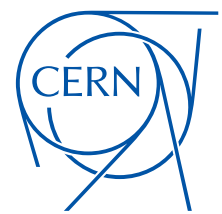
EFT and top: theoretical point of view

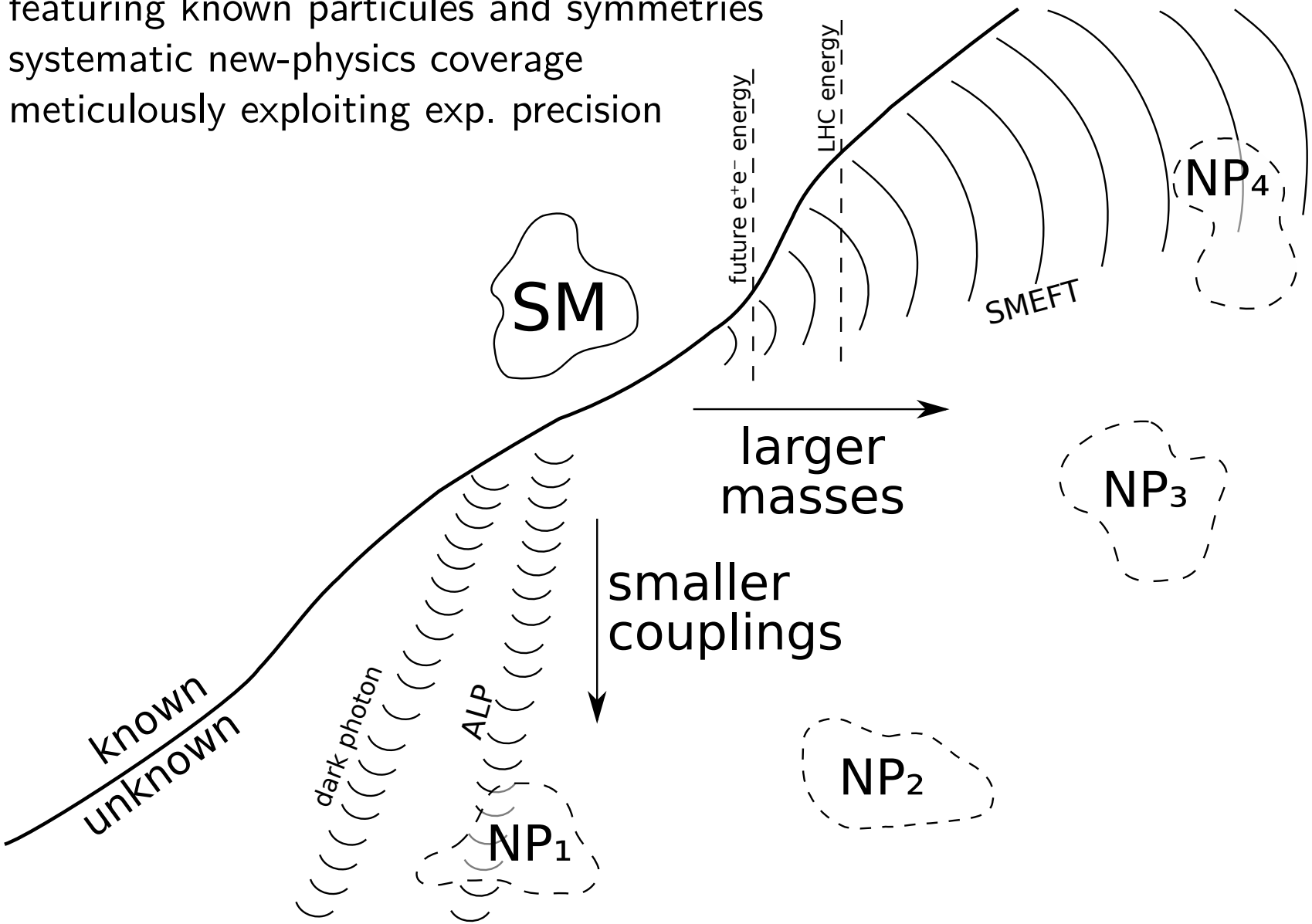
Gauthier Durieux
(CERN)



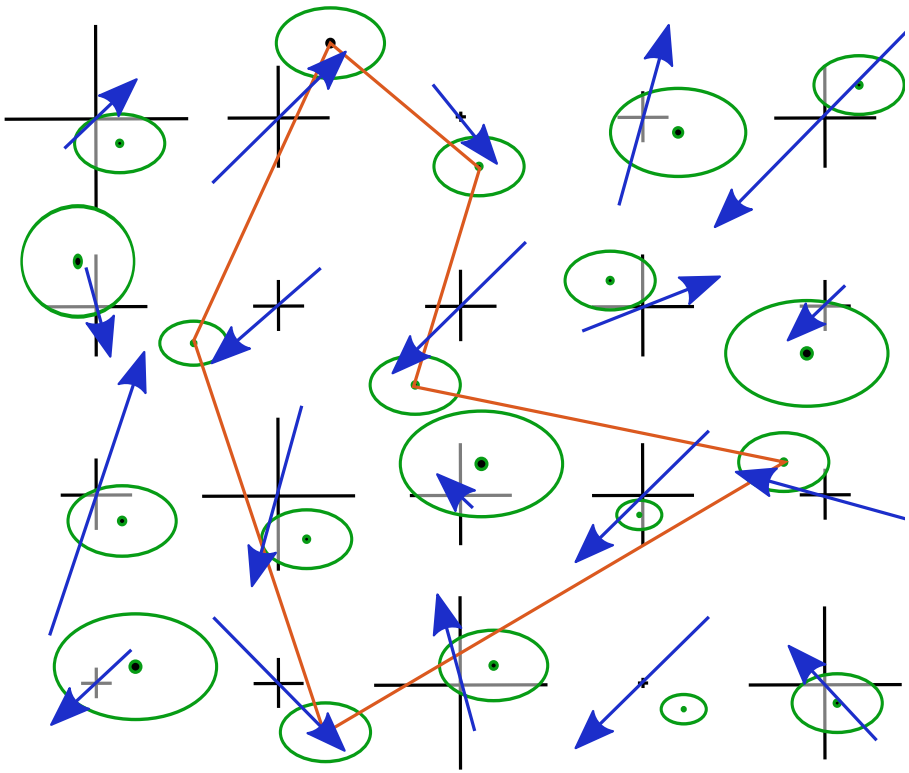
Top LHC France, 6 April 2021

Standard-model effective field theory

- featuring known particules and symmetries
- systematic new-physics coverage
- meticulously exploiting exp. precision



