

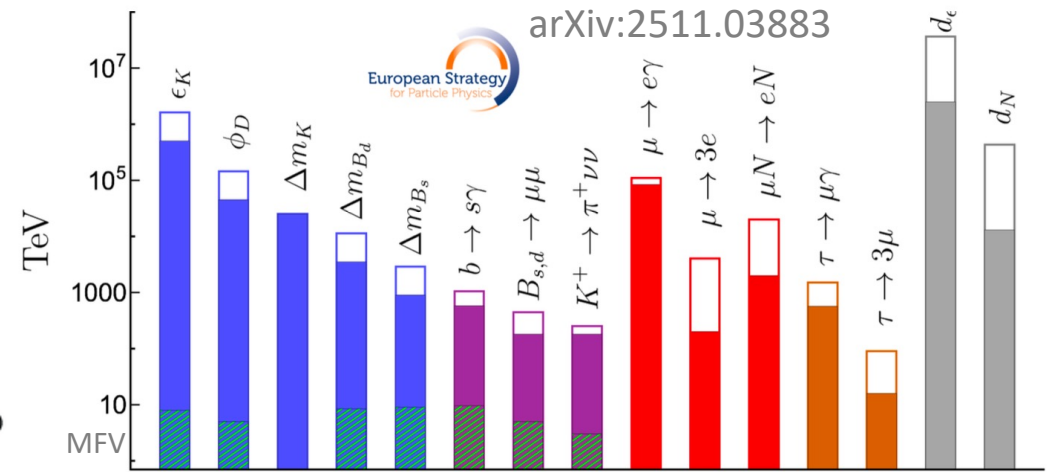
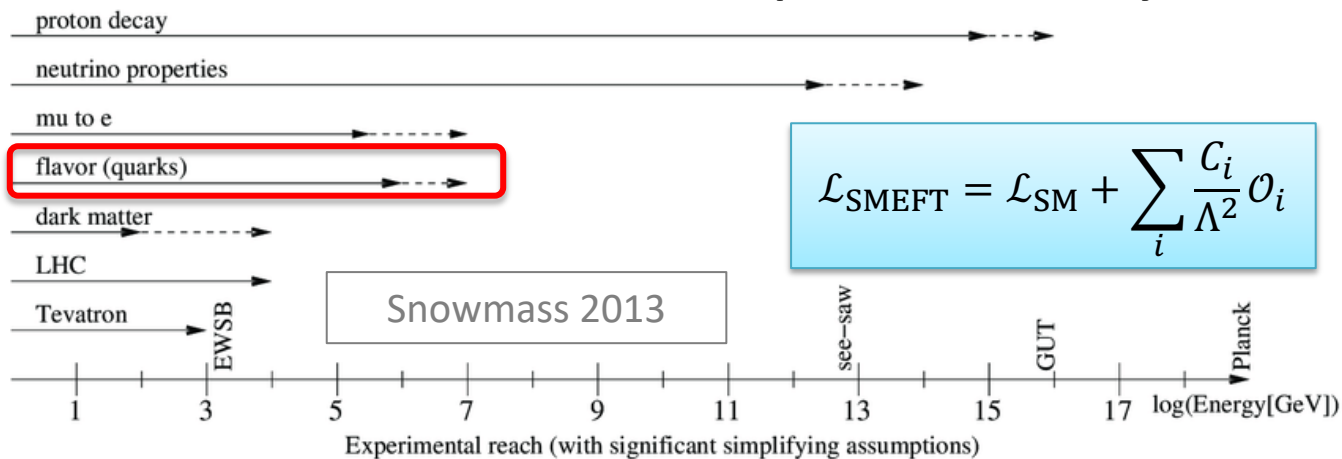
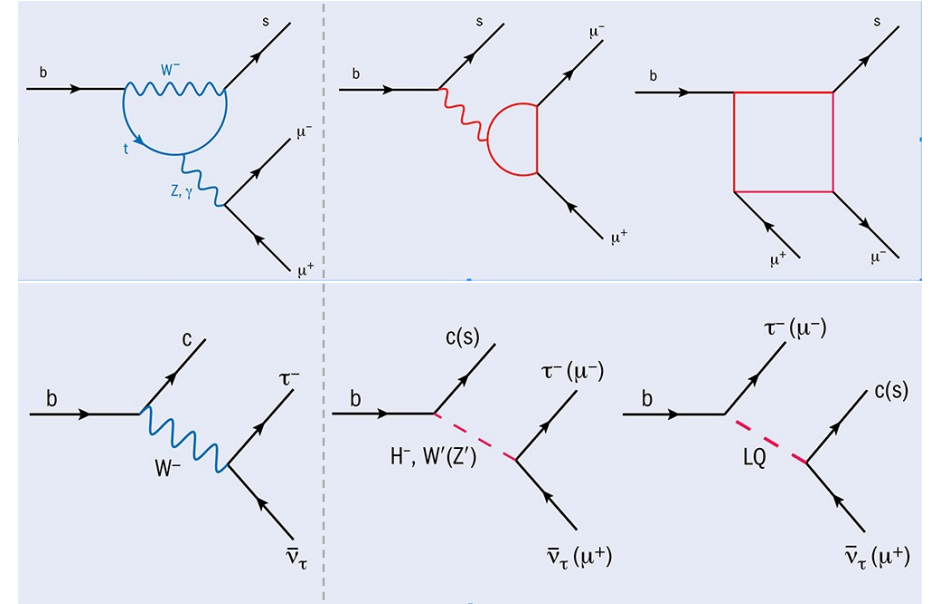
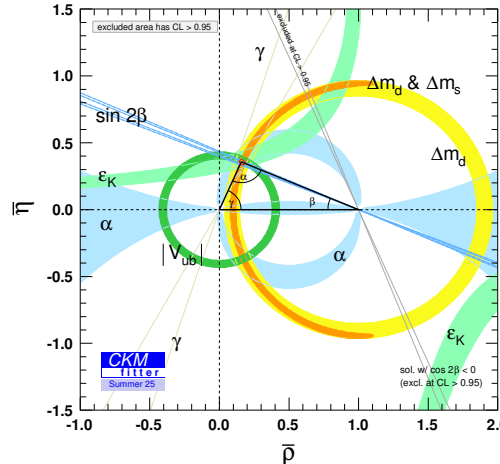
Indirect search for new physics at LHCb

Jibo HE (何吉波), UCAS (中国科学院大学)

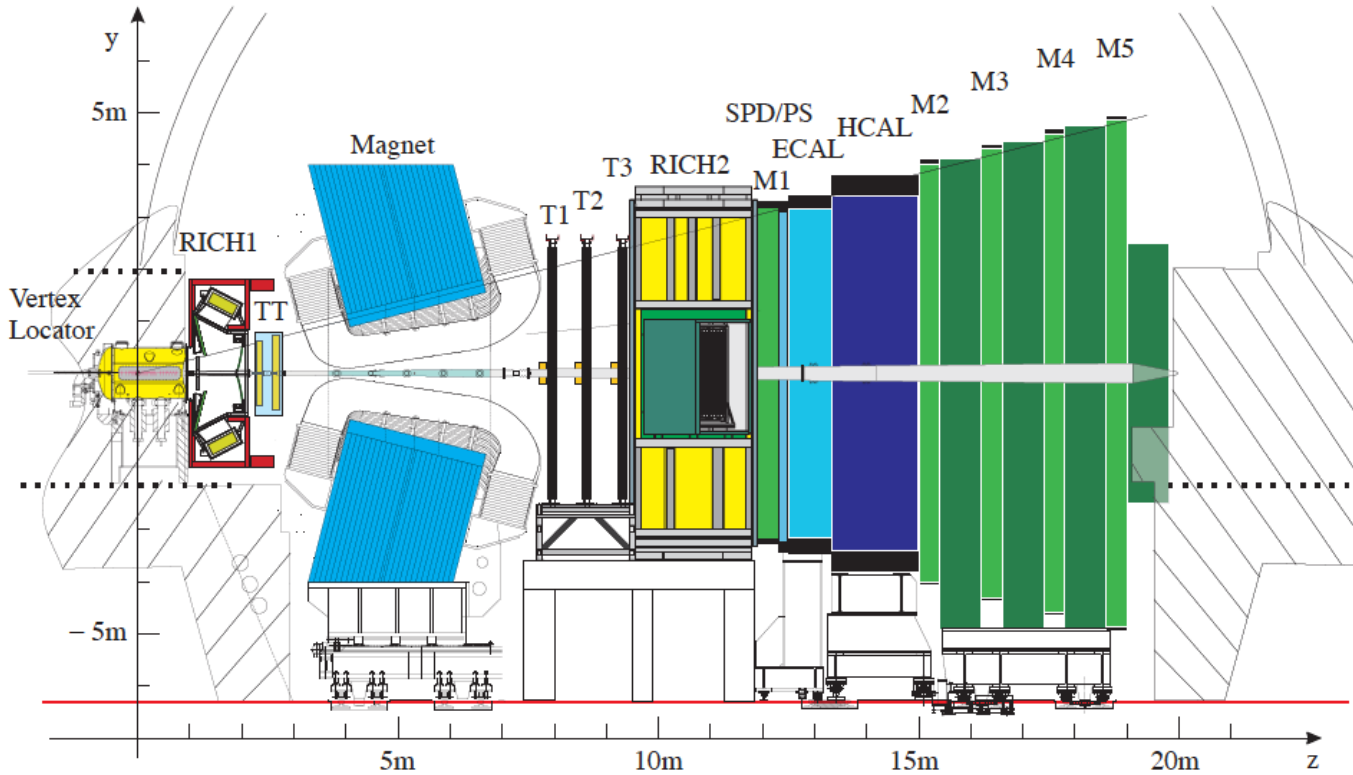
May 24, 2026

Introduction

- Flavor physics
 - FCNC
 - FCCC
 - CKM [Y.H. Yang, 10h40]
- Probe higher energy scale than the direct search, complementary



The LHCb experiment



Vertex Locator

$$\sigma_{PV,x/y} \sim 10 \mu\text{m}, \sigma_{PV,z} \sim 60 \mu\text{m}$$

Tracking (TT, T1-T3)

$$\Delta p/p: 0.4\% \text{ at } 5 \text{ GeV}/c, \text{ to } 0.6\% \text{ at } 100 \text{ GeV}/c$$

RICHs

$$\varepsilon(K \rightarrow K) \sim 95\%, \text{ mis-ID rate } (\pi \rightarrow K) \sim 5\%$$

Muon system (M1-M5)

$$\varepsilon(\mu \rightarrow \mu) \sim 97\%, \text{ mis-ID rate } (\pi \rightarrow \mu) = 1 - 3\%$$

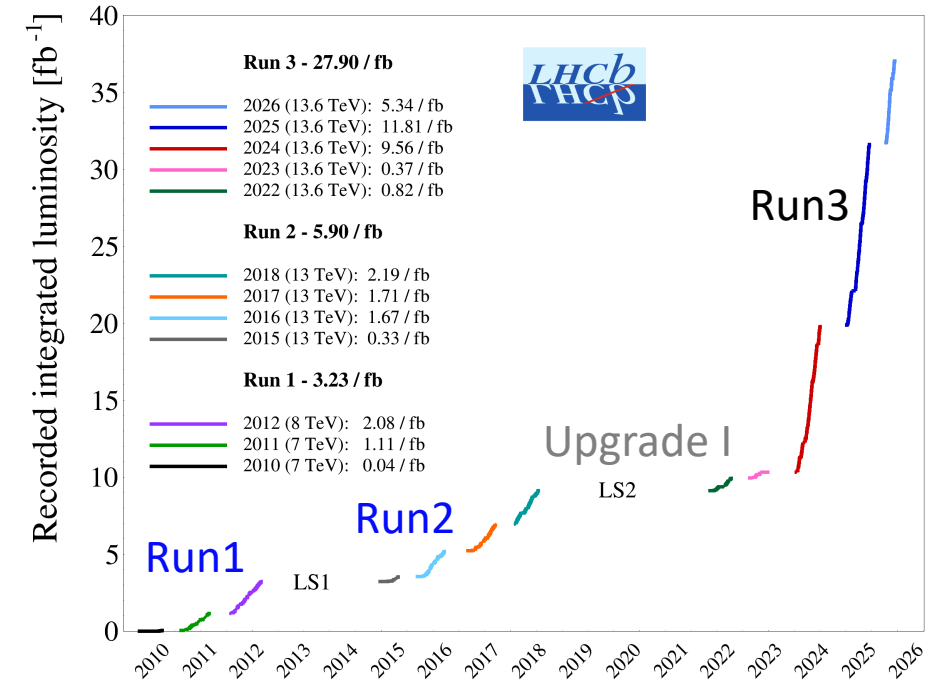
ECAL

$$\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\% \text{ (} E \text{ in GeV)}$$

