For TeV Physics & 31th LHC Mini-Workshop
2025.10.12

Probing Top EW Couplings Indirectly at the EIC

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Based on: 2507.21477

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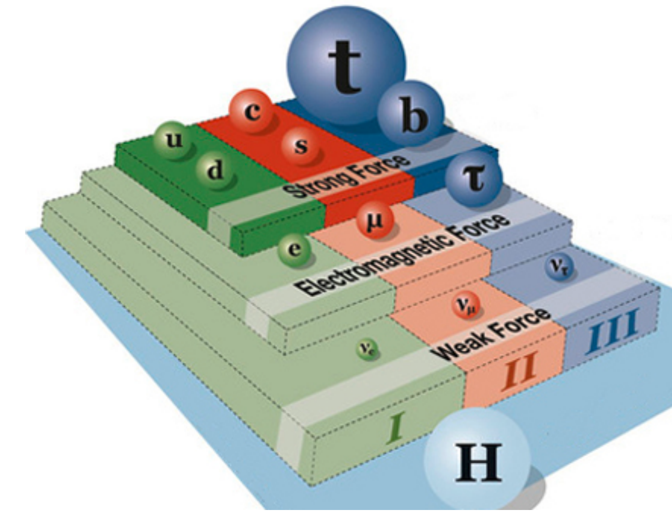
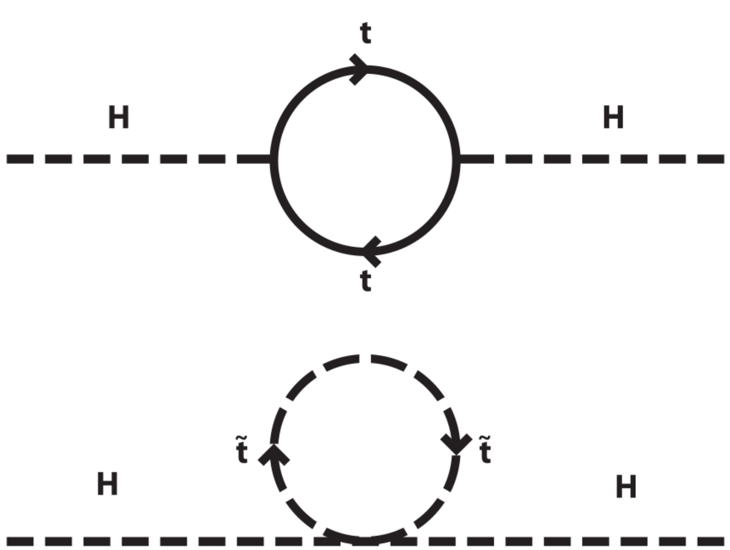
Top in the SM & Beyond

- Special in the SM:

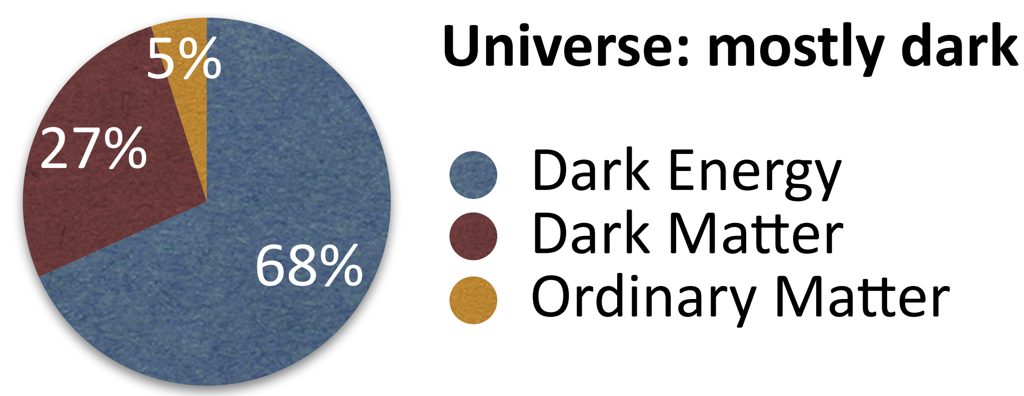
  heaviest; $\mathcal{O}(1)$ Yukawa

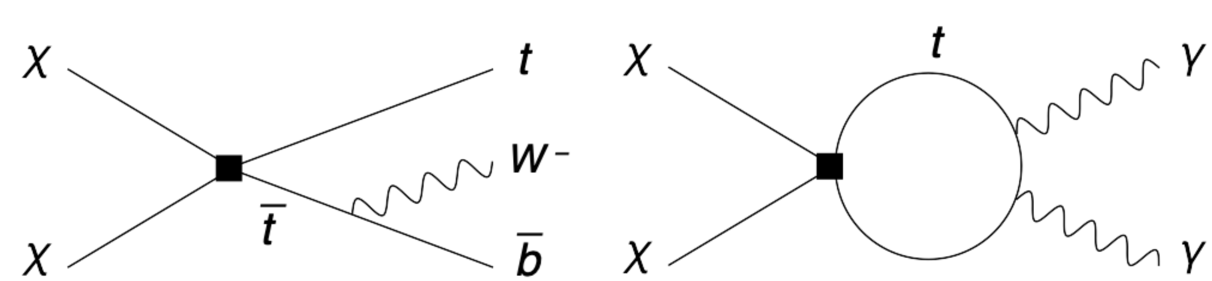


- Hints for BSM: to solve fundamental puzzles
  - Hierarchy problem & top partners



