Amplitude and angular measurements in B decays

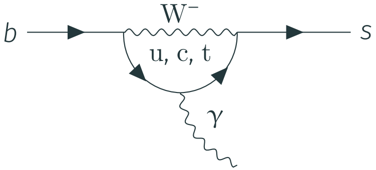
Implications of LHCb measurements and future prospects

Lakshan Madhan
on behalf of the LHCb collaboration

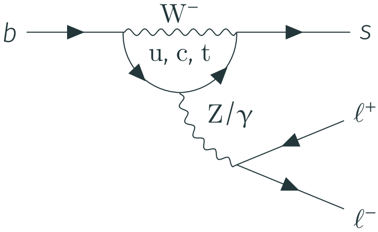
24-10-2024

FCNC decays

Radiative decays



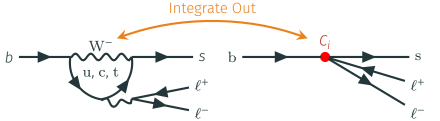
Leptonic Decays



Flavour changing neutral currents (FCNC)
Proceed via loops in SM
Small SM contribution makes them sensitive probes for NP

Studying $\mathrm{b} \to \mathrm{s}\ell^+\ell^-$ transitions

Effective Field Theory approach



$$\mathcal{H}_{SM} \longrightarrow \mathcal{H}_{eff} = -\frac{G_F}{\sqrt{2}} V_{\mathrm{tb}} V^*_{\mathrm{ts}} \sum_i (C_i^{SM} + C_i^{NP}) \mathcal{O}_i$$
+ chiral flipped

Wilson Coefficients: C_i

→ Perturbative, short distance physics

→ Describes heavy SM+NP effects

Operators: $\mathcal{O}_i$

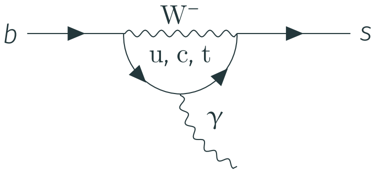
→ Non-perturbative, long distance physics

→ Strong interactions, difficult to calculate

Operator $\mathcal{O}_i$	$\mathrm{B}_{\mathrm{s(d)}} \to \mathrm{V}_{\mathrm{s(d)}}\mu^+\mu^-$	$\mathrm{B}_{\mathrm{s(d)}} \to \mu^+\mu^-$	$\mathrm{B}_{\mathrm{s(d)}} \to \mathrm{V}_{\mathrm{s(d)}}\gamma$
$\mathcal{O}_7$ EM	✓		✓
$\mathcal{O}_9$ Vector dilepton	✓		
$\mathcal{O}_{10}$ Axial-vector dilepton	✓	✓	
$\mathcal{O}_{S,P}$ (Pseudo-)Scalar dilepton	(✓)	✓	

Radiative Decays

Radiative decays



Parameters and Observables

- $\mathcal{B}\,(\mathrm{b} \to \mathrm{s}\gamma) \propto |C_7|^2 + |C_7'|^2$
- CP asymmetry sensitive to $2\mathrm{Im}C_7^{\mathrm{eff}}\ \Delta C_7$
- Photon polarization sensitive to $\frac{C_7'}{C_7}$

Recent LHCb Measurements

Amplitude analysis of $\Lambda_\mathrm{b}^0 \to \mathrm{pK}\gamma$
[JHEP 06 (2024) 098]

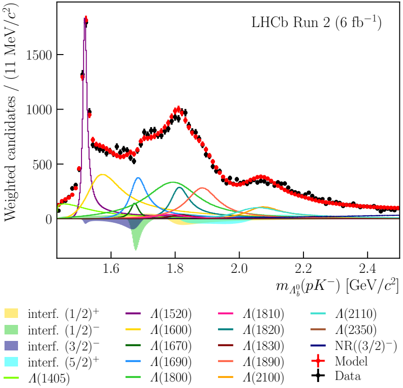
- Studies the composition of the pK spectrum.
- Feeds into interpretations of $\Lambda_\mathrm{b}^0 \to \mathrm{pK}\ell\ell$ decays
- Input to QCD studies

Amplitude analysis of $\mathrm{B}_\mathrm{s}^0 \to \mathrm{K}^+\mathrm{K}^-\gamma$
[JHEP 08 (2024) 093]

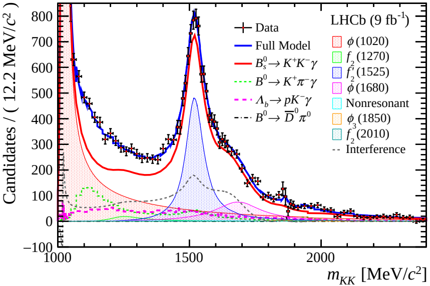
- Studies the composition of $\mathrm{K}^+\mathrm{K}^-$ spectrum
- Measurement of the total tensor contribution $\mathcal{F}_{\{f_2\}} = 16.8 \pm 0.5(stat) \pm 0.7(syst)\%$
- First observation of $\mathrm{B}_\mathrm{s}^0 \to f'_2(1525)\gamma$

Recent LHCb Measurements

Amplitude analysis of $\Lambda_b^0 \to pK\gamma$
[JHEP 06 (2024) 098]



Amplitude analysis of $B_s^0 \to K^+K^-\gamma$
[JHEP 08 (2024) 093]



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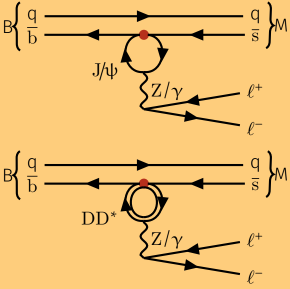
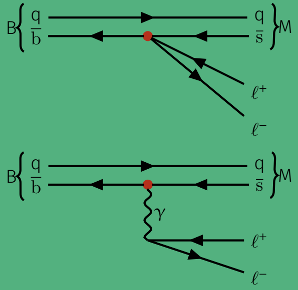
Leptonic Decays

