Exploring lepton-charge asymmetries and parity-violation in large-pT SIDIS

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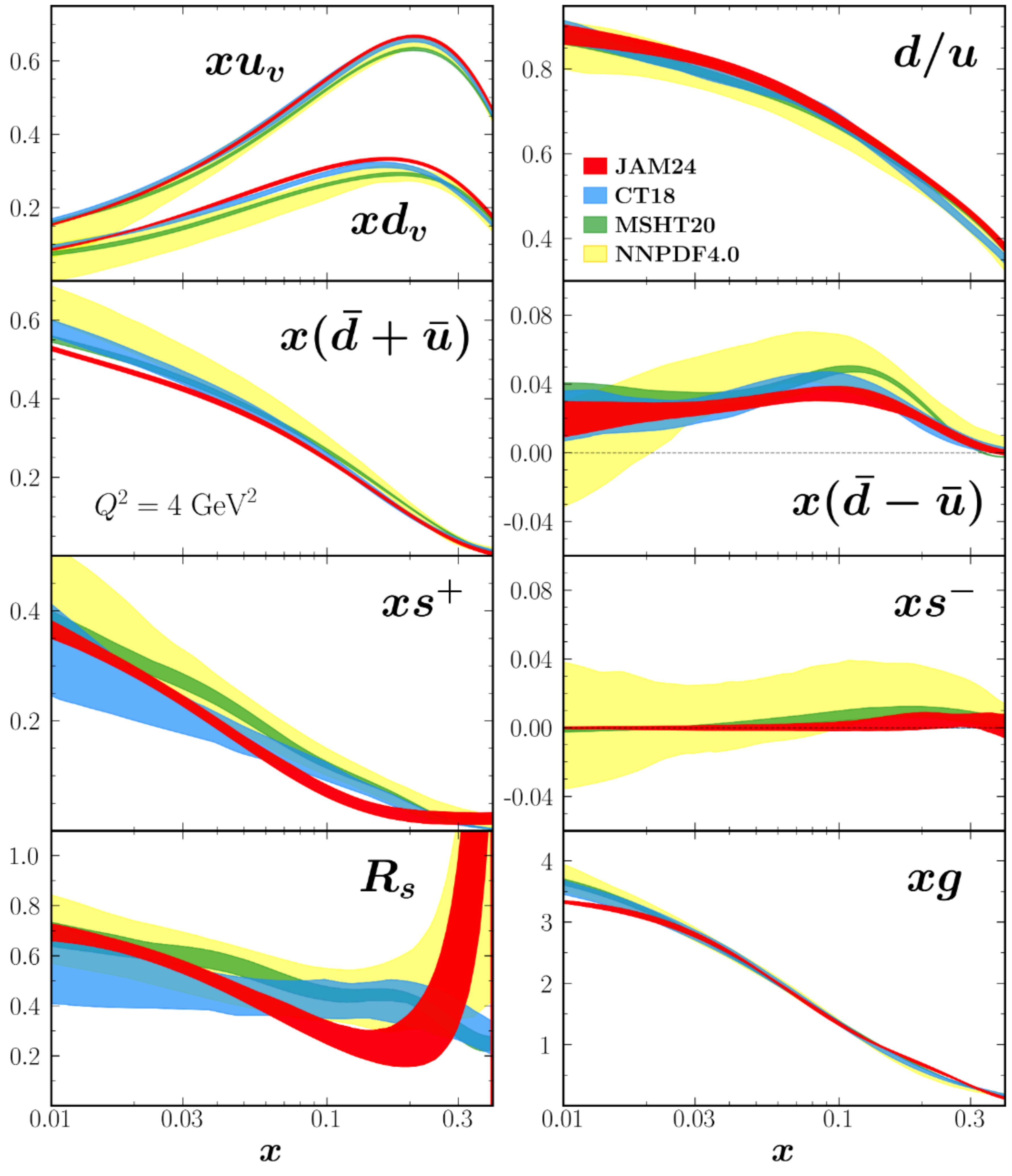
Positron Working Group Workshop — 03/25/25

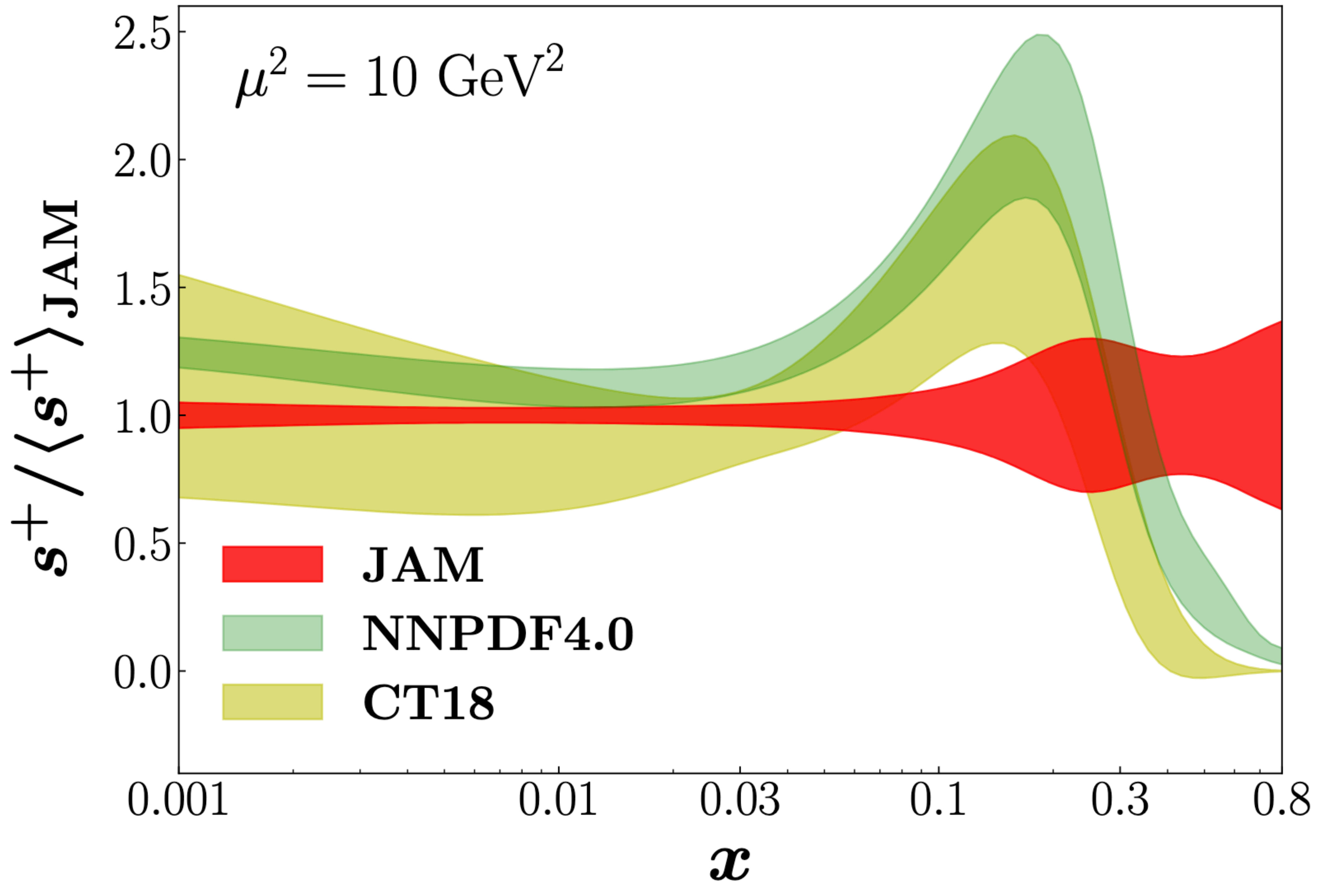
ODU

Jefferson Lab

How strange is the proton?



