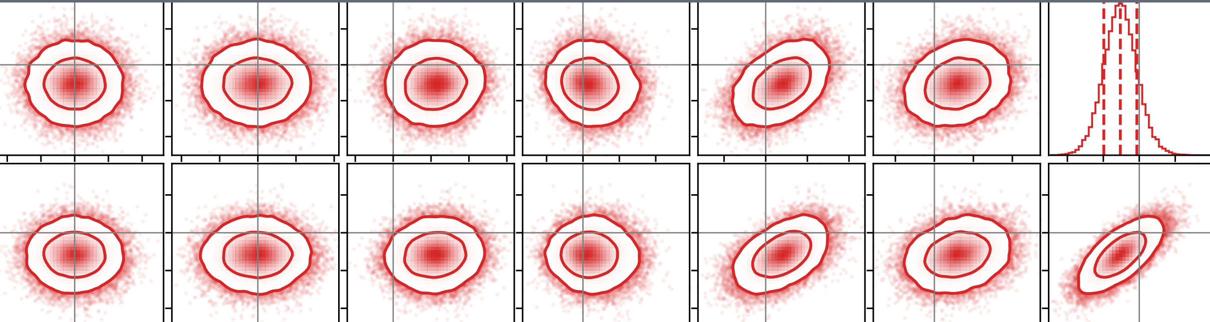
Flavourful Opportunities in Semileptonic B Decays: Connecting Theory and Experiment, MITP, 7 July 2026

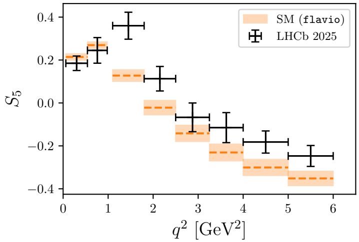
Updates on $b \to s\ell\ell$ global fits

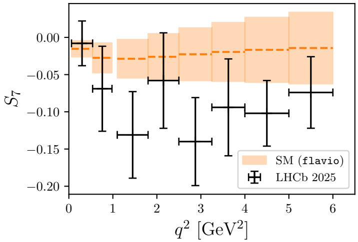
Peter Stangl Johannes Gutenberg University Mainz

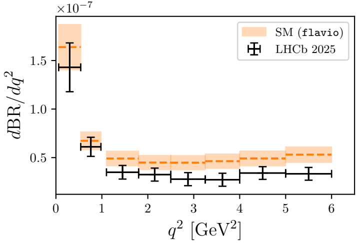


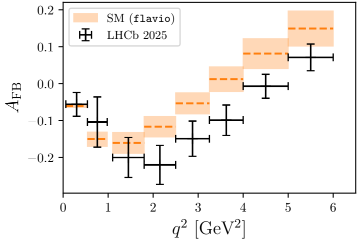
Updated LHCb analysis on $B \to K^* \mu^+ \mu^-$

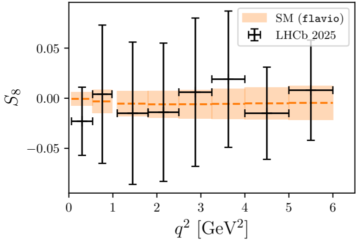
LHCb, arXiv:2512.18053











$b \to s\ell\ell$ Theory Framework

$b \to s\ell\ell$ in the Weak Effective Theory

- Effective Hamiltonian at scale m_b: $\mathcal{H}_{\text{eff}}^{bs\ell\ell} = \mathcal{H}_{\text{eff, sl}}^{bs\ell\ell} + \mathcal{H}_{\text{eff, had}}^{bs\ell\ell}$
- **Semileptonic operators**: ($\mathcal{N} = \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \approx (34\text{ TeV})^{-2}$)

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

$$\begin{aligned}
O_9^{(\prime)bs\ell\ell} &= (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{\ell}\gamma^\mu \ell)\,, & C_9^{\text{SM}} &\approx -4.1\\
O_{10}^{(\prime)bs\ell\ell} &= (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,, & C_{10}^{\text{SM}} &\approx +4.2\\
O_7^{(\prime)bs} &= \frac{m_b}{e}(\bar{s}\sigma_{\mu\nu} P_{R(L)} b)\, F^{\mu\nu}\,, & C_7^{\text{SM}} &\approx -0.3\\
O_S^{(\prime)bs\ell\ell} &= m_b(\bar{s} P_{R(L)} b)(\bar{\ell}\ell)\,,\\
O_P^{(\prime)bs\ell\ell} &= m_b(\bar{s} P_{R(L)} b)(\bar{\ell}\gamma_5\ell)\,.
\end{aligned}$$

- **Hadronic operators**:

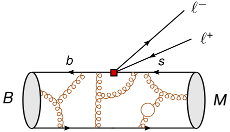
$$\mathcal{H}_{\text{eff, had}}^{bs\ell\ell} = -\mathcal{N}\frac{16\pi^2}{e^2}\left(C_8^{bs} O_8^{bs} + C_8^{\prime bs} O_8^{\prime bs} + \sum_{i=1..6} C_i^{bs\ell\ell} O_i^{bs}\right) + \text{h.c.}$$

$$\text{e.g.} \quad O_1^{bs} = (\bar{s}\gamma_\mu P_L T^a c)(\bar{c}\gamma^\mu P_L T^a b)\,, \quad O_2^{bs} = (\bar{s}\gamma_\mu P_L c)(\bar{c}\gamma^\mu P_L b)\,.$$

Theory of $B \to M\ell\ell$ decays ($M = K, K^*, \phi$)

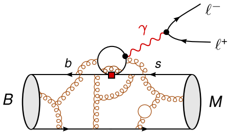
$$\mathcal{M}(B \to M\ell\ell) = \langle M\ell\ell|\mathcal{H}_{\text{eff}}^{bs\ell\ell}|B\rangle = \mathcal{N}\Big[\left(\mathcal{A}_V^\mu + \mathcal{H}^\mu\right)\bar{u}_\ell\gamma_\mu v_\ell + \mathcal{A}_A^\mu\,\bar{u}_\ell\gamma_\mu\gamma_5 v_\ell + \mathcal{A}_S\,\bar{u}_\ell v_\ell + \mathcal{A}_P\,\bar{u}_\ell\gamma_5 v_\ell\Big]$$

Local:



$$\mathcal{A}_V^\mu = -\frac{2im_b}{q^2}\,C_7\langle M|\bar{s}\,\sigma^{\mu\nu}q_\nu\,P_R\,b|B\rangle + C_9\langle M|\bar{s}\,\gamma^\mu\,P_L\,b|B\rangle$$
$$+\,(P_L \leftrightarrow P_R, C_i \to C_i')$$
$$\mathcal{A}_A^\mu = C_{10}\langle M|\bar{s}\,\gamma^\mu\,P_L\,b|B\rangle + (P_L \leftrightarrow P_R, C_i \to C_i')$$
$$\mathcal{A}_{S,P} = C_{S,P}\langle M|\bar{s}\,P_R\,b|B\rangle + (P_L \leftrightarrow P_R, C_i \to C_i')$$

Non-Local:

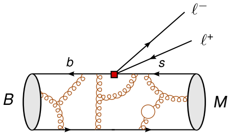


$$\mathcal{H}^\mu = \frac{-16i\pi^2}{q^2}\sum_{i=1..6,8} C_i\int dx^4 e^{iq\cdot x}\langle M|T\{j^\mu_{\text{em}}(x), O_i(0)\}|B\rangle$$

$$j^\mu_{\text{em}} = \sum_q Q_q\,\bar{q}\gamma^\mu q$$

- **Wilson coefficients $C_i = C_i^{\text{SM}} + C_i^{\text{NP}}$**:
  perturbative, short-distance (q^2-independent), parameterize heavy new physics
- local and non-local **hadronic matrix elements**:
  non-perturbative, long-distance (q^2-dependent), **main source of uncertainty**

Local matrix elements



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- Matrix elements $\langle M|\bar{s}\,\Gamma_i\, b|B\rangle$ can be parameterized by:
  - **3 form factors** for each **spin zero** final state, $M = \boldsymbol{K}$
  - **7 form factors** for each **spin one** final state, $M = \boldsymbol{K^*}, \phi$

- Determination of form factors
  - high q^2: **Lattice QCD**

    HPQCD, arXiv:2207.12468
    Fermilab, MILC, arXiv:1509.06235
    Horgan, Liu, Meinel, Wingate, arXiv:1310.3722, arXiv:1501.00367

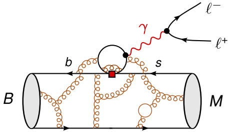
  - low q^2: **Light-cone sum rules** (LCSR)

    Bharucha, Straub, Zwicky, arXiv:1503.05534
    Khodjamirian, Mannel, Pivovarov, Wang, arXiv:1006.4945
    Gubernari, Kokulu, van Dyk, arXiv:1811.00983
    Ball, Zwicky, arXiv:hep-ph/0406232

  - low + high q^2: Combined fit **LCSR + lattice**

    Bharucha, Straub, Zwicky, arXiv:1503.05534
    Gubernari, Reboud, van Dyk, Virto, arXiv:2305.06301
    Altmannshofer, Straub, arXiv:1411.3161