Non-local contributions ($\mathcal{O}_{1q,2q}$)

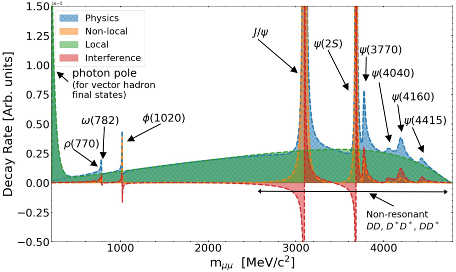
Intermediate states



Local contributions ($\mathcal{O}_{9,10,7}$)



The invariant $m_{\mu\mu}$ spectrum of $B \rightarrow M\mu^+\mu^-$



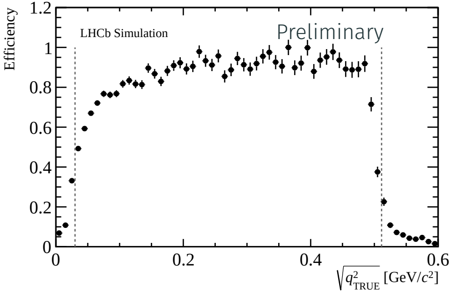
$q^{22}_{\mu\mu}$

Photon Polarisation Measurement using $B_s^0 \to \phi e^+ e^-$

LHCb-PAPER-2024-30
in preparation

NEW

- Fit to $B_s^0 \to \phi e^+ e^-$ in effective $m_{ee} \in [30, 511.37]$ MeV/c^2 using Run1+Run2 (9 fb^{-1}) LHCb data
- Result quoted in effective range due to sharp drops in efficiency at the edges and to allow for theoretical interpretations without simulation input.
  - Follows similar procedure used in the $B^0 \to K^{*0} e^+ e^-$ analysis [JHEP 04 (2015) 064]
- Using $B_s^0 \to \phi\gamma$ as control with γ reconstructed electronically and $m_{ee} < 10$ MeV/c^2

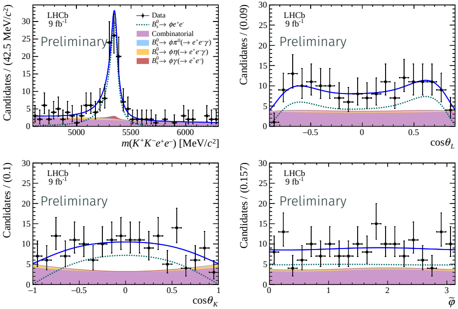


- $A_T^{(2)}$ and $A_T^{\mathcal{I}m CP}$ sensitive to photon polarisation
- $A_T^{\mathcal{R}e CP}$ related to forward-backward asymmetry
- F_L is the longitudinal polarisation

Photon Polarisation Measurement using $B_s^0 \to \phi e^+ e^-$

- A cut of $|cos\theta_l| < 0.9$ imposed to remove $B_s^0 \to D_s^{\mp}(\to \phi e^{\mp}\nu_e) e^{\pm}\nu_e$
- Shape of peaking background component of $B_s^0 \to \phi\gamma$ is extracted from control (m_{KKee}, $\cos\theta_K$) +simulation samples ($\cos\theta_l$, $\tilde{\varphi}$).
- Peaking Backgrounds $B_s^0 \to \phi\eta$ and $B_s^0 \to \phi\pi^0$ modelled from simulation
- Fit with ≈ 100 signal candidates

$$A_T^{(2)} = -0.045 \pm 0.235(stat.) \pm 0.014(syst.)\,,$$
$$A_T^{\mathcal{I}m\mathcal{CP}} = 0.002 \pm 0.247 \pm 0.016\,,$$
$$A_T^{\mathcal{R}e\mathcal{CP}} = 0.116 \pm 0.155 \pm 0.006\,,$$
$$F_L < 11.5\% \text{ at } 90\% \text{ CL}\,.$$



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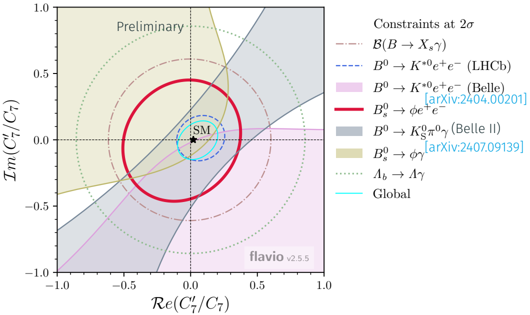
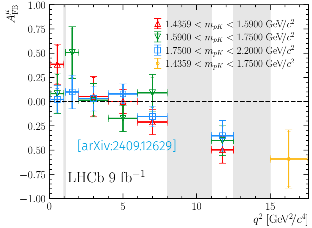


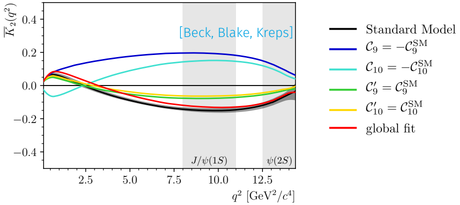
Angular Analysis of $\Lambda_b^0 \to pK^-\mu^+\mu^-$

- Using Run1+Run2 LHCb data of 9 fb^{-1}
- Measured in bins of q^2 and m_{pK}^2 and normalised with $\Lambda_b^0 \to pK^- J/\psi$
- Yields and branching fraction measured from $m_{pK^-\mu^+\mu^-}$
- Decay rate described by 46 angular moments

