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Probing the polarized FF in unpolarized collisions

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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)

Contents

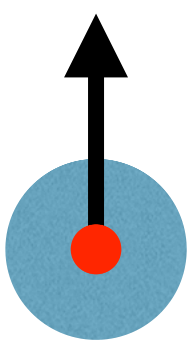
QCD factorization

partonic interaction, perturbative

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

non-perturbative, universal

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



$$\slashed{n}_+\left[f_1 - \frac{(\widehat{\boldsymbol{e}}_p \times \boldsymbol{k}_T)\cdot \boldsymbol{S}_\perp}{M} f_{1T}^\perp\right] + \gamma_5 \slashed{n}_+\left[\lambda g_{1L} + \frac{k_T \cdot S_\perp}{m} g_{1T}^\perp\right] +$$
$$\frac{i[\slashed{k}_T,\slashed{n}_+]}{2m} h_1^\perp + \frac{1}{2}[\slashed{S}_\perp,\slashed{n}_+]\gamma_5 h_{1T} + \frac{[\slashed{k}_T,\slashed{n}_+]\gamma_5}{2m}\left[\lambda h_{1L}^\perp + \frac{k_T\cdot S_\perp}{m} h_{1T}^\perp\right]$$

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

$$\slashed{n}_-\left[D_1 + \frac{(\widehat{\boldsymbol{e}}_j \times \boldsymbol{p}_T)\cdot \boldsymbol{S}_\perp}{zM} D_{1T}^\perp\right] + \gamma_5 \slashed{n}_-\left[\lambda G_{1L} + \frac{p_T \cdot S_\perp}{zM} G_{1T}^\perp\right] +$$
$$\frac{i[\slashed{p}_T,\slashed{n}_-]}{2M} H_1^\perp + \frac{1}{2}[\slashed{S}_\perp,\slashed{n}_-]\gamma_5 H_{1T} + \frac{[\slashed{p}_T,\slashed{n}_-]\gamma_5}{2M}\left[\lambda H_{1L}^\perp + \frac{p_T\cdot S_\perp}{M} H_{1T}^\perp\right]$$

QCD factorization

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

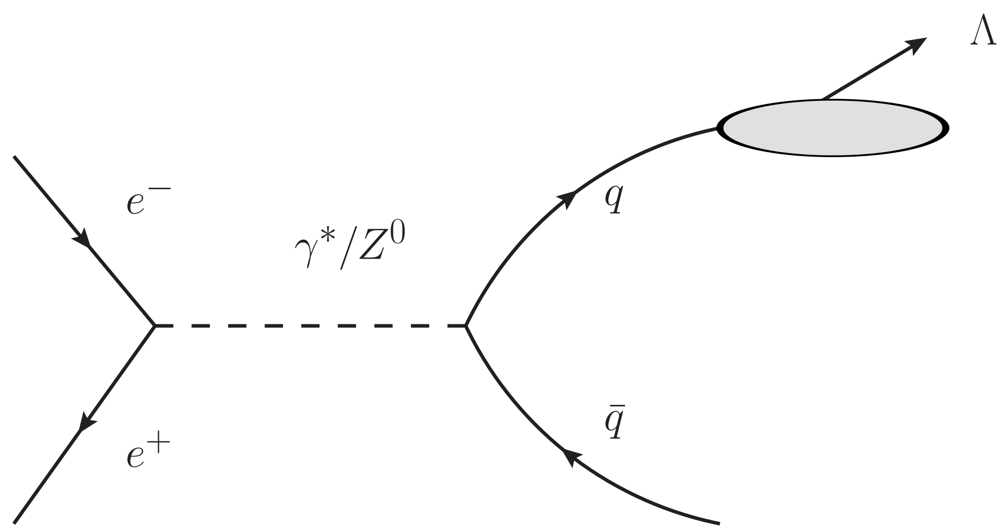
polarized beams
or
weak interaction

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

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

Introduction

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

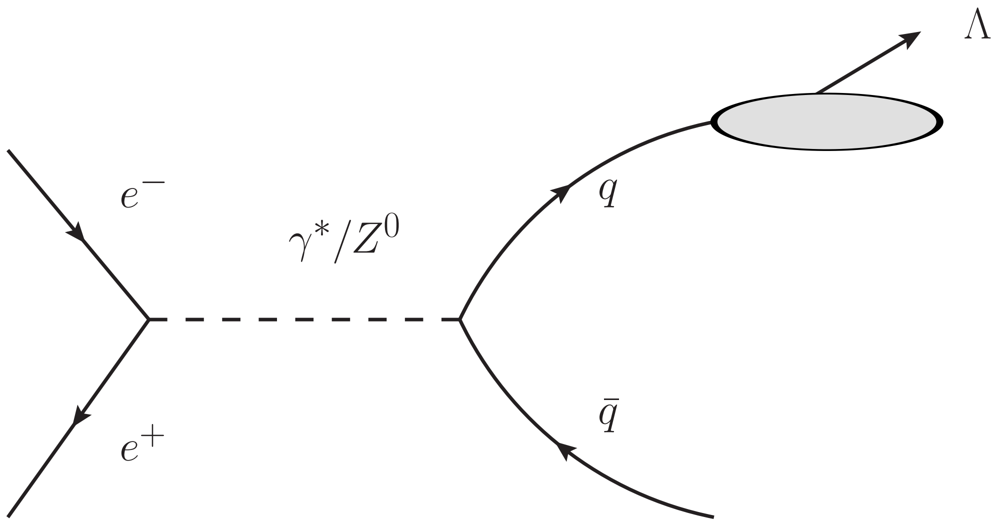
LEP Energy

spin transfer

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

quark polarization

Single Inclusive Λ Production in e⁺e⁻ Annihilation Experiment



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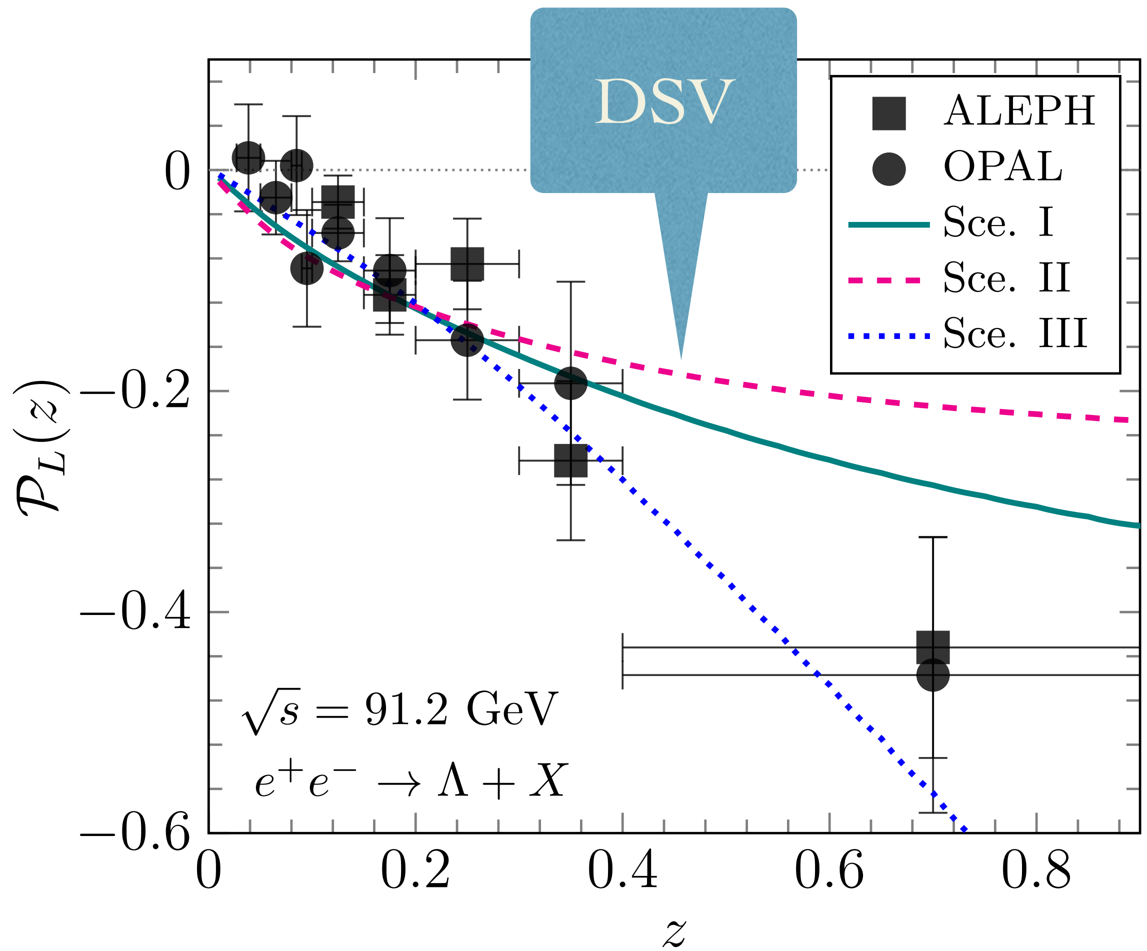
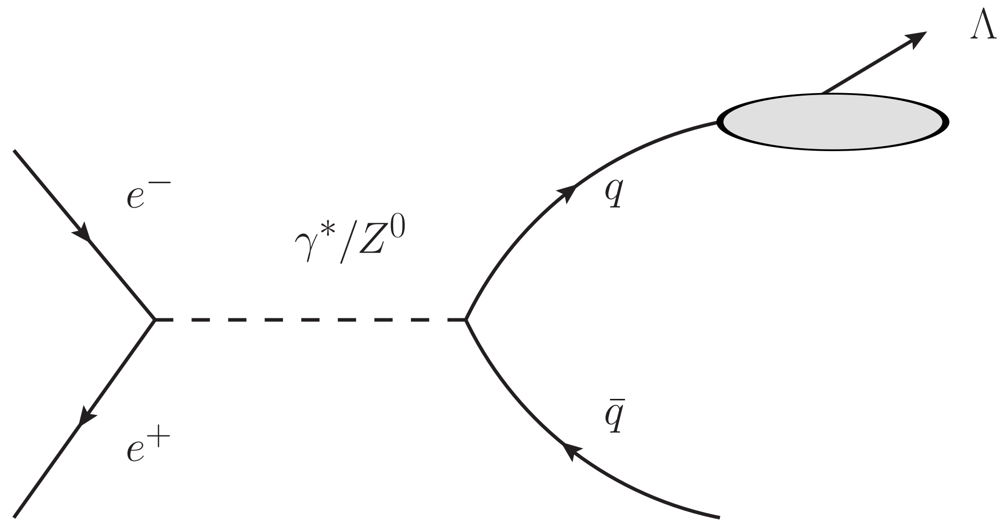


