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

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Based on: 2603.27753 with Sam Christensen and Peter Stangl

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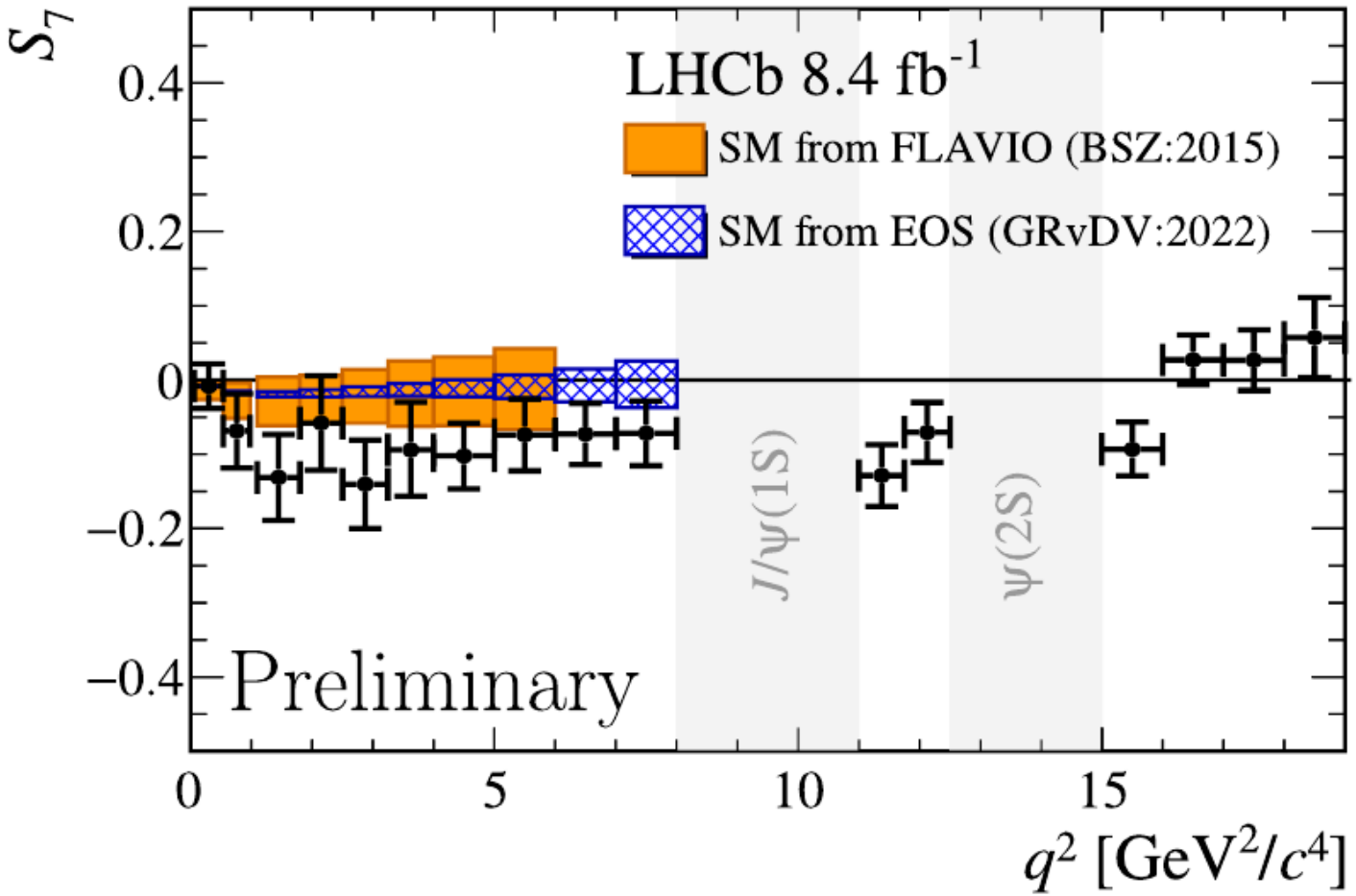
September 9 - 13, 2026

A Recent Result from LHCb

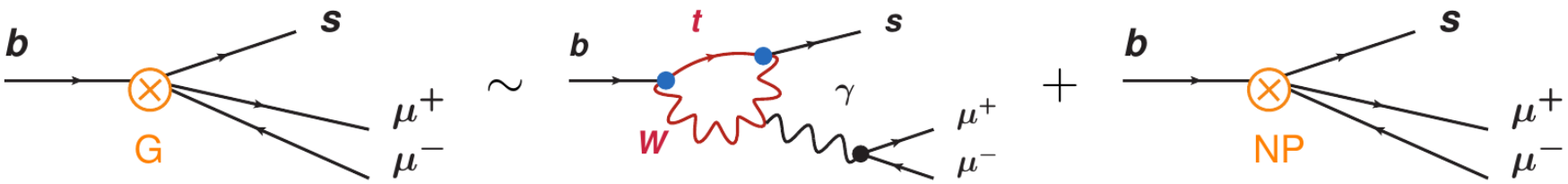
LHCb 2512.18053; LHC seminar by Mark Smith at CERN, Sep. 9, 2025



This talk is about why
I think this result is interesting.

It could be part of a consistent picture
of sizable hadronic effects
in rare $b \to s\ell\ell$ decays
that might be slowly emerging.

New Physics in Rare b Decays



$$G \sim \frac{1}{16\pi^2} \frac{g^4}{m_W^2} \frac{m_t^2}{m_W^2} V_{tb} V_{ts}^* + \frac{C_{NP}}{\Lambda_{NP}^2}$$

measure precisely	calculate precisely the SM contribution	get information on NP coupling and scale

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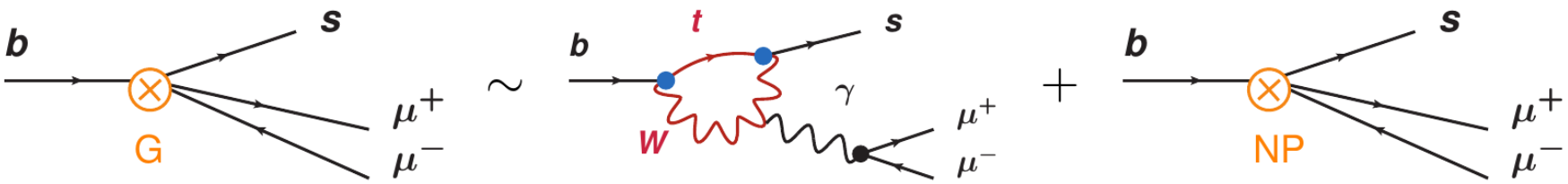

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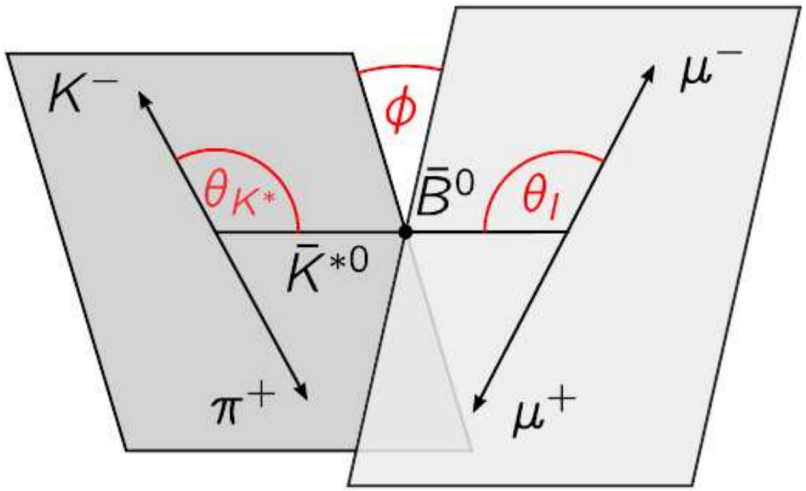
measure precisely	calculate precisely the SM contribution	get information on NP coupling and scale

"Anomalies" in rare b decays could establish
a new scale in particle physics

$$\Lambda_{NP} \sim \frac{4\pi v}{\sqrt{|V_{tb} V_{ts}^*|}} \sim O(10\text{TeV})$$

The $B \to K^*(\to K\pi)\mu^+\mu^-$ Decay

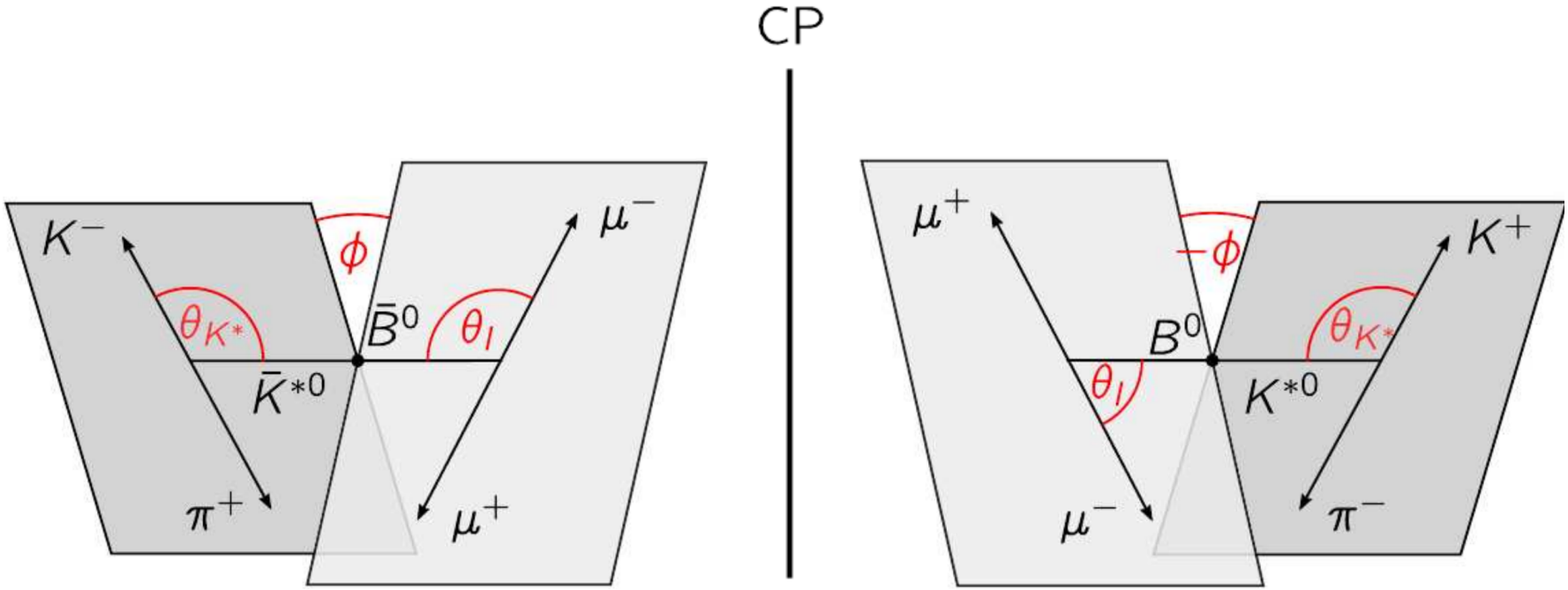


- Kinematics is described by 4 variables.