Non-local matrix elements



$$\mathcal{H}^\mu = \frac{-16 i \pi^2}{q^2} \sum_{i=1..6,8} C_i \int dx^4 e^{iq\cdot x} \langle M | T\{ j^\mu_{\rm em}(x), O_i(0)\} | B \rangle$$

$$j^\mu_{\rm em} = \sum_q Q_q \, \bar{q} \gamma^\mu q$$

- Contributions at low q^2 from QCD factorization (QCDF) — Beneke, Feldmann, Seidel, arXiv:hep-ph/0106067
- **Beyond-QCDF** contributions **the main source of uncertainty**
- Non-local contributions can mimic New Physics in C_9
- Several approaches to estimate beyond-QCDF contributions at low q^2
  - fit of sum of resonances to data — Blake, Egede, Owen, Pomery, Petridis, arXiv:1709.03921
  - direct fit to angular data — Ciuchini, Fedele, Franco, Mishima, Paul, Silvestrini, Valli, arXiv:1512.07157
  - Light-Cone Sum Rules estimates — Khodjamirian, Mannel, Pivovarov, Wang, arXiv:1006.4945; Gubernari, van Dyk, Virto, arXiv:2011.09813
  - analyticity + experimental data on $b \to s c \bar{c}$ — Bobeth, Chrzaszcz, van Dyk, Virto, arXiv:1707.07305; Gubernari, van Dyk, Virto, arXiv:2011.09813; Gubernari, Reboud, van Dyk, Virto, arXiv:2206.03797

Beyond-QCDF contributions: Light-Cone Sum Rules at $q^2 < 0$

- first estimate of **non-factorizable soft-gluon emission** from charm loop

  $\Rightarrow \Delta C_9(q^2) \sim 5 - 20\%\ C_9^{\mathrm{SM}}$ (depending on channel and q^2) Khodjamirian, Mannel, Pivovarov, Wang, arXiv:1006.4945

- reanalysis with **complete basis of three-particle *B*-meson LCDAs** up to twist four

  $\Rightarrow$ result **two orders of magnitude smaller** (strong cancellations and updated inputs)

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  Dominant contribution from **gluon on different light-cone?** Qin, Shen, Wang, Wang, arXiv:2207.02691
  Melikhov, arXiv:2208.04907, arXiv:2302.13673
  Piscopo, Rusov, arXiv:2307.07594

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  Piscopo, Rusov, arXiv:2307.07594

see talk by **Max Ferré** on **B-meson di-light-cone distribution amplitudes** on Thursday [arXiv:2606.20267]

Large Hadronic Effects in $B \to K^{*}\mu\mu$?

Based on Altmannshofer, Christensen, PS, arXiv:2603.27753

Parameterization of non-local effects in $B \to K^* \mu\mu$

- Helicity amplitudes (K^* meson helicity $\lambda \in \{+, -, 0\}$)

$$H_V^\lambda \propto C_9 \tilde{V}_{L\,\lambda} + C_9' \tilde{V}_{R\,\lambda} + \frac{2m_b m_B}{q^2}\left(C_7 \tilde{T}_{L\,\lambda} + C_7' \tilde{T}_{R\,\lambda}\right) - \frac{m_B^2}{q^2} 16\pi^2 h_\lambda(q^2)\,,$$

$$H_A^\lambda \propto C_{10} \tilde{V}_{L\,\lambda} + C_{10}' \tilde{V}_{R\,\lambda}\,,$$

  - $\tilde{V}_{L\,\lambda}$, $\tilde{V}_{R\,\lambda}$, $\tilde{T}_{L\,\lambda}$, $\tilde{T}_{R\,\lambda}$ q^2-dependent local helicity form factors
  - $h_\lambda(q^2)$ functions parameterizing all non-local effects

- Beyond-QCDF contributions:

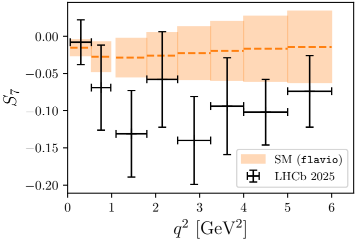
$$\begin{aligned}
\Delta h_0(q^2) &= -\frac{1}{16\pi^2}\left(a_0 + b_0 \frac{q^2}{m_B^2} + \ldots\right)\tilde{T}_{L\,0}\,,\\
\Delta h_-(q^2) &= -\frac{1}{16\pi^2}\left(a_- + b_- \frac{q^2}{m_B^2} + \ldots\right)\tilde{T}_{L\,-}\,,\\
\Delta h_+(q^2) &= -\frac{1}{16\pi^2}\left(a_+ + b_+ \frac{q^2}{m_B^2} + \ldots\right)\tilde{T}_{R\,+}\,,
\end{aligned}$$

