THE UNIVERSITY OF CHICAGO 1890

ENRICO FERMI INSTITUTE

Probing Dimension-6 SMEFT Operators in Rare Z Decays Beyond LHC

Speaker: Inci Karaaslan
with Hengameh Bagherian, Samuel Homiller, LianTao Wang

Future Hadron Colliders and Heavy Bosons Program

CERN has reached a crucial milestone in the advancement of the High-Luminosity Large Hadron Collider (HiLumi LHC) project with the start of the cryogenic cooldown to 1.9 K (-271.3 °C) of its 95-metre-long test stand – a full-scale replica of the innovative equipment that will transform the LHC in the coming years. The test stand is designed to validate the novel magnet system (the inner triplet beam-focusing magnets) and its complex infrastructure, which is a key element in a major upgrade of the LHC that is set to enter operation in 2030.

The LHC will shut down in 2026 to commence the installation of new components for the HL-LHC, including magnet systems based on technology that was not available when the LHC was built. In parallel, the activities of the detector upgrade programmes for the high-luminosity operation of the LHC have made good progress. The HL-LHC will ultimately deliver over a factor of five more data than the LHC, providing a leap forward in precision and new physics discovery potential. The HL-LHC is planned to operate from 2030 to 2041. The completion of the HL-LHC programme according to the current schedule will be critical for the timely implementation of the next flagship collider project.

The electron–positron Future Circular Collider (FCC-ee) is recommended as the preferred option for the next flagship collider at CERN.

The successful completion of the FCC Feasibility Study at CERN, recommended in the 2020 Strategy update, constitutes another major achievement. A coherent baseline design for the FCC programme, including a well-advanced territorial implementation scenario, has been elaborated. The technical feasibility of electron–positron collisions in the FCC has been demonstrated and plausible funding scenarios have been developed.

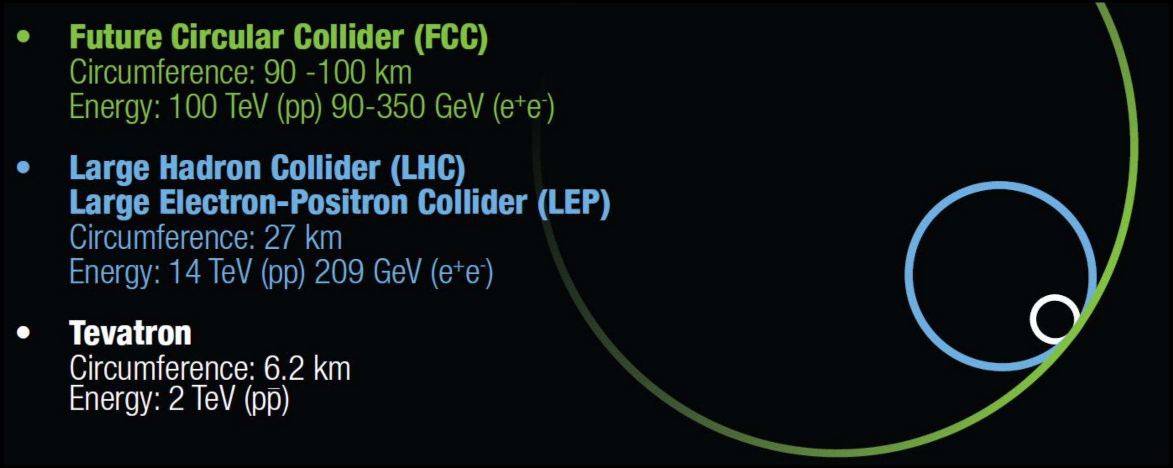
CERN-ESU-2025-002

Future Hadron Colliders and Heavy Bosons Program

Future Improvements to Large Hadron Collider:

- High-Luminosity LHC (HL-LHC) will improve luminosity by ~10x
- Future Circular Collider (FCC) will increase center of mass energy by ~10x

- Producing large samples of W, Z, and diboson (WW, WZ, ZZ) events



$$\text{LHC Run 3: } \sigma_Z = 744 \pm 20 \text{ pb}, \mathcal{L}_{int} \sim 3 \times 10^5 \text{ pb}^{-1}, N_Z = \sigma_Z \times \mathcal{L}_{int} \sim 10^8$$

$$\text{HL-LHC Projected: } \mathcal{L}_{int} \sim 3 \times 10^6 \text{ pb}^{-1}, N_Z \sim 10^9$$

arXiv:2505.03535
CERN-ACC-2018-0056

$$\text{FCC-hh Projected: } \sigma_Z \sim 4 \times 10^5 \text{ pb} \quad , \mathcal{L}_{int} \sim 3 \times 10^6 \text{ pb}^{-1}, N_Z \sim 10^{14}$$

Why do we want to look at single Z at hadron colliders?

1. Aren't Z processes just used as backgrounds to other processes and calibration tools because their production σ and lepton decay rates are well understood?

   Z signals are ideal signals for BSM studies *because* Z is so well understood.

   Potentially the first place to see BSM physics in the EW sector is in anomalous Z couplings and rare decay modes.

