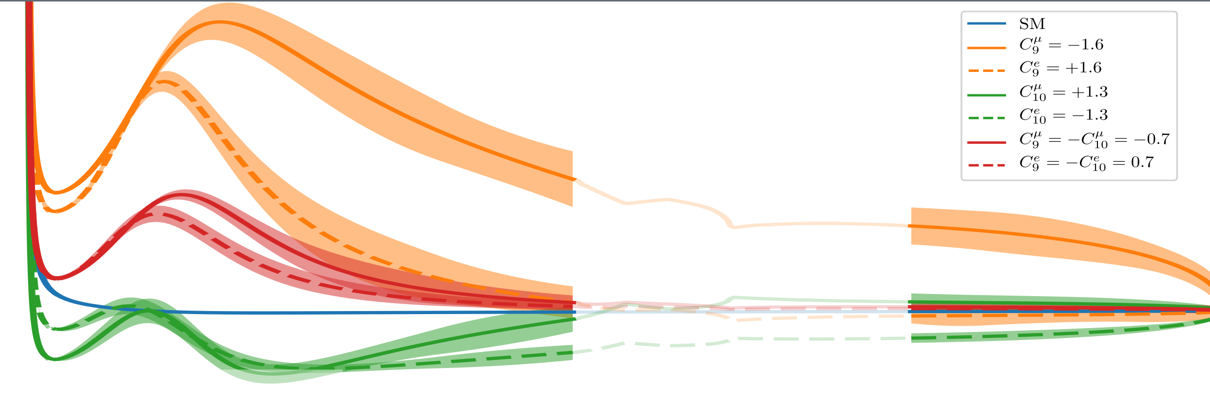
Particle theory seminar, Max-Planck-Institut für Kernphysik, Heidelberg, 2018-02-05

Flavour anomalies: status and implications

David M. Straub Universe Cluster/TUM, Munich



4 years back ...

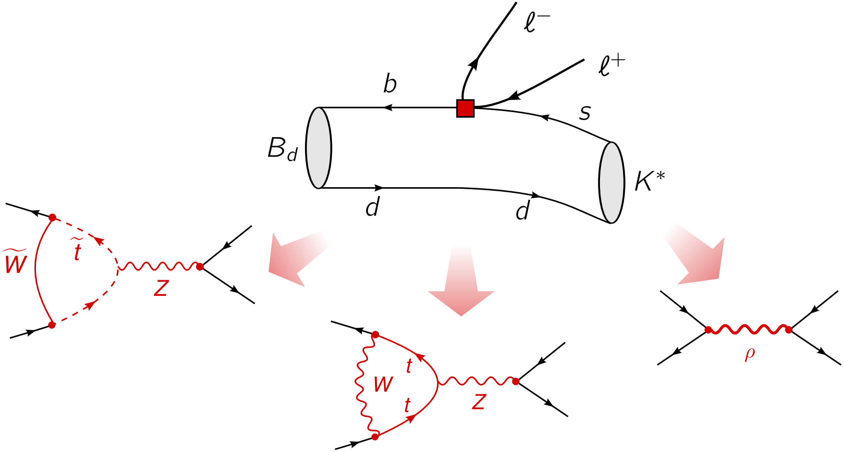
$B_s \to \mu^+\mu^-$ $B \to K^*\mu^+\mu^-$ Status of new physics in rare B decays

Conclusions

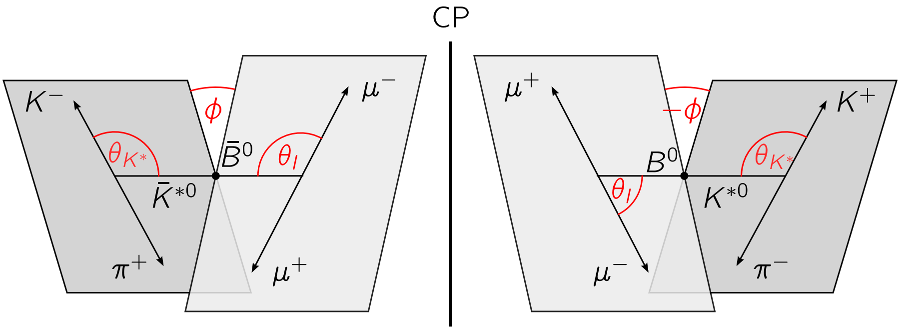
1. $B_s \to \mu^+\mu^-$ closing in on the SM
   - Not there yet! After several improvements, theory unc. well below exp.; exp. still statistics dominated
   - Implications for SUSY: large $\tan\beta$ with light Higgses disfavoured
   - Implications for partial compositeness: starts to probe the parameter space
2. $B \to K^*\mu^+\mu^-$ showing a few tensions with the SM
   - If due to NP, requires contribution to C_9 and C_9'
   - Impossible to explain in SUSY or partial compositeness
   - Only known explanation: light flavour-changing Z'

$b \to s$ FCNC decays

Loop- & CKM-suppressed $\Rightarrow$ sensitive to new physics

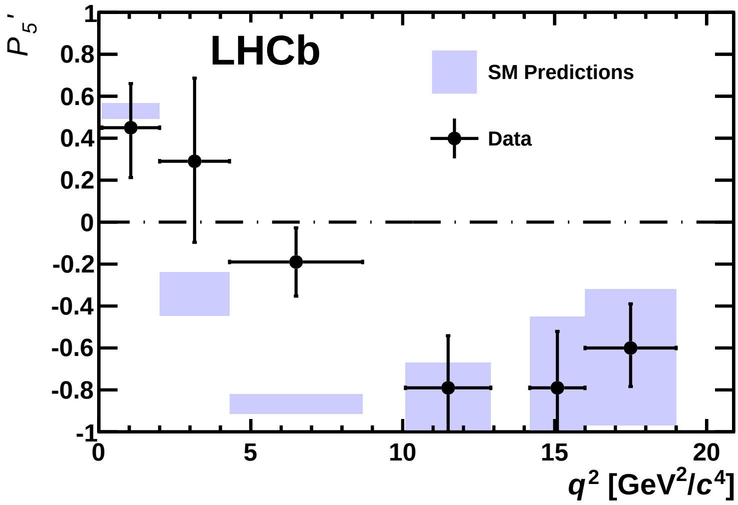


$B \to K^*(\to K\pi)\mu^+\mu^-$ angular distribution

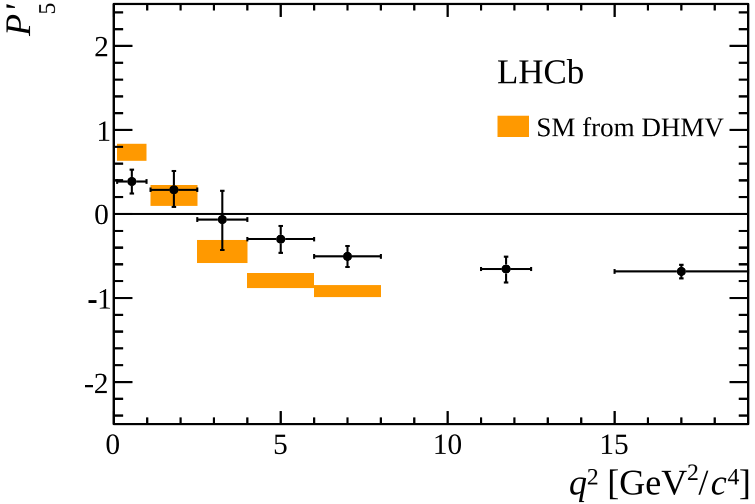


- Gives access to a large number of observables with complementary sensitivity to new physics

