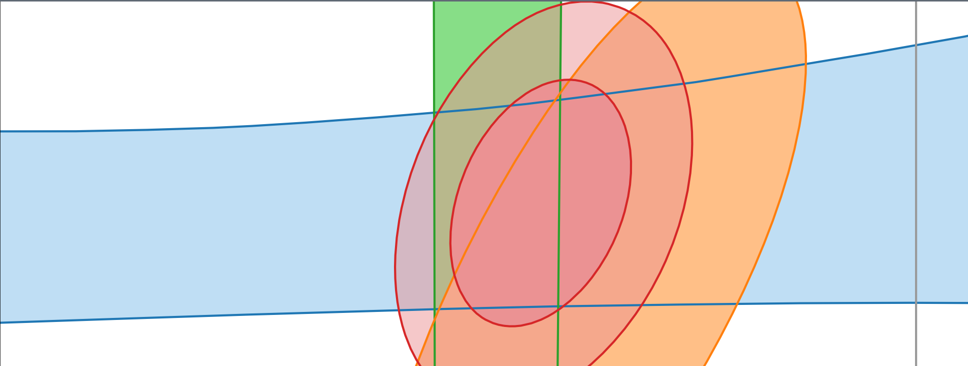
La Thuile 2021 - Les Rencontres de Physique de la Vallée d’Aoste, 10 March 2021

Flavor Fits

Peter Stangl AEC & ITP University of Bern

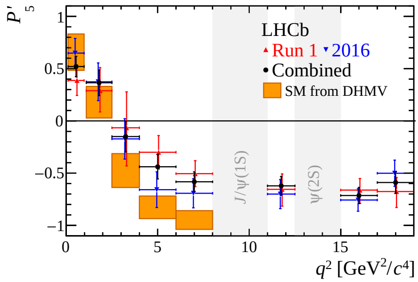


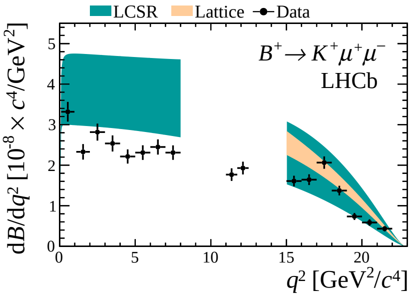
The flavor anomalies

$b \to s\,\mu^+\mu^-$ anomaly

Several LHCb measurements deviate from Standard model (SM) predictions by 2-3σ:

- Angular observables in $B \to K^*\mu^+\mu^-$. LHCb, arXiv:2003.04831, arXiv:2012.13241
- Branching ratios of $B \to K\mu^+\mu^-$, $B \to K^*\mu^+\mu^-$, and $B_s \to \phi\mu^+\mu^-$. LHCb, arXiv:1403.8044, arXiv:1506.08777, arXiv:1606.04731



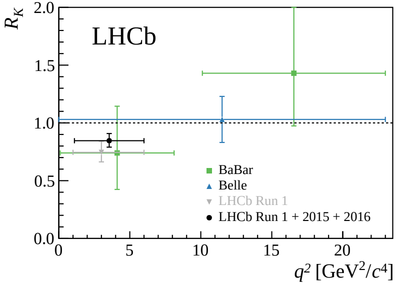


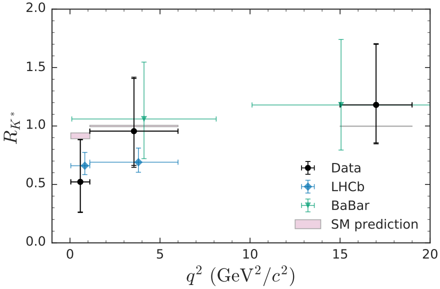
Hints for LFU violation in $b \to s\,\ell^+\ell^-$ decays

Measurements of lepton flavor universality (LFU) ratios $R_K^{[1,6]}$, $R_{K^*}^{[0.045,1.1]}$, $R_{K^*}^{[1.1,6]}$ show deviations from SM by about 2.5σ each.

LHCb, arXiv:1705.05802, arXiv:1903.09252
Belle, arXiv:1904.02440, arXiv:1908.01848

$$R_{K^{(*)}} = \frac{BR(B \to K^{(*)}\mu^+\mu^-)}{BR(B \to K^{(*)}e^+e^-)}$$





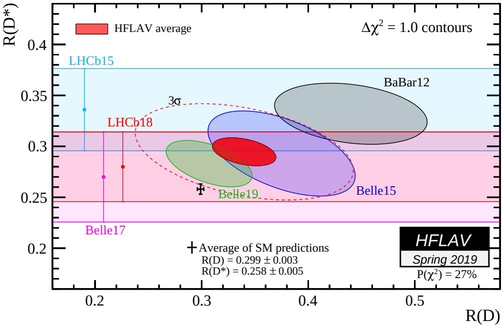
Hints for LFU violation in $b \to c\,\ell\,\nu$ decays

Measurements of LFU ratios R_D and R_{D^*} by BaBar, Belle, and LHCb show combined deviation from SM by about 3-4σ.