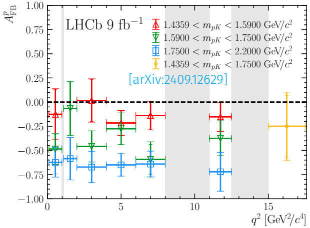
$$\frac{d\Gamma^5}{d\vec{\Phi}} = \frac{3}{8\pi}\sum_{i=0}^{46} K_i(q^2, m_{pK}^2) f(cos\theta_\mu, cos\theta_p, \phi)$$

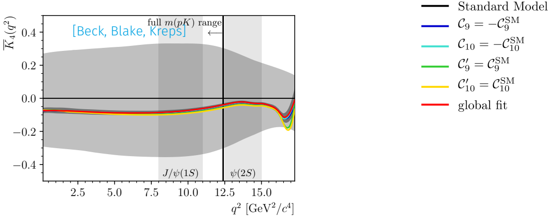
- Forward-backward asymmetry of dimuons sensitive to interference between vector and axial-vector parts. $A_{FB}^{\mu} = \frac{2}{3}\overline{K}_2$
- Similar pattern to what is seen in $B^0 \to K^{*0}\mu^+\mu^-$ decays but consistent with SM (sign change w.r.t mesons due to convention)





Angular Analysis of $\Lambda_b^0 \to pK^-\mu^+\mu^-$



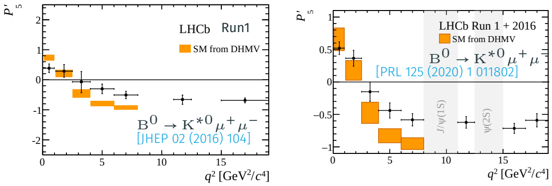


$$A_{FB}^{p} = \frac{3}{2}\overline{K}_4 - \frac{\sqrt{21}}{8}\overline{K}_{10} + \frac{\sqrt{33}}{16}\overline{K}_{16}$$

- Hadronic spectrum qualitatively similar to $\Lambda_b^0 \to pK^-\gamma$ and $\Lambda_b^0 \to pK^-J/\psi$
- Difficult to directly interpret due to unknown interference patterns between the states.
- A more complete understanding of the different contributing states needed.

Angular analyses of $B^0 \to K^{*0}\mu^+\mu^-$

[PRL 125 (2020) 1 011802]



$$\frac{d^4\Gamma(B^0\to K^{*0}\mu^+\mu^-)}{d\vec{\Omega}dq^2} = \sum_i J_i(q^2) f_i(\vec{\Omega})$$

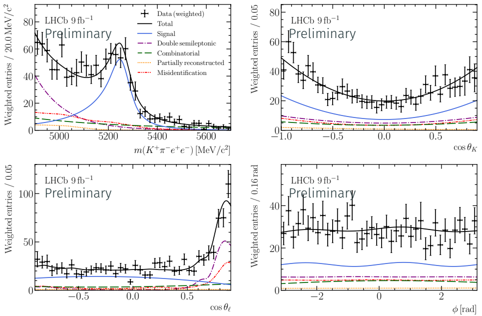
Angular coefficients angular functions

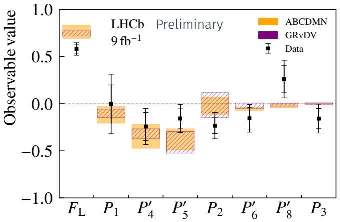
- $J_i(q^2) \propto (\mathcal{A}_\lambda \mathcal{A}^*_\lambda)$, C_i and FF dependent amplitudes.
- Coefficients $P_{1,..,8}$ constructed to cancel form factors to leading order
- Additional nuisance terms introduced for non-resonant S-wave configuration.

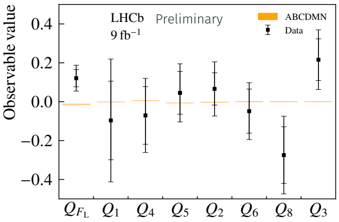
- Global fit to CP averaged observables show deviation with SM change from **3.0σ** to **3.3σ** between **3 fb^{-1}** and **4.6 fb^{-1}**
- Recent preliminary CMS measurement compatible with LHCb [CMS-PAS-BPH-21-002]
- Tensions also seen in $B^+ \to K^{*+}\mu^+\mu^-$ and $B^0_s \to \phi\mu^+\mu^-$ decays
- Large dependence on treatment of SM hadronic effects

Could data help us understand the hadronic effects better?

- Results from fit to $B^0 \to K^{*0}e^+e^-$ in central q^2 ϵ[1.1, 6.0] GeV^2/c^4 using Run1+Run2 (9 fb^{-1}) LHCb data.
- Good agreement seen with SM but similar pattern seen with P_5' as in the muonic mode.
- Construct LFU observables $Q_i = P_i^{\mu} - P_i^{e}$ and refit to data from [PRL 125 (2020) 011802] (consistent S-Wave treatment).
- Results compatible with LFU hypothesis.
  [more on other LFU tests by Sara Celani]







A closer look using $B^0 \to K^{*0}\mu^+\mu^-$ decays

Method 1
Binned

Low model dep.

Work in Progress

- Measure angular observables in q^2 bins
- Update using Run1+Run2 LHCb data

Method 2
Amplitude ansatz

Low model dep.

Work in Progress

- Fit in q^2 regions using a Ansatz $\mathcal{A} = \sum_i \alpha_i L_i(q^2)$
- Extract amplitude components with correlated uncertainties.
- Allows one to recompute any observable and generate synthetic data to study any choice of model.

Discussed Here

Method 3
z Expansion

Med. model dep.

- Fit to q^2 regions using a polynomial to describe the non-local effects.
- Use theoretical and experimental inputs to constrain them.

Method 4
Dispersion

High model dep.