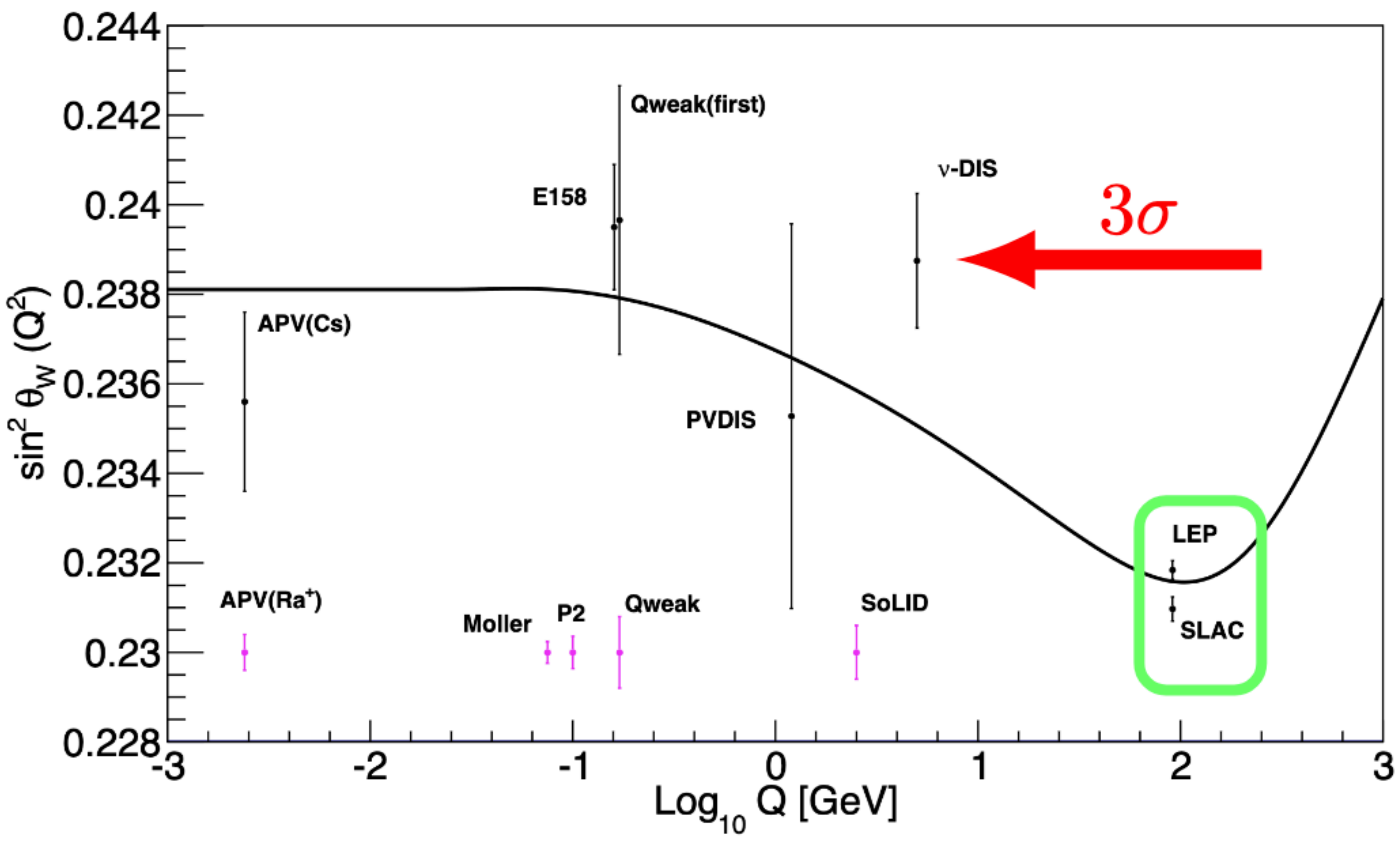
Anderson, Sato, Melnitchouk, arXiv:2501.00665v2 [hep-ph] (2025)

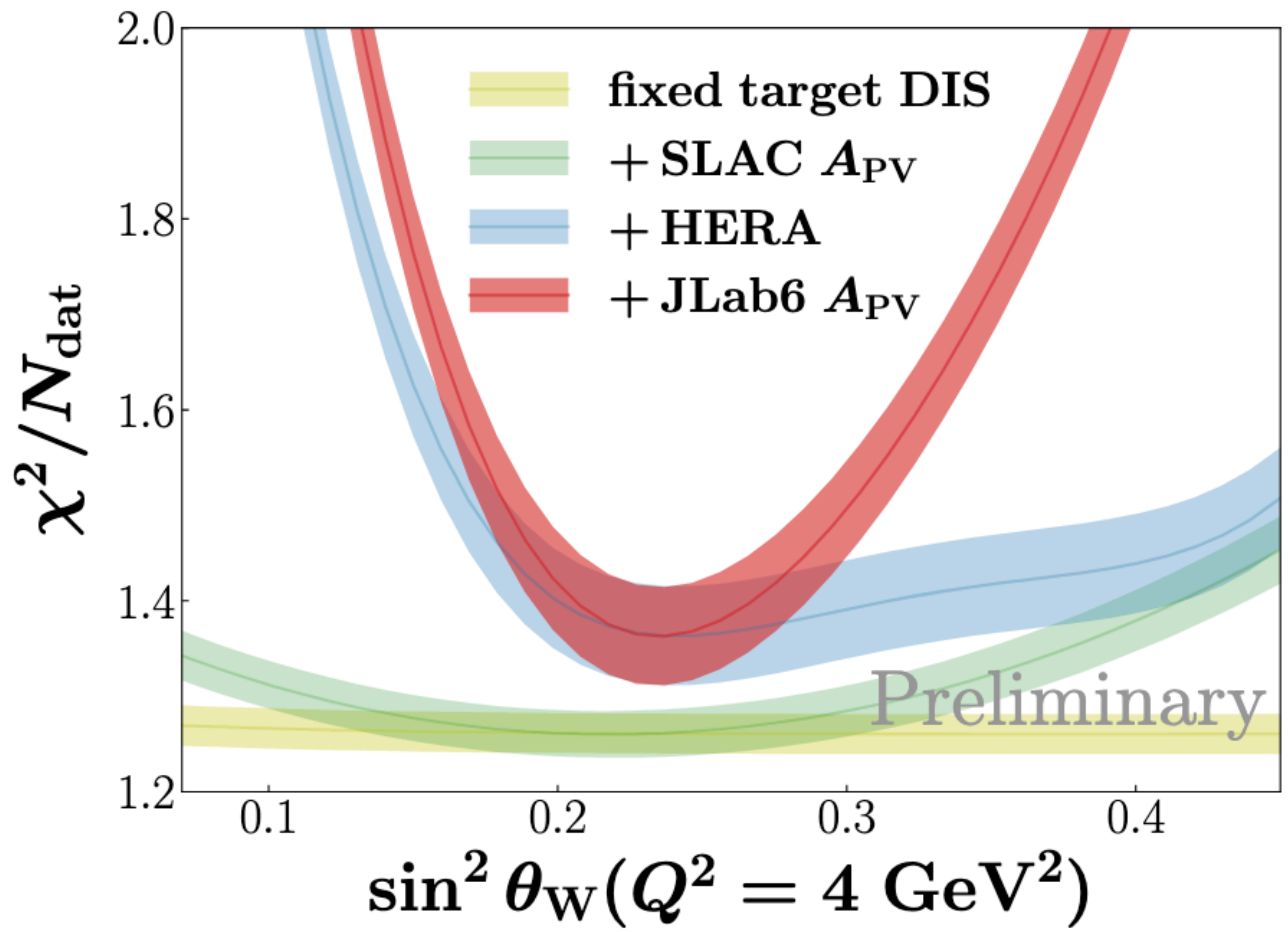


→ size of the strange PDFs? — s^+

→ strange sea asymmetry? — s^-

Opportunities for BSM physics?

