Spin asymmetry and electroweak properties of SM and beyond at the EIC

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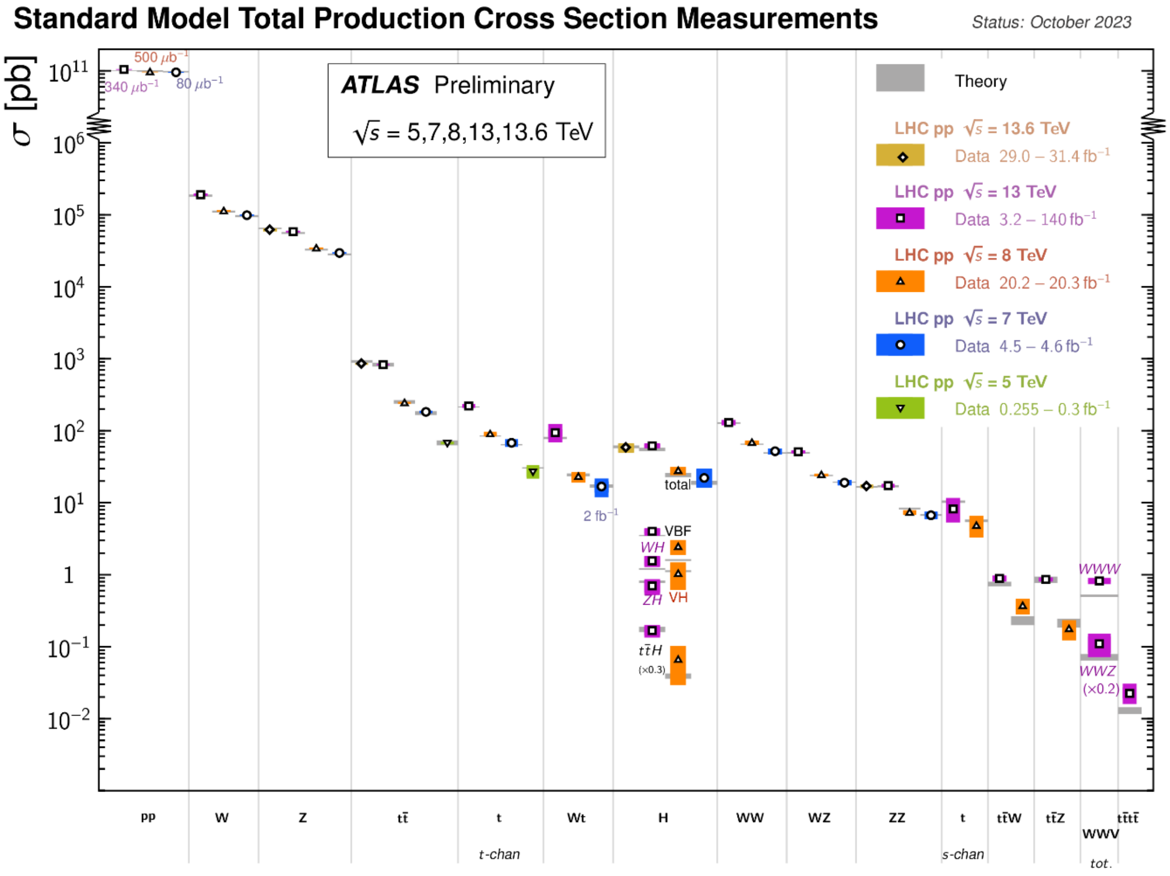
The 4th EIC-Asia Workshop
July 1-5, 2024

The status of SM



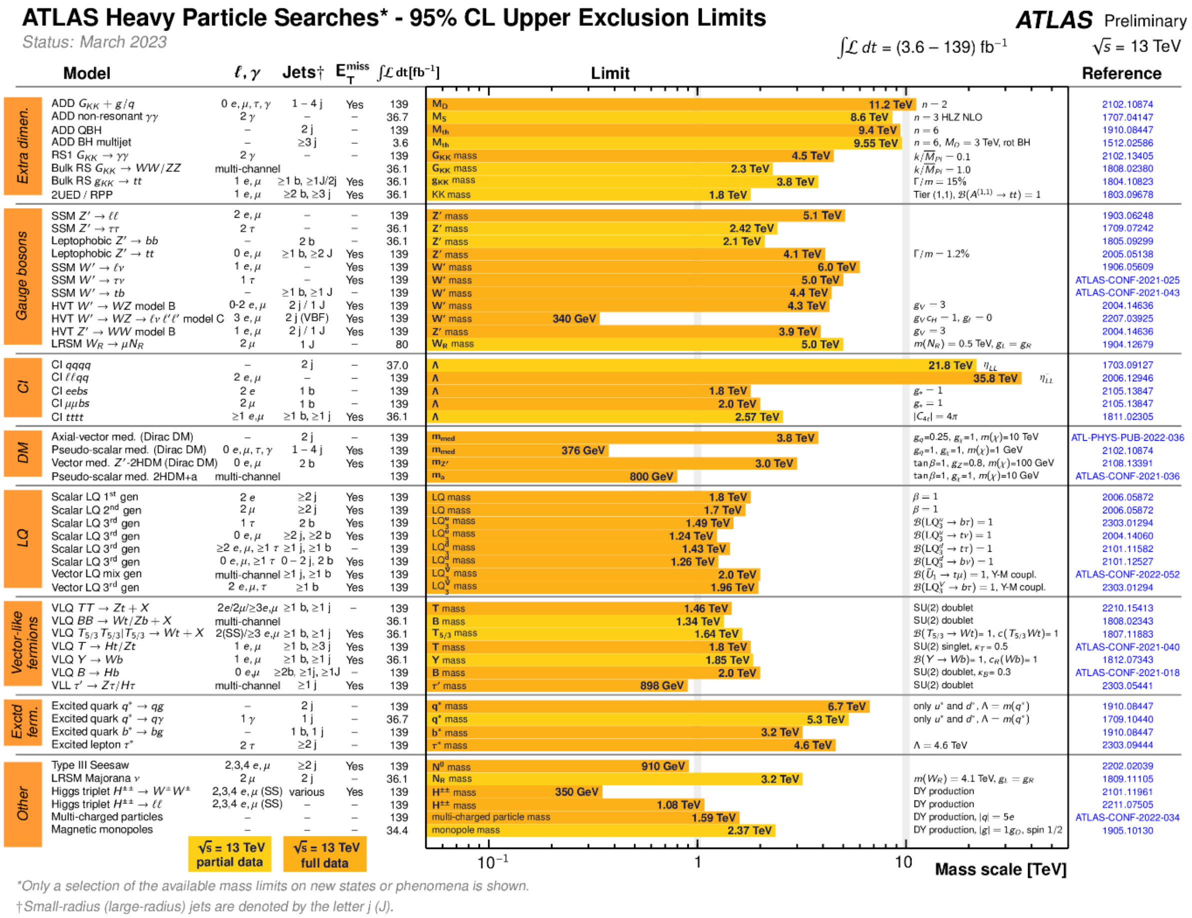
Open questions:

- Dark Matter ?
- neutrino mass?
- matter-antimatter asymmetry?
- W-mass anomaly, muon g-2
- electroweak symmetry breaking?
- Higgs boson (Composite or elementary particle)?
- …

Remarkable agreement between SM theory and data

New Physics beyond the SM new measurements

New Physics Searches @ LHC



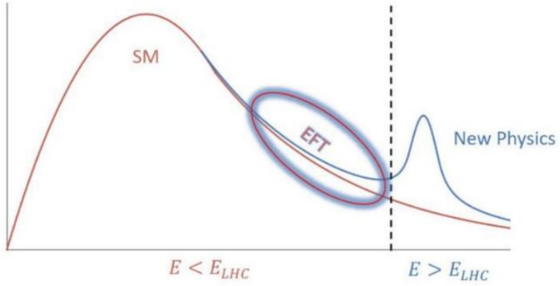
*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).

Top-down approach

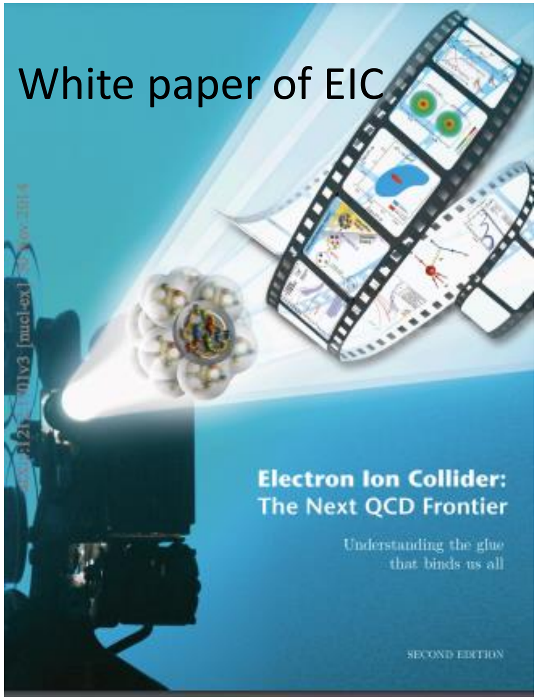
$\mathcal{O}(\mathrm{TeV})$

SMEFT



Bottom-up approach

Why Electron-Ion Collider?