  - Portal to darkness

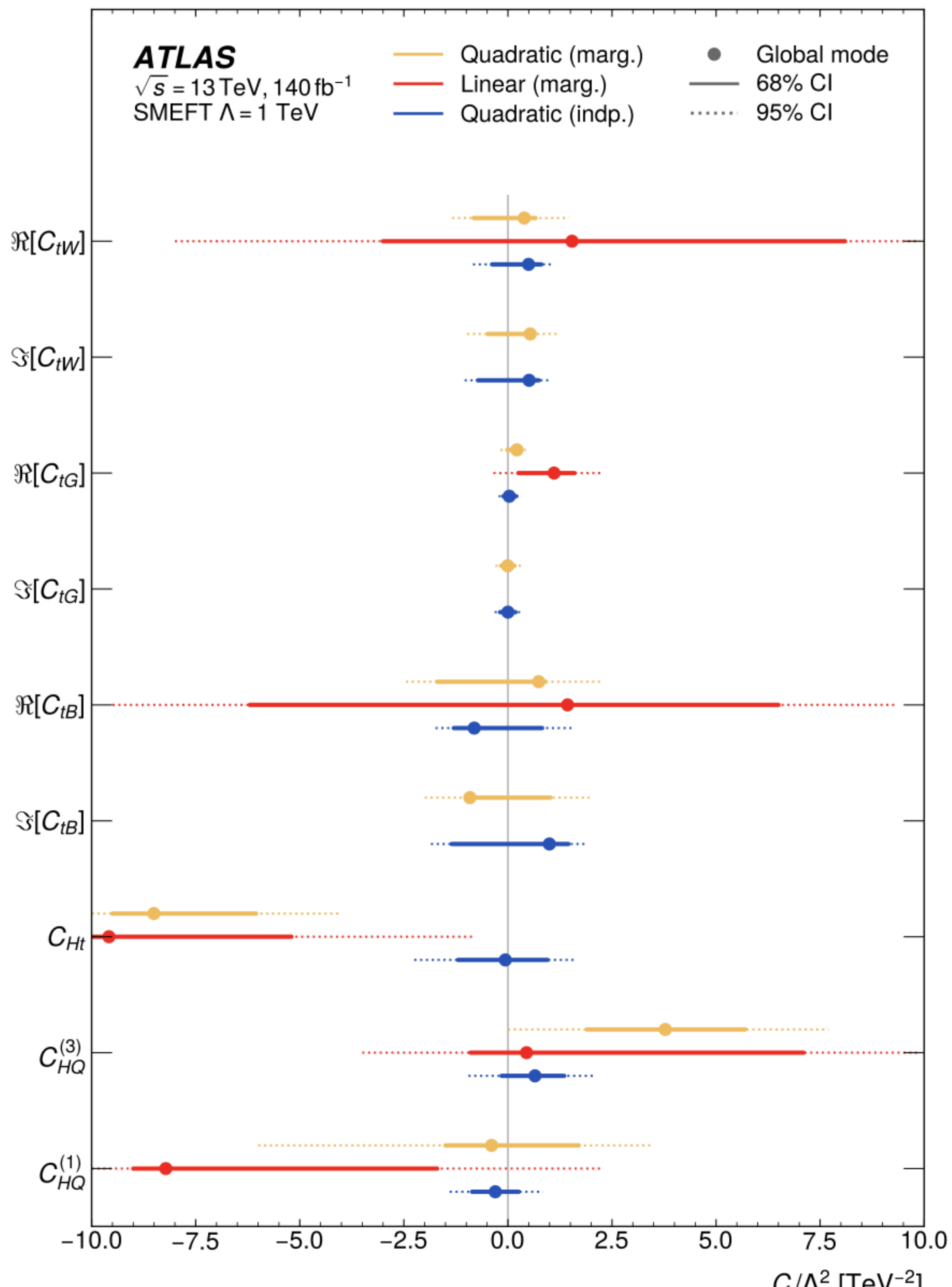




[Y. Zhang]