Approximate expressions in heavy quark limit

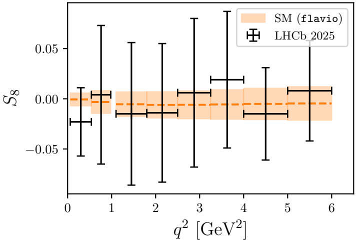
- Helicity form factors expressed by $\xi_\perp(q^2) = \frac{\xi_\perp(0)}{(1-q^2/m_B^2)^2}$, $\xi_\parallel(q^2) = \frac{\xi_\parallel(0)}{(1-q^2/m_B^2)^3}$.
- Helicity amplitudes including beyond-QCDF shifts $a_{0,\pm}$, $b_{0,\pm}$

$$
\begin{aligned}
H_V^0 &\propto -\frac{m_B^2}{4m_{K^*}\sqrt{q^2}}\left(\frac{2m_b}{m_B}(C_7 - C_7') + C_9 - C_9' + a_0 + b_0\frac{q^2}{m_B^2}\right)\frac{\xi_\parallel(0)}{1-q^2/m_B^2} \,, \\
H_V^- &\propto -\left(\frac{m_B^2}{q^2}\left(\frac{2m_b}{m_B}C_7 + a_-\right) + C_9 + b_-\right)\frac{\xi_\perp(0)}{1-q^2/m_B^2} \,, \\
H_V^+ &\propto \left(\frac{m_B^2}{q^2}\left(\frac{2m_b}{m_B}C_7' + a_+\right) + C_9' + b_+\right)\frac{\xi_\perp(0)}{1-q^2/m_B^2} \,, \\
H_A^0 &\propto -\frac{m_B^2}{4m_{K^*}\sqrt{q^2}}(C_{10} - C_{10}')\frac{\xi_\parallel(0)}{1-q^2/m_B^2} \\
H_A^- &\propto -C_{10}\frac{\xi_\perp(0)}{1-q^2/m_B^2} \,, \\
H_A^+ &\propto C_{10}'\frac{\xi_\perp(0)}{1-q^2/m_B^2} \,.
\end{aligned}
$$

Approximate expressions in heavy quark limit – angular obs. S_7 and S_8

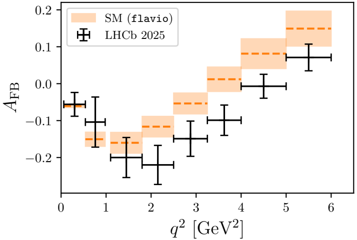


$$S_7^{\rm SM}(q^2) \simeq 1.46\left(\mathrm{Im}\,a_- - \mathrm{Im}\,a_+\right)\frac{\rm GeV}{\sqrt{q^2}} + 0.05\left(\mathrm{Im}\,b_- - \mathrm{Im}\,b_+ - \mathrm{Im}\,a_0\right)\frac{\sqrt{q^2}}{\rm GeV} + 0.002\,\mathrm{Im}\,b_0\,\frac{q^2\sqrt{q^2}}{\rm GeV^3}$$

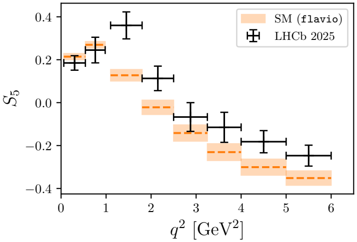


$$S_8^{\rm SM}(q^2) \simeq \left(0.66\left(\mathrm{Im}\,a_- + \mathrm{Im}\,a_+\right) + 0.09\,\mathrm{Im}\,a_0\right)\frac{\rm GeV}{\sqrt{q^2}} + \left(0.02\left(\mathrm{Im}\,b_- + \mathrm{Im}\,b_+\right) - 0.03\,\mathrm{Im}\,a_0 + 0.003\,\mathrm{Im}\,b_0\right)\frac{\sqrt{q^2}}{\rm GeV} - 0.001\,\mathrm{Im}\,b_0\,\frac{q^2\sqrt{q^2}}{\rm GeV^3}$$

Approximate expressions in heavy quark limit – angular obs. A_{FB} and S_5



$$\Delta A_{\mathrm{FB}}^{\mathrm{SM}}(q^2) \simeq 0.86\,\mathrm{Re}\,a_- + 0.10\,\mathrm{Re}\,a_0 + \left(0.03\,\mathrm{Re}\,b_- - 0.03\,\mathrm{Re}\,a_0 + 0.004\,\mathrm{Re}\,b_0\right)\frac{q^2}{\mathrm{GeV}^2} - 0.001\,\mathrm{Re}\,b_0\,\frac{q^4}{\mathrm{GeV}^4}$$



$$\Delta S_5^{\mathrm{SM}}(q^2) \simeq -\left(1.46\left(\mathrm{Re}\,a_- + \mathrm{Re}\,a_+\right) + 0.17\,\mathrm{Re}\,a_0\right)\frac{\mathrm{GeV}}{\sqrt{q^2}} - \left(0.05\left(\mathrm{Re}\,b_- + \mathrm{Re}\,b_+ - \mathrm{Re}\,a_0\right) + 0.006\,\mathrm{Re}\,b_0\right)\frac{\sqrt{q^2}}{\mathrm{GeV}} + 0.002\,\mathrm{Re}\,b_0\,\frac{q^2\sqrt{q^2}}{\mathrm{GeV}^3}$$

