Probing the four-fermion operators via the transverse double spin asymmetry at the Electron-Ion Collider

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arxiv: 2312.xxxxx

第十七届TeV工作组学术研讨会

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SMEFT confronted with NP effects

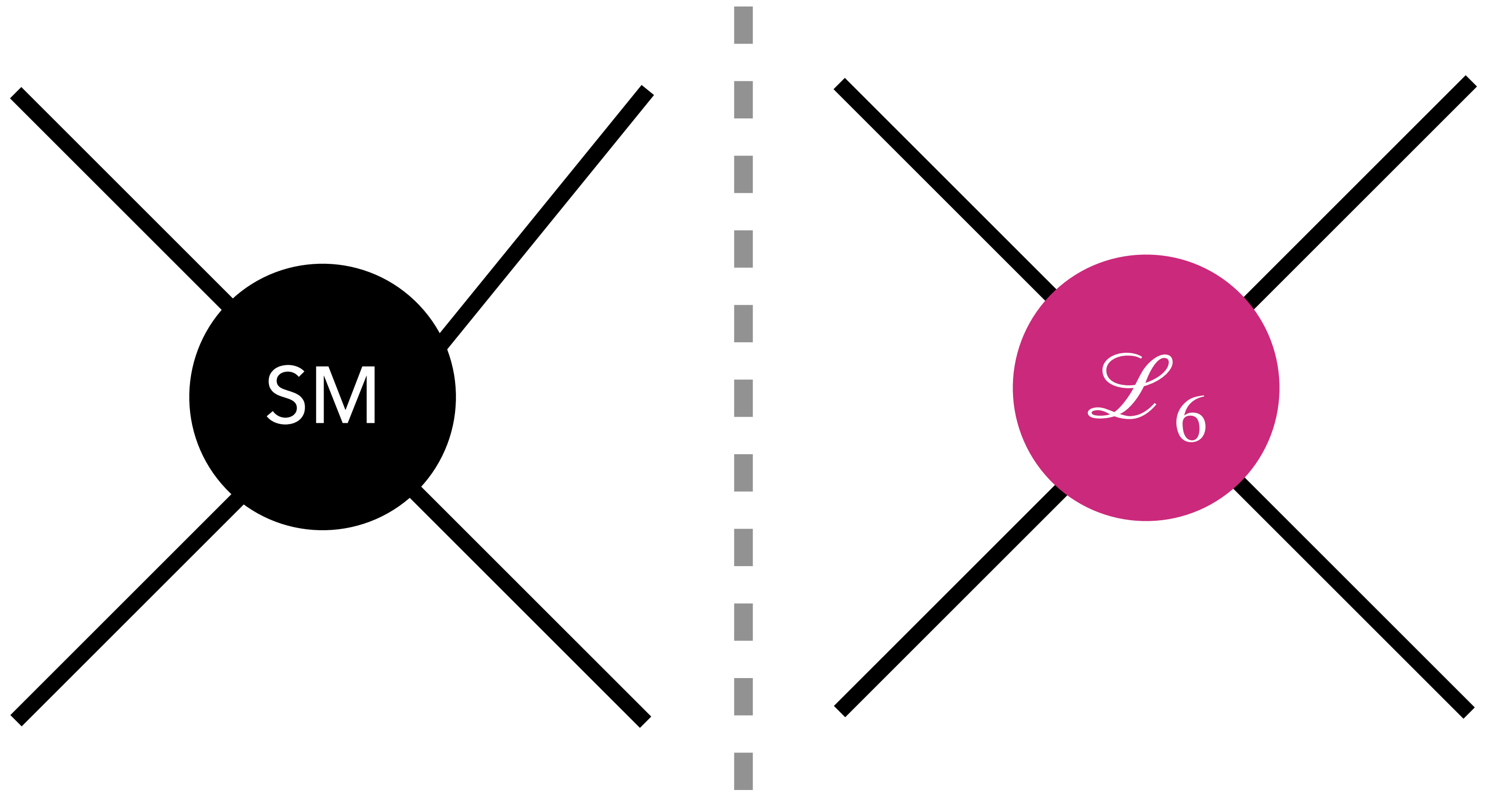
Null result in searching for new particles → **Assume no new light particle with $m < \Lambda_{\mathrm{EW}}$**

$$\mathscr{L}_{\mathrm{SMEFT}} = \mathscr{L}_{\mathrm{SM}} + \mathscr{L}_5 + \mathscr{L}_6 + \mathscr{L}_7 + \cdots$$

$$\frac{\Gamma_i}{\Lambda^2} O_i^{(6)} \qquad C_i \equiv \Gamma_i / \Lambda^2$$

- **Gauge symmetry:** $SU(3)_C \times SU(2)_L \times U(1)_Y$
- **Dynamical degrees of freedom: SM fields**

Λ: NP scale



$$\sim \mathcal{O}(\frac{1}{\Lambda^2})$$

SMEFT confronted with NP effects

$$\mathscr{L}_{\mathrm{SMEFT}} = \mathscr{L}_{\mathrm{SM}} + \mathscr{L}_5 + \mathscr{L}_6 + \mathscr{L}_7 + \cdots \qquad \frac{\Gamma_i}{\Lambda^2} O_i^{(6)}$$

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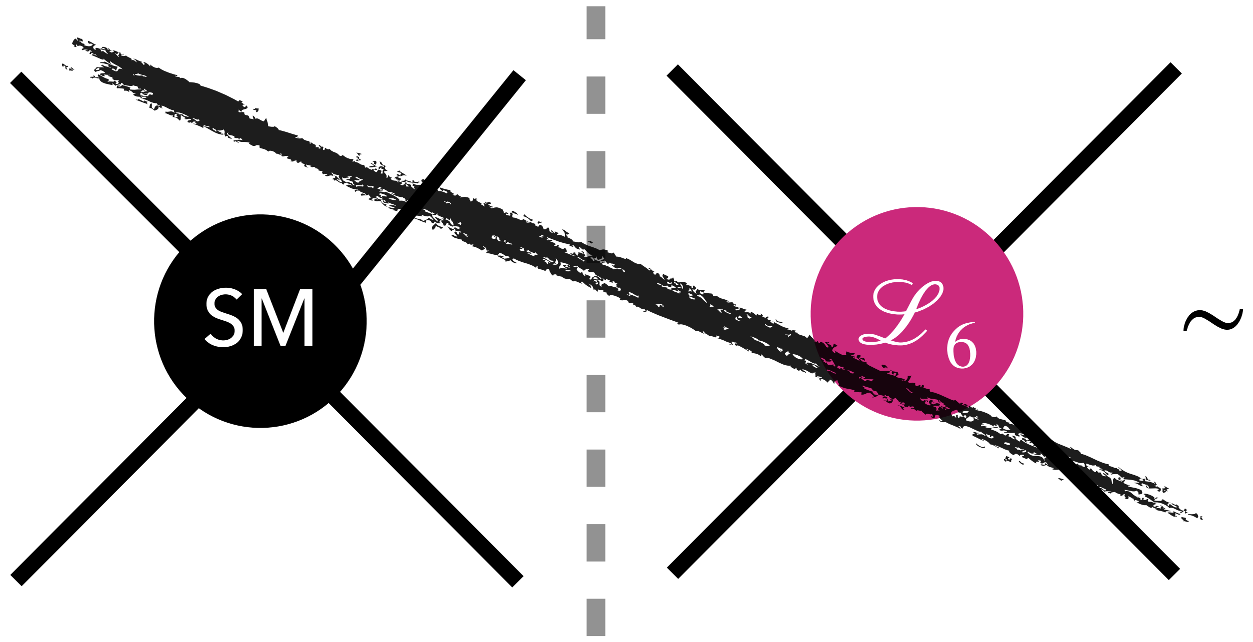
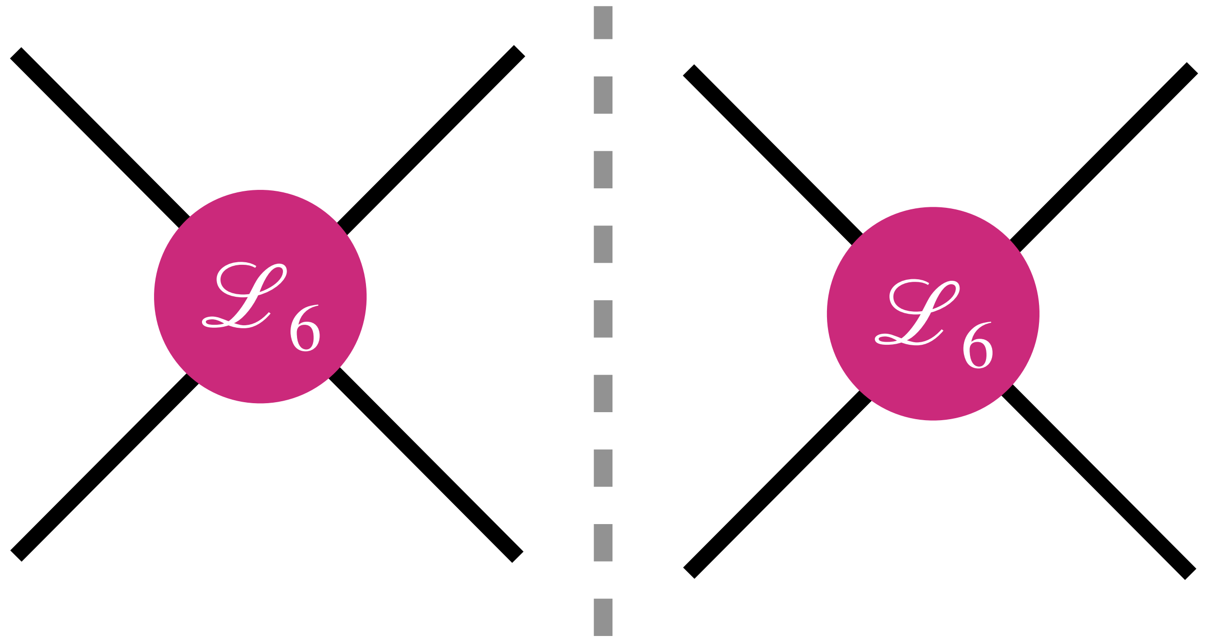


$\sim \mathscr{O}(\frac{1}{\Lambda^2})$



$\sim \mathscr{O}(\frac{1}{\Lambda^4})$

B. Grzadkowski, et al., 1008.4884

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar l_p e_r \varphi)$
$Q_{\widetilde G}$	$f^{ABC} \widetilde G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p u_r \widetilde\varphi)$
Q_W	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star \left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p d_r \varphi)$
$Q_{\widetilde W}$	$\varepsilon^{IJK} \widetilde W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				