- Unbinned fit to the full q^2 spectrum.
- Use dispersion relations to explicitly model non-local states

z-Expansion Amplitude Form

$$\mathcal{A}_\lambda^{L,R} = \mathcal{N}_\lambda \left\{ \left[(C_9 \pm C_9') \mp (C_{10} \pm C_{10}') \right] \mathcal{F}_\lambda(q^2) + \frac{2 m_b M_B}{q^2} \left[(C_7 \pm C_7') \mathcal{F}_\lambda^T(q^2) - 16\pi^2 \frac{M_B}{m_b} \mathcal{H}_\lambda(q^2) \right] \right\}$$

Wilson Coefficients, C_i

- Real part of C_9, C_9', C_{10} and C_{10}' treated as free fit parameters. Imag. fixed to zero

Local Form Factors, $\mathcal{F}_\lambda(q^2)$

- Constrained to LCSR + Lattice inputs
  [Gubernari, Kokulu & van Dyk] + [Horgan, Liu, Meinel & Wingate]

Non-local hadronic matrix elements (charm-loop), $\mathcal{H}_\lambda(q^2)$

- Exploit analytic properties of hadronic matrix elements,
- Following [Gubernari, Reboud, van Dyk & Virto],

$$q^2 \to z(q^2) \equiv \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}}$$

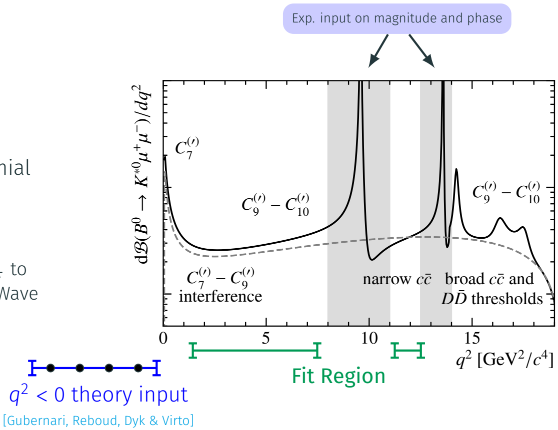
Polarisation
$\lambda \in (\|, \perp, 0)$

$$\mathcal{H}_\lambda(z) = \frac{1 - z z_{J/\psi}}{z - z_{J/\psi}} \frac{1 - z z_{\psi(2S)}}{z - z_{\psi(2S)}} \phi_\lambda^{-1}(z) \sum_k a_{\lambda,k} z^k,$$

- Experimental inputs for magnitudes and phases of resonances [PRD 90 (2014) 112009], [PRD 76 (2007) 031102], [PRD 88 (2013) 074026], [PRD 88 (2016) 052002], [EPJC 72 (2012) 2118]

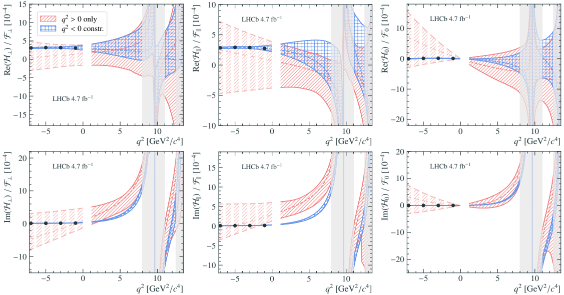
[PRD 109 (2024) 052009]
[PRL 132 (2024) 131801]

- Using 4.7 fb^{-1} of LHCb data (Run1+2016)
- Unbinned fit for FFs, WCs, and non-local polynomial coefficients $a_{\lambda,k}$
- 6D fit to 3 angles, q^2, $m^2(K\pi)$ and $m(K\pi\mu\mu)$
  - → Amplitudes modified to incl. dependence on $m_{K\pi}$ to model P-Wave as relativistic Breit-Wigner and S-Wave with LASS
  - → $m(K\pi\mu\mu)$ modelled with double Crystal Ball
- BF measured relative to $B^0 \to K^+\pi^- J/\psi$



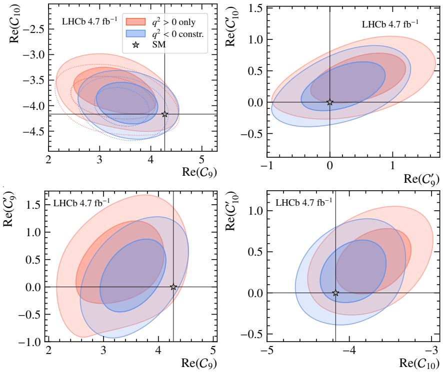
Two versions of fit: **Without** and **with** theory input on non-local component from $q^2 < 0$

[PRD 109 (2024) 052009]
[PRL 132 (2024) 131801]



Good agreement seen between both versions, without and with $q^2 < 0$ theory input

Deviation from SM	ΔC_9	ΔC_{10}	$\Delta C_9'$	$\Delta C_{10}'$
$q^2 > 0$ only	1.9σ	1.5σ	0.9σ	1.5σ
$q^2 < 0$ prior	1.8σ	0.9σ	0.5σ	1.0σ



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Dispersion Amplitude Form

[JHEP 09 (2024) 026]

[Cornella,Isidori,König,Liechti,Owen,Serra]

Non-local effects described as corrections to C_9.

$$C_9 \to C_9^{\text{eff},\lambda} = C_9 + Y_{c\bar{c}}^{(0),\lambda} + \Delta Y_{light}^{1P,\lambda}(q^2) + \Delta Y_{c\bar{c}}^{1P,\lambda}(q^2) + \Delta Y_{c\bar{c}}^{2P,\lambda}(q^2) + Y_{\tau\tau}(q^2)$$

$$C_7^{\text{eff},\lambda} = C_7 + \epsilon^{\lambda} e^{i\omega^0}$$

[Cornella,Isidori,König,Liechti,Owen,Serra]

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$$C_7^{\text{eff},\lambda} = C_7 + \epsilon^{\lambda} e^{i\omega^0}$$