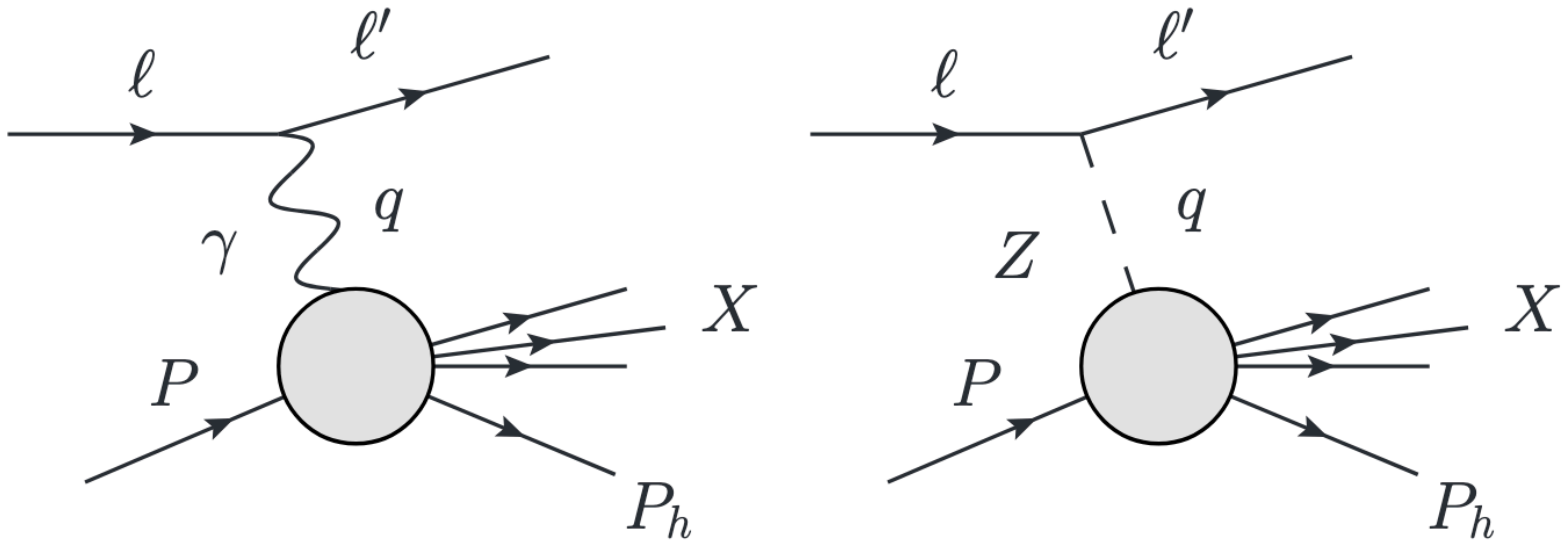




What SoLID PVDIS can offer

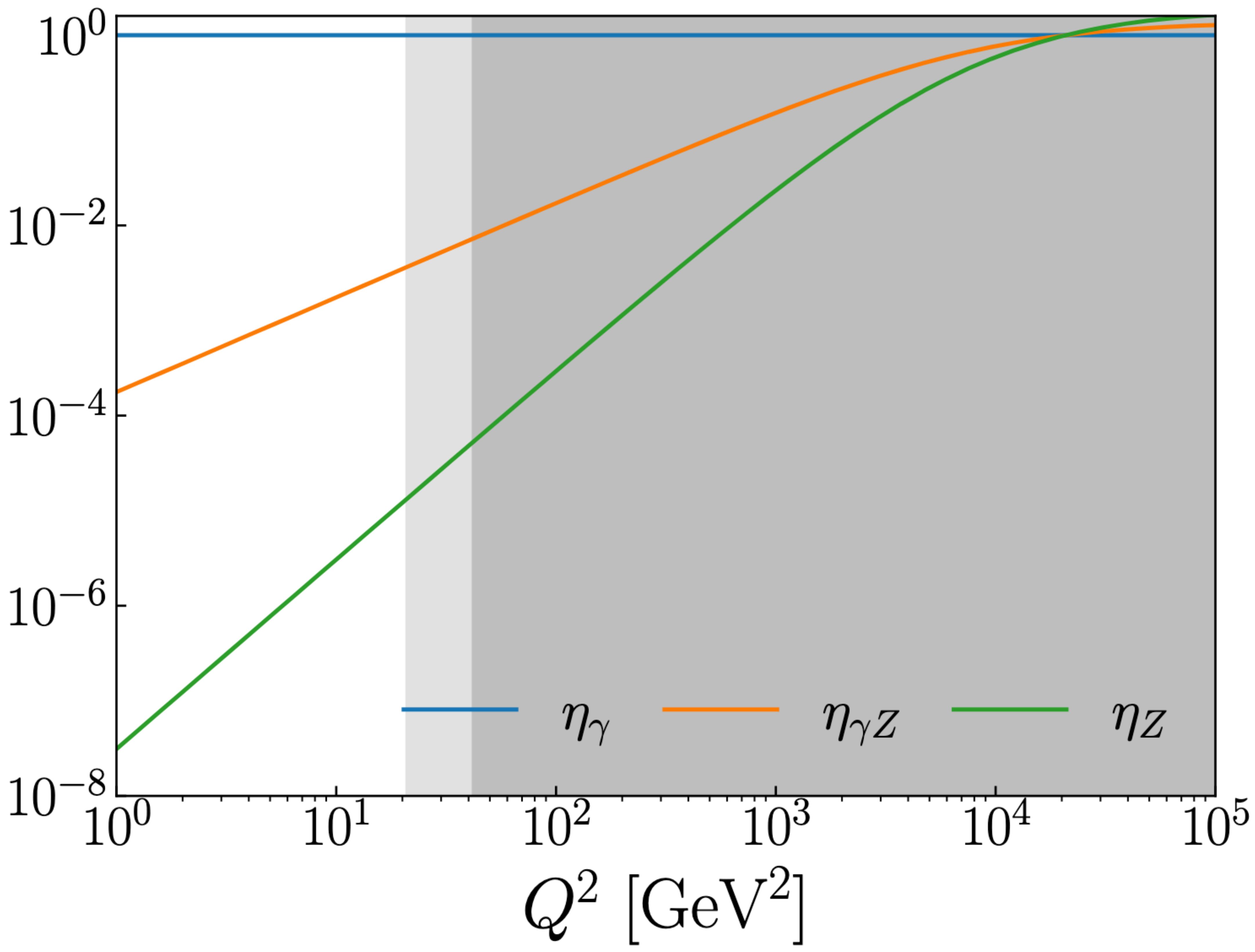
Whitehill *et al.,* In preparation (2025)

