Beyond the Standard Model with low-energy precision tests

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Beyond the SM

- Standard Model is very successful
 - At the LHC
 - Low-energy precision expts.



Beyond the SM











The SM Effective Field Theory

Describing BSM physics

Assumptions

- No new light degrees of freedom
- BSM physics appears above the electroweak scale, $\Lambda \gg v$

•
$$\mathscr{L} = \mathscr{L}_{SM} + \sum_{i} \frac{C_5^{(i)}}{\Lambda} O_5^{(i)} + \sum_{i} \frac{C_6^{(i)}}{\Lambda^2} O_6^{(i)} + \dots$$



The SM Effective Field Theory

Describing BSM physics

Dimension five operators

• One term, generates Majorana neutrino masses

 $\frac{g}{M_T} (\bar{L}^c \tilde{\phi}^*) (\tilde{\phi}^\dagger L)$

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Dimension-six operators

	X^3		φ^6 and $\varphi^4 D^2$			$\psi^2 \varphi^3$		
Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(\varphi^\dagger \varphi)^3$	Q_e	?φ	$(\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$		
$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	$Q_{\varphi \Box}$	$(\varphi^{\dagger}\varphi)\Box(\varphi^{\dagger}\varphi)$	Q_u	ıφ	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}u_{r}\widetilde{\varphi})$		
Q_W	$\varepsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^{\dagger}D^{\mu}\varphi\right)^{\star}\left(\varphi^{\dagger}D_{\mu}\varphi\right)$	Q_d	łφ	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}d_{r}\varphi)$		
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$							
	$X^2 \varphi^2$		$\psi^2 X \varphi$			$\psi^2 \varphi^2 D$		
$Q_{\varphi G}$	$\varphi^{\dagger}\varphiG^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi}^{(i)}$	1) 2l	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\overline{l}_{p}\gamma^{\mu}l_{r}$.)	
$Q_{\varphi \widetilde{G}}$	$\varphi^{\dagger}\varphi\widetilde{G}^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi}^{(i)}$	3) 2l	$(\varphi^{\dagger}i\overleftrightarrow{D}^{I}_{\mu}\varphi)(\bar{l}_{p}\tau^{I}\gamma^{\mu})$	$l_r)$	
$Q_{\varphi W}$	$\varphi^{\dagger}\varphiW^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{\varphi} G^A_{\mu\nu}$	Q_{φ}	pe	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{e}_{p}\gamma^{\mu}e_{r})$	r)	
$Q_{\varphi \widetilde{W}}$	$\varphi^{\dagger}\varphi \widetilde{W}^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \widetilde{\varphi} W^I_{\mu\nu}$	$Q_{\varphi}^{(i)}$	$p_{q}^{(1)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{q}_{p}\gamma^{\mu}q_{r}$.)	$(\bar{L}L)(\bar{R}R)$
$Q_{\varphi B}$	$\varphi^{\dagger}\varphi B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \widetilde{\varphi} B_{\mu\nu}$	$Q_{\varphi}^{(i)}$	$p_q^{(3)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}^{I}_{\mu}\varphi)(\bar{q}_{p}\tau^{I}\gamma^{\mu}e$	$q_r)$	$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$
$Q_{\varphi \widetilde{B}}$	$\varphi^{\dagger}\varphi\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G^A_{\mu\nu}$	Q_{φ}	ou	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}u_{p})$	r)	$(\bar{l}_p \gamma_\mu l_r)(\bar{u}_s \gamma^\mu u_t)$
$Q_{\varphi WB}$	$\varphi^{\dagger}\tau^{I}\varphiW^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W^I_{\mu\nu}$	Q_{φ}	ρd	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{d}_{p}\gamma^{\mu}d_{p})$	r)	$(\bar{l}_p \gamma_\mu l_r)(\bar{d}_s \gamma^\mu d_t)$
$Q_{\varphi \widetilde{W}B}$	$\varphi^{\dagger}\tau^{I}\varphi\widetilde{W}^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	Q_{φ}	rud	$i(\widetilde{\varphi}^{\dagger}D_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}d_{r}$.)	$(\bar{q}_p \gamma_\mu q_r)(\bar{e}_s \gamma^\mu e_t)$
		-		$O^{(1)}$	<u> </u>	$(\bar{u} \sim u)(\bar{d} \sim^{\mu} d_{i})$	$O^{(8)}$	$(q_p \gamma_\mu q_r)(u_s \gamma^\mu u_t)$ $(\bar{q} \gamma T^A q_s)(\bar{u} \gamma^\mu T^A u_t)$
				$Q_{ud}^{(8)}$	$\left \begin{array}{c} (\bar{u}_n) \end{array} \right $	$\gamma_{\mu}T^{A}u_{r})(\bar{d}_{s}\gamma^{\mu}T^{A}d_{t})$	$Q_{qd}^{(1)}$	$\frac{(q_p)_{\mu}(\bar{q}_r)(\bar{d}_s\gamma^{\mu}d_t)}{(\bar{q}_r\gamma_{\mu}q_r)(\bar{d}_s\gamma^{\mu}d_t)}$
				- uu		,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	$Q_{qd}^{(8)}$	$(\bar{q}_p \gamma_\mu T^A q_r) (\bar{d}_s \gamma^\mu T^A d_t)$
		$(\bar{L}R)$	$(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		<u>. </u>	<i>B</i> -viol	ating	·
		Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	Q_{duq}		$\varepsilon^{lphaeta\gamma}\varepsilon_{jk}\left[\left(d_{p}^{lpha} ight) ight]$	$^{T}Cu_{r}^{\beta}$	$\left[(q_s^{\gamma j})^T C l_t^k\right]$
		$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t)$	Q_{qqu}		$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[\left(q_{p}^{\alpha j}\right)\right.$	$^{T}Cq_{r}^{\beta k}$	$\begin{bmatrix} (u_s^{\gamma})^T C e_t \end{bmatrix}$
		$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	$Q_{qqq}^{(1)}$		$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\varepsilon_{mn}\left[\left(q_{p}^{\alpha j}\right)\right]$	$(j)^T C q_r^{\beta}$	$\begin{bmatrix} 3k \\ - \end{bmatrix} \left[(q_s^{\gamma m})^T C l_t^n \right]$
		$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{qqq}^{(3)}$	$\varepsilon^{\alpha\beta\gamma}(\tau^{I}\varepsilon)_{jk}(\tau^{I}\varepsilon)_{mn}\left[(q_{p}^{\alpha j})^{T}Cq_{r}^{\beta k}\right]\left[(q_{s}^{\gamma m})^{T}Cl_{t}^{m}\right]$			$\left[Cq_r^{\beta k}\right]\left[(q_s^{\gamma m})^T Cl_t^n\right]$
		$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	Q_{duu}		$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T\right]$	$Cu_r^\beta]$	$\left[(u_s^{\gamma})^T C e_t \right]$

Dimension five operatorsOne term, generates Majorana neutrino masses

 $\frac{g}{M_T} (\bar{L}^c \tilde{\phi}^*) (\tilde{\phi}^\dagger L)$

Dimension-six operators

- 59 of them
- (2499 including all flavor structures)

have to make some choice of operators...

