Double longitudinal-spin asymmetries in direct photon production at NICA

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Outline

- Motivation
- Introduction
- Basic formalism
- Results
- Conclusions

Motivation

Proton spin composition from the quarks and gluons spin polarization and their motion:

- to test various sum rules
- to understand nonperturbative properties of hadrons

The longitudinal spin decomposition of the proton

$$\frac{1}{2}=\frac{1}{2}\Delta\Sigma+\Delta G+L_q+L_g$$

spin orbital

$$\Delta G=\int_0^1 \Delta g(x)\,dx$$

$\Delta g(x)$ gluon helicity distribution function

difference of probabilities to find a gluon with the same and opposite helicity orientation w.r.t. the spin of the longitudinally polarized nucleon.

Introduction

3 complementary channels to probe the gluon spin inside the proton:
measurements of double helicity asymmetry A_{LL}
of direct photon, jet and charged pion productions in polarized $\vec{p}\,\vec{p}$ collisions

$$A_{LL}^{\gamma} \simeq \frac{\Delta g(x_1)}{g(x_1)} \otimes A_{1p}(x_2) \otimes \hat{a}_{LL}^{gq(\bar{q}) \to \gamma\, q(\bar{q})} + (1 \leftrightarrow 2)$$

Direct photon production: the «cleanest channel»

Compton scattering dominates $gq \to \gamma\, q$

Annihilation $q\bar{q} \to \gamma\, g$

Introduction

Measurement of the A_{LL} asymmetries in the inclusive production of high-pT:

- neutral pions: J. Adam et al. (STAR), Phys. Rev. D 98, 032013 (2018); A. Adare et al. (PHENIX), Phys. Rev. D90, 012007 (2014); Phys. Rev. Lett. 103, 012003 (2009), Phys. Rev. D79, 012003 (2009)
- Charged pions: U. A. Acharya et al. (PHENIX), Phys. Rev. D 102, 032001 (2020).
- Jets: P. Djawotho (STAR), Nuovo Cim. C036, 35 (2013),
- Di-jets: L. Adamczyk et al. (STAR), Phys. Rev. D 95, 071103 (2017); J. Adam et al. (STAR), Phys. Rev. D 98, 032011 (2018).
- Heavy flavors: A. Adare et al. (PHENIX), Phys. Rev. D87, 012011 (2013).
- J/ψ mesons: A. Adare et al. (PHENIX), Phys. Rev. D94, 112008 (2016).

Direct photon A_{LL} asymmetry at LO CPM

$$A_{LL}=\frac{d\sigma^{++}-d\sigma^{+-}}{d\sigma^{++}+d\sigma^{+-}}=\frac{d\Delta\sigma}{d\sigma} \qquad d\Delta\sigma=\sum_{a,b=q\bar{q},g}\int dx_a\,dx_b\,\Delta f_a(x_a,\mu^2)f_b(x_b,\mu^2)\,d\Delta\sigma_{ab}^{\gamma}$$

$\Delta f_a(x_a,\mu^2)$ polarized parton distributions

spin-dependent parton subprocess cross sections $d\Delta\sigma_{ab}^{\gamma}=\frac{\left|\Delta\overline{M_{ab\to\gamma X}}\right|^2}{8\pi}\frac{p_{\gamma T}}{x_a x_b s^2}dp_{\gamma T}\,d\eta$

$$\left|\overline{M_{qg\to\gamma q}}\right|^2=-\frac{16}{3}\pi^2\alpha_{em}\alpha_s Z_q^2\frac{\hat{s}^2+\hat{t}^2}{\hat{s}\hat{t}} \qquad \left|\Delta\overline{M_{qg\to\gamma q}}\right|^2=-\frac{16}{3}\pi^2\alpha_{em}\alpha_s Z_q^2\frac{\hat{s}^2-\hat{t}^2}{\hat{s}\hat{t}}$$

$$\left|\overline{M_{q\bar{q}\to\gamma g}}\right|^2=\frac{128}{9}\pi^2\alpha_{em}\alpha_s Z_q^2\frac{\hat{u}^2+\hat{t}^2}{\hat{u}\hat{t}} \qquad \left|\Delta\overline{M_{q\bar{q}\to\gamma g}}\right|^2=-\frac{128}{9}\pi^2\alpha_{em}\alpha_s Z_q^2\frac{\hat{u}^2+\hat{t}^2}{\hat{u}\hat{t}}$$