BaBar, arXiv:1205.5442, arXiv:1303.0571
LHCb, arXiv:1506.08614, arXiv:1708.08856
Belle, arXiv:1507.03233, arXiv:1607.07923, arXiv:1612.00529, arXiv:1904.08794

$$R_{D^{(*)}} = \frac{BR(B \to D^{(*)}\tau\nu)}{BR(B \to D^{(*)}\ell\nu)}$$

$$\ell \in \{e, \mu\}$$

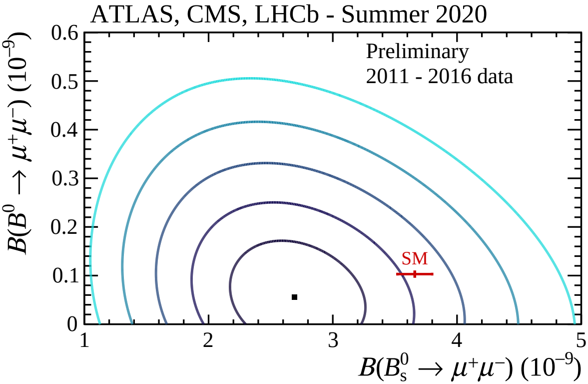


HFLAV, hflav.web.cern.ch

Combination of $B_{s,d} \to \mu^+\mu^-$ measurements

Measurements of BR($B_{s,d} \to \mu^+\mu^-$) by LHCb, CMS, and ATLAS show combined deviation from SM by about 2σ.

LHCb-CONF-2020-002



New physics interpretation

Setup

- Global likelihood from **smelli** python package for comparing theory predictions to experimental data
  Aebischer, Kumar, PS, Straub, arXiv:1810.07698
- Quantify agreement between theory and experiment by likelihood L, $\Delta\chi^2$, and pull

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

$$\text{pull}_{\text{2D}} = 1\sigma, 2\sigma, 3\sigma, \ldots \quad \text{for} \quad \Delta\chi^2 \approx 2.3, 6.2, 11.8, \ldots$$

- New physics scenarios in effective field theories:
  - **Weak Effective Theory (WET)** at scale 4.8 GeV
  - **Standard Model Effective Field Theory (SMEFT)** at scale 4 TeV

$b \to s\ell\ell$ in the weak effective theory

- Effective Hamiltonian at scale m_b: $\mathcal{H}_{\text{eff}}^{bs\ell\ell} = \mathcal{H}_{\text{eff, SM}}^{bs\ell\ell} + \mathcal{H}_{\text{eff, NP}}^{bs\ell\ell}$

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

- Operators considered here ($\ell = e, \mu$)

$$\begin{aligned} O_9^{bs\ell\ell} &= (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)\,, & O_9'^{bs\ell\ell} &= (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell)\,, \\ O_{10}^{bs\ell\ell} &= (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,, & O_{10}'^{bs\ell\ell} &= (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,, \\ O_S^{bs\ell\ell} &= m_b(\bar{s} P_R b)(\bar{\ell}\ell)\,, & O_S'^{bs\ell\ell} &= m_b(\bar{s} P_L b)(\bar{\ell}\ell)\,, \\ O_P^{bs\ell\ell} &= m_b(\bar{s} P_R b)(\bar{\ell}\gamma_5 \ell)\,, & O_P'^{bs\ell\ell} &= m_b(\bar{s} P_L b)(\bar{\ell}\gamma_5 \ell)\,. \end{aligned}$$

- Not considered here
  - Dipole operators: strongly constrained by radiative decays. e.g. [arXiv:1608.02556]
  - Four quark operators: dominant effect from RG running above m_B.

    Jäger, Leslie, Kirk, Lenz [arXiv:1701.09183]

Scenarios with a single Wilson coefficients

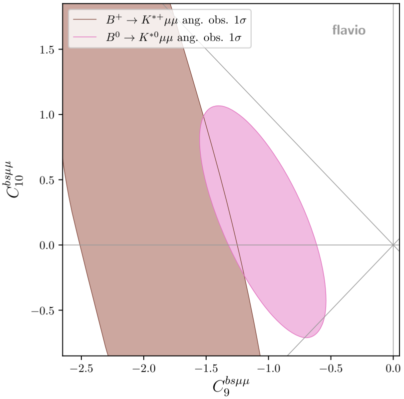
Coefficient	type	best fit	1σ	$\text{pull}_{1D} = \sqrt{\Delta\chi^2}$
$\boldsymbol{C_9^{bs\mu\mu}}$	$\boldsymbol{L \otimes V}$	-0.97	$[-1.11, -0.83]$	$\boldsymbol{6.4\sigma}$
$C_9^{\prime bs\mu\mu}$	$R \otimes V$	$+0.14$	$[-0.04, +0.29]$	0.7σ
$\boldsymbol{C_{10}^{bs\mu\mu}}$	$\boldsymbol{L \otimes A}$	$+0.72$	$[+0.59, +0.85]$	$\boldsymbol{5.8\sigma}$
$C_{10}^{\prime bs\mu\mu}$	$R \otimes A$	-0.18	$[-0.29, -0.07]$	1.7σ
$C_9^{bs\mu\mu} = C_{10}^{bs\mu\mu}$	$L \otimes R$	$+0.16$	$[+0.03, +0.30]$	1.2σ
$\boldsymbol{C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}}$	$\boldsymbol{L \otimes L}$	-0.54	$[-0.61, -0.46]$	$\boldsymbol{6.9\sigma}$