		1					
	X^3		φ^6 and $\varphi^4 D^2$		$\psi^2 \varphi^3$		
Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(arphi^\dagger arphi)^3$	Q_{eq}	$\varphi \qquad (\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$		
$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	$Q_{\varphi \Box}$	$(\varphi^{\dagger}\varphi)\Box(\varphi^{\dagger}\varphi)$	Q_u	$\varphi \qquad (\varphi^{\dagger}\varphi)(\bar{q}_{p}u_{r}\widetilde{\varphi})$		
Q_W	$\varepsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^{\dagger}D^{\mu}\varphi\right)^{\star}\left(\varphi^{\dagger}D_{\mu}\varphi\right)$	Q_d	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}d_{r}\varphi)$		
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$						
	$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$		
$Q_{\varphi G}$	$\varphi^{\dagger}\varphiG^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi}^{(1)}$	$\stackrel{1)}{l} \qquad (\varphi^{\dagger} i \overleftrightarrow{D}_{\mu} \varphi) (\bar{l}_{p} \gamma^{\mu})$	$l_r)$	
$Q_{\varphi \widetilde{G}}$	$\varphi^{\dagger}\varphi\widetilde{G}^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi}^{(3)}$	$\stackrel{3)}{_{l}} \left[(\varphi^{\dagger} i \overleftrightarrow{D}_{\mu}^{I} \varphi) (\bar{l}_{p} \tau^{I} \gamma) \right]$	$^{\mu}l_{r})$	
$Q_{\varphi W}$	$\varphi^{\dagger}\varphiW^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{\varphi} G^A_{\mu\nu}$	Q_{φ}	$e \qquad (\varphi^{\dagger} i \overleftrightarrow{D}_{\mu} \varphi) (\bar{e}_{p} \gamma^{\mu})$	$e_r)$	
$Q_{\varphi \widetilde{W}}$	$\varphi^{\dagger}\varphi\widetilde{W}^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \widetilde{\varphi} W^I_{\mu\nu}$	$Q_{\varphi}^{(1)}$	$ (\varphi^{\dagger}i\overset{\text{l}}{D}_{\mu}\varphi)(\bar{q}_{p}\gamma^{\mu}) $	$q_r)$	$(\bar{L}L)(\bar{R}R)$
$Q_{\varphi B}$	$\varphi^{\dagger}\varphi B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \widetilde{\varphi} B_{\mu\nu}$	$Q_{\varphi}^{(3)}$	$\stackrel{3)}{[q]} \left[(\varphi^{\dagger} i \overleftrightarrow{D}^{I}_{\mu} \varphi) (\bar{q}_{p} \tau^{I} \gamma^{q}) \right]$	$^{\mu}q_r)$	$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$
$Q_{\varphi \widetilde{B}}$	$\varphi^{\dagger}\varphi\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G^A_{\mu\nu}$	Q_{φ}	$\omega_{\mu} \left[(\varphi^{\dagger} i \overleftrightarrow{D}_{\mu} \varphi) (\bar{u}_{p} \gamma^{\mu}) \right]$	u_r)	$(\bar{l}_p \gamma_\mu l_r)(\bar{u}_s \gamma^\mu u_t)$
$Q_{\varphi WB}$	$\varphi^{\dagger}\tau^{I}\varphiW^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W^I_{\mu\nu}$	Q_{φ}	$d_{pd} \left[(\varphi^{\dagger} i \overleftrightarrow{D}_{\mu} \varphi) (\overline{d}_{p} \gamma^{\mu}) \right]$	d_r)	$(l_p \gamma_\mu l_r)(d_s \gamma^\mu d_t)$
$Q_{\varphi \widetilde{W}B}$	$\varphi^{\dagger}\tau^{I}\varphi\widetilde{W}^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi \imath}$	$_{ud} \left[i(\widetilde{\varphi}^{\dagger} D_{\mu} \varphi)(\bar{u}_p \gamma^{\mu} e^{i \varphi}) \right]$	$d_r)$	$(q_p \gamma_\mu q_r)(e_s \gamma^\mu e_t)$ $(\bar{q} \gamma_\mu q_r)(\bar{q} \gamma^\mu q_t)$
		-		$Q_{ud}^{(1)}$	$(\bar{u}_n \gamma_\mu u_r) (\bar{d}_s \gamma^\mu d_t)$	$Q_{au}^{(8)}$	$\frac{(q_p + \mu q_r)(u_s + u_t)}{(\bar{q}_p \gamma_\mu T^A q_r)(\bar{u}_s \gamma^\mu T^A u_t)}$
				$Q_{ud}^{(8)}$	$(\bar{u}_p \gamma_\mu T^A u_r) (\bar{d}_s \gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$\frac{(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)}{(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)}$
						$Q_{qd}^{(8)}$	$(\bar{q}_p \gamma_\mu T^A q_r) (\bar{d}_s \gamma^\mu T^A d_t)$
		$(\bar{L}R)$	$(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		<i>B</i> -vio	olating	
		Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	Q_{duq}	$\varepsilon^{lphaeta\gamma}\varepsilon_{jk}\left[\left(d_{p}^{a}\right)$	Cu_r^{β}	$\left[(q_s^{\gamma j})^T C l_t^k\right]$
		$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[\left(q_{p}^{\alpha}\right)\right]$	$^{j})^{T}Cq_{r}^{\beta k}$	$\left[(u_s^{\gamma})^T C e_t \right]$
		$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	$Q_{qqq}^{(1)}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\varepsilon_{mn}\left[\left(q\right)\right]$	$(a_p^{\alpha j})^T C q_r^{\beta}$	$\left[(q_s^{\gamma m})^T C l_t^n \right]$
		$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{qqq}^{(3)}$	$\varepsilon^{lphaeta\gamma}(\tau^I\varepsilon)_{jk}(\tau^I\varepsilon)_{mr}$	$\left[(q_p^{\alpha j})^T\right]$	$\left[Cq_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
		$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	Q_{duu}	$\varepsilon^{lphaeta\gamma}\left[\left(d_{p}^{lpha} ight) ight.$	$^{T}Cu_{r}^{\beta}$	$\left[(u_s^{\gamma})^T C e_t \right]$

Dimension five operators • One term, generates Majorana neutrino masses

 $\frac{g}{M_T} (\bar{L}^c \tilde{\phi}^*) (\tilde{\phi}^\dagger L)$

 $Q_{lequ}^{(3)} | (\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t) | Q_{duu} |$