Why do we want to look at single Z at hadron colliders?

1. Aren't Z processes just used as backgrounds to other processes and calibration tools because their production σ and lepton decay rates are well understood?

   Z signals are ideal signals for BSM studies *because* Z is so well understood.

   Potentially the first place to see BSM physics in the EW sector is in anomalous Z couplings and rare decay modes.

2. Didn't we already measure the W and Z at LEP?

   Yes!..for on-shell Z couplings at rest (at LEP1). LEP never saw a Z with much boost (γ~1-1.2), LEP never probed the boosted kinematics of decays or the energy-dependent structure of the EW vertices.

Why do we want to look at single Z at hadron colliders?

1. Aren't Z processes just used as backgrounds to other processes and calibration tools because their production σ and lepton decay rates are well understood?

   Z signals are ideal signals for BSM studies *because* Z is so well understood.

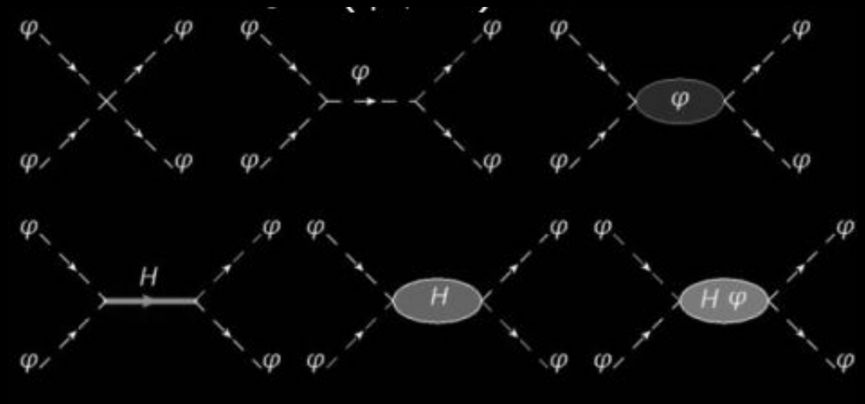
   Potentially the first place to see BSM physics in the EW sector is in anomalous Z couplings and rare decay modes.

2. Didn't we already measure the W and Z at LEP?

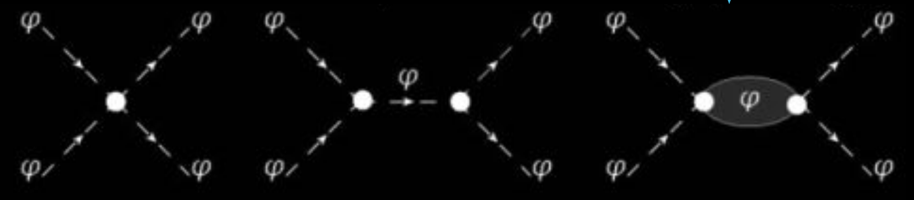
   Yes!..for on-shell Z couplings at rest (at LEP1). LEP never saw a Z with much boost (γ~1-1.2), LEP never probed the boosted kinematics of decays or the energy-dependent structure of the EW vertices.

3. How can we utilize the abundant number of Z bosons to probe new physics?

Effective Field Theories and SMEFT



"integrating out the UV degrees of freedom"



Things appear "simpler" from a distance = We can reduce the dof of a system with increasing L (decreasing E ~ L^{-1})

Consider a QFT with $\phi \rightarrow$ light, H $\rightarrow$ heavy particles:

$$Z_{UV}[J_\phi, J_H] = \int [D\phi][DH] \times exp[i \int d^4x(\mathcal{L}_{UV}(\phi, H) + J_\phi \phi + J_H H)]$$

$$Z_{EFT}[J_\phi] = Z_{UV}[J_\phi, 0]$$

$$Z_{EFT}[J_\phi] = \int [D\phi] \times exp[i \int d^4x(\mathcal{L}_{EFT}(\phi) + J_\phi \phi)]$$

<u>Scale Separation:</u> E$\ll$ Λ

$$\mathcal{L}_{EFT} \supset (\Box_\phi + M^2)^{-1} \approx M^{-2} - M^{-4}\Box_\phi$$

Effective Field Theories and SMEFT

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \frac{1}{\Lambda^3}\mathcal{L}_7 + \frac{1}{\Lambda^4}\mathcal{L}_8 + \ldots$$

