Les Rencontres de Noirmoutier 2026

Probing lepton flavour universality with semileptonic *b*-decays at LHCb

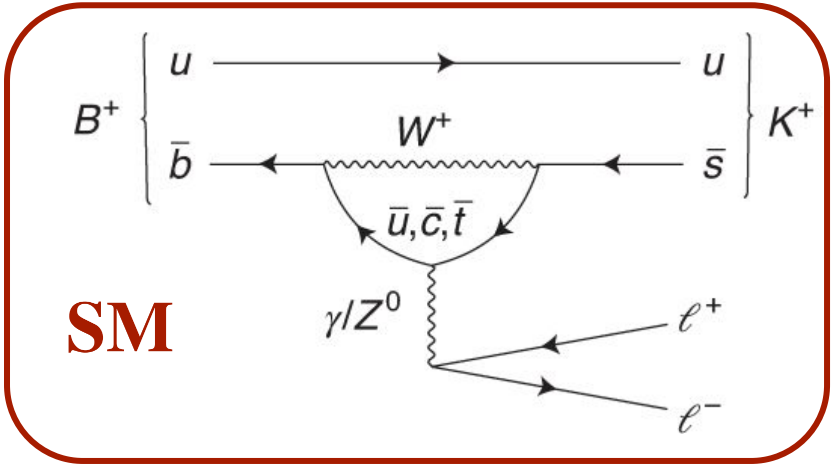
Tommaso Fulghesu[1],
on behalf of LHCb collaboration

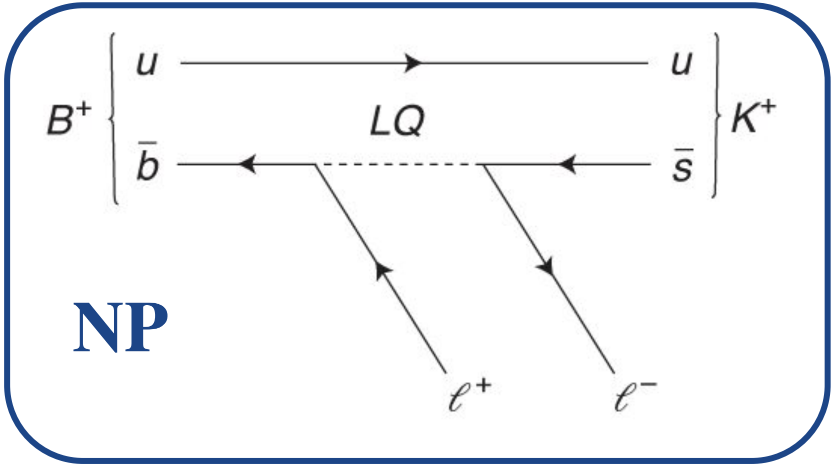
[1]Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France

Lepton flavour universality in the Standard Model

- Standard Model (SM) → **3 lepton flavors** ($e^{\pm}$, $\mu^{\pm}$, $\tau^{\pm}$) **with same couplings to gauge bosons** (γ, $W^{\pm}$, Z^0), not Yukawa ($\mathcal{B}(H\to\mu^+\mu^-) \neq \mathcal{B}(H\to\tau^+\tau^-)$)
  - Differences in decay rates can arise from phase space or long-distance hadronic effects

- **Couplings can be affected by New Physics (NP) contributions** - leptoquarks [JHEP 07 (2019) 168], W' [Phys. Rev. D 92, 054018], Z' [Phys. Rev. D 89, 015005], or extended Higgs sectors [Phys. Rev. D 86, 054014].

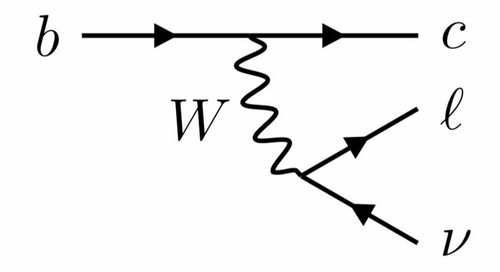




Complementary probes in *b*-decays at LHCb

- Lepton flavour universality measurements in **tree-level $b \to c(u)l\nu$** and **loop-level $b \to s(d)l^+l^-$ transitions** provide sensitive null-tests to New Physics

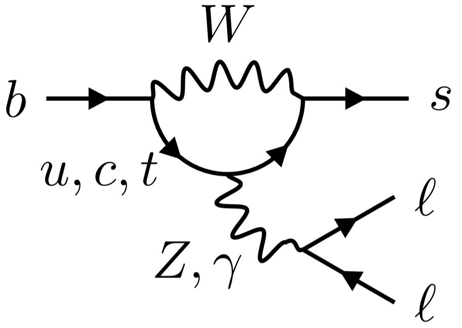
Flavour changing charged current (FCCC)



High signal yields $\mathcal{B} \sim$ *1-10%*

Neutrinos not reconstructed → Challenging analyses

Flavour changing neutral current (FCNC)