Dimension-six operators		X^3		φ^6 and $\varphi^4 D^2$		$\psi^2 arphi^3$	
•	Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(\varphi^{\dagger}\varphi)^{3}$	$Q_{e\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$	
	$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	$Q_{\varphi\Box}$	$(\varphi^{\dagger}\varphi)\Box(\varphi^{\dagger}\varphi)$	$Q_{u\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}u_{r}\widetilde{\varphi})$	
• EQ of thom	Q_W	$\varepsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left \left(\varphi^{\dagger} D^{\mu} \varphi \right)^{\star} \left(\varphi^{\dagger} D_{\mu} \varphi \right) \right $	$Q_{d\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}d_{r}\varphi)$	
• 59 of them	$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$					
 (2499 including all flavor structures) 		$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$	
	$Q_{\varphi G}$	$\varphi^{\dagger}\varphiG^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi l}^{(1)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{l}_{p}\gamma^{\mu}l_{r})$	
have to make some choice of energtors	$Q_{\varphi \widetilde{G}}$	$\varphi^{\dagger}\varphi\widetilde{G}^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$\left[(\varphi^{\dagger} i \overleftrightarrow{D}_{\mu}^{I} \varphi) (\bar{l}_{p} \tau^{I} \gamma^{\mu} l_{r}) \right]$	
have to make some choice of operators	$Q_{\varphi W}$	$\varphi^{\dagger}\varphiW^{I}_{\mu\nu}W^{I\mu\nu}$	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}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \widetilde{\varphi} W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{q}_{p}\gamma^{\mu}q_{r})$	$(\bar{L}L)(\bar{R}R)$
	$Q_{\varphi B}$	$\varphi^{\dagger}\varphi B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \widetilde{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$\left[(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{q}_{p}\tau^{I}\gamma^{\mu}q_{r})\right]$	$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$
	$Q_{\varphi \widetilde{B}}$	$\varphi^{\dagger}\varphi\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}u_{r})$	$(\bar{l}_p \gamma_\mu l_r)(\bar{u}_s \gamma^\mu u_t)$
What to base this choice on?	$Q_{\varphi WB}$	$\varphi^{\dagger}\tau^{I}\varphiW^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{d}_{p}\gamma^{\mu}d_{r})$	$(l_p \gamma_\mu l_r)(d_s \gamma^\mu d_t)$
	$Q_{\varphi \widetilde{W}B}$	$\varphi^{\dagger}\tau^{I}\varphi\widetilde{W}^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^{\dagger}D_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}d_{r})$	$(q_p \gamma_\mu q_r)(e_s \gamma^\mu e_t)$ $(\bar{q}_r \gamma_\mu q_r)(\bar{u}_r \gamma^\mu u_t)$
			-		$Q_{ud}^{(1)}$	$(\bar{u}_p \gamma_\mu u_r) (\bar{d}_s \gamma^\mu d_t)$	$\frac{1}{2} \frac{(q_p \gamma_\mu q_r)(\omega_s \gamma^\mu u_l)}{(\bar{q}_p \gamma_\mu T^A q_r)(\bar{u}_s \gamma^\mu T^A u_l)}$
• UV model					$Q_{ud}^{(8)}$ ($\bar{\imath}$	$\bar{u}_p \gamma_\mu T^A u_r) (\bar{d}_s \gamma^\mu T^A d_t) $	$Q_{qd}^{(1)} \qquad (\bar{q}_p \gamma_\mu q_r) (\bar{d}_s \gamma^\mu d_t)$
Flavor symmetries						, c	$Q_{qd}^{(8)} \left[(\bar{q}_p \gamma_\mu T^A q_r) (\bar{d}_s \gamma^\mu T^A d_t \right]$
• The observables of interest			$(\bar{L}R)$	$(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	1	B-violat:	ng
• The observables of interest			Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^{\alpha})^T C\right]$	$\left[(q_s^{\gamma j})^T C l_t^k \right]$
			$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T (q_p^{\alpha j})^T$	$Cq_r^{\beta k}] \left[(u_s^{\gamma})^T Ce_t \right]$
			$Q_{quqd}^{(0)}$	$\left \begin{array}{c} (\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t) \\ (\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^j T^A d_t) \end{array} \right $	$Q_{qqq}^{(1)}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\varepsilon_{mn}\left[(q_p^{\alpha j})^T\right]$	$\begin{bmatrix} Cq_r^{\beta\kappa} \end{bmatrix} \begin{bmatrix} (q_s^{\gamma m})^T Cl_t^n \end{bmatrix}$
			$Q_{lequ}^{(1)}$	$(l_p^j e_r) \varepsilon_{jk} (\bar{q}_s^{\kappa} u_t)$	$Q_{qqq}^{(0)}$	$\varepsilon^{\alpha\rho\gamma}(\tau^{I}\varepsilon)_{jk}(\tau^{I}\varepsilon)_{mn}\left[\left(q\right)\right]$	$\sum_{p}^{\alpha j} \left[(q_s^{\gamma m})^T C l_t^n \right]$
			$ Q_{leau}^{(0)}$	$\left[(l_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^\kappa \sigma^{\mu\nu} u_t) \right]$	Q_{duu}	$\varepsilon^{\alpha\rho\gamma} (d^{\alpha}_{p})^{T} C_{\gamma}$	$ u_r^{\rho} (u_s^{\gamma})^{I} Ce_t $

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Dimension-six operators		X^3		φ^6 and $\varphi^4 D^2$		$\psi^2 arphi^3$	
	Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(\varphi^{\dagger}\varphi)^{3}$	$Q_{e\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$	
	$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	$Q_{\varphi \Box}$	$(\varphi^{\dagger}\varphi)\Box(\varphi^{\dagger}\varphi)$	$Q_{u\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}u_{r}\widetilde{\varphi})$	
• 50 of thom	Q_W	$\varepsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^{\dagger}D^{\mu}\varphi\right)^{\star}\left(\varphi^{\dagger}D_{\mu}\varphi\right)$	$Q_{d\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}d_{r}\varphi)$	
	$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$					
 (2499 including all flavor structures) 		$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$	
	$Q_{\varphi G}$	$\varphi^{\dagger}\varphiG^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi l}^{(1)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{l}_{p}\gamma^{\mu}l_{r})$	
have to make come chaics of energy	$Q_{\varphi \widetilde{G}}$	$\varphi^{\dagger}\varphi\widetilde{G}^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$\left(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})\right)$	
nave to make some choice of operators	$Q_{\varphi W}$	$\varphi^{\dagger}\varphiW^{I}_{\mu\nu}W^{I\mu\nu}$	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}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \widetilde{\varphi} W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{q}_{p}\gamma^{\mu}q_{r})$	$(\bar{L}L)(\bar{R}R)$
	$Q_{\varphi B}$	$\varphi^{\dagger}\varphiB_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \widetilde{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$\left(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{q}_{p}\tau^{I}\gamma^{\mu}q_{r})\right)$	$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$
	$Q_{\varphi \widetilde{B}}$	$\varphi^{\dagger}\varphi\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}u_{r})$	$(\bar{l}_p \gamma_\mu l_r)(\bar{u}_s \gamma^\mu u_t)$
What to base this choice on?	$Q_{\varphi WB}$	$\varphi^{\dagger}\tau^{I}\varphiW^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{d}_{p}\gamma^{\mu}d_{r})$	$(l_p \gamma_\mu l_r)(d_s \gamma^\mu d_t)$
	$Q_{\varphi \widetilde{W}B}$	$\varphi^{\dagger}\tau^{I}\varphi\widetilde{W}^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^{\dagger}D_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}d_{r})$	$(q_p \gamma_\mu q_r)(e_s \gamma^\mu e_t)$ $(\bar{q}_r \gamma_\mu q_r)(\bar{u}_r \gamma^\mu u_t)$
			-		$Q_{ud}^{(1)}$	$(\bar{u}_p \gamma_\mu u_r) (\bar{d}_s \gamma^\mu d_t) \qquad Q^{(\bar{u}_s \gamma^\mu d_t)}$	$\frac{(q_p \gamma_{\mu} q_r)(\bar{u}_s \gamma^{\mu} \bar{u}_l)}{(\bar{q}_p \gamma_{\mu} T^A q_r)(\bar{u}_s \gamma^{\mu} T^A u_l)}$
• UV model					$Q_{ud}^{(8)}$ (i	$\bar{u}_p \gamma_\mu T^A u_r) (\bar{d}_s \gamma^\mu T^A d_t) \parallel Q^0$	$ \begin{array}{c} {}^{(1)}_{qd} \\ (\bar{q}_p \gamma_\mu q_r) (\bar{d}_s \gamma^\mu d_t) \end{array} $
Flavor symmetries						Q	$\stackrel{(8)}{_{qd}} \left[(\bar{q}_p \gamma_\mu T^A q_r) (\bar{d}_s \gamma^\mu T^A d_t \right]$
• The observables of interest			$(\bar{L}R)$	$(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		<i>B</i> -violatir	ng
• The observables of Interest			Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^{\alpha})^T C\right]$	$u_r^\beta \right] \left[(q_s^{\gamma j})^T C l_t^k \right]$
			$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T C\right]$	$\left[(q_r^{\beta k})^T C e_t \right]$
			$Q_{quqd}^{(8)}$	$\left \begin{array}{c} (\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t) \\ \end{array} \right $	$Q_{qqq}^{(1)}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\varepsilon_{mn}\left\lfloor (q_p^{\alpha j})^T (q_p^{$	$Cq_r^{\beta k} \left[\left[(q_s^{\gamma m})^T Cl_t^n \right] \right]$
			$Q_{lequ}^{(1)}$	$(l_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{qqq}^{(3)}$	$\varepsilon^{\alpha\beta\gamma}(\tau^{I}\varepsilon)_{jk}(\tau^{I}\varepsilon)_{mn} \left[(q_{p}^{\alpha}$	$\begin{bmatrix} \alpha g \\ \beta \end{bmatrix}^T C q_r^{\beta k} \end{bmatrix} \begin{bmatrix} (q_s^{\gamma m})^T C l_t^n \end{bmatrix}$
			$Q_{leau}^{(3)}$	$\left[(l_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^{\kappa} \sigma^{\mu\nu} u_t) \right]$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma} (d^{\alpha}_{p})^{T} C u \rangle$	$ p_r^{\rho} (u_s^{\gamma})^T Ce_t $