Identifying the pattern of new physics



design sensitive observables

- precise measurements
- precise SM predictions
- precise SMEFT predictions

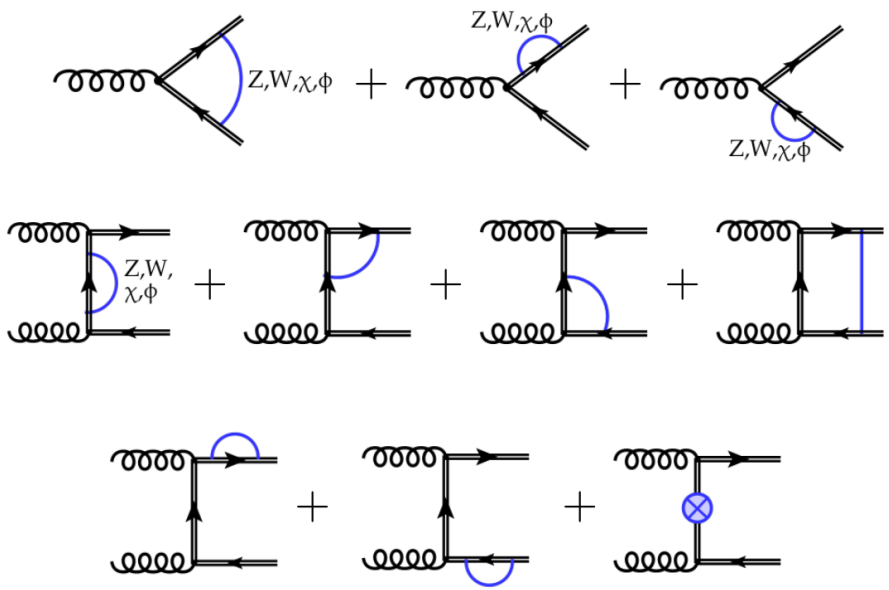
$\rightarrow$ leverage correlations

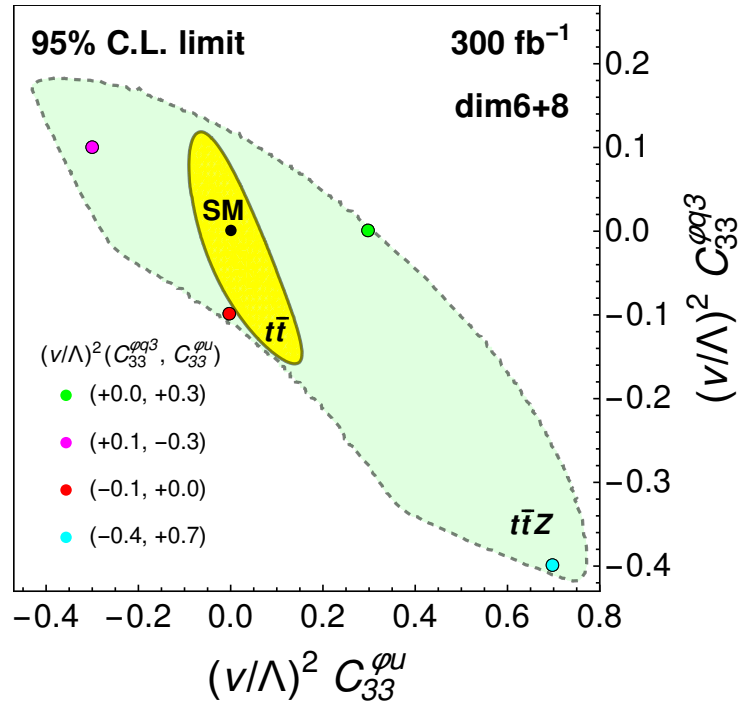
Higher orders

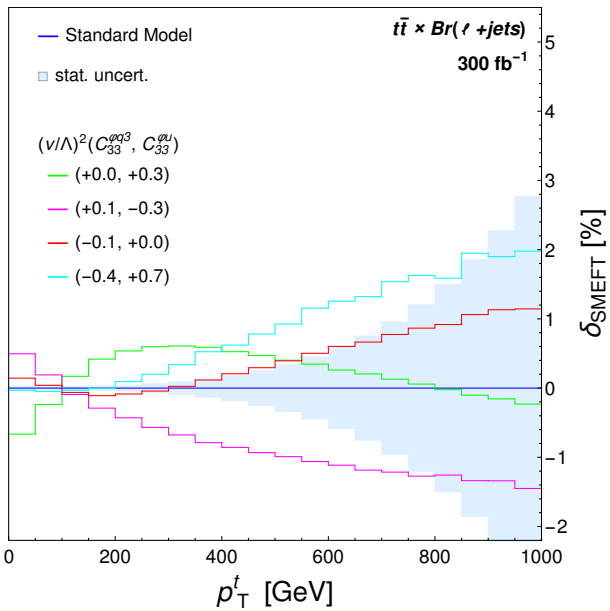
- more accurate central values
- reduced uncertainties
- new sensitivities

$\bar{Q}Q$ current operators in $pp \to t\bar{t}$ loops

[Martini, Schulze '19]







- linear + square in $C^1_{\varphi q}$, $C^3_{\varphi q}$, $C_{\varphi u}$
- assuming $C^1_{\varphi q} + C^3_{\varphi q} = 0$
  from $Z \to b\bar{b}$ constraint
- using $\Delta\varphi_{\ell\ell}$ in $t\bar{t}(Z \to \ell\ell)$ NLO QCD
  and $p_T(t)$ in $t\bar{t}$ NLO QCD+EW
- sys. from state-of-the-art scale unc.:
  correlated flat $\pm 15\%$ in $t\bar{t}Z$, and $\pm 5\%$ in $t\bar{t}$

SMEFT@NLO status

[Degrande, GD, Maltoni, Mimasu, Vryonidou, Zhang '20]
https://feynrules.irmp.ucl.ac.be/wiki/SMEFTatNLO

Operators [67]

- Higgs, electroweak, bosonic [8]
- $\bar{Q}Q, \bar{q}q, \bar{\ell}\ell$ currents $+W, Z$ $(+h)$ [16]
- $\bar{Q}Q$ dipoles (W, Z, γ) and Yukawa [4]
- $\bar{Q}Q + (\bar{Q}Q, \bar{q}q, \bar{\ell}\ell)$ [5+17+17]

