Karlsruhe Institute of Technology

The top-Higgs-flavour connection

FlavCC workshop

22.11.2021

The prominent role of the top quark

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- top quark as main window to the Higgs sector (largest coupling)
- top quark as window to the flavour sector (top-bottom doublet, CKM-matrix, 4-fermion operators)
- top quark as window to new physics (e.g. Higgs portal models, top partner, …)
- LHC is a top factory (~10 top quark pairs per second at LHC@14 TeV)

SMEFT fits in the top sector

- Miralles et al. 2107.13917:

  fit of LHC, LEP, Tevatron data for ttX, tZq, tyq, Z-> bb, top decay

- Ethier, Magni, Maltoni et al. 2105.00006:

  Higgs, top and diboson global fits (NLO), only top Yukawa nonzero,

  36 independent EFT coefficients

- Brivio, Plehn, Westhoff et al. 1910.03606:

  top pairs, single top, ttW, ttZ, top decays

  global analysis at NLO, 22 operators, CP-conserving

ttH

- Abraham, Goncalvez, Han et al 2106.00018:

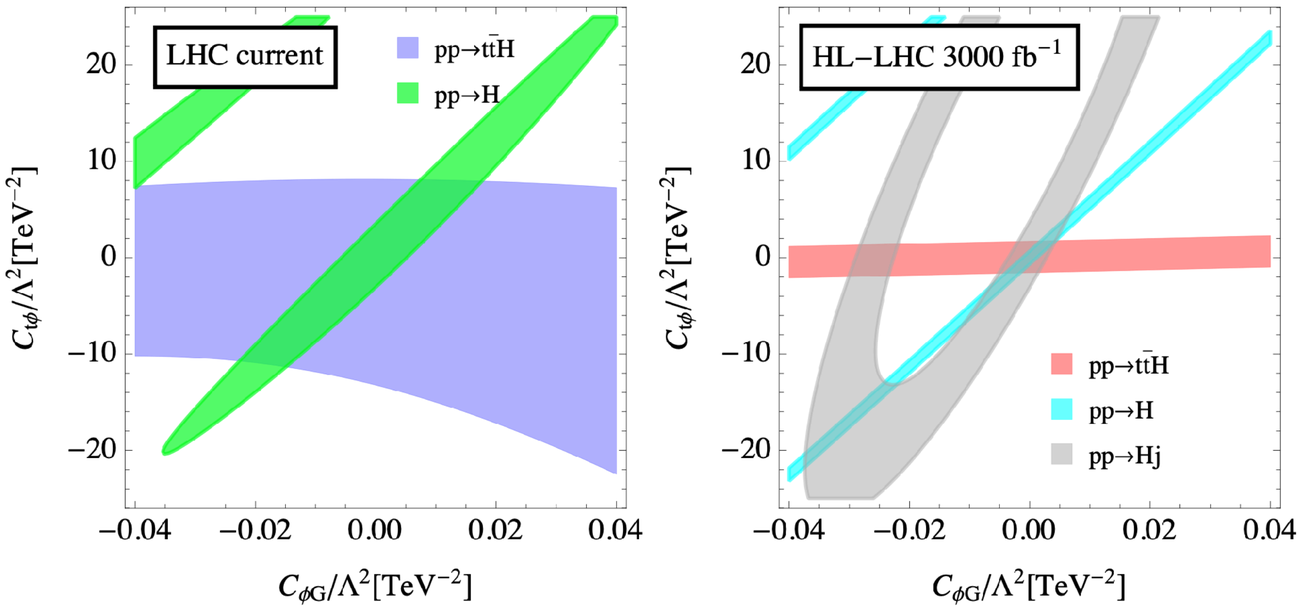
  two operators, $O_{t\phi}, O_{tG}$, focus on large ptH

  (using SMEFT@NLO, Degrande et al. 2008.11743)

- Maltoni, Vryonidou, Zhang 1607.05330:

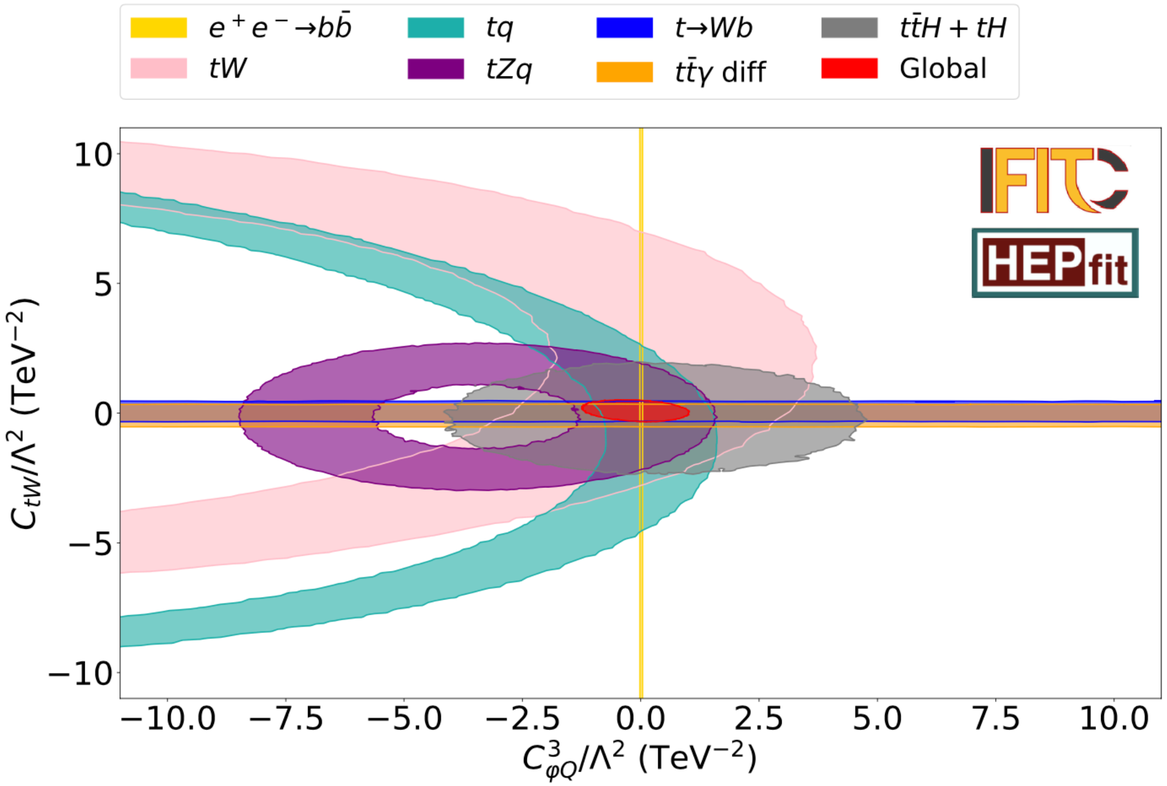
  $O_{t\phi}, O_{tG}, O_{\phi G}$

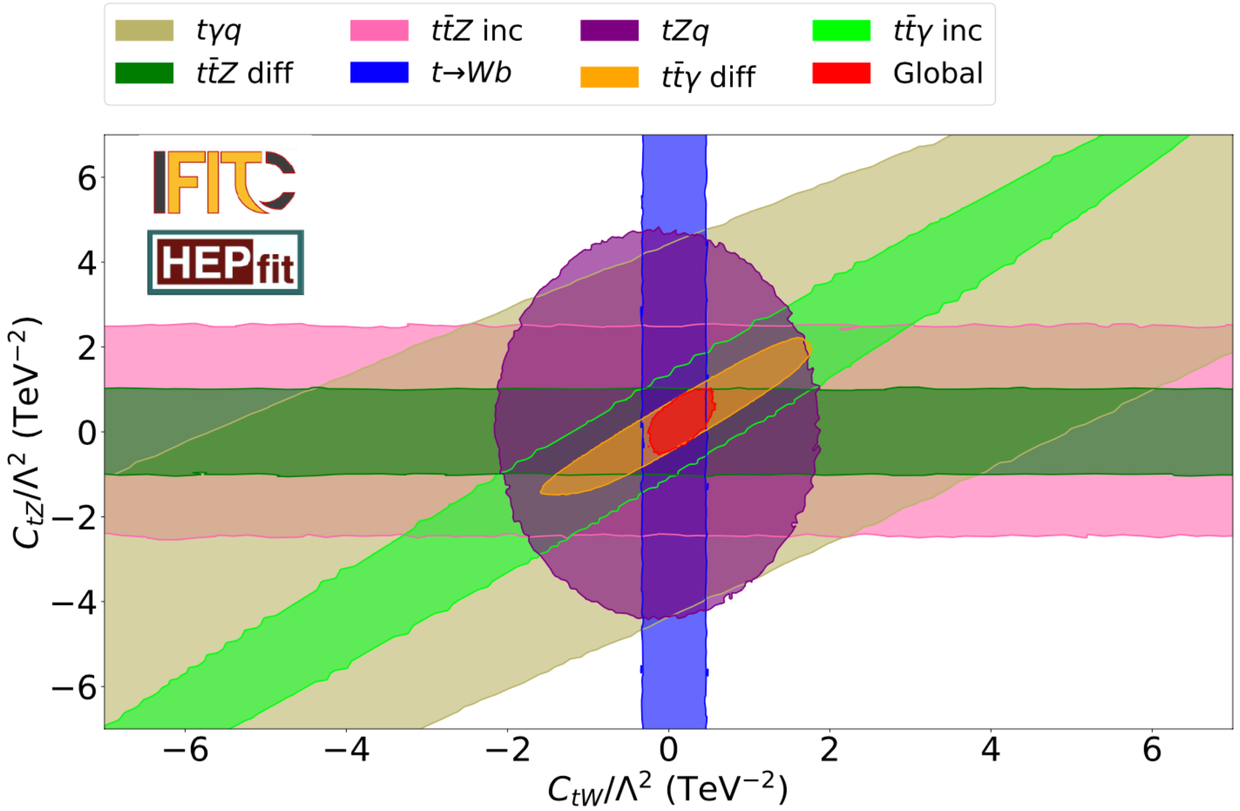
  no 4-fermion operators,
  no CP-violating operators



more global SMEFT fits

Miralles et al. 2107.13917 (using mostly SMEFT@NLO)





