Dihadron helicity correlation

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H.C. Zhang, S.Y. Wei; PLB 839, 137821 (2023)
X.W. Li, Z.X. Chen, S. Cao, S.Y. Wei, PRD 109, 014035 (2024)
Z.X. Chen, H. Dong, S.Y. Wei, arXiv:2404.19202 (2024)

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- Dihadron helicity correlation
- Prediction for UPC and EIC
- Summary

Introduction

QCD factorization

partonic interaction, perturbative

$$\text{Cross Section} = \text{short distance} \otimes \text{long distance}$$

non-perturbative, universal

TMD PDFs: $\mathcal{FT}\langle p|\bar{\psi}(0)\psi(x^-,\vec{x}_\perp)|p\rangle$

$$\not{n}_+\left[f_1 - \frac{(\widehat{\boldsymbol{e}}_p \times \boldsymbol{k}_T)\cdot \boldsymbol{S}_\perp}{M} f_{1T}^\perp\right] + \gamma_5 \not{n}_+\left[\lambda g_{1L} + \frac{k_T\cdot S_\perp}{m} g_{1T}^\perp\right] +$$
$$\frac{i[\not{k}_T, \not{n}_+]}{2m} h_1^\perp + \frac{1}{2}[\not{S}_\perp, \not{n}_+]\gamma_5 h_{1T} + \frac{[\not{k}_T, \not{n}_+]\gamma_5}{2m}\left[\lambda h_{1L}^\perp + \frac{k_T\cdot S_\perp}{m} h_{1T}^\perp\right]$$

TMD FFs: $\mathcal{FT}\langle 0|\psi(0)|hX\rangle\langle hX|\bar{\psi}(x^-,\vec{x}_\perp)|0\rangle$

$$\not{n}_-\left[D_1 + \frac{(\widehat{\boldsymbol{e}}_j \times \boldsymbol{p}_T)\cdot \boldsymbol{S}_\perp}{zM} D_{1T}^\perp\right] + \gamma_5 \not{n}_-\left[\lambda G_{1L} + \frac{p_T\cdot S_\perp}{zM} G_{1T}^\perp\right] +$$
$$\frac{i[\not{p}_T, \not{n}_-]}{2M} H_1^\perp + \frac{1}{2}[\not{S}_\perp, \not{n}_-]\gamma_5 H_{1T} + \frac{[\not{p}_T, \not{n}_-]\gamma_5}{2M}\left[\lambda H_{1L}^\perp + \frac{p_T\cdot S_\perp}{M} H_{1T}^\perp\right]$$

QCD factorization

Baryons (columns) / **Quarks** (rows)

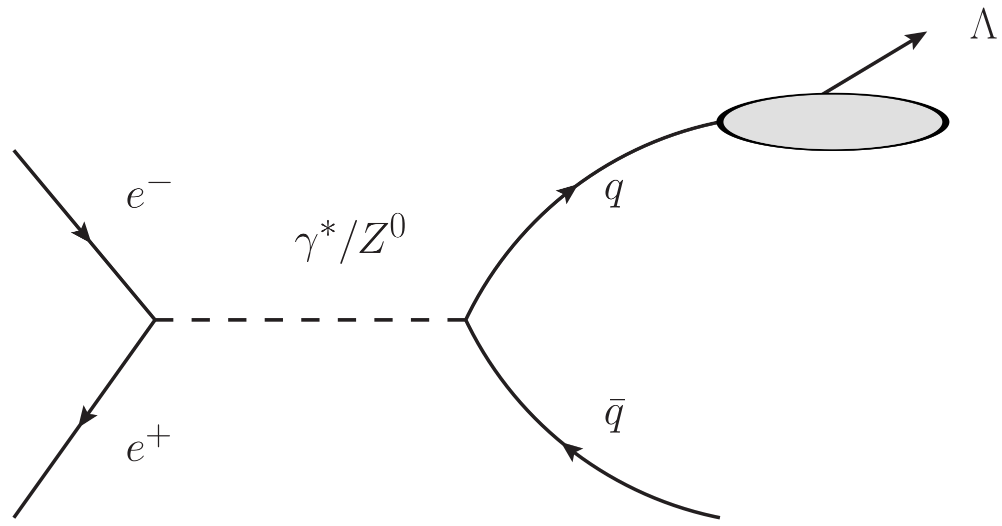
	Unpolarized	L	T
Unpolarized	D_1		$D_{1T}^{\perp}$
L		G_{1L}	$G_{1T}^{\perp}$
T	$H_1^{\perp}$	$H_{1L}^{\perp}$	$H_{1T}, H_{1T}^{\perp}$

polarized beams
or
weak interaction

☑ **G_{1L}, aka, the longitudinal spin transfer**

Number density of longitudinally polarized hadrons produced from longitudinally polarized quarks.

Single Inclusive Λ Production in e⁺e⁻ Annihilation Experiment



Final state quarks gain polarization through weak interaction

γ^* Z^0

$$\frac{d\sigma}{dPS} = \sigma_0 \left[D_{1q}^{\Lambda}(z) + \lambda_q \lambda_\Lambda G_{1Lq}^{\Lambda}(z) \right]$$

Belle Energy

LEP Energy

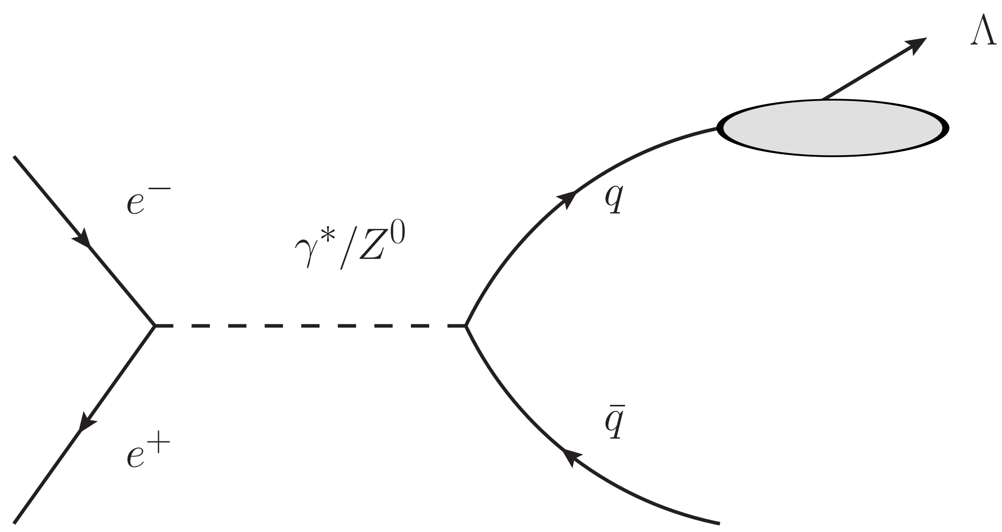
spin transfer

$$\mathscr{P}_L^{\Lambda} = \lambda_q \frac{G_{1Lq}^{\Lambda}}{D_{1q}^{\Lambda}}$$