  Invariant mass squared of the two muons: q^2.
  Three angles: $0 < \theta_{K^*} < \pi$, $0 < \theta_\ell < \pi$, $-\pi < \phi < \pi$.

  $\to$ Many observables accessible from the angular distribution.

The $B \to K^*(\to K\pi)\mu^+\mu^-$ Decay

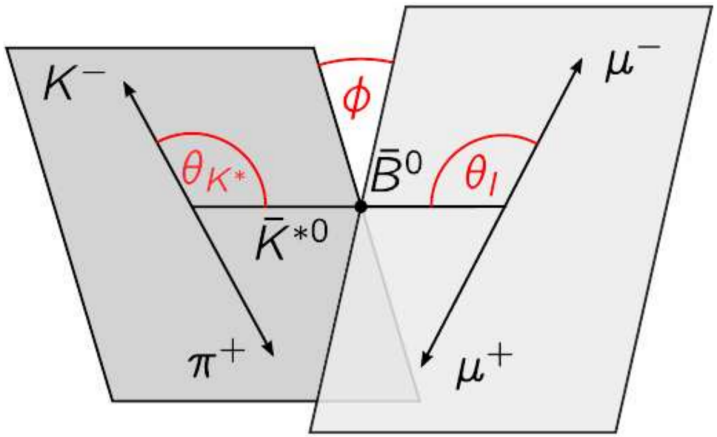


- The decay is self tagging.

  $K^+\pi^-$ final state for B^0.
  $K^-\pi^+$ final state for $\bar{B}^0$.

  $\to$ Easy access to CP asymmetries.

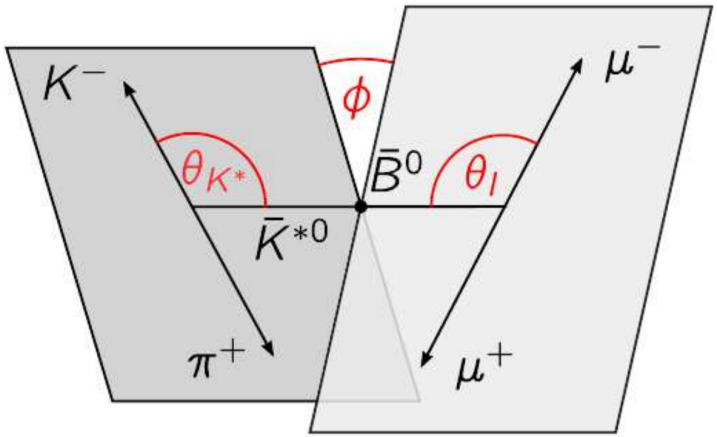
The $B \to K^* \mu^+ \mu^-$ Angular Decay Distribution (part 1)



$$\frac{1}{\frac{d}{dq^2}(\Gamma + \bar{\Gamma})} \frac{d^4(\Gamma + \bar{\Gamma})}{dq^2\, d\vec{\Omega}} =$$

$$\begin{aligned}
= \; & \frac{3}{4}(1 - F_L)\sin^2\theta_{K^*} + F_L \cos^2\theta_{K^*} \\
& + \frac{1}{4}(1 - F_L)\sin^2\theta_{K^*}\cos 2\theta_\ell - F_L \cos^2\theta_{K^*}\cos 2\theta_\ell \\
& + S_3 \sin^2\theta_{K^*}\sin^2\theta_\ell \cos 2\phi + S_4 \sin 2\theta_{K^*}\sin 2\theta_\ell \cos\phi \\
& + S_5 \sin 2\theta_{K^*}\sin\theta_\ell \cos\phi \\
& + \frac{4}{3} A_{FB}\sin^2\theta_{K^*}\cos\theta_\ell + S_7 \sin 2\theta_{K^*}\sin\theta_\ell \sin\phi \\
& + S_8 \sin 2\theta_{K^*}\sin 2\theta_\ell \sin\phi + S_9 \sin^2\theta_{K^*}\sin^2\theta_\ell \sin 2\phi
\end{aligned}$$

The $B \to K^* \mu^+ \mu^-$ Angular Decay Distribution (part 2)



$$\frac{1}{\frac{d}{dq^2}(\Gamma + \bar{\Gamma})} \frac{d^4(\Gamma - \bar{\Gamma})}{dq^2\, d\vec{\Omega}} =$$

$$\begin{aligned}
= \; & \frac{3}{4}(A_{\mathrm{CP}} - A_{F_L}^{\mathrm{CP}}) \sin^2\theta_{K^*} + A_{F_L}^{\mathrm{CP}} \cos^2\theta_{K^*} \\
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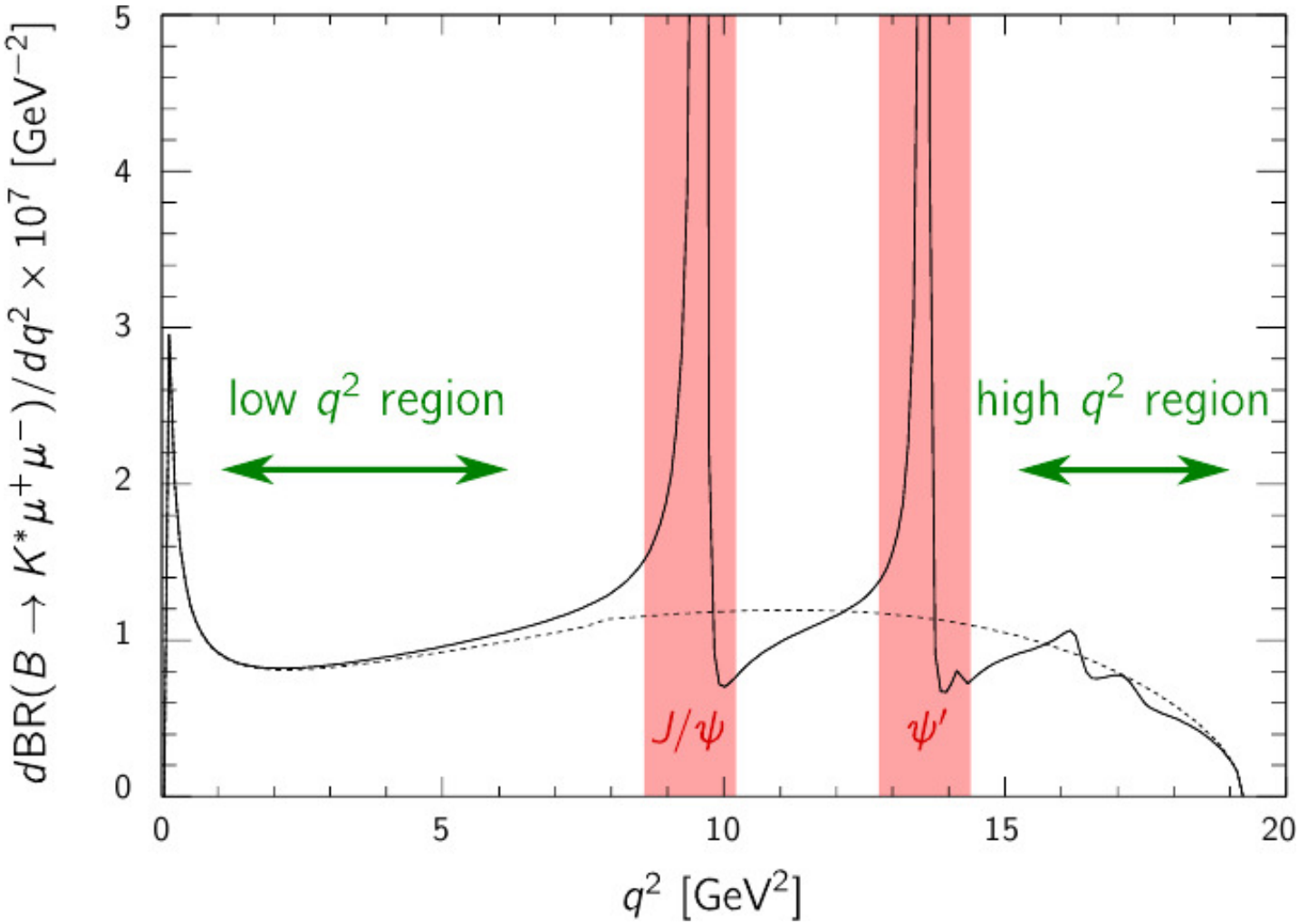
& + A_5 \sin 2\theta_{K^*} \sin\theta_\ell \cos\phi \\
& + \frac{4}{3} A_{\mathrm{FB}}^{\mathrm{CP}} \sin^2\theta_{K^*} \cos\theta_\ell + A_7 \sin 2\theta_{K^*} \sin\theta_\ell \sin\phi \\
& + A_8 \sin 2\theta_{K^*} \sin 2\theta_\ell \sin\phi + A_9 \sin^2\theta_{K^*} \sin^2\theta_\ell \sin 2\phi
\end{aligned}$$

