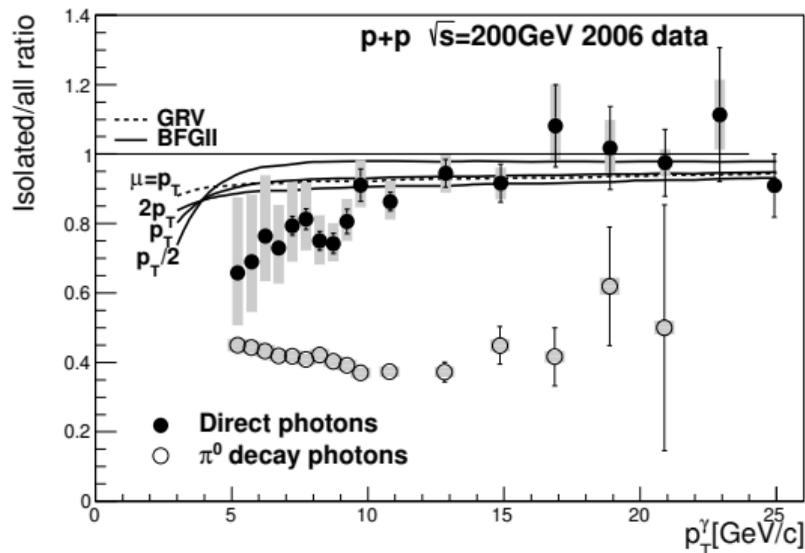
- Gluon spin is important for proton spin decomposition.
- Direct photons have little fragmentation contributions.
- First direct photon xsec and A_{LL} at 510 GeV.
- Independent constraint on the gluon spin contribution.



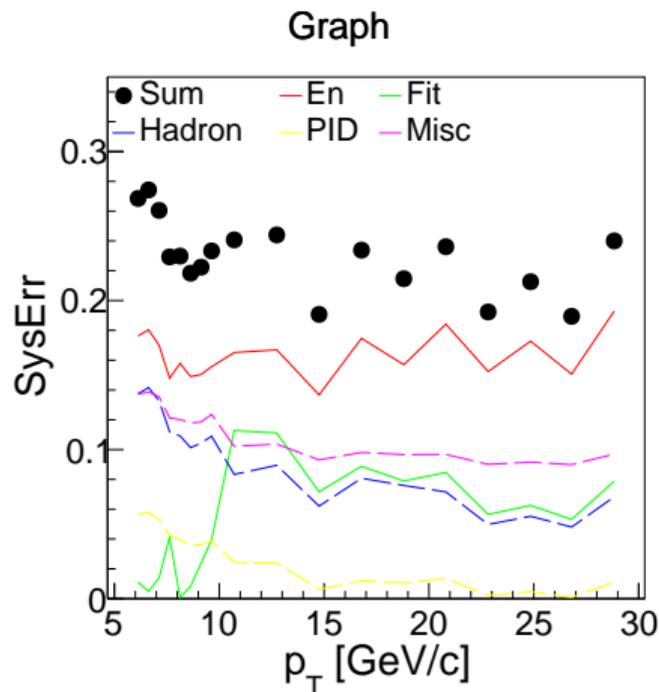
Backup

Previous inclusive xsec at 200 GeV

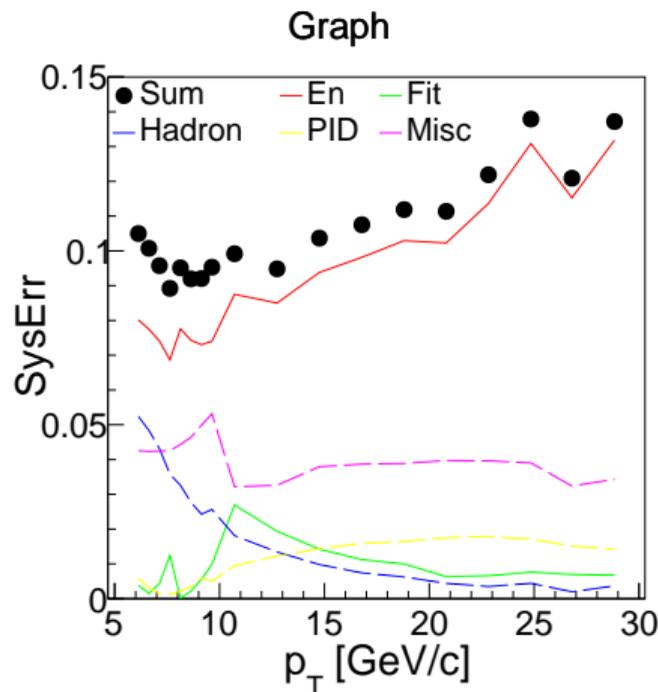
- Cross section consistent with NLO pQCD.
- NLO pQCD overestimates isolated/inclusive ratio.
- PHENIX, PRD 86, 072008 (2012).