$$\mathcal{L}_d = \sum_i C_i \mathcal{O}_i^{(d)}$$

$C_i =$ Wilson coefficients

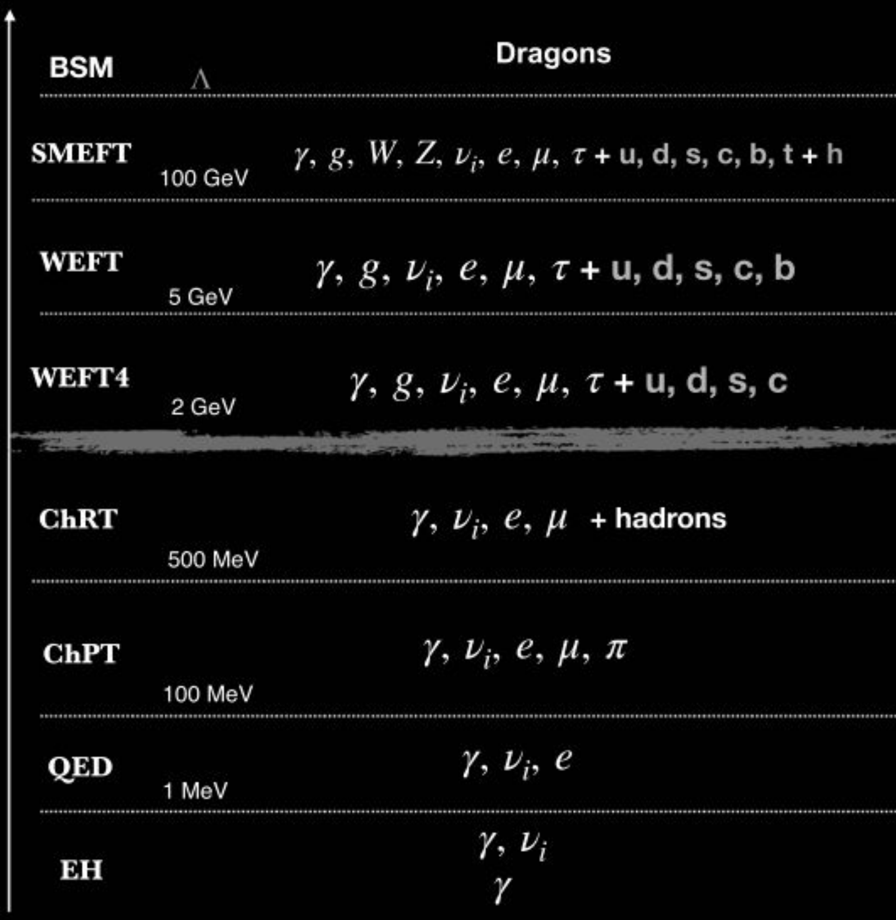
$\mathcal{O}_i^{(d)} =$ gauge-invariant operators forming a basis: a complete, non-redundant set

Key Assumptions:

- New physics is heavy: $100\text{ GeV} \lesssim E \lesssim \Lambda$, where $\Lambda \gg m_W$
- SM symmetries (SU(3)×SU(2)×U(1)) preserved

Power Counting: Expected size of BSM effects ~ (4+n) operator contributes effects of order $(E/\Lambda)^n$

EPJC:s10052-023-11821-3



Dimension-6 SMEFT Operators: Warsaw Basis

arXiv:1008.4884

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

$(\bar LL)(\bar LL)$		$(\bar RR)(\bar RR)$		$(\bar LL)(\bar RR)$	
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}	$(\bar e_p\gamma_\mu e_r)(\bar d_s\gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar q_p\gamma_\mu q_r)(\bar u_s\gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar u_p\gamma_\mu u_r)(\bar d_s\gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar q_p\gamma_\mu T^A q_r)(\bar u_s\gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar u_p\gamma_\mu T^A u_r)(\bar d_s\gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar q_p\gamma_\mu q_r)(\bar d_s\gamma^\mu d_t)$
				$Q_{qd}^{(8)}$	$(\bar q_p\gamma_\mu T^A q_r)(\bar d_s\gamma^\mu T^A d_t)$

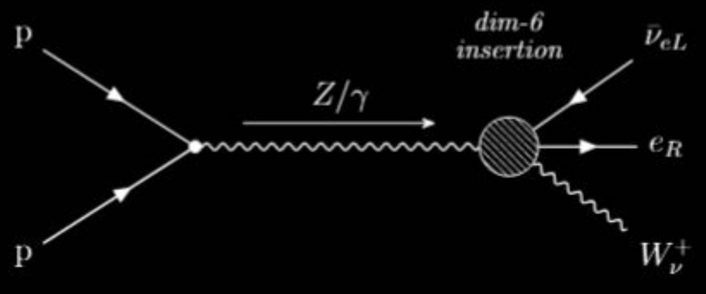
$(\bar LR)(\bar RL)$ and $(\bar LR)(\bar LR)$		B-violating	
Q_{ledq}	$(\bar l_p^j e_r)(\bar d_s q_t^j)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(q_s^{\gamma j})^T C l_t^k\right]$
$Q_{quqd}^{(1)}$	$(\bar q_p^j u_r)\varepsilon_{jk}(\bar q_s^k d_t)$	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}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\varepsilon_{mn}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(1)}$	$(\bar l_p^j e_r)\varepsilon_{jk}(\bar q_s^k u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{lequ}^{(3)}$	$(\bar l_p^j \sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar q_s^k \sigma^{\mu\nu} u_t)$		

Bottom-Up Approach: SMEFT operators cause deviations from SM predictions.

Given how precisely HL-LHC can measure Z decays, what new physics scale Λ can dimension-6 SMEFT operators probe?