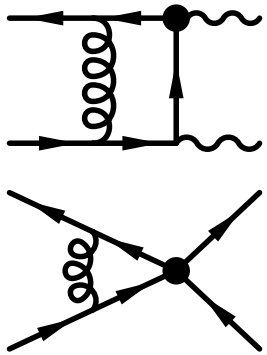
Exact CP and flavour symmetries

compatible with 5FS

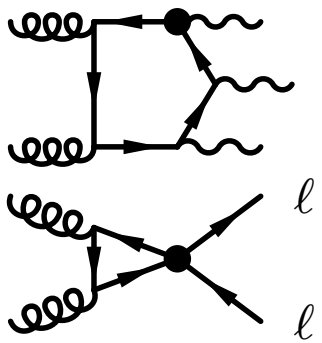
- $U(2)_q \times U(2)_u \times U(3)_d$ — no light-quark right-handed CC, or chiral flip
- $[U(1)_l \times U(1)_e]^3$ — 'diagonality' without LFU, no chiral flips

Processes

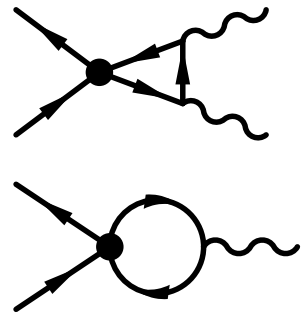
NLO QCD corr. (reals + virtuals)



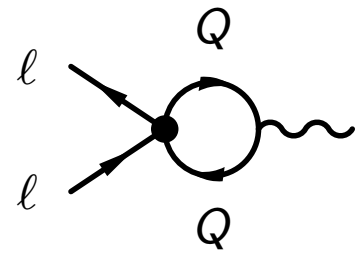
Loop-induced with g_s



Loop-induced with four-quarks



Next: loop-induced with $\bar{Q}Q\bar{\ell}\ell$



+ special mixed NLO QCD/EW: single top + Z, W, h
but no NLO to EW $t\bar{t}$, or to h exchange in $t\bar{t}t\bar{t}$

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Exac

- $U(2)_q \times U(2)_u \times U(3)_d$
- $[U(1)_t \times U(1)$

compatible with 5FS

no light-quark right-handed CC, or chiral flip

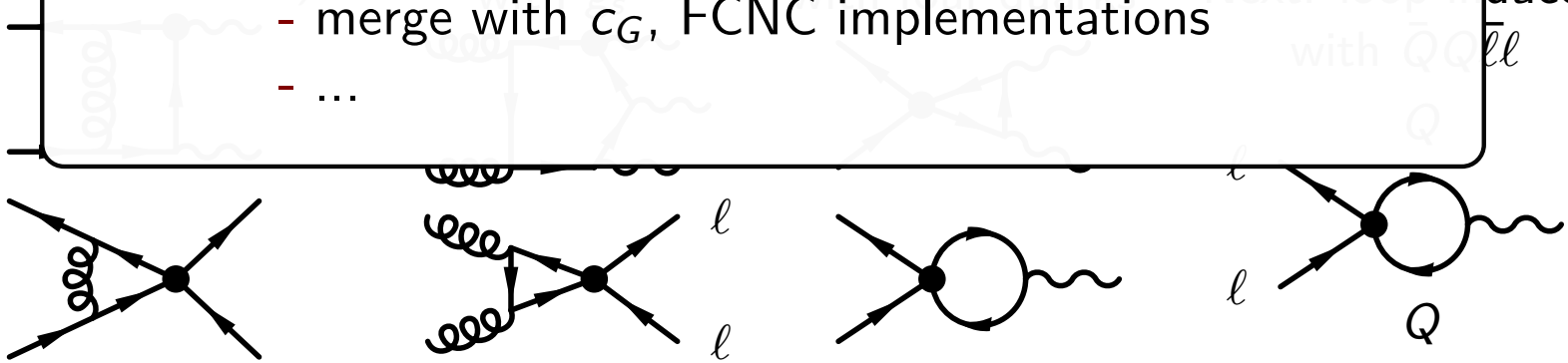
LFU, no chiral flips

Future:
- running and mixing
- CPV
- $U(2)_d$ / massive b / 4FS / b chiral flips
- loop induced $QQ\ell\ell$
- $q\bar{q} + (\bar{q}q, \bar{\ell}\ell)$ four-fermion operators
- (α, m_Z, m_W) inputs in addition to (G_F, m_Z, m_W)
- merge with c_G, FCNC implementations
- ...

Proc

NLO QCD corr. | loop-induced | loop-induced | Next: loop-induced

(rea + virtuals) | with g | with four-quarks | with $\bar{Q}Q\bar{\ell}\ell$



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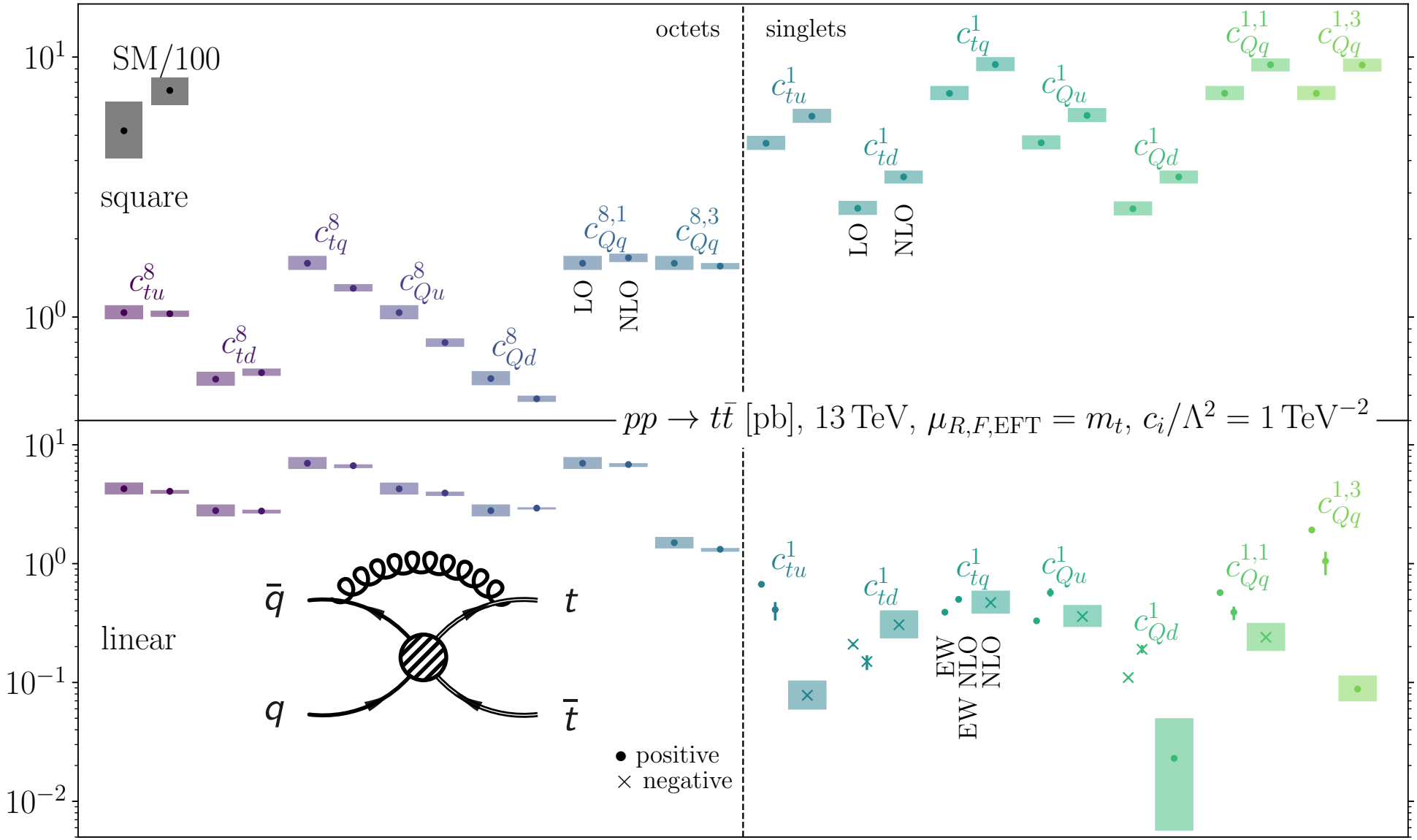
but no NLO to EW $t\bar{t}$, or to h exchange in $t\bar{t}t\bar{t}$