E.L. Berger and J. Qiu Phys. Rev. D, V. 40, P. 778

q=u,d,s

Polarized PDFs

LSS15 *Leader E., Sidorov A. V., Stamenov D. B. Phys. Rev. D91, 054017 (2015)*

DSSV14 *de Florian D., Sassot R., Stratmann M., Vogelsang W. Phys. Rev. Lett. 113, 012001 (2014)*

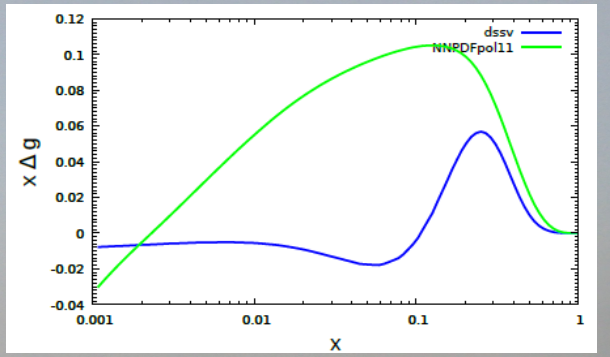
NNPDF-pol1.1 *Nocera E. R. et al. Nucl. Phys. B887, 276 (2014)*

JAM17 *Ethier J .J., Sato N., Melnitchouk W. Phys. Rev. Lett. 119, 132001 (2017)*

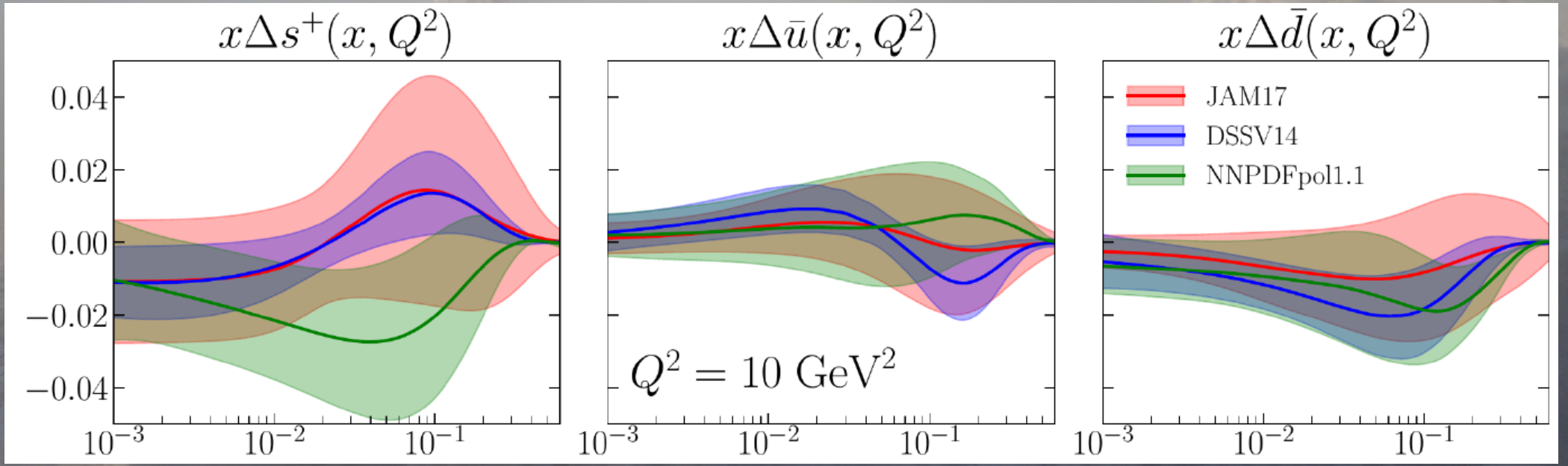
Global QCD fits at NLO accuracy, different data on inclusive DIS measurements

Spin asymmetry measurements from pion and kaon production in SIDIS by HERMES and COMPASS

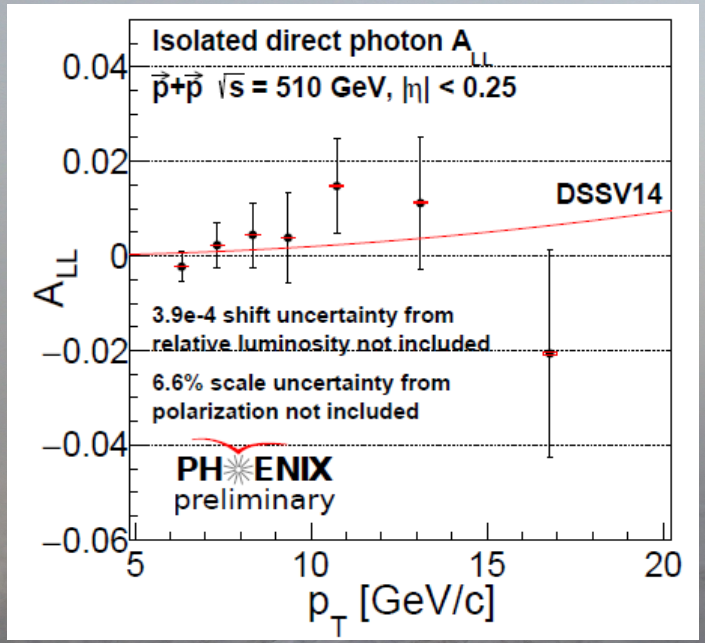
Single-jet production asymmetries in polarized proton-proton collisions measured by STAR