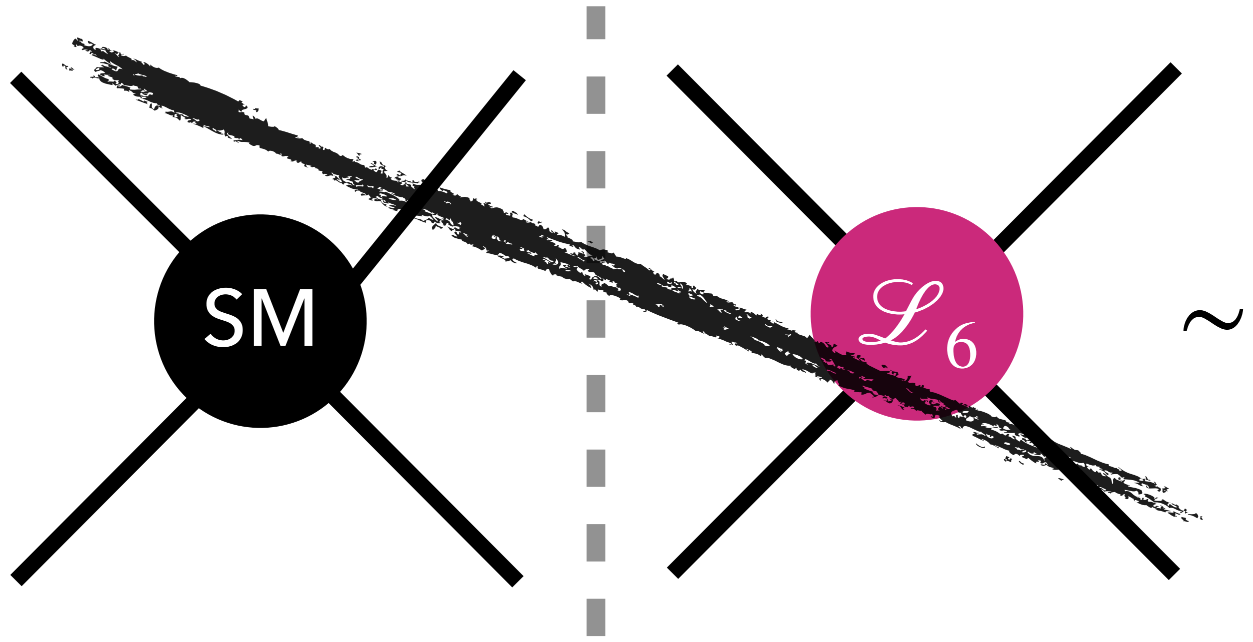
$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eW}	$(\bar l_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar l_p \gamma^\mu l_r)$
$Q_{\varphi\widetilde G}$	$\varphi^\dagger\varphi\, \widetilde G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eB}	$(\bar l_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar l_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uG}	$(\bar q_p \sigma^{\mu\nu} T^A u_r)\widetilde\varphi\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar e_p \gamma^\mu e_r)$
$Q_{\varphi\widetilde W}$	$\varphi^\dagger\varphi\, \widetilde W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uW}	$(\bar q_p \sigma^{\mu\nu} u_r)\tau^I \widetilde\varphi\, W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar q_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar q_p \sigma^{\mu\nu} u_r)\widetilde\varphi\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar q_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi\widetilde B}$	$\varphi^\dagger\varphi\, \widetilde B_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar q_p \sigma^{\mu\nu} T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar u_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar q_p \sigma^{\mu\nu} d_r)\tau^I \varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar d_p \gamma^\mu d_r)$
$Q_{\varphi\widetilde WB}$	$\varphi^\dagger\tau^I\varphi\, \widetilde W^I_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar q_p \sigma^{\mu\nu} d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde\varphi^\dagger D_\mu \varphi)(\bar u_p \gamma^\mu d_r)$

SMEFT confronted with NP effects

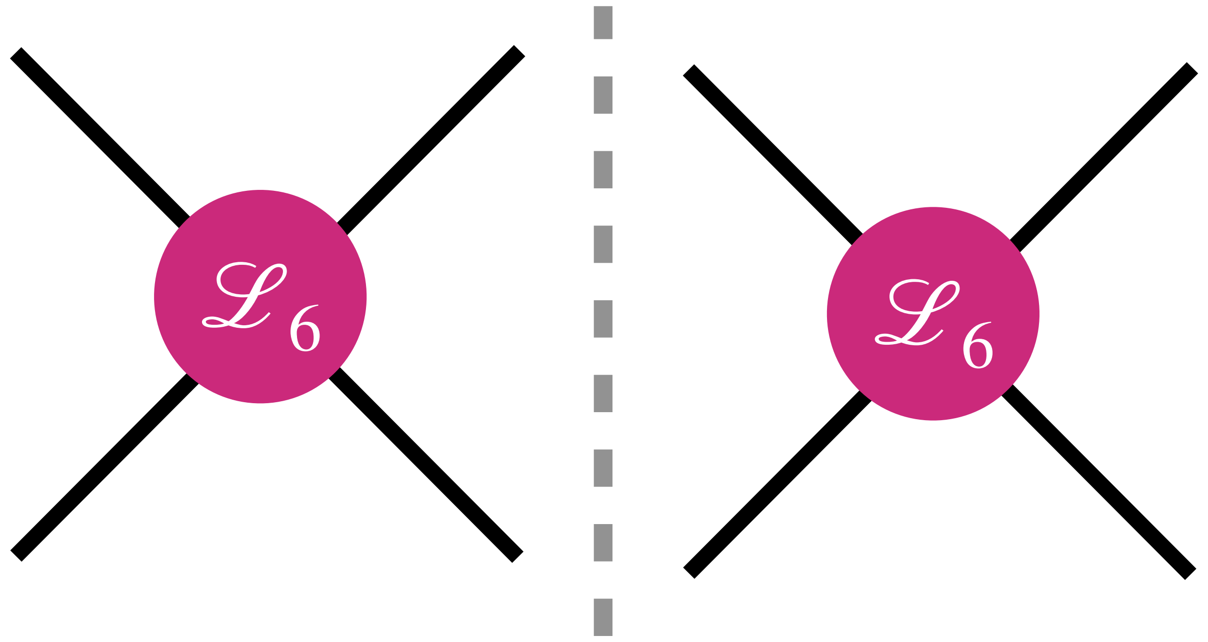
$$\mathscr{L}_{\rm SMEFT} = \mathscr{L}_{\rm SM} + \mathscr{L}_5 + \mathscr{L}_6 + \mathscr{L}_7 + \cdots \qquad \frac{\Gamma_i}{\Lambda^2} O_i^{(6)}$$

Λ: NP scale

B. Grzadkowski, et al., 1008.4884



$\sim \mathcal{O}(\frac{1}{\Lambda^2})$



$\sim \mathcal{O}(\frac{1}{\Lambda^4})$

$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$	Q_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{lu}	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{dd}	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$	Q_{ld}	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{eu}	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{qe}	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p\gamma_\mu\tau^I l_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{ed}	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
				$Q_{qd}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

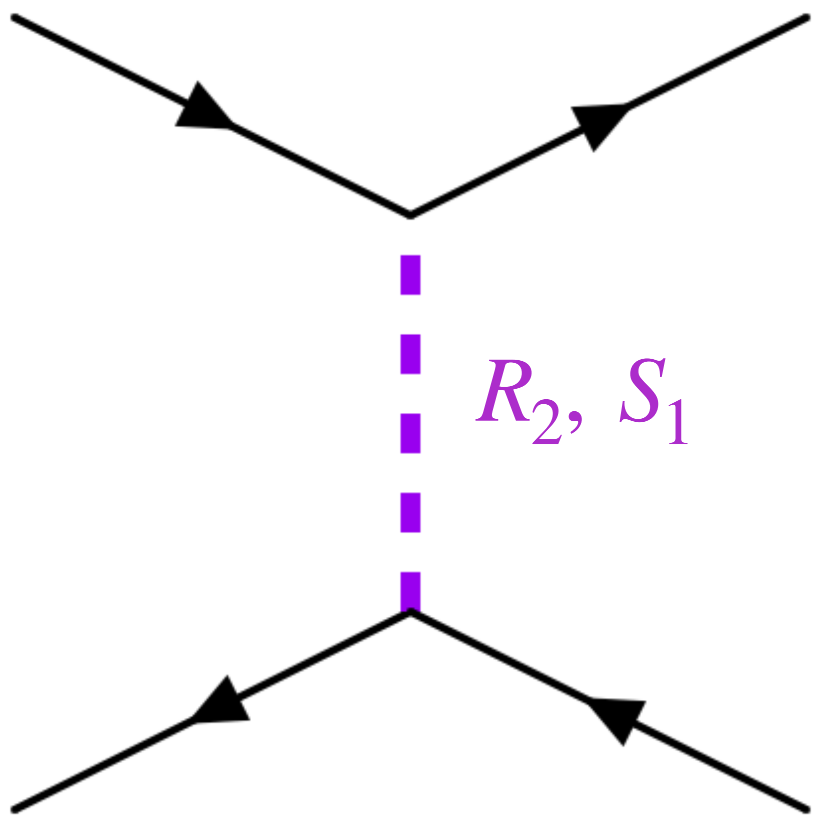
$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-violating	
Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(q_s^{\gamma j})^T C l_t^k\right]$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r)\varepsilon_{jk}(\bar{q}_s^k d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r)\varepsilon_{jk}(\bar{q}_s^k T^A d_t)$	Q_{qqq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r)\varepsilon_{jk}(\bar{q}_s^k u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar{q}_s^k \sigma^{\mu\nu} u_t)$		

SMEFT confronted with NP effects

$\psi^2 X \varphi$	
Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$
Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$
Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r)\widetilde{\varphi}\, G^A_{\mu\nu}$
Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\tau^I \widetilde{\varphi}\, W^I_{\mu\nu}$
Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\widetilde{\varphi}\, B_{\mu\nu}$
Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r)\varphi\, G^A_{\mu\nu}$
Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\tau^I \varphi\, W^I_{\mu\nu}$
Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\varphi\, B_{\mu\nu}$

Muon g-2

D. P. Aguillard et al. (Muon g-2), 2308.06230



$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	
Q_{ledq}	$(\bar{l}^j_p e_r)(\bar{d}_s q^j_t)$
$Q^{(1)}_{quqd}$	$(\bar{q}^j_p u_r)\varepsilon_{jk}(\bar{q}^k_s d_t)$
$Q^{(8)}_{quqd}$	$(\bar{q}^j_p T^A u_r)\varepsilon_{jk}(\bar{q}^k_s T^A d_t)$
$Q^{(1)}_{lequ}$	$(\bar{l}^j_p e_r)\varepsilon_{jk}(\bar{q}^k_s u_t)$
$Q^{(3)}_{lequ}$	$(\bar{l}^j_p \sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar{q}^k_s \sigma^{\mu\nu} u_t)$

Leptoquark

$S_1 \sim (3, 1, -1/3)$
$R_2 \sim (3, 2, 7/6)$

➡ $R_{D^{(*)}}$, muon g-2

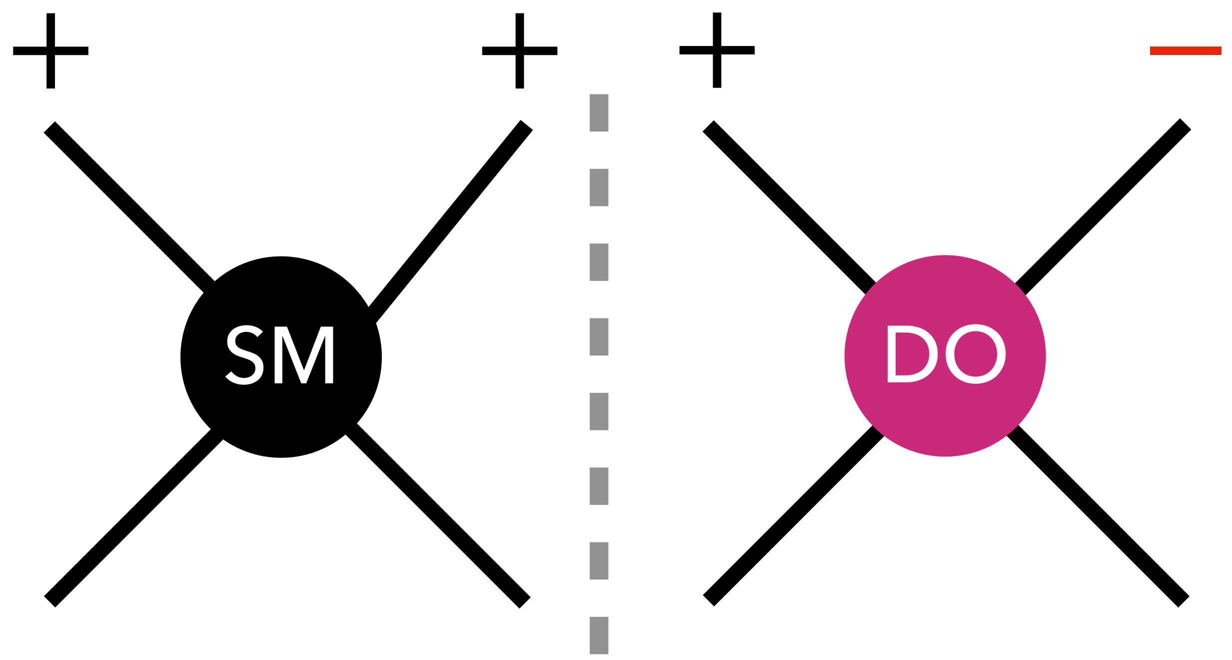
Babu et al., 2009.01771

Lee, 2104.02982

Aebischer et al., 2102.08954

How to extract such NP effects at $\mathcal{O}(1/\Lambda^2)$?