The q^2 Spectrum

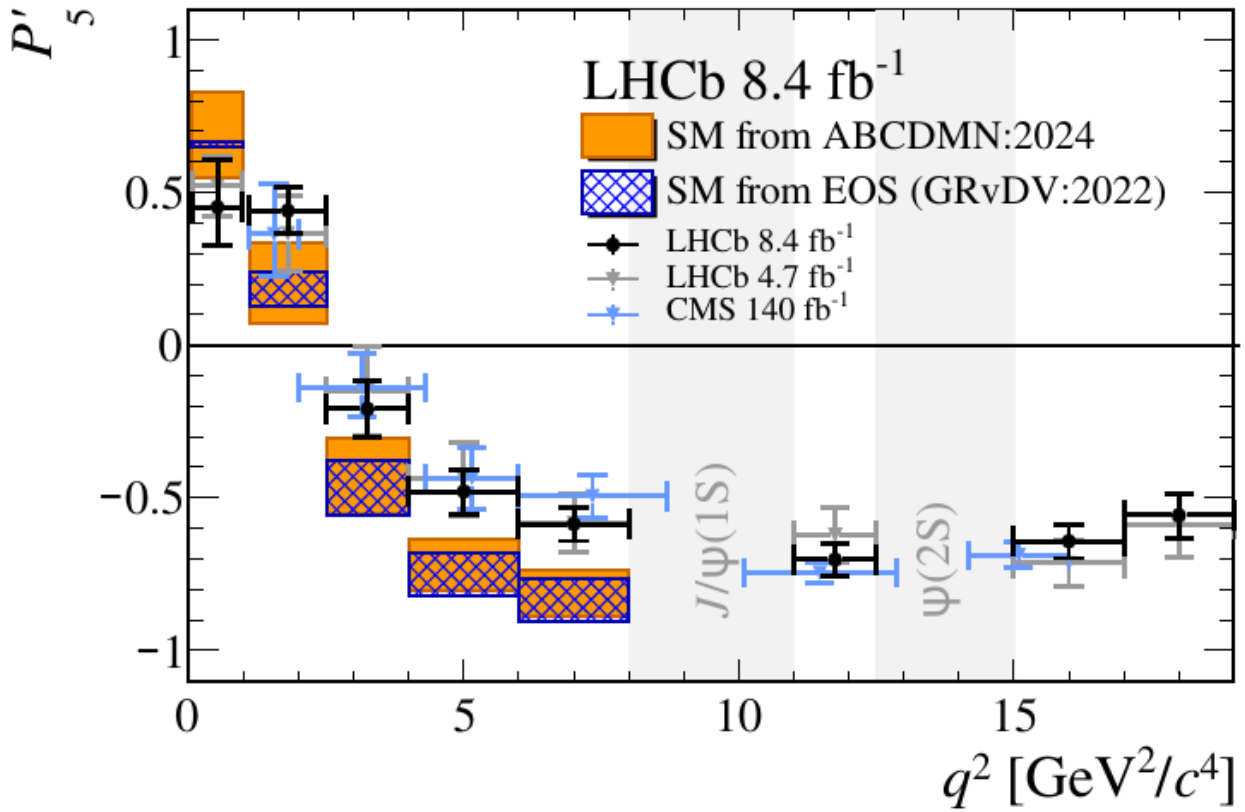


Since many years,
several experimental results on
rare $b \to s\mu\mu$ decays
don't agree well with SM predictions.

"Anomalies" both in branching ratios
and angular distributions.

The "P_5' Anomaly"

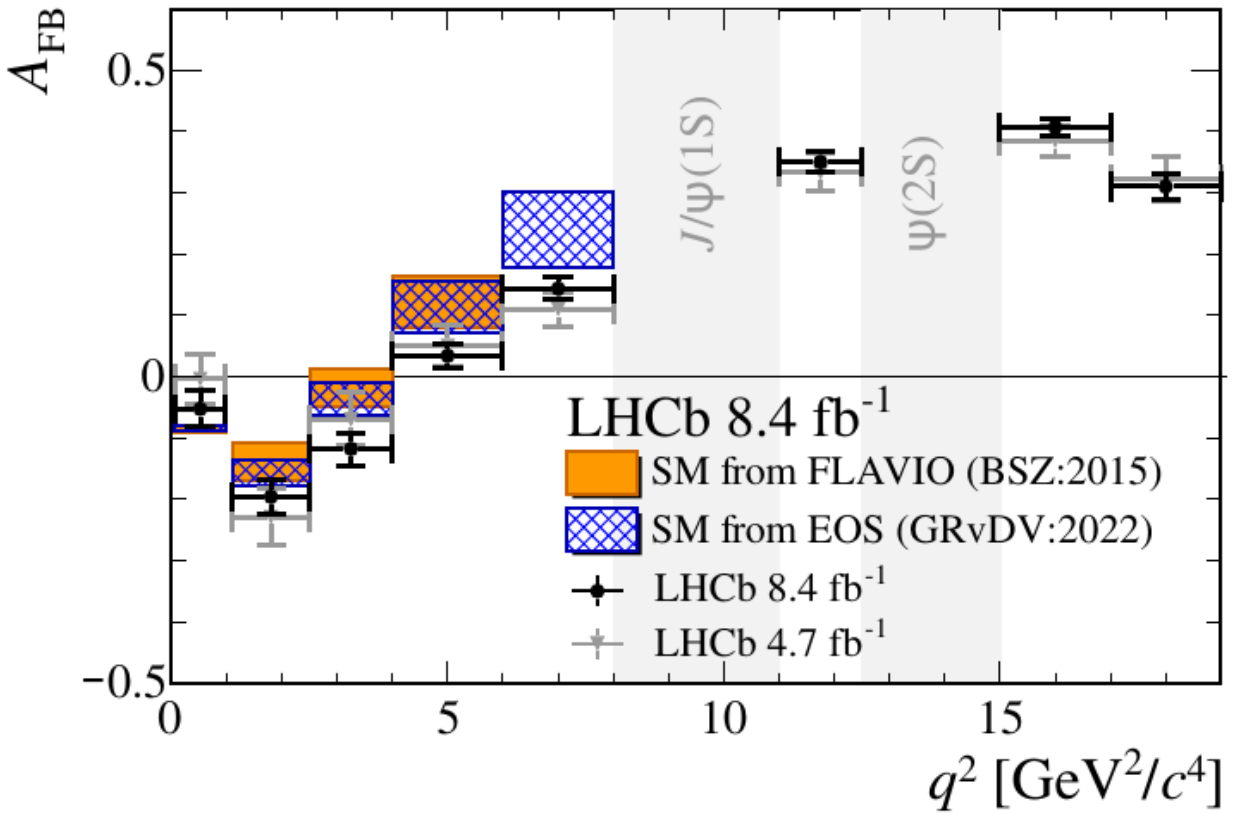
$$P_5' = \frac{S_5}{\sqrt{F_L(1-F_L)}}$$ is off by $\sim 2\sigma - 3\sigma$ in a few bins



LHCb 2512.18053 (also CMS 2411.11820)

The Forward Backward Asymmetry

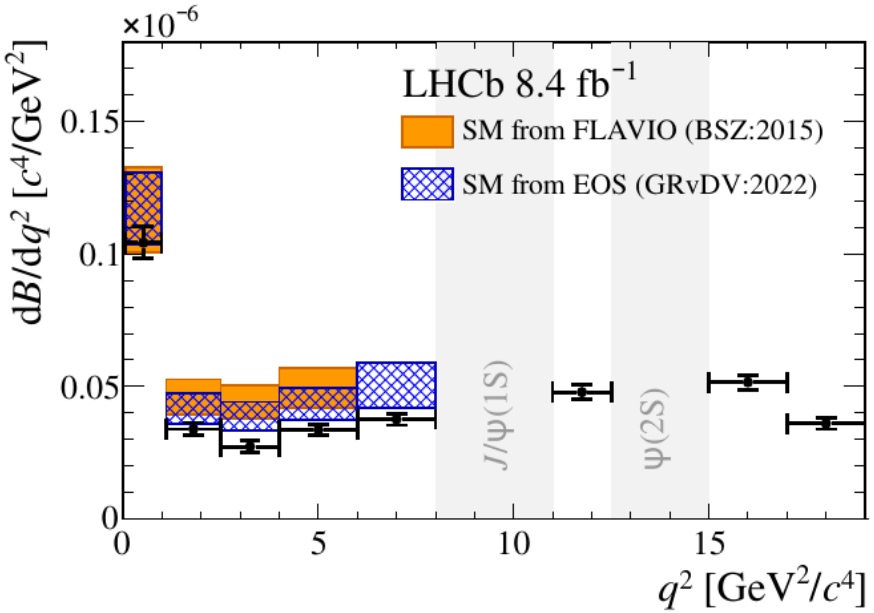
The forward-backward asymmetry is $\sim 1\sigma - 2\sigma$ low in a few bins

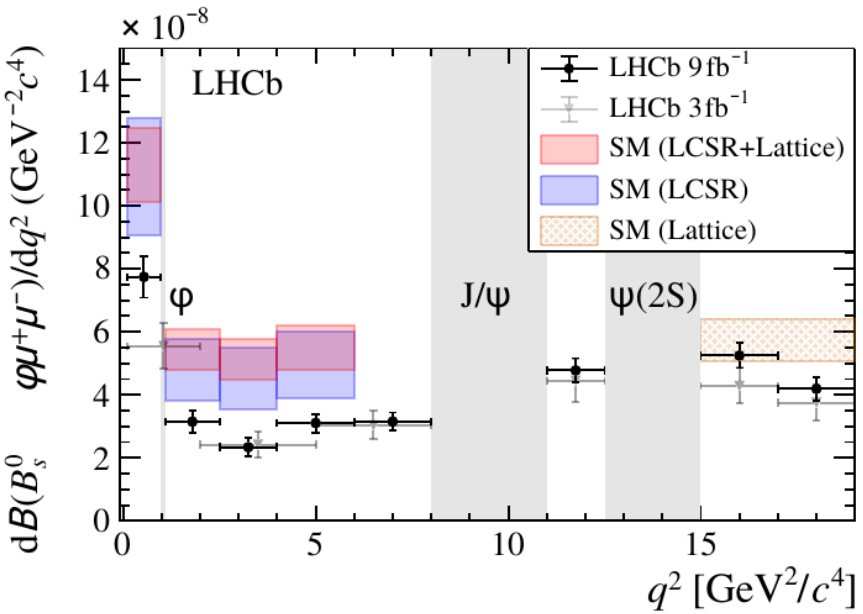


LHCb 2512.18053 (also CMS 2411.11820)

Low Branching Ratios

The $B \to K^* \mu^+ \mu^-$ branching ratio as well as the branching ratios of other related decays, $B \to K \mu^+ \mu^-$ and $B_s \to \phi \mu^+ \mu^-$ are significantly low compared to the SM predictions.





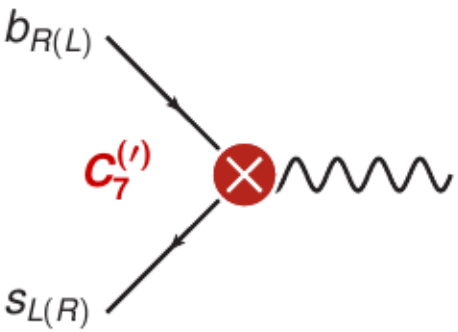
LHCb 2105.14007 + 2512.18053 (also CMS 2401.07090 + 2411.11820)

Could these discrepancies be signs of new physics?

