

Toward a Physically Informed Operator Analysis Framework at the Precision Frontier

Jian-Nan Ding

Chengdu University of Technology

Oct. 31, 2026

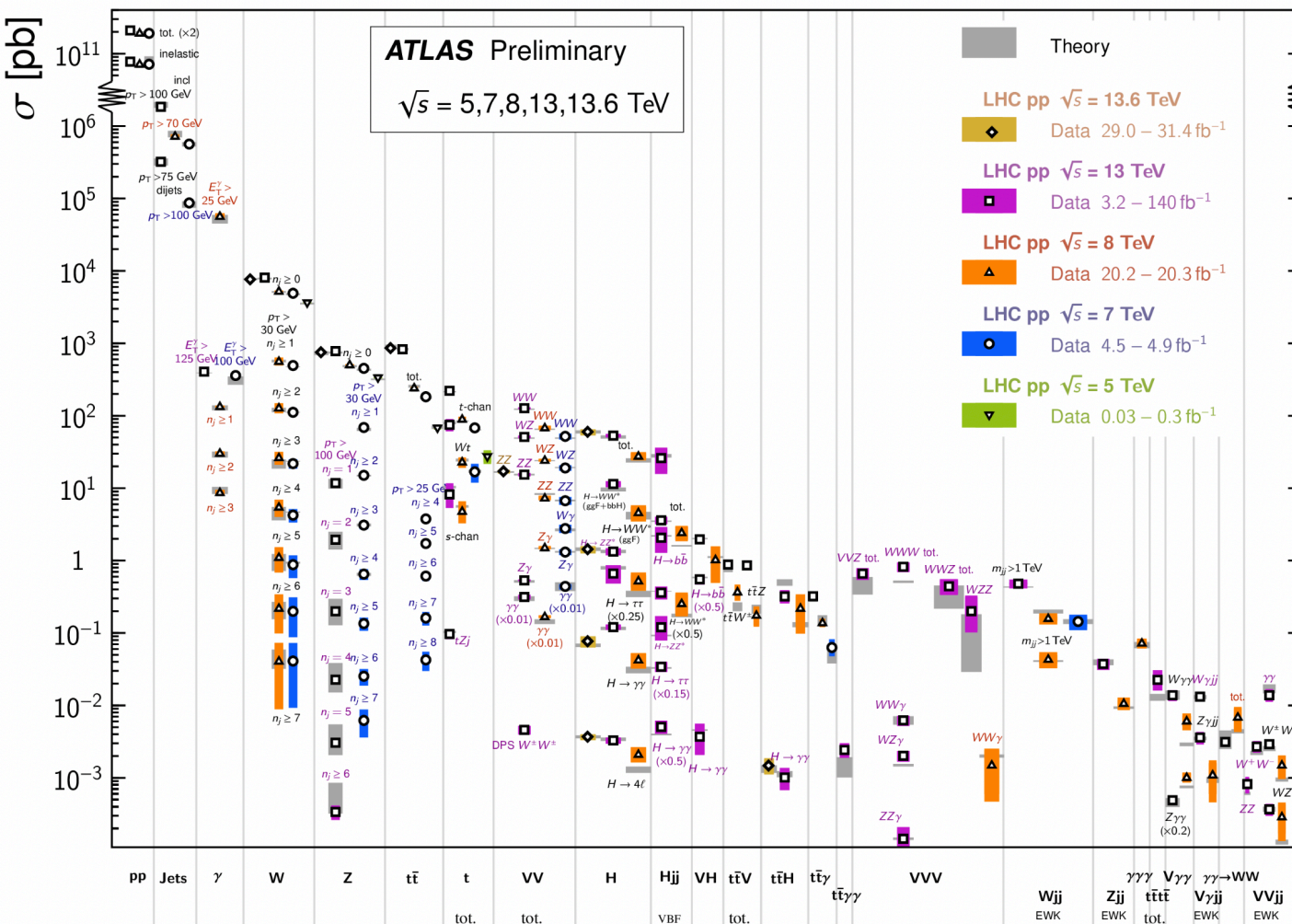
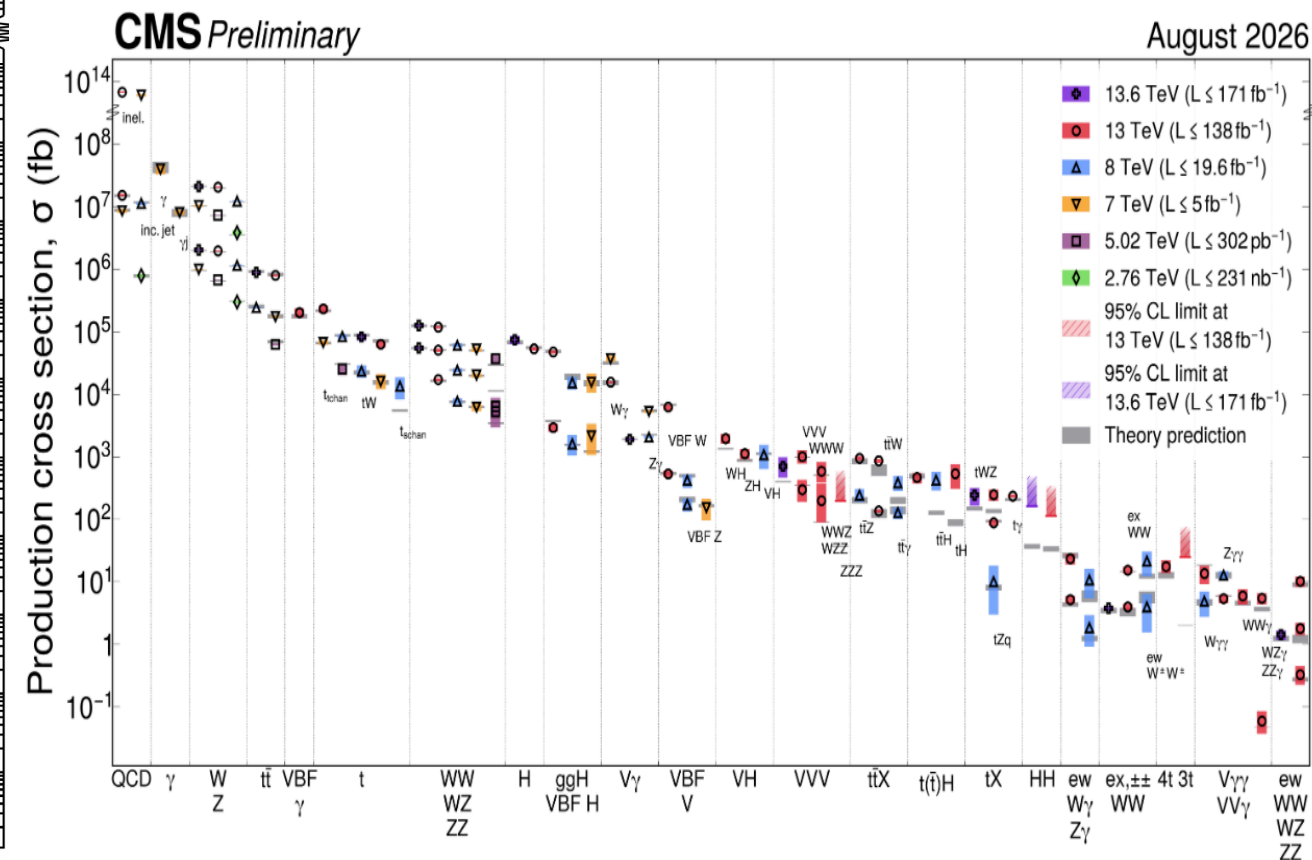
In collaboration with Qing-Hong Cao, Yandong Liu and Fu-Sheng Yu.