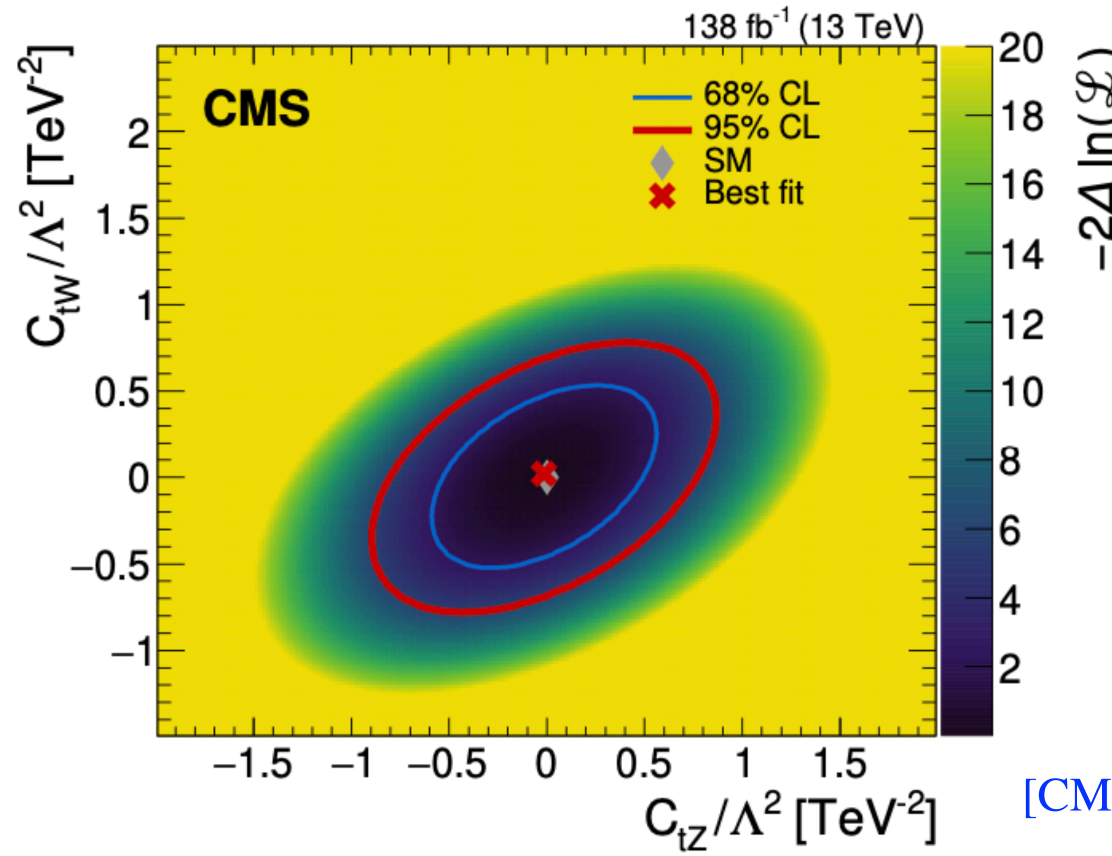
Current Status

$t\bar{t}V$: precisely measured at the LHC



[ATLAS Collaboration]

(a)

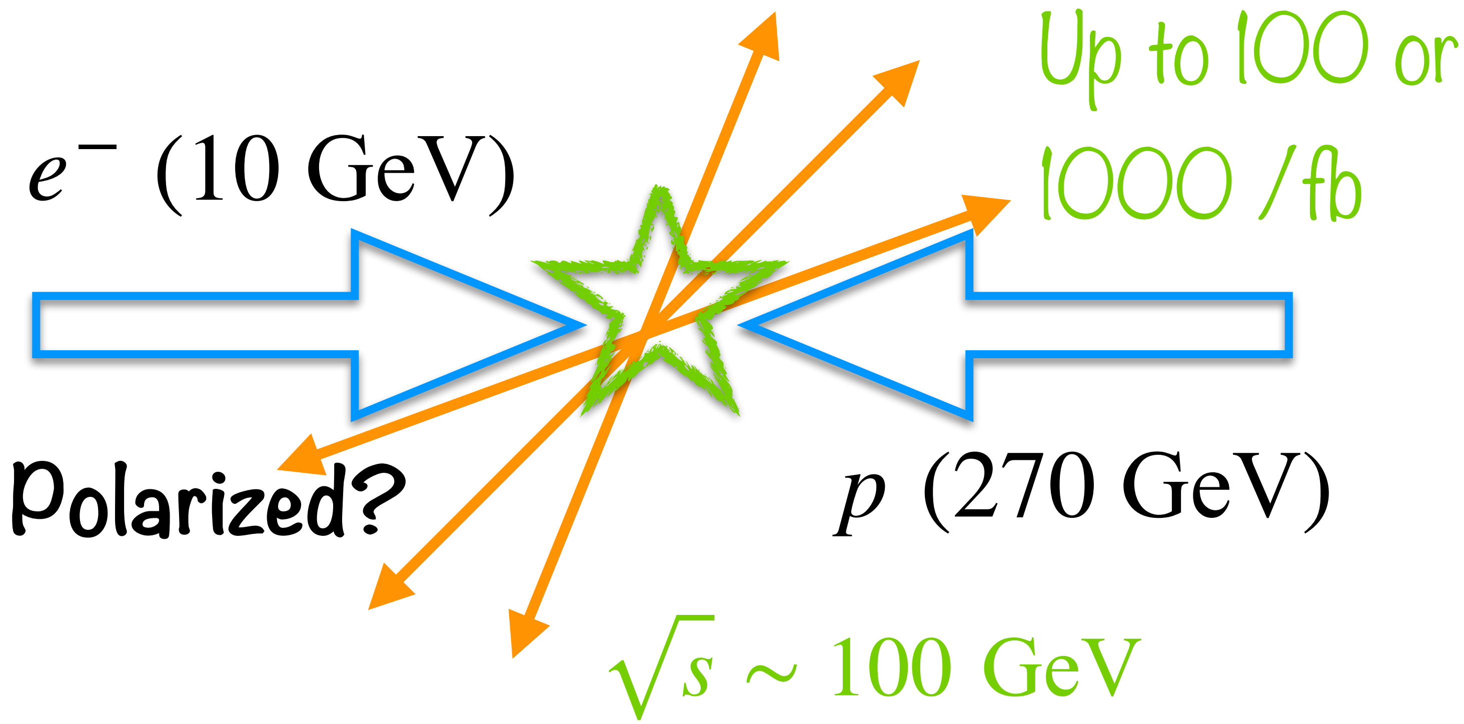


[CMS Collaboration]

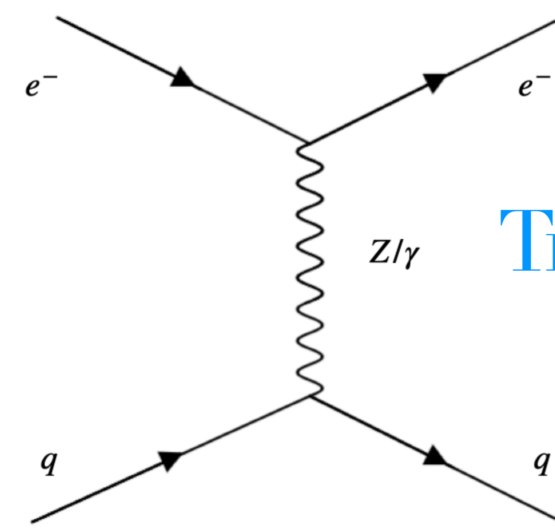
- In the EFT framework
- Well constrained
- **Any complementarity?**

