Overview and challenges of semi-leptonic B decays and implications for new physics

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Rare B decays are excellent tools for

- Testing the Standard Model paradigms and parameters
- Probing New Physics at the intensity frontier

Semi-leptonic B decays: $b \to s\ell\ell$

- FCNC, suppressed in the SM, sensitive to NP
- Several deviations from the SM predictions

$\to$ **Focus of this talk**

- Relevant decays
- Theoretical framework
- The issue of hadronic uncertainties
- New physics interpretations

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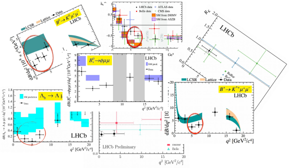

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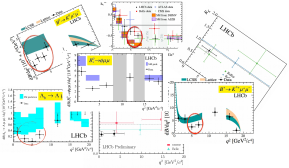

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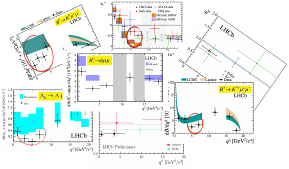

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- **Clean observables**: Lepton Flavour Universality ratios

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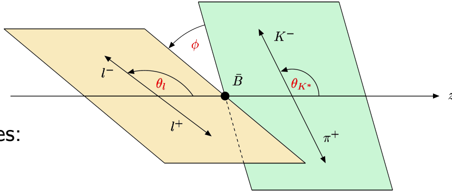
- **Branching fractions**:

$$\begin{aligned} &\mathrm{BR}(B \to K^*\mu^+\mu^-)\\ &\mathrm{BR}(B \to K\mu^+\mu^-)\\ &\mathrm{BR}(B_s \to \phi\mu^+\mu^-)\\ &\mathrm{BR}(\Lambda_b \to \Lambda\mu^+\mu^-)\\ &\ldots \end{aligned}$$

Angular distributions



The full angular distribution of the decay $\bar{B}^0 \to \bar{K}^{*0}\ell^+\ell^-$ ($\bar{K}^{*0} \to K^-\pi^+$) is completely described by four independent kinematic variables: q^2 (dilepton invariant mass squared), θ_ℓ, θ_{K^*}, ϕ

Differential decay distribution:

$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_\ell\, d\cos\theta_{K^*}\, d\phi} = \frac{9}{32\pi} J(q^2, \theta_\ell, \theta_{K^*}, \phi)$$

$J(q^2, \theta_\ell, \theta_{K^*}, \phi) = \sum_i J_i(q^2)\, f_i(\theta_\ell, \theta_{K^*}, \phi)$

↘ angular coefficients J_{1-9}

↘ functions of the spin amplitudes A_0, $A_\parallel$, $A_\perp$, A_t, and A_S

Spin amplitudes: functions of Wilson coefficients and form factors

Main operators:

$$\mathcal{O}_9 = \frac{e^2}{(4\pi)^2}(\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu\ell), \quad \mathcal{O}_{10} = \frac{e^2}{(4\pi)^2}(\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu\gamma_5\ell)$$

$$\mathcal{O}_S = \frac{e^2}{16\pi^2}(\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\,\ell), \quad \mathcal{O}_P = \frac{e^2}{16\pi^2}(\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\gamma_5\ell)$$

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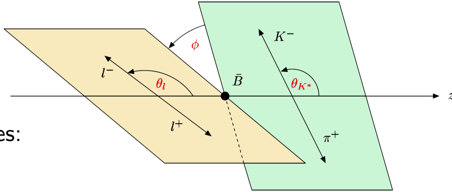

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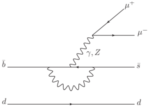
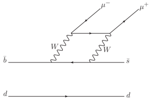




Optimised observables: form factor uncertainties cancel at leading order

$$\langle P_1 \rangle_{\rm bin} = \frac{1}{2} \frac{\int_{\rm bin} dq^2 [J_3 + \bar{J}_3]}{\int_{\rm bin} dq^2 [J_{2s} + \bar{J}_{2s}]} \qquad \langle P_2 \rangle_{\rm bin} = \frac{1}{8} \frac{\int_{\rm bin} dq^2 [J_{6s} + \bar{J}_{6s}]}{\int_{\rm bin} dq^2 [J_{2s} + \bar{J}_{2s}]}$$

$$\langle P'_4 \rangle_{\rm bin} = \frac{1}{\mathcal{N}'_{\rm bin}} \int_{\rm bin} dq^2 [J_4 + \bar{J}_4] \qquad \langle P'_5 \rangle_{\rm bin} = \frac{1}{2\mathcal{N}'_{\rm bin}} \int_{\rm bin} dq^2 [J_5 + \bar{J}_5]$$