Local Contributions

Wilson Coefficients

Real part of C_9, C_9', C_{10} and C_{10}' treated as free fit parameters.
Imaginary part set to 0, implicitly assumes no CPV in $B \rightarrow K^* \mu^+ \mu^-$ decays
(left for a future measurement)

Polarisation dependent shift

Included as a fit parameter to allow for helicity dependent complex phase

[Cornella,Isidori,König,Liechti,Owen,Serra]

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$$C_9 \rightarrow C_9^{\mathrm{eff},\lambda} = C_9 + Y_{c\bar{c}}^{(0),\lambda} + \Delta Y_{light}^{1P,\lambda}(q^2) + \Delta Y_{c\bar{c}}^{1P,\lambda}(q^2) + \Delta Y_{c\bar{c}}^{2P,\lambda}(q^2) + Y_{\tau\tau}(q^2)$$

$$C_7^{\mathrm{eff},\lambda} = C_7 + \epsilon^{\lambda} e^{i\omega^0}$$

Non-Local Contributions

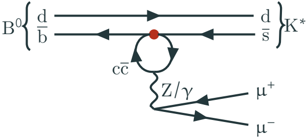
Subtraction term

Theoretically calculated at negative q^2 [Asatrian, Greub, Virto]

Introduced to ensure convergence of dispersion relation.

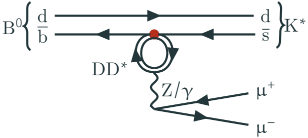
Negligible impact for light resonances

1-particle contributions



Includes vector resonances:
light $\rightarrow$ $\rho(770)$, $\omega(782)$, $\phi(1020)$,
$c\bar{c} \rightarrow J/\psi$, $\psi(2S)$, $\psi(3770)$, $\psi(4040)$, $\psi(4160)$
Mag (except J/ψ) and phase are fit parameters

2-particle contributions



Includes non-resonant:
DD, DD^*, D^*D^*
Real and Imag. parts are fit parameters

[Cornella,Isidori,König,Liechti,Owen,Serra]

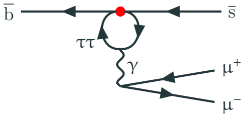
Non-local effects described as corrections to C_9.

$$C_9 \to C_9^{\text{eff},\lambda} = C_9 + Y_{c\bar{c}}^{(0),\lambda} + \Delta Y_{light}^{1P,\lambda}(q^2) + \Delta Y_{c\bar{c}}^{1P,\lambda}(q^2) + \Delta Y_{c\bar{c}}^{2P,\lambda}(q^2) + Y_{\tau\tau}(q^2)$$

$$C_7^{\text{eff},\lambda} = C_7 + \epsilon^{\lambda} e^{i\omega^0}$$

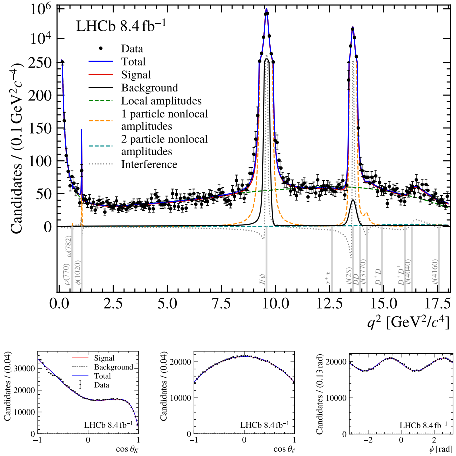
Non-Local Contributions

Tau-scattering contribution



Wilson C_9^{τ} is fit parameter
gives indirect access to BF($B^0 \to K^* \tau^+ \tau^-$)

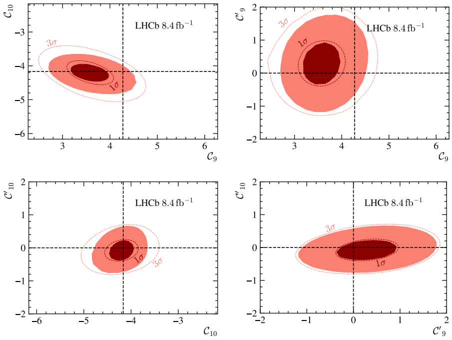
Unbinned fit to full q^2 using 8.4 fb^{-1} (2011+2012, 2016+2017+2018) LHCb data



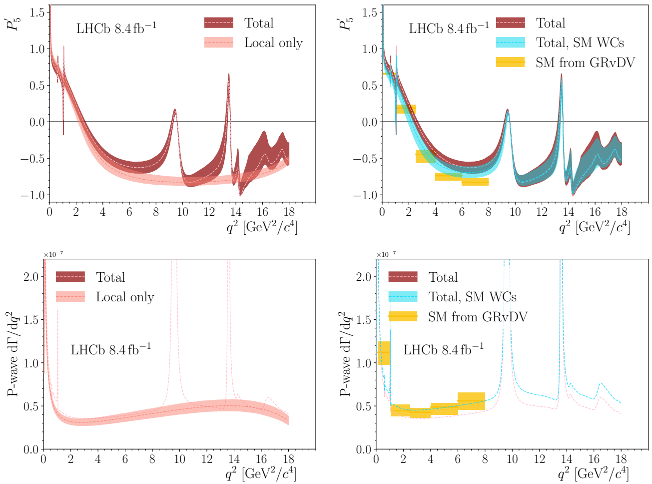
	ΔC_9	ΔC_{10}	$\Delta C_9'$	$\Delta C_{10}'$	C_9^τ
Deviation from SM	2.1σ	0.6σ	0.7σ	0.4σ	0.4σ

$|C_9^\tau| < 500$ at 90% C.L., $C_9^{\tau,SM} \sim 4$

Current best limits $|C_9^\tau| < 680$ (600) at 90% C.L. $C_{10}^\tau = SM$ ($C_{10}^\tau = -C_9^\tau$)
[PRD 108, L011102 (2023)], flavio



[JHEP 09 (2024) 026]



- Modification of differential observable from non-local state
- Cyan band on right calculated by fixing WC to SM values and non-local from data.
- Data seem to prefer non-local values larger than SM prediction
- Nevertheless, Wilson C_9 still prefers a shifted value w.r.t SM (indicated by the **Total** band)
- Missing other non-local components eg. $B \to D^* D_s^+ \to K^* \mu\mu$?. [Ciuchini et al.]