EIC and its Potential

At Brookhaven National Lab

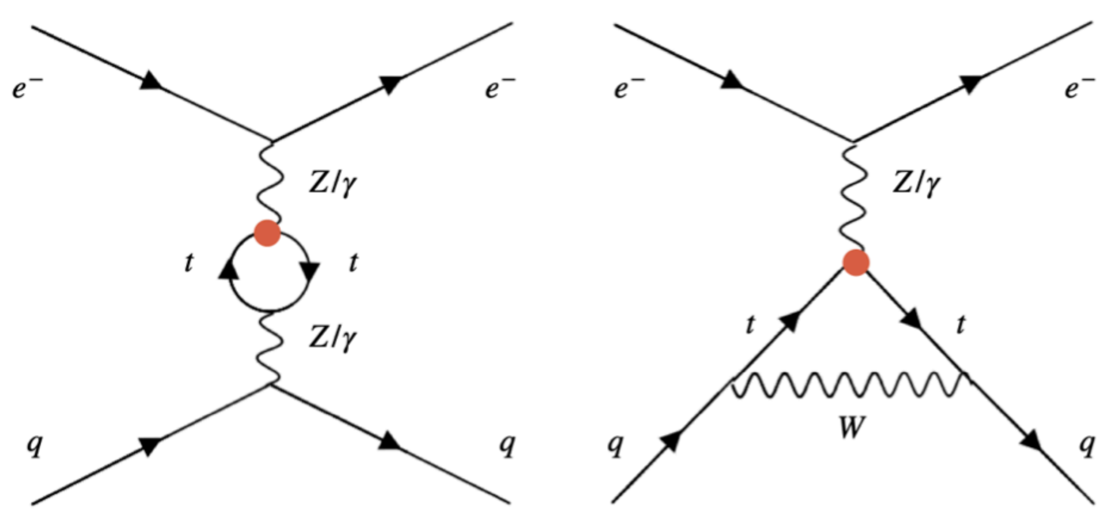


DIS Process



Tree-level SM

- To consider ep collision firstly
- Not only nuclear structure
- Chance for indirect BSM search, like top couplings via loops



Top loops
SMEFT operators

Top Couplings Within SMEFT

- Top-related SMEFT operators $\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_i \frac{C_i}{\Lambda^2}\mathcal{O}_i$

$$\mathcal{O}_{Ht} = i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{t}_R\gamma^\mu t_R)\ ,$$

$$\mathcal{O}_{Hq}^{(1)} = i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{q}_L\gamma^\mu q_L)\ ,$$

$$\mathcal{O}_{Hq}^{(3)} = i(H^\dagger \overleftrightarrow{D}^I_\mu H)(\bar{q}_L\gamma^\mu \sigma^I q_L)\ ,$$

$$\boxed{\mathcal{O}_{tW}} = (\bar{q}_L\sigma^{\mu\nu}\sigma^I t_R)\tilde{H}W^I_{\mu\nu} + h.c.\ ,$$

$$\boxed{\mathcal{O}_{tB}} = (\bar{q}_L\sigma^{\mu\nu} t_R)\tilde{H}B_{\mu\nu} + h.c.\ ,$$

$$\mathcal{O}_{HQ}^{(\pm)} = \mathcal{O}_{Hq}^{(1)} \pm \mathcal{O}_{Hq}^{(3)}$$

$\mathcal{O}_{HQ}^{(+)}$: irrelevant;

tightly constrained via $b\bar{b}Z$ at the LEP

[S. Schael et. al.]

Via SSB

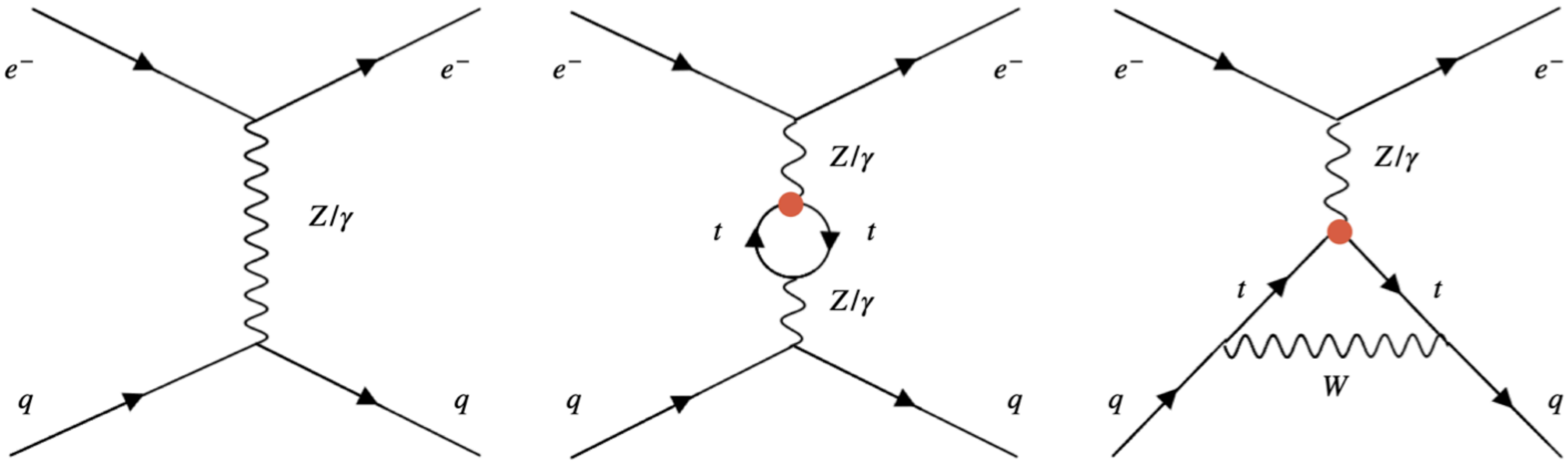
$\mathcal{O}_{tZ}$ & $\mathcal{O}_{t\gamma}$