Current SM Production Measurement at the LHC

- The Standard Model production cross section at ATLAS and CMS.

Standard Model Production Cross Section Measurements

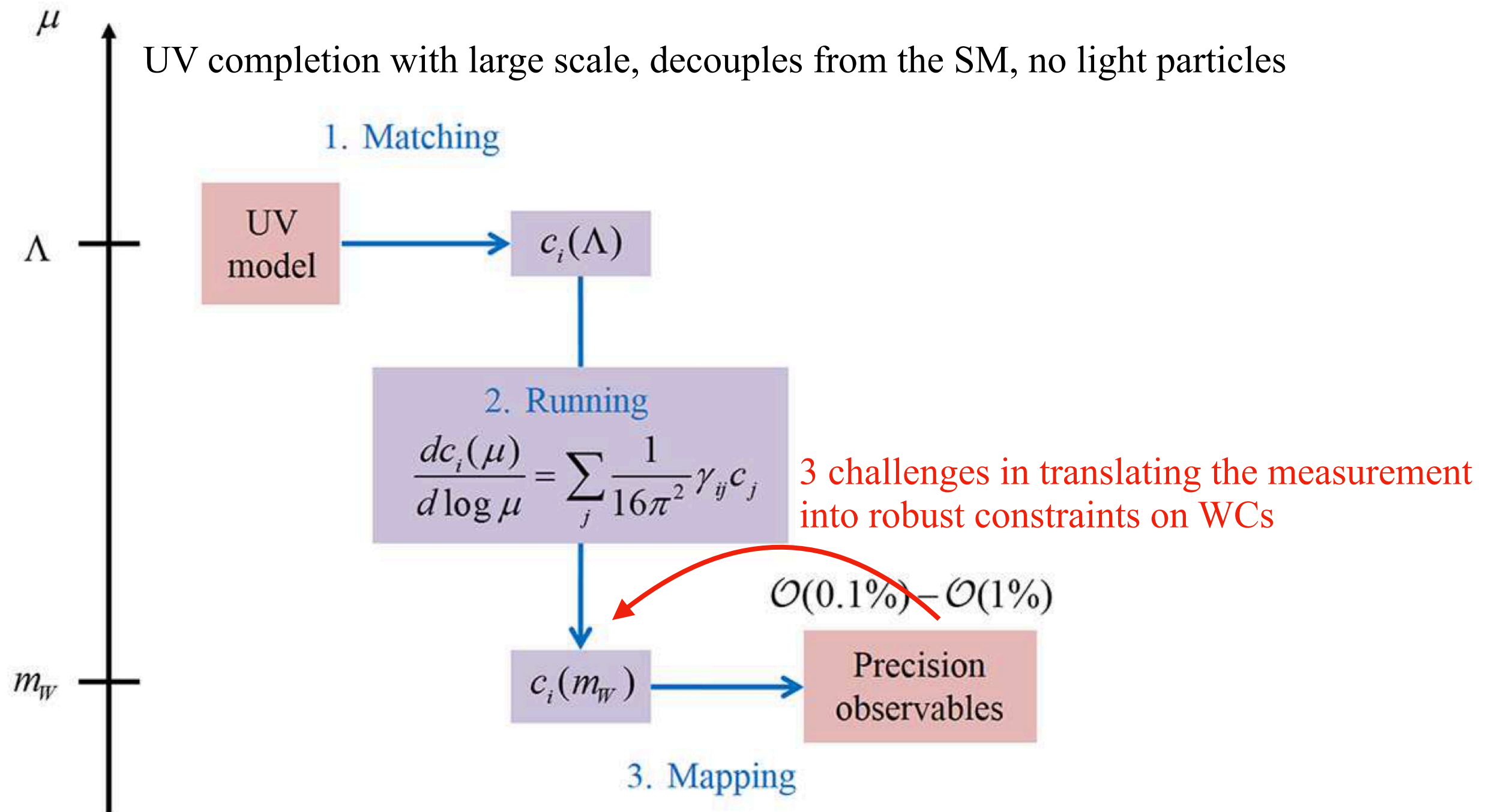
Status: July 2026



- The LHC has entered the era of precision physics, future experimental program is to conduct high-precision measurements of various SM processes, providing a unique window into potential NP.

Standard Model Effective Field Theory

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}}^{(4)} + \frac{c_i}{\Lambda} \mathcal{O}_i^{(5)} + \frac{c_j}{\Lambda^2} \mathcal{O}_j^{(6)} + \dots$$



Henning, Lu, Murayama, 1214.1837

Operator Deluge

- SMEFT at dim-6: 59 operators for 1-generation, and 2499 for 3-generation.

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	$(\varphi^\dagger \varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger \varphi)(\bar{l}_p e_r \varphi)$
$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger \varphi)\Box(\varphi^\dagger \varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger \varphi)(\bar{q}_p u_r \tilde{\varphi})$
Q_W	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$(\varphi^\dagger D^\mu \varphi)^* (\varphi^\dagger D_\mu \varphi)$	$Q_{d\varphi}$	$(\varphi^\dagger \varphi)(\bar{q}_p d_r \varphi)$
$Q_{\tilde{W}}$	$\varepsilon^{IJK} \tilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				
$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger \varphi G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{l}_p \gamma^\mu l_r)$
$Q_{\varphi \tilde{G}}$	$\varphi^\dagger \varphi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	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}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \tilde{\varphi} G_{\mu\nu}^A$	$Q_{\varphi e}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{e}_p \gamma^\mu e_r)$
$Q_{\varphi \tilde{W}}$	$\varphi^\dagger \varphi \tilde{W}_{\mu\nu}^I W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \tilde{\varphi} W_{\mu\nu}^I$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{q}_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger \varphi B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tilde{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu^I \varphi)(\bar{q}_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi \tilde{B}}$	$\varphi^\dagger \varphi \tilde{B}_{\mu\nu} B^{\mu\nu}$	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}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi d}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{d}_p \gamma^\mu d_r)$
$Q_{\varphi \tilde{W}B}$	$\varphi^\dagger \tau^I \varphi \tilde{W}_{\mu\nu}^I B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\tilde{\varphi}^\dagger D_\mu \varphi)(\bar{u}_p \gamma^\mu d_r)$

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

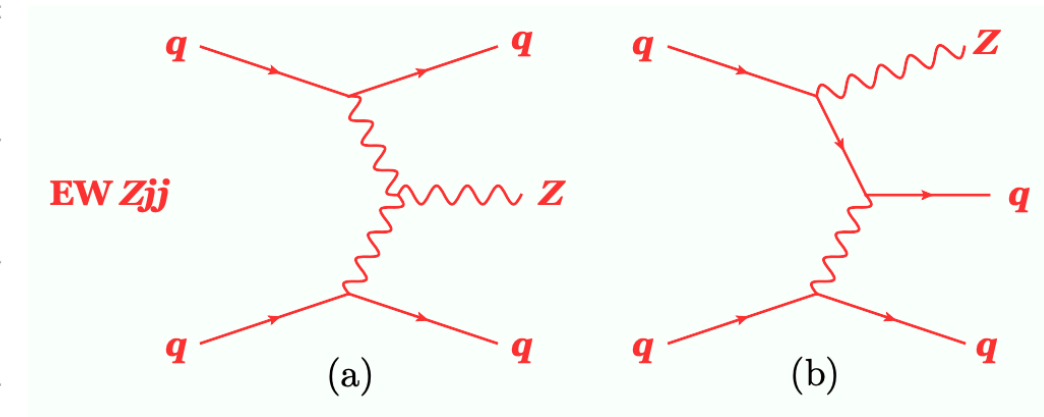
B. Grzadkowski, M. Iskrzynski, et. al., 1008.4884

A complete coefficient determination is intractable without additional physical input.

