

How to Measure the Linear Polarization of a Gluon?

That is the question

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Y.K. Song, S.Y. Wei, L. Yang, J. Zhou, PRL136, 131901 (2026)



Contents

- Introduction
- Coherent effect and CCFM formalism
- Anisotropic EEC, a novel probe
- Summary

Before we dive in, why do we even care?

$$e^+ + e^- \rightarrow \gamma^* \rightarrow q + \bar{q}$$

Single Inclusive

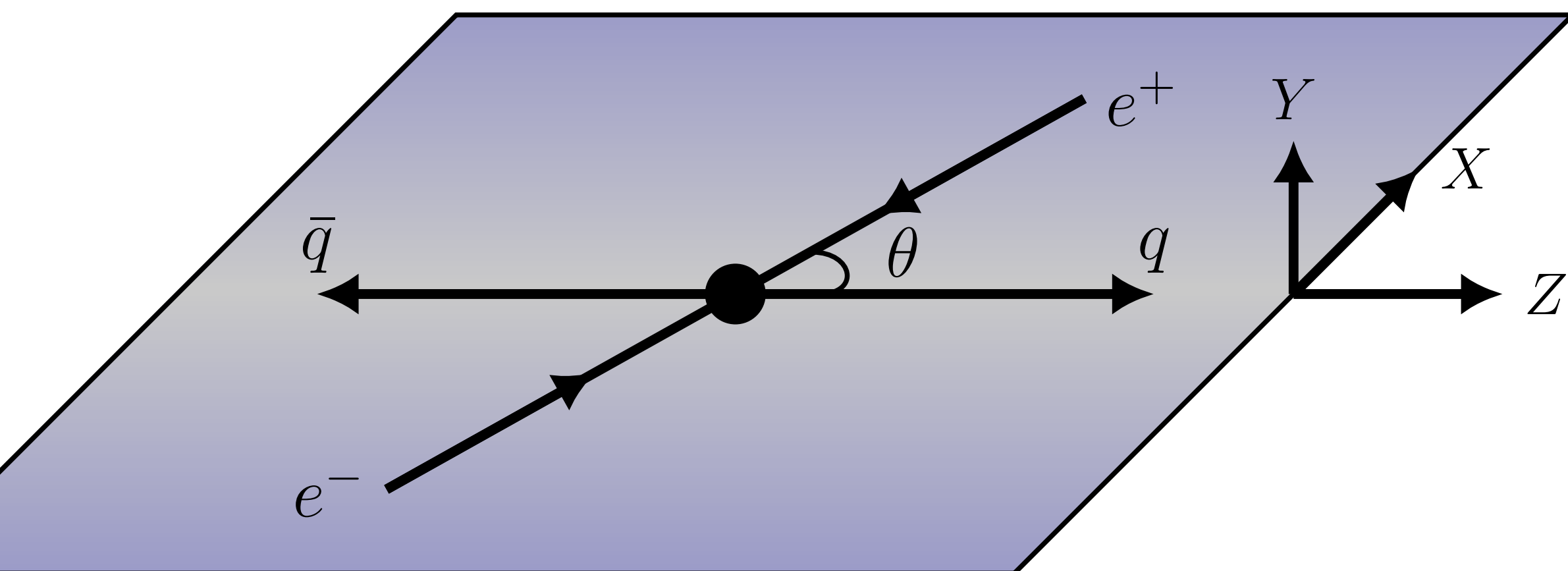
$$P_q = P_{\bar{q}} = 0$$

$q\bar{q}$ Pair Production

$$C_{ZZ} = +1$$

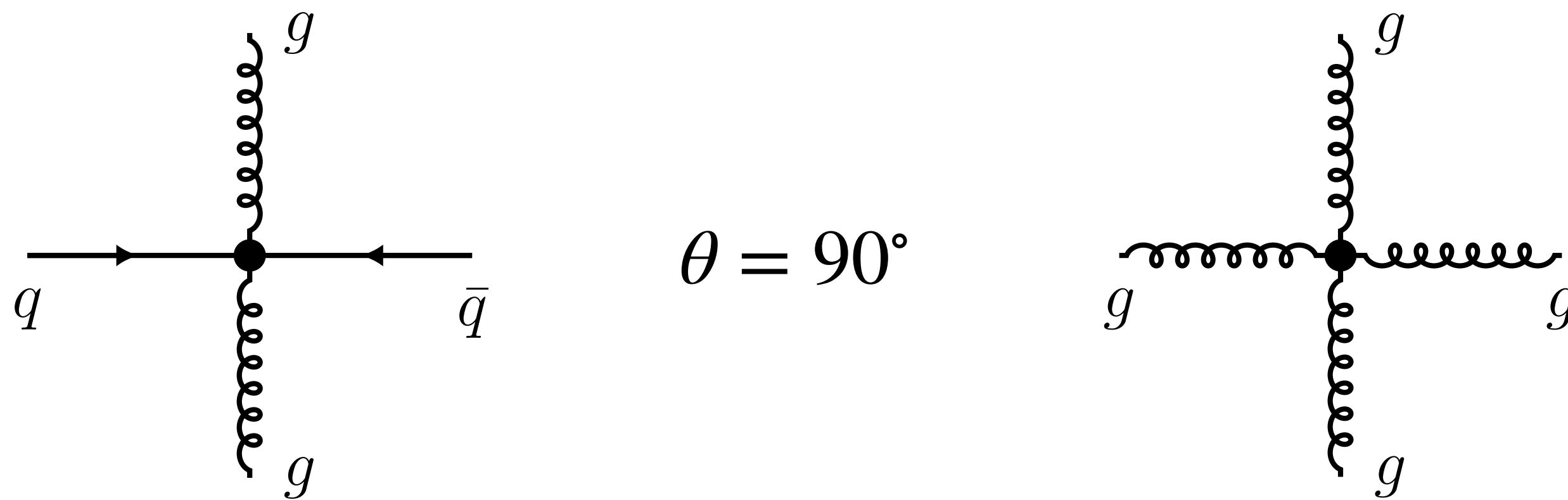
$$C_{XX} = + \frac{\sin^2 \theta}{1 + \cos^2 \theta}$$

$$C_{YY} = - \frac{\sin^2 \theta}{1 + \cos^2 \theta}$$



At $\theta = \pi/2$, the b2b $q\bar{q}$ pair forms a Bell state: $(|++\rangle + |--\rangle)/\sqrt{2}$ with maximal entanglement.

Beyond Single Inclusive Process: Ubiquitous Spin Correlations ep , pp , pA , AA



Linear Polarizations
of the gluon pair
are completely aligned.

Linear Polarizations of
the gluon pair are $\sim 11\%$
aligned.