Related to $t\bar{t}Z$ & $t\bar{t}\gamma$ respectively

- Model-independent
- Different Lorentz structures
- To deviate from the SM, w new couplings

DIS

- Feynman diagrams



Electron polarization: $P_e = 70\,\%\,,\ 0,\ -70\,\%$

- BSM contribution

$$\Lambda = 1\ \text{TeV}$$

Up to interference

$$\sigma = \sigma_{\text{SM}} + \sum_i r_i C_i$$

Two relevant aspects:

- Loop diagrams
- **Shifts due to renormalization**

Star-Scheme

- Renormalization shifts EW inputs
- Formulated with star-scheme [Y. Liu, C. Zhang et. al.]

$$\alpha \to \alpha_* = \alpha + \delta\alpha = \alpha\left(1 - \Pi'_{\gamma\gamma}(q^2) + \Pi'_{\gamma\gamma}(0)\right) \times \left[1 - \frac{d}{dq^2}\Pi_{ZZ}(q^2)|_{q^2=m_Z^2} + \Pi'_{\gamma\gamma}(q^2) + \frac{c_W^2 - s_W^2}{s_W c_W}\Pi'_{\gamma Z}(q^2)\right]$$

$$m_Z^2 \to m_{Z*}^2 = m_Z^2 + \delta m_Z^2 = m_Z^2 + \Pi_{ZZ}(m_Z^2) - \Pi_{ZZ}(q^2) + (q^2 - m_Z^2)\frac{d}{dq^2}\Pi_{ZZ}(q^2)|_{q^2=m_Z^2} \ ,$$

$$s_W^2 \to s_{W*}^2 = s_W^2 + \delta s_W^2 = s_W^2\left[1 + \frac{c_W}{s_W}\Pi'_{\gamma Z}(q^2) + \frac{c_W^2}{c_W^2 - s_W^2}\left(\Pi'_{\gamma\gamma}(0) + \frac{1}{m_W^2}\Pi_{WW}(0) - \frac{1}{m_Z^2}\Pi_{ZZ}(m_Z^2)\right)\right] \ ,$$

Given input λ_i, xsection: $\sigma = \sigma_0 + \frac{\partial\sigma}{\partial\lambda_i} \cdot \delta\lambda_i + \ldots$

- $(\alpha,\ m_Z^2,\ s_W^2)$ as inputs
- Being shifted, s.t. xsection affected
- Always keep linear terms of WCs

Results

- Xsections $\sigma = \sigma_{\rm SM} + \sum_i r_i C_i$

P_e	$\sigma_{\rm SM}$[pb]	r_{Ht}[pb]	$r_{HQ}^{(-)}$[pb]	r_{tZ}[pb]
-70%	96.3	3.39×10^{-2}	-3.06×10^{-2}	1.47×10^{-2}
0	92.9	1.62×10^{-2}	-1.46×10^{-2}	6.18×10^{-3}
$+70\%$	89.7	-1.76×10^{-3}	1.65×10^{-3}	-2.40×10^{-3}

- BSM rather small, compared to the SM predictions

- Polarization matters.

$P_e = -70\%$

$P_e = 0$

$P_e = 70\%$

Observables

- Xsections
  - Assuming statistical uncert only

Luminosity

$$\chi^2(P_e) = \frac{(\sum_i r_i C_i)^2}{\delta^2_{\rm stat}} = \frac{(\sum_i r_i C_i)^2 \mathcal{L}}{\sigma^{(P_e)}_{\rm SM}}$$

  - Only inclusive xsections for fitting

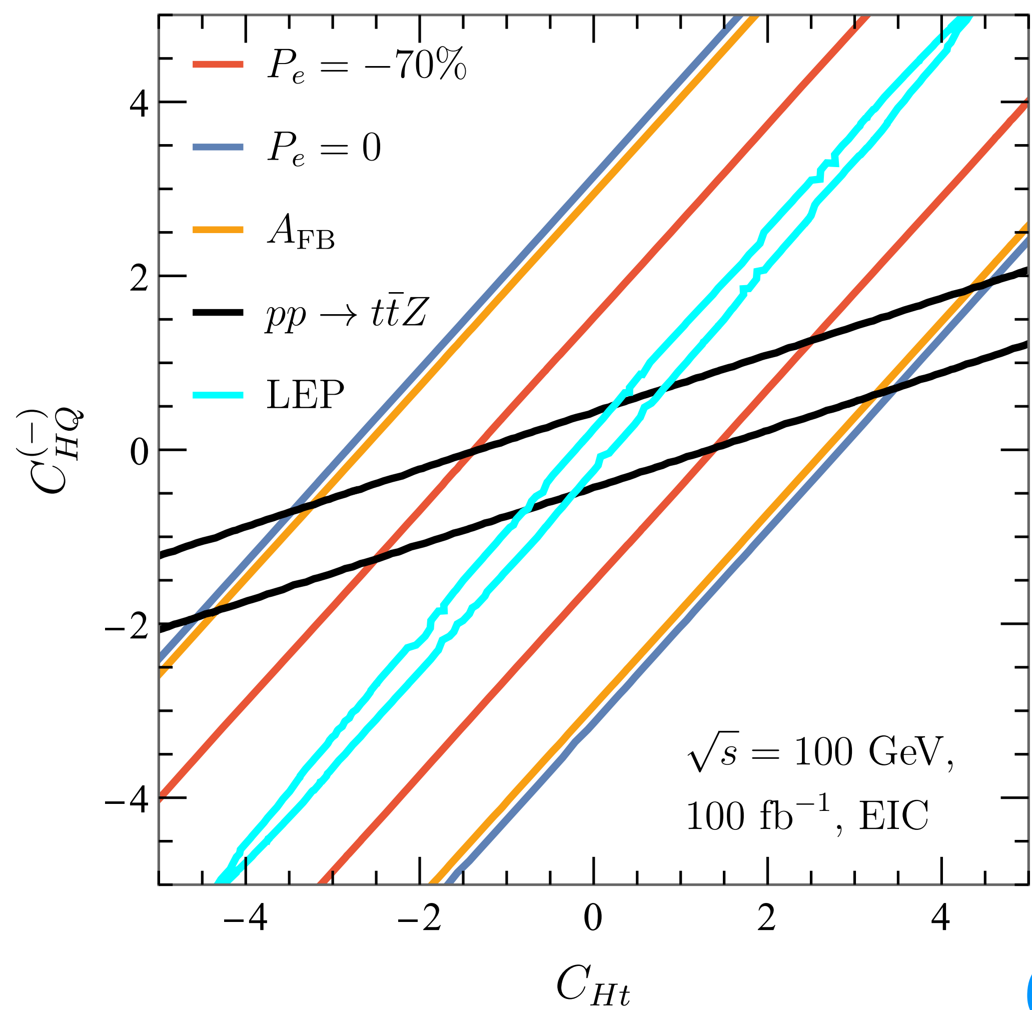
- Polarized Asymmetry score [R. Boughezal et. al.]