White paper of EIC

Electron Ion Collider:
The Next QCD Frontier

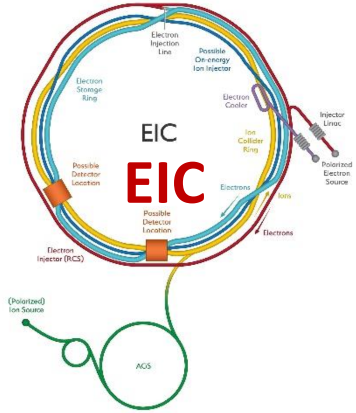
Understanding the glue
that binds us all

SECOND EDITION

1. Explore and image the spin and 3D structure of the nucleon
2. Discover the role of gluons in structure and dynamics
3. Constraint for the PDFs, Polarized and unpolarized
4. Possibilities of Beyond the Standard Model?

$$10 \sim 100\ \mathrm{fb}^{-1}$$

High Polarization: $P_e = P_p = 0.7$

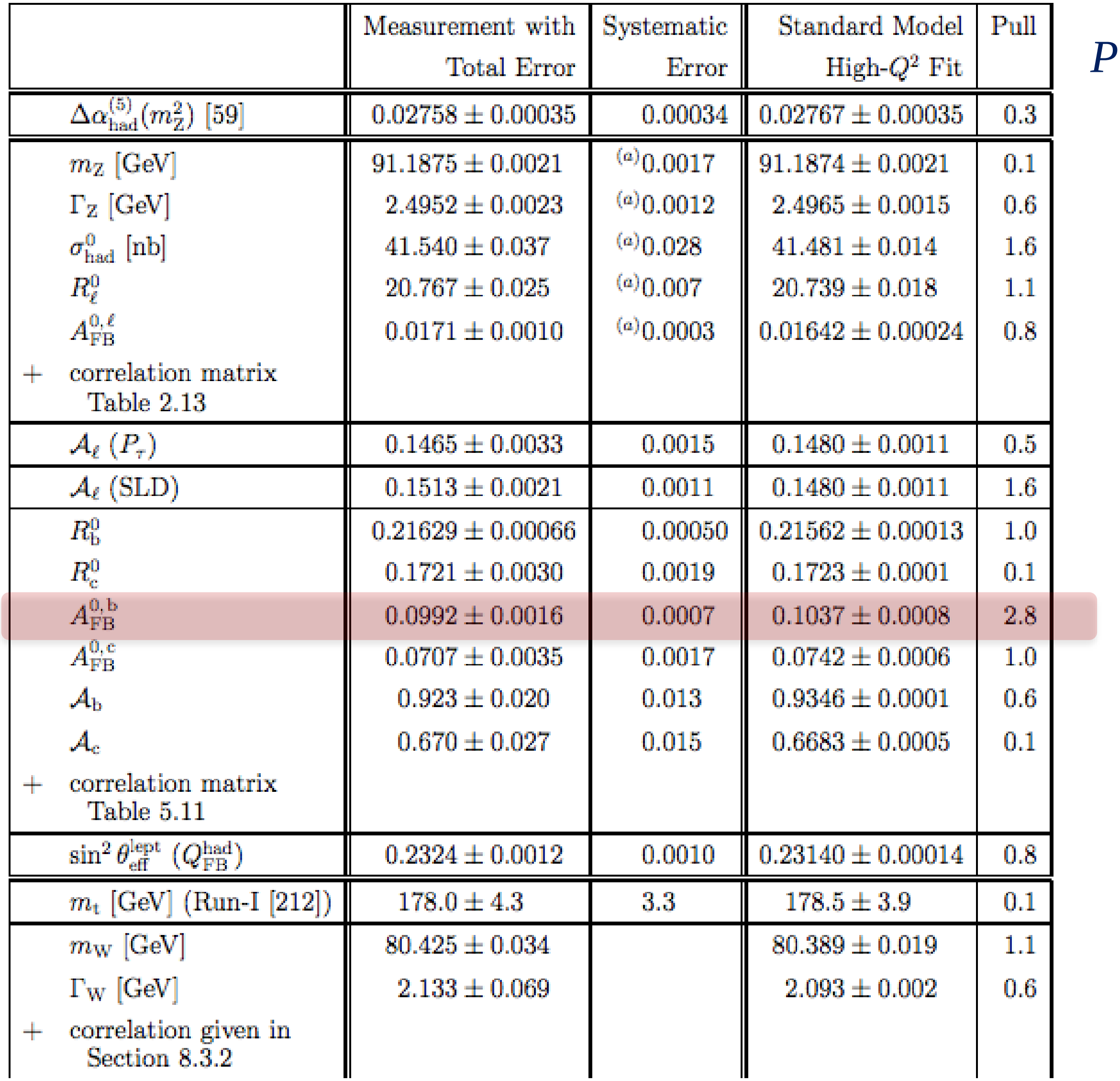


Electroweak properties

EIC is also an important machine for the New Physics

Longitudinal polarization of the electron

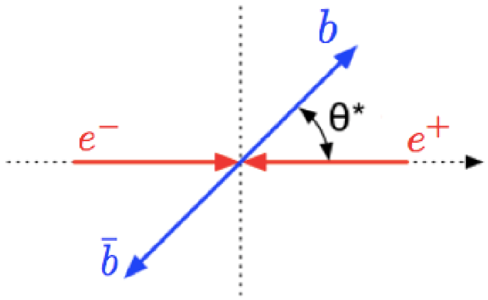
Electroweak Precision measurement

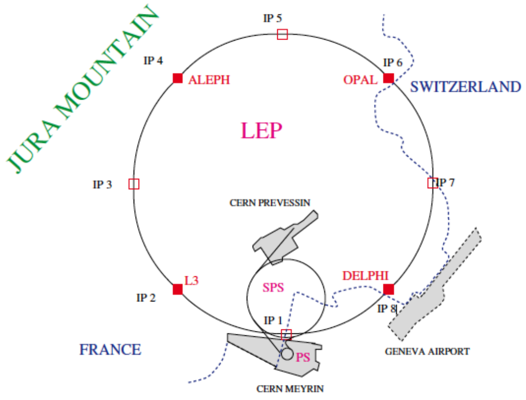


	Measurement with Total Error	Systematic Error	Standard Model High-Q^2 Fit	Pull
$\Delta\alpha_{\rm had}^{(5)}(m_Z^2)$ [59]	0.02758 ± 0.00035	0.00034	0.02767 ± 0.00035	0.3
m_Z [GeV]	91.1875 ± 0.0021	$^{(a)}0.0017$	91.1874 ± 0.0021	0.1
Γ_Z [GeV]	2.4952 ± 0.0023	$^{(a)}0.0012$	2.4965 ± 0.0015	0.6
$\sigma_{\rm had}^0$ [nb]	41.540 ± 0.037	$^{(a)}0.028$	41.481 ± 0.014	1.6
R_ℓ^0	20.767 ± 0.025	$^{(a)}0.007$	20.739 ± 0.018	1.1
$A_{\rm FB}^{0,\ell}$	0.0171 ± 0.0010	$^{(a)}0.0003$	0.01642 ± 0.00024	0.8
+ correlation matrix Table 2.13				
$\mathcal{A}_\ell$ (P_τ)	0.1465 ± 0.0033	0.0015	0.1480 ± 0.0011	0.5
$\mathcal{A}_\ell$ (SLD)	0.1513 ± 0.0021	0.0011	0.1480 ± 0.0011	1.6
R_b^0	0.21629 ± 0.00066	0.00050	0.21562 ± 0.00013	1.0
R_c^0	0.1721 ± 0.0030	0.0019	0.1723 ± 0.0001	0.1
$A_{\rm FB}^{0,b}$	0.0992 ± 0.0016	0.0007	0.1037 ± 0.0008	2.8
$A_{\rm FB}^{0,c}$	0.0707 ± 0.0035	0.0017	0.0742 ± 0.0006	1.0
$\mathcal{A}_b$	0.923 ± 0.020	0.013	0.9346 ± 0.0001	0.6
$\mathcal{A}_c$	0.670 ± 0.027	0.015	0.6683 ± 0.0005	0.1
+ correlation matrix Table 5.11				
$\sin^2\theta_{\rm eff}^{\rm lept}$ $(Q_{\rm FB}^{\rm had})$	0.2324 ± 0.0012	0.0010	0.23140 ± 0.00014	0.8
m_t [GeV] (Run-I [212])	178.0 ± 4.3	3.3	178.5 ± 3.9	0.1
m_W [GeV]	80.425 ± 0.034		80.389 ± 0.019	1.1
Γ_W [GeV]	2.133 ± 0.069		2.093 ± 0.002	0.6
+ correlation given in Section 8.3.2				

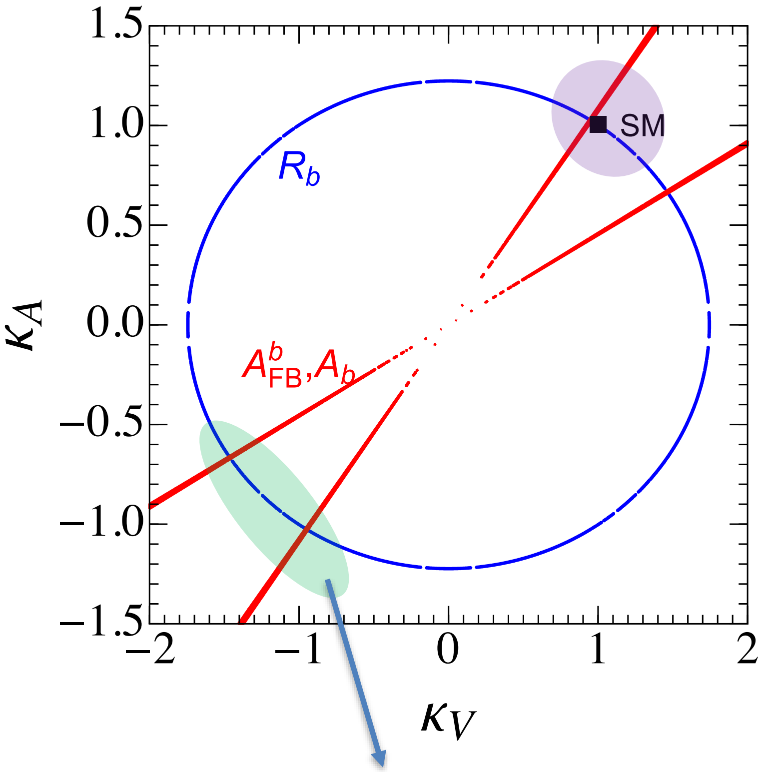
Phys.Rept. 427 (2006) 257-454

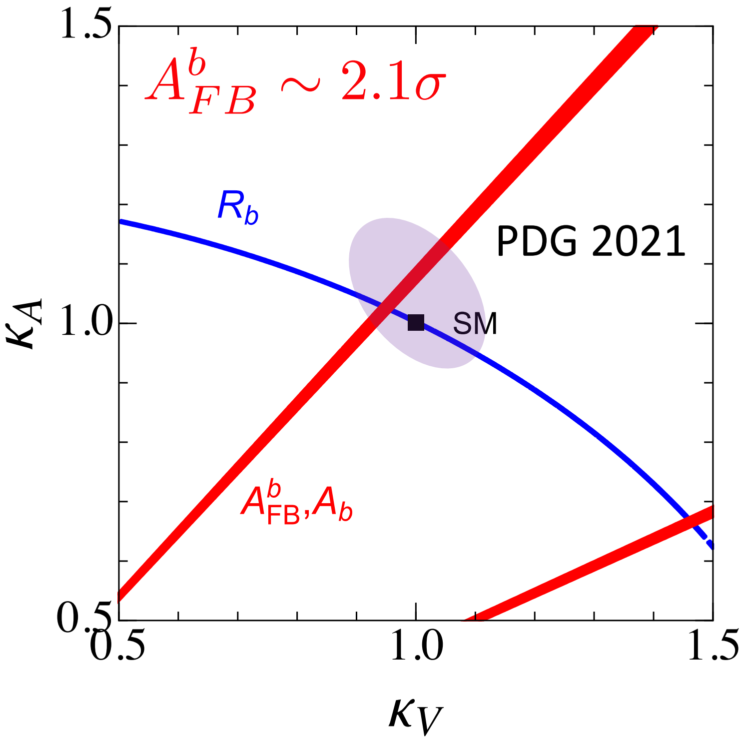
LEP： 1989-2000





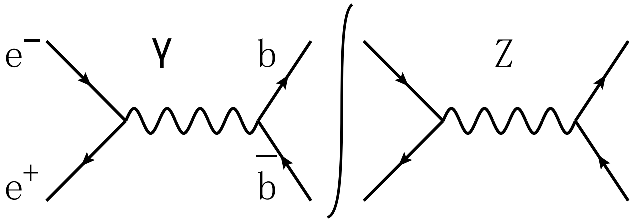
Electroweak Precision measurement





Excluded by off-Z pole data

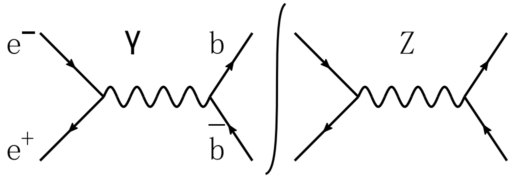
$$\mathcal{L} = \bar{b}\gamma_\mu(\kappa_V g_V - \kappa_A g_A \gamma_5) b Z_\mu$$