- Low energy measurements
 - Neutron/nuclear β decay
 - $K \to (\pi) \ell \nu, \pi \to (\pi) \ell \nu$



 n, K, π

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 - Neutron/nuclear β decay
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- Electroweak precision
 - Measurements at the Z pole
 - $e^+e^- \to Z \to \bar{f}f$

 p, K, π

e, *µ*

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- Low energy measurements
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- Both types involve high precision measurements
 - High relative precision $\leq \mathcal{O}(10^{-3})$
 - Probe high BSM scales, $\Lambda \simeq \sqrt{10^3} v = \mathcal{O}(10 \,\mathrm{TeV})$

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			X^3		φ^6 and $\varphi^4 D^2$	$\psi^2 arphi^3$		
	$(\bar{L}L)(\bar{L}L)$	Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(arphi^\dagger arphi)^3$	$Q_{e\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$	
Q_{ll}	$(\bar{l}_p \gamma_\mu l_r) (\bar{l}_s \gamma^\mu l_t)$	$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	$Q_{\varphi \Box}$	$(\varphi^{\dagger}\varphi)\Box(\varphi^{\dagger}\varphi)$	$Q_{u\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}u_{r}\widetilde{\varphi})$	
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	Q_W	$\varepsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^{\dagger}D^{\mu}\varphi\right)^{\star}\left(\varphi^{\dagger}D_{\mu}\varphi\right)$	$Q_{d\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}d_{r}\varphi)$	
$Q_{qq}^{(3)}$ $Q_{1}^{(1)}$	$\frac{(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)}{(\bar{l}_r \gamma_r l_r)(\bar{q}_r \gamma^\mu q_t)}$	$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$					
$Q_{la}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r) (\bar{q}_s \gamma^\mu \tau^I q_t)$		$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$	
		$Q_{\varphi G}$	$\varphi^{\dagger}\varphiG^{A}_{\mu\nu}G^{A\mu\nu}$	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}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$	
		$Q_{\varphi W}$	$\varphi^{\dagger}\varphiW^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{\varphi} G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{e}_{p}\gamma^{\mu}e_{r})$	
$(\bar{L}R)$	$(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	$Q_{\varphi \widetilde{W}}$	$\varphi^{\dagger}\varphi\widetilde{W}^{I}_{\mu\nu}W^{I\mu\nu}$	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_{ledq}	$(l_p^j e_r)(d_s q_t^j)$	$Q_{\varphi B}$	$\varphi^{\dagger}\varphi B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \widetilde{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}^{I}_{\mu}\varphi)(\bar{q}_{p}\tau^{I}\gamma^{\mu}q_{r})$	
$Q_{quqd}^{(8)}$	$(q_p^j u_r) \varepsilon_{jk}(q_s^* d_t) \\ (\bar{a}^j T^A u_r) \varepsilon_{ik}(\bar{a}^k T^A d_t)$	$Q_{\varphi \widetilde{B}}$	$\varphi^{\dagger}\varphi\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}u_{r})$	
$Q_{lequ}^{(1)}$	$\frac{(q_p - u_r) \varepsilon_{jk}(q_s - u_t)}{(\bar{l}_p^j e_r) \varepsilon_{jk}(\bar{q}_s^k u_t)}$	$Q_{\varphi WB}$	$\varphi^{\dagger}\tau^{I}\varphiW^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{d}_{p}\gamma^{\mu}d_{r})$	
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	$Q_{\varphi \widetilde{W}B}$	$\varphi^{\dagger}\tau^{I}\varphi\widetilde{W}^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^{\dagger}D_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}d_{r})$	

• Low energy measurements

- Described by effective 4-fermion interactions in LEFT (Lee-Yang theory)
- Affected by *charged* currents

 $\mathcal{L}_{LEFT} \sim G_F \epsilon_\Gamma (\bar{u} \Gamma d) (\bar{\ell} \Gamma \nu_\ell)$



				X^3		φ^6 and $\varphi^4 D^2$		$\psi^2 \varphi^3$
		$(\bar{L}L)(\bar{L}L)$	Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(arphi^\dagger arphi)^3$	$Q_{e\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$
	Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	$Q_{\varphi \Box}$	$(\varphi^{\dagger}\varphi)\Box(\varphi^{\dagger}\varphi)$	$Q_{u\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}u_{r}\widetilde{\varphi})$
	$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	Q_W	$\varepsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^{\dagger}D^{\mu}\varphi\right)^{\star}\left(\varphi^{\dagger}D_{\mu}\varphi\right)$	$Q_{d\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}d_{r}\varphi)$
	$\begin{array}{c} Q_{qq}^{(3)} \\ Q_{qq}^{(1)} \end{array}$	$ \begin{array}{c} (\bar{q}_p \gamma_\mu \tau^I q_r) (\bar{q}_s \gamma^\mu \tau^I q_t) \\ (\bar{l}_r \gamma_r l_r) (\bar{q}_r \gamma^\mu q_t) \end{array} $	$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$				
	$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r) (\bar{q}_s \gamma^\mu \tau^I q_t)$		$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$
			$Q_{\varphi G}$	$\varphi^{\dagger}\varphiG^{A}_{\mu\nu}G^{A\mu\nu}$	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}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$
			$Q_{\varphi W}$	$\varphi^{\dagger}\varphiW^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{\varphi} G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{e}_{p}\gamma^{\mu}e_{r})$
	$(\bar{L}R)$	$(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	$Q_{\varphi \widetilde{W}}$	$\varphi^{\dagger}\varphi\widetilde{W}^{I}_{\mu u}W^{I\mu u}$	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_{ledq}	$\begin{pmatrix} (l_p^j e_r)(d_s q_t^j) \\ (-i) & (-k, l) \end{pmatrix}$	$Q_{\varphi B}$	$\varphi^{\dagger}\varphi B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \widetilde{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{q}_{p}\tau^{I}\gamma^{\mu}q_{r})$
	$Q_{quqd}^{(8)}$ $Q_{quqd}^{(8)}$	$(q_p^{\prime}u_r)\varepsilon_{jk}(q_s^{\prime\prime}d_t)$ $(\bar{q}_s^{\prime}T^A u_r)\varepsilon_{ik}(\bar{q}_s^kT^A d_t)$	$Q_{\varphi \widetilde{B}}$	$\varphi^{\dagger}\varphi\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}u_{r})$
($Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk}(\bar{q}_s^k u_t)$	$Q_{\varphi WB}$	$\varphi^{\dagger}\tau^{I}\varphiW^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{d}_{p}\gamma^{\mu}d_{r})$
	$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	$Q_{\varphi \widetilde{W}B}$	$\varphi^{\dagger}\tau^{I}\varphi\widetilde{W}^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^{\dagger}D_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}d_{r})$

