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

Zhongling Ji for the PHENIX Collaboration

UCLA & Stony Brook University
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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.

Challenges in the direct photon measurement:
- Low statistics.
- \( \pi^0 \) 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 \( \text{pb}^{-1} \)) in \( \vec{p} + \vec{p} \)
- EMCal with fine granularity to separate \( \pi^0 \) decay photons up to \( p_T \) of 12 GeV/c, and a shower profile analysis extends the \( \gamma/\pi^0 \) discrimination to beyond 20 GeV/c.
From $A_{LL}$ to $\Delta g$

- Existing RHIC data mainly probe $0.05 < x_g < 0.2$
- PHENIX $\pi^0$ $A_{LL}$ at 510 GeV confirms a nonzero $\Delta g$ 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 $\Delta g$

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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 ($\pi^0$, $\eta$, $\omega$, $\eta'$).

Yield of direct photon:
$$N_{dir} = N_{total} - (1 + A)(1 + R)N_{\pi^0}$$

- $R$: $\pi^0$ one photon missing ratio.
- $A$: Other hadrons' to $\pi^0$'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

Fragmentation: Hard to pass isolation cut

Bremsstrahlung: Hard to pass isolation cut
Results [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.

\[ \hat{p} + \hat{p} \rightarrow \gamma^{\text{iso}} + X, \sqrt{s} = 510 \text{ GeV}, |\eta| < 0.25 \]

\[ A_{LL} \]

\[ p_T \] (GeV/c) 

\[ 5 \quad 10 \quad 15 \quad 20 \]

\[ 0.04 \quad 0.02 \quad 0 \quad -0.02 \quad -0.04 \]

\[ A_{LL} \]

\[ \text{DSSV14 with DSSV_{loc} uncertainty} \]

\[ \text{PHENIX Data} \]

Isolated direct photon cross section 

\[ p+p /\sqrt{s} = 510 \text{ GeV}, |\eta| < 0.25 \]

Isolation cut condition 

\[ r_{\text{cone}} = \sqrt{0.05^2 + (0.5)^2} = 0.5 \]

\[ E_{\text{cone}} < 0.1 \mu \]

NLO pQCD 
(by W. Vogelsang)

NNPDF3.0 PDF
GRV FF

\[ \mu = p_T/2, p_T, 2p_T \]

Data-Theory

\[ \text{PHENIX Data} \]

\[ \text{Theory} \]

Zhongling Ji (UCLA & SBU)