Opportunities for New Physics Searches at the EIC

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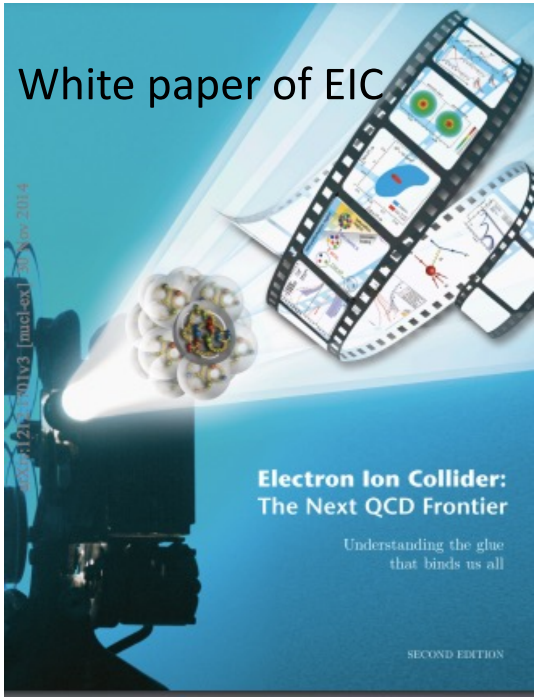
Institute of High Energy Physics

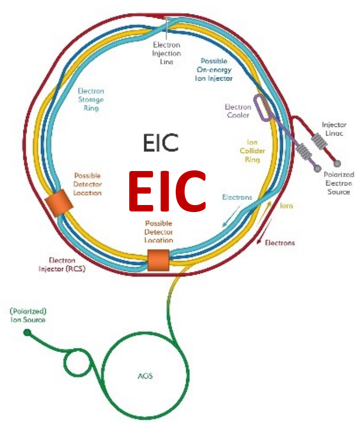
The 1th Annual Conference on Electron-Ion Collider Physics in China

April 19-22, 2026

Electron-Ion Collider

White paper of EIC





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 and FFs, Polarized and unpolarized
4. Possibilities of Beyond the Standard Model?

Low energy: 100 GeV

High Luminosity: $10 \sim 100\ \mathrm{fb}^{-1}$ per year

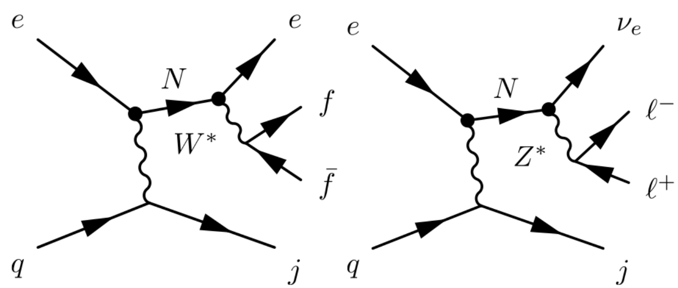
High Polarization: $P_e = P_p = 0.7$

Electroweak properties

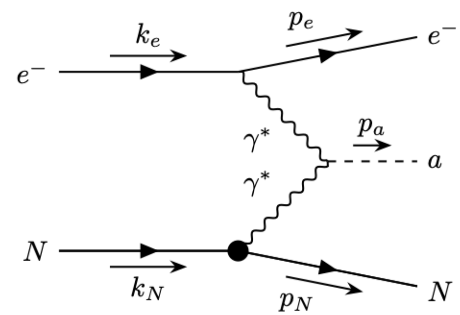
Light new particles and new interactions

Light new particles @ EIC

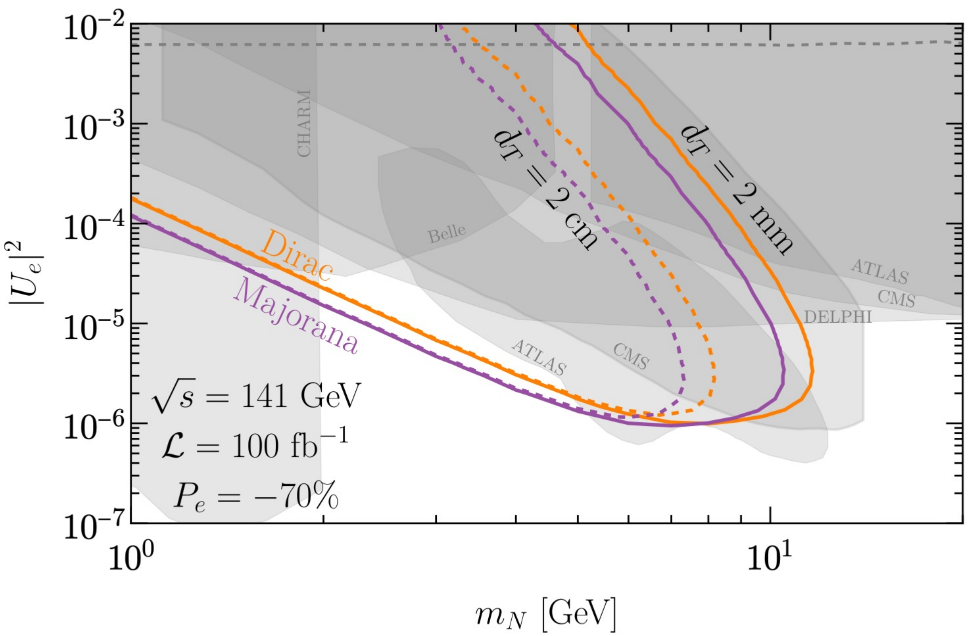
- Light particle, e.g. dark photon, ALP, heavy neutrino: Long-lived particle; displaced vertex strategy

