Flavour constraints on the flavourless SMEFT

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Based on:

Matching for FCNCs in the flavour symmetric SMEFT [1903.00500] with T Hurth, W Shepherd,
The impact of flavour data on global fits of the MFV SMEFT [2003.05432] with T Hurth, W Shepherd, R Aoude

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Introduction and motivation

- BSM particles with new tree level flavour-violating interactions: clearly flavour observables will be sensitive
- What about the other extreme? What if BSM physics is flavourless? Does flavour still have something to say?
- If TeV scale new physics exists, it is looking likely it should have a flavour symmetry
- SMEFT global fits often done assuming $U(3)^5$ flavour symmetry, or MFV. In this context is flavour data irrelevant?

Flavour in the SMEFT

2499 parameters, nearly all of which are elements of flavour matrices

Large hierarchy of constraints on different WCs...

For TeV scale NP, have to assume that many WCs are suppressed way below O(1)

[SMEFT tree level flavour constraints: Silvestrini & Valli 1812.10913]

For Λ close to the TeV scale, need:

Flavour symmetries and/or **FCNCs connected to fermion masses**

eg MFV

eg partial compositenesss

Suppression of tree level FCNCs, and more manageable number of parameters

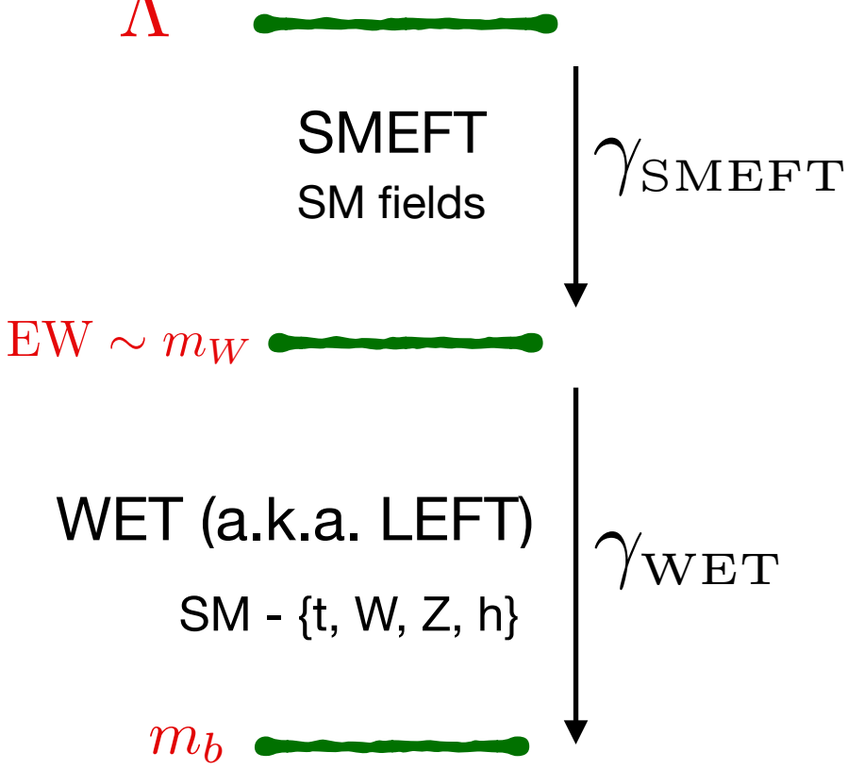
Flavour in the flavour symmetric SMEFT

$$U(3)^5$$

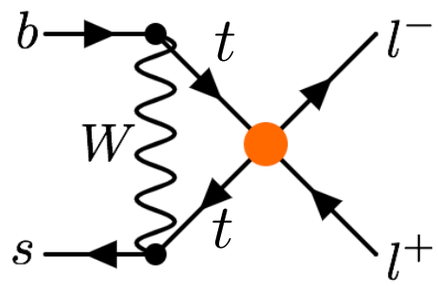
Plus lowest order in spurionic Yukawas

$$Y_u \sim (3, \bar{3}, 1, 1, 1)$$
$$Y_d \sim (3, 1, \bar{3}, 1, 1)$$
$$Y_e \sim (1, 1, 1, 3, \bar{3})$$