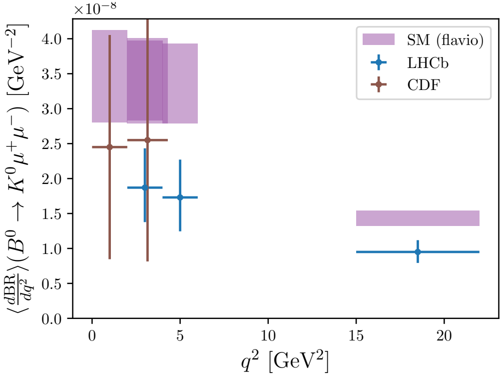
August 2013, LHCb 1 fb^{-1}

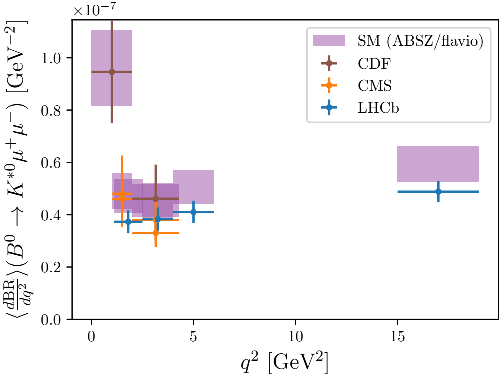


Moriond 2015, LHCb 3 fb^{-1}

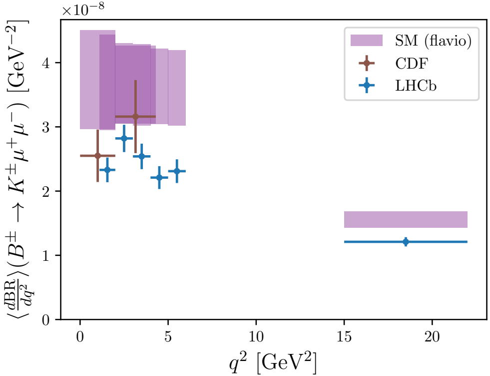


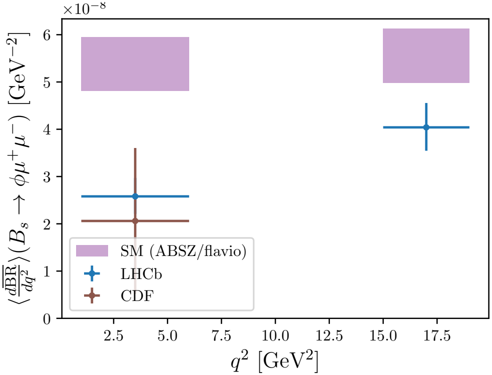
More $b \to s\mu\mu$ anomalies: branching ratios



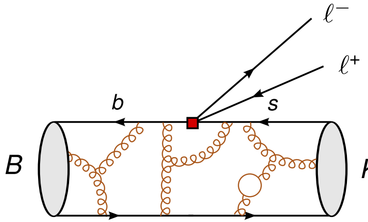


More $b \to s\mu\mu$ anomalies: branching ratios



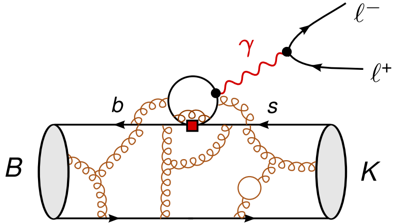


Theoretical challenges



Form factors

- Require non-perturbative calculation, e.g. lattice or light-cone sum rules (LCSR)



"Non-factorisable" hadronic effects

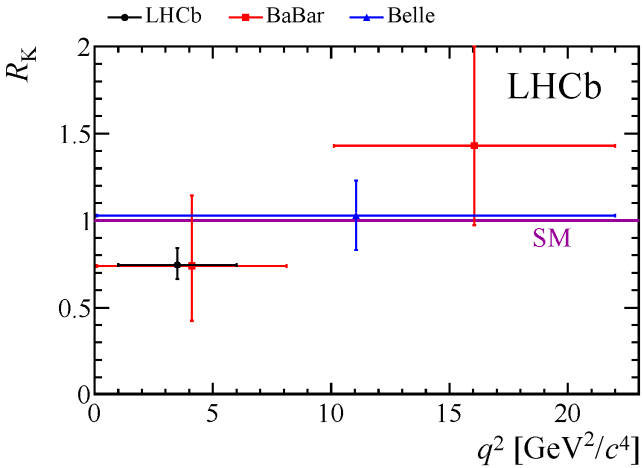
- Problematic since operators like $(\bar{c}_L\gamma^\mu b_L)(\bar{s}_L\gamma^\mu c_L)$ generated by *tree-level W* exchange

Predictions: smoking guns

"In particular, while the electron mode, $B \to X_s e^+ e^-$ remains SM-like, our framework predicts a $\sim$ 20% suppression … of the muonic … mode $B \to X_s \mu^+ \mu^-$. Such modifications are interesting goals for Belle-II."

Altmannshofer et al. 1403.1269

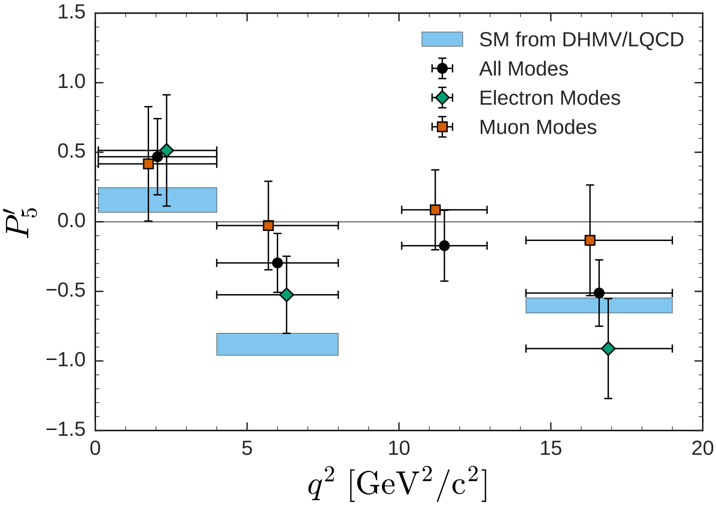
LHCP 2014: R_K



$$R_K = \frac{\text{BR}(B \to K\mu^+\mu^-)_{[1,6]}}{\text{BR}(B \to Ke^+e^-)_{[1,6]}}$$
$$= 0.745^{+0.090}_{-0.074} \pm 0.036$$

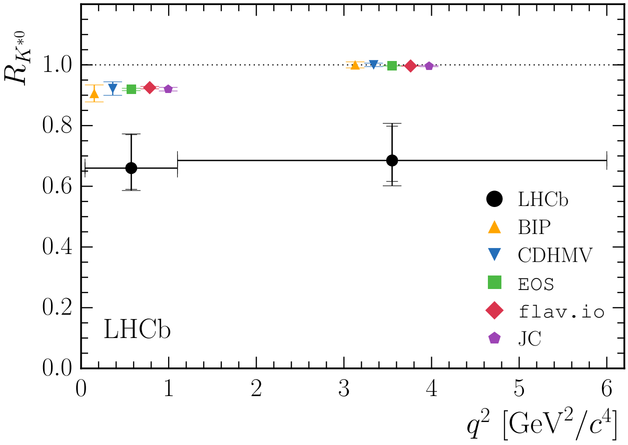
2.4σ

Belle P_5'