Transverse spin asymmetry



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$\psi^2 X \varphi$	
Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$
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Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r)\varphi\, G^A_{\mu\nu}$
Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\tau^I \varphi\, W^I_{\mu\nu}$
Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\varphi\, B_{\mu\nu}$

- Single-spin asymmetry (SSA): ep collider

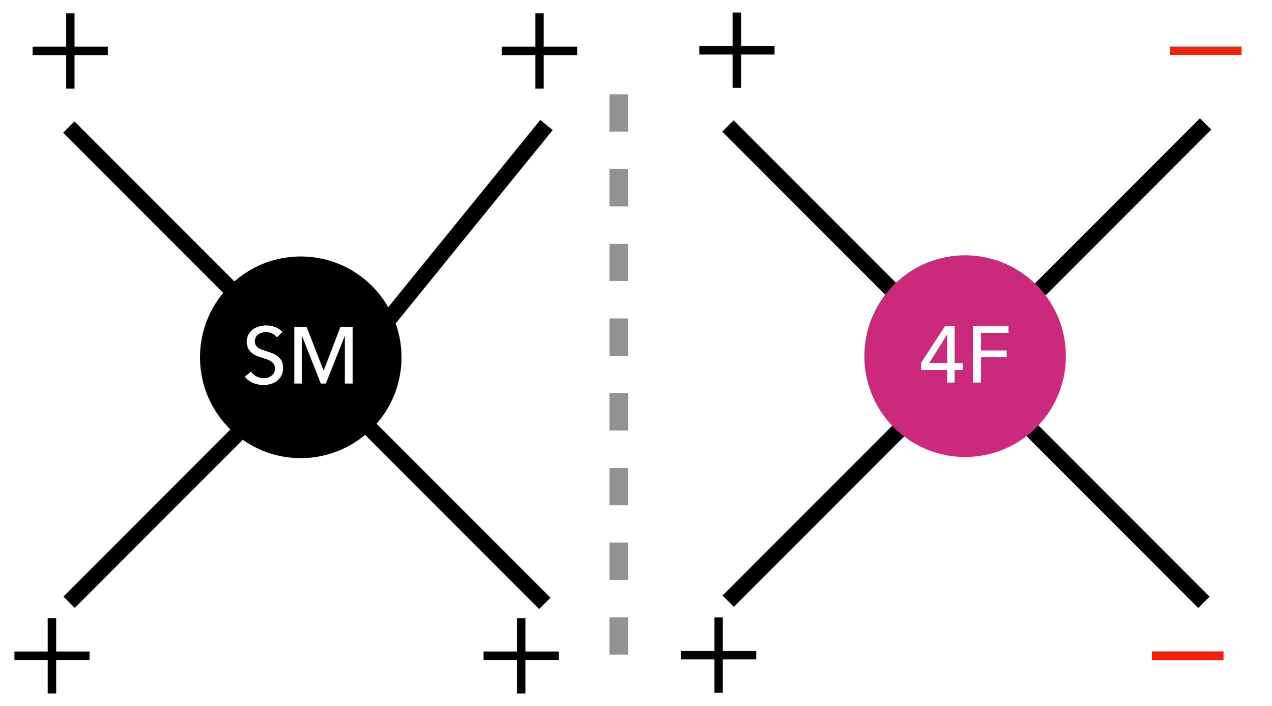
$$A_{TU} = \frac{\sigma\left(e^{\uparrow} p^{U}\right) - \sigma\left(e^{\downarrow} p^{U}\right)}{\sigma\left(e^{\uparrow} p^{U}\right) + \sigma\left(e^{\downarrow} p^{U}\right)}, \qquad A_{UT} = \frac{\sigma\left(e^{U} p^{\uparrow}\right) - \sigma\left(e^{U} p^{\downarrow}\right)}{\sigma\left(e^{U} p^{\uparrow}\right) + \sigma\left(e^{U} p^{\downarrow}\right)}$$

R.Boughezal et al., 2301.02304

Future lepton collider: **X. K. Wen's talk** Wen, Yan, Yu, Yuan, 2307.05236

How to extract such NP effects at $\mathcal{O}(1/\Lambda^2)$?

Transverse spin asymmetry



$\sim \mathcal{O}(\frac{1}{\Lambda^2})$

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Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r)\widetilde{\varphi}\, G^A_{\mu\nu}$
Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\tau^I \widetilde{\varphi}\, W^I_{\mu\nu}$
Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\widetilde{\varphi}\, B_{\mu\nu}$
Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r)\varphi\, G^A_{\mu\nu}$
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$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	
Q_{ledq}	$(\bar{l}^j_p e_r)(\bar{d}_s q^j_t)$
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- Single-spin asymmetry (SSA): ep collider

$$A_{TU} = \frac{\sigma(e^\uparrow p^U) - \sigma(e^\downarrow p^U)}{\sigma(e^\uparrow p^U) + \sigma(e^\downarrow p^U)}, \qquad A_{UT} = \frac{\sigma(e^U p^\uparrow) - \sigma(e^U p^\downarrow)}{\sigma(e^U p^\uparrow) + \sigma(e^U p^\downarrow)}$$

R.Boughezal et al., 2301.02304

Future lepton collider: **X. K. Wen's talk** Wen, Yan, Yu, Yuan, 2307.05236

- Double-spin asymmetry (DSA):

$$A_{TT} = \frac{\sigma(e^\uparrow p^\uparrow) + \sigma(e^\downarrow p^\downarrow) - \sigma(e^\uparrow p^\downarrow) - \sigma(e^\downarrow p^\uparrow)}{\sigma(e^\uparrow p^\uparrow) + \sigma(e^\downarrow p^\downarrow) + \sigma(e^\uparrow p^\downarrow) + \sigma(e^\downarrow p^\uparrow)}$$

Transverse DSA at future Electron-Ion colliders

This talk

Future Electron-Ion Colliders

- Forthcoming EIC in USA and planned EIC in China (EicC)
- Aiming at uncovering the fundamental questions in nuclear physics
  - Precisely determine the spin-dependent parton distribution functions (PDFs)
  - Explore and image spin and 3D structure of the nucleon
  - …

High luminosity

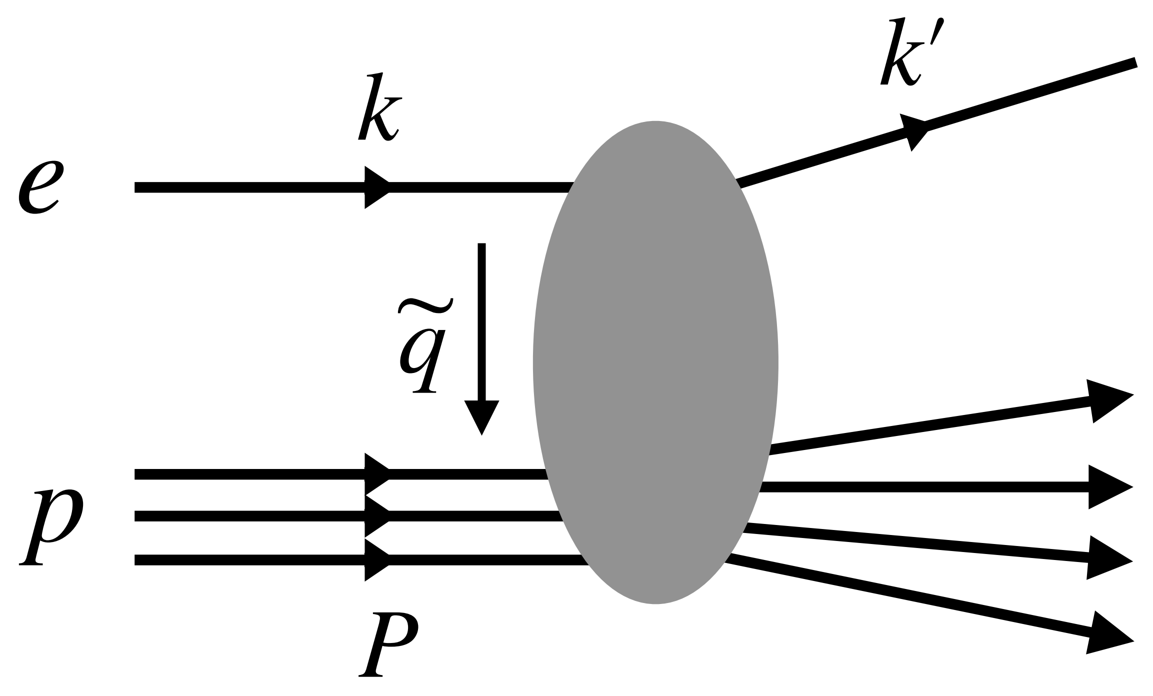
Polarize both the electron and light ion beams simultaneously

EIC Yellow Report, 2103.05419
D. P. Anderle et al., 2102.09222

- Have the potential to probe the EW properties of the SM and search for potential NP effects

Cirigliano et al., 2102.06176
Li, Yan, Yuan, 2112.07747
Yan, Yu, Yuan, 2107.02134
B. Batell et al., 2210.09287
R. Balkin et al., 2310.08827
…

Transverse DSA in the SM

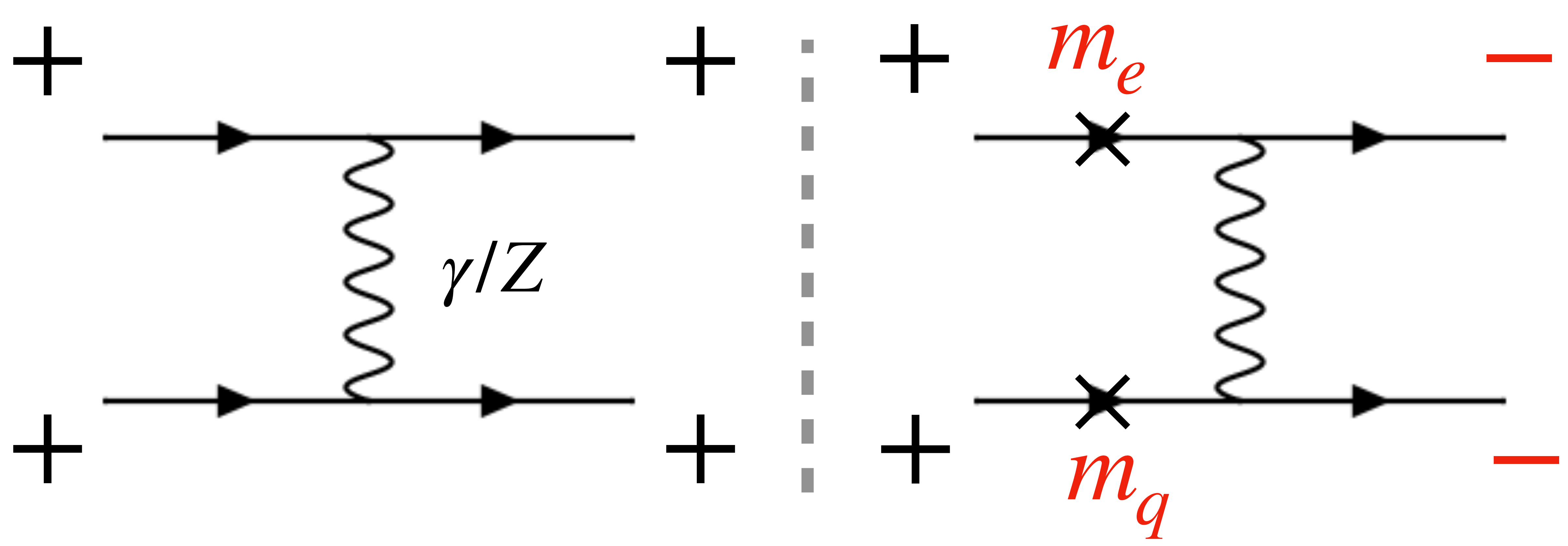


$$A_{TT} = \frac{\sigma\left(e^{\uparrow}p^{\uparrow}\right) + \sigma\left(e^{\downarrow}p^{\downarrow}\right) - \sigma\left(e^{\uparrow}p^{\downarrow}\right) - \sigma\left(e^{\downarrow}p^{\uparrow}\right)}{\sigma\left(e^{\uparrow}p^{\uparrow}\right) + \sigma\left(e^{\downarrow}p^{\downarrow}\right) + \sigma\left(e^{\uparrow}p^{\downarrow}\right) + \sigma\left(e^{\downarrow}p^{\uparrow}\right)}$$