*H. Zhang, [S.Y. Wei](#),
2301.04096;*

*X. Li, Z.X. Chen, S. Cao, [S.Y. Wei](#),
2309.09487;*

*Z.X. Chen, H. Dong, [S.Y. Wei](#),
2404.19202;*

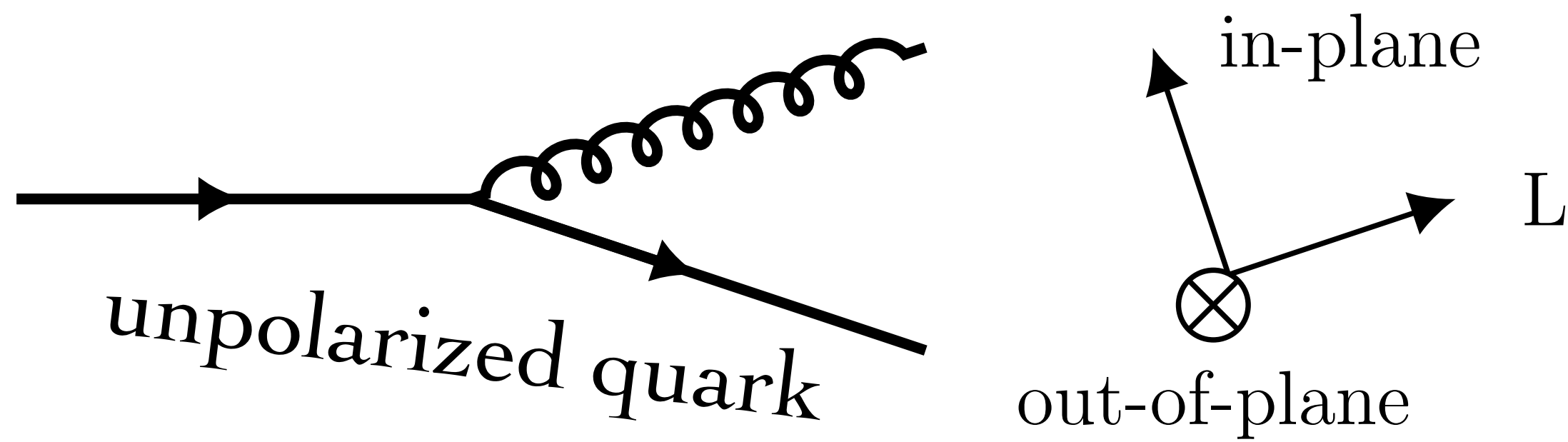
*L. Yang, Y.K. Song, [S.Y. Wei](#),
2410.20917;*

*F. Huang, T.B. Liu, Y.K. Song, [S.Y. Wei](#),
2412.00394;*

*S.J. Lin, M.J. Liu, D.Y. Shao, [S.Y. Wei](#),
2507.15387.*

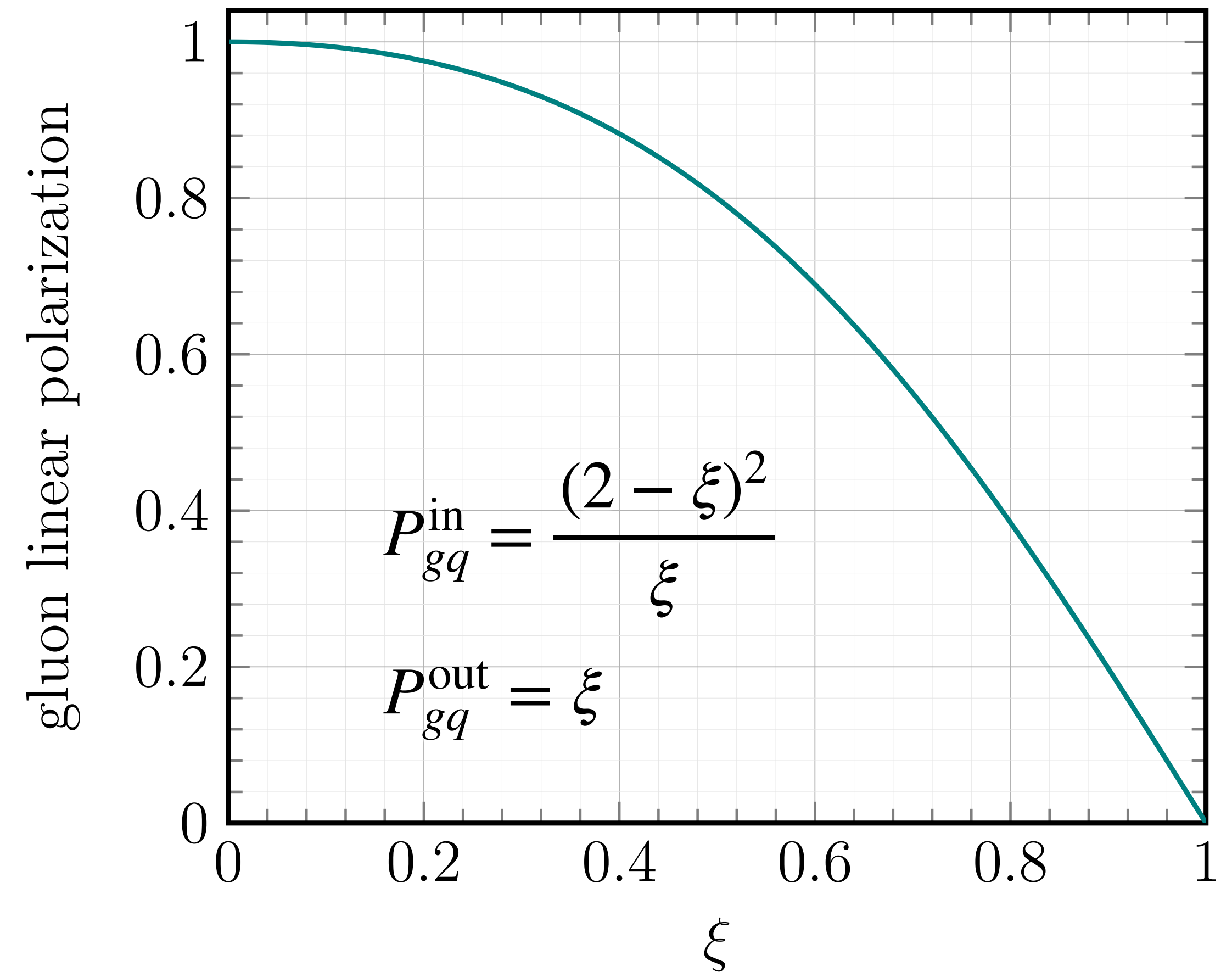
*L. Yang, W.H. Yao, Y.K. Song, [S.Y. Wei](#), J. Zhou,
WIP.*

Another Example: collinear branching



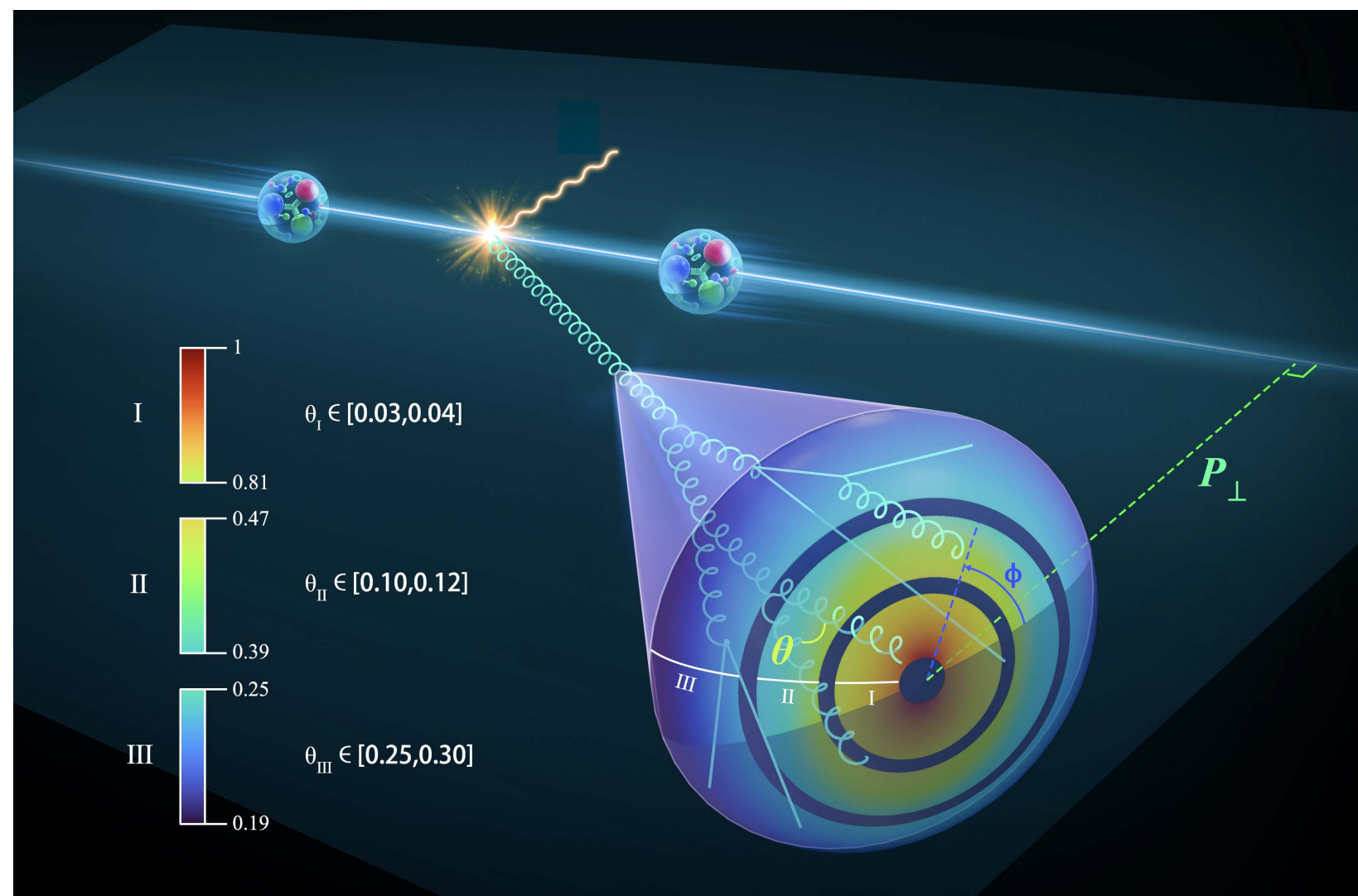
Gluons are linearly polarized inside of the branching plane.

