

Flavour Changing Neutral Current decays at LHCb



C. Langenbruch¹
on behalf of the LHCb collaboration

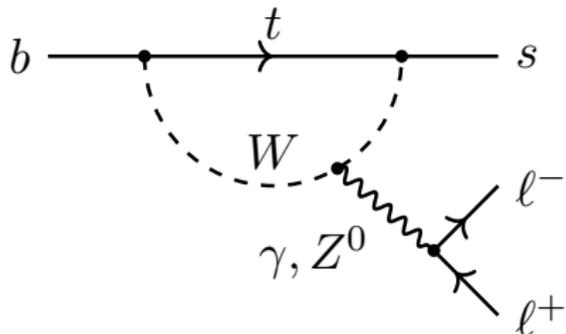
¹Heidelberg University

Moriond Electroweak 2026
La Thuile, March 16th 2026

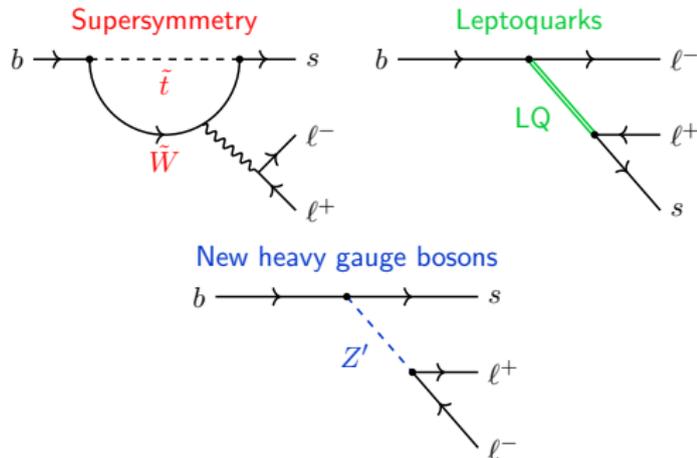


FCNC decays as sensitive probes for New Physics

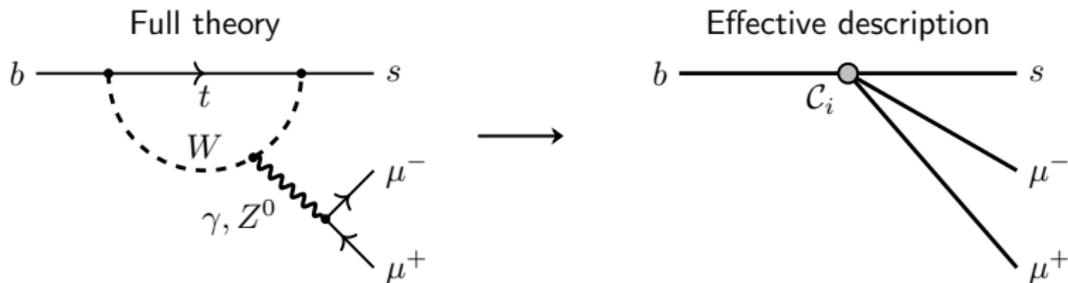
$b \rightarrow s\ell\ell$ decays in the SM



Possible contributions from NP



- FCNC decays heavily (loop-)suppressed in the SM
- New heavy particles can significantly contribute and affect decay rates, angular distributions, and rate asymmetries

Rare B decays in effective field theory

- Model-independent description in effective field theory

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i C_i \mathcal{O}_i$$

Annotations: C_i is the Wilson coefficient ("effective coupling"). \mathcal{O}_i is the Local operator.

$$\Delta\mathcal{H}_{\text{NP}} = \frac{\kappa}{\Lambda_{\text{NP}}^2} \mathcal{O}_i$$

Annotations: κ is the Flavour-violating coupling. Λ_{NP}^2 is the NP scale.

- Rare B decays allow to probe several operators $\mathcal{O}_i^{(\text{NP})}$
- Λ_{NP} up to $\mathcal{O}(100 \text{ TeV})$ reachable [JHEP 11 (2014) 121]

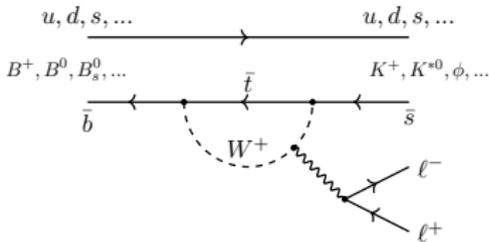
	Wilson coefficient	Operator
γ -penguin ¹	$C_7^{(\ell)}$	$\frac{e}{g^2} m_b (\bar{s} \sigma_{\mu\nu} P_{R(L)} b) F^{\mu\nu}$
ew. penguin	$C_9^{(\ell)}$	$\frac{e^2}{g^2} (\bar{s} \gamma_\mu P_{L(R)} b) (\bar{\mu} \gamma^\mu \mu)$
	$C_{10}^{(\ell)}$	$\frac{e^2}{g^2} (\bar{s} \gamma_\mu P_{L(R)} b) (\bar{\mu} \gamma^\mu \gamma_5 \mu)$
scalar	$C_S^{(\ell)}$	$\frac{e^2}{16\pi^2} m_b (\bar{s} P_{R(L)} b) (\bar{\mu} \mu)$
pseudoscalar	$C_P^{(\ell)}$	$\frac{e^2}{16\pi^2} m_b (\bar{s} P_{R(L)} b) (\bar{\mu} \gamma_5 \mu)$

$b \rightarrow s\gamma$
 $b \rightarrow s\ell\ell$
 $B^0 \rightarrow \mu^+ \mu^-$

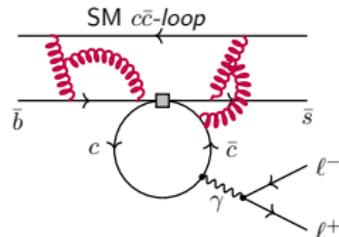
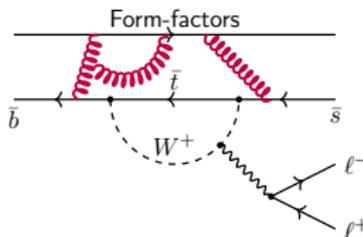


Observables in rare $b \rightarrow sl\ell$ decays and their cleanliness

Quarks bound in hadrons, e.g.



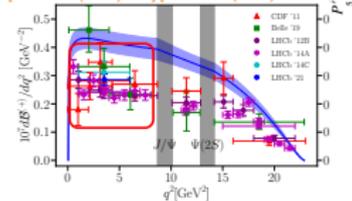
Hadronic uncertainties



$b \rightarrow sl\ell$ Observables

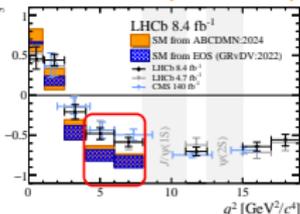
Increasing precision of SM prediction

[JHEP 06 (2014) 133] [PRD 107 (2023) 014511]



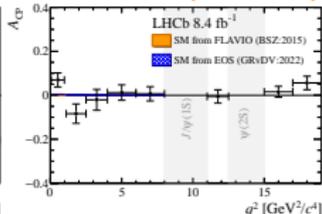
Branching fractions
affected by form-factors
and $c\bar{c}$ -loop

[arXiv:2512.18053]

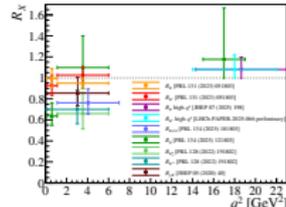


Angular observables
affected by $c\bar{c}$ -loop

[arXiv:2512.18053]

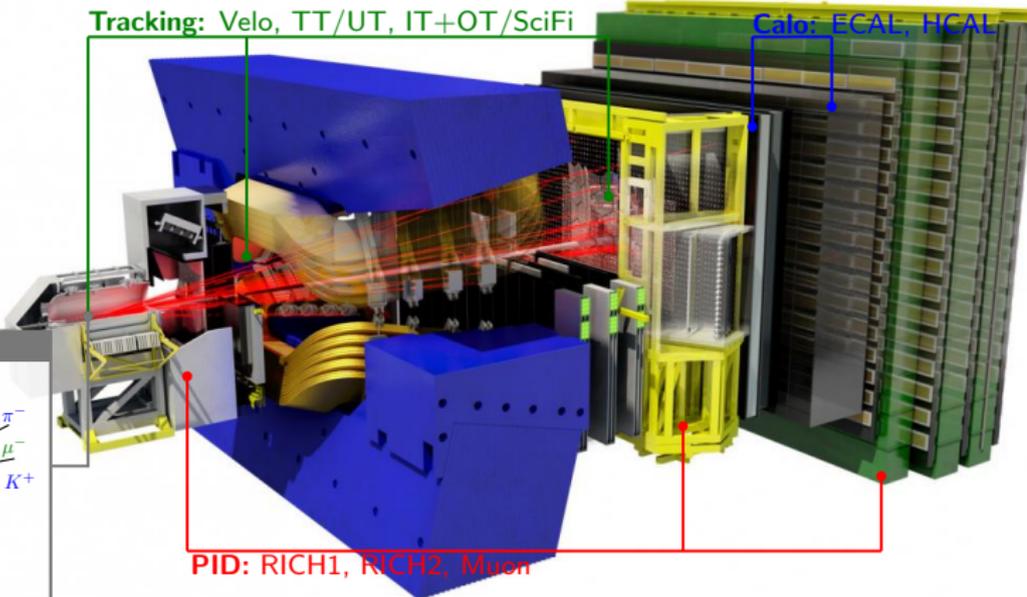
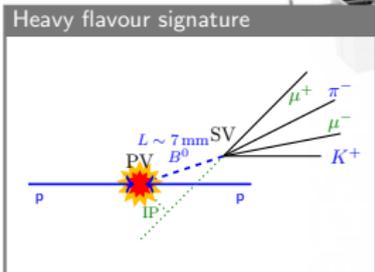
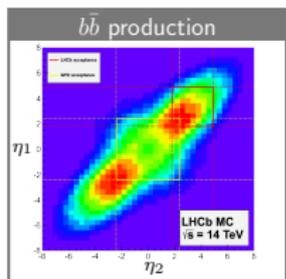


CP-asymmetries
clean



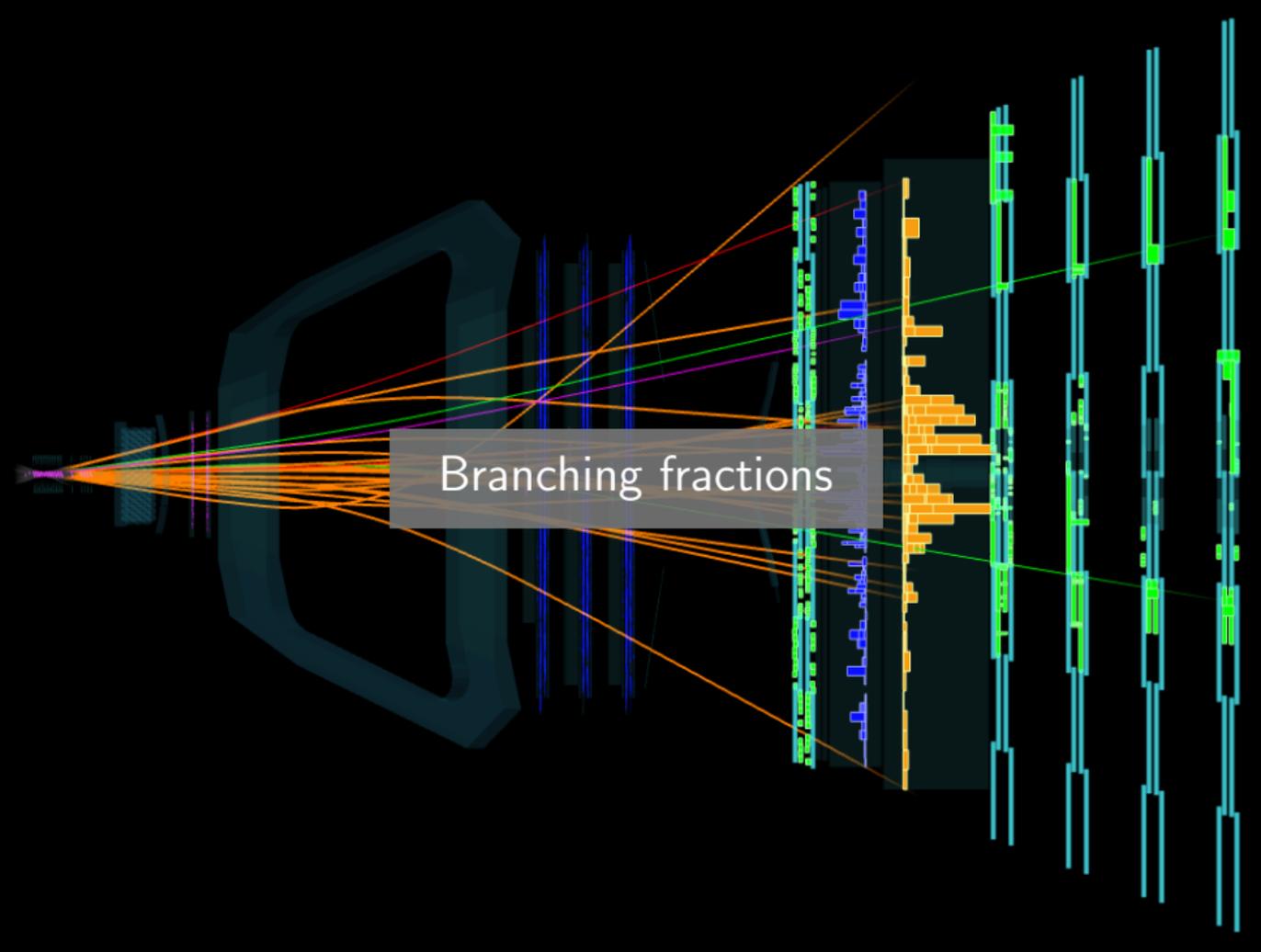
Lepton Universality Tests
clean

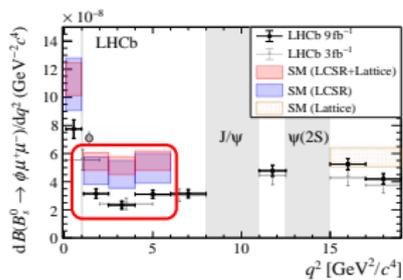
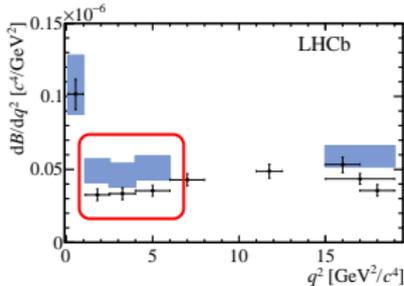
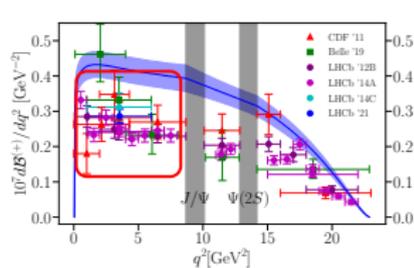
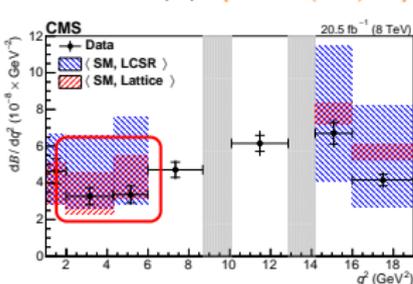
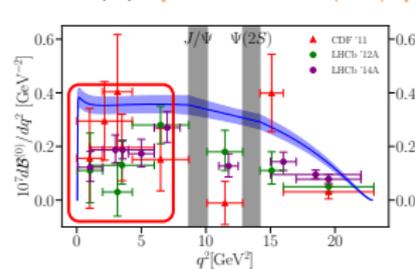
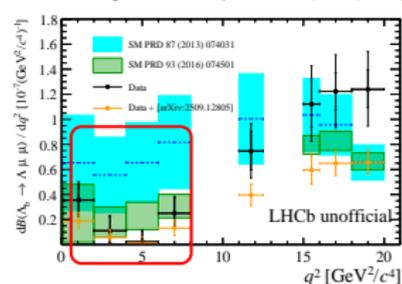
The LHCb detector: Optimized for heavy flavour



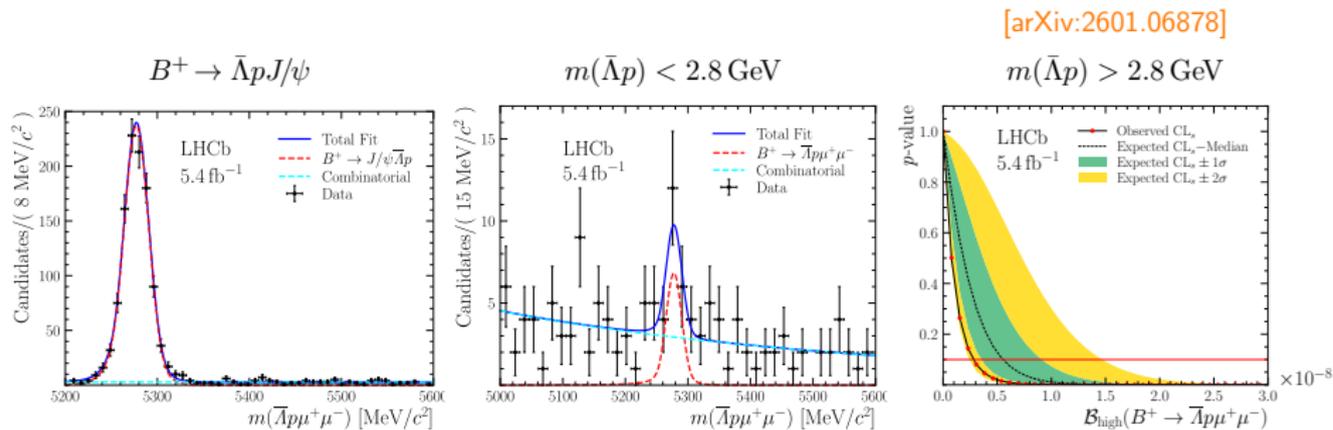
- Large $\sigma_{b\bar{b}}$: $(495 \pm 52) \mu\text{b}$ at 13 TeV [JHEP 10 (2015) 172] predominantly in forward direction \Rightarrow single-arm forward spectrometer with unique $2 < \eta < 5$ coverage [LJMP A30 (2015) 1530022] [JINST 19 (2024) P05065]
- Excellent IP resolution $\sim 20 \mu\text{m}$ to identify B decay vertices, $\Delta p/p = 0.5 - 1\%$
- Particle identification: $\epsilon_{K \rightarrow K} \sim 95\%$, $\epsilon_{\pi \rightarrow K} \sim 5\%$ and $\epsilon_{\mu \rightarrow \mu} \sim 97\%$, $\epsilon_{\pi \rightarrow \mu} \sim 1 - 3\%$
- Low trigger thresholds \rightarrow high ϵ_{sig} , Full software trigger in Run 3 at 40 MHz