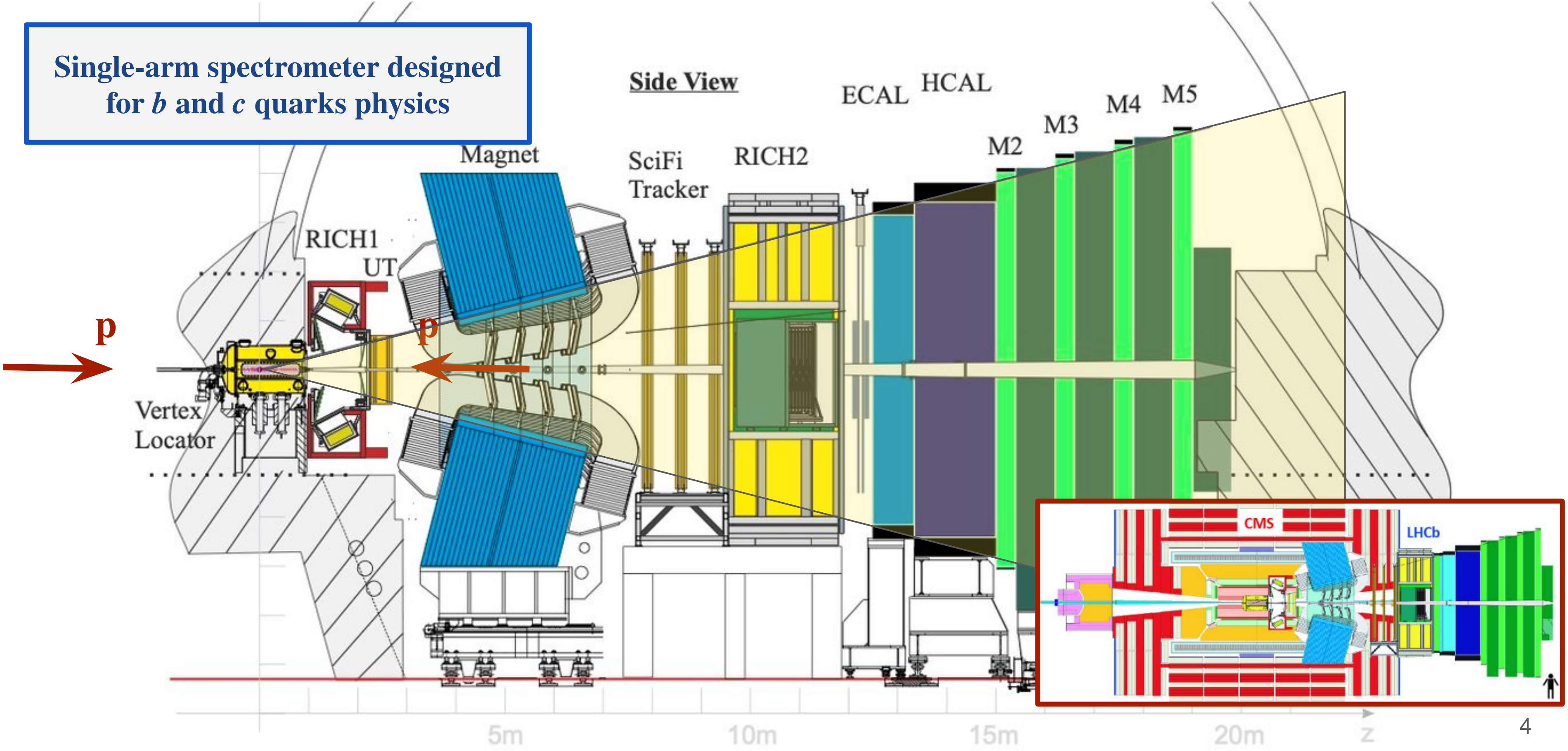
Fully-reconstructed final states

Low signal yields $\mathcal{B} \sim 10^{-6}\text{-}10^{-8}$

- LHCb has access to **all heavy-flavoured *b*-hadron species** including B_c, Λ_b, Ξ_b, Ω_b.

The LHCb detector

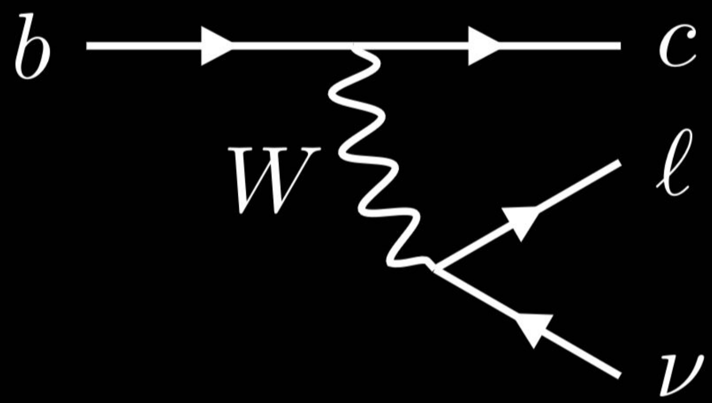
Single-arm spectrometer designed for *b* and *c* quarks physics



Part I of II

I. Flavour changing charged current

$$b \rightarrow c(u)\, l^{-}\, \nu_{l}$$



In this section:

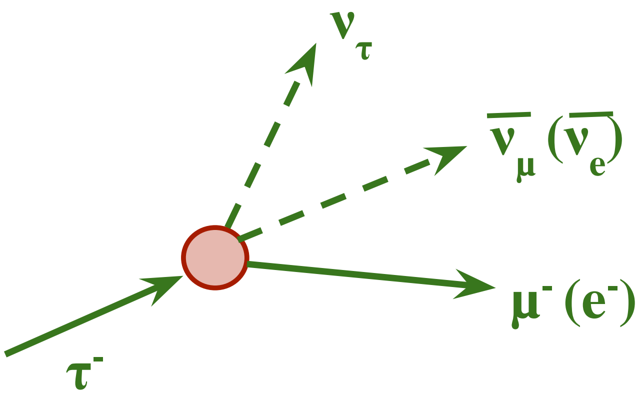
- Missing-neutrino problem
- Tau reconstruction at LHCb
- Most recent LHCb measurements for observables R(D) and R(D*)
- Recent results on R(J/ψ)
- World average agreement and tension

Experimental strategies and challenges in $b \to cl\nu$ decays

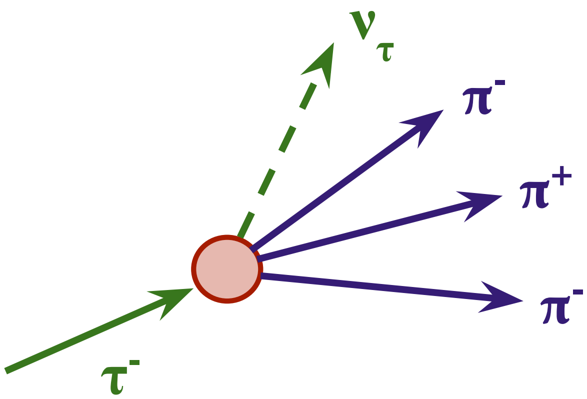
- **Missing neutrino momentum in the final states**
  - **Large partially reconstructed background** contribution
  - ***b*-hadron momentum** needs to be **approximated from visible particles**
  - **Large simulated samples needed** for modelling signal and background

- In $b \to c\tau\nu$, **two decay topologies for tau decays** are used:

Leptonic $\tau \to l\nu_l\nu_\tau$



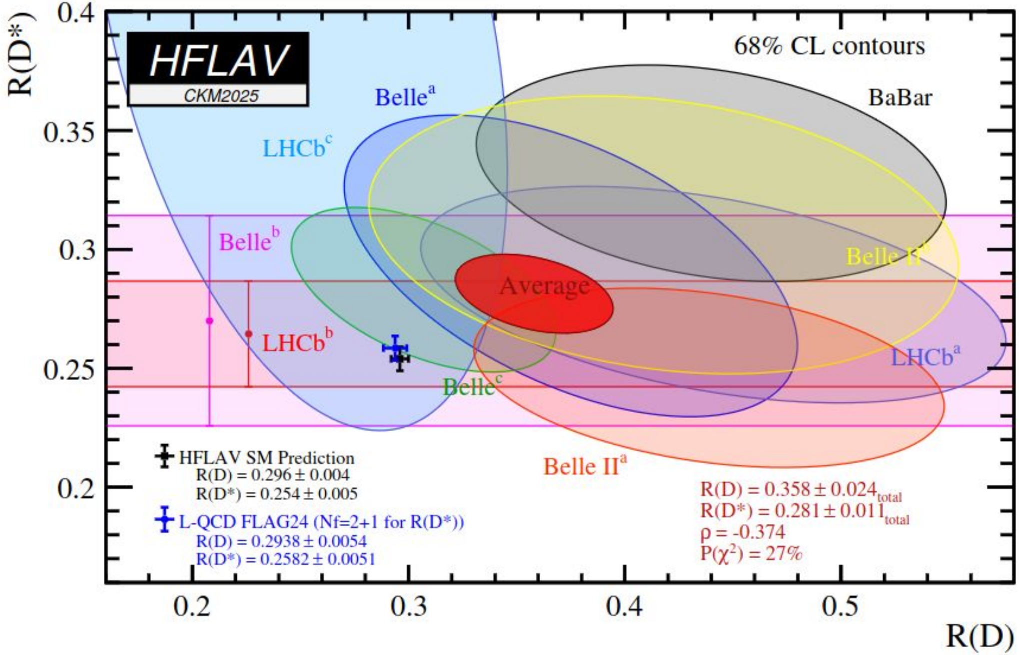
Hadronic $\tau \to \pi\pi\pi\nu_\tau$



R(D) and R(D*)

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$$

Long standing tension of 3.8σ from different experiments!