quark polarization

Introduction

Single Inclusive Λ Production in e⁺e⁻ Annihilation Experiment



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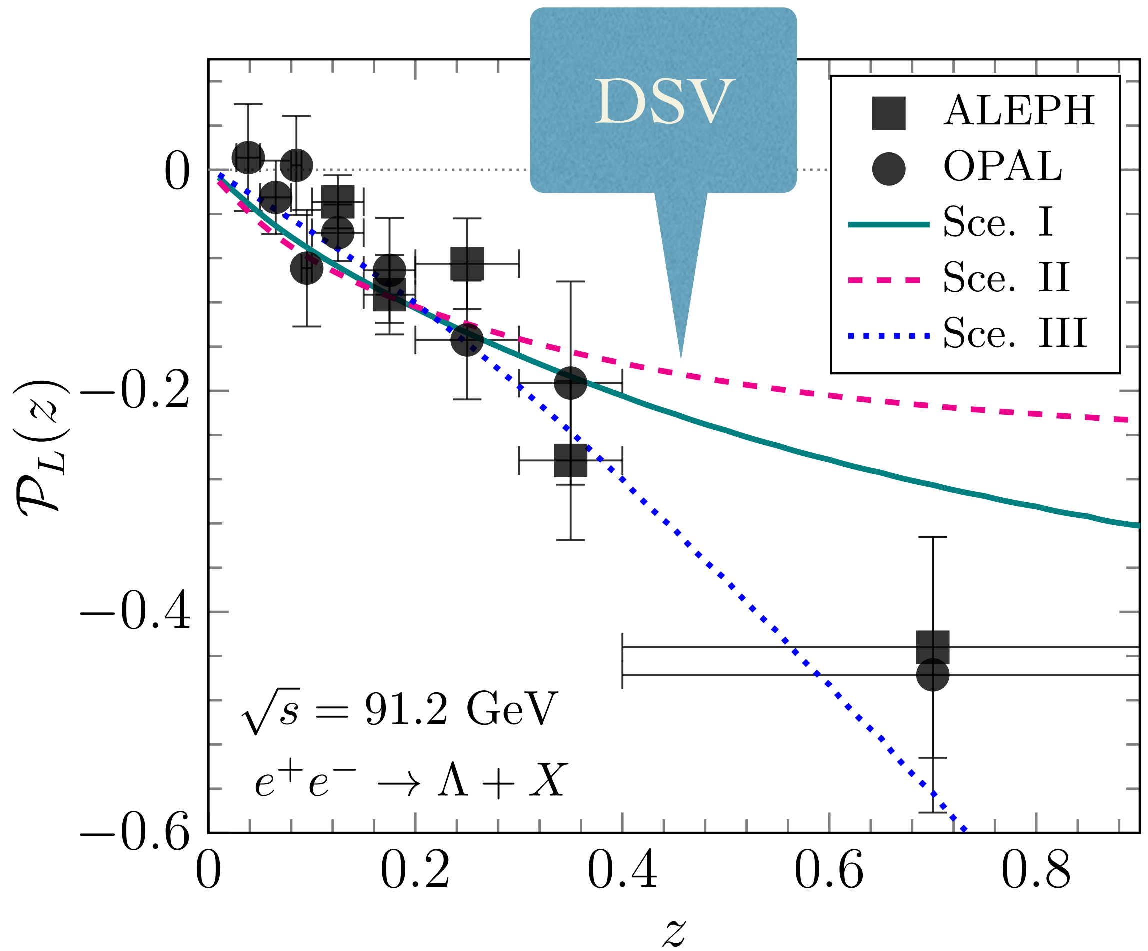
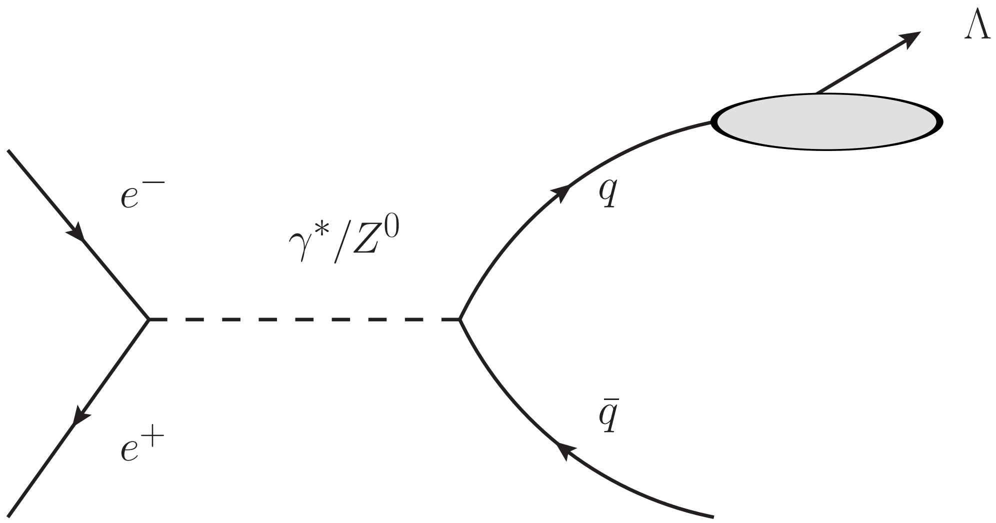


Single Inclusive Λ Production in e⁺e⁻ Annihilation Experiment



Final state quarks gain polarization through weak interaction

γ^* $\quad$ Z^0

$$\frac{d\sigma}{dPS} = \sigma_0 \left[D_{1q}^{\Lambda}(z) + \lambda_q \lambda_\Lambda G_{1Lq}^{\Lambda}(z) \right]$$

Belle Energy

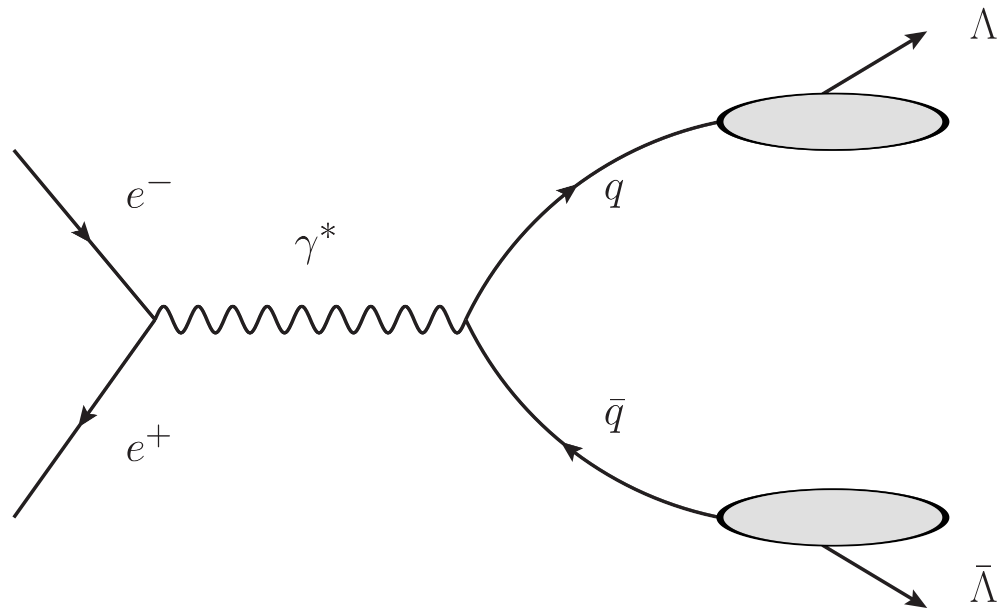
LEP Energy

spin transfer

$$\mathscr{P}_L^{\Lambda} = \lambda_q \frac{G_{1Lq}^{\Lambda}}{D_{1q}^{\Lambda}}$$

quark polarization

$\Lambda\bar{\Lambda}$-pair Production in e⁺e⁻ Annihilation Experiment



Belle Energy

$$\frac{d\sigma}{dPS} = \sigma_0 \left[D_{1q}^{\Lambda}(z_1) D_{1\bar{q}}^{\bar{\Lambda}}(z_2) - \lambda_{\Lambda}\lambda_{\bar{\Lambda}} G_{1Lq}^{\Lambda}(z_1) G_{1L\bar{q}}^{\bar{\Lambda}}(z_2) \right]$$

☑ **Helicity Conservation**

q and $\bar{q}$ are on the same fermion line. They must have opposite helicities.

☑ **Helicity Correlation**

A novel probe to the spin-dependent fragmentation functions

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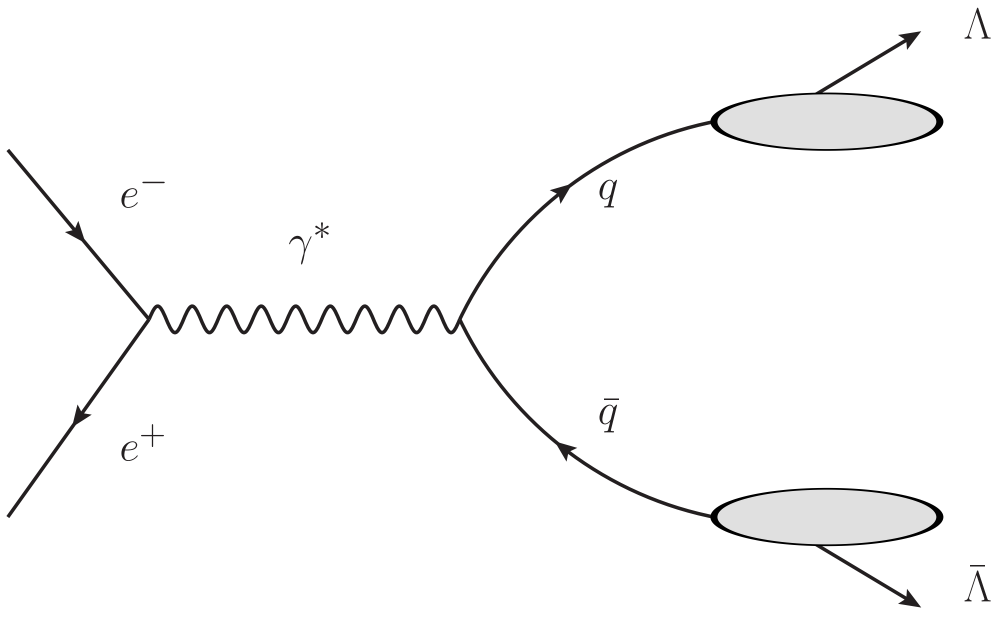
see also Nucl. Phys. B 445 (1995) 380.