HCAL

$$\sigma_E/E \sim 70\%/\sqrt{E} \oplus 10\% \text{ (} E \text{ in GeV)}$$

Total recorded luminosity – pp – 37.0 fb^{-1}



- Run1-2 (2010-2018)**

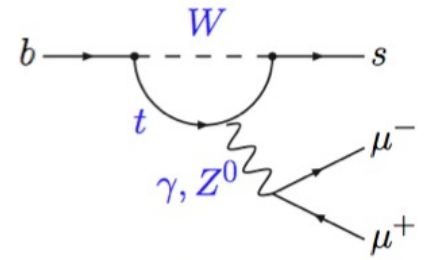
- Luminosity: $\sim 9 \text{ fb}^{-1}$

- Yields, complementary to ATLAS/CMS

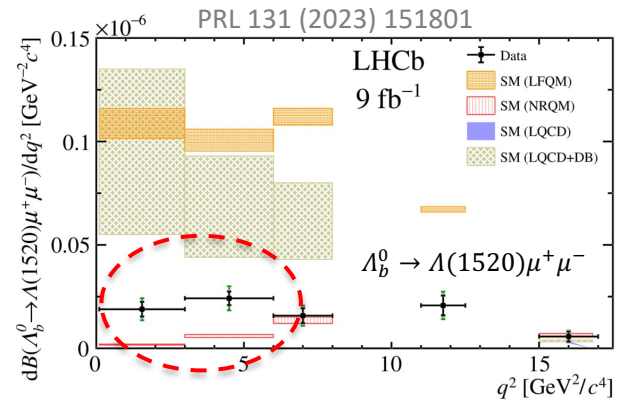
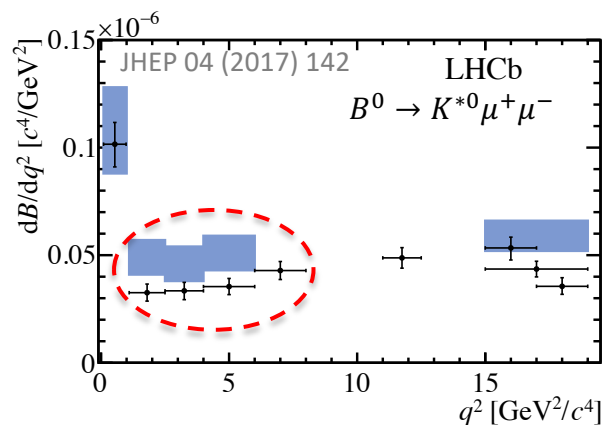
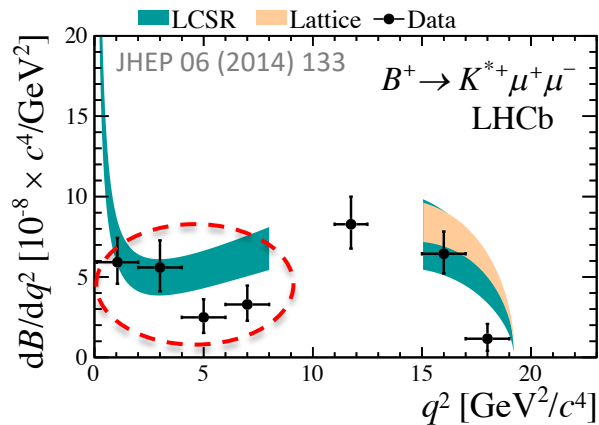
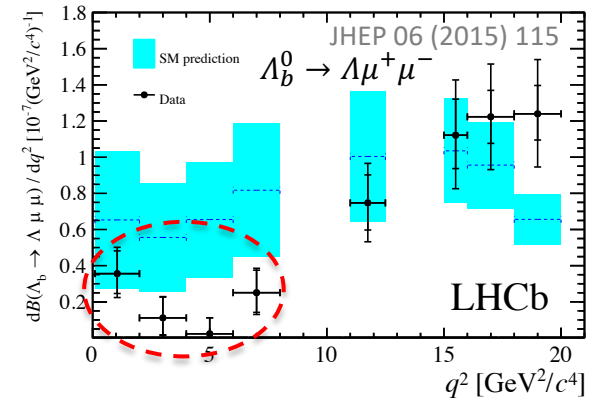
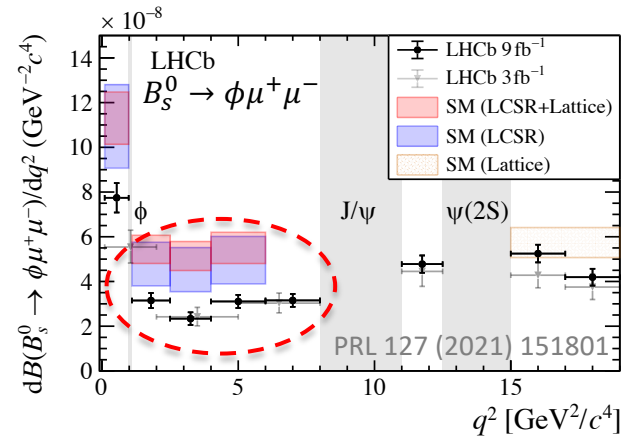
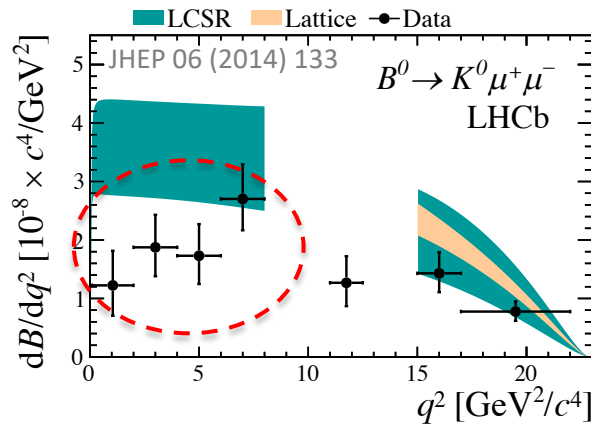
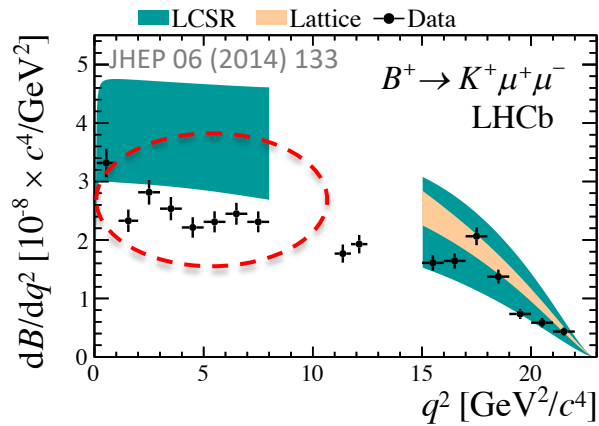
- Muon modes: Down to zero p_T

- Hadronic modes: **Unique**

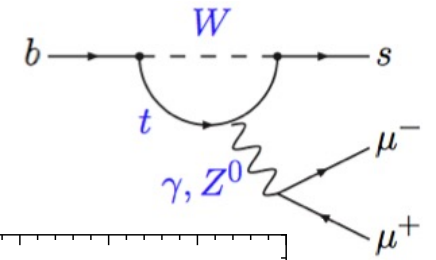
Branching fraction of $b \rightarrow s \mu^+ \mu^-$



- Pattern of tensions seen, theoretical uncertainty?



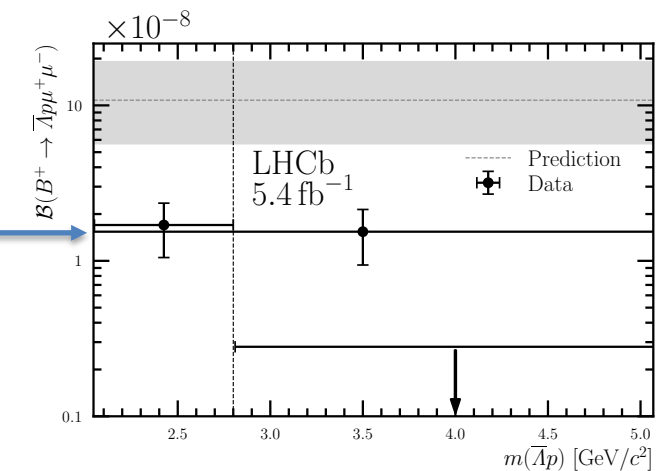
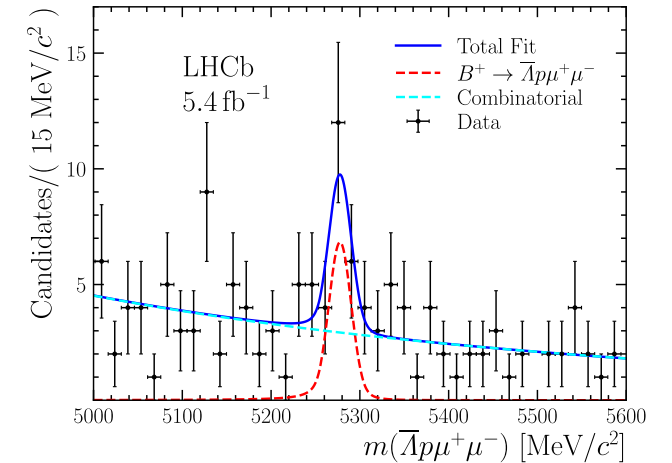
$B^+ \rightarrow \bar{\Lambda} p \mu^+ \mu^-$, first evidence



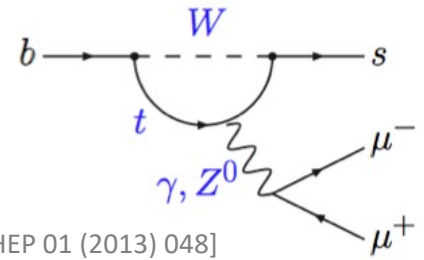
- Rich multibody kinematics and angular observables, offering sensitive probes of potential NP effects
- For $m(\bar{\Lambda} p) < 2.8$ GeV, 1st evidence (3.5σ)

$$\mathcal{B}_{\text{low}}(B^+ \rightarrow \bar{\Lambda} p \mu^+ \mu^-) = (1.70_{-0.56}^{+0.65} \pm 0.17 \pm 0.14) \times 10^{-8}$$

- Consistent with SM within 2σ , di-baryon threshold enhancement?



P'_5 with $B^0 \rightarrow K^{*0} \mu^+ \mu^-$

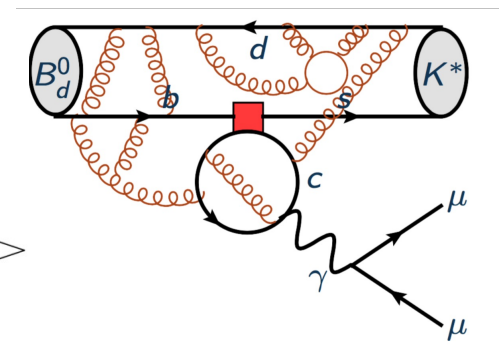
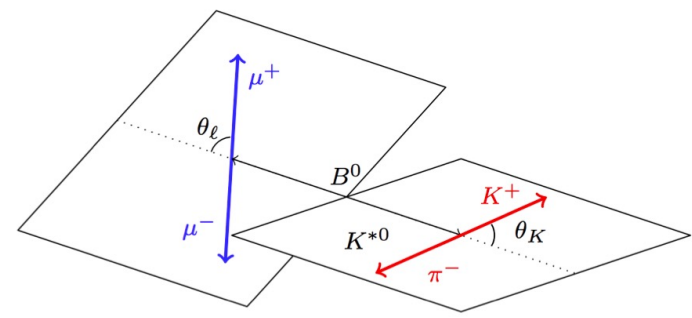
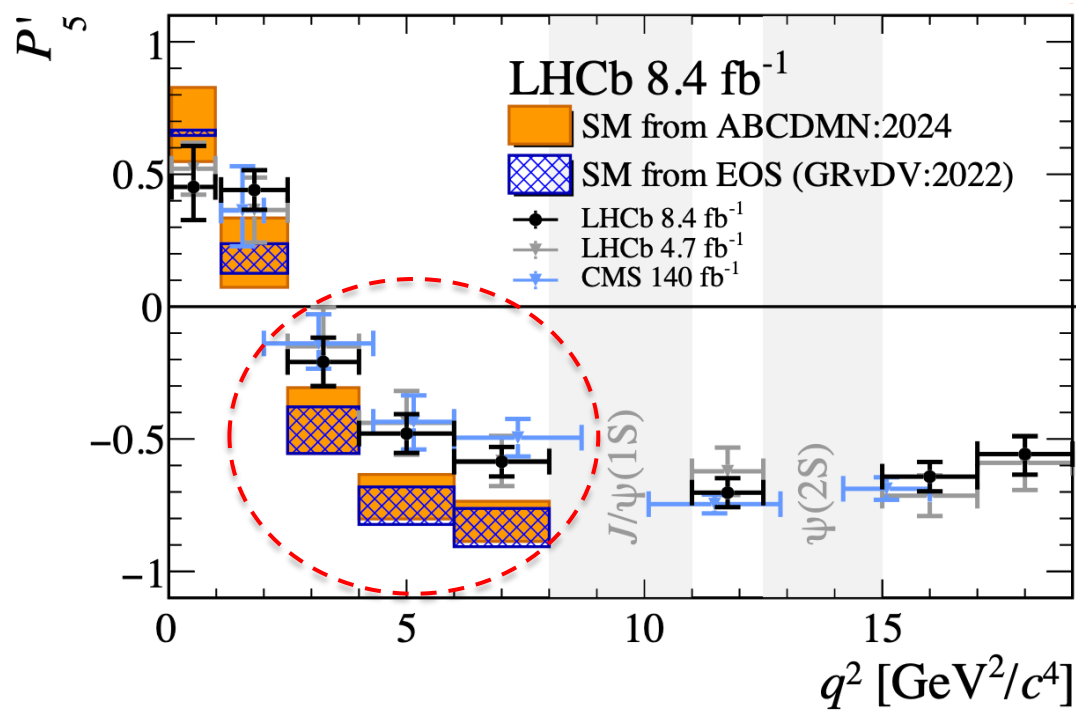