Only small pull for

- Coefficients with $\ell = e$ (cannot explain $b \to s\mu\mu$ anomaly and $B_s \to \mu\mu$)
- Scalar coefficients (can only reduce tension in $B_s \to \mu\mu$)

see also similar fits by other groups:
Algueró et al., arXiv:1903.09578 Ciuchini et al., arXiv:2011.01212 Datta et al., arXiv:1903.10086
Kowalska et al., arXiv:1903.10932 Arbey et al., arXiv:1904.08399

Scenarios with two Wilson coefficients

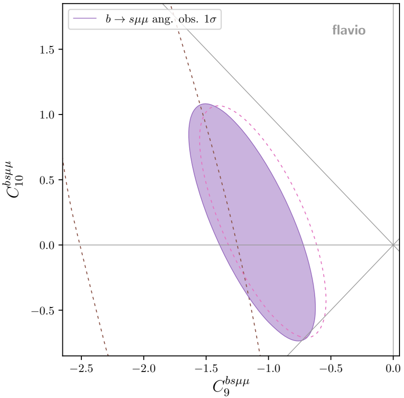


- **2020 results**: Angular observables
  - updated $B^0 \to K^{*0}\mu^+\mu^-$
  - new $B^+ \to K^{*+}\mu^+\mu^-$

compatible at 1σ

WET at 4.8 GeV

Scenarios with two Wilson coefficients



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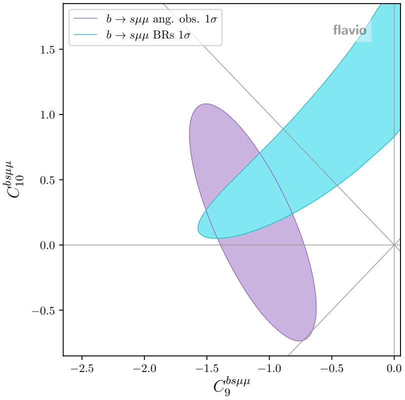

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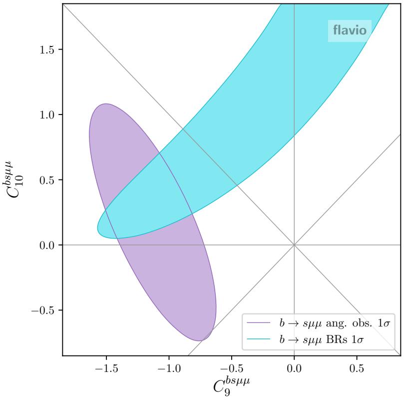

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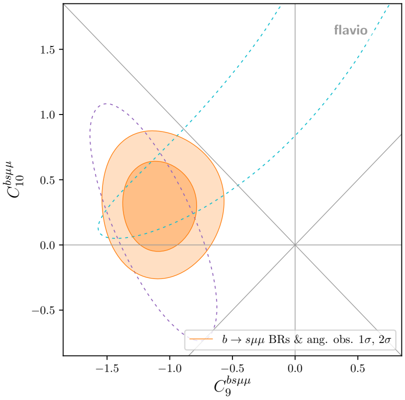

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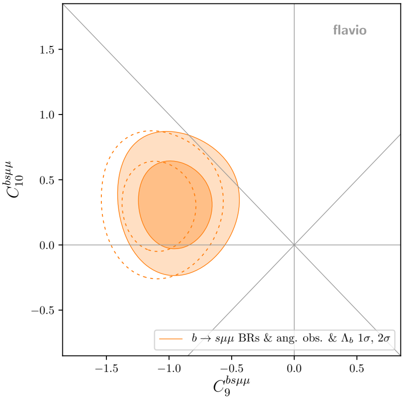

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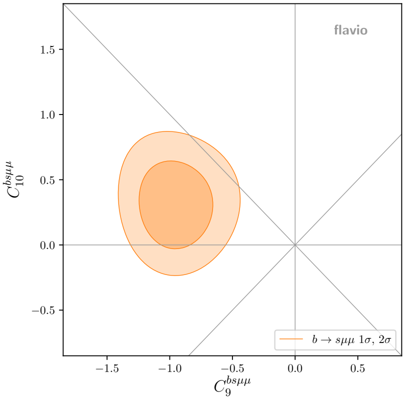

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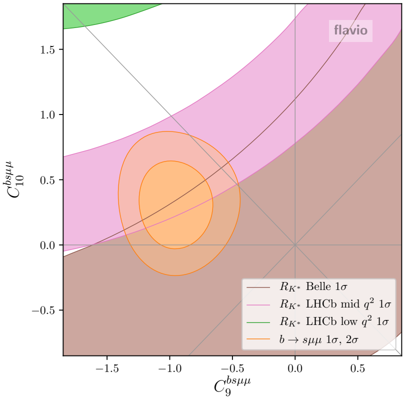
“$b \to s\mu\mu$ anomaly”