[PRD 113 (2026) 012008]

LHCb[a] 2023, muonic
$R(D^0)$, $R(D^{*(+)})$, $D^{*(+)} \to D^0X$
[PRL 131 (2023) 111802]

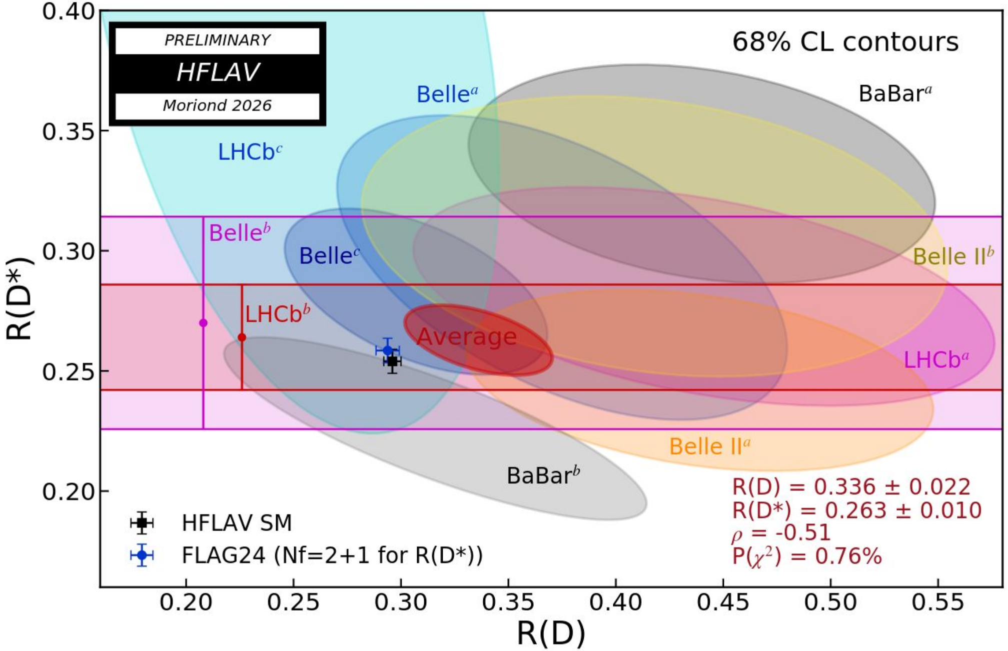
LHCb[b] 2023, hadronic
$R(D^{*+})$, $D^{*+} \to D^0\pi^+$
[PRD 108 (2023) 012018]

LHCb[c] 2025, muonic
$R(D^+)$, $R(D^{*+})$, $D^{*+} \to D^+\pi^0$
[PRD 134 (2025) 061801]

R(D) and R(D*)

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$$

New world average consistent with SM expectations at ~2σ!



[Presented at Moriond QCD 2026]

LHCb[a] 2023, muonic
$R(D^0)$, $R(D^{*(+)})$, $D^{*(+)} \to D^0X$
[PRL 131 (2023) 111802]

LHCb[b] 2023, hadronic
$R(D^{*+})$, $D^{*+} \to D^0\pi^+$
[PRD 108 (2023) 012018]

LHCb[c] 2025, muonic
$R(D^+)$, $R(D^{*+})$, $D^{*+} \to D^+\pi^0$
[PRD 134 (2025) 061801]

R(J/ψ)

$$R(J/\psi) = \frac{\mathcal{B}(B_c^+ \to J/\psi \tau^+ \nu_\tau)}{\mathcal{B}(B_c^+ \to J/\psi \mu^+ \nu_\mu)}$$

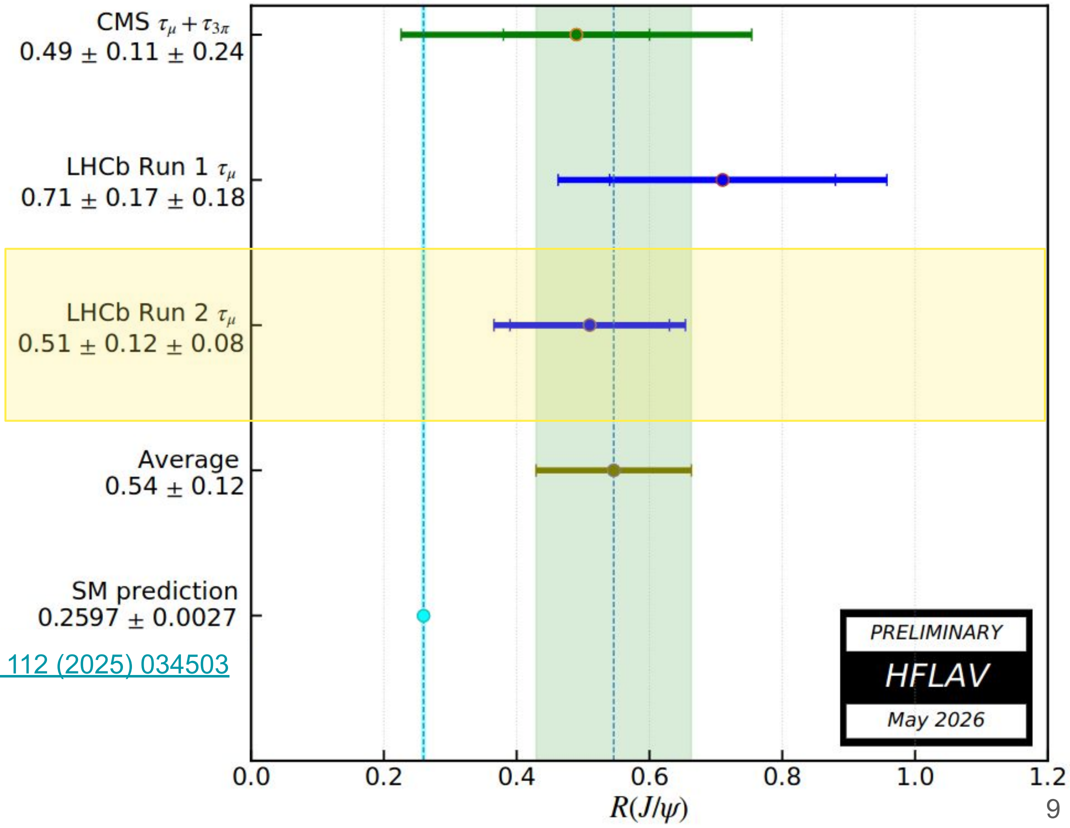
LHCb 2018 (Run 1 data)
[PRL 120, 121801 (2018)]

NEW

LHCb 2026 (Run 2 data)
[LHCb-PAPER-2026-018
(in preparation)]

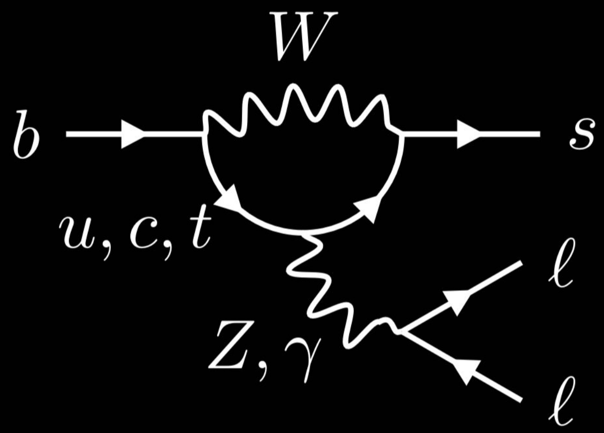
Compatible with SM at 1.8σ and consistent with LHCb Run 1 measurement!