Extensions to PV-SIDIS



$$\frac{\mathrm{d}\sigma_{\lambda_\ell}}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}q_T^2\,\mathrm{d}\varphi} = \frac{\pi\alpha^2 yz}{4Q^4}\sum_j \eta_j C_j L^{\gamma}_{\mu\nu} W_j^{\mu\nu}$$

JLab11, 22, and beyond →



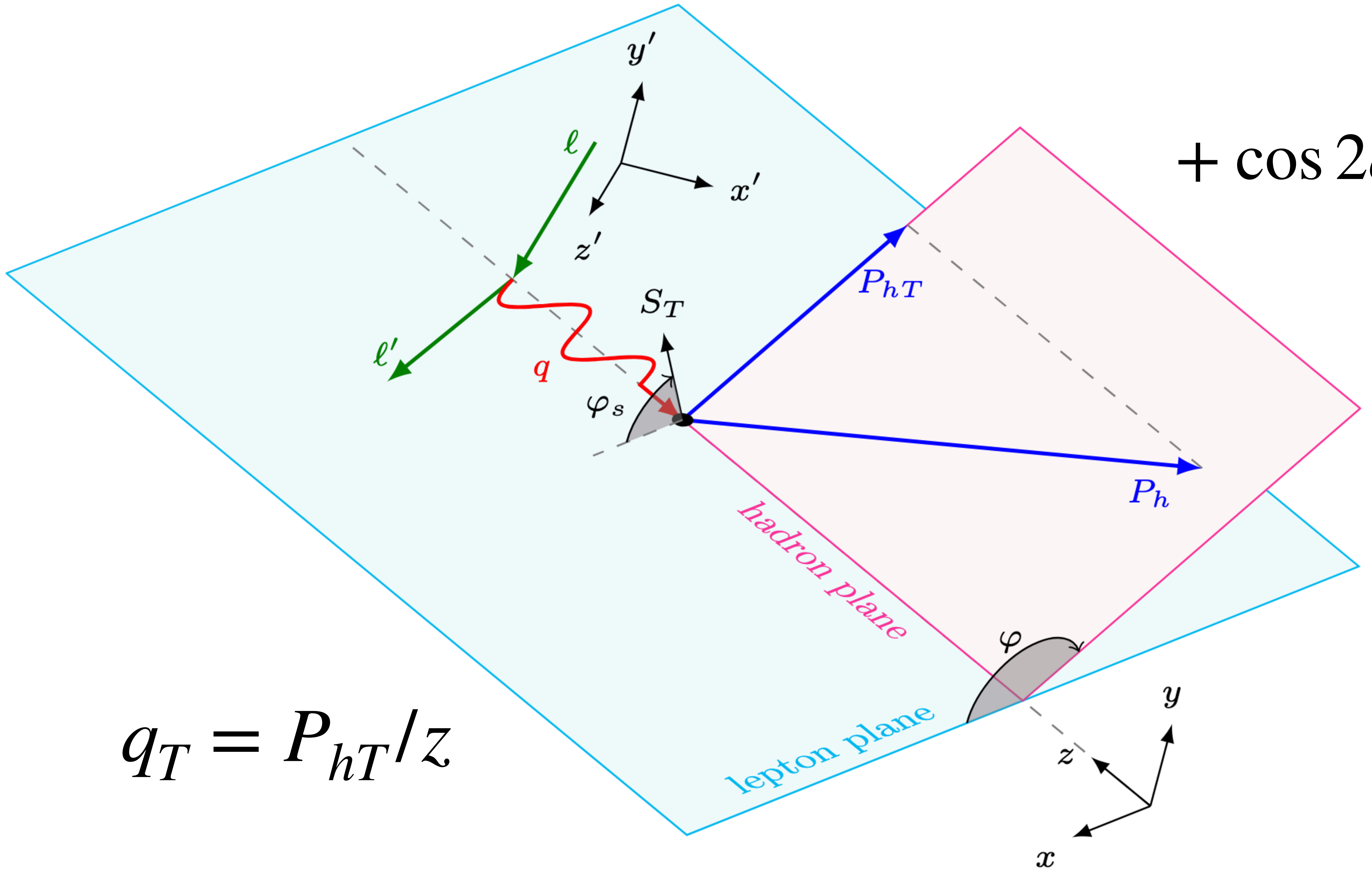
SIDIS in the Breit frame

$$\frac{d\sigma_{UU}}{dx\,dy\,dz\,dq_T^2\,d\varphi} = \frac{\pi\alpha^2 yz}{4Q^4}\Big[-2\mathscr{F}_1^{UU} + \sinh^2\vartheta\,\mathscr{F}_2^{UU} + \frac{1}{2}(2+\sinh^2\vartheta)\mathscr{F}_3^{UU} - 2Q_\ell\mathscr{F}_6^{UU}$$

$$+\cos\varphi\Big(-\sinh 2\vartheta\,\mathscr{F}_4^{UU} + 2Q_\ell\sinh\vartheta\,\mathscr{F}_5^{UU}\Big)$$