$$\langle P'_6 \rangle_{\rm bin} = \frac{-1}{2\mathcal{N}'_{\rm bin}} \int_{\rm bin} dq^2 [J_7 + \bar{J}_7] \qquad \langle P'_8 \rangle_{\rm bin} = \frac{-1}{\mathcal{N}'_{\rm bin}} \int_{\rm bin} dq^2 [J_8 + \bar{J}_8]$$

with

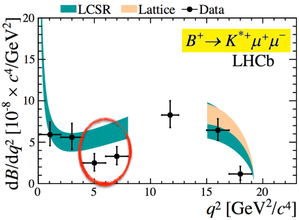
$$\mathcal{N}'_{\rm bin} = \sqrt{- \int_{\rm bin} dq^2 [J_{2s} + \bar{J}_{2s}] \int_{\rm bin} dq^2 [J_{2c} + \bar{J}_{2c}]}$$

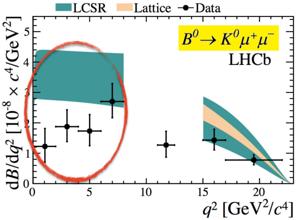
+ CP violating clean observables and other combinations

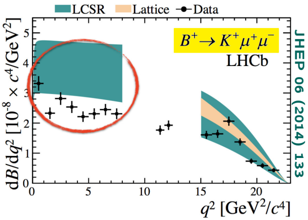
U. Egede et al., JHEP 0811 (2008) 032, JHEP 1010 (2010) 056
J. Matias et al., JHEP 1204 (2012) 104
S. Descotes-Genon et al., JHEP 1305 (2013) 137

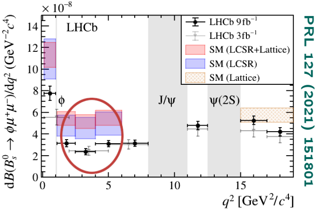
Or alternatively:

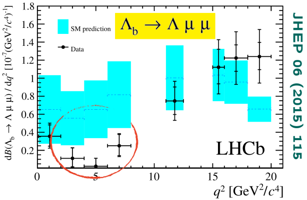
$$S_i = \frac{J_{i(s,c)} + \bar{J}_{i(s,c)}}{\frac{d\Gamma}{dq^2} + \frac{d\bar{\Gamma}}{dq^2}} \,, \qquad P'_{4,5,8} = \frac{S_{4,5,8}}{\sqrt{F_L(1-F_L)}}$$







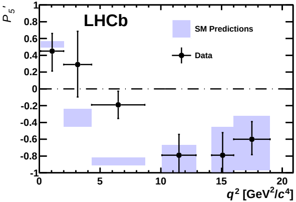




- consistent deviation pattern with the SM predictions
- significance of the deviations between ~ 2 and 3.5 σ
- general trend: EXP $<$ SM in low q^2 regions
- ... but the branching ratios have very large theory uncertainties!

$B^0 \to K^{*0}\mu^+\mu^-$ angular observables, in particular P_5' / S_5

- 2013 (1 fb^{-1}): disagreement with the SM for P_2 and P_5' (PRL 111, 191801 (2013))
- March 2015 (3 fb^{-1}): confirmation of the deviations (LHCb-CONF-2015-002)
- Dec. 2015: 2 analysis methods, both show the deviations (JHEP 1602, 104 (2016))



3.7σ deviation in the 3rd bin

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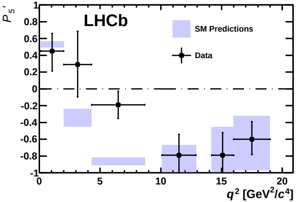

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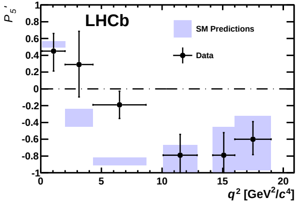

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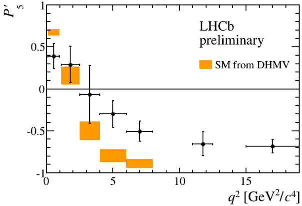

2.9σ in the 4th and 5th bins (3.7σ combined)

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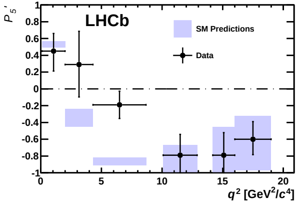

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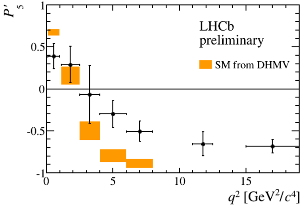