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			X^3		φ^6 and $\varphi^4 D^2$		$\psi^2 arphi^3$
	$(\bar{L}L)(\bar{L}L)$	Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(arphi^\dagger arphi)^3$	$Q_{e\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$
Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	$Q_{\varphi\Box}$	$(\varphi^{\dagger}\varphi)\Box(\varphi^{\dagger}\varphi)$	$Q_{u\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}u_{r}\widetilde{\varphi})$
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	Q_W	$\varepsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^{\dagger}D^{\mu}\varphi\right)^{\star}\left(\varphi^{\dagger}D_{\mu}\varphi\right)$	$Q_{d\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}d_{r}\varphi)$
$\begin{array}{c} Q_{qq}^{(3)} \\ Q_{1}^{(1)} \end{array}$	$\frac{(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)}{(\bar{l}_r \gamma_r l_r)(\bar{q}_s \gamma^\mu q_t)}$	$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$				
$Q_{lq}^{(3)}$	$\frac{(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)}{(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)}$		$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$
		$Q_{\varphi G}$	$\varphi^{\dagger}\varphiG^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi l}^{(1)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\overline{l}_{p}\gamma^{\mu}l_{r})$
		$Q_{\varphi \widetilde{G}}$	$\varphi^{\dagger}\varphi\widetilde{G}^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$
		$Q_{\varphi W}$	$\varphi^{\dagger}\varphiW^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{\varphi} G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{e}_{p}\gamma^{\mu}e_{r})$
$(\bar{L}R)$	$(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	$Q_{\varphi \widetilde{W}}$	$\varphi^{\dagger}\varphi\widetilde{W}^{I}_{\mu\nu}W^{I\mu\nu}$	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_{ledq}	$\begin{pmatrix} (l_p^j e_r)(d_s q_t^j) \\ (-i) & (-k, l) \end{pmatrix}$	$Q_{\varphi B}$	$\varphi^{\dagger}\varphi B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \widetilde{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{q}_{p}\tau^{I}\gamma^{\mu}q_{r})$
$Q_{quqd}^{(8)}$	$(q_p^j u_r) \varepsilon_{jk} (q_s^{\wedge} d_t) (\bar{q}_s^j T^A u_r) \varepsilon_{ik} (\bar{q}_s^{\wedge} T^A d_t)$	$Q_{\varphi \widetilde{B}}$	$\varphi^{\dagger}\varphi\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi) (\bar{u}_p \gamma^\mu u_r)$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk}(\bar{q}_s^k u_t)$	$Q_{\varphi WB}$	$\varphi^{\dagger}\tau^{I}\varphiW^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{d}_{p}\gamma^{\mu}d_{r})$
$Q_{leau}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	$Q_{\omega \widetilde{W}B}$	$\varphi^{\dagger} \tau^{I} \varphi \widetilde{W}^{I}_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^{\dagger}D_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}d_{r})$



		X^3	φ^6 and $\varphi^4 D^2$			$\psi^2 arphi^3$
$(\bar{L}L)(\bar{L}L)$	Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(arphi^\dagger arphi)^3$	$Q_{e\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$
$Q_{ll} \qquad (\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	$Q_{\tilde{G}}$	$f^{ABC} \widetilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	$Q_{\varphi\Box}$	$(\varphi^{\dagger}\varphi)\Box(\varphi^{\dagger}\varphi)$	$Q_{u\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}u_{r}\widetilde{\varphi})$
$Q_{qq}^{(1)} \qquad (\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	Q_W	$\varepsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^{\dagger}D^{\mu}\varphi\right)^{\star}\left(\varphi^{\dagger}D_{\mu}\varphi\right)$	$Q_{d\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}d_{r}\varphi)$
$\begin{array}{c c} Q_{qq}^{(3)} & (\bar{q}_p \gamma_\mu \tau^I q_r) (\bar{q}_s \gamma^\mu \tau^I q_t) \\ Q_t^{(1)} & (\bar{l}_r \gamma_r l_r) (\bar{q}_s \gamma^\mu q_t) \end{array}$	$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$				
$Q_{lg}^{(3)} (\bar{l}_p \gamma_\mu \tau^I l_r) (\bar{q}_s \gamma^\mu \tau^I q_t)$		$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$
	$Q_{\varphi G}$	$\varphi^{\dagger}\varphiG^{A}_{\mu\nu}G^{A\mu\nu}$	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}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$
	$Q_{\varphi W}$	$\varphi^{\dagger}\varphiW^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{\varphi} G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{e}_{p}\gamma^{\mu}e_{r})$
$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	$Q_{\varphi \widetilde{W}}$	$\varphi^{\dagger}\varphi\widetilde{W}^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \widetilde{\varphi} W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{q}_{p}\gamma^{\mu}q_{r})$
$Q_{ledq} \qquad (l_p^j e_r)(d_s q_t^j)$ $Q^{(1)} \qquad (=i_p)_{t=1} (=k_p)_{t=1} (=k_p)_{t$	$Q_{\varphi B}$	$\varphi^{\dagger}\varphi B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \widetilde{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{q}_{p}\tau^{I}\gamma^{\mu}q_{r})$
$ \begin{array}{c c} Q_{quqd}^{(8)} & (q_p^{(a)}u_r)\varepsilon_{jk}(q_s^{(a)}d_t) \\ Q_{rudd}^{(8)} & (\bar{q}_s^{(a)}T^Au_r)\varepsilon_{ik}(\bar{q}_s^{(k)}T^Ad_t) \end{array} $	$Q_{\varphi \widetilde{B}}$	$\varphi^{\dagger}\varphi\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu u} T^A d_r) \varphi G^A_{\mu u}$	$Q_{\varphi u}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}u_{r})$
$Q_{lequ}^{(1)} \qquad (\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{\varphi WB}$	$\varphi^{\dagger}\tau^{I}\varphiW^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{d}_{p}\gamma^{\mu}d_{r})$
$Q_{lequ}^{(3)}$ $(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	$Q_{\omega \widetilde{W}B}$	$\varphi^{\dagger} \tau^{I} \varphi \widetilde{W}^{I}_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^{\dagger}D_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}d_{r})$



			X^3		φ^6 and $\varphi^4 D^2$		$\psi^2 \varphi^3$
	$(\bar{L}L)(\bar{L}L)$	Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(\varphi^\dagger \varphi)^3$	$Q_{e\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$
	$Q_{ll} \qquad (\bar{l}_p \gamma_\mu l_r) (\bar{l}_s \gamma^\mu l_t)$	$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	$Q_{\varphi\Box}$	$(\varphi^{\dagger}\varphi)\Box(\varphi^{\dagger}\varphi)$	$Q_{u\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}u_{r}\widetilde{\varphi})$
	$Q_{qq}^{(1)} \qquad (\bar{q}_p \gamma_\mu q_r) (\bar{q}_s \gamma^\mu q_t)$	Q_W	$\varepsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^{\dagger}D^{\mu}\varphi\right)^{\star}\left(\varphi^{\dagger}D_{\mu}\varphi\right)$	$Q_{d\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}d_{r}\varphi)$
	$\begin{bmatrix} Q_{qq}^{(3)} & (\bar{q}_p \gamma_\mu \tau^I q_r) (\bar{q}_s \gamma^\mu \tau^I q_t) \\ Q_t^{(1)} & (\bar{l}_z \gamma_z l_z) (\bar{q}_z \gamma^\mu q_t) \end{bmatrix}$	$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$				
($Q_{lq}^{(3)} = (\bar{l}_p \gamma_\mu \tau^I l_r) (\bar{q}_s \gamma^\mu \tau^I q_t)$		$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$
		$Q_{\varphi G}$	$\varphi^{\dagger}\varphiG^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi l}^{(1)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\overline{l}_{p}\gamma^{\mu}l_{r})$
		$Q_{\varphi \widetilde{G}}$	$\varphi^{\dagger}\varphi\widetilde{G}^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$
		$Q_{\varphi W}$	$\varphi^{\dagger}\varphiW^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{\varphi} G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{e}_{p}\gamma^{\mu}e_{r})$
	$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	$Q_{\varphi \widetilde{W}}$	$\varphi^{\dagger}\varphi\widetilde{W}^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \widetilde{\varphi} W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{q}_{p}\gamma^{\mu}q_{r})$
1	$Q_{ledq} \qquad (l_p^j e_r)(d_s q_t^j)$	$Q_{\varphi B}$	$\varphi^{\dagger}\varphiB_{\mu u}B^{\mu u}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \widetilde{\varphi} B_{\mu\nu}$	$Q^{(3)}_{\varphi q}$	$(\varphi^{\dagger}i \overset{\leftrightarrow}{D}{}^{I}_{\mu} \varphi)(\bar{q}_{p}\tau^{I}\gamma^{\mu}q_{r})$
	$\begin{bmatrix} Q_{quqd}^{(s)} & (q_p^J u_r) \varepsilon_{jk} (q_s^n d_t) \\ Q^{(8)} & (\bar{q}^j T^A u_r) \varepsilon_{ik} (\bar{q}^k T^A d_t) \end{bmatrix}$	$Q_{\varphi \widetilde{B}}$	$\varphi^{\dagger}\varphi\widetilde{B}_{\mu\nu}B^{\mu\nu}$	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_{lequ}^{(1)} (\bar{l}_p^{j_1} \cdots \bar{u}_r) \varepsilon_{jk} (\bar{q}_s^{k_1} u_t) $	$Q_{\varphi WB}$	$\varphi^{\dagger}\tau^{I}\varphiW^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{d}_{p}\gamma^{\mu}d_{r})$
	$Q_{leau}^{(3)}(\bar{l}_{p}^{j}\sigma_{\mu\nu}e_{r})\varepsilon_{jk}(\bar{q}_{s}^{k}\sigma^{\mu\nu}u_{t})$	$Q_{\omega \widetilde{W}B}$	$\varphi^{\dagger} \tau^{I} \varphi \widetilde{W}^{I}_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^{\dagger}D_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}d_{r})$