- *Large deviation* of the Zbb coupling
- The degeneracy of the Zbb coupling

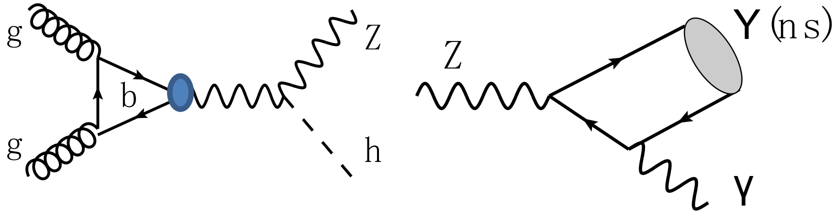
Zbb couplings @ Colliders

A. Lepton colliders:



S. Gori, Jiayin Gu, Lian-Tao Wang, JHEP 04(2016) 062
Bin Yan, C.-P. Yuan and Shu-Run Yuan, PRD108(2023)5, 053001

B. LHC Zh production and Z boson rare decay:

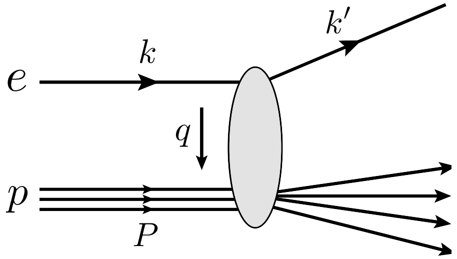


Bin Yan, C.-P. Yuan, PRL127(2021)5,051801

Hongxin Dong, Peng Sun, Bin Yan and C.-P. Yuan, PLB829(2022)137076

C. LHC Z+2b-jet production F. Bishara and Zhuoni Qian, 2306.15109

D. HERA and EIC with polarized lepton beam:

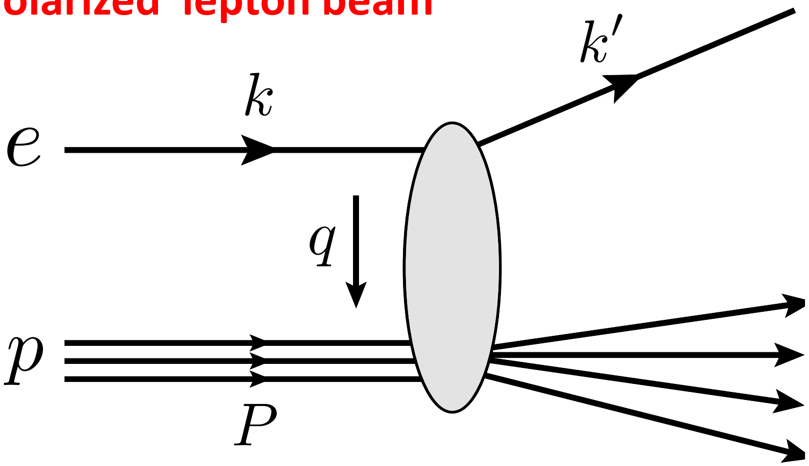


Bin Yan, Zhite Yu and C.-P. Yuan, PLB822(2021)136697
Hai Tao Li, Bin Yan and C.-P. Yuan, PLB833(2022)137300

Zbb couplings @ EIC

Bin Yan, Zhite Yu and C.-P. Yuan, PLB822(2021)136697

Polarized lepton beam



Single-Spin Asymmetry (SSA):

$$A_e^b = \frac{\sigma_{b,+}^{\text{tot}} - \sigma_{b,-}^{\text{tot}}}{\sigma_{b,+}^{\text{tot}} + \sigma_{b,-}^{\text{tot}}}$$

+/−: right/left-handed lepton

1. Photon-only diagrams will cancel in SSA
2. Leading contribution: γ-Z interference
3. Only sensitive to the vector component of the Zbb coupling

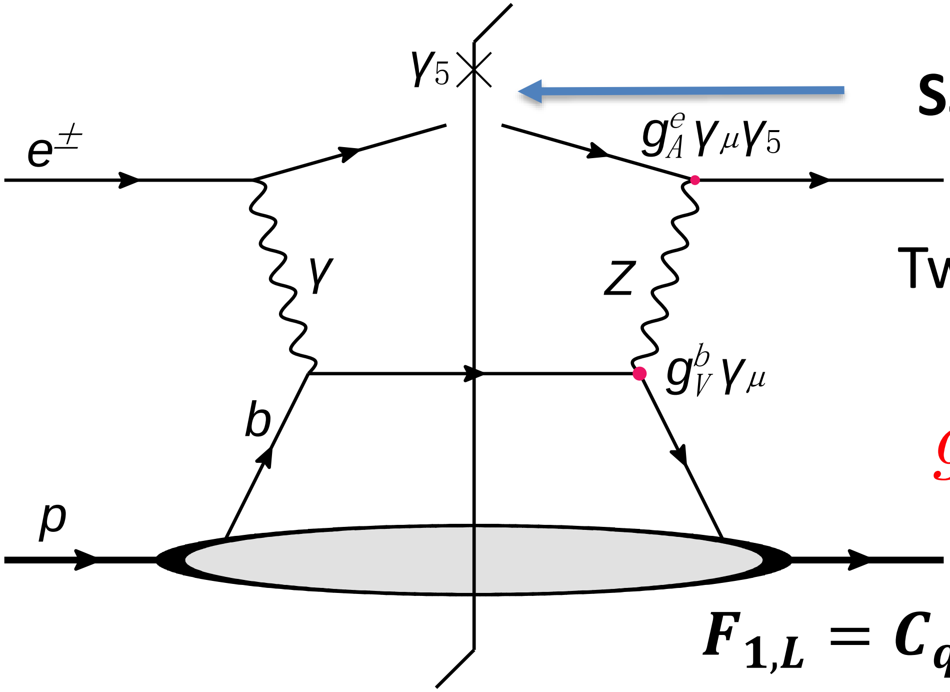
DIS cross section

Polarized cross section

$$F_{1,L,3} \equiv F_{1,L,3}(\lambda_e)$$

$$\frac{d\sigma^{\pm}_{\lambda_e}}{\sigma_0 dx dy} = F_1\left((1-y)^2+1\right) + F_L\frac{1-y}{x} \mp F_3\underline{\lambda_e}\left(y-\frac{y^2}{2}\right)$$

$\lambda_e = \pm 1$: lepton helicity



SSA: $\boldsymbol{\sigma_{b,+} - \sigma_{b,-}}$

Two possible combination:

$g_A^e g_V^b$ ✓

$g_V^e g_A^b$

$\boldsymbol{F_{1,L} = C_q \otimes (q + \bar{q})}$ $\boldsymbol{F_3 = C_q \otimes (q - \bar{q})}$

$$\mathcal{L}_{\text{eff}} = \frac{g_W}{2c_W}\bar{f}\gamma_\mu(g_V^f - g_A^f\gamma_5)fZ_\mu$$

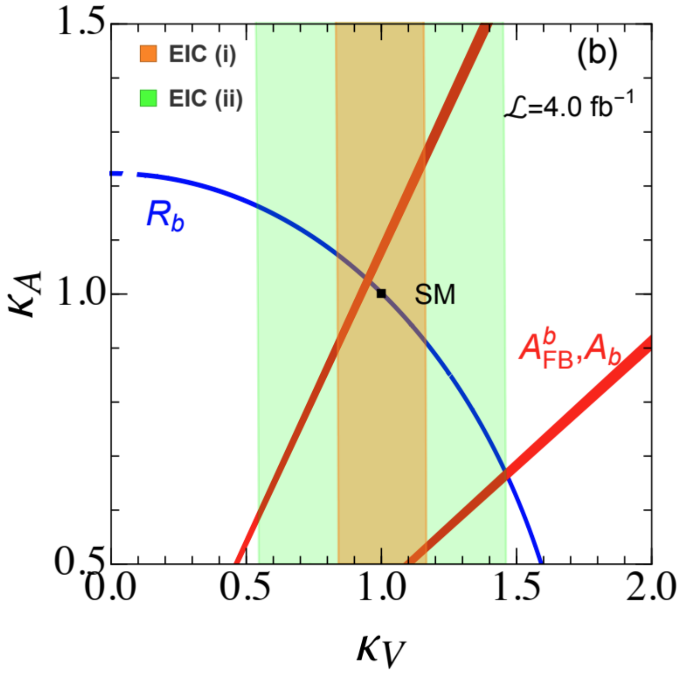
Zbb couplings @ EIC

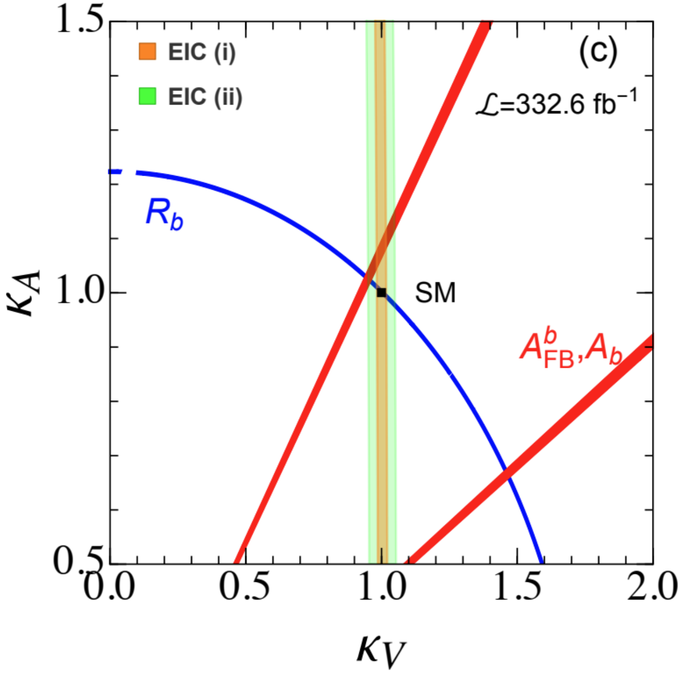
$$(i)\ \epsilon_q^b = 0.001, \qquad \epsilon_c^b = 0.03, \qquad \epsilon_b = 0.7;$$

$$(ii)\ \epsilon_q^b = 0.01, \qquad \epsilon_c^b = 0.2, \qquad \epsilon_b = 0.5.$$

$$E_{\mathrm{cm}} = 141\ \mathrm{GeV}, P_e = 0.7$$

$$\mathcal{L} = \bar{b}\gamma_\mu(\kappa_V g_V - \kappa_A g_A \gamma_5) b Z_\mu$$