Spin-Orbital Entanglement,
see e.g., 2410.16082



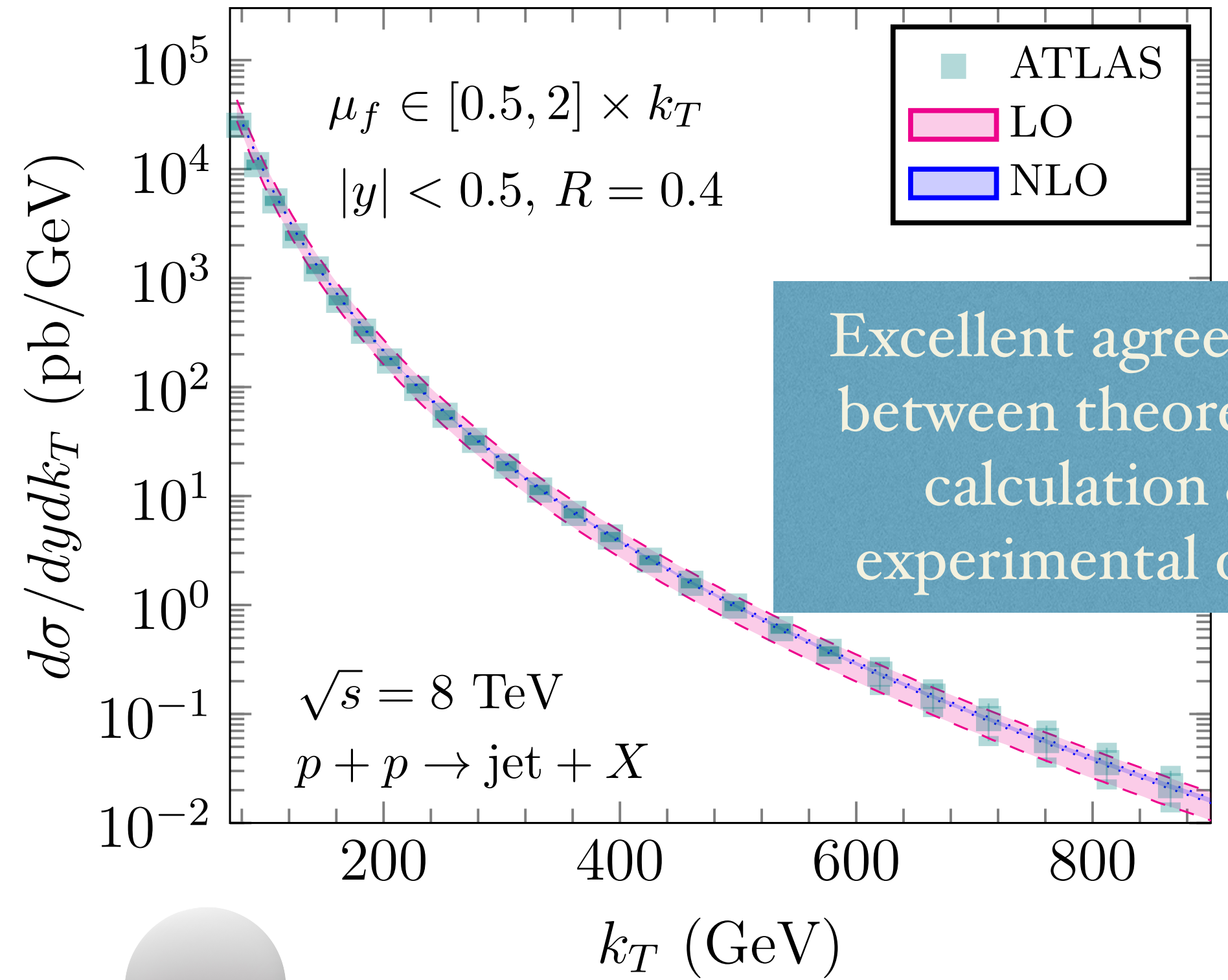
Color Confinement

A high-energy parton \approx co-moving hadrons



Momentum

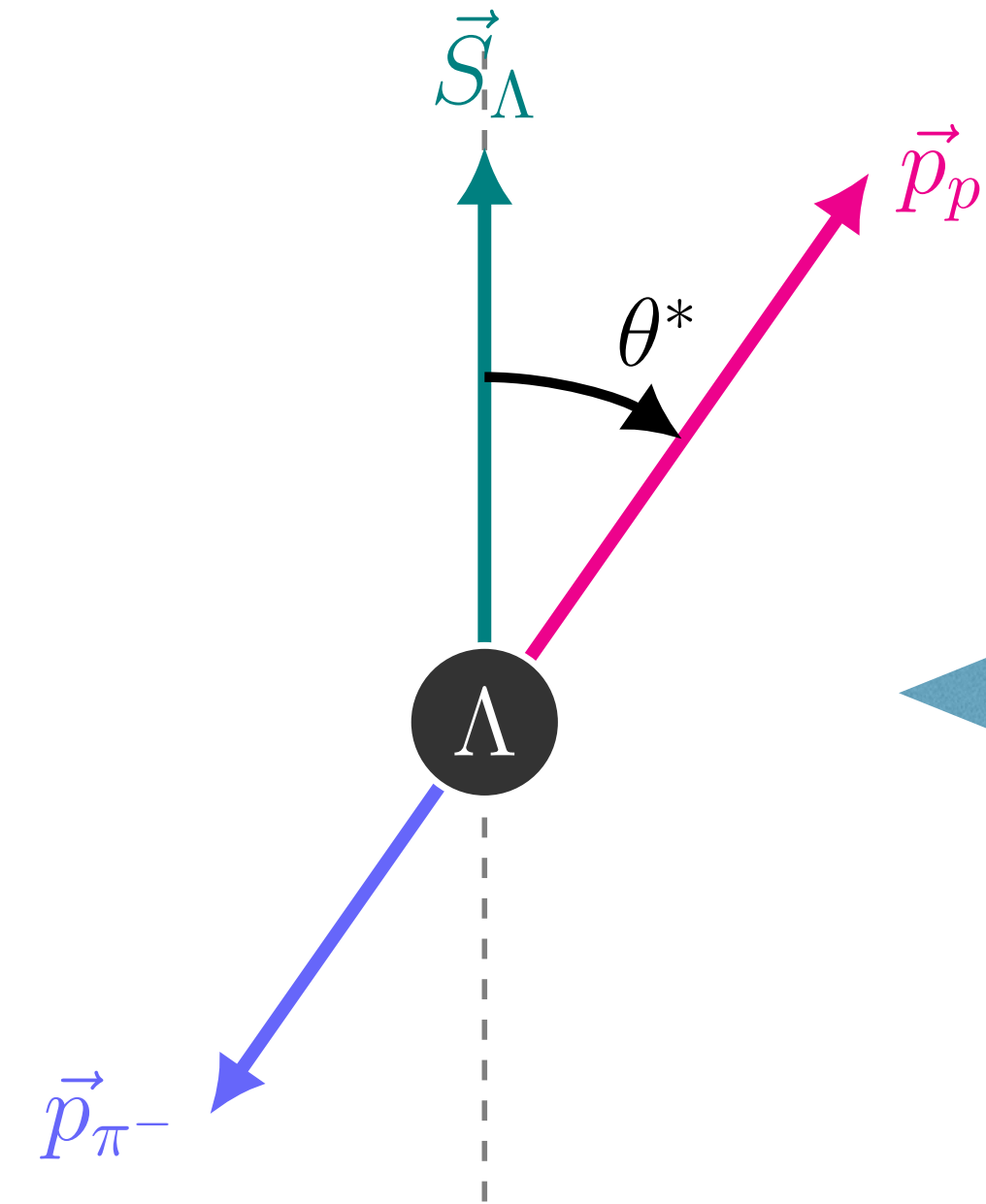
Spin ?