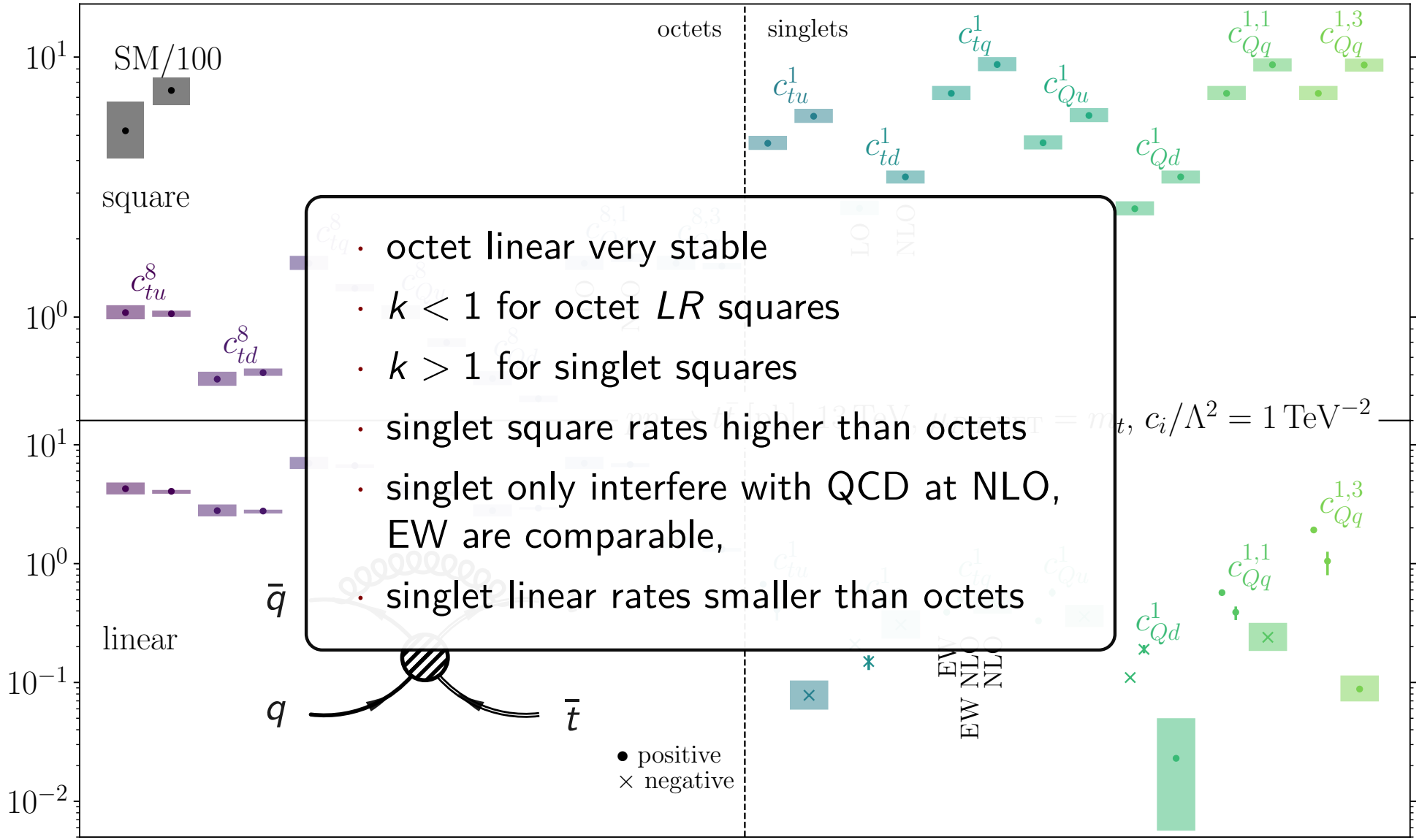
$QQqq$ operators in $pp \to t\bar{t}$

[SMEFT@NLO '20]



$QQqq$ operators in $pp \to t\bar{t}$

[SMEFT@NLO '20]

