Search For New Physics In Top Quark Sector In EFT

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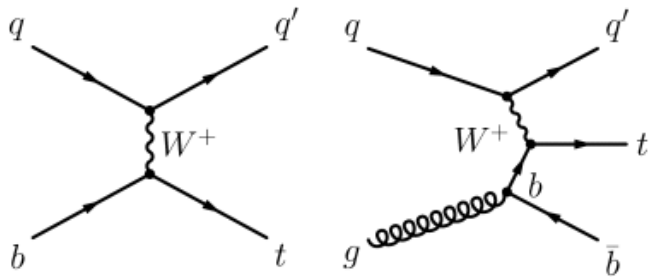
Single top production in the t channel

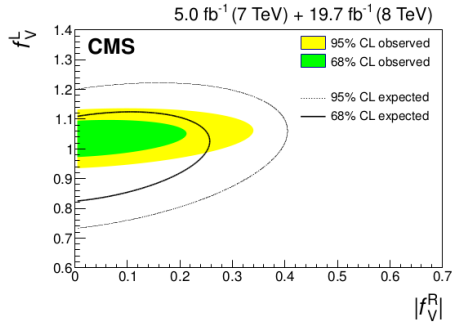
JHEP02(2017)028

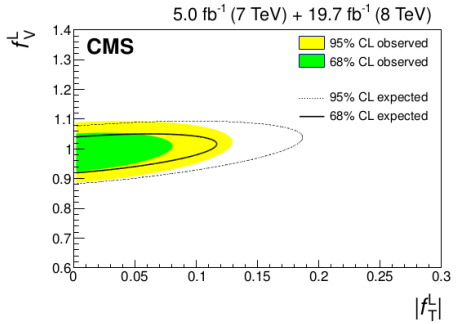
$$\mathfrak{L} = \frac{g}{\sqrt{2}}\bar{\mathrm{b}}\gamma^{\mu}\left(f_{\mathrm{V}}^{\mathrm{L}}P_{\mathrm{L}} + f_{\mathrm{V}}^{\mathrm{R}}P_{\mathrm{R}}\right)\mathrm{t}\mathrm{W}_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{\mathrm{b}}\frac{\sigma^{\mu\nu}\partial_{\nu}\mathrm{W}_{\mu}^{-}}{M_{\mathrm{W}}}\left(f_{\mathrm{T}}^{\mathrm{L}}P_{\mathrm{L}} + f_{\mathrm{T}}^{\mathrm{R}}P_{\mathrm{R}}\right)\mathrm{t} + \mathrm{h.c.}$$

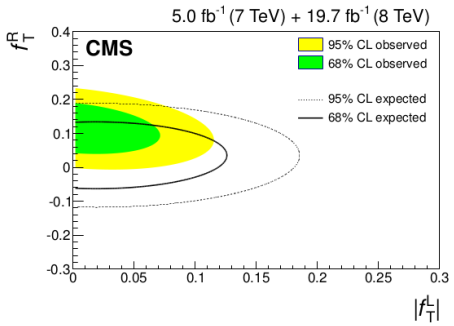


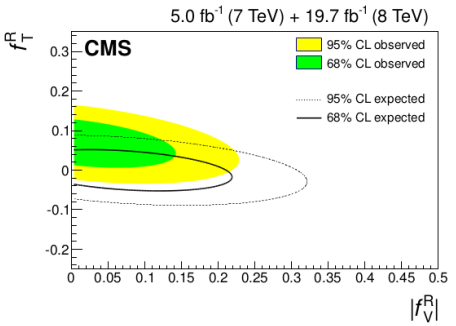
Single top production in the t channel

$$\mathfrak{L} = \frac{g}{\sqrt{2}}\bar{\mathrm{b}}\gamma^{\mu}\left(f_{\mathrm{V}}^{\mathrm{L}}P_{\mathrm{L}} + f_{\mathrm{V}}^{\mathrm{R}}P_{\mathrm{R}}\right)\mathrm{t}\mathrm{W}_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{\mathrm{b}}\frac{\sigma^{\mu\nu}\partial_{\nu}\mathrm{W}_{\mu}^{-}}{M_{\mathrm{W}}}\left(f_{\mathrm{T}}^{\mathrm{L}}P_{\mathrm{L}} + f_{\mathrm{T}}^{\mathrm{R}}P_{\mathrm{R}}\right)\mathrm{t} + \mathrm{h.c.}$$









FCNC

$$\mathfrak{L} = \frac{\kappa_{tqg}}{\Lambda} g_s \bar{q} \sigma^{\mu\nu} \frac{\lambda^a}{2} t G^a_{\mu\nu}$$