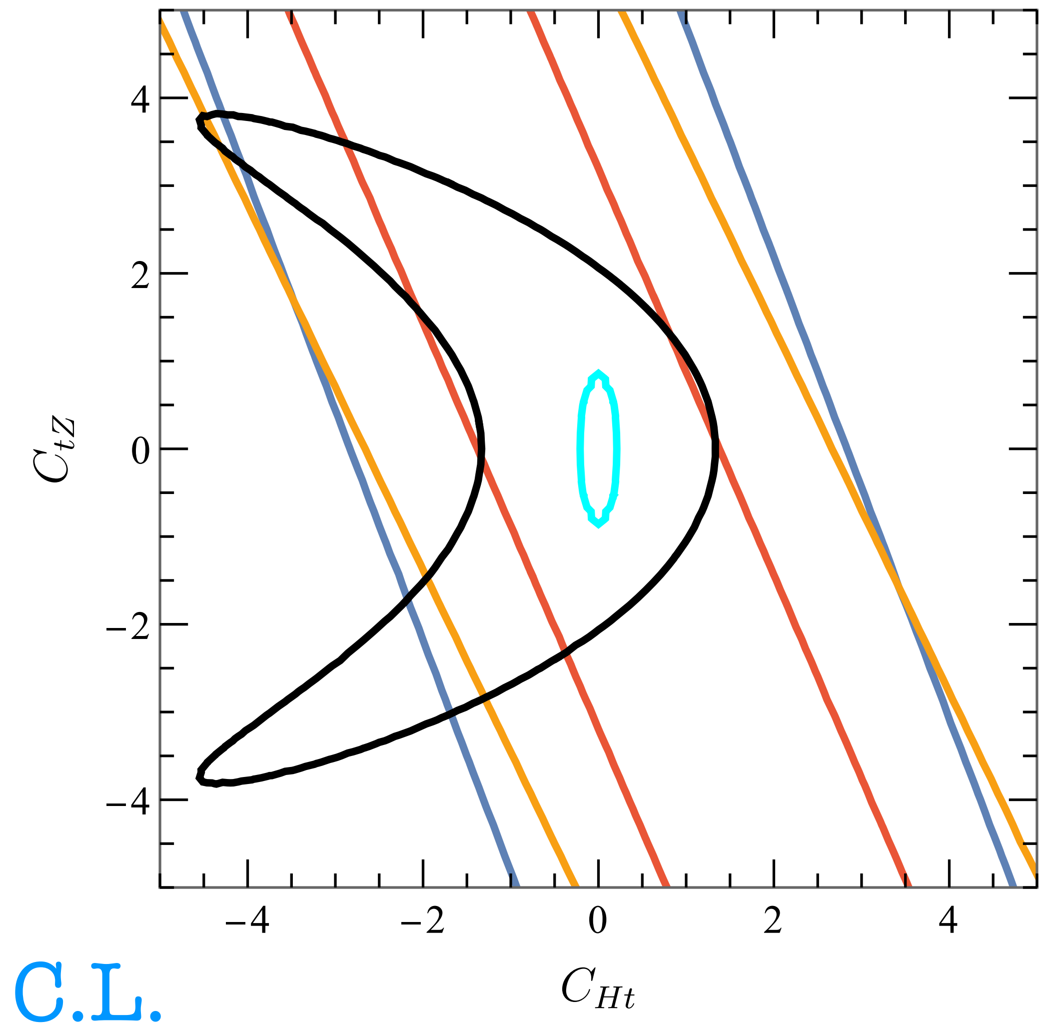
$$A_{\rm FB} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

$$\chi^2(A_{\rm FB}) = \frac{(A_{\rm FB} - A_{\rm FB}^{(\rm SM)})^2}{\delta^2_A}$$

  - Uncert propagated from xsections
  - Half luminosity for $P_e = \pm 70\,\%$ each