Branching fractions



Consistently low \mathcal{B} found for $b \rightarrow s \mu^+ \mu^-$ decaysLHCb $B_s^0 \rightarrow \phi \mu^+ \mu^-$ [PRL 127 (2021) 151801]LHCb $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ [JHEP 11 (2016) 047] $B^+ \rightarrow K^+ \mu^+ \mu^-$ [HPQCD, PRD 107 (2023) 1]CMS $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ [PLB 753 (2016) 424] $B^0 \rightarrow K^0 \mu^+ \mu^-$ [HPQCD, PRD 107 (2023) 1]LHCb $\Lambda_b^0 \rightarrow \Lambda \mu^+ \mu^-$ [JHEP 06 (2015) 115]

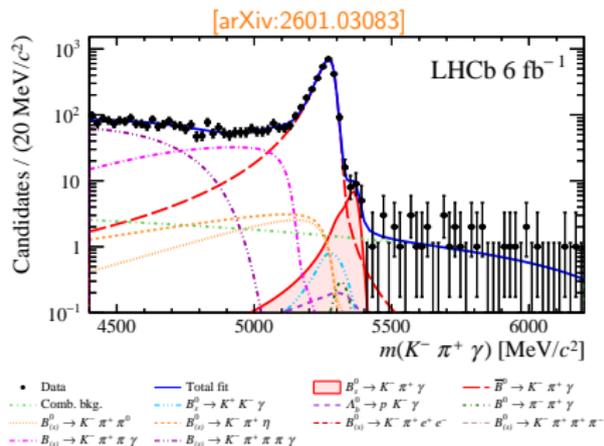
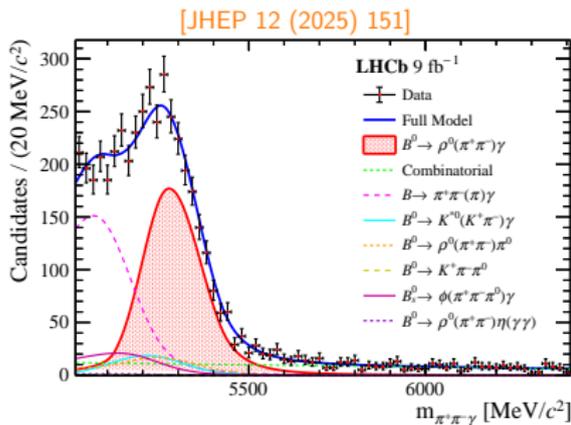
- Data consistently below SM predictions, tensions at $1-3\sigma$ level but significant hadronic uncertainties from form-factors and charm-loop
- Important results from Lattice QCD [HPQCD, PRD 107 (2023) 1]
- $\mathcal{B}(\Lambda_b^0 \rightarrow J/\psi \Lambda)$ update $(6.3 \pm 1.3) \times 10^{-4}$ to $(3.34 \pm 0.31) \times 10^{-4}$ [arXiv:2509.12805] Nb. [PRD 101 (2020) 035023] derived $(3.7 \pm 1.0) \times 10^{-4}$ using f_{Λ_b} from Tevatron only

Evidence for $B^+ \rightarrow \bar{\Lambda}p\mu^+\mu^-$ 

- $b \rightarrow s\mu^+\mu^-$ meson decay with baryonic final state, norm. to $B^+ \rightarrow \bar{\Lambda}pJ/\psi$
- Studied in two regions $m(\bar{\Lambda}p) < 2.8$ GeV and $m(\bar{\Lambda}p) > 2.8$ GeV:
 $\mathcal{B}_{m(\bar{\Lambda}p) < 2.8 \text{ GeV}} = (1.70^{+0.65}_{-0.56} \pm 0.17 \pm 0.14) \times 10^{-8}$ (3.5σ significance)
 $\mathcal{B}_{m(\bar{\Lambda}p) > 2.8 \text{ GeV}} < 2.8 \times 10^{-9}$ at 90% CL
- In agreement with, but 2σ below SM prediction
 $1.08^{+0.82}_{-0.51} \times 10^{-7}$ [JPG 41 (2014) 065002]

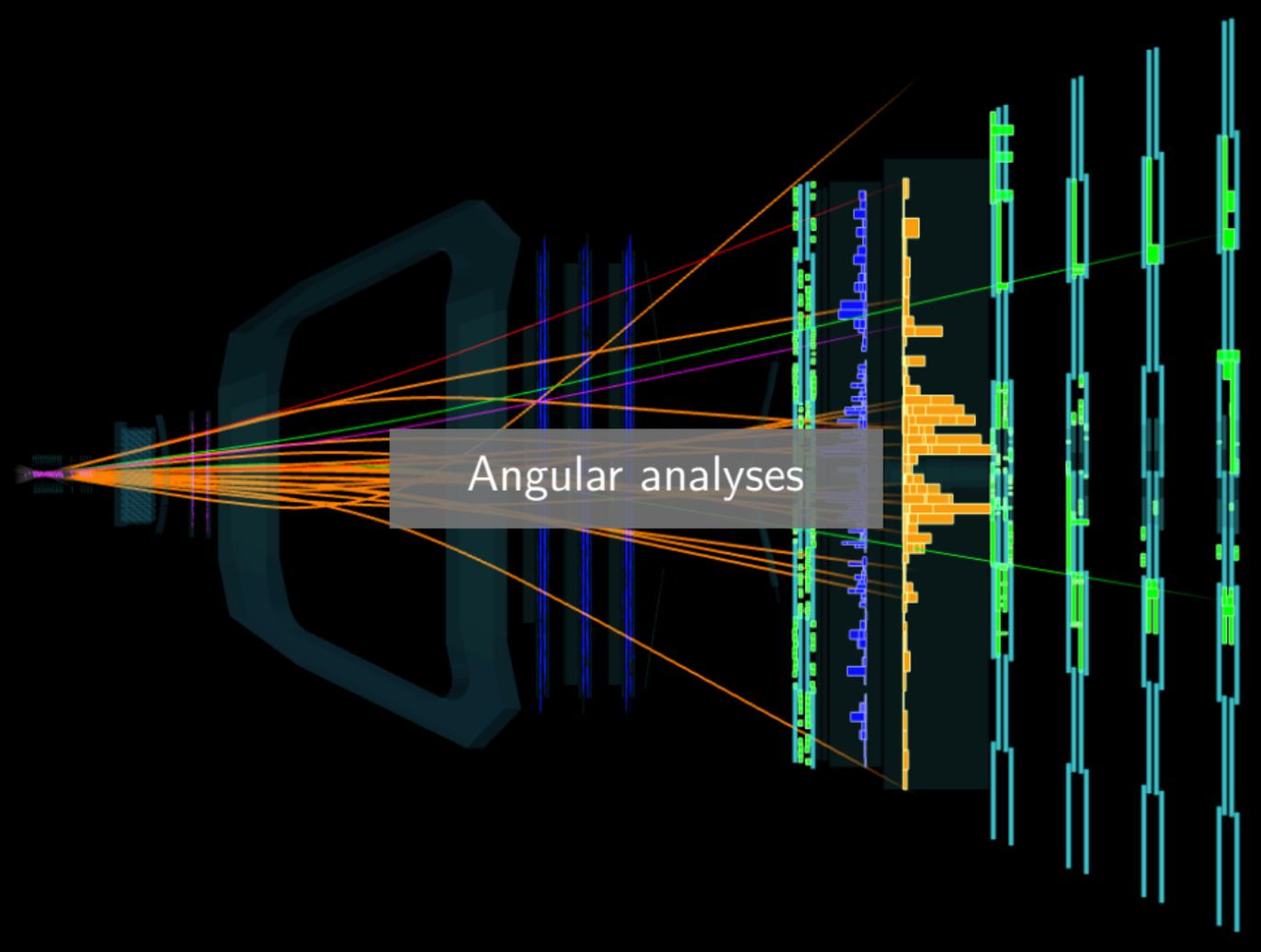
Branching fractions of $B^0 \rightarrow \rho \gamma$ and $B_s^0 \rightarrow K^- \pi^+ \gamma$

- Both $B^0 \rightarrow \rho^0 \gamma$ and $B_s^0 \rightarrow K^- \pi^+ \gamma$ highly suppressed $b \rightarrow d \gamma$ decays
- Sensitive to $\frac{V_{td}}{V_{ts}}$ when normalised to $b \rightarrow s \gamma$ decays (e.g.. $B^0 \rightarrow K^{*0} \gamma$)



- $\frac{\mathcal{B}(B^0 \rightarrow \rho^0 \gamma)}{\mathcal{B}(B^0 \rightarrow K^{*0} \gamma)} = 0.0189 \pm 0.0007 \pm 0.0005$
 $\mathcal{B}(B^0 \rightarrow \rho^0 \gamma) = (7.9 \pm 0.3 \pm 0.2 \pm 0.2) \times 10^{-7}$
- Consistent with world average and world's most precise

- Uses $\gamma \rightarrow e^+ e^-$ conversions for better resolution
- Signal excess corresponding to 3.5σ
- $\frac{\mathcal{B}(B^0 \rightarrow K^- \pi^+ \gamma)}{\mathcal{B}(\bar{B}^0 \rightarrow K^- \pi^+ \gamma)}$ (low $m_{K\pi}$) = $(3.7 \pm 1.2 \pm 0.4) \times 10^{-2}$
- $\frac{\mathcal{B}(B^0 \rightarrow K^- \pi^+ \gamma)}{\mathcal{B}(\bar{B}^0 \rightarrow K^- \pi^+ \gamma)}$ (high $m_{K\pi}$) = $(0.2 \pm 2.7 \pm 1.3) \times 10^{-2}$
- In agreement with SM expectation



Angular analyses

Raw detector output

Event reconstruction

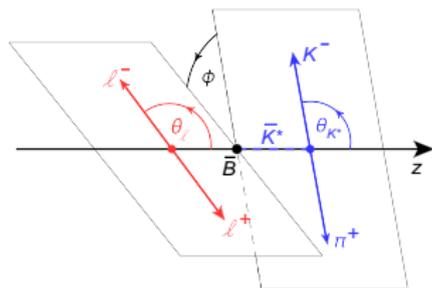
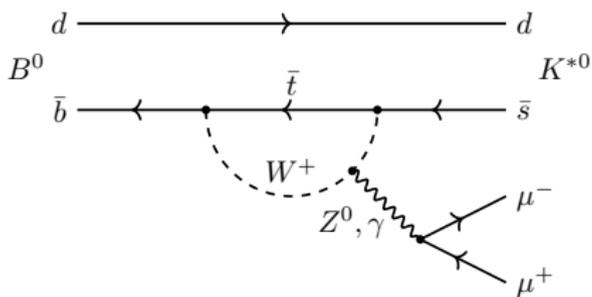
Angular distributions

Angular distributions

Angular distributions

Angular distributions

Angular distributions

Angular analysis of $B^0 \rightarrow K^{*0}[\rightarrow K^+\pi^-]\mu^+\mu^-$ 

- Described by 5 DoF: helicity angles $\vec{\Omega} = (\theta_\ell, \theta_K, \phi)$, $q^2 = m_{\mu\mu}^2$ and $m_{K\pi}$
- Fit of 5D PDF to determine CP -symmetries S_i and CP -asymmetries A_i

$$\frac{1}{d(\Gamma + \bar{\Gamma})/dq^2} \frac{d^5 \bar{\Gamma}}{dq^2 dm_{K\pi} d\vec{\Omega}} = (1 - \hat{F}_S) \frac{9}{64\pi} \sum_i (S_i \pm A_i) f_i(\vec{\Omega}) |\mathcal{B}W_P(m_{K\pi})|^2 \quad \text{P-wave}$$

$$+ \frac{1}{8\pi} \sum_j (\tilde{S}_j \pm \tilde{A}_j) f_j(\vec{\Omega}) F(m_{K\pi}) \quad \text{S-wave+interference}$$

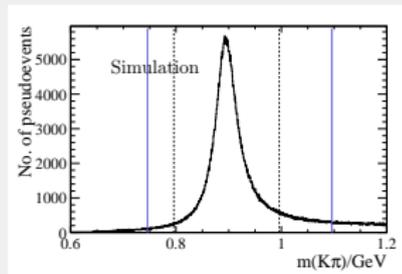
- In full generality 52 observables per q^2 bin
- Perform ratios of observables where **form factors** cancel at leading order

Example: $P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}} \quad \left[\text{S. Descotes-Genon et al., JHEP, 05 (2013) 137} \right]$

Legacy Run 1+2 $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ analysis

More data

- Full Run 1+2 data: $4.7 \text{ fb}^{-1} \rightarrow 8.4 \text{ fb}^{-1}$
Signal yield: $\sim 4600 \rightarrow 12\,400$
- Larger $m_{K\pi}$ mass window and more optimised selection



More observables

- P-wave, S-wave+interference observables, as well as CP -asymmetries
- Provide branching fraction measurement and full set of correlations
- In addition to nominal $\sim 2 \text{ GeV}^2$ wide bins use finer $\sim 1 \text{ GeV}^2$ binning

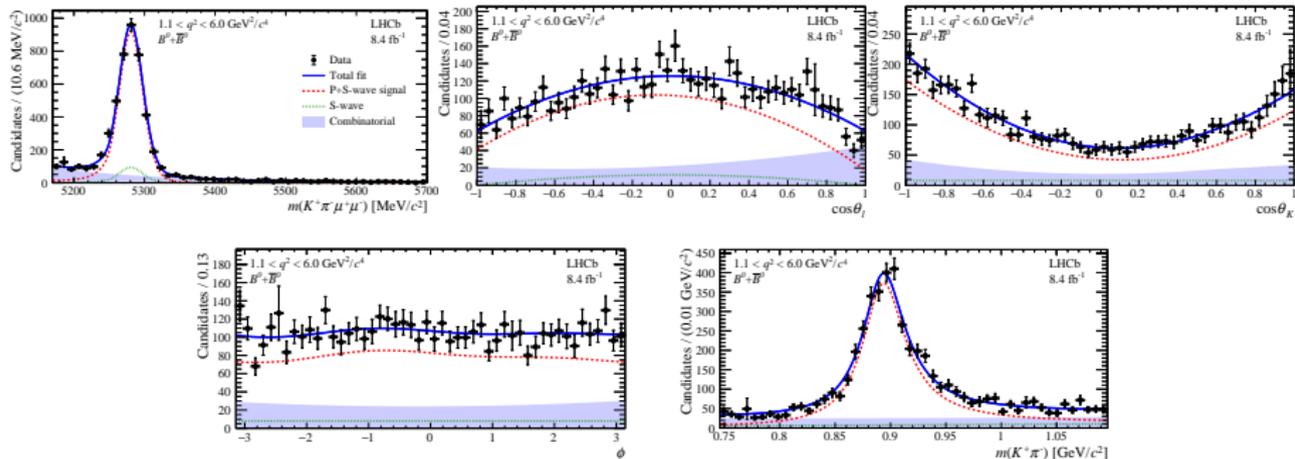
Fewer assumptions

- No longer assume massless leptons throughout
- Branching fraction extracted without model assumptions

Example fit projection

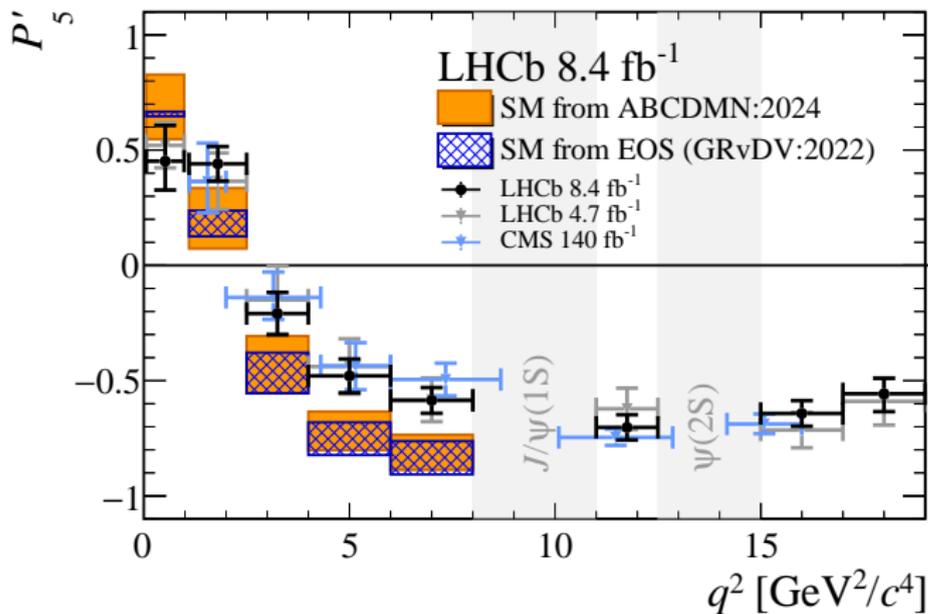
[arXiv:2512.18053]

- Fit projections of the five dimensions for $1.1 < q^2 < 6 \text{ GeV}^2$
- Goodness of fit checked in 5D using BDT [arXiv:1612.07186] and Point-to-point dissimilarity test [JINST 5 (2010) P09004]



Results: P_5'

[arXiv:2512.18053]



ABCDMN:

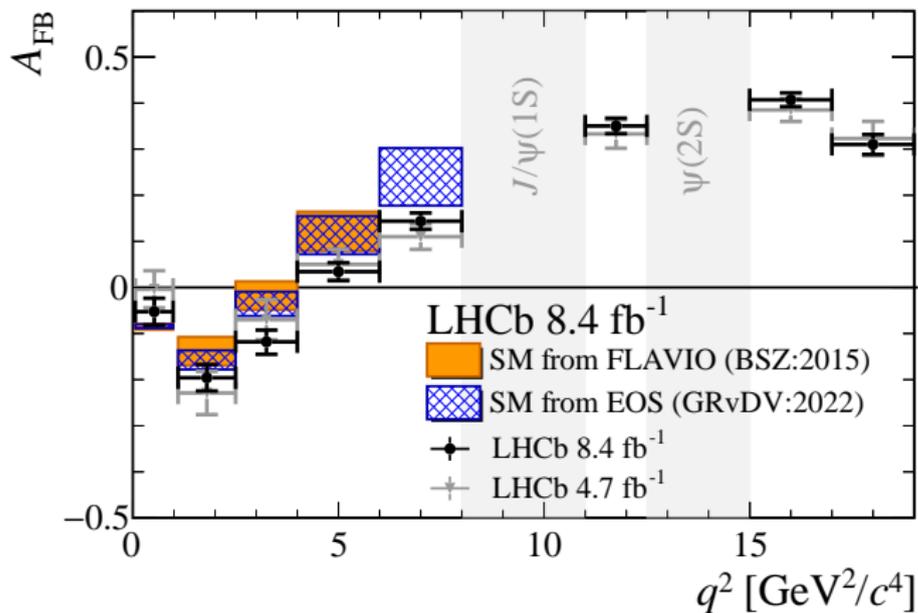
[EPJC 83 (2023) 648]

GRvDV:

[EPJC 82 (2022) 569]

[JHEP 09 (2022) 133]

- P_5' in excellent agreement with both CMS and previous LHCb
- Local deviations 2.7 (2.6) and 3.1 (2.7) σ in [4, 6] and [6, 8] GeV² for EOS (ABCDMN)

Results: A_{FB} [\[arXiv:2512.18053\]](https://arxiv.org/abs/2512.18053)

BSZ:

[\[arXiv:1810.08132\]](https://arxiv.org/abs/1810.08132)[\[JHEP 08 \(2016\) 098\]](https://arxiv.org/abs/1810.08132)

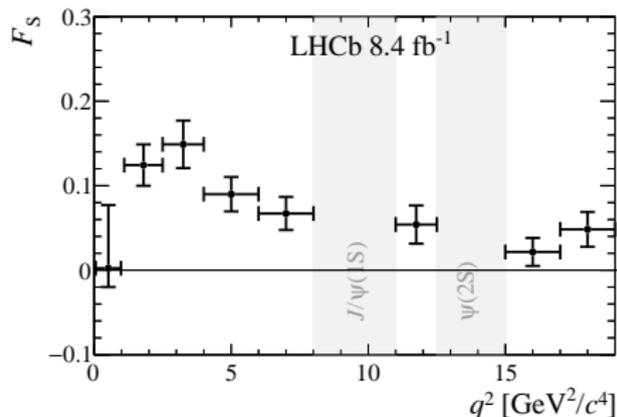
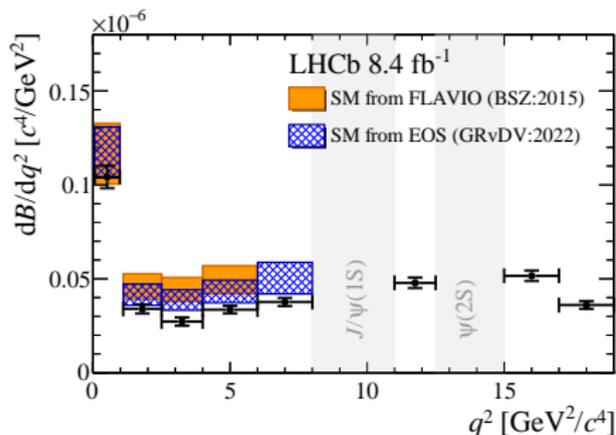
GRvDV:

[\[EPJC 82 \(2022\) 569\]](https://arxiv.org/abs/2202.0569)[\[JHEP 09 \(2022\) 133\]](https://arxiv.org/abs/2202.0569)

- Tensions now also more pronounced in A_{FB}
- Local deviations 2.5 (2.2) and 1.9 (1.7) σ in [2.5, 4] and [4, 6] GeV^2 for EOS (Flavio)

P-wave branching fraction and S-wave fraction

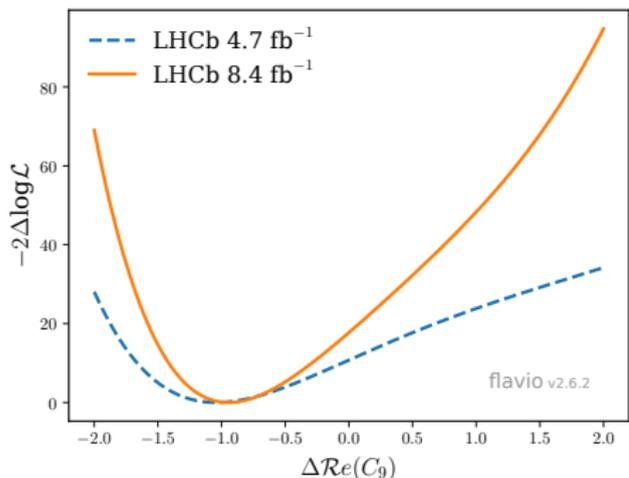
[arXiv:2512.18053]



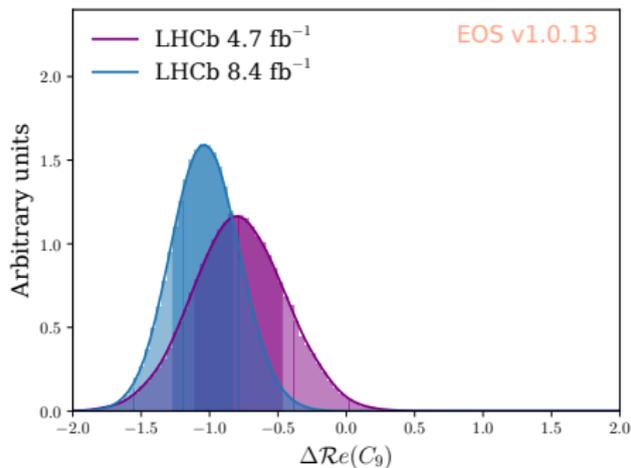
- Branching fraction lower than SM prediction, consistent with other $b \rightarrow s \mu^+ \mu^-$ decays
- No predictions available for F_S and other S-wave/interference obs.
- Remaining observables (incl. CP -asymmetries) in backup

Interpretation in terms of Wilson coefficients

[arXiv:2512.18053]



$$\Delta\text{Re}C_9 = -0.93_{-0.16}^{+0.18}$$

Significance 4.1σ 

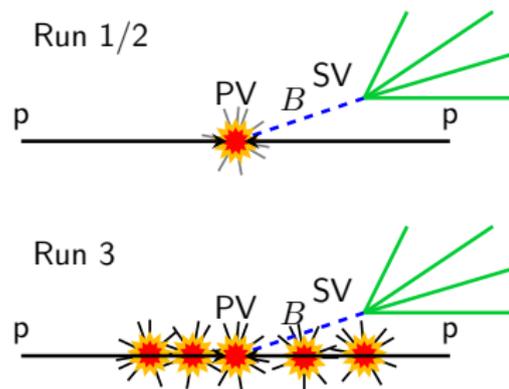
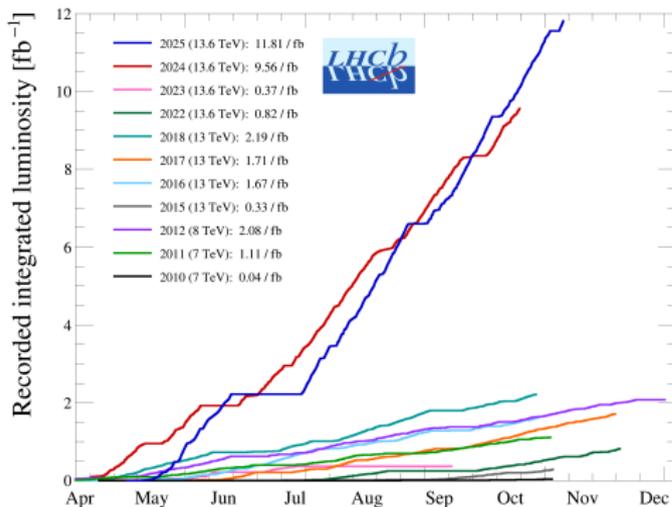
$$\Delta\text{Re}C_9 = -0.94_{-0.22}^{+0.22}$$

Significance 4.0σ

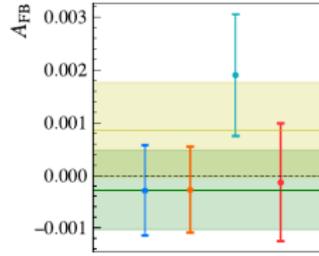
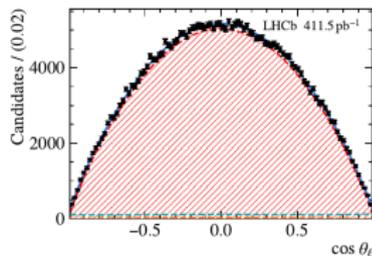
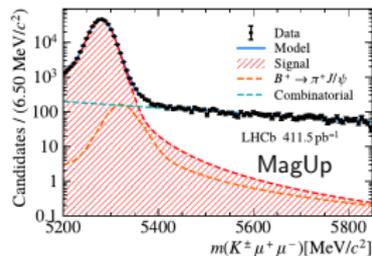
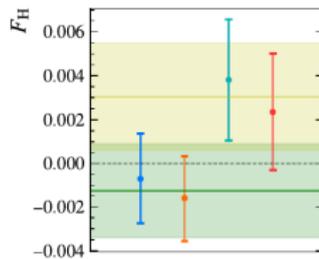
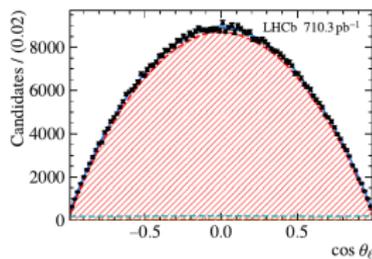
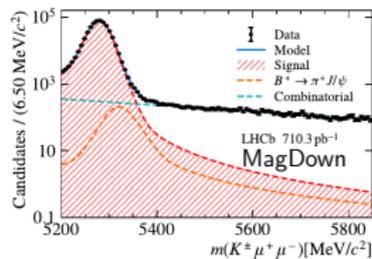
- Combine angular obs. and branching fraction up to 8 GeV^2
- Use two different theory packages with different approaches e.g. different (non-local) FFs, very consistent results
- Open question: NP or underestimated hadronic effect ($c\bar{c}$ -loop)?

Current and future data samples

Total recorded luminosity by year – pp



- LHCb has taken more than 9 fb^{-1} 2024 and more than 11 fb^{-1} in 2025
- A huge Run 3 data sample available for analysis but good understanding of data from [\[Upgrade I\]](#) detector required
- Angular analysis of $B^+ \rightarrow K^+ J/\psi (\rightarrow \mu^+ \mu^-)$ excellent testbed to assess performance and systematic control for future $b \rightarrow s \mu^+ \mu^-$ analyses

Angular analysis of $B^+ \rightarrow K^+ J/\psi (\rightarrow \mu^+ \mu^-)$ 

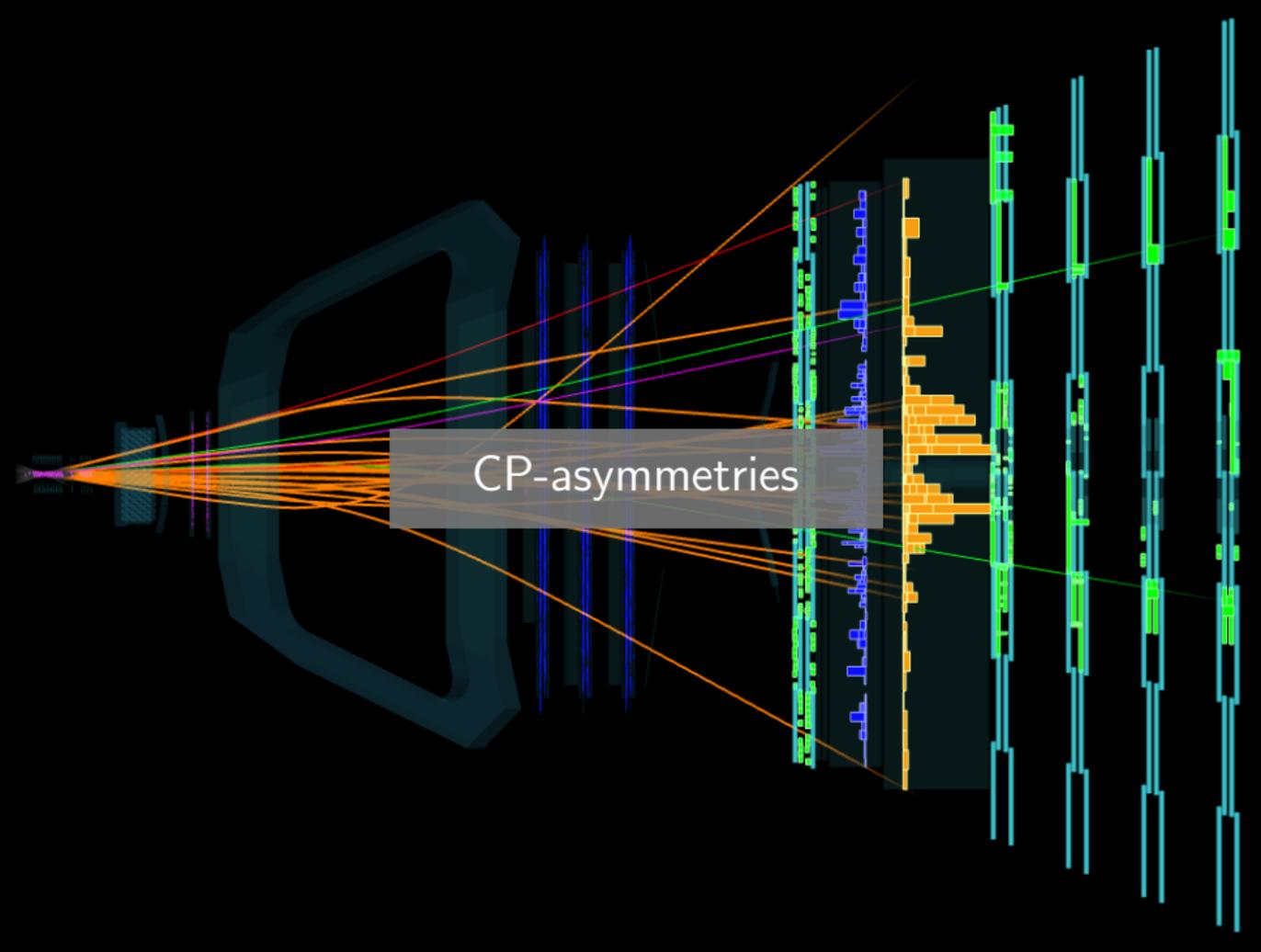
[arXiv:2511.16564]

LHCb 1.1 fb⁻¹

■ MagDown - K⁻
■ MagDown - K⁺
■ MagUp - K⁻
■ MagUp - K⁺
--- SM
■ MagDown
■ MagUp

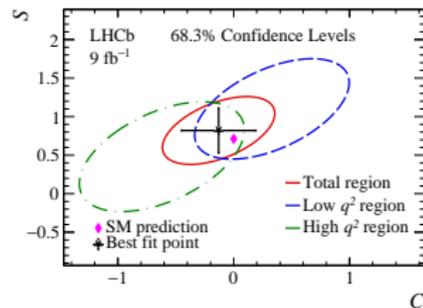
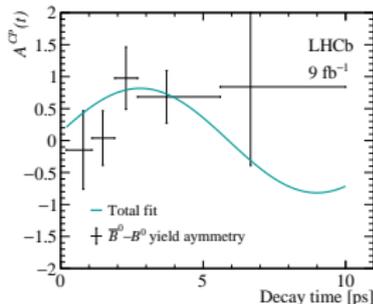
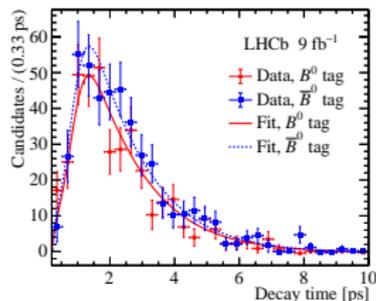
- Differential angular fit of $\frac{1}{\Gamma} \frac{d\Gamma}{d \cos \theta_\ell} = \frac{3}{4}(1 - F_H) + \frac{1}{2}F_H + A_{FB} \cos \theta_\ell$
- Using 1 fb⁻¹ of Run 3 data from 2024 good agreement with SM pred. of 0:
 $A_{FB} = 0.00019 \pm 0.00048_{\text{stat}} \pm 0.00033_{\text{syst}}$, $F_H = 0.0005 \pm 0.0011_{\text{stat}} \pm 0.0014_{\text{syst}}$
- Consistent results for MagnetUp/Down and Kaon charge
- Measured angular dist. across 17 different variables, no syst. deviations gives great confidence in quality of data!

