IAS Program on High Energy Physics (HEP 2024), Hong Kong, Jan. 08-26, 2024
Conference: Jan. 22 - 25, 2024

Transverse Spin Asymmetry as a New Probe of SMEFT Chirality-Flip Operators

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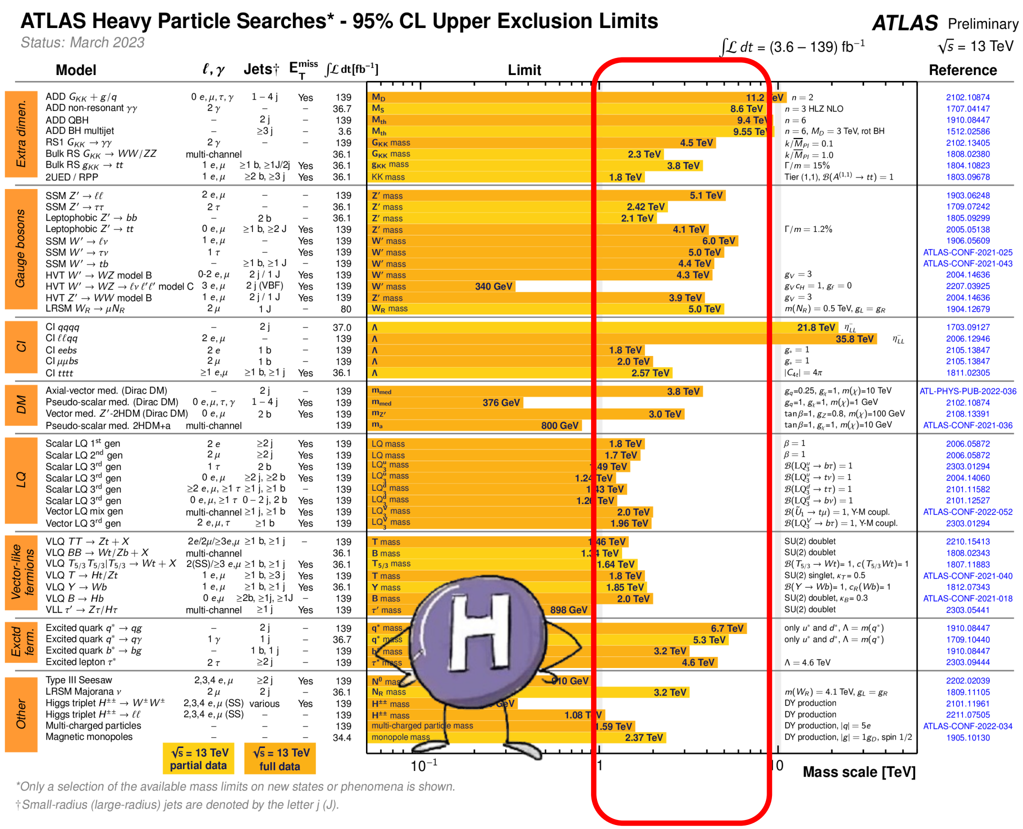
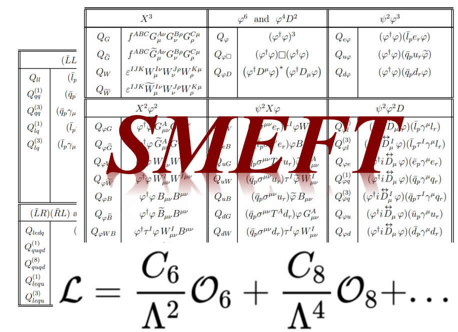
In collaboration with Bin Yan, Zhite Yu and C.-P. Yuan
Phys.Rev.Lett. **131** (2023) 24, 241801
In collaboration with Hao-Lin Wang, Hongxi Xing and Bin Yan
arXiv: 2401.08419

2024/01/23, HKUST-IAS, Hong Kong

New Physics and SMEFT

None new fundamental resonance has been discovered.





B. Grzadkowski, et al. *JHEP* 10 (2010)
W. Buchuller, D. wyler, 1986

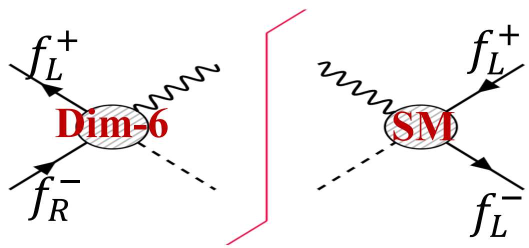
Powerful Tool @ EW

New Physics models excluded to **Multi-TeV** @ LHC. → **$\Lambda \sim \mathcal{O}$(TeV)**

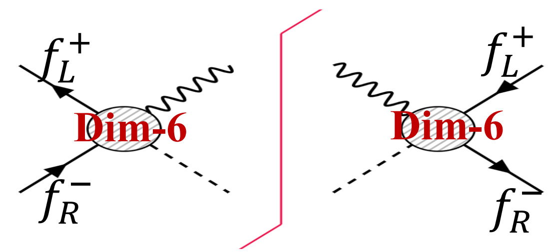
SMEFT Chirality-Flip Operator

$$\mathrm{d}\sigma = \mathrm{d}\sigma_{\mathrm{SM}} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} a_i^{(6)} + \sum_{ij} \frac{C_i^{(6)} C_j^{(6)}}{\Lambda^4} b_{ij}^{(6)}$$

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



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



interference~**0** for tiny mass

Non-interfering Leading effect

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	$\varepsilon^{IJK}W_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$	$Q_{\varphi D}$	$(\varphi^\dagger D^\mu\varphi)^\star(\varphi^\dagger D_\mu\varphi)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$				
$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\tau^I\varphi W_{\mu\nu}^I$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{l}_p\gamma^\mu l_r)$
$Q_{\varphi\widetilde{G}}$	$\varphi^\dagger\varphi\, \widetilde{G}_{\mu\nu}^A G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I\varphi)(\bar{l}_p\tau^I\gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W_{\mu\nu}^I W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{\varphi}\, G_{\mu\nu}^A$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{e}_p\gamma^\mu e_r)$
$Q_{\varphi\widetilde{W}}$	$\varphi^\dagger\varphi\, \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\tau^I\widetilde{\varphi}\, W_{\mu\nu}^I$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{q}_p\gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{\varphi}\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I\varphi)(\bar{q}_p\tau^I\gamma^\mu q_r)$
$Q_{\varphi\widetilde{B}}$	$\varphi^\dagger\varphi\, \widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p\sigma^{\mu\nu}T^A d_r)\varphi\, G_{\mu\nu}^A$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{u}_p\gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W_{\mu\nu}^I B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\tau^I\varphi\, W_{\mu\nu}^I$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{d}_p\gamma^\mu d_r)$
$Q_{\varphi\widetilde{W}B}$	$\varphi^\dagger\tau^I\varphi\, \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^\dagger D_\mu\varphi)(\bar{u}_p\gamma^\mu d_r)$

Table 2: Dimension-six operators other than the four-fermion ones.