Superscripts ↑ , ↓ :

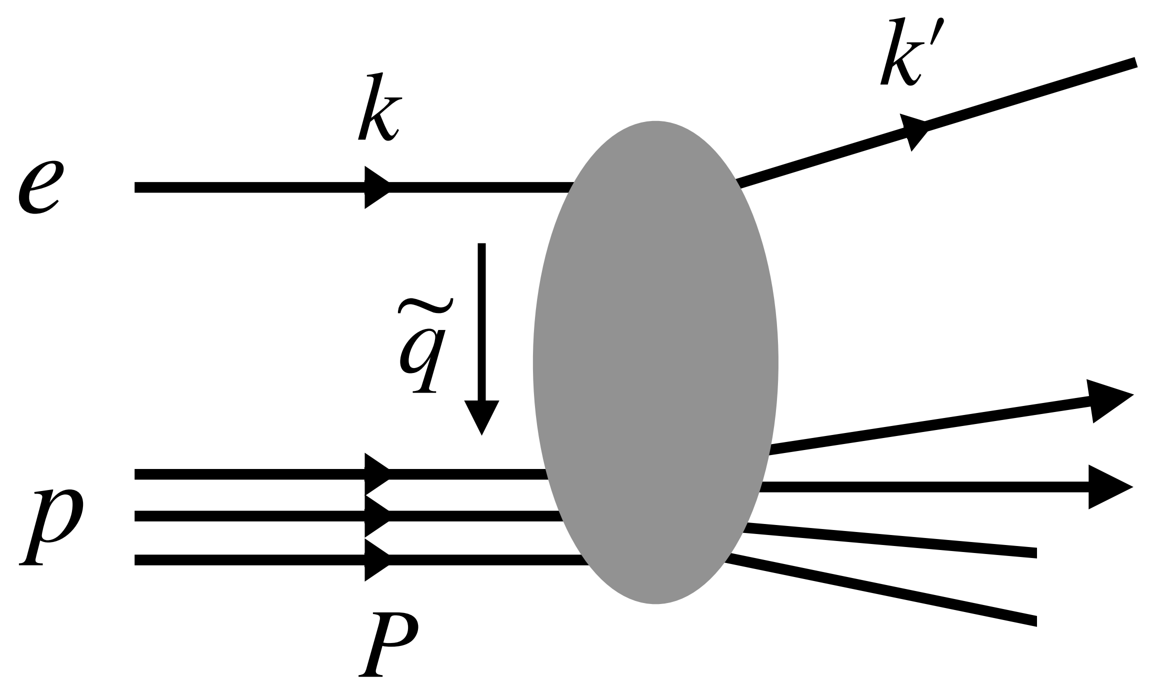
the direction of transverse spins of electron and proton

$$A_{TT}^{\mathrm{SM},\gamma} \sim m_e m_q$$



In the SM, transverse DSA is suppressed by both the electron and quark mass!

Transverse DSA in the SM



$$A_{TT} = \frac{\sigma\left(e^{\uparrow}p^{\uparrow}\right) + \sigma\left(e^{\downarrow}p^{\downarrow}\right) - \sigma\left(e^{\uparrow}p^{\downarrow}\right) - \sigma\left(e^{\downarrow}p^{\uparrow}\right)}{\sigma\left(e^{\uparrow}p^{\uparrow}\right) + \sigma\left(e^{\downarrow}p^{\downarrow}\right) + \sigma\left(e^{\uparrow}p^{\downarrow}\right) + \sigma\left(e^{\downarrow}p^{\uparrow}\right)}$$

Superscripts ↑ , ↓ :

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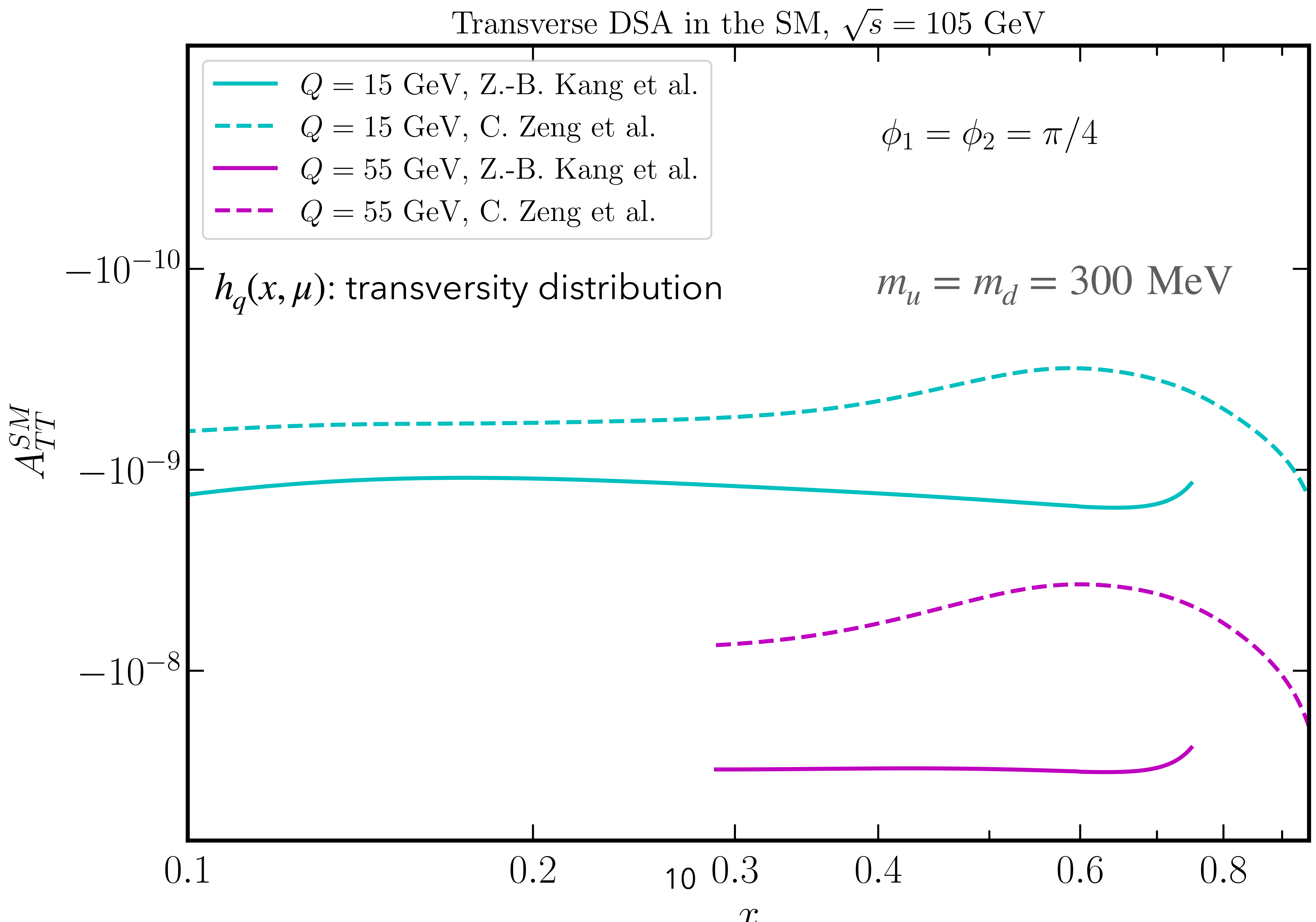
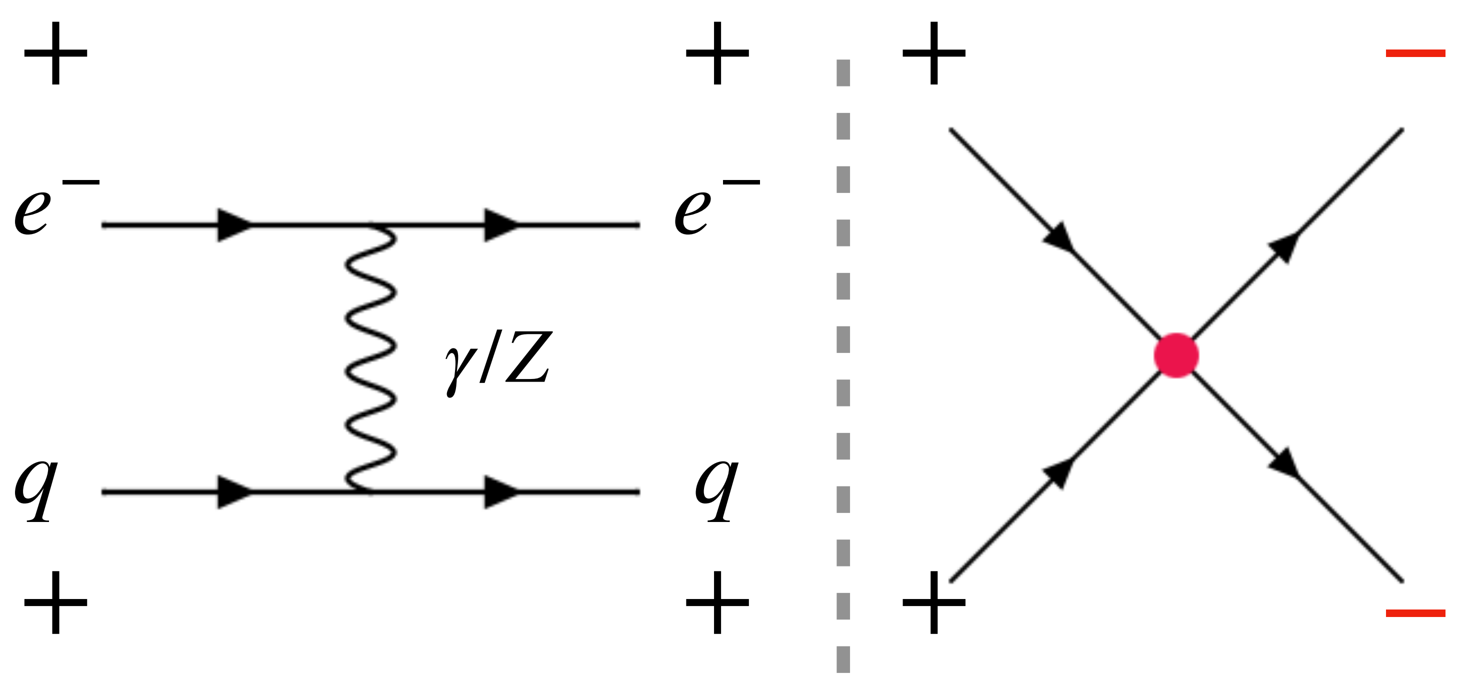