Single Inclusive Λ Production in e⁺e⁻ Annihilation Experiment



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Belle Energy

LEP Energy

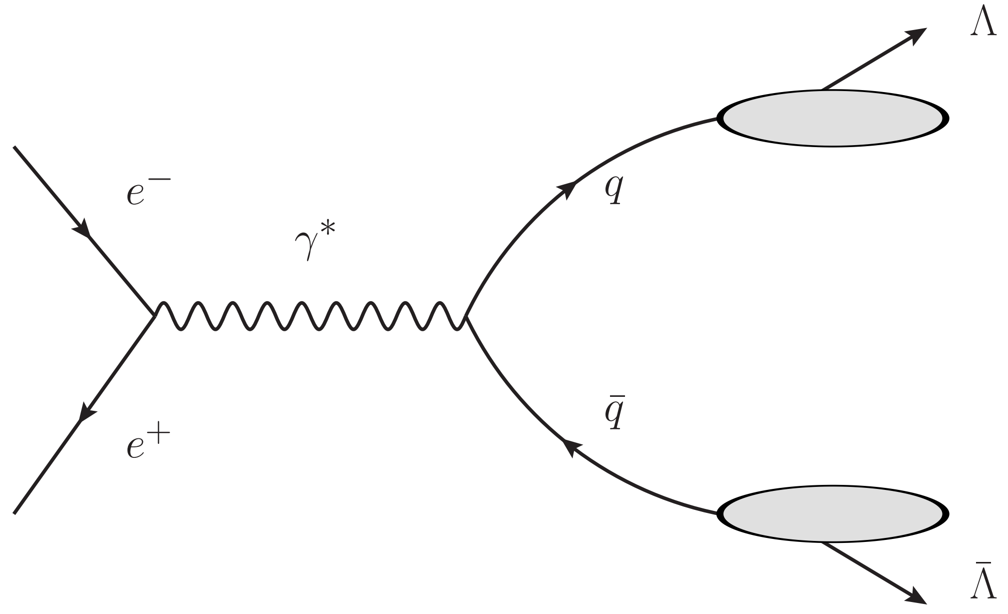
spin transfer

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

quark polarization

Introduction

$\Lambda\bar{\Lambda}$-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**

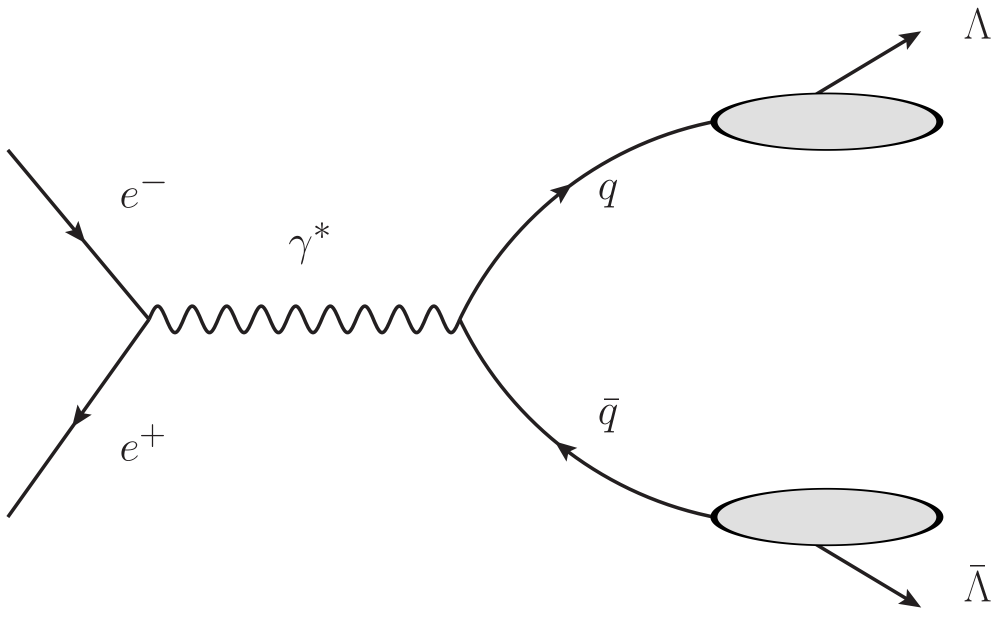
q and $\bar{q}$ are on the same fermion line. They must have opposite helicities.

☑ **Polarization Correlation**

A novel probe to the spin-dependent fragmentation functions

H.C. Zhang, SYW; PLB 839 (2023) 137821
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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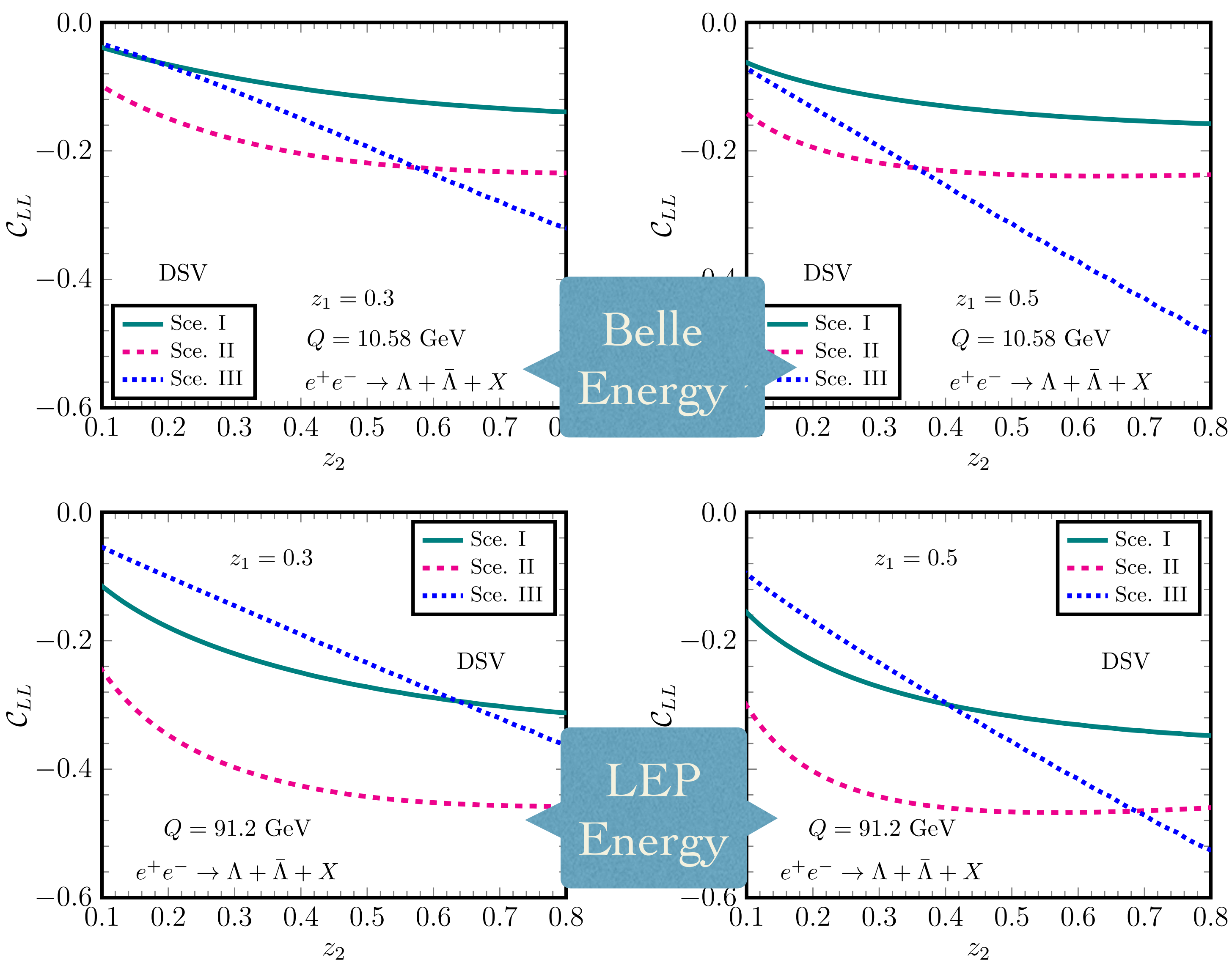
see also Nucl. Phys. B 445 (1995) 380.