$\Longrightarrow$ **No tree level FCNCs**



Loop level matching at mW:
Integrate out loops of Ws, tops



Below mW: contribution to WET operator

$$(\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu P_L l)$$

- Calculated full one-loop matching from MFV SMEFT to operators below weak scale mediating $d_i \to d_j\gamma$, $d_i \to d_j l^+ l^-$, $d_i \to d_j \bar{\nu}\nu$ and meson mixing

Observables and operators

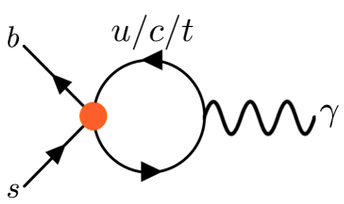
Down-type FCNC processes

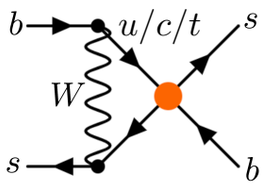
$B_{s,d}$ **mixing** $\quad b \to s\gamma \quad B \to K^{(*)}\bar{\nu}\nu \quad K \to \pi\bar{\nu}\nu$

$b \to s l^+ l^-$

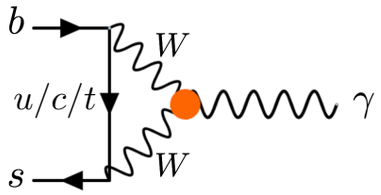
These depend on a total of 27 Warsaw basis coefficients, through diagrams like these:

4 quark operators

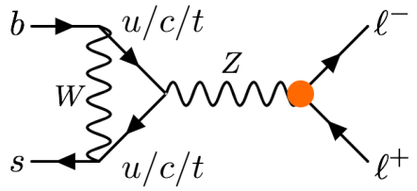


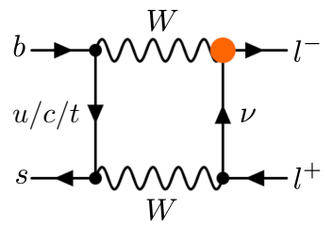


Purely bosonic operators

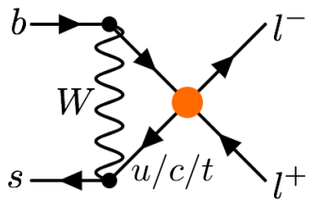


Higgs-lepton operators

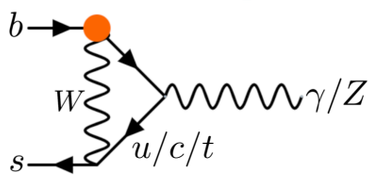


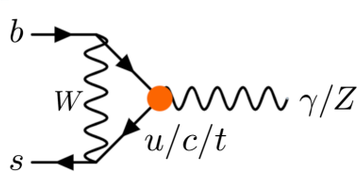


2 quark, 2 lepton operators

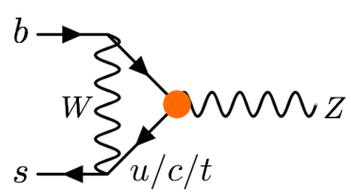


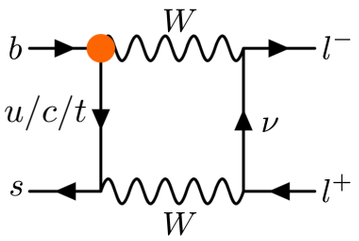
Dipole operators





Higgs-quark operators





[Other matching refs: Aebischer & al 1512.02830, Dekens & Stoffer 1908.09295]

Results of matching calculations

Expressions for WET coeffs in terms of SMEFT coeffs
+ flavour constraints as bounds on those WET coeffs

} **New constraints for global SMEFT fits**

Example: $\Delta M_{s,d}$ observable in $B_{s,d}$ mixing

Constrains BSM coefficients of WET operators

$(\bar{s}_L \gamma^\mu b_L)^2$
$(\bar{d}_L \gamma^\mu b_L)^2$

$$C^{bs}_{1,\text{mix}}(m_W) = 0.09 \pm 0.14$$
$$C^{bd}_{1,\text{mix}}(m_W) = 0.08 \pm 0.14$$