DSA is suppressed by both the electron and quark mass in the SM

Transverse DSA in the SMEFT

$$\mathcal{O}_{ledq} = (\bar{L}^j e)\,(\bar{d} Q^j)\,,$$
$$\mathcal{O}^{(1)}_{lequ} = (\bar{L}^j e)\,\epsilon_{jk}\,(\bar{Q}^k u)\,,$$
$$\mathcal{O}^{(3)}_{lequ} = (\bar{L}^j \sigma^{\mu\nu} e)\,\epsilon_{jk}\,(\bar{Q}^k \sigma_{\mu\nu} u)\,,$$



$$S^\mu_{T,e} = P_{T,e}(0, \cos\phi_1, \sin\phi_1, 0)$$
$$S^\mu_{T,p} = P_{T,p}(0, \cos\phi_2, \sin\phi_2, 0)$$

$$\Delta A_{TT}^{\mathrm{SMEFT},\gamma} = \frac{Q^2/4\pi\alpha}{\sum_q f_q(x)\left[Q_q^2(y^2-2y+2) - \mathcal{F}_Z^{eq}(Q^2)\right]} \times \left(\sum_d Q_d h_d(x,\mu)(y-y^2)\mathrm{Re}\left[C_{ledq}e^{-i\phi_+}\right] + \sum_u Q_u h_u(x) y \mathrm{Re}\left[C^{(1)}_{lequ}e^{-i\phi_-}\right] + \sum_u Q_u h_u(x) 4(y-2)\mathrm{Re}\left[C^{(3)}_{lequ}e^{-i\phi_-}\right]\right)$$

$$\Delta A_{TT}^{\mathrm{SMEFT},Z} = -\frac{1}{4\pi\alpha}\frac{Q^2}{y^2-2y+2}\frac{\tilde{\epsilon}_Q}{s_W^2 c_W^2}\frac{1}{\sum_q Q_q^2 f_q(x)} \times \left(\sum_d (y-y^2)\mathcal{G}_-^{ed} h_d(x)\mathrm{Re}\left[C_{ledq}e^{-i\phi_+}\right] + \sum_u y\mathcal{G}_+^{eu} h_u(x)\mathrm{Re}\left[C^{(1)}_{lequ}e^{-i\phi_-}\right] + \sum_u 4(y-2)\mathcal{G}_+^{eu} h_u(x)\mathrm{Re}\left[C^{(3)}_{lequ}e^{-i\phi_-}\right]\right)$$

DSA are not suppressed by the electron and quark mass in the SMEFT

$$Q^2 = -\tilde{q}^2, \quad x = \frac{Q^2}{2P\cdot\tilde{q}}, \quad y = \frac{2P\cdot\tilde{q}}{2P\cdot k},$$

$f_q(x,\mu)$: PDF

$h_q(x,\mu)$: transversity distribution

Transverse DSA in the SMEFT

- Define the integrated asymmetry for the special case: $\phi_1 = \phi_2 \equiv \phi$:

$$A_{TT}^{w} = \int_0^{2\pi} d\phi \; w(\phi) A_{TT}(\phi)$$

Weight function

$w(\phi) = \cos(2\phi)$	$\mathrm{Re}[C_{ledq}]$
$w(\phi) = \sin(2\phi)$	$\mathrm{Im}[C_{ledq}]$
$w(\phi) = 1$	$\mathrm{Re}\left[C_{lequ}^{(1)}\right]$, $\mathrm{Re}\left[C_{lequ}^{(3)}\right]$

- Adopt two extractions of quark transversity distribution:

Both obtained from the global analyses of the Collins asymmetries in SIDIS and SI e^-e^+ annihilation process measurement within the TMD factorization

$$h_1^q(x, Q_0) = N_q^h x^{a_q}(1-x)^{b_q} \frac{(a_q+b_q)^{a_q+b_q}}{a_q^{a_q} b_q^{b_q}} \times \frac{1}{2}\left(f_1^q(x, Q_0) + g_1^q(x, Q_0)\right),$$

- $h_u \neq 0,\ h_d \neq 0$

Kang, Prokudin, Sun, Yuan, PRD 93, 014009 (2016), 1505.05589

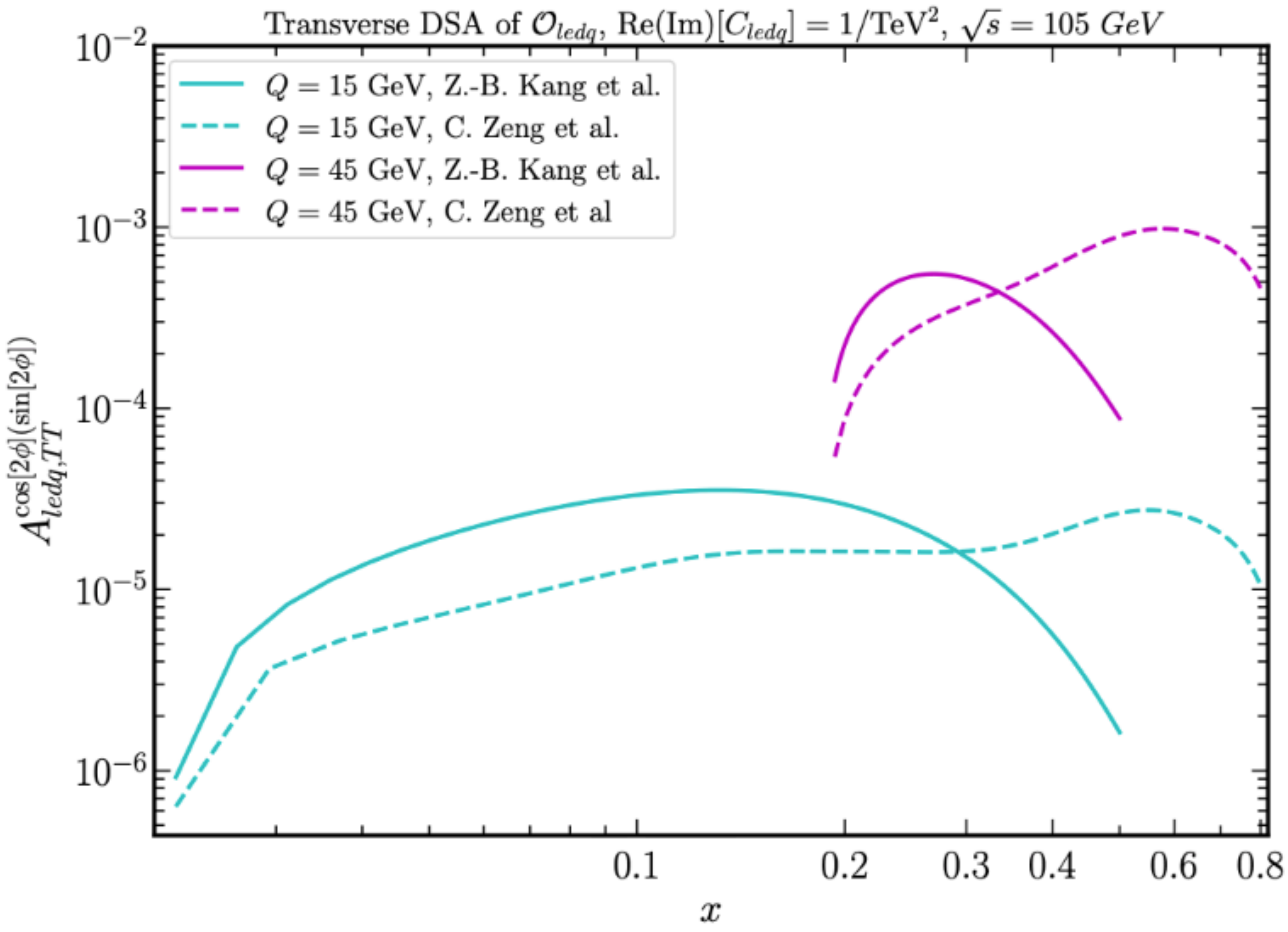
$$h_{1,u\leftarrow p}(x,\mu_0) = N_u \frac{(1-x)^{\alpha_u} x^{\beta_u}(1+\epsilon_u x)}{n(\beta_u, \epsilon_u, \alpha_u)} \times f_{1,u\leftarrow p}(x,\mu_0),$$

$$h_{1,\bar{u}\leftarrow p}(x,\mu_0) = N_{\bar{u}} \frac{(1-x)^{\alpha_{\bar{u}}} x^{\beta_{\bar{u}}}(1+\epsilon_{\bar{u}} x)}{n(\beta_{\bar{u}}, \epsilon_{\bar{u}}, \alpha_{\bar{u}})} \times \Big(f_{1,u\leftarrow p}(x,\mu_0) - f_{1,\bar{u}\leftarrow p}(x,\mu_0)\Big),$$

- $h_u \neq 0,\ h_d \neq 0,\ h_{\bar{u}} \neq 0,\ h_{\bar{d}} \neq 0$

Zeng, Dong, Liu, Sun, and Zhao, 2310.15532

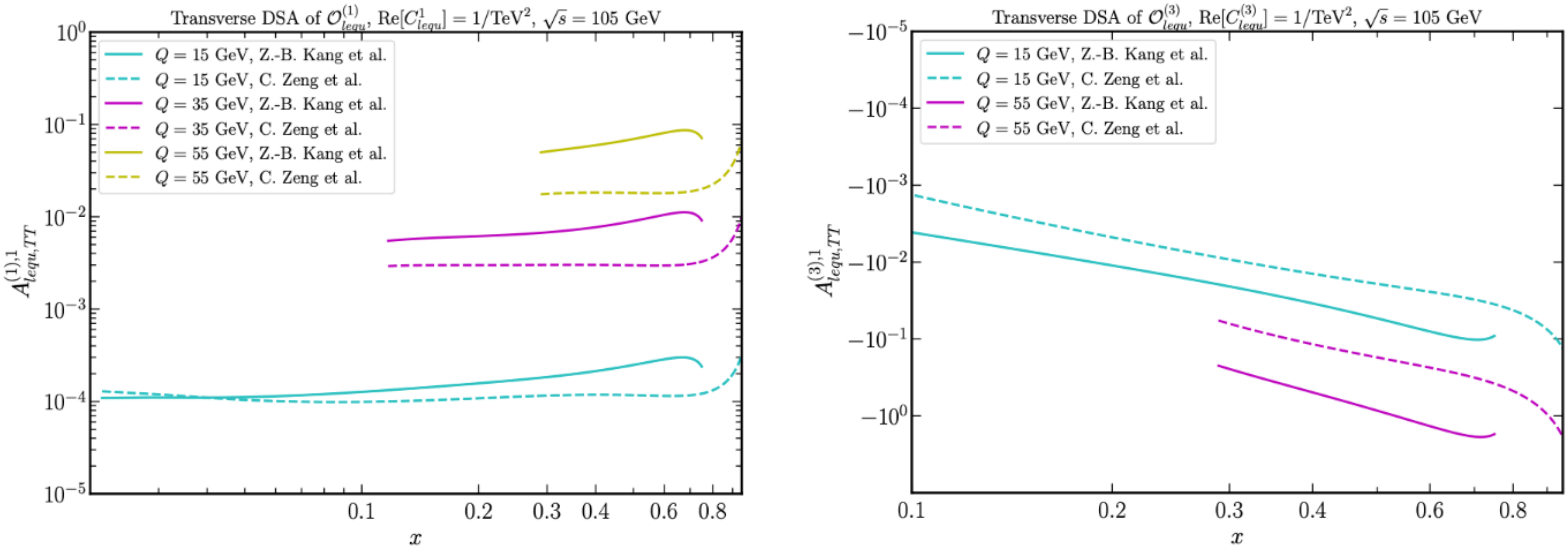
Transverse DSA in the SMEFT



$$\mathcal{O}_{ledq} = (\bar{L}^j e)(\bar{d} Q^j),$$
$$\mathcal{O}^{(1)}_{lequ} = (\bar{L}^j e)\,\epsilon_{jk}\,(\bar{Q}^k u),$$
$$\mathcal{O}^{(3)}_{lequ} = (\bar{L}^j \sigma^{\mu\nu} e)\,\epsilon_{jk}\,(\bar{Q}^k \sigma_{\mu\nu} u),$$

$$A^w_{TT} = \int_0^{2\pi} d\phi\, w(\phi) A_{TT}(\phi)$$

Transverse DSA in the SMEFT



Significant enhancements for $\mathcal{O}^{(1)}_{lequ}$ and $\mathcal{O}^{(3)}_{lequ}$