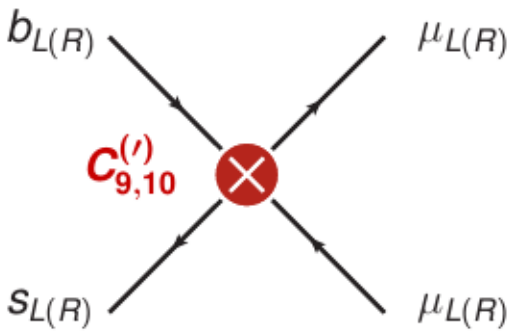
Model Independent New Physics Analysis

$$\mathcal{H}_{\text{eff}}^{b\to s} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i \left(C_i \mathcal{O}_i + C_i' \mathcal{O}_i' \right)$$

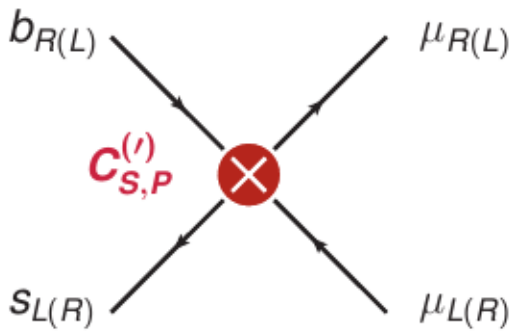
magnetic dipole operators



semileptonic operators



scalar operators



$$C_7^{(\prime)} (\bar{s} \sigma_{\mu\nu} P_{R(L)} b) F^{\mu\nu} \quad , \quad C_9^{(\prime)} (\bar{s} \gamma_\mu P_{L(R)} b)(\bar{\mu} \gamma^\mu \mu) \quad , \quad C_S^{(\prime)} (\bar{s} P_{R(L)} b)(\bar{\mu} P_{L(R)} \mu)$$

$$C_{10}^{(\prime)} (\bar{s} \gamma_\mu P_{L(R)} b)(\bar{\mu} \gamma^\mu \gamma_5 \mu)$$

neglecting tensor operators and additional scalar operators

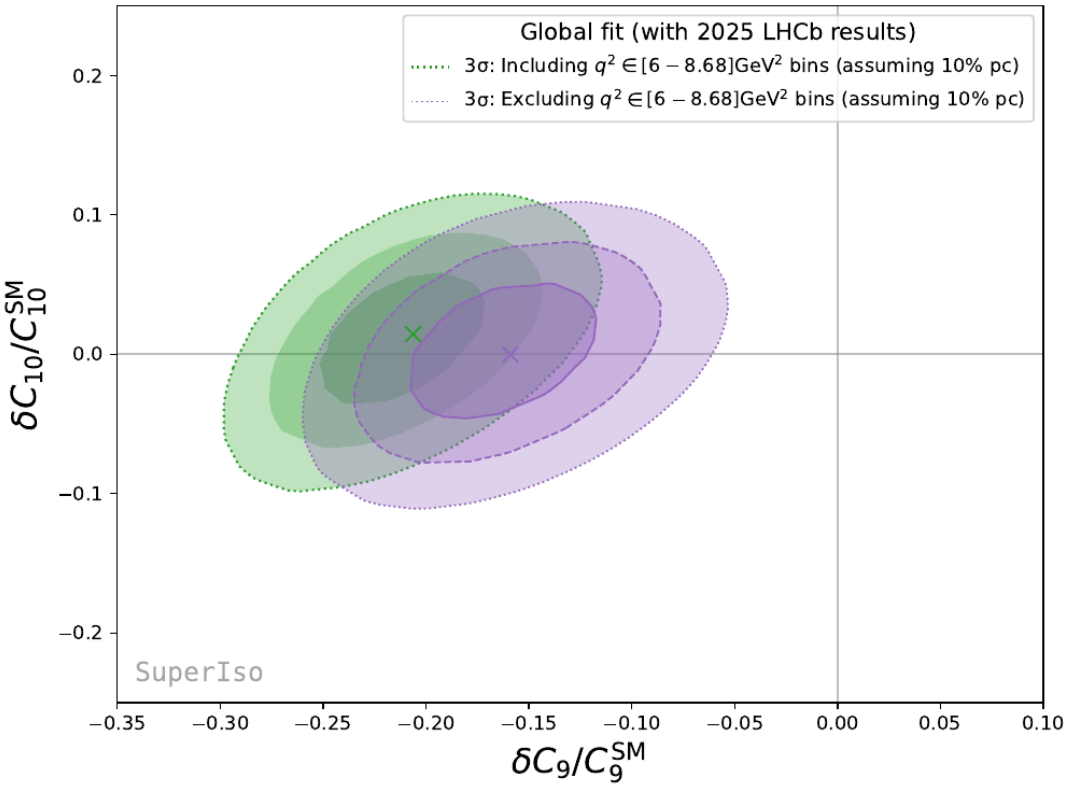
(they are dimension 8 in SMEFT: Alonso, Grinstein, Martin Camalich 1407.7044)

Complementary Sensitivity

	C_7, C_7'	C_9, C_9'	C_{10}, C_{10}'	C_S, C_S'
$B \to (X_s, K^*)\gamma$	★			
$B_s \to \phi\gamma$	★			
$B \to (X_s, K, K^*)\ \mu^+\mu^-$	★	★	★	⋆
$B_s \to \phi\ \mu^+\mu^-$	★	★	★	⋆
$\Lambda_b \to \Lambda\ \mu^+\mu^-$	★	★	★	⋆
$B_s \to \mu^+\mu^-$			★	★

$\to$ perform global fits of the data to either constrain new physics or find preference for new physics in these coefficients

New Physics Fit: Status End of 2025



Hurth et al. 2508.09986

+ many others

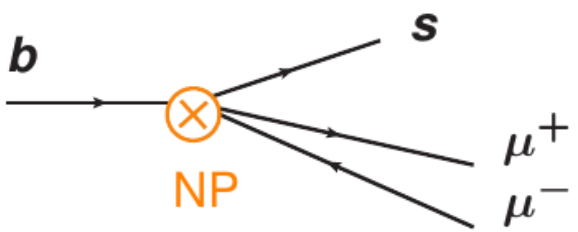
$$\delta C_9\,(\bar{s}\gamma_\alpha P_L b)(\bar{\ell}\gamma^\alpha \ell)$$

$$\delta C_{10}\,(\bar{s}\gamma_\alpha P_L b)(\bar{\ell}\gamma^\alpha \gamma_5 \ell)$$

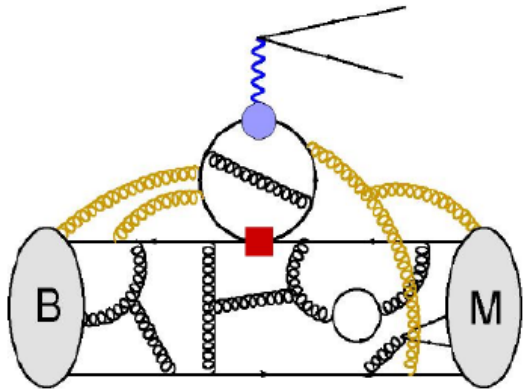
- Since more than 10 years, the data points consistently to a shift in the Wilson coefficient C_9.
- Quoted significances are around $(3-6)\sigma$ (depend heavily on assumptions about the SM uncertainties)
- $\delta C_9/C_9^{\text{SM}} \simeq -0.2$ corresponds to a new physics scale of

$$\Lambda_{\text{NP}} \sim 40\,\text{TeV}$$

New Physics or Underestimated Hadronic Effects?



or



Long distance hadronic effects ("charm loops") can mimic new physics in C_9.

Lot's of activity to better understand the charm loops:
lattice QCD, QCD factorization, dispersion relations, unitarity bounds, data driven methods, generic parameterizations, models, ...

... Ciuchini et al. 2212.10516; Gubernari et al. 2206.03797, 2305.06301;
LHCb 2312.09102, 2405.17347, 2603.12477; Bordone et al. 2401.18007;
Isidori, Polonski, Tinari 2405.17551, 2507.17824; Capdevila et al. 2504.00949; Hurth et al. 2508.09986;
Frezzotti et al. 2508.03655; Juttner 2603.15487; WA, Christensen, Stangl 2603.27753;
Alvarez-Cartelle et al. 2605.06567; Ciuchini et al. 2607.03531; Bordone, Isidori, Tinari 2607.09458
... and many others ...

Distinguishing New Physics from Hadronics

(heavy) New Physics	Hadronic Contributions
described by local four fermion operator	long distance QCD effects

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Distinguishing New Physics from Hadronics

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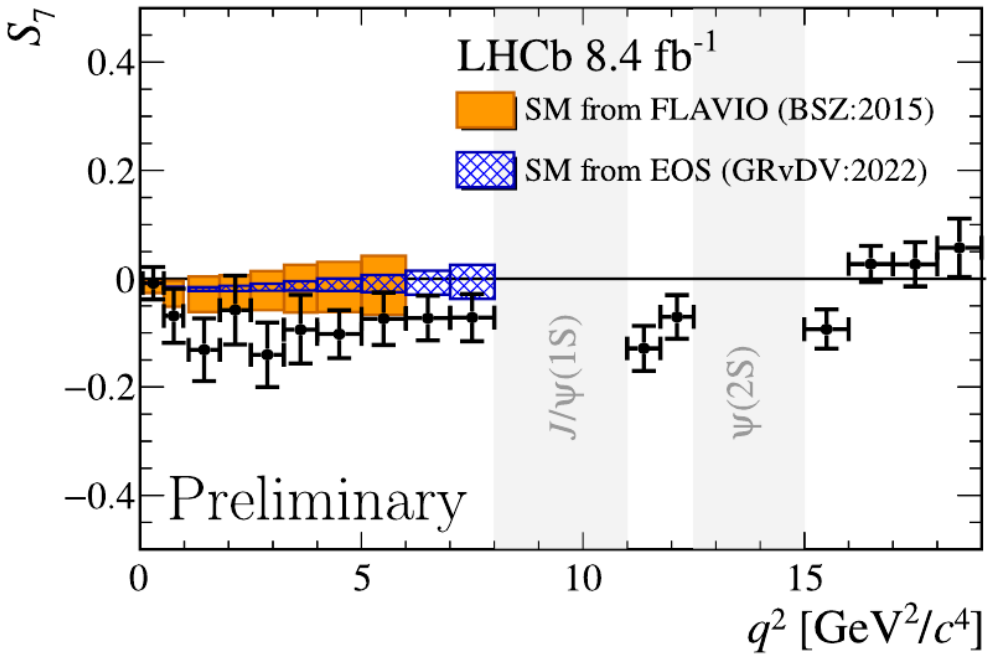
could violate lepton flavor universality	lepton flavor universal ✓
cannot give a strong phase **?**	could give strong phases **?**