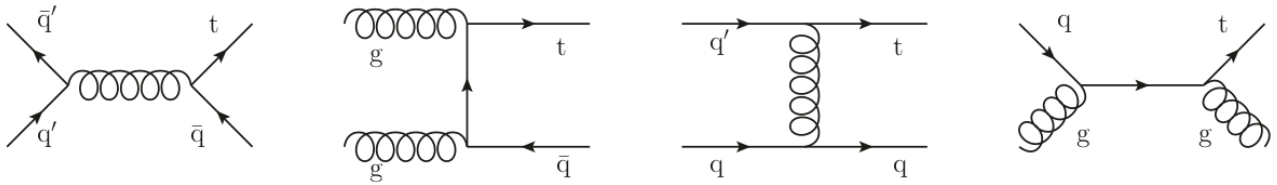
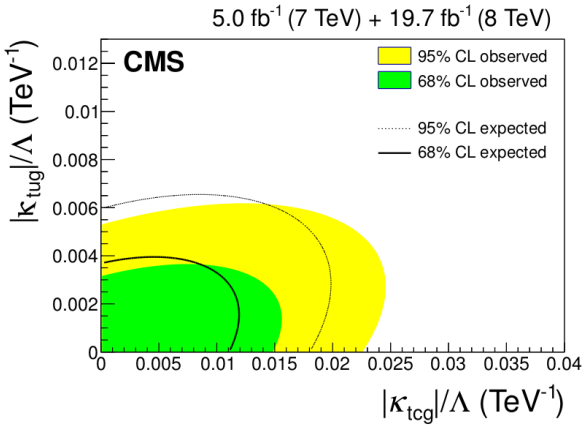
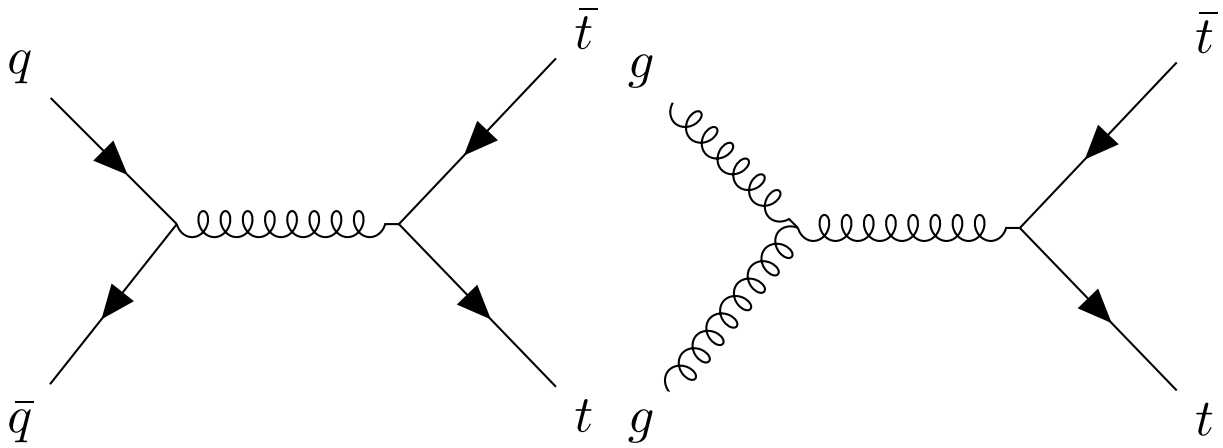


Figure 8. Representative Feynman diagrams for the FCNC processes.



Top Quark Pairs

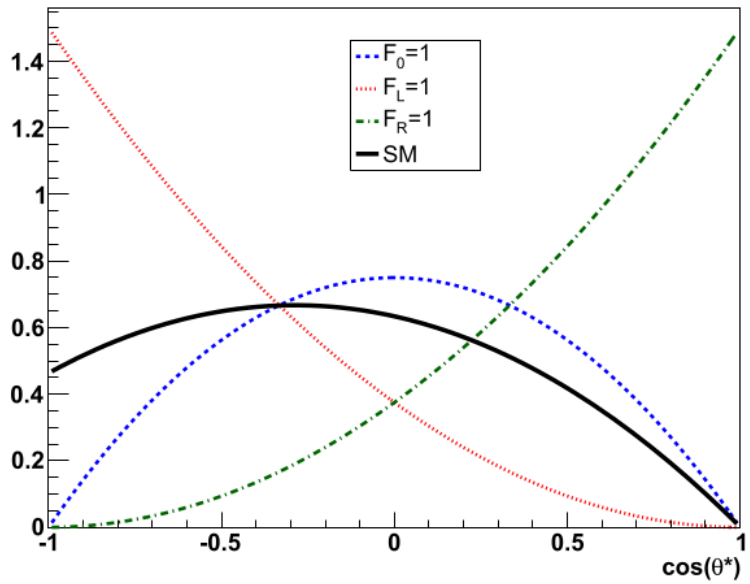
Physics Letters B 762 (2016) 512534

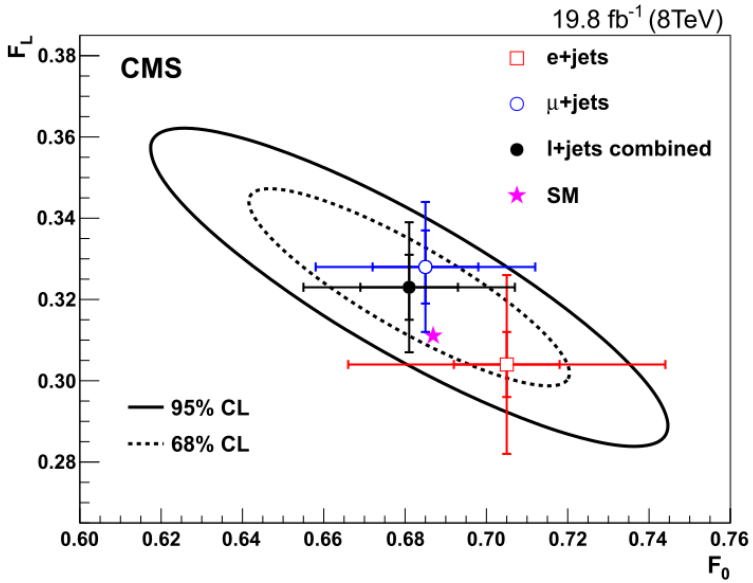


Top Quark Pairs

W boson helicity fractions:

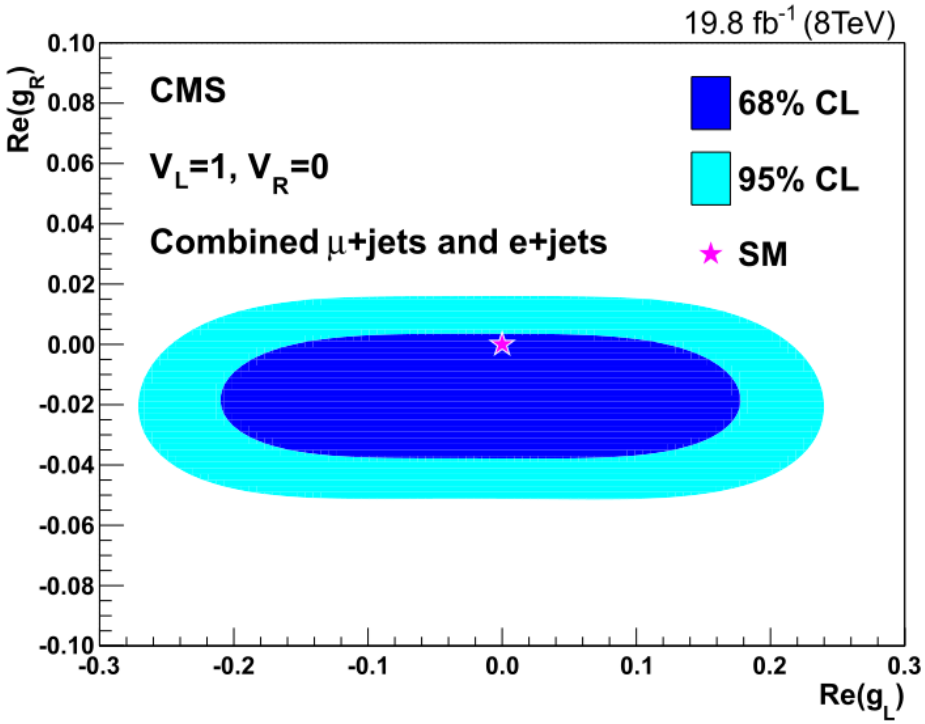
$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta^*} = \frac{3}{8}(1-\cos\theta^*)^2 F_{\mathrm{L}} + \frac{3}{4}(\sin\theta^*)^2 F_0 + \frac{3}{8}(1+\cos\theta^*)^2 F_{\mathrm{R}}$$





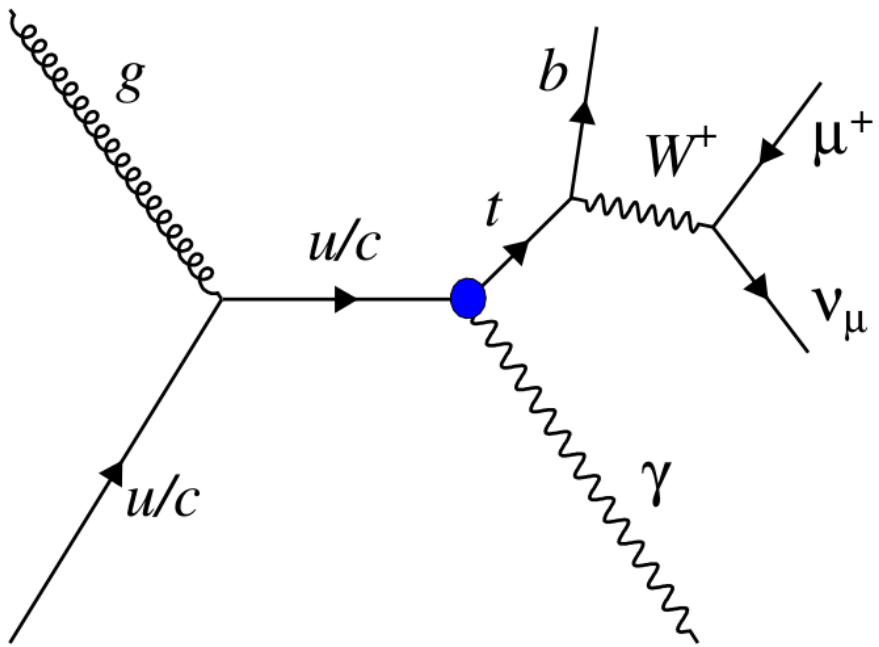
Top Quark Pairs

$$\mathcal{L}_{\mathrm{Wtb}} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}\left(V_{\mathrm{L}}P_{\mathrm{L}} + V_{\mathrm{R}}P_{\mathrm{R}}\right)tW_{\mu}^{-}$$
$$-\frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_{\mathrm{W}}}\left(g_{\mathrm{L}}P_{\mathrm{L}} + g_{\mathrm{R}}P_{\mathrm{R}}\right)tW_{\mu}^{-} + \mathrm{h.c.}$$



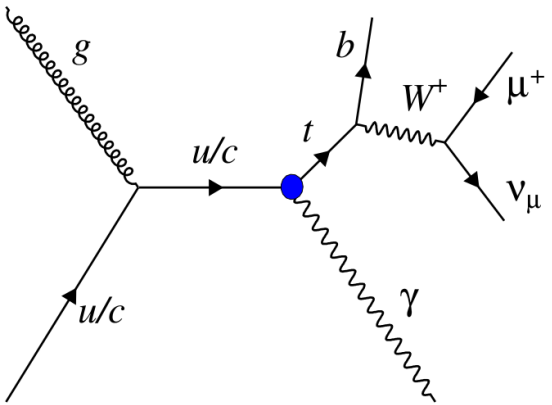
single top quark production in association with a photon

$$\mathcal{L}_{\text{eff}} = -eQ_{\text{t}} \sum_{\text{q=u,c}} \bar{\text{q}} \frac{i\sigma^{\mu\nu} q_\nu}{\Lambda} \left(\kappa^{\text{L}}_{\text{tq}\gamma} P_{\text{L}} + \kappa^{\text{R}}_{\text{tq}\gamma} P_{\text{R}}\right) \text{t} A_\mu + \text{h.c.}$$