Sensitivity at EIC and EicC

$$A_{TT}^{w} = \frac{1}{|P_{T,e}||P_{T,p}|}\frac{\int_0^{2\pi} d\phi w(\phi)\Big(N\uparrow\uparrow(\phi) + N\downarrow\downarrow(\phi) - N\uparrow\downarrow(\phi) - N\downarrow\uparrow(\phi)\Big)}{N\uparrow\uparrow + N\downarrow\downarrow + N\uparrow\downarrow + N\downarrow\uparrow}$$

$$\delta A_{TT} \simeq = \frac{1/|P_{T,e}||P_{T,p}|}{\sqrt{4\mathscr{L}\sigma(P_{T,e(p)} = 0)}},$$

EIC: $\sqrt{S} = 105$ GeV, $Q \in [15,65]$ GeV

EicC: $\sqrt{S} = 16.7$ GeV, $Q \in [6,11]$ GeV

$$\chi^2 = \sum_i \left[\frac{A_i^{\rm th} - A_i^{\rm exp}}{\delta A_i}\right]^2$$

Bins across the (Q, x) space

$x \in [0.1, 0.8]$

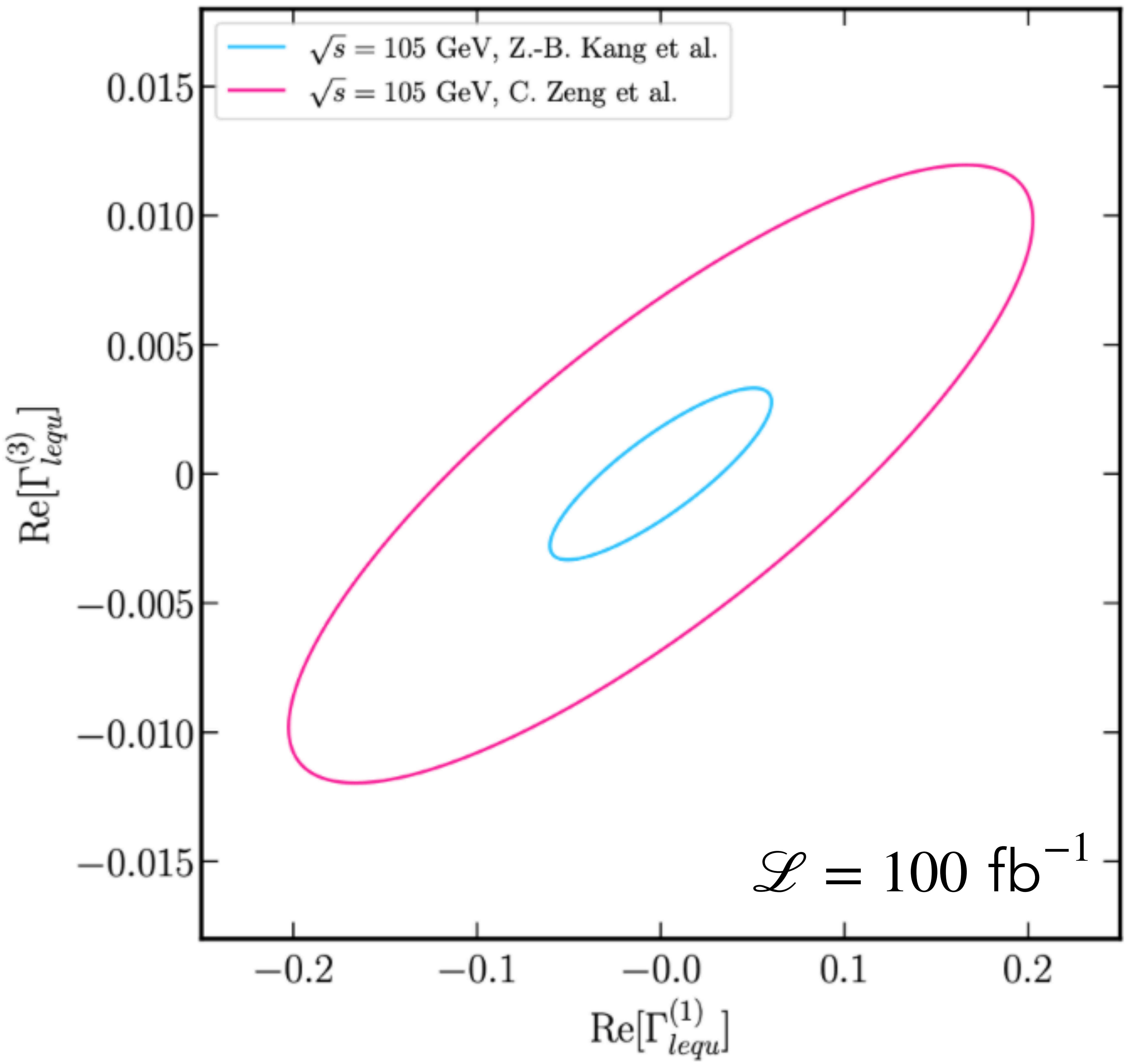
$0.01 \leq y \leq 0.95$

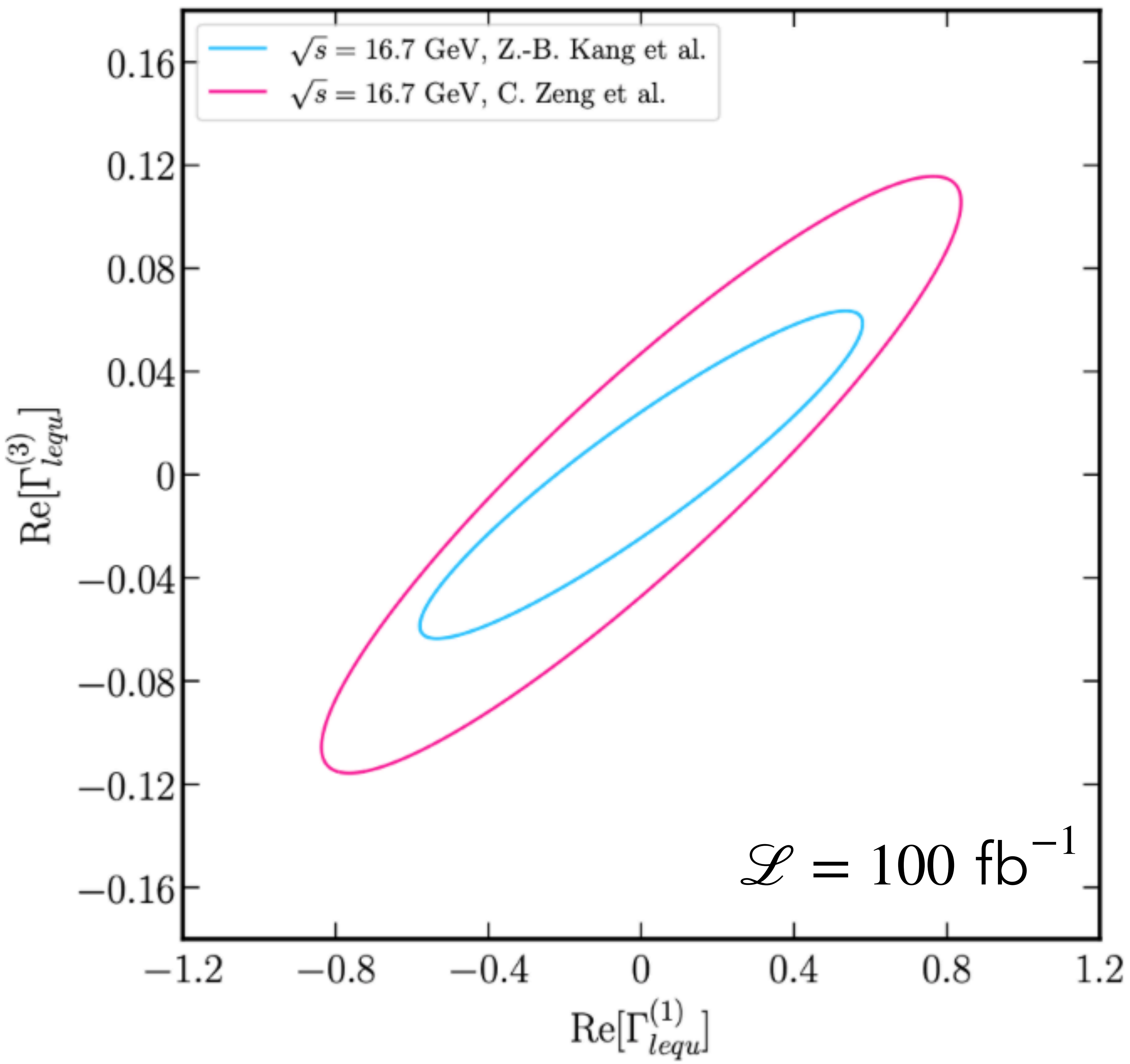
$|P_{T,e}| = |P_{T,p}| = 0.7$

$\mathscr{L} = 100\ \text{fb}^{-1}$

CM energy	Transversity	Limits on $\sqrt{C_i^{-1}}$ [TeV]		
		$\mathcal{O}_{ledq}$	$\mathcal{O}_{lequ}^{(1)}$	$\mathcal{O}_{lequ}^{(3)}$
EIC with $E_{\rm cm} = 105$ GeV	Z.-B. Kang et al.	0.91	6.78	28.88
	C. Zeng et al.	0.97	3.61	14.86
EicC with $E_{\rm cm} = 16.7$ GeV	Z.-B. Kang et al.	0.35	2.66	8.40
	C. Zeng et al.	0.57	2.10	6.51