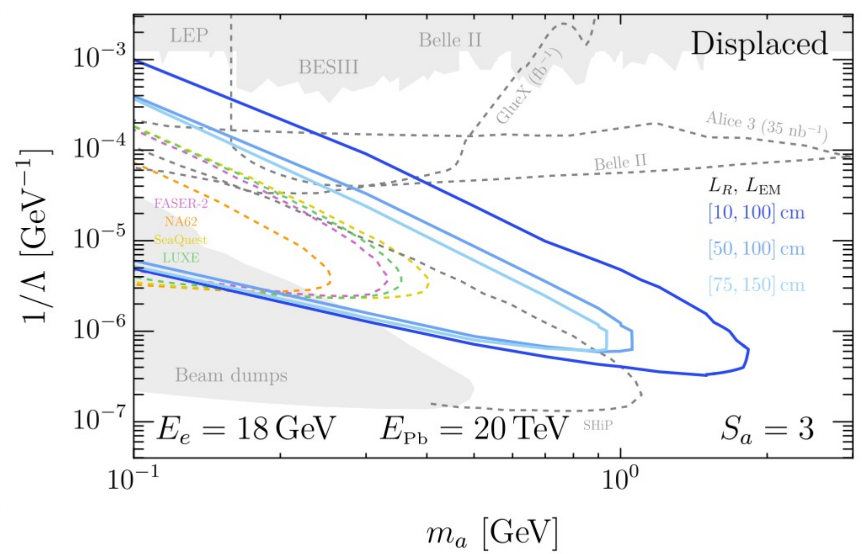


B. Batell, T. Ghosh, T. Han, K. Xie, JHEP 03 (2023) 020



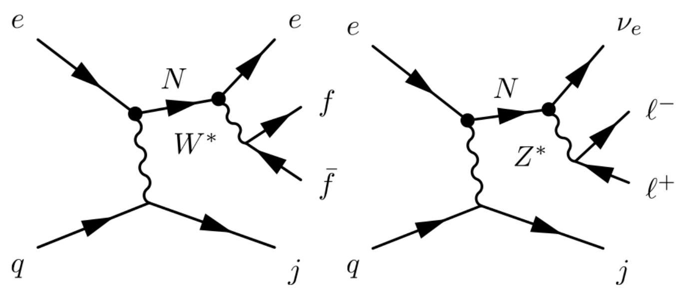
R. Balkin et al, JHEP 02 (2024) 123

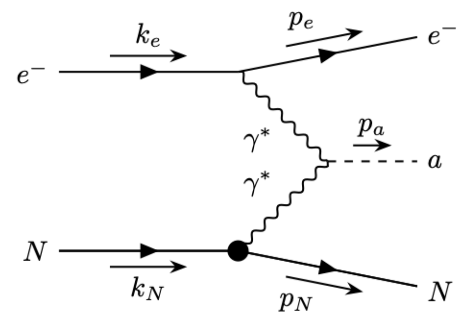


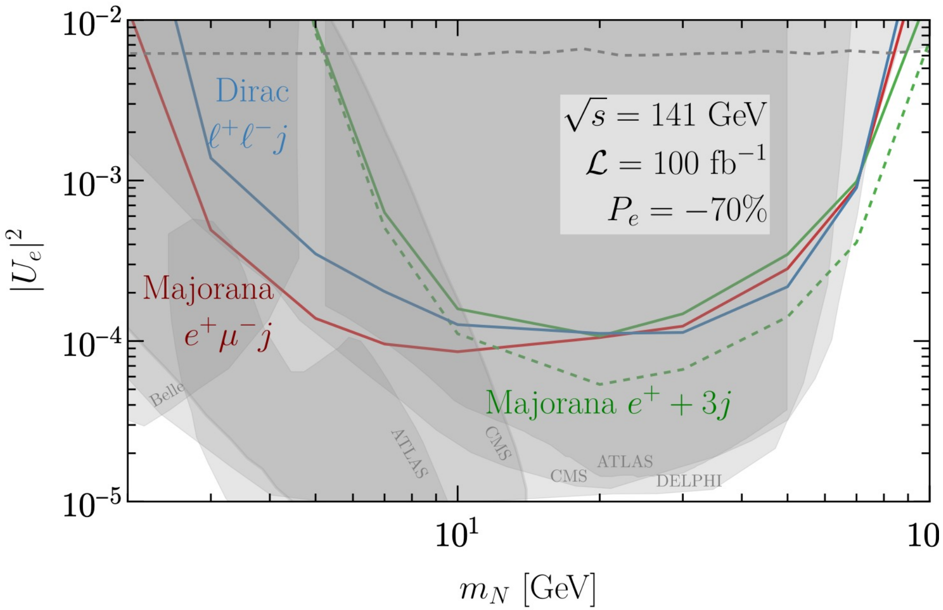


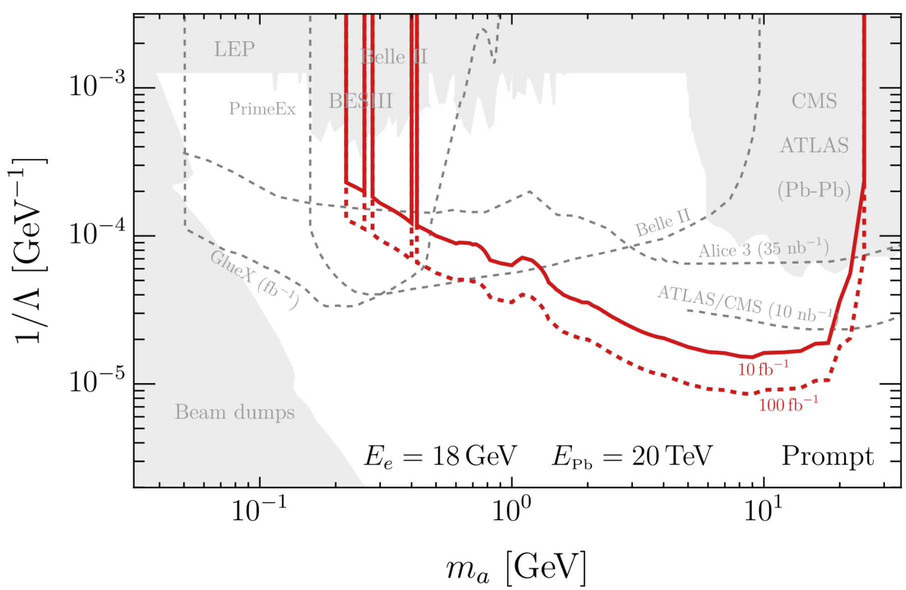
Light new particles @ EIC

- Light particle, e.g. dark photon, ALP, heavy neutrino: Prompt decay









Why Long-lived particle @ EIC

- Ultra-clean environment

Minimal Pile-up, much lower fake displaced vertex rate

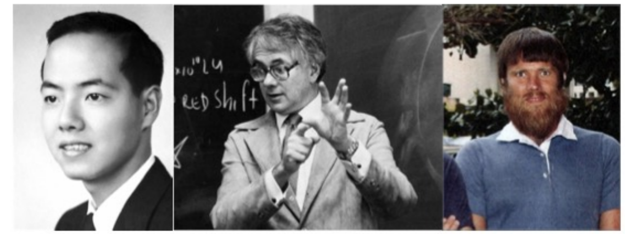
- Boost-enhanced decay lengths $L = \beta\gamma c\tau$
- Coherent nuclear enhancement $\sigma \propto Z^2$

Other possibilities:

- Dark photon: H. Davoudiasl, R. Marcarelli, E. T. Neil, PRD 108 (2023) 7; B. Yan, PLB 833 (2022) 137384
- ALP: Q. Gao, D. Lin, H. Liu, T. Ma, JHEP 06 (2025) 070; Y. Liu, B. Yan, CPC 47 (2023) 043113
- Invisible dark boson: H. Davoudiasl, H. Liu, PRD 112 (2025) 075001
- Invisible meson decay： R. Balkin, T. Coren, A. Jentsch, H. Liu, M. Ovchynnikov, 2601.00068
- …

New physics ≠ new particles

Glashow-Weinberg-Salam
1961 1967



Lee-Georgi-Glashow
1960 1972

From Jiang Hao's slides

UV theory

Four-fermion EFT

V-A

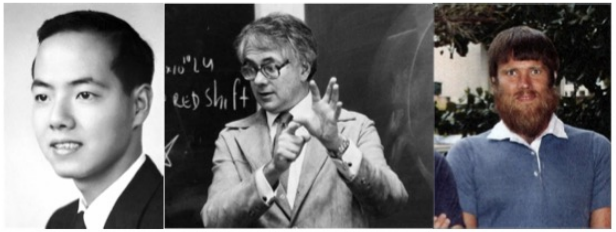