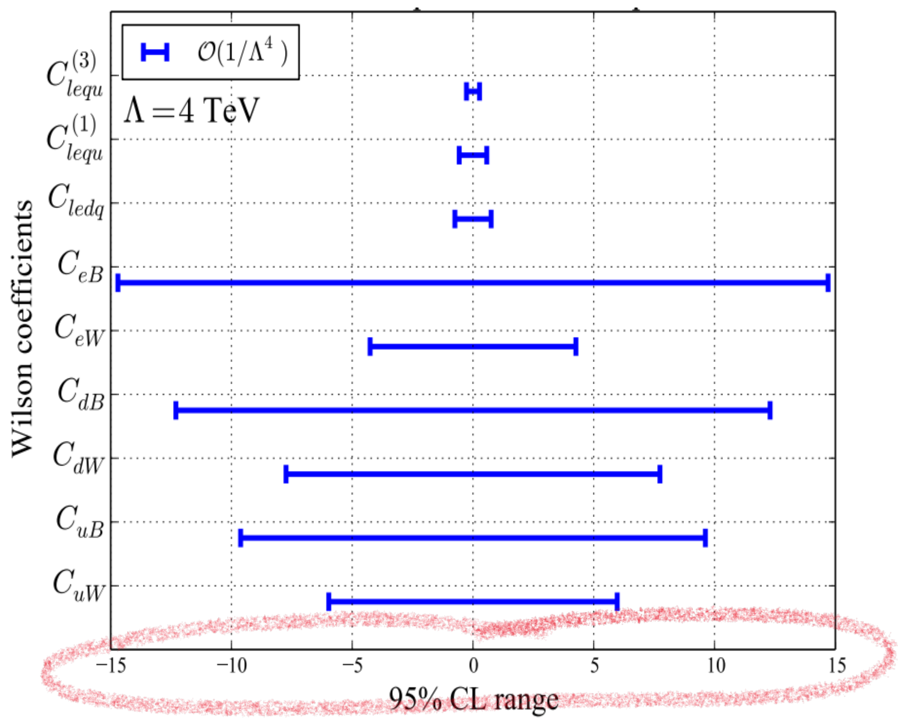
$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$	Q_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$	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}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$		
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j\sigma_{\mu\nu}e_r)\varepsilon_{jk}(\bar{q}_s^k\sigma^{\mu\nu}u_t)$				

Table 3: Four-fermion operators.

Data for Chirality-Flip Operator

Constrained poorly in traditional methods via cross-section and width

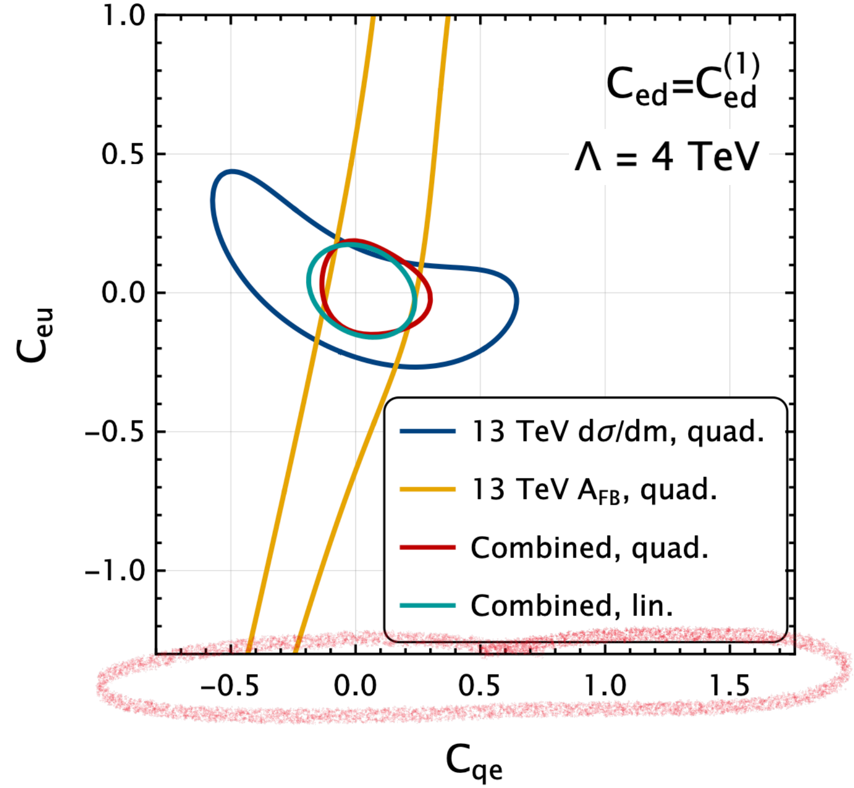
$\mathcal{O}(1/\Lambda^4)$



Single-Parameter-Analysis DY@LHC

(R. Boughezal et al. *Phys.Rev.D* 104 (2021)…)

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

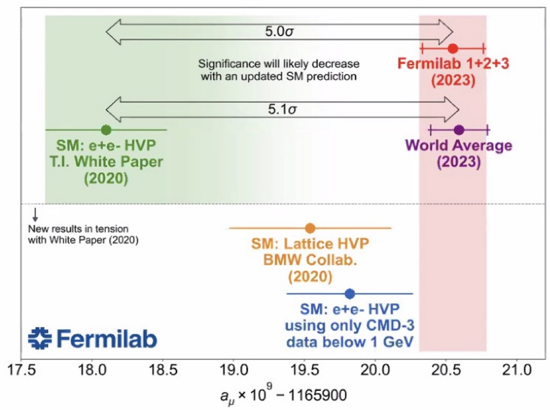


(R. Boughezal et al. *arXiv:* 2303.08257)

New Physics with Chirality-Flip Operator

Direct & Dominant Effect

Dipole Operator: $(g-2)$? EDM ?



D.P. Aguillard et al., (Muon g-2), *Phys.Rev.Lett.* 131 (2023) 16

same NP source ?

Z only detected by colliders

Indirect probes of NP quantum effects

Scalar/Tensor Four-Fermion operator:

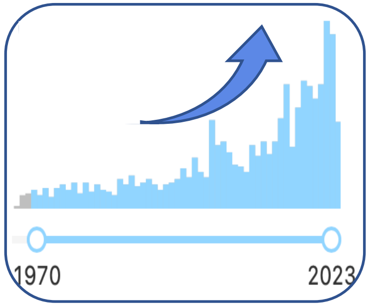
Leptoquark ?

New scalar or gauge boson ?

$$R_\pi = \frac{\Gamma(\pi^+ \to e^+\nu)}{\Gamma(\pi^+ \to \mu^+\nu)}$$

$R_K, R_{D^{(*)}}$

Low-energy data ?