That is the question we want to address.

Spin Transfer: a journey from parton to hadron

The gluon linear polarization cannot be inherited by Λ hyperons in the collinear factorization



Self-analyzing power of Λ weak decay

Quark hadronization:

$$\mathcal{D}(q \rightarrow \Lambda) = D_{1,q}^\Lambda(z) + \lambda_q \lambda_\Lambda G_{1L,q}^\Lambda(z) + \mathbf{S}_{T,q} \cdot \mathbf{S}_{T,\Lambda} H_{1T,q}^\Lambda(z)$$

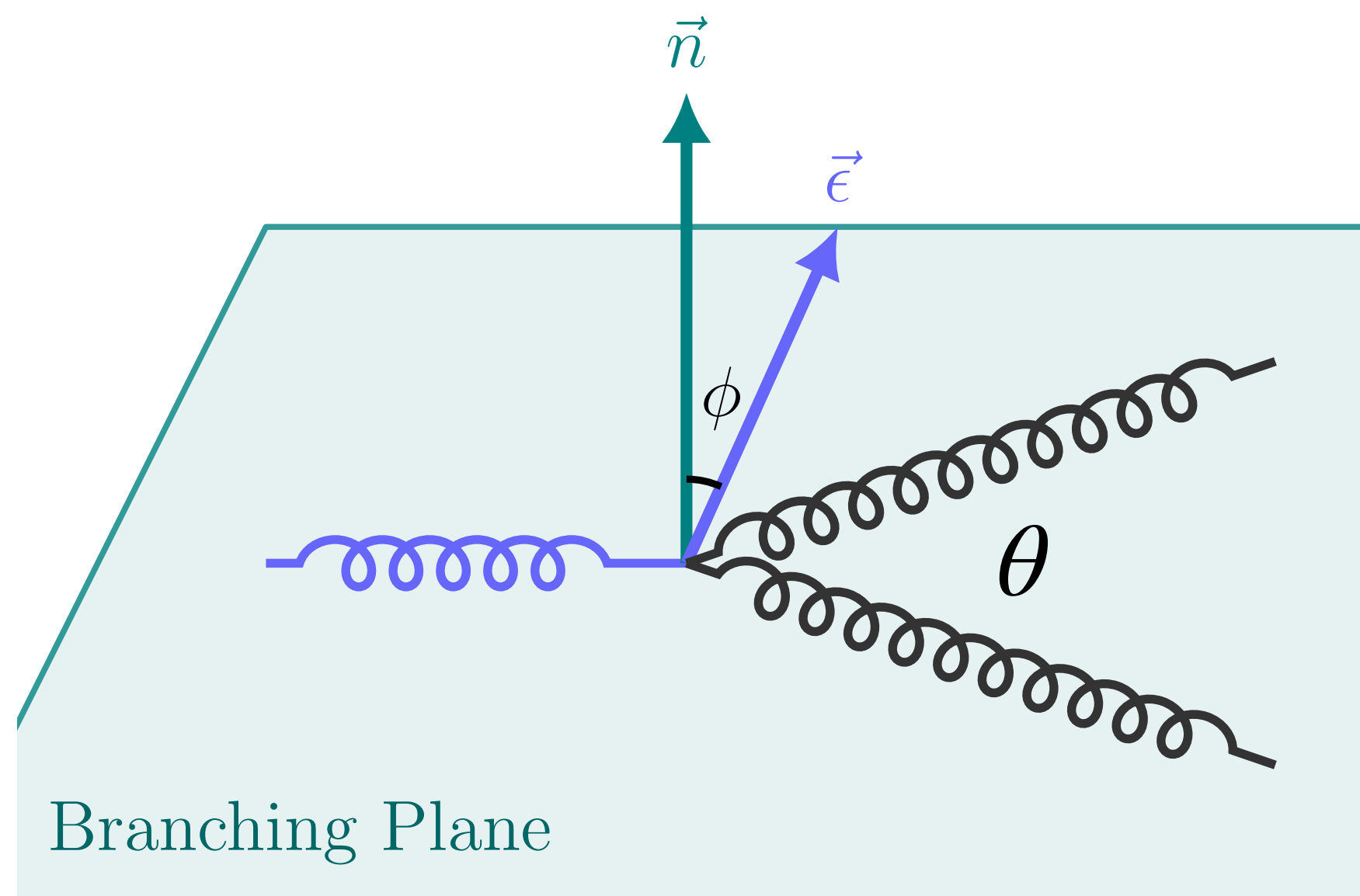
Gluon hadronization:

$$\mathcal{D}(g \rightarrow \Lambda) = D_{1,g}^\Lambda(z) + \lambda_g \lambda_\Lambda G_{1L,g}^\Lambda(z)$$

Solution: Anisotropy

Branching of a Linearly Polarized Gluon

Anisotropic EEC becomes a novel probe of gluon linear polarization



Since the linear polarization of the parent gluon specifies a transverse direction, the parton branchings are no longer isotropic.