SM from DHMV/LQCD
All Modes
Electron Modes
Muon Modes
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
P_5'
0
5
10
15
20
q^2 [GeV^2/c^2]

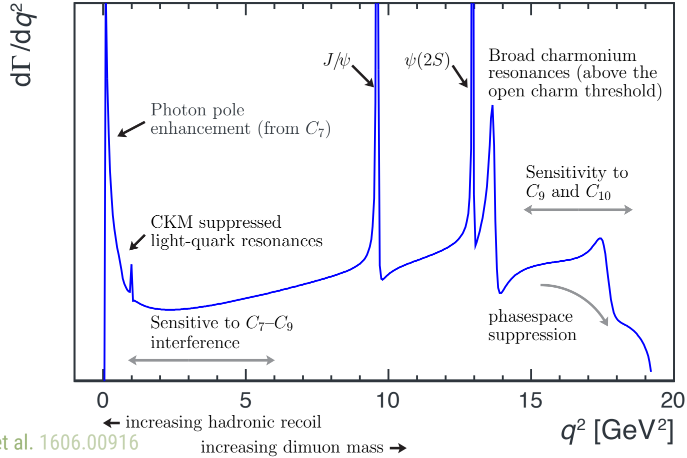
Easter 2017: R_{K^*}



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

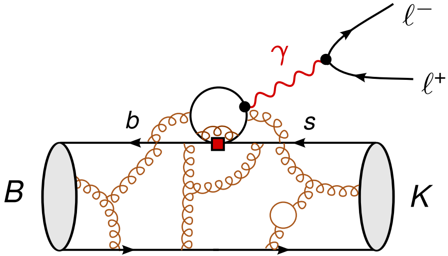
2.2 & 2.4σ

Cartoon: q^2 dependence of $B \to K^*\ell^+\ell^-$



Blake et al. 1606.00916

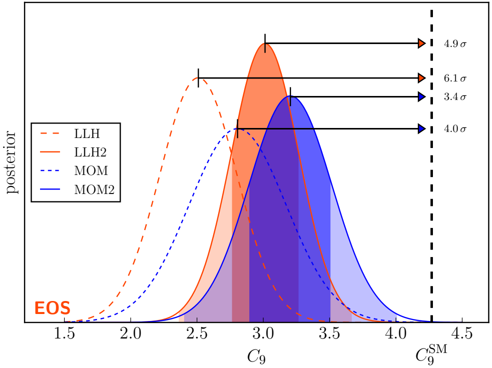
Hadronic uncertainties beyond form factors



- Partly calculable at low q^2 with QCDF Beneke et al. hep-ph/0106067
- Argued to have small impact on q^2-integrated observables at high q^2 Beylich et al. 1101.5118
- Remaining contributions enter error estimate

Using data to constrain hadronic contribution

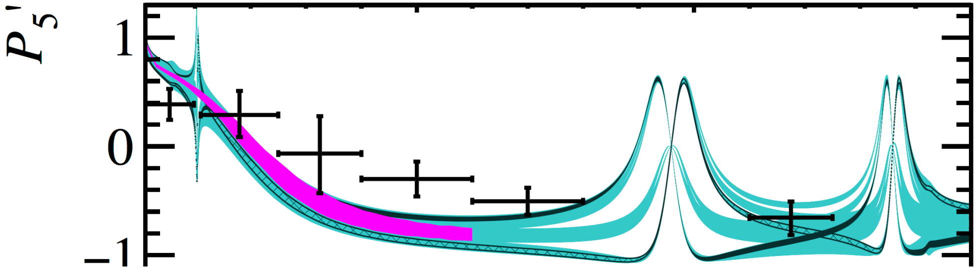
- Use $b \to c\bar{c}s$ data & analyticity to extract/constrain the contribution Bobeth et al. 1707.07305



- LLH: only $q^2 < m^2_{J/\psi}$; LLH2: including inter-resonance bin; MOM(2): method-of-moment results

Recent developments: BW-resonance model

- Modeling the hadronic contribution as a sum of Breit-Wigners; shown to be numerically compatible with more sophisticated parametrization from previous slide
  Blake et al. 1709.03921



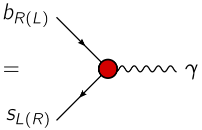
- Cyan: varying the phase of the resonances
- Purple: SM prediction according to `flavio`

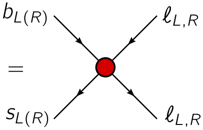
1. Neutral current anomalies
   - Overview of measurements
   - Comments on hadronic uncertainties
   - Model-independent new physics analysis
2. Charged current anomalies
3. Combined explanations
4. Fundamental Partial Compositeness

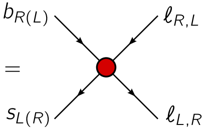
Effective theory

NP effects model-independently described by modification of Wilson coefficients of dim.-6 operators

$$\mathcal{H}_{\text{eff}} = -\frac{4\,G_F}{\sqrt{2}}\frac{e^2}{16\pi^2} V_{tb}V_{ts}^* \sum_i C_i O_i + \text{h.c.}$$

$\mathcal{O}_7^{(\prime)} =$ 

$\mathcal{O}_{9,10}^{(\prime)} =$ 

$\mathcal{O}_{S,P}^{(\prime)} =$ 

$$O_7^{(\prime)} = \frac{m_b}{e}(\bar{s}\sigma_{\mu\nu}P_{R(L)}b)F^{\mu\nu} \qquad O_8^{(\prime)} = \frac{m_b g_s}{e^2}(\bar{s}\sigma_{\mu\nu}T^a P_{R(L)}b)G^{a\mu\nu}$$

$$O_9^{(\prime)} = (\bar{s}\gamma_\mu P_{L(R)}b)(\bar{\ell}\gamma^\mu\ell) \qquad O_{10}^{(\prime)} = (\bar{s}\gamma_\mu P_{L(R)}b)(\bar{\ell}\gamma^\mu\gamma_5\ell)$$

$$O_S^{(\prime)} = (\bar{s}P_{R(L)}b)(\bar{\ell}\ell) \qquad O_P^{(\prime)} = (\bar{s}P_{R(L)}b)(\bar{\ell}\gamma_5\ell)$$

Sensitivity to Wilson coefficients

Decay	$C_7^{(\prime)}$	$C_9^{(\prime)}$	$C_{10}^{(\prime)}$	$C_{S,P}^{(\prime)}$
$B \to X_s \gamma$	X			
$B \to K^* \gamma$	X			
$B \to X_s \ell^+ \ell^-$	X	X	X	
$B \to K^{(*)} \ell^+ \ell^-$	X	X	X	
$B_s \to \mu^+ \mu^-$			X	X

Different observables are complementary in constraining NP

- Global analysis can be used to resolve ambiguities
- Apparent deviation from the SM in one observable can be cross-checked in related mode

Model-independent fit to $C_{9,10}^{(\prime)}$ Altmannshofer et al. 1703.09189

Fit individual or pairs of WCs to

- Angular observables in $B^0 \to K^{*0}\mu^+\mu^-$ (CDF, LHCb, ATLAS, CMS)
- $B^{0,\pm} \to K^{*0,\pm}\mu^+\mu^-$ branching ratios (CDF, LHCb, CMS)
- $B^{0,\pm} \to K^{0,\pm}\mu^+\mu^-$ branching ratios (CDF, LHCb)
- $B_s \to \varphi\mu^+\mu^-$ branching ratio (CDF, LHCb)
- $B_s \to \varphi\mu^+\mu^-$ angular observables (LHCb)
- $B \to X_s\mu^+\mu^-$ branching ratio (BaBar)

