Flavour and its Relation to Heavy New Physics - Quo vadis?

Wolfgang Altmannshofer waltmann@ucsc.edu

🔘 UC SANTA CRUZ

CKM 2023

The 12th International Workshop on the CKM Unitarity Triangle

Santiago de Compostela, Spain, September 18 - 22, 2023

This is a very broad topic and I will omit many important points.

I will try to give an honest overview but some statements will be my (biased) opinion.

Do not hesitate to challenge everything I say.

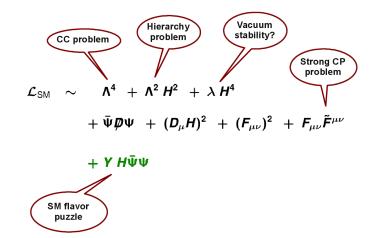
Quo Vadimus?



$$\mathcal{L}_{SM} \sim \Lambda^4 + \Lambda^2 H^2 + \lambda H^4 + \bar{\Psi} \not{D} \Psi + (D_\mu H)^2 + (F_{\mu\nu})^2 + F_{\mu\nu} \tilde{F}^{\mu\nu} + Y H \bar{\Psi} \Psi$$

The SM is a renormalizable QFT; could be valid up to the Planck scale;

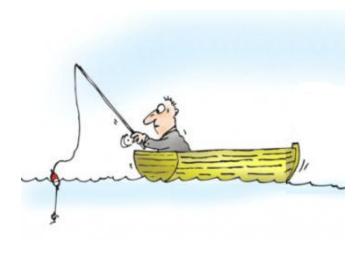
No Guaranteed Discoveries



The SM is a renormalizable QFT; could be valid up to the Planck scale; Many puzzles + astrophysical/cosmological evidence for new physics; But no guarantee for discoveries in terrestrial experiments.

Wolfgang Altmannshofer (UCSC)

Fishing Expeditions



Promising Indirect Probes of New Physics

Test bedrock assumptions of particle physics

Lorentz invariance; CPT invariance; ... $(\Lambda \gtrsim M_{\text{Planck}} \sim 10^{19} \text{ GeV})$

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Test (approximate) accidental symmetries of the SM

Baryon Number: e.g. proton decay ($\Lambda \sim \Lambda_{GUT} \sim 10^{16}~GeV)$

Lepton Number: e.g. neutrinoless double beta decay ($\Lambda \sim \Lambda_{see\text{-saw}} \sim 10^{12}~\text{GeV})$

Flavor: e.g. flavor changing neutral currents $(\Lambda \sim 10^3 - 10^8 \mbox{ GeV})$

CP: e.g. electric dipole moments ($\Lambda \sim 10^3 - 10^8~GeV)$

Probe more generic new physics

Promising Indirect Probes of New Physics

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Flavor: e.g. flavor changing neutral currents $(\Lambda \sim 10^3 - 10^8 \mbox{ GeV})$

CP: e.g. electric dipole moments ($\Lambda \sim 10^3 - 10^8~GeV$)

Test "ordinary" Standard Model processes

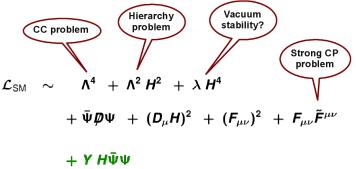
Higgs precision program; Electroweak precision observables; muon anomalous magnetic moment; ... $(\Lambda \sim 10^3~GeV)$

Probe more generic new physics

Effective Field Theories

If new physics is heavy, EFTs provide a powerful organization principle

(for light new physics, see talk by Martin Bauer on Thursday)

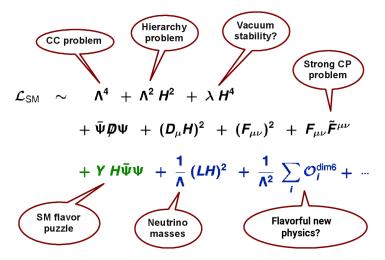




Effective Field Theories

If new physics is heavy, EFTs provide a powerful organization principle

(for light new physics, see talk by Martin Bauer on Thursday)



	$1: X^3$ 2:		$2: H^6$ $3: H'$			${}^{4}D^{2}$		$5: \psi^2 H^3 + h.c.$		
Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_H (.	$H^{\dagger}H)^{3}$	$Q_{H\square}$	(H^{\dagger})	$H)\square(H^{\dagger}H)$	I)	Q_{eH}	$(H^{\dagger}H)(\bar{l}_{p}e_{r}H)$	
$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$			Q_{HD}	$(H^{\dagger}D_{\mu}$	H) [*] (H^{\dagger})	$D_{\mu}H$	Q_{uH}	$(H^{\dagger}H)(\bar{q}_{p}u_{r}\tilde{H})$	
Q_W	$\epsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$							Q_{dH}	$(H^{\dagger}H)(\bar{q}_p d_r H)$	
$Q_{\widetilde{W}}$	$\epsilon^{IJK} \widetilde{W}^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$									
	$4:X^2H^2$	6	$: \psi^2 X H$	+ h.c.			1	$7: \psi^2 H^2$	D	
Q_{HG}	$H^{\dagger}H G^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu})$	$e_r)\tau^I HW$	1 μν	$Q_{Hl}^{(1)}$		$(H^{\dagger}i\overset{\bullet}{J}$	$\vec{D}_{\mu}H)(\bar{l}_{p}\gamma^{\mu}l_{r})$	
$Q_{H\tilde{G}}$	$H^{\dagger}H \widetilde{G}^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^\mu$	$\nu e_r)HB_p$	ν	$Q_{Hl}^{(3)}$			${}^{I}_{\mu}H)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$	
Q_{HW}	$H^{\dagger}H W^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu})$	$T^A u_r) \tilde{H}$	$G^{A}_{\mu\nu}$	Q_{He}		$(H^{\dagger}i\overleftarrow{I}$	$\vec{D}_{\mu}H)(\bar{e}_p\gamma^{\mu}e_r)$	
$Q_{H\widetilde{W}}$	$H^{\dagger}H \widetilde{W}^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu})$	$u_r \tau^I \tilde{H} V$	$V^{I}_{\mu\nu}$	$Q_{H_{4}}^{(1)}$			$\vec{D}_{\mu}H)(\bar{q}_p\gamma^{\mu}q_r)$	
Q_{HB}	$H^{\dagger}H B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^\mu$	$\nu u_r)\tilde{H}B_i$	uν	$Q_{H_{5}}^{(3)}$		$(H^{\dagger}i\overleftrightarrow{D}$	${}^{I}_{\mu}H)(\bar{q}_{p}\tau^{I}\gamma^{\mu}q_{r})$	
$Q_{H\widetilde{B}}$	$H^{\dagger}H \tilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu})$	$T^A d_r)H$	$^{4}d_{r})HG^{A}_{\mu\nu}$		Q_{Hu}		$\vec{D}_{\mu}H)(\bar{u}_p\gamma^{\mu}u_r)$	
Q_{HWB}	$H^{\dagger}\tau^{I}H W^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu})$	$(d_r)\tau^I H V$	$V^{I}_{\mu\nu}$	Q_{Ha}		$(H^{\dagger}i\overleftarrow{I}$	$\vec{D}_{\mu}H)(\bar{d}_{p}\gamma^{\mu}d_{r})$	
$Q_{H\widetilde{W}B}$	$H^{\dagger}\tau^{I}H \widetilde{W}^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu}$	$\nu d_r)H B_j$	w	Q_{Hud} +	h.c.	$i(\widetilde{H}^{\dagger}I)$	$(\bar{u}_p \gamma^\mu d_r)$	
	$8:(\bar{L}L)(\bar{L}L)$		8:($\bar{R}R)(\bar{R}R)$)		8:	$(\bar{L}L)(\bar{R}I)$	7)	
Q_{ll}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	Q_{ee}	(ē	$_{p}\gamma_{\mu}e_{r})(\bar{e}_{s}$	$\gamma^{\mu}e_t$)	Q_{le}	($\bar{l}_p \gamma_\mu l_r)(\bar{\epsilon}$	$(s\gamma^{\mu}e_t)$	
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_j$	$\gamma_{\mu}u_{r})(\bar{u},$	$\gamma^{\mu}u_t$)	Q_{fu}	($\bar{l}_p \gamma_\mu l_r)(\bar{u}$	$_{s}\gamma^{\mu}u_{t})$	
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	Q_{dd}	(<i>d</i>	$_{p}\gamma_{\mu}d_{r})(\bar{d}_{s})$	$\gamma^{\mu}d_{t})$	Q_{ld}	($\bar{l}_p \gamma_\mu l_r)(\dot{a}$	$\bar{l}_s \gamma^{\mu} d_t$)	
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$	Q_{eu}	(\bar{e}_i)	$\gamma_{\mu}e_{r})(\bar{u}_{s}$	$\gamma^{\mu}u_t$)	Q_{qe}	($\bar{q}_p \gamma_\mu q_r)(i$	$\bar{e}_s \gamma^{\mu} e_t$)	
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	Q_{ed}	(\bar{e}_i)	$\gamma_{\mu}e_{r})(\bar{d}_{s})$	$\gamma^{\mu}d_t$)	$Q_{qu}^{(1)}$	(6	$\bar{q}_p \gamma_\mu q_r)(i$	$i_s \gamma^{\mu} u_t$)	
		$Q_{ud}^{(1)}$	(ū	$_{p}\gamma_{\mu}u_{r})(\bar{d}_{t}$	$\gamma^{\mu}d_{t})$	$Q_{qu}^{(8)}$	$(\bar{q}_p \gamma_l)$	$_{\mu}T^{A}q_{r})(i$	$i_s \gamma^{\mu} T^A u_t$)	
		$Q_{ud}^{(8)}$	$(\bar{u}_p \gamma_\mu$	$T^A u_r)(\bar{d}_i$	$\gamma^{\mu}T^{A}d_{t})$	$Q_{qd}^{(1)}$	- ($\bar{q}_p \gamma_\mu q_r)(e$	$\bar{l}_s \gamma^{\mu} d_t$)	
						$Q_{qd}^{(8)}$	$(\bar{q}_p \gamma$	$_{\mu}T^{A}q_{r})(a$	$\bar{l}_s \gamma^{\mu} T^A d_t$)	
	$8 : (\bar{L}R)($	$\bar{R}L$) + h.	.c.	8:(1	$(\bar{L}R)(\bar{L}R)$	+ h.c.				
	Q_{ledq} (1	$(\bar{d}_s q)$	(j) ($Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r)\epsilon_j$	$k(\bar{q}_s^k d_t)$				
			0	$2_{quad}^{(8)}$ ($\bar{q}_p^j T^A u_r) \epsilon_j$	$_{k}(\bar{q}_{s}^{k}T^{A}d)$)			

 $Q_{lequ}^{(1)}$

 $(\bar{l}_{p}^{j}e_{r})\epsilon_{jk}(\bar{q}_{s}^{k}u_{t})$ $Q_{lem}^{(3)}$ $(\bar{l}_{p}^{j}\sigma_{\mu\nu}e_{r})\epsilon_{jk}(\bar{q}_{s}^{k}\sigma^{\mu\nu}u_{t})$