			X^3		φ^6 and $\varphi^4 D^2$		$\psi^2 \varphi^3$
	$(\bar{L}L)(\bar{L}L)$	Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(arphi^\dagger arphi)^3$	$Q_{e\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$
	$Q_{ll} \qquad (\bar{l}_p \gamma_\mu l_r) (\bar{l}_s \gamma^\mu l_t)$	$Q_{\widetilde{G}}$	$f^{ABC} \tilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	$Q_{\varphi\Box}$	$(\varphi^{\dagger}\varphi)\Box(\varphi^{\dagger}\varphi)$	$Q_{u\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}u_{r}\widetilde{\varphi})$
	$\begin{array}{c c}Q_{qq}^{(1)} & (\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t) \\ \end{array}$	Q_W	$\varepsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^{\dagger}D^{\mu}\varphi\right)^{\star}\left(\varphi^{\dagger}D_{\mu}\varphi\right)$	$Q_{d\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}d_{r}\varphi)$
	$\begin{bmatrix} Q_{qq}^{(3)} & (\bar{q}_p \gamma_\mu \tau^I q_r) (\bar{q}_s \gamma^\mu \tau^I q_t) \\ Q_s^{(1)} & (\bar{l}_r \gamma_s l_r) (\bar{q}_s \gamma^\mu q_t) \end{bmatrix}$	$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$				
($Q_{lq}^{(3)} (\bar{l}_p \gamma_\mu \tau^I l_r) (\bar{q}_s \gamma^\mu \tau^I q_t)$		$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$
		$Q_{\varphi G}$	$\varphi^{\dagger}\varphiG^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W^I_{\mu\nu}$	$Q^{(1)}_{arphi l}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{l}_{p}\gamma^{\mu}l_{r})$
		$Q_{\varphi \widetilde{G}}$	$\varphi^{\dagger}\varphi\widetilde{G}^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{arphi l}^{(3)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$
		$Q_{\varphi W}$	$\varphi^{\dagger}\varphiW^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{\varphi} G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{e}_{p}\gamma^{\mu}e_{r})$
	$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	$Q_{\varphi \widetilde{W}}$	$\varphi^{\dagger}\varphi\widetilde{W}^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \widetilde{\varphi} W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{q}_{p}\gamma^{\mu}q_{r})$
1	$Q_{ledq} \qquad (l_p^j e_r)(d_s q_t^j)$	$Q_{\varphi B}$	$\varphi^{\dagger}\varphiB_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \widetilde{\varphi} B_{\mu\nu}$	$Q^{(3)}_{\varphi q}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{q}_{p}\tau^{I}\gamma^{\mu}q_{r})$
	$\begin{array}{c c}Q_{quqd} & (q_p^* u_r)\varepsilon_{jk}(q_s^* a_t)\\Q^{(8)} & (\bar{q}_p^* T^A u_r)\varepsilon_{jk}(\bar{q}_s^k T^A d_t)\end{array}$	$Q_{\varphi \widetilde{B}}$	$\varphi^{\dagger}\varphi\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}u_{r})$
	$Q_{lequ}^{(1)} = (\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{\varphi WB}$	$\varphi^{\dagger}\tau^{I}\varphiW^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{arphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{d}_{p}\gamma^{\mu}d_{r})$
($Q_{leau}^{(3)}$ $(\bar{l}_{p}^{j}\sigma_{\mu\nu}e_{r})\varepsilon_{jk}(\bar{q}_{s}^{k}\sigma^{\mu\nu}u_{t})$	$Q_{\omega \widetilde{W}B}$	$\varphi^{\dagger} \tau^{I} \varphi \widetilde{W}^{I}_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^{\dagger}D_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}d_{r})$



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• Shifts to
$$G_F$$
, m_Z , $\sin^2 \theta_W$

		X^3		φ^6 and $\varphi^4 D^2$		$\psi^2 arphi^3$
$(\bar{L}L)(\bar{L}L)$	Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(arphi^\dagger arphi)^3$	$Q_{e\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$
$Q_{ll} \qquad (\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	$Q_{\widetilde{G}}$	$f^{ABC} \tilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	$Q_{\varphi\Box}$	$(\varphi^{\dagger}\varphi)\Box(\varphi^{\dagger}\varphi)$	$Q_{u\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}u_{r}\widetilde{\varphi})$
$Q_{qq}^{(2)} = (\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	Q_W	$\varepsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^{\dagger} D^{\mu} \varphi \right)^{\star} \left(\varphi^{\dagger} D_{\mu} \varphi \right)$	$Q_{d\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}d_{r}\varphi)$
$\begin{bmatrix} Q_{qq}^{(0)} & (\bar{q}_p \gamma_\mu \tau^I q_r) (\bar{q}_s \gamma^\mu \tau^I q_t) \\ Q^{(1)} & (\bar{l} \sim l) (\bar{q} \sim \gamma^\mu q_t) \end{bmatrix}$	$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$				
$Q_{lq}^{(3)} = (\bar{l}_p \gamma_\mu \tau^I l_r) (\bar{q}_s \gamma^\mu \tau^I q_t)$		$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$
	$Q_{\varphi G}$	$\varphi^{\dagger}\varphiG^{A}_{\mu\nu}G^{A\mu\nu}$	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}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q^{(3)}_{arphi l}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$
	$Q_{\varphi W}$	$\varphi^{\dagger}\varphiW^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{\varphi} G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{e}_{p}\gamma^{\mu}e_{r})$
$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	$Q_{\varphi \widetilde{W}}$	$\varphi^{\dagger}\varphi\widetilde{W}^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \widetilde{\varphi} W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{q}_{p}\gamma^{\mu}q_{r})$
$Q_{ledq} \qquad (l_p^j e_r)(d_s q_t^j)$ $Q_{1}^{(1)} \qquad (\bar{a} l_q) \in (\bar{a}^k d)$	$Q_{\varphi B}$	$\varphi^{\dagger}\varphi B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \widetilde{\varphi} B_{\mu\nu}$	$Q^{(3)}_{\varphi q}$	$(\varphi^{\dagger}i\overleftrightarrow{D}^{I}_{\mu}\varphi)(\bar{q}_{p}\tau^{I}\gamma^{\mu}q_{r})$
$\begin{bmatrix} Q_{quqd} & (q_p^{-}a_r)\varepsilon_{jk}(q_s^{-}a_t) \\ Q_{-}^{(8)} & (\bar{q}_r^{-}T^A u_r)\varepsilon_{ik}(\bar{q}_s^{k}T^A d_t) \end{bmatrix}$	$Q_{\omega \widetilde{B}}$	$\varphi^{\dagger}\varphi\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu \nu} T^A d_r) \varphi G^A_{\mu \nu}$	$Q_{\varphi u}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}u_{r})$
$Q_{legu}^{(1)} \qquad (\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{\varphi WB}$	$\varphi^{\dagger}\tau^{I}\varphiW^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{arphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{d}_{p}\gamma^{\mu}d_{r})$
$Q^{(3)}_{lequ}(\bar{l}^{j}_{p}\sigma_{\mu\nu}e_{r})\varepsilon_{jk}(\bar{q}^{k}_{s}\sigma^{\mu\nu}u_{t})$	$Q_{\varphi \widetilde{W}B}$	$\varphi^{\dagger} \tau^{I} \varphi \widetilde{W}^{I}_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{arphi ud}$	$i(\widetilde{\varphi}^{\dagger}D_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}d_{r})$