single top quark production in association with a photon

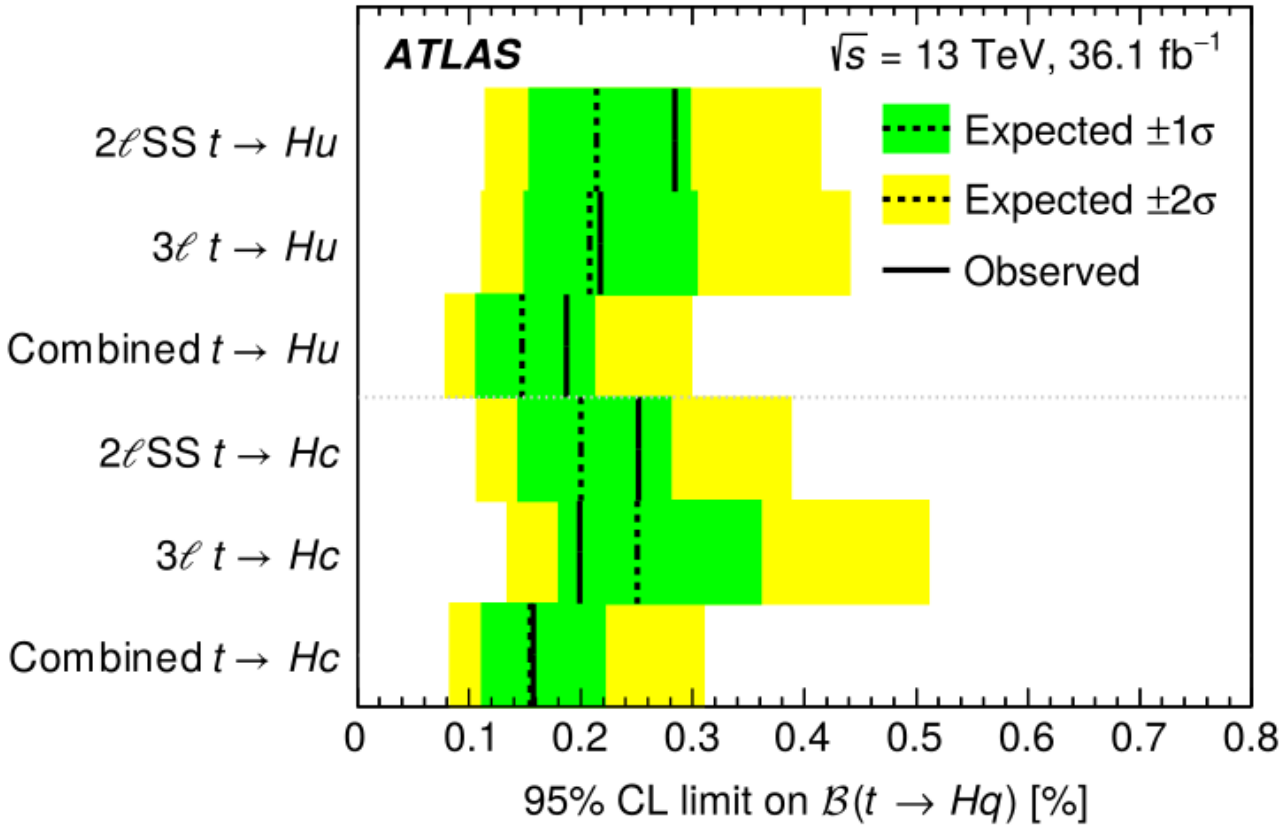
JHEP04(2016)035



	Exp. limit (LO)	$\pm 1\sigma$ (exp. limit)
$\sigma_{tu\gamma}\,\mathcal{B}$ (fb)	40	30–56
$\sigma_{tc\gamma}\,\mathcal{B}$ (fb)	39	30–55
$\kappa_{tu\gamma}$	0.036	0.032–0.043
$\kappa_{tc\gamma}$	0.111	0.098–0.132
$\mathcal{B}(t \to u\gamma)$	2.7×10^{-4}	$(2.0 - 3.8) \times 10^{-4}$
$\mathcal{B}(t \to c\gamma)$	2.5×10^{-3}	$(1.9 - 3.6) \times 10^{-3}$