Helicity Amplitude Approach

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

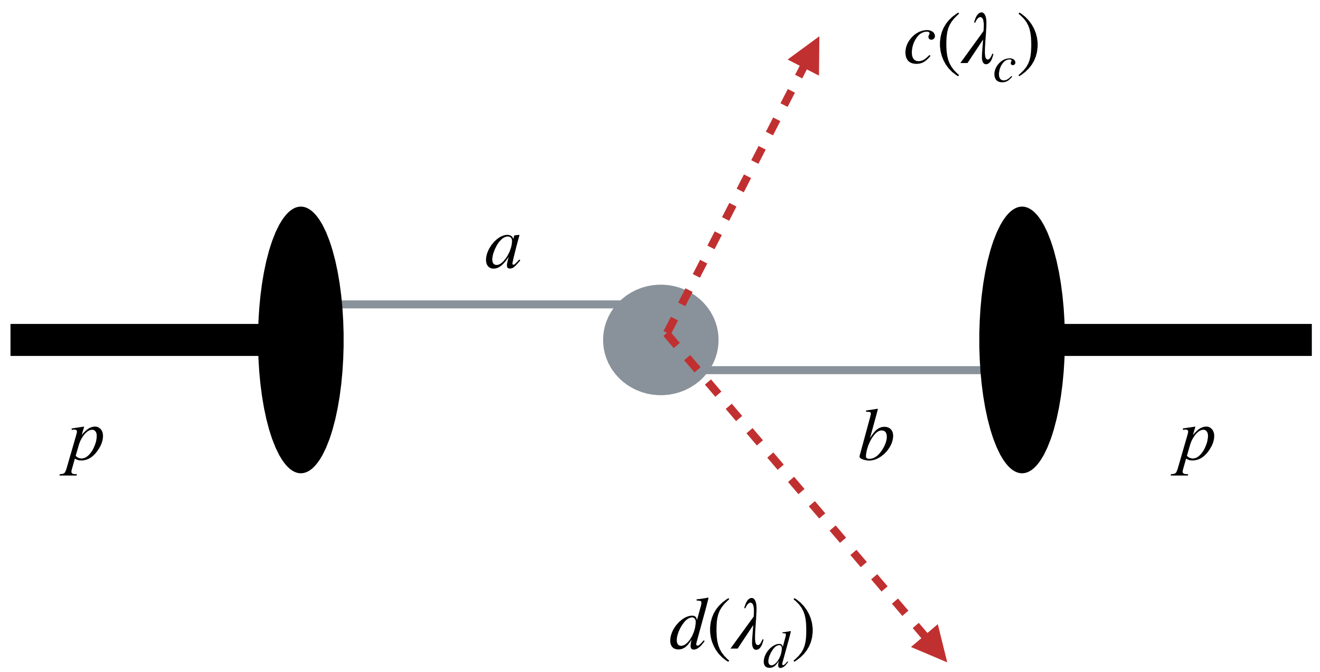
$$C_{LL} = \frac{\text{same signs} - \text{opposite signs}}{\text{total cross section}} = \frac{\sum_q \sigma_0 G_{1Lq}^{\Lambda}(z_1) G_{1L\bar{q}}^{\bar{\Lambda}}(z_2)}{\sum_q \sigma_0 D_{1q}^{\Lambda}(z_1) D_{1\bar{q}}^{\bar{\Lambda}}(z_2)} \propto \langle \cos\theta_1^* \cos\theta_2^* \rangle$$



- ☑ The polarization 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.

Helicity Amplitude Approach

Applying to the unpolarized pp collisions

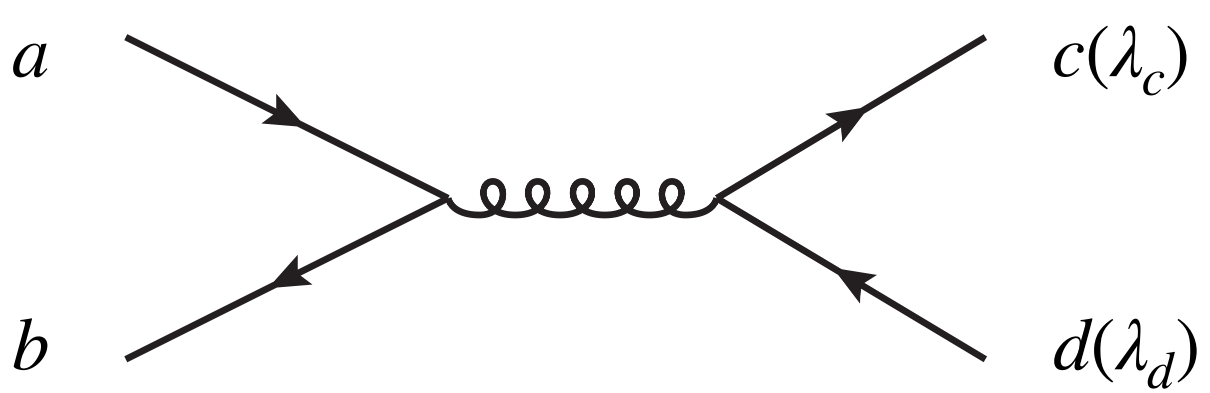


$$a + b \to c(\lambda_c) + d(\lambda_d)$$

☑ **Are λ_c and λ_d correlated?**

Yes!

