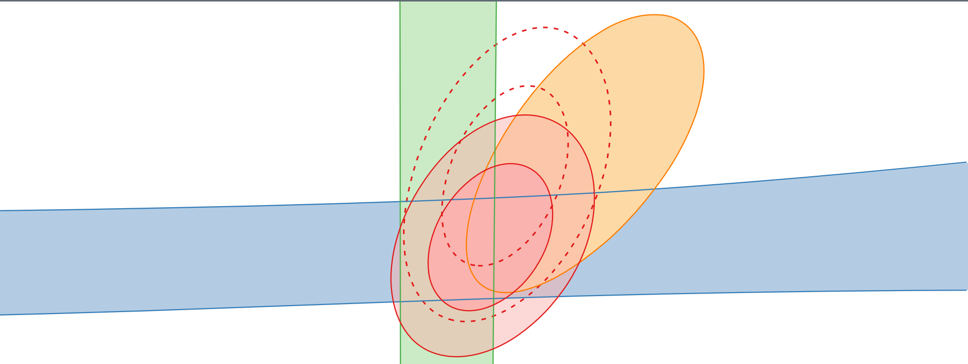
2019-04-24, SM@LHC, Zurich

A Global Likelihood for Precision Constraints and Flavour Anomalies

David M. Straub Universe Cluster/TUM, Munich



Outline

1 The global SMEFT likelihood

- What is it?
- Why is it useful?
- Where do we stand?
- What's missing?

2 Applications

- Electroweak precision observables
- Interpretation of *B* anomalies

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SMEFT: *lingua franca* for new physics from flavour to Higgs

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{D>4} \sum_i \frac{1}{\Lambda_{\text{NP}}^{D-4}} C_i^{(D)} O_i^{(D)}$$

Buchmuller and Wyler; Grzadkowski, Iskrzynski, Misiak, and Rosiek 1008.4884

Model-independent parametrization of new physics in

- low-energy processes (quark flavour, lepton flavour, magnetic moments, ...) Talk by J. Virto
- EW & Higgs physics Talk by V. Sanz
- top physics Talk by E. Vryonidou
- high-p_T processes as long as $E \ll \Lambda_{\text{NP}}$ Talk by J. Fuentes-Martin

Assumptions

- $\Lambda_{\text{NP}} \gg v$ (as hinted by LHC unfortunately)
- No new light particles (but can be extended)
- Approximately linearly realized EWSB (but OK if $f \gg v$)

SMEFT fits & SMEFT likelihoods

By now a standard exercise:

- take a subsector of observables (say, Higgs & EW physics or top or B)
  - possibly make assumptions on flavour structure
- express all observables in terms of SMEFT Wilson coefficients (WCs)
- marginalize/profile over theory uncertainties ("nuisances")
- obtain likelihood (fit) in WC space

$$\vec{C}(\mu) \xrightarrow{\text{compute}} \vec{O}(\vec{C}(\mu), \vec{n}) \xrightarrow{\text{include exp.}} L(\vec{O}, \vec{O}_{\text{exp}}) = L(\vec{C}(\mu), \vec{n}) \xrightarrow{\text{marginalize}} L(\vec{C}(\mu))$$

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BUT when different scales μ are involved (Λ_{NP}, M_Z, m_b, ...) the $\vec{C}$ space *does not factorize* into subsectors due to renormalization group effects

- Need to consider the **global** (in $\vec{O}$ and $\vec{C}$ space) SMEFT likelihood
  - cannot make assumptions on flavour structure
- Need to include RG effects
- Need to deal with thousands of WCs

Global SMEFT likelihood: why is it useful?

1. Model-independent analyses of new physics
    - Test model-independent correlations between observables
    - Check credibility of NP interpretation of “anomalies”
    - predict room for NP in future measurements

Global SMEFT likelihood: why is it useful?

1. Model-independent analyses of new physics
   - Test model-independent correlations between observables
   - Check credibility of NP interpretation of “anomalies”
   - predict room for NP in future measurements
2. Testing dynamical NP models
   - imposing low-energy constraints on new model split into two parts:
     - Model building:
       $$\mathcal{L}_{\text{NP}}(\vec{\theta}) \to \vec{C}(\vec{\theta}) \ @ \ \Lambda_{\text{NP}}$$
     - *Model-independent* pheno: done once and for all!
       $$\vec{C} \to \vec{O}(\vec{C}) \to L(\vec{O}(\vec{C}), \vec{O}_{\text{exp}})$$
   - Tremendously simplifies analyses of NP models!

