Flavor assumptions in SMEFT

contribution by

Sebastian Bruggisser, Susanne Westhoff
Heidelberg University

Danny van Dyk
Technical University Munich

LHC EFT WG meeting | Jan 25, 2022 | online

Key questions

How does the flavor structure of SMEFT operators impact…

1.

… predictions of LHC observables?

2.

… global analyses across energy scales?

Flavor assumptions

$$C_{\phi q}^{(1),kl} O_{\phi q}^{(1),kl} = C_{\phi q}^{(1),kl} (H^\dagger \, i\overleftrightarrow{D^\mu} \, H)(\overline{Q}^k \gamma_\mu Q^l)$$

- Universality: $U(3)^5$ symmetry $C_{\phi q}^{(1)} = \begin{pmatrix} a & & \\ & a & \\ & & a \end{pmatrix}$

- 3rd generation: $C_{\phi q}^{(1)} = \begin{pmatrix} 0 & & \\ & 0 & \\ & & a \end{pmatrix}$

- Minimal flavor violation: SM-like flavor breaking

$$C_{\phi q}^{(1)} = a\,\mathbf{1} + b\,Y_U Y_U^\dagger + c\,Y_D Y_D^\dagger + \ldots \;\; = \begin{pmatrix} a & & \\ & a & \\ & & a + b\,y_t^2 \end{pmatrix} + \mathcal{O}(y_b^2)$$

Flavor assumptions

$$C_{\phi q}^{(1),kl} O_{\phi q}^{(1),kl} = C_{\phi q}^{(1),kl} (H^\dagger i\overleftrightarrow{D^\mu} H)(\overline{Q}^k \gamma_\mu Q^l)$$

- Universality: $U(3)^5$ symmetry $\quad C_{\phi q}^{(1)} = \begin{pmatrix} a & & \\ & a & \\ & & a \end{pmatrix}$

- 3rd generation: $\quad C_{\phi q}^{(1)} = \begin{pmatrix} 0 & & \\ & 0 & \\ & & a \end{pmatrix}$

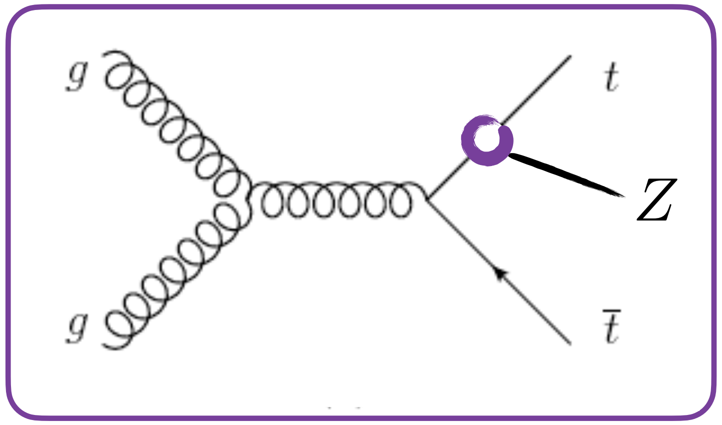
- Minimal flavor violation: SM-like flavor breaking

$$C_{\phi q}^{(1)} = a\,\mathbf{1} + b\,Y_U Y_U^\dagger + c\,Y_D Y_D^\dagger + \ldots \; = \begin{pmatrix} a & & \\ & a & \\ & & a + b\,y_t^2 \end{pmatrix} + \mathcal{O}(y_b^2)$$