CP-asymmetries

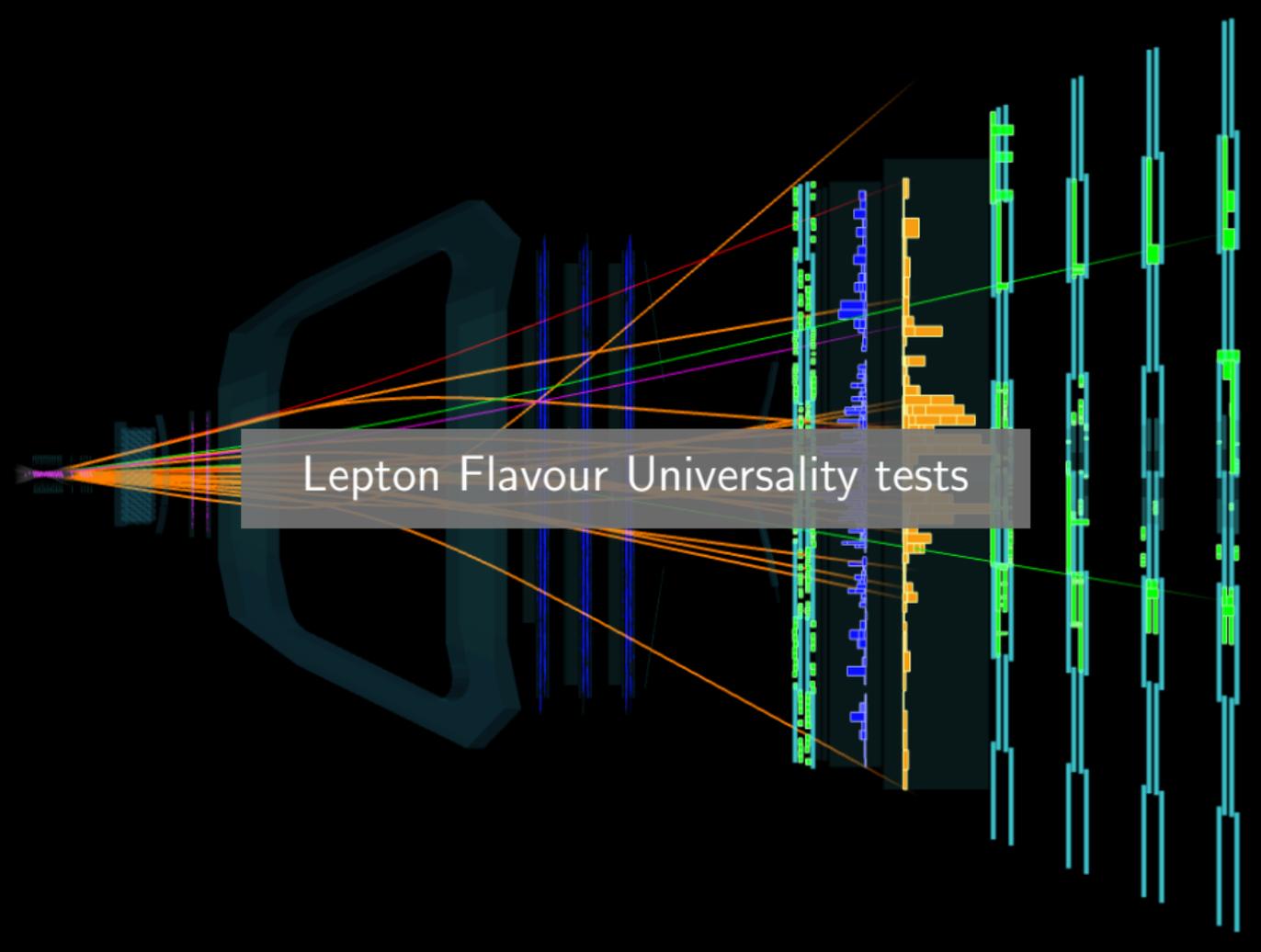


Time-dependent CP-asymmetry in $B^0 \rightarrow K_S^0 \mu^+ \mu^-$

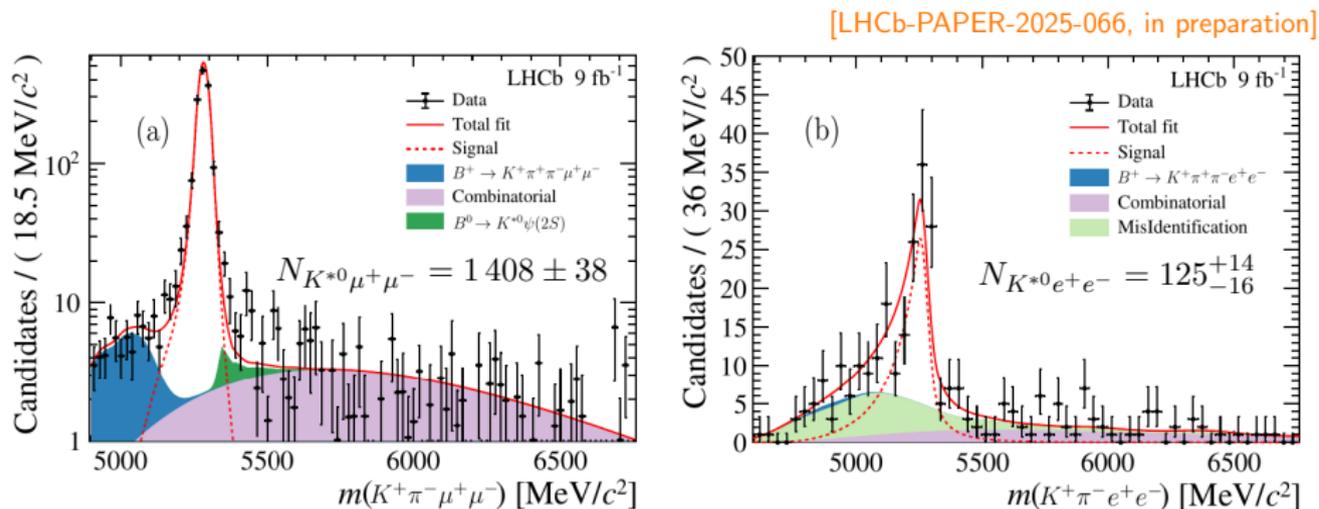
[LHCb-PAPER-2025-062, in preparation]



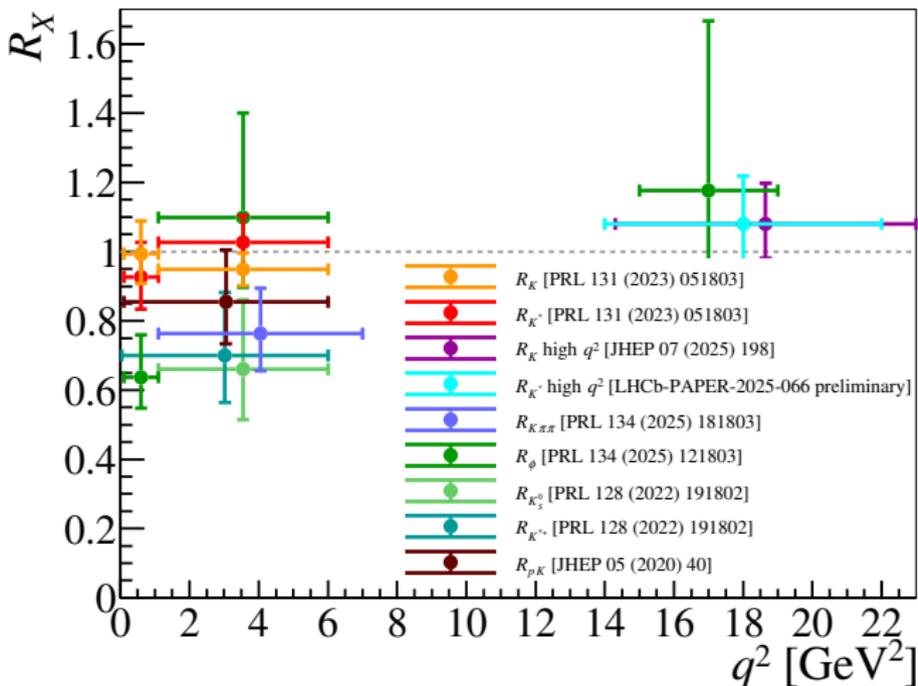
- First time-dep. measurement of CPV in $b \rightarrow s \ell^+ \ell^-$ processes using Run 1+2
- Time-dep. CP-asymmetry $A_{CP} = S \sin(\Delta m_d t) - C \cos(\Delta m_d t)$, where S mixing-induced, C direct CPV
- SM expectation $S = \sin 2\beta_d$, $C = 0$
- Integrated over full q^2 range of obtain 941 ± 55 signal events, resulting in $S = +0.82 \pm 0.29 \pm 0.05$ and $C = -0.13 \pm 0.32 \pm 0.04$, in good agreement with SM prediction



Lepton Flavour Universality tests

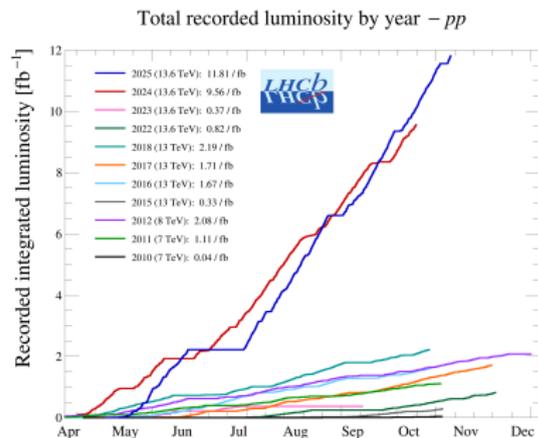
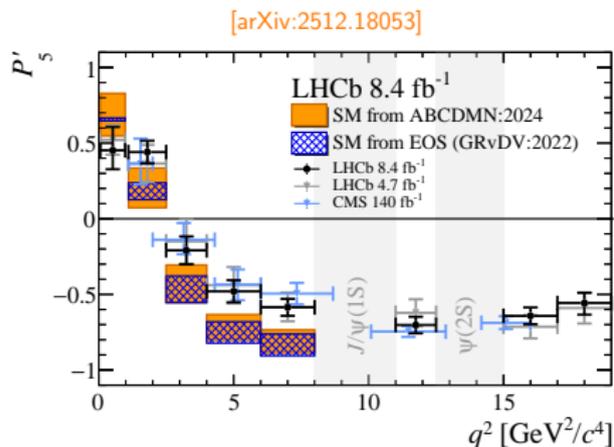
$R_{K^{*0}}$ at high q^2 

- LFU test with $B^0 \rightarrow K^{*0}\ell^+\ell^-$ at $q^2 > 14 \text{ GeV}^2/c^4$ using Run 1+2 data
- Validation using charmonium decays $r_{J/\psi} = 1.035 \pm 0.013 \pm 0.035$ and $R_{\psi(2S)} = 1.034 \pm 0.033 \pm 0.012$
- $R_{K^{*0}} = 1.08^{+0.14}_{-0.12} \pm 0.07$ in excellent agreement with SM prediction

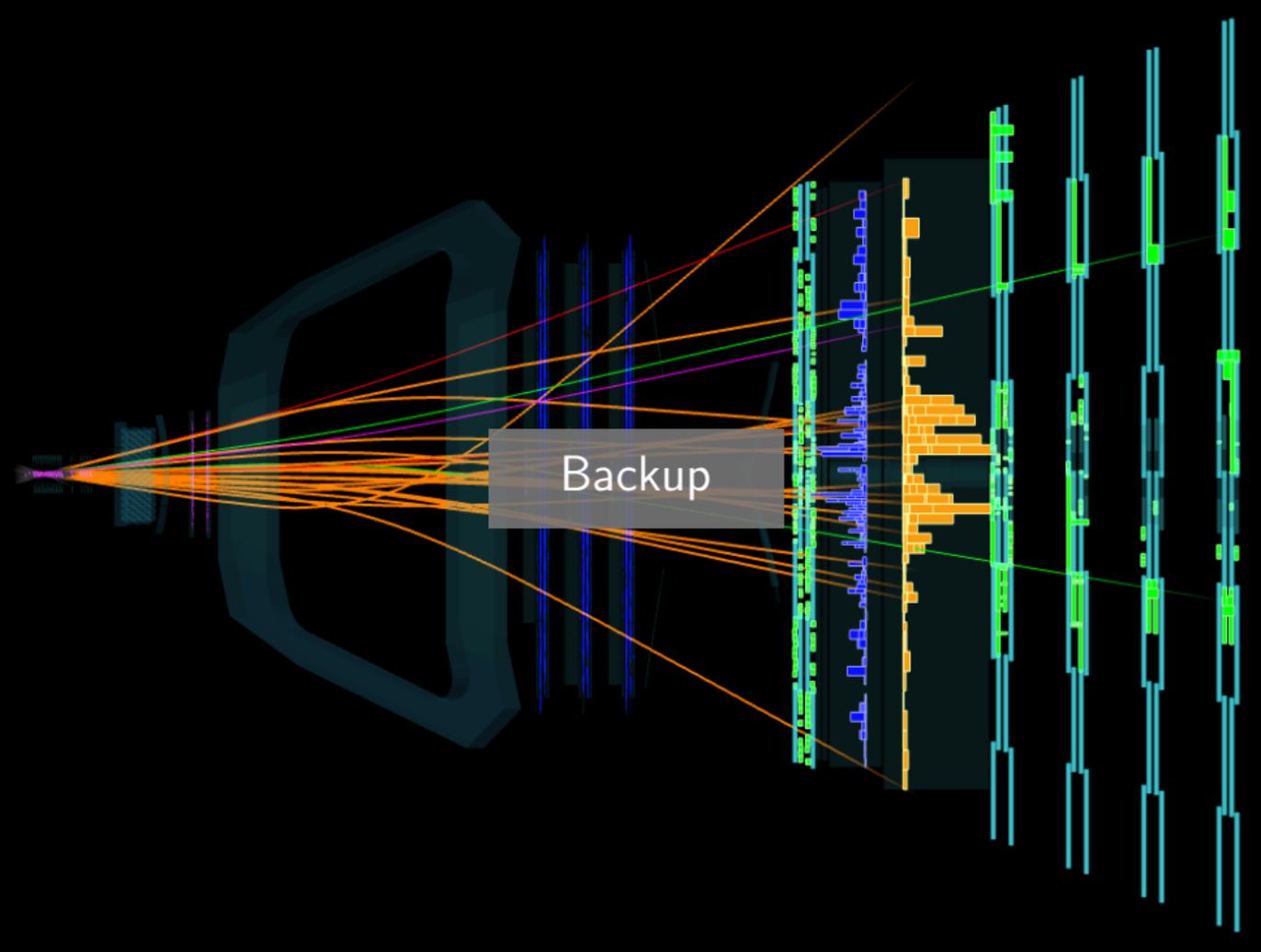
Summary LFU tests in rare $b \rightarrow sl^+l^-$ decays

- In good agreement with SM prediction of unity
- Branching fractions of electron modes consistent with muon modes

Summary and Conclusions



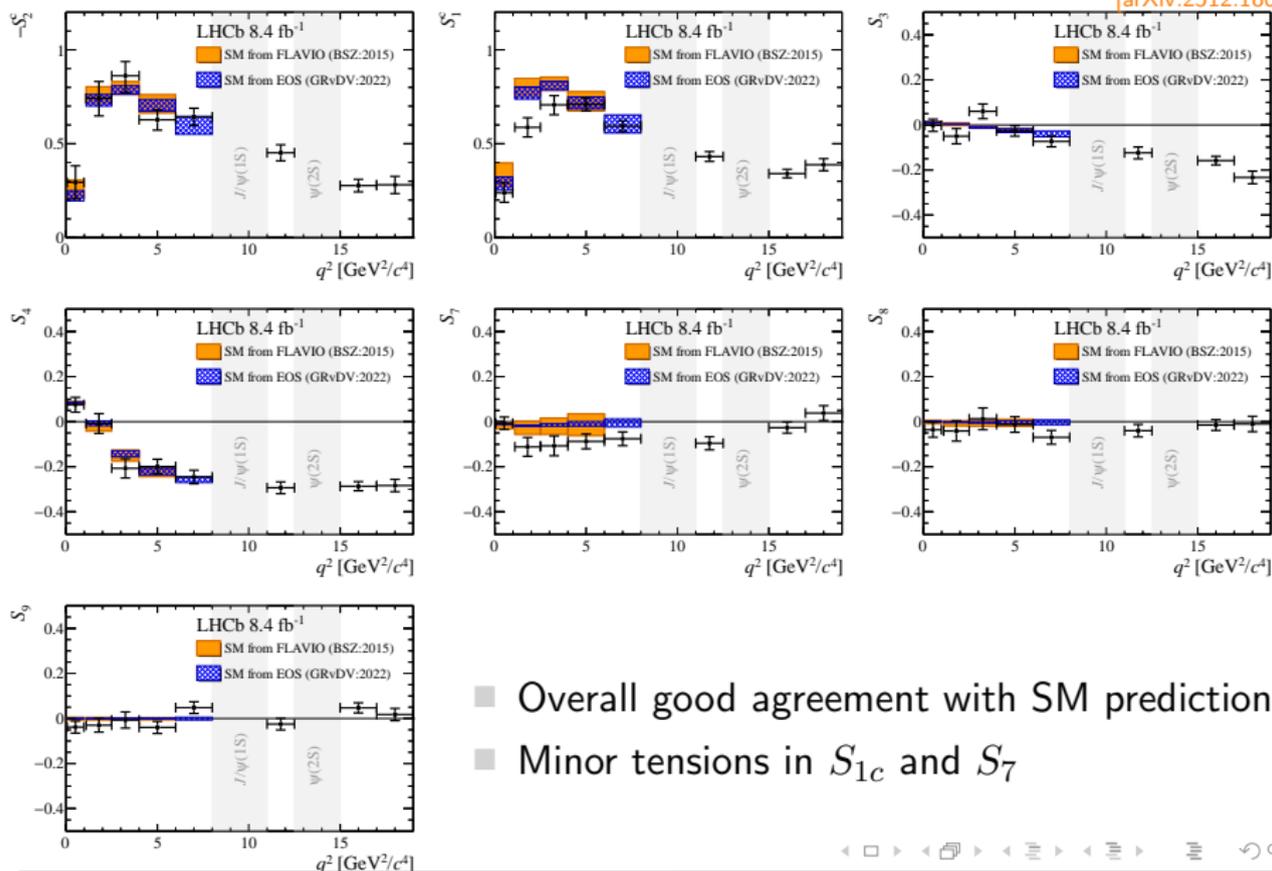
- Final analyses using Run 1+2 arriving: Consistent tensions with SM predictions in $b \rightarrow s \mu^+ \mu^-$ branching fractions and angular analyses remain
- Legacy analysis of $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ sees tension of around 4σ [arXiv:2512.18053]
- Preparation for analysis of Run 3 data in full swing, data quality very promising (see e.g. [arXiv:2511.16564])
- Current and future data samples will allow for measurements with unprecedented precision, $> 22 \text{ fb}^{-1}$ on tape in Run 3