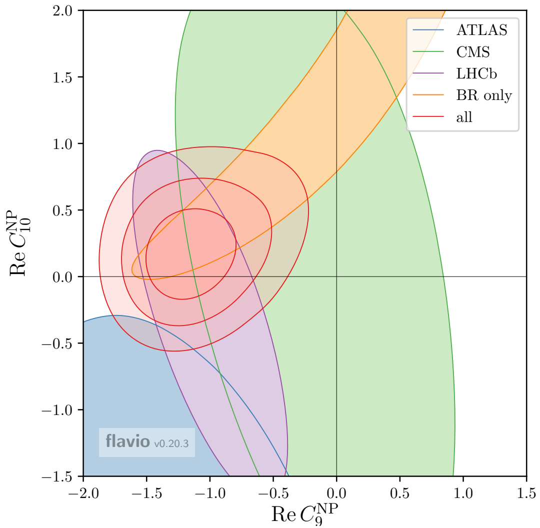
NB, R_K & R_{K^*} not used as constraints (yet)!

1D results

Coeff.	best fit	1σ	2σ	pull
C_9^{NP}	-1.21	$[-1.41, -1.00]$	$[-1.61, -0.77]$	5.2σ
C_9'	$+0.19$	$[-0.01, +0.40]$	$[-0.22, +0.60]$	0.9σ
C_{10}^{NP}	$+0.79$	$[+0.55, +1.05]$	$[+0.32, +1.31]$	3.4σ
C_{10}'	-0.10	$[-0.26, +0.07]$	$[-0.42, +0.24]$	0.6σ
$C_9^{NP} = C_{10}^{NP}$	-0.30	$[-0.50, -0.08]$	$[-0.69, +0.18]$	1.3σ
$C_9^{NP} = -C_{10}^{NP}$	-0.67	$[-0.83, -0.52]$	$[-0.99, -0.38]$	4.8σ
$C_9' = C_{10}'$	$+0.06$	$[-0.18, +0.30]$	$[-0.42, +0.55]$	0.3σ
$C_9' = -C_{10}'$	$+0.08$	$[-0.02, +0.18]$	$[-0.12, +0.28]$	0.8σ

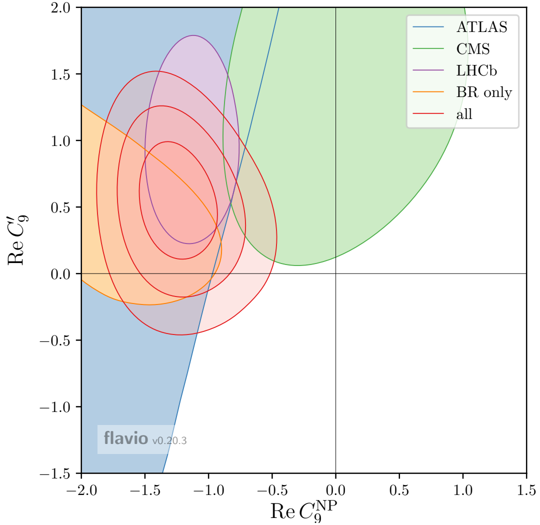
$$\text{pull} \equiv \sqrt{\chi^2_{\text{SM}} - \chi^2_{\text{best fit}}} \qquad \text{(for 1D)}$$

2D results



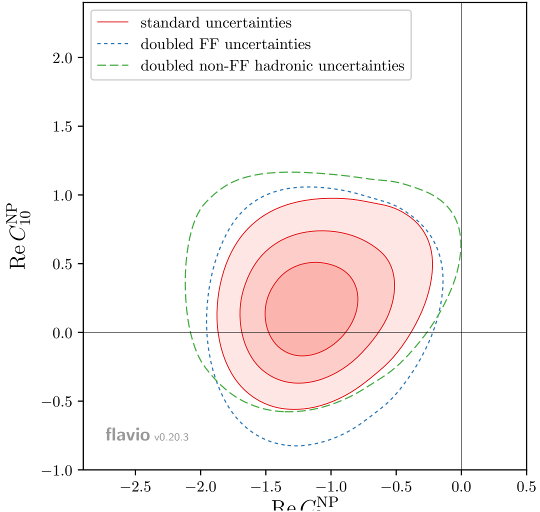
- best fit $(C_9^{\mathrm{NP}}, C_{10}^{\mathrm{NP}}) = (-1.15, +0.26)$
- pull 5.0σ

2D results



- best fit $(C_9^{\text{NP}}, C_9') = (-1.25, +0.59)$
- pull 5.3σ

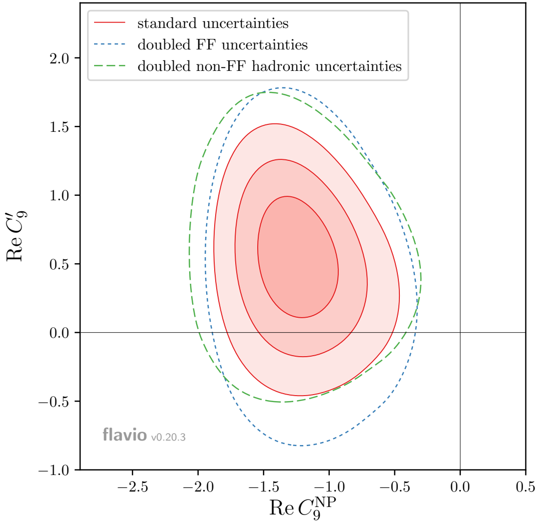
Impact of enlarging uncertainties



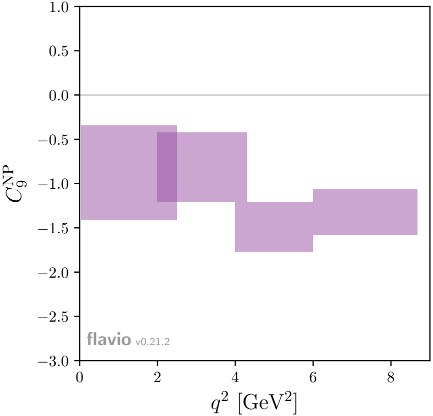
Doubling form-factor *or* “non-factorizable” hadronic uncertainties:

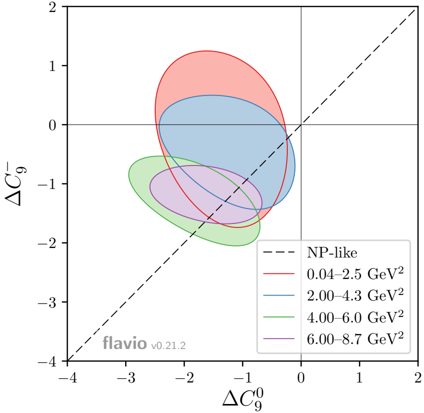
- Significance decreases but stays well above 3σ
- best-fit point hardly affected

Impact of enlarging uncertainties



q^2 dependence of C_9 best-fit





- NP in C_9 would give helicity and q^2 independent effect
- NP in $b \to c\bar{c}s$ would give helicity independent but q^2 dependent effect
- hadronic effect could be helicity and q^2 dependent

flavio

All the numerics have been performed using:
`flavio` – a Python package for flavour phenomenology in the SM & beyond

- Documentation: <https://flav-io.github.io/>
- Code: <https://github.com/flav-io/flavio>