2499 baryon number conserving dim. 6 operators in total

Grzadkowski et al. 1008.4884,

Alonso et al 1312.2014

	$1: X^3$		A_{θ}	3 : H	${}^{4}D^{2}$	5	$5: \psi^2 H^3 + h.c.$	
Q_G	$\int^{ABC} G^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	Q_H (1	$(H^{\dagger}H)^{3} = Q_{L}$	H^{\uparrow} (H^{\uparrow} .	$H)\Box(H^{\dagger}H)$	Q_{eH}	$(H^{\dagger}H)(\bar{l}_{p}e, H)$	
$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$		Q_{E}	$(H^{\dagger}D_{\mu}$	H) [*] ($H^+D_{\mu}H$)	Q_{uH}	$(H^{\dagger}H)(\bar{q}_{p}u_{r}\widetilde{H})$	
Q_W	$\epsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$			•		Q_{dH}	$(H^{\dagger}H)(\bar{q}_{p}d_{r}H)$	
$Q_{\widetilde{W}}$	$\epsilon^{IJK} \widetilde{W}^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$							
	$4:X^2H^2$	6	$\psi^2 X H + ha$			$7: \psi^2 H^2$	D	
Q_{HG}	$H^{\dagger}HG^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I$	$HW^{I}_{\mu\nu}$	$Q_{H!}^{(1)}$	$(\Pi^{\dagger}i^{\dagger})$	$\vec{\mathcal{D}}_{\mu} II (\bar{l}_p \gamma^{\mu} l_{\tau})$	
$Q_{H\widetilde{G}}$	$H^{\dagger}H {\widetilde G}^A_{\mu\nu}G^{A\mu\nu}$	Q_{zB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) E$	$B_{\mu\nu}$	$Q_{Hl}^{(3)}$	$(H^{\dagger}i\overleftarrow{D}$	${}^{I}_{\mu}H)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$	
Q_{HW}	$H^{\dagger}HW^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r)$	$\tilde{H} G^A_{\mu\nu}$	Q_{He}		$\vec{D}_{\mu}H)(\bar{e}_{p}\gamma^{\mu}e_{r})$	
$Q_{H\widetilde{W}}$	$H^{\dagger}H \widetilde{W}^{I}_{\mu\nu} W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_F \sigma^{\mu u} u_r) \tau^I$	$\tilde{H} W^{I}_{\mu\nu}$	$Q_{Hq}^{(1)}$		$\vec{D}_{\mu}H)(\bar{q}_{p}\gamma^{\mu}q_{r})$	
Q_{HB}	$H^{*}H B_{\mu\nu}B^{\mu\nu}$	Q_{nB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \hat{I}$	$I B_{\mu\nu}$	$Q_{Hq}^{(3)}$		${}^{I}_{\mu}H)(\bar{q}_{\rho}\tau^{I}\gamma^{\mu}q_{r})$	
$Q_{H\widetilde{B}}$	$H^{*}H \widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_{g}\sigma^{\mu\nu}T^{A}d_{r})HG^{A}_{\mu\nu}$		Q_{Hu}	$(H^{\dagger}i\overleftrightarrow{D}_{\mu}H)(\bar{u}_{p}\gamma^{\mu}u_{r})$		
Q_{HWB}	$H^\dagger \tau^I H W^I_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^l$	$H W^{I}_{\mu\nu}$	Q_{Hd}		$\vec{D}_{\mu}H)(\bar{d}_{p}\gamma^{\mu}d_{r})$	
$Q_{H\widetilde{W}B}$	$H^\dagger \tau^I H \widetilde{W}^I_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_{\nu}\sigma^{\mu\nu}d_{\tau})E$	$I B_{\mu\nu}$	Q_{Hud} + h.c.	$i(\widetilde{H}^*L$	$(\bar{v}_{\rho}\gamma^{\mu}d_{r})$	
	$8: (\bar{L}L)(\bar{L}L)$		$8 : (\bar{R}R)(.$	RR)	8 :	$(\bar{L}L)(\bar{R}I)$	0	
20	$(\bar{l}_{p}\gamma_{\mu}l_{r})(\bar{l}_{s}\gamma^{\mu}l_{t})$	Q_{ee}	$(\bar{e}_p \gamma_\mu e_r$	$(\bar{e}_s \gamma^{\mu} e_t)$	Q_{lv}	$(\bar{l}_p \gamma_\mu l_\tau)(\bar{e}$	$(_{s}\gamma^{\mu}e_{t})$	
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_p \gamma_\mu u_r$	$(\bar{u}_s \gamma^{\mu} u_t)$	Q_{lu}	$(\bar{l}_p \gamma_\mu l_r)(\bar{u}$	$_{s}\gamma^{\mu}u_{t})$	
			$(\bar{d}_p \gamma_\mu d_r)(\bar{d}_s \gamma^\mu d_l)$					
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^J q_r)(\bar{q}_s \gamma^\mu \tau^J q_t)$	Q_{dd}	$(d_p \gamma_\mu d_r)$	Mus.1. at)	Q_{ld}	$(\bar{l}_p \gamma_\mu l_r)(\bar{d}$	$_{s}\gamma^{\mu}d_{t})$	
$Q_{lq}^{\left(1\right)}$	$(\bar{q}_p \gamma_\mu \tau^j q_r)(\bar{q}_s \gamma^\mu \tau^j q_t)$ $(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$	Q_{dd} Q_{eu}	$(\bar{e}_{p}\gamma_{\mu}e_{\tau})$	$(\bar{u}_s \gamma^{\mu} u_t)$	Q_{qe} ($(\bar{l}_p \gamma_\mu l_r)(d$ $(\bar{q}_p \gamma_\mu q_r)(d$		
		Q_{eu} Q_{od}	$(\bar{e}_{p}\gamma_{\mu}e_{\tau})$		$Q_{qe} = 0$ $Q_{qx}^{(1)} = 0$		$\bar{\epsilon}_s \gamma^{\mu} e_t$)	
$Q_{lq}^{\left(1\right)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_i)$	Q_{eu} Q_{od} $Q_{nd}^{(1)}$	$(\bar{e}_p \gamma_\mu e_r)$ $(\bar{e}_p \gamma_\mu e_r)$ $(\bar{u}_p \gamma_\mu u_r)$	$(\bar{u}_s \gamma^{\mu} u_t)$ $(\bar{d}_s \gamma^{\mu} d_t)$ $)(\bar{d}_s \gamma^{\mu} d_t)$	$Q_{qx} = (Q_{qx})$ $Q_{qx}^{(1)} = (Q_{qx})$ $Q_{qx}^{(8)} = (\bar{q}_{p\gamma})$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_\mu T^A q_r)(\bar{q}_\mu T^A q_r)(\bar{q}_\mu q_\mu q_\mu)(\bar{q}_\mu q_\mu q_\mu q_\mu)(\bar{q}_\mu q_\mu q_\mu)(\bar{q}_\mu q_\mu q_\mu)(\bar{q}_\mu q_\mu q_\mu q_\mu)(\bar{q}_\mu q_\mu q_\mu q_\mu q_\mu)(\bar{q}_\mu q_\mu q_\mu q_\mu q_\mu q_\mu)(\bar{q}_\mu q_\mu q_\mu q_\mu q_\mu q_\mu q_\mu q_\mu q_\mu q_\mu q$	$\tilde{\epsilon}_s \gamma^{\mu} v_t$) $\tilde{\epsilon}_s \gamma^{\mu} u_t$) $\tilde{\epsilon}_s \gamma^{\mu} T^A u_t$)	
$Q_{lq}^{\left(1\right)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_i)$	Q_{eu} Q_{od}	$(\bar{e}_p \gamma_\mu e_r)$ $(\bar{e}_p \gamma_\mu e_r)$ $(\bar{u}_p \gamma_\mu u_r)$	$(\bar{u}_s \gamma^{\mu} u_t)$ $(\bar{d}_s \gamma^{\mu} d_t)$	$egin{array}{c} Q_{qe} & (Q_{qg}^{(1)}) & (Q_{qg}^{(2)}) & (Q_{qg}^{(3)}) & (Q_{qg}^{(1)}) & (Q_{qd}^{(1)}) & (Q_{qd}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_\mu T^A q_r)(\bar{q}_p \gamma_\mu $	$\bar{\epsilon}_s \gamma^{\mu} e_t$) $\bar{i}_s \gamma^{\mu} u_t$) $\bar{i}_s \gamma^{\mu} T^A u_t$) $\bar{l}_s \gamma^{\mu} d_t$)	
$Q_{lq}^{\left(1\right)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_i)$	Q_{eu} Q_{od} $Q_{nd}^{(1)}$	$(\bar{e}_p \gamma_\mu e_r)$ $(\bar{e}_p \gamma_\mu e_r)$ $(\bar{u}_p \gamma_\mu u_r)$	$(\bar{u}_s \gamma^{\mu} u_t)$ $(\bar{d}_s \gamma^{\mu} d_t)$ $)(\bar{d}_s \gamma^{\mu} d_t)$	$egin{array}{c} Q_{qe} & (Q_{qg}^{(1)}) & (Q_{qg}^{(2)}) & (Q_{qg}^{(3)}) & (Q_{qg}^{(1)}) & (Q_{qd}^{(1)}) & (Q_{qd}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_\mu T^A q_r)(\bar{q}_p \gamma_\mu $	$i_s \gamma^{\mu} v_t$) $i_s \gamma^{\mu} u_t$) $i_s \gamma^{\mu} T^A u_t$)	
$Q_{lq}^{\left(1\right)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_i)$	Q_{eu} Q_{od} $Q_{nd}^{(1)}$ $Q_{nd}^{(8)}$	$(\bar{e}_{p}\gamma_{\mu}e_{r})$ $(\bar{e}_{p}\gamma_{\mu}e_{r})$ $(\bar{u}_{p}\gamma_{\mu}u_{r})$ $(\bar{u}_{p}\gamma_{\mu}T^{A}u_{r})$	$(\bar{u}_s \gamma^{\mu} u_t)$ $(\bar{d}_s \gamma^{\mu} d_t)$ $)(\bar{d}_s \gamma^{\mu} d_t)$	$\begin{array}{c} Q_{qc} & (\\ Q_{qx}^{(1)} & (\\ Q_{qx}^{(2)} & (\\ Q_{qx}^{(3)} & (\\ \bar{Q}_{qd}^{(2)} & (\\ Q_{qd}^{(4)} & (\\ Q_{qd}^{(8)} & (\\ \bar{Q}_{pq}) \end{array} \end{array}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_\mu T^A q_r)(\bar{q}_p \gamma_\mu $	$\bar{\epsilon}_s \gamma^{\mu} e_t$) $\bar{i}_s \gamma^{\mu} u_t$) $\bar{i}_s \gamma^{\mu} T^A u_t$) $\bar{l}_s \gamma^{\mu} d_t$)	
$Q_{lq}^{\left(1\right)}$	$\begin{split} (\bar{l}_{p}\gamma_{\mu}l_{\tau})(\bar{q}_{s}\gamma^{\mu}q_{t}) \\ (\bar{l}_{p}\gamma_{\mu}\tau^{t}l_{\tau})(\bar{q}_{s}\gamma^{\mu}\tau^{t}q_{s}) \end{split}$	Q_{eu} Q_{od} $Q_{nd}^{(1)}$ $Q_{nd}^{(8)}$ $Q_{nd}^{(8)}$ $\bar{R}L) + h.$	$(\bar{e}_{p}\gamma_{\mu}e_{\tau})$ $(\bar{e}_{p}\gamma_{\mu}e_{r})$ $(\bar{u}_{p}\gamma_{\mu}u_{r})$ $(\bar{u}_{p}\gamma_{\mu}T^{A}u_{r})$ c. 8	$(\bar{u}_a \gamma^{\mu} u_t)$ $(\bar{d}_a \gamma^{\mu} d_t)$ $)(\bar{d}_a \gamma^{\mu} d_t)$ $)(\bar{d}_s \gamma^{\mu} T^A d_t)$ $: (\bar{L}R)(\bar{L}R)$	$\begin{array}{c} Q_{qc} & (\\ Q_{qx}^{(1)} & (\\ Q_{qx}^{(2)} & (\\ Q_{qx}^{(3)} & (\\ \bar{Q}_{qd}^{(2)} & (\\ Q_{qd}^{(4)} & (\\ Q_{qd}^{(8)} & (\\ \bar{Q}_{pq}) \end{array} \end{array}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_\mu T^A q_r)(\bar{q}_p \gamma_\mu $	$\bar{\epsilon}_s \gamma^{\mu} e_t$) $\bar{i}_s \gamma^{\mu} u_t$) $\bar{i}_s \gamma^{\mu} T^A u_t$) $\bar{l}_s \gamma^{\mu} d_t$)	
$Q_{lq}^{\left(1\right)}$	$ \frac{(\tilde{l}_p \gamma_\mu l_r)(\tilde{q}_s \gamma^\mu q_t)}{(\tilde{l}_p \gamma_\mu \tau^I l_r)(\tilde{q}_s \gamma^\mu \tau^I q_t)} $ $ \underline{(\tilde{l}_p \gamma_\mu \tau^I l_r)(\tilde{q}_s \gamma^\mu \tau^I q_t)} $ $ \underline{(\tilde{l}_R)(l_s R)(l_s R$	Q_{eu} Q_{od} $Q_{nd}^{(1)}$ $Q_{nd}^{(8)}$ $Q_{nd}^{(8)}$ $\bar{R}L) + h.$	$(\vec{e}_p \gamma_\mu e_{\tau_i})$ $(\vec{e}_p \gamma_\mu e_{\tau_i})$ $(\vec{u}_p \gamma_\mu u_r)$ $(\vec{u}_p \gamma_\mu T^A u_r)$	$(\bar{u}_a \gamma^{\mu} u_t)$ $(\bar{d}_a \gamma^{\mu} d_t)$ $)(\bar{d}_a \gamma^{\mu} d_t)$ $)(\bar{d}_s \gamma^{\mu} T^A d_t)$ $: (\bar{L}R)(\bar{L}R)$	$\begin{array}{c c} Q_{qc} & (\\ Q_{qz}^{(1)} & (\\ Q_{qz}^{(2)} & (\\ Q_{qd}^{(2)} & (\\ Q_{qd}^{(2)} & (\\ Q_{qd}^{(2)} & (\\ Q_{qd}^{(k)} & (\\ \\ q_{qd}^{(k)} & (\\ \\ q_{gk}^{(k)} & (\\ \\ q_k^{(k)} & (\\ \\ q_k^{(k)} & d_k) \end{array}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_\mu T^A q_r)(\bar{q}_p \gamma_\mu $	$\bar{\epsilon}_s \gamma^{\mu} e_t$) $\bar{i}_s \gamma^{\mu} u_t$) $\bar{i}_s \gamma^{\mu} T^A u_t$) $\bar{l}_s \gamma^{\mu} d_t$)	
$Q_{lq}^{\left(1\right)}$	$ \frac{(\tilde{l}_p \gamma_\mu l_r)(\tilde{q}_s \gamma^\mu q_t)}{(\tilde{l}_p \gamma_\mu \tau^I l_r)(\tilde{q}_s \gamma^\mu \tau^I q_t)} $ $ \underline{(\tilde{l}_p \gamma_\mu \tau^I l_r)(\tilde{q}_s \gamma^\mu \tau^I q_t)} $ $ \underline{(\tilde{l}_R)(l_s R)(l_s R$	Q_{eu} Q_{od} $Q_{nd}^{(1)}$ $Q_{nd}^{(8)}$ $Q_{nd}^{(8)}$ $\bar{R}L) + h.$	$(\bar{e}_{\mu}\gamma_{\mu}e_{\tau})$ $(\bar{e}_{p}\gamma_{\mu}e_{r})$ $(\bar{u}_{p}\gamma_{\mu}u_{r})$ $(\bar{u}_{p}\gamma_{\mu}T^{A}u_{r})$ c. 8	$\begin{split} &(\bar{u}_s \gamma^{\mu} u_t) \\ &(\bar{d}_s \gamma^{\mu} d_t) \\ &)(\bar{d}_s \gamma^{\mu} d_t) \\ &)(\bar{d}_s \gamma^{\mu} T^A d_t) \\ &: (\bar{L}R)(\bar{L}R) \cdot \\ &\hline &(\bar{d}_p^{\mu} u_r) e; \end{split}$	$\begin{array}{c} Q_{qe} & (Q_{qx}) \\ Q_{qx}^{(1)} & (Q_{qx}) \\ Q_{qx}^{(2)} & (Q_{qx}) \\ Q_{qd}^{(1)} & (Q_{qd}) \\ Q_{qd}^{(1)} & (Q_{pq}) \\ + \text{ h.c.} \\ \frac{1}{p_k(\bar{q}_k^k d_k)} \\ \frac{1}{p_k(\bar{q}_k^k d_k)} \end{array}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_p \gamma_\mu q_r)(\bar{q}_\mu T^A q_r)(\bar{q}_p \gamma_\mu $	$\bar{\epsilon}_s \gamma^{\mu} e_t$) $\bar{i}_s \gamma^{\mu} u_t$) $\bar{i}_s \gamma^{\mu} T^A u_t$) $\bar{l}_s \gamma^{\mu} d_t$)	