Building a global SMEFT likelihood: requirements

1. An agreed upon convention and exchange format for thousands of WCs (ideally supported by multiple tools)
2. Implementation of RG running and matching of *all* dimension-6 WCs above and below the EW scale
3. Expression of all relevant observables in terms of WCs at appropriate scale

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2. Implementation of RG running and matching of *all* dimension-6 WCs above and below the EW scale ✓
3. Expression of all relevant observables in terms of WCs at appropriate scale ✓

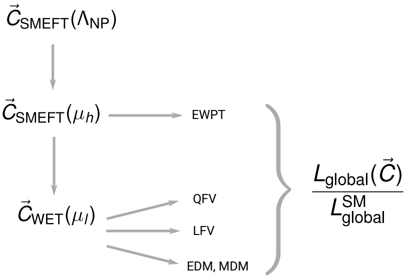
1. **Wilson coefficient exchange format (WCxf)** Aebischer et al. 1712.05298 `https://wcxf.github.io/`
   - Authored by developers of 10 public SMEFT-related codes
2. **wilson** Aebischer, J. Kumar, and DMS 1804.05033 `https://wilson-eft.github.io`
   - Based on series of papers by Alonso, Jenkins, Manohar, Stoffer, Trott
   - SMEFT running inherited from DsixTools Celis, Fuentes-Martin, Vicente, and Virto 1704.04504
3. **flavio** DMS 1810.08132 `https://flav-io.github.io`
   - Extended beyond flavour physics

The case for open source

- We believe that publishing everything as open source (in particular also the functions $O(\vec{C}(\mu))$ and their experimental likelihoods) is crucial to make this useful
- It allows to account for
  - Changes in experimental data (happens all the time!)
  - Changes in theory predictions/uncertainties (& adjusting level of conservativeness…)
- This effort should be global also in theorist space!

Building a global SMEFT likelihood Aebischer, J. Kumar, Stangl, and DMS 1810.07698

- Based on this toolbox, we have started building the **SME**FT **Li**ke**LI**hood
  - **smelli** `https://github.com/smelli/smelli`
- So far, 265 observables included
  - Rare *B* and *K* Decays
  - LFU tests in charged-current *B* and *K* decays
  - Meson-antimeson mixing
  - ε'/ε
  - $(g-2)_{e,\mu,\tau}$
  - LFV & LFC τ and μ decays
  - *Z* and *W* pole EWPT



The nuisance-free likelihood

- To avoid the (costly) marginalization over nuisance parameters, we only include observables where one of two approximations is justified:
  1. theory uncertainties can be **neglected**
     - the case e.g. for limits on LFV decays
  2. theory and experimental uncertainties can be approximated as **Gaussian** and the size of theory uncertainties is **weakly affected by NP**
     - the case e.g. for $B \to K^* \mu^+ \mu^-$ observables
- We then approximate the likelihood by
  1. Just fixing $\vec{\theta} = \vec{\theta}_0$
  2. Determining a covariance matrix for the experimental and theoretical uncertainties (in the SM!) and combine them ("adding errors in quadrature")

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This works well except for observables where uncertainties of NP contributions are much larger than for SM predictions, e.g. neutron EDM, CPV in $B \to DK$, …

Summary: smelli

smelli is an open source Python package (built on other tools) that provides:

$$L_{\mathrm{SMEFT}}(\vec{C}, \mu)$$

for completely general $\vec{C}$ and arbitrary μ, with no need to marginalize over nuisance parameters.

Missing pieces

- Treatment of CKM matrix
  - We do not include rates of semi-leptonic (charged-current) B and K decays which affect the extraction of CKM elements
  - Elegant procedure to include them recently outlined Descotes-Genon et al. 1812.08163
  - Implementation in **smelli** to appear soon work in progress, Falkowski, Gonzalez-Alonso, DMS
- More global in observable space
  - Higgs production & decay Talks by S. Pataraia, V. Sanz
  - top physics Talk by E. Vryonidou
    - Need to drop flavour symmetry assumptions of existing analyses see e.g. Hartland et al. 1901.05965
  - EDMs
  - high-p_T contact interaction searches
  - diboson production
  - ...

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It's open source – please join us!

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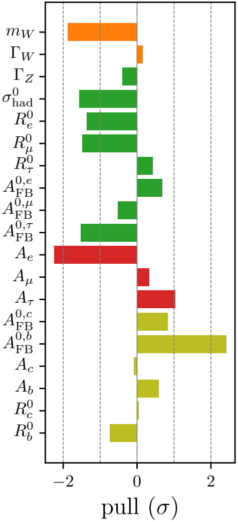
Electroweak precision observables



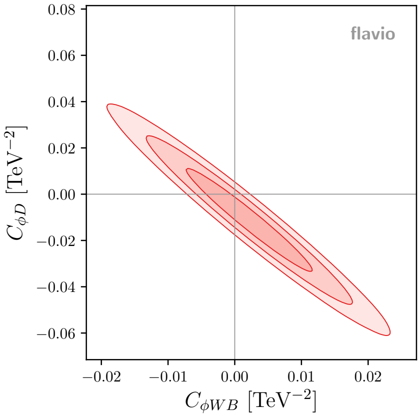
- We have implemented all the relevant *Z* and *W* pole observables, not assuming LFU, in `flavio`