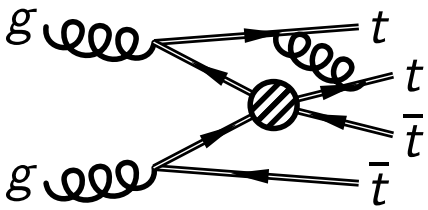


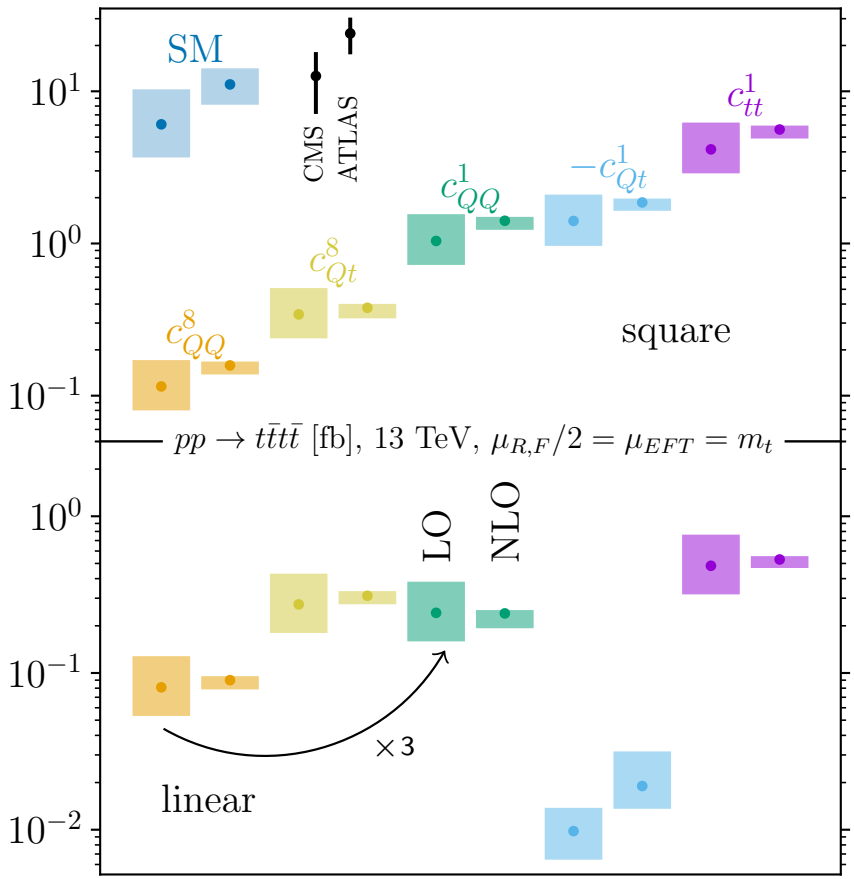
- octet linear very stable
- $k < 1$ for octet LR squares
- $k > 1$ for singlet squares
- singlet square rates higher than octets
- singlet only interfere with QCD at NLO, EW are comparable,
- singlet linear rates smaller than octets

$QQQQ$ operators in $pp \to t\bar{t}t\bar{t}$ and $t\bar{t}$

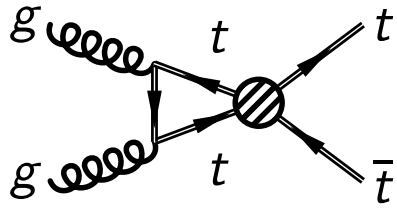
[SMEFT@NLO '20]

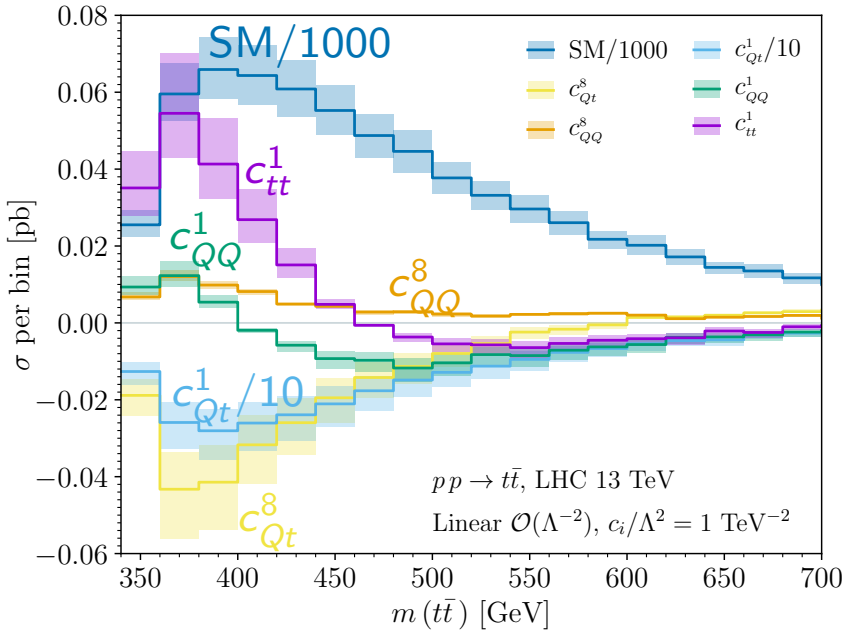
NLO accuracy and unc.