2499 baryon number conserving dim. 6 operators in total

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4 fermion interactions

	$1 : X^{3}$		q_{θ}		3 : F	I^4D^2		$5:\psi^2H^3+{\rm h.c.}$		
Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_H (i	$H^{\dagger}H)^{3}$	$Q_{H\square}$	(H	$(H^{\dagger}H) \Box (H^{\dagger}H)$	()	Q_{eH}	$(H^{\dagger}H)(\bar{l}_{p}e,H)$	
$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$			Q_{HD}	$(H^{\dagger}D)$	$(H)^* (H^*)$	$D_{\mu}H)$	Q_{uff}	$(H^{+}H)(\bar{q}_{p}u_{r}\widetilde{H})$	
Q_W	$\epsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$							Q_{dH}	$(H^\dagger H)(\bar{q}_p d_r H)$	
$Q_{\widetilde{W}}$	$\epsilon^{IJK} \widetilde{W}^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$									
	$4:X^2H^2$	6	$: \psi^2 X H$	' + h.c.			1	$7: \psi^2 H^2$	D	
Q_{HG}	$H^{\dagger}HG^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu})$	$e_r \tau^I HW$	$V^{I}_{\mu\nu}$	$Q_{H!}^{(1)}$			$\vec{D}_{\mu}II)(\bar{l}_{p}\gamma^{\mu}l_{\tau})$	
$Q_{H\widetilde{G}}$	$H^{\dagger}H\widetilde{G}^{A}_{\mu u}G^{A\mu u}$	Q_{zB}	$(\bar{l}_p \sigma^\mu$	$\nu e_{\tau})HB_{\mu}$	æ	$Q_{H^{2}}^{(3)}$			$^{I}_{\mu}H)(\bar{l}_{p} au^{I}\gamma^{\mu}l_{r}) =$	
Q_{HW}	$H^{\dagger}H W^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p\sigma^{\mu\nu})$	$U^A v_r) \tilde{H}$	$G^A_{\mu\nu}$	Q_{Ho}			$\vec{P}_{\mu}H)(\bar{e}_{p}\gamma^{\mu}e_{r})$	
$Q_{H\widetilde{W}}$	$H^{\dagger}H \widetilde{W}^{I}_{\mu\nu} W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_{\rm F}\sigma^{\mu\nu})$	$u_r)\tau^I \hat{H} V$	$V^{I}_{\mu\nu}$	$Q_{Hq}^{(1)}$			$\vec{\partial}_{\mu}H)(\bar{q}_{p}\gamma^{\mu}q_{r})$	
Q_{HB}	$H^{*}H B_{\mu\nu}B^{\mu\nu}$	Q_{nB}		$v u_r) \tilde{H} B$	·	$Q_{Hq}^{(3)}$			${}^{I}_{\mu}H)(\bar{q}_{p}\tau^{I}\gamma^{\mu}q_{r})$	
$Q_{H\widetilde{B}}$	$H^*H \tilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}		$T^A d_r H$		Q_{Hu}			$\vec{D}_{\mu}H)(\bar{u}_p\gamma^{\mu}u_{\tau})$	
Q_{HWB}	$H^{\dagger}\tau^{I}HW^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}		$(d_\tau)\tau^I H V$		Q_{Hd}		$(H^{\dagger}iL$	$\vec{O}_{\mu}H)(\bar{d}_{p}\gamma^{\mu}d_{r})$	
$Q_{H\widetilde{W}B}$	$H^{\dagger}\tau^{I}H\widetilde{W}^{I}_{\mu\nu}B^{\mu\nu}$	Q_{AB}	$(\bar{q}_{\nu}\sigma^{\mu}$	$\nu d_r H B$	μυ	$Q_{Hud} +$	h.c.	$i(\widetilde{H}^*L$	$(\bar{u}_p \gamma^\mu d_r)$	
	$8:(\bar{L}L)(\bar{L}L)$	\sim	8:(4	$\bar{R}R)(\bar{R}R$)		8:	$(\bar{L}L)(\bar{R}F)$	1)	
Q_{11}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	Q_{ee}	(ē _j	$_{p}\gamma_{\mu}e_{r})(\bar{e}_{i}$	$\gamma^{\mu}e_t$)	Q_{lv}	($\bar{l}_p \gamma_\mu l_\tau)(\bar{e}$	$_{s}\gamma^{\mu}e_{t})$	
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_j$	$\gamma_{\mu}u_{r})(\bar{u}$	$s\gamma^{\mu}u_{l})$	Q_{lu}		$\bar{l}_{p}\gamma_{\mu}l_{\tau})(\bar{u}$		
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^J q_r)(\bar{q}_s \gamma^\mu \tau^J q_t)$) Q _{dd}	I	$\gamma_{\mu}d_{r})(\bar{d}$		Q_{ld}	($\bar{l}_p \gamma_\mu l_r)(d$	$(_{s}\gamma^{\mu}d_{t})$	
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_i)$	Q_{eu}		$\gamma_{\mu}e_{\tau})(\bar{u}_{z})$		Q_{qe}	($\bar{q}_{p}\gamma_{\mu}q_{r})(\bar{\epsilon}$	$\epsilon_s \gamma^{\mu} v_t$)	
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^J l_r)(\bar{q}_s \gamma^\mu \tau^J q_i)$			$_{o}\gamma_{\mu}e_{r})(\bar{d}_{i}$		$Q_{q_{2}}^{(1)}$		$\bar{l}_p \gamma_\mu q_r)(\bar{u}$		
		$Q_{nd}^{(1)}$	1	$_{p}\gamma_{\mu}u_{r})(d$		$Q_{q_{2}}^{(8)}$			$i_s \gamma^{\mu} T^A u_i)$	
		$Q_{ud}^{(8)}$	$(\bar{u}_p \gamma_\mu)$	$T^A u_r)(\bar{d}$	$\gamma^{\mu}T^{A}d_{i}$			$\bar{q}_p \gamma_\mu q_r)(\dot{a}$		
						$Q_{qd}^{(8)}$	$(\bar{q}_P\gamma_l$	$_{\mu}T^{A}q_{r})(\dot{a}$	$\bar{l}_s \gamma^{\mu} T^A d_t$	
	$8 : (\bar{L}R)($	$\bar{R}L$) + h.	c.	8:($\bar{L}R)(\bar{L}R)$	+ h.c.				
	Q _{ledy} (i	$(\bar{d}_{s}q_{t})$	i) 4	$p_{gugd}^{(1)}$	$(\bar{q}_p^j u_r)$	$_{jk}(\bar{q}_{s}^{k}d_{t})$				
			4	2 ⁽⁸⁾ gugd ($\bar{q}_p^j T^A u_r)$	$_{jk}(\bar{q}_{s}^{k}T^{A}d_{t}$)			
			6	2 lega						
		Ģ	$Q_{lequ}^{(3)}$ ($\bar{l}_{p}^{j}\sigma_{\mu\nu}c_{\tau})\epsilon$	$_{jk}(\bar{q}^k_s\sigma^{;\mu\nu}u)$)				