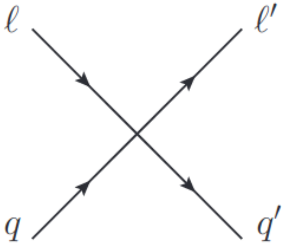
The minimal luminosities needed to resolve the degeneracy or exclude LEP AFB data:

$(i): \mathcal{L} > 0.5\ \mathrm{fb}^{-1};\ (ii): \mathcal{L} > 4.0\ \mathrm{fb}^{-1}.$ $(i): \mathcal{L} > 42.0\ \mathrm{fb}^{-1};\ (ii): \mathcal{L} > 332.6\ \mathrm{fb}^{-1}.$

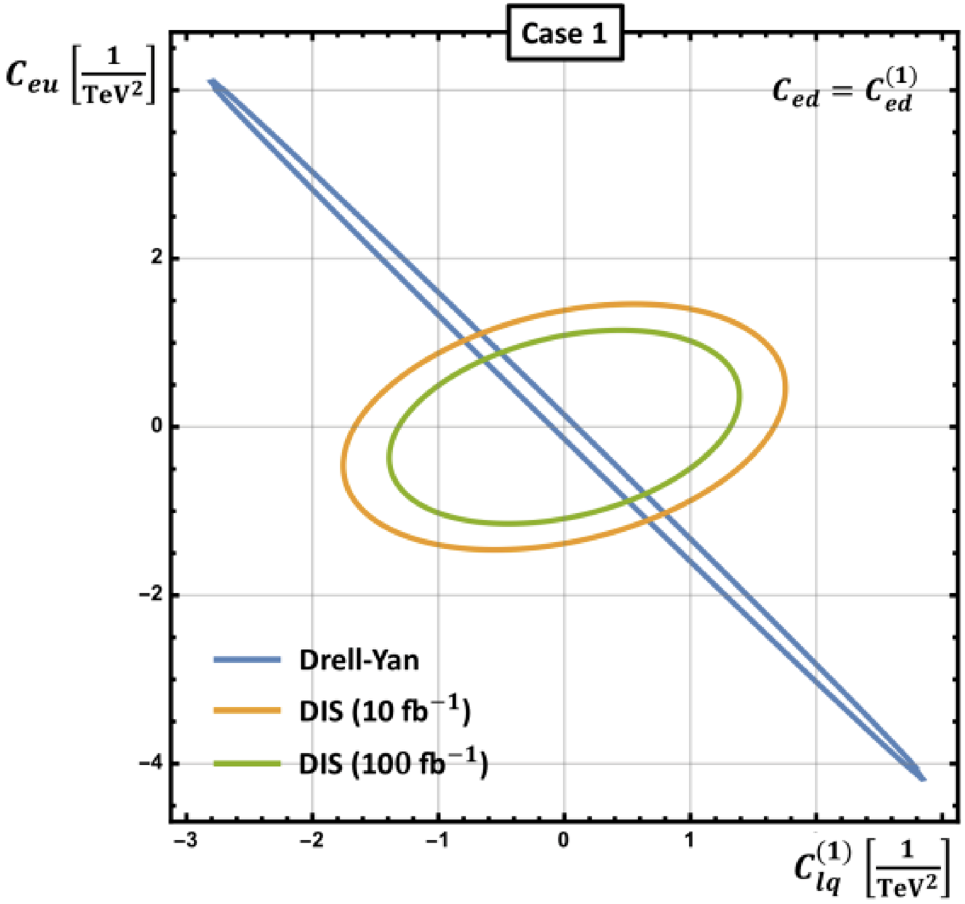
Four-fermion operators

R. Boughezal, F. Petriello, D. Wiegand, PRD 101 (2020) 11,116002

$$P_e = \pm 0.7$$



$$M_{\text{int}}^{\gamma} \sim C_{eu}(1+P_e) + C_{\ell q}^{(1)}(1-P_e)$$



$\mathcal{O}_{lq}^{(1)}$	$(\bar{l}\gamma^{\mu}l)(\bar{q}\gamma_{\mu}q)$	$\mathcal{O}_{lu}$	$(\bar{l}\gamma^{\mu}l)(\bar{u}\gamma_{\mu}u)$
$\mathcal{O}_{lq}^{(3)}$	$(\bar{l}\gamma^{\mu}\tau^{I}l)(\bar{q}\gamma_{\mu}\tau^{I}lq)$	$\mathcal{O}_{ld}$	$(\bar{l}\gamma^{\mu}l)(\bar{d}\gamma_{\mu}d)$
$\mathcal{O}_{eu}$	$(\bar{e}\gamma^{\mu}e)(\bar{u}\gamma_{\mu}u)$	$\mathcal{O}_{qe}$	$(\bar{q}\gamma^{\mu}q)(\bar{e}\gamma_{\mu}e)$
$\mathcal{O}_{ed}$	$(\bar{e}\gamma^{\mu}e)(\bar{d}\gamma_{\mu}d)$		

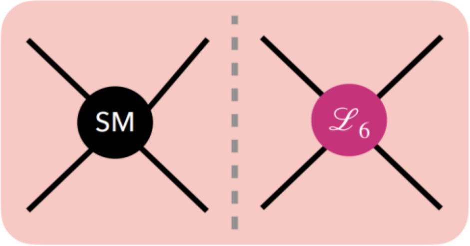
Polarization of the electron plays the key role to resolve the degeneracies from LHC data

