B physics anomalies and lepton flavour universality in $b \to sll$ transitions

on behalf of the LHCb collaboration

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Why $b \rightarrow s \ell \ell$ transitions?

- **Flavour changing neutral currents**
  In the **Standard Model**: Forbidden at tree level, occur through loops

- **New physics** processes can contribute and change the branching ratios and angular distributions
Parametrising new physics

- Description of FCNC in term of an effective hamiltonian which is expanded in operators $\mathcal{O}_i$ encoding short-distance physics and their coupling strengths $C_i$ (the Wilson coefficients)

\[
H_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \left[ C_i(\mu) \mathcal{O}_i(\mu) + C'_i(\mu) \mathcal{O}'_i(\mu) \right]
\]

- Variables of interest:

$C_{7}^{(i)}$: Strength of the couplings to photons
$C_{9}^{(i)}$ and $C_{10}^{(i)}$: Strength of the couplings to leptons
Different regions in di-lepton invariant mass $q^2$

$\frac{d\Gamma}{dq^2}$

$C_7'$ - $C_9'$ interference

$J/\psi(1S)$

$\psi(2S)$

$C_9'$ and $C_{10}'$

Long distance contributions from $c\bar{c}$ above open charm threshold
What can we do? Which observables?

- Branching ratios (but high hadronic uncertainties)
- Angular distributions
- Lepton flavour universality tests
  Ratios of branching fractions between channels with muons and with electrons as a null test of the SM (much less hadronic uncertainties because ratio)
Results of analyses using Run 1 data
Branching fraction measurements

- Results consistently lower than SM (but high hadronic uncertainties)
Branching fraction measurements

- Use all possible decays with a $b \to s l l$ transition
- Same trend

\[ B^0 \to K^{*0} \mu\mu \]

\[ B_S \to \phi \mu\mu \]

\[ \Lambda_b \to \Lambda \mu\mu \]
A $b \rightarrow dll$ transition

- FCNC but CKM suppressed

$B^+ \rightarrow \pi^+\mu\mu$
Angular analyses

- 4 distributions using the 4-body final state
- 3 angles and the di-lepton invariant mass squared

- Give access to observables (such as $A_{FB}$, $F_L$, $S_5$) that depend on one or several Wilson coefficients

- But also depend on hadronic matrix elements
Angular analyses

- Full angular analysis of $B^0 \rightarrow K^{*0}\mu\mu$
- CP averaged angular observables 3σ away from SM
Angular analyses

- Less form-factor dependent observable: $P'_5$
  \[ P'_5 = \frac{S'_5}{\sqrt{F_L(1 - F_L)}} \]
- Still slightly away from SM ($2.8\sigma$ and $3.0\sigma$)
- Compatible with BELLE in the low $q^2$ region
Angular analyses

- Repeated with several $b \rightarrow sll$ transitions

- $\Lambda_b$ decays give access to different combinations of Wilson coefficients
Angular analyses

- Full angular analysis of $B^0 \rightarrow K^{*0}ee$ at very low $q^2$ in the [0.002 - 1.120] GeV$^2$/c$^4$ range
- Challenging due to Bremsstrahlung
- Sensitive to $C_7$ and $C_7'$ (which are found to be consistent with SM)

Values:

$F_L = 0.16 \pm 0.06 \pm 0.03$

$A_T^{(2)} = -0.23 \pm 0.23 \pm 0.05$

$A_T^{\text{Im}} = +0.14 \pm 0.22 \pm 0.05$

$A_T^{\text{Re}} = +0.10 \pm 0.18 \pm 0.05$

References:

JHEP 04 (2015) 064
Lepton flavour universality tests

- Use **ratio of branching fractions** to cancel theoretical uncertainties
  
  \[
  R_H = \frac{\int \frac{d\Gamma(B \rightarrow H \mu^+\mu^-)}{dq^2} \ dq^2}{\int \frac{d\Gamma(B \rightarrow He^+e^-)}{dq^2} \ dq^2}
  \]

- In SM, \( R_H = 1 \) (up to phase-space corrections and Higgs contributions at the % level: arXiv:1605.07633)
  Deviation from 1 would be clear sign of NP

- Difficult because of **Bremsstrahlung**
Lepton flavour universality tests - Results

Tensions with SM predictions:

2.6σ level in $R_K$

2.2-2.5σ level in $R_{K^*}$
Hadronic uncertainties would not affect LFU

With only LFU (and $b \rightarrow s\gamma$) results, discrepancy of more than $3\sigma$ with SM
Combinations of branching ratios, angular analyses and lepton-flavour unitarity tests

- Use all available data plus constraints from $b \to s\gamma$ transitions and $B_S \to \mu\mu$ to obtain more information on the Wilson coefficients
- Reaches more than $4\sigma$ discrepancy from SM
- In favour of new physics in $C_9$ and $C_{10}$ (that would couple more to muons from LFU tests)

Capdevila et al. (arXiv:1704.05340)

This is just an example...
Many others here:
Many analyses exploiting $b \rightarrow sll$ transitions have been performed using LHCb Run 1 data.

Even though there is no evidence of new physics from any single analysis, global fits show a clear tension with the SM.
The way to go

- Effort ongoing to try to control hadronic uncertainties

- Update all analyses with Run 2 data (~5 fb\(^{-1}\) expected)

- New measurements
  - \(R_\phi\) (suppressed by \(f_s/f_d\) but narrow mass window)
  - \(R_{pK}\)
  - \(R_{K\pi\pi}\)

- Studies of lepton flavour violation
  - \(B_{(S)} \rightarrow e\mu\) (arXiv:1710.04111)
  - \(B \rightarrow K\epsilon\mu\)
Thanks for your attention!