  Efrati, Falkowski, and Soreq 1503.07872, Brivio and Trott 1706.08945, see also Ellis, Murphy, Sanz, and You 1803.03252, Talk by V. Sanz

- SM pulls in good agreement e.g. with Gfitter

  Baak et al. 1407.3792

Oblique parameters



- Reproducing the EWPO constraint on the electrowewak S and T parameters cf. Ellis, Murphy, Sanz, and You 1803.03252

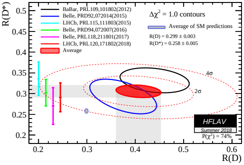
$$S \propto C_{\varphi WB}, \quad T \propto -C_{\varphi D}$$

$$O_{\varphi D} = \left(\varphi^\dagger D^\mu \varphi\right)^* \left(\varphi^\dagger D_\mu \varphi\right)$$
$$O_{\varphi WB} = \varphi^\dagger \tau^I \varphi W^I_{\mu\nu} B^{\mu\nu}$$

Discrepancies in B physics

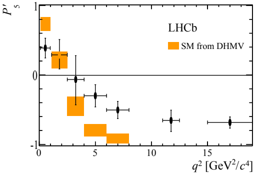
R_D & R_D^* anomalies

- $b \to c\tau\nu$ vs. $c\mu\nu$



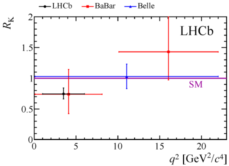
$B \to K^*\mu\mu$ anomalies

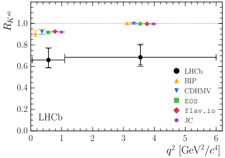
- $b \to s\mu\mu$



R_K & R_K^* anomalies

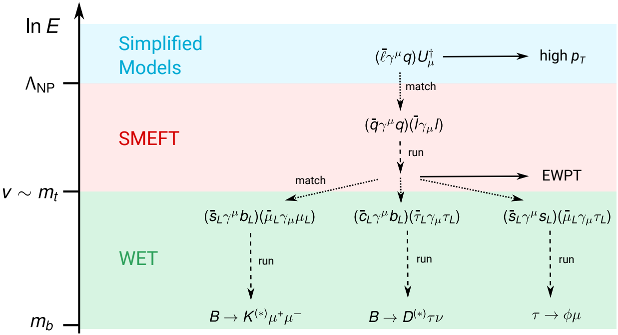
- $b \to s\mu\mu$ vs. see



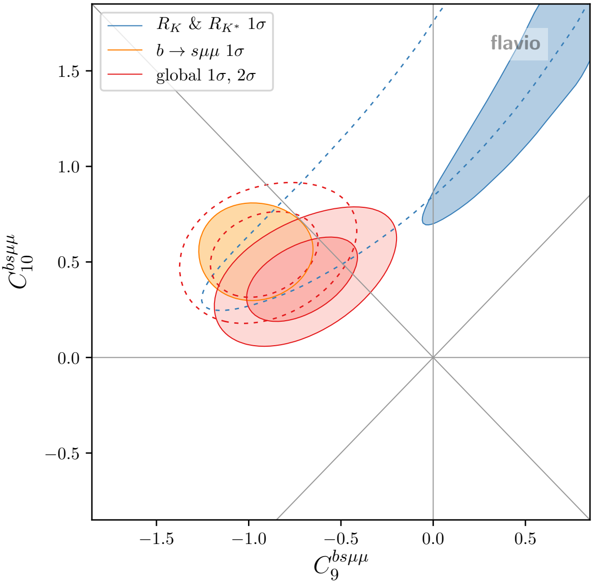


Interpretation of discrepancies: hierarchy of effective theories

1. $b \to s\ell\ell$ observables in WET
2. $b \to s\ell\ell$ & $b \to c\tau\nu$ in SMEFT
3. Simplified models



$b \to s\ell\ell$ in WET: muonic C_9 vs. C_{10} Aebischer et al. 1903.10434



$C_9^{bs\mu\mu}$ $(\bar{s}_L \gamma^\mu b_L)(\mu \gamma_\mu \mu)$

$C_{10}^{bs\mu\mu}$ $(\bar{s}_L \gamma^\mu b_L)(\mu \gamma_\mu \gamma_5 \mu)$

- Dashed: before Moriond 2019
- good agreement between $R_{K^{(*)}}$ & $b \to s\mu\mu$
- Excellent for models with LH leptons ($C_9 = -C_{10}$)

See also Algueró et al. 1903.09578, Kowalska, D. Kumar, and Sessolo 1903.10932, Ciuchini et al. 1903.09632, Arbey et al. 1904.08399, Talks by J. Virto, T. Humair