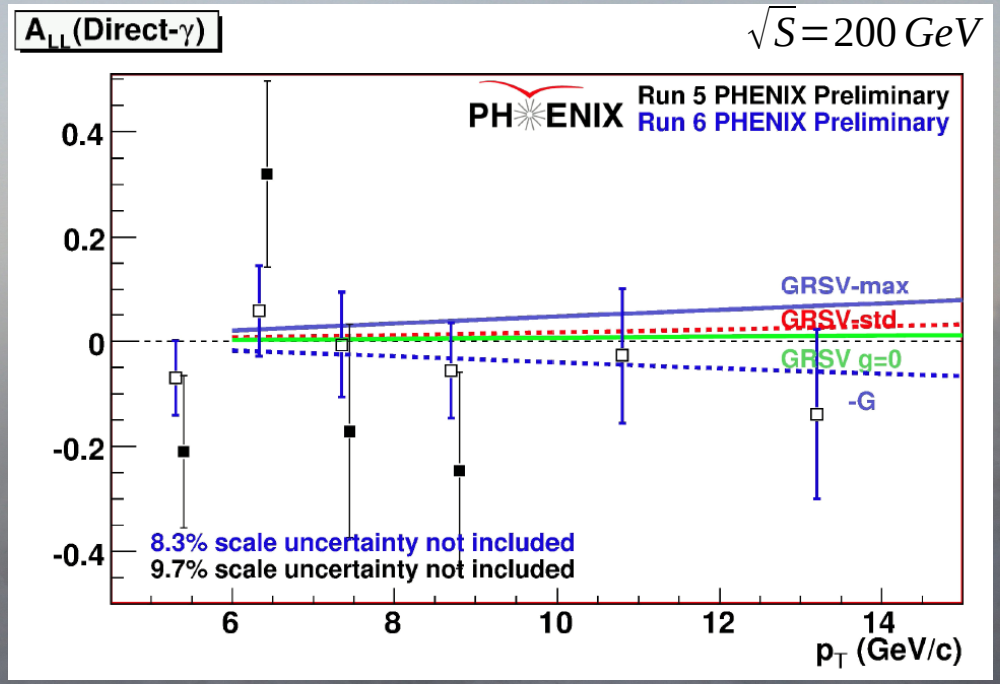
Ethier J. J. and Nocera E. R. Annu. Rev. Nucl. Part. Sci. 70 (2020)