If parity is not conserved in β decay, the most general form of Hamiltonian can be written as

$$\begin{aligned} H_{\text{int}} = {} & (\psi_p^\dagger\gamma_4\psi_n)(C_S\psi_e^\dagger\gamma_4\psi_\nu + C_S'\psi_e^\dagger\gamma_4\gamma_5\psi_\nu) \\ & + (\psi_p^\dagger\gamma_4\gamma_\mu\psi_n)(C_V\psi_e^\dagger\gamma_4\gamma_\mu\psi_\nu + C_V'\psi_e^\dagger\gamma_4\gamma_\mu\gamma_5\psi_\nu) \\ & + \tfrac{1}{2}(\psi_p^\dagger\gamma_4\sigma_{\lambda\mu}\psi_n)(C_T\psi_e^\dagger\gamma_4\sigma_{\lambda\mu}\psi_\nu \\ & + C_T'\psi_e^\dagger\gamma_4\sigma_{\lambda\mu}\gamma_5\psi_\nu) + (\psi_p^\dagger\gamma_4\gamma_\mu\gamma_5\psi_n) \\ & \times(-C_A\psi_e^\dagger\gamma_4\gamma_\mu\gamma_5\psi_\nu - C_A'\psi_e^\dagger\gamma_4\gamma_\mu\psi_\nu) \\ & + (\psi_p^\dagger\gamma_4\gamma_5\psi_n)(C_P\psi_e^\dagger\gamma_4\gamma_5\psi_\nu + C_P'\psi_e^\dagger\gamma_4\psi_\nu), \qquad \text{(A.1)} \end{aligned}$$

LEFT

New physics ≠ new particles

Glashow-Weinberg-Salam
1961 1967



Lee-Georgi-Glashow
1960 1972

Searching for new interactions play an important role in probing NP

V-A

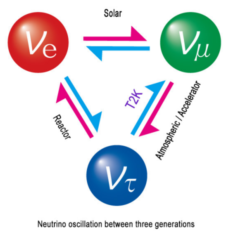
If parity is not conserved in β decay, the most general form of Hamiltonian can be written as