- Described by effective 4-fermion interactions in LEFT (Lee-Yang theory)
- Affected by *charged* currents

Berthier, Trott '15; de Blas et al '22,'21; Balkin et al '22; Bagnaschi et al '22

			X^3		φ^6 and $\varphi^4 D^2$		$\psi^2 arphi^3$
	$(\bar{L}L)(\bar{L}L)$	Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(arphi^\dagger arphi)^3$	$Q_{e\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$
	$Q_{ll} \qquad (\bar{l}_p \gamma_\mu l_r) (\bar{l}_s \gamma^\mu l_t)$	$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	$Q_{\varphi \Box}$	$(\varphi^{\dagger}\varphi)\Box(\varphi^{\dagger}\varphi)$	$Q_{u\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}u_{r}\widetilde{\varphi})$
	$Q_{qq}^{(1)} \qquad (\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t) $	Q_W	$\varepsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^{\dagger}D^{\mu}\varphi\right)^{\star}\left(\varphi^{\dagger}D_{\mu}\varphi\right)$	$Q_{d\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{q}_{p}d_{r}\varphi)$
	$Q_{qq}^{(3)} = \begin{pmatrix} (\bar{q}_p \gamma_\mu \tau^I q_r) (\bar{q}_s \gamma^\mu \tau^I q_t) \\ (\bar{l} \gamma l) (\bar{q} \gamma^\mu q_t) \end{pmatrix}$	$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$				
	$ \begin{array}{c} Q_{lq} \\ Q_{lq}^{(3)} \\ Q_{lq}^{(3)} \end{array} \begin{pmatrix} (v_p + \mu v_r) \langle q_s + q_t \rangle \\ (\bar{l}_p \gamma_\mu \tau^I l_r) (\bar{q}_s \gamma^\mu \tau^I q_t) \end{pmatrix} $		$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$
		$Q_{\varphi G}$	$\varphi^{\dagger}\varphiG^{A}_{\mu\nu}G^{A\mu\nu}$	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}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$
		$Q_{\varphi W}$	$\varphi^{\dagger}\varphiW^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{\varphi} G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{e}_{p}\gamma^{\mu}e_{r})$
	$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	$Q_{\varphi \widetilde{W}}$	$\varphi^{\dagger}\varphi\widetilde{W}^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \widetilde{\varphi} W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{q}_{p}\gamma^{\mu}q_{r})$
($Q_{ledq} \qquad (l_p^j e_r)(d_s q_t^j)$ $Q^{(1)} \qquad (\bar{z}_{t}^j) = (\bar{z}_{t}^k d)$	$Q_{\varphi B}$	$\varphi^{\dagger}\varphi B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \widetilde{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{q}_{p}\tau^{I}\gamma^{\mu}q_{r})$
	$\begin{bmatrix} Q_{quqd} & (q_p^{a}u_r)\varepsilon_{jk}(q_s^{a}t_t) \\ Q_{quqd}^{(8)} & (\bar{q}_p^{j}T^Au_r)\varepsilon_{jk}(\bar{q}_s^kT^Ad_t) \end{bmatrix}$	$Q_{\varphi \widetilde{B}}$	$\varphi^{\dagger}\varphi\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}u_{r})$
	$Q_{lequ}^{(1)} \qquad (\bar{l}_p^j e_r) \varepsilon_{jk}(\bar{q}_s^k u_t)$	$Q_{\varphi WB}$	$\varphi^{\dagger}\tau^{I}\varphiW^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{d}_{p}\gamma^{\mu}d_{r})$
	$Q_{lequ}^{(3)}(\bar{l}_p^j\sigma_{\mu\nu}e_r)\varepsilon_{jk}(\bar{q}_s^k\sigma^{\mu\nu}u_t)$	$Q_{\varphi \widetilde{W}B}$	$\varphi^{\dagger} \tau^{I} \varphi \widetilde{W}^{I}_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{arphi u c}$	$i(\widetilde{\varphi}^{\dagger}D_{\mu}\varphi)(\bar{u}_{p}\gamma^{\mu}d_{r})$

• LHC measurements

- Described in SMEFT
- $pp \rightarrow \ell \ell, \ell \nu_\ell$ affected by *charged & neutral* currents

• Use HighPT package at dimension-six level



Example: Explaining a heavy W

de Blas et al '22,'21; Balkin et al '22; Bagnaschi et al '22

- SMEFT analyses explaining m_W
 - Assume $U(3)^5$: 8 flavor-independent couplings
 - Fit to electroweak precision data



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Same couplings contribute to $|V_{ud}|^2 + |V_{us}|^2 - 1 = v^2(C_{\Delta} - 2C_{lq}^{(3)})$



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A more 'global' low-energy analysis

- Include all couplings that significantly affect EWPO and low-energy
- Should not significantly change when including more observables
 - Couplings that are very constrained by *other* measurements cannot play a role

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- Flavor-changing neutral currents are very constrained • e.g. by $K \to (\pi)\overline{\ell}\ell$, $D \to (\pi)\overline{\ell}\ell$ • Induced by several operators, e.g. $C_{lq}^{(u,d)}$ $C_{lq}^{(u,d)}$ $C_{lq}^{(u,d)}$ $C_{lq}^{(u,d)}$ $C_{lq}^{(u,d)}$ $\ell \to \ell$ q' q
 - Only combinations that do not induce FCNCs can significantly affect low-energy, EWPO
 - Keep the diagonal of

$$C_{Hq,lq}^{(d)} \equiv C_{Hq,lq}^{(1)} + C_{Hq,lq}^{(3)}$$
$$C_{Hq,lq}^{(u)} \equiv V \left[C_{Hq,lq}^{(1)} - C_{Hq,lq}^{(3)} \right] V^{\dagger}$$













Effect on CKM unitarity



What is improving CKM unitarity?



What is improving CKM unitarity?



What is improving CKM unitarity?



- Nonzero right-handed couplings preferred
 - Simple solution with only $\tilde{e_R}$ survives in much more general fit
- Could be probed at the LHC in WZ production

See Heleen's talk Cirigliano, Crivellin, Hoferichter, Moulson, PLB '23

Summary

- EFTs can systematically describe any heavy new physics
- Allow one to compare measurements from LHC, EWPO to low energies

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Summary

- EFTs can systematically describe any heavy new physics
- Allow one to compare measurements from LHC, EWPO to low energies

- Can be used to investigate discrepancies
- Need a rationale to decide which couplings to include
- Not all choices are robust when adding more observables



- Low-energy and EWP observables still probe $\Lambda \sim 10~{\rm TeV}$
- Nonzero right-handed couplings still preferred





Backup slides

β , π , *K* decay input

Meson decays

	P_{l2}	K _{l3}					
Observable	value	Ref.	Observable	value	Ref.		
R_{π}	$1.2344(30)\cdot 10^{-4}$	[53]	$ ilde{V}^e_{us}f^K_+(0) $	0.21626(40)	[10]		
R_K	$2.488(9)\cdot 10^{-5}$	[26]	$ ilde{V}^{\mu}_{us}f^K_+(0) $	0.21667(52)	[10]		
$\Gamma(K_{\mu 2})$	$5.134(10) \cdot 10^{-7} s^{-1}$	[26]	$\log C$	0.1985(70)	[12]		
$\operatorname{Br}(\pi_{\mu 2})$	0.9998770(4)	[26]	$2\epsilon_T^{s\mu}rac{B_T(0)}{f_+(0)}$	0.0007(71)	[11]		
$ au_{\pi^+}$	$2.6033(5) \cdot 10^{-8}s$	[26]					

Nuclear decays

Parent	J_i	J_f	Type	Observable	Ref.
⁶ He	0	1	${ m GT}/eta^-$	ã	[37]
$^{32}\mathrm{Ar}$	0	0	${\rm F}/\beta^+$	$ ilde{a}$	[38]
$^{38m}\mathrm{K}$	0	0	${\rm F}/\beta^+$	$ ilde{a}$	[39]
60 Co	5	4	GT/β^-	$ ilde{A}$	[40]
⁶⁷ Cu	3/2	5/2	GT/β^-	$ ilde{A}$	[41]
¹¹⁴ In	1	0	GT/β^-	$ ilde{A}$	[42]
$^{14}O/^{10}C$			$\text{F-GT}/\beta^+$	P_F/P_{GT}	[43]
$^{26}\mathrm{Al}/^{30}\mathrm{P}$			$\text{F-GT}/\beta^+$	P_F/P_{GT}	[44]

Table 13:Data from correlation measurements in pure Fermi and pure Gamow-Teller decaysused in the fits.Slightly simplified version of [§].