Using Dimension-6 SMEFT Operators: O_{eW} Case Study

Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$



$$\mathcal{L} \supset \frac{c_{eW}}{\Lambda^2}\left(\left(\bar{l}_p\,\sigma^{\mu\nu} e_r\right)\tau^I H\, W^I_{\mu\nu}\right)$$

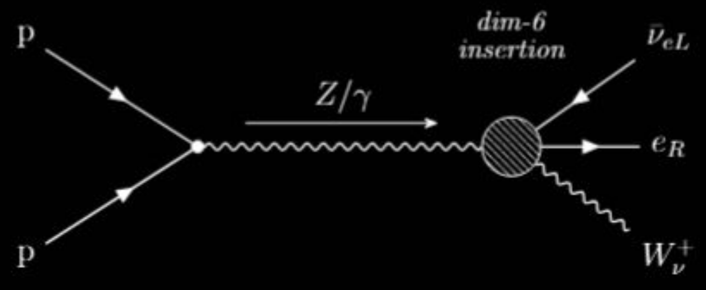
$$(\tau^I W^I_{\mu\nu})H = \begin{pmatrix} W^3_{\mu\nu} & \sqrt{2}\,W^+_{\mu\nu} \\ \sqrt{2}\,W^-_{\mu\nu} & -W^3_{\mu\nu} \end{pmatrix} \cdot \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v+h \end{pmatrix} = \frac{v+h}{\sqrt{2}}\begin{pmatrix} \sqrt{2}\,W^+_{\mu\nu} \\ -W^3_{\mu\nu} \end{pmatrix}$$

$$\bar{l}_p\left[(\tau^I W^I_{\mu\nu})H\right] = (\bar{\nu}_{eL},\ \bar{e}_L)\cdot \frac{v+h}{\sqrt{2}}\begin{pmatrix} \sqrt{2}\,W^+_{\mu\nu} \\ -W^3_{\mu\nu} \end{pmatrix} = (v+h)\,\bar{\nu}_{eL}\,W^+_{\mu\nu} - \frac{v+h}{\sqrt{2}}\,\bar{e}_L\,W^3_{\mu\nu}.$$

$$\boxed{\mathcal{O}_{eW} = (v+h)\,\bar{\nu}_{eL}\,\sigma^{\mu\nu} e_r\,W^+_{\mu\nu} - \frac{v+h}{\sqrt{2}}\,\bar{e}_L\,\sigma^{\mu\nu} e_r\,W^3_{\mu\nu} + \text{h.c.}}$$

Using Dimension-6 SMEFT Operators: O_{eW} Case Study

Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$



Using the electroweak mixing relation: $W^3_\mu = \cos\theta_W\, Z_\mu + \sin\theta_W\, A_\mu$,

$$W^+_{\mu\nu} = \hat{W}^+_{\mu\nu} - ig\cos\theta_W\left(Z_\mu W^+_\nu - Z_\nu W^+_\mu\right) - ig\sin\theta_W\left(A_\mu W^+_\nu - A_\nu W^+_\mu\right).$$

$$\mathcal{L} \supset \frac{c_{eW}}{\Lambda^2} \cdot v\,\bar{\nu}_{eL}\,\sigma^{\mu\nu} e_r \cdot \left[-ig\cos\theta_W\left(Z_\mu W^+_\nu - Z_\nu W^+_\mu\right)\right] + \text{h. c.}$$

Now use the antisymmetry $\sigma^{\mu\nu} = -\sigma^{\nu\mu}$: $\sigma^{\mu\nu}\left(Z_\mu W^+_\nu - Z_\nu W^+_\mu\right) = 2\,\sigma^{\mu\nu} Z_\mu W^+_\nu$.

$$\mathcal{L}_{ZW\nu e} = -\frac{2ig_W v\cos\theta_W}{\Lambda^2}\, c_{eW}\,\bar{\nu}_{eL}\,\sigma^{\mu\nu} e_r\, Z_\mu W^+_\nu \;+\; \text{h. c.}$$

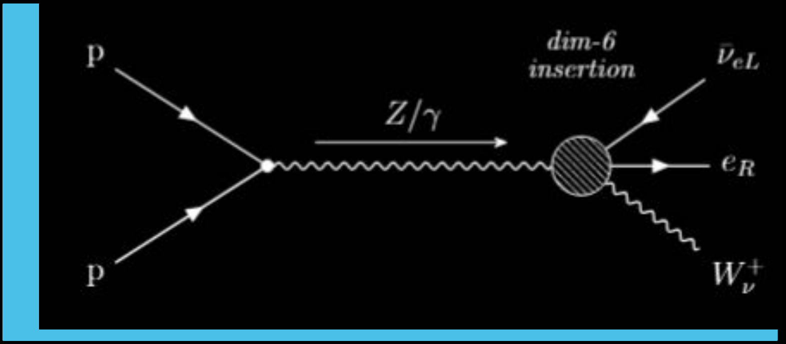
$$\mathcal{M}_{ZW\nu e} \sim \frac{c_{eW}}{\Lambda^2} \cdot \left(-2g_W v\cos\theta_W\right) \cdot \bar{u}(\nu_e)\,\sigma^{\mu\nu}\, v(e_R)\,\varepsilon_\mu(Z)\,\varepsilon_\nu(W^+)$$

$$W^+_{\mu\nu} = \underbrace{\partial_\mu W^+_\nu - \partial_\nu W^+_\mu}_{\hat{W}^+_{\mu\nu}} - ig\left(W^3_\mu W^+_\nu - W^3_\nu W^+_\mu\right)$$

