Karlsruhe Institute of Technology

TRR 257 - Particle Physics Phenomenology after the Higgs Discovery

Anomalous couplings in the top quark sector

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Motivation

Goal: providing a framework to scrutinise couplings involving top quarks

$$pp \to t\bar{t},\ pp \to t\bar{t} + X\ ,\ X = H, \gamma, Z, W^{\pm}$$

including off-shell effects and anomalous couplings within

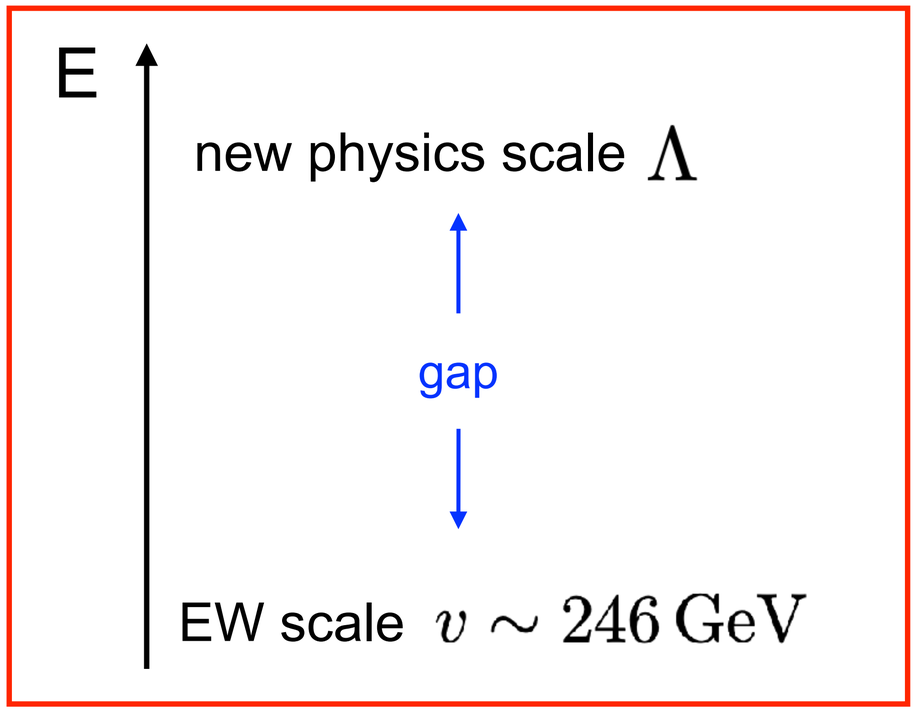
Standard Model Effective Field Theory (**SMEFT**)

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{\mathrm{dim6}} + \mathcal{O}(\frac{1}{\Lambda^3})$$