A similar measurement with $B^+ \to K^+ \mu^+ \mu^-$ in progress

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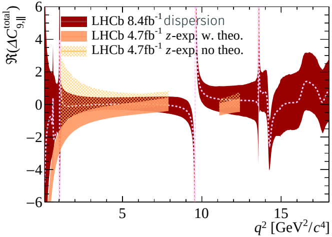
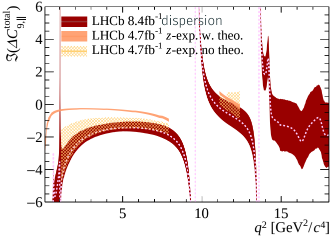
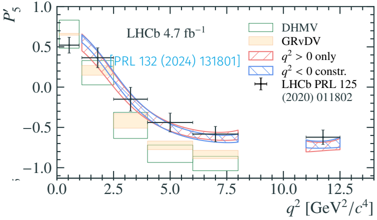
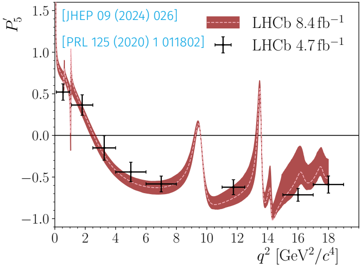
Compatibility of $B^0 \to K^{*0}\mu^+\mu^-$ Analyses

- Polarisation dependent amplitude of non-local states (eg. ||)
- Good agreement seen between the two analyses.









- Comparison of P'_5 with binned analysis (black points)
- Good agreement between the different analyses

Data consistently prefers a deviation from SM

Conclusion

- The study of FCNC B decays is an important research topic at LHCb.
- Amplitude and angular measurements of such decays offer a wide and complimentary information.
- Many measurements statistically dominated, however for our most sensitive probes the systematics are becoming more and more important.
- Currently some dominant systematics are external (normalisation mode and form factor).
- Theory inputs on local and non-local form factors crucial for measurements and interpretations. [see talk by Arianna and Martin]

What can be done from experiment side to help extract C_9^{NP} accurately?

Interpretations of old measurements becomes difficult with updates to model
How could we work together to address this issue?

Thanks for your attention!

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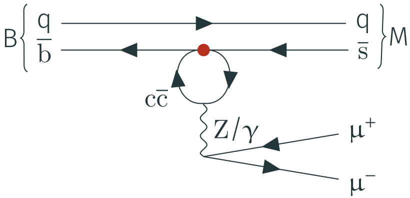
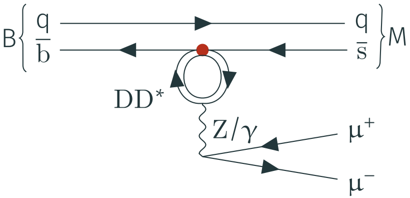
Backup

Non-local charm-loop effects

Experimentally can mimic NP and difficult to estimate theoretically





Can we measure these non-local effects from data?

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Angular Analysis of $B_s^0 \to \phi e^+ e^-$ in low q^2

[LHCb-PAPER-2024-30] NEW
in preparation

$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\cos\theta_L\,\mathrm{d}\cos\theta_K\,\mathrm{d}\tilde{\varphi}} = \frac{9}{32\pi}\Big\{\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K$$
$$+\left[\frac{1}{4}(1-F_L)\sin^2\theta_K - F_L\cos^2\theta_K\right]\cos 2\theta_L$$
$$+\frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_L\cos 2\tilde{\varphi}$$
$$+(1-F_L)A_T^{\mathcal{R}e CP}\sin^2\theta_K\cos\theta_L$$
$$+\frac{1}{2}(1-F_L)A_T^{\mathcal{I}m CP}\sin^2\theta_K\sin^2\theta_L\sin 2\tilde{\varphi}\Big\}\,.$$

$$\lim_{q^2\to 0} A_{\mathrm{T}}^{(2)}(q^2) = \frac{2\left[\mathcal{R}e[C_7]\mathcal{R}e[C_7'] + \mathcal{I}m[C_7]\mathcal{I}m[C_7'] + \frac{y}{2}[(\mathcal{R}e[C_7])^2 - (\mathcal{I}m[C_7])^2]\right]}{(\mathcal{R}e[C_7])^2 + (\mathcal{I}m[C_7])^2}\,, \quad (1)$$

$$\lim_{q^2\to 0} A_{\mathrm{T}}^{\mathcal{I}m CP}(q^2) = \frac{2\left[\mathcal{R}e[C_7]\mathcal{I}m[C_7'] - \mathcal{I}m[C_7]\mathcal{R}e[C_7'] - y\mathcal{R}e[C_7]\mathcal{I}m[C_7]\right]}{(\mathcal{R}e[C_7])^2 + (\mathcal{I}m[C_7])^2}\,, \quad (2)$$

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Angular Analysis of $B_s^0 \to \phi e^+ e^-$ in low q^2