2499 baryon number conserving dim. 6 operators in total

Grzadkowski et al. 1008.4884, Alonso et al 1312.2014

4 fermion interactions

dipole transitions

	$1: X^3$	2:1	T_{0}		3:H	$^{4}D^{2}$		$5:\psi^2H^3+{\rm h.c.}$		
Q_G	$\int^{ABC} G^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	Q_H (1	$(H^{\dagger}H)^{3}$	$Q_{H\square}$	(H^{\dagger})	$H)\Box(H^{\dagger}H)$	I)	Q_{eH}	$(H^{\dagger}H)(\bar{l}_{p}e,H)$	
$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$			Q_{HD}	$(H^{\dagger}D_{\mu}$	$H)^* (H^* I$	$D_{\mu}H)$	Q_{uH}	$(H^{+}H)(\bar{q}_{p}u_{r}\tilde{H})$	
Q_W	$\epsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$							Q_{dH}	$(H^\dagger H)(\bar{q}_p d_r H)$	
$Q_{\tilde{V}\tilde{r}}$	$\epsilon^{IJK} \widetilde{W}^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$									
	$4:X^2H^2$	6	$:\psi^2 XH$	+ h.c.			1	$7 : \psi^2 H^2$	0	
Q_{HG}	$H^{\dagger}HG^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r$.) τ ^I HW	1 μν	$Q_{H!}^{(1)}$			$\vec{D}_{\mu}II)(\bar{l}_{p}\gamma^{\mu}l_{\tau})$	
$Q_{H\bar{G}}$	$H^{\dagger}H {\widetilde G}^A_{\mu\nu}G^{A\mu\nu}$	Q_{zB}	$(\bar{l}_p \sigma^{\mu\nu} e$	$e_\tau HB_\mu$	p.	$Q_{R!}^{(3)}$		$(H^{\dagger}i\overleftarrow{D}$	${}^{I}_{\mu}H)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$	
Q_{HW}	$H^{\dagger}HW^{I}_{\mu\nu}W^{Iu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A v_r) \tilde{H} G^A_{\mu\nu}$			Q_{He}			$(\tilde{e}_p \gamma^{\mu} e_r)$	
$Q_{H\widetilde{W}}$	$H^{\dagger}H \widetilde{W}^{I}_{\mu\nu} W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_{\bar{r}}\sigma^{\mu u}u_r)\tau^I \hat{H} W^I_{\mu u}$			$Q_{Hq}^{(1)}$			$\overrightarrow{q}_{\mu}H)(\overline{q}_{p}\gamma^{\mu}q_{r})$	
Q_{HB}	$H^{-}H B_{\mu\nu}B^{\mu\nu}$	Q_{nB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tilde{H} B_{\mu\nu}$			$Q_{Hq}^{(3)}$		$(H^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}H)(q_{p}\tau^{I}\gamma^{\mu}q_{r})$		
$Q_{H\widetilde{B}}$	$H^{-}H \widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_{p}\sigma^{\mu\nu}T^{A}d_{r})HG^{A}_{\mu\nu}$			Q_{Hu}		$(H^{\dagger}i\overleftrightarrow{D}_{\mu}H)(\bar{u}_{p}\gamma^{\mu}u_{\tau})$		
Q_{HWB}	$H^\dagger \tau^I H W^I_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I H W^I_{\mu\nu}$			Q_{Hd}		$(H^{\dagger}i\overleftrightarrow{D}_{\mu}H)(\bar{d}_{p}\gamma^{\mu}d_{r})$		
$Q_{H\widetilde{W}B}$	$H^\dagger \tau^I H {\widetilde W}^I_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_{\nu}\sigma^{\mu\nu}\sigma)$	$d_\tau)H B_\mu$	w	$Q_{IIud} +$	h.c.	$i(\widetilde{H}^*L$	$(\bar{v}_{\rho} H)(\bar{v}_{\rho} \gamma^{\mu} d_{r})$	
	$8:(\bar{L}L)(\bar{L}L)$	_	$8:(\bar{R}$	$R)(\bar{R}R)$		\sim	8:	$(\bar{L}L)(\bar{R}I)$	1)	
Q_{11}	$8: (\bar{L}L)(\bar{L}L)$ $(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	Qee	-	$R)(\bar{R}R)$ $\gamma_{\mu}e_{r})(\bar{e}_{s}$		Q _{tv}	_	$(\bar{L}L)(\bar{R}I)$ $(\bar{l}_p \gamma_\mu l_\tau)(\bar{e}$		
$Q_{qq}^{(1)}$		Q _{ee} Q _{uu}	$(\bar{e}_p\gamma$		$\gamma^{\mu}e_t$)	Q _{te} Q _{tu}	($_{s}\gamma^{\mu}e_{t})$	
$Q_{qq}^{(1)}$ $Q_{qq}^{(3)}$	$(\bar{l}_{p}\gamma_{\mu}l_{r})(\bar{l}_{s}\gamma^{\mu}l_{t})$		$(\bar{e}_p \gamma$ $(\bar{u}_p \gamma$	$\gamma_{\mu}e_{r})(\bar{e}_{s}$	$\gamma^{\mu}e_t$) $\gamma^{\mu}u_t$)		($(\bar{l}_p \gamma_\mu l_\tau)(\bar{e}$	$s\gamma^{\mu}e_{!})$ $s\gamma^{\mu}u_{t})$	
$Q_{qq}^{(1)}$ $Q_{qq}^{(3)}$ $Q_{lq}^{(1)}$	$\begin{split} & (\bar{l}_{j} \gamma_{\mu} l_{\tau}) (\bar{l}_{s} \gamma^{\mu} l_{t}) \\ & (\bar{q}_{p} \gamma_{\mu} q_{r}) (\bar{q}_{s} \gamma^{\mu} q_{t}) \\ & (\bar{q}_{p} \gamma_{\mu} \tau^{\dagger} q_{r}) (\bar{q}_{s} \gamma^{\mu} \tau^{\dagger} q_{t}) \\ & (\bar{l}_{p} \gamma_{\mu} l_{\tau}) (\bar{q}_{s} \gamma^{\mu} q_{t}) \end{split}$	Q_{uu}	$(\bar{e}_p\gamma$ $(\bar{u}_p\gamma)$ $(\bar{d}_p\gamma)$	$\gamma_{\mu}e_{r})(\bar{e}_{s})$ $\gamma_{\mu}u_{r})(\bar{u}_{s})$	$\gamma^{\mu} e_t$) $\gamma^{\mu} u_t$) $\gamma^{\mu} d_t$)	Q_{lu} Q_{ld} Q_{qe}	($(\bar{l}_p \gamma_\mu l_\tau)(\bar{e})$ $(\bar{l}_p \gamma_\mu l_\tau)(\bar{v})$	$s\gamma^{\mu}e_{t})$ $s\gamma^{\mu}u_{t})$ $s\gamma^{\mu}d_{t})$	
$Q_{qq}^{(1)}$ $Q_{qq}^{(3)}$	$\begin{split} & (\bar{l}_{g}\gamma_{\mu}l_{r})(\bar{l}_{s}\gamma^{\mu}l_{t}) \\ & (\bar{q}_{p}\gamma_{\mu}q_{r})(\bar{q}_{s}\gamma^{\mu}q_{t}) \\ & (\bar{q}_{p}\gamma_{\mu}\tau^{1}q_{r})(\bar{q}_{s}\gamma^{\mu}\tau^{i}q_{t}) \end{split}$	Quu Qdd Qcu Qcd	$(\bar{e}_p \gamma$ $(\bar{u}_p \gamma)$ $(\bar{d}_p \gamma)$ $(\bar{e}_p \gamma)$	$\gamma_{\mu} e_r)(\bar{e}_s$ $\gamma_{\mu} u_r)(\bar{u}_s$ $\gamma_{\mu} d_r)(\bar{d}_s$	$\gamma^{\mu} e_t$) $\gamma^{\mu} u_t$) $\gamma^{\mu} d_t$) $\gamma^{\mu} u_t$)	Q_{lu} Q_{ld} Q_{qe} $Q_{qg}^{(1)}$	(() ()	$\bar{l}_p \gamma_\mu l_\tau)(\bar{e}$ $\bar{l}_p \gamma_\mu l_\tau)(\bar{e}$ $\bar{l}_p \gamma_\mu l_\tau)(\bar{e}$ $\bar{l}_p \gamma_\mu l_\tau)(\bar{e}$	$s_s \gamma^{\mu} e_t$) $s_s \gamma^{\mu} u_t$) $s_s \gamma^{\mu} d_t$) $s_s \gamma^{\mu} v_t$)	
$Q_{qq}^{(1)}$ $Q_{qq}^{(3)}$ $Q_{lq}^{(1)}$	$\begin{split} & (\bar{l}_{j} \gamma_{\mu} l_{\tau}) (\bar{l}_{s} \gamma^{\mu} l_{t}) \\ & (\bar{q}_{p} \gamma_{\mu} q_{r}) (\bar{q}_{s} \gamma^{\mu} q_{t}) \\ & (\bar{q}_{p} \gamma_{\mu} \tau^{\dagger} q_{r}) (\bar{q}_{s} \gamma^{\mu} \tau^{\dagger} q_{t}) \\ & (\bar{l}_{p} \gamma_{\mu} l_{\tau}) (\bar{q}_{s} \gamma^{\mu} q_{t}) \end{split}$	Q_{uu} Q_{dd} Q_{eu} Q_{od} $Q_{ud}^{(1)}$	$(\bar{e}_p\gamma)$ $(\bar{u}_p\gamma)$ $(d_p\gamma)$ $(\bar{e}_p\gamma)$ $(\bar{e}_p\gamma)$	$\gamma_{\mu}e_{r})(\bar{e}_{s}$ $\gamma_{\mu}u_{r})(\bar{u}_{s}$ $\gamma_{\mu}d_{r})(\bar{d}_{s}$ $\gamma_{\mu}e_{r})(\bar{u}_{s}$	$\gamma^{\mu}e_t$) $\gamma^{\mu}u_t$) $\gamma^{\mu}d_t$) $\gamma^{\mu}u_t$) $\gamma^{\mu}u_t$)	Q_{lu} Q_{ld} Q_{qe} $Q_{qx}^{(1)}$ $Q_{qx}^{(8)}$ $Q_{qx}^{(8)}$	(((((((((((((($\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu l_r})(\overline{d}$ $\overline{q_p \gamma_\mu q_r})(\overline{d}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$	$s_{\sigma}\gamma^{\mu}e_{t}$) $s_{\sigma}\gamma^{\mu}u_{t}$) $s_{\sigma}\gamma^{\mu}u_{t}$) $s_{\sigma}\gamma^{\mu}u_{t}$) $s_{\sigma}\gamma^{\mu}v_{t}$) $s_{\sigma}\gamma^{\mu}T^{A}u_{t}$)	
$Q_{qq}^{(1)}$ $Q_{qq}^{(3)}$ $Q_{tq}^{(1)}$	$\begin{split} & (\bar{l}_{j} \gamma_{\mu} l_{\tau}) (\bar{l}_{s} \gamma^{\mu} l_{t}) \\ & (\bar{q}_{p} \gamma_{\mu} q_{r}) (\bar{q}_{s} \gamma^{\mu} q_{t}) \\ & (\bar{q}_{p} \gamma_{\mu} \tau^{\dagger} q_{r}) (\bar{q}_{s} \gamma^{\mu} \tau^{\dagger} q_{t}) \\ & (\bar{l}_{p} \gamma_{\mu} l_{\tau}) (\bar{q}_{s} \gamma^{\mu} q_{t}) \end{split}$	Quu Qdd Qcu Qcd	$(\bar{e}_p\gamma)$ $(\bar{u}_p\gamma)$ $(\bar{d}_p\gamma)$ $(\bar{e}_p\gamma)$ $(\bar{e}_p\gamma)$ $(\bar{u}_p\gamma)$	$\gamma_{\mu}e_r)(\bar{e}_s$ $\gamma_{\mu}u_r)(\bar{u}_s$ $\gamma_{\mu}d_r)(\bar{d}_s$ $\gamma_{\mu}e_r)(\bar{u}_s$ $\gamma_{\mu}e_r)(\bar{d}_s$ $\gamma_{\mu}u_r)(\bar{d}_s$	$\gamma^{\mu}e_t$) $\gamma^{\mu}u_t$) $\gamma^{\mu}d_t$) $\gamma^{\mu}u_t$) $\gamma^{\mu}u_t$)	Q_{lu} Q_{ld} Q_{qe} $Q_{qg}^{(1)}$ $Q_{qg}^{(2)}$ $Q_{qg}^{(2)}$ $Q_{qd}^{(2)}$	(((((((((($\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$	$s_{\sigma}^{\gamma \mu} e_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} T^{A} u_{t}$) $s_{\sigma}^{\gamma \mu} T^{A} u_{t}$)	
