Top Quark Decays in Standard Model Extensions

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Motivation

- Top decays are a direct and sensitve probe for new physics at the scale of $\sim 100\,\mathrm{GeV}$.
- Top quarks decay dominantly via $t \to Wb$. Due to the parity violating nature of the electroweak interactions we can obtain information about the structure of the Wtb vertex as well as its overall strength.
- The large number of top events at the LHC will allow us to measure the structure of the Wtb vertex at percent level accuracy.

Anomalous Couplings

The (onshell) amplitude $\mathcal{M}$ for $t(p) \to b(k)\, W(q)$ can be decomposed as

$$\mathcal{M} = -\frac{g}{\sqrt{2}}\varepsilon_\mu^* \bar{u}(k)\Big[(V_{tb}^* + f_L)\gamma^\mu P_L + f_R \gamma^\mu P_R + i\frac{\sigma^{\mu\nu}q_\nu}{m_W}(g_L P_L + g_R P_R)\Big]u(p) \quad .$$

The form factors $f_{L,R}$ and $g_{L,R}$ receive contributions from loops of SM and non-SM particles. They are IR divergent. To parametrise the "new physics" we define

$$f_{L,R}^{\text{NS}} = f_{L,R}^{\text{BSM}} - f_{L,R}^{\text{SM}} \quad , \quad g_{L,R}^{\text{NS}} = g_{L,R}^{\text{BSM}} - g_{L,R}^{\text{SM}} \quad .$$

If the SM extension does not introduce new IR divergent diagrams, the IR divergences cancel in the difference.

Observables

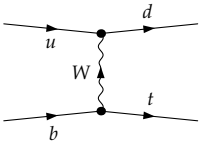
Observables sensitive to $f_{L,R}$, $g_{L,R}$ are

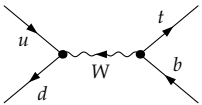
- The helicity fractions

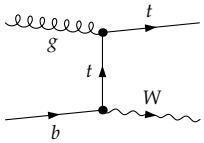
$$F_\lambda = B(t \to b\,W(\lambda)) \quad ,$$

  where $\lambda = 0, \pm$ is the helicity of the W boson. They can be determined from the angular distribution of the W decay products.

- Three different single top production modes







Detection/Exclusion limits

ATLAS sensitivities for the anomalous couplings

- using only helicity fractions F_λ:

$$f_R(2\sigma): \ [-0.055, 0.13] \quad ,$$
$$g_L(2\sigma): \ [-0.058, 0.026] \quad , \quad g_R(2\sigma): \ [-0.026, 0.031] \quad .$$

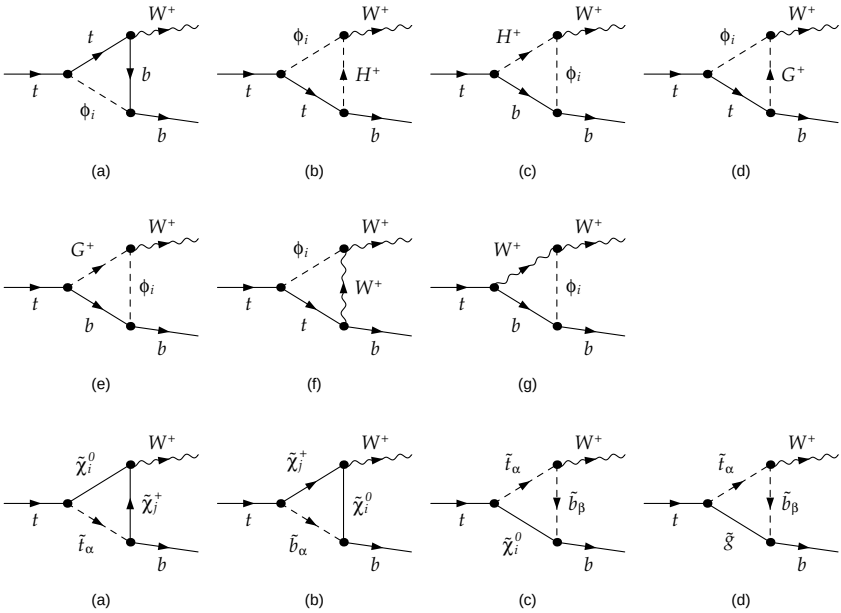
[Aguilar-Saavedra, Carvalho, Castro, Onofre, Veloso, Eur. Phys. J. **C53** (2008) 689]