$b \to s\ell\ell$ in SMEFT

- Generating $C_9^{bs\ell\ell} = -C_{10}^{bs\ell\ell}$ in SMEFT is simple:

$$O_{lq}^{(1)} = (\bar\ell\gamma^\mu\ell)(\bar q\gamma^\mu q)$$
$$O_{lq}^{(3)} = (\bar\ell\gamma^\mu\tau^a\ell)(\bar q\gamma^\mu\tau^a q)$$

Matching:

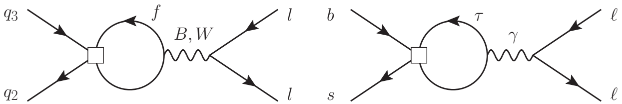
$$C_9^{bs\ell_i\ell_i} \propto \quad [C_{lq}^{(1)}]_{ii23} + [C_{lq}^{(3)}]_{ii23} + \ldots$$
$$C_{10}^{bs\ell_i\ell_i} \propto -[C_{lq}^{(1)}]_{ii23} - [C_{lq}^{(3)}]_{ii23} + \ldots$$

- UV completions: Z', leptoquarks
- Interesting connection:

$$[O_{lq}^{(3)}]_{3323} \supset (\bar c_L\gamma^\mu b_L)(\tau_L\gamma_\mu\nu_{\tau L})$$

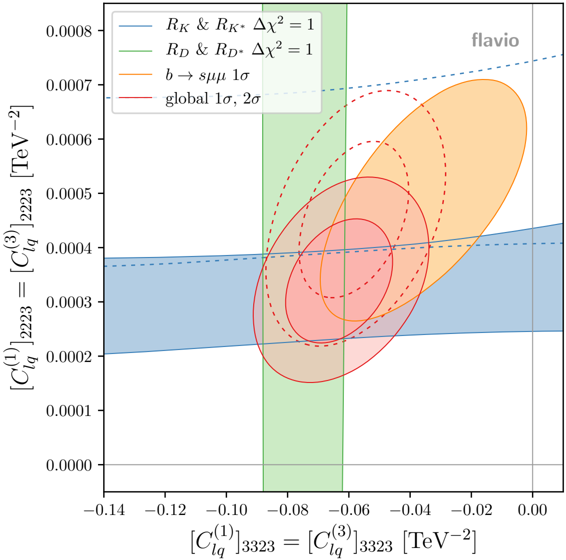
  - Common origin for $b \to s\ell\ell$ & $b \to c\tau\nu$ anomalies

Semitauonic NP & lepton flavour *universal* C_9



- A semitauonic operator *unavoidably generates* a LFU contribution to C_9 through RG running above and below the EW scale Bobeth and Haisch 1109.1826
- This effect has the right sign and rough size to explain the $b \to s\mu\mu$ data (except $R_{K^{(*)}}$)! Crivellin, Greub, Müller, and Saturnino 1807.02068

Semitauonic vs. semimuonic NP Aebischer et al. 1903.10434



$[C_{lq}^{(1)}]_{ii23}(\bar{\ell}_i\gamma^\mu\ell_i)(\bar{q}_2\gamma^\mu q_3)$

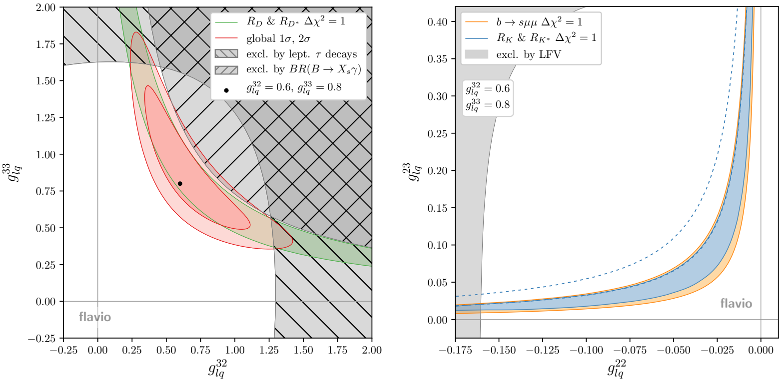
$[C_{lq}^{(3)}]_{ii23}(\bar{\ell}_i\gamma^\mu\tau^a\ell_i)(\bar{q}_2\gamma^\mu\tau^a q_3)$

- Where $R_{K^{(*)}}$ & $b \to s\mu\mu$ agree at 1σ: non-zero semitauonic WCs
- Solution coincides with semitauonic WCs that generate right size of $R_{D^{(*)}}$!