$$
\begin{aligned}
H_{\text{int}} = & (\psi_p^\dagger\gamma_4\psi_n)(C_S\psi_e^\dagger\gamma_4\psi_\nu + C_S'\psi_e^\dagger\gamma_4\gamma_5\psi_\nu) \\
& + (\psi_p^\dagger\gamma_4\gamma_\mu\psi_n)(C_V\psi_e^\dagger\gamma_4\gamma_\mu\psi_\nu + C_V'\psi_e^\dagger\gamma_4\gamma_\mu\gamma_5\psi_\nu) \\
& + \tfrac{1}{2}(\psi_p^\dagger\gamma_4\sigma_{\lambda\mu}\psi_n)(C_T\psi_e^\dagger\gamma_4\sigma_{\lambda\mu}\psi_\nu \\
& + C_T'\psi_e^\dagger\gamma_4\sigma_{\lambda\mu}\gamma_5\psi_\nu) + (\psi_p^\dagger\gamma_4\gamma_\mu\gamma_5\psi_n) \\
& \times(-C_A\psi_e^\dagger\gamma_4\gamma_\mu\gamma_5\psi_\nu - C_A'\psi_e^\dagger\gamma_4\gamma_\mu\psi_\nu) \\
& + (\psi_p^\dagger\gamma_4\gamma_5\psi_n)(C_P\psi_e^\dagger\gamma_4\gamma_5\psi_\nu + C_P'\psi_e^\dagger\gamma_4\psi_\nu), \qquad \text{(A.1)}
\end{aligned}
$$

