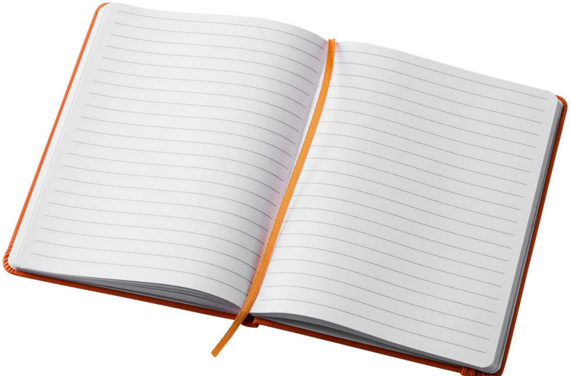
HEFT 2018, Mainz

Towards a global SMEFT likelihood

David M. Straub Universe Cluster/TUM, Munich



Testing models: the aim

NP theory

$$\mathcal{L}(\vec{\theta})$$

Parameters

$$\downarrow$$

$$\vec{\mathcal{O}}(\vec{\theta})$$

Observable prediction

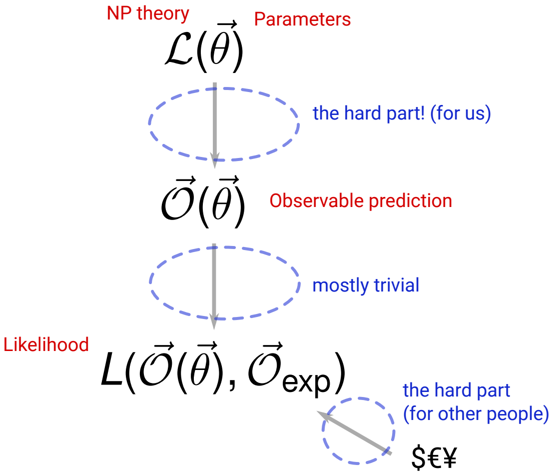
$$\downarrow$$

Likelihood

$$L(\vec{\mathcal{O}}(\vec{\theta}), \vec{\mathcal{O}}_{\text{exp}})$$

Measurement

Testing models: the aim



The role of SMEFT

$$\mathcal{L}(\vec{\theta})$$

↓

SMEFT Wilson coeffs. $\vec{C}(\vec{\theta})$

↓

$$\vec{\mathcal{O}}(\vec{C}(\vec{\theta}))$$

↓

SMEFT Likelihood

$$L(\vec{\mathcal{O}}(\vec{C}), \vec{\mathcal{O}}_{\text{exp}})$$

The role of SMEFT

$$\mathcal{L}(\vec{\theta})$$

Model building ...

See also talks by Javier FM, Juan C, José S

SMEFT Wilson coeffs. $\vec{C}(\vec{\theta})$

Model independent!

Focus of this talk

$$\vec{\mathcal{O}}(\vec{C}(\vec{\theta}))$$

SMEFT Likelihood

$$L(\vec{\mathcal{O}}(\vec{C}), \vec{\mathcal{O}}_{\text{exp}})$$

The *global* SMEFT likelihood

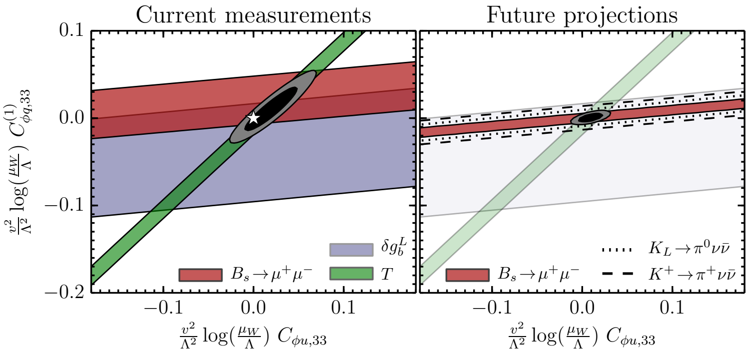
- In practice we often consider

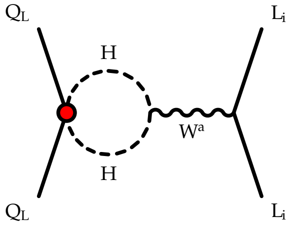
$$L(\vec{C}) = L_{\text{EW + Higgs}}(\vec{C}_{\text{EW + Higgs}}) \times \ldots$$
$$L(\vec{C}) = L_{\text{top physics}}(\vec{C}_{\text{top physics}}) \times \ldots$$
$$L(\vec{C}) = L_{B\text{ physics}}(\vec{C}_{B\text{ physics}}) \times \ldots$$
$$L(\vec{C}) = L_{\text{LFV}}(\vec{C}_{\text{LFV}}) \times \ldots$$