Main goal: lower the barrier between model building and flavour pheno

Now directly supports new physics in terms of SMEFT operators Aebischer et al. 1712.05298

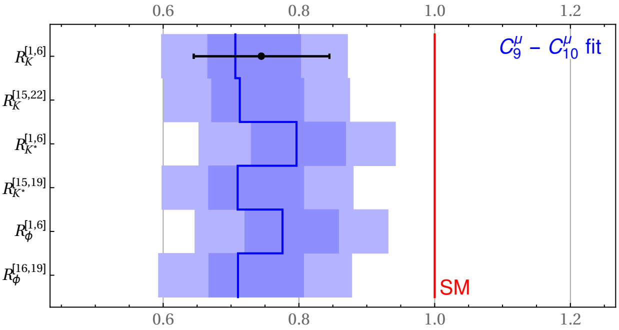
Predictions for LFU tests

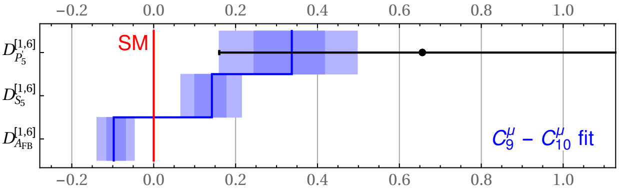
Using the model-independent fit to $b \to s\mu^+\mu^-$ observables and *assuming* the corresponding $b \to s e^+ e^-$ observables to be free from NP, can *predict* LFU ratios/differences

$$R_X = \frac{\text{BR}(B \to X\mu\mu)}{\text{BR}(B \to Xee)}$$

$$D_{\mathcal{O}} = \mathcal{O}(B \to K^*\mu\mu) - \mathcal{O}(B \to K^*ee)$$

Predictions for LFU tests





LFU fit Altmannshofer et al. 1704.05435

We now fit Wilson coefficients of lepton flavour dependent operators:

$$O_9^{(\prime)\ell} = (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{\ell}\gamma^\mu \ell) \qquad O_{10}^{(\prime)\ell} = (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{\ell}\gamma^\mu \gamma_5 \ell) \tag{1}$$

Observables:

- R_K (LHCb)
- R_{K^*} (LHCb)
- $D_{P'_{4,5}} = P'_{4,5}(B \to K^* \mu\mu) - P'_{4,5}(B \to K^* ee)$ (Belle)

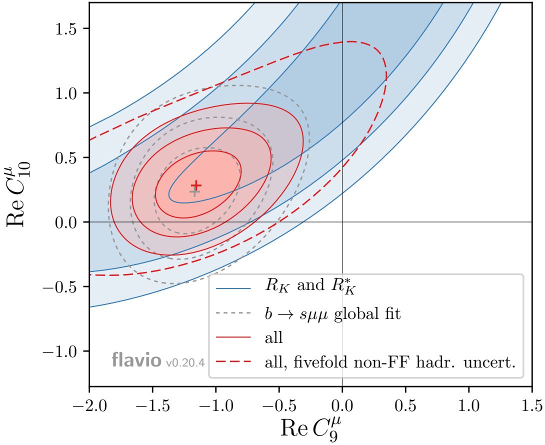
These observables/measurements are *disjoint* from the ones used in the $b \to s\mu\mu$ fit!

1D results

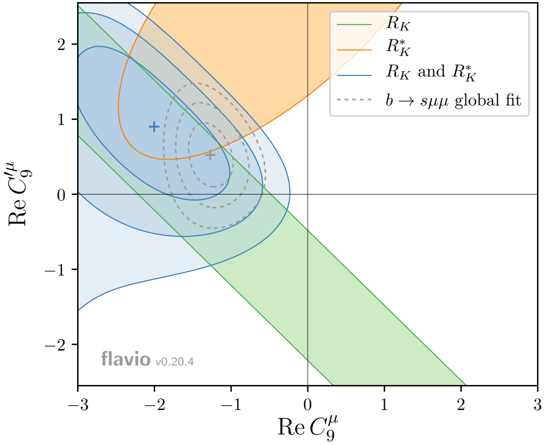
Coeff.	best fit	1σ	2σ	pull
C_9^μ	-1.59	$[-2.15, -1.13]$	$[-2.90, -0.73]$	4.2σ
C_{10}^μ	$+1.23$	$[+0.90, +1.60]$	$[+0.60, +2.04]$	4.3σ
C_9^e	$+1.58$	$[+1.17, +2.03]$	$[+0.79, +2.53]$	4.4σ
C_{10}^e	-1.30	$[-1.68, -0.95]$	$[-2.12, -0.64]$	4.4σ
$C_9^\mu = -C_{10}^\mu$	-0.64	$[-0.81, -0.48]$	$[-1.00, -0.32]$	4.2σ
$C_9^e = -C_{10}^e$	$+0.78$	$[+0.56, +1.02]$	$[+0.37, +1.31]$	4.3σ
$C_9^{\prime\,\mu}$	-0.00	$[-0.26, +0.25]$	$[-0.52, +0.51]$	0.0σ
$C_{10}^{\prime\,\mu}$	$+0.02$	$[-0.22, +0.26]$	$[-0.45, +0.49]$	0.1σ
$C_9^{\prime\,e}$	$+0.01$	$[-0.27, +0.31]$	$[-0.55, +0.62]$	0.0σ
$C_{10}^{\prime\,e}$	-0.03	$[-0.28, +0.22]$	$[-0.55, +0.46]$	0.1σ

$$\text{pull} \equiv \sqrt{\chi^2_{\text{SM}} - \chi^2_{\text{best fit}}} \qquad \text{(for 1D)}$$

2D results: $R_{K^{(*)}}$ vs. $b \to s\mu\mu$

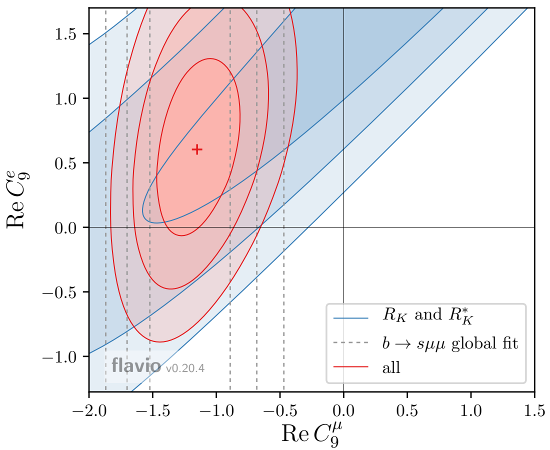


C_9^μ vs. $C_9'^\mu$



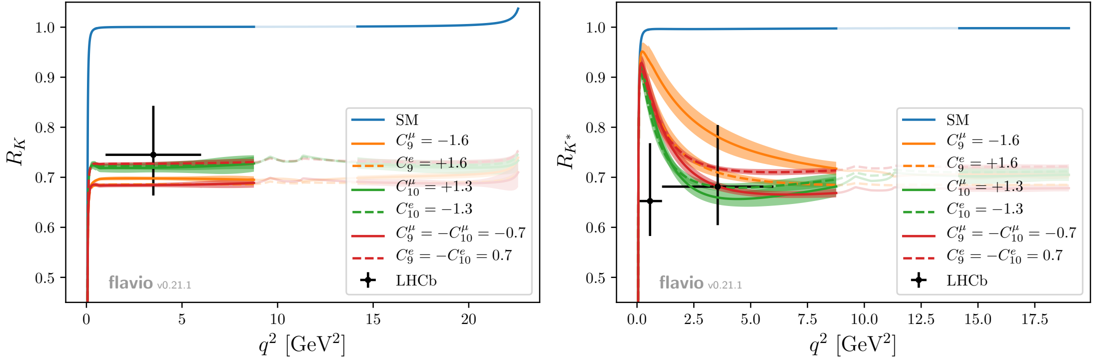
- Right-handed currents not favoured by data

C_9^μ vs. C_9^e



- NP in $b \to se^+e^-$ not required by data (but not excluded either!)