Matching result:

$$C^{b(s,d)}_{1,\text{mix}}(m_W) = 0.25\, C_{uW} + 0.61\, (C^{(3)}_{Hq} + C'_{ll} - 2C^{(3)}_{Hl}) + 0.28\, (C^{(3)\prime}_{qq} - C^{(1)\prime}_{qq} - 2C^{(3)}_{qq})$$

Constrained WET coefficient

Linear combination of SMEFT coeffs, in units of 1/TeV²

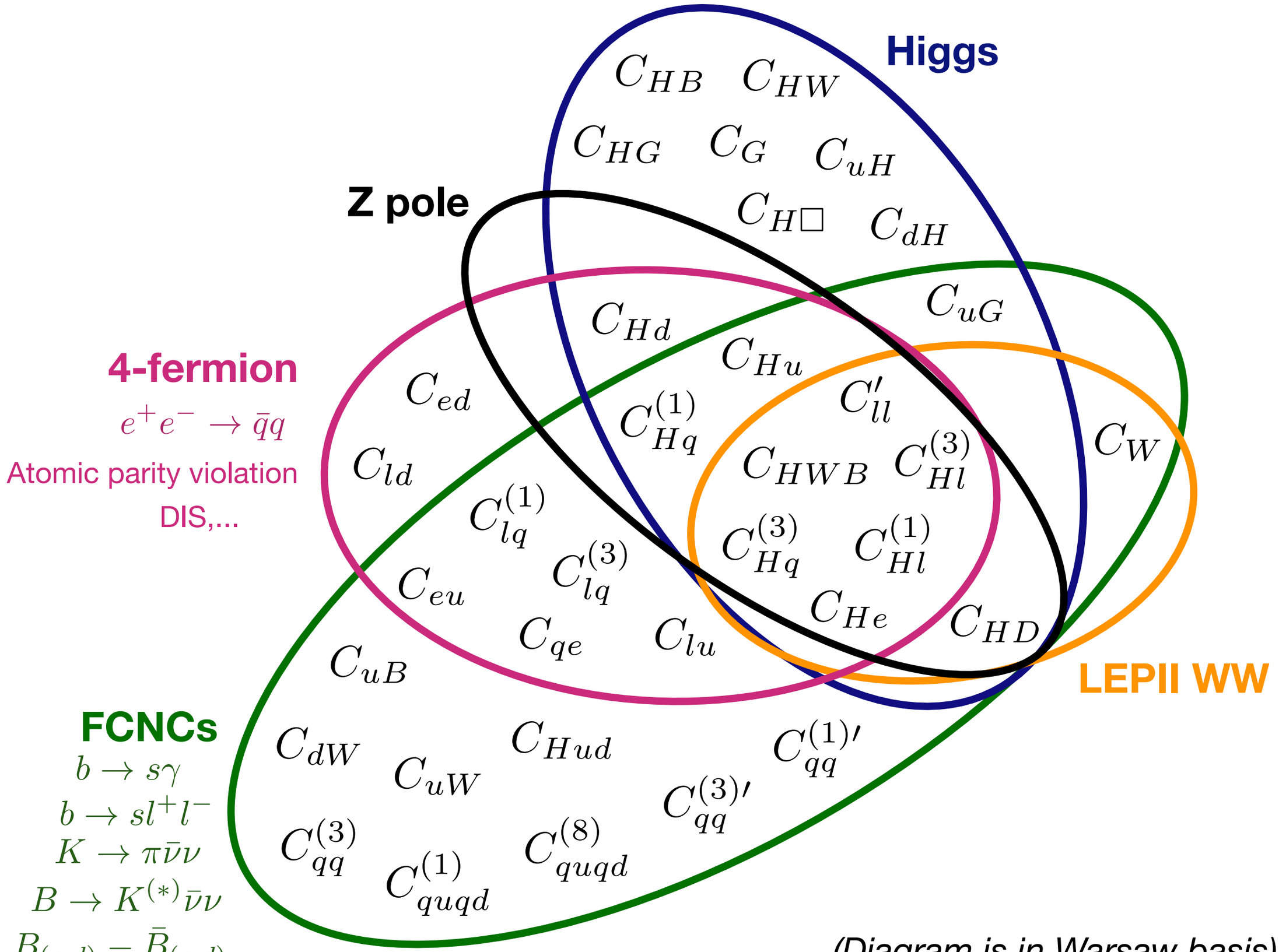
Flavour vs existing constraints

Many of the operators involved in the matching are already (well) constrained in traditional SMEFT fits

But there are flat directions in global fits: more operators than independent constraints

To get a full picture...