How to probe Chirality-Flip operators at $\mathcal{O}(1/\Lambda^2)$?

How to Probe Chirality-Flip Operator at $1/\Lambda^2$

Traditional method: @ $|C_{CF}|^2/\Lambda^4$, suffer from contaminations

Our proposal:

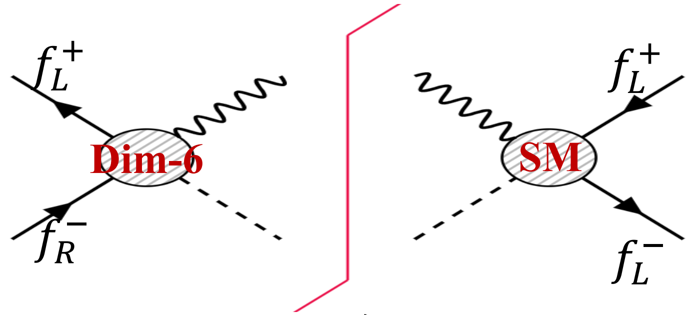
Ken-ichi Hikasa, *Phys.Rev.D* 33 (1986) 3203
Phys.Rev.D 38 (1988) 1439

- Transverse polarization effect of beams

  Interference of the different helicity amplitudes

$$\rho = \frac{1}{2}(1+\boldsymbol{\sigma}\cdot\boldsymbol{s}) = \frac{1}{2}\begin{pmatrix} 1+\lambda & b_{\rm T}e^{-i\phi_0} \\ b_{\rm T}e^{i\phi_0} & 1-\lambda \end{pmatrix}$$

$$\boldsymbol{s} = (b_1, b_2, \lambda) = (b_{\rm T}\cos\phi_0, b_{\rm T}\sin\phi_0, \lambda)$$



$|h=+\rangle\langle h=-|$

$\mathcal{O}(1/\Lambda^2)$ leading effect

- Breaking rotational invariance

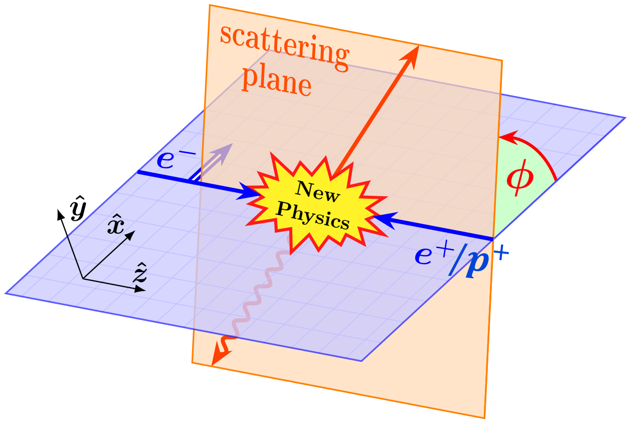
  Nontrivial azimuthal behavior

- **Transverse Spin Asymmetries**

  X.-K.W, BY, ZY, C.-P.Y, *Phys.Rev.Lett.* 131 (2023) 24

  R. Boughezal et al., *Phys.Rev.D* 107 (2023) 07

  H.-L. W, **X.-K.W**, HX, BY *arXiv:* 2401.08419

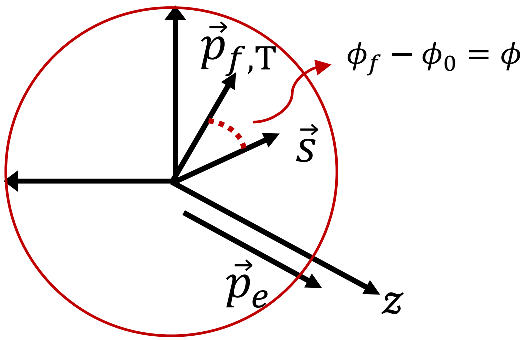


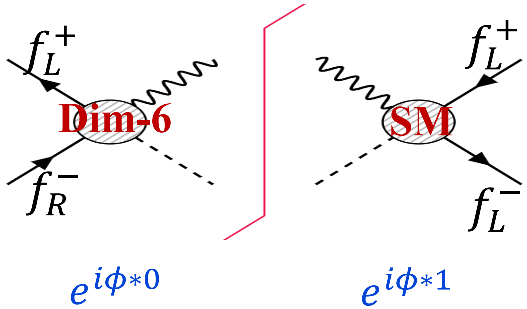
Transverse Spin Polarization

Spin dependent amplitude square:

$$|\mathcal{M}|^2 = \rho_{\alpha_1\alpha_1'}(\boldsymbol{s})\rho_{\alpha_2\alpha_2'}(\bar{\boldsymbol{s}})\mathcal{M}_{\alpha_1\alpha_2}(\phi)\mathcal{M}^*_{\alpha_1'\alpha_2'}(\phi)$$

$$\mathcal{M}_{\lambda_1,\lambda_2}(\theta,\phi) = e^{i(\lambda_1-\lambda_2)\phi}\mathcal{T}_{\lambda_1,\lambda_2}(\theta)$$





STSAA@ee collider:

dipole operator → $\mathcal{M}_{\pm\pm}$, massless SM → $\mathcal{M}_{\pm\mp}$

DSA@eP collider:

Four-F operator → $\mathcal{M}_{-i,-j}$, massless SM → $\mathcal{M}_{ij}$

X.-K.W, BY, ZY, C.-P.Y, work in progress

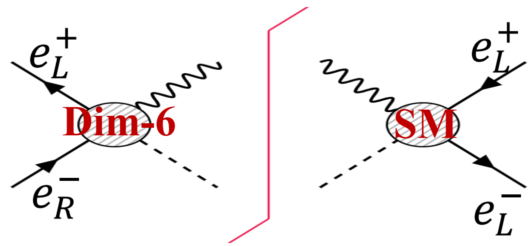
	U	L	T	
U	$\lvert\mathcal{M}\rvert^2_{UU} \to 1$	$\lvert\mathcal{M}\rvert^2_{UL} \to 1$	$\lvert\mathcal{M}\rvert^2_{UT} \to \cos\phi, \sin\phi$	→ STSAA
L	$\lvert\mathcal{M}\rvert^2_{LU} \to 1$	$\lvert\mathcal{M}\rvert^2_{LL} \to 1$	$\lvert\mathcal{M}\rvert^2_{LT} \to \cos\phi, \sin\phi$	
T	$\lvert\mathcal{M}\rvert^2_{TU} \to \cos\phi, \sin\phi$	$\lvert\mathcal{M}\rvert^2_{TL} \to \cos\phi, \sin\phi$	$\lvert\mathcal{M}\rvert^2_{TT} \to 1, \cos 2\phi, \sin 2\phi$	→ DSA