A New Puzzle Piece

Hint for a non-zero angular observable S_7 in $B \to K^* \mu^+ \mu^-$

LHCb 2512.18053



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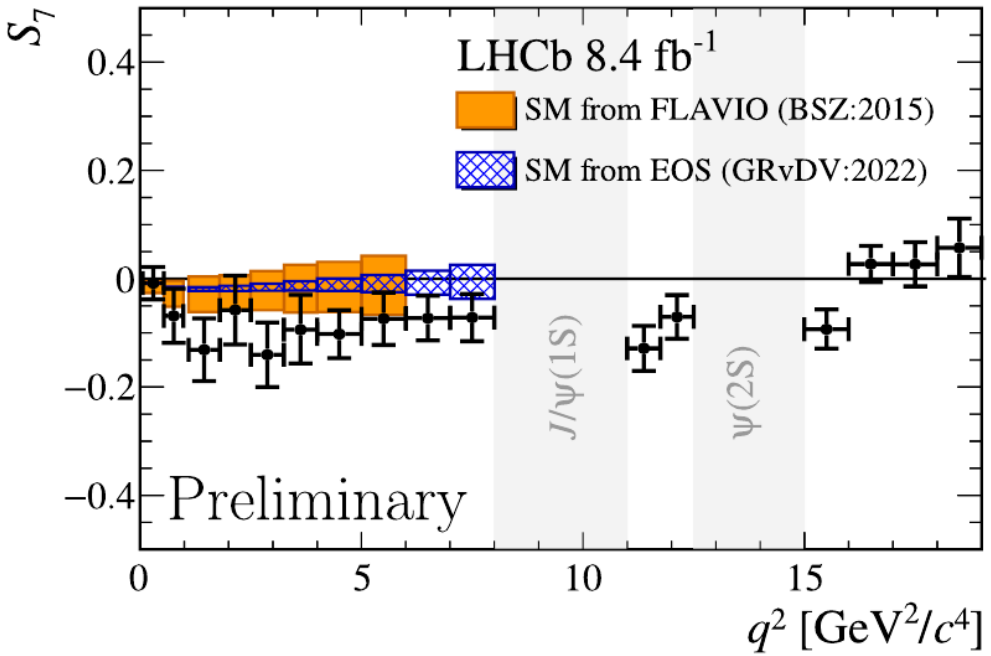
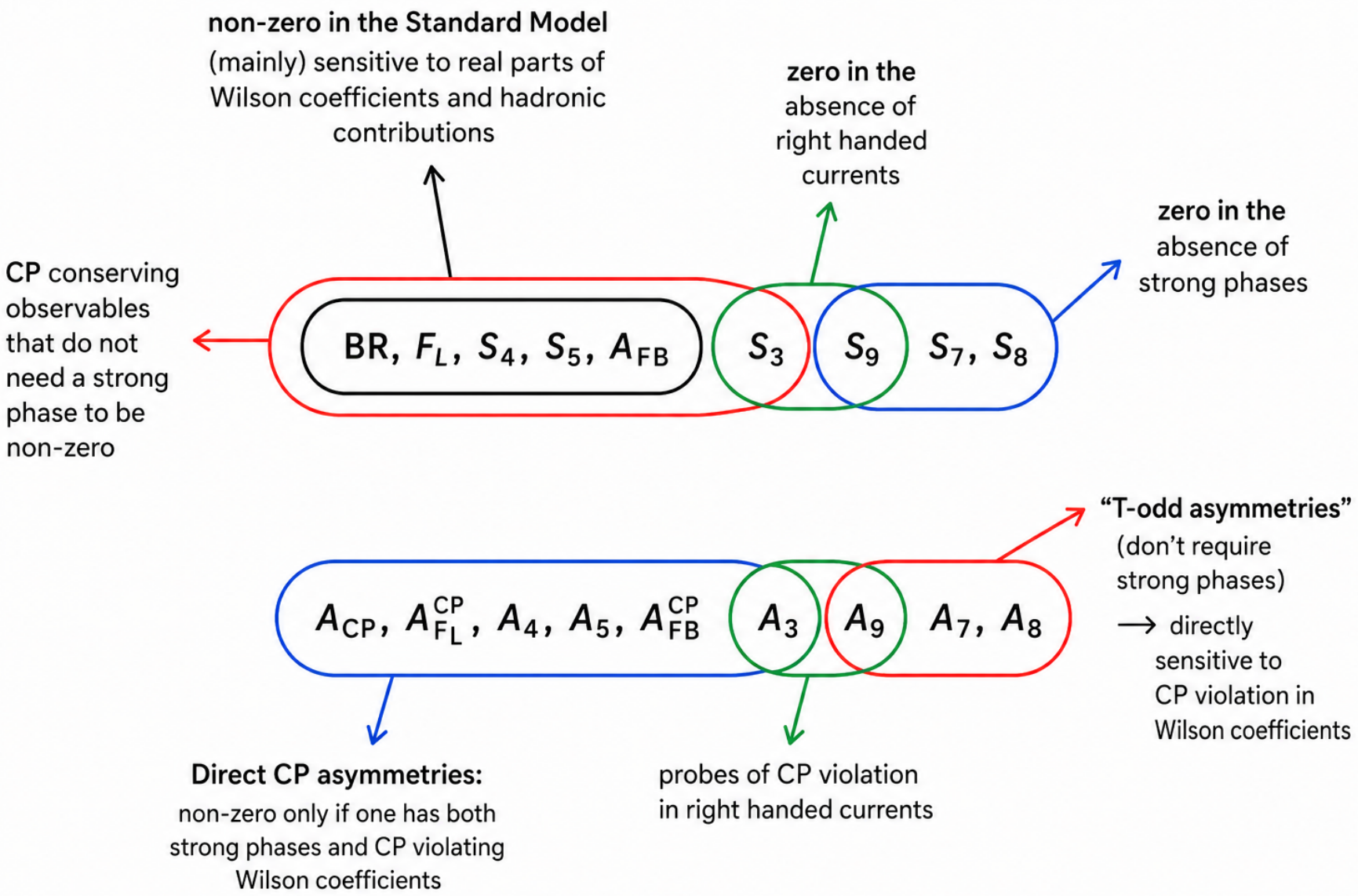
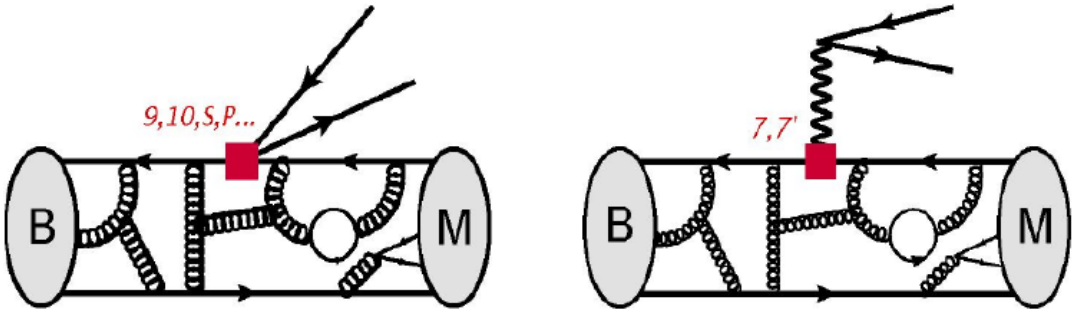


- Significance for non-zero S_7 it not yet very high ($\sim 1\sigma$ accross a handful of q^2 bins), but implications might be profound.
- S_7 is special: It is not very sensitive to new physics. Instead a non-zero S_7 requires the presence of a strong phase that would need to come from a long distance effect.

Anatomy of $B \to K^* \mu^+ \mu^-$ Observables



$B \to K^* \mu^+ \mu^-$ Amplitudes



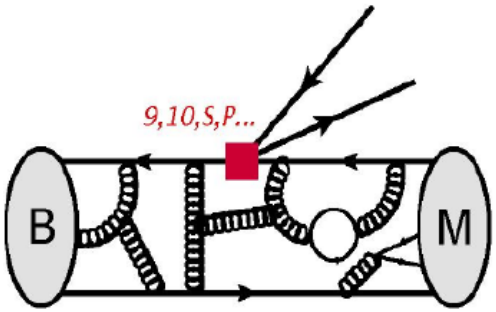
$$H_V^\lambda \propto C_9 \tilde{V}_{L\lambda} + C_9' \tilde{V}_{R\lambda} + \frac{2 m_b m_B}{q^2} \left(C_7 \tilde{T}_{L\lambda} + C_7' \tilde{T}_{R\lambda} \right)$$

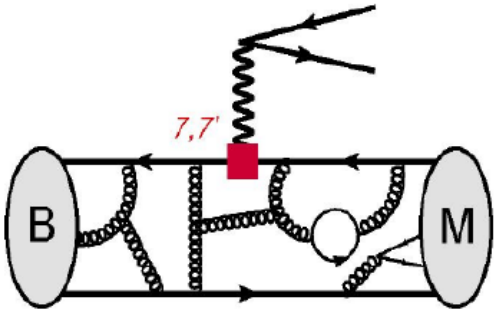
$$H_A^\lambda \propto C_{10} \tilde{V}_{L\lambda} + C_{10}' \tilde{V}_{R\lambda}$$

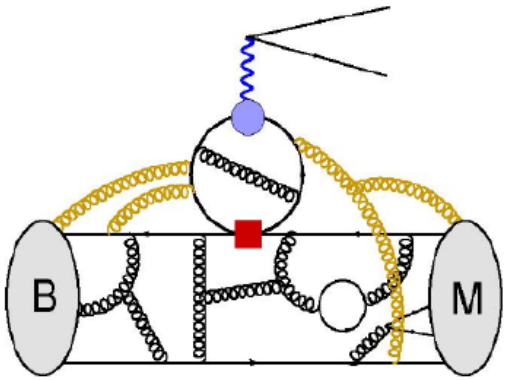
- Wilson coefficients: can contain weak phases (CP violating)
- local form factors:

$$\tilde{V}_{L/R\lambda}(q^2), \tilde{T}_{L/R\lambda}(q^2) \propto \langle K_\lambda^*(k) | \bar{s} \Gamma_\lambda^{(V,T)} b | B(k+q) \rangle$$

$B \to K^* \mu^+ \mu^-$ Amplitudes







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

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

- Wilson coefficients: can contain weak phases (CP violating)
- local form factors:

$$\tilde{V}_{L/R\lambda}(q^2), \tilde{T}_{L/R\lambda}(q^2) \propto \langle K_\lambda^*(k) | \bar{s} \Gamma_\lambda^{(V,T)} b | B(k+q) \rangle$$

- non-local form factors: can contain strong phases (CP conserving)

$$h_\lambda(q^2) \propto \int d^4x \, e^{iqx} \langle K_\lambda^*(k) | T \{ j_{\text{em}}^\mu(x), C_i \mathcal{O}_i(0) \} | B(k+q) \rangle$$

Parameterizing Possible Hadronic Effects

WA, Christensen, Stangl 2603.27753

- Introduce a very simple but flexible parameterization of hadronic effects, by adding q^2 dependent correction terms to the $B \to K^* \mu^+ \mu^-$ decay amplitudes:

  (see e.g. Jager et al. 1212.2263; WA, Straub 1411.3161; WA, Stangl 2103.13370; Ciuchini et al. 2212.10516; Hurth et al. 2508.09986; ...)