- using helicity fractions and single top production:

$$f_L(1\sigma): [-0.15, 0.11] \quad , \quad f_R(1\sigma): [-0.25, 0.25] \quad ,$$
$$g_L(1\sigma): [-0.16, 0.16] \quad , \quad g_R(1\sigma): [-0.012, 0.024] \quad .$$

[Aguilar-Saavedra, Nucl. Phys. **B804** (2008) 160]

MSSM Diagrams



MSSM Parameters

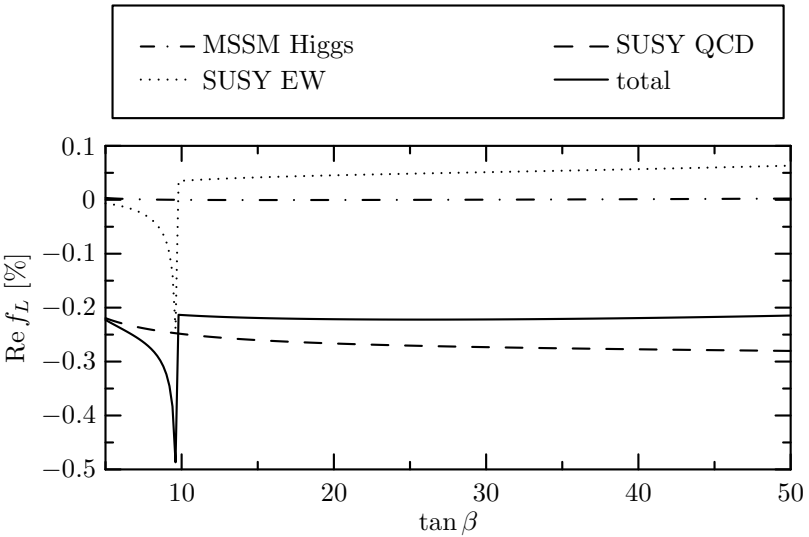
$$\mu = 250\,\text{GeV} \quad , \quad M_1 = 62\,\text{GeV} \quad , \quad M_2 = 130\,\text{GeV} \quad ,$$
$$m_{H^+} = 250\,\text{GeV} \quad , \quad m_{\tilde{g}} = 350\,\text{GeV} \quad ,$$
$$M_{L_i} = M_{E_i} = M_{Q_i} = M_{D_i} = M_{U_{1,2}} = 400\,\text{GeV} \quad ,$$
$$A_{L_i} = A_{U_{1,2}} = A_{D_i} = 0 \quad ,$$
$$M_{U_3} = 250\,\text{GeV} \quad , \quad A_{U_3} = 700\,\text{GeV} \quad .$$

	$\tan\beta = 5$	$\tan\beta = 50$
m_{h_0}	115 GeV	120 GeV
m_{H_0}	238 GeV	232 GeV
m_{A_0}	237 GeV	236 GeV
α	-0.092π	-0.002π
$m_{\chi_1^+}$	105 GeV	115 GeV
$m_{\chi_1^0}$	56 GeV	60 GeV

	$\tan\beta = 5$	$\tan\beta = 50$
$m_{\tilde{t}_1}$	131 GeV	99 GeV
$m_{\tilde{t}_2}$	511 GeV	518 GeV
$\theta_{\tilde{t}}$	0.19π	0.19π
$m_{\tilde{b}_1}$	395 GeV	319 GeV
$m_{\tilde{b}_2}$	409 GeV	471 GeV
$\theta_{\tilde{b}}$	-0.23π	-0.25π

MSSM Results

$$|\operatorname{Im} f_{L,R}| \ll |\operatorname{Re} f_{L,R}| \quad , \quad |\operatorname{Im} g_{L,R}| \ll |\operatorname{Re} g_{L,R}| \quad ,$$
$$|\operatorname{Re} f_R|, |\operatorname{Re} g_L| \ll |\operatorname{Re} g_R| \ll |\operatorname{Re} f_L| \quad .$$



Topcolour-Assisted Technicolour (TC2)