Transverse polarization of electron and proton

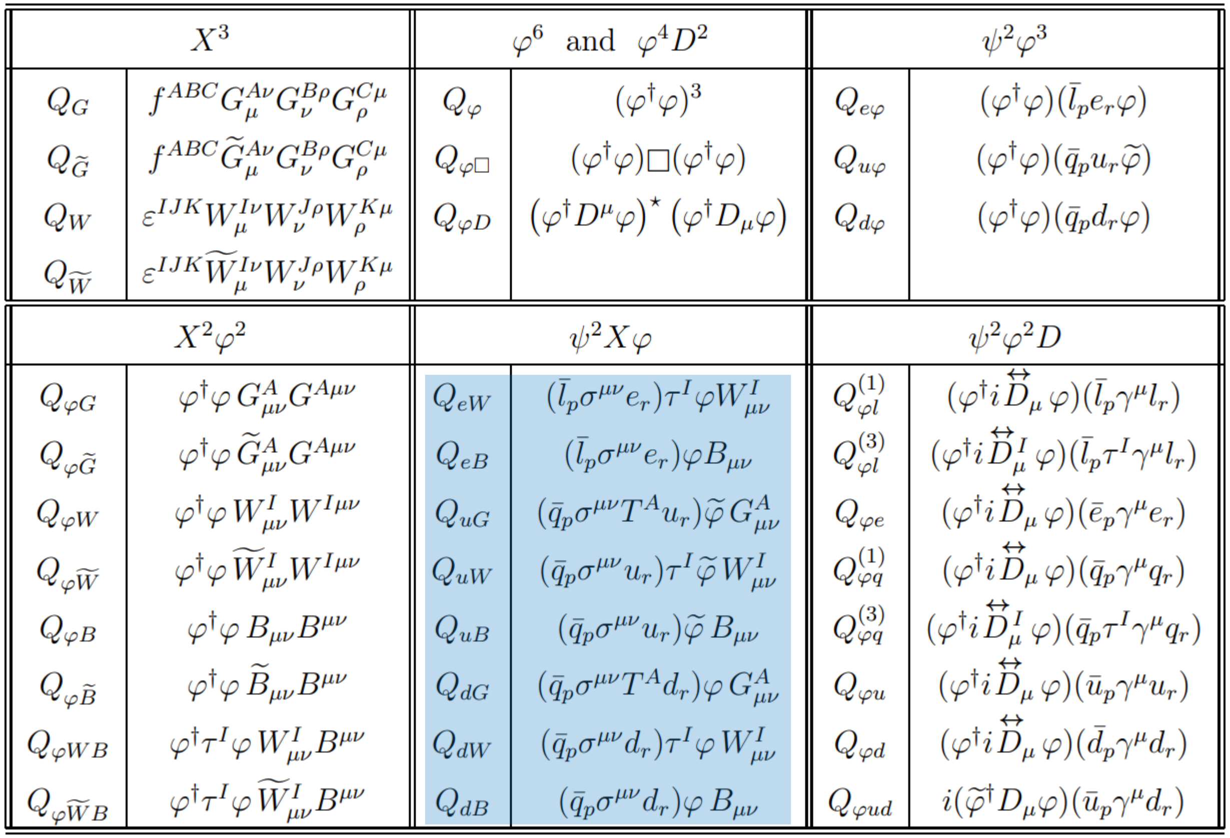
New Physics and SMEFT

B. Grzadkowski et al, 2010

Interference effects



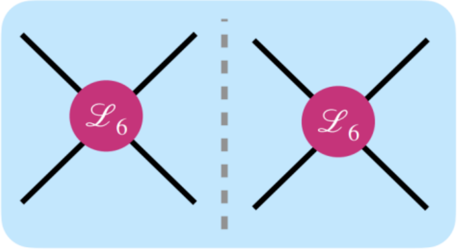
$\sim \mathcal{O}(\frac{1}{\Lambda^2})$



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

Chirality-flipped operators

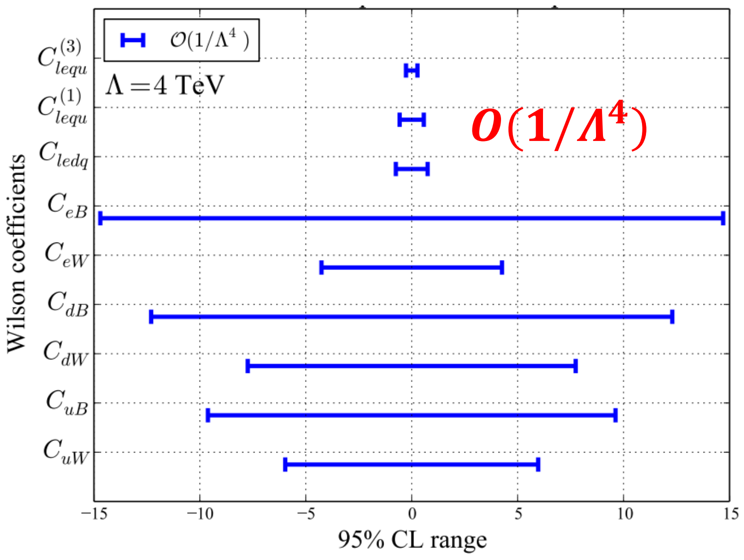


$\sim \mathcal{O}(\frac{1}{\Lambda^4})$

The constraints will be very weak

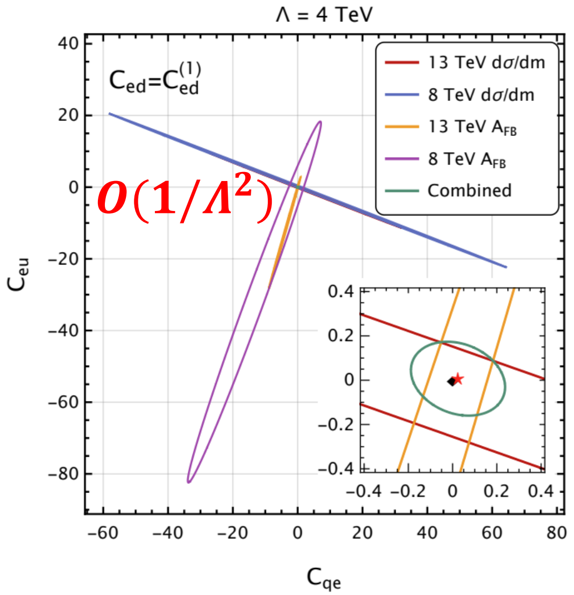
Example: Dipole Operator

Single-Parameter-Analysis: EW dipole couplings are poorly constrained



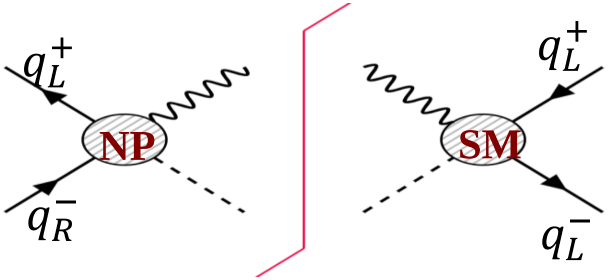
$O(1/\Lambda^4)$

R. Boughezal et al. *Phys.Rev.D* 104 (2021) 9, 095022



$O(1/\Lambda^2)$

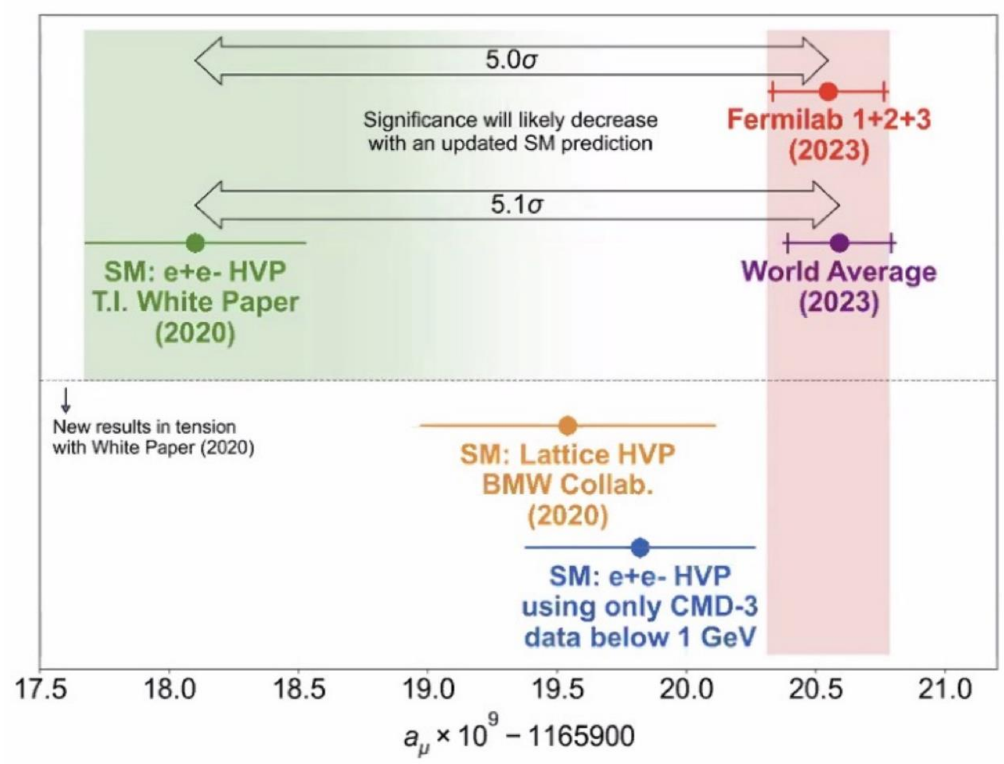
R. Boughezal et al, 2303.08257



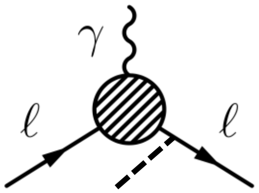
Leading contribution: $\left|\frac{c_{dipole}}{\Lambda^2}\right|^2$

=0 for the cross section

New Physics and Dipole Operator

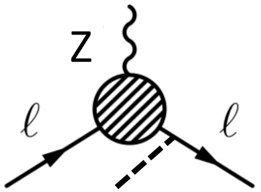


Loop-induced by the BSM

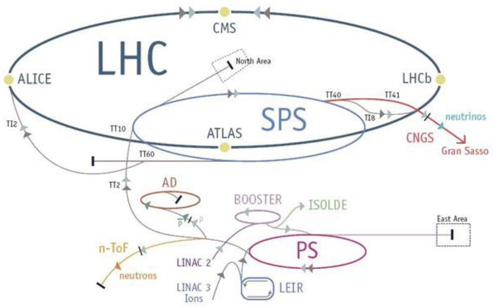


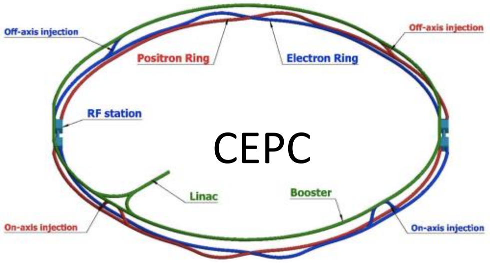
May have same physics source

$B_{\mu\nu}, W_{\mu\nu}$



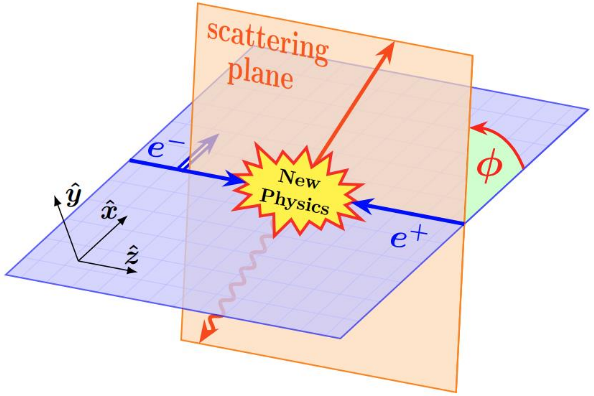
How to probe the electroweak dipole operators?





How to Probe Dipole Operator

Is it possible to probe the dipole operators at $o\left(\frac{1}{\Lambda^2}\right)$?

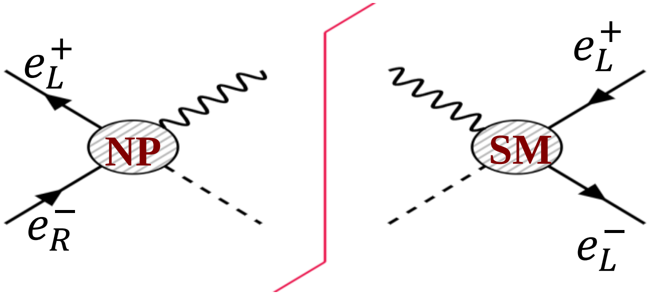


Transversely polarized effect of beams:

The interference between the different helicity states

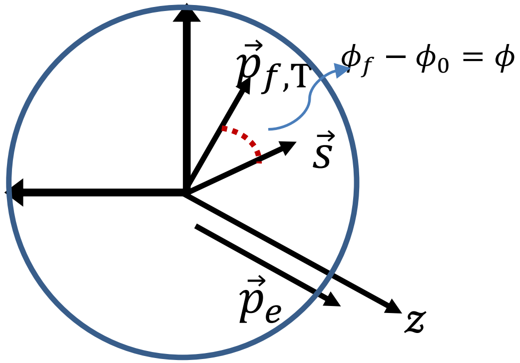
$$\boldsymbol{s} = (b_1, b_2, \lambda) = \underline{(b_{\mathrm{T}} \cos\phi_0, b_{\mathrm{T}} \sin\phi_0, \lambda)}$$

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



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

Breaking the rotational invariance & A nontrivial azimuthal behavior



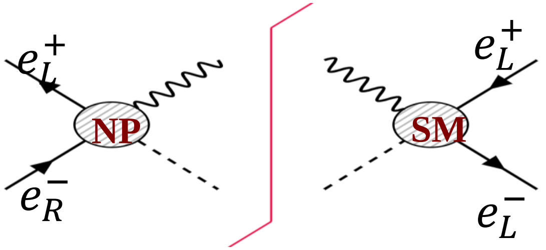
Xin-Kai Wen, Bin Yan, Zhite Yu, C.-P. Yuan,
PRL 131 (2023) 241801

Transverse Spin Polarization

Xin-Kai Wen, Bin Yan, Zhite Yu, C.-P. Yuan, PRL 131 (2023) 241801

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

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



$e^{i\phi*0}$ $e^{i\phi}$

$M\infty e^{i(\alpha 1-\alpha 2)\phi}$

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

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

$\mathrm{Re}[C_{dipole}]$ $\mathrm{Im}[C_{dipole}]$ SM & other NP

CP-conserving CP-violation

- Linearly dependent on the dipole couplings C_{dipole} and spin b_T
- Without depending on other NP operators