- Allow all operators at once
- Constrain with many different observables



4-fermion

$e^+e^- \to \bar{q}q$

Atomic parity violation

DIS,...

FCNCs

$b \to s\gamma$

$b \to sl^+l^-$

$K \to \pi\bar{\nu}\nu$

$B \to K^{(*)}\bar{\nu}\nu$

$B_{(s,d)} - \bar{B}_{(s,d)}$

(Diagram is in Warsaw basis)

Global fit

Observables: Higgs, Z-pole, LEPII WW, $e^+e^- \to \bar{q}q$ off the Z pole, low energy precision measurements, flavour } **186 observables**

$$\{C_{H\Box}, C_{HWB}, C_{HD}, C_{HW}, C_{HB}, C_{HG}, C_W, C_G, C_{Hl}^{(1)}, C_{Hl}^{(3)}, C_{Hq}^{(1)}, C_{Hq}^{(3)}, C_{Hu}, C_{Hd}, C_{He},$$
$$C_{Hud}, C_{uH}, C_{dH}, C_{uW}, C_{dW}, C_{uB}, C_{uG}, C'_{ll}, C_{lq}^{(3)}, C_{lq}^{(1)}, C_{qe}, C_{lu}, C_{ld}, C_{eu}, C_{ed},$$
$$C_{qq}^{(1)\prime}, C_{qq}^{(3)}, C_{qq}^{(3)\prime}, C_{quqd}^{(1)}, C_{quqd}^{(8)}, C_{quqd}^{(1)\prime}, C_{quqd}^{(8)\prime}\}.$$

} **36 coefficients**

Method of least squares

[PDG Statistics review]

$$\boldsymbol{\mu}(\boldsymbol{\theta}) = \boldsymbol{\mu}_{SM} + \mathbf{H} \cdot \boldsymbol{\theta}$$

matrix

vector of SMEFT coeffs

vector of SMEFT predictions for the observables

covariance matrix of measurements

Fisher matrix $\mathbf{F} = \mathbf{H}^T \mathbf{V}^{-1} \mathbf{H} = \mathbf{U}^{-1}$

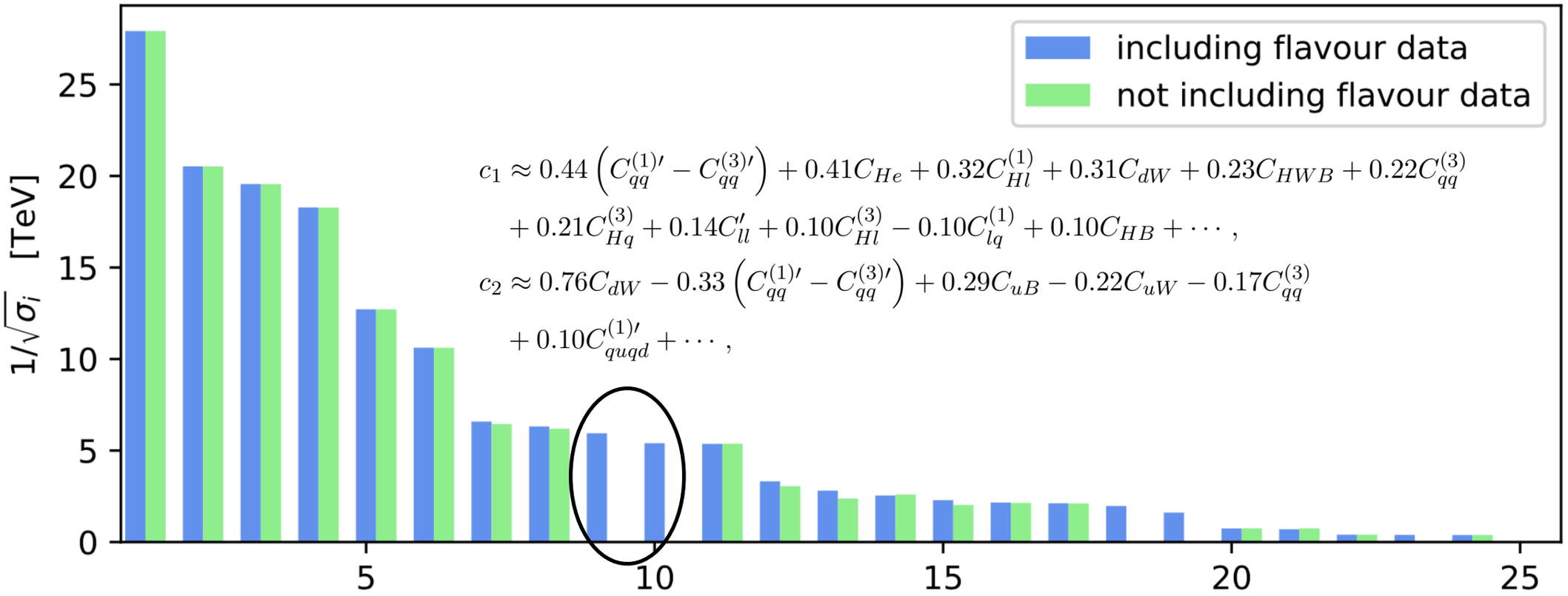
Output of the fit: covariance matrix in Wilson coeff space