Using Dimension-6 SMEFT Operators: O_{eW} Case Study

generic observable σ: $$\sigma = \int \left| \mathcal{M}_{\mathrm{SM}} + \frac{c_{eW}}{\Lambda^2} \mathcal{M}_{\mathrm{EFT}} \right|^2 d\Phi$$

$$= \underbrace{\int |\mathcal{M}_{\mathrm{SM}}|^2 \, d\Phi}_{\sigma_{\mathrm{SM}}} + \frac{c_{eW}}{\Lambda^2} \underbrace{\int 2\,\mathrm{Re}(\mathcal{M}^*_{\mathrm{SM}} \mathcal{M}_{\mathrm{EFT}}) \, d\Phi}_{\sigma_{\mathrm{int}}} + \frac{c^2_{eW}}{\Lambda^4} \underbrace{\int |\mathcal{M}_{\mathrm{EFT}}|^2 \, d\Phi}_{\sigma_{\mathrm{quad}}}.$$



What kinematic variables can we look at?

- Mainly invariant mass:
  - The two main leptons: e, μ
  - All outgoing particles: e, μ, ν_e, ν_μ

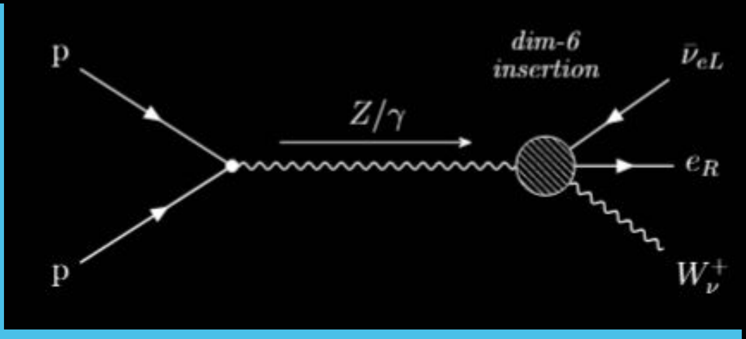
Name	Process	Feature(s)
WW	WW	Irreducible
Top quarks		
$t\bar{t}$	$t\bar{t} \to WbW\bar{b}$	Unidentified b-quarks
t	tW	Unidentified b-quark
	$t\bar{b}$, $tq\bar{b}$	q or b misidentified as ℓ; unidentified b-quarks
Misidentified leptons (Misid)		
Wj	$W+$jet(s)	j misidentified as ℓ
jj	Multijet production	jj misidentified as $\ell\ell$; misidentified neutrinos
Other dibosons		
VV	$W\gamma$	γ misidentified as e
	$W\gamma^*$, WZ, $ZZ \to \ell\ell\,\ell\ell$	Unidentified lepton(s)
	$ZZ \to \ell\ell\,\nu\nu$	Irreducible
	$Z\gamma$	γ misidentified as e; unidentified lepton
Drell-Yan (DY)		
$ee/\mu\mu$	$Z/\gamma^* \to ee,\ \mu\mu$	Misidentified neutrinos
$\tau\tau$	$Z/\gamma^* \to \tau\tau \to \ell\nu\nu\,\ell\nu\nu$	Irreducible