$U_1 \sim (3,1)_{2/3}$ vector leptoquark Aebischer et al. 1903.10434

- Minimal implementation of the semitauonic + -muonic scenario

$$\mathcal{L}_{U_1} \supset g_{lq}^{ji} (\bar{q}^i \gamma^\mu l^j) U_\mu + \text{h.c.}$$



- Main constraints: $\tau \to \ell\nu\nu$, $\tau \to \phi\mu$, $B \to K\tau\mu$

cf. Barbieri, Isidori, Pattori, and Senia 1512.01560, Alonso, Grinstein, and Martin Camalich 1505.05164, Calibbi, Crivellin, and Ota 1506.02661, Fajfer and Košnik 1511.06024, Hiller, Loose, and Schönwald 1609.08895, Bhattacharya et al. 1609.09078, Buttazzo, Greljo,

Conclusions

- All tools are on the table to construct a SMEFT likelihood that is *global* in Wilson coefficient and observable space
- We have started to construct a *nuisance-free* SMEFT likelihood (available as **smelli** package) containing
  - quark flavour
  - lepton flavour
  - EWPT
- Interpreting *B* anomalies in SMEFT or simplified models is a straightforward application
  - Pattern of WCs as generated e.g. by vector leptoquark gives much higher likelihood than SM
- Missing pieces
  - Treatment of CKM: work in progress
  - More observables: Higgs, top, …?
- The project is **open to contributions** (not necessarily code!)

Backup

Treatment of nuisance parameters

- Theory predictions depend not only on Wilson coefficients $\vec{C}$ but also on (uncertain) parameters $\vec{\theta}$, (form factors, bag parameters, …)

$$L_{\text{SMEFT}}(\vec{C},\vec{\theta}) = \prod_i L_{\text{exp}}\left(\vec{O}_i^{\text{exp}}, \vec{O}_i^{\text{th}}\left(\vec{C},\vec{\theta}\right)\right) \times L_\theta(\vec{\theta})\,,$$

- How to get rid of them?
  - frequentist profile likelihood: *optimize* over $\vec{\theta}$ directions
  - Bayesian marginal posterior: *integrate* over $\vec{\theta}$ directions
- both computationally very demanding and time consuming!

The nuisance-free likelihood

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$$L_{\text{SMEFT}}(\vec{C}) = \prod_{i \in 1.} L_{\text{exp}}\left(\vec{O}_i^{\text{exp}}, \vec{O}_i^{\text{th}}\left(\vec{C}, \vec{\theta}_0\right)\right) \prod_{i \in 2.} \widetilde{L}_{\text{exp}}\left(\vec{O}_i^{\text{exp}}, \vec{O}_i^{\text{th}}\left(\vec{C}, \vec{\theta}_0\right)\right)$$

This works well except for observables where uncertainties of NP contributions are much larger than SM predictions, e.g. neutron EDM, $\Delta A_{\text{CP}}(D \to PP)$, …

$b \to s\ell\ell$ in WET

Effective Hamiltonian with operators contributing at LO at $\mu \sim m_b$:

$$\mathcal{H}_{\text{eff, NP}}^{bs\ell\ell} = -\mathcal{N}\left(C_7^{bs}O_7^{bs} + C_7^{\prime bs}O_7^{\prime bs}\sum_{\ell=e,\mu}\sum_{i=9,10,S,P}\left(C_i^{bs\ell\ell}O_i^{bs\ell\ell} + C_i^{\prime bs\ell\ell}O_i^{\prime bs\ell\ell}\right)\right) + \text{h.c.}$$

$$\begin{aligned}
O_7^{bs} &= \frac{m_b}{e}(\bar{s}\sigma_{\mu\nu}P_R b)F^{\mu\nu}\,, & O_7^{\prime bs} &= \frac{m_b}{e}(\bar{s}\sigma_{\mu\nu}P_L b)F^{\mu\nu}\,,\\
O_9^{bs\ell\ell} &= (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\ell)\,, & O_9^{\prime bs\ell\ell} &= (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu\ell)\,,\\
O_{10}^{bs\ell\ell} &= (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\gamma_5\ell)\,, & O_{10}^{\prime bs\ell\ell} &= (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu\gamma_5\ell)\,,\\
O_S^{bs\ell\ell} &= (\bar{s}P_R b)(\bar{\ell}\ell)\,, & O_S^{\prime bs\ell\ell} &= (\bar{s}P_L b)(\bar{\ell}\ell)\,,\\
O_P^{bs\ell\ell} &= (\bar{s}P_R b)(\bar{\ell}\gamma_5\ell)\,, & O_P^{\prime bs\ell\ell} &= (\bar{s}P_L b)(\bar{\ell}\gamma_5\ell)\,.
\end{aligned}$$

Pulls in single-coefficient scenarios

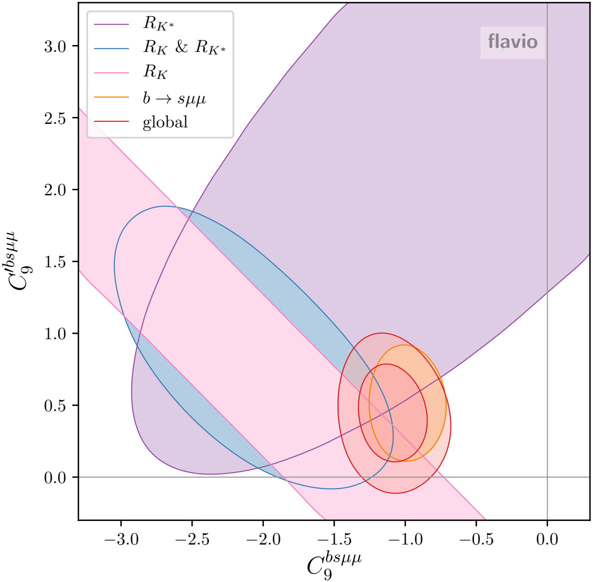
- First step: maxima of the global likelihood along 1D directions given by $b \to s\mu\mu$ WET operators