Projections at the EIC

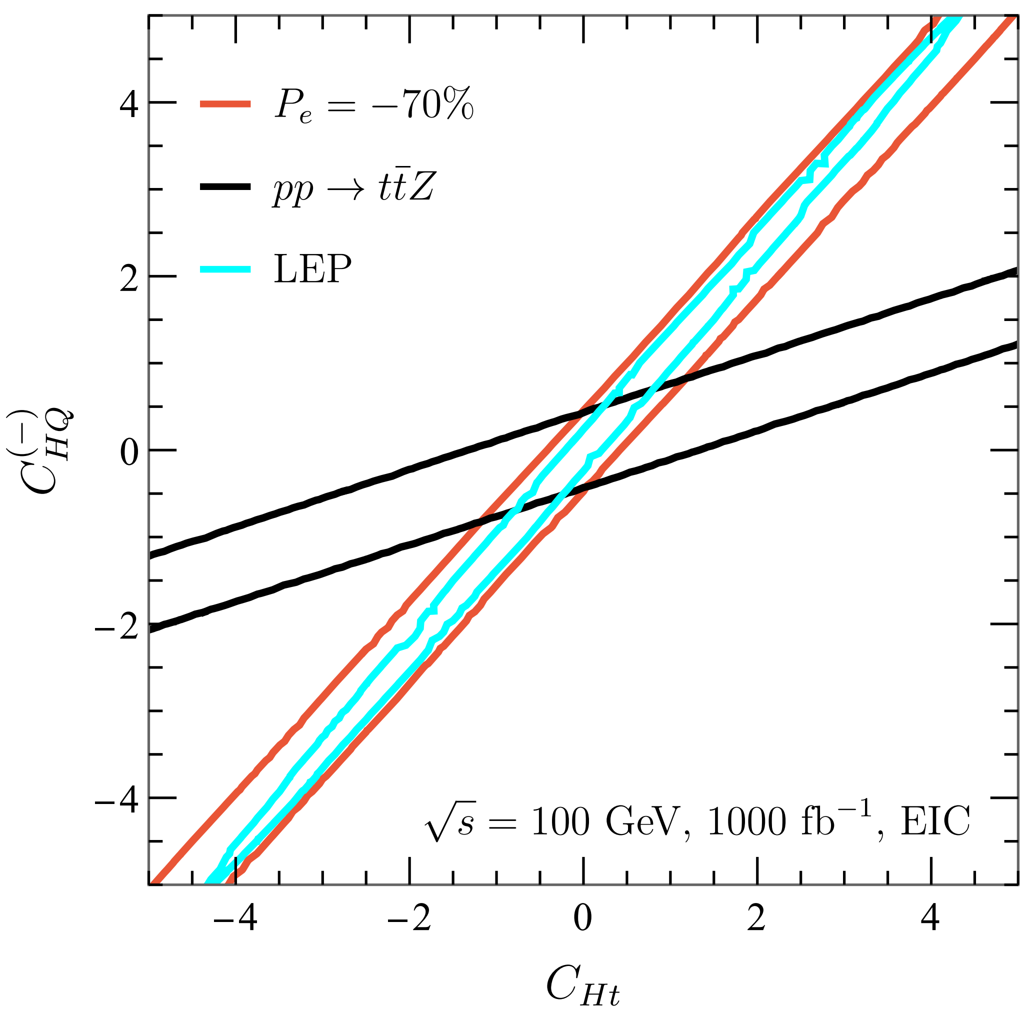




68% C.L.

- Different orientations: complementarity!
- A_{FB} comparable with $P_e = 0$,
  but worse than $P_e = -70\,\%$
- Worse than the LEP

High Luminosity



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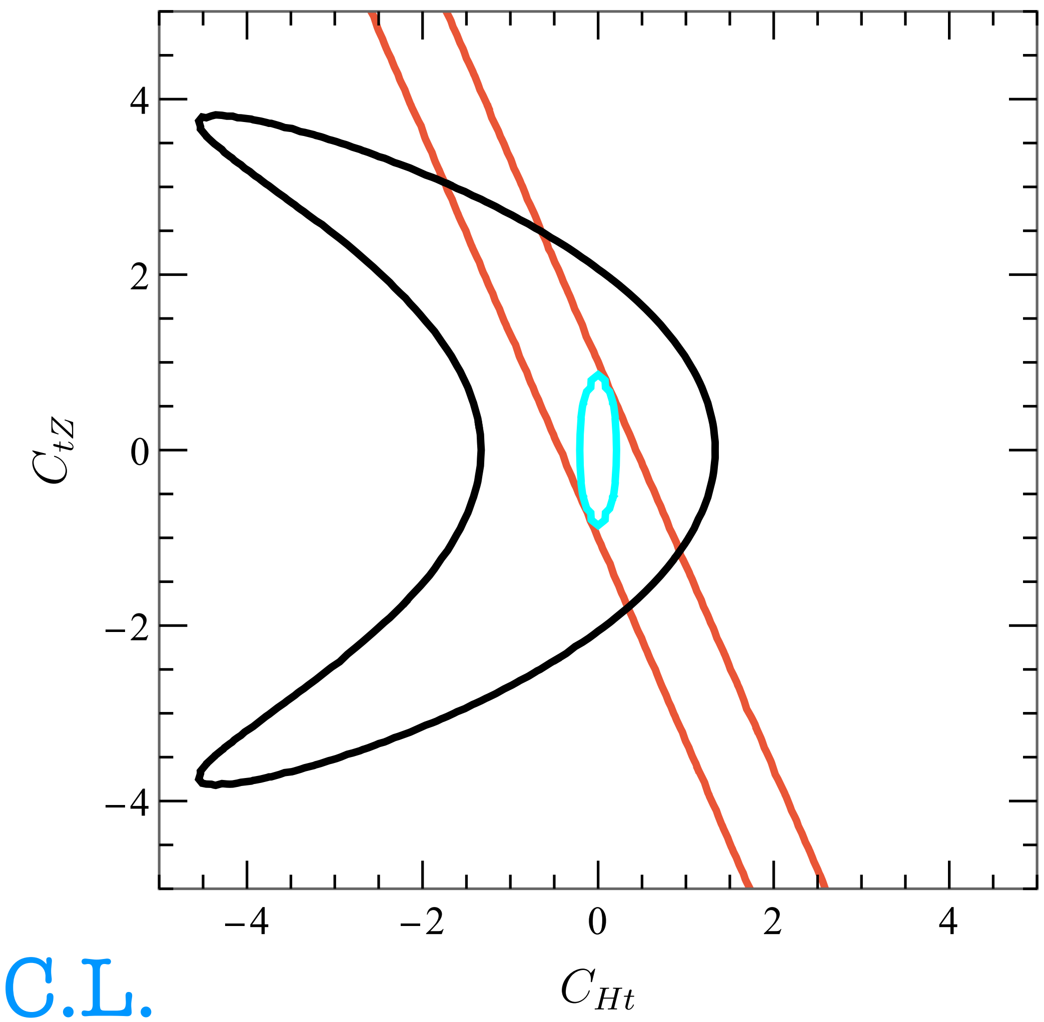