G. Moortgat-Pick et al. *Phys.Rept.* 460 (2008), *JHEP* 01 (2006)

A New Probe of Dipole Operators @ee collider

$$\frac{2\pi\, d\sigma^i}{\sigma^i\, d\phi} = 1 + \underline{A_R^i(b_T, \bar{b}_T)}\cos\phi + \underline{A_I^i(b_T, \bar{b}_T)}\sin\phi + \underline{b_T\,\bar{b}_T\,B^i}\cos 2\phi + \mathcal{O}(1/\Lambda^4)$$

$\mathrm{Re}[C_{dipole}]$	$\mathrm{Im}[C_{dipole}]$	SM & other NP
$\vec{s}\cdot\vec{p}_f \propto \cos\phi$	$\vec{s}\times\vec{p}_f \propto \sin\phi$	
CP-conserving	CP-violation	



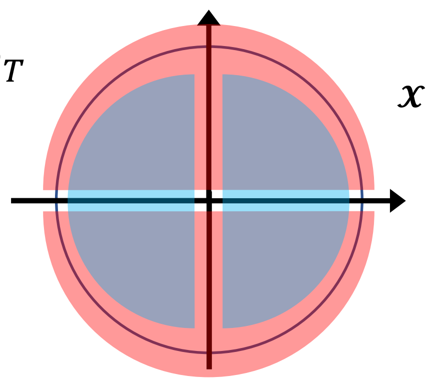
Single Transverse Spin Azimuthal Asymmetry (STSAA)

X.-K.W, BY, ZY, C.-P.Y, *Phys.Rev.Lett.* 131 (2023) 24

Linearly dependent on the dipole couplings C_{dipole} and spin b_T

$$A_{LR}^i = \frac{\sigma^i(\cos\phi>0)-\sigma^i(\cos\phi<0)}{\sigma^i(\cos\phi>0)+\sigma^i(\cos\phi<0)} = \frac{2}{\pi}A_R^i$$

$$A_{UD}^i = \frac{\sigma^i(\sin\phi>0)-\sigma^i(\sin\phi<0)}{\sigma^i(\sin\phi>0)+\sigma^i(\sin\phi<0)} = \frac{2}{\pi}A_I^i,$$



Pinning down Dipole Operators @ee collider

$$\mathcal{L}_{\rm eff} = -\frac{1}{\sqrt{2}}\bar{\ell}_L\sigma^{\mu\nu}\left(g_1\Gamma^e_B B_{\mu\nu} + g_2\Gamma^e_W\sigma^a W^a_{\mu\nu}\right)\frac{H}{v^2}e_R + \text{h.c.}$$

$$A^i_{LR} = \frac{\sigma^i(\cos\phi>0)-\sigma^i(\cos\phi<0)}{\sigma^i(\cos\phi>0)+\sigma^i(\cos\phi<0)} = \frac{2}{\pi}A^i_R$$

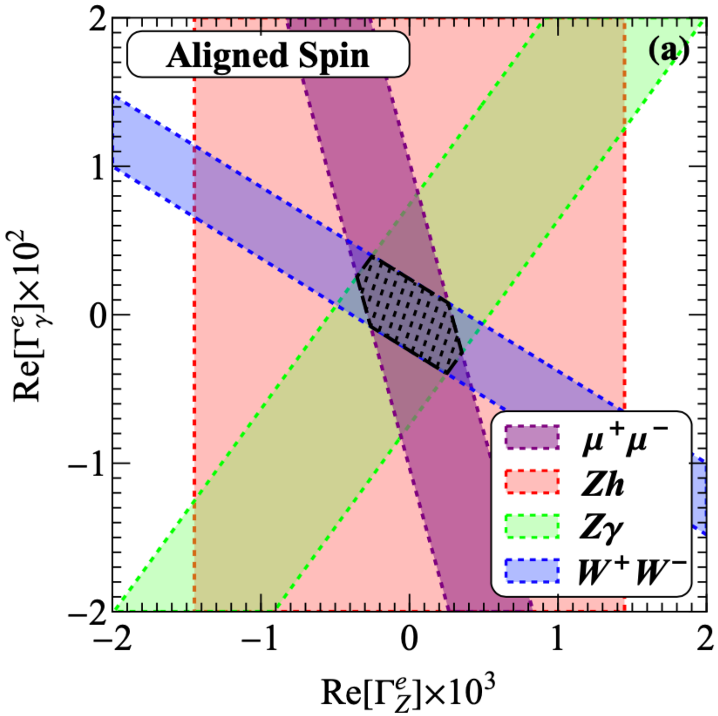
Aligned Spin

$$\phi_0 = \bar{\phi}_0 = 0$$

Opposite Spin

$$(\phi_0, \bar{\phi}_0) = (0, \pi)$$

$\sqrt{s} = 250$ GeV, $\mathcal{L} = 5$ ab^{-1}



$$\Gamma^e_\gamma = \Gamma^e_W - \Gamma^e_B$$

$$\Gamma^e_Z = c^2_W\Gamma^e_W + s^2_W\Gamma^e_B$$

Much stronger sensitivity than other approaches by 1~2 orders

The sensitivity to Γ^e_Z is much stronger than Γ^e_γ

- Parity property of helicity amplitude

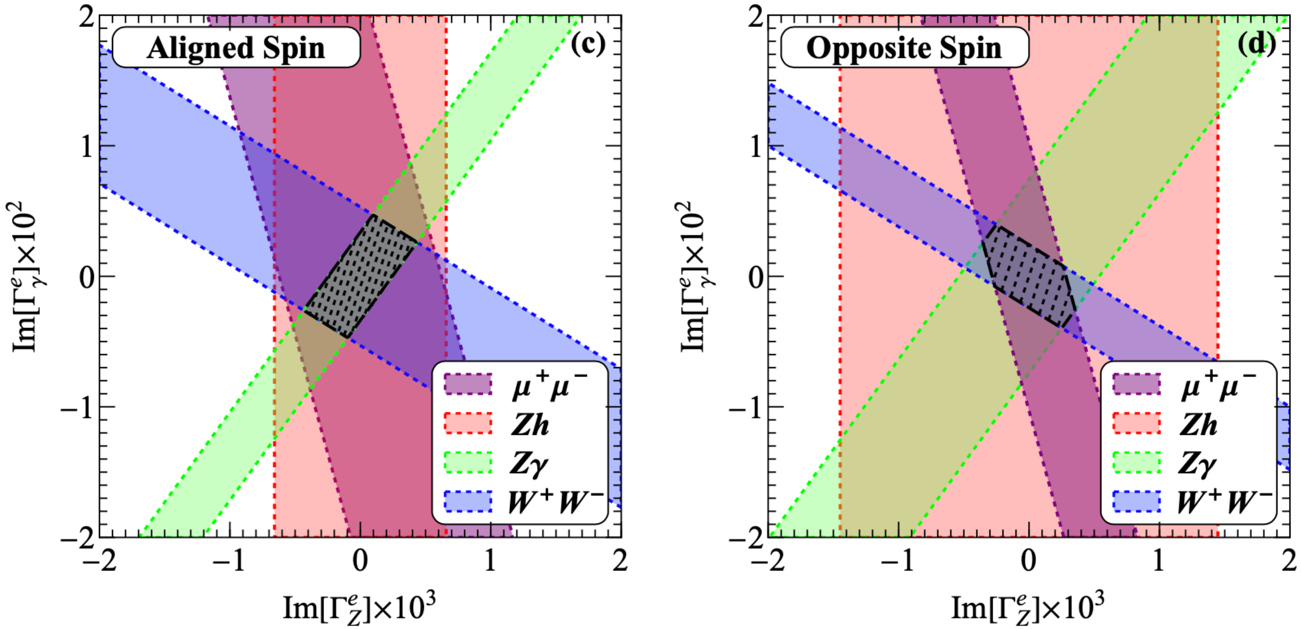
Pinning down Dipole Operators @ee collider