Sensitivity at EIC and EicC



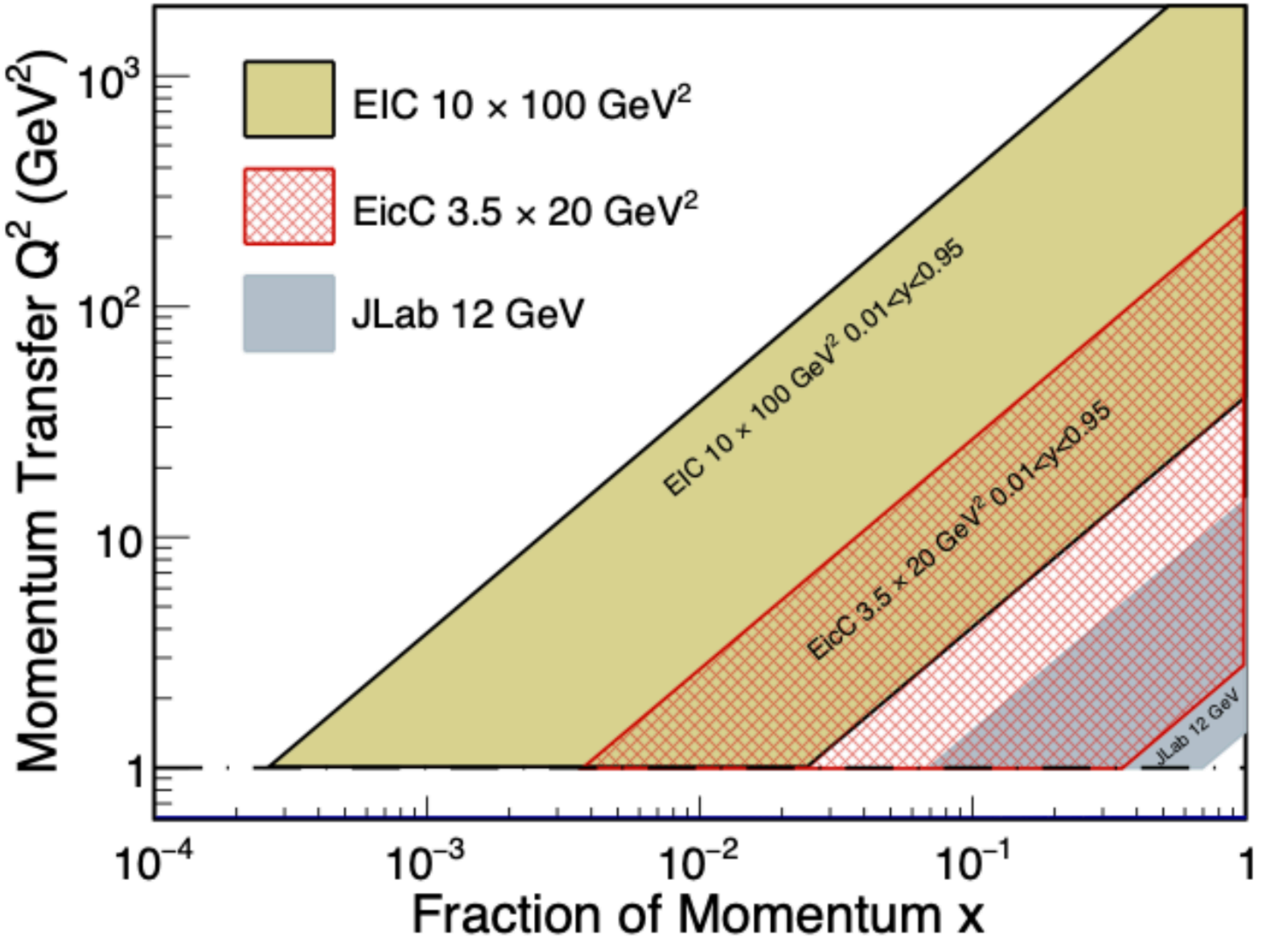


Summary

- We explored the possibilities of probing the scalar and tensor type four-fermion operators by using the transverse DSA of the electron and proton beams in inclusive DIS at the EIC/EicC
- We demonstrate that the interference between these operators and SM leads to nontrival azimuthal $\cos 2\phi$ and $\sin 2\phi$ distributions and are linearly dependent on the Wilson coefficients associated with these operators at the $\mathcal{O}(1/\Lambda^2)$, without any suppression from the electron and quark masses
- The results depend on the quark transversities, which are expected to be precisely determined at EIC & EicC
- The results are not significantly affected by the presence of other NP operators in DIS process

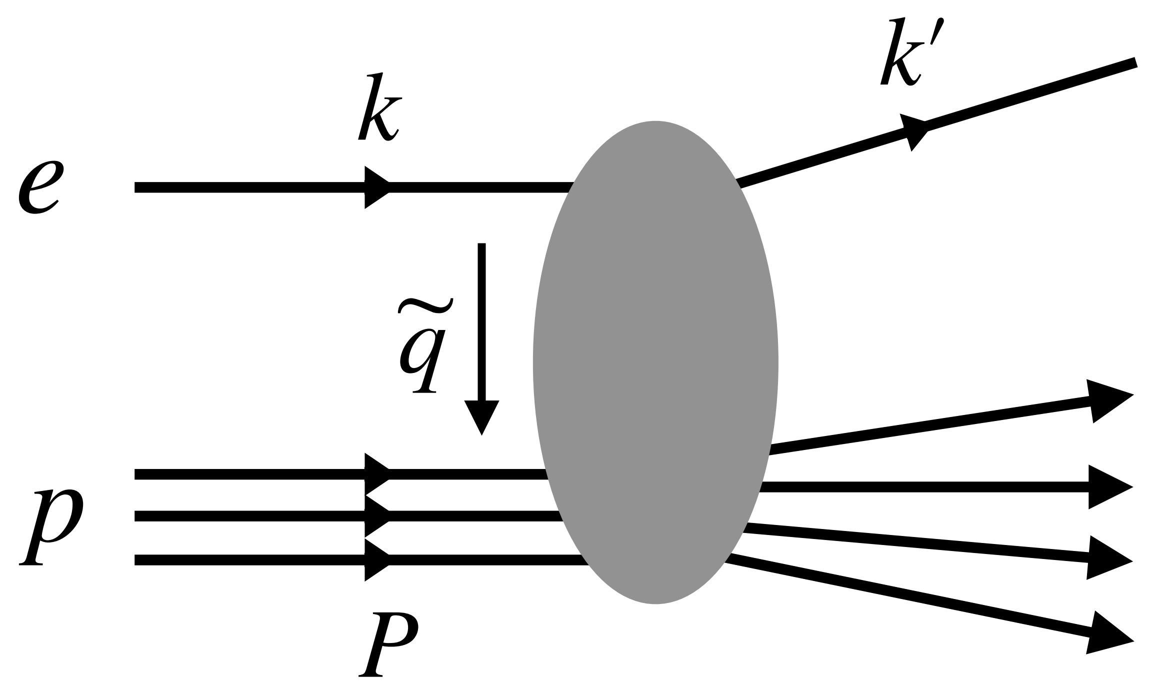
Thank You!

Future Electron-Ion Colliders



D. P. Anderle et al., 2102.09222

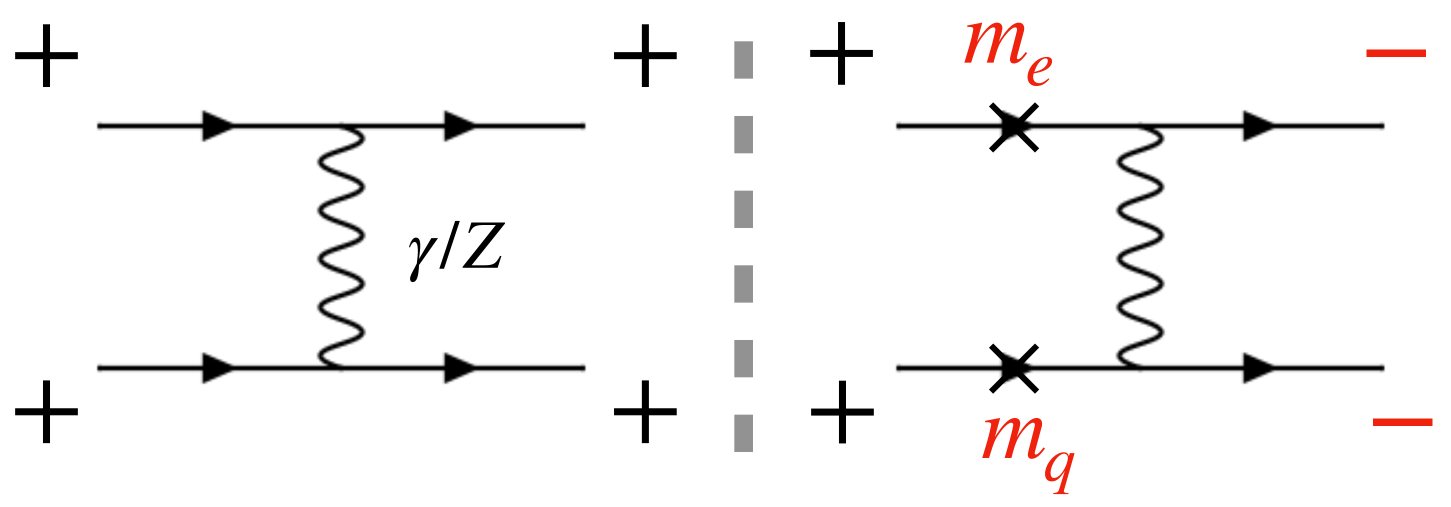
Transverse DSA in the SM



$$S^{\mu}_{T,e} = P_{T,e}(0, \cos\phi_1, \sin\phi_1, 0)$$

$$S^{\mu}_{T,p} = P_{T,p}(0, \cos\phi_2, \sin\phi_2, 0)$$

$$Q^2 = -\tilde{q}^2, \quad x = \frac{Q^2}{2P\cdot\tilde{q}}, \quad y = \frac{2P\cdot\tilde{q}}{2P\cdot k},$$



$$A_{TT} = \frac{\sigma(e^{\uparrow}p^{\uparrow}) + \sigma(e^{\downarrow}p^{\downarrow}) - \sigma(e^{\uparrow}p^{\downarrow}) - \sigma(e^{\downarrow}p^{\uparrow})}{\sigma(e^{\uparrow}p^{\uparrow}) + \sigma(e^{\downarrow}p^{\downarrow}) + \sigma(e^{\uparrow}p^{\downarrow}) + \sigma(e^{\downarrow}p^{\uparrow})}$$

Superscripts ↑ , ↓ :

the direction of transverse spins of electron and proton

$$A^{\mathrm{SM},\gamma}_{TT} = \frac{2y^2\left[(1-y)\cos\phi_+ - (1+y)\cos\phi_-\right]}{Q^2}$$

$$\times \frac{\sum_q m_e m_q Q_q^2 h_q(x,\mu)}{\sum_q f_q(x,\mu)\left[Q_q^2(y^2-2y+2) - \mathcal{F}^{eq}_Z(Q^2)\right]}$$

$f_q(x,\mu)$: PDF

$h_q(x,\mu)$: transversity distribution

$$\phi_+ \equiv \phi_1 + \phi_2,$$

$$\phi_- \equiv \phi_1 - \phi_2$$

$$\mathcal{F}^{eq}_Z(Q^2) \equiv 2\frac{\tilde{\epsilon}_Q}{s_W^2 c_W^2} Q_q\left((y^2-2y+1)\mathcal{G}^{eq}_- + \mathcal{G}^{eq}_+\right)$$

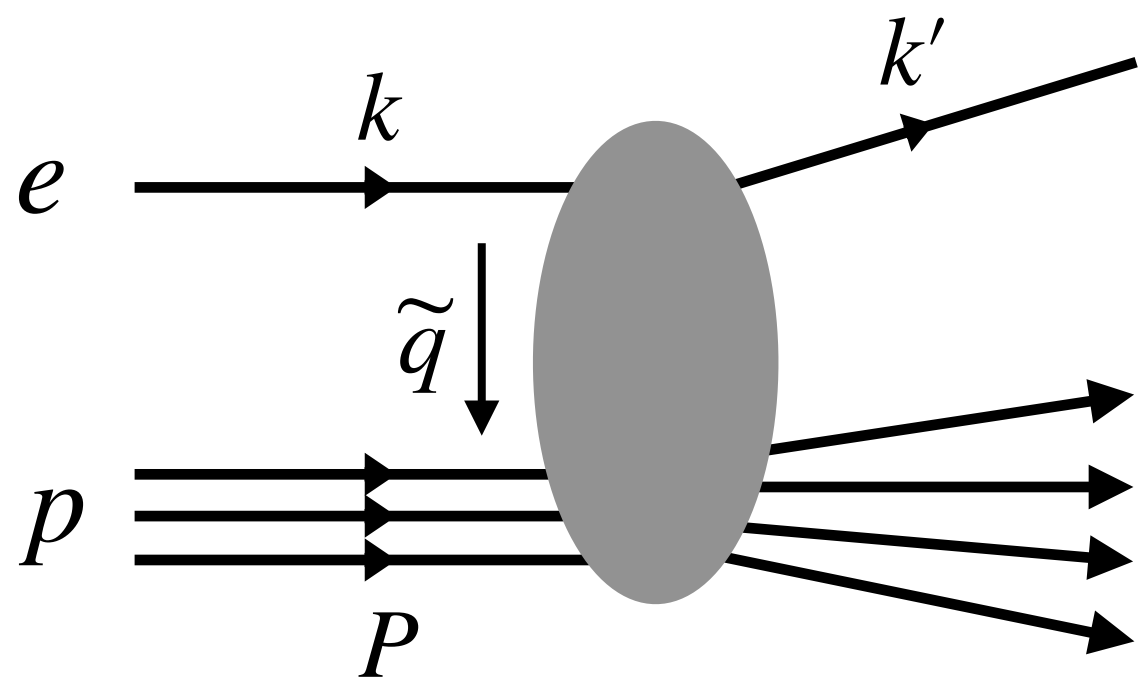
Suppressed by both the electron and quark mass!