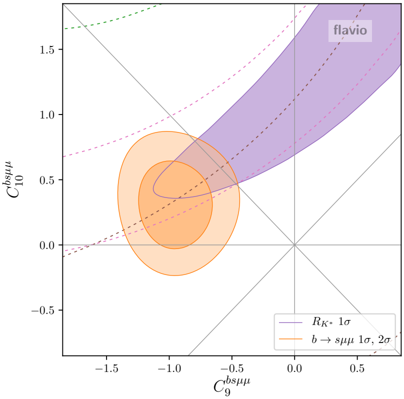
Scenarios with two Wilson coefficients



- Some tension between different R_{K^*} measurements, in particular due to "low-q^2 bin" $R_{K^*}^{[0.045,1.1]}$ by LHCb

WET at 4.8 GeV

Scenarios with two Wilson coefficients



WET at 4.8 GeV

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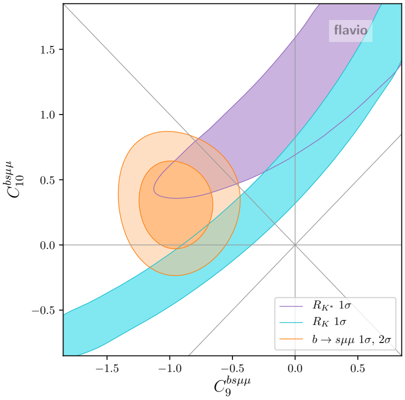

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- Combination of R_{K^*} measurements compatible with $b \to s\mu\mu$ observables at 1σ
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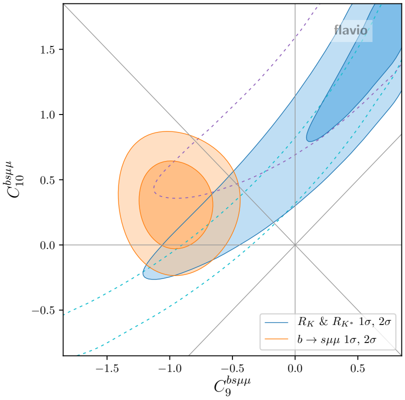
WET at 4.8 GeV

Scenarios with two Wilson coefficients



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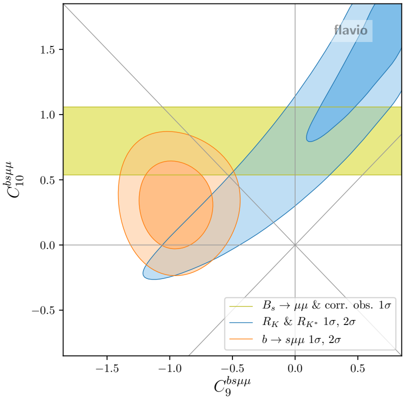
- Combination of R_{K^*} measurements compatible with $b \to s\mu\mu$ observables at 1σ
- R_K closer to SM than R_{K^*} but smaller uncertainty
- Combination of R_K & R_{K^*} in slight tension with $b \to s\mu\mu$ observables

WET at 4.8 GeV

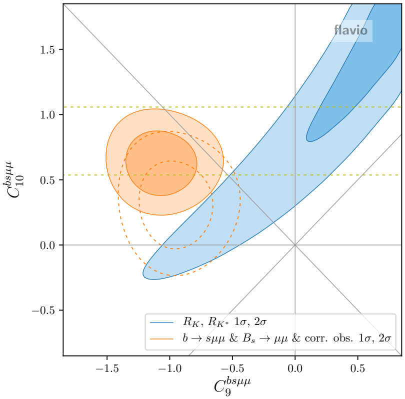
Scenarios with two Wilson coefficients



- $B_s \to \mu^+\mu^-$ and correlated observables ($\Delta F = 2$) prefer positive $C_{10}^{bs\mu\mu}$

WET at 4.8 GeV

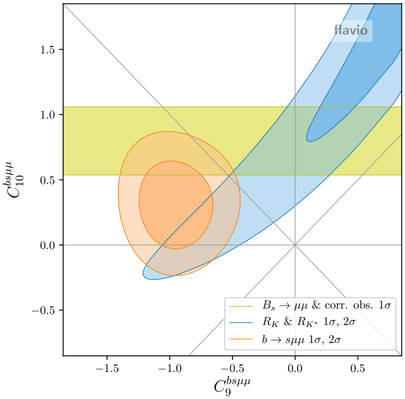
Scenarios with two Wilson coefficients



- $B_s \to \mu^+\mu^-$ and correlated observables ($\Delta F = 2$) prefer positive $C_{10}^{bs\mu\mu}$
- Combination of $B_s \to \mu^+\mu^-$ and other $b \to s\mu\mu$ observables:
  - $b \to s\mu\mu$ & $B_s \to \mu\mu$ & corr. obs. depend only on muonic coeff.
  - R_K & R_{K^*} sensitive to LFUV, insensitive to universal coeff.