Backup

Results: Remaining CP -symmetries (config 1)

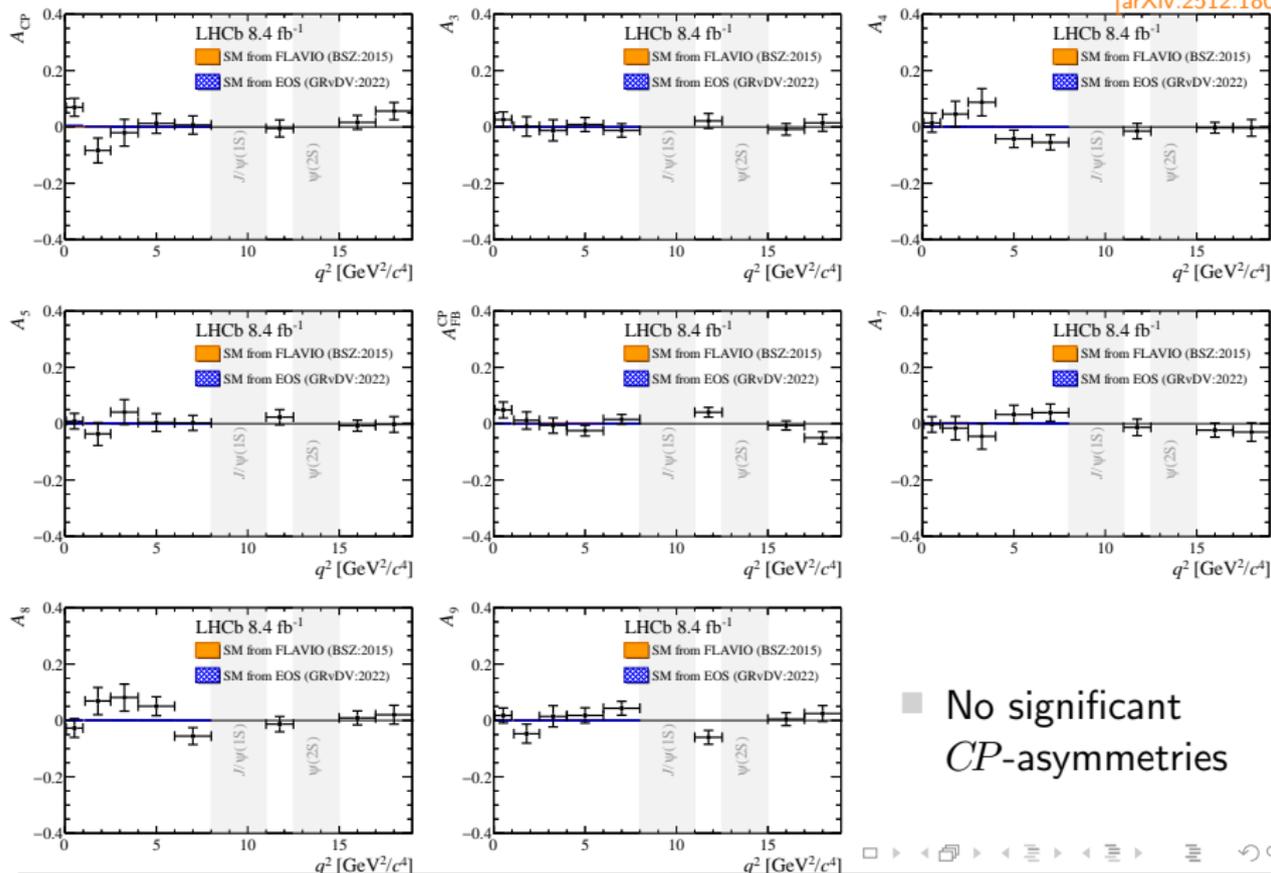
[arXiv:2512.18053]



- Overall good agreement with SM predictions
- Minor tensions in S_{1c} and S_7

CP -asymmetries (config 4)

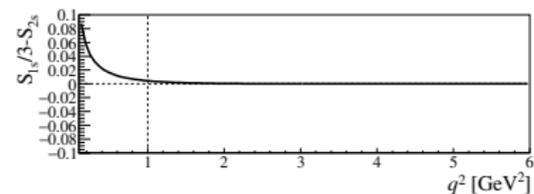
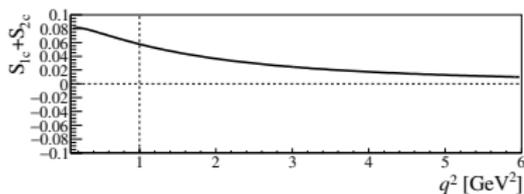
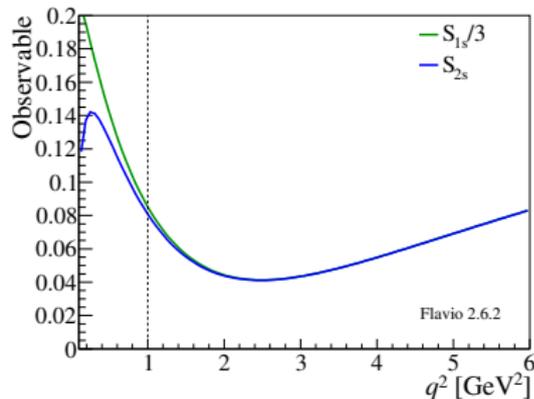
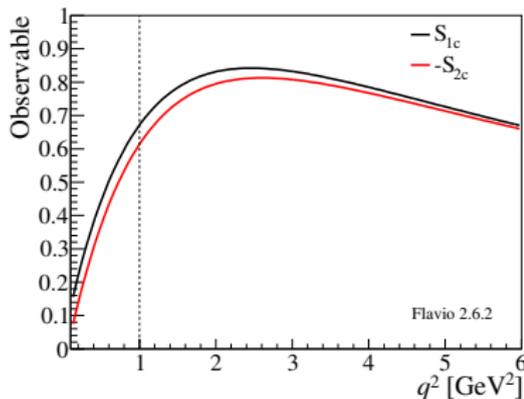
[arXiv:2512.18053]



■ No significant
 CP -asymmetries

Massive leptons

- 11 independent CP -averaged angular observables
- Reduce to 8 when assuming no scalars, tensors and massless leptons
 $S_{1c} = -S_{2c}$ ✗ $S_{1s} = 3S_{2s}$ ✓ $S_{6c} = 0$ ✓
- Nominal: Fully massive $q^2 < 1 \text{ GeV}^2$, assume $S_{1s} = 3S_{2s}$ at $q^2 > 1 \text{ GeV}^2$ (“partially massive”)



Observables and fit configurations

Tradeoff: N_{obs} /fewer assumptions \Leftrightarrow better stat. behaviour/precision

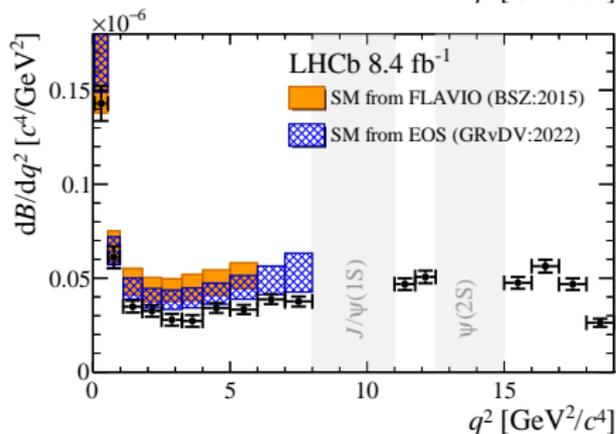
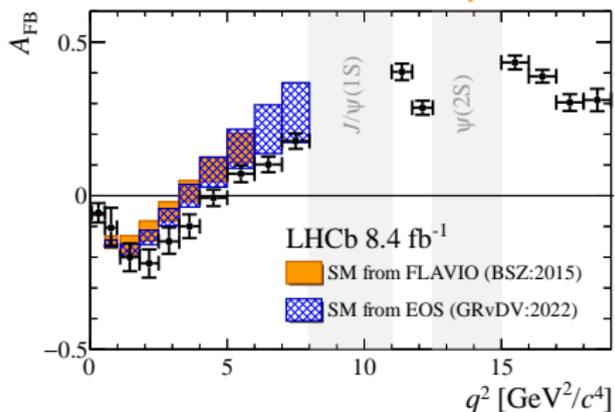
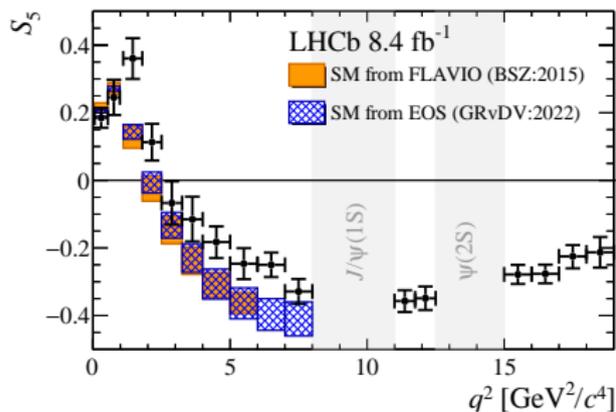
$$\underline{N_{\text{obs}}(N_{\text{obs}}^{q^2 < 1 \text{ GeV}^2})}$$

- | | | |
|---|--|---------|
| 1 | CP -averages only, S_i basis, partially massive ¹
Default for S_i basis | 21 (26) |
| 2 | CP -averages only, $P_i^{(\prime)}$ basis, partially massive
Default for P_i basis | 21 (26) |
| 3 | Fully massive model, CP -averages only, S_i basis
For effect of massive leptons | 26 |
| 4 | CP -averages + CP -asymmetries, S_i basis, massless leptons ¹
For CP -asymmetries | 40 (52) |
| 5 | CP -averages only, $P_i^{(\prime)}$ basis, massless leptons
For comparison with [PRL 125 (2020) 011802] | 20 |
| 6 | CP -averages only, S_i basis, partially massive, narrow q^2 bins
For better q^2 resolution | 21 (26) |

¹Fully massive $q^2 < 1 \text{ GeV}^2$

Narrow q^2 bins (config 6)

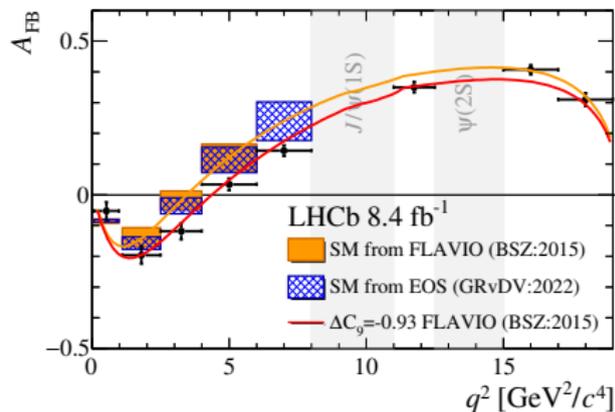
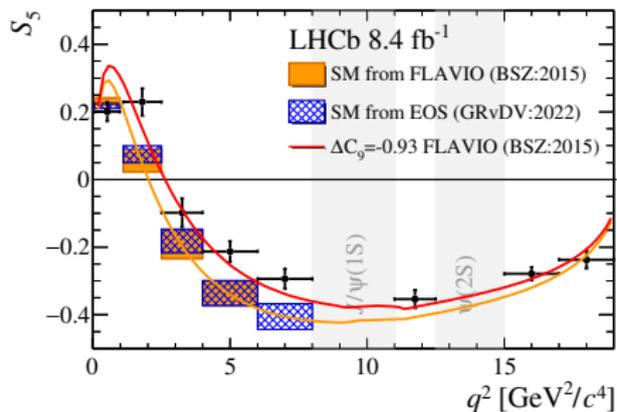
[arXiv:2512.18053]



- Tradeoff between statistical uncertainty/better q^2 resolution
- In excellent agreement with regular-sized q^2 bins

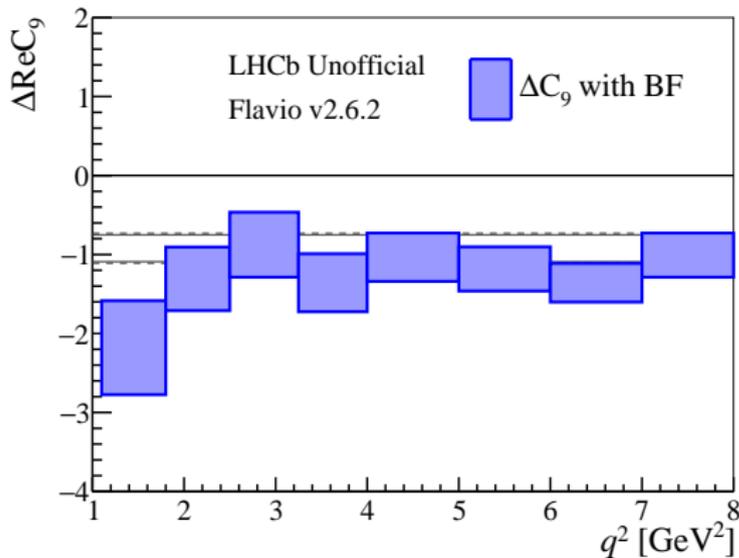
Improved description of data with $\Delta\mathcal{R}eC_9 = -0.93$

[arXiv:2512.18053]

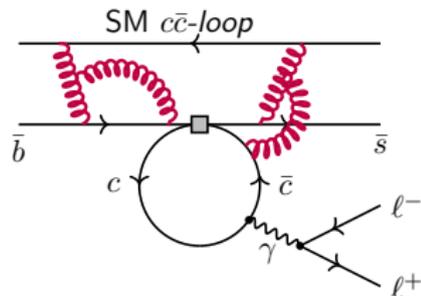
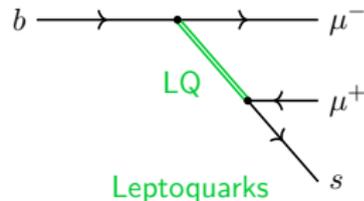


- For illustration overlaid central value for $\Delta\mathcal{R}eC_9 = -0.93$
- Clearly improved description of the data

Dependence of shift of $\text{Re}C_9$ on q^2



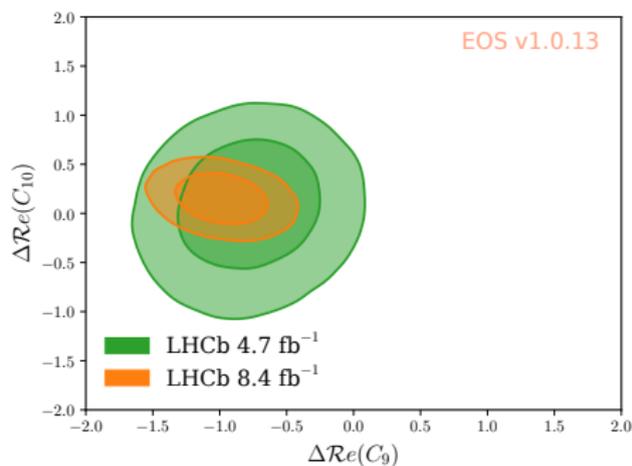
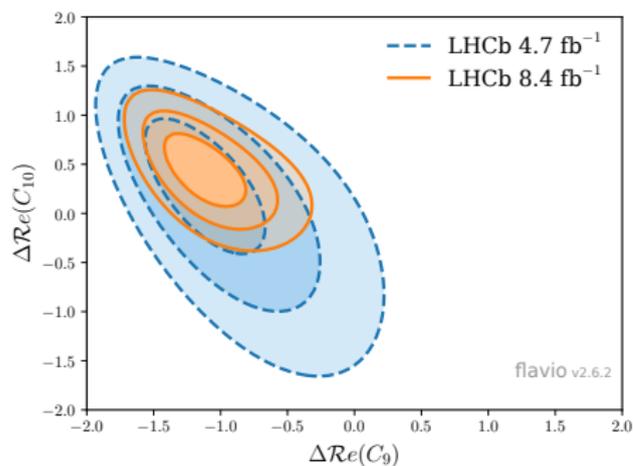
Possible NP contribution



- Shift in $\text{Re}C_9$ quite consistent across q^2 bins
- Open question: NP or underestimated hadronic contributions (charm-loop)?
 - If shift due to heavy NP $\rightarrow q^2$ -independent
 - If shift due to charm-loop \rightarrow might expect rise towards J/ψ -region

Interpretation in terms of Wilson coefficients

[arXiv:2512.18053]



- Tension most pronounced in $\mathcal{R}eC_9$

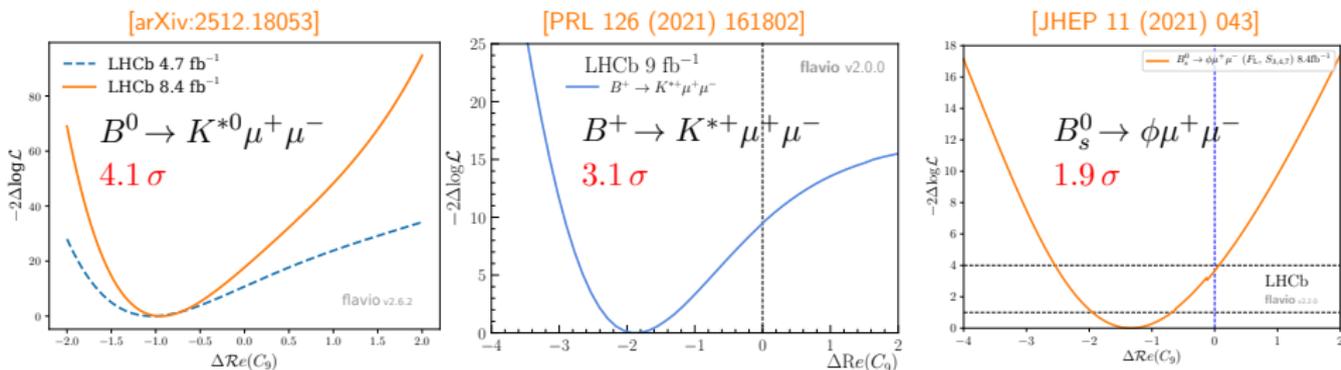


$B^0 \rightarrow K^{*0} \mu^+ \mu^-$ systematic uncertainties

[arXiv:2512.18053]