Table 15: The experimental input used for kaon and π decays. Note that the determinations of $|\tilde{V}_{us}^{\ell}f_{+}^{K}(0)|$ involve a correlation not shown in the table.

Hadronic matrix elements

Е	Baryon decays	K and π decays			
g_A	1.246(28)	[45]	$f_{+}(0)$	0.9698(17)	[45]
g_S	1.02(10)	[45]	$\frac{f_{K\pm}}{f_{\pi\pm}}$	1.1932(21)	[45]
g_T	0.989(34)	[45]	$f_{K^{\pm}}$	$155.7(3)\mathrm{MeV}$	[45]
Δ_R^V	0.02467(22)	[46]	RC_{π}	0.0332(3)	[47]
$rac{\Delta_R^A - \Delta_R^V}{2}$	0.00013(13)	[48]	c_1^π	-2.4(5)	[49]
$\left \begin{array}{c} g_1/f_1 \right _{\Lambda ightarrow p}$	0.72(7)	[9, 50]	$\Delta_{ m CT}$	-0.0035(80)	[51]
			$\frac{B_T(0)}{f_+(0)}$	0.68(3)	[52]

Table 14: The hadronic input that enters β decays. We approximate $g_V = 1$, which holds to high precision. Whenever appropriate the value at a renormalization scale $\mu = 2$ GeV is given.

Electroweak precision input

Obs.	Expt. Va	lue	SM Predicti	on	Obs.	Expt. Val	ue	SM Predict	ion
$\Gamma_Z ({\rm GeV})$	2.4955(23)	[2, 29]	2.49414(56)	6]	$m_W(\text{GeV})$	80.4335(94)	[30]	80.3545(42)	6]
$\sigma_{ m had}^0({ m nb})$	41.480(33)	[2, 29]	41.4929(53)	[6]	$\Gamma_W ({ m GeV})$	2.085(42)	[26]	2.08782(52)	6]
R_e^0	20.804(50)	[2, 29]	20.7464(63)	6]	R_{Wc}	0.49(4)	[26]	0.50	
R^0_μ	20.784(34)	[2, 29]			R_{σ}	0.998(41)	[31]	1	
$R_{ au}^0$	20.764(45)	[2, 29]			${\rm Br}(W \to e\nu)$	0.1071(16)	[26]	0.108386(24)	6]
$A^{0,e}_{ m FB}$	0.0145(25)	[2, 29]	0.016191(70)	6]	$Br(W \to \mu \nu)$	0.1063(15)	[26]	0.108386(24)	6]
$A_{ m FB}^{0,\mu}$	0.0169(13)	[2, 29]			$Br(W \to \tau \nu)$	0.1138(21)	[26]	0.108386(24)	6]
$A_{ m FB}^{0, au}$	0.0188(17)	[2, 29]			$\frac{\Gamma(W \to \mu\nu)}{\Gamma(W \to e\nu)}$	0.982(24)	[26]	1	
R_b^0	0.21629(66)	[2]	0.215880(19)	6]	$\frac{\Gamma(W \to \mu \nu)}{\Gamma(W \to e \nu)}$	1.020(19)	[26]		
R_c^0	0.1721(30)	[2]	0.172198(20)	6]	$\frac{\Gamma(W \to \mu \nu)}{\Gamma(W \to e \nu)}$	1.003(10)	[26]		
$A_{\rm FB}^{0,b}$	0.0996(16)	[2]	0.10300(23)	6]	$\frac{\Gamma(W \to \tau \nu)}{\Gamma(W \to e \nu)}$	0.961(61)	[26]		
$A_{\rm FB}^{0,c}$	0.0707(35)	[2]	0.07358(18)	6]	$\frac{\Gamma(W \to \tau \nu)}{\Gamma(W \to \mu \nu)}$	0.992(13)	[26]		_
\mathcal{A}_{c}	0.67(3)	[2]	0.66775(14)	6]	$A_4(0-0.8)$	0.0195(15)	[32]	0.0144(7)	7]
\mathcal{A}_b	0.923(20)	[2]	0.934727(25)	6]	$A_4(0.8-1.6)$	0.0448(16)	[32]	0.0471(17)	7]
\mathcal{A}_{e}	0.1516(21)	[2]	0.14692(32)	6]	$A_4(1.6-2.5)$	0.0923(26)	[32]	0.0928(21)	7]
\mathcal{A}_{μ}	0.142(15)	[2]			$A_4(2.5 - 3.6)$	0.1445(46)	[32]	0.1464(21)	7]
$\mathcal{A}_{ au}$	0.136(15)	[2]			$g_V^{(u)}$	0.201(112)	[33]	0.192	34]
$\mathcal{A}_e^{ au ext{ pol}}$	0.1498(49)	[2]			$g_V^{(d)}$	-0.351(251)	[33]	-0.347	34]
$\mathcal{A}_{ au}^{ au \mathrm{pol}}$	0.1439(43)	[2]			$g_A^{(u)}$	0.50(11)	[33]	0.501	34]
\mathcal{A}_s	0.895(91)	35]	0.935637(26)	[6]	$g_A^{(d)}$	-0.497(165)	[33]	-0.502	34]
R_{uc}	0.166(9)	[26]	0.172220(20)	6]					

Table 11: Input parameters and EWPOs used in the analysis. Each shaded block indicates a set of correlated observables. Entries without an explicit SM prediction share their SM value with the observable above.

Collider measurements

Process	Experiment	Lumi.	$x_{ m obs}$	x	Ref.
$pp \to \tau^+ \tau^-$	ATLAS	$139{ m fb}^{-1}$	$m_T^{\mathrm{tot}}(\tau_h^1, \tau_h^2, E_T)$	$m_{ au au}$	[?]
$pp ightarrow \mu^+ \mu^-$	CMS	$140{\rm fb}^{-1}$	$m_{\mu\mu}$	$m_{\mu\mu}$	[?]
$pp ightarrow e^+e^-$	CMS	$137{ m fb}^{-1}$	m_{ee}	m_{ee}	[?]
$pp \to \tau^\pm \nu$	ATLAS	$139{\rm fb}^{-1}$	$m_T(au_h, ot\!$	$p_T(au)$	[?]
$pp ightarrow \mu^{\pm} u$	ATLAS	$139{ m fb}^{-1}$	$m_T(\mu, { ot\!\!\!/} E_T)$	$p_T(\mu)$	[62]
$pp \to e^\pm \nu$	ATLAS	$139{ m fb}^{-1}$	$m_T(e, E_T)$	$p_T(e)$	62]
$pp \to \tau^\pm \mu^\mp$	CMS	$138{\rm fb}^{-1}$	$m^{ m col}_{ au_h\mu}$	$m_{ au\mu}$	[?]
$pp \to \tau^\pm e^\mp$	CMS	$138{\rm fb}^{-1}$	$m^{ m col}_{ au_h e}$	$m_{ au e}$	[?]
$pp \to \mu^\pm e^\mp$	CMS	$138{\rm fb}^{-1}$	$m_{\mu e}$	$m_{\mu e}$	[?]

Table 16: Experimental searches by the ATLAS and CMS collaborations that are available in HighPT.