Traditional “one-operator-at-a-time” EFT analysis

- The constraints on Wilson coefficients at LHC:

Wilson coefficient	Includes $ \mathcal{M}_{d6} ^2$	95% confidence interval [TeV ⁻²]		p -value (SM)
		Expected	Observed	
c_W/Λ^2	no	[-0.30, 0.30]	[-0.19, 0.41]	45.9%
	yes	[-0.31, 0.29]	[-0.19, 0.41]	43.2%
$\tilde{c}_W/\Lambda^2$	no	[-0.12, 0.12]	[-0.11, 0.14]	82.0%
	yes	[-0.12, 0.12]	[-0.11, 0.14]	81.8%
c_{HWB}/Λ^2	no	[-2.45, 2.45]	[-3.78, 1.13]	29.0%
	yes	[-3.11, 2.10]	[-6.31, 1.01]	25.0%
$\tilde{c}_{HWB}/\Lambda^2$	no	[-1.06, 1.06]	[0.23, 2.34]	1.7%
	yes	[-1.06, 1.06]	[0.23, 2.35]	1.6%



ATLAS, 2006.15458

- The constraints on Wilson coefficients at LHC:

$$\begin{aligned} \Delta\mathcal{L}_{2\text{HDM}} = & (D_\mu \varphi)^\dagger (D^\mu \varphi) - M^2 \varphi^\dagger \varphi - \frac{\lambda_\varphi}{4} (\varphi^\dagger \varphi)^2 \\ & + (\eta_H H^\dagger H + \eta_\varphi \varphi^\dagger \varphi) (\tilde{H}^\dagger \varphi + \varphi^\dagger \tilde{H}) \\ & - \lambda_1 (\tilde{H}^\dagger H) (\varphi^\dagger \varphi) - \lambda_2 (\tilde{H}^\dagger \varphi)^\dagger (\tilde{H}^\dagger \varphi) - \lambda_3 ((\tilde{H}^\dagger \varphi)^2 + (\varphi^\dagger \tilde{H})^2). \end{aligned}$$

T. D. Lee, 1973
John F. Gunion et al., 2003
G. C. Branco et al., 2012

Operator	Wilson Coefficients
$\mathcal{O}_W$	$C_W = \frac{g^3}{5760\pi^2 M^2}$
$\mathcal{O}_{HW}$	$C_{HW} = \frac{g^2}{768\pi^2 M^2} (2\lambda_1 + \lambda_2)$
$\mathcal{O}_{HWB}$	$C_{HWB} = \frac{gg'\lambda_2}{384\pi^2 M^2}$

Ignoring crucial inter-operator correlation and risk overestimating individual sensitivities.

Assumptions of the Optimized EFT Analysis Framework

- Under the assumption that NP effects are perturbative, we truncate the SMEFT expansion at dim-6, focusing exclusive on their interference terms.

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}}^{(4)} + \frac{c_i}{\Lambda} \mathcal{O}_i^{(5)} + \frac{c_j}{\Lambda^2} \mathcal{O}_j^{(6)} + \dots$$

$$\sigma_{\text{tot}} \propto |\mathcal{M}_{\text{tot}}|^2 = |\mathcal{M}_{\text{SM}}|^2 + \frac{c_i}{\Lambda^2} |\mathcal{M}_{\text{SM}}^* \mathcal{M}_i| + \mathcal{O}\left(\frac{E^4}{\Lambda^4}\right)$$

- Rather than treating all operators simultaneously, we first identify a target operator set relevant to a specific NP sector, pruning those already tightly constrained by existing data.

Top-quark operators: $\{\mathcal{O}_{qq}^{(3)}, \mathcal{O}_{uW}, \mathcal{O}_{Hq3}\}$

EWK bosonic operators: $\{\mathcal{O}_W, \mathcal{O}_{HW}, \mathcal{O}_{HB}, \mathcal{O}_{HWB}, \mathcal{O}_{HD}\}$

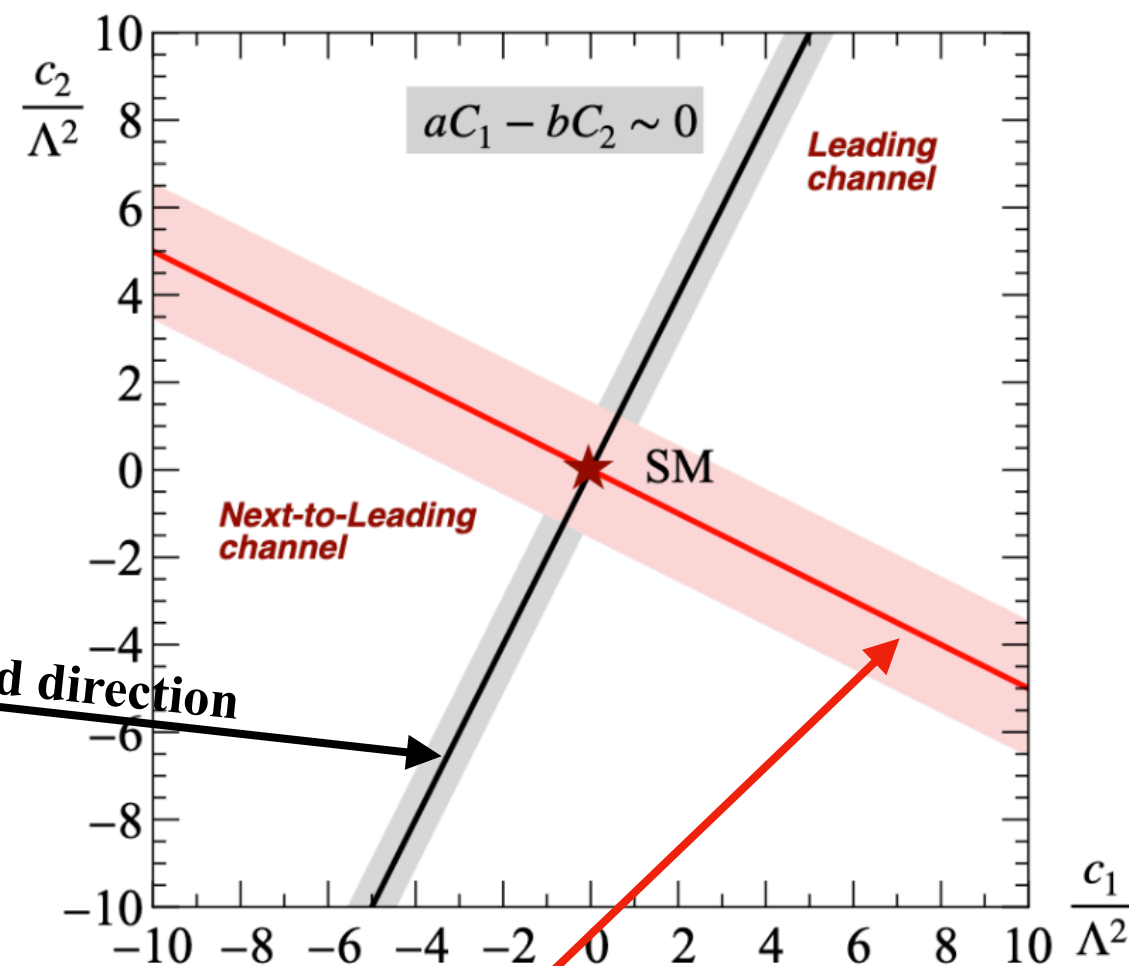
The Optimized EFT Analysis Framework

- **Leading channel (LC):** relevant SM process with large cross section and clean experimental signal:

$$\sigma_{\text{obs}} = \sigma_{\text{SM}} + \delta\sigma(\mathcal{O}_1, \mathcal{O}_2).$$

When the measurement is consistent with SM:

$$\delta\sigma = \sigma_{\text{obs}} - \sigma_{\text{SM}} = a\frac{c_1}{\Lambda^2} - b\frac{c_2}{\Lambda^2} \simeq 0.$$



Break this degeneracy and further constrain WCs?