Helicity Amplitude Approach



$\sigma_{\lambda_q \lambda_{\bar{q}}}$ denotes the differential X of $q\bar{q}$-pair production

$$\sigma_{+-} = \sigma_{-+} = \sigma_0/2$$

$$\sigma_{++} = \sigma_{--} = 0$$

$\mathscr{D}$ denotes the helicity dependent fragmentation function

$$\mathscr{D}(\lambda_q, \lambda_\Lambda, z) = D_{1q}(z) + \lambda_q \lambda_\Lambda G_{1Lq}(z)$$

Physical interpretation:

$$\frac{d\sigma}{dPS} = \sigma_{+-} \otimes \mathscr{D}_q(+, \lambda_\Lambda, z_1) \otimes \mathscr{D}_{\bar{q}}(-, \lambda_{\bar{\Lambda}}, z_2) + \sigma_{-+} \otimes \mathscr{D}_q(-, \lambda_\Lambda, z_1) \otimes \mathscr{D}_{\bar{q}}(+, \lambda_{\bar{\Lambda}}, z_2)$$

$$= \sigma_0 \left[D_{1q}^{\Lambda}(z_1) D_{1\bar{q}}^{\bar{\Lambda}}(z_2) - \lambda_\Lambda \lambda_{\bar{\Lambda}} G_{1Lq}^{\Lambda}(z_1) G_{1L\bar{q}}^{\bar{\Lambda}}(z_2) \right]$$

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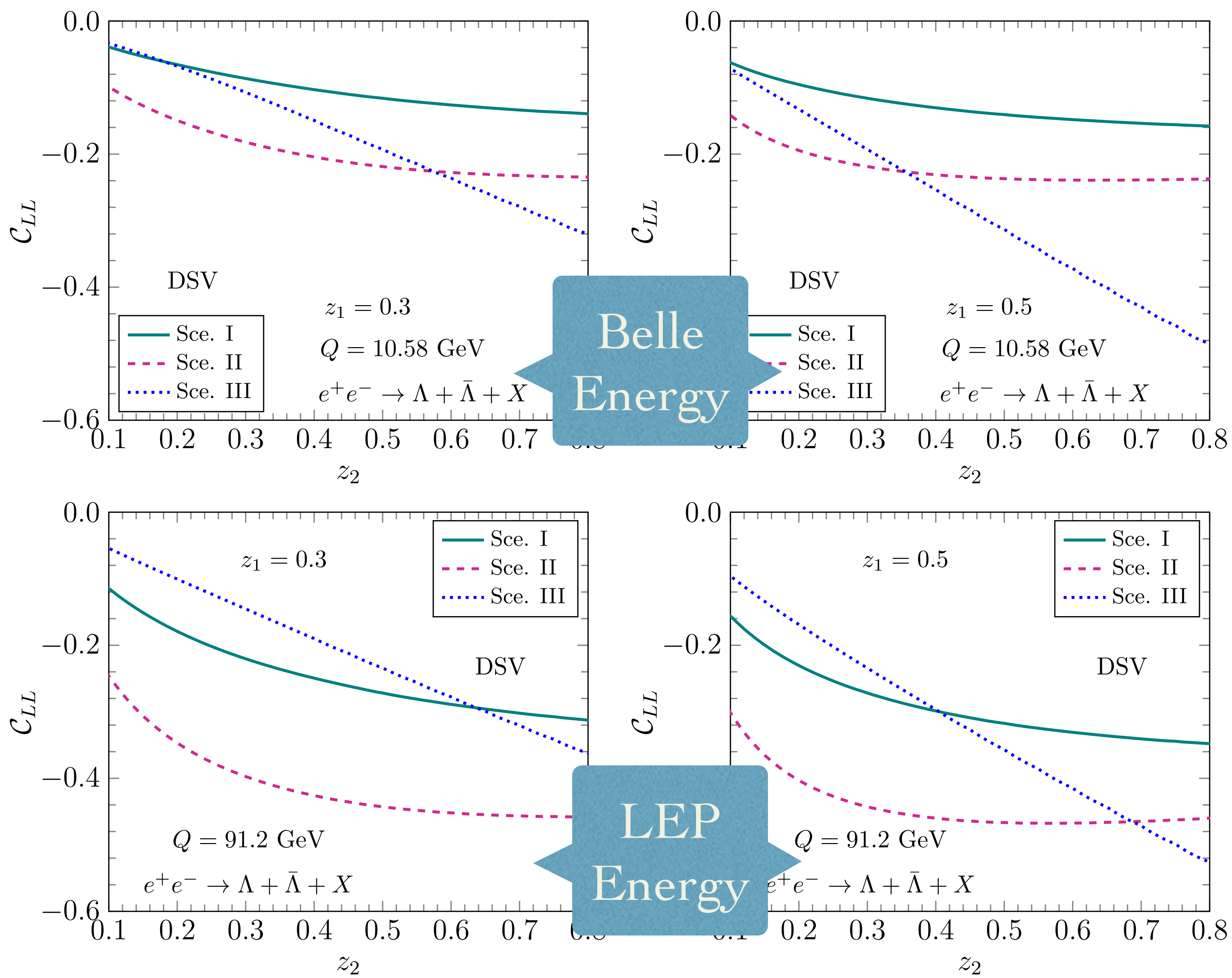
see also Nucl. Phys. B 445 (1995) 380.

Dihadron helicity correlation

Helicity Correlation of $\Lambda\bar{\Lambda}$-pair

$$C_{LL} = \frac{\text{same signs} - \text{opposite signs}}{\text{total cross section}} = \frac{\sum_q \sigma_0 G_{1Lq}^{\Lambda}(z_1) G_{1L\bar{q}}^{\bar{\Lambda}}(z_2)}{\sum_q \sigma_0 D_{1q}^{\Lambda}(z_1) D_{1\bar{q}}^{\bar{\Lambda}}(z_2)} \propto \langle \cos\theta_1^* \cos\theta_2^* \rangle$$



- The helicity correlation at the Belle energy has a similar magnitude with that at the LEP energy.
- It is now possible to extract the longitudinal spin transfer at Belle experiment.

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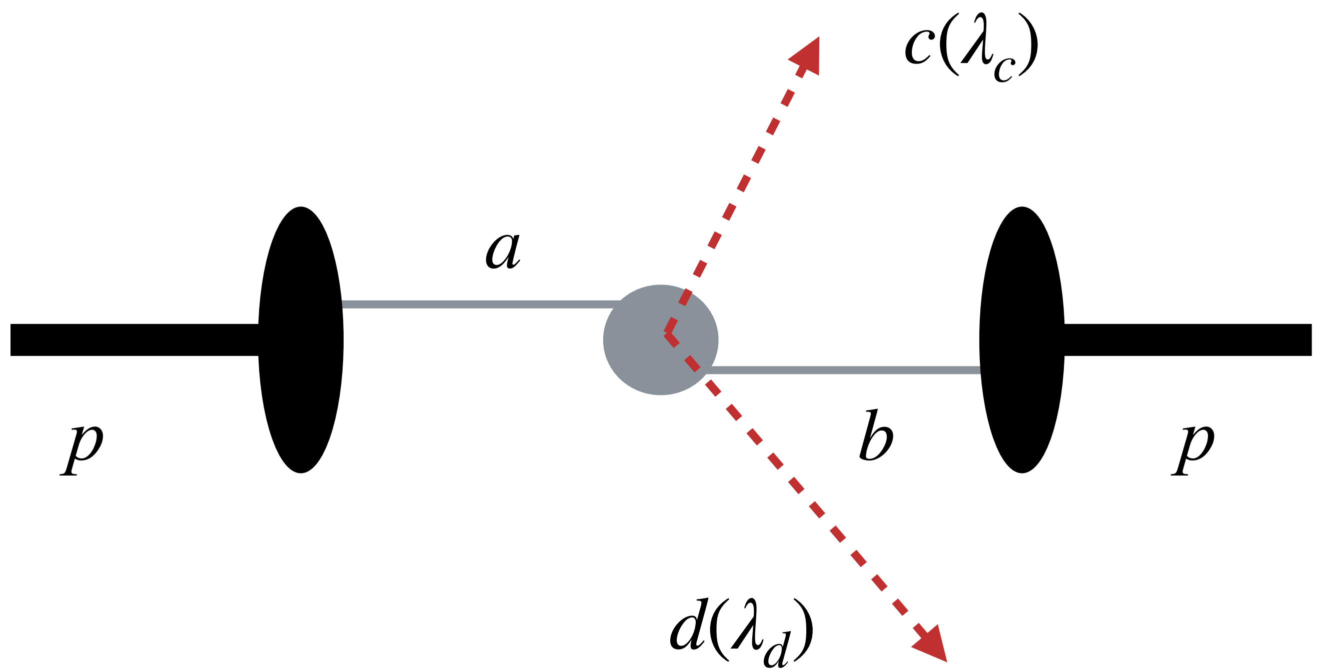
Applying to the unpolarized pp collisions

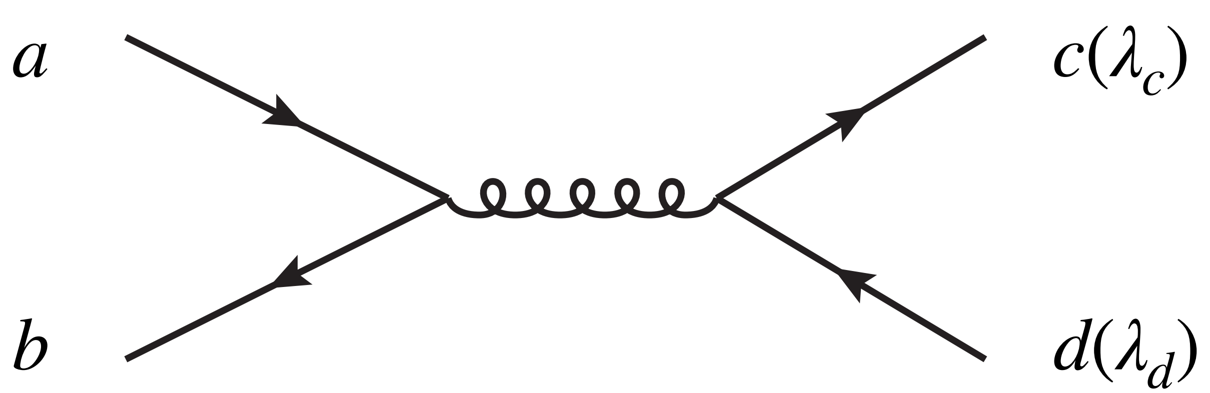


$$a + b \to c(\lambda_c) + d(\lambda_d)$$

☑ **Are λ_c and λ_d correlated?**

Yes!