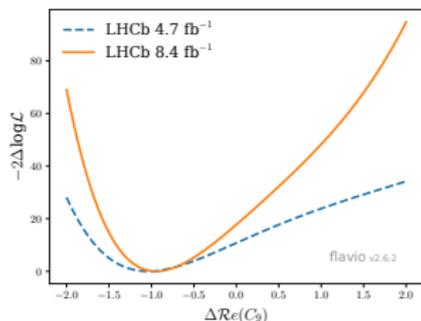
Source	S_2^c	$A_{FB}, S_1^c - S_9$	$P_1 - P_8$	F_S, S_{1a}^c	$S_{1b}^{c, re/im}, S_{S1}^{re/im} - S_{S5}^{re/im}$	$dB/dq^2 \times 10^7$
S-wave $m(K\pi)$ model	< 0.010	< 0.010	< 0.010	< 0.010	< 0.070	< 0.010
Acceptance stat. uncertainty	< 0.010	< 0.010	< 0.050	< 0.010	< 0.020	< 0.010
Angular background model	< 0.025	< 0.010	< 0.025	< 0.010	< 0.020	< 0.010
Peaking backgrounds	< 0.025	< 0.010	< 0.025	< 0.020	< 0.020	< 0.010
$m(K^+\pi^-)$ background model	< 0.010	< 0.010	< 0.020	< 0.020	< 0.010	< 0.020
Ghost tracks	< 0.010	< 0.010	< 0.020	< 0.010	< 0.010	< 0.010
Trigger efficiency	< 0.010	< 0.010	< 0.020	< 0.010	< 0.010	< 0.015
$B^+ \rightarrow K^+ \mu \mu$ background veto	< 0.010	< 0.010	< 0.010	< 0.010	< 0.020	< 0.010
q^2 dependent angular model	< 0.010	< 0.010	< 0.010	< 0.010	< 0.020	< 0.010
Peaking background in control mode	< 0.000	< 0.000	< 0.000	< 0.000	< 0.000	< 0.015
Detection asymmetry	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Production asymmetry	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Acceptance variation with q^2	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
B^0 kinematic data-simulation differences	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Kaon momentum distribution	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Pion momentum distribution	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
$m(K^+\pi^-\mu^+\mu^-)$ model	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
PID calibration stat. uncertainty	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
PID calibration KDE	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Punzi effect in weighted fits	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Momentum resolution	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Asymmetry of tracking efficiency	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Tracking efficiency	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
D-wave contribution	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Final-state radiation	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Hadron range parameter	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
B^0 decay time	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
$m(K^+\pi^-) - m(K^+\pi^-\mu^+\mu^-)$ correlation	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Neuman construction nuisance	< 0.010	< 0.010	< 0.075	< 0.025	< 0.025	< 0.000

Consistency with other $b \rightarrow s \mu^+ \mu^-$ angular analyses



- Use flavio [arXiv:1810.08132] to determine tension with SM hypothesis
- Variation of vector coupling $\text{Re}(C_9)$ results in improved description of data
- Consistent trend for $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ [arXiv:2512.18053], $B^+ \rightarrow K^{*+} \mu^+ \mu^-$ [PRL 126 (2021) 161802] and $B_s^0 \rightarrow \phi \mu^+ \mu^-$ [JHEP 11 (2021) 043] angular observables

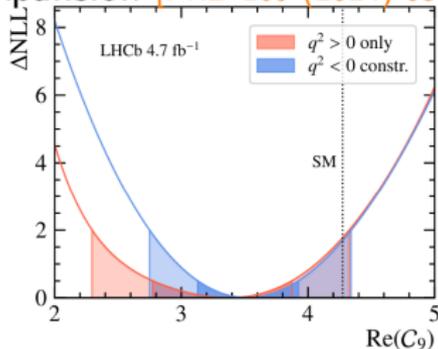
Comparison with unbinned results



$$\Delta \text{Re} C_9 = -0.93^{+0.18}_{-0.16}$$

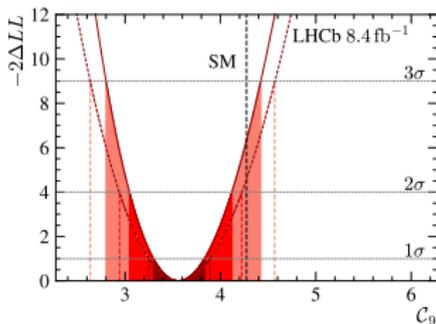
- Unbinned parameterize **charm loop**:
 $C_9^{\text{eff}} = C_9 + \mathcal{H}_{0,\parallel,\perp}(q^2)$
- Shifts in C_9 consistent
- Fewer parameters in binned analysis, smaller uncertainties

z-Expansion [PRD 109 (2024) 052009]



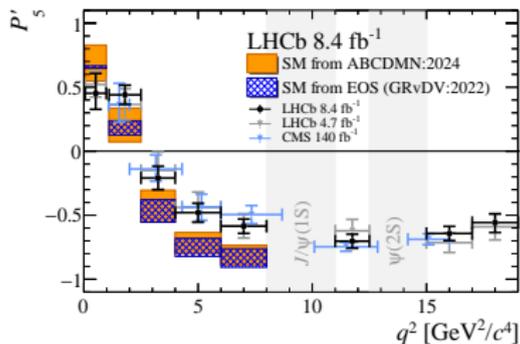
$$\Delta \text{Re} C_9 = -0.93^{+0.53}_{-0.57}$$

Amplitude model [JHEP 09 (2024) 026]



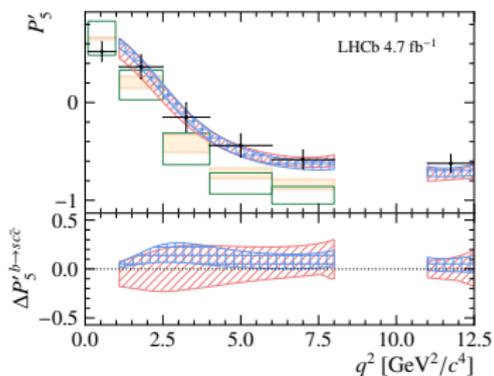
$$\Delta \text{Re} C_9 = -0.71 \pm 0.33$$

Comparison with unbinned results

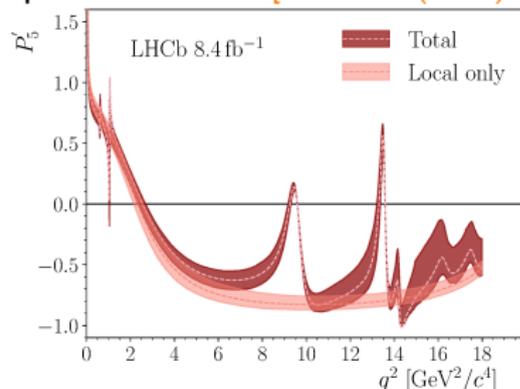


- Excellent agreement of angular observables

z-Expansion [PRD 109 (2024) 052009]

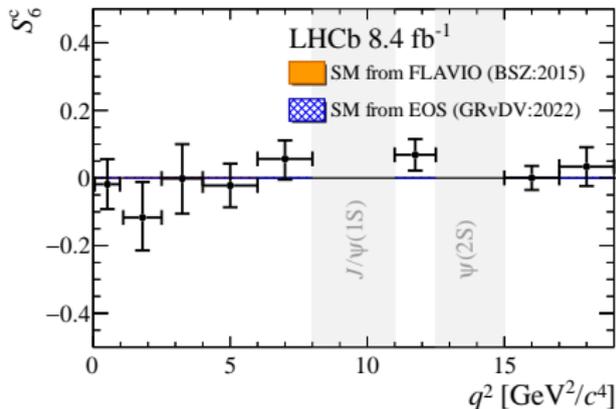
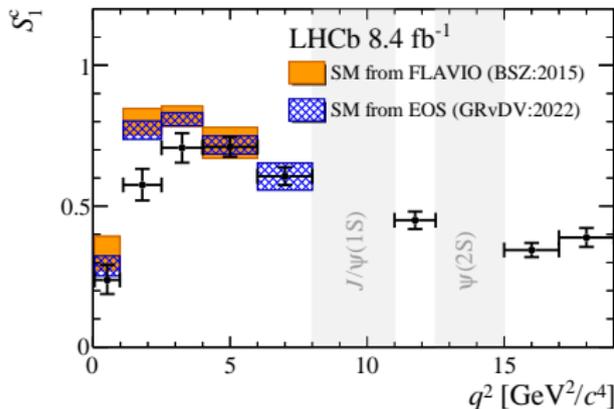
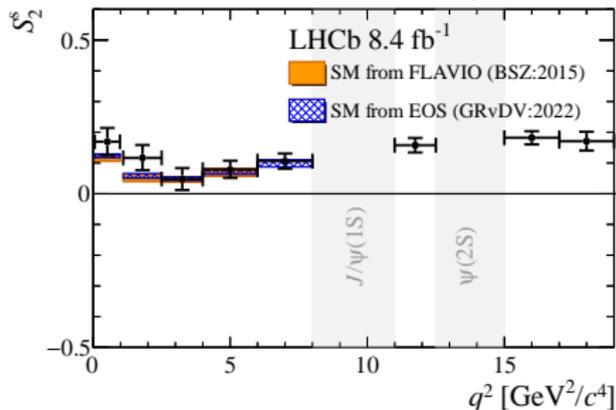
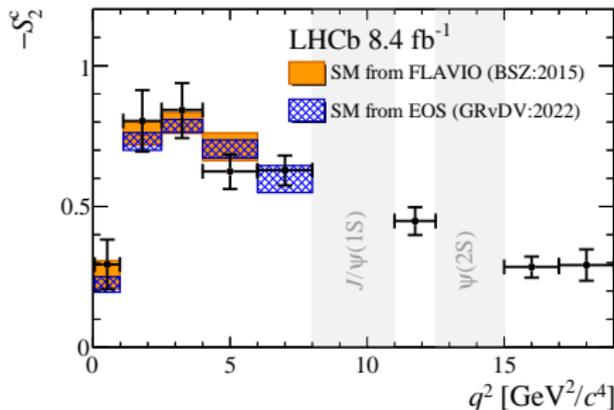


Amplitude model [JHEP 09 (2024) 026]



Massive leptons (config 3)

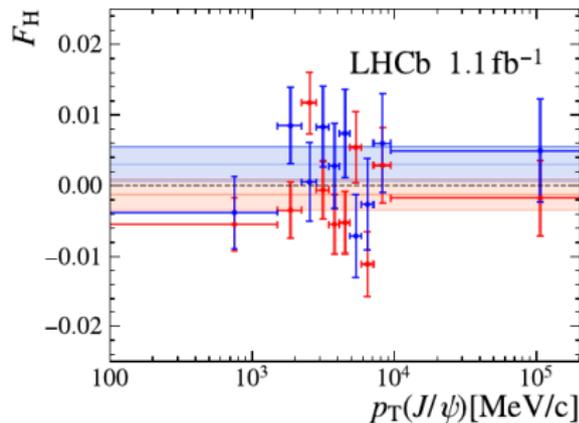
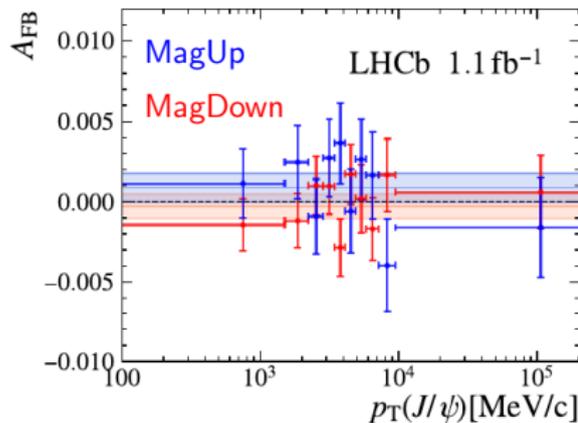
[arXiv:2512.18053]





Stability of results from $B^+ \rightarrow K^+ J/\psi (\rightarrow \mu^+ \mu^-)$

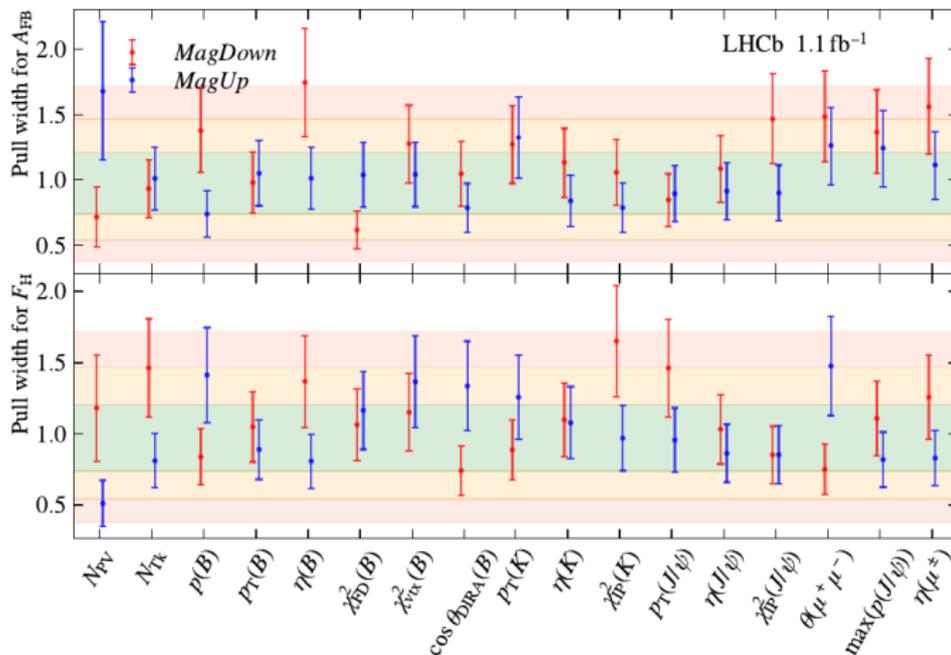
[arXiv:2511.16564]



- No systematic deviations observed in angular obs. depending on $p_T(J/\psi)$
- Measured angular dist. across 17 different variables, no syst. deviations gives great confidence in quality of data!

Stability of results from $B^+ \rightarrow K^+ J/\psi (\rightarrow \mu^+ \mu^-)$

[arXiv:2511.16564]



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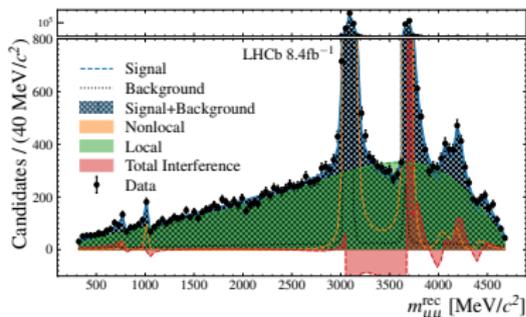
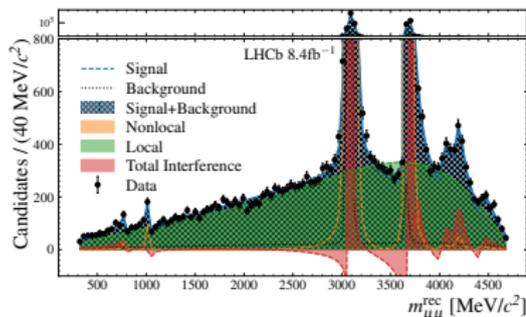
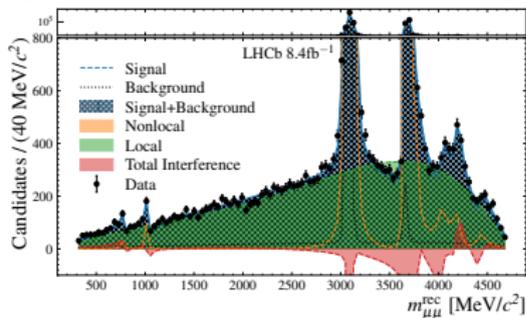
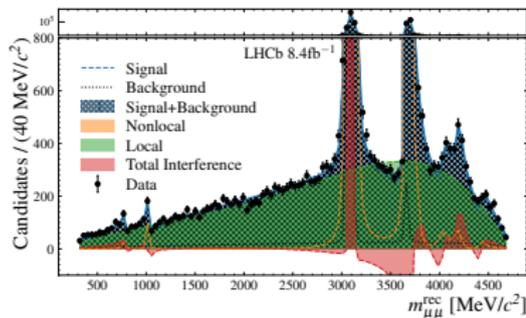
Systematics $B^+ \rightarrow J/\psi K^+$

[arXiv:2511.16564]

Systematic source	<i>MagDown</i>		<i>MagUp</i>	
	A_{FB}	F_{H}	A_{FB}	F_{H}
Simulation sample size	44	103	39	104
Alternative scheme for $w_{\text{kin.}\&\text{mult.}}$	3	114	4	90
Simulation corrections	14	30	12	24
Truth-matching	7	28	2	51
Signal mass model	1	25	1	17
Choice of hyperparameters in $w_{\text{kin.}\&\text{mult.}}$	1	19	1	17
Multiple candidates removal	0	5	7	20
Orders of combinatorial	4	8	4	10
Tracking corrections	1	6	1	7
Uncertainty on PID corrections	1	2	0	1
Higher order efficiency	0	1	1	1
Total systematic uncertainty	47	162	42	153
Total statistical uncertainty	59	141	80	191