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

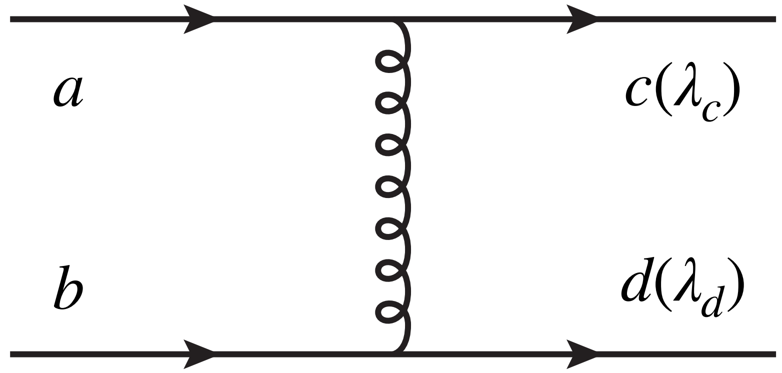


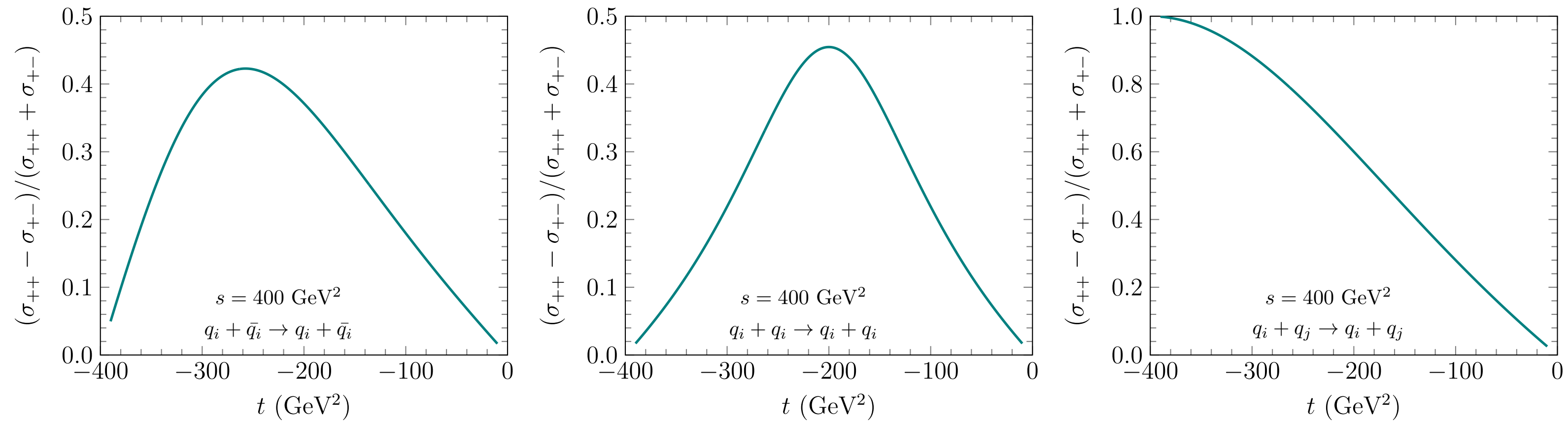
$$g + g \to q + \bar{q}$$

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

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

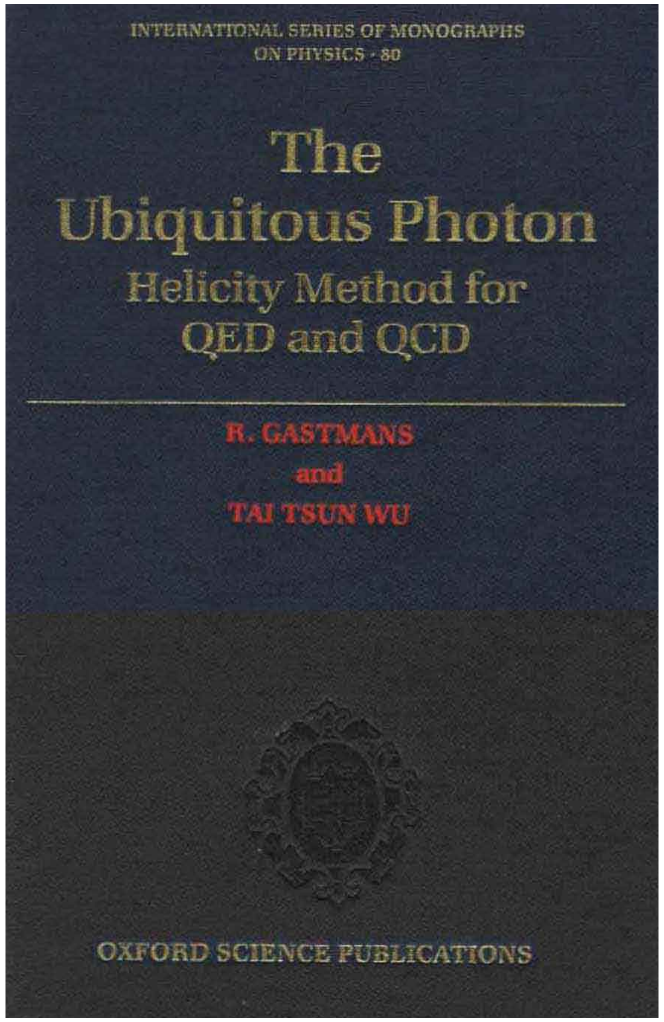
"t-channel diagrams": prefer same-sign correlation



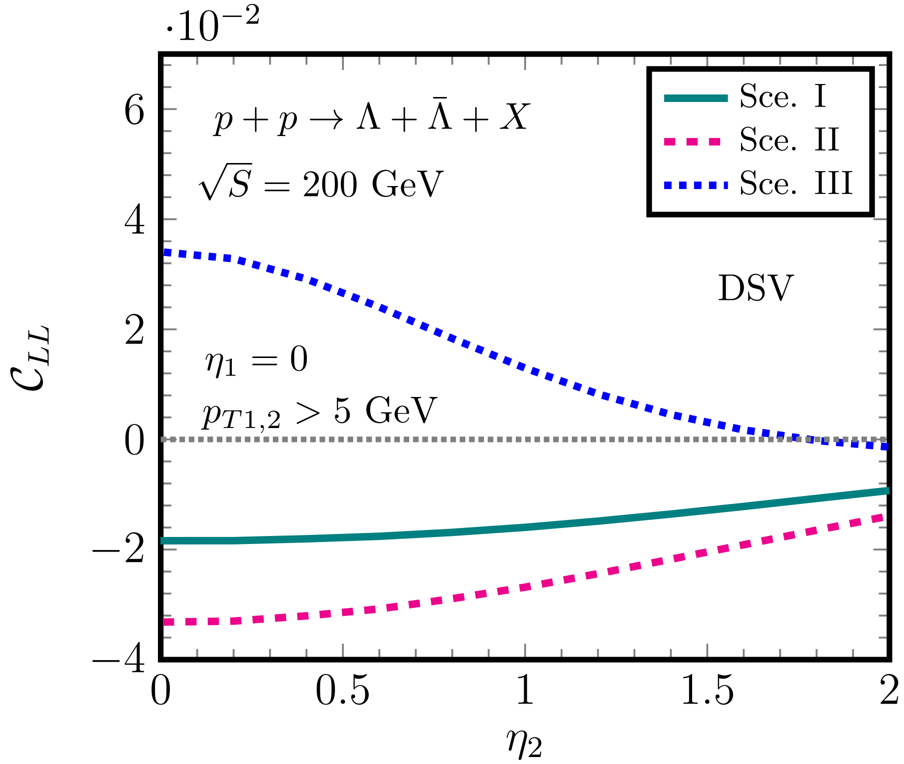


To summarize

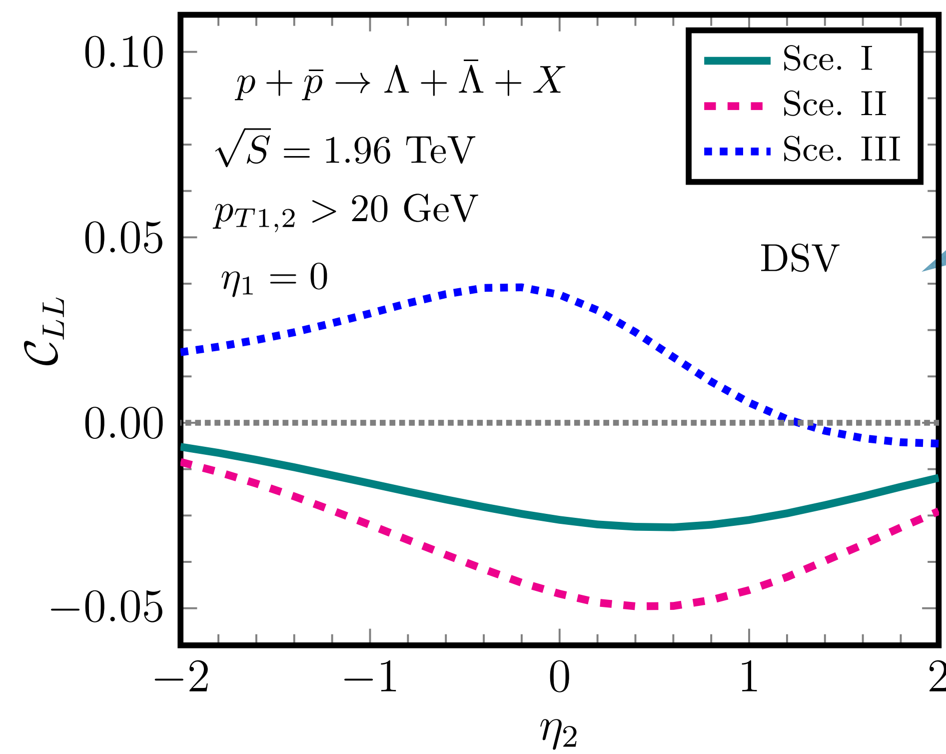
- ☑ "s-channel": $\sigma_{+-} = \sigma_{-+} > \sigma_{++} = \sigma_{--} = 0$
- ☑ "t-channel": $\sigma_{++} = \sigma_{--} > \sigma_{+-} = \sigma_{-+} > 0$
- ☑ Probe polarized FF in unpolarized pp collisions
- ☑ Explore the circularly polarized gluon FF