[PRD 113 (2026) 012008]



II. Flavour changing neutral current

$b \rightarrow s(d)\, l^- \, l^+$



In this section:

- Electrons vs muons at LHCb
- Sensitivity to New Physics effects for b→sll decays
- Invariant di-lepton mass squared q^2 spectrum
- R_X observables

Sensitivity to New Physics in $b \to s l^+ l^-$ decays

- **Effective field theory**

$$H_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i (C_i O_i + C_i' O_i')$$

Wilson coefficients

Operators

Operators in $b \to s\ell\ell$ transitions

$$O_7^{(\prime)} \propto (\bar{s}\sigma_{\mu\nu} P_{R(L)} b) F^{\mu\nu}$$
$$O_9^{(\prime)} \propto (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{l}\gamma_\mu l)$$
$$O_{10}^{(\prime)} \propto (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{l}\gamma_\mu \gamma_5 l)$$

- **New Physics enter through shift of the Wilson coefficients:** $C_i^{(\prime)} = C_i^{(\prime)SM} + C_i^{(\prime)NP}$

Sensitivity to New Physics in $b \to s l^+ l^-$ decays

- **Effective field theory**

$$H_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i (C_i O_i + C_i' O_i')$$

Wilson coefficients

Operators

Operators in $b \to s\ell\ell$ transitions

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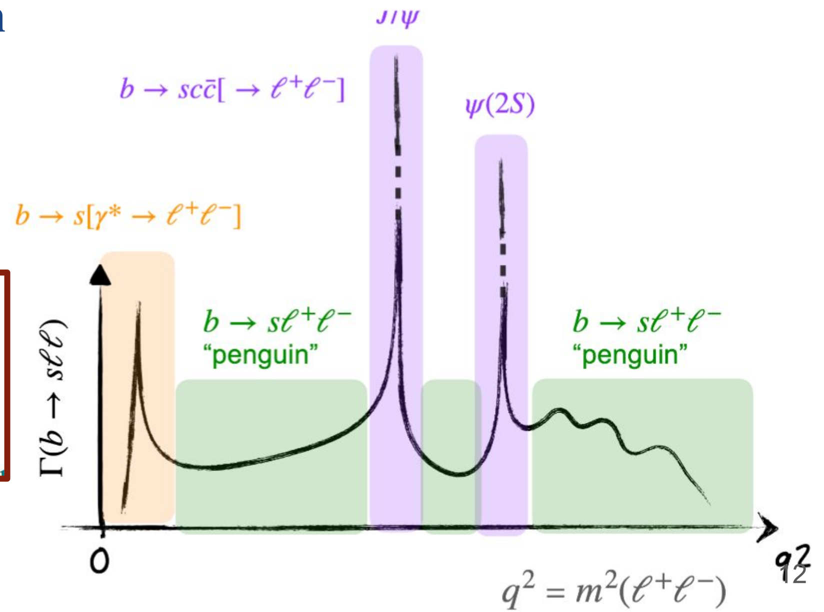
$$O_{10}^{(\prime)} \propto (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{l}\gamma_\mu \gamma_5 l)$$

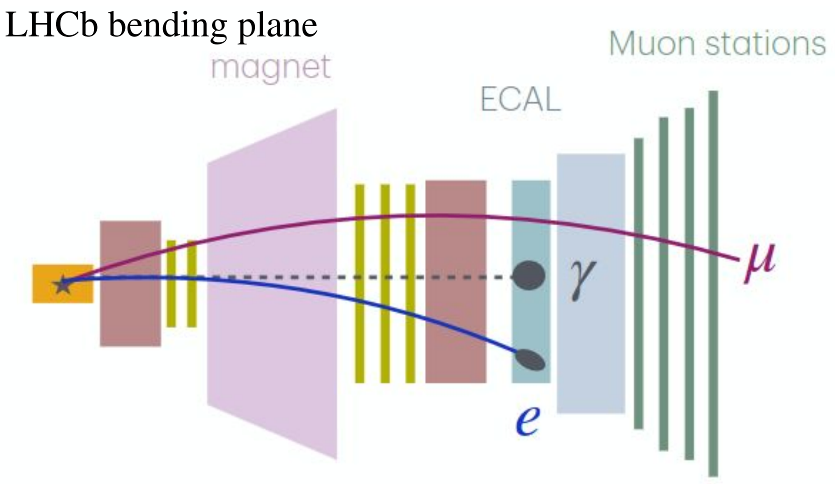
- **New Physics enter through shift of the Wilson coefficients:** $C_i^{(\prime)} = C_i^{(\prime)SM} + C_i^{(\prime)NP}$
- **Measurement of double ratio** using $c\bar{c}$ resonances as control mode

$$R_{K,K^*}(q_a^2, q_b^2) = \frac{\int_{q_a^2}^{q_b^2} \frac{d\Gamma(B^{(+,0)} \to K^{(+,*0)}\mu^+\mu^-)}{dq^2} dq^2}{\int_{q_a^2}^{q_b^2} \frac{d\Gamma(B^{(+,0)} \to K^{(+,*0)}e^+e^-)}{dq^2} dq^2} \times \frac{\Gamma(J/\psi \to e^+e^-)}{\Gamma(J/\psi \to \mu^+\mu^-)}$$

Measured to be 1

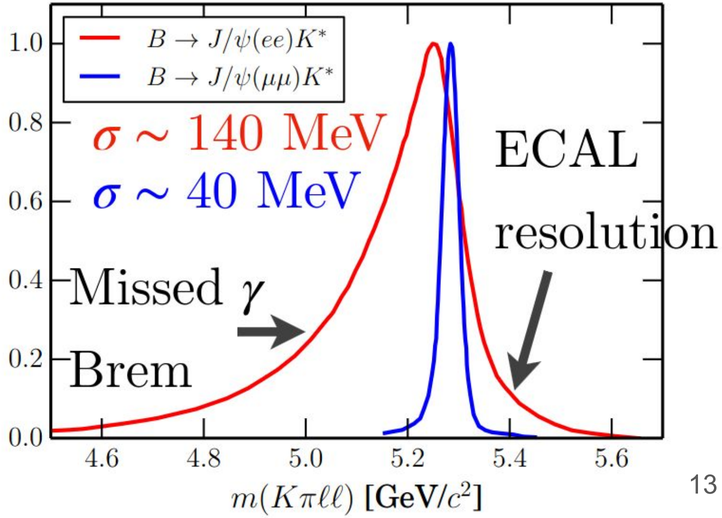


Electrons and muons at LHCb



Clear signature in muon stations

Electrons have lower trigger efficiency than muons
Bremsstrahlung emission → before magnet, recovery procedure $O(50\%)$ efficient (limited by ECAL resolution)