Numerical analysis

Numerical analysis – Tools and Setup

- **flavio** `https://flav-io.github.io` Straub, arXiv:1810.08132
  - **Theory predictions**: flavour physics and many other observables (EWPO, Higgs, β-decays, EDMs, DY tails, ...)
  - Database of **measurements**

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  - **Precomputed theory predictions** in terms of polynomials in Wilson coefficients and hadronic parameters
  - Standardised JSON format developed within LHC EFT WG & LHC Higgs WG

Brivio, Mimasu, PS (editors), Biekötter, Cueto Gómez, Knight, Mantani, Rossi, Rossia, Smolkovič, arXiv:2511.17348

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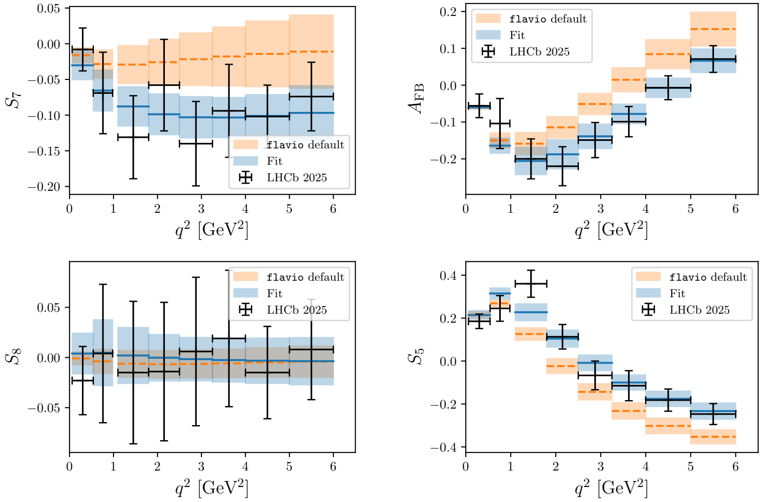
- **jelli** – **J**AX **E**FT **Li**ke**li**hoods `https://github.com/jelli-pheno` Smolkovič, PS, arXiv:2603.15801
  - `flavio` $\longrightarrow$ `POPxf` (export `flavio` predictions into POPxf)
  - Based on `JAX` $\Rightarrow$ Just-In-Time (**JIT**) compilation, **automatic differentiation**
  - **gradient-based** frequentist and Bayesian inference in **large parameter spaces**
  - $\mathcal{O}$(10 s) per point $\longrightarrow$ $\mathcal{O}$(ms) per point