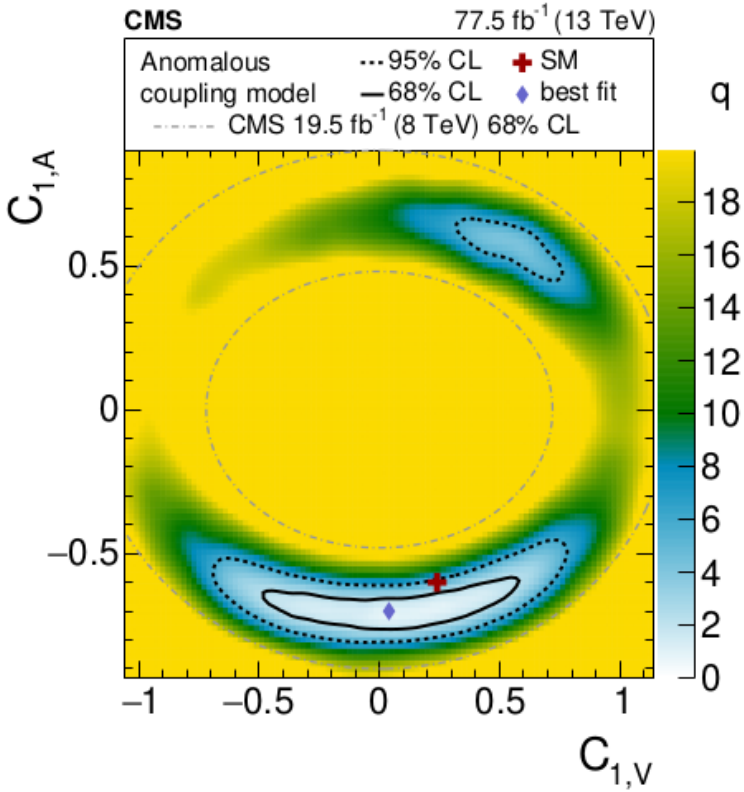
$t\bar{t}$ Pairs

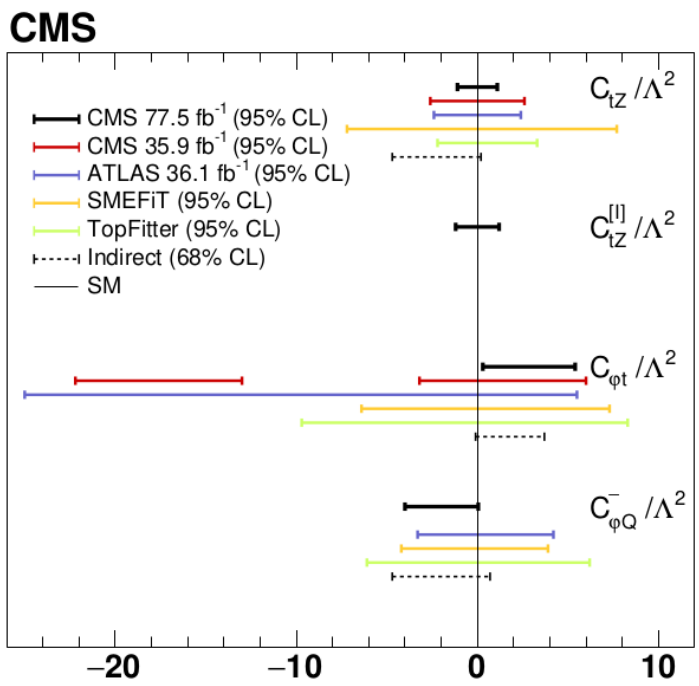
PhysRevD.98.032002



JHEP03(2020)056

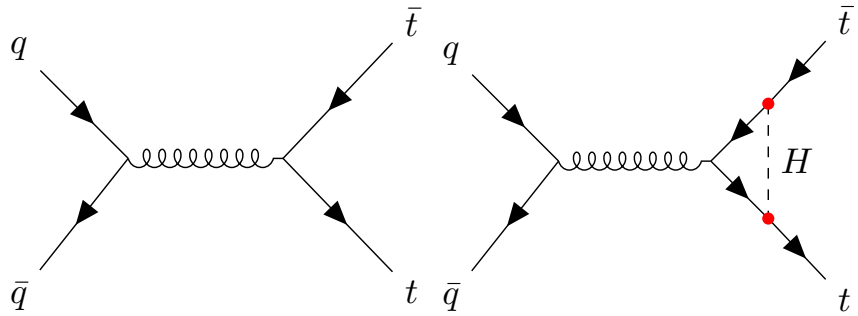
$$\mathcal{L} = e\bar{u}_t \left[\gamma^\mu \left(C_{1,\,V} + \gamma_5 C_{1,\,A} \right) + \frac{i\sigma^{\mu\nu} p_\nu}{m(Z)} \left(C_{2,\,V} + i\gamma_5 C_{2,\,A} \right) \right] v_t Z_\mu$$