isotropic term

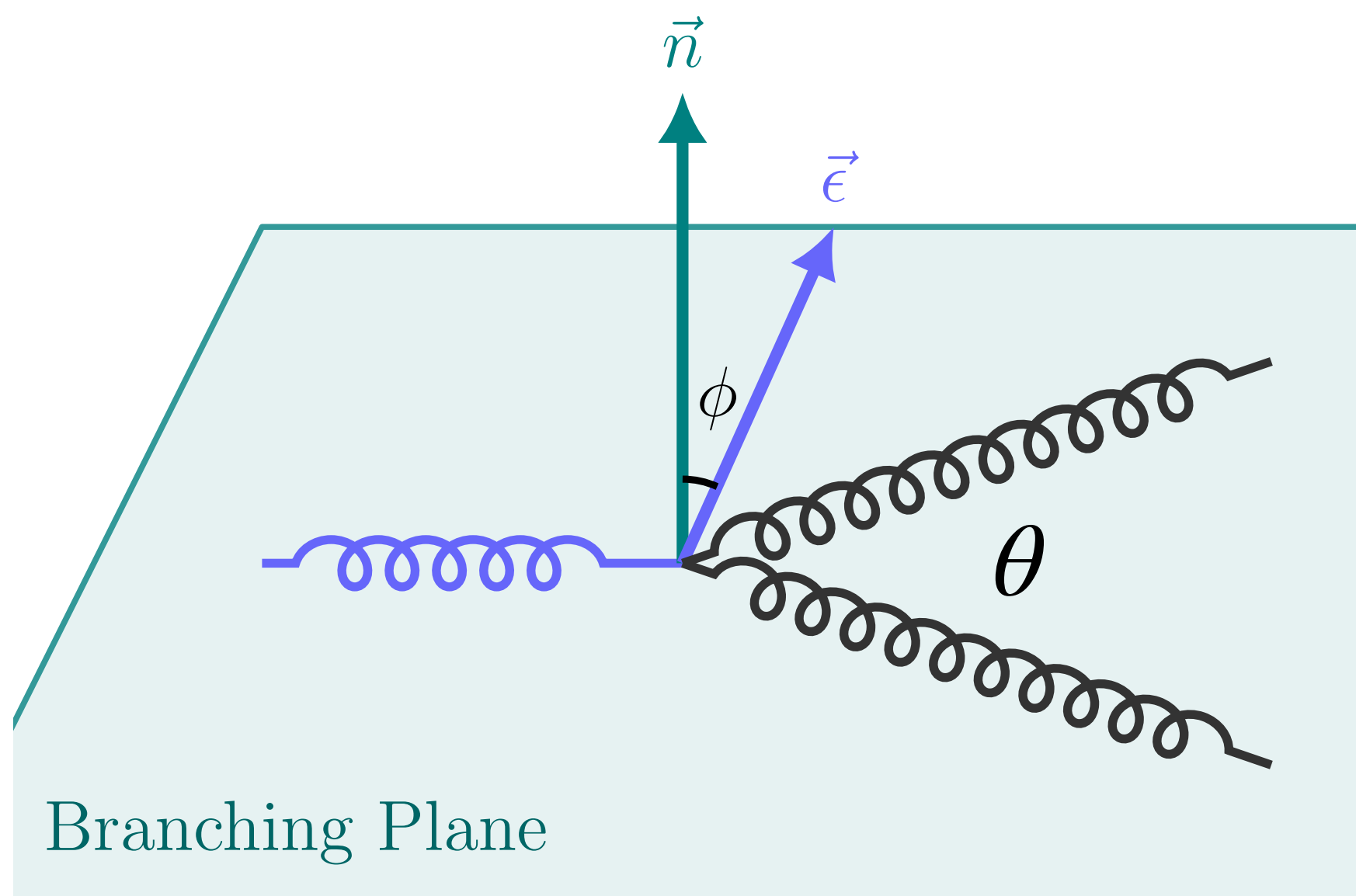
anisotropic term

$$P_{g \rightarrow gg}(\xi, \phi) = 2N_c \left[\frac{1-\xi}{\xi} + \frac{\xi}{1-\xi} + \xi(1-\xi) + \xi(1-\xi) \cos 2\phi \right]$$

$$P_{g \rightarrow q\bar{q}}(\xi, \phi) = \frac{1}{2} \left[\xi^2 + (1-\xi)^2 - 2\xi(1-\xi) \cos 2\phi \right]$$

Branching of a Linearly Polarized Gluon

Anisotropic EEC becomes a novel probe of gluon linear polarization



$$\frac{d\langle \text{EEC} \rangle}{d\theta d\phi} = \sum_{i,j} \delta(\theta_{ij} - \theta) \delta(\phi_{ij,g} - \phi) \frac{E_i E_j}{E_g^2},$$

isotropic term

anisotropic term

$$P_{g \rightarrow gg}(\xi, \phi) = 2N_c \left[\frac{1-\xi}{\xi} + \frac{\xi}{1-\xi} + \xi(1-\xi) + \xi(1-\xi) \cos 2\phi \right]$$

$$P_{g \rightarrow q\bar{q}}(\xi, \phi) = \frac{1}{2} \left[\xi^2 + (1-\xi)^2 - 2\xi(1-\xi) \cos 2\phi \right]$$

EEC and Jet Functions

θ -integrated EEC

$$\langle \text{EEC} \rangle = \sum_{i=q,g} \int dx x^2 H_i(x, \mu) J_i(\ln x^2 \kappa) \quad \kappa = (\theta E_g)^2 / \mu^2$$

Unpolarized Jet Function $J_i(\ln \kappa)$ follows the DGLAP evolution equation

$$\frac{\partial J_i(\ln \kappa)}{\partial \ln \mu^2} = \frac{\alpha_s}{2\pi} \sum_j \int_0^1 dy y^2 P_{ij}(y) J_j(\ln(y^2 \kappa))$$

Polarized Jet Function $J_{g,T}(\ln \kappa)$

$$\frac{\partial J_{g,T}(\ln \kappa)}{\partial \ln \mu^2} = \frac{\alpha_s}{2\pi} \int_0^1 dy y^2 P_{gg}^T(y) J_{g,T}(\ln(y^2 \kappa))$$

Diagonal
Equation

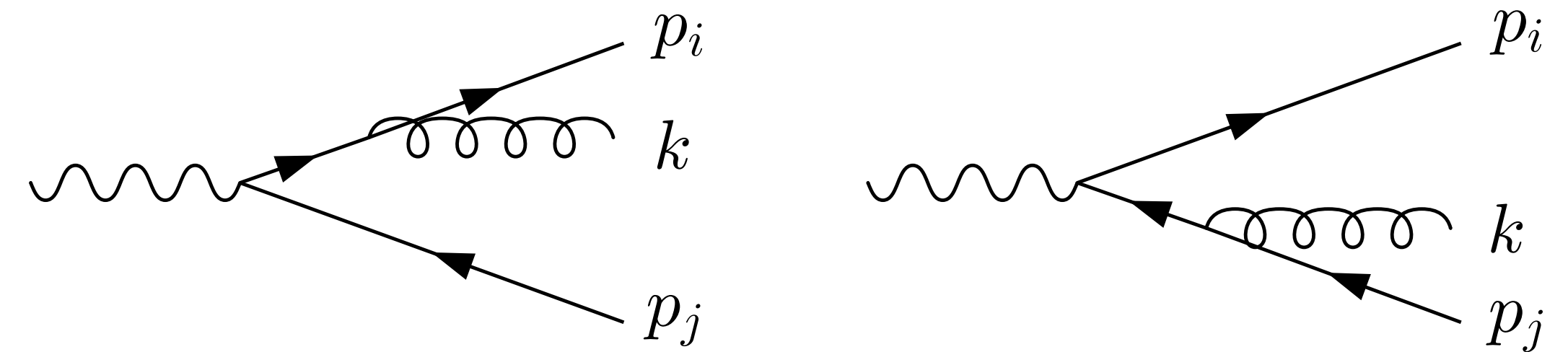
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Coherent Effect & Angular Ordering

See, e.g., *R.K. Ellis, et al, QCD and Collider Physics*

$$\langle W_{ij}^{(i)} \rangle_\phi = \int_0^{2\pi} \frac{d\phi_{ik}}{2\pi} W_{ij}^{(i)} = \frac{1}{E_k^2 (1 - \cos \theta_{ik})} \Theta(\theta_{ij} - \theta_{ik})$$



CCFM evolution equation:

$$\mathcal{A}(x, k, p) = \bar{\alpha}_s \int_x^1 \frac{dz}{z} \int \frac{d^2q}{\pi q^2} \theta(p - zq) \Delta_{\text{ns}}(k, z, q) \mathcal{A}\left(\frac{x}{z}, k', q\right)$$

Ciafaloni, NPB 1988; Catani, Fiorani, Marchesini, NPB 1990.