Loop-induced sensitivities





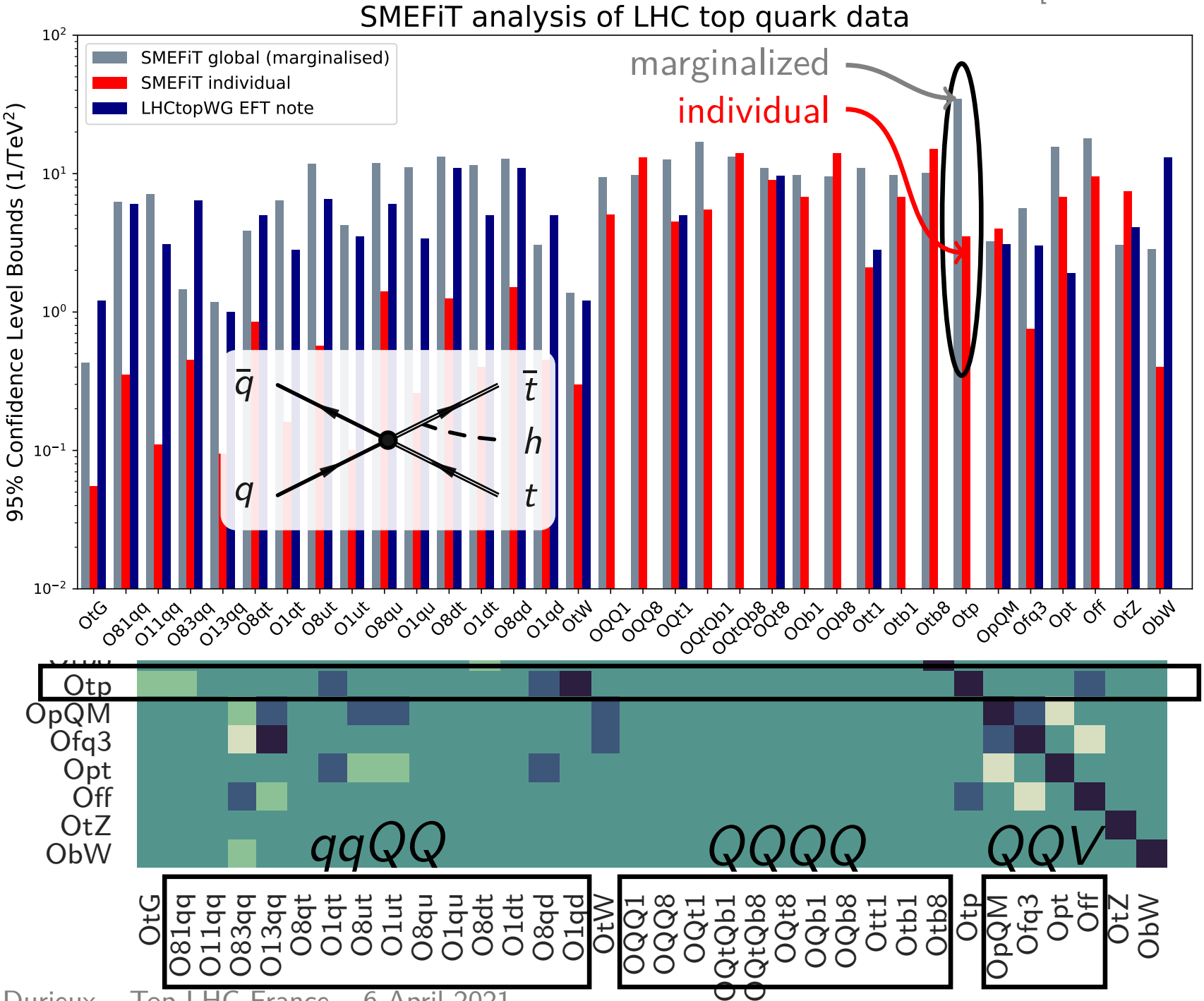
m_t suppressed, no energy growth

strong channel/differential cancellations

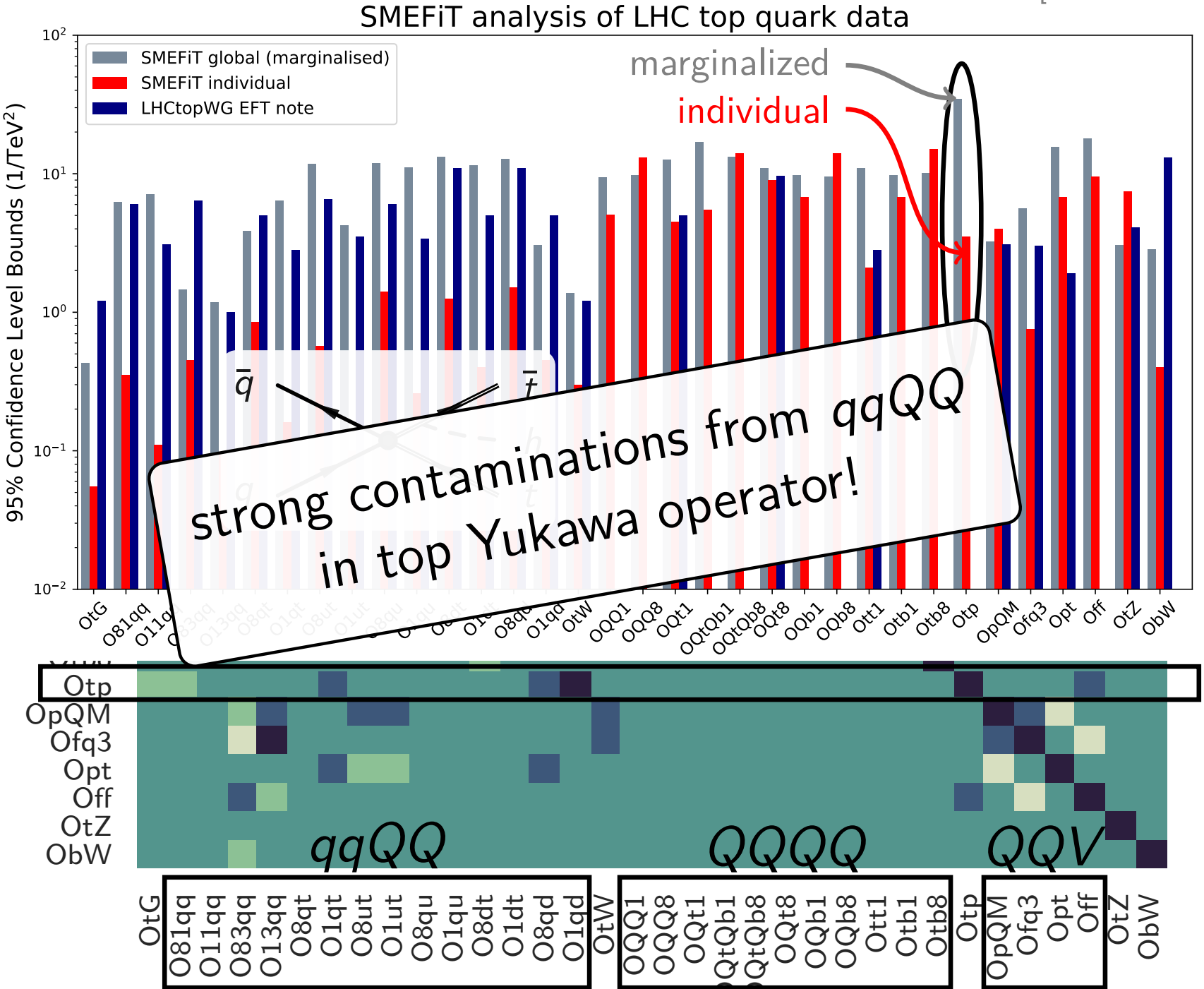
sensitivity to be examined in fits!

Global analyses

[Hartland et al. '19]