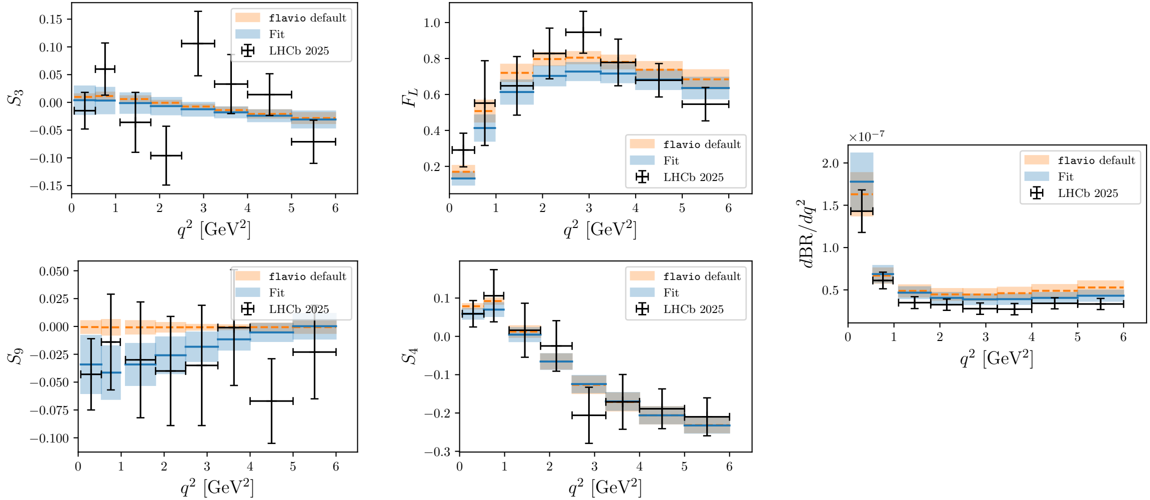
Fit Results – Hadronic Parameters

Mean and Standard Deviation of Posterior Samples

$\mathrm{Re}\, a_0$	-0.77 ± 0.52
$\mathrm{Re}\, b_0$	-2.45 ± 3.59
$\mathrm{Re}\, a_-$	-0.03 ± 0.04
$\mathrm{Re}\, b_-$	-1.04 ± 0.37
$\mathrm{Re}\, a_+$	0.01 ± 0.03
$\mathrm{Re}\, b_+$	0.09 ± 0.70
$\mathrm{Im}\, a_0$	-0.07 ± 0.77
$\mathrm{Im}\, b_0$	-0.38 ± 5.62
$\mathrm{Im}\, a_-$	0.00 ± 0.06
$\mathrm{Im}\, b_-$	-0.58 ± 1.00
$\mathrm{Im}\, a_+$	0.03 ± 0.04
$\mathrm{Im}\, b_+$	0.42 ± 0.76



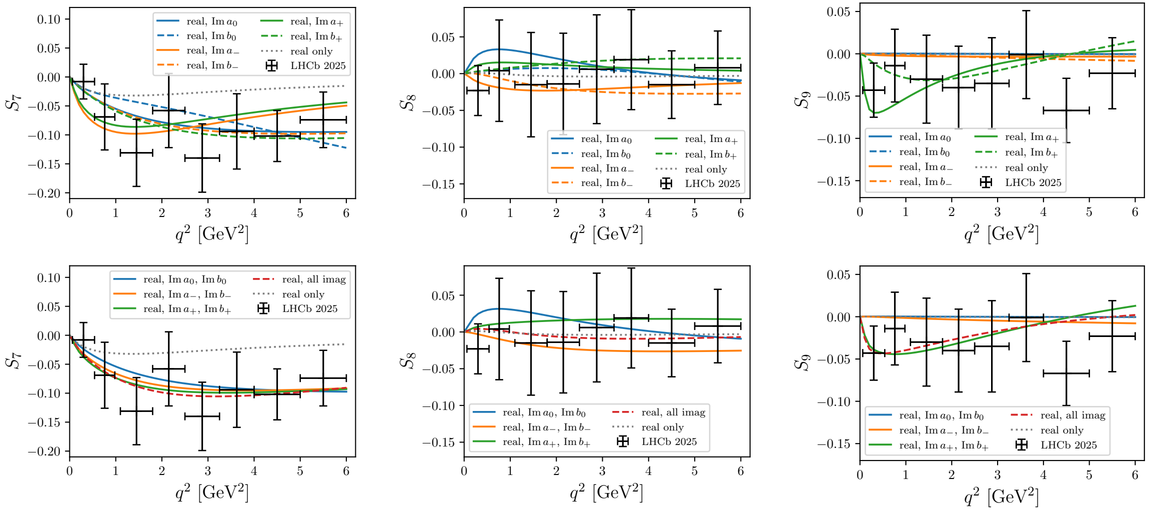
Fit Results – Hadronic Parameters



Fit Results – Imaginary Hadronic Parameters

Scenario	χ^2	$\mathrm{pull}_\mathrm{real}$	N_par	dof	χ^2/dof	p-value
real only	63.6	–	6	66	0.96	0.561
real, $\mathrm{Im}\,a_0$	53.8	$3.1\,\sigma$	7	65	0.83	0.838
real, $\mathrm{Im}\,b_0$	54.7	$3.0\,\sigma$	7	65	0.84	0.814
real, $\mathrm{Im}\,a_-$	54.2	$3.1\,\sigma$	7	65	0.83	0.829
real, $\mathrm{Im}\,b_-$	51.8	$3.4\,\sigma$	7	65	0.80	0.883
real, $\mathrm{Im}\,a_+$	52.7	$3.3\,\sigma$	7	65	0.81	0.863
real, $\mathrm{Im}\,b_+$	50.3	$3.6\,\sigma$	7	65	0.77	0.911
real, $\mathrm{Im}\,a_0$, $\mathrm{Im}\,b_0$	53.8	$2.7\,\sigma$	8	64	0.84	0.815
real, $\mathrm{Im}\,a_-$, $\mathrm{Im}\,b_-$	51.6	$3.0\,\sigma$	8	64	0.81	0.867
real, $\mathrm{Im}\,a_+$, $\mathrm{Im}\,b_+$	49.2	$3.4\,\sigma$	8	64	0.77	0.914
real, all imag	47.8	$2.4\,\sigma$	12	60	0.80	0.871