For the imaginary parts of dipole couplings, things are similar

Aligned Spin
$\phi_0 = \bar{\phi}_0 = 0$
Opposite Spin
$(\phi_0, \bar{\phi}_0) = (0, \pi)$

$$A^i_{UD} = \frac{\sigma^i(\sin\phi > 0) - \sigma^i(\sin\phi < 0)}{\sigma^i(\sin\phi > 0) + \sigma^i(\sin\phi < 0)} = \frac{2}{\pi} A^i_I$$

$\sqrt{s} = 250$ GeV, $\mathcal{L} = 5$ ab^{-1}



Why the limit difference between the Aligned Spin and the Opposite Spin? ➢ CP property

Offering a new opportunity for directly probing potential CP-violating effects.

From Lepton Collider to EICs

Upcoming Electron-Ion Collider in USA and planned EIC in China (EicC)

A. Accardi et al., *Eur.Phys.J.A* 52 (2016) 9, 268
R. A. Khalek et al., *Nucl.Phys.A* 1026 (2022) 122447
D. P. Anderle et al., *Front.Phys.(Beijing)* 16 (2021) 6, 64701

Electron Ion Collider:

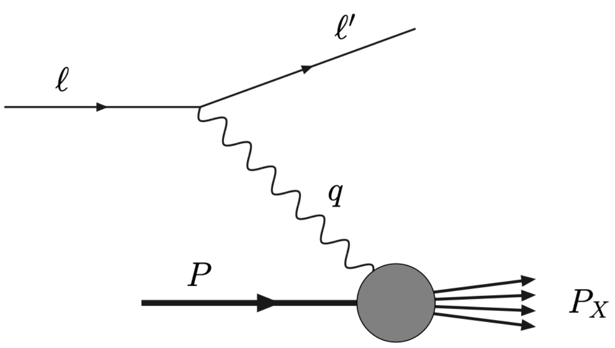
The Next QCD Frontier : Understanding the glue that binds us all

- Explore and image the spin and 3D structure of the nucleon
- Discover the role of gluons in structure and dynamics
- Precisely determine the spin-(in)dependent PDFs
- Probe the electroweak properties of the SM
- Search for potential **NP effects**
- ……

B. Yan, *Phys.Lett.B* 833 (2022) 137384
H.-T. Li et al., *Phys.Lett.B* 833 (2022) 137300
R. Boughezal, et al., *Phys.Rev.D* 107 (2023) 7
Y. Liu et al., *Chin.Phys.C* 47 (2023) 4, 043113
B. Yan et al., *Phys.Lett.B* 822 (2021) 136697
V. Cirigliano, *JHEP* 03 (2021) 256

As we expected:

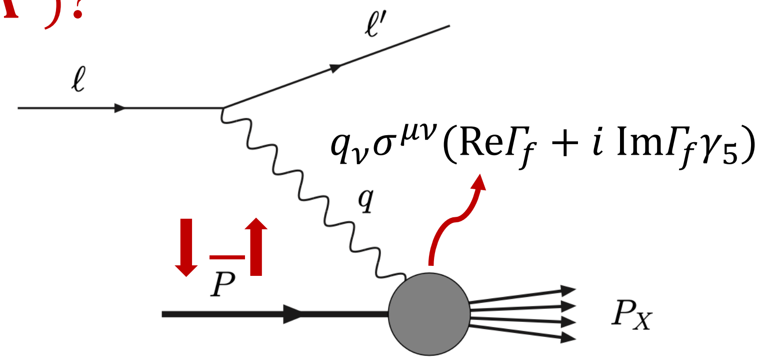
- ✓ High Polarization ~0.7
- ✓ High luminosity ~100fb^{-1}
- ✓ Moderate energy ~ 120 GeV



Transverse SSA @EICs

How to probe **quark** dipole operator **at $\mathcal{O}(1/\Lambda^2)$**?

- Polarized DIS
- Need transverse PDF



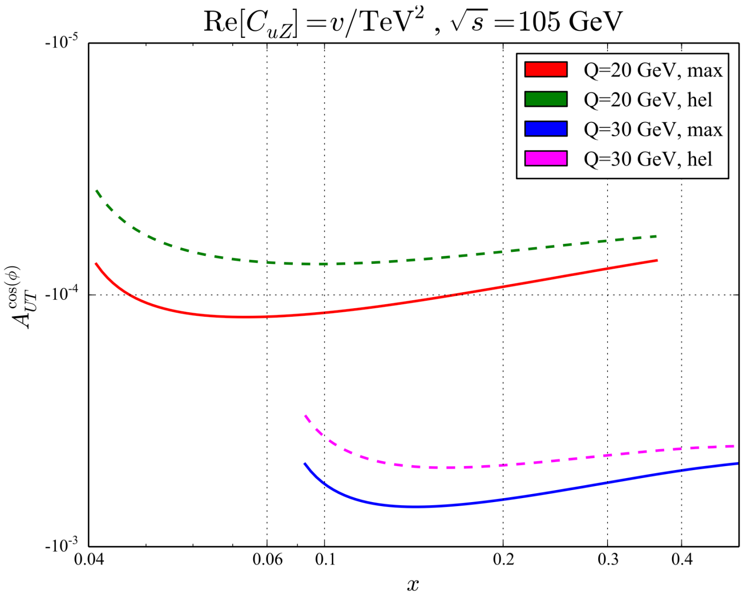
Transverse Single-Spin-Asymmetry (SSA)

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

$\Rightarrow$

$$\mathrm{Re}\Gamma_f \to \cos(\phi_S - \phi_l)$$

$$\mathrm{Im}\Gamma_f \to \sin(\phi_S - \phi_l)$$



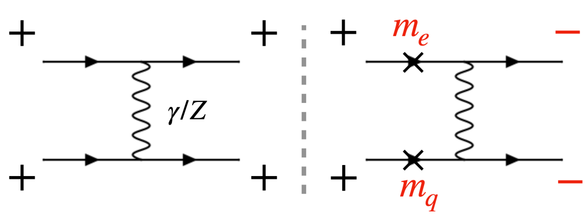
R. Boughezal, et al., *Phys.Rev.D* 107 (2023) 7