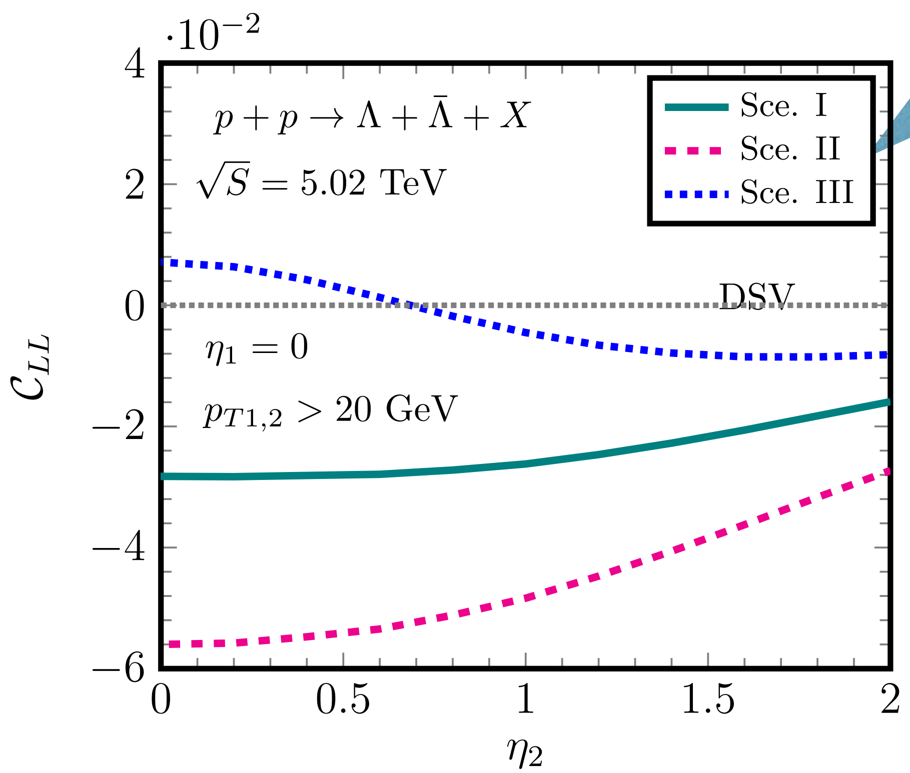
Polarization Correlation in unpolarized pp collisions



RHIC



Tevatron

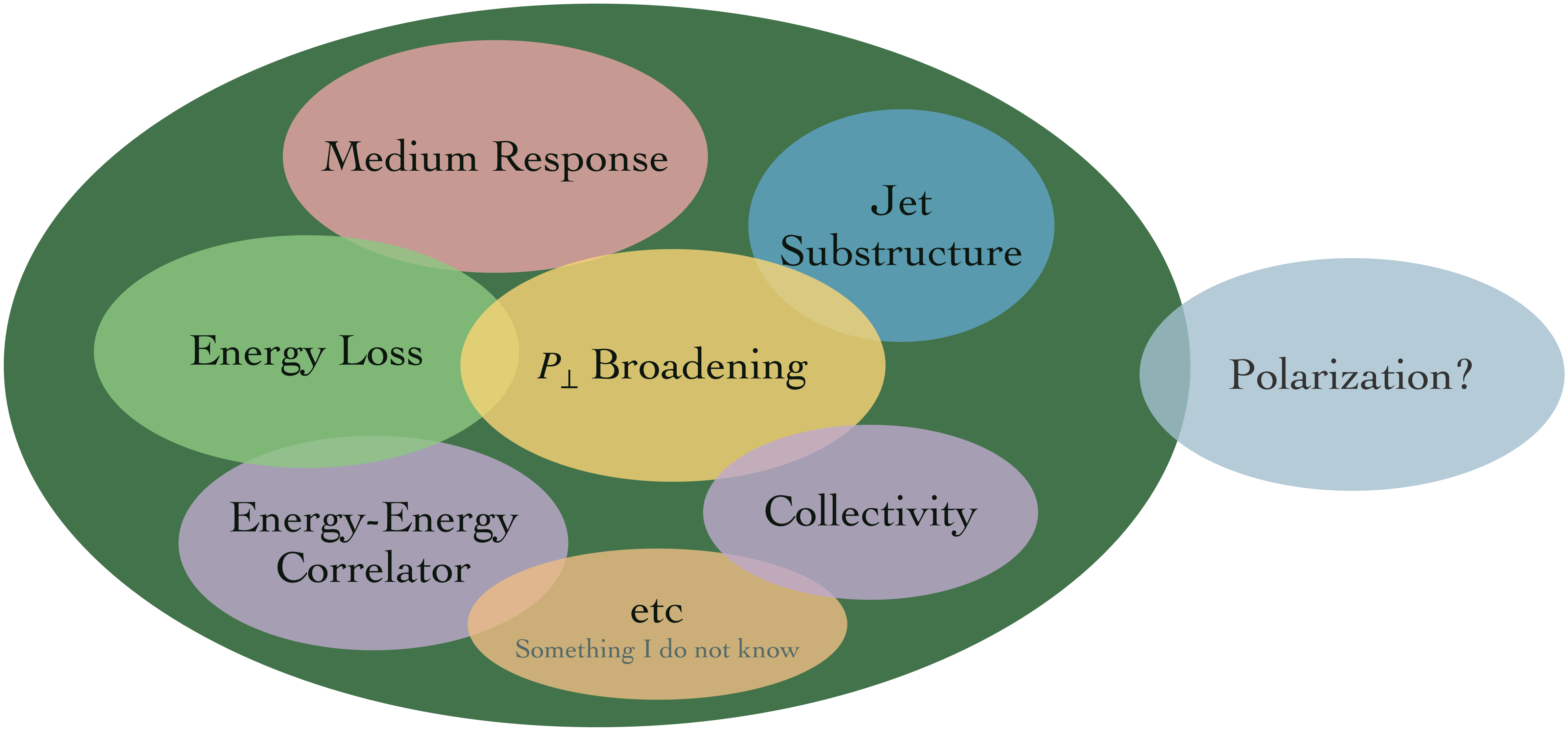


LHC

Equipped with longitudinal polarization correlation of dihadron, we can explore polarized fragmentation function (G_{1L}) in unpolarized pp collisions.