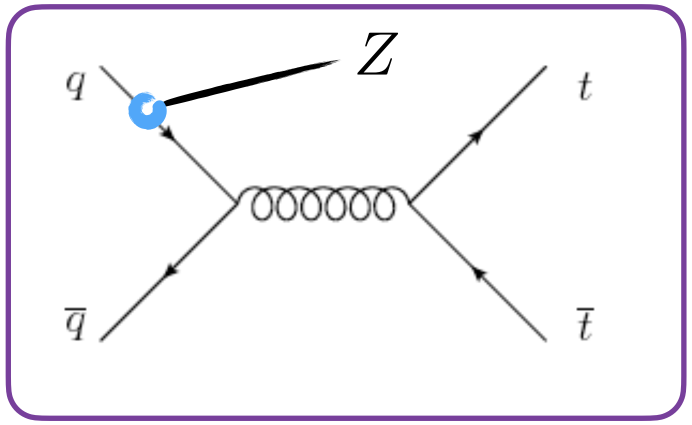
Flavor breaking in SMEFT:
specify a reference direction (up or down mass basis).

Flavor effects in ‚flavorless' observables

Example: $t\bar{t}Z$ production



+



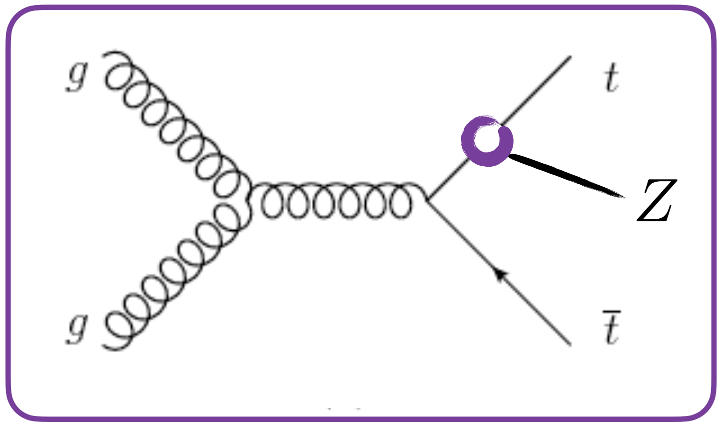
$$\sigma_{t\bar{t}Z}\,[\mathrm{pb}] = 0.679 + 0.023\, a_{\phi q}^{(3)} - 0.070 A_{\phi q}^{(-)} \qquad A = a + b\, y_t^2$$

$q\bar{q}$ contributions probe flavor universality.

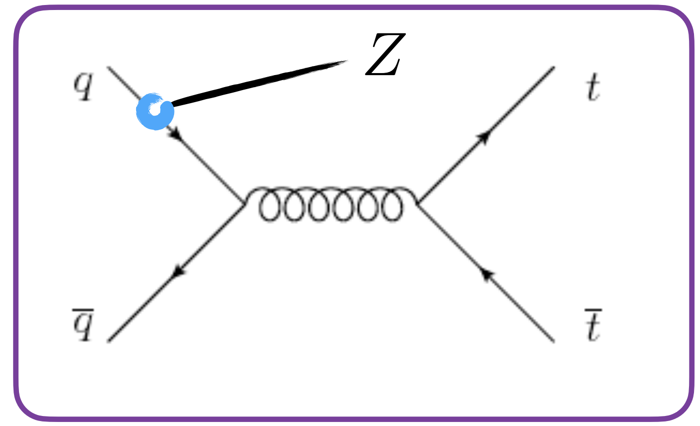
Flavor effects in ‚flavorless' observables

Example: $t\bar{t}Z$ production

QCD:

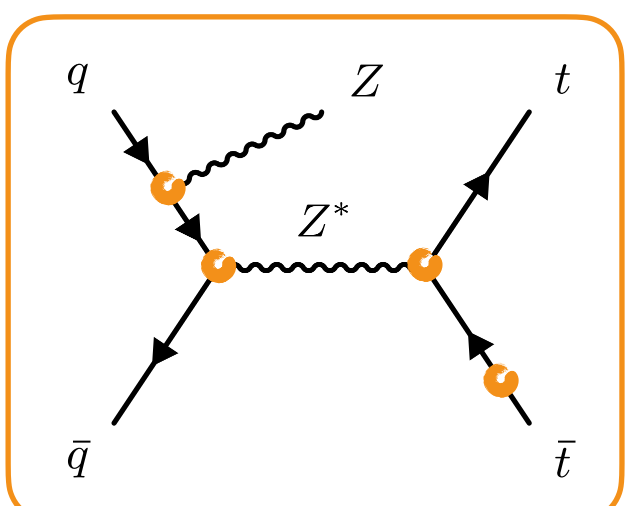


+



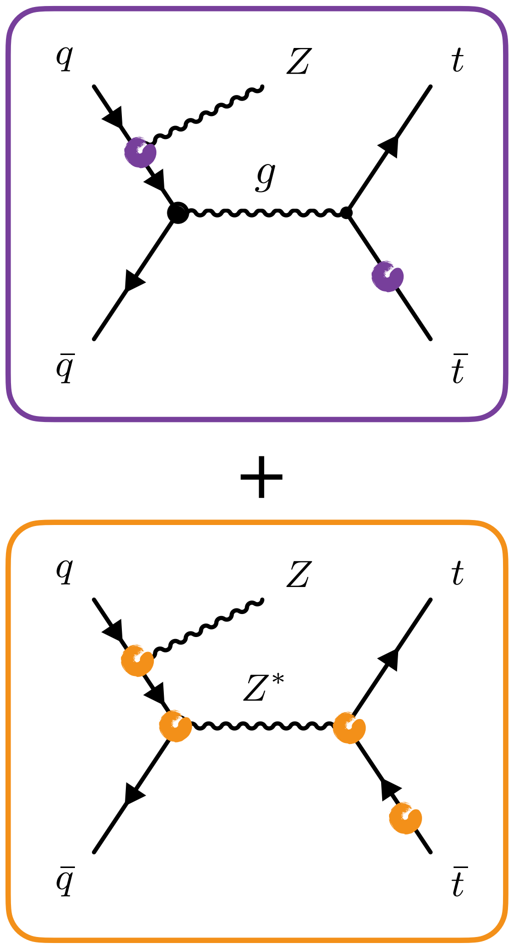
$$\sigma_{t\bar{t}Z}\,[\mathrm{pb}] = 0.679 + 0.023\, a_{\phi q}^{(3)} - 0.070 A_{\phi q}^{(-)}$$