[LHCb-PAPER-2024-30] NEW
in preparation

Source of systematic	$A_T^{(2)}$	$A_T^{\mathcal{I}m CP}$	$A_T^{\mathcal{R}e CP}$	F_L
$\Delta\Gamma_s/\Gamma_s$	0.008	< 0.001	< 0.001	< 0.001
Corrections to simulation	0.002	<0.001	<0.001	0.010
Acceptance function modelling	<0.001	<0.001	0.001	0.002
Simulation sample size for acceptance	0.006	0.008	0.005	0.002
Background contamination	0.009	0.014	0.004	0.006
Angles resolution	-0.005	< 0.001	-	-
Total systematic uncertainty	0.014	0.016	0.006	0.012
Statistical uncertainty	0.235	0.247	0.155	+0.056

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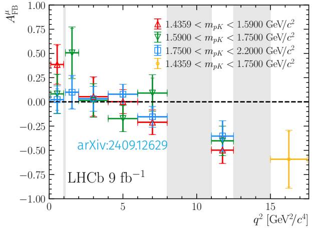
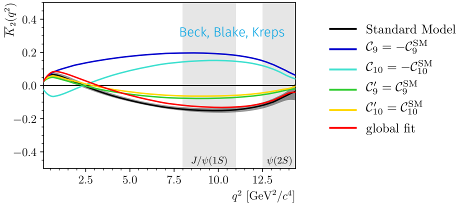
Angular Analysis of $\Lambda_b^0 \to pK^-\mu^+\mu^-$

[LHCb-PAPER-2024-24]
arXiv: 2409.12629

- Yields and branching fraction measured from $m_{pK^-\mu^+\mu^-}$
- The sPlot technique is used derive weights to separate signal and background.
- With further efficiency corrections moments derived from weighted sum over basis functions.

$$\overline{K}_i = \frac{1}{N}\sum_{\text{event n}} w(\vec{\Phi}_n) f_i(\vec{\Omega}_n)$$





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Angular Analysis of $B^0 \to K^{*0} e^+ e^-$ in central q^2

[LHCb-PAPER-2024-22]
in preparation

$1.1 < q^2 < 6.0\ \mathrm{GeV}^2/c^4$				$1.1 < q^2 < 6.0\ \mathrm{GeV}^2/c^4$	
F_{L}	$0.58 \pm 0.05 \pm 0.05$	F_L	$0.58 \pm 0.04 \pm 0.05$	$Q_{F_{\mathrm{L}}}$	$0.12 \pm 0.05 \pm 0.05$
S_3	$-0.00 \pm 0.04 \pm 0.02$	P_1	$-0.00 \pm 0.20 \pm 0.24$	Q_1	$-0.10 \pm 0.26 \pm 0.24$
S_4	$-0.12 \pm 0.07 \pm 0.04$	P'_4	$-0.24 \pm 0.15 \pm 0.12$	Q_4	$-0.07 \pm 0.17 \pm 0.12$
S_5	$-0.08 \pm 0.05 \pm 0.03$	P'_5	$-0.16 \pm 0.11 \pm 0.10$	Q_5	$0.05 \pm 0.13 \pm 0.10$
A_{FB}	$-0.15 \pm 0.05 \pm 0.04$	P_2	$-0.23 \pm 0.08 \pm 0.11$	Q_2	$0.07 \pm 0.10 \pm 0.11$
S_7	$-0.08 \pm 0.06 \pm 0.04$	P'_6	$-0.16 \pm 0.11 \pm 0.09$	Q_6	$-0.05 \pm 0.14 \pm 0.09$
S_8	$0.13 \pm 0.07 \pm 0.06$	P'_8	$0.26 \pm 0.15 \pm 0.14$	Q_8	$-0.28 \pm 0.17 \pm 0.14$
S_9	$0.07 \pm 0.05 \pm 0.02$	P_3	$-0.16 \pm 0.11 \pm 0.11$	Q_3	$0.22 \pm 0.14 \pm 0.11$

Preliminary results. First error statistical

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z-expansion analysis of $B^0 \to K^{*0}\mu^+\mu^-$ systematics

[PRD 109 (2024) 052009]
[PRL 132 (2024) 131801]

	Systematic uncertainties			
	$\mathcal{C}_9$	$\mathcal{C}_{10}$	$\mathcal{C}'_9$	$\mathcal{C}'_{10}$
Amplitude model				
S-wave form factors	< 0.01	< 0.01	< 0.01	< 0.01
S-wave non-local hadronic	0.02	0.02	0.14	0.04
S-wave $m_{K\pi}$				
[i] LASS parameters	< 0.01	< 0.01	< 0.01	< 0.01
[ii] $m_{K\pi}$ model	< 0.01	< 0.01	0.05	0.03
Exotic states on hadronic inputs	0.01	< 0.01	0.02	< 0.01
Total	**0.02**	**0.02**	**0.15**	**0.05**
External inputs on BR				
$\mathcal{B}(B \to J/\psi K^+\pi^-)$	0.05	0.08	0.02	0.01
Fraction of $B \to J/\psi K^+\pi^-$ in $m_{K\pi} \in$100 MeV	0.03	0.03	0.01	< 0.01
Others	0.03	0.04	0.03	0.01
Total	**0.07**	**0.09**	**0.04**	**0.01**
Background model				
Chebyshev polynomial order	0.01	0.01	0.01	< 0.01
Combinatorial shape on $m_{K\pi}$	0.02	< 0.01	0.02	< 0.01
Background factorisation	0.01	0.01	0.01	0.01
Peaking background	0.01	< 0.01	0.02	0.01
Total	**0.03**	**0.02**	**0.03**	**0.01**
Experimental effects				
Acceptance parametrisation	< 0.01	< 0.01	< 0.01	< 0.01
Statistical uncertainty on acceptance	0.02	< 0.01	0.02	< 0.01
Total	**0.02**	**< 0.01**	**0.02**	**< 0.01**
Total systematic uncertainty	**0.08**	**0.10**	**0.16**	**0.05**