Direct photon producion: recent experimental results

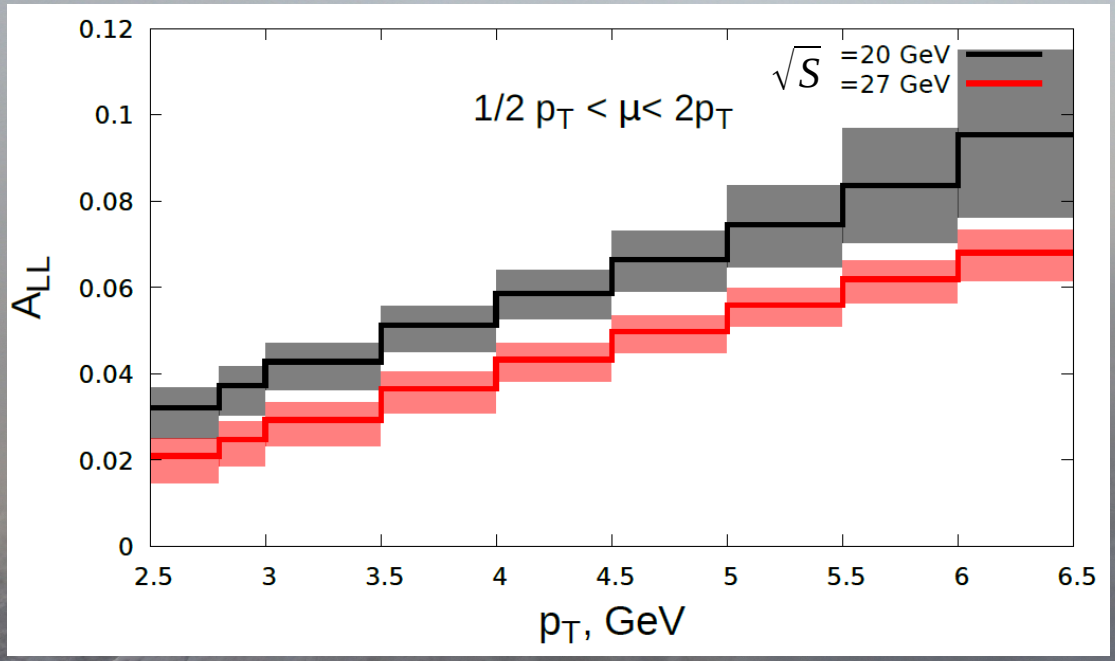


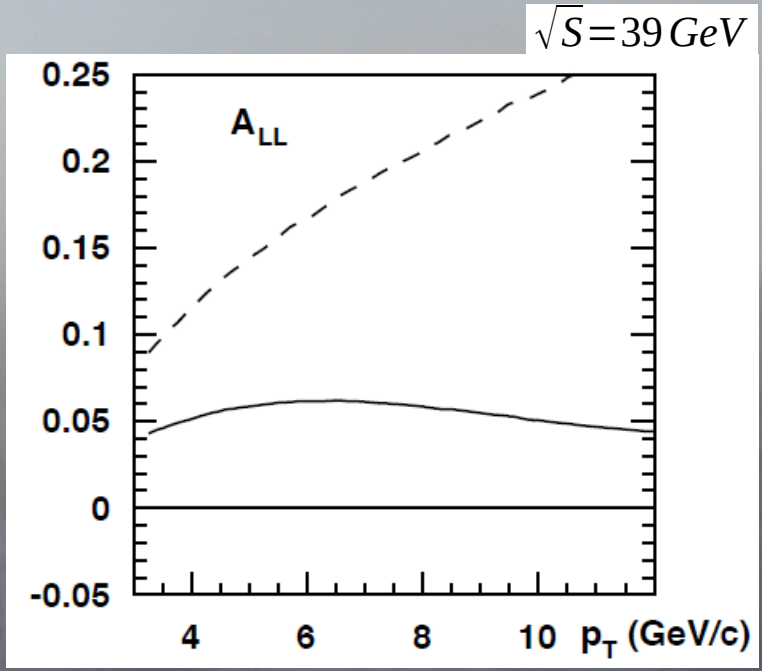
Z. Ji for the PHENIX Collaboration
Proceedings for the XXVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, Stony Brook University, New York, USA, 12-16 April 2021; SciPost Phys. Proc. 8, 090 (2022)



R. Bennett and Phenix Collaboration
AIP Conference Proceedings 1149, 265 (2009)

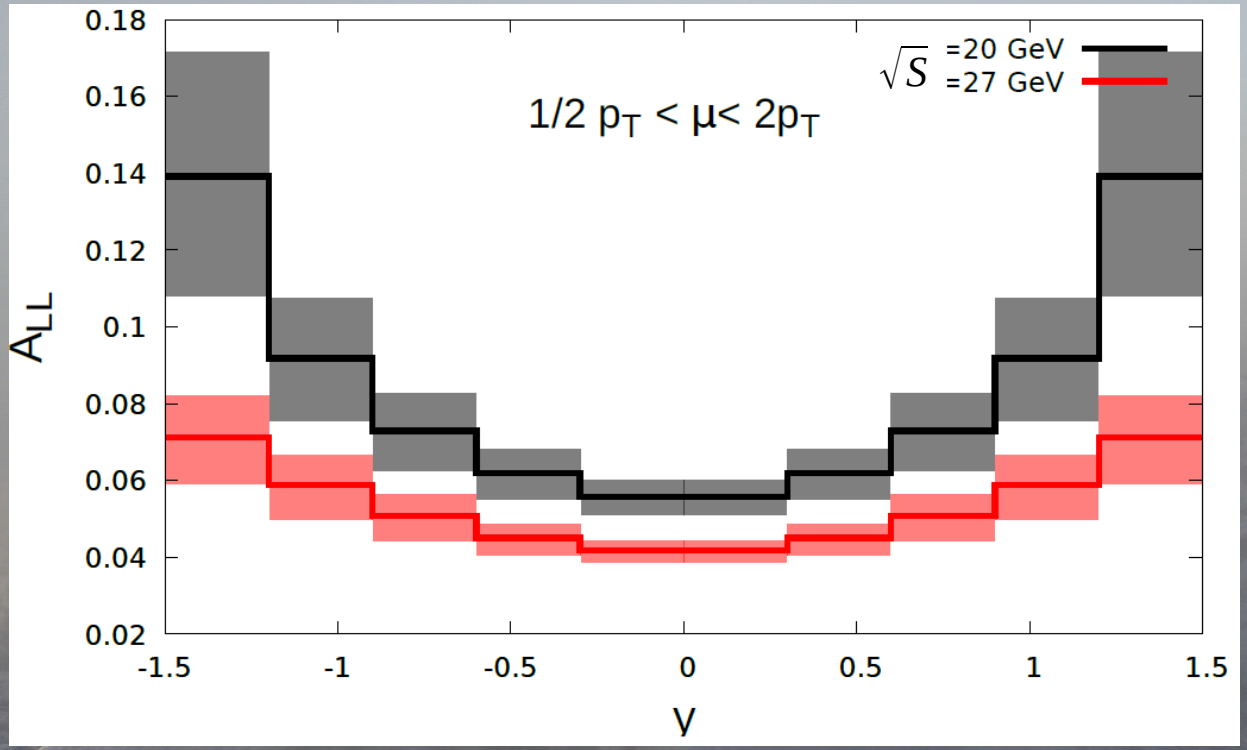
A_{LL} asymmetry $p_{\gamma T}$ spectra at LO CPM