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

- Such polynomials should work well at low q^2.
- Our approach: treat the coefficients a_λ and b_λ as free complex parameters and fit them to the data.

Simple Analytic Approximation for S_7

WA, Christensen, Stangl 2603.27753

- The observable S_7 depends on the imaginary parts of the a_λ and b_λ and vanishes in their absence.
- Same is true for the observables S_8 and S_9, that depend on different linear combinations of the $\mathrm{Im}\, a_\lambda$ and $\mathrm{Im}\, b_\lambda$.

$$S_7^{\mathrm{SM}}(q^2) \simeq -\frac{4 m_{K^*}\sqrt{q^2}}{m_B^2}\frac{\xi_\perp(0)}{\xi_\parallel(0)} C_{10}^{\mathrm{SM}} \left(\frac{m_B^2}{q^2}\left(\mathrm{Im}\, a_- - \mathrm{Im}\, a_+\right) + \mathrm{Im}\, b_- - \mathrm{Im}\, b_+ - \mathrm{Im}\, a_0 - \mathrm{Im}\, b_0 \frac{q^2}{m_B^2}\right)\frac{1}{D_{\mathrm{SM}}}$$

$$D_{\mathrm{SM}} = \left(C_{10}^{\mathrm{SM}}\right)^2 + \left(\frac{2m_b}{m_B} C_7^{\mathrm{SM}} + C_9^{\mathrm{SM}} + \mathrm{Re}\, a_0 + \mathrm{Re}\, b_0 \frac{q^2}{m_B^2}\right)^2 + \left(\mathrm{Im}\, a_0 + \mathrm{Im}\, b_0 \frac{q^2}{m_B^2}\right)^2$$

- The above expression holds in the SM. However, also in the presence of new physics, S_7, S_8, and S_9 vanish in the absence of imaginary hadronic parameters.

Simple Analytic Approximations for $S_5 \propto P_5'$ and A_{FB}

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- $S_5 \propto P_5'$ and A_{FB} depend on the real parts of the a_λ and b_λ.

$$A_{FB}^{SM}(q^2) \simeq -\frac{24 m_{K^*}^2 q^2}{m_B^4} \frac{\xi_\perp^2(0)}{\xi_\parallel^2(0)} C_{10}^{SM} \left(C_9^{SM} + \text{Re}\, b_- + \frac{m_B^2}{q^2} \left(\frac{2m_b}{m_B} C_7^{SM} + \text{Re}\, a_- \right) \right) \frac{1}{D_{SM}}$$

$$S_5^{SM}(q^2) \simeq \frac{4 m_{K^*} \sqrt{q^2}}{m_B^2} \frac{\xi_\perp(0)}{\xi_\parallel(0)} C_{10}^{SM} \left(\frac{m_B^2}{q^2} \left(\frac{2m_b}{m_B} C_7^{SM} + \text{Re}\, a_- + \text{Re}\, a_+ \right) + \frac{2m_b}{m_B} C_7 + 2C_9^{SM} + \text{Re}\, b_- + \text{Re}\, b_+ + \text{Re}\, a_0 + \text{Re}\, b_0 \frac{q^2}{m_B^2} \right) \frac{1}{D_{SM}}$$

- If we can establish robust evidence for imaginary parts of a_λ and b_λ (through S_7), it is plausible that there are also non-zero real parts with values in the same ballpark.

Fitting Hadronic Parameters

- We fit the following 12 hadronic parameters, keeping all Wilson coefficients fixed to their SM values

$$\left\{ \mathrm{Re}\, a_\lambda \,,\;\; \mathrm{Im}\, a_\lambda \,,\;\; \mathrm{Re}\, b_\lambda \,,\;\; \mathrm{Im}\, b_\lambda \right\} , \qquad \lambda = 0, \pm$$

- We take into account the full set of CP-averaged observables in $B \to K^* \mu^+ \mu^-$ at low dimuon invariant mass $q^2 < 6\,\mathrm{GeV}^2$

$$F_L = -S_2^c \,,\;\; S_3 \,,\;\; S_4 \,,\;\; S_5 \,,\;\; A_{\mathrm{FB}} \,,\;\; S_7 \,,\;\; S_8 \,,\;\; S_9 \,,\;\; \frac{d\mathrm{BR}}{dq^2}$$

- LHCb (2512.18053) presents their results in 6 different configurations (different q^2 binning, treatment of lepton masses, ...)

- We use configuration (vi) which has 8 narrow q^2 bins at low $q^2 < 6\,\mathrm{GeV}^2$ for each of the 9 CP-averaged observables; and configuration (iv) which has 4 broad q^2 bins at low $q^2 < 6\,\mathrm{GeV}^2$ for each of the 9 CP-averaged observables.

Results of the Hadronic Fit

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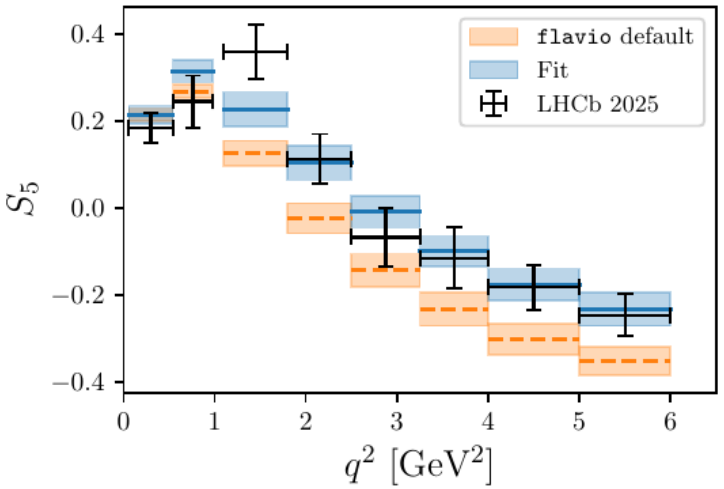

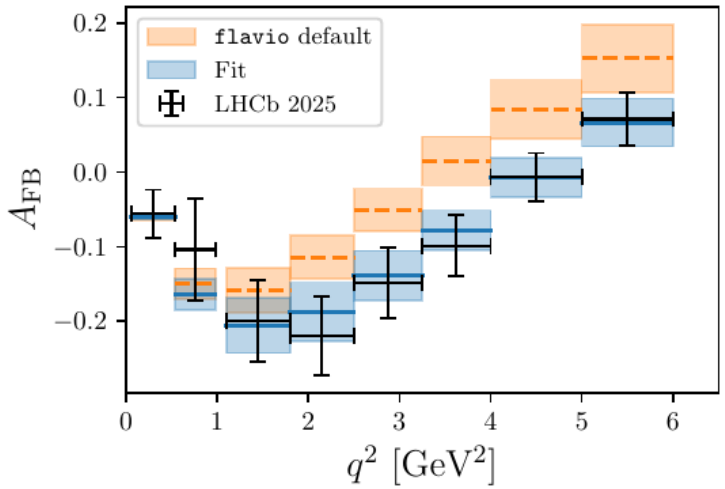

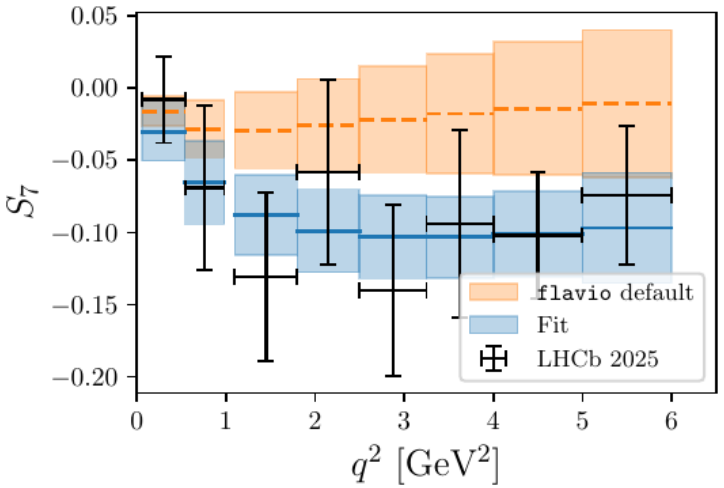

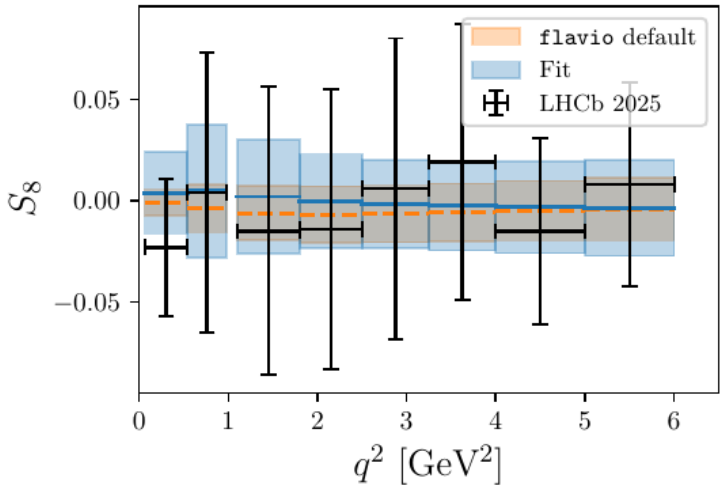

We obtain an excellent fit of the $B \to K^* \mu^+ \mu^-$ data.

Results of the Hadronic Fit

- Fit shows strong preference for

$$\mathrm{Re}\, a_0 \sim \mathrm{Re}\, b_- \sim -1$$

  mimicking a shift in $\mathrm{Re}(C_9)$.

- No individual imaginary part differs from zero by more than 1σ.

- The fit distributes the imaginary parts into various hadronic parameters.
  (table shows the mean and standard deviation of likelihood samples)

- In the best fit point, the real and imaginary parts of the hadronic parameters are in the same ballpark.

$\rightarrow$ (Weak) hint that S_7, P_5', A_{FB} might have the same hadronic origin.