"s-channel diagrams": just like e^+e^- annihilation, maximum correlation



$$g + g \to q + \bar{q}$$

$$q_i + \bar{q}_i \to q_j + \bar{q}_j$$

$$q + \bar{q} \to g + g$$

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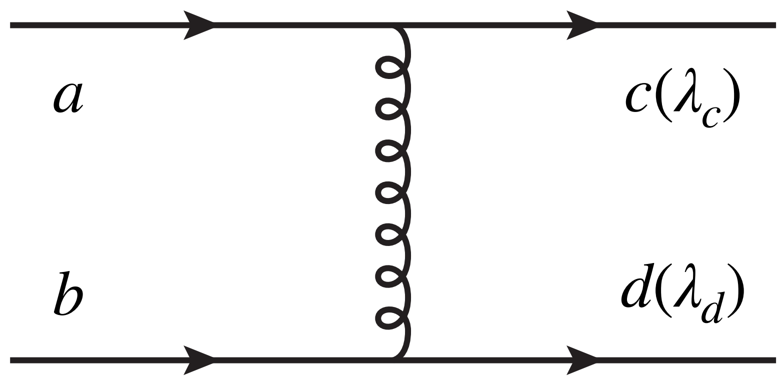
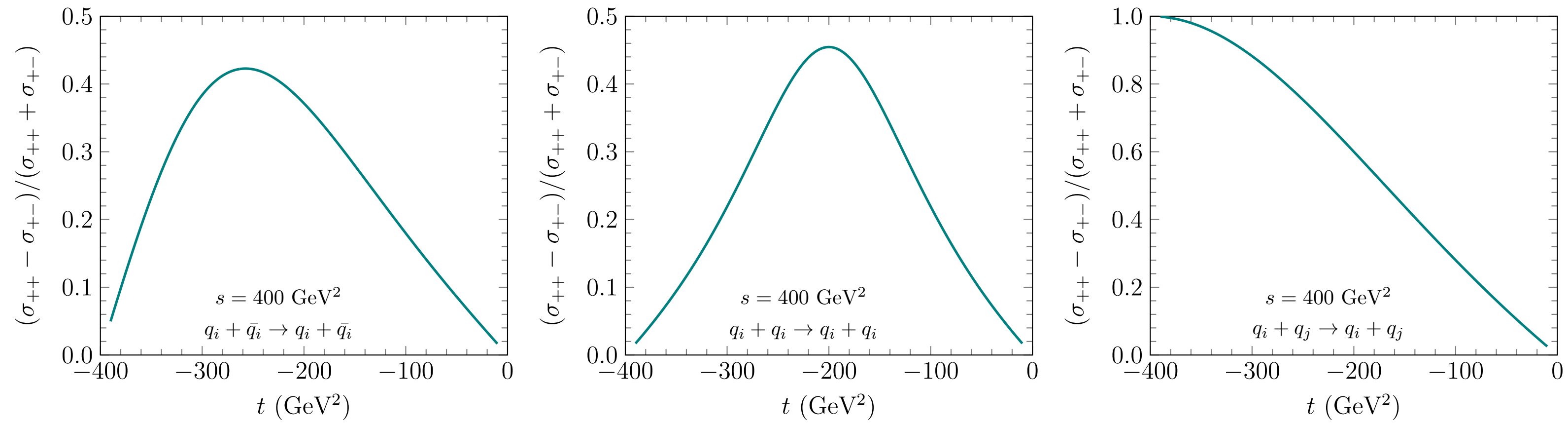
Dihadron helicity correlation

"t-channel diagrams": prefer same-sign correlation





To summarize

- "s-channel": $\sigma_{+-} = \sigma_{-+} > \sigma_{++} = \sigma_{--} = 0$
- "t-channel": $\sigma_{++} = \sigma_{--} > \sigma_{+-} = \sigma_{-+} > 0$
- Probe polarized FF in unpolarized pp collisions
- Explore the circularly polarized gluon FF