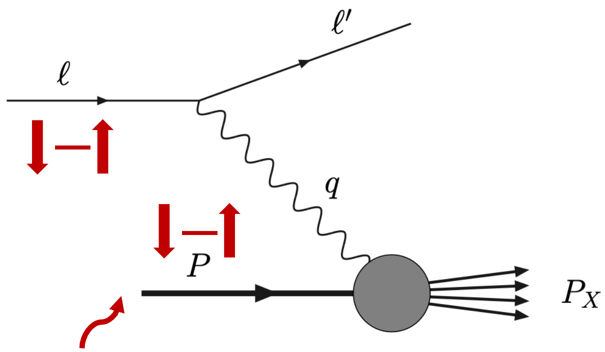
Transverse DSA @EICs

Transverse Double-Spin-Asymmetry (DSA)

H.-L. Wang, **X.-K. Wen**, H. Xing and Y. Bin, *arXiv:* 2401.08419

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

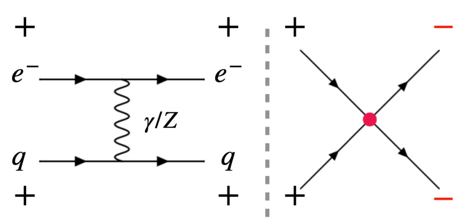




$h(x,\mu)$: transversity distribution

Z.-B. Kang et al., *Phys.Rev.D* 93 (2016) 1
C. Zeng et al., *arXiv:* 2310.15532
JAM collaboration *arXiv:*2205.00999

$$A_{TT}^{SM} \sim m_e m_q \cdot h(x,\mu)$$



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

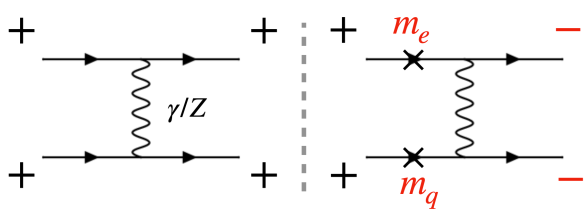
$$A_{TT}^{SMEFT} \sim \frac{Q^2}{\Lambda^2} \cdot h(x,\mu) \cdot Re\left[C_{ledq} \cdot e^{-i2(\phi_1+\phi_2)} + C_{lequ}^{(1,3)} \cdot e^{-i2(\phi_1-\phi_2)}\right]$$

2ϕ and **flat** shape

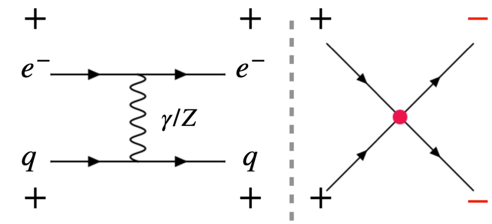
The azimuthal behavior due to parity property of bilinear in operators

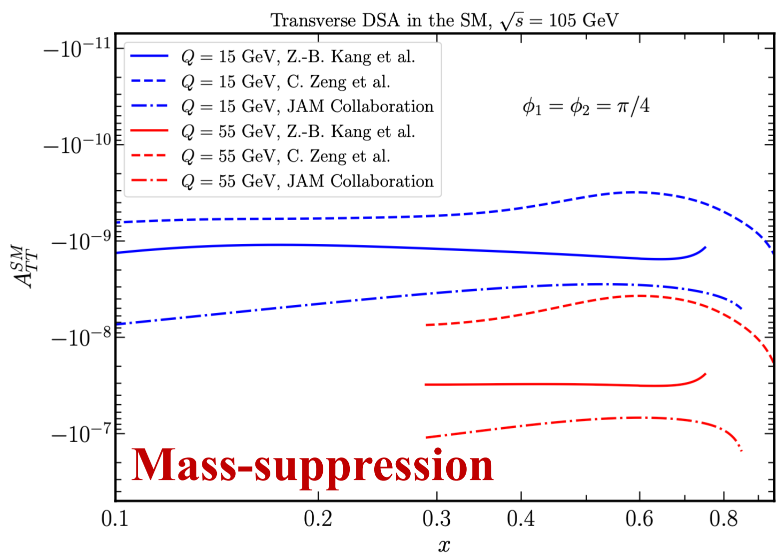
Probing four-fermion operators @EIC & EicC