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	Config (vi) (CP av.)	Config (iv) (CP av.)
$\widetilde{\mathrm{Re}\, a_0}$	-0.77 ± 0.52	-1.04 ± 0.52
$\mathrm{Re}\, b_0$	-2.45 ± 3.59	1.18 ± 3.66
$\mathrm{Re}\, a_-$	-0.03 ± 0.04	-0.06 ± 0.04
$\widetilde{\mathrm{Re}\, b_-}$	-1.04 ± 0.37	-0.77 ± 0.35
$\mathrm{Re}\, a_+$	0.01 ± 0.03	0.02 ± 0.03
$\widetilde{\mathrm{Re}\, b_+}$	0.09 ± 0.70	-0.15 ± 0.61
$\mathrm{Im}\, a_0$	-0.07 ± 0.77	-0.90 ± 0.78
$\mathrm{Im}\, b_0$	-0.38 ± 5.62	4.85 ± 6.70
$\mathrm{Im}\, a_-$	0.00 ± 0.06	-0.01 ± 0.07
$\mathrm{Im}\, b_-$	-0.58 ± 1.00	-0.56 ± 0.97
$\mathrm{Im}\, a_+$	0.03 ± 0.04	0.04 ± 0.04
$\mathrm{Im}\, b_+$	0.42 ± 0.76	0.27 ± 0.72

Preference for Imaginary Hadronic Contributions

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- Swtiching on individual imaginary parts, the fit improves by $\sim 3\sigma$.

Scenario	χ^2	$\text{pull}_{\text{real}}$
real only	63.6	–
real, $\text{Im}\, a_0$	53.8	$3.1\,\sigma$
real, $\text{Im}\, b_0$	54.7	$3.0\,\sigma$
real, $\text{Im}\, a_-$	54.2	$3.1\,\sigma$
real, $\text{Im}\, b_-$	51.8	$3.4\,\sigma$
real, $\text{Im}\, a_+$	52.7	$3.3\,\sigma$
real, $\text{Im}\, b_+$	50.3	$3.6\,\sigma$

Preference for Imaginary Hadronic Contributions

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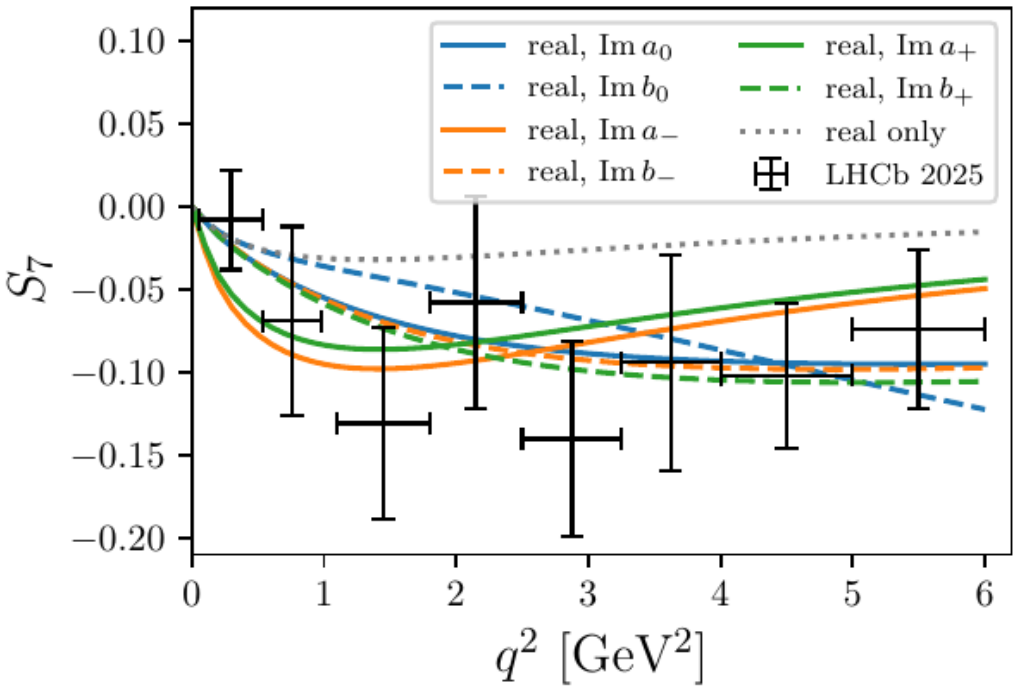
- Swtiching on individual imaginary parts, the fit improves by $\sim 3\sigma$.
- Any hadronic parameter can explain a slightly negative S_7.



Preference for Imaginary Hadronic Contributions

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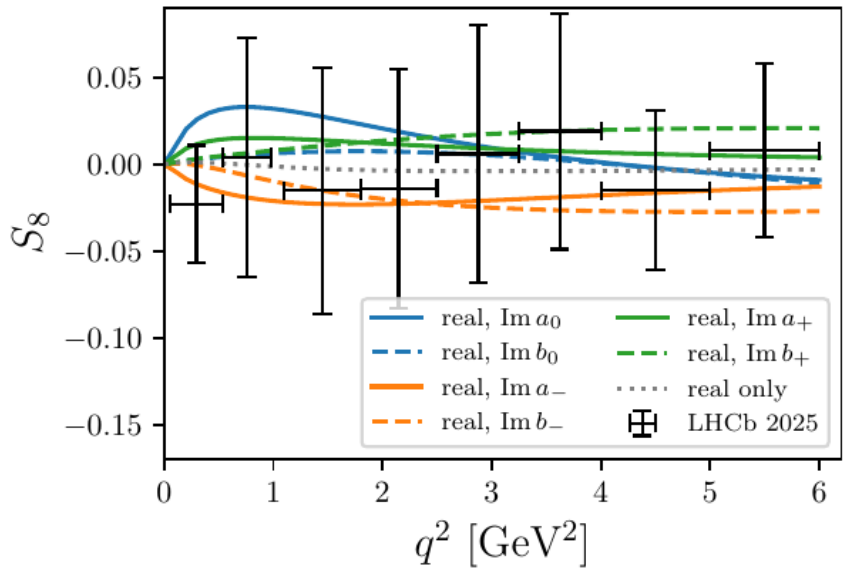
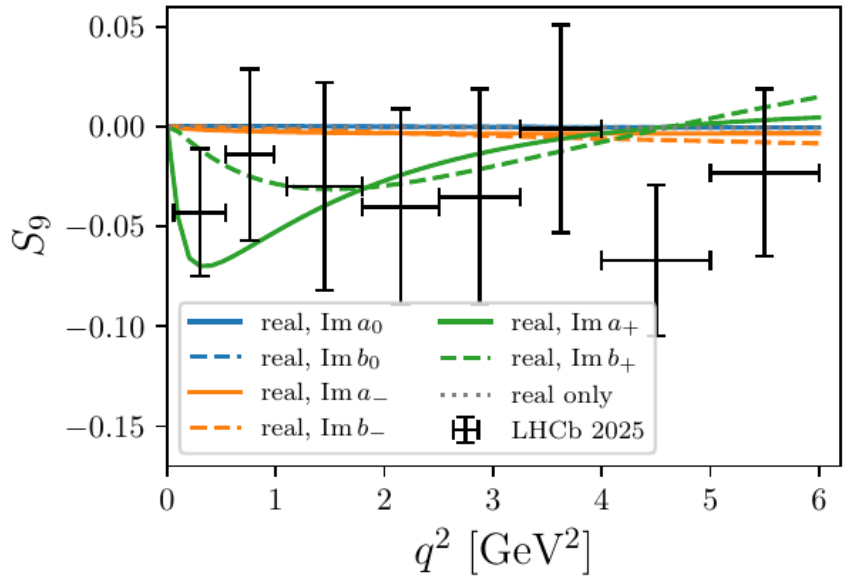
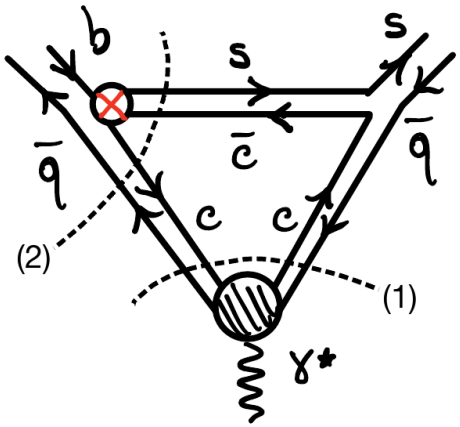
- Swtiching on individual imaginary parts, the fit improves by $\sim 3\sigma$.
- Any hadronic parameter can explain a slightly negative S_7.
- Each parameter predicts a characteristic pattern for S_8 and S_9.
- More precise data is needed to distinguish the different cases.

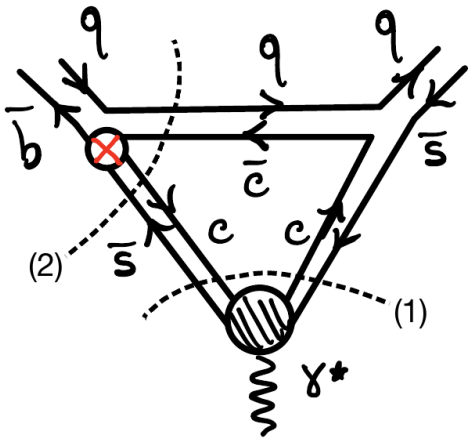


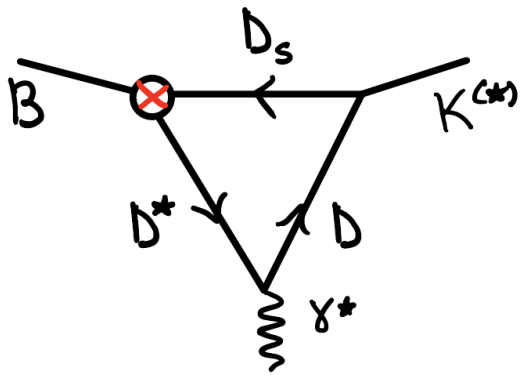


Open Issues

- What could be the origin of the large hadronic contributions?







- Triangle diagrams involving e.g. intermediate $D_s D^*$ or $D_s^* D$ states?