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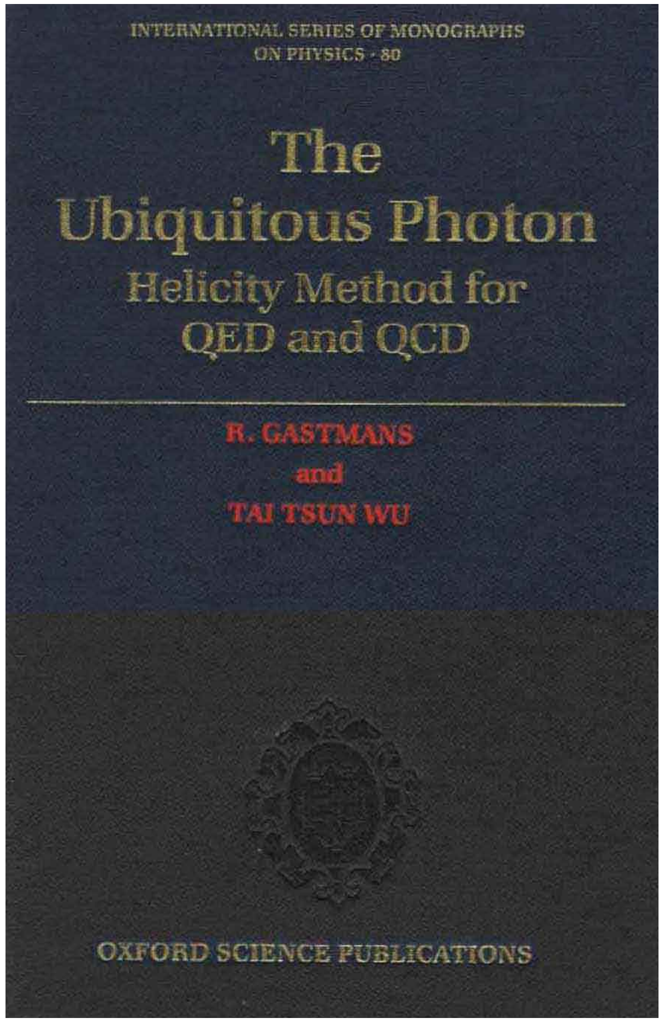
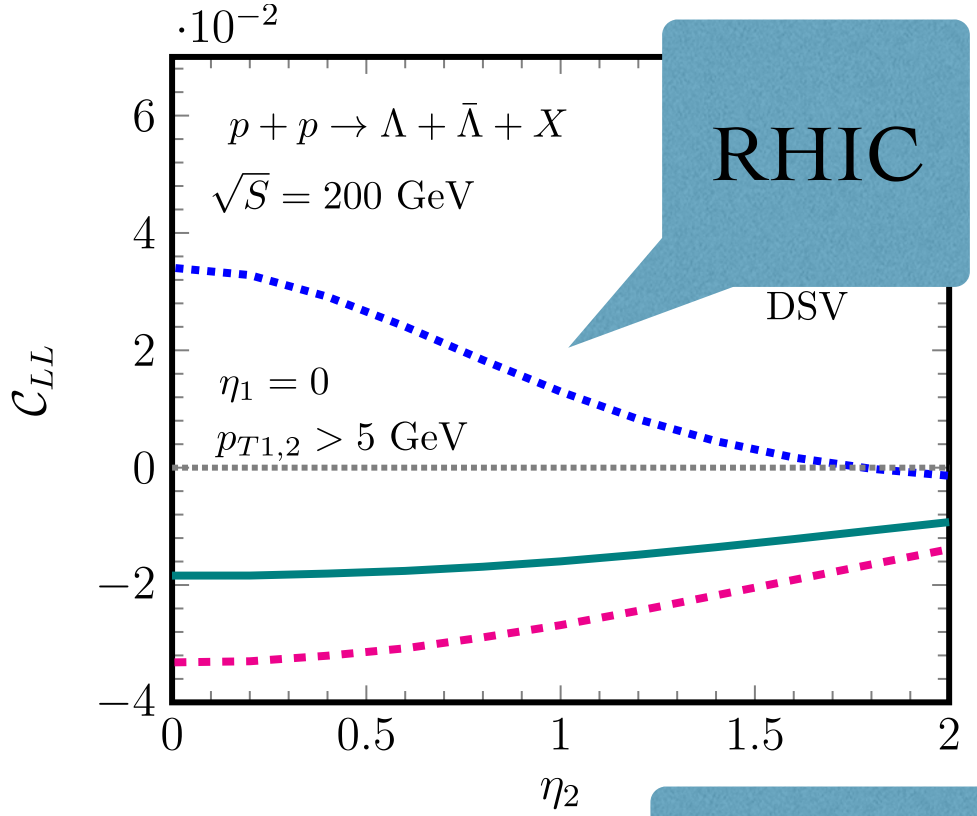
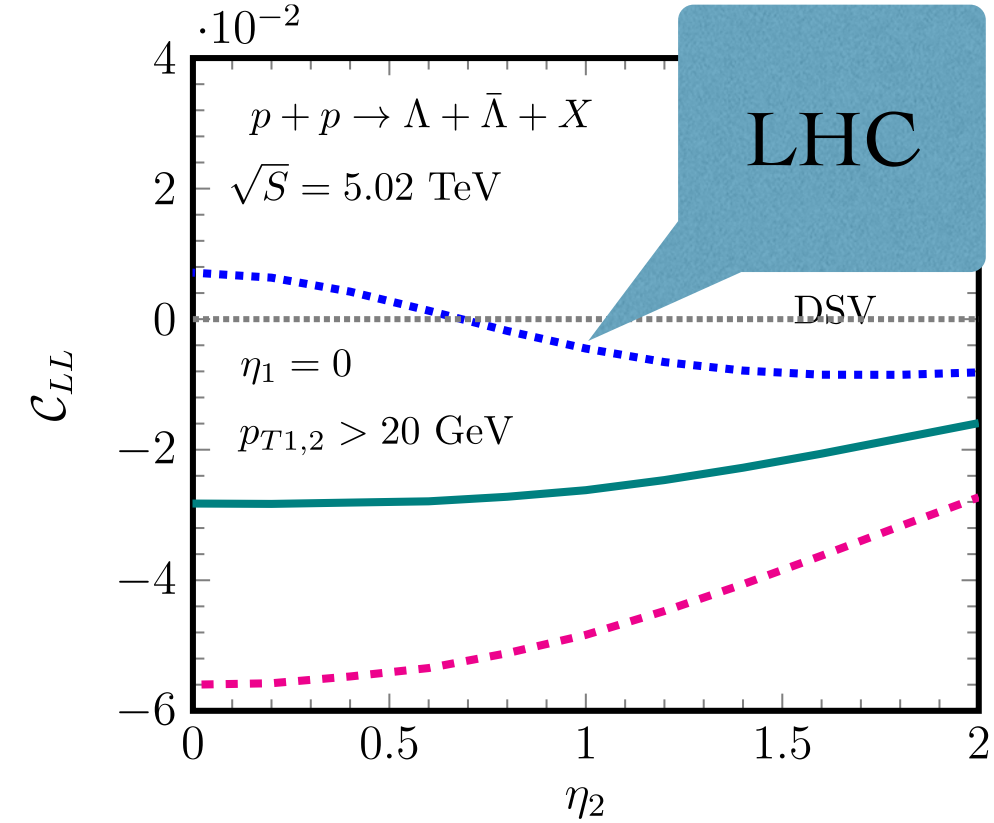
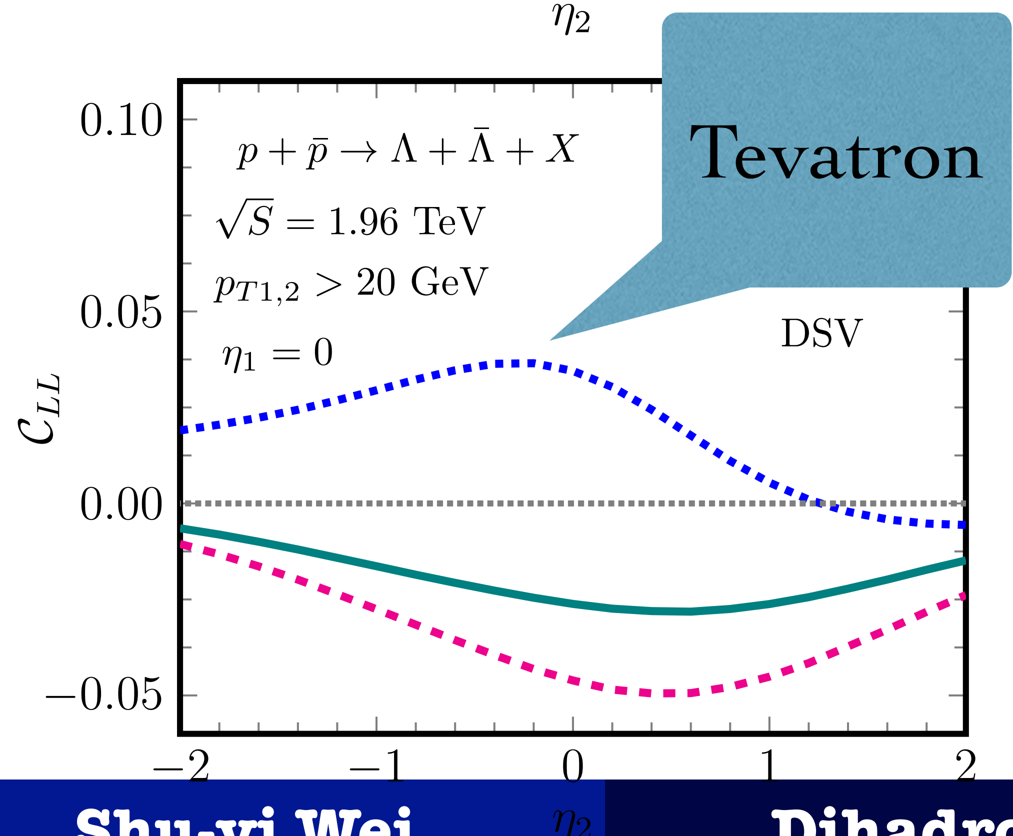


Helicity Amplitude Approach

Polarization Correlation in unpolarized pp collisions







- ☑ Smaller, but none-zero
- ☑ Distinguish different scenarios
- ☑ Avoid contamination of polarized PDF
- ☑ Probe gluon spin transfer

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Helicity Amplitude Approach

Helicity Correlation in central and peripheral AA collisions

$$\text{A toy model: } \left.\frac{d\sigma}{d\text{PS}}\right|_{AA} = \text{Energy Loss} \otimes \left.\frac{d\sigma}{d\text{PS}}\right|_{pp}$$