- But actually the likelihood *does not factorize* since RG effects mix different sectors
  - several nice examples in the literature

Example 1: anomalous t couplings vs. flavor Brod et al. 1408.0792

$$[C_{\varphi q}^{(1,3)}]_{33} \to C_{lq}^{(1,3)}, \ldots$$

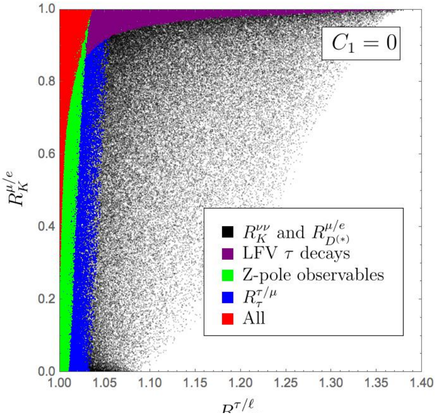


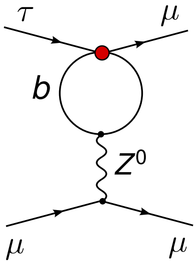


Example 2: *B* anomalies vs. LFV Feruglio et al. 1705.00929

Lepton flavor universality violation in *B* decays implies charged lepton flavor violation

$$[C_{lq}^{(1,3)}]_{3333} \to C_{\varphi l}^{(1,3)}, C_{ll}, \ldots$$





Don’t forget about flavor

- Much higher scales probed than in Higgs physics (e.g. up to $\sim 10^5$ TeV in K CPV)
  - even small mixing effects can lead to surprisingly strong constraints
- *Most* of the operators in SMEFT violate flavor!

SMEFT counting Alonso et al. 1312.2014

Operator type	$n_g = 1$	$n_g = 3$
bosonic	15	15
$\psi^2\varphi^3$ ($\to$ mass)	6	54
$\psi^2\varphi^2 D$ ($\to V$ couplings)	9	81
$\psi^2 X\varphi$ (dipole)	16	144
ψ^4	30	2205

So you want to do a *fit* in 2499+ dimensions?

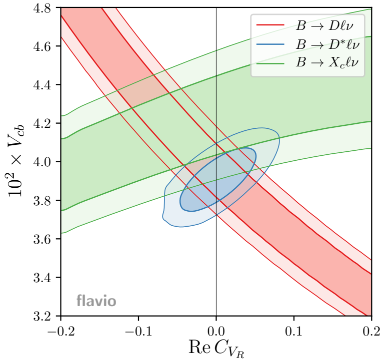
No.

This is neither realistic nor particularly useful.

But the *likelihood* can be used to perform *fits* in the parameter space of *dynamical models* (or well-motivated [?] subsets of the Wilson coefficients).

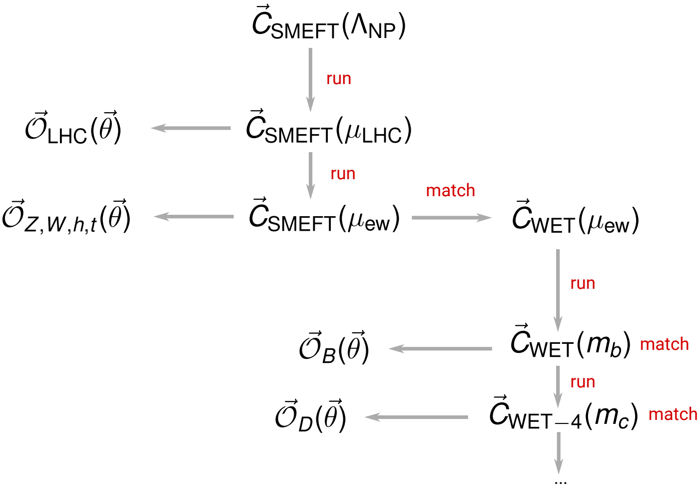
Flavor: subtleties & challenges

- Just as in the EW sector, SM parameters are modified by $D = 6$ terms
- Example: new physics in $b \to c\ell\nu$ ($\ell = e, \mu$) affecting the extraction of the CKM element V_{cb} Jung and Straub 1801.01112