$$\mathcal{G}^{eq}_+ \equiv g_V^e g_V^q + g_A^e g_A^q$$

$$\mathcal{G}^{eq}_- \equiv g_V^e g_V^q - g_A^e g_A^q$$

$$\tilde{\epsilon}_Q \equiv \frac{Q^2}{Q^2 + m_Z^2}$$

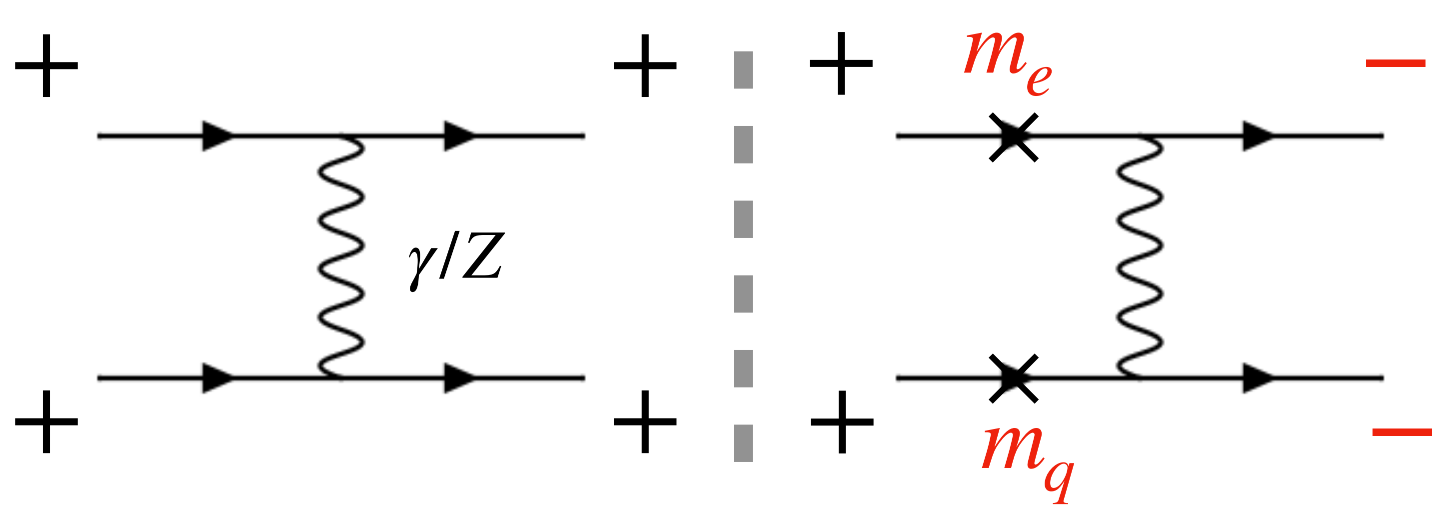
Transverse DSA in the SM



$$S^{\mu}_{T,e} = P_{T,e}(0, \cos\phi_1, \sin\phi_1, 0)$$

$$S^{\mu}_{T,p} = P_{T,p}(0, \cos\phi_2, \sin\phi_2, 0)$$

$$Q^2 = -\tilde{q}^2, \quad x = \frac{Q^2}{2P\cdot\tilde{q}}, \quad y = \frac{2P\cdot\tilde{q}}{2P\cdot k},$$



$$A_{TT} = \frac{\sigma(e^\uparrow p^\uparrow) + \sigma(e^\downarrow p^\downarrow) - \sigma(e^\uparrow p^\downarrow) - \sigma(e^\downarrow p^\uparrow)}{\sigma(e^\uparrow p^\uparrow) + \sigma(e^\downarrow p^\downarrow) + \sigma(e^\uparrow p^\downarrow) + \sigma(e^\downarrow p^\uparrow)}$$

Superscripts ↑ , ↓ :

the direction of transverse spins of electron and proton

$$A^{\mathrm{SM},\gamma Z}_{TT} = \frac{-4y}{s_W^2 c_W^2 (Q^2 + m_Z^2)(y^2 - 2y + 2)} \frac{1}{\sum_q Q_q^2 f_q(x,\mu)}$$

$$\times \sum_q m_e m_q Q_q h_q(x,\mu)\left[\cos\phi_+ y(1-y)\mathcal{G}^{eq}_- - \cos\phi_-(1+y)\left((y-1)\mathcal{G}^{eq}_- + \mathcal{G}^{eq}_+\right)\right]$$

$f_q(x,\mu)$: PDF

$h_q(x,\mu)$: transversity distribution

Suppressed by both the electron and quark mass!

$$\mathcal{G}^{eq}_+ \equiv g_V^e g_V^q + g_A^e g_A^q$$

$$\mathcal{G}^{eq}_- \equiv g_V^e g_V^q - g_A^e g_A^q$$

Anti-quark channel:

$$g_A^q \to -g_A^q \quad \Longleftrightarrow \quad \mathcal{G}^{eq}_+ \leftrightarrow \mathcal{G}^{eq}_-$$

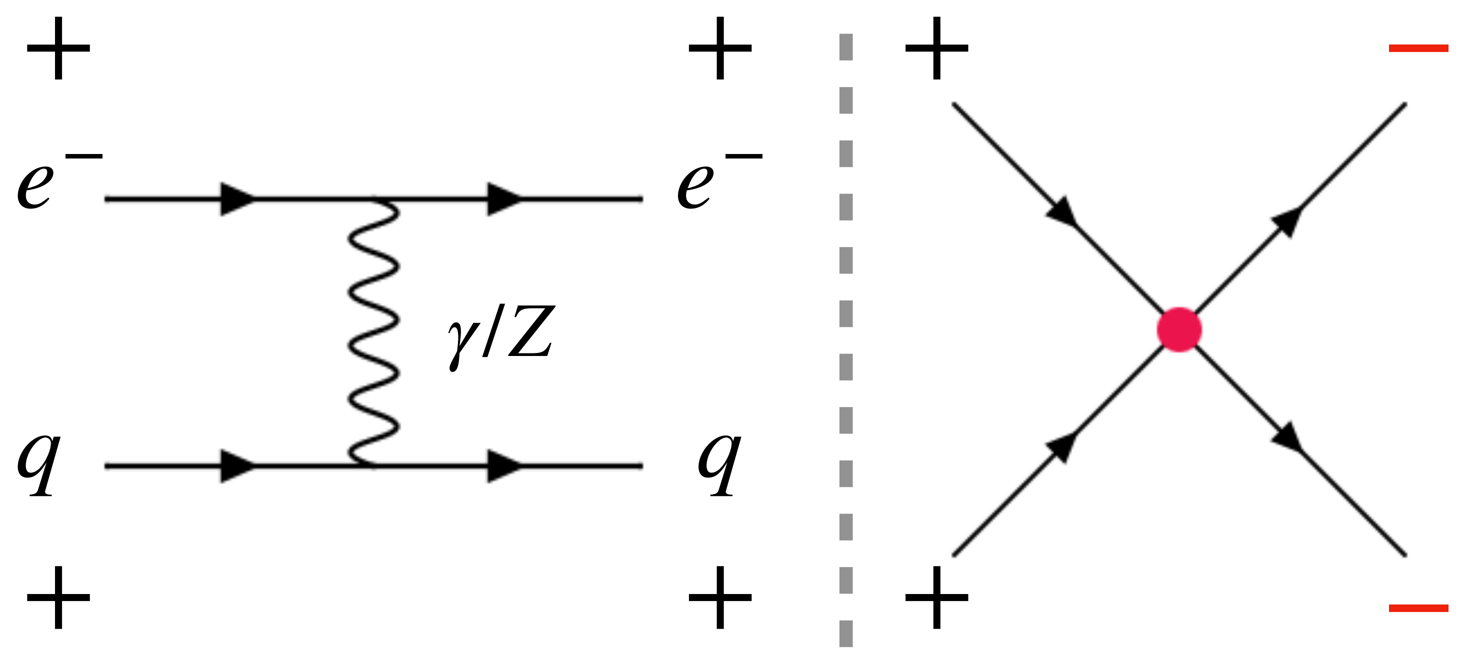
Transverse DSA in the SMEFT

$$\mathcal{O}_{ledq} = (\bar{L}^j e)(\bar{d} Q^j),$$
$$\mathcal{O}^{(1)}_{lequ} = (\bar{L}^j e)\epsilon_{jk}(\bar{Q}^k u),$$
$$\mathcal{O}^{(3)}_{lequ} = (\bar{L}^j \sigma^{\mu\nu} e)\epsilon_{jk}(\bar{Q}^k \sigma_{\mu\nu} u),$$

$$\Delta A_{TT}^{\mathrm{SMEFT},\gamma} = \frac{Q^2/4\pi\alpha}{\sum_q f_q(x)\left[Q_q^2(y^2-2y+2) - \mathcal{F}_Z^{eq}(Q^2)\right]} \times \Bigg(\sum_d Q_d h_d(x,\mu)(y-y^2)\mathrm{Re}\left[C_{ledq} e^{-i\phi_+}\right] + \sum_u Q_u h_u(x) y \,\mathrm{Re}\left[C^{(1)}_{lequ} e^{-i\phi_-}\right] + \sum_u Q_u h_u(x) 4(y-2)\mathrm{Re}\left[C^{(3)}_{lequ} e^{-i\phi_-}\right] \Bigg)$$

$$\Delta A_{TT}^{\mathrm{SMEFT},Z} = -\frac{1}{4\pi\alpha}\frac{Q^2}{y^2-2y+2}\frac{\tilde{\epsilon}_Q}{s_W^2 c_W^2}\frac{1}{\sum_q Q_q^2 f_q(x)} \times \Bigg(\sum_d (y-y^2)\mathcal{G}_-^{ed} h_d(x)\mathrm{Re}\left[C_{ledq} e^{-i\phi_+}\right] + \sum_u y\,\mathcal{G}_+^{eu} h_u(x)\mathrm{Re}\left[C^{(1)}_{lequ} e^{-i\phi_-}\right] + \sum_u 4(y-2)\mathcal{G}_+^{eu} h_u(x)\mathrm{Re}\left[C^{(3)}_{lequ} e^{-i\phi_-}\right] \Bigg)$$

DSA are not suppressed by the electron and quark mass in the SMEFT



Anti-quark channel: $g_A^q \to -g_A^q \quad \Longleftrightarrow \quad \mathcal{G}_+^{eq} \leftrightarrow \mathcal{G}_-^{eq}$

$$C_{ledq} \to -C_{ledq}, \qquad C^{(1)}_{lequ} \to -C^{(1)}_{lequ}$$