Fragmentation of circularly polarized gluons

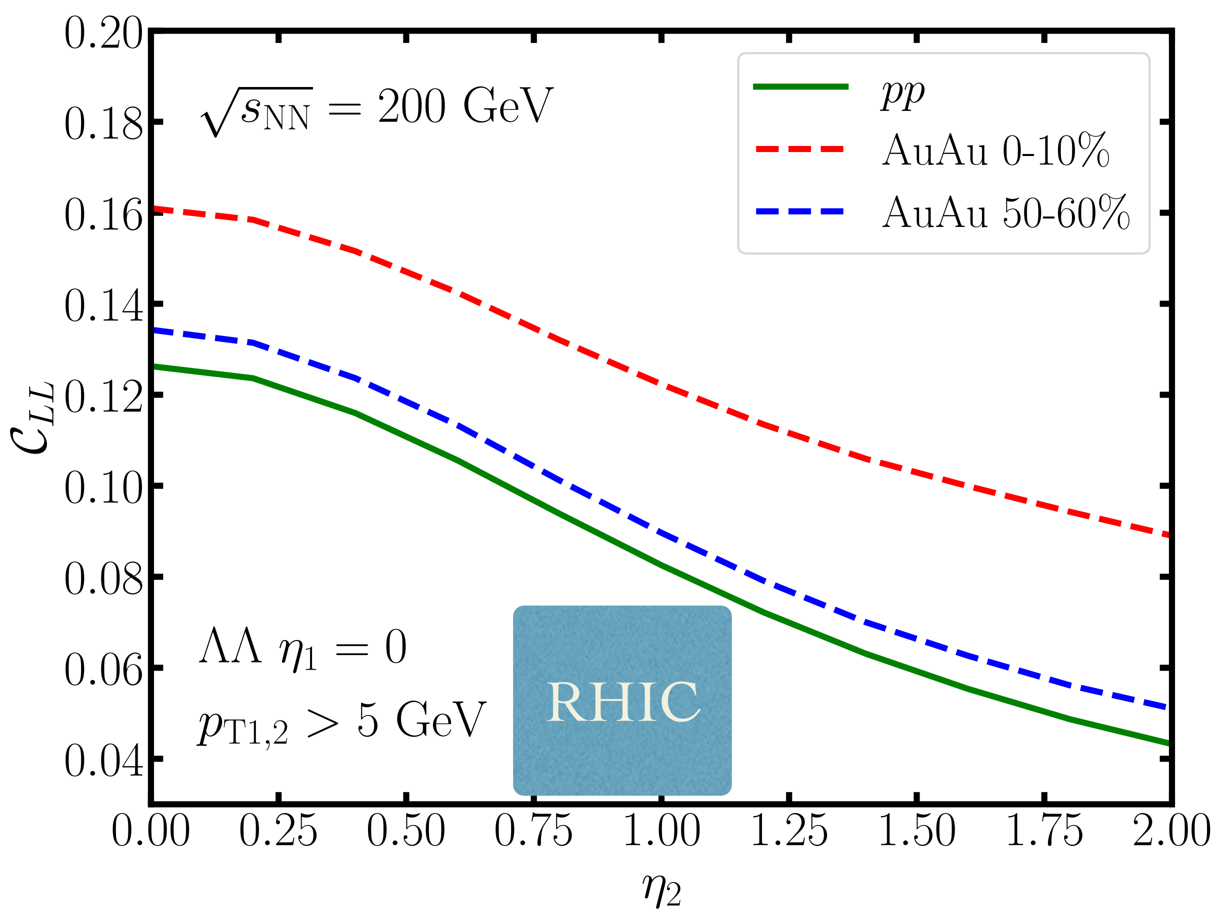
Keywords of Jet Quenching



Unpolarized Beams
+
Strong Interaction → Unpolarized Jets

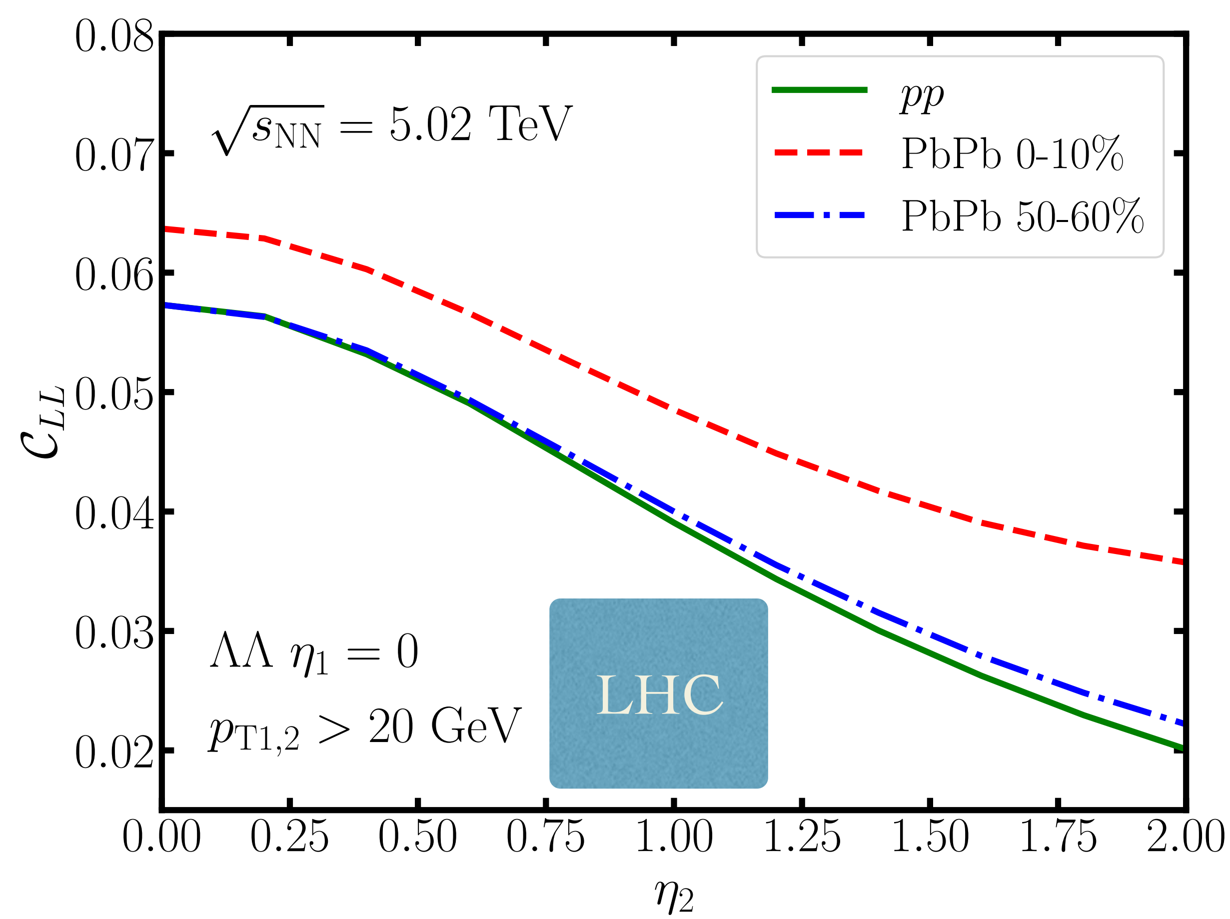
Polarization Correlation in central and peripheral AA collisions

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



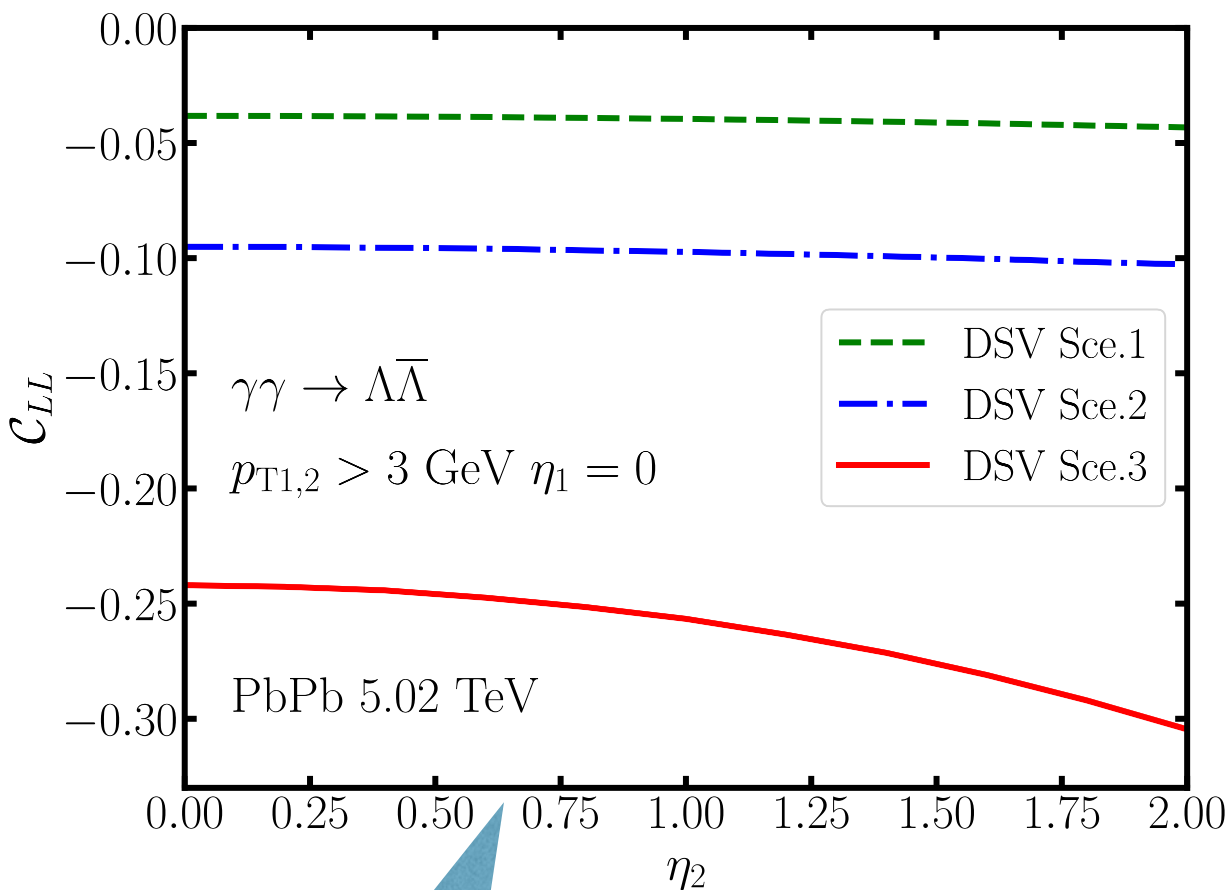
Clear Enhancement in central AA collisions