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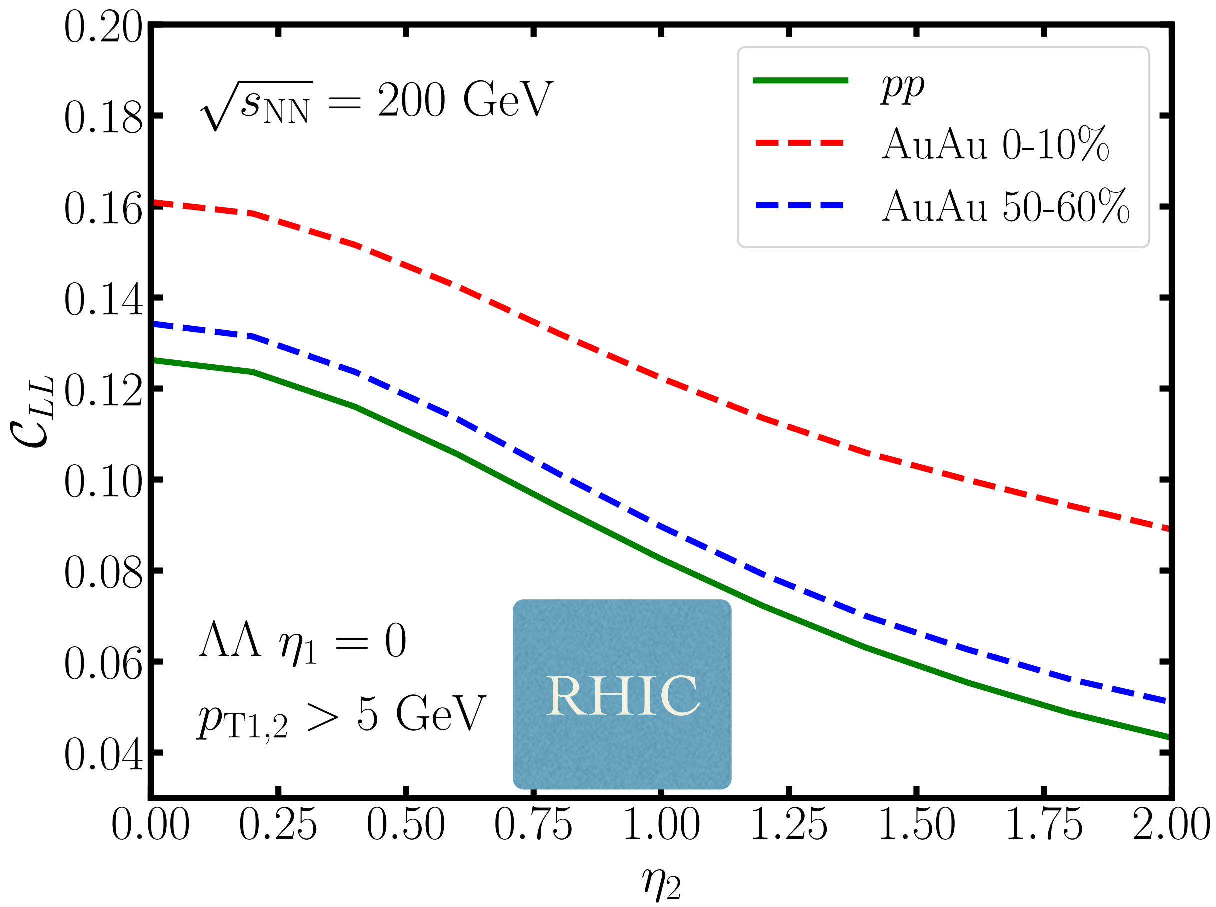
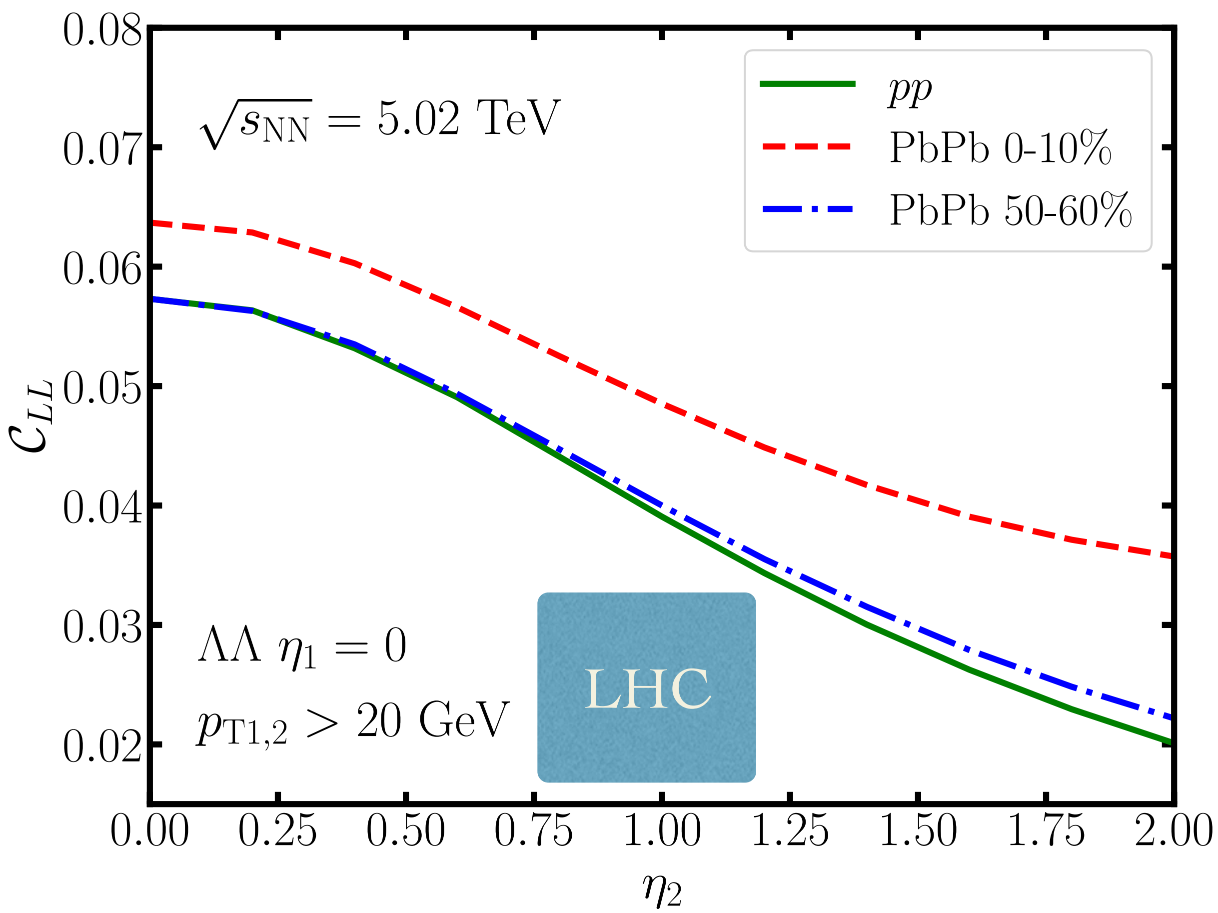
Phys.Rev.D 109, 014035 (2024)



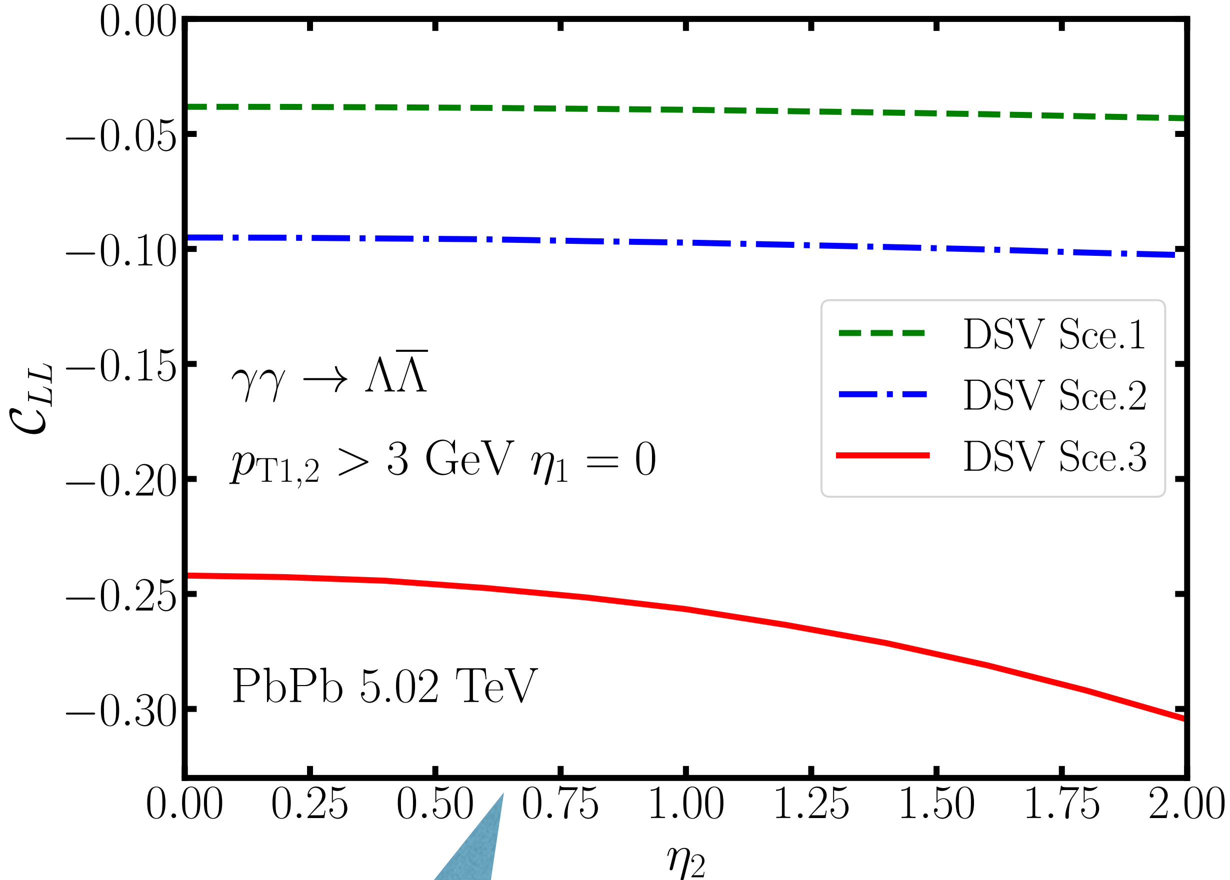
- ☑ Much larger luminosity
- ☑ Jet Quenching + Polarization