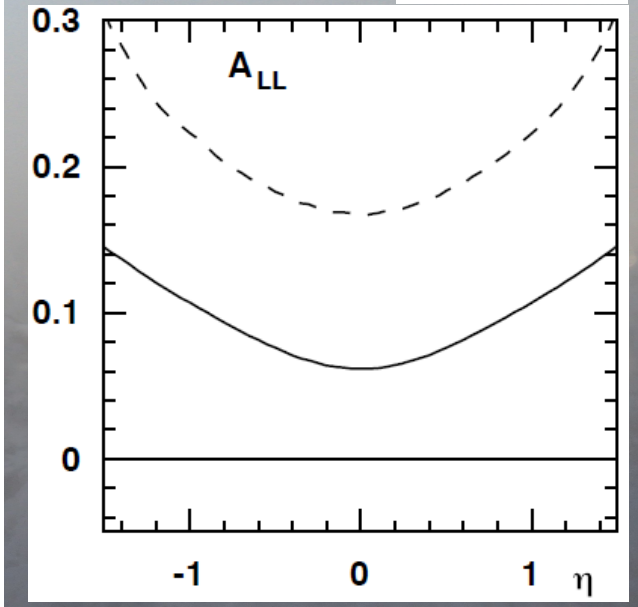


M. Anselmino, E. Andreeva, V. Korotkov, F. Murgia, W. D. Nowak, S. Nurushev, O. Teryaev, and A. Tkabladze, in Future physics at HERA. Proceedings, Workshop, Hamburg, Germany, September 25, 1995-May 31, 1996. Vol. 1, 2 (1996),

A_{LL} asymmetry photon rapidity spectra at LO CPM



$\sqrt{S} = 39\,GeV$



M. Anselmino, E. Andreeva, V. Korotkov, F. Murgia, W. D. Nowak, S. Nurushev, O. Teryaev, and A. Tkabladze, in Future physics at HERA. Proceedings, Workshop, Hamburg, Germany, September 25, 1995-May 31, 1996.

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Polarized and unpolarized isolated prompt photon production beyond the leading order

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(Received 24 January 1994)

We present a simple and accurate analytical method for calculating the cross section for polarized and unpolarized *isolated* prompt photon production in next-to-leading order, taking into account also the next-to-leading-order fragmentation contribution in the unpolarized case. We demonstrate the good accuracy of our method over a wide range of the isolation parameters and study the effects the isolation cuts have on the cross section at colliders.

Conclusions

- Longitudinally polarized protons at SPD NICA are capable of probing the gluon spin at leading order.
- The new constraints on $\Delta g(x)$ can be extracted from future measurements of A_{LL}
- We calculated A_{LL} at LO CPM for c.m.e. of 20 GeV and 27 GeV in the central rapidity region and predict the asymmetries up to 18%.
- Our predictions are consistent with earlier results at the c.m.e. energy of 39 GeV and could be complemented by further calculations of jet and charged pion production.
- More precise predictions could be obtained by the NLO calculation using the exact analytical formulas.


Thank you for attention!