Single Transverse Spin Asymmetries

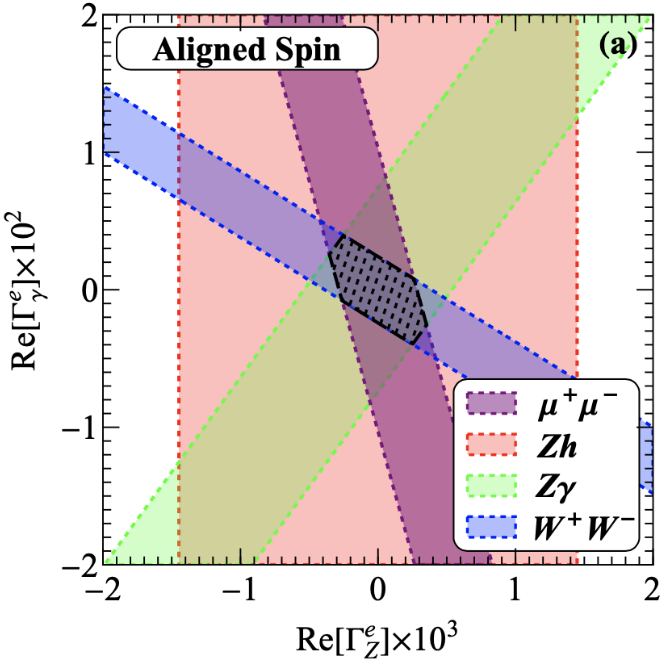
$$A_{LR}^{i} = \frac{\sigma^i(\cos\phi > 0) - \sigma^i(\cos\phi < 0)}{\sigma^i(\cos\phi > 0) + \sigma^i(\cos\phi < 0)} = \frac{2}{\pi} A_R^i$$

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

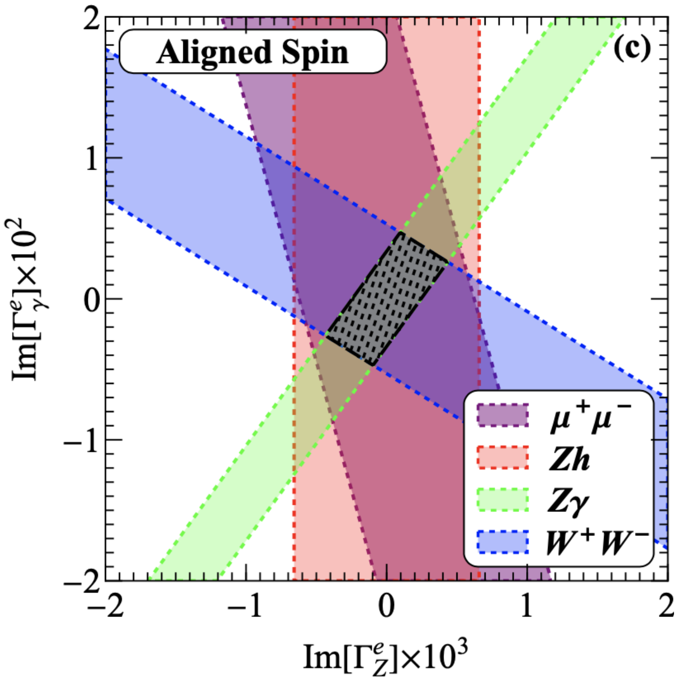
$\sqrt{s} = 250\ \text{GeV}, \mathcal{L} = 5\ \text{ab}^{-1}$ $\quad (b_T, \bar{b}_T) = (0.8, 0.3)$

Xin-Kai Wen, Bin Yan, Zhite Yu, C.-P. Yuan,

PRL 131 (2023) 241801



CP-conserved dipole operator



CP-violated dipole operator

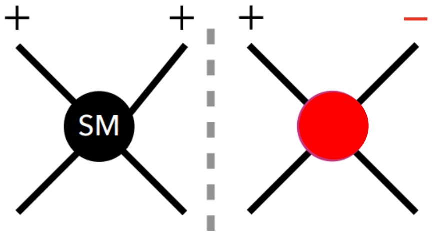
- Our bounds are much stronger than other approaches by 1~2 orders of magnitude

Transverse spin effects@ EIC

- Dipole operators

R. Boughezal, D. Florian, F. Petriello, W. Vogelsang,
PRD 107 (2023) 7, 075028

$$
\begin{aligned}
\mathcal{O}_{eW} &= (\bar{l}\sigma^{\mu\nu}e)\tau^I\varphi W^I_{\mu\nu}, \\
\mathcal{O}_{eB} &= (\bar{l}\sigma^{\mu\nu}e)\varphi B_{\mu\nu}, \\
\mathcal{O}_{uW} &= (\bar{q}\sigma^{\mu\nu}u)\tau^I\varphi W^I_{\mu\nu}, \\
\mathcal{O}_{uB} &= (\bar{q}\sigma^{\mu\nu}u)\varphi B_{\mu\nu}, \\
\mathcal{O}_{dW} &= (\bar{q}\sigma^{\mu\nu}d)\tau^I\varphi W^I_{\mu\nu}, \\
\mathcal{O}_{dB} &= (\bar{q}\sigma^{\mu\nu}d)\varphi B_{\mu\nu}.
\end{aligned}
$$



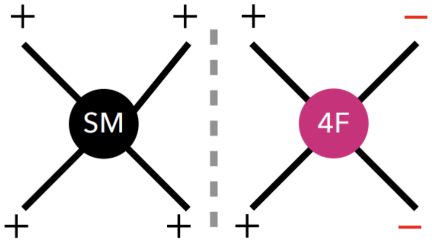
$\sim \mathcal{O}(\frac{1}{\Lambda^2})$

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

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

- Scalar and tensor four fermion operators

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



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

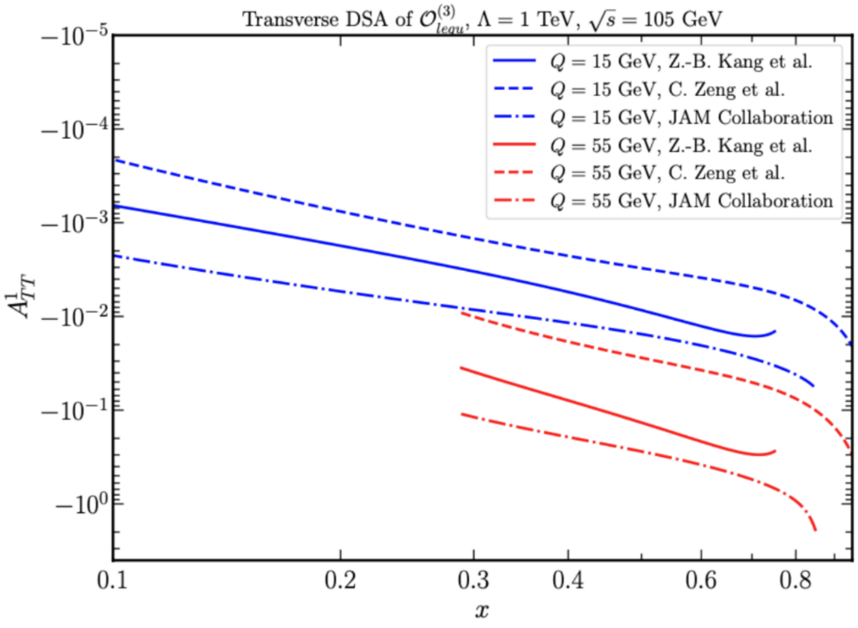
Hao-Lin Wang, Xin-Kai Wen, Hongxi Xing, Bin Yan,
2401.08419 (PRD)

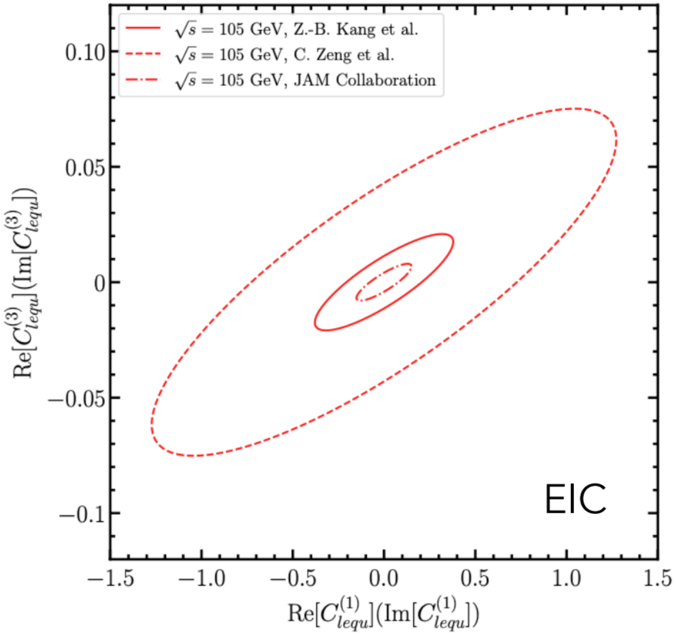
$$A_{TT} = \frac{\sigma\left(e^{\uparrow}p^{\uparrow}\right) + \sigma\left(e^{\downarrow}p^{\downarrow}\right) - \sigma\left(e^{\uparrow}p^{\downarrow}\right) - \sigma\left(e^{\downarrow}p^{\uparrow}\right)}{\sigma\left(e^{\uparrow}p^{\uparrow}\right) + \sigma\left(e^{\downarrow}p^{\downarrow}\right)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

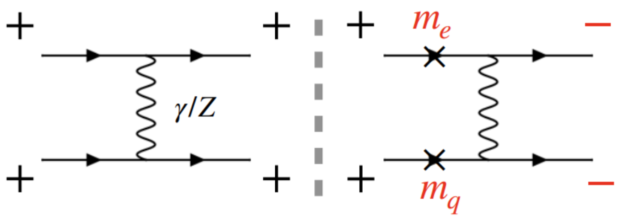
Transverse spin effects@ EIC

Hao-Lin Wang, Xin-Kai Wen, Hongxi Xing, Bin Yan, PRD 109 (2024) 095025

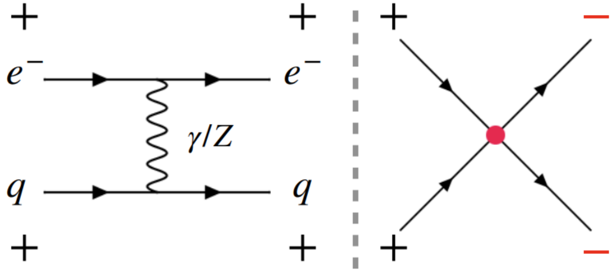
$P_{T,e} = P_{T,p} = 0.7, \mathcal{L} = 100\ \mathrm{fb}^{-1}$