$Q_{qq}^{(1)}$ $Q_{qq}^{(3)}$ $Q_{lq}^{(1)}$	$\begin{split} & (\bar{l}_{j} \gamma_{\mu} l_{\tau}) (\bar{l}_{s} \gamma^{\mu} l_{t}) \\ & (\bar{q}_{p} \gamma_{\mu} q_{r}) (\bar{q}_{s} \gamma^{\mu} q_{t}) \\ & (\bar{q}_{p} \gamma_{\mu} \tau^{\dagger} q_{r}) (\bar{q}_{s} \gamma^{\mu} \tau^{\dagger} q_{t}) \\ & (\bar{l}_{p} \gamma_{\mu} l_{\tau}) (\bar{q}_{s} \gamma^{\mu} q_{t}) \end{split}$	Q_{uu} Q_{dd} Q_{eu} Q_{od} $Q_{ud}^{(1)}$	$(\bar{e}_p\gamma)$ $(\bar{u}_p\gamma)$ $(\bar{d}_p\gamma)$ $(\bar{e}_p\gamma)$ $(\bar{e}_p\gamma)$ $(\bar{u}_p\gamma)$	$\gamma_{\mu}e_r)(\bar{e}_s$ $\gamma_{\mu}u_r)(\bar{u}_s$ $\gamma_{\mu}d_r)(\bar{d}_s$ $\gamma_{\mu}e_r)(\bar{u}_s$ $\gamma_{\mu}e_r)(\bar{d}_s$ $\gamma_{\mu}u_r)(\bar{d}_s$	$\gamma^{\mu}e_t$) $\gamma^{\mu}u_t$) $\gamma^{\mu}u_t$) $\gamma^{\mu}u_t$) $\gamma^{\mu}u_t$) $\gamma^{\mu}d_t$) $\gamma^{\mu}d_t$)	Q_{lu} Q_{ld} Q_{qe} $Q_{qx}^{(1)}$ $Q_{qx}^{(8)}$ $Q_{qx}^{(8)}$	(((((((((($\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$	$s_{\sigma}\gamma^{\mu}e_{t}$) $s_{\sigma}\gamma^{\mu}u_{t}$) $s_{\sigma}\gamma^{\mu}u_{t}$) $s_{\sigma}\gamma^{\mu}u_{t}$) $s_{\sigma}\gamma^{\mu}v_{t}$) $s_{\sigma}\gamma^{\mu}T^{A}u_{t}$)	
$Q_{qq}^{(1)}$ $Q_{qq}^{(3)}$ $Q_{lq}^{(1)}$	$\begin{split} & (\bar{l}_{j} \gamma_{\mu} l_{\tau}) (\bar{l}_{s} \gamma^{\mu} l_{t}) \\ & (\bar{q}_{p} \gamma_{\mu} q_{r}) (\bar{q}_{s} \gamma^{\mu} q_{t}) \\ & (\bar{q}_{p} \gamma_{\mu} \tau^{\dagger} q_{r}) (\bar{q}_{s} \gamma^{\mu} \tau^{\dagger} q_{t}) \\ & (\bar{l}_{p} \gamma_{\mu} l_{\tau}) (\bar{q}_{s} \gamma^{\mu} q_{t}) \end{split}$	Q_{uu} Q_{dd} Q_{cu} Q_{cd} $Q_{nd}^{(1)}$ $Q_{ud}^{(8)}$	$ \begin{array}{c} (\bar{e}_p \gamma \\ (\bar{u}_p \gamma \\ (\bar{d}_p \gamma \\ (\bar{e}_v \gamma \\ (\bar{e}_p \gamma \\ (\bar{u}_p \gamma \mu T))))))))))))))))))))))))))))))))$	$\gamma_{\mu} e_r)(\bar{e}_s$ $\gamma_{\mu} u_r)(\bar{u}_s$ $\gamma_{\mu} d_r)(\bar{d}_s$ $\gamma_{\mu} e_r)(\bar{d}_s$ $\gamma_{\mu} e_r)(\bar{d}_s$ $\gamma_{\mu} u_r)(\bar{d}_s$	$\gamma^{\mu}e_t$) $\gamma^{\mu}u_t$) $\gamma^{\mu}u_t$) $\gamma^{\mu}u_t$) $\gamma^{\mu}u_t$) $\gamma^{\mu}d_t$) $\gamma^{\mu}d_t$)	Q_{lu} Q_{ld} Q_{qe} $Q_{qe}^{(1)}$ $Q_{qg}^{(2)}$ $Q_{qd}^{(2)}$ $Q_{qd}^{(3)}$ $Q_{qd}^{(8)}$ $Q_{qd}^{(8)}$	(((((((((($\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$	$s_{\sigma}^{\gamma\mu}e_{t})$ $s_{\sigma}^{\gamma\mu}u_{t})$ $s_{\sigma}^{\gamma\mu}u_{t})$ $s_{\sigma}^{\gamma\mu}u_{t})$ $s_{\sigma}^{\gamma\mu}u_{t})$ $s_{\sigma}^{\gamma\mu}n_{t})$ $s_{\sigma}^{\gamma\mu}T^{A}u_{i})$	
$Q_{qq}^{(1)}$ $Q_{qq}^{(3)}$ $Q_{lq}^{(1)}$	$\begin{split} & (\vec{l}_{p} \gamma_{\mu} l_{\tau}) (\vec{l}_{n} \gamma^{\mu} l_{t}) \\ & (\vec{q}_{p} \gamma_{\mu} q_{\tau}) (\vec{q}_{n} \gamma^{\mu} q_{t}) \\ & (\vec{q}_{p} \gamma_{\mu} \tau^{i} q_{r}) (\vec{q}_{n} \gamma^{\mu} \tau^{i} q_{t}) \\ & (\vec{q}_{p} \gamma_{\mu} l_{\tau}) (\vec{q}_{n} \gamma^{\mu} q_{t}) \\ & (\vec{l}_{p} \gamma_{\mu} \tau^{i} l_{\tau}) (\vec{q}_{n} \gamma^{\mu} \tau^{i} q_{t}) \end{split}$	Q_{uu} Q_{dd} Q_{cu} Q_{cd} $Q_{nd}^{(1)}$ $Q_{ud}^{(8)}$ $Q_{ud}^{(8)}$ $\tilde{t}L) + h.$	$\langle \bar{e}_p \gamma$ $\langle \bar{u}_p \gamma$ $\langle \bar{d}_p \gamma$ $\langle \bar{e}_p \gamma$ $\langle \bar{e}_p \gamma$ $\langle \bar{u}_p \gamma_{\mu} T$ $\langle \bar{u}_p \gamma_{\mu} T$	$\gamma_{\mu} e_r)(\bar{e}_s$ $\gamma_{\mu} u_r)(\bar{u}_s$ $\gamma_{\mu} d_r)(\bar{d}_s$ $\gamma_{\mu} e_r)(\bar{d}_s$ $\gamma_{\mu} e_r)(\bar{d}_s$ $\gamma_{\mu} u_r)(\bar{d}_s$	$\gamma^{\mu} e_t$) $\gamma^{\mu} u_t$) $\gamma^{\mu} d_t$) $\gamma^{\mu} u_t$) $\gamma^{\mu} d_t$) $\gamma^{\mu} d_t$) $\gamma^{\mu} T^A d_t$)	Q_{lu} Q_{ld} Q_{qe} $Q_{qx}^{(1)}$ $Q_{qx}^{(2)}$ $Q_{qy}^{(8)}$ $Q_{qd}^{(8)}$ $Q_{qd}^{(8)}$ $Q_{qd}^{(8)}$ + h.c.	(((((((((($\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$	$s_{\sigma}^{\gamma \mu} e_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} T^{A} u_{t}$) $s_{\sigma}^{\gamma \mu} T^{A} u_{t}$)	
$Q_{qq}^{(1)}$ $Q_{qq}^{(3)}$ $Q_{lq}^{(1)}$	$\frac{(\tilde{l}_{p}\gamma_{p}l_{r})(\tilde{l}_{n}\gamma^{\mu}l_{t})}{(\tilde{q}_{p}\gamma_{p}q_{r})(\tilde{q}_{n}\gamma^{\mu}q_{t})}$ $\frac{(\tilde{q}_{p}\gamma_{p}q_{r})(\tilde{q}_{n}\gamma^{\mu}q_{t})}{(\tilde{q}_{p}\gamma_{p}r^{\dagger}q_{r})(\tilde{q}_{n}\gamma^{\mu}r^{\dagger}q_{t})}$ $\frac{(\tilde{r}_{p}\gamma_{p}l_{r})(\tilde{q}_{n}\gamma^{\mu}q_{t})}{(\tilde{l}_{p}\gamma_{p}q_{r})(\tilde{q}_{n}\gamma^{\mu}r^{\dagger}q_{t})}$ $\frac{S:(\tilde{L}R)(l)}{1}$	Q_{uu} Q_{dd} Q_{cu} Q_{cd} $Q_{nd}^{(1)}$ $Q_{ud}^{(8)}$ $Q_{ud}^{(8)}$ $\tilde{t}L) + h.$	$(\overline{e}_{p}\gamma)$ $(\overline{d}_{p}\gamma)$ $(\overline{d}_{p}\gamma)$ $(\overline{e}_{p}\gamma)$ $(\overline{e}_{p}\gamma)$ $(\overline{u}_{p}\gamma_{u}T)$ $(\overline{u}_{p}\gamma_{u}T)$ $(\overline{u}_{j}\gamma)$ $\overline{Q}_{q}^{(i)}$	$\gamma_{\mu} e_r)(\bar{e}_s$ $\gamma_{\mu} u_r)(\bar{u}_s$ $\gamma_{\mu} u_r)(\bar{u}_s$ $\gamma_{\mu} e_r)(\bar{u}_s$ $\gamma_{\mu} e_r)(\bar{d}_s$ $\gamma_{\mu} u_r)(\bar{d}_s$ $e^{iA} u_r)(\bar{d}_s$ $8 : (\bar{I})^{(1)}$ rugel	$\gamma^{\mu} e_t$) $\gamma^{\mu} u_t$) $\gamma^{\mu} u_t$) $\gamma^{\mu} u_t$) $\gamma^{\mu} u_t$) $\gamma^{\mu} d_t$) $\gamma^{\mu} d_t$) $\gamma^{\mu} T^A d_t$) $\overline{t} R)(\overline{L}R)$ -	Q_{lu} Q_{ld} Q_{qq} Q_{qq} Q_{qq} Q_{qq} Q_{qd} Q_{qd} Q_{qd} Q_{qd} $k + h.c.$ $k(\bar{q}_{s}^{k}d_{t})$	(((((((((($\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$	$s_{\sigma}^{\gamma \mu} e_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} T^{A} u_{t}$) $s_{\sigma}^{\gamma \mu} T^{A} u_{t}$)	
$Q_{qq}^{(1)}$ $Q_{qq}^{(3)}$ $Q_{tq}^{(1)}$	$\frac{(\tilde{l}_{p}\gamma_{p}l_{r})(\tilde{l}_{n}\gamma^{\mu}l_{t})}{(\tilde{q}_{p}\gamma_{p}q_{r})(\tilde{q}_{n}\gamma^{\mu}q_{t})}$ $\frac{(\tilde{q}_{p}\gamma_{p}q_{r})(\tilde{q}_{n}\gamma^{\mu}q_{t})}{(\tilde{q}_{p}\gamma_{p}r^{\dagger}q_{r})(\tilde{q}_{n}\gamma^{\mu}r^{\dagger}q_{t})}$ $\frac{(\tilde{r}_{p}\gamma_{p}l_{r})(\tilde{q}_{n}\gamma^{\mu}q_{t})}{(\tilde{l}_{p}\gamma_{p}q_{r})(\tilde{q}_{n}\gamma^{\mu}r^{\dagger}q_{t})}$ $\frac{S:(\tilde{L}R)(l)}{1}$	Q_{uu} Q_{dd} Q_{cu} Q_{cd} $Q_{nd}^{(1)}$ $Q_{ud}^{(8)}$ $Q_{ud}^{(8)}$ $\tilde{t}L) + h.$	$(\bar{v}_p \gamma (\bar{u}_p \gamma (\bar{v}_p \gamma (\bar{v}) \gamma (\bar{v}_p \gamma (\bar{v}$	$\frac{\gamma_{\mu}e_r)(\bar{e}_s}{\gamma_{\mu}u_r)(\bar{u}_s}$ $\frac{\gamma_{\mu}u_r)(\bar{u}_s}{\gamma_{\mu}d_r)(\bar{d}_s}$ $\frac{\gamma_{\mu}e_r)(\bar{u}_s}{\gamma_{\mu}e_r)(\bar{d}_o}$ $\frac{\gamma_{\mu}u_r)(\bar{d}_s}{\gamma_{\mu}u_r)(\bar{d}_s}$ $\frac{8:(\bar{I})^{(1)}}{\gamma_{\mu}u_r}$	$\gamma^{\mu} e_t$) $\gamma^{\mu} u_t$) $\gamma^{\mu} u_t$) $\gamma^{\mu} u_t$) $\gamma^{\mu} u_t$) $\gamma^{\mu} u_t$) $\gamma^{\mu} d_t$) $\gamma^{\mu} T^A d_t$) $(\bar{t} R) (\bar{L} R) \cdot (\bar{t} R) \cdot (\bar{t} R)$	Q_{lu} Q_{ld} Q_{qx} $Q_{qx}^{(1)}$ Q_{qx} $Q_{qx}^{(2)}$ $Q_{qx}^{(8)}$ $Q_{qd}^{(8)}$ $Q_{qd}^{(8)}$ $k(\bar{q}_{s}^{k}d_{t})$	(((((((((($\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu l_r})(\overline{e}$ $\overline{l_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$ $\overline{q_p \gamma_\mu q_r})(\overline{e}$	$s_{\sigma}^{\gamma \mu} e_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} u_{t}$) $s_{\sigma}^{\gamma \mu} T^{A} u_{t}$) $s_{\sigma}^{\gamma \mu} T^{A} u_{t}$)	