Clear Enhancement in central AA collisions

Prediction for the UPC and EIC

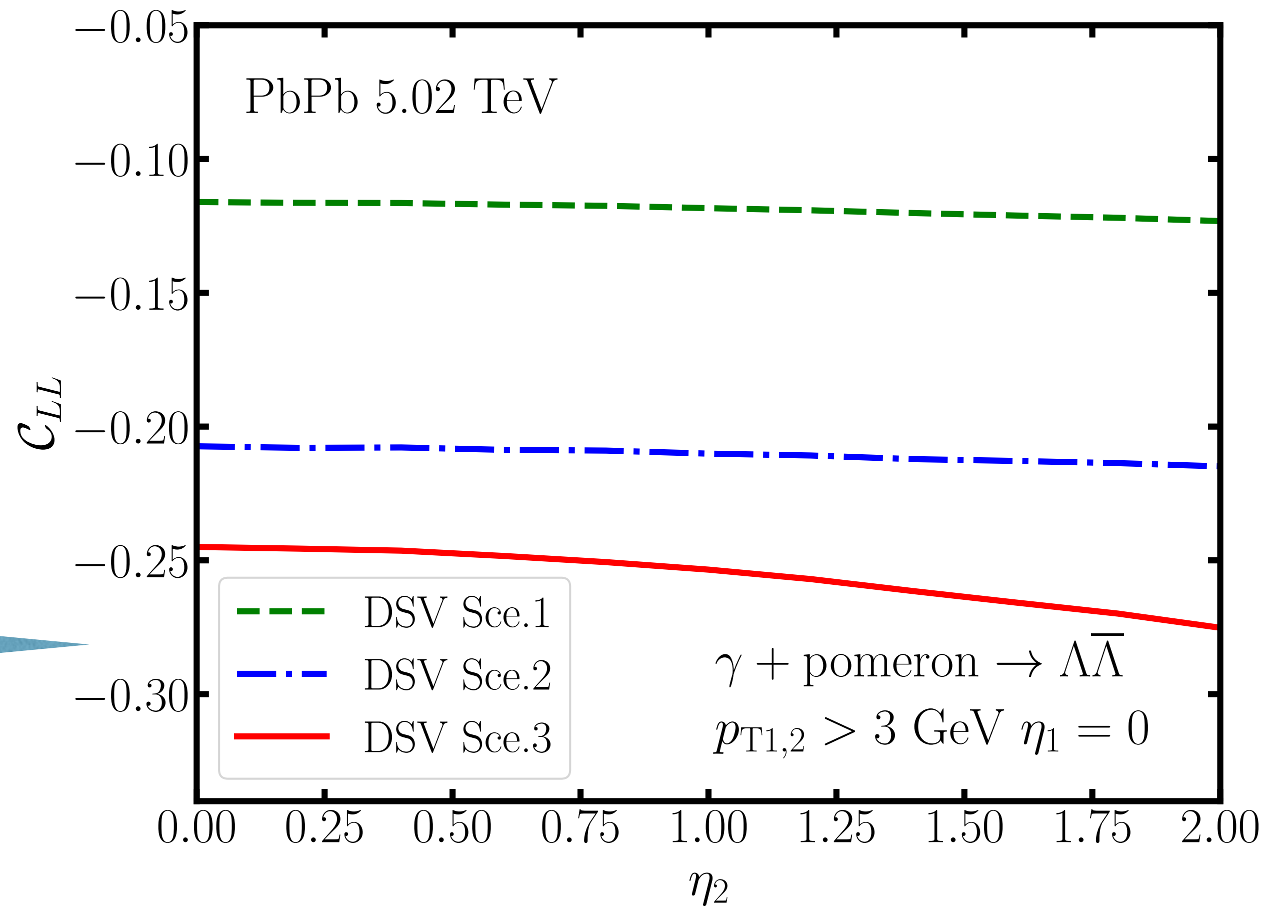
Helicity Correlation in ultra-peripheral AA collisions: Type I



$\gamma + \gamma$

- ☑ Much larger luminosity
- ☑ Pomeron + Polarization

$\gamma + \mathbb{P}$



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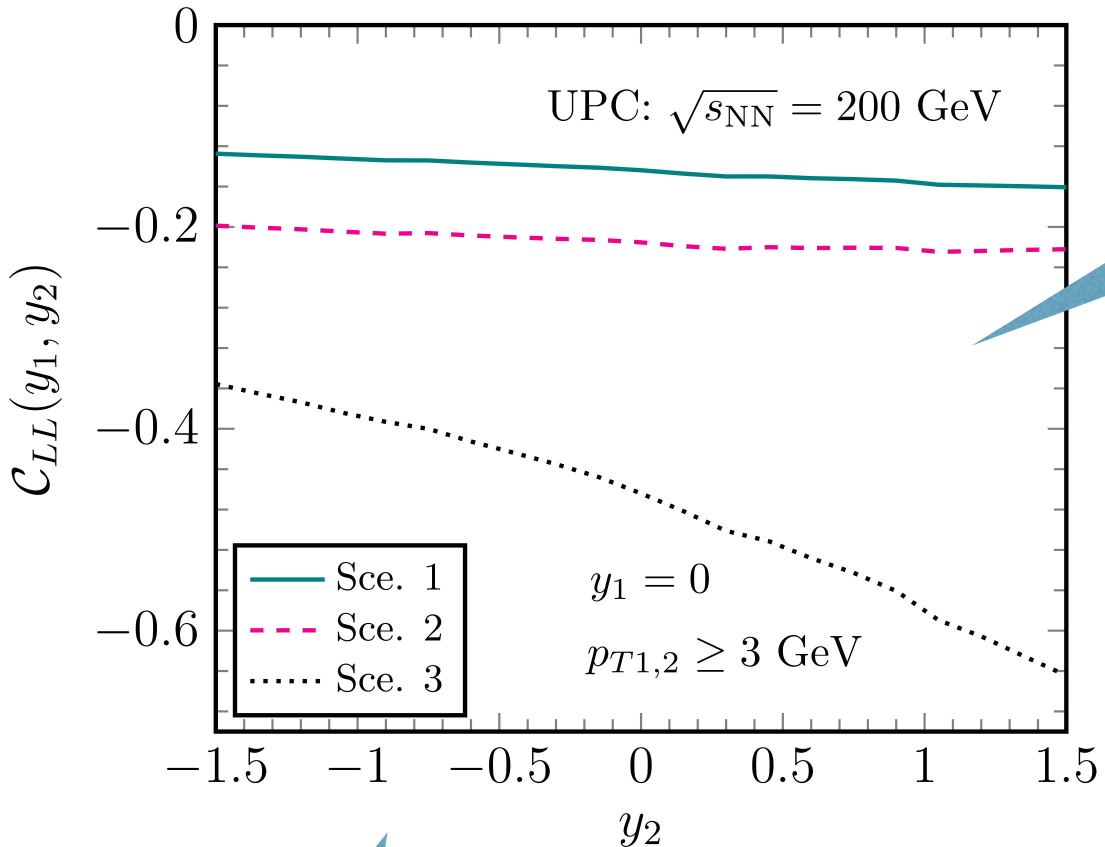
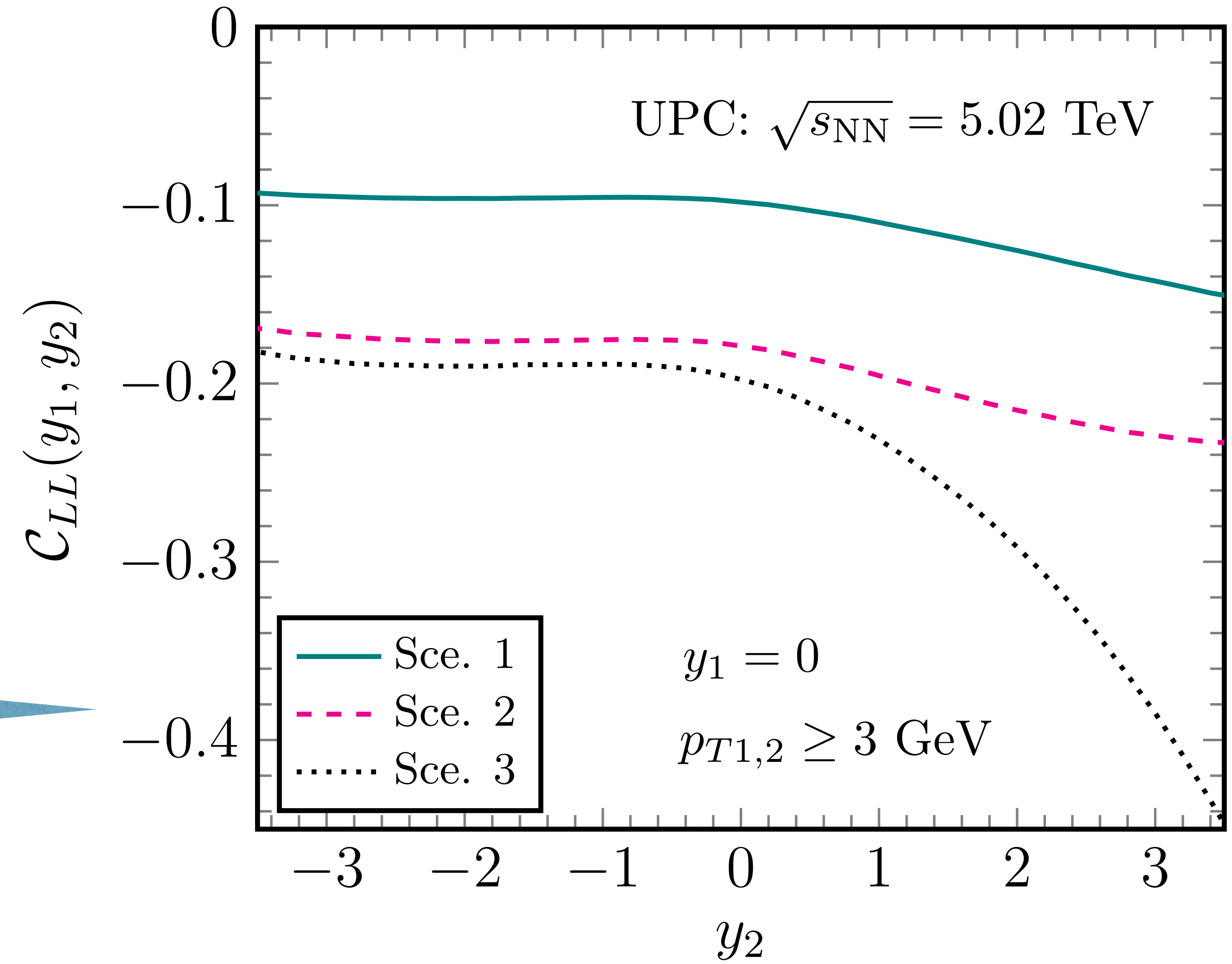
Helicity Correlation in ultra-peripheral AA collisions: Type II