WET at 4.8 GeV

Scenarios with two Wilson coefficients



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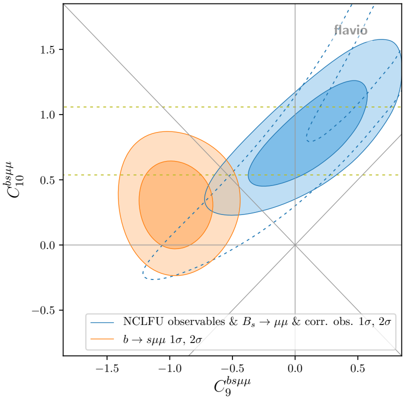
WET at 4.8 GeV

Scenarios with two Wilson coefficients



WET at 4.8 GeV

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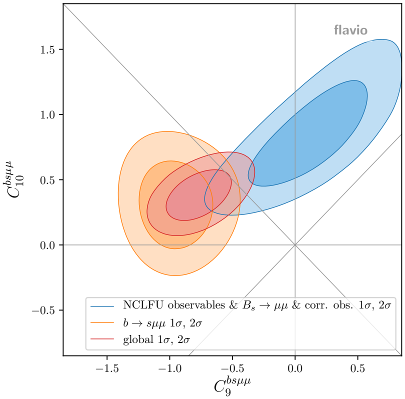
  - $b \to s\mu\mu$ & $B_s \to \mu\mu$ & corr. obs. depend only on muonic coeff.
  - R_K & R_{K^*} sensitive to LFUV, insensitive to universal coeff.
- Combination of $B_s \to \mu^+\mu^-$ and NC LFU observables ($R_K, R_{K^*}, D_{P_{4',5'}}$)
  - NCLFU obs. & $B_s \to \mu\mu$: very clean theory prediction, insensitive to universal $C_9^{\text{univ.}}$
  - $b \to s\mu\mu$ sensitive to univ. coeff. possibly afflicted by underestimated hadr. uncert.

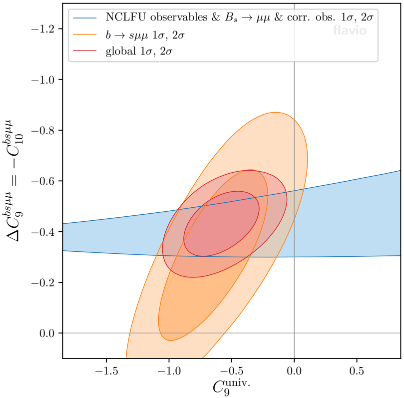
Scenarios with two Wilson coefficients



WET at 4.8 GeV

- Global fit in $C_9^{bs\mu\mu}$-$C_{10}^{bs\mu\mu}$ plane prefers negative $C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}$
- Tension between fits to $b \to s\mu\mu$ observables and R_K & R_{K^*} could be reduced by **LFU** contribution to $\boldsymbol{C_9}$

Scenarios with two Wilson coefficients



WET at 4.8 GeV

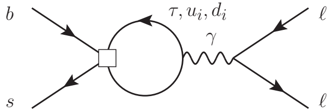
- Perform two-parameter fit in space of $\boldsymbol{C_9^{\text{univ.}}}$ and $\boldsymbol{\Delta C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}}$:

$$C_9^{bsee} = C_9^{bs\tau\tau} = C_9^{\text{univ.}}$$
$$C_9^{bs\mu\mu} = C_9^{\text{univ.}} + \Delta C_9^{bs\mu\mu}$$
$$C_{10}^{bsee} = C_{10}^{bs\tau\tau} = 0$$
$$C_{10}^{bs\mu\mu} = -\Delta C_9^{bs\mu\mu}$$

scenario first considered in
Algueró et al., arXiv:1809.08447

- Preference for **non-zero** $\boldsymbol{C_9^{\text{univ.}}}$

- $\boldsymbol{C_9^{\text{univ.}}}$ can arise from RG effects:

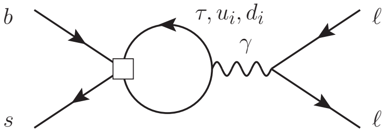


Bobeth, Haisch, arXiv:1109.1826
Crivellin, Greub, Müller, Saturnino, arXiv:1807.02068

The global picture in the SMEFT

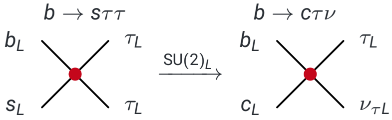
RG effects require scale separation

- Consider **SMEFT at 4 TeV**



Possible operators:

- $[\boldsymbol{O_{lq}^{(3)}}]_{3323} = (\bar{\boldsymbol{l}}_3\gamma_\mu\boldsymbol{\tau}^a\boldsymbol{l}_3)(\bar{\boldsymbol{q}}_2\gamma^\mu\boldsymbol{\tau}^a\boldsymbol{q}_3)$:
  Might also **explain $R_{D^{(*)}}$ anomalies!**

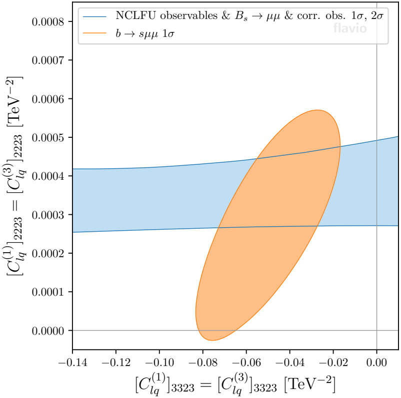


- $[\boldsymbol{O_{lq}^{(1)}}]_{3323} = (\bar{\boldsymbol{l}}_3\gamma_\mu\boldsymbol{l}_3)(\bar{\boldsymbol{q}}_2\gamma^\mu\boldsymbol{q}_3)$:
  Strong constraints from $B \to K\nu\nu$ require $[\boldsymbol{C_{lq}^{(1)}}]_{3323} \approx [\boldsymbol{C_{lq}^{(3)}}]_{3323}$