- ☑ Much larger luminosity
- ☑ Jet Quenching + Polarization



Polarization and Jet Quenching

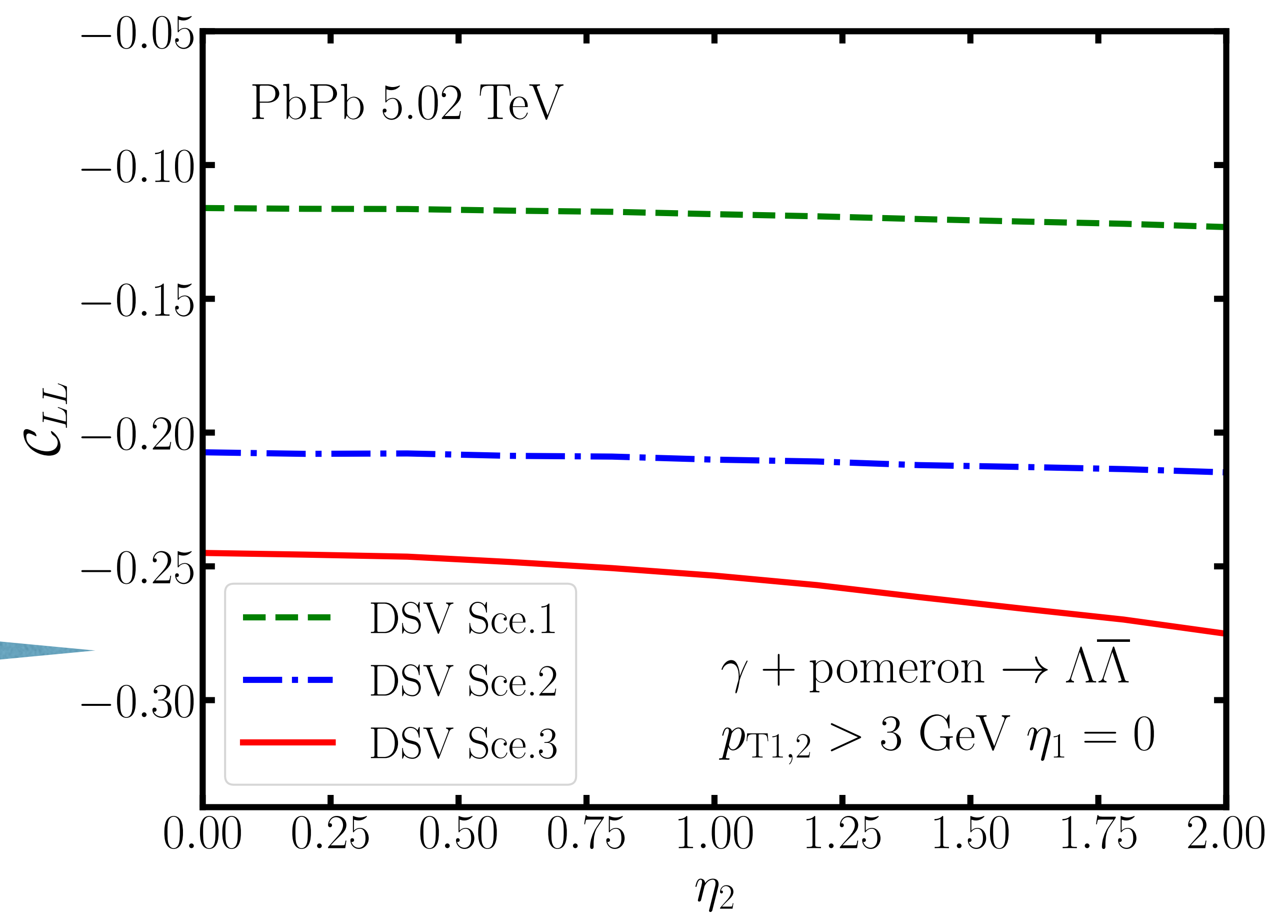
Polarization Correlation in ultra-peripheral AA collisions



$\gamma + \gamma$

- ☑ Much larger luminosity
- ☑ Pomeron + Polarization

$\gamma + \mathbb{P}$



Summary and Outlook

- ☑ Spin effects can also be studied in unpolarized collisions.
- ☑ The combination of hadron polarization and jet quenching offers a new platform to study the jet medium interaction.

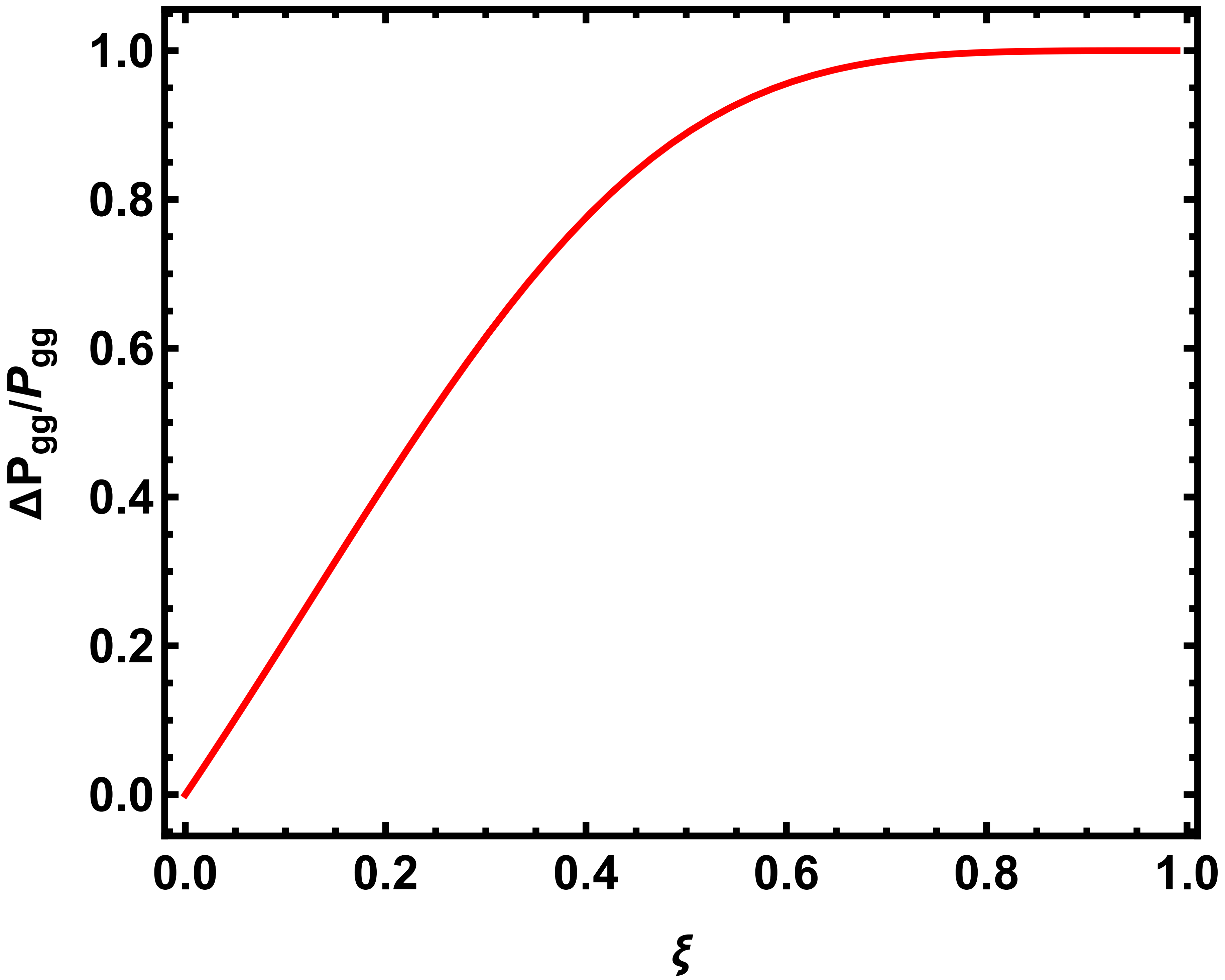
Besides this talk, we also studied other spin effects in unpolarized collisions.

Phys.Lett.B 816, 136217 (2021).

Phys.Rev.D105, 034027 (2022).

MERCI!