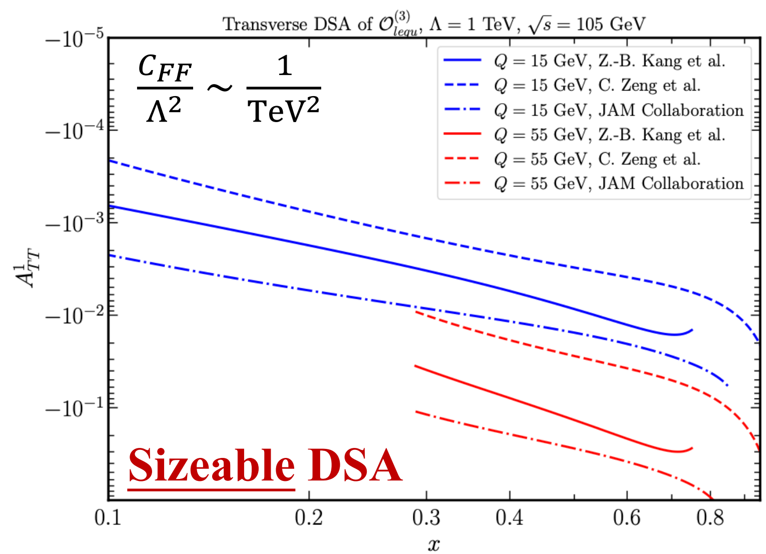
SM



Scalar/Tensor four-fermion operator







H.-L. Wang, **X.-K. Wen**, H. Xing and Y. Bin, *arXiv:* 2401.08419

- *without contamination from the SM and other NP*
- *without mass-suppression*

Probing four-fermion operators @EIC & EicC

H.-L. Wang, **X.-K. Wen**, H. Xing and Y. Bin, *arXiv:* 2401.08419

scalar/tensor four-fermion operator

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

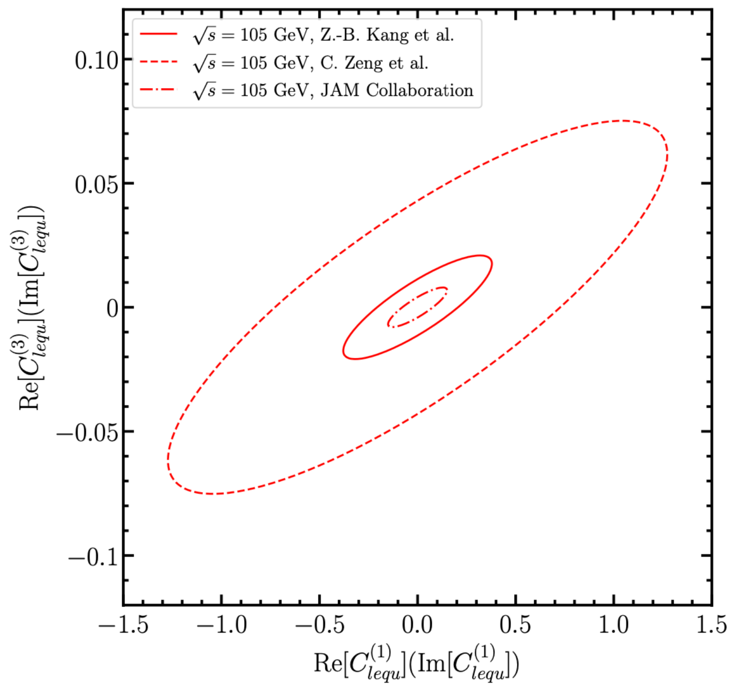
Transversity	Limits on $\mathrm{Re}[C_{ledq}](\mathrm{Im}[C_{ledq}])$	
	EIC (105 GeV)	EicC (16.7 GeV)
Z.-B. Kang et al [63]	5.16	34.60
C. Zeng et al [64]	4.53	13.72
JAM Collaboration [65]	5.12	29.69

$x \in [0.1, 0.8], Q \in [15, 65]\mathrm{GeV}$

$0.01 \le y \le 0.95$

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

EIC: $\sqrt{s} = 105$ GeV, $\mathcal{L} = 100\ \mathrm{fb}^{-1}$



- ✓ Our results are *stronger or comparable* to other $\mathcal{O}(1/\Lambda^4)$-approaches
- ✓ Enabling direct study of potential CP-violating effects.

Summary

- ✓ The muon g-2 data and many NP models may hint SMEFT chirality-flip operators
- ✓ Chirality-flip operators are difficult to be probed since the leading effects $@1/\Lambda^4$
- ✓ We propose a new method to linearly probe them $@1/\Lambda^2$ via *transverse polarized beams*
- ✓ Simultaneously constraining well both Re & Im parts
  - ➢ without contaminations from other NP and SM, without mass-suppression
  - ➢ offering a new opportunity for directly probing potential CP-violating effects.
- ✓ Our bound have much stronger sensitivity than other approaches by 1~2 orders
- ✓ Future colliders (Z/Higgs/Top factory…)

  Polarized Muon collider, **hadron colliders**, **Electron-Ion Collider**

Thank you

Backup

BACKUP

Backup: Some Formulae

$$|\Theta,\chi\rangle_1 = \cos\frac{\Theta}{2}|h=+\rangle + \sin\frac{\Theta}{2}e^{i\chi}|h=-\rangle$$

Superposition of the two helicity states along polarization $\vec{s}(\Theta,\chi)$

$$T_{h\bar{h}} = \langle\phi,\ldots|T|\chi,\bar{\chi}\rangle = \langle\phi=0,\ldots|T|\chi-\phi,\bar{\chi}-\phi\rangle$$

2-to-2 rotational invariance

Ken-ichi Hikasa, *Phys.Rev.D* 33 (1986) 3203, *PhysRevD.*38 (1988) 1439

$$|\mathcal{M}|^2(\boldsymbol{s},\bar{\boldsymbol{s}},\theta,\phi) = \sum_{\alpha_1,\alpha_2,\alpha_1',\alpha_2'} \rho_{\alpha_1,\alpha_1'}(\boldsymbol{s})\,\bar{\rho}_{\alpha_2,\alpha_2'}(\bar{\boldsymbol{s}})\,\mathcal{M}_{\alpha_1,\alpha_2}(i\to f;\theta,\phi)\,\mathcal{M}^\dagger_{\alpha_1',\alpha_2'}(i\to f;\theta,\phi)$$

$$\boldsymbol{s} = (b_1,b_2,\lambda) = (b_{\rm T}\cos\phi_0, b_{\rm T}\sin\phi_0,\lambda)$$

$$\rho = \frac{1}{2}(1+\boldsymbol{\sigma}\cdot\boldsymbol{s})$$

$$\mathcal{M}_{\lambda_1,\lambda_2}(\theta,\phi) = e^{i(\lambda_1-\lambda_2)\phi}\mathcal{T}_{\lambda_1,\lambda_2}(\theta)$$

$$|\mathcal{M}|^2_{TU} = \frac{1}{2}b_{\rm T}{\rm Re}\left[e^{i(\phi-\phi_0)}\left(\mathcal{T}_{++}\mathcal{T}^\dagger_{-+} + \mathcal{T}_{+-}\mathcal{T}^\dagger_{--}\right)\right]$$

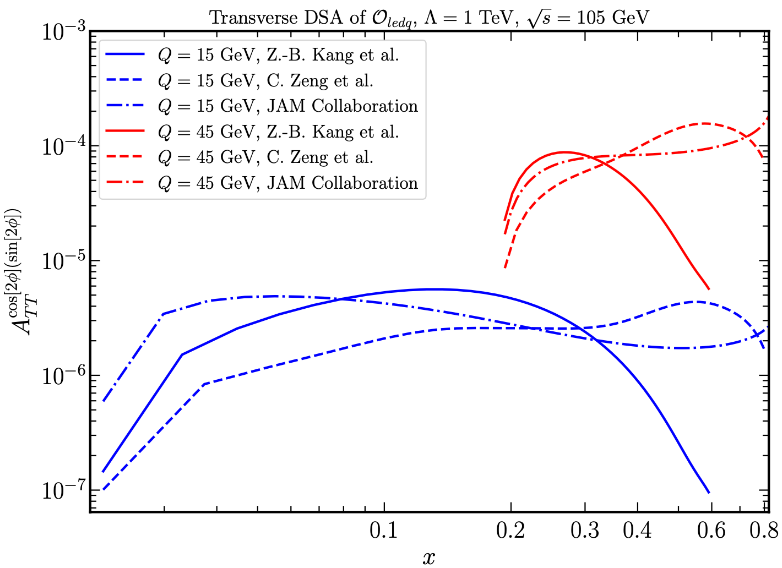
$$T_{-\lambda_a,-\lambda_b,-\lambda_c,-\lambda_d}(\theta) = \eta\cdot(-1)^{\lambda-\mu}\cdot T_{\lambda_a,\lambda_b,\lambda_c,\lambda_d}(\theta)$$