Evolution of the jet function

DGLAP

CCFM

$$\frac{\partial J_i(\ln \kappa)}{\partial \ln \mu^2} = \frac{\alpha_s}{2\pi} \sum_j \int_0^1 dy y^2 P_{ij}(y) J_j(\ln(y^2 \kappa)) \longrightarrow \frac{\partial}{\partial \ln \mu^2} \frac{J_g(\ln \kappa)}{\Delta_s(\mu^2)} = \frac{\alpha_s}{2\pi} \frac{1}{\Delta_s(\mu^2)} \int_{\Lambda/\mu}^{1-\Lambda/\mu} dy y^2 \left[\tilde{P}_{gg}(y) J_g(\ln \kappa) + \tilde{P}_{gq}(y) J_q(\ln \kappa) \right]$$

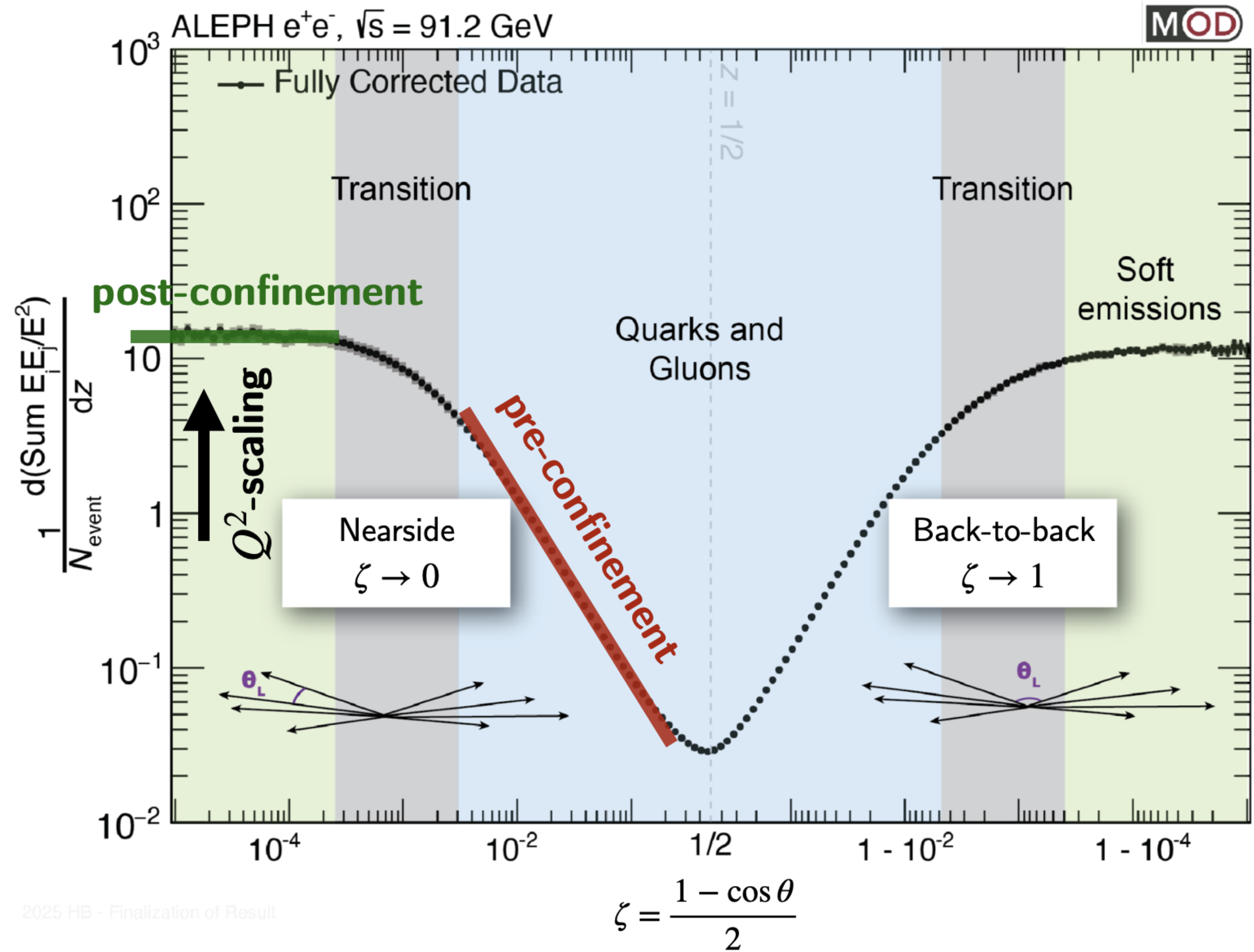
$\Lambda \sim 0.5 \text{ GeV}$ is an IR parameter, implementing the coherent AO

Coherent effect and CCFM formalism



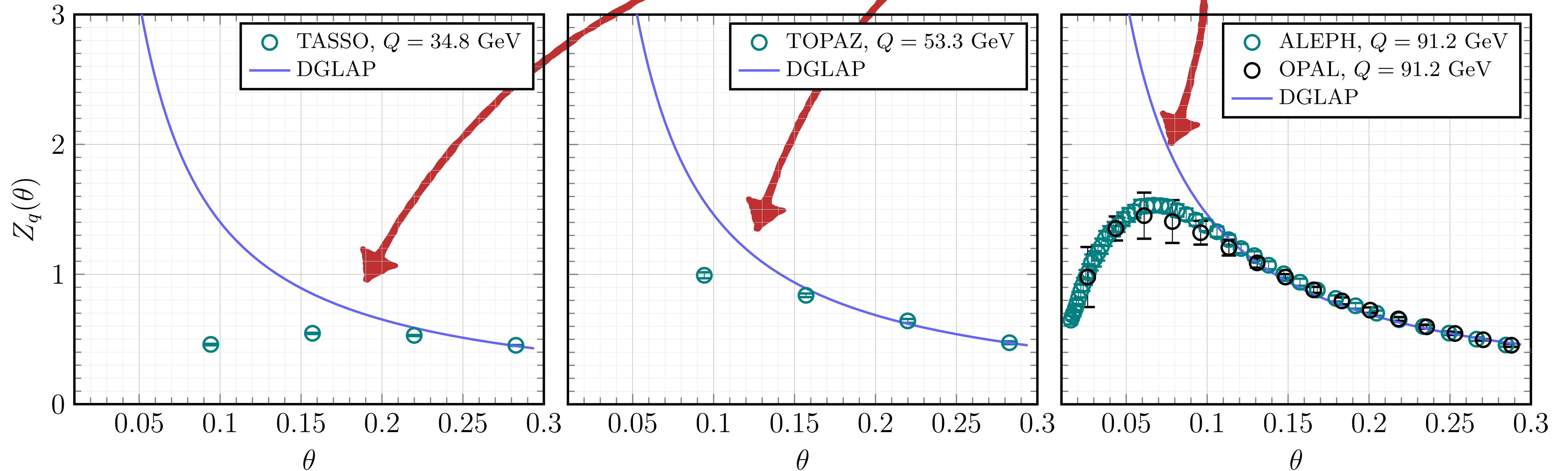
Describing e^+e^- Data

C.H. Chang, H. Chen, X. Liu,
D. Simmons-Duffin, F. Yuan,
H.X. Zhu, PRL136, 081903 (2026).