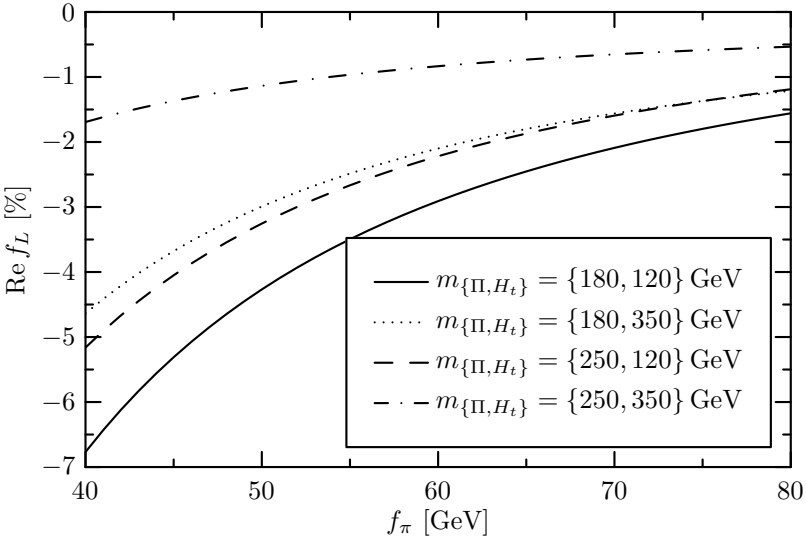
Introduce two new types of strong interactions:

- Technicolour interactions of techni-fermions T. The condensate $v_T = \langle \bar{T}T \rangle$ is responsible for most of EWSB.
- Topcolour interactions of top-quarks only. The condensate $f_\pi = \langle \bar{t}t \rangle$ is responsible for the large top mass.

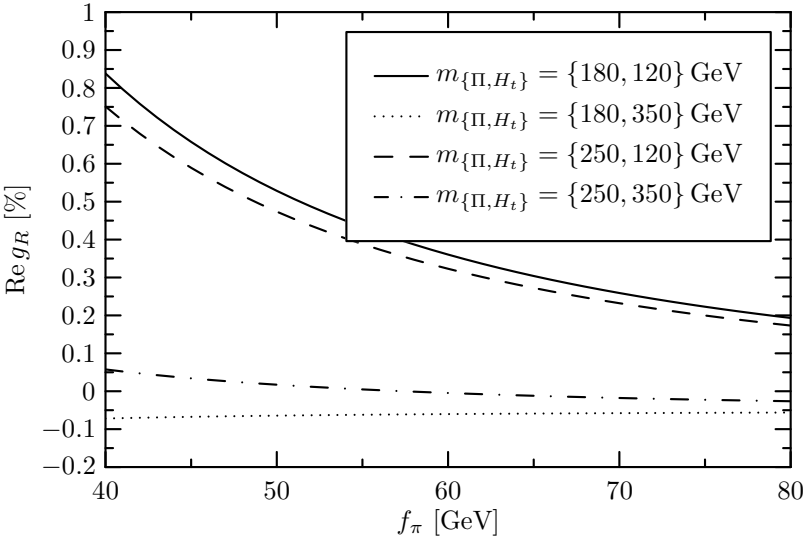
The bound states of the techni-fermions and the top form two $SU(2)_L$ doublets. The physical spin-0 states are:

- a top-Higgs H_t with mass $< 2m_t$.
- a techni-Higgs H_{TC} with mass $\sim 1\,\mathrm{TeV}$.
- a top-pion multiplet $\Pi^{0,\pm}$ with masses between 180 to $250\,\mathrm{GeV}$.

TC2 Results


0
−1
−2
−3
−4
−5
−6
−7
40
50
60
70
80
Re f_L [%]
f_π [GeV]
$m_{\{\Pi,H_t\}} = \{180, 120\}$ GeV
$m_{\{\Pi,H_t\}} = \{180, 350\}$ GeV
$m_{\{\Pi,H_t\}} = \{250, 120\}$ GeV
$m_{\{\Pi,H_t\}} = \{250, 350\}$ GeV

TC2 Results


$m_{\{\Pi,H_t\}} = \{180, 120\}$ GeV
$m_{\{\Pi,H_t\}} = \{180, 350\}$ GeV
$m_{\{\Pi,H_t\}} = \{250, 120\}$ GeV
$m_{\{\Pi,H_t\}} = \{250, 350\}$ GeV
$\mathrm{Re}\, g_R$ [%]
f_π [GeV]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
40
50
60
70
80