- **Subleading channel (SLC):** exhibits a distinct functional dependence on this two operators, despite typically processing small cross sections.

$$\delta\sigma_{\text{sub}} = \frac{mc_1 + nc_2}{\Lambda^2}.$$

A secondary constraints is obtained in the absence of any observed deviation from the SM in this SLC:

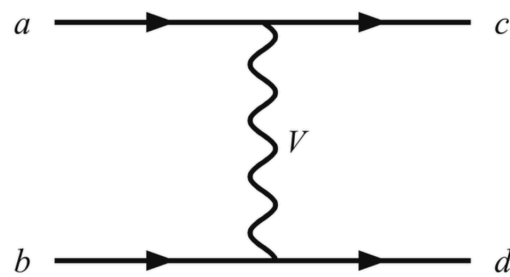
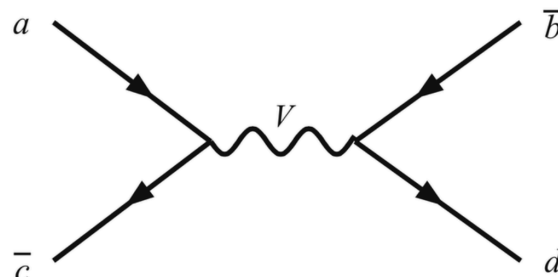
$$mc_1 + nc_2 \simeq 0.$$

Either UV model does not manifest these operators, or the NP scale is sufficiently large to remaining decoupled from current LHC reach.

Identification of optimal LC/SLC pairs

- We categorize the selection logic into three representative strategies:

- Correlation of Operators Across Multiple Processes.



**Different initial-state PDFs
and
Distinct kinematic regimes**

- Operator Reduction via Higgs Field Backgrounds.

$$H \rightarrow \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + h(x) \end{pmatrix},$$

$$\mathcal{O}_{HWB} = H^\dagger \tau^I H W_{\mu\nu}^I B_{\mu\nu}$$

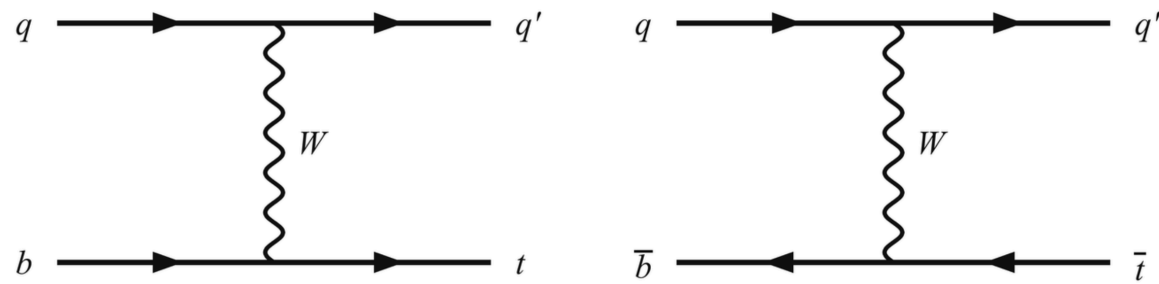
- Operator Expansion via Field Strength Tensors.

$$\mathcal{O}_W = \epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$$

$$W_{\mu\nu}^I = \partial_\mu W_\nu^I - \partial_\nu W_\mu^I - g\epsilon^{IJK} W_\mu^J W_\nu^K$$

Single Top: Correlation Across Multiple Processes

- Single top and anti-top quark production:



$$\mathcal{O}_{qq}^{(3)} = (\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_p \gamma^\mu \tau^I q_r)$$

$$\mathcal{O}_{uW} = (\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \tilde{H} W_{\mu\nu}^I$$

$$\mathcal{O}_{Hq3} = (H^\dagger i \overleftrightarrow{D}_\mu^I H)(\bar{q}_p \tau^I \gamma^\mu q_r)$$

- The normalized contributions of operators:

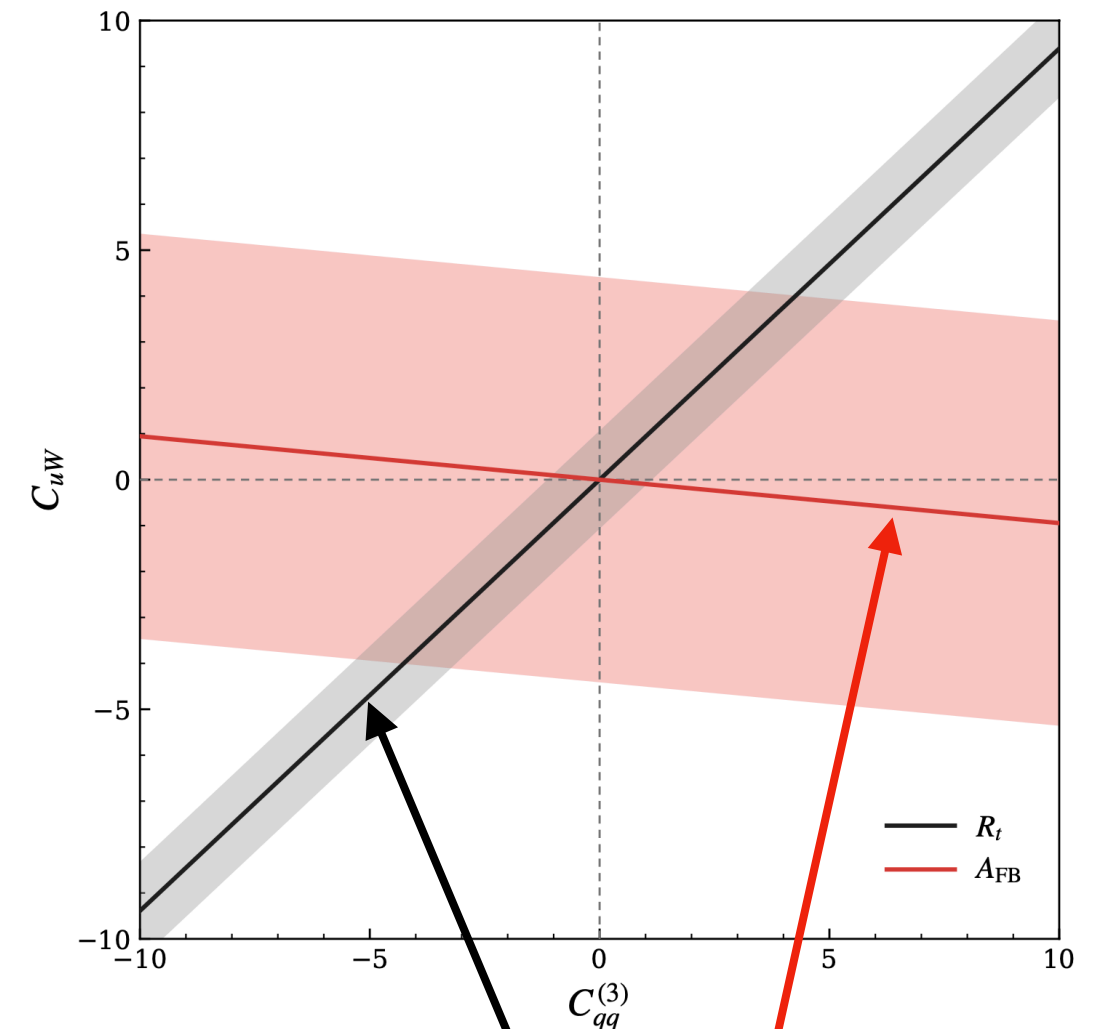
$$\sigma_{t+\bar{t}} = \sigma_t + \sigma_{\bar{t}}, \quad R_t = \frac{\sigma_t}{\sigma_{\bar{t}}}, \quad A_{\text{FB}} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

$$\frac{\sigma_{t+\bar{t}}}{\sigma_{t+\bar{t}}^0} = 1 - 0.059 C_{qq}^{(3)} + 0.075 C_{uW} + 0.060 C_{Hq3},$$

$$\frac{R_t}{R_t^0} = 1 - 0.0308 C_{qq}^{(3)} + 0.0328 C_{uW},$$

$$\frac{A_{\text{FB}}}{A_{\text{FB}}^0} = 1 - 0.0033 C_{qq}^{(3)} - 0.0349 C_{uW},$$