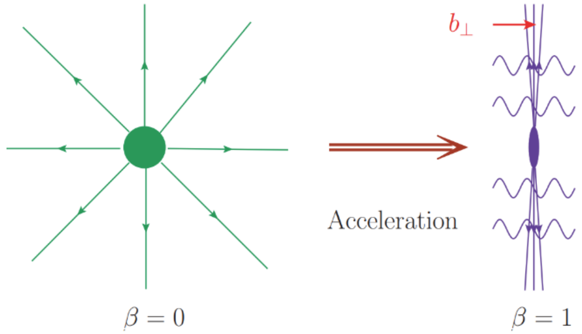


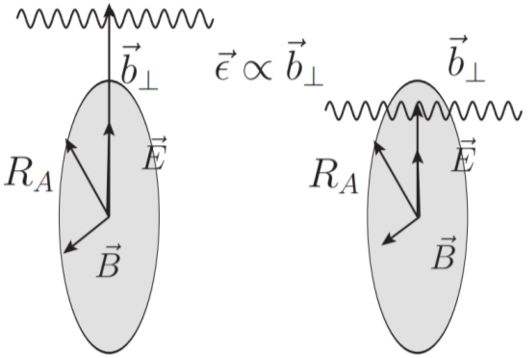


DSA in SM will be suppressed by electron and quark masses $O(10^{-7} \sim 10^{-9})$

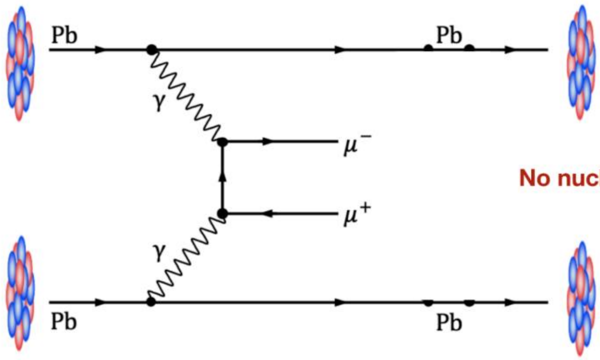


Linear polarization @ UPCs





C.Li, J.Zhou, Y.J.Zhou, Phys. Lett. B. 795, 576 (2019)

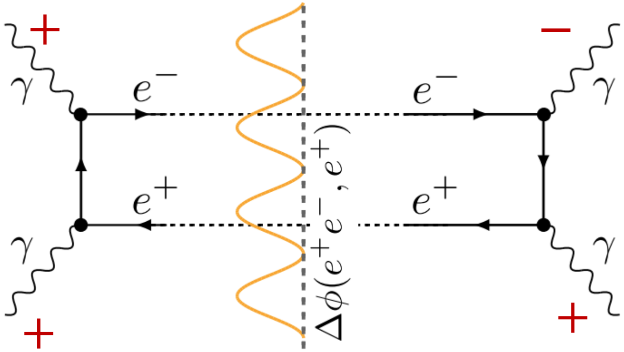


No nucleus breakup

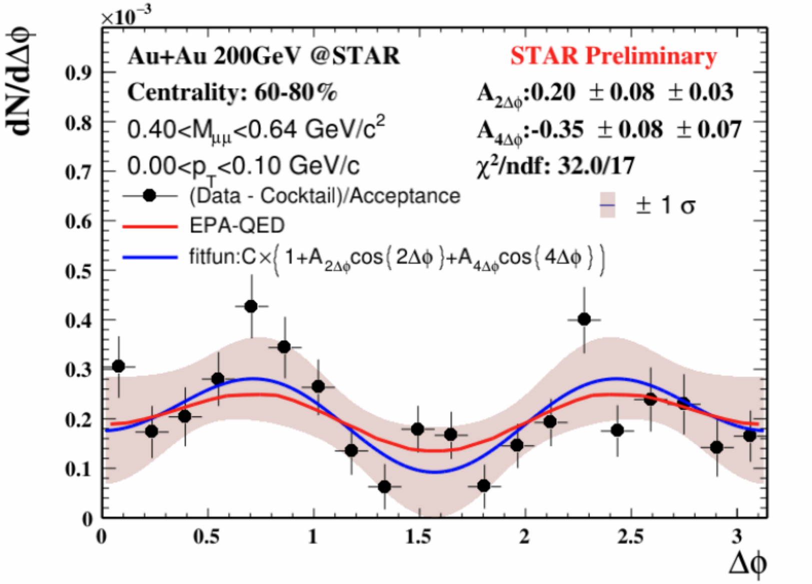
- Ultra-relativistic charged nuclei produce highly Lorentz contracted electromagnetic field
- Weizsacker-Williams equivalent photon approximation
- Photons are linearly polarized
- Large quasi-real photon flux $\propto Z^2$
- The impact parameter $b_\perp > 2R_A$

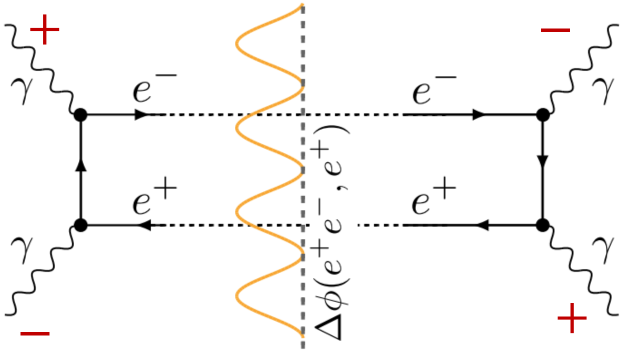
Linear polarization @ UPCs

D. Y. Shao, C. Zhang, J. Zhou, Y. Zhou, PRD107 (2023) 3, 036020

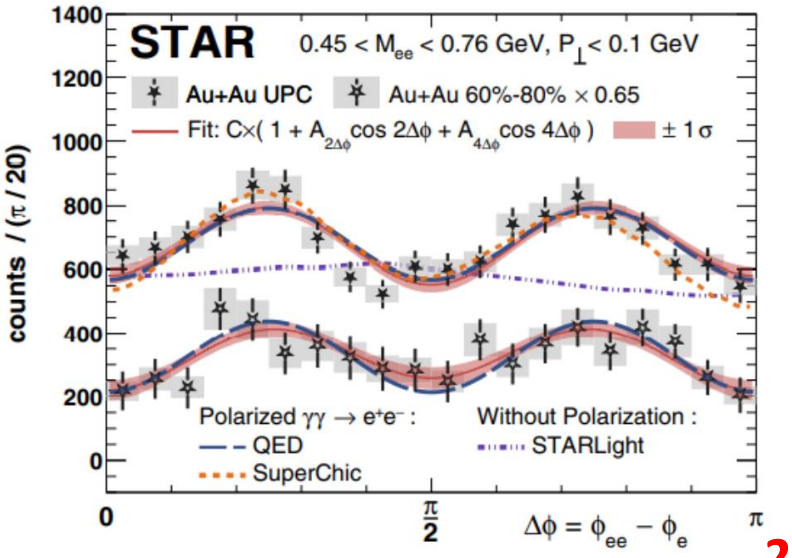


$$\frac{m_e^2}{p_T^2}\,cos2\Delta\phi$$

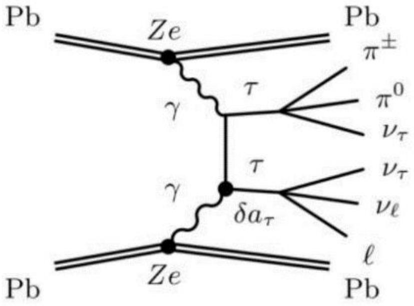




$$cos4\Delta\phi$$

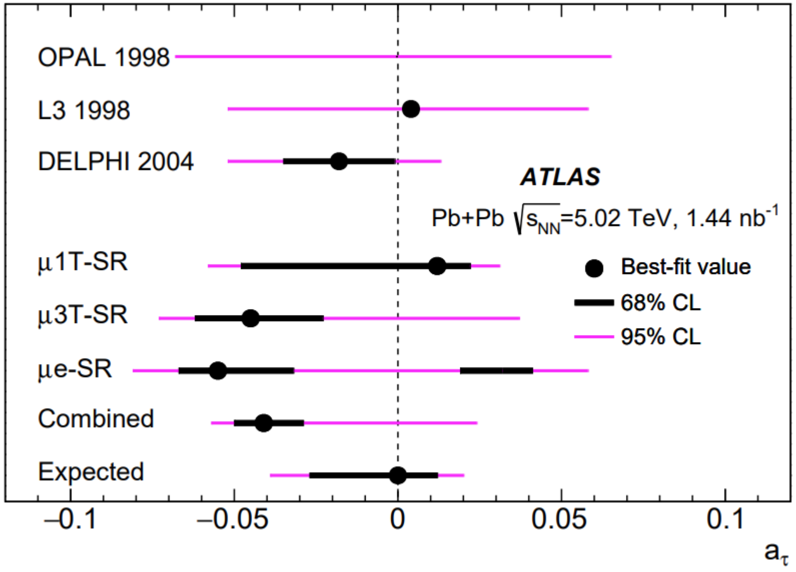


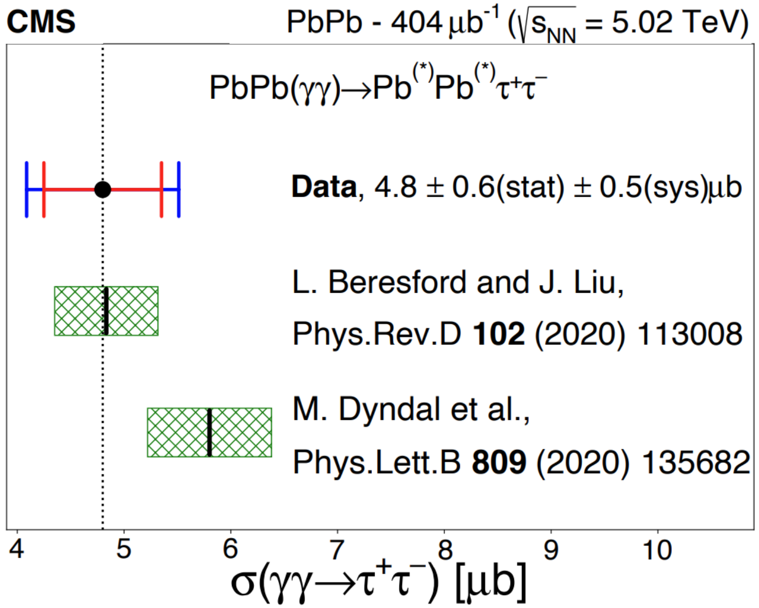
Tau pair production @ UPCs



$$\Gamma^{\mu}_{\text{eff.}}(q^2) = -ie\left[iF_2(q^2) + F_3(q^2)\gamma^5\right]\frac{\sigma^{\mu\nu}q_\nu}{2m_\tau}$$

$$F_2(0) = a_\tau, \quad F_3(0) = 2\frac{m_\tau d_\tau}{e}$$





Phys. Rev. Lett. 131 (2023) 15, 151802

Phys. Rev. Lett. 131 (2023) 151803

Linear polarization @ UPCs

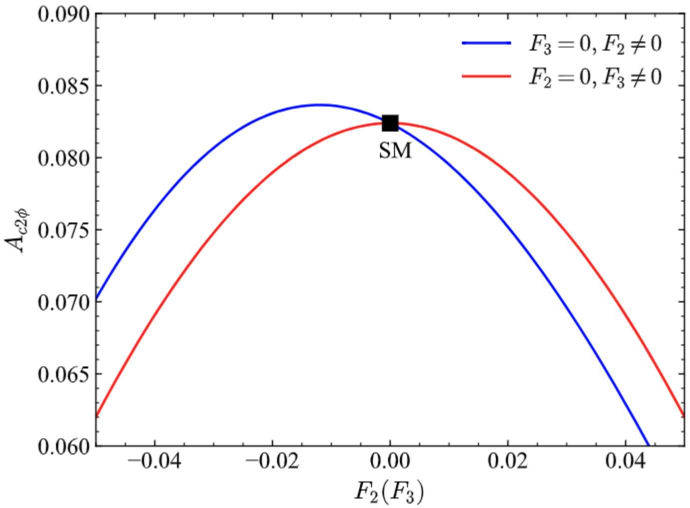
Dingyu Shao, Bin Yan, Shu-Ruan Yuan, Cheng Zhang, 2310.14153