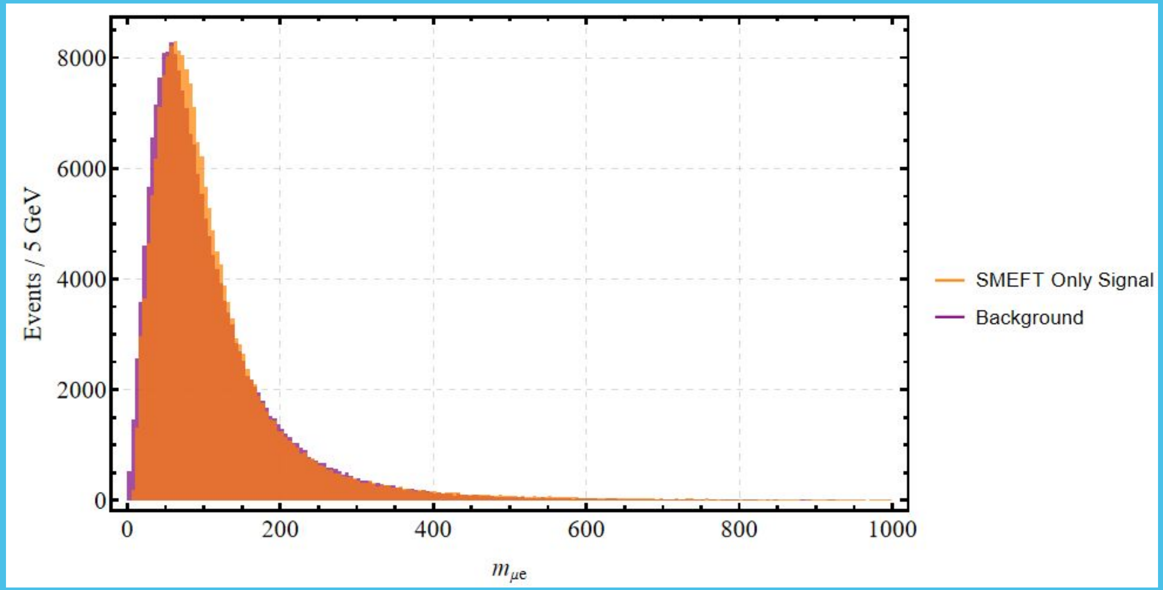
CERN-PH-EP-2014-270

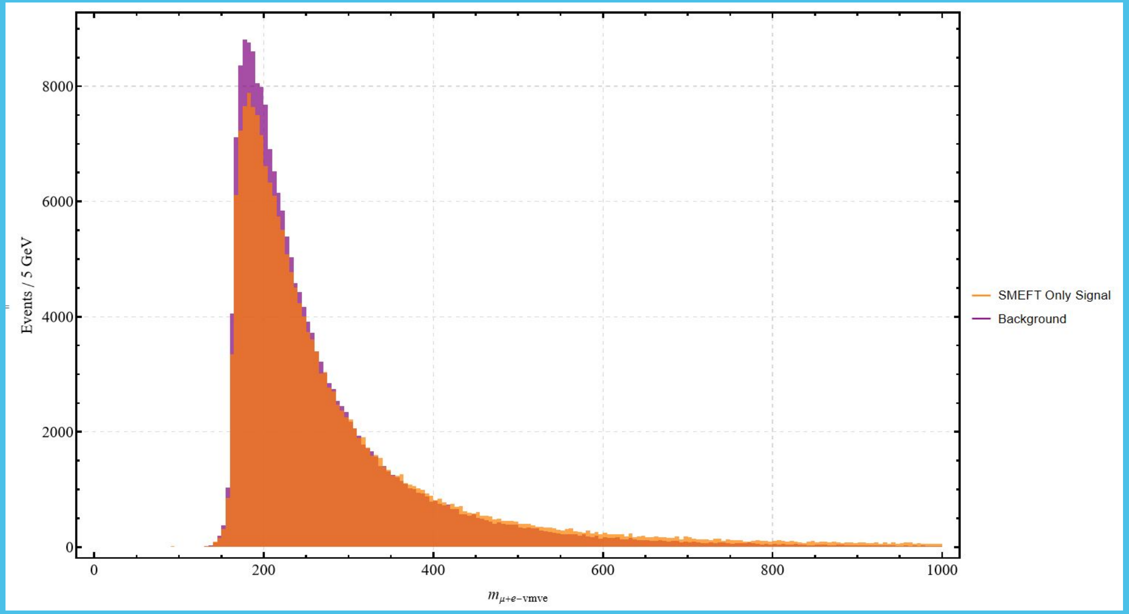
Using Dimension-6 SMEFT Operators: O_{eW} Case Study

$$\sigma = \int \left| \mathcal{M}_{\rm SM} + \frac{c_{eW}}{\Lambda^2}\mathcal{M}_{\rm EFT} \right|^2 d\Phi$$