Systematic uncertainties of cross sections

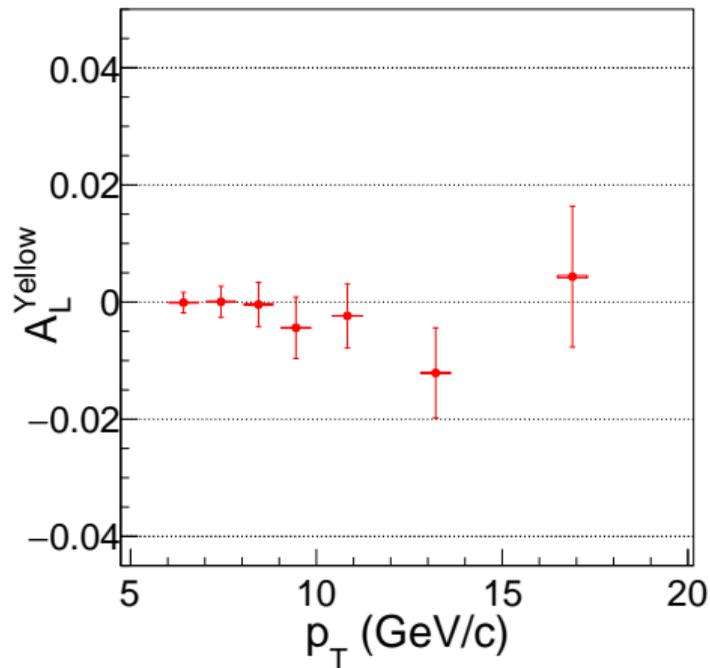
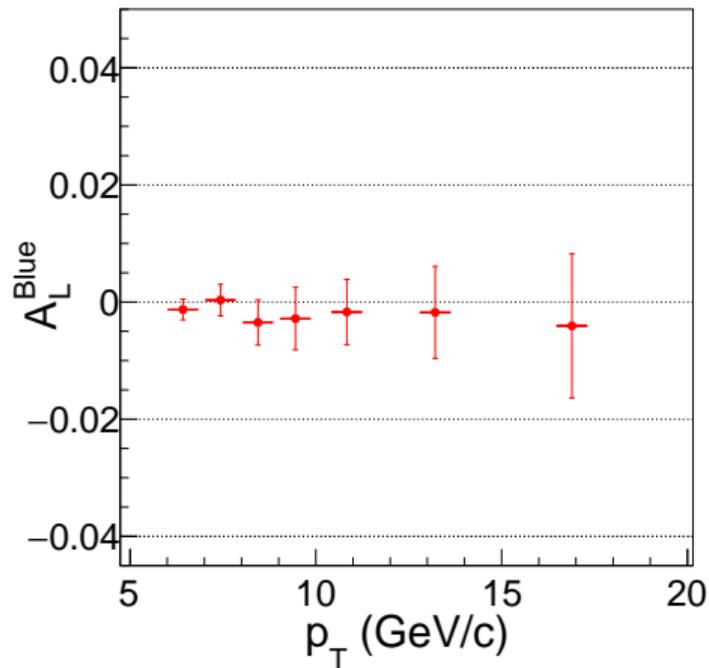


Inclusive cross section



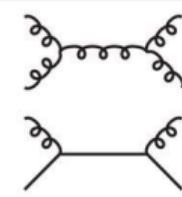
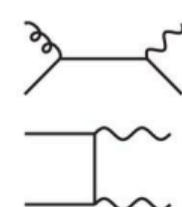
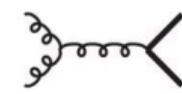
Isolated cross section

A_L cross checks

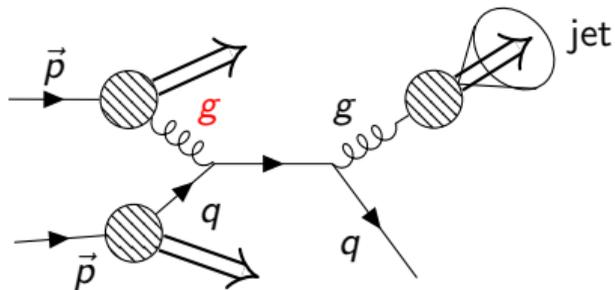


Processes probing parton helicity densities

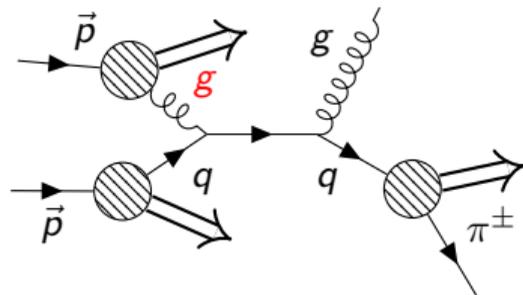


Reaction	Dom. partonic process	probes	LO Feynman diagram
$\vec{p}\vec{p} \rightarrow \pi + X$	$\vec{g}\vec{g} \rightarrow gg$ $\vec{q}\vec{g} \rightarrow qg$	Δg	
$\vec{p}\vec{p} \rightarrow \text{jet}(s) + X$	$\vec{g}\vec{g} \rightarrow gg$ $\vec{q}\vec{g} \rightarrow qg$	Δg	(as above)
$\vec{p}\vec{p}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

Jet and charged pion productions



Jet production



Charged pion production

- Larger statistics: not suppressed by small QED coupling.
- π^\pm : separate u and d quark.
- RHIC 200 GeV data probe $0.05 < x < 0.2$
- RHIC 510 GeV data probe $0.02 < x < 0.08$