[S. Descotes-Genon, et al., JHEP 01 (2013) 048]

- $P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}}$, less form-factor dependent

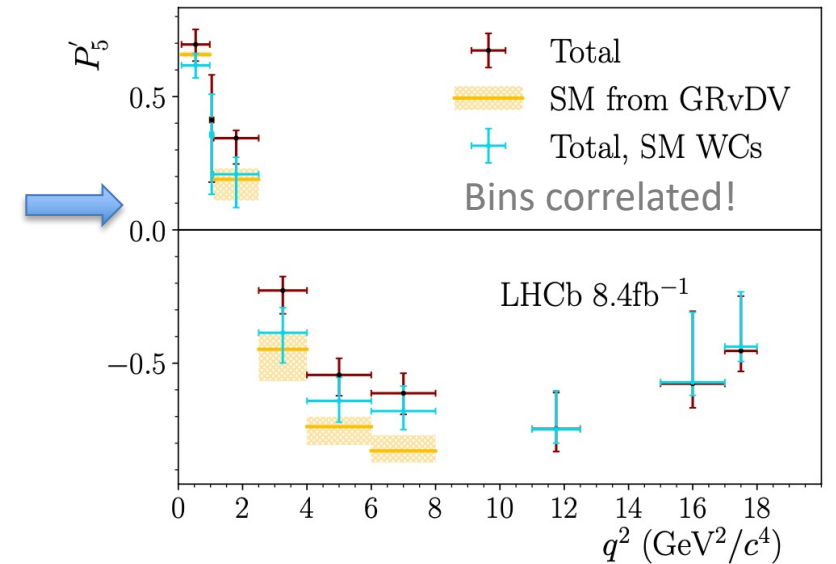
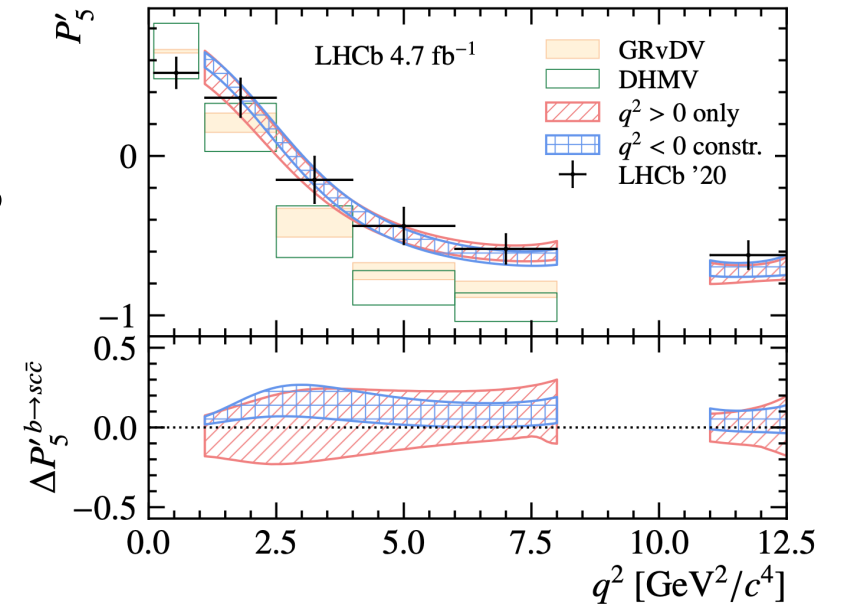
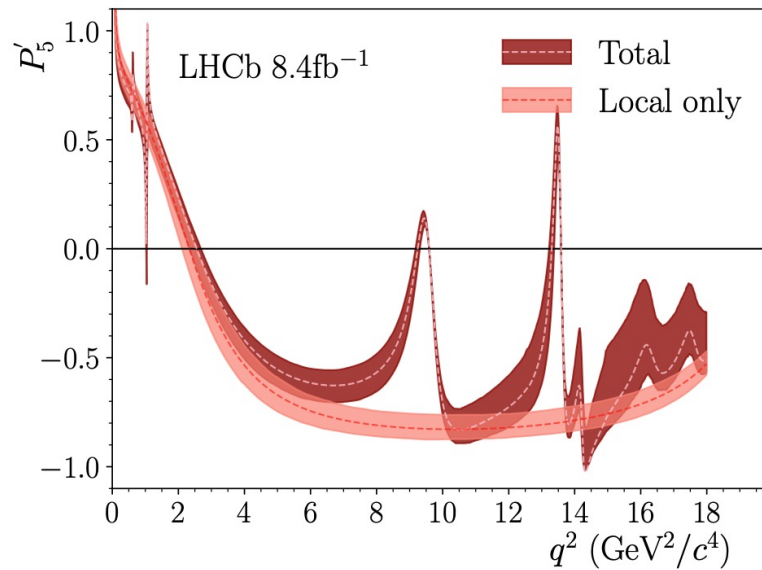
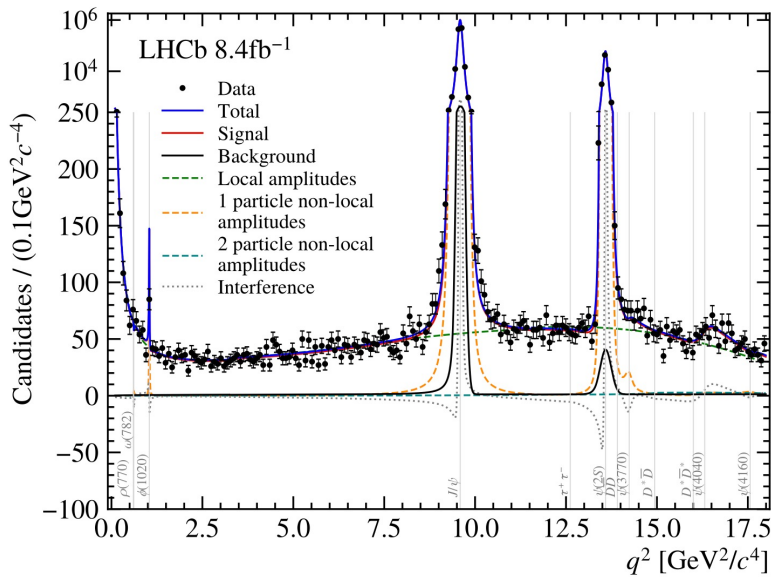
$$\frac{1}{d(\Gamma + \bar{\Gamma})/dq^2} \frac{d^3(\Gamma + \bar{\Gamma})}{d\vec{\Omega}} = \frac{9}{32\pi} \left[\frac{3}{4}(1 - F_L) \sin^2 \theta_K + F_L \cos^2 \theta_K + \frac{1}{4}(1 - F_L) \sin^2 \theta_K \cos 2\theta_\ell \right. \\ \left. - F_L \cos^2 \theta_K \cos 2\theta_\ell + S_3 \sin^2 \theta_K \sin^2 \theta_\ell \cos 2\phi \right. \\ \left. + S_4 \sin 2\theta_K \sin 2\theta_\ell \cos \phi + S_5 \sin 2\theta_K \sin \theta_\ell \cos \phi \right. \\ \left. + \frac{4}{3} A_{FB} \sin^2 \theta_K \cos \theta_\ell + S_7 \sin 2\theta_K \sin \theta_\ell \sin \phi \right. \\ \left. + S_8 \sin 2\theta_K \sin 2\theta_\ell \sin \phi + S_9 \sin^2 \theta_K \sin^2 \theta_\ell \sin 2\phi \right]$$

[arXiv:2512.18053]



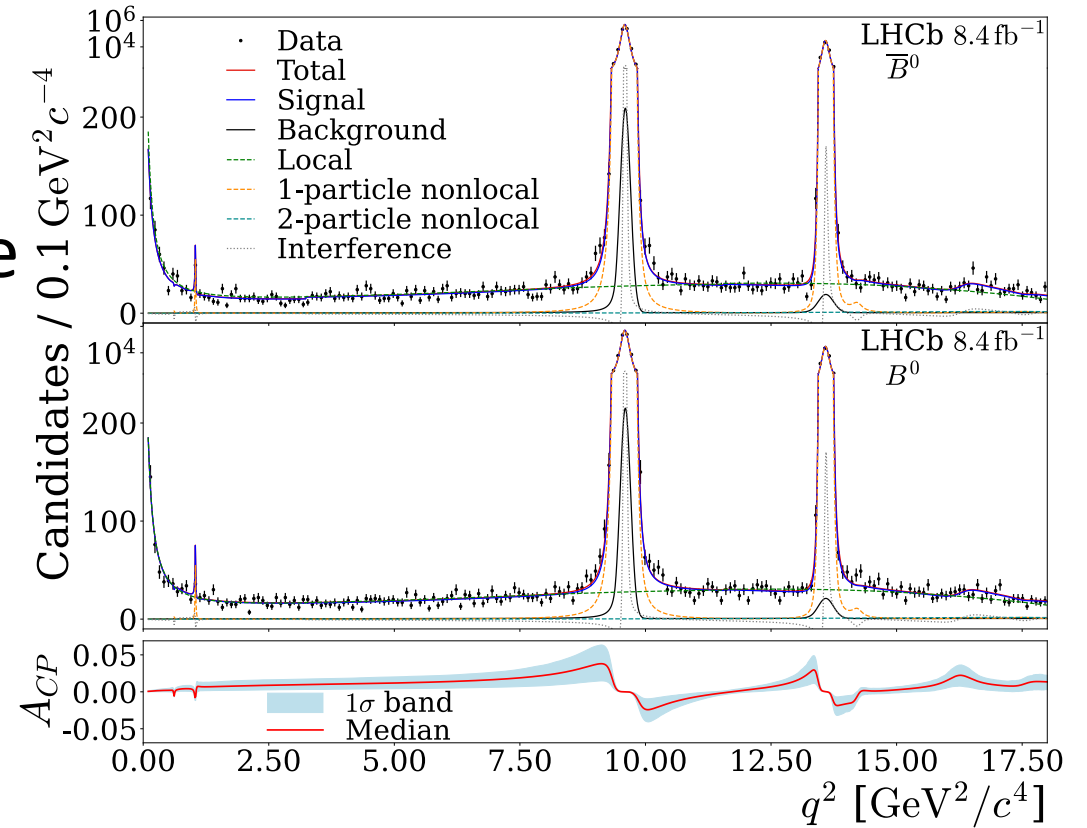
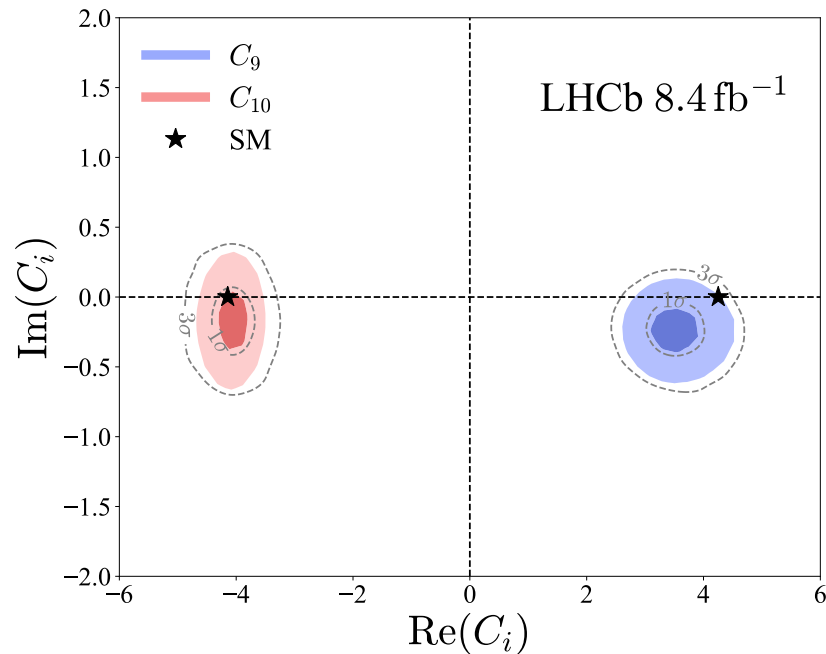
Charm loop

- Model of local and nonlocal contributions to extract Wilson co-efficiency [PRL 132 (2024) 131801]
- Model of both 1-(2-) particle amplitudes, whole dimuon region [JHEP 09 (2024) 026]



CPV in $B^0 \rightarrow K^{*0} \mu^+ \mu^-$

- Full angular distribution exploited, sensitivity to T -even asym. gained in addition to T -odd
- Precision on imaginary parts improved by one order of magnitude