Qing-Hong Cao, Hao-ran Jiang, Guo-Jin Zeng, 2105.04464



$$\left. \frac{\sigma_{t+\bar{t}}}{\sigma_{t+\bar{t}}^0} \right|_{\text{Exp}} = 0.95 \pm 0.14$$

$$\left. \frac{R_t}{R_t^0} \right|_{\text{Exp}} = 1 \pm 0.035 \quad \text{LC}$$

$$\left. \frac{A_{\text{FB}}}{A_{\text{FB}}^0} \right|_{\text{Exp}} = 0.877 \pm 0.154 \quad \text{SLC}$$

Future Experimental efforts should prioritize improve measurements of A_{FB} , as its currently limited precision restricts the sensitivity to NP.

Higgs Decay: Operator Reduction via Higgs Filed Backgrounds

- Electroweak bosonic operators:

$$\mathcal{O}_{HW} = H^\dagger H W_{\mu\nu}^I W^{I\mu\nu},$$

$$\mathcal{O}_{HB} = H^\dagger H B_{\mu\nu} B^{\mu\nu},$$

$$\mathcal{O}_{HWB} = H^\dagger \tau^I H W_{\mu\nu}^I B^{\mu\nu},$$

$$\mathcal{O}_{HD} = (H^\dagger D^\mu H)^* (H^\dagger D_\mu H),$$

$H \rightarrow v$

$$\mu_{m_Z} \equiv \frac{\delta m_Z^2}{m_Z^2} = \frac{v^2}{2} \left[\frac{4m_W}{m_Z} \sqrt{1 - \frac{m_W^2}{m_Z^2}} C_{HWB} + C_{HD} \right]$$

$$\simeq \frac{v^2}{2} (1.66 C_{HWB} + C_{HD}), \quad \text{LC}$$

$$m_Z^{\text{LEP}} = 91.1876 \pm 0.0021 \quad \text{S. Schael et al., hep-ex/0509008}$$

$H \rightarrow h : h \rightarrow \gamma\gamma, Z\gamma, WW^*(\rightarrow 2\ell 2\nu)$ **SLC**

$$\mu_{\gamma\gamma} = 1 - 14.3 C_{HW} - 49.8 C_{HB} + 26.7 C_{HWB} - 0.0303 C_{HD},$$

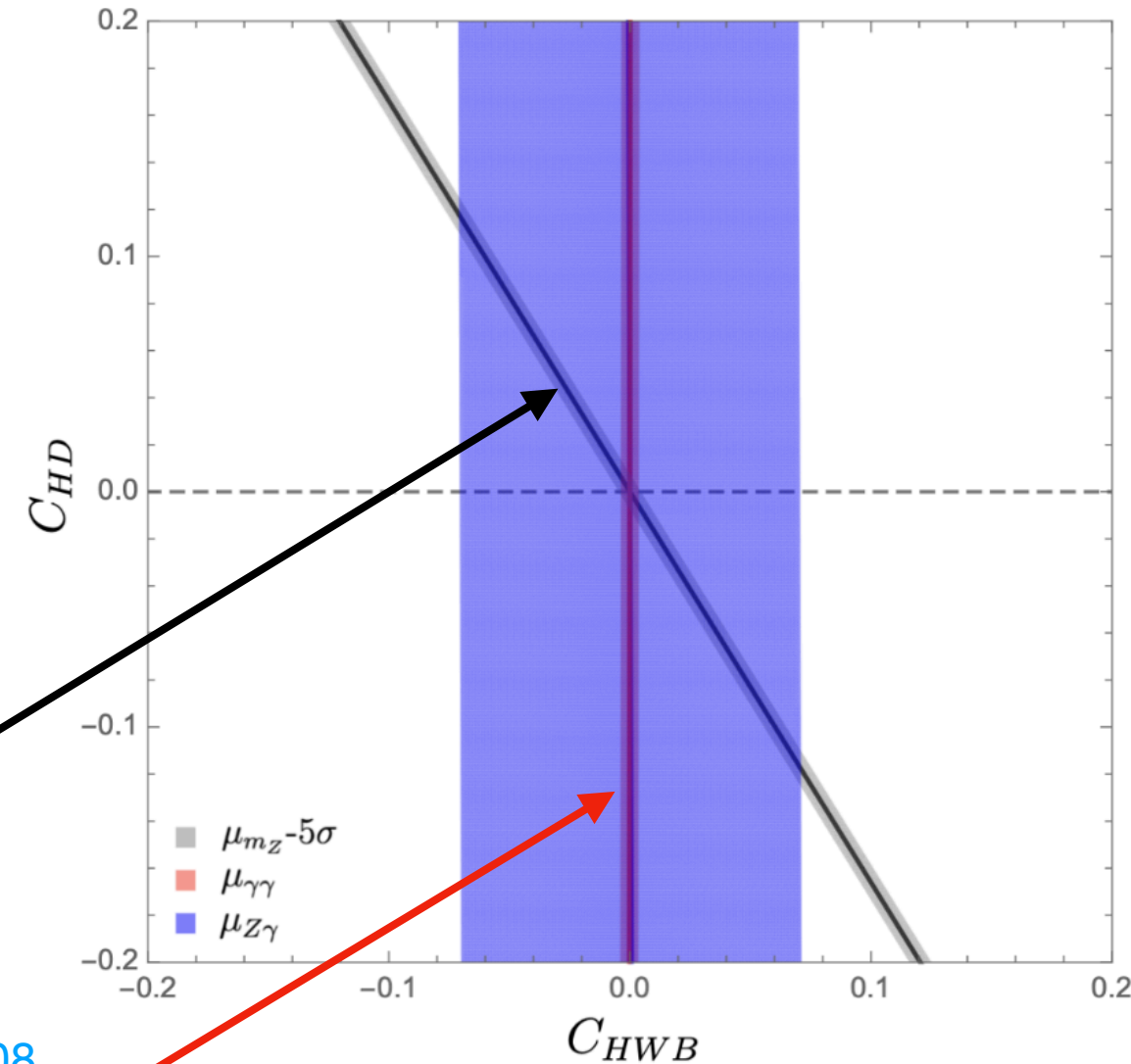
$$\mu_{WW^*} = 1 - 0.0908 C_{HW} - 0.0303 C_{HD},$$

$$\mu_{Z\gamma} = 1 + 14.9 C_{HW} - 14.9 C_{HB} - 9.91 C_{HWB} - 0.0303 C_{HD},$$

$$\mu_{\gamma\gamma}^{\text{exp}} \simeq 1.04 \pm 0.10 \quad \text{ATLAS, 2207.00348}$$

$$\mu_{WW^*}^{\text{exp}} \simeq 1.19 \pm 0.13 \quad \text{ATLAS, 2504.07686}$$

$$\mu_{Z\gamma}^{\text{exp}} \simeq 2.2 \pm 0.7 \quad \text{ATLAS \& CMS, 2309.03501}$$