RHIC



$\gamma + q$ or $\gamma + g$

LHC



$\gamma + q$ or $\gamma + g$

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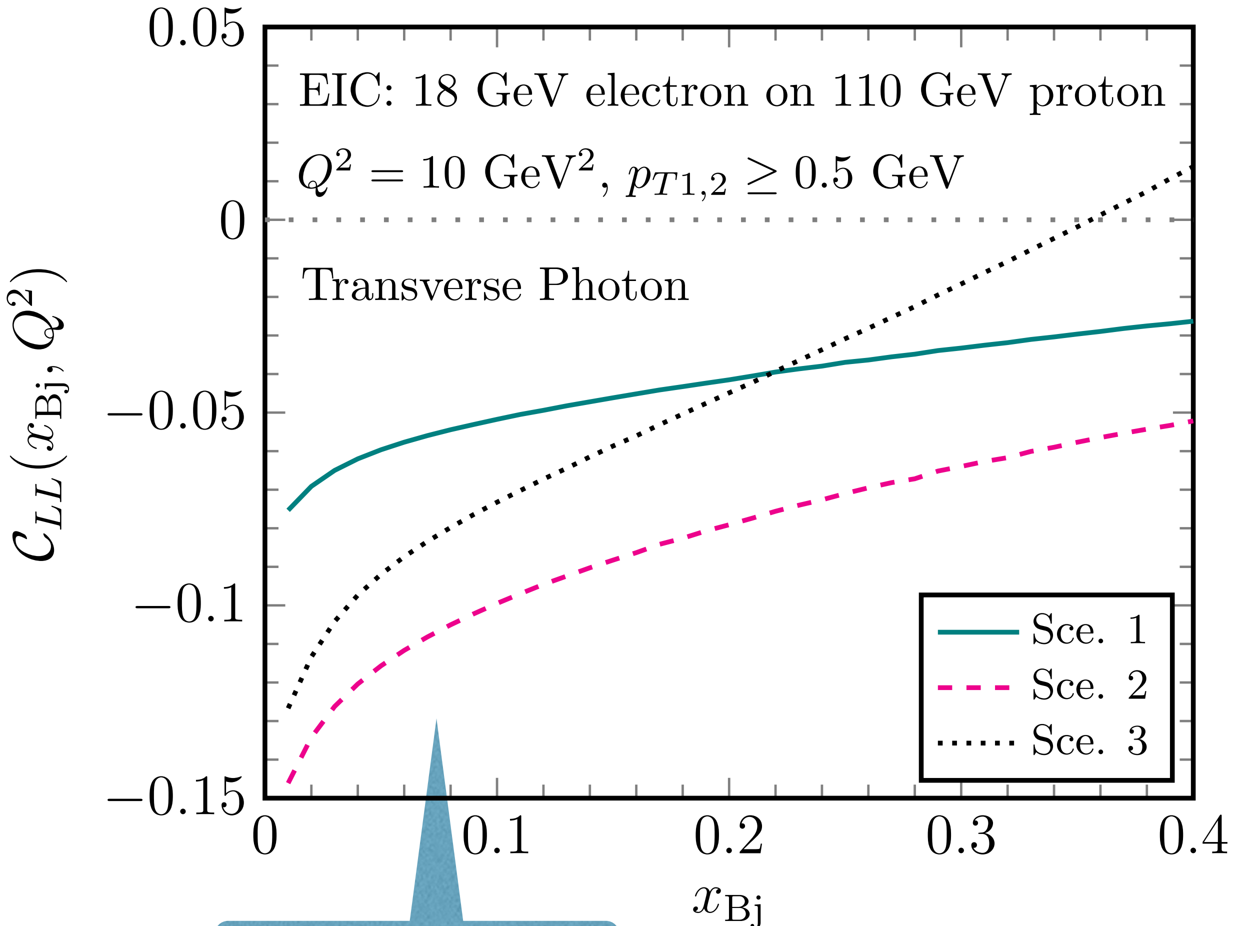
arXiv:2404.19202.

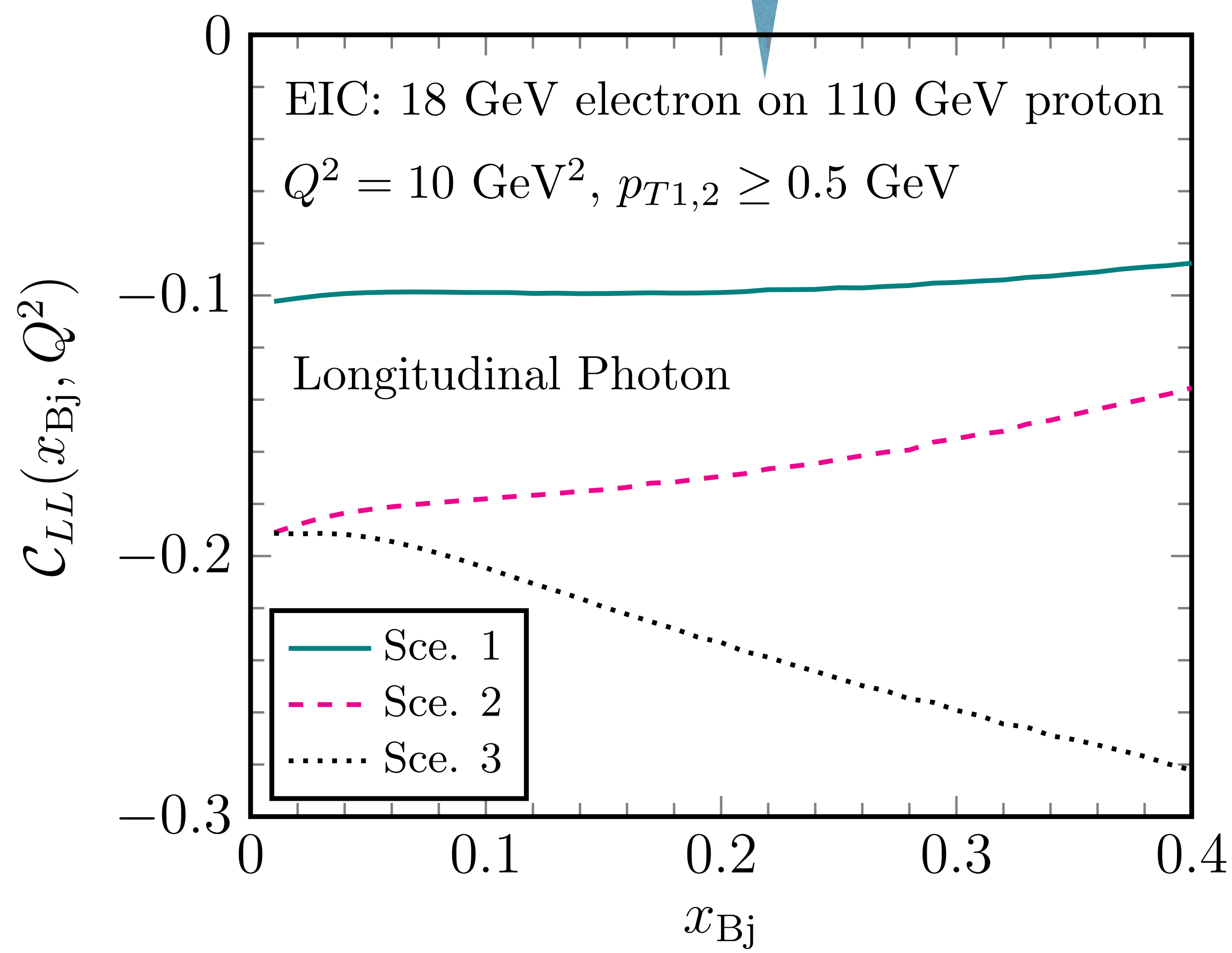
Helicity Correlation at future EIC

$\gamma^* + q$ or $\gamma^* + g$



Transverse photon

Longitudinal photon



Z.X. Chen, H. Dong, S.Y. Wei; **arXiv:2404.19202.**

Summary

- Spin effects can also be studied in unpolarized collisions.
- Dihadron helicity correlation in various high energy collisions offers a novel platform to investigate the flavor dependence of the G_{1L} fragmentation function.

Besides this talk, we also studied other spin effects in unpolarized collisions.

Phys.Lett.B 816, 136217 (2021).
Phys.Rev.D105, 034027 (2022).
Phys.Lett.B 850, 138509 (2024).
arXiv:2403.06133

Thanks for your attention!

The End

Backups