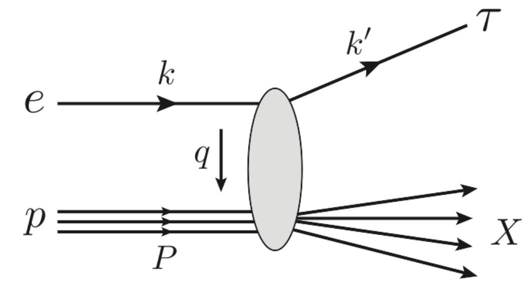
LEFT

Flavor Physics @ EIC

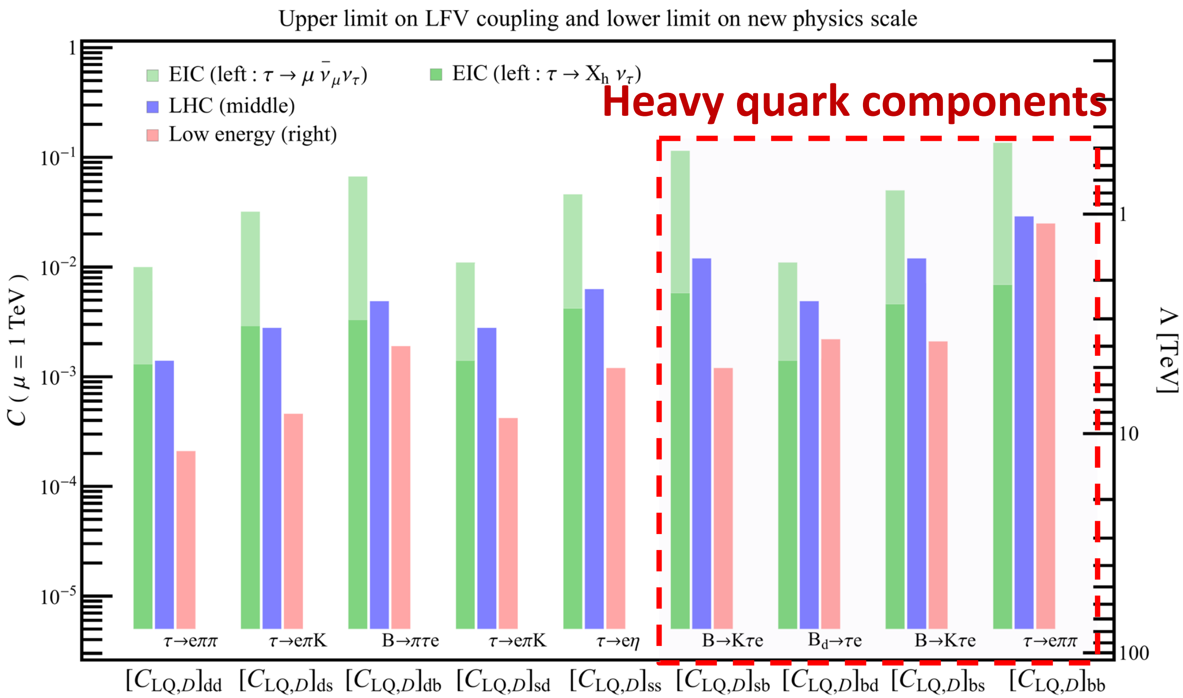
➢ Charged Lepton Flavor Violation

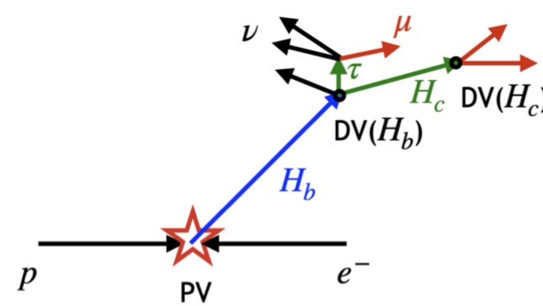


$$BR \sim \left(\frac{m_\nu}{m_W}\right)^2 \sim 10^{-44}$$



Four-Fermion operators $\mathcal{L} = 100\ \mathrm{fb}^{-1}$





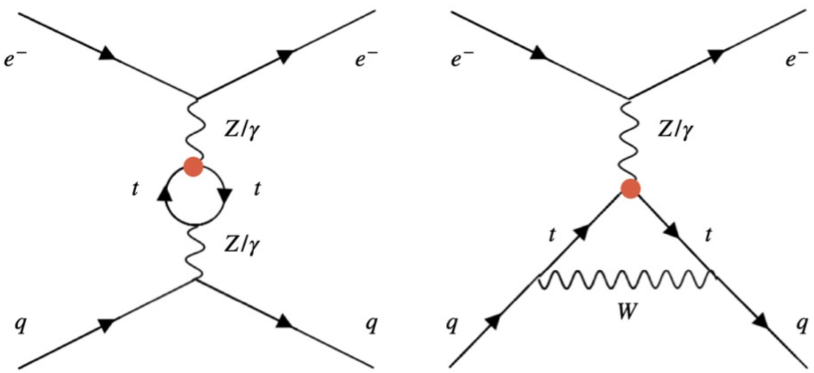
From jets to hadrons，Secondary Vertex

Y. Deng, X. Jiang, T. Liu, B. Yan, JHEP 06 (2025) 157

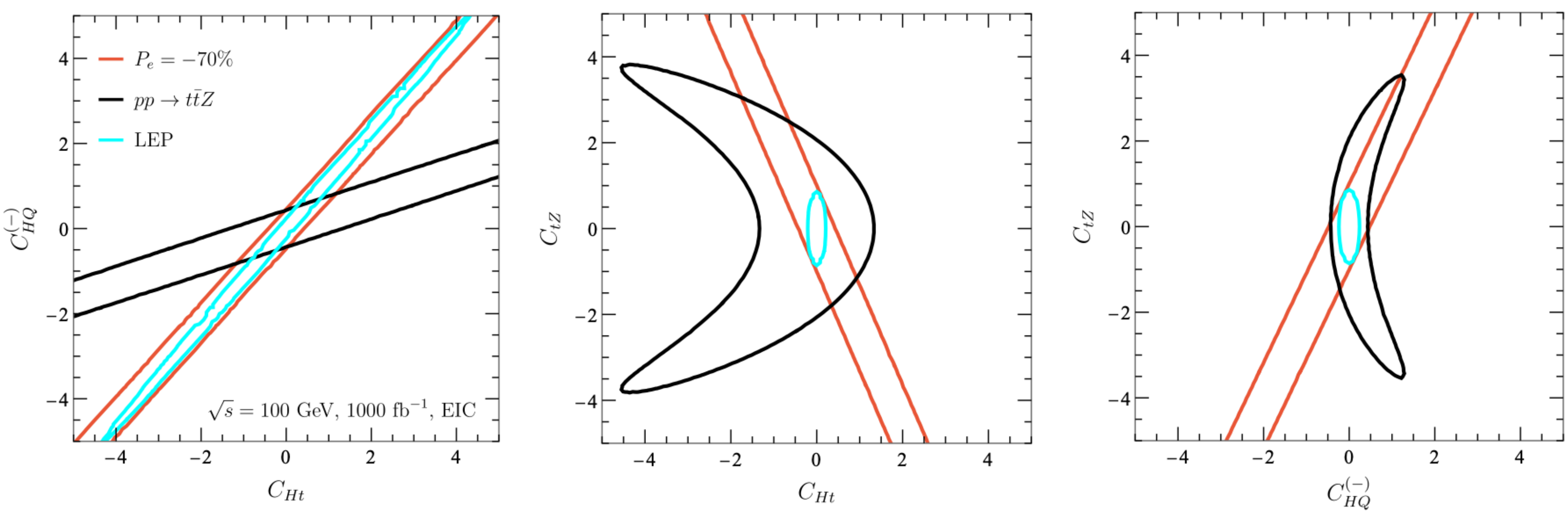
V. Cirigliano, K. Fuyuto, C. Lee, E. Mereghetti, B. Yan, JHEP 03 (2021) 256

Electroweak precision measurement @ EIC

- The longitudinal polarized electron



- Linearly sensitive to the dipole couplings
- Competitive with the LEP
- Complementary with LHC

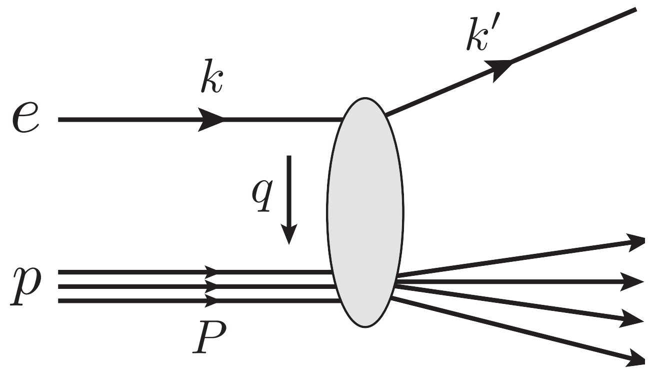


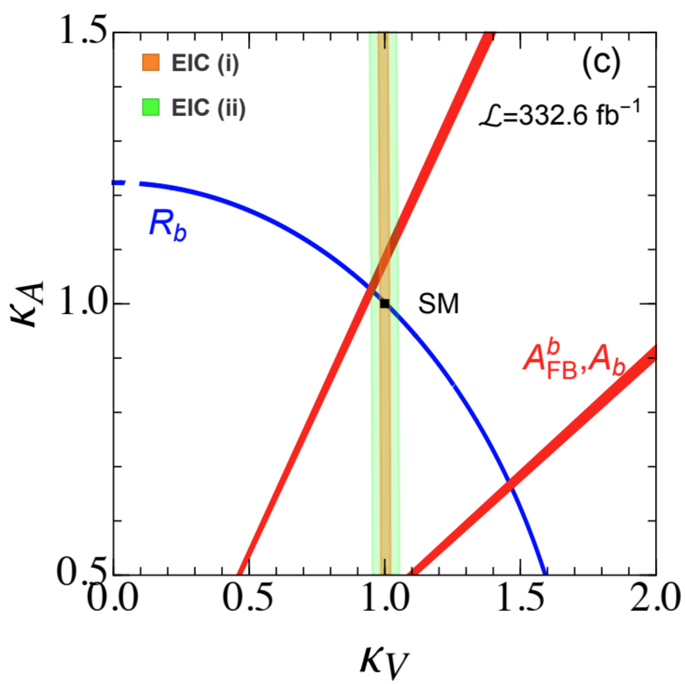
$gL : C_{HQ}^{(-)},\ gR : C_{Ht}$

X.-H. Jiang, Y. Liu, B. Yan, PRD112 (2025) 111303 (Letter)