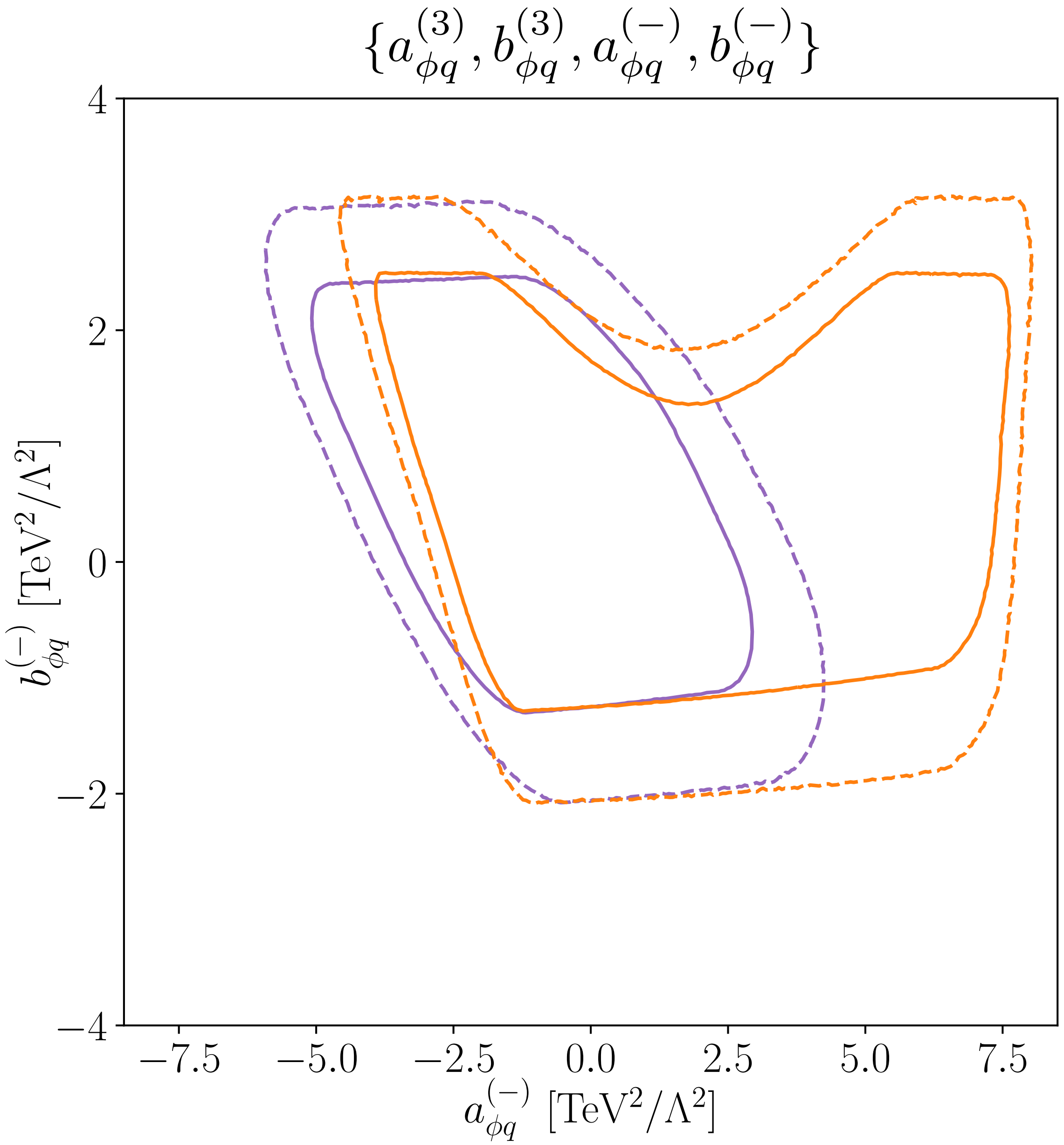
EW:



$$+\mathbf{0.008}(a_{\phi q}^{(-)})^2 + \mathbf{0.004}(a_{\phi q}^{(+)})^2$$

$t\underline{t}Z$ production in top-flavor fit



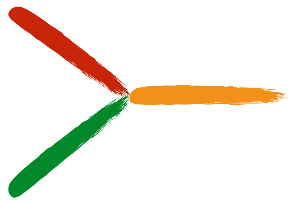


Electroweak contributions are sensitive to flavor assumption.

Bruggisser, Schäfer, van Dyk, Westhoff 2021

The TeV-GeV connection

Λ



$$C_i(\Lambda) = F(g_k, m_k)$$

flavor-sensitive

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{C_i}{\Lambda^2} O_i + \ldots$$

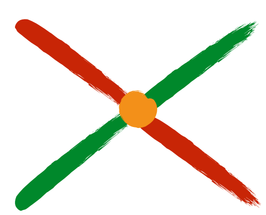
100 GeV

$$\mathcal{C}_a(m_b) = F(C_i(m_t))$$

flavor-sensitive

$$\mathcal{L}_{\mathrm{WET}} = \mathcal{L}_{\mathrm{QCD}} + \mathcal{L}_{\mathrm{QED}} + \sum_a \mathcal{C}_a \mathcal{O}_a + \ldots$$