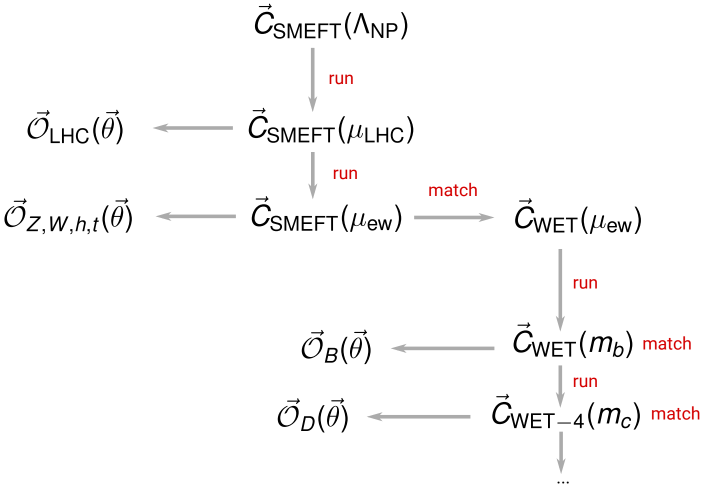


$$C_{V_R} \propto C_{\varphi ud}^{23}$$

Building a *global* SMEFT likelihood: ingredients



Building a *global* SMEFT likelihood: ingredients



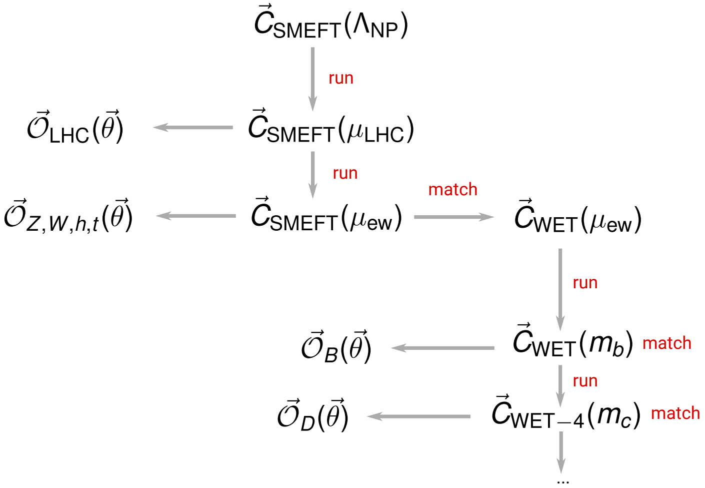
First challenge: we need to exchange thousands of Wilson coefficients in different EFTs, in different bases, at different scales. Need conventions!

Wilson coefficient exchange format (WCxf)