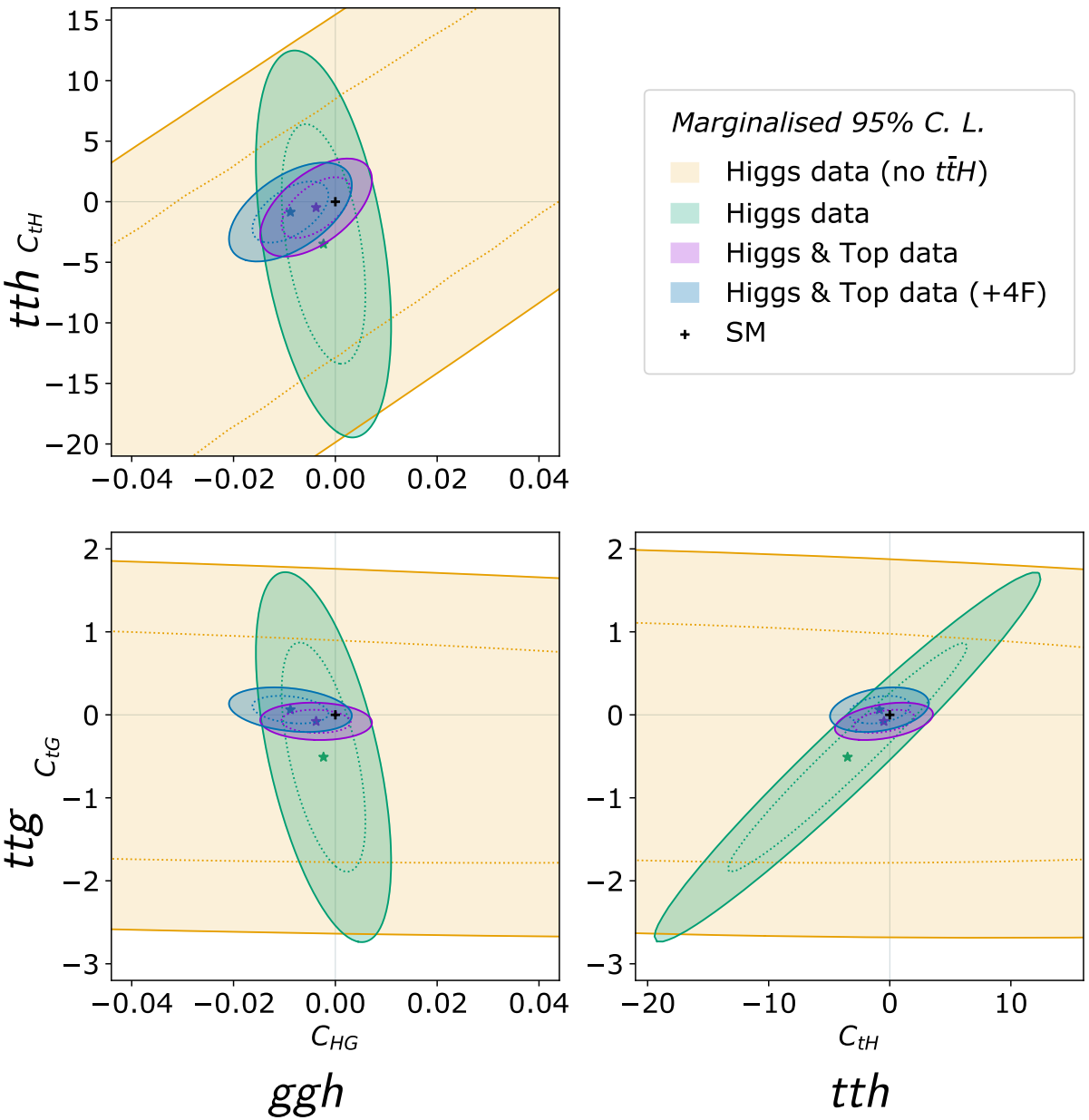


[Hartland et al. '19]



[Ellis et al. '20]

Fitmaker: EW+Higgs+top



- 34 op. in total
- linear dependences only

← Higgs/top complementarity among C_{HG}, C_{tH}, C_{tG}

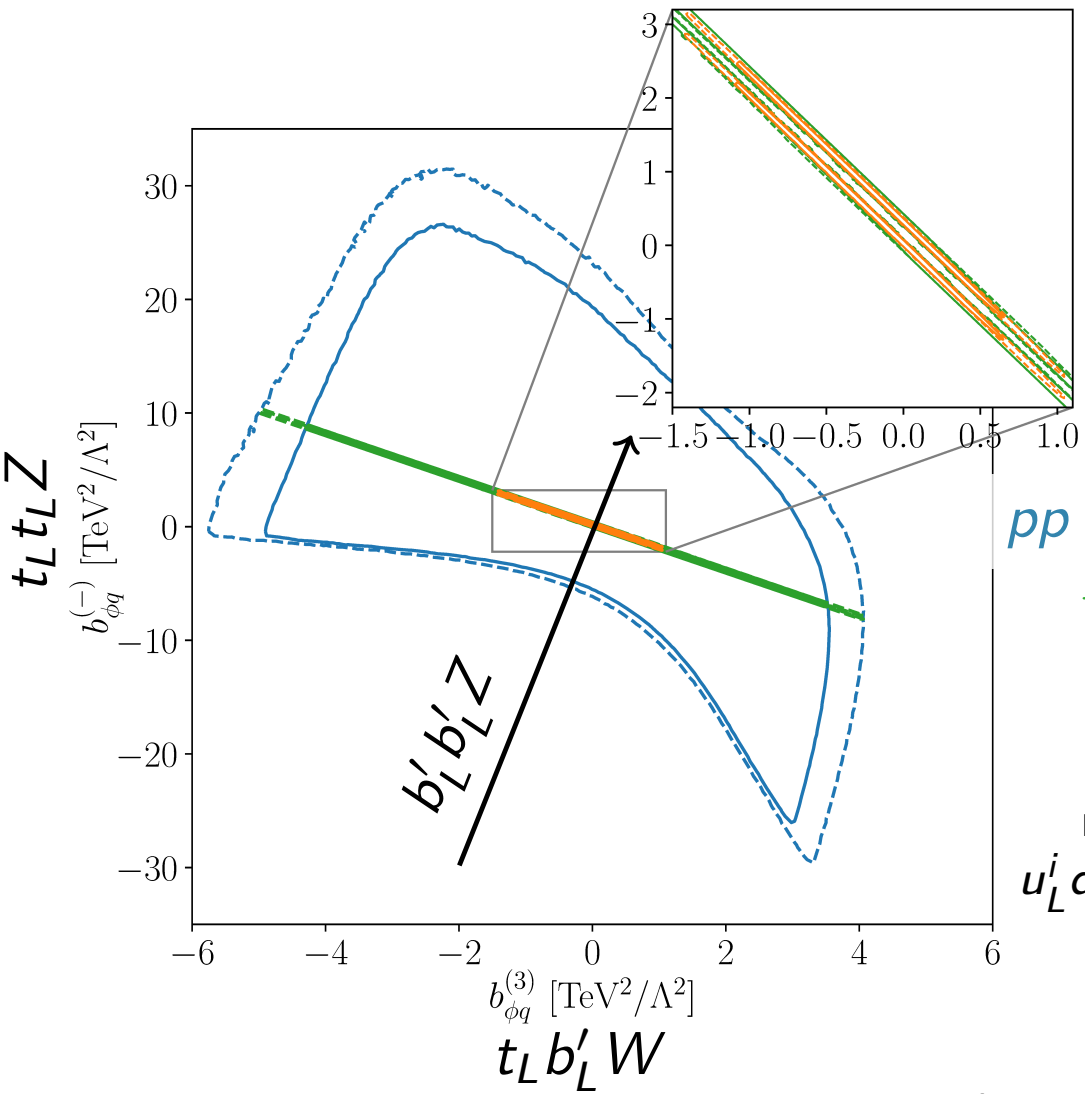
- in subset of 9 'Higgs' op. $C_{H\Box}$, C_{HG}, C_{HW}, C_{HB}, C_{tG}, C_{tH}, C_{bH}, $C_{\tau H}$, $C_{\mu H}$
- marginally affected by additional four-quark operators
- also for the top Yukawa op.