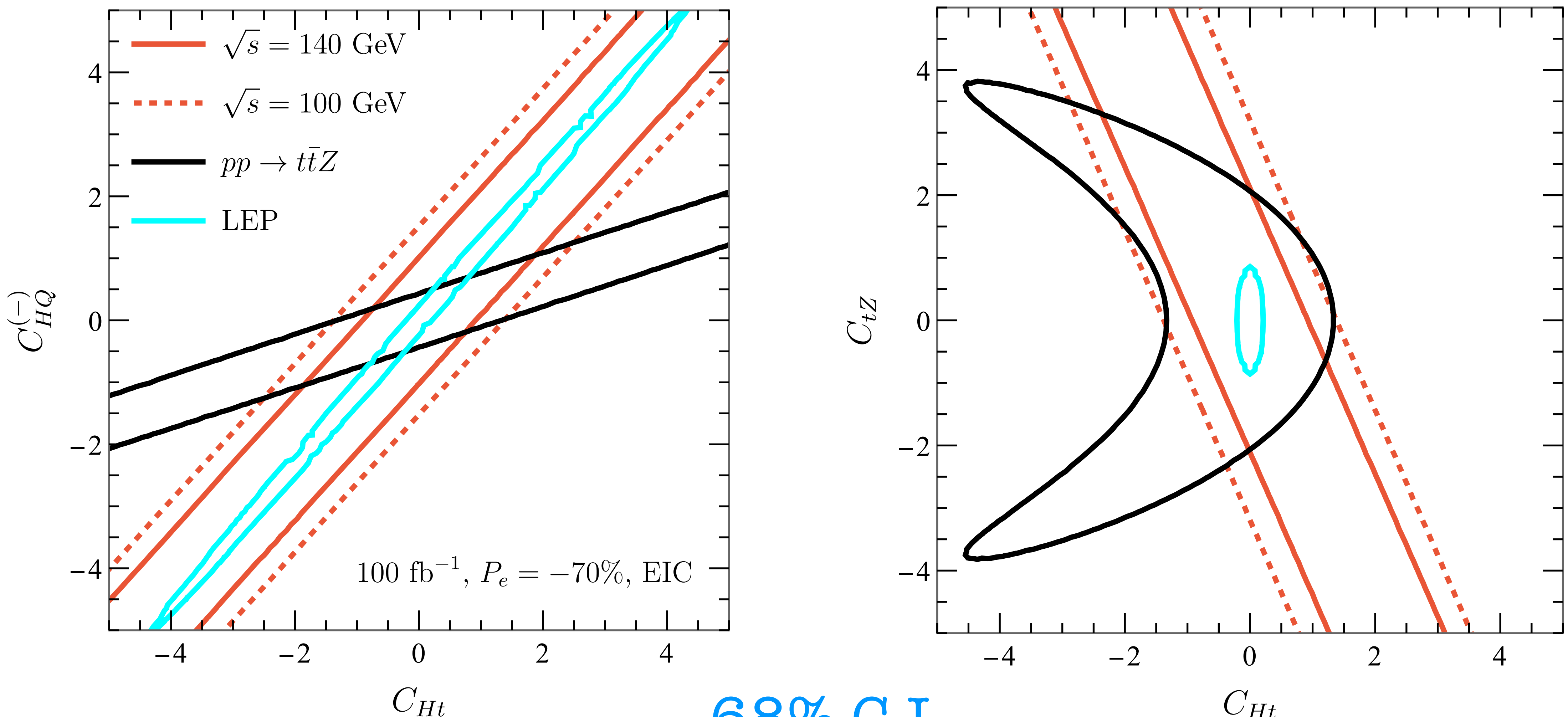
- Reaching $\mathcal{O}(0.1)$ along one given direction, while the other being free
- When 1000 /fb, competitive with the LEP

Summary

- Top couplings indirectly constrained at the EIC
- Polarization, to be crucial
- Huge potential of the EIC: to complement others
- Proton beam polarization?
- Other possible observables at the EIC?

Back-Up

Higher Central Energy



68% C.L.

Higher energy further improves performance at the EIC

Renormalization

$$r_i = \sigma_{i0} + \boxed{\sigma_{i1}} \log \frac{\mu^2_{\rm EFT}}{Q^2}$$

Finite

Log

- Hardly fully captured by RGE
- Renormalization scale dependence
- $|Q^2| \sim 20$ GeV at the EIC