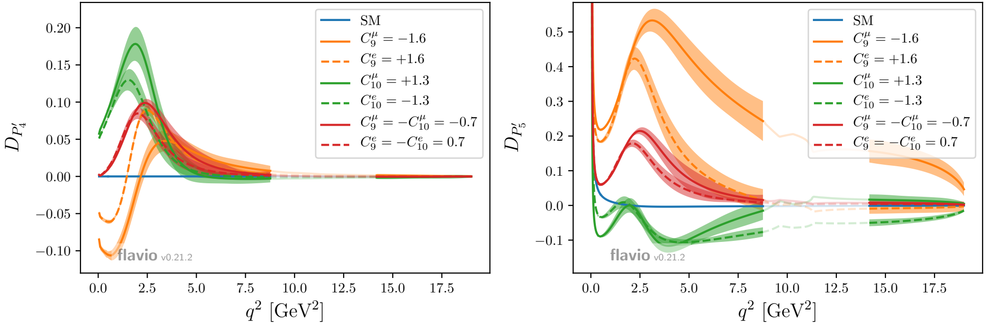
$R_{K^{(*)}}$ in different scenarios



- Impossible to distinguish different best-fit scenarios on the basis of $R_{K^{(*)}}$ alone

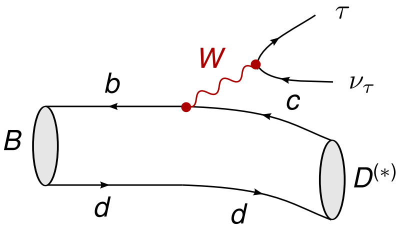
Predictions for angular observables

$$D_{P'_{4,5}} = P'_{4,5}(B \to K^* \mu\mu) - P'_{4,5}(B \to K^* ee)$$



- $D_{P'_{4,5}}$ can clearly distinguish hypotheses with C_9 vs. C_{10}
- might even be able to distinguish suppression of $\mu\mu$ vs. enhancement of ee mode

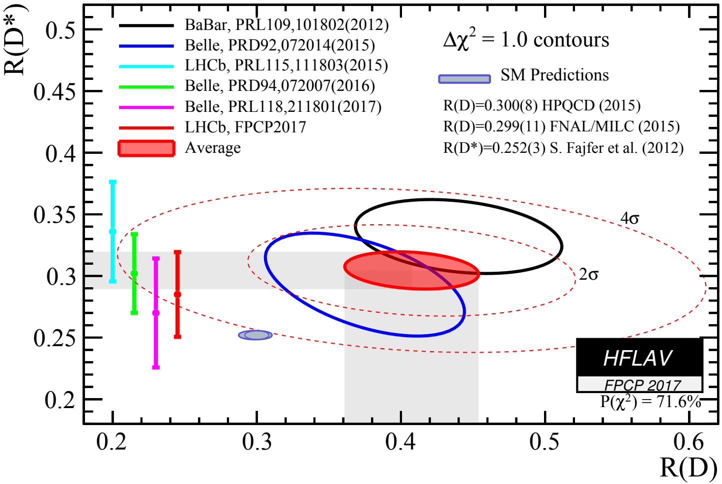
R_D & R_{D^*}



- Decays $B \to D^{(*)}\ell\nu$ with $\ell = e$ or μ used to measure CKM element V_{cb}
- $B \to D^{(*)}\tau\nu$ different due to τ mass, but hadronic uncertainties (form factors) very small in ratio

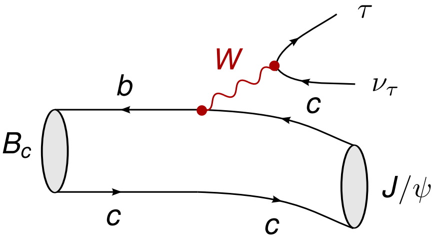
$$\Rightarrow R_{D^*} = \frac{\text{BR}(B \to D^{(*)}\tau\nu)}{\text{BR}(B \to D^{(*)}\ell\nu)} \text{ is a powerful test of LFU!}$$

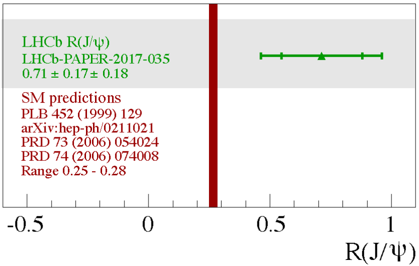
The $R_{D^{(*)}}$ anomalies



$\approx 4\sigma$

Cross-checks: $R_{J/\psi}$





- Interesting cross-check: bigger than expected as well
- Uncertainties (both theo & exp) still too large to draw conclusions

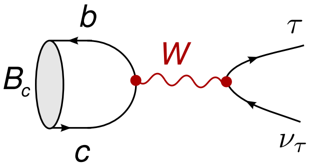
Effective theory for $b \to c\tau\nu$

$$\mathcal{H}_{\text{eff}} = \frac{4G_F}{\sqrt{2}} V_{cb} \left(O_{V_L} + \sum_i C_i O_i + \text{h.c.} \right)$$

$$\begin{aligned}
O_{V_L} &= (\bar{c}_L \gamma^\mu b_L)(\bar{\ell}_L \gamma_\mu \nu_{\tau L}) \qquad & O_{S_R} &= (\bar{c}_L b_R)(\bar{\ell}_R \nu_{\tau L}) \qquad & O_T &= (\bar{c}_R \sigma^{\mu\nu} b_L)(\bar{\ell}_R \sigma_{\mu\nu} \nu_{\tau L}) \\
O_{V_R} &= (\bar{c}_R \gamma^\mu b_R)(\bar{\ell}_L \gamma_\mu \nu_{\tau L}) \qquad & O_{S_L} &= (\bar{c}_R b_L)(\bar{\ell}_R \nu_{\tau L}) & &
\end{aligned}$$

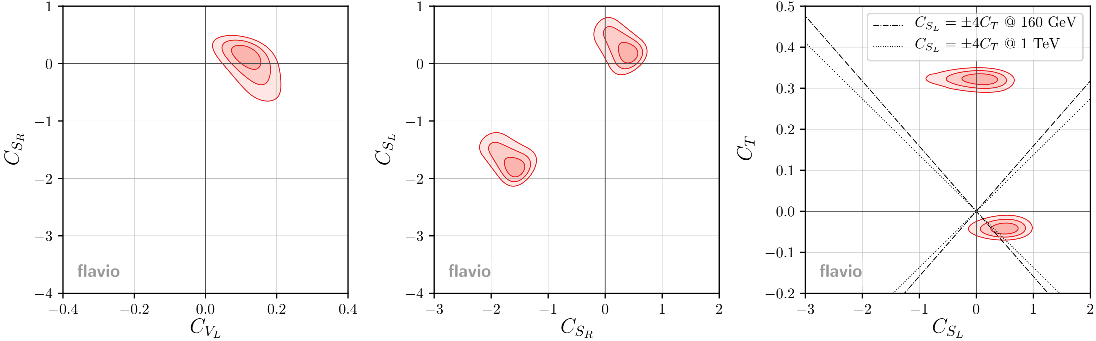
- O_{V_R} is LFU at dimension 6 in SMEFT (can only arise from modification of $\bar{c}_R b_R W$ vertex) $\Rightarrow$ ignore
- Ignoring $b \to c\tau\nu_{e,\mu}$ for simplicity (contributions relevant in concrete models!)