Coeff.	Dirac structure	best fit	1σ	pull
$C_9^{bs\mu\mu}$	$L \otimes V$	-0.95	$[-1.10, -0.79]$	5.8σ
$C_9^{\prime bs\mu\mu}$	$R \otimes V$	$+0.09$	$[-0.07, +0.24]$	0.5σ
$C_{10}^{bs\mu\mu}$	$L \otimes A$	$+0.73$	$[+0.59, +0.87]$	5.6σ
$C_{10}^{\prime bs\mu\mu}$	$R \otimes A$	-0.19	$[-0.30, -0.07]$	1.6σ
$C_9^{bs\mu\mu} = C_{10}^{bs\mu\mu}$	$L \otimes R$	$+0.20$	$[+0.05, +0.35]$	1.4σ
$C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}$	$L \otimes L$	-0.53	$[-0.62, -0.45]$	6.5σ

$$\text{pull} = \sqrt{\Delta x^2}\,, \qquad \text{where} \; -\frac{1}{2}\Delta - x^2 = \ln L(\vec{0}) - \ln L(\vec{C}_{\text{best fit}})\,.$$

- Strong improvement of fit compared to SM
- For the first time, $C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}$, predicted by LQ et al., fits better than $C_9^{bs\mu\mu}$

Muonic C_9 vs. C_9'



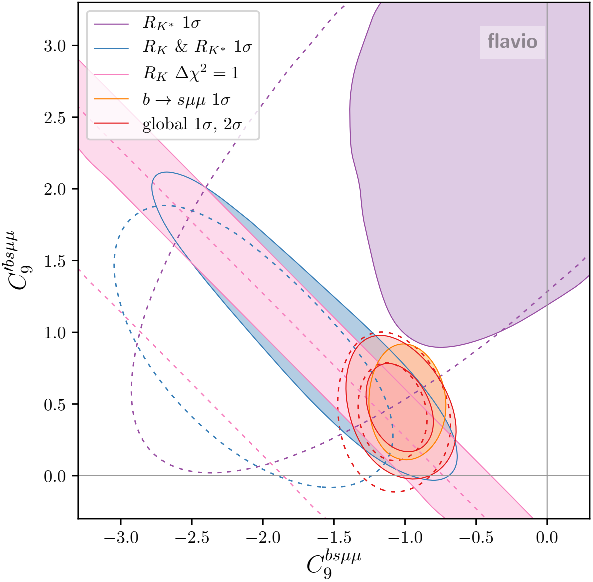
$C_9^{bs\mu\mu}\ (\bar{s}_L \gamma^\mu b_L)(\mu \gamma_\mu \mu)$

$C_9'^{bs\mu\mu}\ (\bar{s}_R \gamma^\mu b_R)(\mu \gamma_\mu \mu)$

Pre-Moriond

- No preference for $C_9' \neq 0$

Muonic C_9 vs. C_9'



$C_9^{bs\mu\mu}$ $(\bar{s}_L \gamma^\mu b_L)(\mu \gamma_\mu \mu)$

$C_9'^{bs\mu\mu}$ $(\bar{s}_R \gamma^\mu b_R)(\mu \gamma_\mu \mu)$

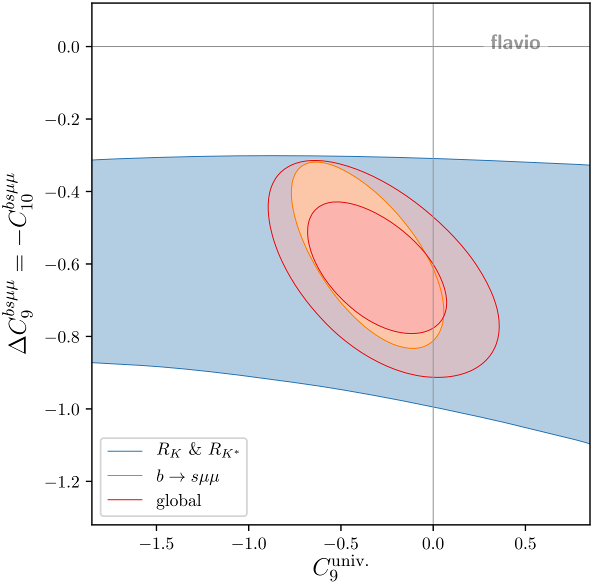
Pre-Moriond

- No preference for $C_9' \neq 0$

Now

- Slight preference for $C_9' > 0$ driven by interplay between R_K and $b \to s\mu\mu$