Buras et al., arXiv:1409.4557

- $[O_{qe}]_{2333} = (\bar{q}_2\gamma_\mu q_3)(\bar{e}_3\gamma^\mu e_3)$ cannot explain $R_{D^{(*)}}$
- Four-quark operators cannot explain $R_{D^{(*)}}$, models yielding large enough contributions already in tension with data

The global picture in the SMEFT

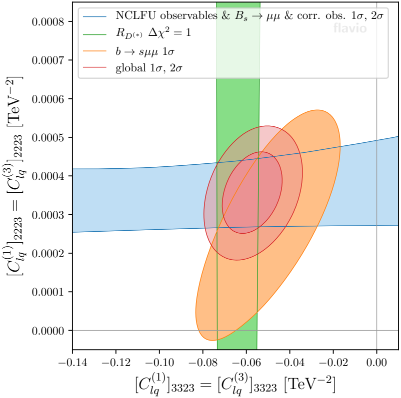


$$[C_{lq}^{(1)}]_{3323} = [C_{lq}^{(3)}]_{3323} \quad \Rightarrow \quad C_9^{\text{univ.}} \quad \text{(RG effect)}$$

$$[C_{lq}^{(1)}]_{2223} = [C_{lq}^{(3)}]_{2223} \quad \Rightarrow \quad \Delta C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}$$

- Clear preference for **non-zero** $[C_{lq}^{(1)}]_{3323} = [C_{lq}^{(3)}]_{3323}$

The global picture in the SMEFT



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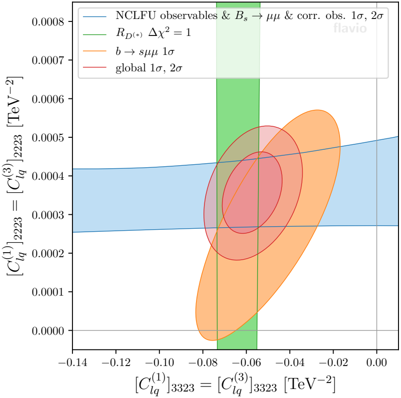
- Clear preference for **non-zero** $[C_{lq}^{(1)}]_{3323} = [C_{lq}^{(3)}]_{3323}$
- ***$R_{D^{(*)}}$* explanation**:
  Very good agreement between $R_{D^{(*)}}$, $R_{K^{(*)}}$ and $b \to s\mu\mu$ explanations

The global picture in the SMEFT



$$[C_{lq}^{(1)}]_{3323} = [C_{lq}^{(3)}]_{3323} \quad \Rightarrow \quad C_9^{\text{univ.}} \quad \text{(RG effect)}$$

$$[C_{lq}^{(1)}]_{2223} = [C_{lq}^{(3)}]_{2223} \quad \Rightarrow \quad \Delta C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}$$

- Clear preference for **non-zero** $[C_{lq}^{(1)}]_{3323} = [C_{lq}^{(3)}]_{3323}$
- $R_{D^{(*)}}$ **explanation**:
  Very good agreement between $R_{D^{(*)}}$, $R_{K^{(*)}}$ and $b \to s\mu\mu$ explanations
- **Only a simple SMEFT scenario**
  $\Rightarrow$ Consider explicit models that yield this coefficients
  $\Rightarrow$ Good candidate: U_1 **Leptoquark**

see talks by Javier Fuentes-Martín and Julie Pagès

All these scenarios are merely parameterizations,
not actual new physics models.

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Having an effect *only* in one or two Wilson coefficients is *impossible* to get in any model.

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to get in any model.

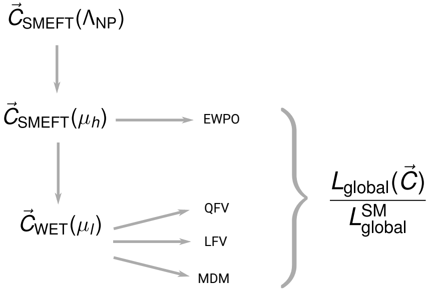
Need to consider actual models!

smelli – the SMEFT likelihood

- The **WET** and **SMEFT likelihood function** used for all plots in this talk is public and provided by a Python package:
  - **smelli** - the **SME**FT **L**ike**LI**hood `https://github.com/smelli/smelli`

Aebischer, Kumar, PS, Straub, arXiv:1810.07698

- More than 400 observables included
  - Rare B decays
  - Semi-leptonic B and K decays
  - Meson-antimeson mixing
  - FCNC K decays
  - (LFV) tau and muon decays
  - Z and W pole EWPOs
  - $g-2$
  - beta decays *new*
  - Higgs physics *new* Falkowski, Straub arXiv:1911.07866



- Just plug in the Wilson coefficients predicted by **your model**!