- single top important
- top decay important

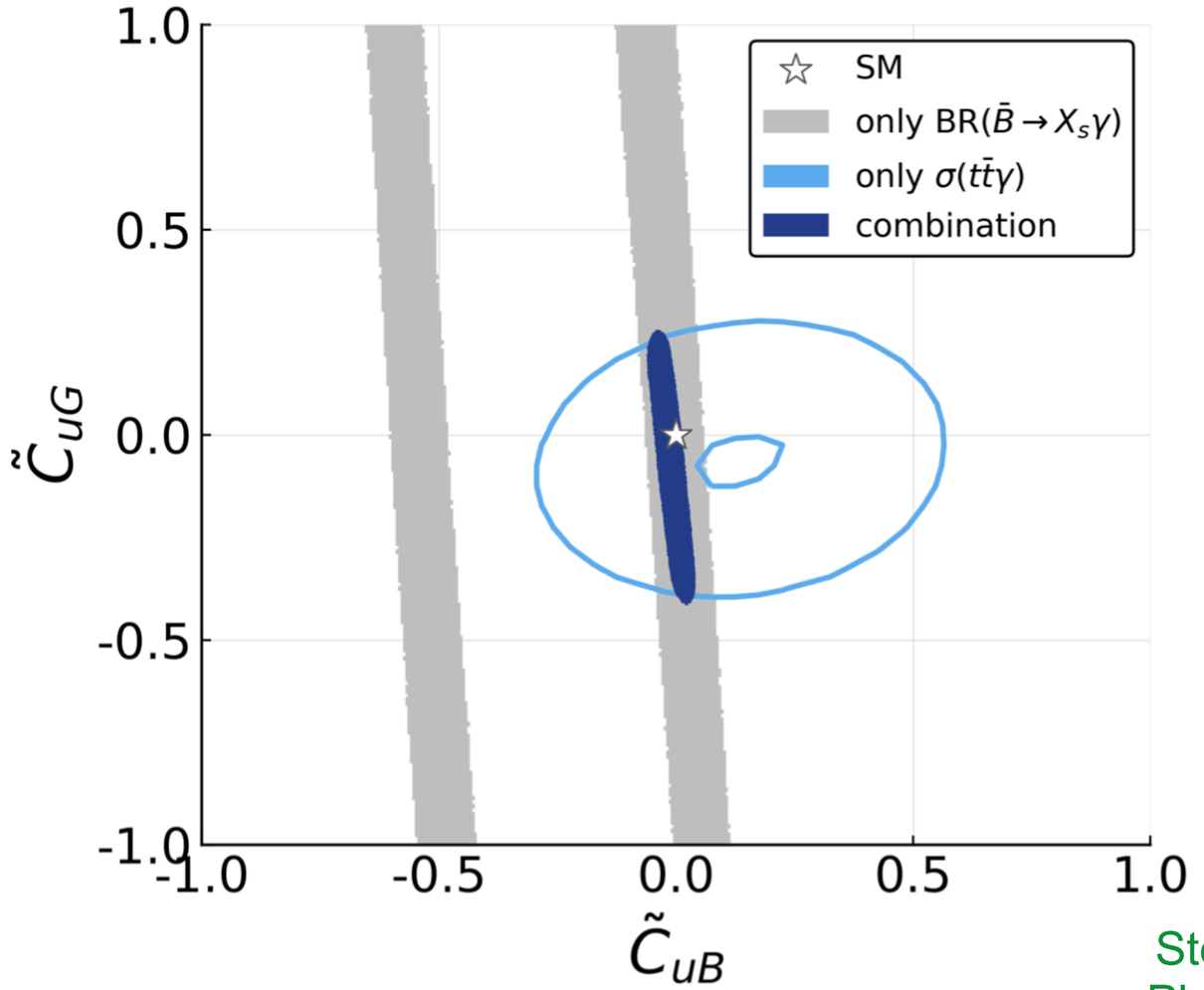
top + flavour:

- Brugisser, Schäfer, van Dyk, Westhoff, 2101.07273
- Bissmann, (Erdmann), Grunwald, Hiller, Kröninger, 2012.10456, 1909.13632
- Blanke, Pani, Polesello, Rovelli, 2010.10530

- need matching SMEFT (scale ~mZ) to WET (scale ~mb)
- operator mixing through RGE

combined fit high- and low energy observables

complementary information,
breaks degeneracies



Stefan Bissmann
PhD Thesis, 2021

flavour connection

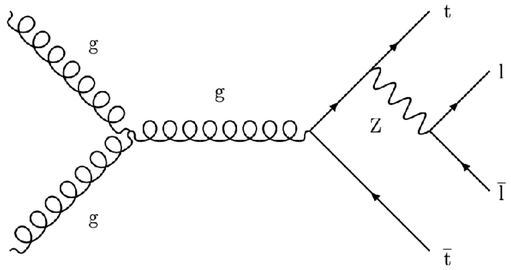
- go beyond SMEFT@NLO (diagonal CKM, minimal flavour violation)

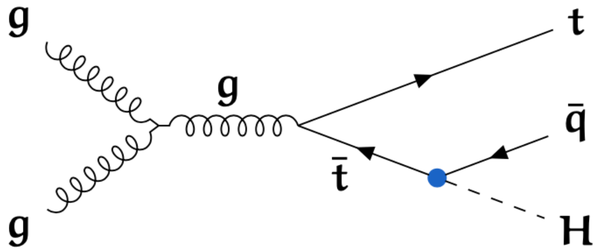
- make connection to tests of lepton flavour universality, B-anomalies:

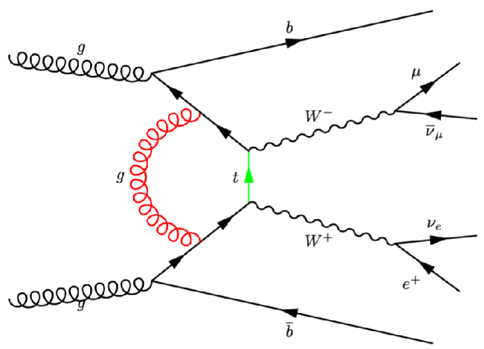
- consider single top, two-fermion-phi operators

- include four-fermion operators in ttX

- include off-shell top decays -> 4-fermion operators with two leptons







CMS analysis

Search for new physics in top quark production with additional leptons …
2012.04120

35 event categories depending on number of leptons, charge, number of b-jets

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

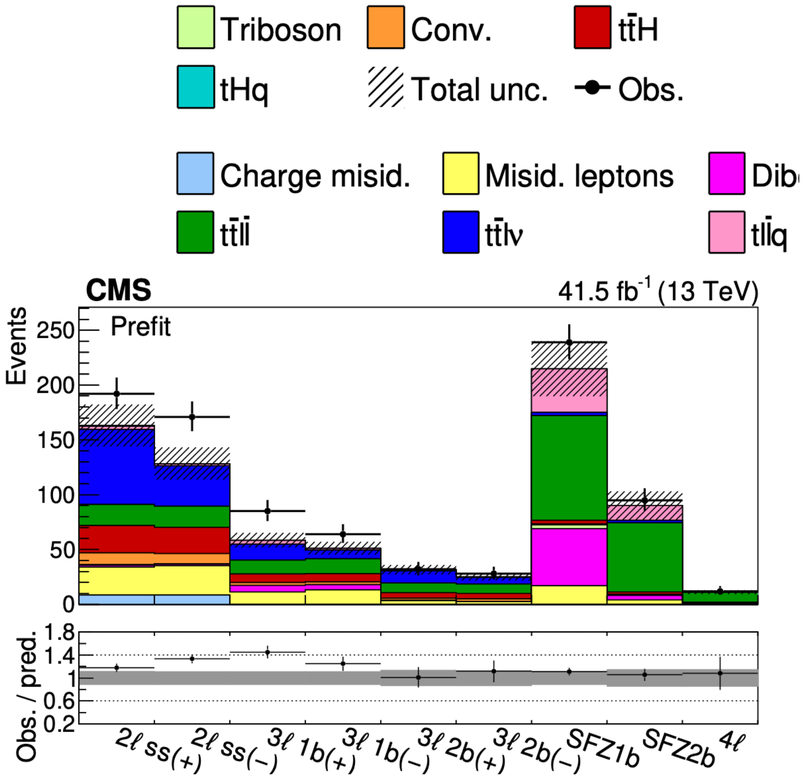
fit 16 Wilson coefficients

Operators involving two quarks and one or more bosons

Operator	Definition	WC	Lead processes affected
$\ddagger O_{u\varphi}^{(ij)}$	$\bar{q}_i u_j \tilde{\varphi} (\varphi^\dagger \varphi)$	$c_{t\varphi} + i c_{t\varphi}^I$	$t\bar{t}H$, 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, $tl\bar{l}q$
$O_{\varphi q}^{3(ij)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I \varphi)(\bar{q}_i \gamma^\mu \tau^I q_j)$	$c_{\varphi Q}^3$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, 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, $tl\bar{l}q$
$\ddagger O_{uG}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} T^A u_j)\, \tilde{\varphi} G_{\mu\nu}^A$	$g_s(c_{tG} + i c_{tG}^I)$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$

Operators involving two quarks and two leptons

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



2012.04120

Summary

- combined fits of collider and flavour observables can break degeneracies and give important information

- 4-fermion operators important, in particular 2-lepton 2-quark operators (LFU)

- no full picture without accurate description of top quark decays
  (tt: include singly resonant, non-resonant, operators)