 $B^+ \rightarrow K^+ \mu^+ \mu^-$ unbinned using Run 1+2 data

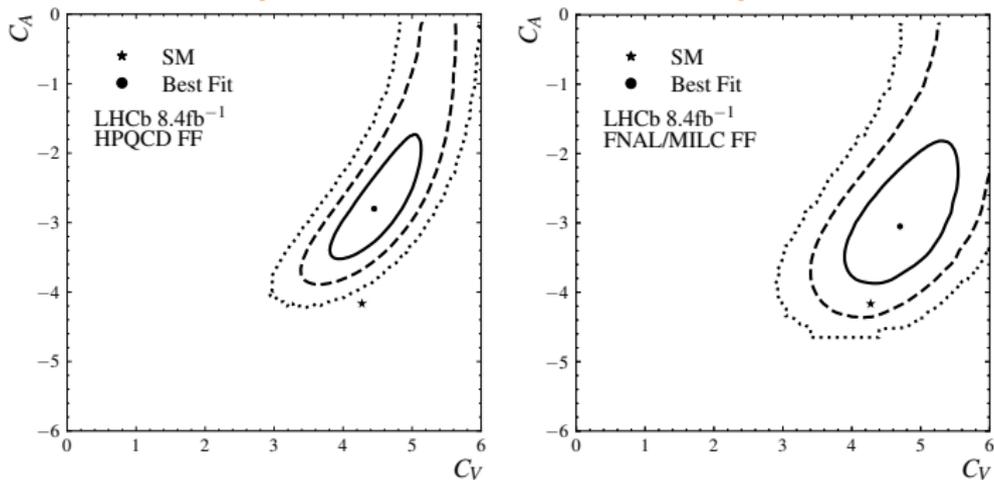
[LHCb-PAPER-2025-055, in preparation]



- Model-dependent analysis of long- and short-distance contributions
- Non-local amplitudes are modeled with dispersion relation approach
- Four-fold degeneracy of the strong phases $\delta_{J/\psi}$ and $\delta_{\psi(2S)}$

$B^+ \rightarrow K^+ \mu^+ \mu^-$ unbinned using Run 1+2 data

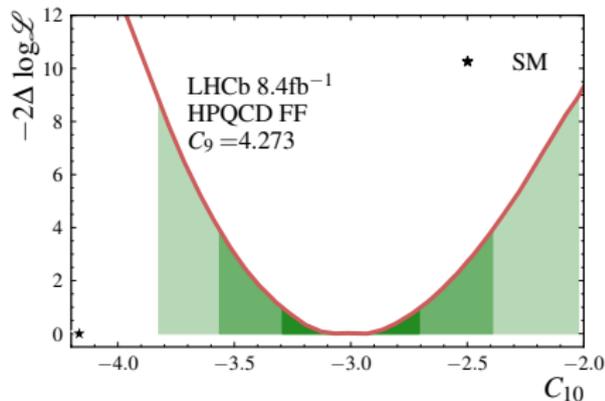
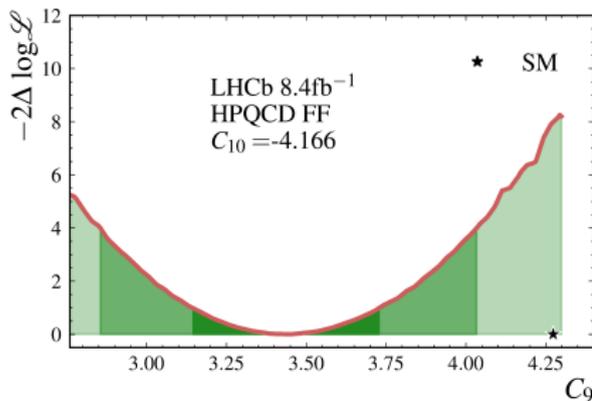
[LHCb-PAPER-2025-055, in preparation]



- SM compatibility depends on FFs used:
 4.0σ for HPQCD, 1.6σ for FNAL/MILC
- Negative shift of C_9 when fixing C_{10} to SM (both HPQCD)
- Positive shift of C_{10} when fixing C_9 to SM

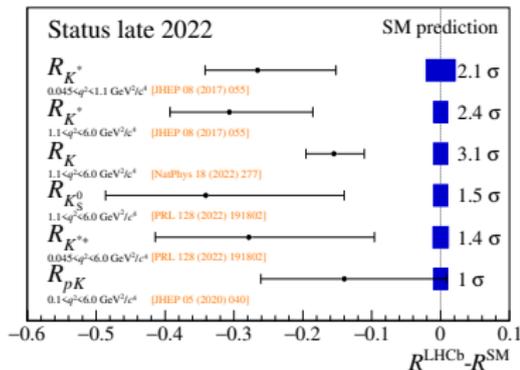
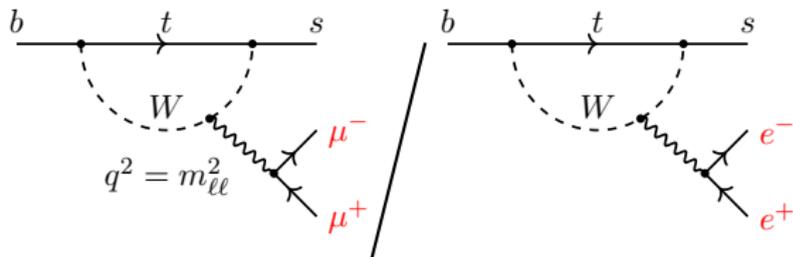
$B^+ \rightarrow K^+ \mu^+ \mu^-$ unbinned using Run 1+2 data

[LHCb-PAPER-2025-055, in preparation]



- SM compatibility depends on FFs used:
 4.0σ for HPQCD, 1.6σ for FNAL/MILC
- Negative shift of C_9 when fixing C_{10} to SM
 Positive shift of C_{10} when fixing C_9 to SM (both HPQCD)

Lepton universality in rare $b \rightarrow sl^+l^-$ decays



- Lepton flavour universality central property of SM
- Testable using ratios of branching fractions of rare $b \rightarrow sl^+l^-$ decays:

$$R_{K,K^*} = \frac{\mathcal{B}(B^{(+,0)} \rightarrow K^{(+,*0)} \mu^+ \mu^-)}{\mathcal{B}(B^{(+,0)} \rightarrow K^{(+,*0)} e^+ e^-)}$$

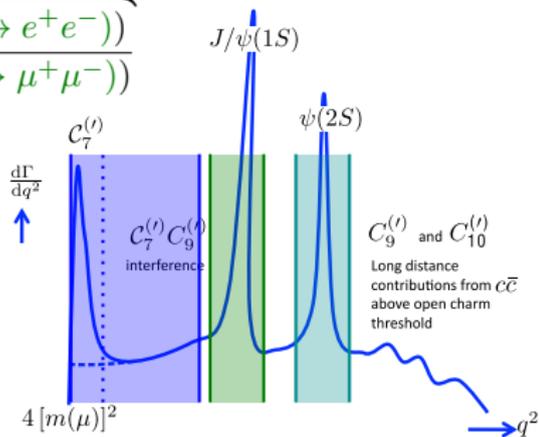
- Exactly unity in SM, differences only through lepton mass effects
- QED corrections $\mathcal{O}(1\%)$ [EPJC 76 (2016) 440]
- Hadronic uncertainties (form factors etc.) cancel in the ratio

Analysis strategy: Double ratio (Example: R_K)

- Analysis strategy: Double ratio of rare modes $B^+ \rightarrow K^+ \ell^+ \ell^-$ with resonant decays $B^+ \rightarrow K^+ J/\psi (\rightarrow \ell^+ \ell^-)$:

$$R_K = \frac{\mathcal{B}(B^+ \rightarrow K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \rightarrow K^+ e^+ e^-)} \times \overbrace{\frac{\mathcal{B}(B^+ \rightarrow K^+ J/\psi (\rightarrow e^+ e^-))}{\mathcal{B}(B^+ \rightarrow K^+ J/\psi (\rightarrow \mu^+ \mu^-))}}^{r_{J/\psi}^{-1} = 1 \text{ [PRD 88 (2013) 3]}}$$

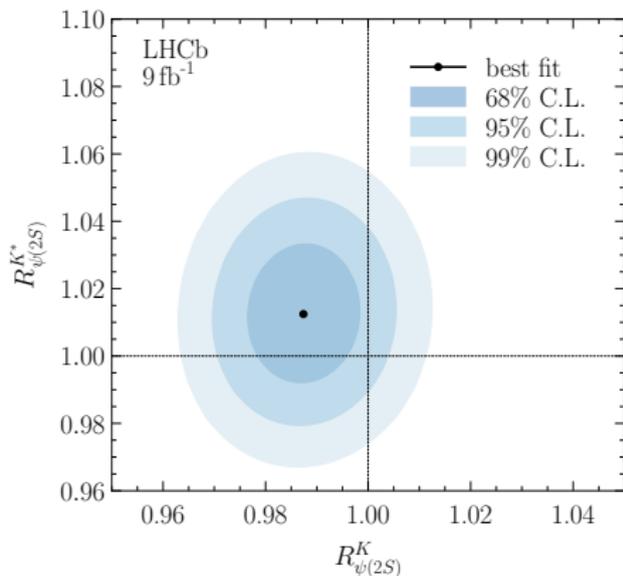
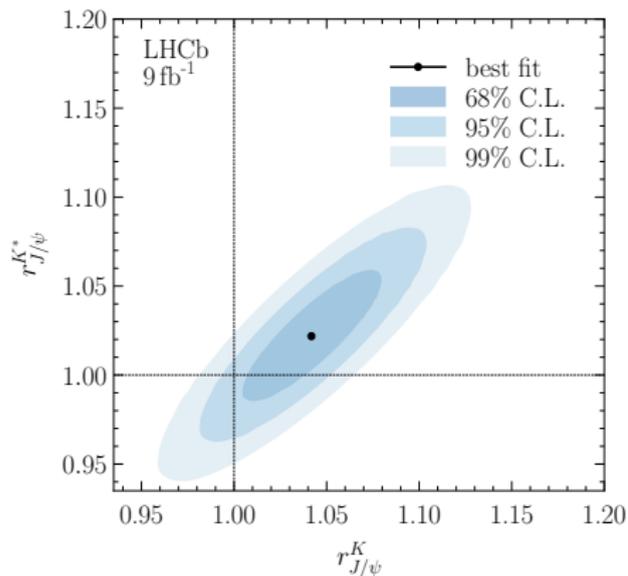
- Electron** and **Muon** reconstruction very different at LHCb
- Efficiencies from corrected simulation
- Double ratio cancels most experimental systematic effects in efficiency ratios



- Important cross-checks: $r_{J/\psi} = \frac{\mathcal{B}(B^+ \rightarrow K^+ J/\psi (\rightarrow \mu^+ \mu^-))}{\mathcal{B}(B^+ \rightarrow K^+ J/\psi (\rightarrow e^+ e^-))}$ and

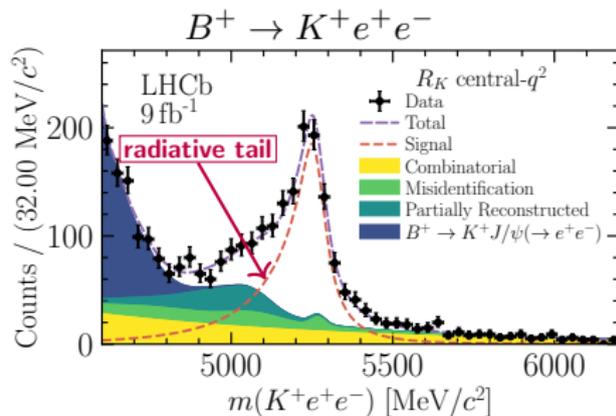
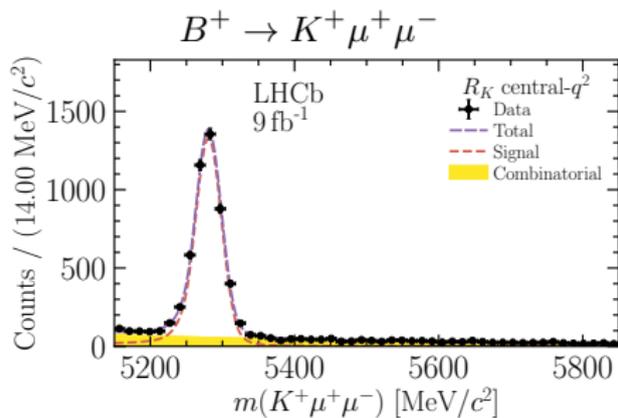
$$R_{\psi(2S)} = \frac{\mathcal{B}(B^+ \rightarrow K^+ \psi(2S) (\rightarrow \mu^+ \mu^-))}{\mathcal{B}(B^+ \rightarrow K^+ \psi(2S) (\rightarrow e^+ e^-))} \times \frac{\mathcal{B}(B^+ \rightarrow K^+ J/\psi (\rightarrow e^+ e^-))}{\mathcal{B}(B^+ \rightarrow K^+ J/\psi (\rightarrow \mu^+ \mu^-))}$$

Crosschecks $r_{J/\psi}$ and $R_{\psi(2S)}$



- Both $r_{J/\psi}$ and $R_{\psi(2S)}$ compatible with unity at better than 2σ

Experimental challenges for electron modes at LHCb

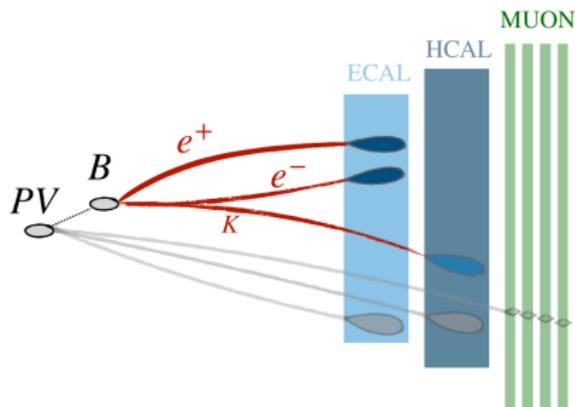
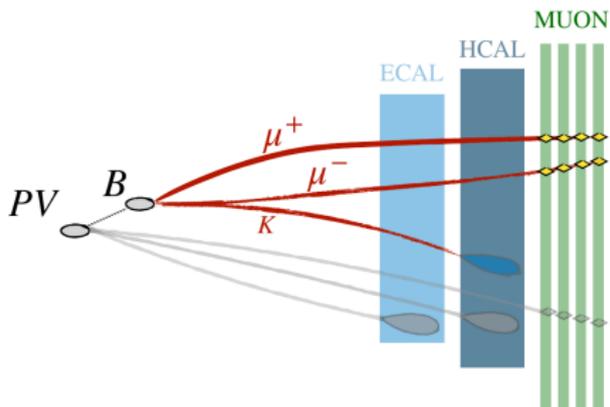


[arXiv:2212.09152] [arXiv:2212.09153]

Experimental Challenges for electron modes:

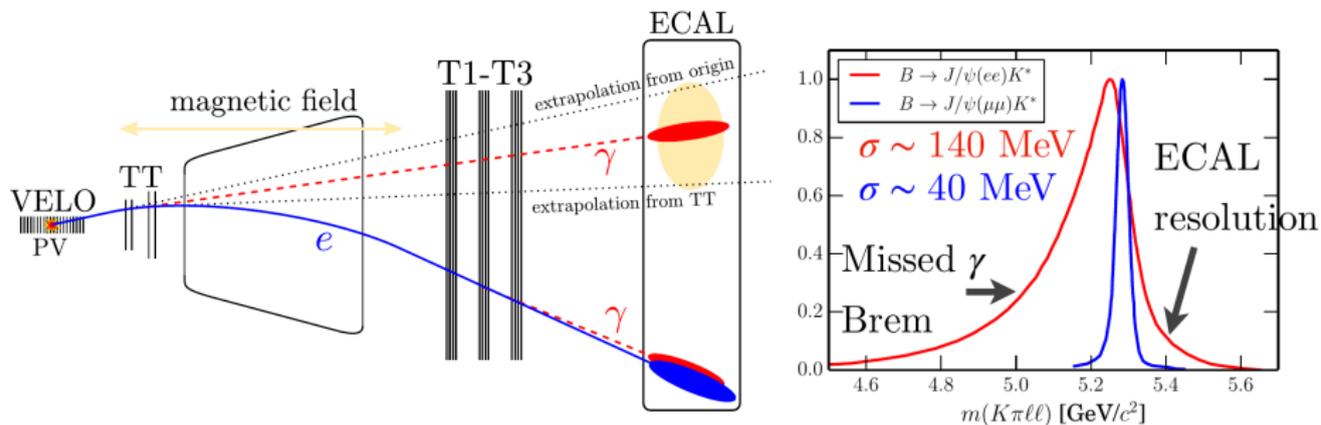
- 1 Low e trigger efficiencies due to higher thresholds compared to muons
- 2 Electrons strongly emit **Bremsstrahlung** traversing material
Brem- γ recovery has limited efficiency and degrades mass resolution
- 3 Contribution from several background sources, bkg. modeling critical

Experimental challenge: 1. Electron trigger



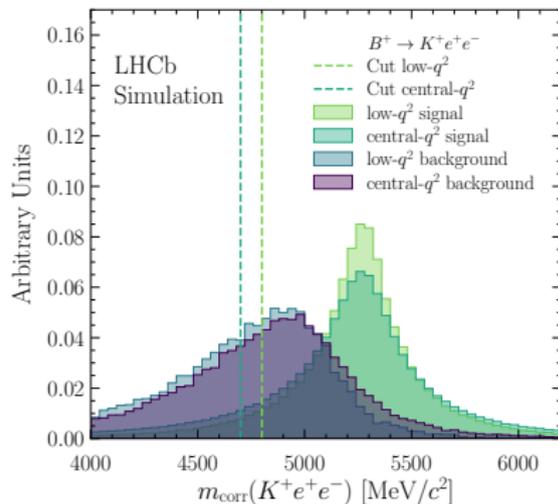
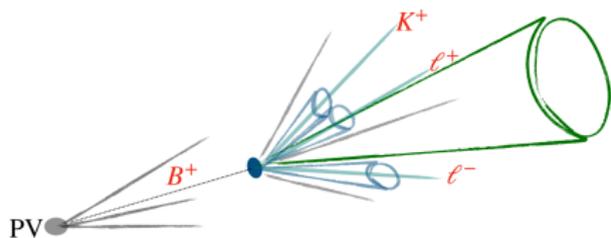
- Trigger signatures for muon and electron modes very different
- Lower L0 p_T thresholds for muons (1.5–1.8 GeV/ c) compared to electrons (2.5–3.0 GeV) \rightarrow challenging for e^+e^- modes
- Combine exclusive trigger categories to improve ϵ for electron modes:
 - 1 Trigger on rest of event (independent of signal)
 - 2 Trigger on e/μ from signal