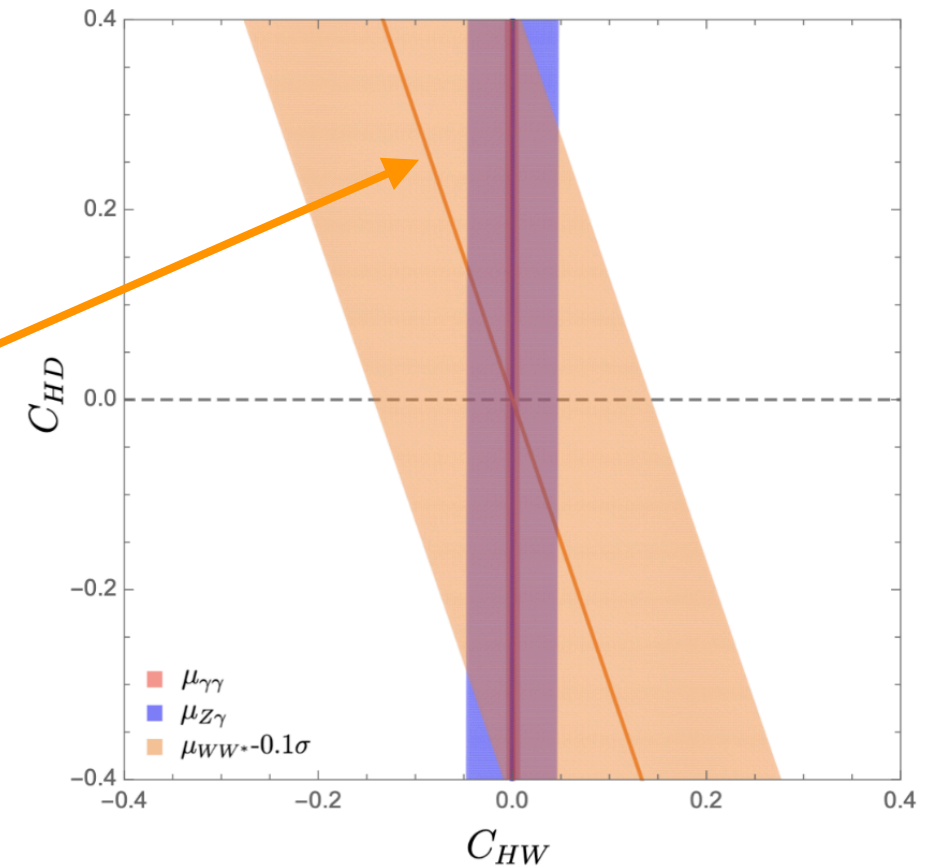


Higgs Decay: Operator Reduction via Higgs Filed Backgrounds

- Since WW channel solely dependent on O_{HW} and O_{HD} , it anchors the additional direction induced by O_{HD} .

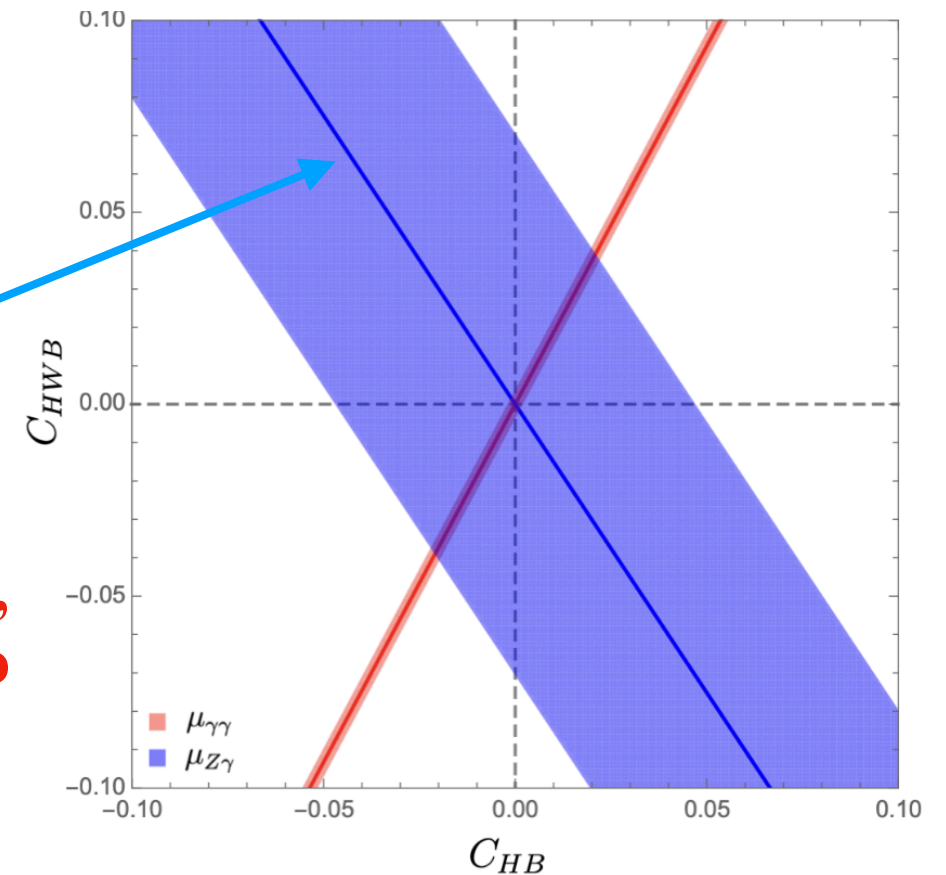
$$\mu_{\gamma\gamma} = 1 - 14.3 C_{HW} - 49.8 C_{HB} + 26.7 C_{HWB} - 0.0303 C_{HD},$$

$$\mu_{WW^*} = 1 - 0.0908 C_{HW} - 0.0303 C_{HD},$$



- The orthogonality of correlation in $Z\gamma$ channel make this channel be crucial in lifting the degeneracy along $O_{HB} - O_{HWB}$ direction.

$$\mu_{Z\gamma} = 1 + 14.9 C_{HW} - 14.9 C_{HB} - 9.91 C_{HWB} - 0.0303 C_{HD},$$



Z mass measurement defines the dominant blind direction, $\gamma\gamma$ channel provide sensitivity approximately orthogonal to the blind direction, while WW^* and $Z\gamma$ anchors the additional operator direction induced by O_{HW} and O_{HB} .

EWK Boson Production: Operator Expansion via Field Strength Tensors

- The operators relevant to aTGCs and aQGCs:

$$\mathcal{O}_W = \epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu},$$

$$\mathcal{O}_{HWB} = H^\dagger \tau^I H W_{\mu\nu}^I B^{\mu\nu},$$

- NP contributions to ZW and EWK – jjZW through VBS channel:

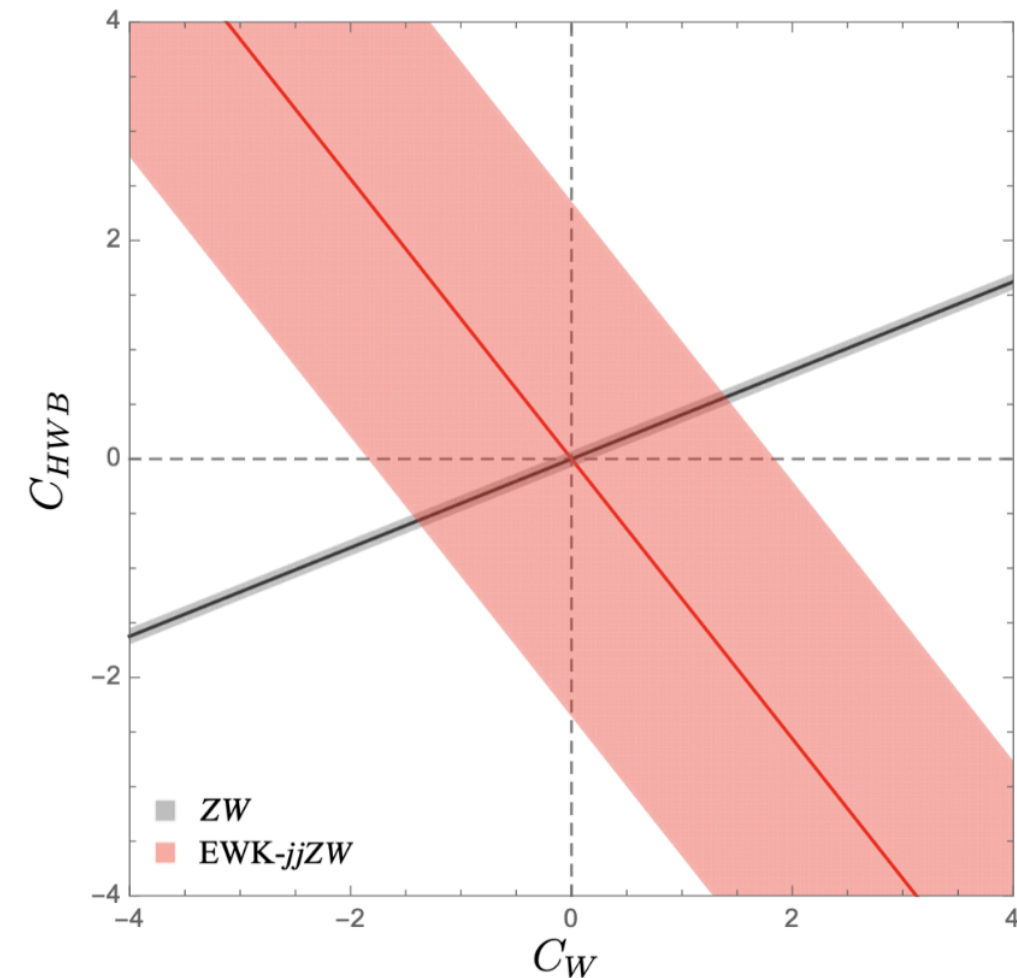
$$\delta\sigma_{3\ell 1\nu}^{ZW} = [-0.833 C_W + 2.052 C_{HWB}] \text{ fb}, \quad \text{LC}$$

$$\delta\sigma_{2j 3\ell 1\nu}^{jjZW} = [0.0082 C_W + 0.0064 C_{HWB}] \text{ fb}, \quad \text{SLC}$$

- Kinematic selection cuts for gauge boson productions:

ZW production: $n_j = 0, n_\ell = 3, p_\ell^T > 15 \text{ GeV}, p_{\ell_1}^T > 25 \text{ GeV}, |\eta_\ell| < 2.5,$
 $p_{\ell_W}^T > 20 \text{ GeV}, \Delta R(\ell_W, \ell_Z) > 0.3, \Delta R(\ell_Z, \ell_Z) > 0.2,$
 $|m_{\ell\ell}^Z - m_Z| < 10 \text{ GeV}, m_W^T > 30 \text{ GeV},$

EWK – jjZW : $n_j = 2, n_b = 0, p_j^T > 40 \text{ GeV}, |\eta_j| < 5.0,$
 $n_\ell = 3, p_\ell^T > 15 \text{ GeV}, p_{\ell_1}^T > 25 \text{ GeV}, |\eta_\ell| < 2.5,$
 $p_{\ell_W}^T > 20 \text{ GeV}, \Delta R(\ell_W, \ell_Z) > 0.3, \Delta R(\ell_Z, \ell_Z) > 0.2,$
 $|m_{\ell\ell}^Z - m_Z| < 10 \text{ GeV}, m_W^T > 30 \text{ GeV},$
 $\eta_{j1} \cdot \eta_{j2} < 0, m_{jj} > 500 \text{ GeV}.$



ZW production first define the leading constraint and the associated blind direction, while EWK – jjZW production provides the subleading but complementary information.

- Traditional EFT analysis with “one-operator-at-a-time” assumption usually ignore the crucial operator correlation and risk overestimating sensitivities, while interpreting high-dimensional results from global analysis within a concrete physical context remains elusive.
- We propose an optimized EFT analysis strategy that identifies leading and subleading channels for a given operator set, enabling precise and rapid constraints on Wilson coefficients while lifting parameter degeneracies.
- We illustrate this EFT approach using three classes of processes: single top production, Higgs decay, and multi-gauge boson production.
- Within the optimized EFT analysis framework, future experimental efforts should prioritize precise measurements on A_{FB} , μ_{VV} and EWK – $jjZW$, which are crucial for further constraining the relevant operators.

Thank you!

Backup

Higgs to VV Decay

$$\mathcal{L}_{h \rightarrow \gamma\gamma} = (C_{\text{SM}}^{\gamma\gamma} + C_{\text{SMEFT}}^{\gamma\gamma}) h F_{\mu\nu} F^{\mu\nu},$$

$$C_{\text{SM}}^{\gamma\gamma} = \frac{\alpha_{\text{em}}}{8\pi v} A_{\text{SM}}^{\gamma\gamma},$$

$$C_{\text{SMEFT}}^{\gamma\gamma} = v \left(s_W^2 C_{HW} + c_W^2 C_{HB} - s_W c_W C_{HWB} - \frac{v}{4} C_{HD} A_{\text{SM}}^{\gamma\gamma} \right),$$

It is useful to express the SMEFT contributions as a shift to the dimensionless SM amplitude,

$$A_{\text{SM}}^{\gamma\gamma} \rightarrow A_{\text{SM}}^{\gamma\gamma} + A_{\text{SMEFT}}^{\gamma\gamma}, \quad (\text{A4})$$

with

$$A_{\text{SMEFT}}^{\gamma\gamma} = -\frac{v^2}{4} C_{HD} A_{\text{SM}}^{\gamma\gamma} + \frac{8\pi v}{\alpha_{\text{em}}} C_{\gamma\gamma}. \quad (\text{A5})$$

$$C_{\gamma\gamma} = s_W^2 C_{HW} + c_W^2 C_{HB} - s_W c_W C_{HWB}.$$

$$\Gamma(h \rightarrow \gamma\gamma) = \frac{\alpha_{\text{em}}^2 m_h^3}{256\pi^3 v^2} |A_{\text{SM}}^{\gamma\gamma} + A_{\text{SMEFT}}^{\gamma\gamma}|^2,$$

$$\begin{aligned} \mu_{\gamma\gamma} &\equiv \frac{\Gamma_{\text{SM}}^{\gamma\gamma} + \Gamma_{\text{int}}^{\gamma\gamma}}{\Gamma_{\text{SM}}^{\gamma\gamma}} \\ &= 1 - \frac{v^2}{2} C_{HD} + \frac{16\pi v}{\alpha_{\text{em}} A_{\text{SM}}^{\gamma\gamma}} C_{\gamma\gamma} \\ &= 1 - 14.3 C_{HW} - 49.8 C_{HB} \\ &\quad + 26.7 C_{HWB} - 0.0303 C_{HD}. \end{aligned}$$

Collider Phenomenology in Gauge Boson Production

- Kinematic selection cuts in ZW production:

$$n_j = 0, n_\ell = 3, p_\ell^T > 15 \text{ GeV}, p_{\ell_1}^T > 25 \text{ GeV}, |\eta_\ell| < 2.5, \\ p_{\ell_W}^T > 20 \text{ GeV}, \Delta R(\ell_W, \ell_Z) > 0.3, \Delta R(\ell_Z, \ell_Z) > 0.2, \\ |m_{\ell\ell}^Z - m_Z| < 10 \text{ GeV}, m_W^T > 30 \text{ GeV},$$