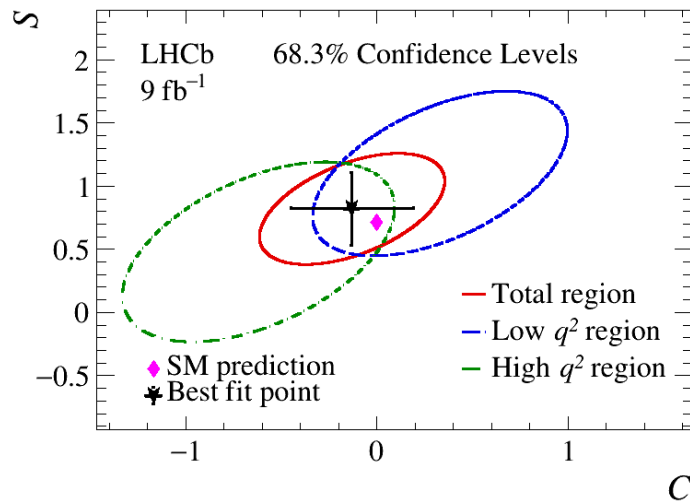
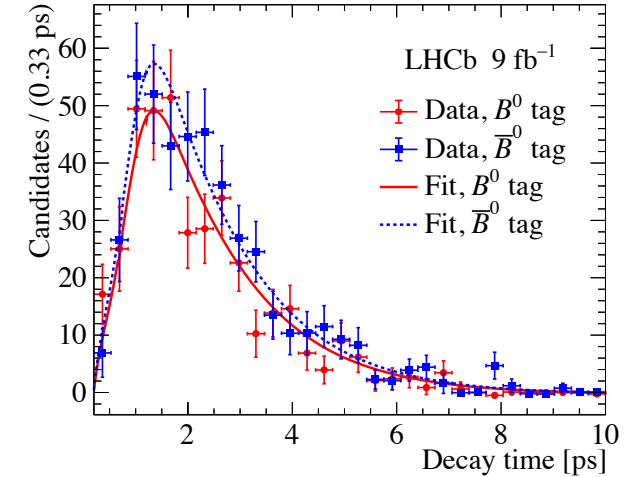
Time-dependent CPV in $B^0 \rightarrow K_S^0 \mu^+ \mu^-$

- 1st study of time-dependent CPV in $b \rightarrow s \ell \ell$

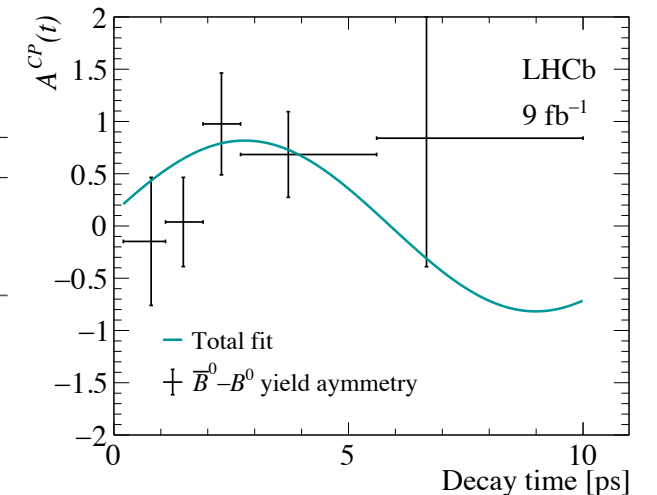
$$\mathcal{A}^{CP}(t) \equiv \frac{\Gamma(\bar{B}^0(t) \rightarrow K_S^0 \mu^+ \mu^-) - \Gamma(B^0(t) \rightarrow K_S^0 \mu^+ \mu^-)}{\Gamma(\bar{B}^0(t) \rightarrow K_S^0 \mu^+ \mu^-) + \Gamma(B^0(t) \rightarrow K_S^0 \mu^+ \mu^-)}$$

$$\approx S \sin(\Delta m_d t) - C \cos(\Delta m_d t)$$

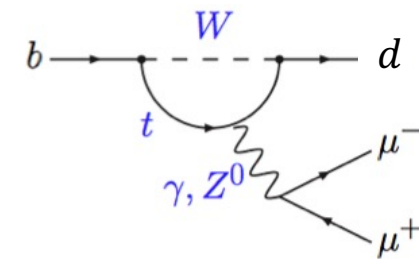
- Results consistent with SM



q^2 range [GeV ² /c ⁴]	C	S
Total	-0.13 ± 0.32	$+0.82 \pm 0.29$
Low: $q^2 < 8.0$	$+0.33 \pm 0.44$	$+1.10 \pm 0.43$
High: $11.0 < q^2 < 15.0$ or $q^2 > 17.5$	-0.62 ± 0.47	$+0.48 \pm 0.47$



$$B^+ \rightarrow \pi^+ \mu^+ \mu^-$$



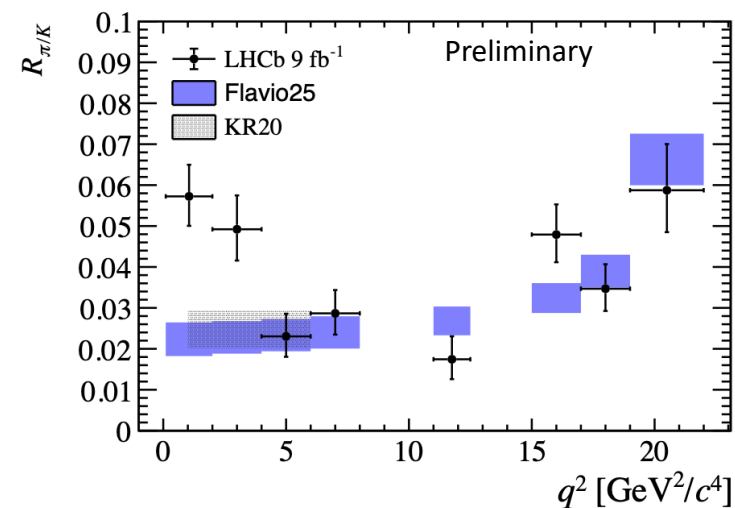
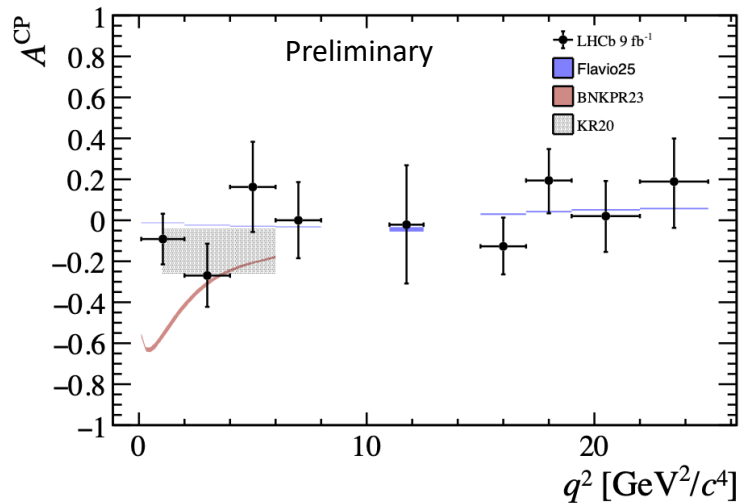
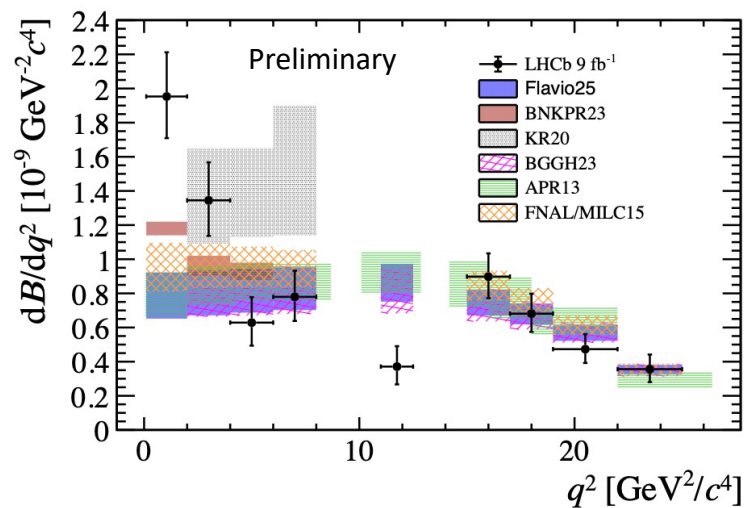
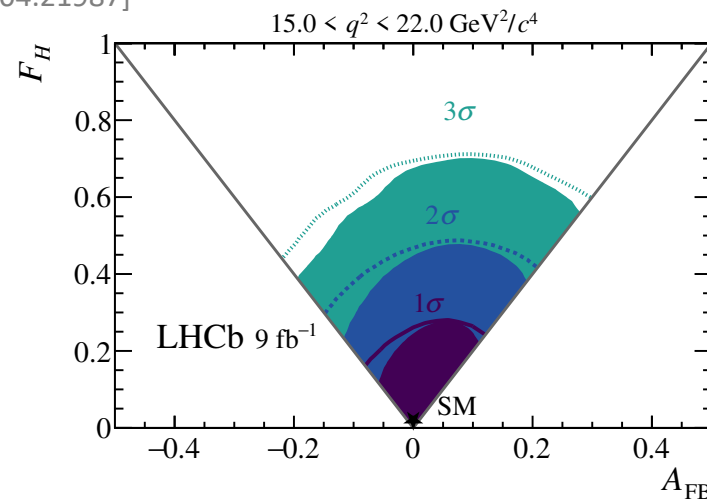
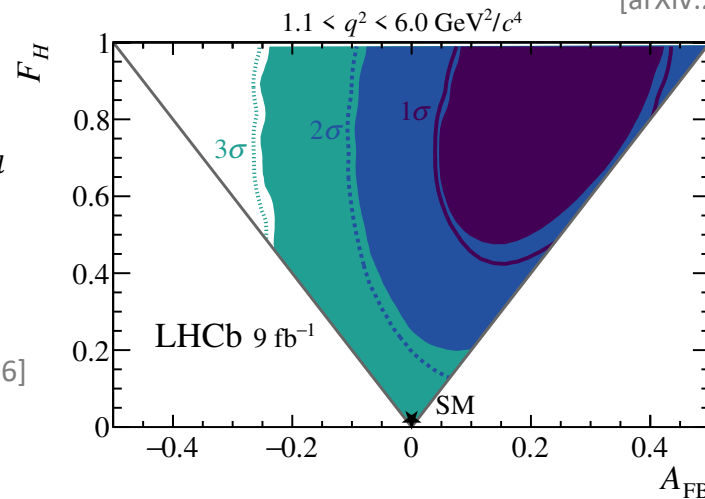
- First angular analysis

$$\frac{1}{\Gamma} \frac{d\Gamma}{d \cos \theta_l} = \frac{3}{4} (1 - F_H) (1 - \cos^2 \theta_l) + \frac{F_H}{2} + A_{FB} \cos \theta_l$$

- Differential BR and CP asymmetry [LHCb-Paper-2026-016]

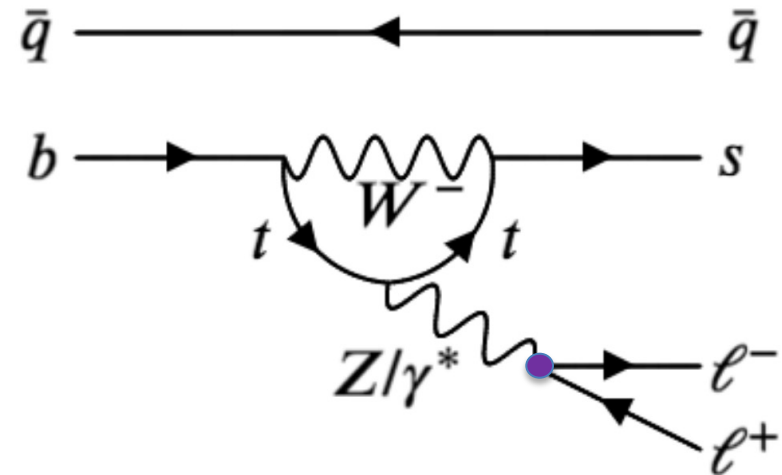
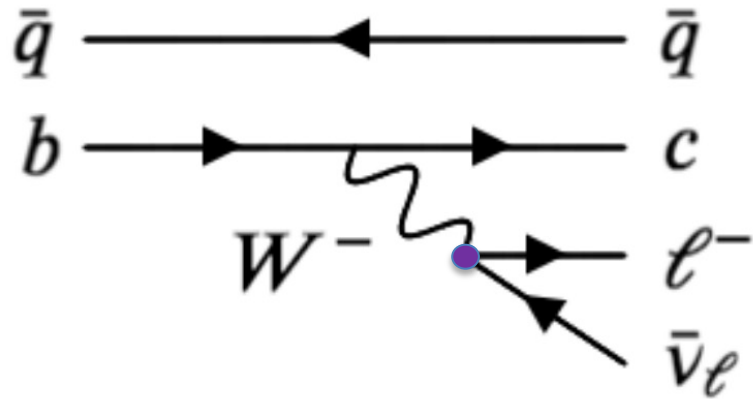
$$\left| \frac{V_{td}}{V_{ts}} \right| = 0.241^{+0.030}_{-0.027}$$