Experimental challenge: 2. Bremsstrahlung



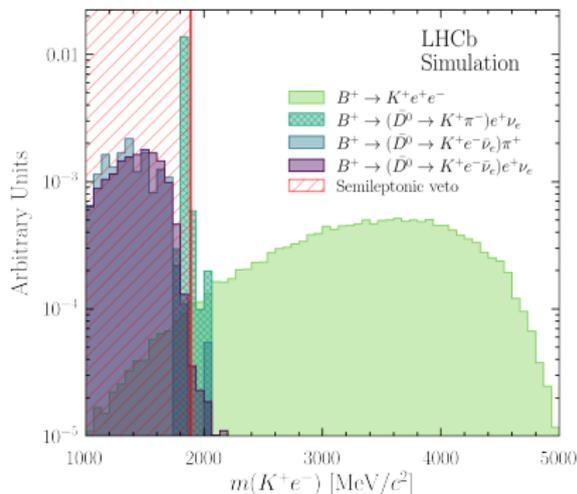
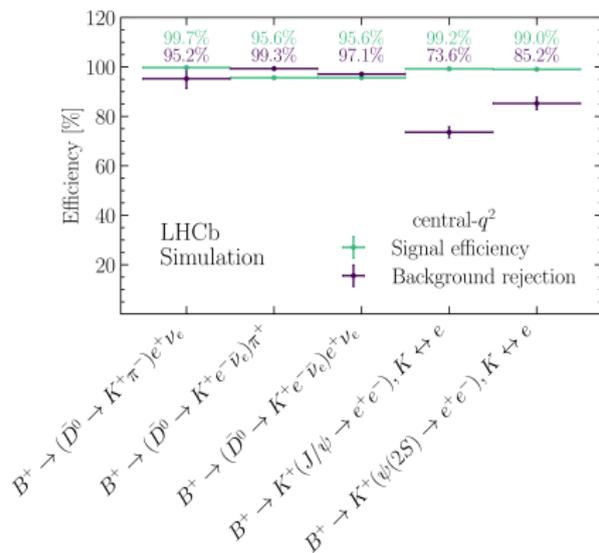
- Correct electron momentum by adding matching photons ($E_T > 75 \text{ MeV}/c^2$) reconstructed in the ECAL
- Bremsstrahlung recovery $\sim 50\%$ efficient, well simulated
- Bremsstrahlung reconstruction impacts momentum resolution
 \rightarrow higher background pollution and more sensitive to bkg. modeling

Experimental challenge: 3. Background suppression



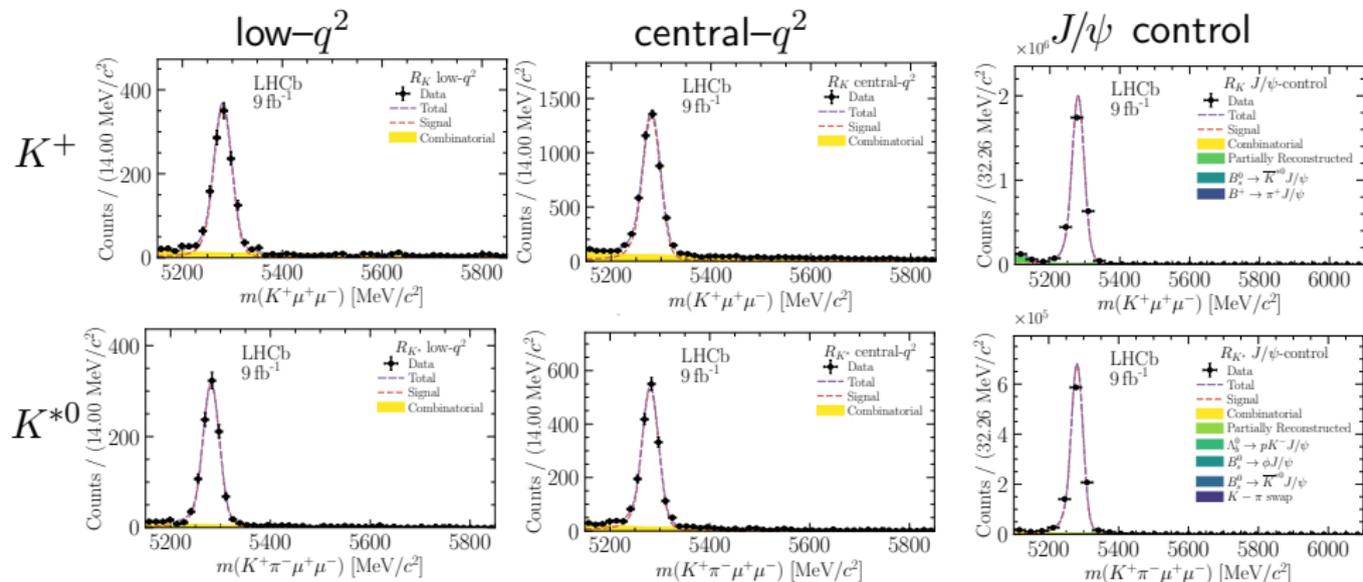
- Combinatorial backgrounds: suppressed using multivariate classifier using kinematic and vertex quality information
- Partially reconstructed:
 - 1 MVA using track/vertex isolation
 - 2 Corrected mass exploiting PV/SV
- Specific backgrounds: vetos combining PID and kinematic criteria

Experimental challenge: 3. Background suppression



- Combinatorial backgrounds: suppressed using multivariate classifier using kinematic and vertex quality information
- Partially reconstructed:
 - MVA using track/vertex isolation
 - Corrected mass exploiting PV/SV
- Specific backgrounds: vetos combining PID and kinematic criteria

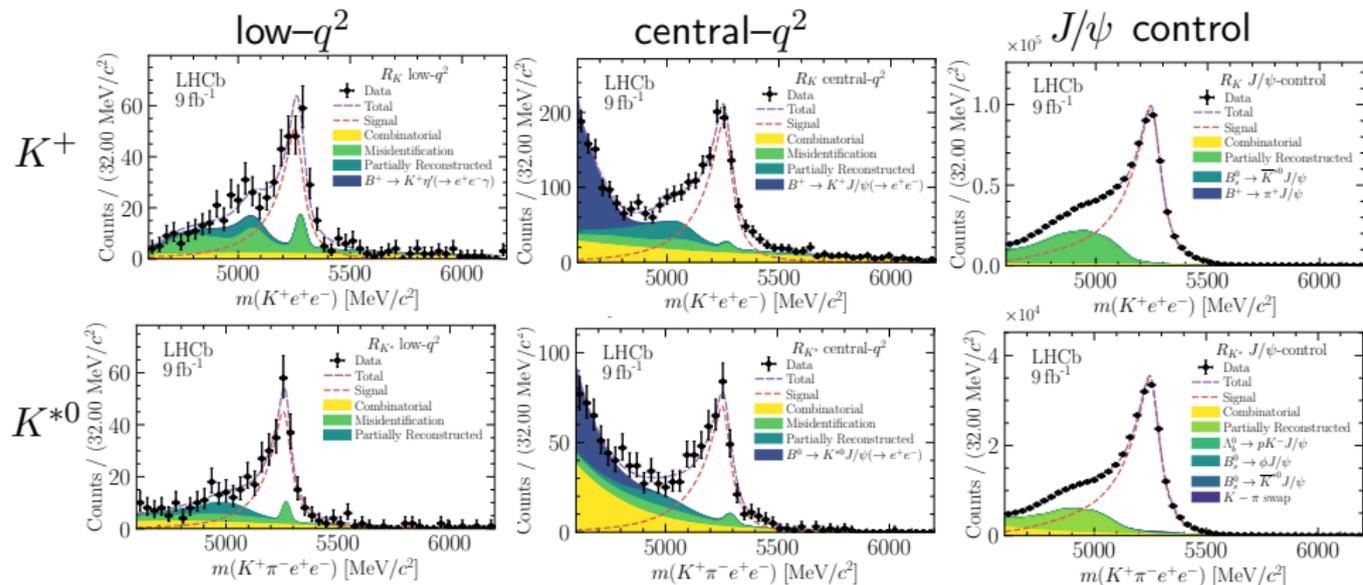
Muon mode fits



- Muon mode is very clean!
- Muon branching fraction compatible with published results

[JHEP 06 (2014) 133] [JHEP 11 (2016) 047]

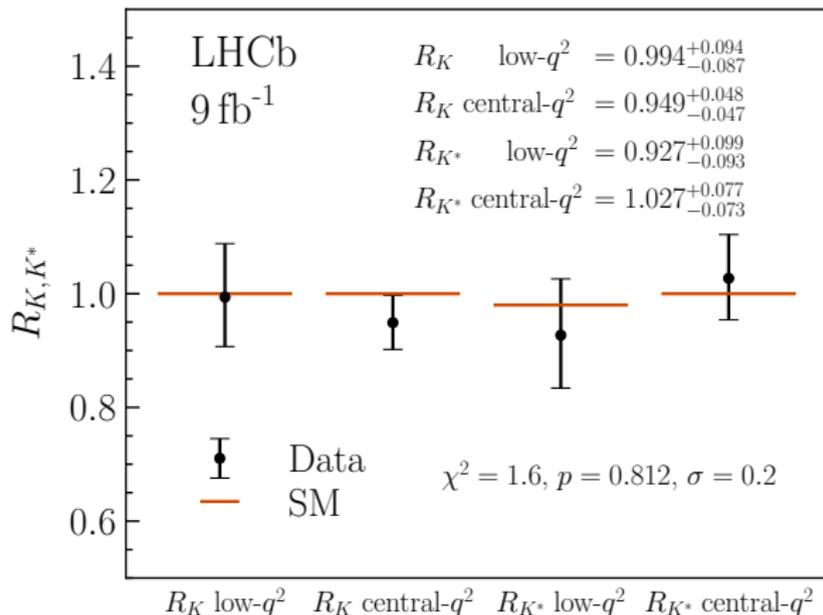
Electron mode fits



- Good fit quality when including all components
- Brems. tails from J/ψ entering rare modes constrained in sim. fit
- Partially reconstructed bgk. from $K^{*0}e^+e^-$ constrained in $K^+e^+e^-$

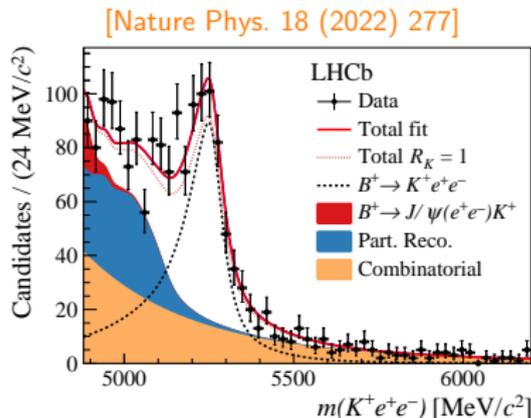
R_K and R_{K^*} results

[arXiv:2212.09152] [arXiv:2212.09153]



- Most precise test of LFU in $b \rightarrow s \ell^+ \ell^-$ transitions
- Compatible with the SM at 0.2σ using simple χ^2 test

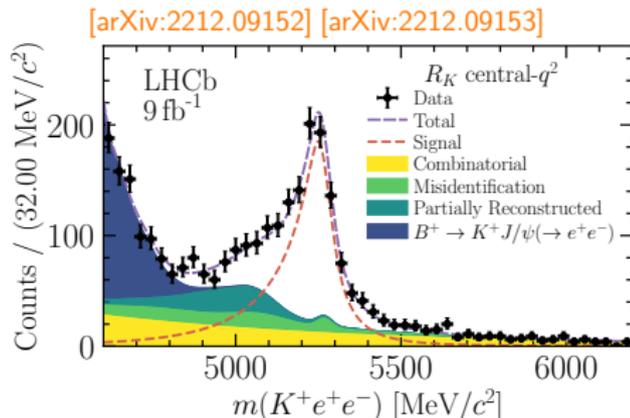
Difference to previous R_K analysis



$$R_K = 0.846_{-0.039-0.012}^{+0.042+0.013}$$

[Nature Phys. 18 (2022) 277]

→

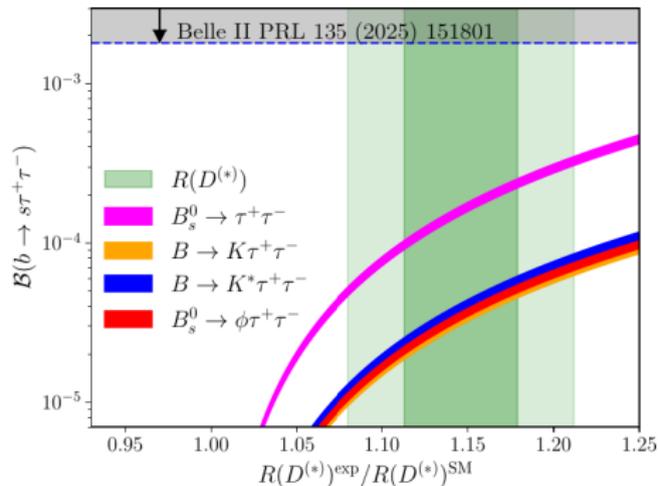
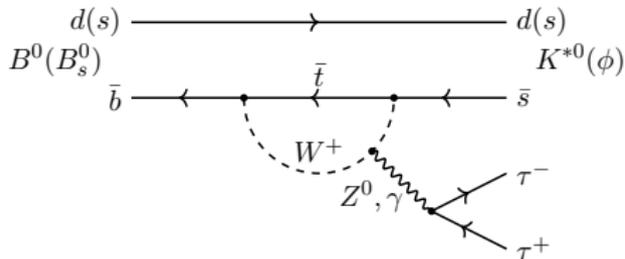


$$R_K = 0.949_{-0.041-0.022}^{+0.042+0.022}$$

[arXiv:2212.09152] [arXiv:2212.09153]

- Different selection allows for statistical scatter of ± 0.033
- Shift of ~ 0.1 due to pollution by residual misidentified backgrounds present and not accounted for in [Nature Phys. 18 (2022) 277]
 - Tighter particle identification cuts: Shift of +0.064
 - Explicit inclusion of residual misid. backgrounds: Shift of +0.038

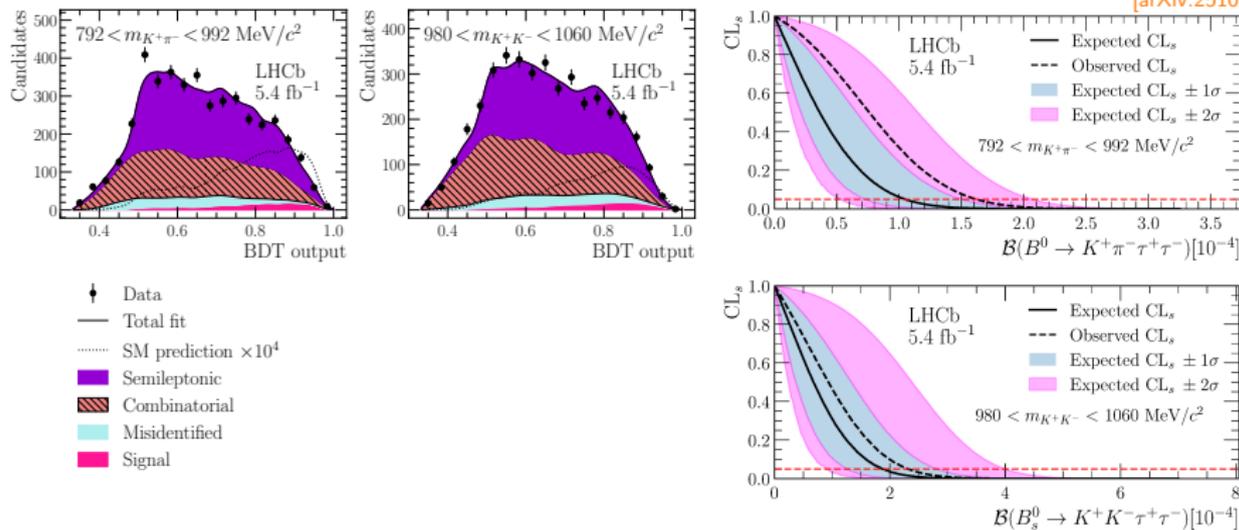
Search for $B \rightarrow K^+ \pi^- (K^+ K^-) \tau^+ \tau^-$



- SM prediction at the order of 10^{-7} [PRL 120 (2018) 181802]
- Could have large NP effects in $b \rightarrow s \tau^+ \tau^-$ decays [PRL 120 (2018) 181802]
- Most stringent limit from Belle II $\mathcal{B}(B^0 \rightarrow K^{*0} \tau^+ \tau^-) < 1.8 \times 10^{-3}$ [PRL 135 (2025) 151801] and preliminary $\mathcal{B}(B^+ \rightarrow K^+ \tau^+ \tau^-) < 8.7 \times 10^{-4}$ at 90%
- New search using $\tau^+ \rightarrow \mu^+ \nu_\mu \bar{\nu}_\tau$ decays [arXiv:2510.13716]

Exclusion limits for $B \rightarrow K^+ \pi^- (K^+ K^-) \tau^+ \tau^-$

[arXiv:2510.13716]



- B mass cannot be fully reconstructed, instead fit BDT output
- Obtained upper limits using 5.4 fb^{-1} Run 2 data:
 - $\mathcal{B}(B^0 \rightarrow K^{*0} \tau^+ \tau^-) < 2.8 \times 10^{-4} (2.5 \times 10^{-4})$ at 95% (90%) CL
 - $\mathcal{B}(B_s^0 \rightarrow \phi \tau^+ \tau^-) < 4.7 \times 10^{-4} (4.1 \times 10^{-4})$ at 95% (90%) CL
- Can be interpreted as limit on Δ^2 under assumption $\Delta = \Delta C_9^{\tau\tau} = -\Delta C_{10}^{\tau\tau}$:
 - $\Delta^2 < 2.9 \times 10^4 (2.5 \times 10^4)$ at 95% (90%)