$$+\cos 2\varphi\Big(\frac{1}{2}\sinh^2\vartheta\,\mathscr{F}_3^{UU}\Big)\Big]$$

- $\sinh\vartheta = \frac{2}{y}\sqrt{1-y}$



$q_T = P_{hT}/z$

Unpolarized beam

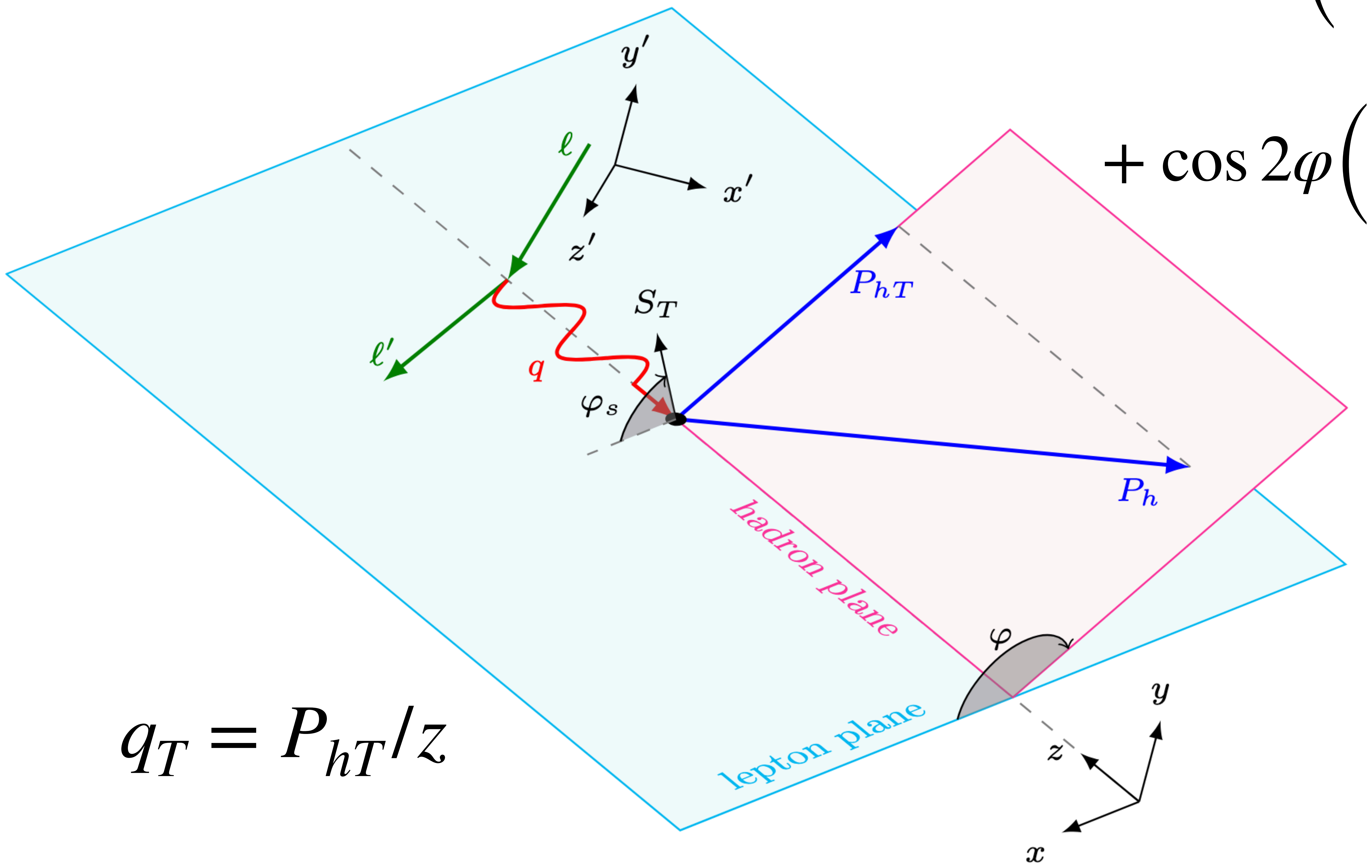
SIDIS in the Breit frame

$$\frac{d\sigma_{LU}}{dx\,dy\,dz\,dq_T^2\,d\varphi} = \frac{\pi\alpha^2 yz}{4Q^4}\Big[-2Q_\ell \mathscr{F}_1^{LU} + Q_\ell \sinh^2\vartheta \mathscr{F}_2^{LU} + \frac{1}{2}Q_\ell(2+\sinh^2\vartheta)\mathscr{F}_3^{LU} - 2\mathscr{F}_6^{LU}$$

$$+ \cos\varphi\Big(-Q_\ell \sinh 2\vartheta \mathscr{F}_4^{LU} + 2\sinh\vartheta \mathscr{F}_5^{LU}\Big)$$

$$+ \cos 2\varphi\Big(\frac{1}{2}Q_\ell \sinh^2\vartheta \mathscr{F}_3^{LU}\Big)\Big]$$

- $\sinh\vartheta = \frac{2}{y}\sqrt{1-y}$



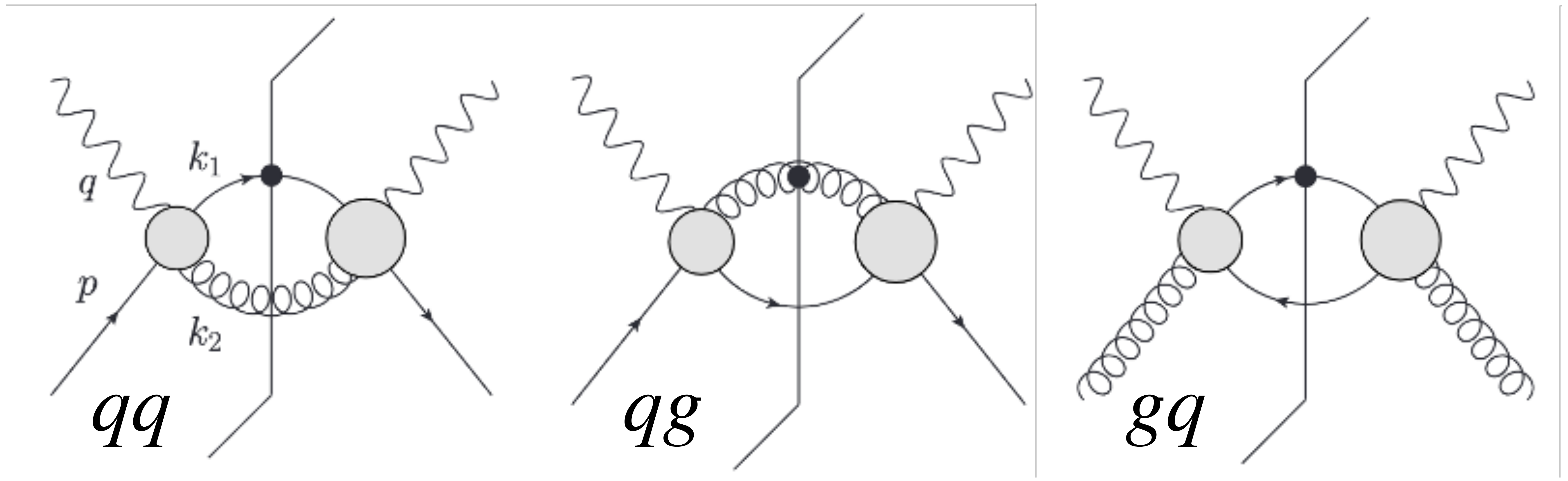
$q_T = P_{hT}/z$

Polarized beam

Collinear factorization

$$W^{\mu\nu} = \sum_{ij} \int_{\xi_{\min}}^{1} \frac{d\xi}{\xi} \int_{\zeta_{\min}}^{1} \frac{d\zeta}{\zeta^2} \widehat{W}_{ij}^{\mu\nu} f_{i/P}(\xi) D_{h/j}(\zeta)$$

$$\to \xi_{\min} = x\left(1 + \frac{z}{1-z}\frac{q_T^2}{Q^2}\right)$$



$$\mathscr{F}_{i(PC)}^{[\gamma,\gamma Z,Z]} = \sum_q \left[e_q^2,\ 2e_q g_V^q,\ (g_V^q)^2 + (g_A^q)^2\right]\left\{H_{i,qq} \otimes q^+ \otimes D_q + H_{i,qg} \otimes q^+ \otimes D_g + H_{i,gq} \otimes g \otimes D_{q^+}\right\}$$

$$\mathscr{F}_{i(PV)}^{[\gamma,\gamma Z,Z]} = \sum_q \left[0,\ 2e_q g_A^q,\ 2g_V^q g_A^q\right]\left\{H_{i,qq} \otimes q^- \otimes D_q + H_{i,qg} \otimes q^- \otimes D_g + H_{i,gq} \otimes g \otimes D_{q^-}\right\}$$

Parity-violating asymmetry

$$A_{\mathrm{PV}} = \frac{\mathrm{d}\sigma_{LU,0}}{\mathrm{d}\sigma_{UU,0}} \approx \frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left[2g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}} Y_1 + g_V^e \frac{F_3^{\gamma Z}}{F_1^{\gamma}} Y_3\right]$$