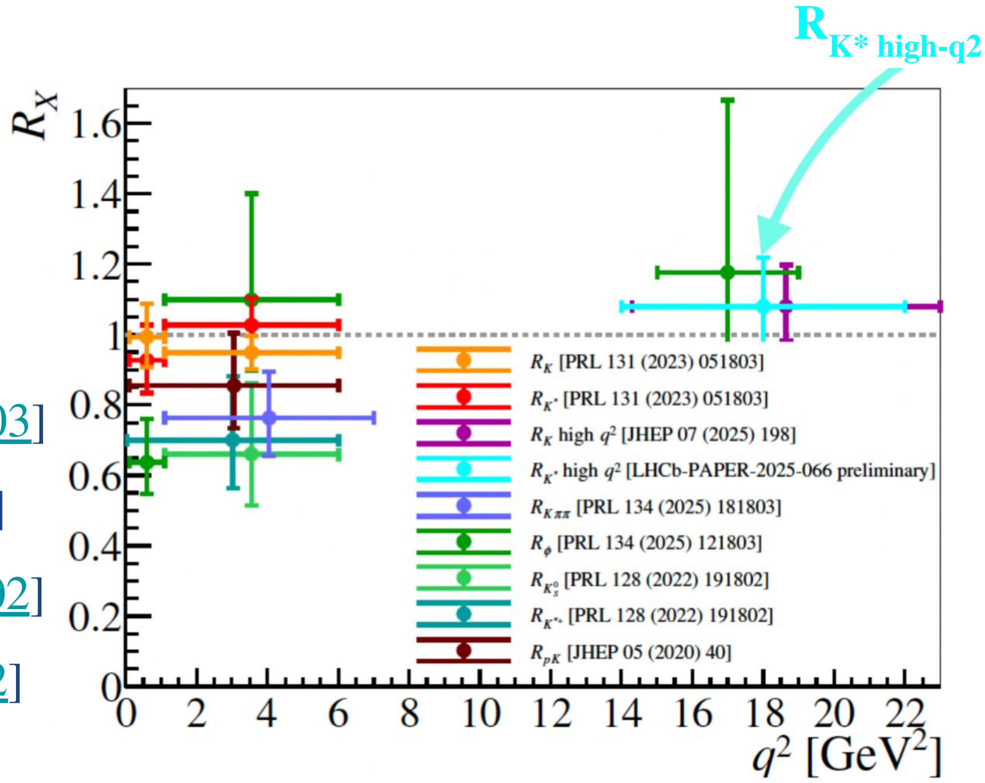


Wider fit range for electrons than muons

- more background
- more sensitive to peaking structures
- lineshapes are brem-dependent

Lepton flavour universality tests in $b \to s l^+ l^-$ decays

- R_K [Phys. Rev. D 108 (2023) 032002]
- R_{K^*} [Phys. Rev. D 108 (2023) 032002]
- $R_{K\ \text{high-}q2}$ [JHEP 07 (2025) 198]
- $R_{K^*\ \text{high-}q2}$ [arxiv:2604.08631] NEW
- $R_{K\pi\pi}$ [Phys. Rev. Lett 134 (2025) 181803]
- R_ϕ [Phys. Rev. Lett 134 (2025) 121803]
- $R_{K^{*+}}$ [Phys. Rev. Lett 128 (2022) 191802]
- R_{Ks} [Phys. Rev. Lett 128 (2022) 191802]
- R_{pK} [JHEP 05 (2020) 040]



❖ **Overall picture is in good agreement with the SM predictions in $b \to sll$ LFU tests**

Conclusions

Tommaso Fulghesu[1],
on behalf of LHCb collaboration

[1]Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France

Where we currently stand

- Lepton flavour universality tests in $b \rightarrow cl\nu$ and $b \rightarrow sll$ transitions → R(D) vs R(D*) and R(J/ψ) in FCCC, R_X tests in FCNC
  - ongoing exploration $b \rightarrow ul\nu$ transitions and $b \rightarrow cl\nu$ electronic tau decays for FCCC, and $b \rightarrow dll$ decays [arXiv:2604.26784] and $b \rightarrow s\tau\tau$ decays [Phys. Rev. Lett. **136** (2026) 181802] for FCNC

Where we currently stand

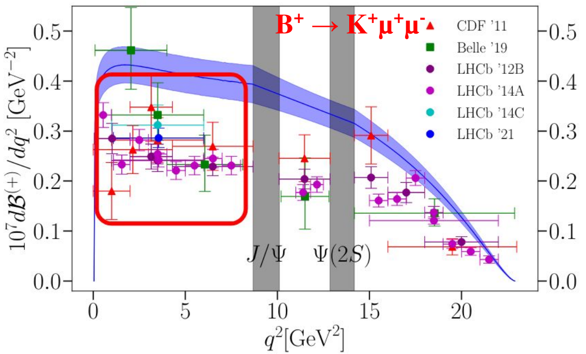
- Lepton flavour universality tests in $b \to c l \nu$ and $b \to s l l$ transitions → R(D) vs R(D*) and R(J/ψ) in FCCC, R_X tests in FCNC
  - ➢ ongoing exploration $b \to u l \nu$ transitions and $b \to c l \nu$ electronic tau decays for FCCC, and $b \to d l l$ decays [arXiv:2604.26784] and $b \to s \tau\tau$ decays [Phys. Rev. Lett. **136** (2026) 181802] for FCNC

- **Complementary measurements in other observables**, see D. Guadagnoli's talk

INCREASING SM PRECISION

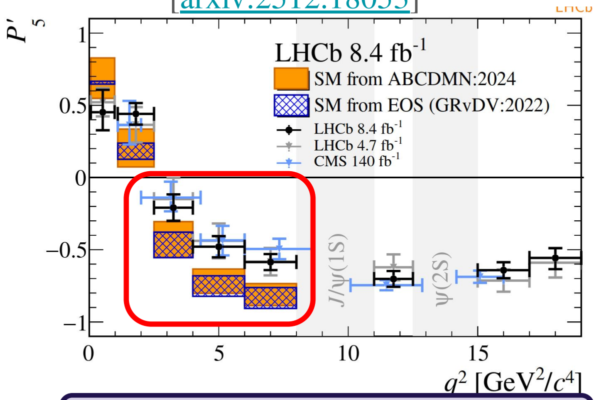
Deviations from SM predictions in b→sll FCNC

[Phys. Rev. D **107**, 119903 (2023)]



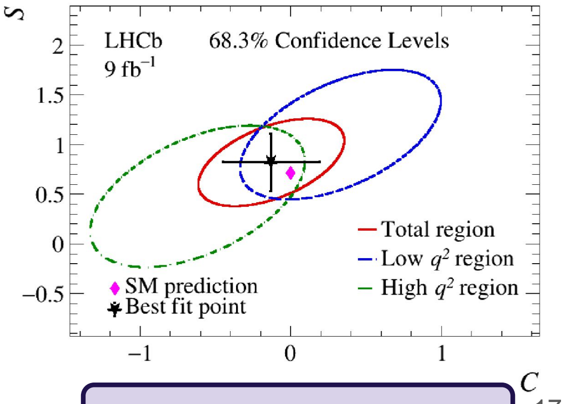
BRANCHING RATIOS

[arxiv:2512.18053]