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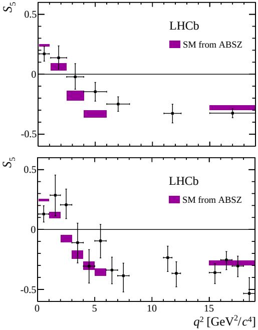

3.4σ combined fit (likelihood)

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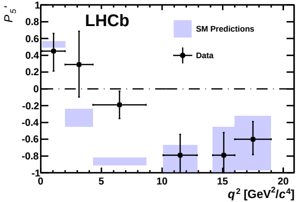

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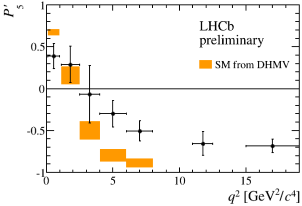

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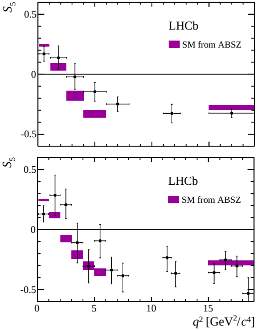
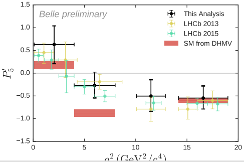


Belle supports LHCb
(arXiv:1604.04042)
tension at 2.1σ



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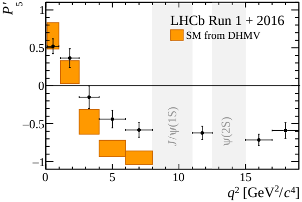
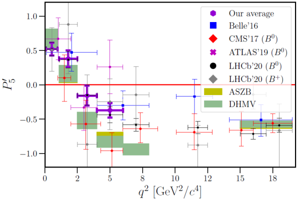
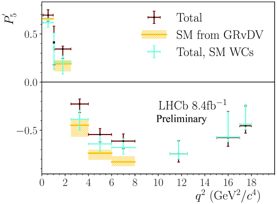
$P_5'(B^0 \to K^{*0}\mu^+\mu^-)$: Current situation



Phys. Rev. Lett. 125, 011802 (2020)



ATLAS-CONF-2017-023
CMS-PAS-BPH-15-008



Moriond QCD 2024

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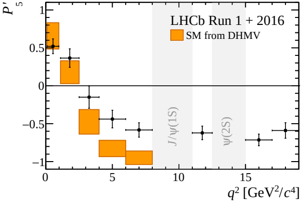

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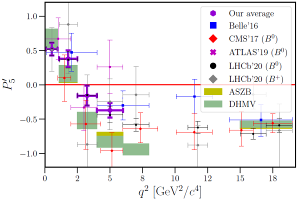

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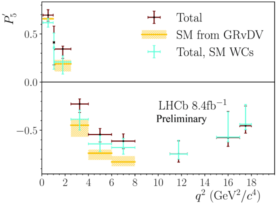
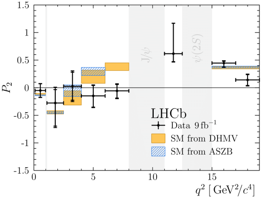
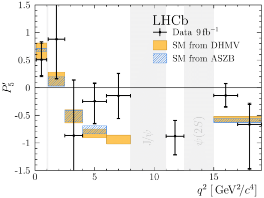


Moriond QCD 2024

First measurement of $B^+ \to K^{*+}\mu^+\mu^-$ angular observables

using the full Run 1 and Run 2 dataset (9 fb^{-1}):





Phys. Rev. Lett. 126, 161802 (2021)

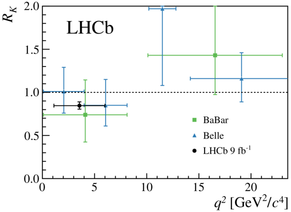
Lepton flavour universality in $B^+ \to K^+ \ell^+ \ell^-$

$$R_K = BR(B^+ \to K^+ \mu^+ \mu^-)/BR(B^+ \to K^+ e^+ e^-)$$

- SM prediction very accurate: $R_K^{\rm SM} = 1.0006 \pm 0.0004$
- March 2021 using 9 fb^{-1}

$$R_K^{\rm exp} = 0.846^{+0.042}_{-0.039}({\rm stat})^{+0.013}_{-0.012}({\rm syst})$$

- **3.1**σ tension in the [1.1-6] GeV^2 bin



Nature Phys. 18 (2022) 3, 277

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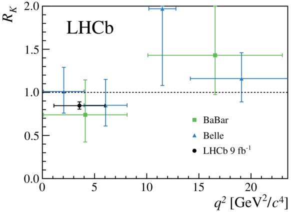

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Lepton flavour universality in $B^0 \to K^{*0} \ell^+ \ell^-$