Electroweak precision measurement @ EIC

- The longitudinal polarized electron





Single-Spin Asymmetry (SSA):

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

$+/-$: right/left-handed lepton

$$(i)\ \epsilon_q^b = 0.001, \quad \epsilon_c^b = 0.03, \quad \epsilon_b = 0.7;$$
$$(ii)\ \epsilon_q^b = 0.01, \quad \epsilon_c^b = 0.2, \quad \epsilon_b = 0.5.$$

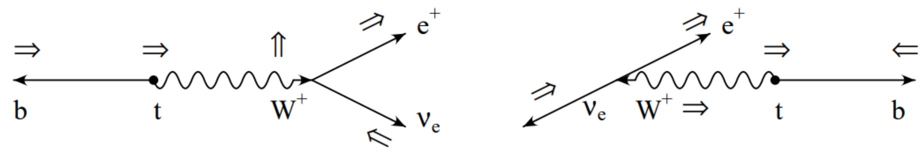
$$E_{\rm cm} = 141\ {\rm GeV}, P_e = 0.7$$

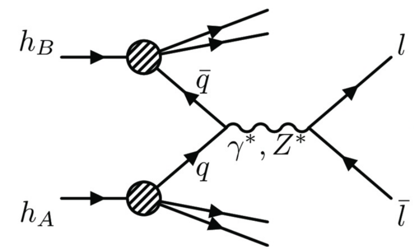
$$\mathcal{L} = \bar{b}\gamma_\mu(\kappa_V g_V - \kappa_A g_A \gamma_5) b Z_\mu$$