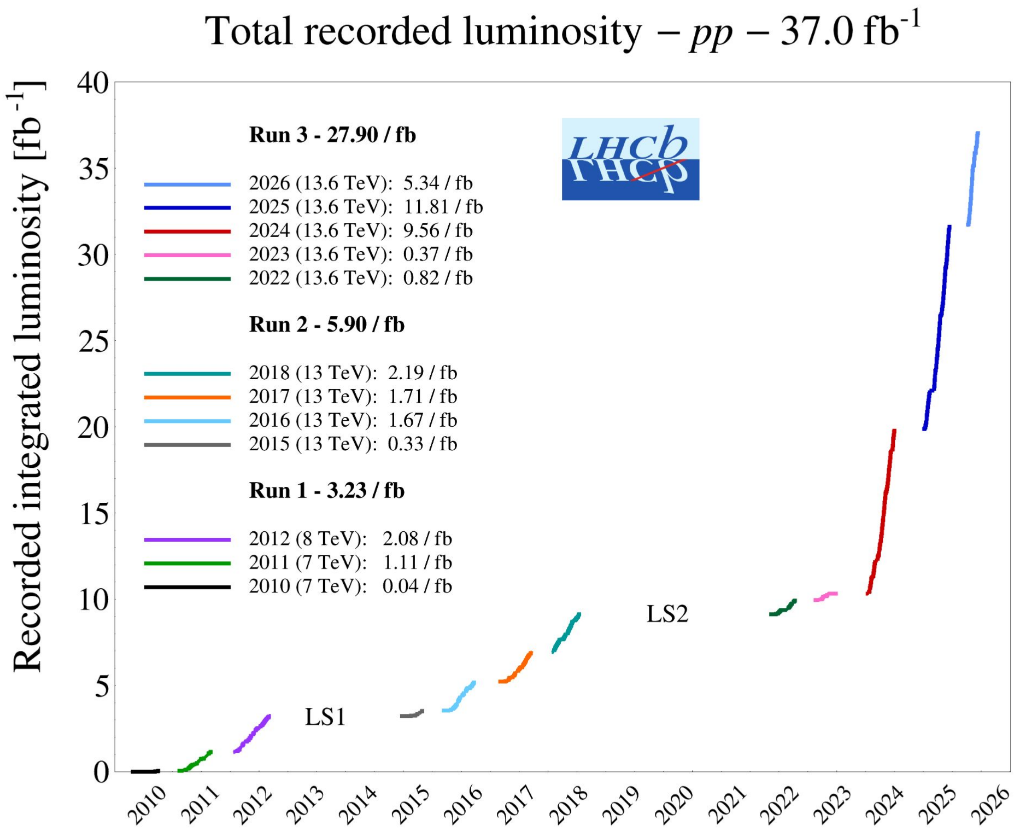
ANGULAR OBSERVABLES

[arXiv:2603.13223]



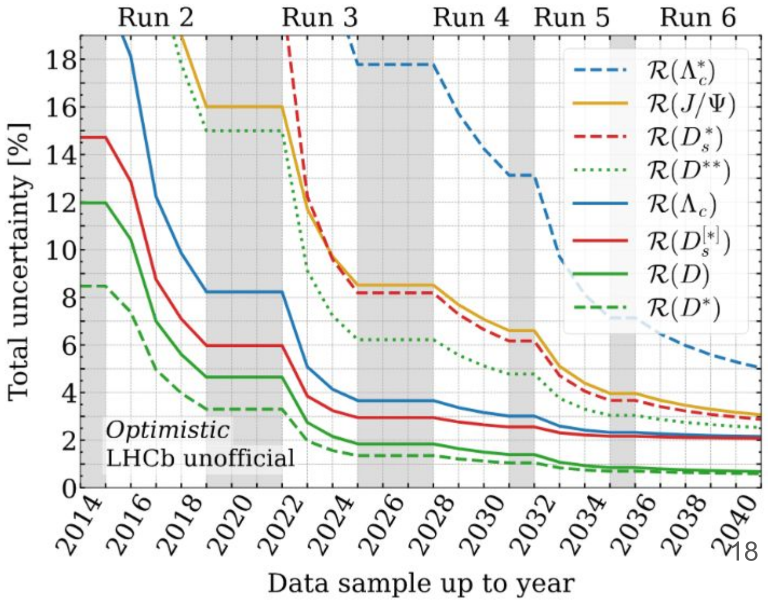
CP-ASYMMETRY

Outlook and future prospects



Huge statistics collected during the Run 3 by LHCb will lead to an unprecedented precision on lepton flavour universality measurements!

[Rev. Mod. Phys (2022) **94**, 015003]



Supplementary material

Tommaso Fulghesu[1],
on behalf of LHCb collaboration

[1]Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France

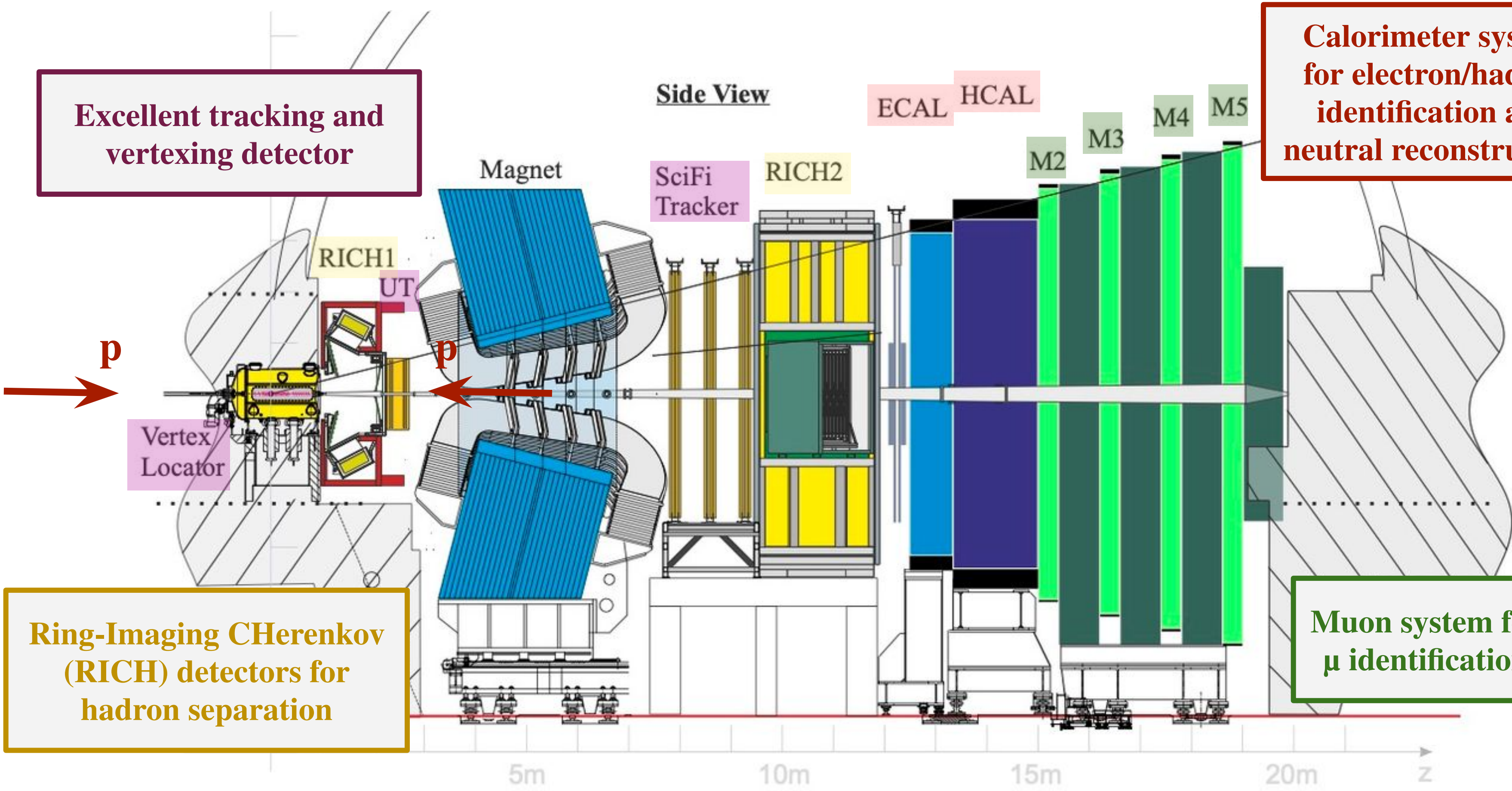
The LHCb detector

Excellent tracking and vertexing detector

Calorimeter system for electron/hadron identification and neutral reconstruction

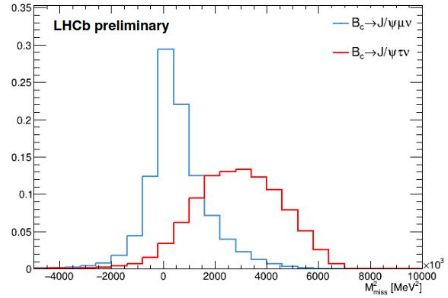
Ring-Imaging CHerenkov (RICH) detectors for hadron separation