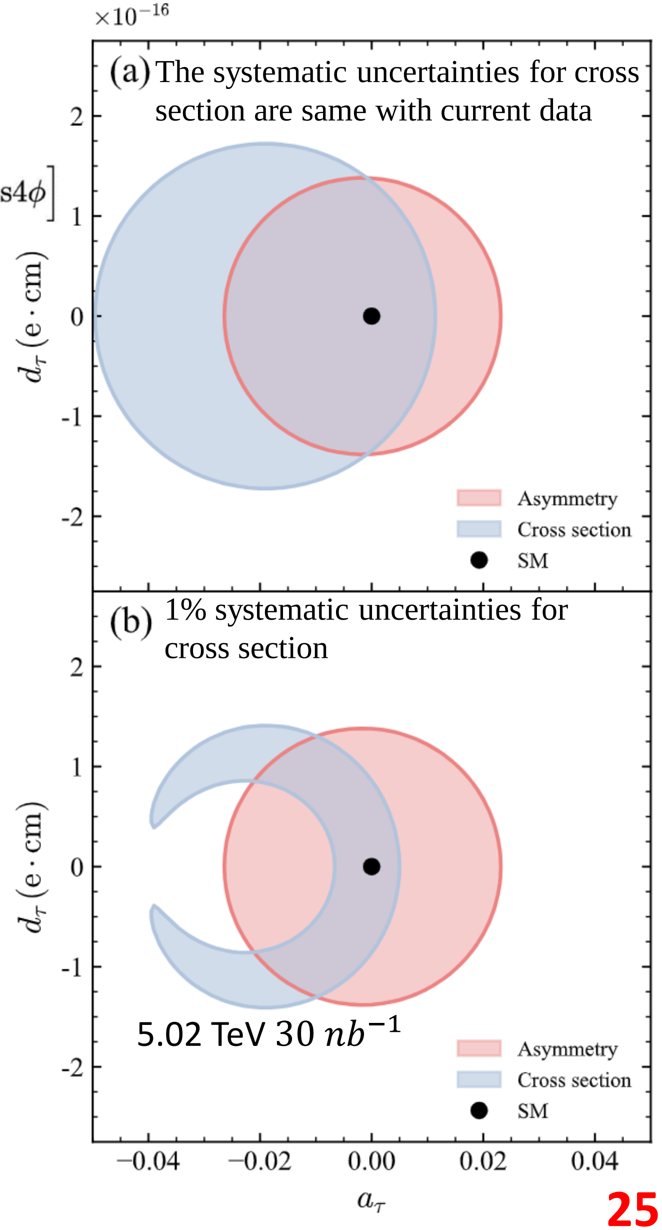
$$d\sigma \sim \left[A_0 + B_0^{(1)}F_2 + B_0^{(2)}F_2^2 + C_0^{(2)}F_3^2 + \left(A_2 + B_2^{(2)}F_2^2 + C_2^{(2)}F_3^2\right)\cos 2\phi + A_4 \cos 4\phi\right]$$

$$F_2(0) = a_\tau, \quad F_3(0) = 2\frac{m_\tau d_\tau}{e}$$

Suppressed by lepton mass

$$A_{c2\phi} = \frac{\sigma(\cos 2\phi > 0) - \sigma(\cos 2\phi < 0)}{\sigma(\cos 2\phi > 0) + \sigma(\cos 2\phi < 0)}$$





(a) The systematic uncertainties for cross section are same with current data

(b) 1% systematic uncertainties for cross section

5.02 TeV 30 nb^{-1}

Summary

- EIC is an important machine for probing the new physics;
- The longitudinal polarized beams: Zbb couplings;
- The transversely polarized beams : Chirality-flipped interactions
- The photons from UPCs are linearly polarized and can be used to probe the NP

The search for new physics at the EIC is just beginning

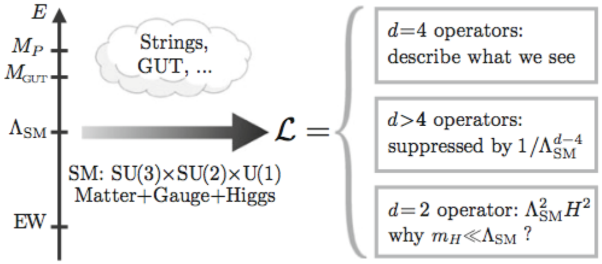
Thank you!

New Physics and EFT

1. The κ framework for the couplings:

BSM physics is expected to affect the production modes and decay channels by a SM like interactions

2. The Standard Model Effective Field Theory



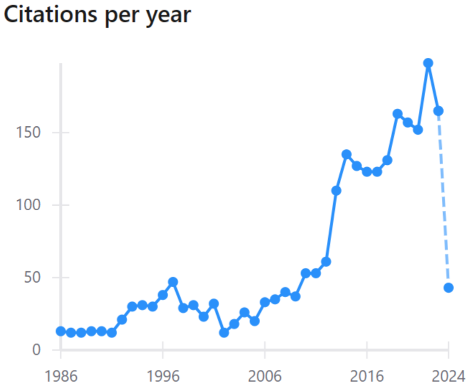
Linear realized EFT

Higgs is a fundamental particle
Weak interacting

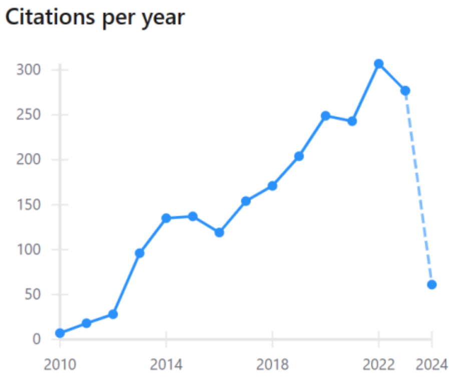
W. Buchuller, D. wyler 1986
B. Grzadkowski et al, 2010
L. Lehman, A. Marin, 2015
B. Henning et al, 2015
H-L. Li et al, 2020
Murphy, 2020

$$\mathcal{L} = \frac{C_6}{\Lambda^2}\mathcal{O}_6 + \frac{C_8}{\Lambda^4}\mathcal{O}_8 + \ldots$$

W. Buchuller, D. wyler 1986



B. Grzadkowski et al, 2010

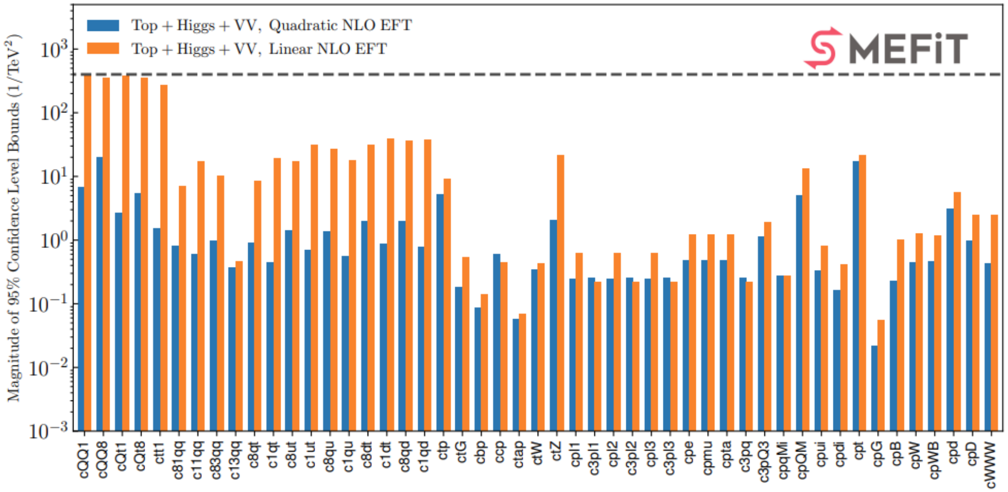


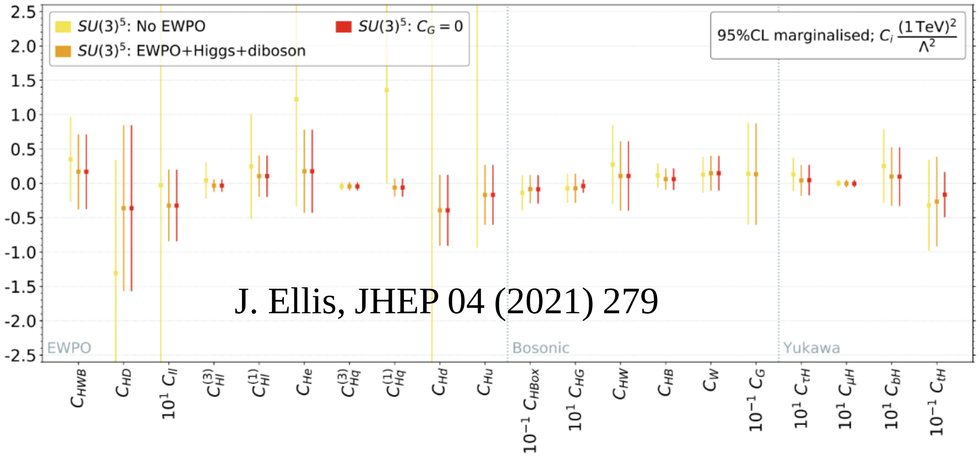
3. Higgs Effective Field Theory

Callan, Coleman, Wess, Zumino, 1969
The electroweak chiral Lagrangian+light Higgs, A.C. Longhitano, 1980,....

Global analysis @ SMEFT

SMEFiT Collaboration, JHEP 11 (2021) 089





J. Ellis, JHEP 04 (2021) 279

The SMEFT approach allows for the combination

◆ Higgs data

◆ Electroweak precision observables

◆ Diboson production

◆ Top quark Physics

◆ ……

SMEFT is becoming one of the standard tool for the LHC experimental analysis