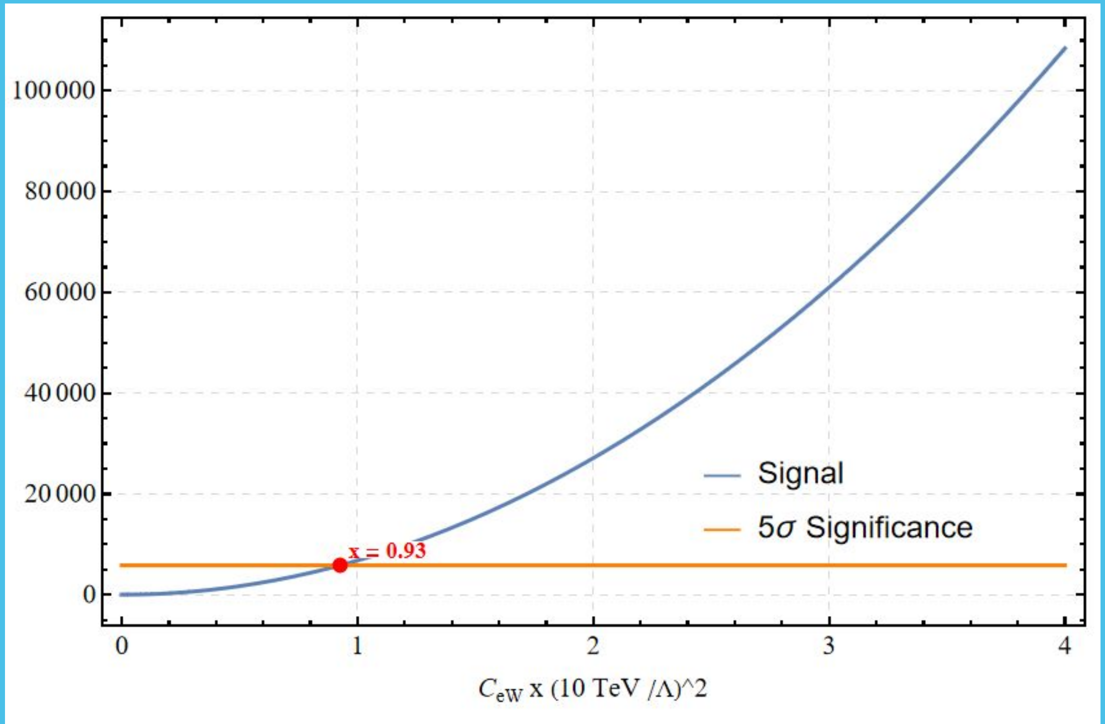
$$= \underbrace{\int |\mathcal{M}_{\rm SM}|^2 \, d\Phi}_{\sigma_{\rm SM}} + \frac{c_{eW}}{\Lambda^2} \underbrace{\int 2\,{\rm Re}(\mathcal{M}^*_{\rm SM}\mathcal{M}_{\rm EFT})\, d\Phi}_{\sigma_{\rm int}} + \frac{c_{eW}^2}{\Lambda^4} \underbrace{\int |\mathcal{M}_{\rm EFT}|^2 \, d\Phi}_{\sigma_{\rm quad}}.$$