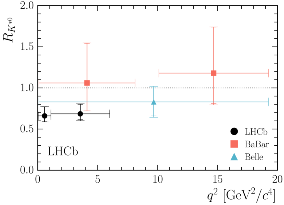
$$R_{K^*} = BR(B^0 \to K^{*0} \mu^+ \mu^-)/BR(B^0 \to K^{*0} e^+ e^-)$$

- LHCb measurement from April 2017 using 3 fb^{-1}
- Two q^2 regions: [0.045-1.1] and [1.1-6.0] GeV^2

$$R_{K^*}^{\rm exp,bin1} = 0.66^{+0.11}_{-0.07}({\rm stat}) \pm 0.03({\rm syst})$$

$$R_{K^*}^{\rm exp,bin2} = 0.69^{+0.11}_{-0.07}({\rm stat}) \pm 0.05({\rm syst})$$

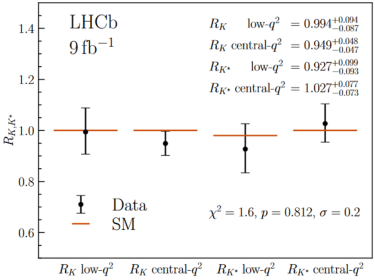
- **2.2-2.5σ** tension in each bin



JHEP 08 (2017) 055

December 2022 update

- LHCb measurement from Dec 2022 using 9 fb^{-1}
- New modelling of residual backgrounds due to misidentified hadronic decays
- Results fully compatible with the SM



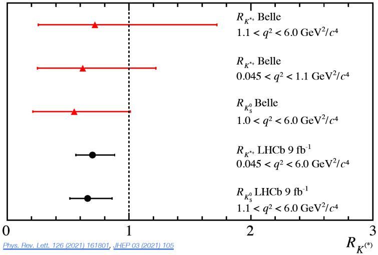
LHCb, PRL 131 (2023) 5, 051803, PRD 108 (2023) 3, 032002

Two other LFU measurements (October 2021) with 9 fb^{-1}:

$B^+ \to K^{*+}\ell^+\ell^-$ and $B^0 \to K^0_S\,\ell^+\ell^-$

$R_{K^{*+}} = 0.70^{+0.18}_{-0.13}(stat)^{+0.03}_{-0.04}(syst)$ and $R_{K^0_S} = 0.66^{+0.20}_{-0.15}(stat)^{+0.02}_{-0.04}(syst)$

Phys.Rev.Lett. 128 (2022) 19, 191802



More measurements to come:

$B^0_s \to \phi\ell^+\ell^-$, $B \to \pi\ell^+\ell^-$, $B \to K\pi^+\pi^-\ell^+\ell^-$, ...

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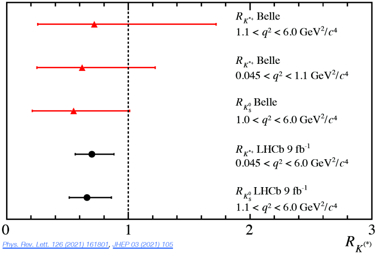

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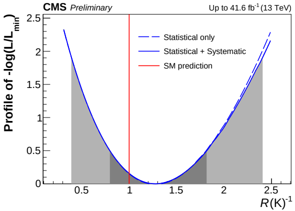
$$B^0_s \to \phi\ell^+\ell^-,\ B \to \pi\ell^+\ell^-,\ B \to K\pi^+\pi^-\ell^+\ell^-, \ldots$$

First R_K measurement by CMS:

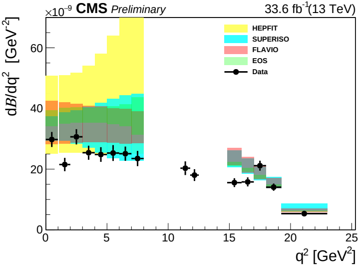
CMS, 2401.07090



$$R_K = 0.78^{+0.46}_{-0.23}(\mathrm{stat})^{+0.09}_{-0.05}(\mathrm{syst})$$

Uncertainty dominated by the low stats of $B \to Kee$

Differential BR measurement of $B^+ \to K^+\mu^+\mu^-$:

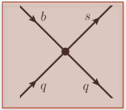


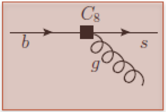
Hadronic effects and theory uncertainties

Theoretical framework

Effective Hamiltonian for $b \to s\ell\ell$ transitions: $\mathcal{H}_{\rm eff} = \mathcal{H}_{\rm eff}^{\rm had} + \mathcal{H}_{\rm eff}^{\rm sl}$

$$\mathcal{H}_{\rm eff}^{\rm had} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[\sum_{i=1\dots6} C_i O_i + C_8 O_8\right]$$