Basis for implementation

- Computing hundreds of relevant flavour observables properly accounting for theory uncertainties
  - **flavio** `https://flav-io.github.io` Straub, arXiv:1810.08132
  - Already used in $O(100)$ papers since 2016

- Representing and exchanging thousands of Wilson coefficient values, different EFTs, possibly different bases
  - **Wilson coefficient exchange format (WCxf)** `https://wcxf.github.io/` Aebischer et al., arXiv:1712.05298

- RG evolution above* and below the EW scale, matching from SMEFT to the weak effective theory (WET)
  - **wilson** `https://wilson-eft.github.io` Aebischer, Kumar, Straub, arXiv:1804.05033

* based on DsixTools Celis, Fuentes-Martin, Vicente, Virto, arXiv:1704.04504

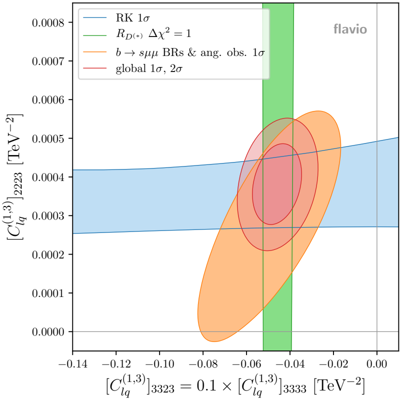
Conclusions

Conclusions

- New and updated measurements of $B^0 \to K^{*0}\mu^+\mu^-$ and $B^+ \to K^{*+}\mu^+\mu^-$ angular observables and new combination of $B_s \to \mu\mu$.
- New physics in the single muonic Wilson coefficients $\boldsymbol{C_9^{bs\mu\mu}}$, $\boldsymbol{C_{10}^{bs\mu\mu}}$, and $\boldsymbol{C_9^{bs\mu\mu}} = -\boldsymbol{C_{10}^{bs\mu\mu}}$ gives clearly better fit to data than SM (pull $\approx 6\sigma$).
- Slight tension between $R_{K^{(*)}}$ and $b \to s\mu\mu$ in $C_9^{bs\mu\mu}$-$C_{10}^{bs\mu\mu}$ scenario can be reduced by **lepton flavor universal $\boldsymbol{C_9^{\text{univ.}}}$**.
- Lepton flavor universal $C_9^{\text{univ.}}$ can be generated through **RG effects** from semi-tauonic Wilson coefficients that can **explain $\boldsymbol{R_{D^{(*)}}}$**.
- EFT scenarios are a good guide for model building but cannot replace actual models. Do a **flavor fit** in **your model** with `smelli`: `https://github.com/smelli/smelli`

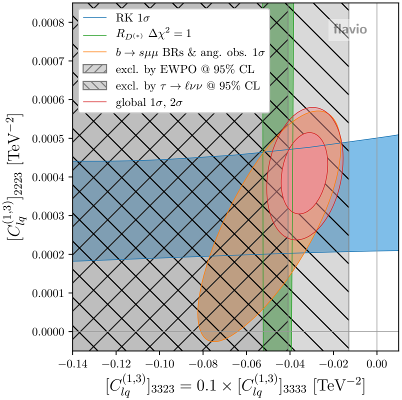
Backup slides

The global picture in the SMEFT



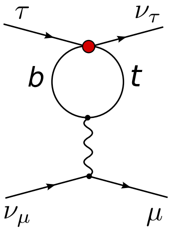
- $[C_{lq}^{(1,3)}]_{3323} = 0.1 \times [C_{lq}^{(1,3)}]_{3333}$ as expected from e.g. $U(2)$ flavor symmetry

The global picture in the SMEFT



- $[C_{lq}^{(1,3)}]_{3323} = 0.1 \times [C_{lq}^{(1,3)}]_{3333}$ as expected from e.g. $U(2)$ flavor symmetry
- Large 3rd gen. coefficient modifies LFU in τ and Z decays, strongly constrained

Feruglio, Paradisi, Pattori, arXiv:1705.00929



Slightly different results by different groups

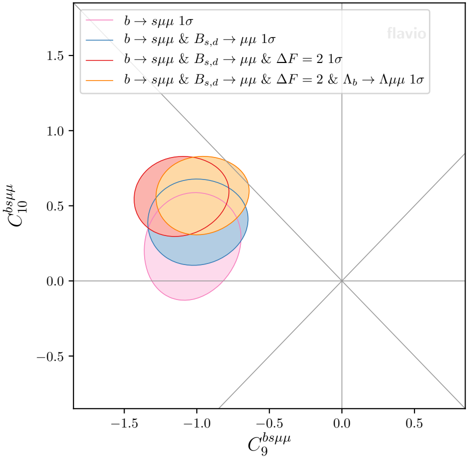
Descotes-Genon, PS, Talk at Beyond the Flavour Anomalies
https://conference.ippp.dur.ac.uk/event/876/