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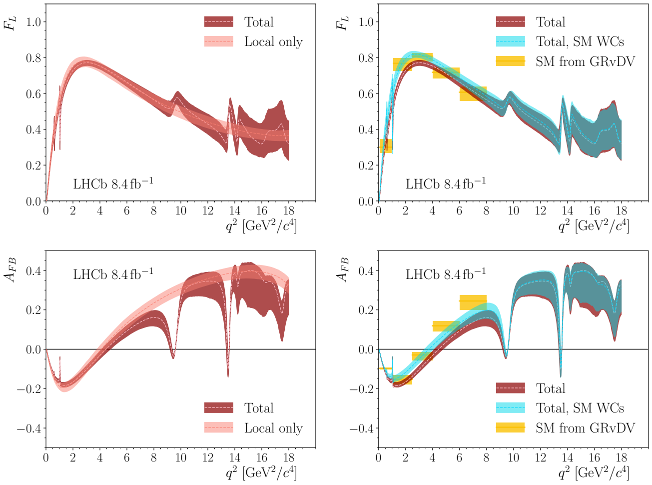
Dispersion, Impact of non-local

[JHEP 09 (2024) 026]



- Modification of differential observable from non-local state
- Cyan band on right calculated by fixing WC to SM values and non-local from data.
- Data seem to prefer non-local values larger than SM prediction
- Nevertheless, Wilson C_9 still prefers a shifted value w.r.t SM (indicated by the Total band)

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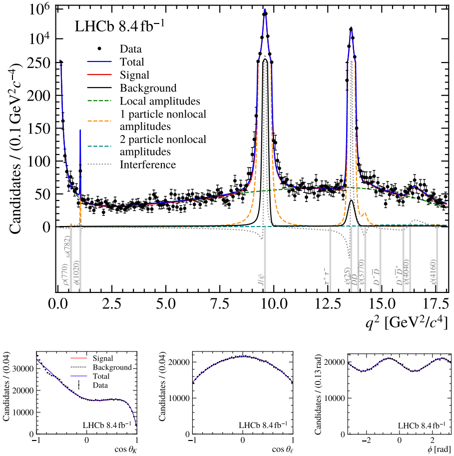
Dispersion Fit Result

[JHEP 09 (2024) 026]

Unbinned fit to full q^2 using 8.4 fb^{-1} (2011+2012, 2016+2017+2018) LHCb data



- Total 150 fit parameters
- From simulation:
  - → Acceptance model
- From data:
  - → Resolution
  - → S-Wave Parameters
  - → Background model
  - → Non-local states
- From theory
  - → Local $B \to K^*$ form factors gaussian constrained [Gubernari, Reboud, van Dyk & Virto]
  - → Subtraction point for $c\bar{c}$ [Asatrian, Greub & Virto]

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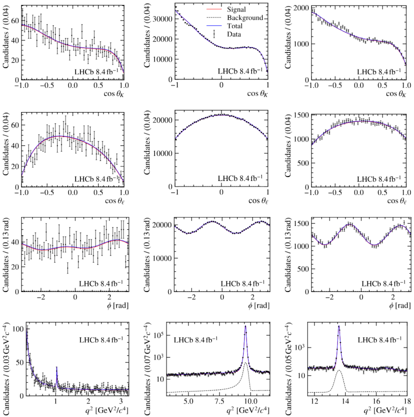
Dispersion Fit Result

[JHEP 09 (2024) 026]



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Dispersion analysis of $B^0 \to K^{*0} \mu^+ \mu^-$ dominant systematics

[JHEP 09 (2024) 026]

	Branch.	Exotic		Model		
Variable	Frac.	$\psi(2S)$	J/ψ	$D\bar{D}$	$\psi(4160)$	$\psi(3770)$
$\lvert C_9 \rvert$	45.37%	8.45%	10.71%	24.53%	2.55%	3.77%
$\lvert C_{10} \rvert$	86.20%	3.78%	9.63%	4.46%	0.99%	1.51%
$Re(C'_9)$	3.85%	13.32%	20.32%	7.10%	5.07%	6.39%
$Re(C'_{10})$	6.81%	17.63%	22.11%	7.65%	0.80%	2.29%
$Re(C_9^{\tau})$	4.93%	15.70%	12.29%	30.56%	1.50%	9.42%

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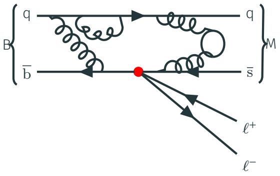
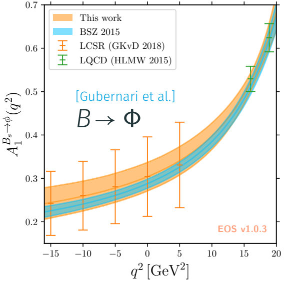
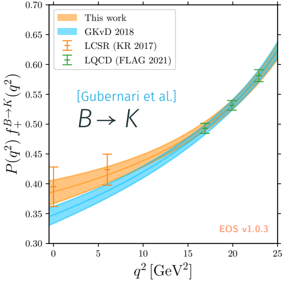
Local Hadronic effects



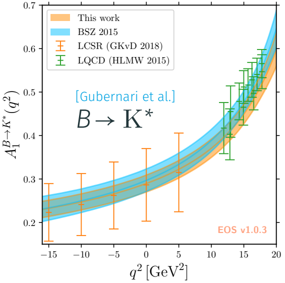




The form factors are difficult to calculate and leading source of theoretical uncertainty.
Two complimentary approaches,

- Lattice QCD in high q^2 region (low hadronic recoil) [HPQCD], [FNAL/MILC]
- Light Cone Sum Rules in low or -ve q^2 region [Gubernari et al.], [Khodjamirian and Rusov], [Bharucha, Bharucha and Zwicky], [Khodjamirian et al.]

Interpolate to full q^2



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