2499 baryon number conserving dim. 6 operators in total

Grzadkowski et al. 1008.4884, Alonso et al 1312.2014

4 fermion interactions

dipole transitions

Z-penguins

	$1: X^{3}$		I^6	$3 : H^4D^2$				$5: \psi^2 H^3 + h.c.$		
Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_H (1	$(H^{\dagger}H)^{3}$	$Q_{H\square}$	(H^{\dagger})	$H)\Box(H^{\dagger}H)$	I)	$Q_{eH} = (H^{\dagger}H)(\bar{l}_{p}e, H)$		
$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$			Q_{HD}	$(H^{\dagger}D_{\mu}$	$H)^{*}(H^{*})$	$D_{\mu}H)$	$Q_{uH} = (H^{\dagger}H)(\bar{q}_{p}u_{r}\tilde{H})$		
Q_W	$\epsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$							$Q_{dH} = (H^{\dagger}H)(\bar{q}_p d_r H)$		
$Q_{\widetilde{W}}$	$\epsilon^{IJK} \widetilde{W}^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$							<u> </u>		
	$4:X^2H^2$	6	$\psi^2 X H$	+ h.c.			7	: $\psi^{2}H^{2}D$		
Q_{HG}	$H^{\dagger}HG^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu})$	$e_r)\tau^I III$	$V^{I}_{\mu\nu}$	$Q_{H_{1}}^{(1)}$		$(H^{\dagger}i\overleftrightarrow{D}_{\mu}H)(\bar{l}_{p}\gamma^{\mu}l_{\tau})$		
$Q_{H\widetilde{G}}$	$H^{\dagger}H\widetilde{G}^{A}_{\mu u}G^{A\mu u}$	Q_{zB}	$(\bar{l}_p \sigma^\mu$	$\nu e_r)HB$	1.00	$Q_{H_{1}}^{(3)}$		$(H^{\dagger}i\overleftrightarrow{D}{}^{I}_{\mu}H)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})=$		
Q_{HW}	$H^{\dagger}H W^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_{p}\sigma^{\mu\nu})$	$({}^{A}u_{r})\tilde{H}$	$G^A_{\mu\nu}$	Q_{He}		$(H^{\dagger}i\overleftrightarrow{D}_{\mu}H)(\ddot{e}_{p}\gamma^{\mu}e_{r})$		
$Q_{H\widetilde{W}}$	$H^{\dagger}H \widetilde{W}^{I}_{\mu\nu} W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_{\rm F}\sigma^{\mu u})$	$u_r)\tau^I \tilde{H}$	$W^{I}_{\mu\nu}$	$Q_{Hq}^{(1)}$		$(H^{\dagger}i\overleftrightarrow{D}_{\mu}H)(\bar{q}_{p}\gamma^{\mu}q_{r})$		
Q_{HB}	$H^{-}H B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu})$	$v u_r) \tilde{H} I$	3,10	$Q_{Hg}^{(3)}$		$(H^{\dagger}i \overleftrightarrow{D}_{\mu}^{I} H)(\bar{q}_{p} \tau^{I} \gamma^{\mu} q_{r})$		
$Q_{H\widetilde{B}}$	$H^{*}H \tilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu})$	$T^A d_r)H$	$G^A_{\mu\nu}$	Q_{Hu}		$(H^{\dagger}i\overleftrightarrow{D}_{\mu}H)(\bar{u}_{p}\gamma^{\mu}u_{r})$		
Q_{HWB}	$H^{\dagger}\tau^{I}HW^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu \nu} \sigma^{\mu} $	$(l_r)\tau^l H$	$W^{I}_{\mu\nu}$	Q_{Ha}		$(H^{\dagger}i\overleftrightarrow{D}_{\mu}H)(\bar{d}_{p}\gamma^{\mu}d_{r})$		
$Q_{H\widetilde{W}E}$	$H^{\dagger}\tau^{I}H\widetilde{W}^{I}_{\mu\nu}B^{\mu\nu}$	Q_{AB}	$(\bar{q}_{\nu}\sigma^{\mu}$	$(d_r)HE$	$\beta_{\mu\nu}$	Q_{Hud} +	h.c.	$i(\widetilde{H}^{*}D_{\mu}H)(\bar{u}_{p}\gamma^{\mu}d_{r})$		
	$8:(\bar{L}L)(\bar{L}L)$		8:(4	$\bar{R}R)(\bar{R}I$	2)		8:($\bar{L}L)(\bar{R}R)$		
Q_{11}	$(\bar{l}_p \gamma_\mu l_r) (\bar{l}_s \gamma^\mu l_t)$	Q_{ee}	(ē ₁	$\gamma_{\mu}e_{r})(\bar{e}$	$s\gamma^{\mu}e_t)$	Q_{lv}	()	$_{p}\gamma_{\mu}l_{\tau})(\bar{e}_{s}\gamma^{\mu}e_{t})$		
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	Q_{uu}	(ū,	$\gamma_{\mu}u_r)(i$	$i_s \gamma^{\mu} u_t$)	Q_{lu}	(\bar{l})	$_{\mu}\gamma_{\mu}i_{\tau})(\bar{u}_{s}\gamma^{\mu}u_{t})$		
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^J q_r)(\bar{q}_s \gamma^\mu \tau^J q_t)$	Q_{dd}	(\bar{d}_i)	$(\gamma_{\mu}d_r)(c$	$i_s \gamma^{\mu} d_t$	Q_{Id}	(1	$_{p}\gamma_{\mu}l_{r})(\bar{d}_{s}\gamma^{\mu}d_{t})$		
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_i)$	Q_{eu}	(\bar{e}_{t})	$\gamma_{\mu}e_{\tau})(\bar{u}$	$_{s}\gamma^{\mu}u_{t})$	Q_{qe}	$(\bar{q}$	$(\bar{v}_s \gamma_\mu q_r)(\bar{v}_s \gamma^\mu v_t)$		
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau' l_r)(\bar{q}_s \gamma^\mu \tau^I q_i)$	Q_{cd}	$(\bar{e}_i$	$\gamma_{\mu}e_{r})(\dot{a}$	$(\sigma \gamma^{\mu} d_t)$	$Q_{q_{2}}^{(1)}$	$(\bar{q}$	$_{p}\gamma_{\mu}q_{r})(\bar{u}_{s}\gamma^{\mu}u_{t})$		
		$Q_{nd}^{(1)}$	(<i>ū</i> ₁	$\gamma_{\mu}u_r)(\dot{\epsilon}$	$l_s \gamma^{\mu} d_t$)	$Q_{qu}^{(8)}$	$(\bar{q}_p \gamma_\mu$	$T^A q_r)(\bar{u}_s \gamma^{\mu} T^A u_i)$		
		$Q_{ud}^{(8)}$	$(\bar{u}_p \gamma_\mu)$	$T^A u_r)(\dot{c}$	$\bar{l}_s \gamma^{\mu} T^A d_i$)	$Q_{qd}^{(1)}$	(ą	$p\gamma_{\mu}q_{r})(\bar{d}_{s}\gamma^{\mu}d_{t})$		
						$Q_{qd}^{(8)}$	$(\bar{q}_p\gamma_p$	$T^A q_r)(\bar{d}_s \gamma^{\mu} T^A d_t)$		
	$8 : (\bar{L}R)($	$\bar{R}L$) + h.		8:	$(\bar{L}R)(\bar{L}R)$	+ h.c.				
	Q_{ledg} (1	$(\bar{d}_s q_t)$	i) 4	quqd	$(\bar{q}_p^j u_r)e$	$_{ik}(\bar{q}_{s}^{k}d_{t})$				
			4	(8) gugd	$(\bar{q}_p^j T^A u_r) \epsilon_j$	$_{ik}(\bar{q}_s^kT^Ad_i$)			
			6	$2_{lequ}^{(1)}$	$(\bar{l}_{p}^{j}e_{r})\epsilon_{j}$	$_{k}(\bar{q}_{s}^{k}u_{t})$				

 $Q_{legu}^{(3)} = (\tilde{l}_{p}^{j}\sigma_{\mu\nu}e_{r})\epsilon_{jk}(\bar{q}_{s}^{k}\sigma^{\mu\nu}u_{t})$