LF *universal* vs. purely muonic NP



$C_9^{univ.}\,(\bar{s}_L\gamma^\mu b_L)\sum_\ell(\ell\gamma_\mu\ell)$

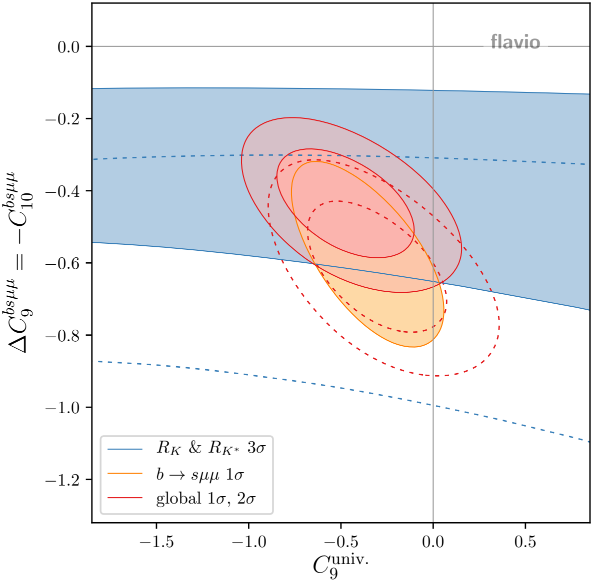
$\Delta C_9^{bs\mu\mu}\,(\bar{s}_L\gamma^\mu b_L)(\mu\gamma_\mu\mu)$

$C_{10}^{bs\mu\mu}\,(\bar{s}_L\gamma^\mu b_L)(\mu\gamma_\mu\gamma_5\mu)$

Pre-Moriond

- NP solution compatible with $C_9^{univ.} = 0$, i.e. purely muonic NP

LF *universal* vs. purely muonic NP



$C_9^{univ.}\,(\bar{s}_L\gamma^\mu b_L)\sum_\ell(\ell\gamma_\mu\ell)$

$\Delta C_9^{bs\mu\mu}\,(\bar{s}_L\gamma^\mu b_L)(\mu\gamma_\mu\mu)$

$C_{10}^{bs\mu\mu}\,(\bar{s}_L\gamma^\mu b_L)(\mu\gamma_\mu\gamma_5\mu)$

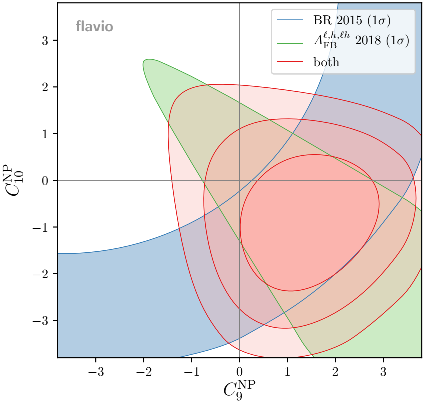
Pre-Moriond

- NP solution compatible with $C_9^{univ.} = 0$, i.e. purely muonic NP

Now

- Interplay between $R_{K^{(*)}}$ & $b \to s\mu\mu$ leads to preference for $C_9^{univ.} < 0$

$\Lambda_b \to \Lambda\mu^+\mu^-$



- LHCb 2018 update Aaij et al. 1808.00264 of 2015 analysis Aaij et al. 1503.07138 with more data and better control over signs ;)
- Theory relies on lattice form factors Detmold and Meinel 1602.01399, following Meinel and Dyk 1603.02974

(Slide shown at CKM 2018)

Installing smelli

- Prerequisite: working installation of **Python** version **3.5** or above
- Installation from the command line:

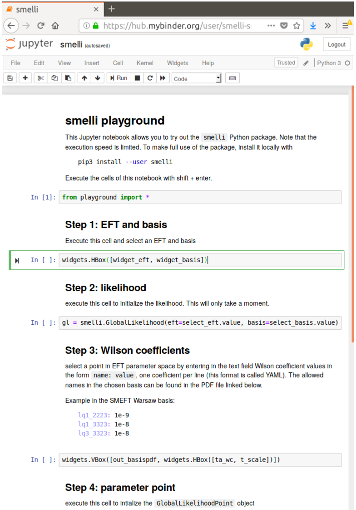
```
python3 -m pip install smelli --user
```

- downloads `smelli` with all dependencies from Python package archive (PyPI)
- installs it in user's home directory (no need to be root)

Using smelli

As any Python package, **smelli** can be used

- as library imported from other scripts
- directly in the command line interpreter
- in an interactive session → we recommend the **Jupyter notebook**



Try out **smelli** in a Jupyter notebook at
`https://github.com/smelli/smelli-playground`