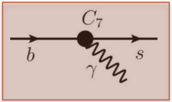


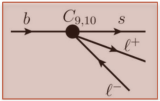
$O_{1,2} \propto (\bar{s}\,\Gamma_m\, c)\,(\bar{c}\,\Gamma_n\, b)$

$O_8 \propto (\bar{s}\,\sigma^{\mu\nu} T^a P_R\, b)\, G^a_{\mu\nu}$

$O_{3-6} \propto (\bar{s}\,\Gamma_m\, b)\,\Sigma_q\,(\bar{q}\,\Gamma_n\, q)$

$$\mathcal{H}_{\rm eff}^{\rm sl} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[\sum_{i=7,9,10} C_i^{(\prime)} O_i^{(\prime)}\right]$$





$$O_7 = \frac{e}{(4\pi)^2} m_b (\bar{s}\sigma^{\mu\nu} P_R b) F_{\mu\nu}$$

$$O_9 = \frac{e^2}{(4\pi)^2} (\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \ell)$$

$$O_{10} = \frac{e^2}{(4\pi)^2} (\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \gamma_5 \ell)$$

+ chirality flipped operators (O_i')

Most relevant for (semi-) leptonic decays

Short-distance effects: Wilson coefficients $C_i(\mu)$

- o Calculated perturbatively up to NNLL
- o Contain all the contributions from scales $> \mu$

Long-distance effects: matrix elements of operators $\langle O_i \rangle$:

- o Require non-perturbative methods
- o Introduce the main theoretical uncertainties

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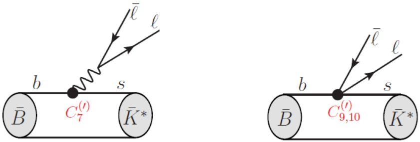
$\langle \bar{K}^* \ell^+ \ell^- | H_{\rm eff}^{\rm sl} | \bar{B} \rangle$:



⇒ $B \to K^*$ form factors $V, A_{0,1,2}, T_{1,2,3}$ or alternatively $\tilde{V}_\lambda, \tilde{T}_\lambda, \tilde{S}$ (λ = helicity of K^*)

Helicity amplitudes:

$$H_V(\lambda) \approx -i\, N' \Big\{ (C_9 - C_9') \tilde{V}_\lambda(q^2) + \frac{m_B^2}{q^2} \Big[\frac{2\,\hat{m}_b}{m_B} (C_7^{\rm eff} - C_7') \tilde{T}_\lambda(q^2) \Big] \Big\}$$

$$H_A(\lambda) = -i\, N' (C_{10} - C_{10}') \tilde{V}_\lambda(q^2)$$

$$H_P = i\, N' \Big\{ \frac{2\, m_\ell \hat{m}_b}{q^2} (C_{10} - C_{10}') \Big(1 + \frac{m_s}{m_b} \Big) \tilde{S}(q^2) \Big\}$$

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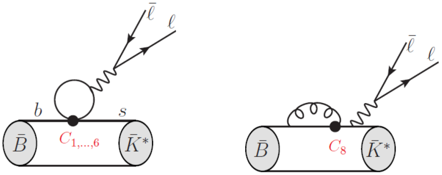

$H_{\rm eff}^{\rm had}$ contributes to $b \to s\bar{\ell}\ell$ through virtual photon exchange $\Rightarrow$ affect only the $H_V(\lambda)$

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$$H_A(\lambda) = -i\,N'(C_{10} - C_{10}')\tilde{V}_\lambda(q^2)$$

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$$\langle \bar{K}^* \ell^+ \ell^- \big| H_{\rm eff}^{\rm had} \big| \bar{B} \rangle: \; \mathcal{A}_\lambda^{\rm (had)} = -\, i \frac{e^2}{q^2} \int d^4x e^{-iq\cdot x} \langle \ell^+ \ell^- | j_\mu^{\rm em,lept}(x) | 0 \rangle \times \int d^4y \, e^{iq\cdot y} \langle \bar{K}_\lambda^* | T\{ j^{\rm em,had,\mu}(y) \mathcal{H}_{\rm eff}^{\rm had}(0) \} | \bar{B} \rangle$$