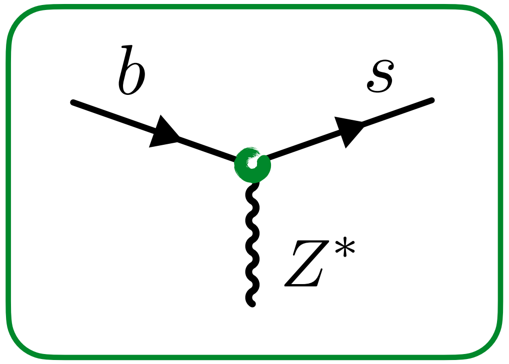
1 GeV



Aebischer et al. 2015 & 2017; Dekens et al. 2017 & 2019; Hurth et al. 2019

Flavor in rare B decays

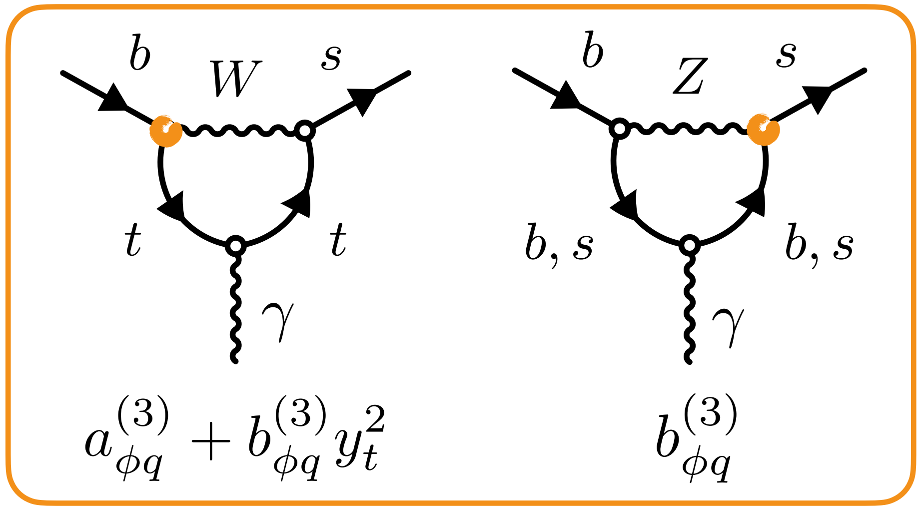
Tree level: flavor-breaking



$$\sum (C_{\phi q}^{(1),kk} + C_{\phi q}^{(3),kk})\, V_{k3} V_{k2}^* \sim (b_{\phi q}^{(1)} + b_{\phi q}^{(3)}) y_t^2$$

$$\mathcal{B}(B_s \to \mu^+\mu^-) \times 10^9 = 3.57 - 41.0\, b_{\phi q}^{(+)} + 117.8 (b_{\phi q}^{(+)})^2$$