Λ: New physics scale

SMEFT

applicable if electroweak scale and new physics scale are well separated



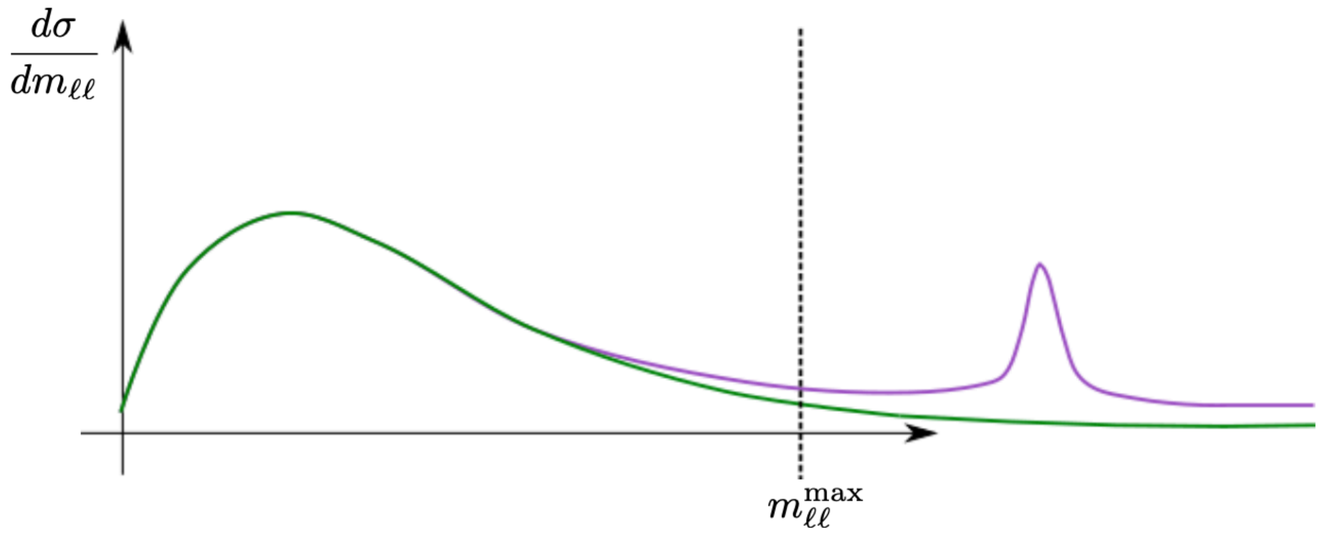


figure: Maeve Madigan, Top 2022

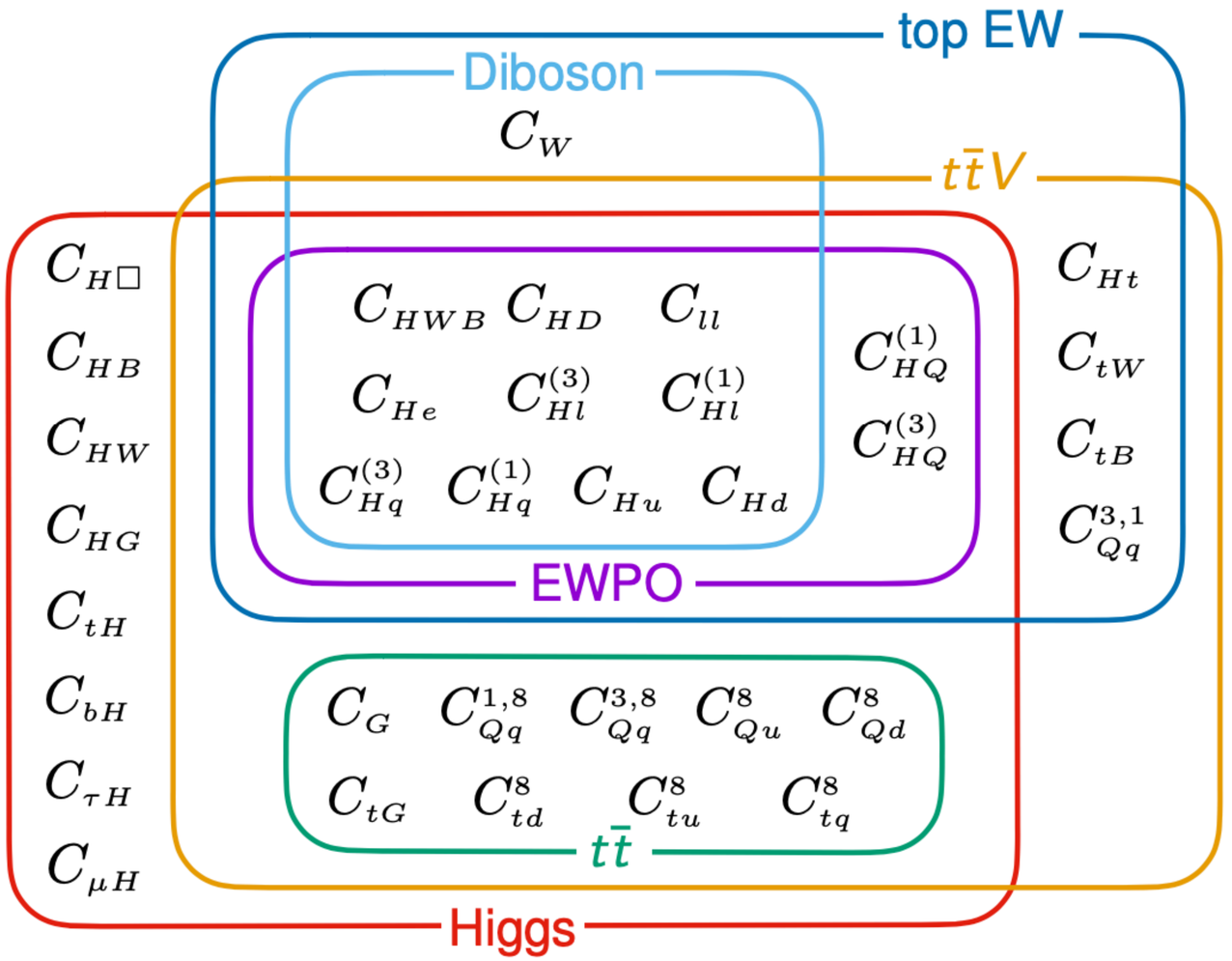
SMEFT

inclusion of top quark decays involves

- purely boson operators
- two-fermion operators
- four-fermion operators

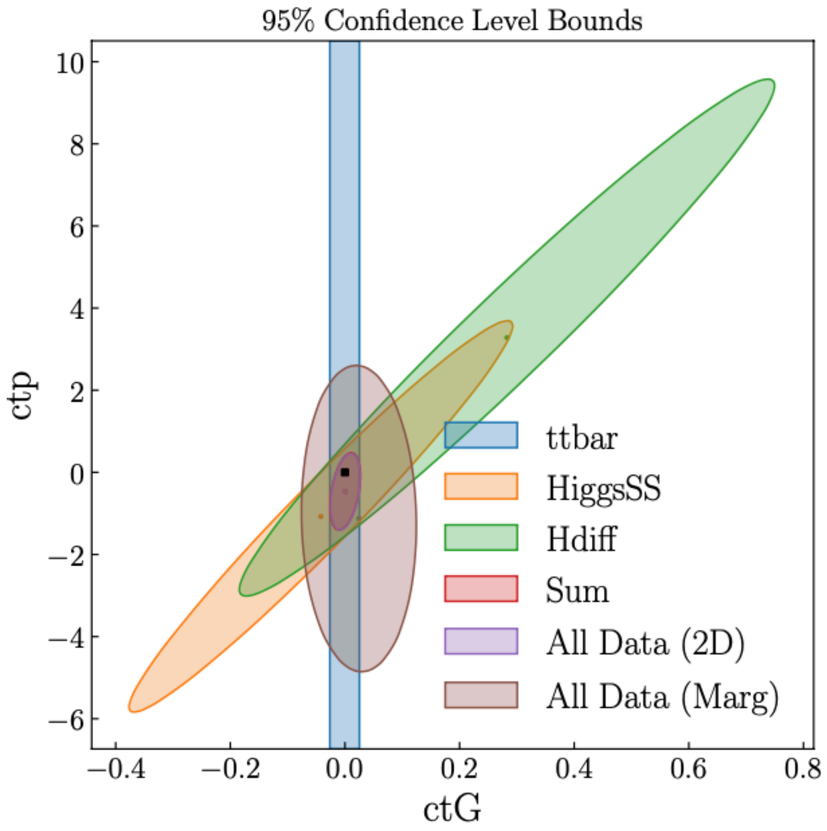
example	3rd generation quarks	
$\mathcal{O}_{\varphi Q}^{(1)}$	$c_{\varphi Q}^{(1)}$ (*)	$i(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{Q}\,\gamma^\mu\, Q)$
$\mathcal{O}_{\varphi Q}^{(3)}$	$c_{\varphi Q}^{(3)}$	$i(\varphi^\dagger \overleftrightarrow{D}_\mu \tau_I \varphi)(\bar{Q}\,\gamma^\mu\, \tau^I Q)$
$\mathcal{O}_{\varphi t}$	$c_{\varphi t}$	$i(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{t}\,\gamma^\mu\, t)$
$\mathcal{O}_{tW}$	c_{tW}	$i(\bar{Q}\tau^{\mu\nu}\,\tau_I\, t)\,\tilde{\varphi}\, W_{\mu\nu}^I + \text{h.c.}$
$\mathcal{O}_{tB}$	c_{tB} (*)	$i(\bar{Q}\tau^{\mu\nu}\, t)\,\tilde{\varphi}\, B_{\mu\nu} + \text{h.c.}$
$\mathcal{O}_{tG}$	c_{tG}	$ig_S\,(\bar{Q}\tau^{\mu\nu}\, T_A\, t)\,\tilde{\varphi}\, G_{\mu\nu}^A + \text{h.c.}$
$\mathcal{O}_{t\varphi}$	$c_{t\varphi}$	$\left(\varphi^\dagger\varphi\right)\bar{Q}\, t\,\tilde{\varphi} + \text{h.c.}$
$\mathcal{O}_{b\varphi}$	$c_{b\varphi}$	$\left(\varphi^\dagger\varphi\right)\bar{Q}\, b\,\varphi + \text{h.c.}$