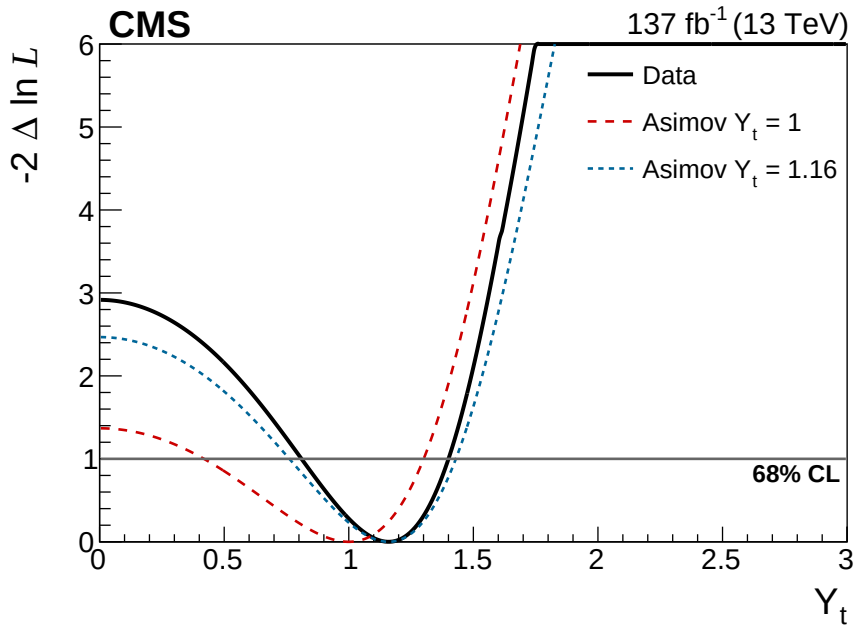




Top Quark Pairs including EW NLO

Phys.Rev.D102 092013



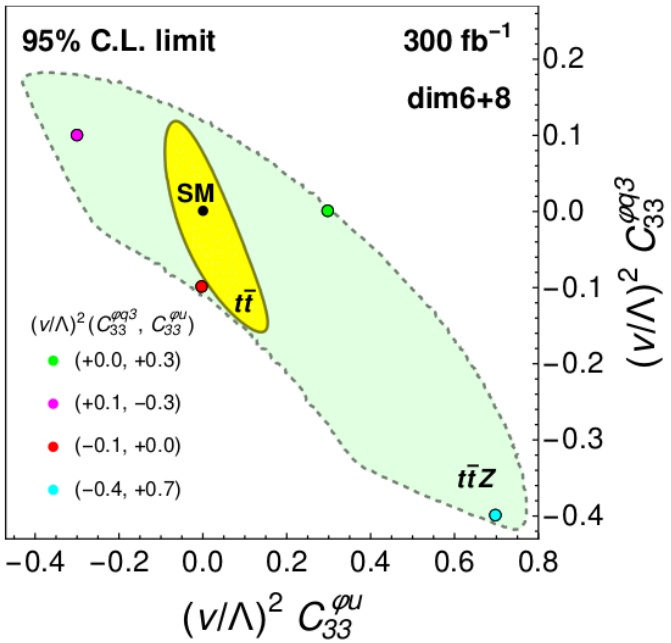


Top Quark Pairs including EW NLO

JHEP04(2020)017

$$\mathrm{SM}: \Gamma^{\mu}_{\mathrm{Ztt}} = \frac{-\mathrm{ie}}{\mathrm{s_w c_w}} \gamma^{\mu} \left(\mathrm{d}^{\mathrm{Z}}_{\mathrm{L}} \mathrm{P_L} + \mathrm{d}^{\mathrm{Z}}_{\mathrm{R}} \mathrm{P_R} \right) \quad \text{with} \quad \mathrm{P_{R/L}} = \frac{1}{2} \left(1 \pm \gamma_5 \right)$$

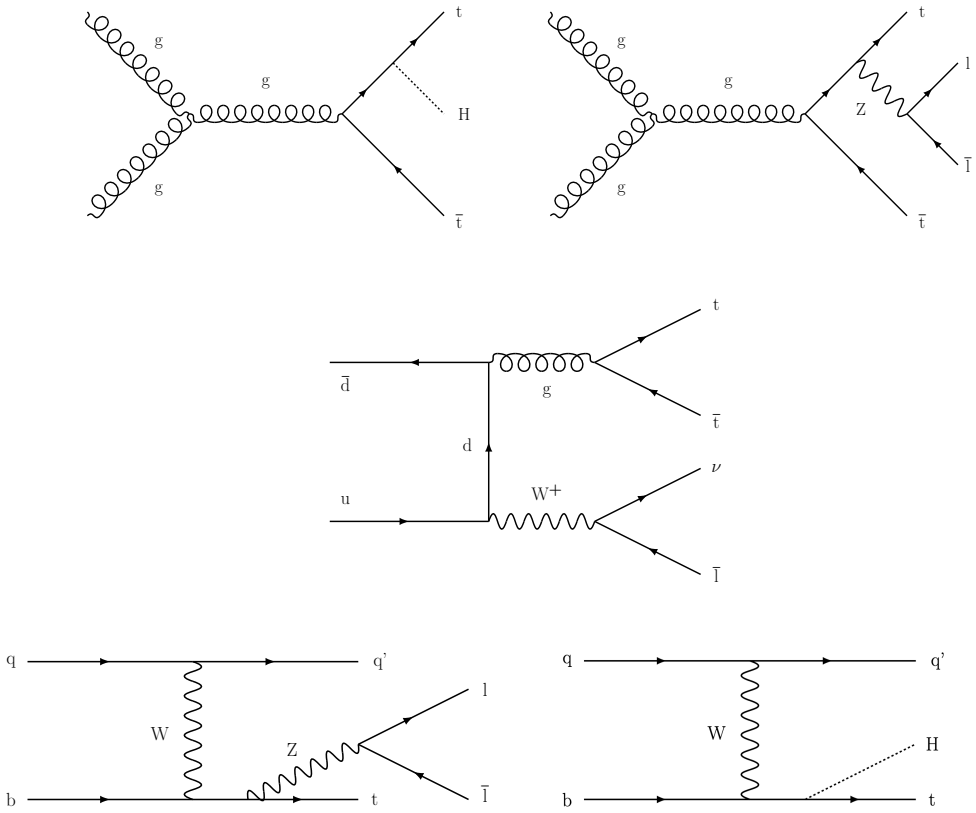
$$d_{\mathrm{L}}^{Z} \to d_{\mathrm{L}}^{Z,\mathrm{SM}} + \frac{1}{2} \frac{v^2}{\Lambda^2} \left(C_{33}^{\varphi q3} - C_{33}^{\varphi q1} \right), \quad \text{and} \quad d_{\mathrm{R}}^{Z} \to d_{\mathrm{R}}^{Z,\mathrm{SM}} - \frac{1}{2} \frac{v^2}{\Lambda^2} C_{33}^{\varphi u}$$



Using associated top quark to probe for new physics

JHEP 03 (2021) 095

Signal: $t\bar{t}l\bar{l}, t\bar{t}l\nu, tl\bar{l}q, t\bar{t}H, tHq$



Using associated top quark to probe for new physics

JHEP 03 (2021) 095

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \sum_{d,i} \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}$$

$$\mathcal{M} = \mathcal{M}_{\text{SM}} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{M}_i$$

$$w_i\left(\frac{\vec{c}}{\Lambda^2}\right) = s_{0i} + \sum_j s_{1ij} \frac{c_j}{\Lambda^2} + \sum_j s_{2ij} \frac{c_j^2}{\Lambda^4} + \sum_{j,k} s_{3ijk} \frac{c_j}{\Lambda^2} \frac{c_k}{\Lambda^2}$$

Sixteen dimension-six operators

arXiv:1008.4884v3 [hep-ph], arXiv:1704.03888v5 [hep-ph]