Constraint from $B_c \to \tau\nu$



- Can be strongly enhanced by scalar operators
- sensitive to $C_{S_R} - C_{S_L}$
- Even though the decay has not been measured or searched for, theoretical arguments allow to constrain $\text{BR}(B_c \to \tau\nu) \lesssim 0.3$ Li et al. 1605.09308, Alonso et al. 1611.06676
- Reinterpreting an old LEP1 search for $B^+ \to \tau\nu$ allows to constrain $\text{BR}(B_c \to \tau\nu) \lesssim 0.1$ Akeroyd and Chen 1708.04072

Model-independent fit to $b \to c\tau\nu$



- Fit to R_D, R_{D^*}, $B_c \to \tau\nu$
- Not a full fit: $d\Gamma/dq^2$, τ pol., $R_{J/\psi}$ missing

Combined explanations: SMEFT considerations

- Heavy NP must respect $SU(2)_L \times U(1)_Y$ gauge invariance $\Rightarrow D = 6$ SMEFT (ignoring non-linear HEFT) Alonso et al. 1407.7044, Aebischer et al. 1512.02830, ...
- Only considering operators that affect $b \to s\mu^+\mu^-$, $b \to c\tau\nu$, violate LFU

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

- $[C_{lq}^{(1)}]^{2223} \to C_9 = -C_{10}$
- $[C_{lq}^{(3)}]^{2223} \to C_9 = -C_{10}$
- $[C_{ld}]^{2223} \to C_9 = C_{10}$

through RG mixing:

- $[C_{lu}]^{2233} \to C_9 = -C_{10}$ Celis et al. 1704.05672

*(basis where $M_{d,l}$ are diagonal)

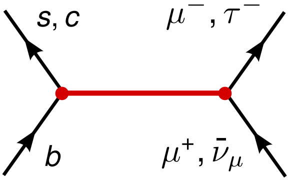
$b \to c\tau\nu$

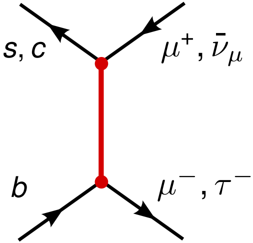
- $[C_{lq}^{(3)}]^{33i3} \to C_{V_L}$
- $[C_{ledq}]^{333i*} \to C_{S_R}$
- $[C_{lequ}^{(1)}]^{333i} \to C_{S_L}$
- $[C_{lequ}^{(3)}]^{333i} \to C_T$

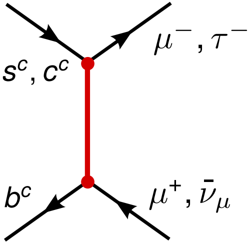
through RG mixing: no qualitative change

González-Alonso et al. 1706.00410

Tree-level models





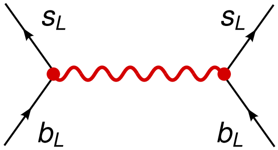


Single-mediator tree-level models

Model	$C_{lq}^{(1)}$	$C_{lq}^{(3)}$	C_{qe}	C_{lu}	C_{ledq}	$C_{lequ}^{(1)}$	$C_{lequ}^{(3)}$
Z'	×		×	×			
V'		×					
H'					×	×	
S_1	×	×				×	×
R_2			×	×		×	×
S_3	×	×					
U_1	×	×			×		
U_3	×	×					
V_2			×		×		
$\tilde{V}_2$				×			

- Some models generate R_D at tree, $R_K(*)$ at 1-loop Bauer and Neubert 1511.01900, Bečirević and Sumensari 1704.05835

Generic constraints: B_s mixing

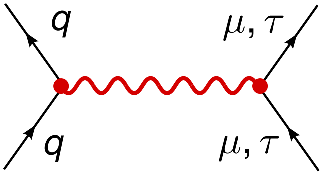


- Forces Z' (or vector triplet) models into regime with strong couplings to muons

$$g_{bsZ'}/m_{Z'} \lesssim 0.01/(2.5\,\mathrm{TeV})$$

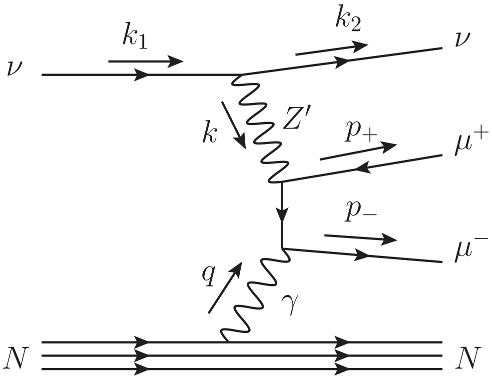
Altmannshofer and Straub 1308.1501

Generic constraints: $pp \to \mu\mu, \tau\tau$



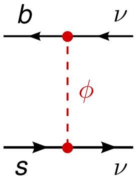
- Resonances searches
- contact interaction searches

Generic constraints: Neutrino trident



Altmannshofer et al. 1403.1269, Altmannshofer et al. 1406.2332

Generic constraints: $B \to K\nu\bar{\nu}$



- S_1, S_3, U_3 leptoquarks generate $b \to s\nu\bar{\nu}$ at tree level
  Buras et al. 1409.4557
- B factory searches constrain
  $\text{BR}(B \to K\nu\bar{\nu})/\text{BR}(B \to K\nu\bar{\nu})_{\text{SM}} \lesssim 3$

- S_1: $C_L^{\nu_\mu} \gg C_9^\mu$
- S_3: $C_L^{\nu_\mu} = \frac{1}{2} C_9^\mu$
- U_3: $C_L^{\nu_\mu} = 2 C_9^\mu$

- Particularly problematic if $R_{D^{(*)}}$ should be explained: large contributions to $b \to s\nu_\tau\bar{\nu}_\tau$, $b \to s\nu_\mu\bar{\nu}_\tau$, $b \to s\nu_\tau\bar{\nu}_\mu$
- Possible to suppress using cancellation between S_1 and S_3 contribution Crivellin et al. 1703.09226

Combined explanations: summary

- If both anomalies are due to a *single & simple* source of NP, the least constrained option currently seems to be the leptoquark U_1
  - B_s mixing contribution suppressed by loop factor
  - $B \to K\nu\bar{\nu}$ contribution suppressed by loop factor
- *Vector* leptoquark calls for UV completion. Model building attempts underway, most based on Pati-Salam (PS) gauge group, $SU(4) \times SU(2) \times SU(2)$
  - Composite PS leptoquark Barbieri et al. 1611.04930, Barbieri and Tesi 1712.06844
  - $SU(4) \times SU(3) \times SU(2) \times U(1)$ Di Luzio et al. 1708.08450, cf. v2 of Assad et al. 1708.06350
  - PS with additional vector-like fermions Calibbi et al. 1709.00692
  - Three-site PS Bordone et al. 1712.01368
  - PS in warped extra dimensions Blanke and Crivellin 1801.07256