[arXiv:2604.21987]



Lepton flavour universality

- Leptons (e, μ, τ) have identical coupling to gauge bosons



– which means, e.g.,

$$R_K = \frac{\mathcal{B}(B^+ \rightarrow K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \rightarrow K^+ e^+ e^-)} \cong 1$$

$\mathcal{O}(10^{-4})$ uncertainty

[C. Bobeth *et al.*, JHEP 12 (2007) 040]

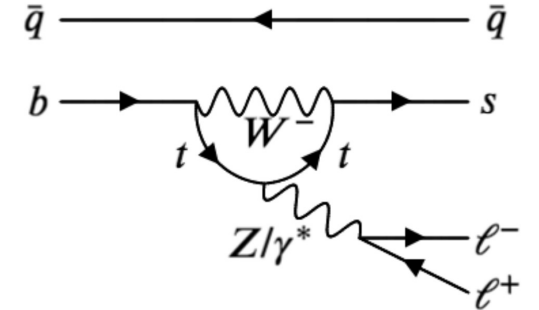
$\mathcal{O}(1\%)$ QED correction

[M. Bordone *et al.*, EJPC 76 (2016) 440]

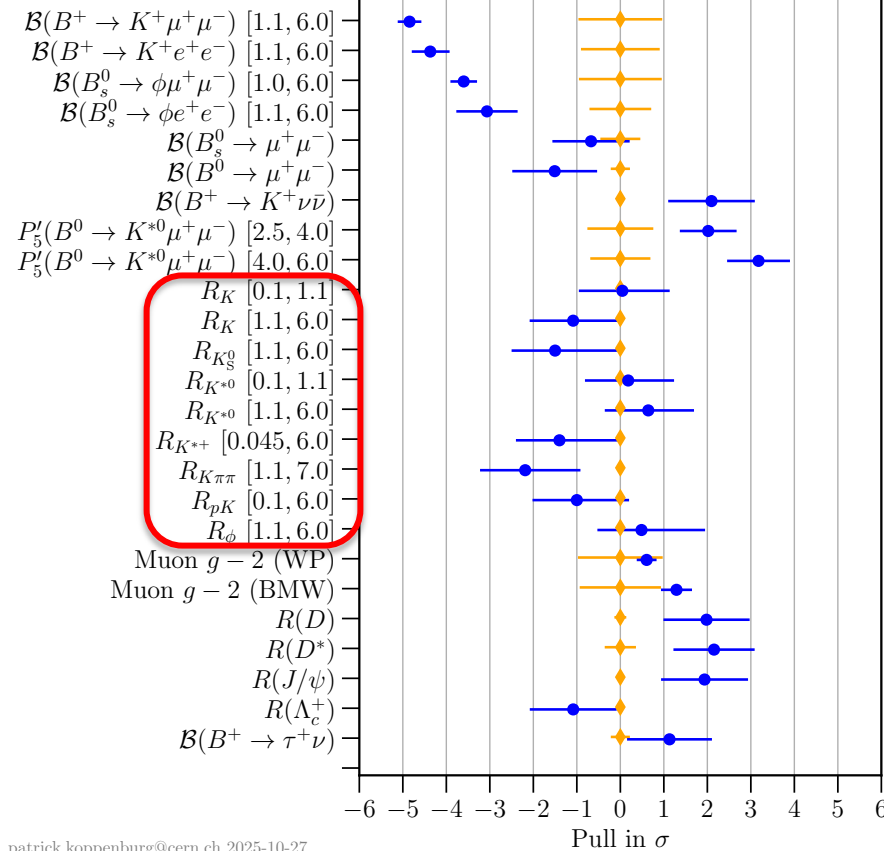
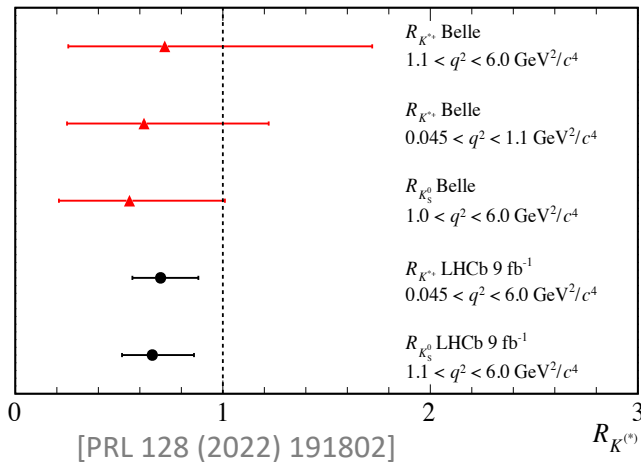
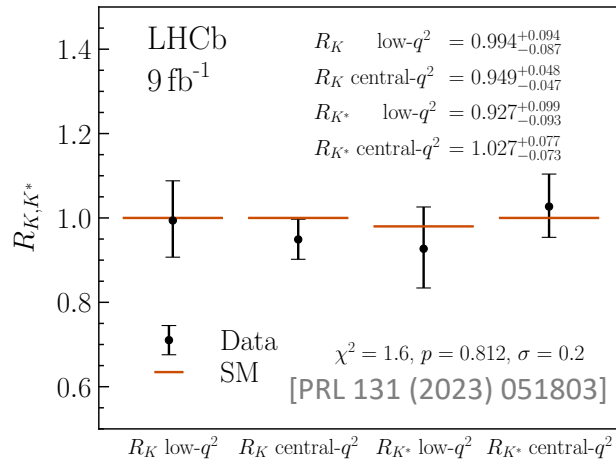
- Lepton flavour universality violation? **New Physics!**

LFU in $b \rightarrow s \ell^+ \ell^-$ decays

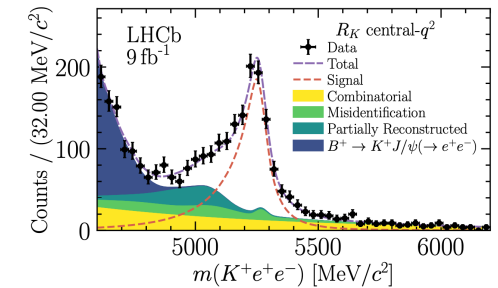
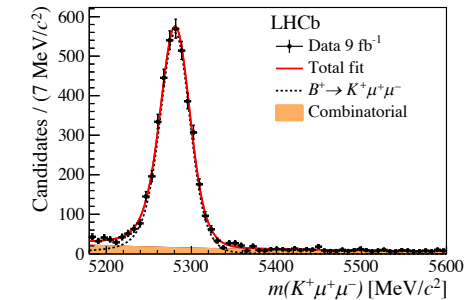
- All consistent with Standard Model for now



$$R_X = \frac{\mathcal{B}(H_b \rightarrow X \mu^+ \mu^-)}{\mathcal{B}(H_b \rightarrow X e^+ e^-)}$$

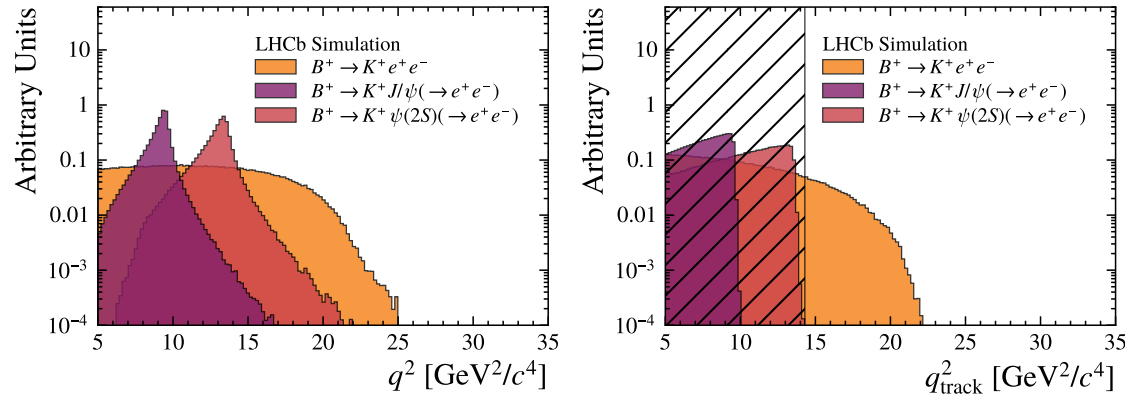


patrick.koppenburg@cern.ch 2025-10-27



LFU in high- q^2

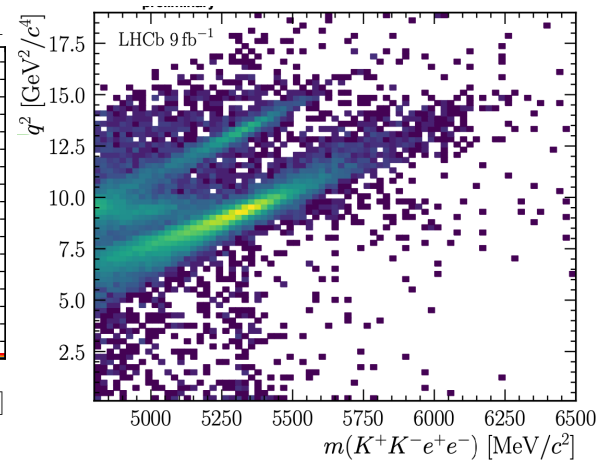
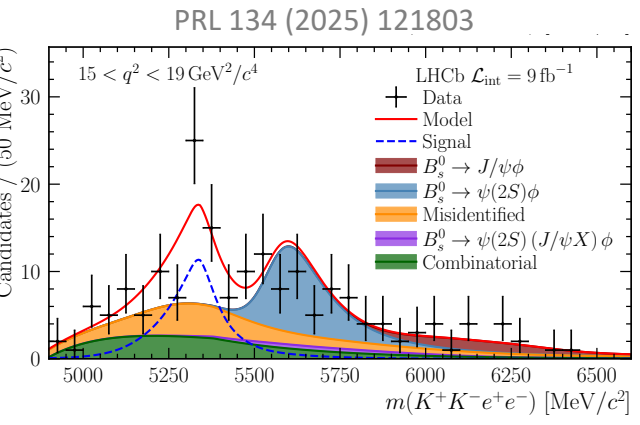
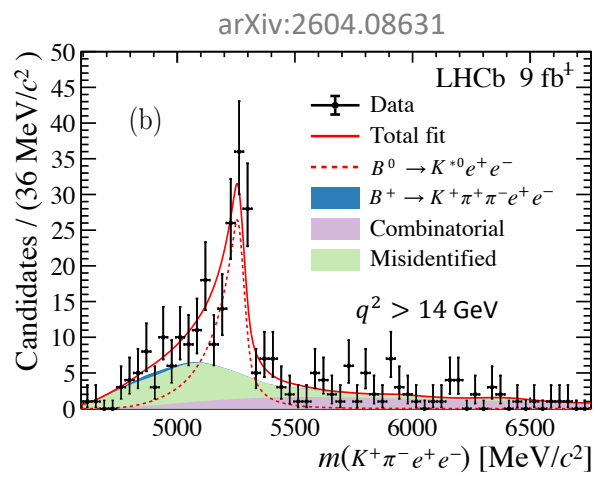
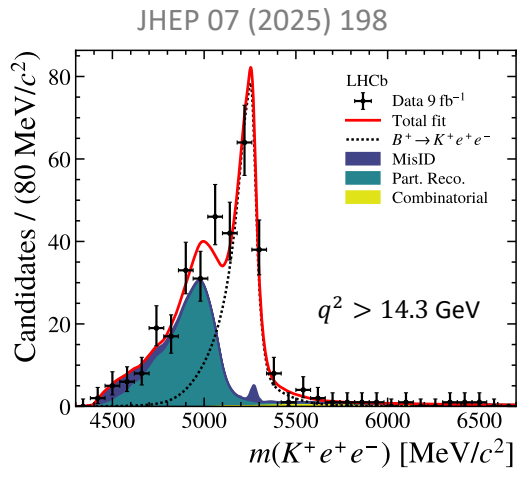
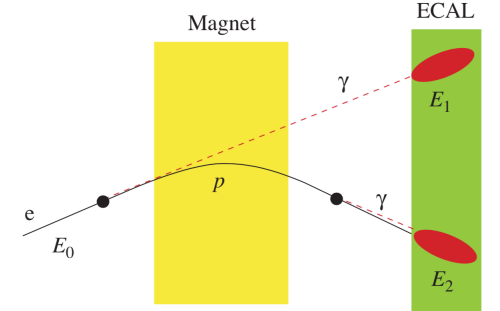
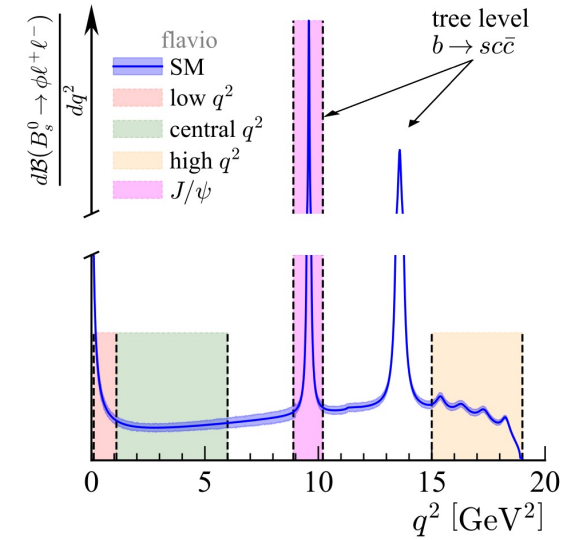
- Challenging due to brem (over-)correction