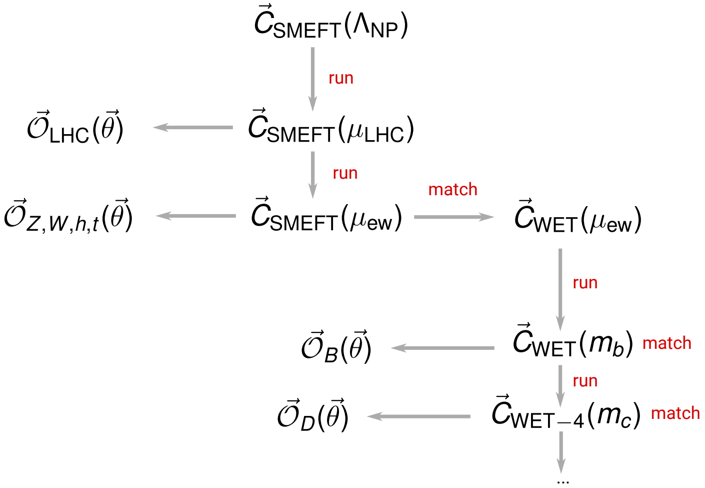
Aebischer et al. 1712.05298

- A data exchange format for Wilson coefficients beyond the SM, supported already by 10 public codes, see `https://wcxf.github.io/`
- Main ideas:
  - Do not enforce but *define* EFT and basis and facilitate translation & matching (cf. Rosetta Falkowski et al. 1508.05895)
  - public EFT & basis files fixing a non-redundant set of operators in a given basis
  - data file for Wilson coefficient values based on established formats (JSON, YAML)
- Implemented for SMEFT and the weak effective theory (WET)
  - Extension to DM-EFT etc. possible

Building a *global* SMEFT likelihood: ingredients



Building a *global* SMEFT likelihood: ingredients



2nd challenge: perform the running & matching in SMEFT & WET

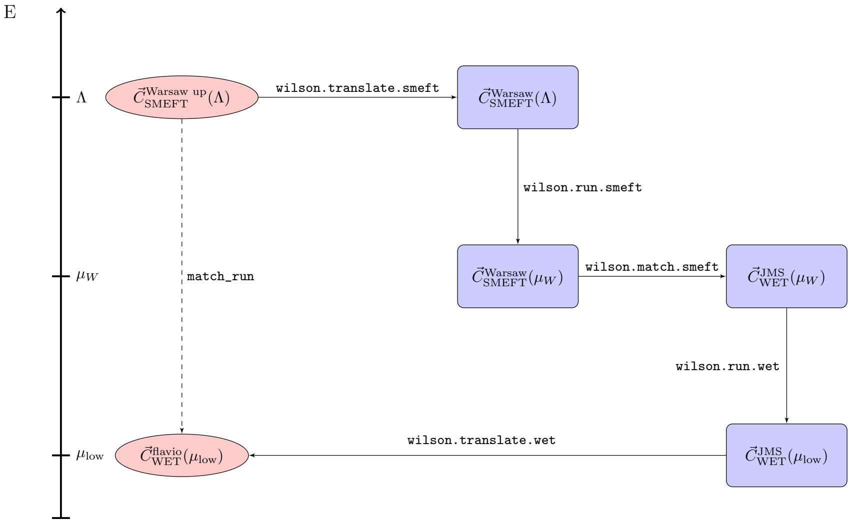
wilson

- *Brand new* open source Python package which can do
  - SMEFT 1-loop running for *all* $D = 6$ operators
  - SMEFT $\to$ WET matching for *all* $D = 6$ operators
  - WET (QCD & QED) 1-loop running for *all* $D = 6$ operators
- Uses WCxf everywhere to represent WC values
- Paper Aebischer et al. 1804.05033
- Web site `https://wilson-eft.github.io`
  - Try it live in your browser!

More on wilson

- Based on
  - complete one-loop SMEFT RGE Jenkins et al. 1308.2627, Jenkins et al. 1310.4838, Alonso et al. 1312.2014
    - Based on DsixTools Celis et al. 1704.04504
  - complete one-loop QCD & QED RGE Aebischer et al. 1704.06639, Jenkins et al. 1711.05270
  - complete tree-level matching of SMEFT onto the WET Aebischer et al. 1512.02830, Jenkins et al. 1709.04486
- Important innovations
  - Automatically determines self-consistent values of SM parameters in SMEFT
  - Diagonalization of QCD & QED anomalous dimensions for very fast solution of RGE for all operators

wilson: internal workflow



wilson: simple example

- $B_s \to \mu^+\mu^-$ Wilson coefficient C_{10} radiatively induced by $C_{\varphi u}^{33}$ at 1 TeV

```
from wilson import Wilson
w = Wilson({'phiu_33': 1e-6}, scale=1e3, eft='SMEFT', basis='Warsaw')
wc = w.match_run(scale=4.2, eft='WET', basis='flavio')
wc['C10_bsmumu']
```

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wc['C10_bsmumu']
```

- Even simpler: interface to flavio