2499 baryon number conserving dim. 6 operators in total

Grzadkowski et al. 1008.4884, Alonso et al 1312.2014

4 fermion interactions

dipole transitions

Z-penguins

Higgs penguins

	$1: X^3$	2:I	T_{θ}	$3: H^4D^2$				$5: \psi^2 H^3 + h.c.$		
Q_G	$\int^{ABC} G^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	Q_H (1	$H^{\dagger}H)^{3}$	$Q_{H\square}$	$2_{H\square}$ $(H^{\dagger}H)\square(H^{\dagger}H)$			Q_{eH}	$(H^{\dagger}H)(\bar{l}_{p}e,H)$	
$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	·		Q_{HD}	$(H^{\dagger}D_{\mu}$	$H)^{*}(H^{*}I)$	$\partial_{\mu}H)$	Q_{uff}	$(H^{+}H)(\bar{q}_{p}u_{r}\widetilde{H})$	
Q_W	$\epsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$							Q_{dH}	$(H^{\dagger}H)(\bar{q}_p d_r H)$	
$Q_{\tilde{W}}$	$\epsilon^{IJK} \widetilde{W}^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$									
	$4:X^2H^2$	6	$: \psi^2 X H$	+ h.c.			7	$: \psi^2 H^2$	D	
Q_{HC}	$H^{\dagger}HG^{A}_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} \epsilon$	$(\tau)\tau^{I}HW$	$\frac{71}{\mu\nu}$	$Q_{H!}^{(1)}$		$(\Pi^{\dagger}i^{\dagger})$	$\vec{\mathcal{D}}_{\mu} II (\bar{l}_{p} \gamma^{\mu} l_{\tau})$	
$Q_{H\widetilde{G}}$	$H^{\dagger}H \widetilde{G}^{A}_{\mu\nu} G^{A\mu\nu}$	Q_{zB}	$(\bar{l}_p \sigma^{\mu i}$	$(e_\tau)HB_\mu$	æ	$Q_{H!}^{(3)}$		$(H^{\dagger}i\overleftarrow{D}$	${}^{I}_{\mu}H)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$	
Q_{HW}	$H^{\dagger}H W^{I}_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_{p}\sigma^{\mu\nu}T)$	$(A_{v_r})\tilde{H}$	$G^A_{\mu\nu}$	Q_{He}		$(H^{\dagger}i\dot{T}$	$\vec{D}_{\mu}H)(\bar{e}_{p}\gamma^{\mu}e_{r})$	
$Q_{H\widetilde{W}}$	$H^{\dagger}H \widetilde{W}^{I}_{\mu\nu} W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_{\rm F}\sigma^{\mu\nu}u$	$(r)\tau^I \hat{H} V$	$V^{I}_{\mu\nu}$	$Q_{Hq}^{(1)}$		$(H^{\dagger}i\overset{\leftarrow}{I}$	$\overrightarrow{\partial}_{\mu}H)(\overline{q}_{p}\gamma^{\mu}q_{r}) =$	
Q_{HB}	$H^{-}H B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tilde{H} B_{\mu\nu}$			$Q_{Hq}^{(3)}$			${}^{I}_{\mu}H)(\bar{q}_{\rho}\tau^{I}\gamma^{\mu}q_{\tau})$	
$Q_{H\widetilde{B}}$	$H^*H \tilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_{p}\sigma^{\mu u}T^{A}d_{r})HG^{A}_{\mu u}$			Q_{Hu}		$(H^{\dagger}i\overleftarrow{I}$	$\dot{\vec{D}}_{\mu}H)(\bar{u}_p\gamma^{\mu}u_{\tau})$	
Q_{HWB}		Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I H W^I_{\mu\nu}$			Q_{Hd}	Q_{Hd}		$\vec{D}_{\mu}H)(\bar{d}_{p}\gamma^{\mu}d_{r})$	
$Q_{H\widetilde{W}E}$	$H^{\dagger}\tau^{I}H \widetilde{W}^{I}_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar{q}_{\nu}\sigma^{\mu i}$	$(d_r)HB_i$	uv	Q_{Hud} +	h.c.	$i(\widetilde{H}^*I$	$(\bar{u}_p \gamma^\mu d_r)$	
	$8:(\bar{L}L)(\bar{L}L)$	_	8 : (İ	$\bar{R}R)(\bar{R}R$)		8:1	$(\bar{L}L)(\bar{R}I)$	1)	
Q_{1l}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p$	$\gamma_{\mu} e_r)(\bar{e}_s$	$\gamma^{\mu}e_t$)	Q_{lv}	6	$(p\gamma_{\mu}l_{\tau})(\dot{\epsilon}$	$_{s}\gamma^{\mu}e_{t})$	
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_p$	$\gamma_{\mu}u_r)(\bar{u}_i$	$\gamma^{\mu}u_{t})$	Q_{lu}	(1	$_{p}\gamma_{\mu}i_{\tau})(i$	$_{s}\gamma^{\mu}u_{t})$	
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^j q_r)(\bar{q}_s \gamma^\mu \tau^j q_l)$	Q_{dd}	$(\bar{d}_p$	$\gamma_{\mu}d_r)(\bar{d}_c$	$\gamma^{\mu}d_{t})$	Q_{ld}	(1	$p_{\mu}\gamma_{\mu}l_{\tau})(c$	$(_{s}\gamma^{\mu}d_{t})$	
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_i)$	Q_{eu}	$(\bar{e}_p$	$\gamma_{\mu}e_{\tau})(\bar{u}_{s}$	$\gamma^{\mu}u_{l})$			$(p\gamma_{\mu}q_{r})($	$\bar{\epsilon}_s \gamma^{\mu} v_t$)	
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau' l_r)(\bar{q}_s \gamma^\mu \tau^I q_i)$	Q_{cd}	1	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$				$_{p}\gamma_{\mu}q_{r})(i$	$i_s \gamma^{\mu} u_t$)	
			1	$\gamma_{\mu}u_r)(\bar{d}_i$				$_{\mu}T^{A}q_{r})(\bar{u}_{s}\gamma^{\mu}T^{A}u_{i})$		
		$Q_{ud}^{(8)}$	$(\bar{u}_p \gamma_\mu)$	$(^{A}u_{r})(\bar{d}_{r})$	$\gamma^{\mu}T^{A}d_{i})$	$Q_{qd}^{(1)}$		$(q_p \gamma_\mu q_r)(q_r)$		
						$Q_{qd}^{(8)}$	$(\bar{q}_p \gamma_t$	$T^A q_r)(e$	$\bar{l}_s \gamma^{\mu} T^A d_t$	
	$8 : (\bar{L}R)(\bar{L}R)$	$\bar{R}L$) + h.	c.	8:($\bar{L}R)(\bar{L}R)$	+ h.c.				
	Q_{ledq} (\bar{l}	$(\bar{d}_s q_t)(\bar{d}_s q_t)$	i) Q	(1) quqd	$(\bar{q}_p^j u_r)e$	$_{jk}(\bar{q}_{s}^{k}d_{t})$	_			
			Q	(8) gugd ($\bar{q}_p^j T^A u_r) \epsilon_j$	$_{jk}(\bar{q}_{s}^{k}T^{A}d_{t}$)			
				$Q_{lequ}^{(1)} = (\bar{l}_{p}^{j}e_{r})\epsilon_{jk}(\bar{q}_{s}^{k}u_{i})$						
			Q	lega	$(l_p^j e_r) \epsilon_j$	$k(q_s^n u_t)$				

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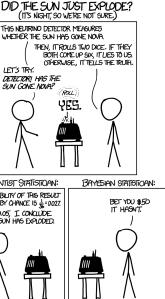
"Leave no stone unturned" = probe as many operators as possible

Guidance from Anomalies?

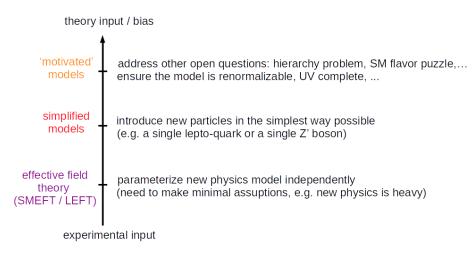
 $\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-) \ [1.1, 6.0]$ $\mathcal{B}(B^+ \to K^+ e^+ e^-)$ [1.1, 6.0] $\mathcal{B}(B^+ \to K^+ \nu \bar{\nu})$ - $\begin{array}{c} \mathcal{B}(B^0_s \to \phi \mu^+ \mu^-) \ [1.1, 6.0] \\ \mathcal{B}(B^0_s \to \mu^+ \mu^-) \\ \mathcal{B}(B^0 \to \mu^+ \mu^-) \end{array}$ $P'_5(B^0 \to K^{*0} \mu^+ \mu^-)$ [2.5, 4.0] $P_5'(B^0 \to K^{*0} \mu^+ \mu^-)$ [4.0, 6.0] R_K [0.1, 1.1] - R_K [1.1, 6.0] - $R_{K_s^0}$ [1.1, 6.0] - $R_{K^{*0}}$ [0.1, 1.1] $R_{K^{*0}}$ [1.1, 6.0] - $R_{K^{*+}}$ [0.045, 6.0] - R_{pK} [0.1, 6.0] -Muon q - 2 (WP) – Muon q = 2 (BMW) -R(D) - $R(D^*)$ $R(J/\psi)$ - $R(\Lambda_c^+) = \mathcal{B}(B^+ \to \tau^+ \nu) =$ Δm_d Δm_{*} $\dot{2}$ ŝ. 5 0 6 Pull in σ

Establishing Anomalies

LET'S TRY. DETECTOR! HAS THE SUN GONE NOVA? (ROLL) YÊŜ Extraordinary claims require extraordinary evidence. FREQUENTIST STATISTICIAN: THE PROBABILITY OF THIS RESULT HAPPENING BY CHANCE IS 1 = 0.027. SINCE P<0.05, I CONCLUDE THAT THE SUN HAS EXPLODED.

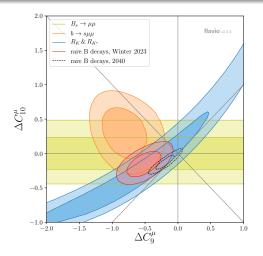


Bottom-Up Approach to Anomalies



(inspired by Marco Nardecchia)

Example: Current Status of $b \rightarrow s\ell\ell$ Anomalies



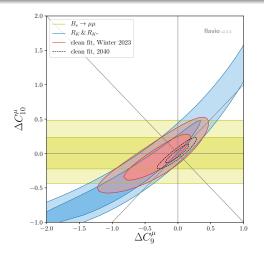
WA, Gadam, Profumo 2306.15017

(also Greljo et al. 2212.10497; Ciuchini et al. 2212.10516; Alguero et al. 2304.07330; Guadagnoli et al. 2308.00034; ...) $\Delta C_9^{\mu}(\bar{s}\gamma_{\alpha}P_Lb)(\bar{\mu}\gamma^{\alpha}\mu)$

 $\Delta C^{\mu}_{10}(\bar{s}\gamma_{\alpha}P_{L}b)(\bar{\mu}\gamma^{\alpha}\gamma_{5}\mu)$

- LFU ratios in agreement with SM
- ► $B_s \rightarrow \mu^+ \mu^-$ branching ratio in agreement with SM
- b → sµµ observables (P'₅ and semileptonic BRs) prefer non-standard C₉
- Tensions in the global fit (actually not too terrible...)
 - $\Delta C_9^\mu \simeq -0.53 \pm 0.18$
 - $\Delta C^\mu_{10}\simeq -0.16\pm 0.13$

Approach 1: Ignore $b \rightarrow s \mu \mu$



WA, Gadam, Profumo 2306.15017

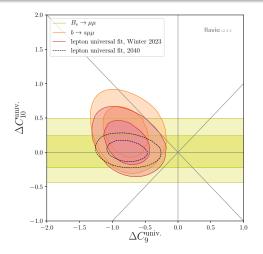
(also Greljo et al. 2212.10497; Ciuchini et al. 2212.10516; Alguero et al. 2304.07330; Guadagnoli et al. 2308.00034; ...) $\Delta C_9^{\mu} (\bar{s} \gamma_{\alpha} P_L b) (\bar{\mu} \gamma^{\alpha} \mu)$ $\Delta C_{10}^{\mu} (\bar{s} \gamma_{\alpha} P_I b) (\bar{\mu} \gamma^{\alpha} \gamma_5 \mu)$

- LFU ratios in agreement with SM
- ► $B_s \rightarrow \mu^+ \mu^-$ branching ratio in agreement with SM
- b → sµµ observables (P'₅ and semileptonic BRs) "fixed" by hadronic physics
- Constraints on muon specific New Physics

$$\Delta C_9^\mu \simeq -0.28 \pm 0.33$$

 $\Delta C^\mu_{10}\simeq -0.07\pm 0.22$

Approach 2: Assume NP is Lepton Universal



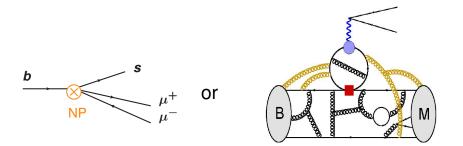


(also Greljo et al. 2212.10497; Ciuchini et al. 2212.10516; Alguero et al. 2304.07330; Guadagnoli et al. 2308.00034; ...) $\Delta C_9^{\text{univ.}}(\bar{s}\gamma_{\alpha}P_Lb)(\bar{\ell}\gamma^{\alpha}\ell)$

 $\Delta C_{10}^{\text{univ.}}(\bar{s}\gamma_{\alpha}P_{L}b)(\bar{\ell}\gamma^{\alpha}\gamma_{5}\ell)$

- LFU ratios don't give constraints
- ► $B_s \rightarrow \mu^+ \mu^-$ branching ratio in agreement with SM
- b → sµµ observables (P'₅ and semileptonic BRs) prefer non-standard C₉
- ~ 3σ preference for new physics in C₉
 - $\Delta C_9^{
 m univ.}\simeq -0.80\pm 0.22$
 - $\Delta C_{10}^{ ext{univ.}} \simeq +0.12 \pm 0.20$

New Physics or Underestimated Hadronic Effects?



It is very difficult to distinguish lepton flavor universal new physics in C_9 from a long distance hadronic effect.

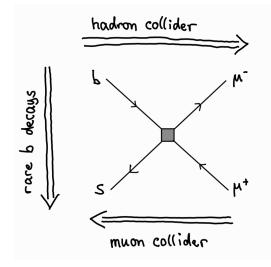
 $\Delta C_9^{\text{univ.}}(\bar{s}\gamma_{\alpha}P_Lb)(\bar{\ell}\gamma^{\alpha}\ell)$

(Inclusive $B \rightarrow X_s \ell \ell$ will be very important!)

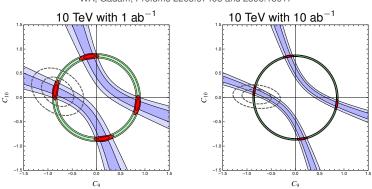
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Flavour and BSM: Quo Vadis?

Probing Hints of New Physics From All Angles



Sensitivity of a Muon Collider



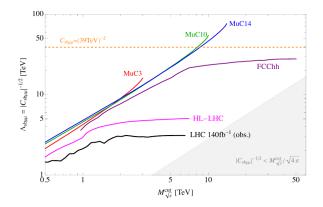
WA, Gadam, Profumo 2203.07495 and 2306.15017

- ▶ Branching ratio (green) and A_{FB} (blue) are complementary.
- ▶ If there is new physics in $b \rightarrow s\ell\ell$, a 10 TeV muon collider would clearly see it, and one does not need to worry about long distance QCD.