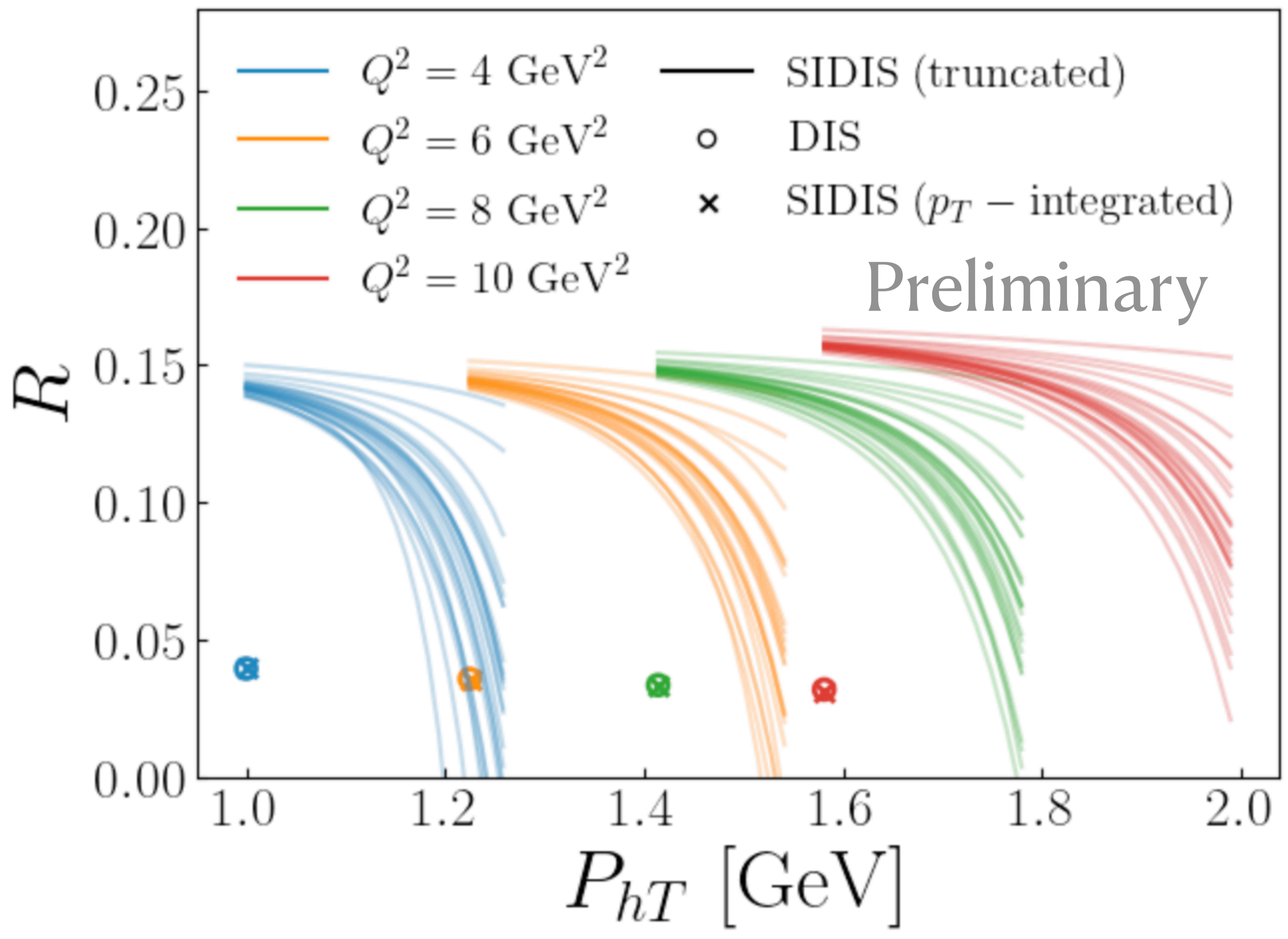
$$g_A^e = -1/2, \quad g_V^e = -1/2 + 2\sin^2\theta_{\mathrm{W}}$$

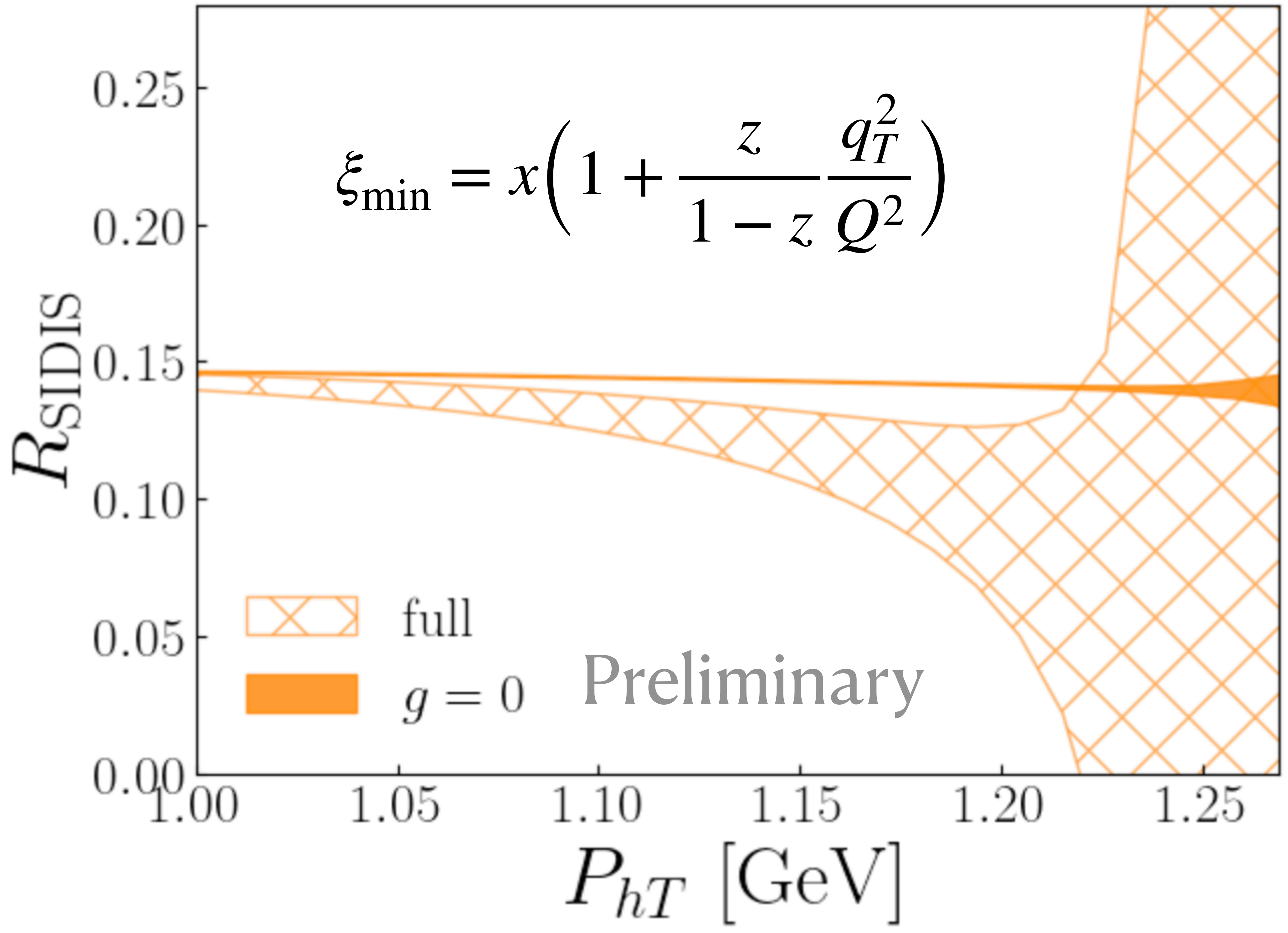
$$Y_1 = \left(\frac{1+R^{\gamma Z}}{1+R^{\gamma}}\right)\frac{1+(1-y)^2 - \frac{y^2}{2}\left[1+r^2-\frac{2r^2}{1+R^{\gamma Z}}\right]}{1+(1-y)^2 - \frac{y^2}{2}\left[1+r^2-\frac{2r^2}{1+R^{\gamma}}\right]}, \quad r^2 = 1 + \frac{4M^2x^2}{Q^2}$$

$$Y_3 = \left(\frac{1+R^{\gamma Z}}{1+R^{\gamma}}\right)\frac{1-(1-y)^2}{1+(1-y)^2 - \frac{y^2}{2}\left[1+r^2-\frac{2r^2}{1+R^{\gamma}}\right]}, \quad R^i = \frac{F_2^i}{2xF_1^i} - 1$$