  Ciuchini, Fedele, Franco, Paul, Silvestrini, Valli 2212.10516

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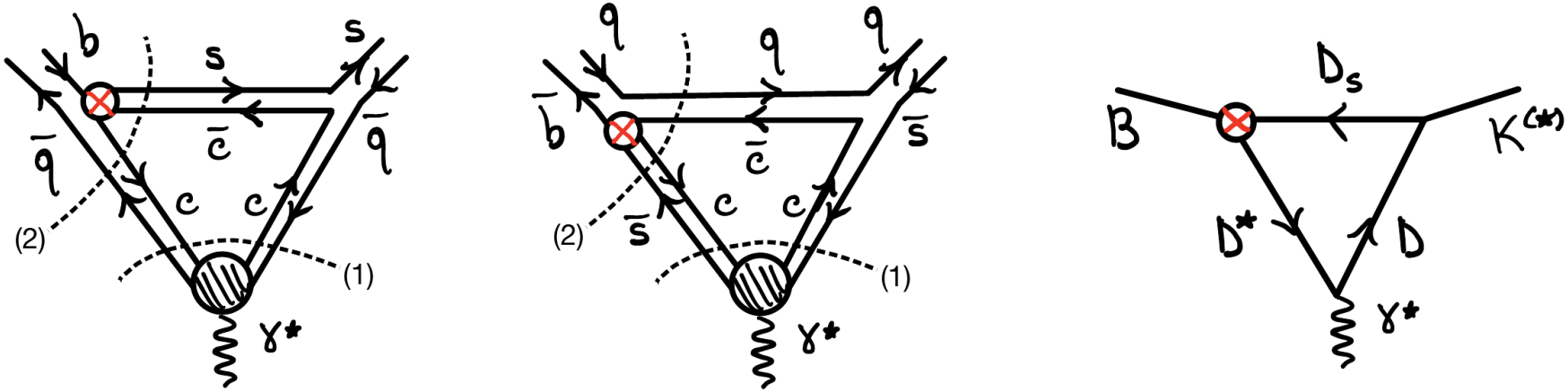

- Triangle diagrams involving e.g. intermediate $D_s D^*$ or $D_s^* D$ states?

  Ciuchini, Fedele, Franco, Paul, Silvestrini, Valli 2212.10516

- At present, large hadronic effects are not supported by model calculations and might be in tension with arguments based on unitarity and analyticity.

  Khodjamirian et al. 1006.4945; Gubernari et al. 2011.09813, 2206.03797;

  Isidori, Polonski, Tinari 2405.17551, 2507.17824; Mutke et al. 2406.14608;

  Mahajan et al. 2409.00181; Gopal et al 2412.04388; Hoferichter et al. 2604.01284 ...

Moving Forward

S_7 might be an indication of large hadronic effects;
or it might go away with more data.

It might be related to P_5';
but it could also be an independent effect.

Regardless, one can perform simultaneous fits of hadronic parameters and new physics Wilson coefficients that are "orthogonal" to C_9.

Simultaneous Fit of Hadronics and New Physics

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- We add to the fit parameters the following Wilson coefficients

$$\text{Re}\, C_9^{(\prime)\,\text{NP}} \;,\quad \text{Im}\, C_9^{(\prime)\,\text{NP}} \;,\quad \text{Re}\, C_{10}^{(\prime)\,\text{NP}} \;,\quad \text{Im}\, C_{10}^{(\prime)\,\text{NP}}$$

- We add the CP asymmetries as additional observables

$$A_3 \;,\quad A_4 \;,\quad A_5 \;,\quad A_{\text{FB}}^{\text{CP}} \;,\quad A_7 \;,\quad A_8 \;,\quad A_9 \;,\quad A_{\text{CP}}$$

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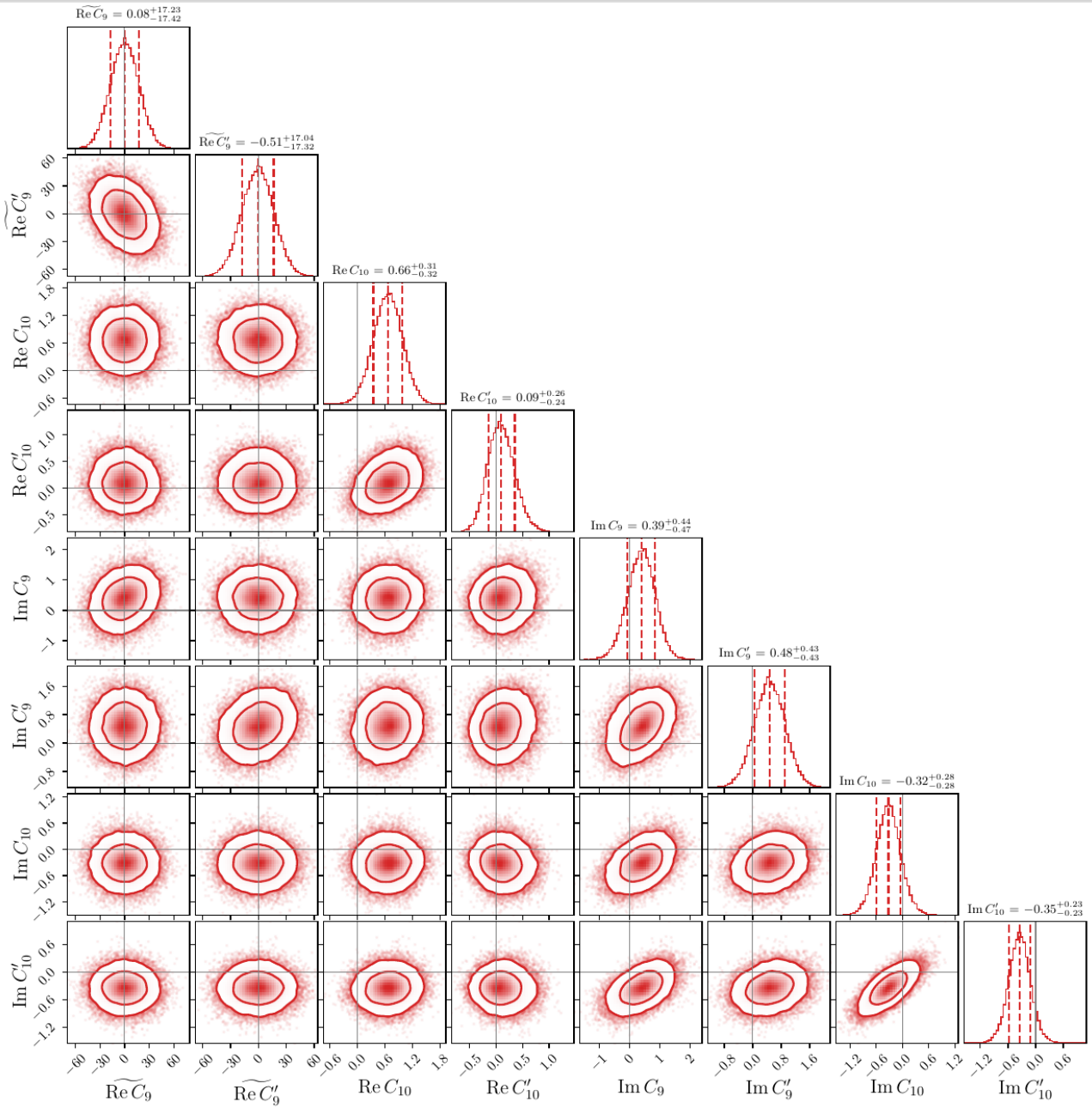
- Fit contains two flat directions (essentially by construction)

$$\text{Re}\, C_9^{\text{NP}} - \text{Re}\, a_0 - \text{Re}\, b_- \;,\quad \text{Re}\, C_9^{\prime\,\text{NP}} + \text{Re}\, a_0 - \text{Re}\, b_+$$

$\rightarrow$ No sensitivity to $\text{Re}\, C_9^{\text{NP}}$ and $\text{Re}\, C_9^{\prime\,\text{NP}}$.

- We find that the fit retains sensitivity to all other Wilson coefficients.

Corner Plots



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Robustness of the Results

	Config (iv) (CP av. + asym.)		
	$\mathrm{Re}\, C_9^{(\prime)}$ free	$\mathrm{Re}\, C_9^{(\prime)} = 0$	`flavio` default
$\widetilde{\mathrm{Re}\, C_9}$	0.05 ± 17.41	–	-0.88 ± 0.29
$\widetilde{\mathrm{Re}\, C_9'}$	-0.64 ± 17.21	–	0.32 ± 0.59
$\mathrm{Re}\, C_{10}$	0.66 ± 0.31	0.65 ± 0.32	0.71 ± 0.29
$\mathrm{Re}\, C_{10}'$	0.10 ± 0.25	0.10 ± 0.25	-0.24 ± 0.35
$\mathrm{Im}\, C_9$	0.39 ± 0.46	0.41 ± 0.45	0.12 ± 0.43
$\mathrm{Im}\, C_9'$	0.48 ± 0.44	0.48 ± 0.42	0.66 ± 0.49
$\mathrm{Im}\, C_{10}$	-0.31 ± 0.28	-0.30 ± 0.29	0.18 ± 0.24
$\mathrm{Im}\, C_{10}'$	-0.35 ± 0.24	-0.34 ± 0.24	-0.28 ± 0.28

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- Results for the Wilson coefficients (other than Re C_9 and Re C_9') are robust and depend only mildly on how the hadronic parameters are treated.
- All new physics contributions to Wilson coefficients are more or less compatible with zero.

[flavio default means that hadronic parameters are not included in the fit. They are set to zero and their (small) uncertainties are propagated into the theory covariance matrix.]

Summary and Outlook

- Recent LHCb results on $B \to K^* \mu^+ \mu^-$ provide a new intriguing piece of information on the rare B decay anomalies.
- Hint for non-zero S_7 cannot be accommodated by heavy new physics but requires a sizable hadronic effect with a strong phase.
- The observed central values of S_7 indicate a hadronic effect of approximately the same size required to explain P_5'.
- With more precise data on S_7, S_8, S_9 it should be possible to determine which hadronic parameters have to be non-zero.

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- The observed central values of S_7 indicate a hadronic effect of approximately the same size required to explain P_5'.
- With more precise data on S_7, S_8, S_9 it should be possible to determine which hadronic parameters have to be non-zero.
- Combined fits of hadronic contributions and Wilson coefficients retain sensitivity to new physics (other than Re C_9 and Re C_9')
- Plan to extend our fit including all other $b \to s\ell\ell$ data.
  Our fitting framework is sufficiently flexible and efficient to accommodate the large number of additional observables and hadronic parameters.

Back Up

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**

- **POPxf** – **P**olynomial **O**bservable **P**rediction e**x**change **f**ormat `https://github.com/pop-xf` — Brivio, Mimasu, PS (editors), Biekötter, Cueto Gómez, Knight, Mantani, Rossi, Rossia, Smolkovič, arXiv:2511.17348
  - **Precomputed theory predictions** in terms of polynomials in Wilson coefficients and hadronic parameters
  - Standardised JSON format developed within LHC EFT WG & LHC Higgs WG

- **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**
  - $\mathcal{O}(10\,\text{s})$ per point $\longrightarrow$ $\mathcal{O}(\text{ms})$ per point

[see talk by Peter Stangl at MITP workshop, 7 July 2026]