$$R_K = 1.08_{-0.09}^{+0.11} \pm 0.04$$

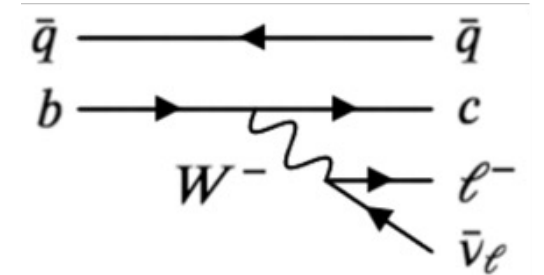
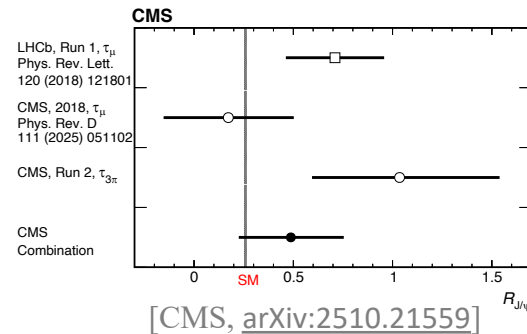
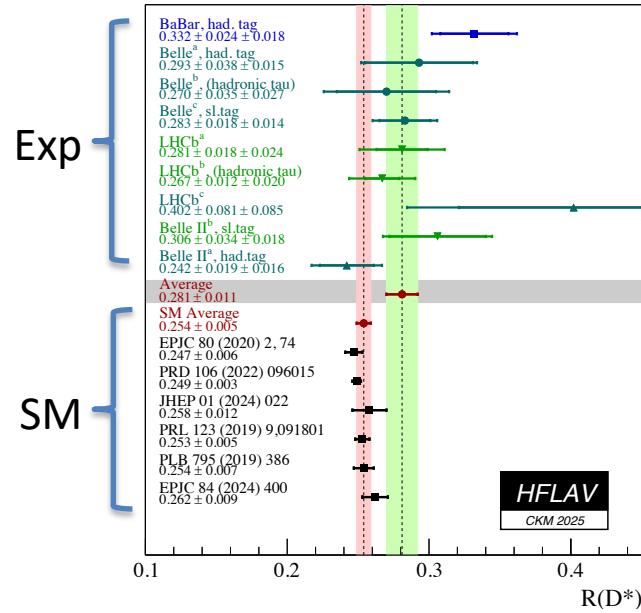
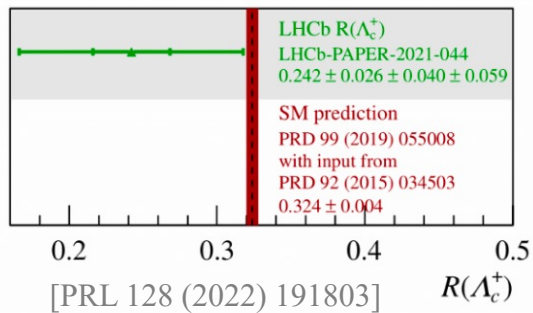
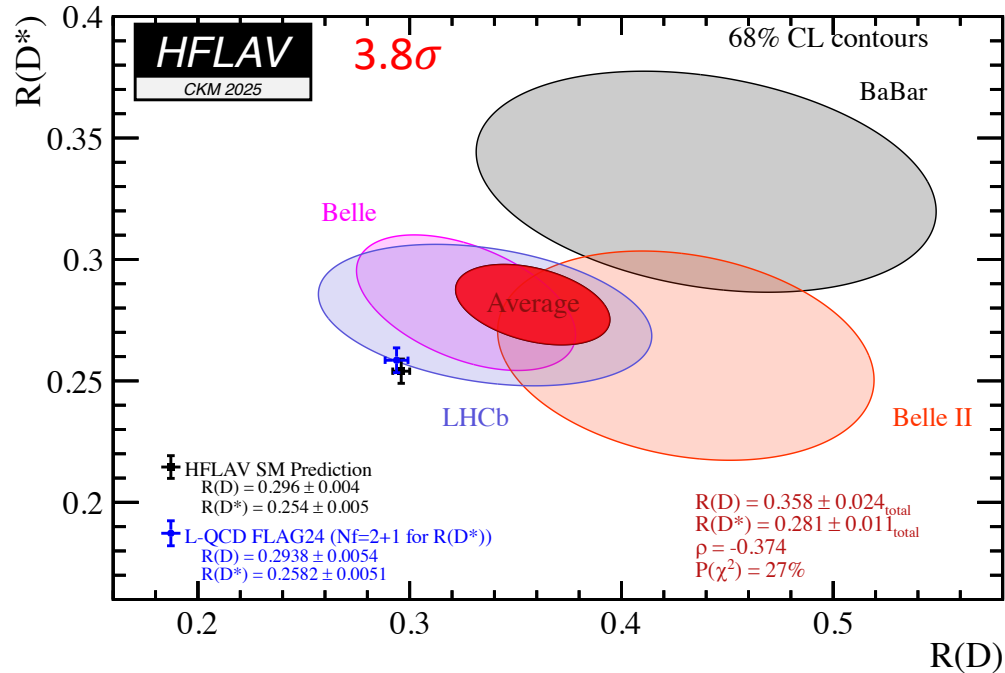
$$R_{K^*0} = 1.08_{-0.12}^{+0.14} \pm 0.07$$

$$R_\phi^{-1} = 0.85_{-0.23}^{+0.24} \pm 0.10$$



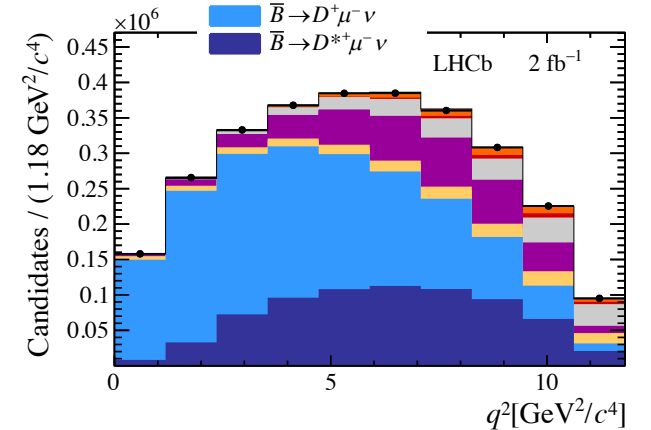
LFU in $b \rightarrow c \ell \nu$ decays

- Deviations from SM seen by Babar/Belle/LHCb



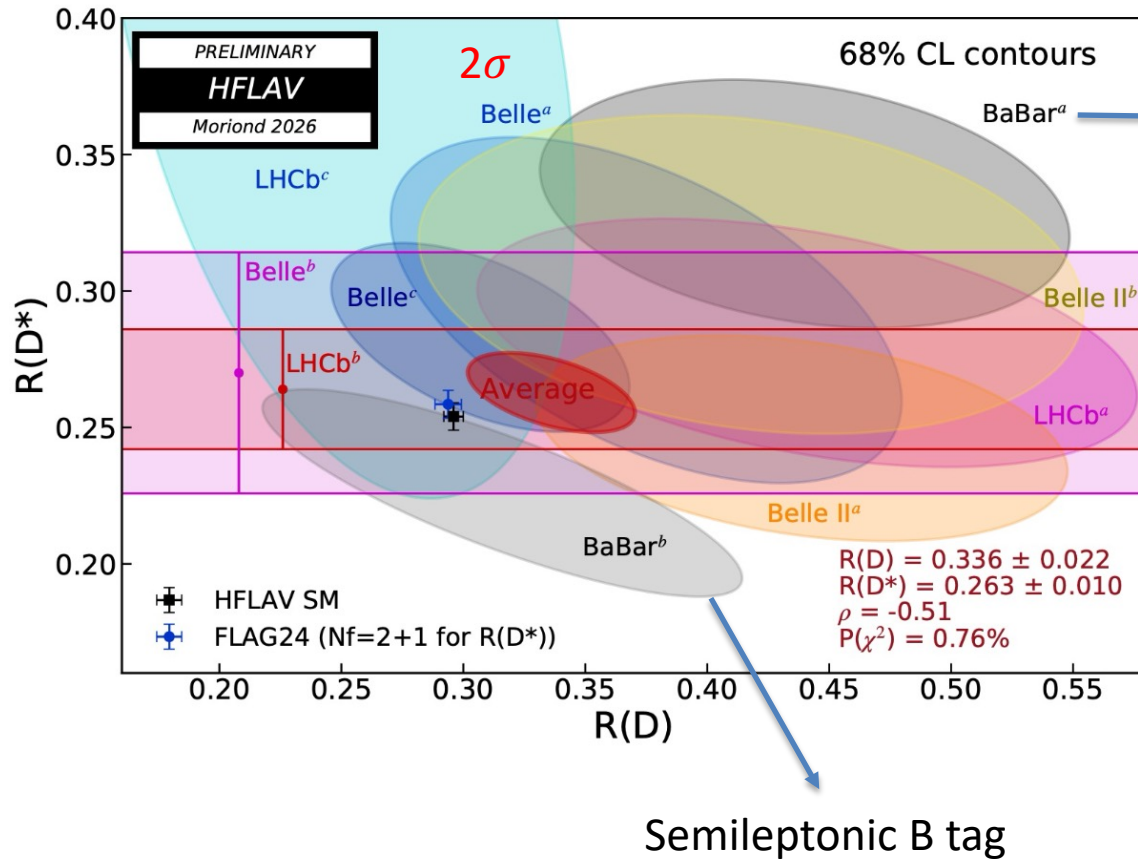
$$R(H_c) = \frac{\mathcal{B}(H_b \rightarrow H_c \tau^- \bar{\nu}_\tau)}{\mathcal{B}(H_b \rightarrow H_c \mu^- \bar{\nu}_\mu)}$$

- $\bar{B} \rightarrow D^+ \tau^- \nu$
- $\bar{B} \rightarrow D^{*+} \tau^- \nu$
- $\bar{B} \rightarrow D^+ X_c X$
- $\bar{B} \rightarrow D^{*+} \mu^- \tau^- \nu$
- Comb + misID
- $\bar{B} \rightarrow D^+ \mu^- \nu$
- $\bar{B} \rightarrow D^{*+} \mu^- \nu$

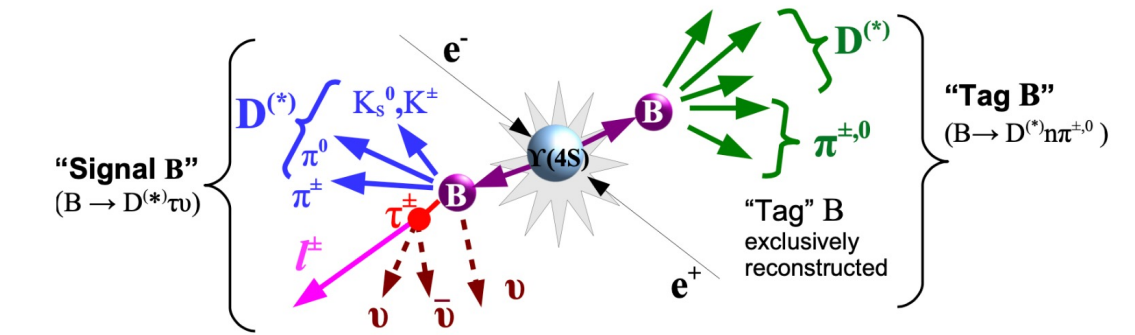


$R(D^{(*)})$ by Babar

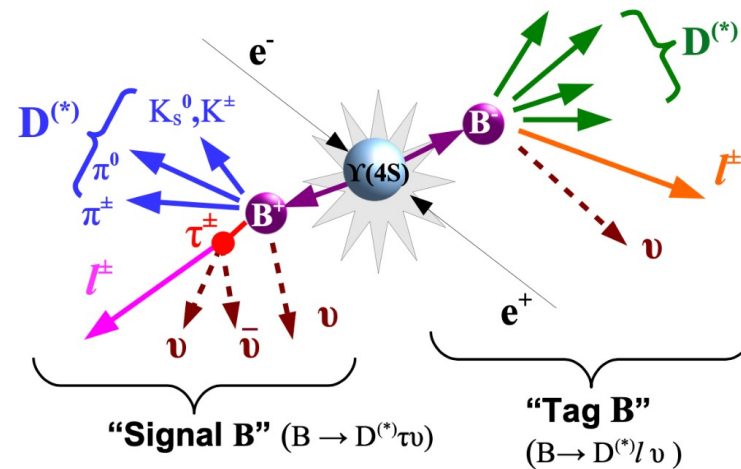
- Preliminary results at Moriond QCD 2026