B. Yan, Z. Yu, C.-P. Yuan, PLB822(2021)136697
H. T. Li, B. Yan. C.-P. Yuan, PLB 833 (2022) 137300

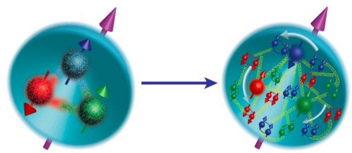
Spin effects in Electroweak and QCD

- Spin is measured from its decay products: top quark, gauge bosons

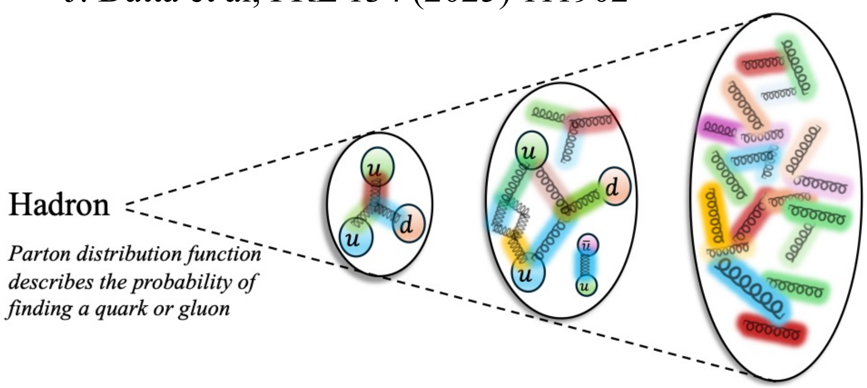


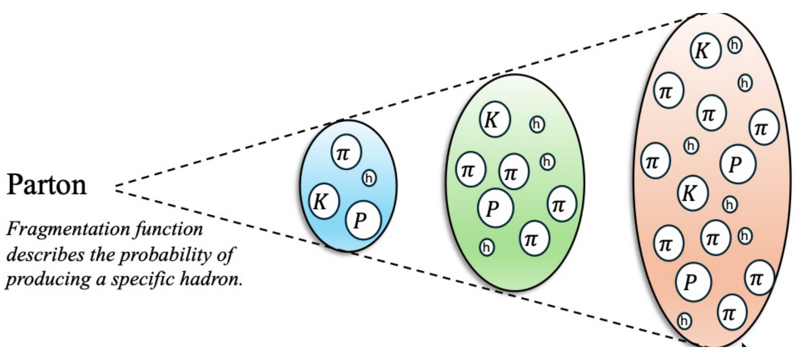


- Spin from nonperturbative QCD: PDFs and FFs



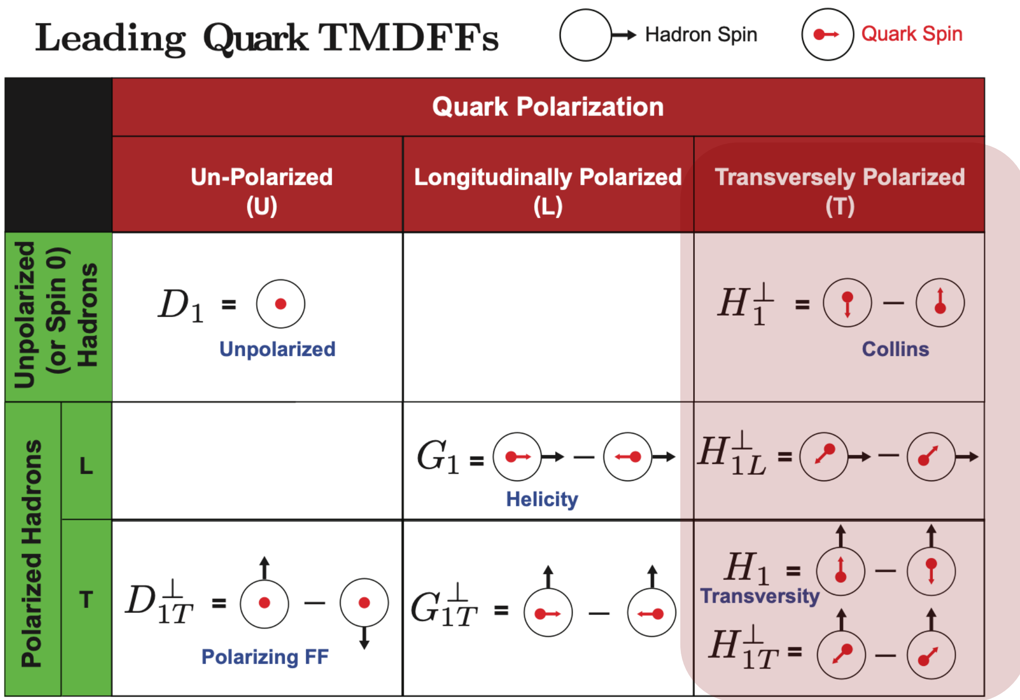
J. Datta et al, PRL 134 (2025) 111902

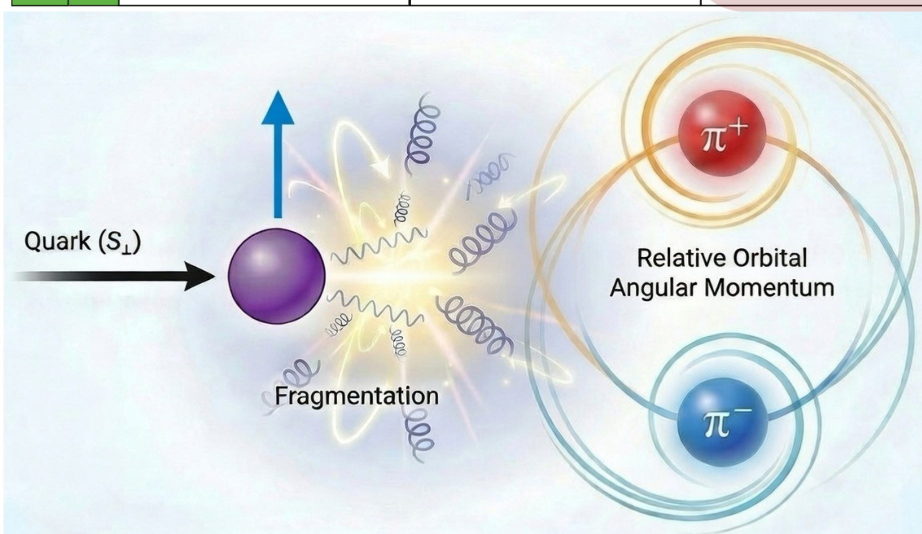




- Spin phenomena in QCD arise from the intrinsic correlations between parton transverse momentum, spin, and hadronization dynamics

Chiral-odd FFs: Transverse spin of quark





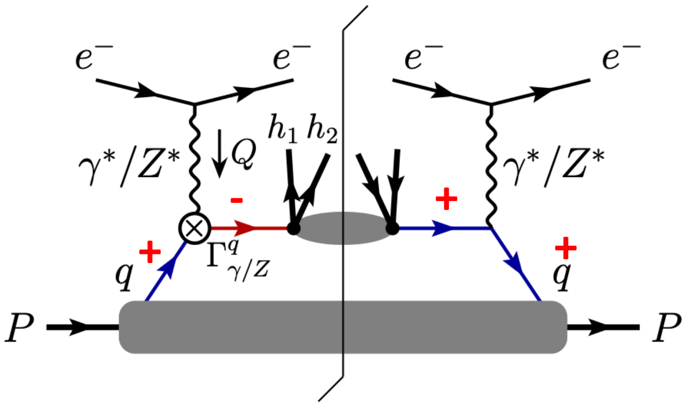
Transverse spin of quark:
The interference between the different helicity states

Transverse momentum dependent factorization

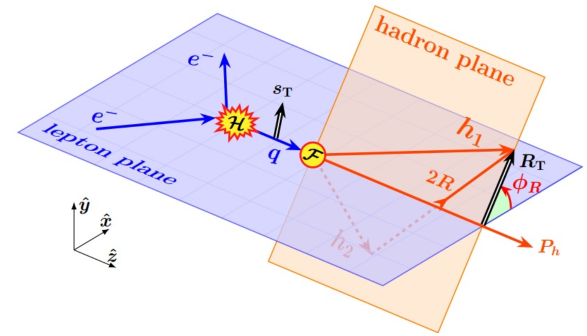
Interference Dihadron Fragmentation
Collinear factorization

Transverse spin effects of quark @ EIC

- The transverse spin of quarks can be generated by the quark dipole moments



$O(1/\Lambda^2)$



$\bar{q}_L \sigma_{\mu\nu} q_R A^{\mu\nu}, \bar{q}_L \sigma_{\mu\nu} q_R Z^{\mu\nu}$

- The interference dihadron fragmentation function: **chiral-odd**

$$\frac{d\sigma}{dx\, dy\, dz\, dM_h\, d\phi_R} = \frac{N}{2\pi} \sum_q f_q(x,Q) \big[D_{h_1 h_2/q}(z, M_h; Q)$$

$$- (\boldsymbol{s}_{T,q}(x,Q) \times \hat{\boldsymbol{R}}_T)^z H_{h_1 h_2/q}(z, M_h; Q) \big] C_q(x,Q)$$

$$s_q^x = \frac{2}{C_q} \left(w_\gamma^q \, \mathrm{Re}\,\Gamma_\gamma^q + w_Z^q \, \mathrm{Re}\,\Gamma_Z^q \right)$$

$$s_q^y = \frac{2}{C_q} \left(w_\gamma^q \, \mathrm{Im}\,\Gamma_\gamma^q + w_Z^q \, \mathrm{Im}\,\Gamma_Z^q \right)$$