	Basic Cut (fb)	Optimized Cuts (fb)
$\mathcal{O}_W$	-1.064	-0.833
$\mathcal{O}_{HWB}$	2.359	2.052
ZW (SM)	78.554	64.789
ZZ	5.862	3.133

- Kinematic selection cuts in EWK-jjZW production:

$$n_j = 2, n_b = 0, p_j^T > 40 \text{ GeV}, |\eta_j| < 5.0, \\ n_\ell = 3, p_\ell^T > 15 \text{ GeV}, p_{\ell_1}^T > 25 \text{ GeV}, |\eta_\ell| < 2.5, \\ p_{\ell_W}^T > 20 \text{ GeV}, \Delta R(\ell_W, \ell_Z) > 0.3, \Delta R(\ell_Z, \ell_Z) > 0.2, \\ |m_{\ell\ell}^Z - m_Z| < 10 \text{ GeV}, m_W^T > 30 \text{ GeV}, \\ \eta_{j_1} \cdot \eta_{j_2} < 0, m_{jj} > 500 \text{ GeV}.$$

	Basic Cut (fb)	Optimized Cuts (fb)
$\mathcal{O}_W$	0.0171	0.0082
$\mathcal{O}_{HWB}$	0.0133	0.0064
jjZW (QCD)	4.110	0.442
jjZW (EWK)	0.356	0.219
jjZZ (QCD)	0.198	0.014
jjZZ (EWK)	0.014	0.013

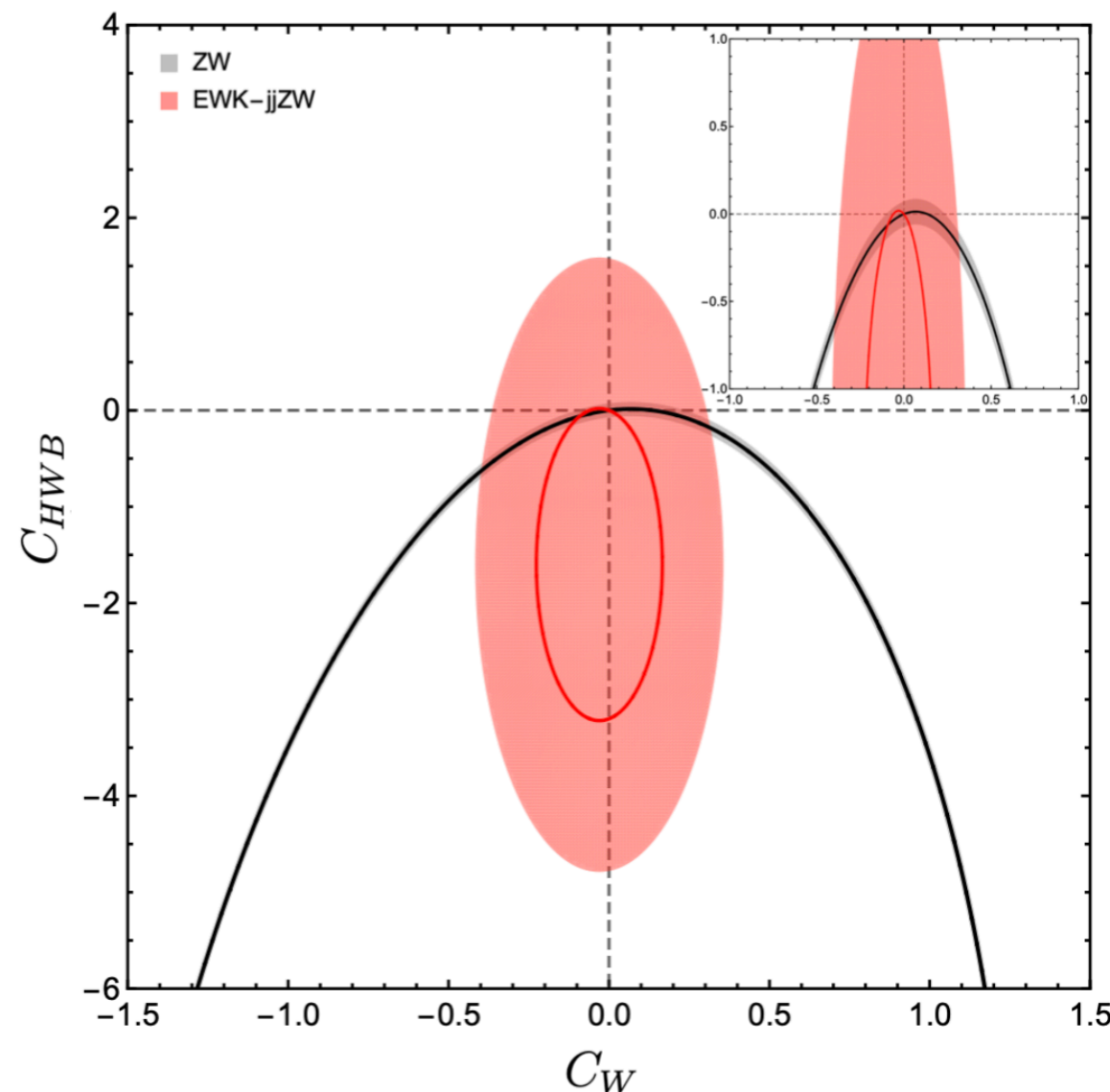
LC/SLC framework at Quadratic Level

- The cut-flow for ZW and EWK-jjZW production at quadratic level:

	Basic Cut (fb)	Optimized Cuts (fb)
$ \mathcal{O}_W ^2$	8.255	6.221
$ \mathcal{O}_{HWB} ^2$	0.098	0.082
$ \mathcal{O}_W \cdot \mathcal{O}_{HWB} $	-0.352	-0.254

	Basic Cut (fb)	Optimized Cuts (fb)
$ \mathcal{O}_W ^2$	0.3166	0.1357
$ \mathcal{O}_{HWB} ^2$	0.0036	0.0020

- The operator correlation at quadratic level:



Experimental correlation matrix

- Single top and anti-top production channels:

$$\rho = \begin{bmatrix} \rho_{qq} & \rho_{qq-uW} & \rho_{qq-Hq3} \\ \rho_{qq-uW} & \rho_{uW} & \rho_{uW-Hq3} \\ \rho_{qq-Hq3} & \rho_{uW-Hq3} & \rho_{Hq3} \end{bmatrix} = \begin{bmatrix} 1 & -0.97 & -0.19 \\ -0.97 & 1 & -0.31 \\ -0.19 & -0.31 & 1 \end{bmatrix}$$

- Higgs decay channels:

$$\rho = \begin{bmatrix} \rho_{HW} & \rho_{HW-HB} & \rho_{HW-HWB} & \rho_{HW-HD} \\ \rho_{HB-HW} & \rho_{HB} & \rho_{HB-HWB} & \rho_{HB-HD} \\ \rho_{HW-HWB} & \rho_{HB-HWB} & \rho_{HWB} & \rho_{HWB-HD} \\ \rho_{HW-HD} & \rho_{HB-HD} & \rho_{HWB-HD} & \rho_{HD} \end{bmatrix} \simeq \begin{bmatrix} 1 & 1 & 1 & -1 \\ 1 & 1 & 1 & -1 \\ 1 & 1 & 1 & -1 \\ -1 & -1 & -1 & 1 \end{bmatrix}$$

- Gauge boson production channels:

$$\rho = \begin{bmatrix} \rho_W & \rho_{W-HWB} \\ \rho_{W-HWB} & \rho_{HWB} \end{bmatrix} = \begin{bmatrix} 1 & 0.99 \\ 0.99 & 1 \end{bmatrix}$$