Hadronic B tag

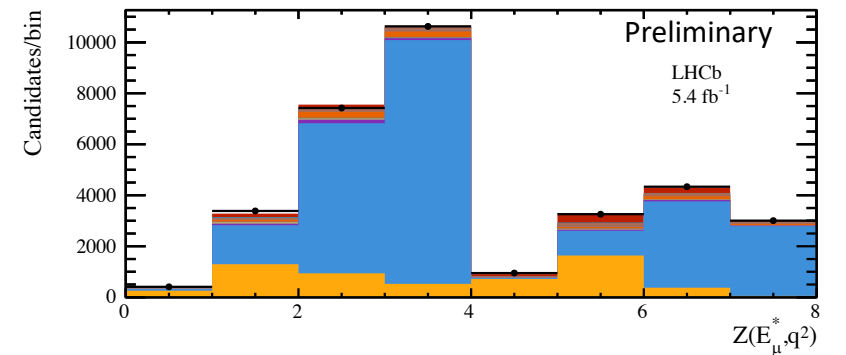
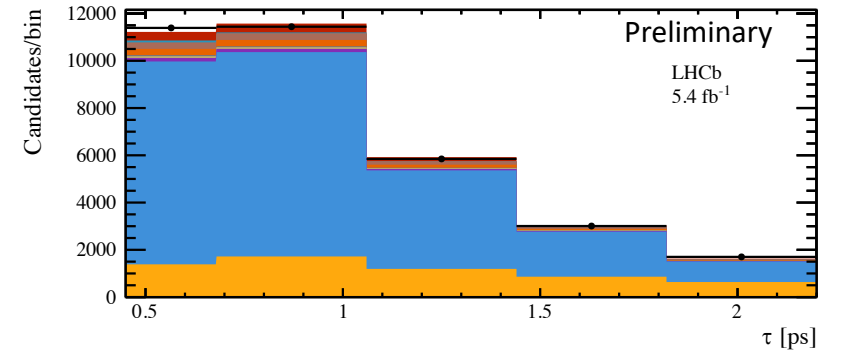
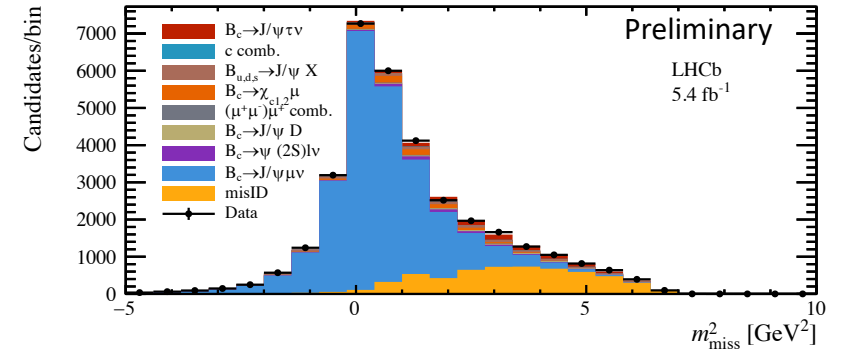
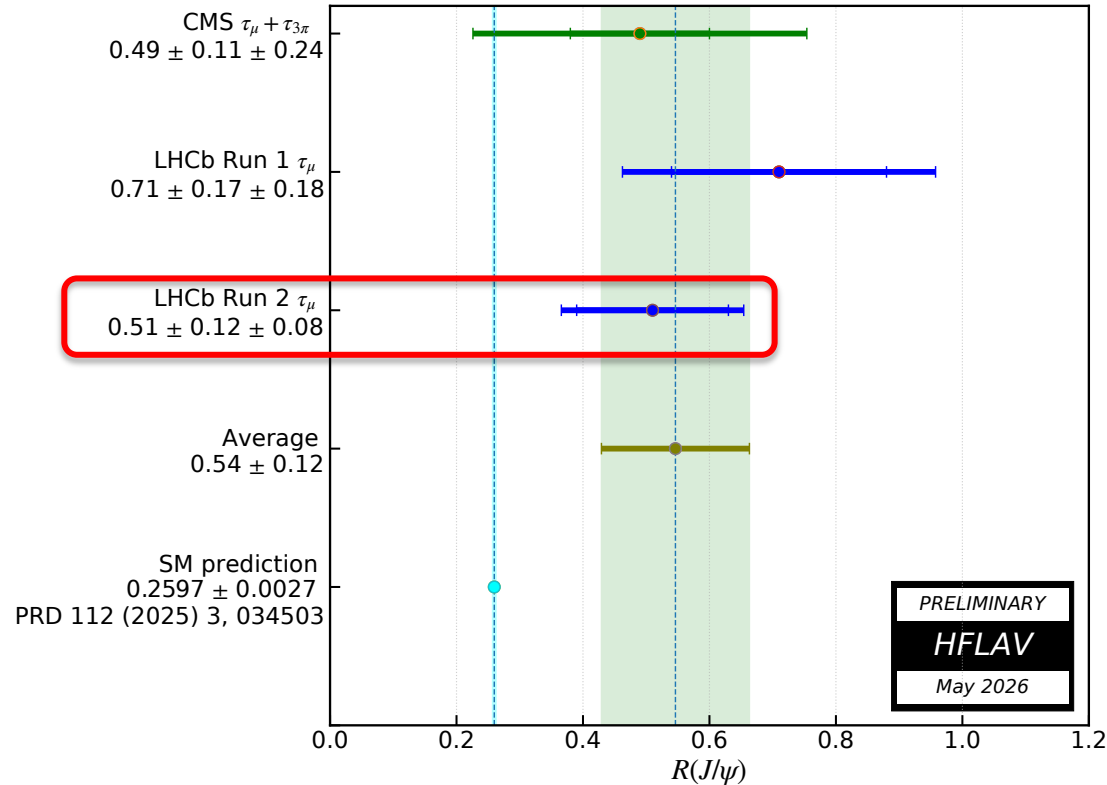


[Credits: Eli Ben-Haim]

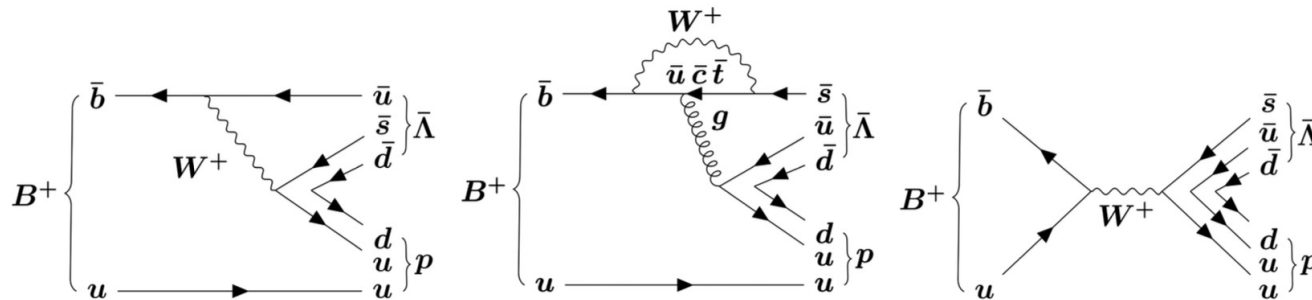


$R(J/\psi)$ with Run 2 data

- Consistent with SM within 1.8σ



$$B^+ \rightarrow \bar{\Lambda} p$$

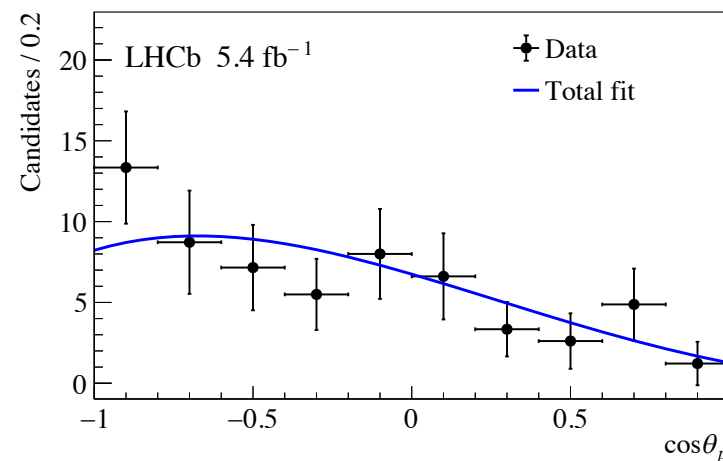
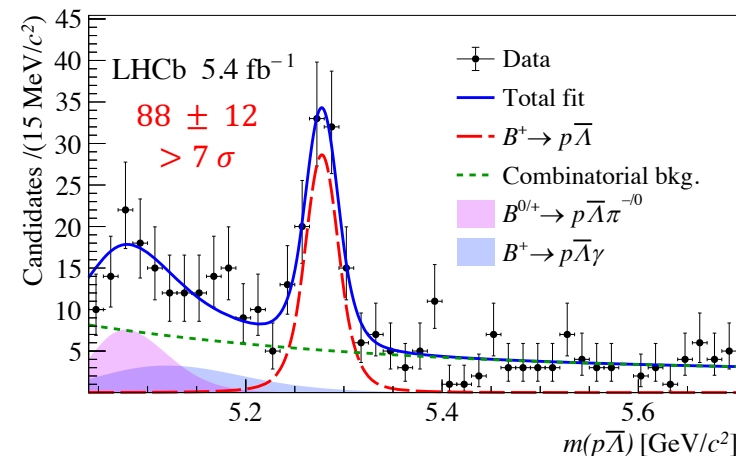


- Interference between tree-level and penguin, sensitive to NP
- First observation

$$\mathcal{B}(B^+ \rightarrow \bar{\Lambda} p) = (1.24 \pm 0.17 \pm 0.05 \pm 0.03) \times 10^{-7}$$

- Weak decay parameter

$$\alpha_B = 0.87^{+0.26}_{-0.29} \pm 0.09$$



$$B^+ \rightarrow \bar{\Lambda} p \bar{p} p$$

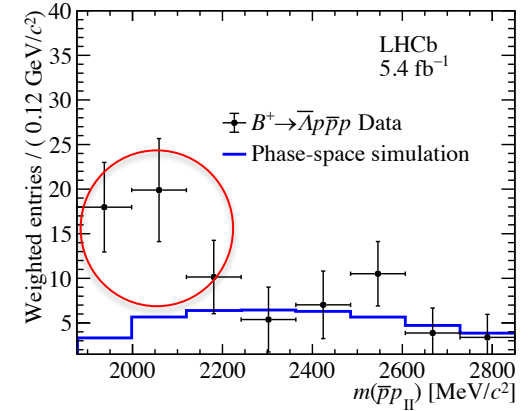
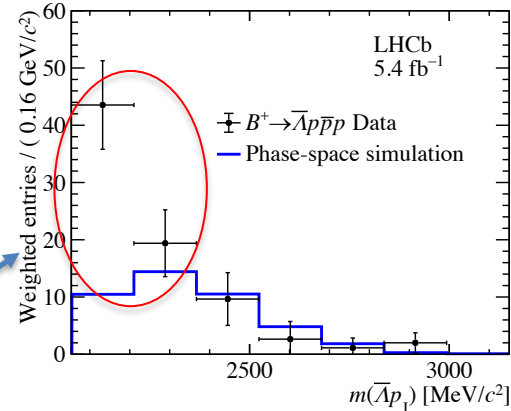
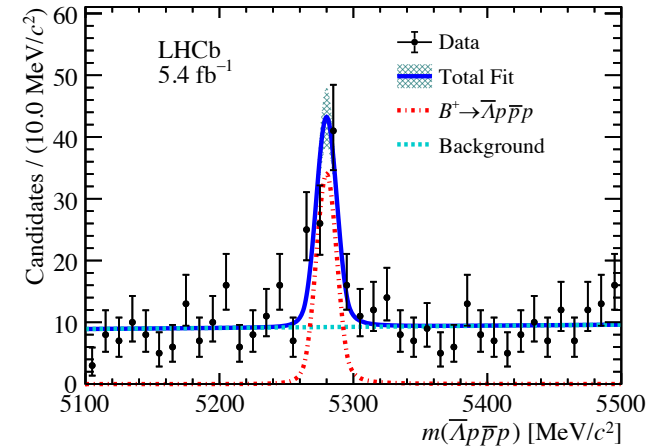
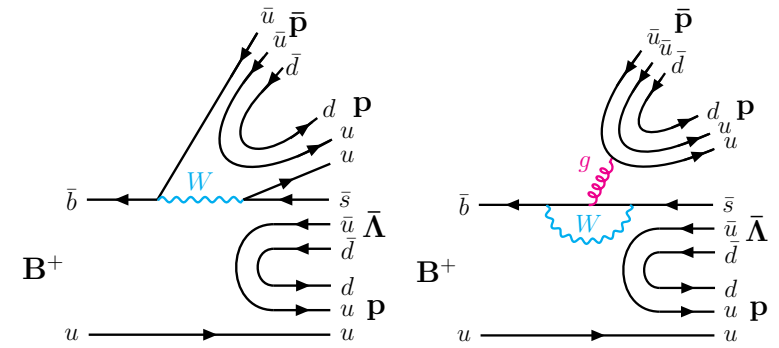
- Interference between tree-level and penguin, sensitive to NP
- First observation

$$\mathcal{B}(B^+ \rightarrow \bar{\Lambda} p \bar{p} p) = (2.15 \pm 0.35 \pm 0.12 \pm 0.28) \times 10^{-7}$$