```
from flavio import np_prediction
np_prediction('BR(Bs->mumu)', w)
```

flavio

- Open source Python package for flavor in the SM and beyond
  - Web site `https://flav-io.github.io`
  - Repository `https://github.com/flav-io/flavio`
- Used in $O(20)$ papers in the last 2 years
- New physics in terms of Wilson coefficients of dimension-6 operators
- 1089 observables implemented
  - K^0, B^0, D^0 mixing
  - K, B, D neutral-current and charged current decays
  - τ and μ LFV decays
  - Neutron EDM
  - Thanks to *wilson*, extension to EWPT & Higgs possible!

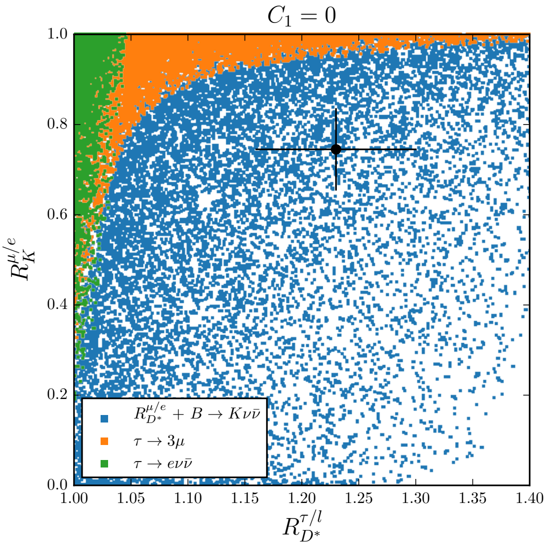
Example application

- Reproducing the analysis of
  Feruglio et al. 1606.00524, Feruglio et al. 1705.00929, Cornella et al. 1803.00945
- Only $[C_{lq}^{(1,3)}]_{3333} = C_{1,3}$ at a scale Λ in some weak basis that is related to the mass basis by small mixing angles
- In the basis where M_d & M_l are diagonal:

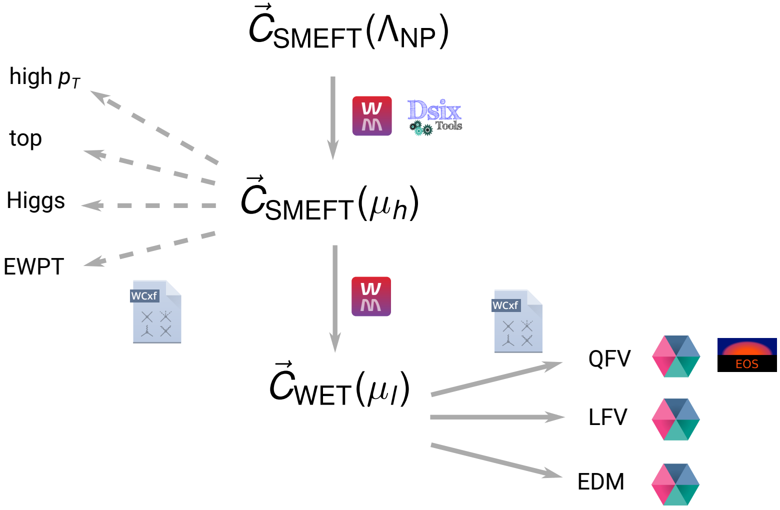
$$\left[C_{lq}^{(1)}\right]_{ijkl} = \lambda^{\ell}_{ij}\lambda^{q}_{kl}\,C_1\,, \quad \left[C_{lq}^{(3)}\right]_{ijkl} = \lambda^{\ell}_{ij}\lambda^{q}_{kl}\,C_3\,.$$