Fit Results – Imaginary Hadronic Parameters



Probing CP violating New Physics

Constrained and Unconstrained Directions in Parameter Space

- In presence of **New Physics Wilson Coefficient**, the parameters $\mathrm{Re}\, a_0$, $\mathrm{Re}\, b_-$, $\mathrm{Re}\, b_+$, $\mathrm{Re}\, C_9^{\mathrm{NP}}$, $\mathrm{Re}\, C_9'^{\,\mathrm{NP}}$ enter heavy-quark-limit amplitudes **only through the combinations**

$$v_0 = \mathrm{Re}\, a_0 + \mathrm{Re}\, C_9^{\mathrm{NP}} - \mathrm{Re}\, C_9'^{\,\mathrm{NP}} \qquad (H_V^0)$$

$$v_- = \mathrm{Re}\, b_- + \mathrm{Re}\, C_9^{\mathrm{NP}} \qquad (H_V^-)$$

$$v_+ = \mathrm{Re}\, b_+ + \mathrm{Re}\, C_9'^{\,\mathrm{NP}} \qquad (H_V^+)$$

Constrained and Unconstrained Directions in Parameter Space

- In presence of **New Physics Wilson Coefficient**, the parameters $\mathrm{Re}\,a_0$, $\mathrm{Re}\,b_-$, $\mathrm{Re}\,b_+$, $\mathrm{Re}\,C_9^{\mathrm{NP}}$, $\mathrm{Re}\,C_9'^{\,\mathrm{NP}}$ enter heavy-quark-limit amplitudes **only through the combinations**

$$\begin{aligned} v_0 &= \mathrm{Re}\,a_0 + \mathrm{Re}\,C_9^{\mathrm{NP}} - \mathrm{Re}\,C_9'^{\,\mathrm{NP}} && (H_V^0) \\ v_- &= \mathrm{Re}\,b_- + \mathrm{Re}\,C_9^{\mathrm{NP}} && (H_V^-) \\ v_+ &= \mathrm{Re}\,b_+ + \mathrm{Re}\,C_9'^{\,\mathrm{NP}} && (H_V^+) \end{aligned}$$

- Orthogonal directions are **unconstrained**

$$\begin{aligned} u &= \mathrm{Re}\,C_9^{\mathrm{NP}} - \mathrm{Re}\,a_0 - \mathrm{Re}\,b_- \\ u' &= \mathrm{Re}\,C_9'^{\,\mathrm{NP}} + \mathrm{Re}\,a_0 - \mathrm{Re}\,b_+ \end{aligned}$$

Constrained and Unconstrained Directions in Parameter Space

- In presence of **New Physics Wilson Coefficient**, the parameters $\mathrm{Re}\, a_0$, $\mathrm{Re}\, b_-$, $\mathrm{Re}\, b_+$, $\mathrm{Re}\, C_9^{\mathrm{NP}}$, $\mathrm{Re}\, C_9'^{\,\mathrm{NP}}$ enter heavy-quark-limit amplitudes **only through the combinations**

$$\begin{aligned}
v_0 &= \mathrm{Re}\, a_0 + \mathrm{Re}\, C_9^{\mathrm{NP}} - \mathrm{Re}\, C_9'^{\,\mathrm{NP}} && (H_V^0) \\
v_- &= \mathrm{Re}\, b_- + \mathrm{Re}\, C_9^{\mathrm{NP}} && (H_V^-) \\
v_+ &= \mathrm{Re}\, b_+ + \mathrm{Re}\, C_9'^{\,\mathrm{NP}} && (H_V^+)
\end{aligned}$$

- Orthogonal directions are **unconstrained**

$$\begin{aligned}
u &= \mathrm{Re}\, C_9^{\mathrm{NP}} - \mathrm{Re}\, a_0 - \mathrm{Re}\, b_- \\
u' &= \mathrm{Re}\, C_9'^{\,\mathrm{NP}} + \mathrm{Re}\, a_0 - \mathrm{Re}\, b_+
\end{aligned}$$

- Coordinate change to constrained and unconstrained directions

$$\begin{pmatrix} v_0 \\ v_- \\ v_+ \\ u \\ u' \end{pmatrix} = M \begin{pmatrix} \mathrm{Re}\, a_0 \\ \mathrm{Re}\, b_- \\ \mathrm{Re}\, b_+ \\ \mathrm{Re}\, C_9^{\mathrm{NP}} \\ \mathrm{Re}\, C_9'^{\,\mathrm{NP}} \end{pmatrix} \quad \text{with} \quad M = \begin{pmatrix} 1 & 0 & 0 & 1 & -1 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 \\ -1 & -1 & 0 & 1 & 0 \\ 1 & 0 & -1 & 0 & 1 \end{pmatrix}$$