	All			LFUV		
1D Hyp.	$1\,\sigma$	Pull_{SM}	p-value	$1\,\sigma$	Pull_{SM}	p-value
$\mathcal{C}_{9\mu}^{\text{NP}}$	$[-1.19, -0.88]$	6.3	37.5 %	$[-1.25, -0.61]$	3.3	60.7 %
$\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{10\mu}^{\text{NP}}$	$[-0.59, -0.41]$	5.8	25.3 %	$[-0.50, -0.28]$	3.7	75.3 %
$\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{9'\mu}$	$[-1.17, -0.87]$	6.2	34.0 %	$[-2.15, -1.05]$	3.1	53.1 %

Coefficient	type	best fit	1σ	$\text{pull}_{\text{1D}} = \sqrt{\Delta\chi^2}$
$\boldsymbol{C_9^{bs\mu\mu}}$	$\boldsymbol{L \otimes V}$	-0.93	$[-1.07, -0.79]$	$\boldsymbol{6.2\sigma}$
$C_9'^{bs\mu\mu}$	$R \otimes V$	$+0.14$	$[-0.02, +0.31]$	0.9σ
$\boldsymbol{C_{10}^{bs\mu\mu}}$	$\boldsymbol{L \otimes A}$	$+0.71$	$[+0.58, +0.84]$	$\boldsymbol{5.7\sigma}$
$C_{10}'^{bs\mu\mu}$	$R \otimes A$	-0.20	$[-0.29, -0.08]$	1.7σ
$C_9^{bs\mu\mu} = C_{10}^{bs\mu\mu}$	$L \otimes R$	$+0.15$	$[+0.02, +0.29]$	1.2σ
$\boldsymbol{C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}}$	$\boldsymbol{L \otimes L}$	-0.53	$[-0.61, -0.46]$	$\boldsymbol{6.9\sigma}$

C_9 vs. $C_9 = -C_{10}$ with global likelihood

Likelihood contours for different sets of observables taken into account



- **Most groups** doing fits of $b \to s\ell\ell$ observables **do not include $\Delta F = 2$** obs.: They do not depend on $b \to s\ell\ell$ Wilson coefficients
- In **global likelihood**, $\Delta F = 2$ obs. naturally **included** (global!)
- Choice whether to include them or not: **clear difference** in $C_{10}^{bs\mu\mu}$ direction (red contour vs. blue contour)
- This explained the differences between the different groups!

Why does the inclusion of $\Delta F = 2$ observables
has such an impact on the fit in the $C_{10}^{bs\mu\mu}$ direction if
$\Delta F = 2$ observables do not depend on $C_{10}^{bs\mu\mu}$?

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Theory correlations...

Correlations in a toy example

- Correlations for observables O_1, O_2 (uncertainties $\sigma_{1,2}$, correlation coeff. ρ):

$$-2\ln\mathcal{L}(O_1,O_2)=\frac{1}{1-\rho^2}\left(\frac{D_1^2}{\sigma_1^2}+\frac{D_2^2}{\sigma_2^2}-2\rho\frac{D_1\,D_2}{\sigma_1\,\sigma_2}\right)\,, \qquad D_{1,2}=(O_{1,2}-\hat{O}_{1,2})$$

- If $D_1(C_{10})$ depends on C_{10} and D_2 is constant in C_{10}, then $\Delta\ln\mathcal{L}$ between $C_{10}=0$ and $C_{10}=\tilde{C}_{10}$ yields

$$\Delta\ln\mathcal{L}\propto\frac{D_1^2(0)-D_1^2(\tilde{C}_{10})}{\sigma_1^2}-2\,\rho\,D_2\,\frac{D_1(0)-D_1(\tilde{C}_{10})}{\sigma_1\,\sigma_2}$$

- First term is present whether we include O_2 or not (up to $\frac{1}{1-\rho^2}$ prefactor)
- **Second term makes a difference**
  - if $\rho\neq 0$, i.e. **O_1 and O_2 are correlated**
  - if $D_2\neq 0$, i.e. experimental estimate **$\hat{O}_2$ shows deviation from SM prediction** O_2

Correlations in the global likelihood

The same is true for $\Delta F = 2$ observables, in particular ϵ_K:

- theory predictions of ϵ_K and $BR(B_s \to \mu\mu)$ are correlated, $BR(B_s \to \mu\mu)$ depends on C_{10}
- experimental estimate of ϵ_K shows deviation from SM prediction

Should we include $\boldsymbol{\Delta F = 2}$ observables in $b \to s\ell\ell$ fit or not?

Two different assumptions:

- **Including them** and only varying C_{10} means we assume all other Wilson Coefficients $C_i = 0$, i.e. we fix the SM point in these directions
- **Excluding them** is (nearly) equivalent to setting certain $C_i \neq 0$ such that theory prediction and experimental estimate of $\Delta F = 2$ observables agree

Bayesian approach: marginalise over "nuisance coefficients" C_i

- **Including them** and only varying C_{10} corresponds to prior on C_i strongly peaked around SM value $C_i = 0$
- **Excluding them** is equivalent to flat prior that allows the posterior for C_i to be peaked around $C_i \neq 0$

What can we learn from this?

- There are different assumptions we can make by including or excluding certain observables
- It is not obvious (at least to me) if there is a “correct” one, but we should be aware of the differences
- The $\Delta\chi^2$ values between best-fit point and SM point can be different and one has to think about what “SM point” actually means if one does not fix $C_i = 0$