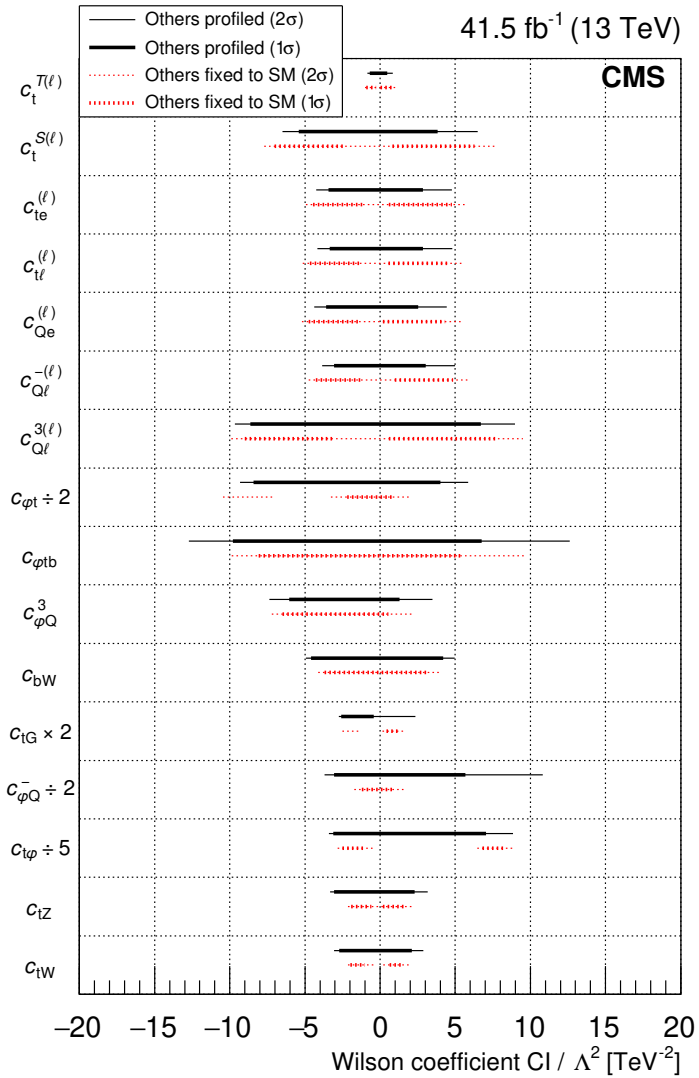
Operators involving two quarks and one or more bosons			
Operator	Definition	WC	Processes affected
$^{\ddagger}O_{u\varphi}^{(ij)}$	$\bar{q}_i u_j \tilde{\varphi} (\varphi^\dagger \varphi)$	$c_{t\varphi} + i c_{t\varphi}^I$	$t\bar{t}H$, tHq
$O_{\varphi q}^{1(ij)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{q}_i \gamma^\mu q_j)$	$c_{\varphi Q}^- + c_{\varphi Q}^3$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$O_{\varphi q}^{3(ij)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar{q}_i \gamma^\mu \tau^I q_j)$	$c_{\varphi Q}^3$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$O_{\varphi u}^{(ij)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{u}_i \gamma^\mu u_j)$	$c_{\varphi t}$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$
$^{\ddagger}O_{\varphi ud}^{(ij)}$	$(\tilde{\varphi}^\dagger i D_\mu \varphi)(\bar{u}_i \gamma^\mu d_j)$	$c_{\varphi tb} + i c_{\varphi tb}^I$	$t\bar{t}H$, $tl\bar{l}q$, tHq
$^{\ddagger}O_{uW}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} \tau^I u_j)\, \tilde{\varphi} W_{\mu\nu}^I$	$c_{tW} + i c_{tW}^I$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$^{\ddagger}O_{dW}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} \tau^I d_j)\, \varphi W_{\mu\nu}^I$	$c_{bW} + i c_{bW}^I$	$t\bar{t}H$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$^{\ddagger}O_{uB}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} u_j)\, \tilde{\varphi} B_{\mu\nu}$	$(c_W c_{tW} - c_{tZ})/s_W + i(c_W c_{tW}^I - c_{tZ}^I)/s_W$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$^{\ddagger}O_{uG}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} T^A u_j)\, \tilde{\varphi} G_{\mu\nu}^A$	$c_{tG} + i c_{tG}^I$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$

Sixteen dimension-six operators

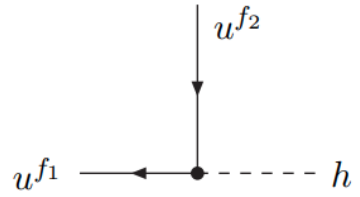
arXiv:1008.4884v3 [hep-ph], arXiv:1704.03888v5 [hep-ph]

Operators involving two quarks and two leptons			
Operator	Definition	WC	Processes affected
$O_{\ell q}^{1(ijkl)}$	$(\bar{\ell}_i\gamma^\mu \ell_j)(\bar{q}_k\gamma^\mu q_\ell)$	$c_{Q\ell}^{-(\ell)} + c_{Q\ell}^{3(\ell)}$	$t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$
$O_{\ell q}^{3(ijkl)}$	$(\bar{\ell}_i\gamma^\mu \tau^I \ell_j)(\bar{q}_k\gamma^\mu \tau^I q_\ell)$	$c_{Q\ell}^{3(\ell)}$	$t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$
$O_{\ell u}^{(ijkl)}$	$(\bar{\ell}_i\gamma^\mu \ell_j)(\bar{u}_k\gamma^\mu u_\ell)$	$c_{t\ell}^{(\ell)}$	$t\bar{t}l\bar{l}$
$O_{e\bar{q}}^{(ijkl)}$	$(\bar{e}_i\gamma^\mu e_j)(\bar{q}_k\gamma^\mu q_\ell)$	$c_{Qe}^{(\ell)}$	$t\bar{t}l\bar{l}$, $tl\bar{l}q$
$O_{eu}^{(ijkl)}$	$(\bar{e}_i\gamma^\mu e_j)(\bar{u}_k\gamma^\mu u_\ell)$	$c_{te}^{(\ell)}$	$t\bar{t}l\bar{l}$
$\ddagger O_{\ell equ}^{1(ijkl)}$	$(\bar{\ell}_i e_j)\ \varepsilon\ (\bar{q}_k u_\ell)$	$c_t^{S(\ell)} + ic_t^{SI(\ell)}$	$t\bar{t}l\bar{l}$, $tl\bar{l}q$
$\ddagger O_{\ell equ}^{3(ijkl)}$	$(\bar{\ell}_i\sigma^{\mu\nu} e_j)\ \varepsilon\ (\bar{q}_k\sigma_{\mu\nu} u_\ell)$	$c_t^{T(\ell)} + ic_t^{TI(\ell)}$	$t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$