Constrained and Unconstrained Directions in Parameter Space

- Beyond heavy quark limit, determine constrained and unconstrained directions numerically
  - **Sample** all parameters with prior, Gaussian $\mathcal{N}(\mu = 0, \sigma = 10)$
  - Compute sample **covariance matrix**
  - Consider **5 × 5 block** corresponding to $\mathrm{Re}\, a_0$, $\mathrm{Re}\, b_-$, $\mathrm{Re}\, b_+$, $\mathrm{Re}\, C_9^{\mathrm{NP}}$, $\mathrm{Re}\, C_9'^{\mathrm{NP}}$
  - **Eigendecomposition** yields **three small** and **two large** eigenvalues
    $\Rightarrow$ **three constrained** and **two unconstrained** directions
  - Linear comb. of constrained direct. that reduce to hadronic parameters if $\mathrm{Re}\, C_9^{\mathrm{NP}} = \mathrm{Re}\, C_9'^{\mathrm{NP}} = 0$
  - Linear comb. of unconstrained direct. that reduce to Wilson coeff. if hadronic pars are zero

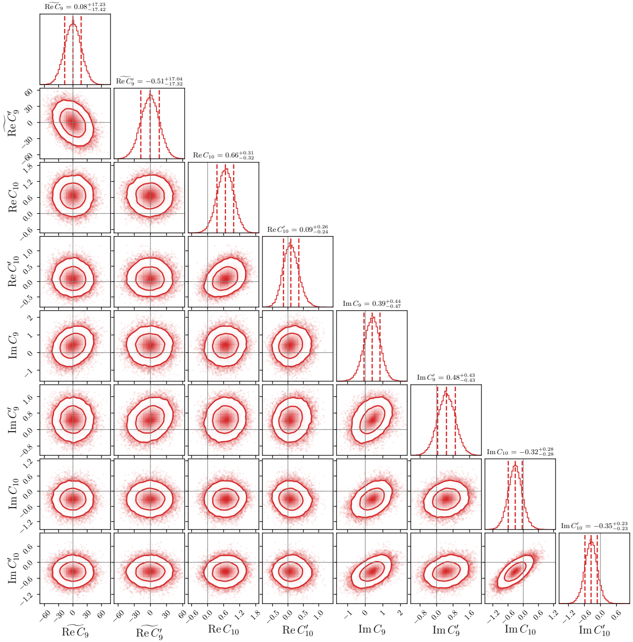
$$\begin{pmatrix} \widetilde{\mathrm{Re}\, a_0} \\ \widetilde{\mathrm{Re}\, b_-} \\ \widetilde{\mathrm{Re}\, b_+} \\ \widetilde{\mathrm{Re}\, C_9^{\mathrm{NP}}} \\ \widetilde{\mathrm{Re}\, C_9'^{\mathrm{NP}}} \end{pmatrix} = \widetilde{M} \begin{pmatrix} \mathrm{Re}\, a_0 \\ \mathrm{Re}\, b_- \\ \mathrm{Re}\, b_+ \\ \mathrm{Re}\, C_9^{\mathrm{NP}} \\ \mathrm{Re}\, C_9'^{\mathrm{NP}} \end{pmatrix} \quad \text{with} \quad \widetilde{M} \approx \begin{pmatrix} 1 & 0 & 0 & 0.93 & -0.93 \\ 0 & 1 & 0 & 1.09 & -0.08 \\ 0 & 0 & 1 & -0.08 & 1.09 \\ -0.93 & -1.09 & 0.08 & 1 & 0 \\ 0.93 & 0.08 & -1.09 & 0 & 1 \end{pmatrix}$$

Results

Combined Sampling of 12 hadronic parameters
8 Wilson coefficients.

Mean and Standard Deviation of Posterior Samples

$\widetilde{\mathrm{Re}\,C_9}$	0.05 ± 17.41
$\widetilde{\mathrm{Re}\,C_9'}$	-0.64 ± 17.21
$\mathrm{Re}\,C_{10}$	0.66 ± 0.31
$\mathrm{Re}\,C_{10}'$	0.10 ± 0.25
$\mathrm{Im}\,C_9$	0.39 ± 0.46
$\mathrm{Im}\,C_9'$	0.48 ± 0.44
$\mathrm{Im}\,C_{10}$	-0.31 ± 0.28
$\mathrm{Im}\,C_{10}'$	-0.35 ± 0.24



Conclusions & Outlook

Conclusions & Outlook

- Large new dataset from LHCb on $B \to K^* \mu\mu$
- Small **downward shift of S_7** angular observable
  $\Rightarrow$ observation of **sizeable S_7** would indicate **sizeable strong phase**
- At low q^2, non-local hadronic effects parameterized by simple polynomial with complex coefficients fit the data very well
- $\sim$ **3 σ pull for imaginary hadronic parameters**
- Sizeable strong phase increases sensitivity to CP violating new physics
- Apart from two flat directions, combined fit of hadronic parameters and Wilson coefficients can **constrain CP violating and conserving new physics**
- Where could a large strong phase come from?
  - Anomalous branch cuts from $D^{(*)}D_s^{(*)}$ rescattering?
  - Complex-valued di-light-cone distribution amplitudes (DLCDAs)?
  - ...?