In general "naïve" factorization not applicable

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$$\longrightarrow \frac{e^2}{q^2}\epsilon_\mu L_V^\mu \Big[\underbrace{Y(q^2)\tilde{V}_\lambda}_{\text{fact., perturbative}} + \underbrace{\text{LO in } \mathcal{O}(\frac{\Lambda}{m_b}, \frac{\Lambda}{E_{K^*}})}_{\text{non-fact., QCDf}} + \underbrace{h_\lambda(q^2)}_{\text{power corrections, unknown}} \Big]$$

$$\left(C_9^{\rm eff} \equiv C_9 + Y(q^2)\right)$$

Helicity amplitudes:

$$H_V(\lambda) = -i\,N'\Big\{(C_9^{\rm eff} - C_9')\tilde{V}_\lambda(q^2) + \frac{m_B^2}{q^2}\Big[\frac{2\,\hat{m}_b}{m_B}(C_7^{\rm eff} - C_7')\tilde{T}_\lambda(q^2) - 16\pi^2\mathcal{N}_\lambda(q^2)\Big]\Big\}$$

$$H_A(\lambda) = -i\,N'(C_{10} - C_{10}')\tilde{V}_\lambda(q^2)$$

$$H_P = i\,N'\Big\{\frac{2\,m_\ell\hat{m}_b}{q^2}(C_{10} - C_{10}')\Big(1 + \frac{m_s}{m_b}\Big)\tilde{S}(q^2)\Big\}$$

Local form factors

- **At high q^2**: computed on the lattice

  In particular for: $B \to K(^*)$ and $B_s \to \phi$

  - HPQCD (2013/2023)
  - FNAL/MILC (2015)
  - Horgan et al. (2015)
  - HPQCD (2023)

- **At low q^2**: (mostly) Light-Cone Sum Rule (LCSR)

  $\to$ Challenging systematic uncertainties

  - Bharucha, Straub and Zwicky, 1503.05534
  - Khodjamirian/Rusov, 1703.04765
  - Gubernari, Kokulu and van Dyk, 1811.00983
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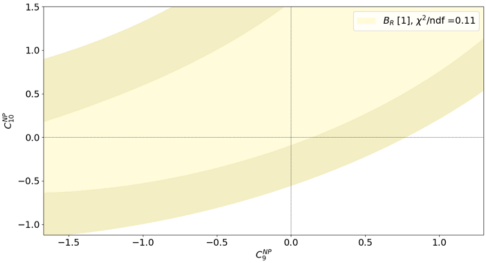
Fit to $B \to K^* \mu\mu$ branching ratios at low q^2



→ Large sensitivity to local form factors

→ Significant impacts on the fits!

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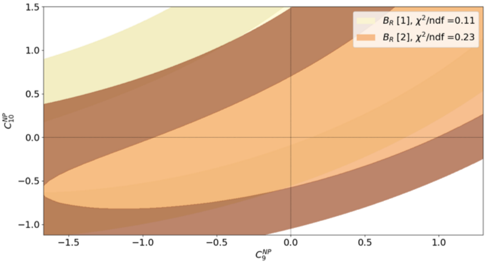

→ Large sensitivity to local form factors

→ Significant impacts on the fits!

Many observables $\rightarrow$ **Global fits** of the $bs\ell\ell$ data

Relevant $\mathcal{O}$perators:

$$\mathcal{O}_7,\ \mathcal{O}_8,\ \mathcal{O}_{9\mu,e}^{(\prime)},\ \mathcal{O}_{10\mu,e}^{(\prime)} \quad \text{and} \quad \mathcal{O}_{(S,P)} \propto (\bar{s}_L b_R)(\bar{\ell}(1,\gamma_5)\ell)$$

NP manifests itself in the shifts of the individual coefficients with respect to the SM values:

$$C_i(\mu) = C_i^{\rm SM}(\mu) + \delta C_i$$

$\rightarrow$ Scans over the values of δC_i

$\rightarrow$ Calculation of flavour observables

$\rightarrow$ Comparison with experimental results

$\rightarrow$ Constraints on the Wilson coefficients C_i

Theoretical uncertainties and correlations

- Monte Carlo analysis
- variation of the "standard" input parameters: masses, scales, CKM, ...
- decay constants taken from the latest lattice results
- $B \to K^{(*)}$ and $B_s \to \phi$ form factors are obtained from the lattice+LCSR combinations, including all the correlations
- Parameterisation of uncertainties from power corrections:

$$A_k \to A_k \left(1 + a_k \exp(i\phi_k) + \frac{q^2}{6\ \mathrm{GeV}^2} b_k \exp(i\theta_k)\right)$$

$|a_k|$ between 10 to 60%, $b_k \sim 2.5 a_k$
Low recoil: $b_k = 0$

$\Rightarrow$ Computation of a (theory + exp) correlation matrix

Global fits of the observables obtained by minimisation of

$$\chi^2 = \left(\vec{O}^{\rm th} - \vec{O}^{\rm exp}\right) \cdot (\Sigma_{\rm th} + \Sigma_{\rm exp})^{-1} \cdot \left(\vec{O}^{\rm th} - \vec{O}^{\rm exp}\right)$$

$(\Sigma_{\rm th} + \Sigma_{\rm exp})^{-1}$ is the inverse covariance matrix.