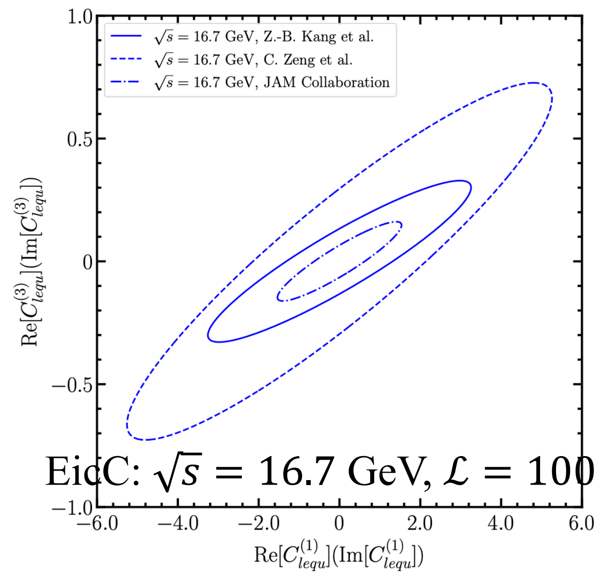
$$\eta = \frac{\eta_c\eta_d}{\eta_a\eta_b}\cdot(-1)^{s_a+s_b-s_c-s_d}$$

$$\begin{aligned}|M|^2 = |M|^2_{\rm unpol} &- \frac{1}{2}\lambda_T\bar{\lambda}_T{\rm Re}[T^*_{++}T_{--}] \\ &- \frac{1}{2}\lambda_T\bar{\lambda}_T{\rm Re}[e^{-2i\phi}T^*_{+-}T_{-+}] \\ &+ \frac{1}{2}\lambda_T{\rm Re}\left[e^{-i\phi}(T^*_{+-}T_{--} + T^*_{++}T_{-+})\right] \\ &- \frac{1}{2}\bar{\lambda}_T{\rm Re}\left[e^{-i\phi}(T^*_{+-}T_{++} + T^*_{--}T_{-+})\right]\end{aligned}$$

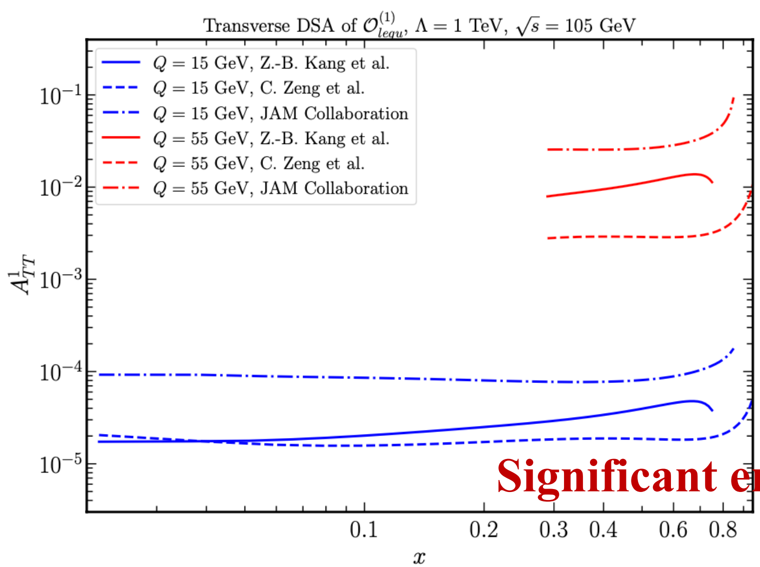
X.-K.W, BY, ZY, C.-P.Y, works in progress

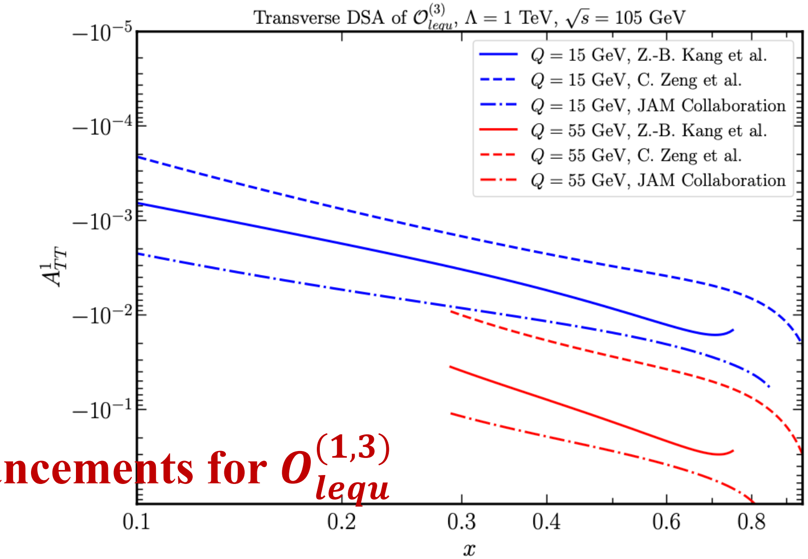
Backup





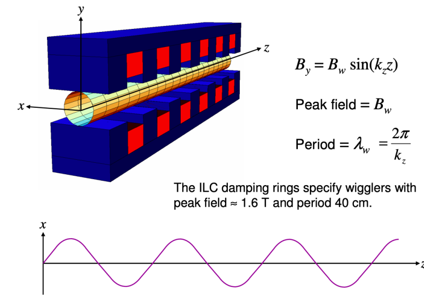
EicC: $\sqrt{s} = 16.7$ GeV, $\mathcal{L} = 100\ \mathrm{fb}^{-1}$





Significant enhancements for $O^{(1,3)}_{lequ}$

Backup: Polarized beam realization



Transverse polarization is more natural

Sokolov-Ternov effect (92.4%, minutes-hours, 50GeV)

Laser-assistant

Spin-precession

Photon-based scheme:

Polarized positrons are produced via pair production in a thin target from circularly-polarized photons with energy of multi-MeV (up to about 100 MeV). The cost difference between an polarized source and an upgrade from a unpolarized source is small (~ 1%). At 500 GeV, loss of polarization <1%, at IP <0.25%.

Polarized electron source consists of a polarized high-power laser beam and a high- voltage dc gun with a semiconductor photocathode.

Only polarization parallel or anti-parallel to the guide fields of the damping ring is preserved.

Need to avoid spin-orbit coupling resonance depolarizing effects.

The spin rotator systems between the damping rings and the main linacs *permit the setting of arbitrary polarization vector orientations* at the IP.

Polarized-photons source:

I. a high-energy electron beam (>~ 150 GeV) passing through a short period, helical undulator. (E-166, SLAC)

II. Compton backscattering of laser light off a GeV energy-range electron beam. (KEK)

In both schemes a polarization of about |Pe+ | ≥ 90% is reported.

G. Moortgat-Pick et al. *Phys.Rept.* 460 (2008), hep-ph/0507011