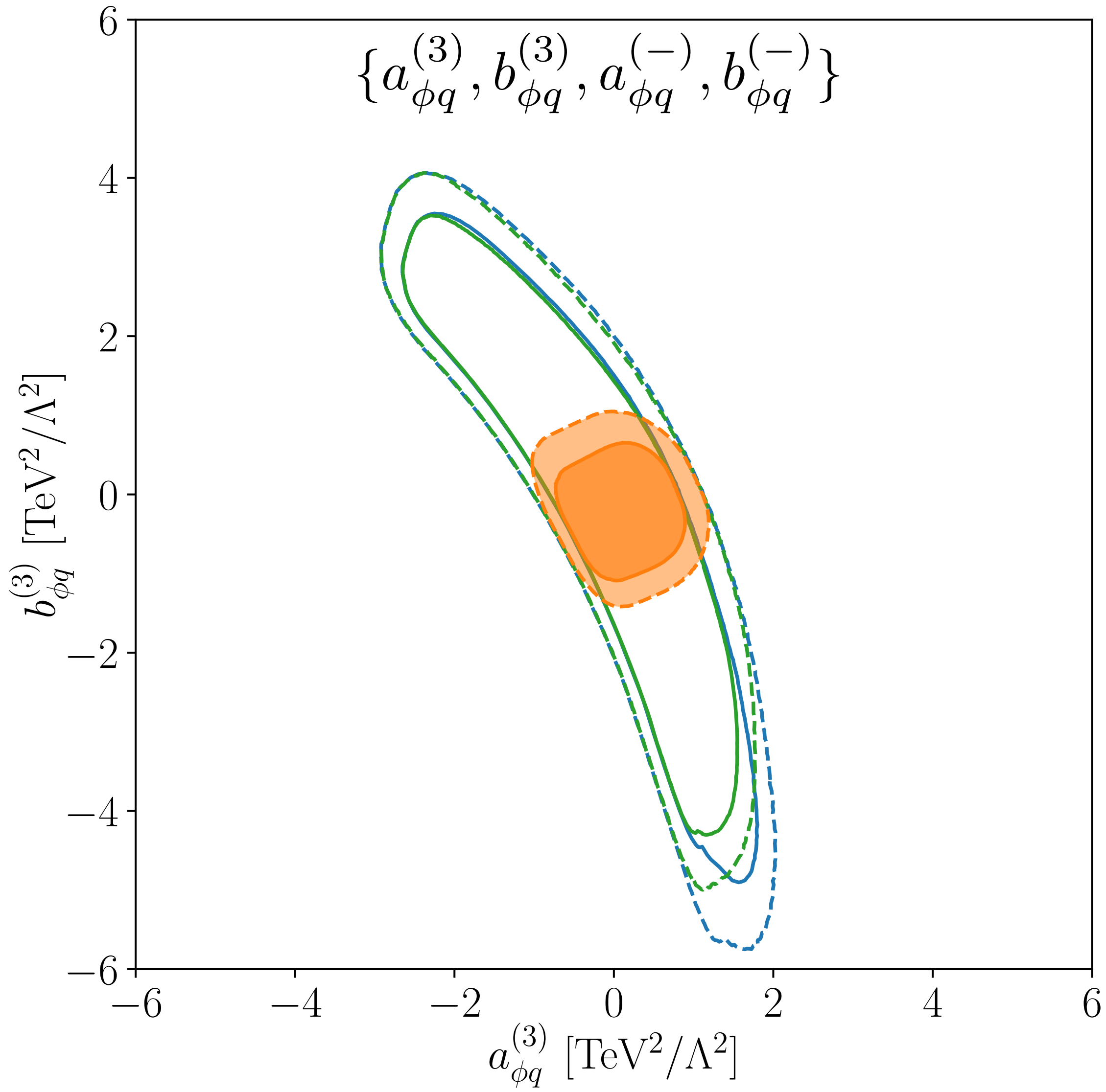
Loop level: flavor-diagonal & flavor-breaking



$$\mathcal{B}(B \to X_s \gamma) \times 10^4 = 3.26 + 0.36\, a_{\phi q}^{(3)} - 0.76\, b_{\phi q}^{(3)}$$

Flavor breaking in MFV

Combined fit to top data & $\mathcal{B}(B_s \to \mu^+\mu^-)$ & $\mathcal{B}(B \to X_s\gamma)$



top processes

QCD

$pp \to t\bar{t}$

$pp \to t\bar{t}Z, t\bar{t}W$

EW

$pp \to tj, tZj$

$pp \to tW$

$t \to bW$

TeV-GeV connection resolves flavor structure.

Bruggisser, Schäfer, van Dyk, Westhoff 2021

Thoughts about flavor assumptions

Organize effects of

- flavor breaking (light versus heavy quarks)
- flavor alignment (up-type versus down-type quarks)

CKM mixing

- is often sub-leading in LHC observables
- induces non-trivial effects at one-loop (rare B decays)
- needed for global analysis of top and bottom observables