173 observables relevant for leptonic and semileptonic decays:

- $\mathrm{BR}(B \to X_s \gamma)$
- $\mathrm{BR}(B \to X_d \gamma)$
- $\mathrm{BR}(B \to K^* \gamma)$
- $\Delta_0(B \to K^* \gamma)$
- $\mathrm{BR}^{\rm low}(B \to X_s \mu^+\mu^-)$
- $\mathrm{BR}^{\rm high}(B \to X_s \mu^+\mu^-)$
- $\mathrm{BR}^{\rm low}(B \to X_s e^+e^-)$
- $\mathrm{BR}^{\rm high}(B \to X_s e^+e^-)$
- $\mathrm{BR}(B_s \to \mu^+\mu^-)$
- $\mathrm{BR}(B_s \to e^+e^-)$
- $\mathrm{BR}(B_d \to \mu^+\mu^-)$
- R_K in the low q^2 bin
- R_{K^*} in 2 low q^2 bins
- $\mathrm{BR}(B \to K^0\mu^+\mu^-)$
- $\mathrm{BR}(B \to K^+\mu^+\mu^-)$
- $\mathrm{BR}(B \to K^* e^+e^-)$
- $B \to K^{*0}\mu^+\mu^-$: BR, F_L, A_{FB}, S_3, S_4, S_5, S_7, S_8, S_9 in 8 low q^2 and 4 high q^2 bins
- $B^+ \to K^{*+}\mu^+\mu^-$: BR, F_L, A_{FB}, S_3, S_4, S_5, S_7, S_8, S_9 in 5 low q^2 and 2 high q^2 bins
- $B_s \to \phi\mu^+\mu^-$: BR, F_L, S_3, S_4, S_7 in 3 low q^2 and 2 high q^2 bins
- $\Lambda_b \to \Lambda\mu^+\mu^-$: BR, A_{FB}^{ℓ}, A_{FB}^{h}, $A_{FB}^{\ell h}$, F_L in the high q^2 bin

Computations performed using **SuperIso** public program

Comparison of one-operator NP fits:

Fit to only LFUV ratios and $B_{s,d} \to \ell^+\ell^-$

pre-$R_{K^{(*)}}$ update ($\chi^2_{\rm SM} = 30.63$)			
	b.f. value	$\chi^2_{\rm min}$	${\rm Pull}_{\rm SM}$
δC_9^e	0.83 ± 0.21	10.8	4.4σ
δC_9^μ	-0.80 ± 0.21	11.8	4.3σ
δC_{10}^e	-0.81 ± 0.19	8.7	4.7σ
δC_{10}^μ	0.50 ± 0.14	16.2	3.8σ
$\delta C_{\rm LL}^e$	0.43 ± 0.11	9.7	4.6σ
$\delta C_{\rm LL}^\mu$	-0.33 ± 0.08	12.4	4.3σ

post-$R_{K^{(*)}}$ update ($\chi^2_{\rm SM} = 9.37$)			
	b.f. value	$\chi^2_{\rm min}$	${\rm Pull}_{\rm SM}$
δC_9^e	0.17 ± 0.16	8.2	1.1σ
δC_9^μ	-0.18 ± 0.16	8.1	1.1σ
δC_{10}^e	-0.15 ± 0.14	8.3	1.1σ
δC_{10}^μ	0.15 ± 0.12	7.7	1.3σ
$\delta C_{\rm LL}^e$	0.08 ± 0.08	8.2	1.1σ
$\delta C_{\rm LL}^\mu$	-0.09 ± 0.07	7.7	1.3σ

$\delta C_{\rm LL}^\ell$ basis corresponds to $\delta C_9^\ell = -\delta C_{10}^\ell$.

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Comparison of one-operator NP fits:

Fit to **all** observables

post-$R_{K^{(*)}}$ update ($\chi^2_{\rm SM} = 271.0$)			
	b.f. value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
δC_7	-0.02 ± 0.01	267.2	1.9σ
δC_{Q_1}	-0.04 ± 0.03	270.3	0.8σ
δC_{Q_2}	-0.01 ± 0.01	270.4	0.8σ
δC_9	-0.96 ± 0.13	230.7	6.3σ
δC_{10}	0.15 ± 0.15	270.0	1.0σ