Ethier et al, 2105.00006



Ellis, Madigan, Sanz, You 2012.02779

Complementarity to Higgs observables



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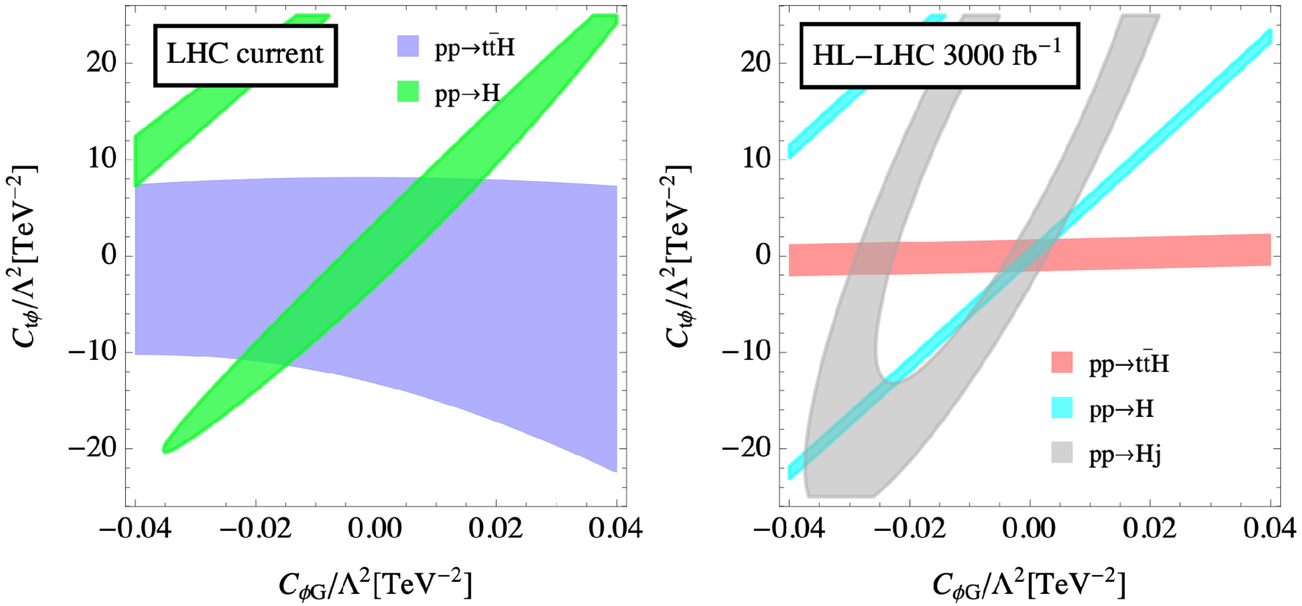