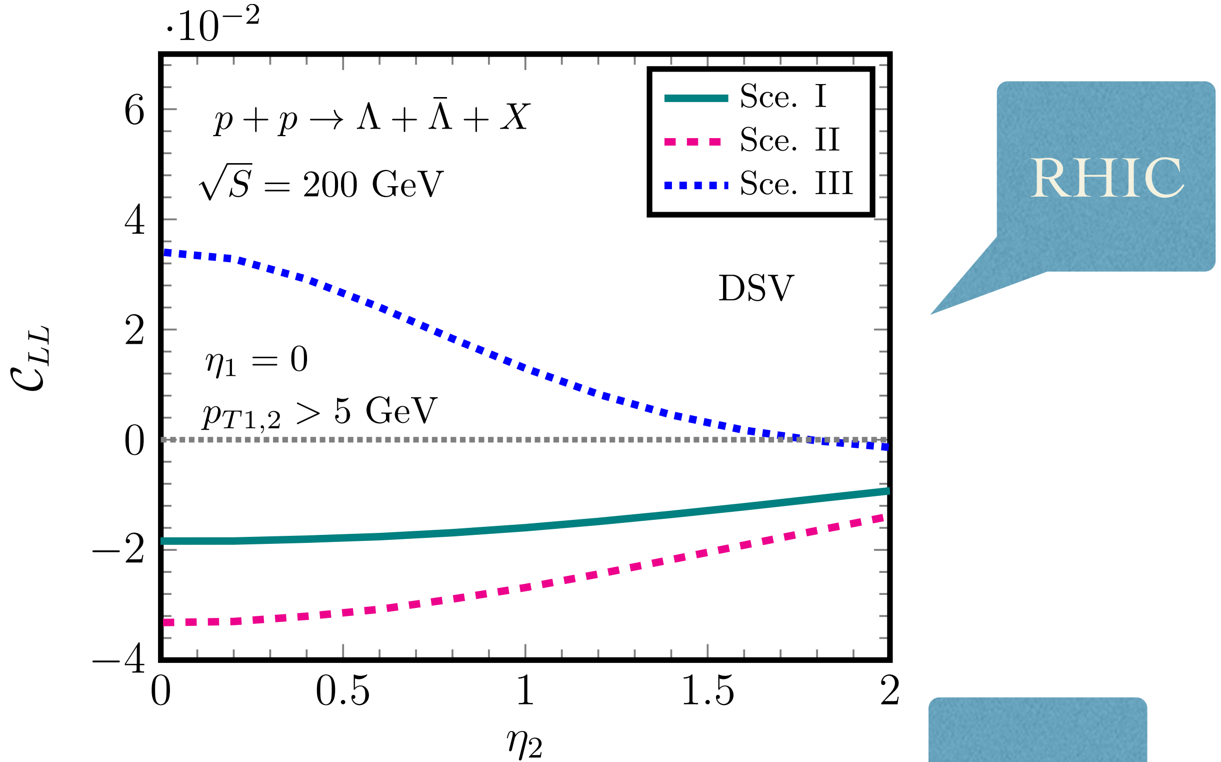
The End

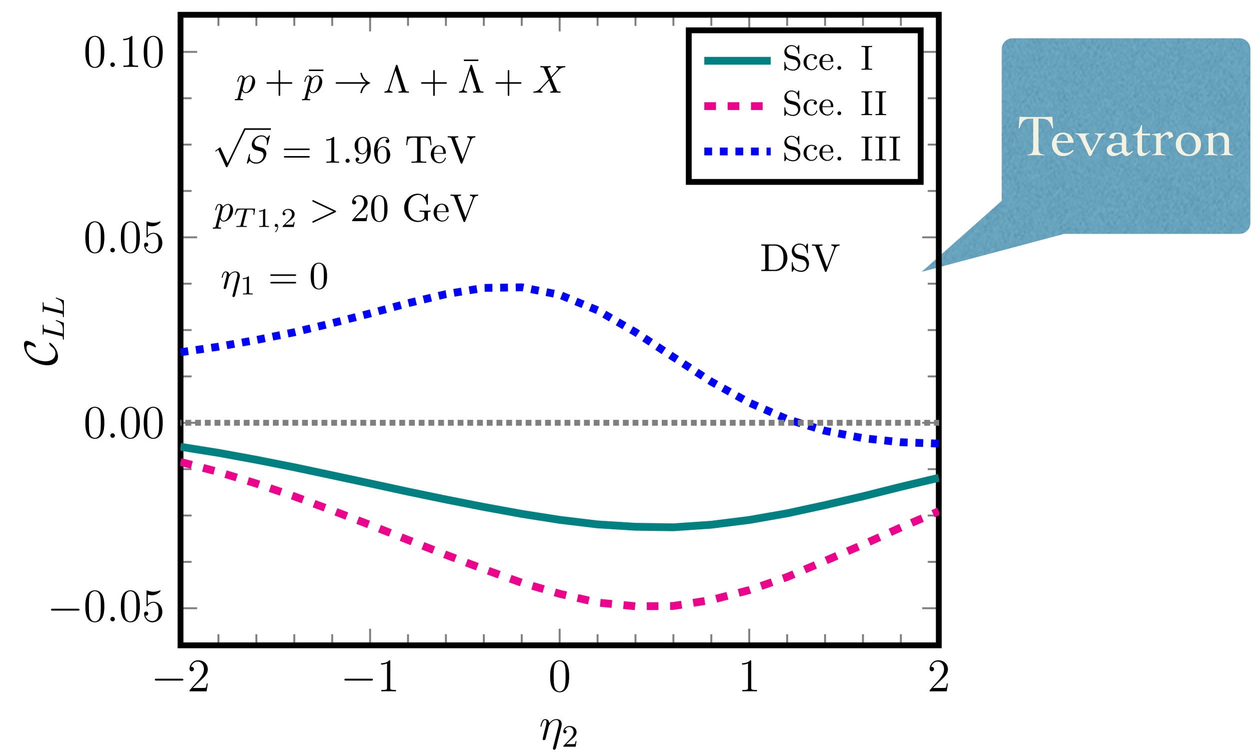


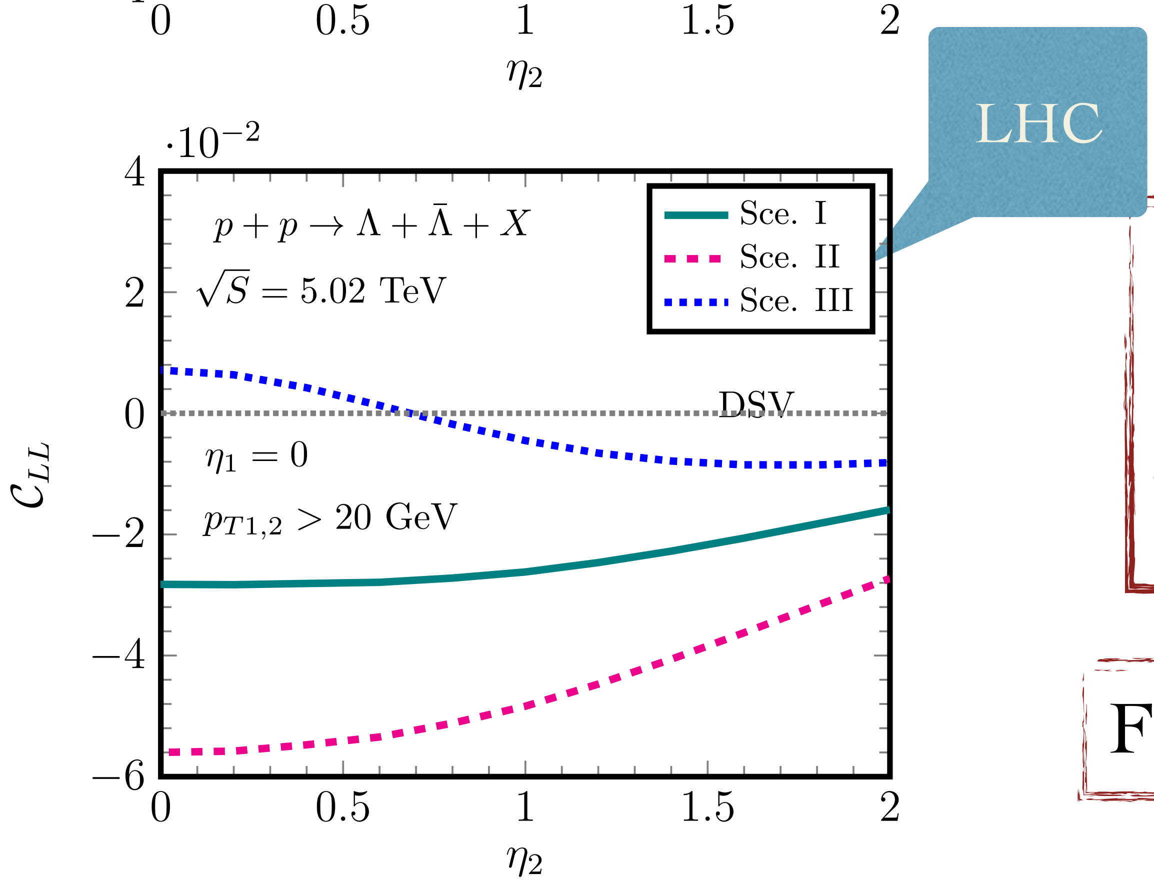
1.0
0.8
0.6
0.4
0.2
0.0
$\Delta P_{gg}/P_{gg}$
0.0
0.2
0.4
0.6
0.8
1.0
ξ

Probing G_{1L} in unpolarized pp collisions

Polarization Correlation in unpolarized pp collisions







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