With the assumption of 10% power corrections

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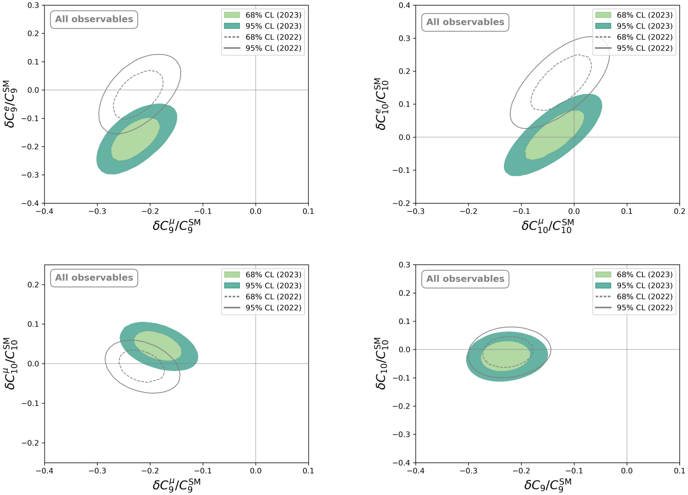
Two operator fits to to all observables



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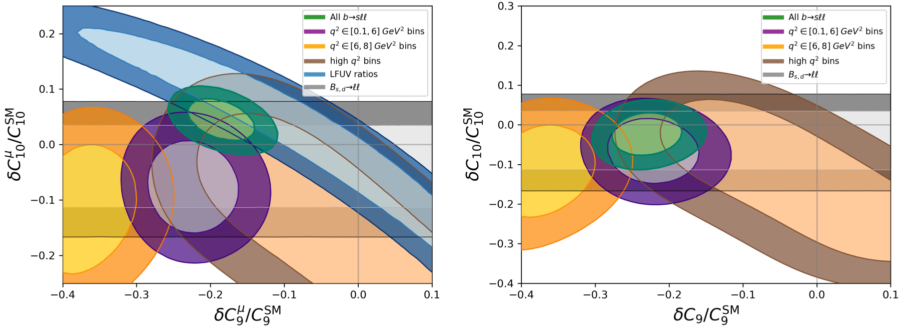
Impact of different sets of observables:



With the assumption of 10% power corrections

T. Hurth, FM, S. Neshatpour, PRD 108 (2023) 11, 115037

Conclusion

- Several persisting deviations from the SM predictions in $b \to s\ell\ell$ transitions since 2013
- C_9 continues to be the Wilson coeffcient which can include most of the NP effects
- LFUV components are mostly suppressed

New Physics or Not New Physics?

- More work is needed to assess the hadronic uncertainties
- The measurement of the electron modes will be very important
- Cross-check with other ratios, and also inclusive modes will be very useful

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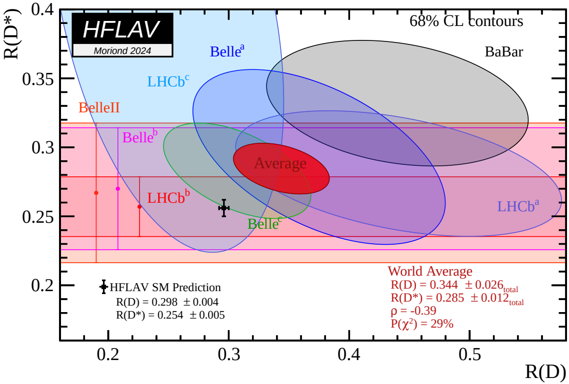
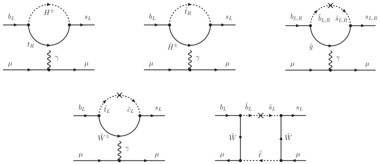
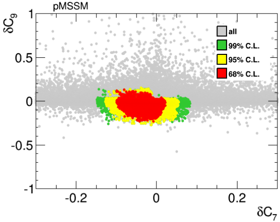
Backup


HFLAV
Moriond 2024
68% CL contours
BaBar
Belle[a]
LHCb[c]
BelleII
Belle[b]
Average
LHCb[b]
Belle[c]
LHCb[a]
HFLAV SM Prediction
R(D) = 0.298 ± 0.004
R(D*) = 0.254 ± 0.005
World Average
R(D) = 0.344 ± 0.026 total
R(D*) = 0.285 ± 0.012 total
ρ = -0.39
P(χ2) = 29%
R(D*)
R(D)
0.4
0.35
0.3
0.25
0.2
0.2
0.3
0.4
0.5

Contributions to C_9 can come from Z and photon penguins, and box diagrams

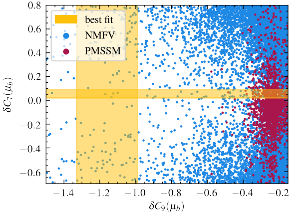


PMSSM:



FM, S. Neshatpour, J. Virto, Eur. Phys. J. C74 (2014) no.6, 2927

PMSSM with non-minimal flavour violation:



M.A. Boussejra, FM, G. Uhlrich, arXiv:2201.04659