Eigenvectors of the Fisher matrix: linear combinations of SMEFT coeffs

Eigenvalues of the Fisher matrix: $1/\sigma_i^2$

Constraints

Observables: Higgs, Z-pole, LEPII WW, $e^+e^- \to \bar{q}q$ off the Z pole, low energy precision measurements, flavour



Without flavour: 12 flat directions
With flavour: 7 flat directions

Flavour in Z pole flat directions

In the Wilson coeff space of Z pole data...

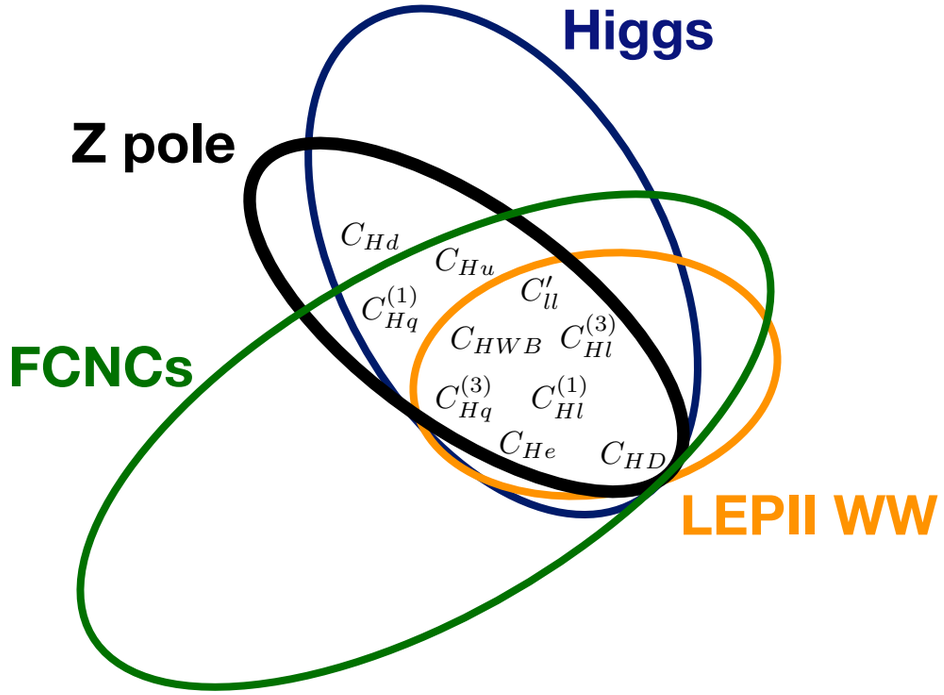
$$\{C_{HWB}, C_{HD}, C_{Hl}^{(1)}, C_{Hl}^{(3)}, C_{Hq}^{(1)}, C_{Hq}^{(3)}, C_{Hu}, C_{Hd}, C_{He}, C'_{ll}\}$$