(see also Huang et al. 2103.01617; Asadi et al. 2104.05720; Azatov et al. 2205.13552)

Comparing Muon and Hadron Colliders

Azatov et al. 2205.13552



- FCC-hh probes considerably more parameter space than high-luminosity LHC.
- ► The most pessimistic case (only bsµµ operator and nothing else) can only be probed by a high-energy muon collider.

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Beyond Anomalies

- ▶ "Bread and Butter": continue to improve well established probes: e.g. mass differences in meson mixing; $B \to X_s \gamma$; $B_s \to \mu^+ \mu^-$; ...
- requires high precision hadronic matrix elements from the lattice
- requires high precision CKM input (\rightarrow need to sort out V_{cb} and V_{ub} !)

Beyond Anomalies

- ▶ "Bread and Butter": continue to improve well established probes: e.g. mass differences in meson mixing; $B \rightarrow X_s \gamma$; $B_s \rightarrow \mu^+ \mu^-$; ...
- requires high precision hadronic matrix elements from the lattice
- requires high precision CKM input (\rightarrow need to sort out V_{cb} and V_{ub} !)
- Explore new processes where O(1) NP effects are still possible.
- $\rightarrow\,$ obtain qualitatively new information on a new types of processes

Examples for the near future:

- $B \rightarrow K^{(*)} \nu \bar{\nu}$ (new intriguing results from Belle II)
- CP violation in $D^0 \overline{D}^0$ oscillations
- rare kaon decays $K \to \pi \nu \bar{\nu}, ...$
- $b \rightarrow d\ell\ell$ decays

$b ightarrow d\ell\ell$ Decays at LHCb

In the future, expect a $b \rightarrow d\ell\ell$ program that parallels the effort for $b \rightarrow s\ell\ell$ decays

► this includes many processes:

$$\begin{split} B^{0} &\to \mu^{+}\mu^{-} , \quad B^{+} \to \pi^{+}\ell^{+}\ell^{-} , \quad B^{0} \to \pi^{+}\pi^{-}\ell^{+}\ell^{-} , \quad B_{s} \to \mathcal{K}_{s}\ell^{+}\ell^{-} , \\ B_{s} \to \mathcal{K}^{*}(\to \mathcal{K}\pi)\ell^{+}\ell^{-} , \quad \Lambda_{b} \to p\pi\ell^{+}\ell^{-} \end{split}$$

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and many observables:

branching ratios, angular distributions, LFU ratios

$$m{R}_{\pi} = rac{\int_{q^2_{ ext{min}}}^{q^2_{ ext{max}}} dq^2 \; ext{BR}(m{B} o \pi \mu^+ \mu^-)}{\int_{q^2_{ ext{min}}}^{q^2_{ ext{max}}} dq^2 \; ext{BR}(m{B} o \pi m{e}^+ m{e}^-)}$$

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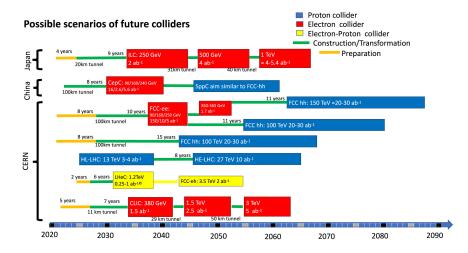
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- ► already existing measurements of $b \rightarrow d$ processes can be used to probe new physics (Rusov 1911.12819; Bause, Gisbert, Golz, Hiller 2209.04457)
- ▶ $b \rightarrow d$ will become the new $b \rightarrow s$ (after high-lumi phase, will have ~ comparable statistics for $b \rightarrow d$ as there is now for $b \rightarrow s$)

Wolfgang Altmannshofer (UCSC)

The Far Future



Circular e^+e^- Colliders are Flavor Factories

Running on the Z pole allows one to probe the flavor structure of Z couplings with extreme precision.

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In addition one gets very large samples of all *b* hadrons, *c* hadrons, τ 's with large boost in a clean environment. Circular e^+e^- Colliders are Flavor Factories

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Running at higher \sqrt{s} can probe e.g. FCNC single top production or lepton flavor violating 4-fermion contact interactions Circular e^+e^- Colliders are Flavor Factories

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Running at higher \sqrt{s} can probe e.g. FCNC single top production or lepton flavor violating 4-fermion contact interactions

 \Rightarrow unique sensitivity to a large number of flavor processes that are not accessible at LHC(b) or Belle II

b Hadrons from 10^{13} *Z* bosons

 $\overline{B^+/B^-}$ B_s^0/\overline{B}_s^0 $B_c^+/\overline{B}_c^ B^0/\overline{B}^0$ Particle production (10^9) $\Lambda_b/\overline{\Lambda}_b$ $c\overline{c}$ $\tau^+\tau^-$ Belle II 27.527.5 n/a n/a n/a 65 45FCC-ee 620 150130170620 4 600

FCC-ee Snowmass Whitepaper 2203.06520

► FCC-ee/CEPC vs. Belle II:

- order of magnitude more B^+ and B^0 , unique opportunities for B_s , B_c , and Λ_b .
- *bb* from Z decays are highly boosted.
- ► FCC-ee/CEPC vs. LHCb:
 - lower yields at e⁺e⁻ colliders, but cleaner environment.
 - much easier access to final states with neutrals (π^0 , γ , neutrinos).

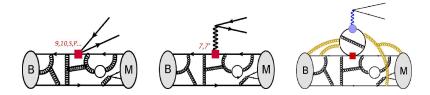
$$B_s \to \tau \tau$$
, $B \to K^* \tau \tau$, $B_s \to \phi \nu \bar{\nu}$, $B_c \to \tau \nu$,...

- ► No guaranteed discoveries anymore.
- ► We are in exploratory mode → "Leave no stone unturned"
- ► Anomalies need to be followed up in every way possible.
- Beyond anomalies, one can expect qualitatively new insights into flavored new physics from a number of processes in the near future.
- ► In the far future, circular e⁺e⁻ colliders could enable a very impactful flavor program.



Back Up

$b \rightarrow s \ell \ell$ Amplitudes



$$\mathcal{A}_{\lambda}^{L,R} = \mathcal{N}_{\lambda} \left\{ (C_9 \mp C_{10}) \mathcal{F}_{\lambda}(q^2) + \frac{2m_b M_B}{q^2} \left[C_7 \mathcal{F}_{\lambda}^{\mathsf{T}}(q^2) - 16\pi^2 \frac{M_B}{m_b} \mathcal{H}_{\lambda}(q^2) \right] \right\} + \mathcal{O}(\alpha^2)$$

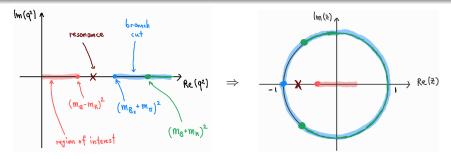
► Local (Form Factors): $\mathcal{F}_{\lambda}^{(T)}(q^2) = \langle \bar{M}_{\lambda}(k) | \bar{s} \Gamma_{\lambda}^{(T)} b | \bar{B}(k+q) \rangle$

► Non-Local : $\mathcal{H}_{\lambda}(q^2) = i \mathcal{P}^{\lambda}_{\mu} \int d^4x \, e^{iq \cdot x} \, \langle \bar{\mathcal{M}}_{\lambda}(k) | T\{j^{\mu}_{em}(x), \mathcal{C}_i \, \mathcal{O}_i(0)\} | \bar{\mathcal{B}}(q+k) \rangle$

(talk by Javier Virto at Flavour@TH workshop, CERN May 11, 2023)

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Parameterization of the Local Form Factors



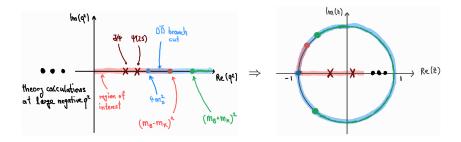
The form factors can be parameterized by a power series in z with bounded coefficients.

Boyd, Grinstein, Lebed hep-ph/9412324; Caprini, Lellouch, Neubert hep-ph/9712417; Bourrely, Caprini, Lellouch 0807.2722; ...

Flynn, Juttner, Tsang 2303.11285; Gubernari, Reboud, van Dyk, Virto 2305.06301

$$\mathcal{F}(q^2) = rac{1}{\mathcal{B}_{\mathcal{F}}(z)\phi_{\mathcal{F}}(z)}\sum_k lpha_k^{\mathcal{F}} p_k^{\mathcal{F}}(z) \ , \quad \sum_{\mathcal{F},k} |lpha_k^{\mathcal{F}}|^2 < 1$$

Parameterization of the Charm Loop



Proposed parameterization analogous to the local form factors.
 Works for q² below the DD branch cut.

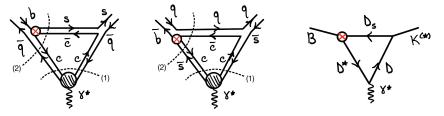
Bobeth, Chrzaszcz, van Dyk, Virto 1707.07305; Gubernari, van Dyk, Virto 2011.09813; Gubernari, Reboud, van Dyk, Virto 2206.03797

$$\mathcal{H}(q^2) = rac{1}{\mathcal{B}_{\mathcal{H}}(z)\phi_{\mathcal{H}}(z)}\sum_k eta_k^{\mathcal{H}} p_k^{\mathcal{H}}(z) \ , \quad \sum_{\mathcal{H},k} |eta_k^{\mathcal{H}}|^2 < 1$$

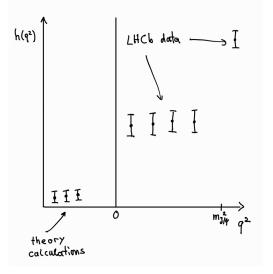
Additional Charm Loop Effects?

► The charm loop also gives "triangle diagrams" involving e.g. intermediate D_sD̄ states

Ciuchini, Fedele, Franco, Paul, Silvestrini, Valli 2212.10516

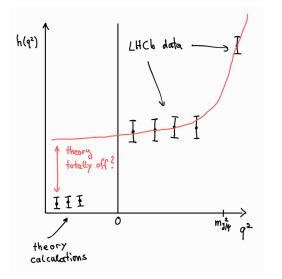


- ▶ E.g. decay $B \rightarrow D_s D^*$ followed by rescattering $D_s D^* \rightarrow K^{(*)} \gamma^*$
- ▶ How disruptive are they to the proposed parameterization?



[Note: This is highly oversimplified]

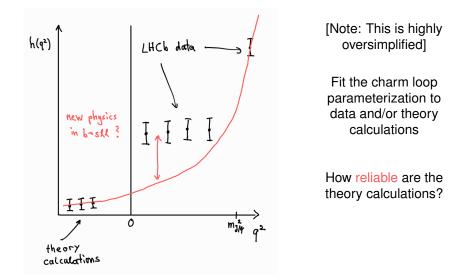
Fit the charm loop parameterization to data and/or theory calculations

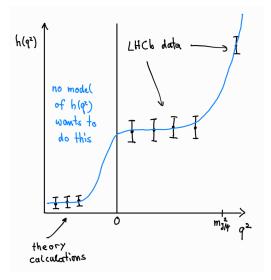


[Note: This is highly oversimplified]

Fit the charm loop parameterization to data and/or theory calculations

How reliable are the theory calculations?





[Note: This is highly oversimplified]

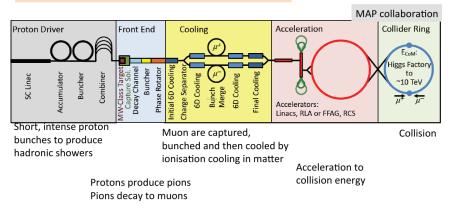
Fit the charm loop parameterization to data and/or theory calculations

How reliable are the theory calculations?

Is the parameterization robust / sufficiently generic?

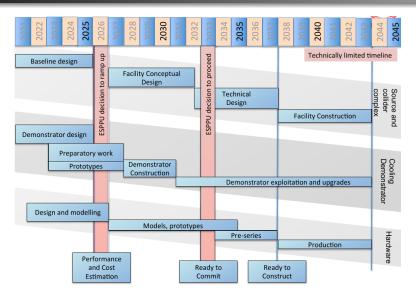
A Muon Collider?

Muon collider design is driven by finite muon lifetime



talk by D. Schulte @ Muon Collider Agora, Feb 16 2022

A Muon Collider!



talk by D. Schulte @ Muon Collider Agora, Feb 16 2022

Wolfgang Altmannshofer (UCSC)