Describing e^+e^- Data

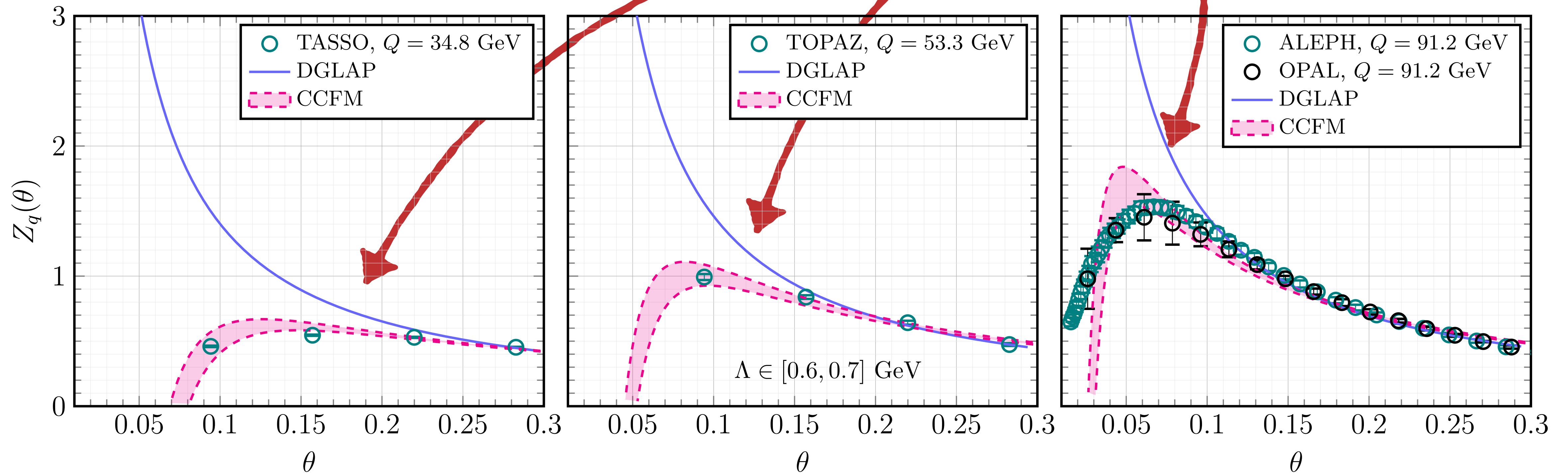
“Confinement Transition”



K. Lee, A. Pathak, I.W. Stewart, Z. Sun, 2405.19396; K. Lee, I. Stewart, 2507.11495; C.H. Chang, H. Chen, X. Liu, D. Simmons-Duffin, F. Yuan, H.X. Zhu, 2507.15923; E. Herrmann, Z.B. Kang, J. Penttala, C. Zhang, 2507.17704; Z.B. Kang, A. Metz, D. Pitonyak, C. Zhang, 2507.17444; Y. Guo, W. Vogelsang, F. Yuan, W. Zhao, 2512.15896.

Describing e^+e^- Data

“Confinement Transition”



The unphysical increase is effectively tamed in the CCFM by incorporating coherence effects, alongside an IR cutoff

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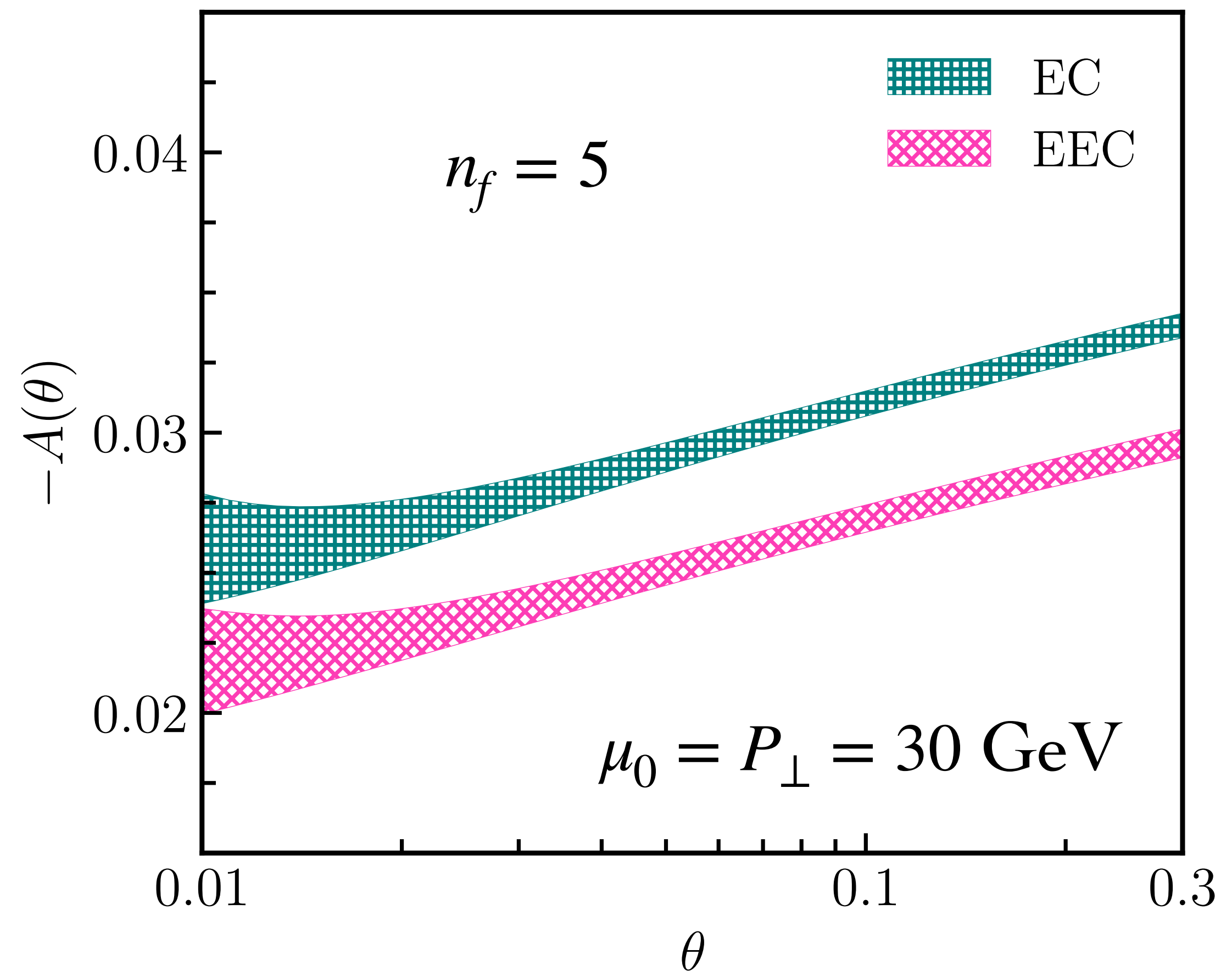
Analyzing Power $A(\theta)$

$$A(\theta) \equiv \frac{\int dy y(1-y) [P_{gg}^{2\phi} + 2n_f P_{qg}^{2\phi}] J_{g,T}}{\int dy y(1-y) \left\{ [\tilde{P}_{gg} + 2n_f \tilde{P}_{qg}] J_g + [\tilde{P}_{qq} + \tilde{P}_{gq}] J_q \right\}}$$