```
from wilson import Wilson
w = Wilson(
 {'lq3_3333': ll_33 * lq_33 * C3,
  'lq1_3333': ll_33 * lq_33 * C1,
  'lq3_2223': ll_22 * lq_23 * C3, ...},
 scale=1e3, eft='SMEFT', basis='Warsaw')
from flavio import np_prediction
np_prediction('<Rmue>(B+->Kll)', w, 1, 6)
np_prediction('Rtaul(B->D*lnu)', w)
np_prediction('BR(tau->mumumu)', w)
...
```

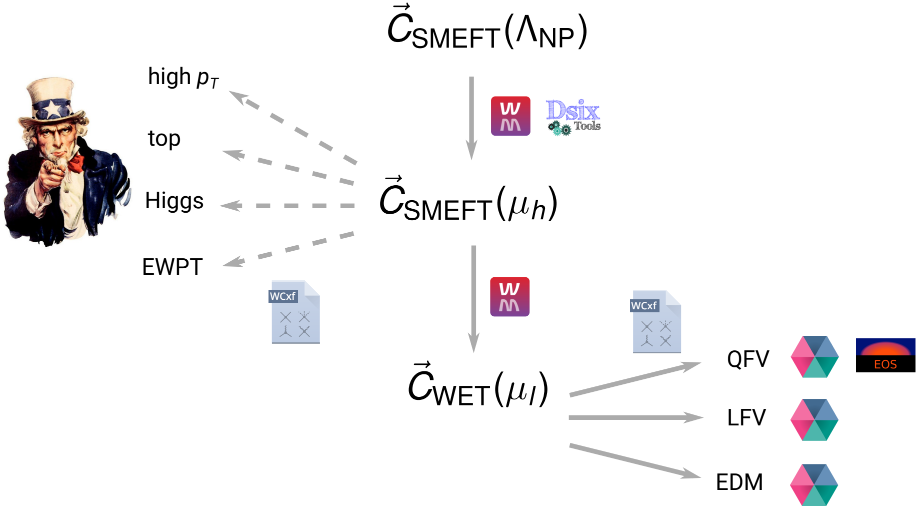
Plot Aebischer et al. 1804.05033



Summary: the global SMEFT likelihood



Summary: the global SMEFT likelihood



Conclusions

- Vast majority of SMEFT $D = 6$ operators probed by low-energy precision measurements, many sensitive to very high scales
- SMEFT likelihood $L(\vec{C}(\Lambda_{\text{NP}}))$ does *not* factorize into "flavor $\times$ EW $\times \ldots$"
- Ingredients for a *global* SMEFT likelihood almost completely there, thanks to effort of the community & tools built on it. Highlighted here:
  - WCxf for Wilson coefficient exchange
  - wilson for running & matching
  - flavio for low-energy precision observables and likelihoods
  - See also: DsixTools, SMEFTsim, EOS, [HEPfit]
- To do: open tools for top, Higs, & EWPT in terms of WCxf!

Backup

WCxf examples: EFT file

```yaml
eft: SMEFT
metadata:
  description: >
    Standard Model Effective Field Theory with linearly realized
    electroweak symmetry breaking.
sectors:
  dB=dL=0:
    tex: \Delta B=\Delta L=0
    description: Baryon and lepton number conserving operators
  dB=dL=1:
    tex: \Delta B=\Delta L=1
    description: Baryon number violating operators that conserve $B-L$
  dL=2:
    tex: \Delta L=2
    description: Operators violating lepton number by two units
```

WCxf examples: basis file


```
eft: SMEFT
basis: Warsaw
metadata:
  description: >
    Basis suggested by Grzadkowski, Iskrzyński, Misiak, and Rosiek [...]
sectors:
  dB=dL=0:
    G:
      real: true
      tex: f^{ABC} G_\mu^{A \nu} G_\nu^{B \rho} G_\rho^{C \mu}
    Gtilde:
      real: true
      tex: f^{ABC} \widetilde G_\mu^{A \nu} G_\nu^{B \rho} G_\rho^{C \mu}
    W:
      real: true
      tex: \epsilon^{IJK} W_\mu^{I \nu} W_\nu^{J \rho} W_\rho^{K \mu}
    ...
```

WCxf examples: coefficient file


```yaml
eft: SMEFT
basis: Warsaw
scale: 160.0
values:
  G: 9.298977469992998e-09
  Gtilde: 3.3033200969269584e-09
  W: 3.818508801650694e-09
  Wtilde: 9.005842974540492e-09
  dB_11:
    Im: 7.088804605377087e-09
    Re: 4.440182014344588e-09
  dB_12:
    Im: 8.12530368624381e-09
    Re: 2.7519814904006103e-09
  dB_13:
    Im: 7.631669514460633e-09
    Re: 5.022409128374413e-09
  ...
```