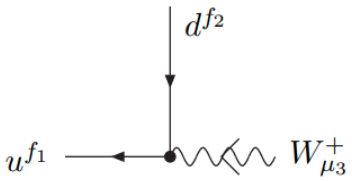
Sixteen WCs


Others profiled (2σ)
Others profiled (1σ)
Others fixed to SM (2σ)
Others fixed to SM (1σ)
41.5 fb-1 (13 TeV)
CMS
$c_t^{T(\ell)}$
$c_t^{S(\ell)}$
$c_{te}^{(\ell)}$
$c_{t\ell}^{(\ell)}$
$c_{Qe}^{(\ell)}$
$c_{Q\ell}^{-(\ell)}$
$c_{Q\ell}^{3(\ell)}$
$c_{\varphi t} \div 2$
$c_{\varphi tb}$
$c_{\varphi Q}^{3}$
c_{bW}
$c_{tG} \times 2$
$c_{\varphi Q}^{-} \div 2$
$c_{t\varphi} \div 5$
c_{tZ}
c_{tW}
–20 –15 –10 –5 0 5 10 15 20
Wilson coefficient CI / Λ^2 [TeV^{-2}]

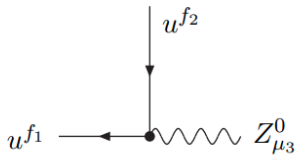
Top Quark and $H/W/Z$ Vertices in EFT



$$-\frac{i}{v}\delta_{f_1f_2}m_{u_{f_1}} - iv\delta_{f_1f_2}C^{\varphi\Box}m_{u_{f_1}} + \frac{iv}{4}\delta_{f_1f_2}C^{\varphi D}m_{u_{f_1}} + \frac{iv^2}{\sqrt{2}}\left(P_L C^{u\varphi *}_{f_2f_1} + P_R C^{u\varphi}_{f_1f_2}\right)$$



$$-\frac{i\bar{g}}{\sqrt{2}}K_{f_1f_2}\gamma^{\mu_3}P_L - 2vp_3^\nu K_{f_1g_1}C^{dW}_{g_1f_2}\sigma^{\mu_3\nu}P_R - \frac{i\bar{g}v^2}{\sqrt{2}}K_{f_1g_1}C^{\varphi q3}_{g_1f_2}\gamma^{\mu_3}P_L - \frac{i\bar{g}v^2}{2\sqrt{2}}C^{\varphi ud}_{f_1f_2}\gamma^{\mu_3}P_R - 2vp_3^\nu K_{g_1f_2}\sigma^{\mu_3\nu}P_L C^{uW*}_{g_1f_1}$$



$$\begin{aligned}
&+\frac{i}{6\sqrt{\bar{g}^2+\bar{g}'^2}}\delta_{f_1f_2}\left(\left(\bar{g}'^2-3\bar{g}^2\right)\gamma^{\mu_3}P_L + 4\bar{g}'^2\gamma^{\mu_3}P_R\right)\\
&-\frac{i\bar{g}\bar{g}'v^2}{6\left(\bar{g}^2+\bar{g}'^2\right)^{3/2}}\delta_{f_1f_2}C^{\varphi WB}\left(\left(3\bar{g}'^2-\bar{g}^2\right)\gamma^{\mu_3}P_L - 4\bar{g}^2\gamma^{\mu_3}P_R\right)\\
&-\frac{\sqrt{2}\bar{g}v}{\sqrt{\bar{g}^2+\bar{g}'^2}}p_3^\nu\left(C^{uW*}_{f_2f_1}\sigma^{\mu_3\nu}P_L + C^{uW}_{f_1f_2}\sigma^{\mu_3\nu}P_R\right)\\
&+\frac{\sqrt{2}\bar{g}'v}{\sqrt{\bar{g}^2+\bar{g}'^2}}p_3^\nu\left(C^{uB*}_{f_2f_1}\sigma^{\mu_3\nu}P_L + C^{uB}_{f_1f_2}\sigma^{\mu_3\nu}P_R\right)\\
&+\frac{1}{2}iv^2\sqrt{\bar{g}^2+\bar{g}'^2}K_{f_1g_2}K^*_{f_2g_1}C^{\varphi q1}_{g_2g_1}\gamma^{\mu_3}P_L\\
&-\frac{1}{2}iv^2\sqrt{\bar{g}^2+\bar{g}'^2}K_{f_1g_2}K^*_{f_2g_1}C^{\varphi q3}_{g_2g_1}\gamma^{\mu_3}P_L\\
&+\frac{1}{2}iv^2\sqrt{\bar{g}^2+\bar{g}'^2}C^{\varphi u}_{f_1f_2}\gamma^{\mu_3}P_R
\end{aligned}$$