Maltoni, Vryonidou, Zhang 1607.05330:

CMS analysis

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Operators involving two quarks and one or more bosons			
Operator	Definition	WC	Lead processes affected
$^{\ddagger}O_{u\varphi}^{(ij)}$	$\bar{q}_i u_j \tilde{\varphi} (\varphi^\dagger \varphi)$	$c_{t\varphi} + ic_{t\varphi}^I$	$t\bar{t}H$, 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, $tl\bar{l}q$
$O_{\varphi u}^{(ij)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{u}_i \gamma^\mu u_j)$	$c_{\varphi t}$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$
$^{\ddagger}O_{\varphi ud}^{(ij)}$	$(\tilde{\varphi}^\dagger i D_\mu \varphi)(\bar{u}_i \gamma^\mu d_j)$	$c_{\varphi tb} + ic_{\varphi tb}^I$	$t\bar{t}H$, $tl\bar{l}q$, tHq
$^{\ddagger}O_{uW}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} \tau^I u_j)\, \tilde{\varphi} W_{\mu\nu}^I$	$c_{tW} + ic_{tW}^I$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$^{\ddagger}O_{dW}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} \tau^I d_j)\, \varphi W_{\mu\nu}^I$	$c_{bW} + ic_{bW}^I$	$t\bar{t}H$, $t\bar{t}l\bar{l}$, 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
$^{\ddagger}O_{uG}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} T^A u_j)\, \tilde{\varphi} G_{\mu\nu}^A$	$g_s(c_{tG} + ic_{tG}^I)$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$

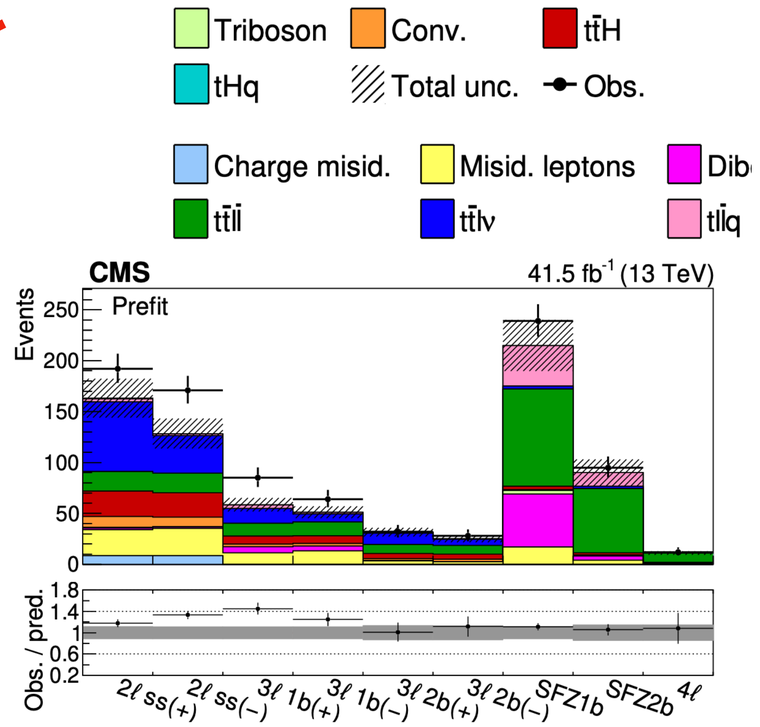
Operators involving two quarks and			
Operator	Definition	WC	Lead processes affected
$O_{\ell q}^{1(ijkl)}$	$(\bar{\ell}_i \gamma^\mu \ell_j)(\bar{q}_k \gamma^\mu q_\ell)$	$c^{-(\ell)}$	$t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$
$O_{\ell q}^{3(ijkl)}$	$(\bar{\ell}_i \gamma^\mu \tau^I \ell_j)(\bar{q}_k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

35 event categories

depending on number of leptons, charge, number of b-jets

fit of 16 Wilson coefficients

inclusion of decays with off-shell effects important!



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