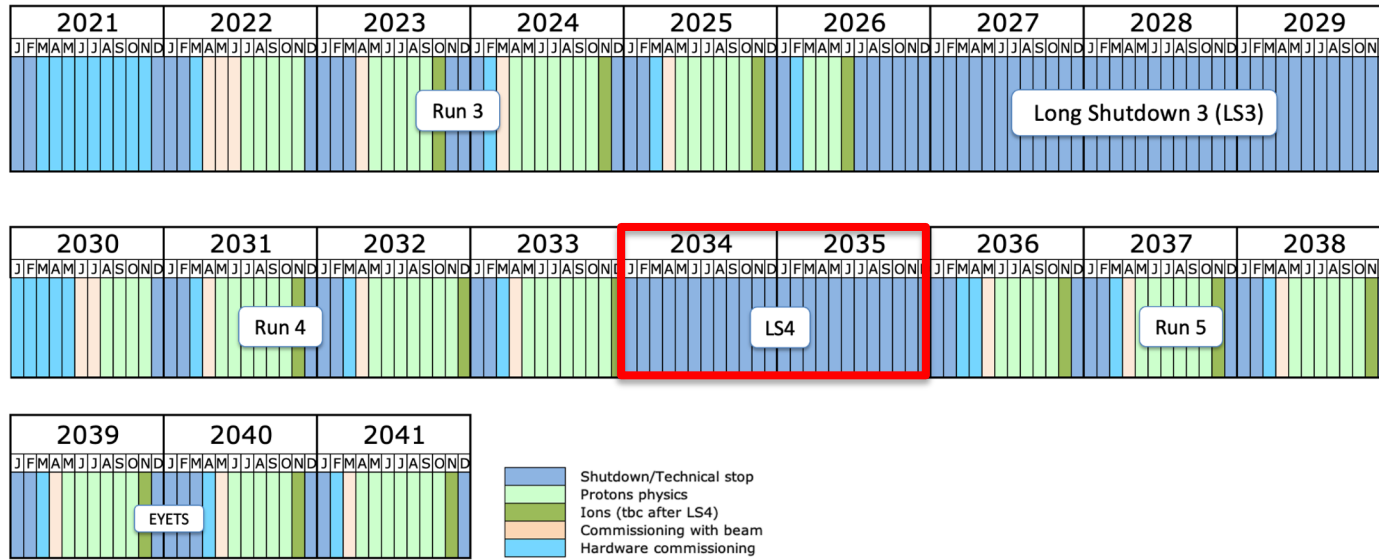
- CP asymmetry

$$\mathcal{A}_{CP} = (5.4 \pm 15.6 \pm 2.4)\%$$

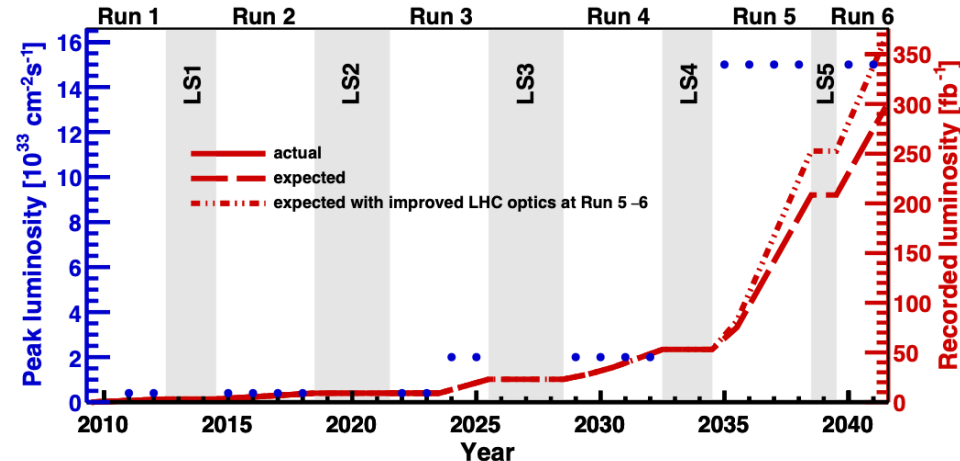
- Double threshold enhancement



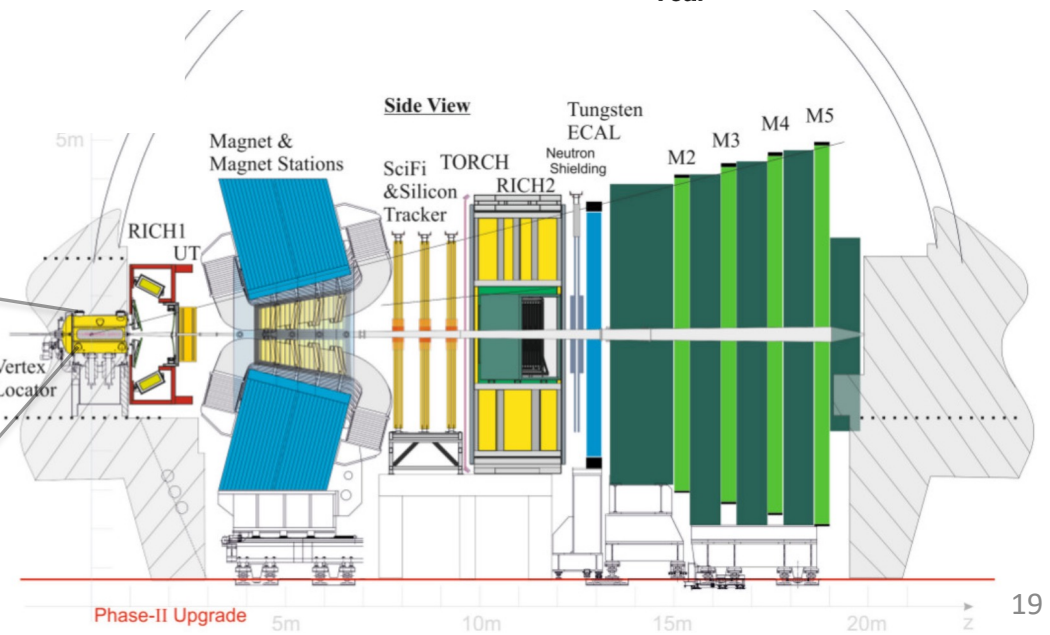
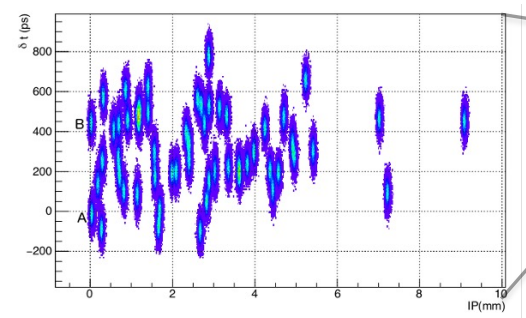
The LHCb upgrades



Last update: September 24



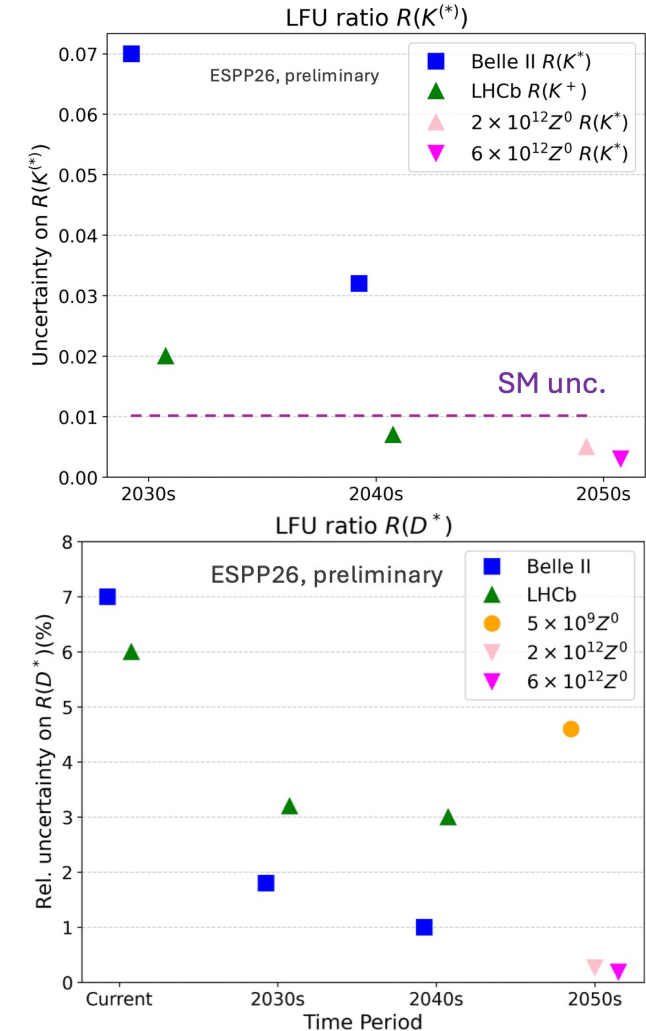
Upgrade II, 4D detector, Timing, $\mathcal{O}(10 \text{ ps})$, is essential



Prospects

- LHCb upgrades (2025: 23 fb⁻¹, Upgrade-II: 300 fb⁻¹)

Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II	ATLAS & CMS
EW Penguins					
$R_K (1 < q^2 < 6 \text{ GeV}^2 c^4)$	0.1 [274]	0.025	0.036	0.007	—
$R_{K^*} (1 < q^2 < 6 \text{ GeV}^2 c^4)$	0.1 [275]	0.031	0.032	0.008	—
R_ϕ, R_{pK}, R_π	—	0.08, 0.06, 0.18	—	0.02, 0.02, 0.05	—
CKM tests					
γ , with $B_s^0 \rightarrow D_s^+ K^-$	(⁺¹⁷ ₋₂₂)° [136]	4°	—	1°	—
γ , all modes	(^{+5.0} _{-5.8})° [167]	1.5°	1.5°	0.35°	—
$\sin 2\beta$, with $B^0 \rightarrow J/\psi K_S^0$	0.04 [606]	0.011	0.005	0.003	—
ϕ_s , with $B_s^0 \rightarrow J/\psi \phi$	49 mrad [44]	14 mrad	—	4 mrad	22 mrad [607]
ϕ_s , with $B_s^0 \rightarrow D_s^+ D_s^-$	170 mrad [49]	35 mrad	—	9 mrad	—
$\phi_s^{s\bar{s}}$, with $B_s^0 \rightarrow \phi \phi$	154 mrad [94]	39 mrad	—	11 mrad	Under study [608]
a_{sl}^s	33×10^{-4} [211]	10×10^{-4}	—	3×10^{-4}	—
$ V_{ub} / V_{cb} $	6% [201]	3%	1%	1%	—
$B_s^0, B^0 \rightarrow \mu^+ \mu^-$					
$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-)/\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)$	90% [264]	34%	—	10%	21% [609]
$\tau_{B_s^0 \rightarrow \mu^+ \mu^-}$	22% [264]	8%	—	2%	—
$S_{\mu\mu}$	—	—	—	0.2	—
$b \rightarrow c \ell^- \bar{\nu}_\ell$ LUV studies					
$R(D^*)$	0.026 [215, 217]	0.0072	0.005	0.002	—
$R(J/\psi)$	0.24 [220]	0.071	—	0.02	—
Charm					
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4} [610]	1.7×10^{-4}	5.4×10^{-4}	3.0×10^{-5}	—
$A_\Gamma (\approx x \sin \phi)$	2.8×10^{-4} [240]	4.3×10^{-5}	3.5×10^{-4}	1.0×10^{-5}	—
$x \sin \phi$ from $D^0 \rightarrow K^+ \pi^-$	13×10^{-4} [228]	3.2×10^{-4}	4.6×10^{-4}	8.0×10^{-5}	—
$x \sin \phi$ from multibody decays	—	($K3\pi$) 4.0×10^{-5}	($K_S^0 \pi\pi$) 1.2×10^{-4}	($K3\pi$) 8.0×10^{-6}	—



Summary

- Many interesting results from LHCb
 - Deviations of BR from predictions in low- q^2 persist
 - Angular analysis, P'_5
 - Experimental efforts to understand non-local, charm-loop effects
 - CPV in $B^0 \rightarrow K^{*0} \mu^+ \mu^-$, $B^0 \rightarrow K_S^0 \mu^+ \mu^-$
 - LFU in high- q^2
 - LFU in FCCC, $R(J/\psi)$ updated
- Stay tuned w/ LHCb upgrade (50 fb⁻¹) & upgrade-II (300 fb⁻¹)
 - Trigger efficiency for hadronic modes improved by factor of ~ 2
- Your suggestions are always appreciated!