Interference effects

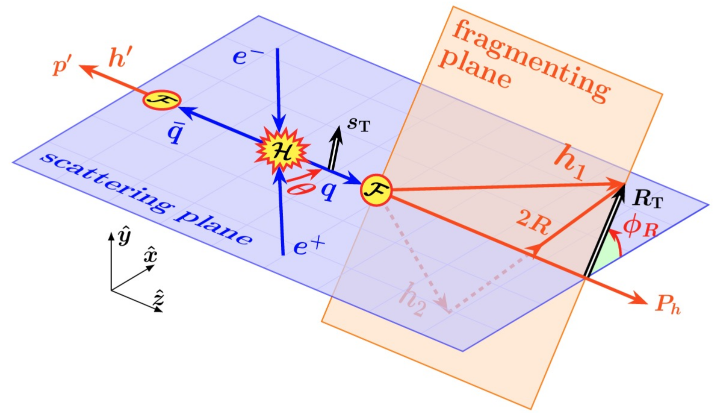
Nucleon energy correlator
See Yingsheng Huang's talk

The flat direction in flavor space of dipole couplings?

Xin-Kai Wen, Bin Yan, Zhite Yu, C.-P. Yuan, 2408.07255

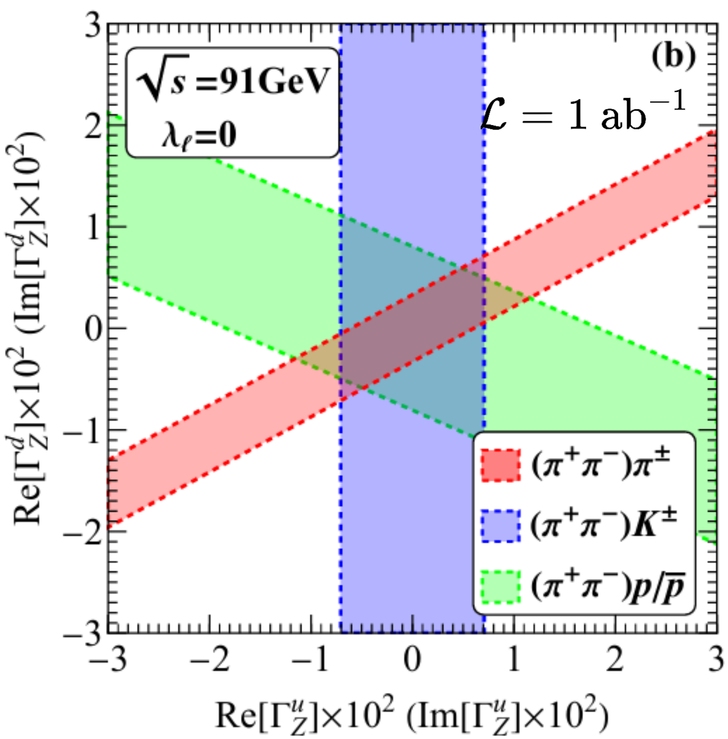
Transverse spin effects of quark @ CEPC

Xin-Kai Wen, Bin Yan, Zhite Yu, C.-P. Yuan, PRD 112 (2025) 053004



$$\frac{d\sigma}{dy\,dz\,d\bar{z}\,dM_h\,d\phi_R} = \frac{1}{32\pi^2 s}\sum_{q,\,q\to\bar{q}} C_q(y)\,D_{\bar{q}}^{h'}(\bar{z})$$

$$\times\left[D_q^{h_1h_2}(z, M_h) - (\boldsymbol{s}_{T,q}(y)\times\hat{\boldsymbol{R}}_T)^z H_q^{h_1h_2}(z, M_h)\right]$$



$$A_{UD}^{h'} = \frac{\sigma^{h'}(\sin\phi_R > 0) - \sigma^{h'}(\sin\phi_R < 0)}{\sigma^{h'}(\sin\phi_R > 0) + \sigma^{h'}(\sin\phi_R < 0)}$$

$$A_{LR}^{h'} = \frac{\sigma^{h'}(\cos\phi_R > 0) - \sigma^{h'}(\cos\phi_R < 0)}{\sigma^{h'}(\cos\phi_R > 0) + \sigma^{h'}(\cos\phi_R < 0)}$$

$O(1/\Lambda^2)$ $\quad \bar{q}_L\sigma_{\mu\nu}q_R A^{\mu\nu},\ \bar{q}_L\sigma_{\mu\nu}q_R Z^{\mu\nu}$

- The flat direction can be closed by combing more processes
- Z-boson dipole: O(0.001)

Transverse spin effects

- Dipole operators

  R. Boughezal, D. Florian, F. Petriello, W. Vogelsang, PRD 107 (2023) 7, 075028
  Y. Huang, X.-B. Tong, H. L. Wang, PRL 136 (2026) 131902

- Scalar and tensor four fermion operators

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

- Quantum entanglement of Light quarks

  Kun Cheng, Bin Yan, PRL 135 (2025) 011902
  Qing-Hong Cao, Guanghui Li, Xin-Kai Wen, Bin Yan, 2509.18276

- Light quark Yukawa coupling and flavor structure

  Qing-Hong Cao, Xin-Kai Wen, Bin Yan, Shu-Tao Zhang, 2512.16492

- Color-Octet Mechanism in NRQCD

  Zhiguo He, Guanghui Li, Yu-Jie Tian, Xin-Kai Wen, Bin Yan, 2603.18874

Summary

- The EIC provides a powerful platform to probe new physics, including light new particles and novel interactions

- Longitudinal polarized electron beams enable high-precision electroweak measurements

- QCD spin physics offers new opportunities: polarization and correlations as sensitive probes of new physics

Thank you!