Flavour anomalies and partial compositeness

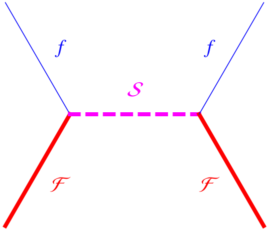
- Partial compositeness: crucial ingredient of viable composite Higgs models
- Linear coupling of fermions to composite operators generates fermion masses

$$\mathcal{L} \supset \lambda q \mathcal{Q}$$

- $b \to s\mu^+\mu^-$ anomalies could be explained if either left- or right-handed muons have a significant degree of compositeness
  - Basic idea, composite LH muons Niehoff et al.
  - Extra dimensional realization Megias et al. 1608.02362
  - Relation to EWSB, composite RH leptons Carmona and Goertz 1510.07658, Carmona and Goertz 1712.02536

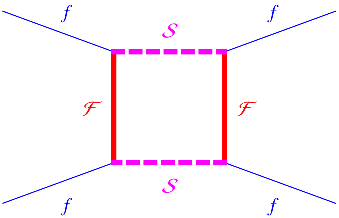
Fundamental Partial Compositeness (FPC) Sannino et al. 1607.01659

- Partial compositenss $\mathcal{L} \supset \lambda q \mathcal{Q}$: hard to realize if $\mathcal{Q}$ is "baryon"
- UV completion possible if $\mathcal{Q}$ is scalar-fermion bound state: $\mathcal{Q} \sim \mathcal{F}\mathcal{S}$



Fermion masses

$f\, f \mathcal{F}\mathcal{F} \sim f\, f\, H$

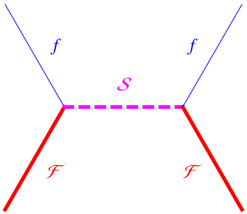


Flavour physics

f^4

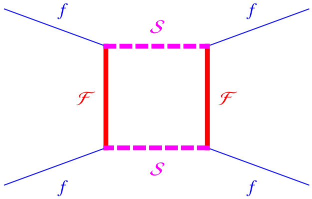
Minimal FPC Cacciapaglia et al. 1704.07845

- Gauge group $\mathrm{Sp}(N_{\mathrm{TC}})$
- NB: EW symmetry broken by (composite) Higgs VEV, not by condensate!
- Global symmetry breaking coset $\mathrm{SU}(4)/\mathrm{Sp}(4) \sim \mathrm{SO}(6)/\mathrm{SO}(5)$
- Scalar sector invariant under global $\mathrm{Sp}(2N_{\mathcal{S}}) = \mathrm{Sp}(24)_{\mathcal{S}}$



Fermion masses

$f\,f\mathcal{F}\mathcal{F} \sim f\,f\,H$



Flavour physics

f^4

EFT for FPC

- EFT with operators invariant and the full global symmetries of the theory $\to$ match to weak effective theory
- All low-energy phenomenology fixed in terms of fundamental parameters of the UV theory and Wilson coefficients of TC operators

$$\mathcal{O}^1_{4f} = \frac{1}{64\pi^2\Lambda_2}(\psi^{i_1}{}_{a_1}\psi^{i_2}{}_{a_2})(\psi^{\dagger\, i_3 a_3}\psi^{\dagger\, i_4 a_4})\Sigma^{a_1 a_2}\Sigma^\dagger_{a_3 a_4}\epsilon_{i_1 i_2}\epsilon_{i_3 i_4}$$

$$\ldots$$

$$\mathcal{O}^8_{4f} = \frac{1}{128\pi^2\Lambda_2}(\psi^{i_1}{}_{a_1}\psi^{i_2}{}_{a_2})(\psi^{i_3}{}_{a_3}\psi^{i_4}{}_{a_4})\Sigma^{a_1 a_2}\Sigma^{a_3 a_4}\,(\epsilon_{i_1 i_4}\epsilon_{i_2 i_3} - \epsilon_{i_1 i_3}\epsilon_{i_2 i_4})$$

$$\mathcal{O}_{\Pi f} = \frac{i}{32\pi^2}(\psi^{\dagger\, i_1 a_1}\bar{\sigma}_\mu \psi^{i_2}{}_{a_2})\,\Sigma^\dagger_{a_1 a_3}\overleftrightarrow{D}^\mu \Sigma^{a_3 a_2}\,\epsilon_{i_1 i_2}$$

EFT for FPC

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$$\ldots$$

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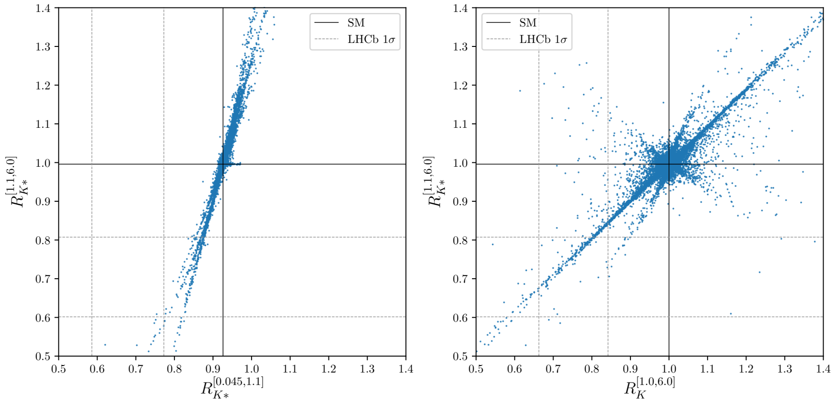
- Now: numerical analysis, reproducing masses & mixings of (partially composite) SM spectrum, varying all free parameters (fundamental & “TC-hadronic”)

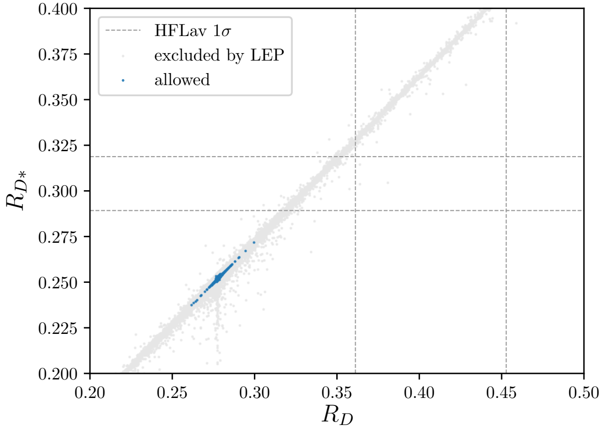
Sannino et al. 1712.07646

Predictions for $R_{K^{(*)}}$ Sannino et al. 1712.07646



- Taking into account constraints from Z pole EWPT, $\Delta F = 2$
- We can explain all $R_{K^{(*)}}$ anomalies!

Predictions for $R_{D^{(*)}}$ Sannino et al. 1712.07646



- Taking into account LEP Z pole constraints, we cannot explain R_D and R_{D^*}

Conclusions

- Several tantalizing anomalies in B physics:
  - $b \to s\mu\mu$ branching ratios and angular observables: subject to hadronic uncertainties but statistically significant
  - R_K & R_K^*: theoretically very clean but statistically not too significant. But perfectly consistent with $b \to s\mu\mu$ anomalies!
  - R_D & R_D^*: theoretically clean & statistically significant
- We are running out of theory excuses to explain away these anomalies!
- Combined NP explanation of all anomalies possible!
- Experimental prospects very promising
  - R_K & R_K^* from LHC Run 2
  - Upcoming Belle-II experiment with clean e^+-e^- environment