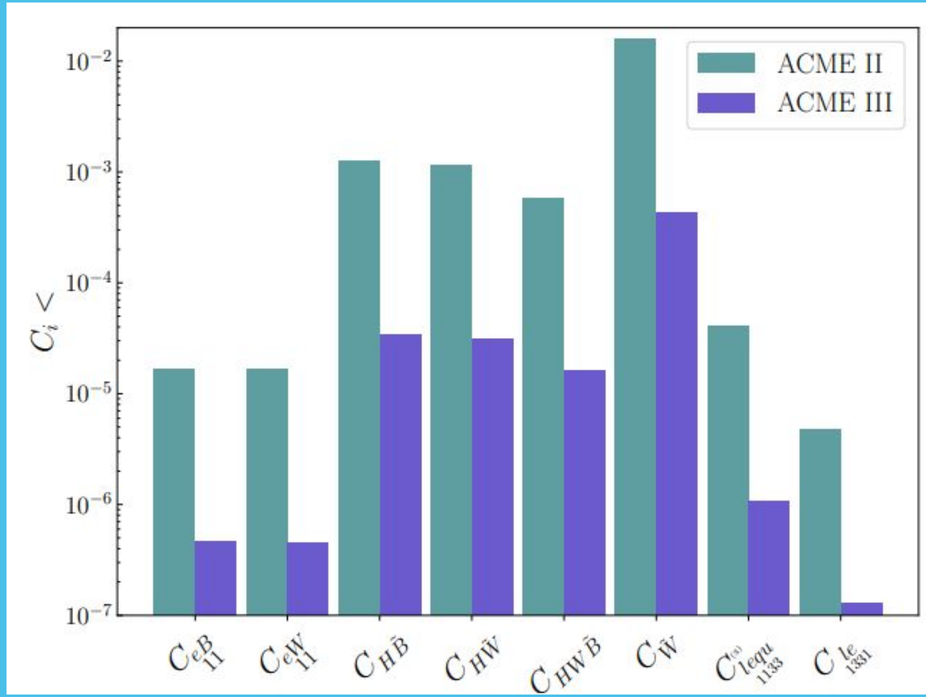




Using Dimension-6 SMEFT Operators: O_{eW} Case Study



arXiv:2109.15085



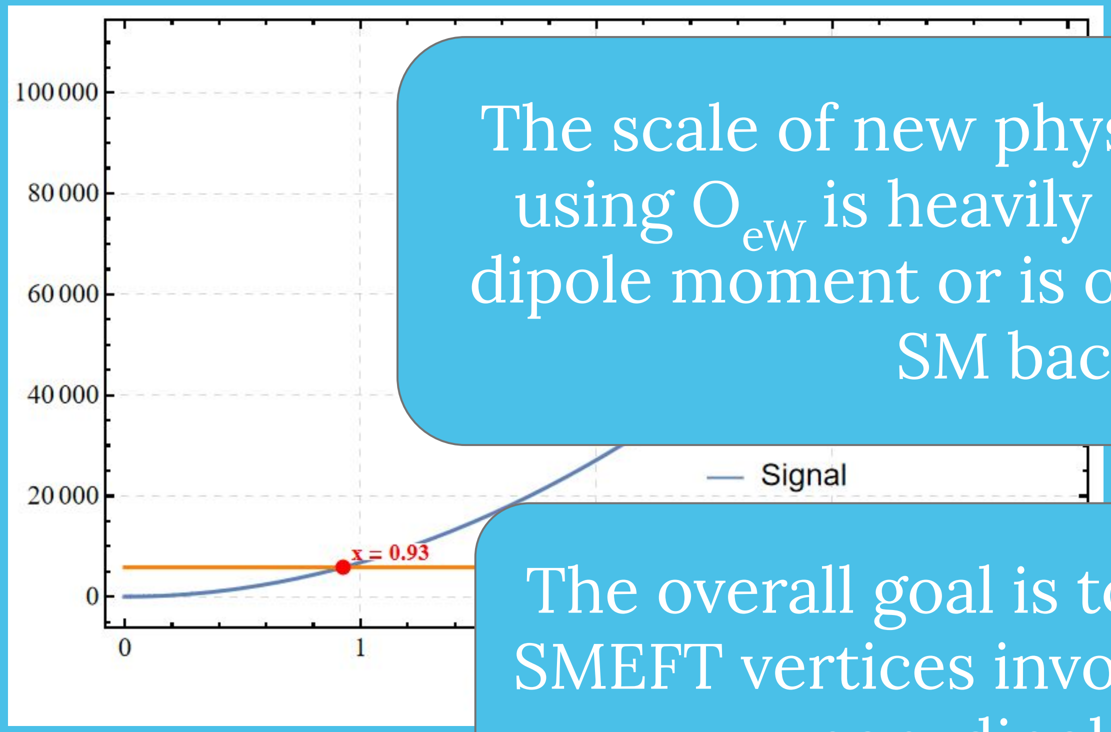
$$C_{eW} \times \left(\frac{(10\ \text{TeV})^2}{\Lambda^2} \right)^2 \sim 0.93$$

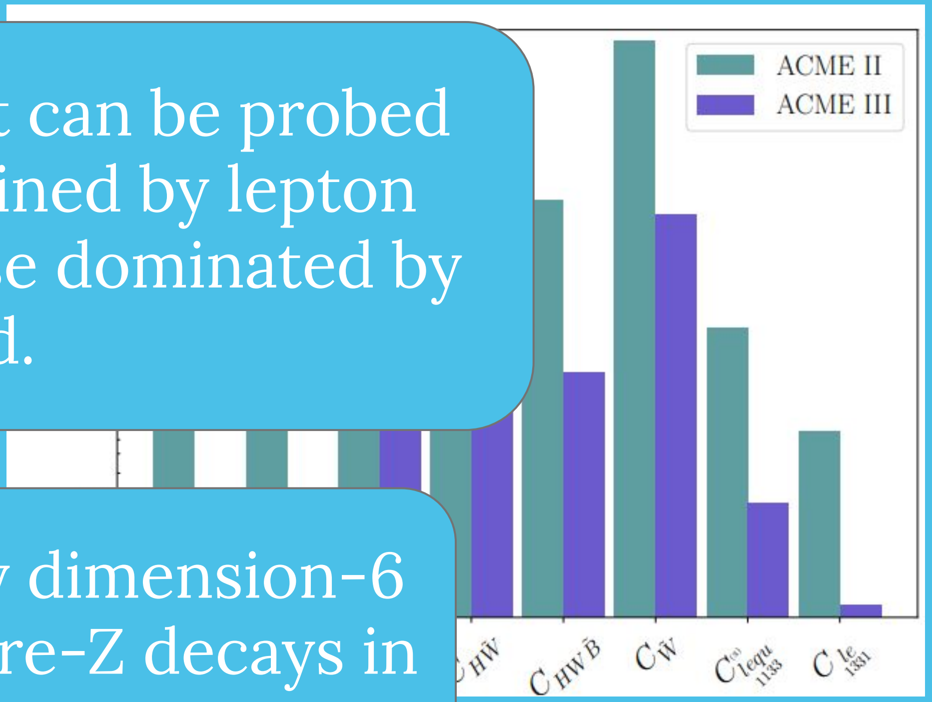
$$\Lambda_{proj} \sim 10.14\ \text{TeV for } C_{eW} = 1$$

From lepton EDM constraint: $C_{eW} \lesssim 2 \times 10^{-5}$ for $\Lambda = 5$ TeV,

$$\Lambda_{EDM} \sim 1118\ \text{TeV}$$

Using Dimension-6 SMEFT Operators: O_{eW} Case Study





The scale of new physics that can be probed using O_{eW} is heavily constrained by lepton dipole moment or is otherwise dominated by SM background.

The overall goal is to survey dimension-6 SMEFT vertices involving rare-Z decays in non-dipole operators.

$$C_{eW} \times \left(\frac{(1\ldots}{\Lambda^2} \right) \sim 0.93$$

$\Lambda_{proj} \sim 10.14$ TeV for $C_{eW} = 1$

From lepton EDM constraint: $C_{eW} \lesssim 2 \times 10^{-5}$,

$\Lambda_{EDM} \sim 1118$ TeV