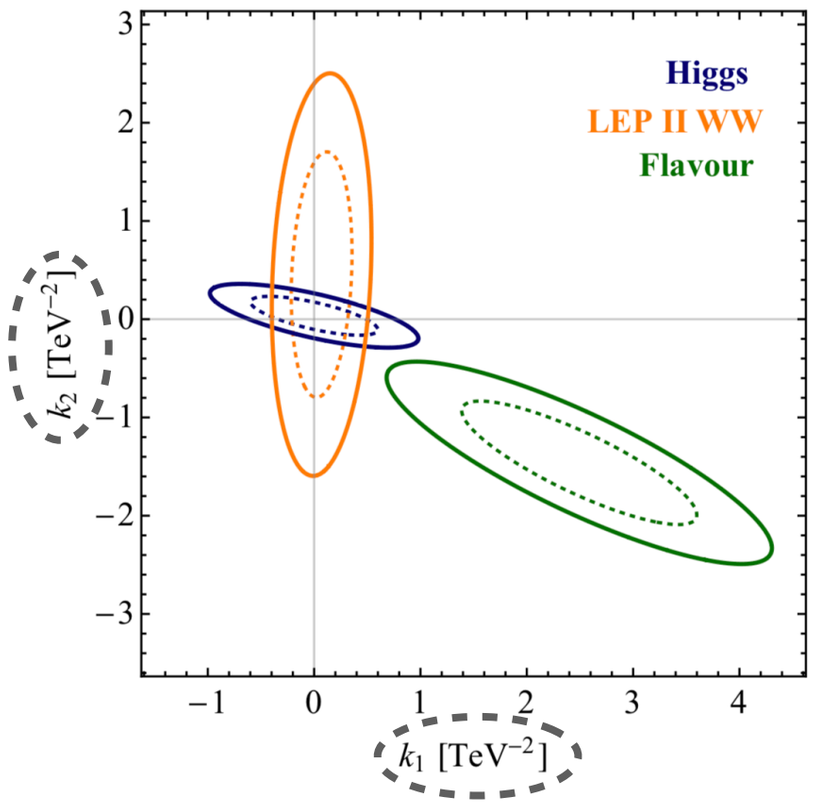
there are *two directions* that are unconstrained

$$k_1 = 0.369\Big(\frac{1}{3}C_{Hd} - 2C_{HD} + C_{He} + \frac{1}{2}C_{Hl}^{(1)} - \frac{1}{6}C_{Hq}^{(1)} - \frac{2}{3}C_{Hu} - 5.12(C_{Hq}^{(3)} + C_{Hl}^{(3)}) + 3.62C_{HWB}\Big),$$

$$k_2 = -0.118\Big(\frac{1}{3}C_{Hd} - 2C_{HD} + C_{He} + \frac{1}{2}C_{Hl}^{(1)} - \frac{1}{6}C_{Hq}^{(1)} - \frac{2}{3}C_{Hu} + 0.77(C_{Hq}^{(3)} + C_{Hl}^{(3)}) + 0.56C_{HWB}\Big).$$

Fit to this space of 10 coefficients and plot contours in the plane of the flat directions, profiling over the 8 orthogonal directions





[SMEFT predictions for Z pole observables from Brivio & Trott 1701.06424,
SMEFT predictions for LEPII WW from Berthier, Bjorn, Trott 1606.06693,
SMEFT predictions for Higgs signal strengths from Ellis, Murphy, Sanz, You 1803.03252]

Summary

- Flavour measurements suggest possibility of NP with flavour symmetries

  What information can be extracted in this case?

- Calculated the loop level matching for SMEFT with MFV flavour symmetry to WET operators responsible for down type FCNCs

- Provide explicit expressions to consistently incorporate the most constraining flavour data into MFV or $U(3)^5$ fits

- Flavour can provide strong new constraints within these global fits

- Lots of flavour data to come, how can we use it best?