Using smelli

- Step 1: Import package and initalize `GlobalLikelihood` class

```python
import smelli
gl = smelli.GlobalLikelihood()
```

possible arguments are

- `eft=WET` to use Wilson coefficients in weak effective theory (no EWPOs) (default: `eft=SMEFT`)
- `basis=` to select different WCxf basis (default: `basis=Warsaw` for SMEFT, `basis=flavio` for WET)

Using smelli

- Step 2: Select point in Wilson coefficient space using `parameter_point` method
- Three possible input formats:
  - Python dictionary with Wilson coefficient name/value pair and input scale

```
glp = gl.parameter_point({'lq1_2223': 1e-8}, scale=1000)
```

    fixes Wilson coefficient $[C_{lq}^{(1)}]_{2223}$ to 10^{-8} GeV^{-2} at scale 1 TeV 10pt

  - WCxf data file in YAML or JSON format (specified by file path)

```
glp = gl.parameter_point('my_wc.yaml')
```

  - instance of class `wilson.Wilson` from `wilson` package

```
glp = gl.parameter_point(wilson_instance)
```

Using smelli

Step 3: Get results from `GlobalLikelihoodPoint` instance `glp` defined in step 2

The most important methods are:

```
glp.log_likelihood_global()
```

returns $\ln \Delta L = \ln\left(\frac{L_{\text{global}}(\vec{C})}{L^{\text{SM}}_{\text{global}}}\right)$

```
glp.log_likelihood_dict()
```

returns Python dictionary with contributions to $\ln \Delta L$ from different sets of observables (EWPOs, charged current LFU, neutral current LFU,…)

```
glp.obstable()
```

returns table listing individual observables with their experimental and theoretical central values and uncertainties

Using smelli

```
glp = gl.parameter_point({}, scale=1000)
glp.obstable(min_pull='2.35')
```

returns observables with highest pull in Standard Model (no Wilson coefficient set)

Observable	Prediction	Measurement	Pull
$\langle \frac{dBR}{dq^2} \rangle(B_s \to \varphi\mu^+\mu^-)^{[1.0,6.0]}$	$(5.37 \pm 0.65) \times 10^{-8}\ \frac{1}{\text{GeV}^2}$	$(2.57 \pm 0.37) \times 10^{-8}\ \frac{1}{\text{GeV}^2}$	3.8σ
a_μ	$(1.1659182 \pm 0.0000004) \times 10^{-3}$	$(1.1659209 \pm 0.0000006) \times 10^{-3}$	3.5σ
$\langle P_5' \rangle(B^0 \to K^{*0}\mu^+\mu^-)^{[4,6]}$	-0.756 ± 0.074	-0.21 ± 0.15	3.3σ
$R_{\tau\ell}(B \to D^*\ell^+\nu)$	0.248	0.306 ± 0.018	3.3σ
$\langle A_{FB}^{\ell h} \rangle(\Lambda_b \to \Lambda\mu^+\mu^-)^{[15,20]}$	0.1400 ± 0.0075	0.250 ± 0.041	2.6σ
$\langle R_{\mu e} \rangle(B^\pm \to K^\pm\ell^+\ell^-)^{[1.0,6.0]}$	1.000	0.745 ± 0.098	2.6σ
ε'/ε	$(-0.3 \pm 6.0) \times 10^{-4}$	$(1.66 \pm 0.23) \times 10^{-3}$	2.6σ
$\text{BR}(W^\pm \to \tau^\pm\nu)$	0.1084	0.1138 ± 0.0021	2.6σ
$\langle R_{\mu e} \rangle(B^0 \to K^{*0}\ell^+\ell^-)^{[1.1,6.0]}$	1.00	0.68 ± 0.12	2.5σ
$R_{\tau\ell}(B \to D\ell^+\nu)$	0.281	0.406 ± 0.050	2.5σ
$\langle \frac{dBR}{dq^2} \rangle(B^\pm \to K^\pm\mu^+\mu^-)^{[15.0,22.0]}$	$(1.56 \pm 0.12) \times 10^{-8}\ \frac{1}{\text{GeV}^2}$	$(1.210 \pm 0.072) \times 10^{-8}\ \frac{1}{\text{GeV}^2}$	2.5σ
$A_{FB}^{0,b}$	10.31×10^{-2}	$(9.92 \pm 0.16) \times 10^{-2}$	2.4σ
$\langle \frac{dBR}{dq^2} \rangle(B^0 \to K^0\mu^+\mu^-)^{[15.0,22.0]}$	$(1.44 \pm 0.11) \times 10^{-8}\ \frac{1}{\text{GeV}^2}$	$(9.6 \pm 1.6) \times 10^{-9}\ \frac{1}{\text{GeV}^2}$	2.4σ
$\langle R_{\mu e} \rangle(B^0 \to K^{*0}\ell^+\ell^-)^{[0.045,1.1]}$	0.93	0.65 ± 0.12	2.4σ