Comments about $R_{\text{DIS}}/R_{\text{SIDIS}}$

$$\sigma_0 = F_{UU,L} + \varepsilon F_{UU,T} \Rightarrow R = \frac{F_{UU,L}}{F_{UU,T}}$$



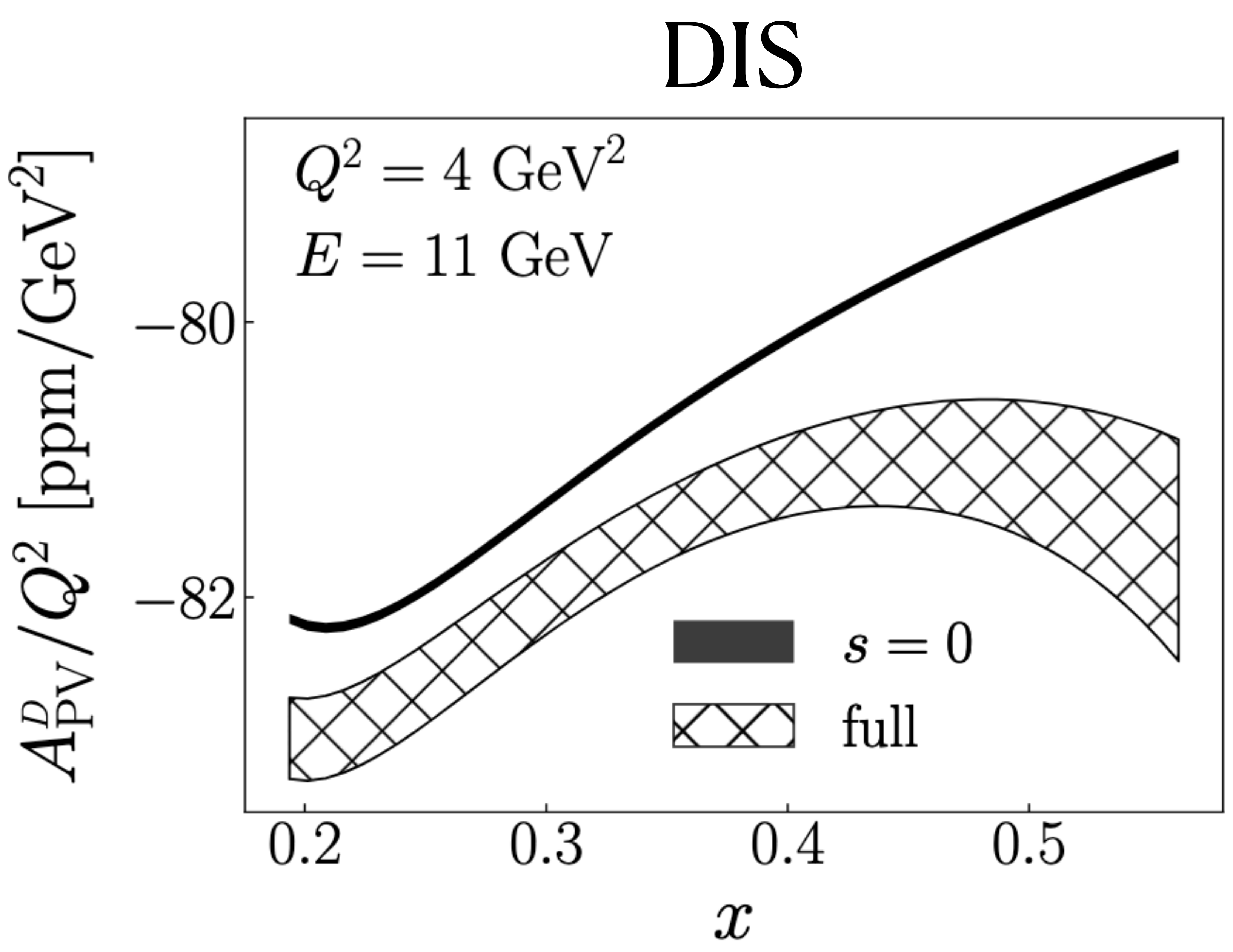


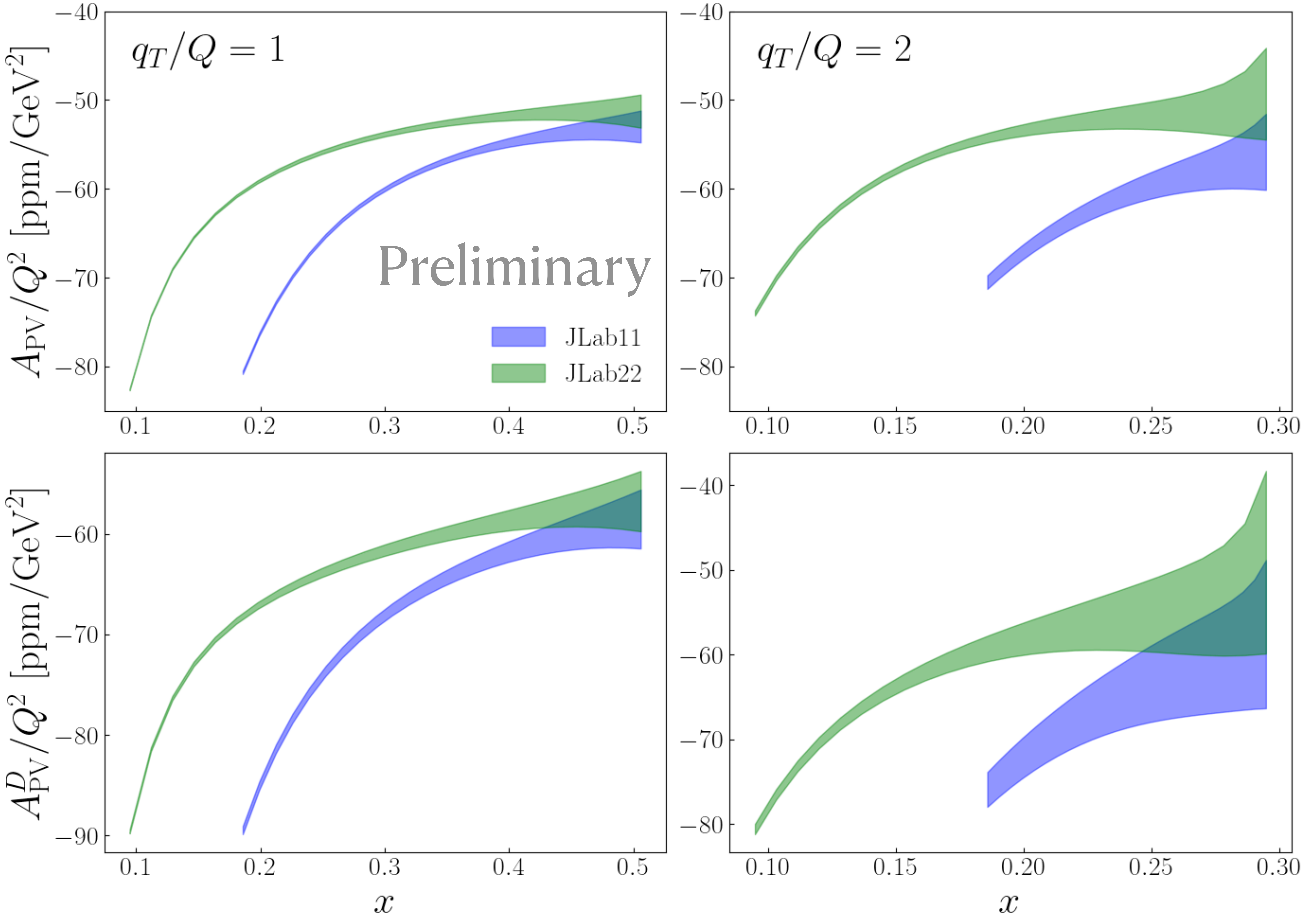
(1) important interplay between R_{SIDIS} and A_{PV}