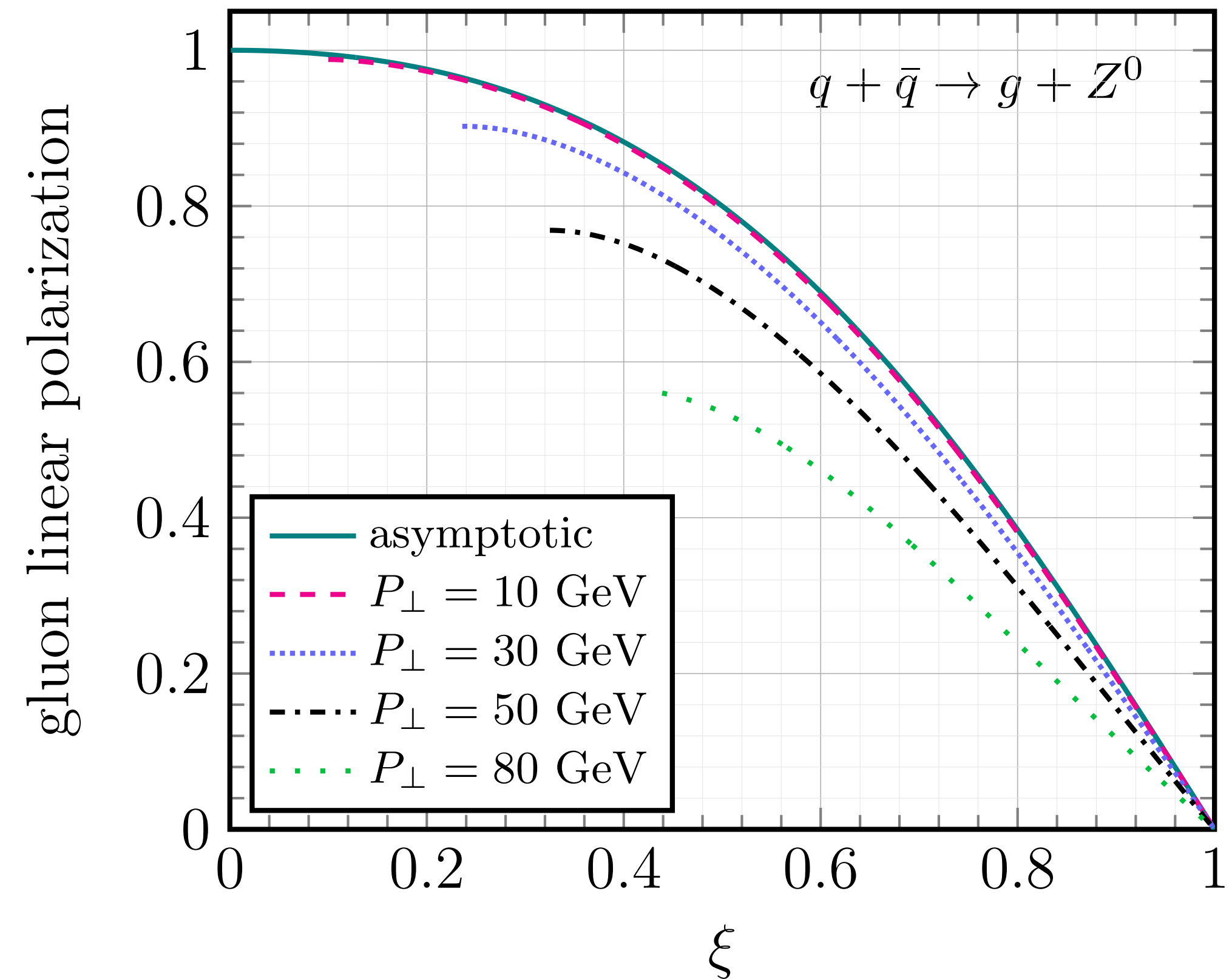
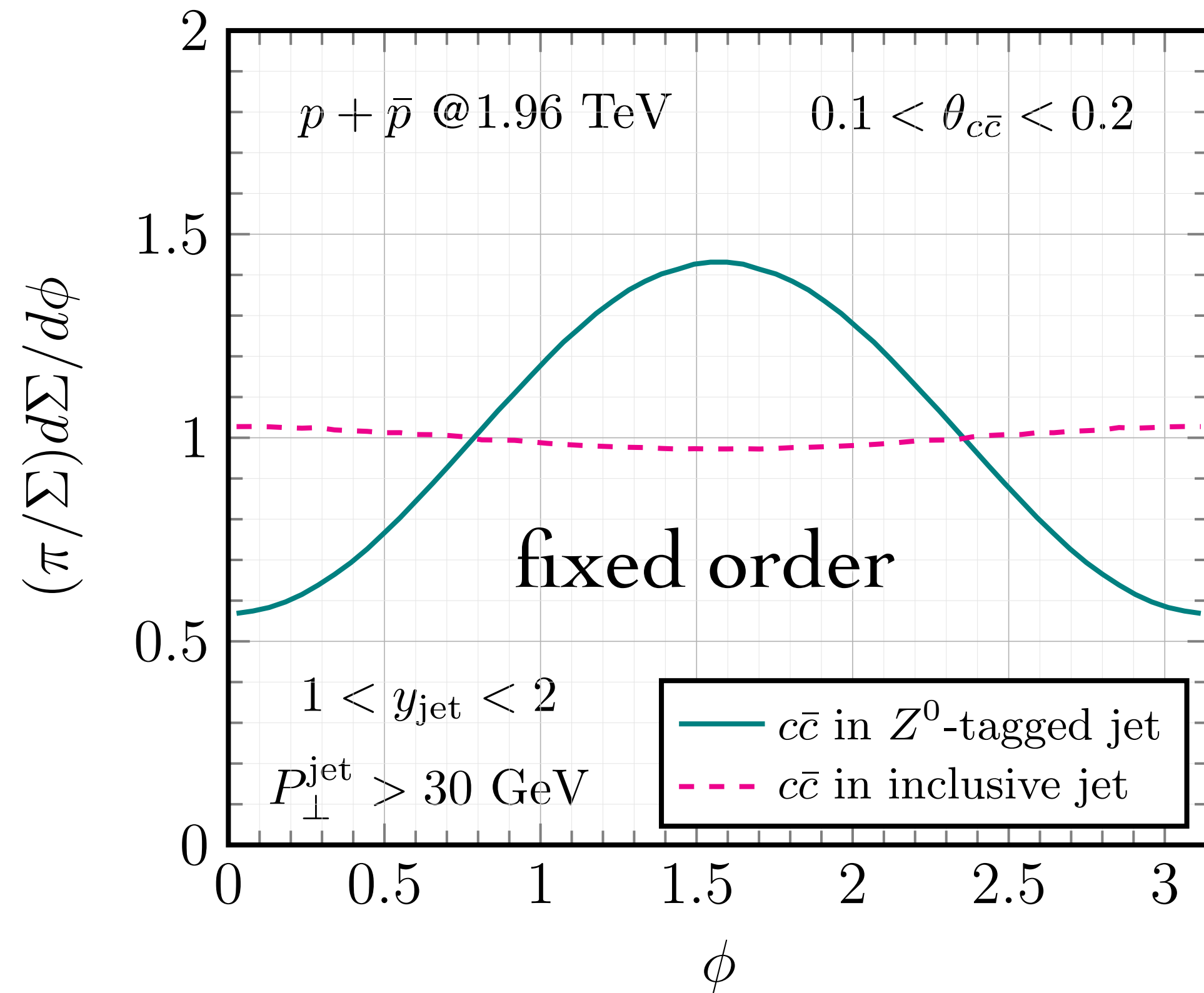
Partial cancellation between
 $g \rightarrow gg$ and $g \rightarrow q\bar{q}$ branchings

$$P_{gg}^{2\phi}(y) = 2N_c y(1-y)$$

$$P_{qg}^{2\phi}(y) = -y(1-y)$$



Realistic Configuration: $Z^0 + (g \rightarrow c\bar{c})$ production v.s. inclusive $(g \rightarrow c\bar{c})$ production



In Z^0 -tagged process, gluon can be considered as collinearly radiated by the quark when $P_{\perp} \ll M_Z$, generating a sizable linear polarization

- Gluon linear polarization emerges in unpolarized high energy collisions.
- The anisotropic EEC is a novel probe.
- Coherent effect is naturally encoded in the AO of CCFM equation, providing a smooth transition into the non-perturbative regime.

Thank you very much for your attention!