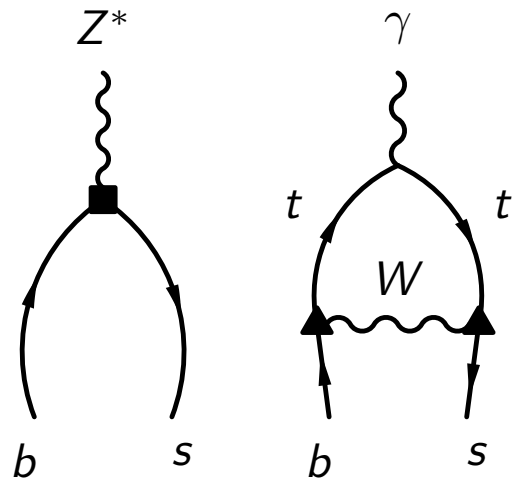
Sfitter: top+bottom

[Bruggisser et al. '21]

$B_s \to \mu^+\mu^-$ constrains $Zb'_L b'_L$
$B \to X_s\gamma$ probing $t_L b'_L W$

with $b'_L \equiv V_{td} d_L + V_{ts} s_L + V_{tb} b_L$





$pp \to ttZ, tZ, tW, tj$
$+ B_s \to \mu^+\mu^-$
$+ B \to X_s\gamma$
(no $Z \to bb$)

marginalized over
$u^i_L d^i_L W / u^i_L u^i_L Z / d^i_L d^i_L Z$,
$\Delta\chi^2 = 2.3$ & 6

($q_L q_L q_L q_L$ op. also studied)

EFTfitter: top+bottom

[Bißmann et al. '20]

Operators [8]

- top dipoles [3]
- top currents [3]
- $b'_L b'_L \ell\ell$ [2]

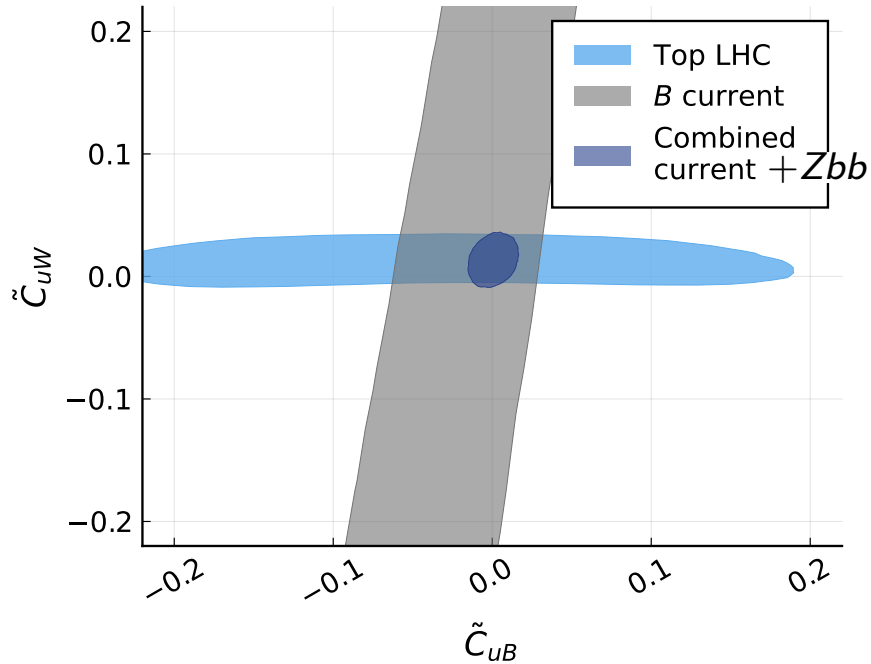
Constraints

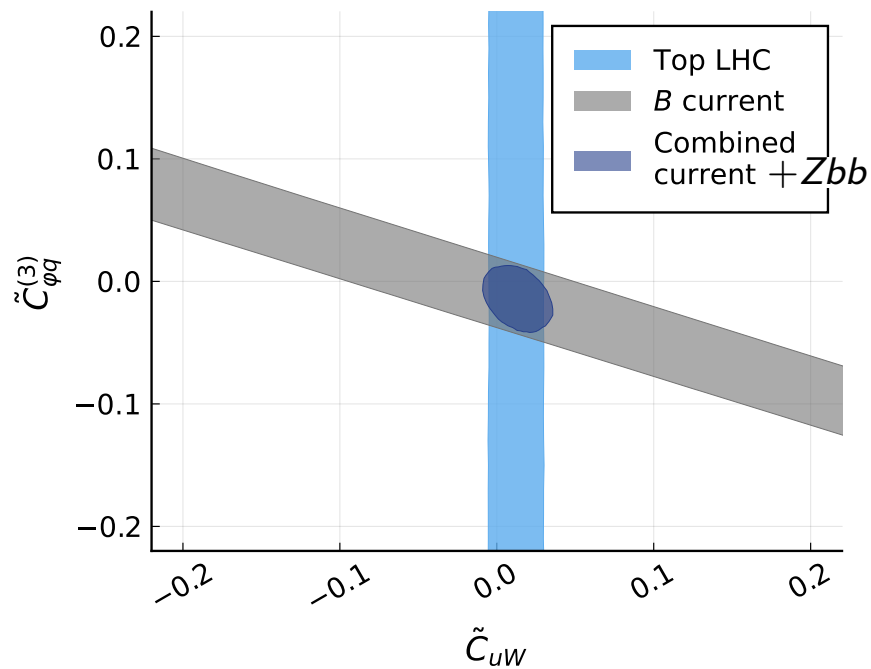
- $t\bar{t}$, $t\bar{t}\gamma$, $t\bar{t}Z$ rates
- W helicity fractions
- $Z \to b\bar{b}$ (at tree level)
- $b \to s\gamma$, $b \to s\ell\ell$ (`flavio+wilson`)
- B_s mixing, $b \to s\nu\bar{\nu}$

\+ future $e^+e^- \to t\,\bar{t}$ (σ,A_{FB})

Improvements from b

- mostly on C_{uB}, $C^3_{\varphi q}$ ($b \to s\gamma$)
- not much in $C_{\varphi u}$
- none in C_{tW}, C_{tG}





EFT and top

strive to sharpen possible new-physics pattern

with
- precise sensitive measurements (run-3!)
- higher orders and global analyses

reduce EFT theory uncertainties

(yet to be included in fits!)

leverage loop sensitivities

combine top with EW/Higgs/b datasets