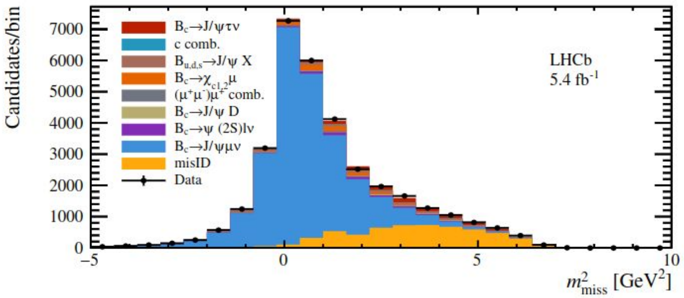
Muon system for μ identification



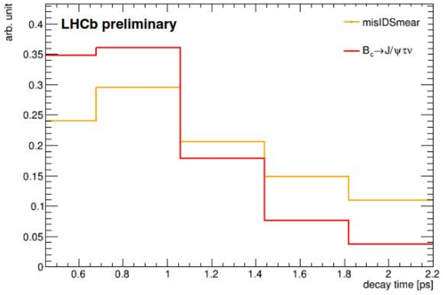
R(J/ψ): strategy

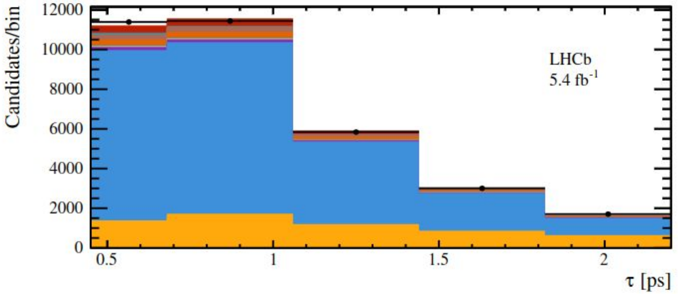
Missing mass to distinguish signal and normalization, 2 extra neutrinos mean larger missing mass



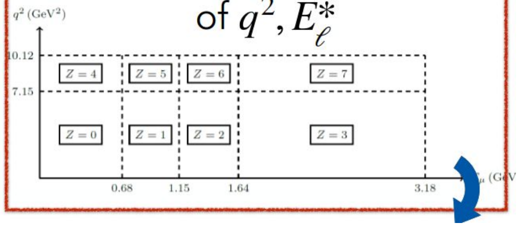


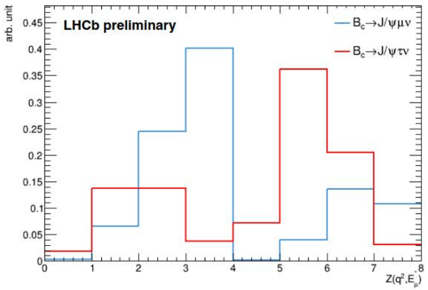
Decay time distinguishes largest background, misID—light Bs have 3x longer lifetime than B_c

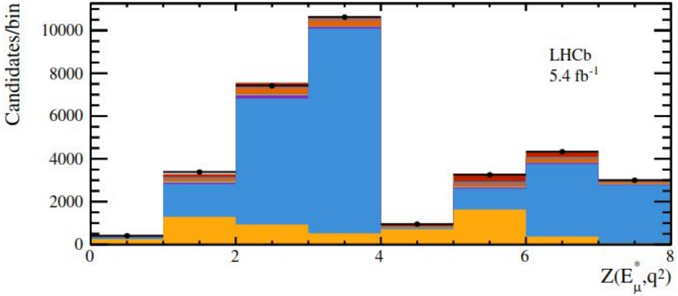




$Z(q^2, E^*_\ell)$: binned function of q^2, E^*_ℓ







R(J/ψ): systematics

More reliable checks on misID modeling, also significantly reduced relative to Run-1

Tighter selection overall—lose a bit of statistics but made up for in systematics!

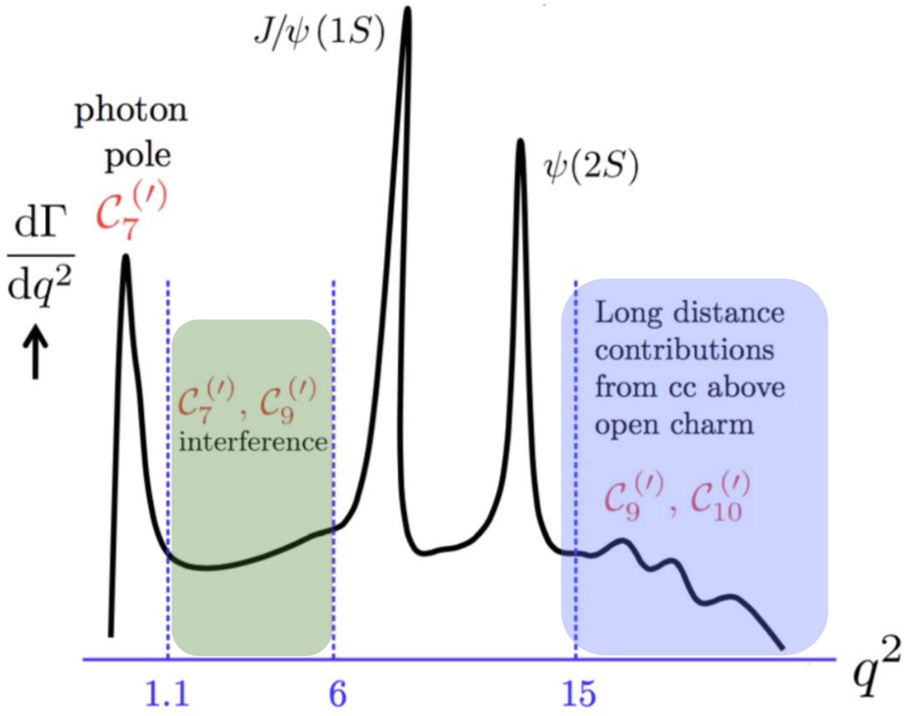
Source of uncertainty on $\mathcal{R}(J/\psi)$	Value $(\times 10^{-2})$
Simulation statistical uncertainty	5.9
$B_c^+ \to \psi(2S)\ell^+\nu$ modeling	2.6
MisID composition estimation	2.5
Simulation corrections	2.0
$B_c^+ \to J/\psi\,\ell^+\,\nu$ form factors	1.8
$B_c^+ \to \chi_c\,\mu^+\nu$ scaling	1.5
Efficiency ratio	1.3
Fragmentation background modeling	1.3
MisID decay-in-flight correction	1.1
$(J/\psi + \mu^+)$ combinatorial modeling	0.6
MisID decay-in-flight smearing	0.3
$B_c^+ \to \psi(2S)\,\ell^+\nu$ scaling	0.3
$\mathcal{B}(\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau)$	0.2
Trimuon effect	0.1
Systematic uncertainty	7.9
Statistical uncertainty	11.9
Total uncertainty	14.3