(2) can constrain high-x glue

Whitehill *et al.*, In Preparation (2025)

$A_{\rm PV}$ in SIDIS





$$A^D_{\rm PV,DIS} \approx -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left[\left(\frac{9}{5} - 4\sin^2\theta_{\rm W}\right) + \frac{2}{25}\frac{s^+}{u^+ + d^+}\right]$$

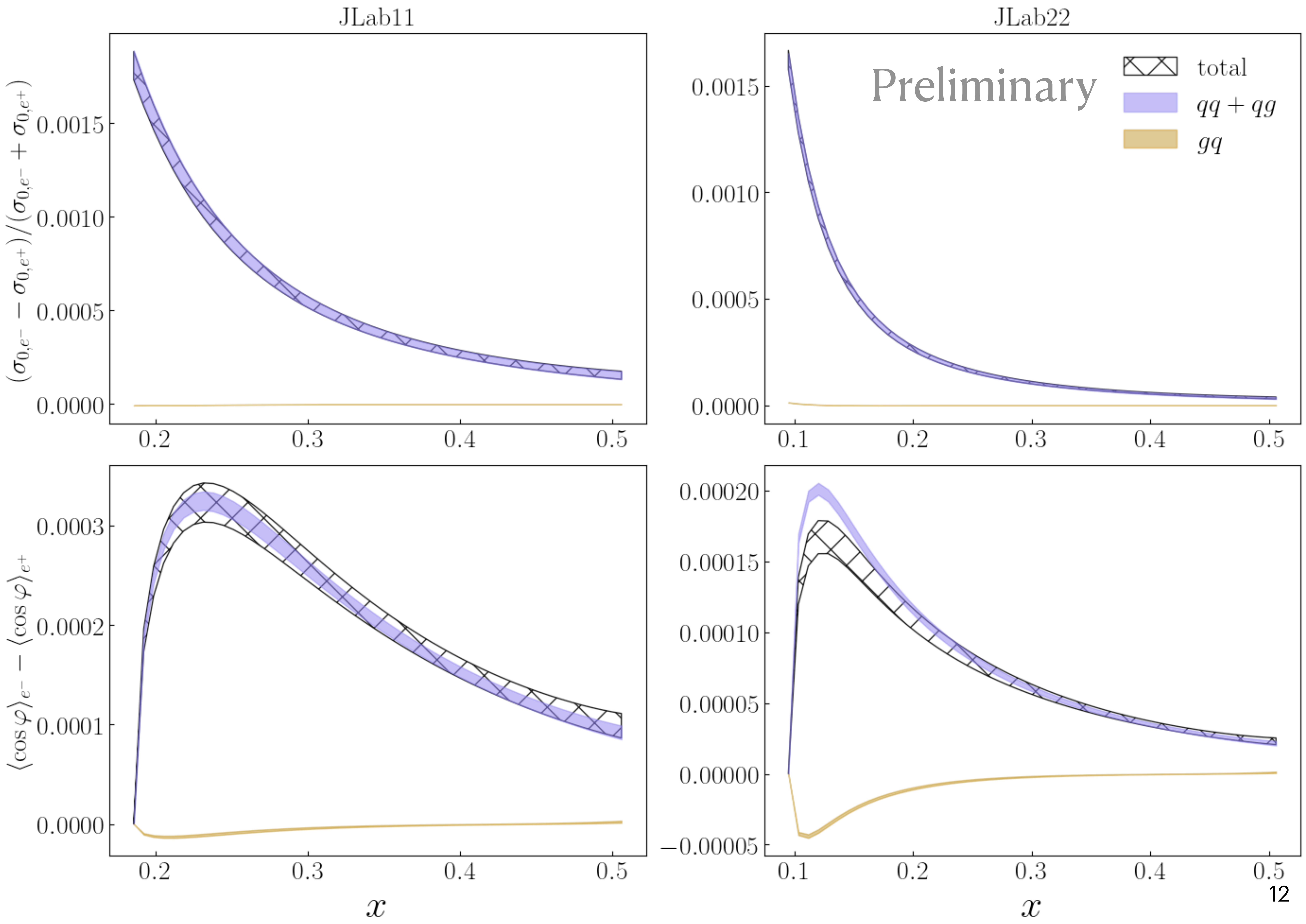
SIDIS has (1) stronger dependence on x, (2) larger uncertainty at high-p_T

Lepton charge asymmetry

$$\frac{\sigma_{0,e^-} - \sigma_{0,e^+}}{\sigma_{0,e^-} + \sigma_{0,e^+}} \approx \frac{\sigma_{0,e^-} - \sigma_{0,e^+}}{2\sigma_0^\gamma} \sim \frac{\mathscr{F}_6^{\gamma Z}}{F_1^\gamma}$$

$$\langle \cos\varphi \rangle_{e^-} - \langle \cos\varphi \rangle_{e^+} = \frac{\sigma_{1,e^-}}{\sigma_{0,e^-}} - \frac{\sigma_{1,e^+}}{\sigma_{0,e^+}}$$

$$\approx \frac{\sigma_{0,e^-} - \sigma_{0,e^+}}{\sigma_0^\gamma} \sim \frac{\mathscr{F}_5^{\gamma Z}}{F_1^\gamma}$$



Summary/Remarks

Preliminary study of PV and LCA in large-p_T SIDIS

→ lots of parallels with inclusive DIS

→ Distinct advantages in SIDIS:

(1) $A_{\rm PV}$ sensitive to strangeness — enhanced signal in SIDIS (e.g. kaon production)?

(2) extra leverage through angular modulations

→ DIS $A_{\rm PV}^{D}$ strongly sensitive to $\sin^2\theta_{\rm W}$ ⇒ primed for tests of BSM physics

→ SIDIS depends more strongly on kinematics ⇒ is $\sin^2\theta_{\rm W}$ signal weaker?

→ How much does QED radiation modify the story? Other systematic effects … ?