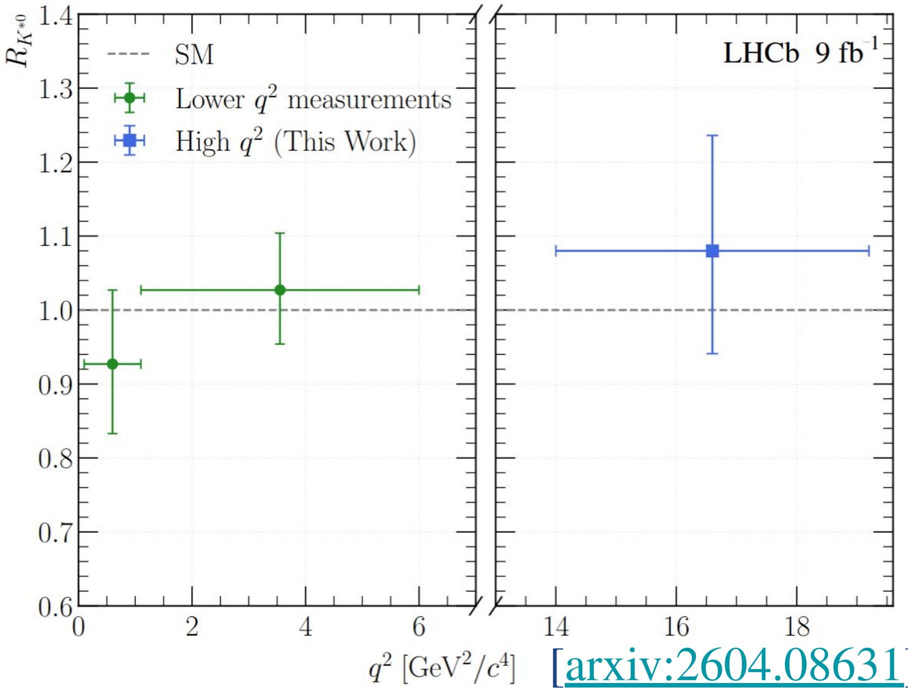
Lattice QCD calculations of form factors enable huge reduction of largest systematic uncertainty in Run-1 measurement

$\sigma_{\text{stat,Run-2}} \approx 0.65\sigma_{\text{stat,Run-1}}$

$\sigma_{\text{sys,Run-2}} \approx 0.5\sigma_{\text{sys,Run-1}}$

R(K*) at high q^2





[arxiv:2604.08631]

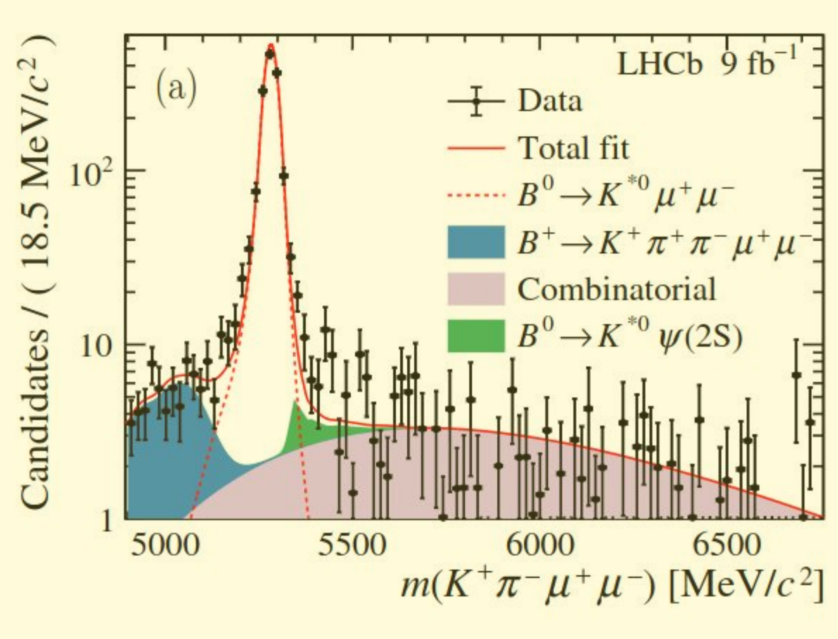
$$R_{K^{*0}} = 1.08^{+0.14}_{-0.12}\ (\text{stat.}) \pm 0.07\ (\text{syst.})$$

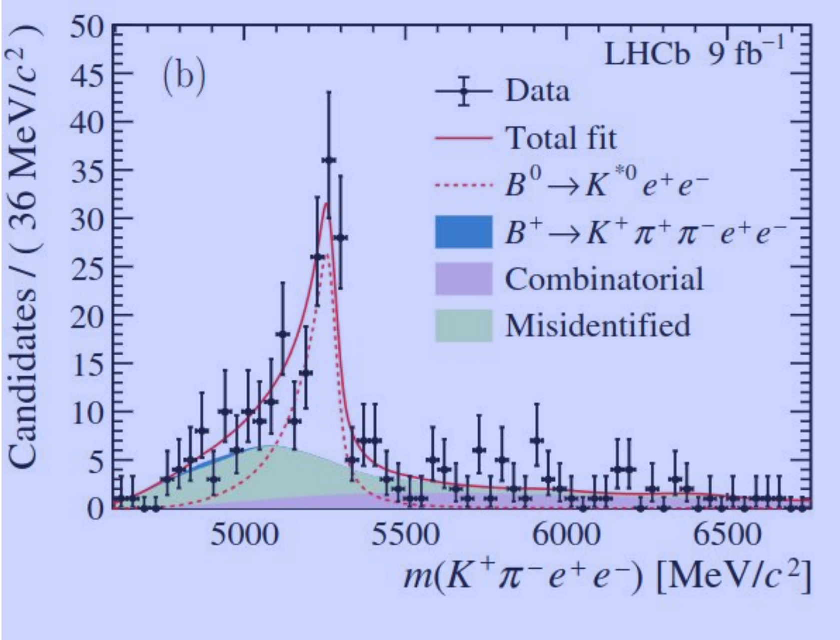
in agreement with SM predictions

R(K*) at high q²: strategy

from simulation

$$R_{K^{*0}} = \frac{N/\varepsilon\,(B^0 \to K^{*0}\mu^+\mu^-)}{N/\varepsilon\,(B^0 \to K^{*0}J/\psi\ (\to \mu^+\mu^-))} \Bigg/ \frac{N/\varepsilon\,(B^0 \to K^{*0}e^+e^-)}{N/\varepsilon\,(B^0 \to K^{*0}J/\psi\ (\to e^+e^-))}$$





R(K*) at high q^2: systematics

Source	Uncertainty [%]
Efficiency correction	1.2
Kinematic and topological dependence	0.7
Model dependence	2.0
q^2 smearing	0.9
Integrated luminosity	0.9
Misidentified background	5.2
Signal lineshape	1.7
Combinatorial background	1.3
Partially reconstructed background	2.0

➔ **Misidentified $B \to K^* h^+ h^-$ contributions**, relevant only for electron mode