PROCEEDINGS OF SCIENCE

# Recent results from LHCb on charged current decays of *b*-hadrons

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The principle of Lepton Flavour Universality in the Standard Model is challenged by persistent tensions in semileptonic B-decays. The ratios $R(D)$ and $R(D^*)$, in particular, show a combined discrepancy with predictions of over three standard deviations. This proceeding presents three recent LHCb results that investigate this anomaly. We report a new precision measurement of $R(D^+)$ and $R(D^{*+})$ using muonic $\tau$ decays, which confirms the tension. This is followed by the first search for semitauonic decays to excited $D^{**}$ states, which finds that this key background is insufficient to explain the anomaly. Finally, a measurement of the $\Lambda \to p\mu^-\bar{\nu}_\mu$ decay provides a complementary test of LFU in the baryon sector, finding results consistent with the Standard Model and sharpening the focus of the flavour puzzle.

*The 17th International Conference on Heavy Quarks and Leptons (HQL 2025)*
*15-19 September, 2025*
*Peking University, Beijing, China*

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PoS(HQL2025)027

## 1. Introduction

Charged-current decays of $b$-hadrons provide a powerful means to test the Standard Model (SM), particularly the principle of Lepton Flavour Universality (LFU). A significant, long-standing tension exists between the SM predictions and the world average of the measured ratios $R(D^{(*)}) = \mathcal{B}(B \to D^{(*)}\tau^-\bar{\nu}_\tau)/\mathcal{B}(B \to D^{(*)}\ell^-\bar{\nu}_\ell)$, where $\ell = e, \mu$. As shown in Fig. 1, this anomaly deviates by more than three standard deviations [1] and represents one of the most compelling hints for new physics in the flavour sector. The following proceedings present a comprehensive update on this puzzle from the LHCb experiment, detailing three recent, complementary analyses. We report a new precision measurement of $R(D^+)$ and $R(D^{*+})$; the first direct search for $B \to D^{**}\tau\nu$ decays to probe a key systematic background; and a new test of LFU in the baryon sector via the decay $\Lambda \to p\mu^-\bar{\nu}_\mu$.

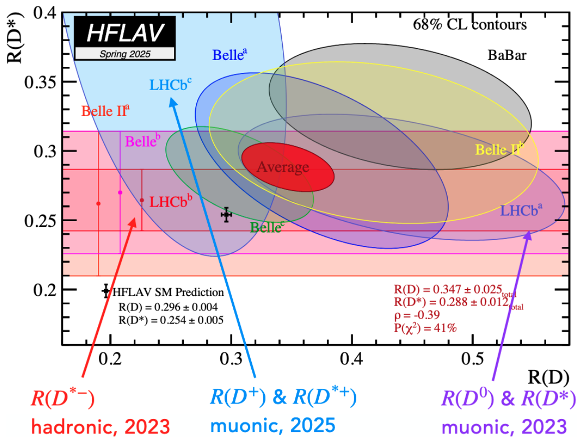


**Figure 1:** Status of $R(D)$ vs $R(D^*)$ measurements, showing the world average (red) in tension with the SM prediction (black). Plot from HFLAV [1].

## 2. Experimental and Analysis Techniques

The measurements presented herein were performed with the LHCb detector, a single-arm forward spectrometer at the LHC designed for precision heavy-flavour physics [2, 3]. While the detector's excellent performance is essential, the analyses of semileptonic final states require a set of advanced techniques to overcome inherent experimental challenges:

- **Missing Neutrinos:** The undetected neutrinos in the final state prevent direct reconstruction of the parent $b$-hadron's momentum. To recover powerful kinematic variables like the momentum transfer squared ($q^2$), a $B$-rest frame approximation [4] is used to estimate the $b$-hadron's kinematics from its visible decay products and flight direction.
- **Partially Reconstructed Backgrounds:** Large backgrounds from decays with missing particles can mimic the signal signature. These are suppressed using a multivariate track isolation algorithm [5]. This tool is also used to select background-enriched control regions, allowing for data-driven constraints in the final fit.

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- **Form-Factor Modelling:** The kinematic shapes of signal and background templates depend on the underlying form-factor parametrisations. To handle this without generating computationally prohibitive numbers of simulated samples, the HAMMER tool [6] is used for efficient event-by-event reweighting to different physics models.

- **Simulation Statistics:** The demand for high-statistics simulated samples is met by a fast simulation framework. This "tracker-only" approach retains the full detail of the crucial tracking systems while parametrising the response of other detector components. This significantly reduces computational requirements, yielding a speed-up factor of approximately eight in CPU time and reducing the required disk space by around 40% compared to a full simulation [7].

## 3. Probing LFU in $B$-Meson Decays

The LFU anomaly is primarily driven by measurements in the $b \to c$ transition. Recent LHCb results have focused on a two-pronged strategy: improving the precision of the $R(D^{(*)})$ measurements themselves and directly investigating potential experimental origins of the discrepancy.

A new measurement of $R(D^+)$ and $R(D^{*+})$ was performed using 2 fb$^{-1}$ of data collected by LHCb [7]. The analysis leverages the muonic $\tau$ decay, where the identical reconstructed final state for signal ($\bar{B}^0 \to D^{(*)+}\tau^-\bar{\nu}_\tau$) and normalization ($\bar{B}^0 \to D^{(*)+}\mu^-\bar{\nu}_\mu$) modes allows for significant cancellation of systematic uncertainties related to reconstruction and particle identification. The signal yields are extracted from a 3D template fit. The discriminating variables are the missing mass squared, $m^2_{\text{miss}} = (p_B - p_{D^{(*)}} - p_\mu)^2$; the muon energy in the approximated $B$-meson rest frame, $E^*_\mu$; and the four-momentum transfer squared, $q^2 = (p_B - p_{D^{(*)}})^2$. The fit, with the projection of the results shown in Fig. 2, yields:

$$R(D^{*+}) = 0.402 \pm 0.081(\text{stat}) \pm 0.085(\text{syst}),$$
$$R(D^{+}) = 0.249 \pm 0.043(\text{stat}) \pm 0.047(\text{syst}),$$

with a correlation of $\rho = -0.39$. The dominant systematic uncertainties arise from the limited size of the simulated samples and the modelling of the hadronic form factors. This precision result is consistent with the existing world average and confirms the persistence of the anomaly.

A critical question is whether this tension could be explained by an underestimated feed-down background from decays to excited $D^{**}$ states, another dominant systematic in such analyses. To address this, LHCb performed the first direct search for $B^- \to D^{**0}\tau^-\bar{\nu}_\tau$ using the full 9 fb$^{-1}$ Run 1 and 2 dataset [8]. The search, using hadronic $\tau$ decays, found the first evidence for this decay at $3.5\sigma$, with the signal extraction shown in Fig. 3. The measured LFU ratio for the narrow excited states is:

$$R(D^{**0}_{1,2}) = 0.13 \pm 0.03(\text{stat}) \pm 0.01(\text{syst}) \pm 0.02(\text{ext}).$$

This value is consistent with the SM prediction [9]. This result implies that the contribution from this background source is insufficient to explain the $R(D^{(*)})$ tension. It provides strong evidence that the anomaly is not an artifact of this particular background and supplies a crucial data-driven constraint that will improve the precision of all future measurements.



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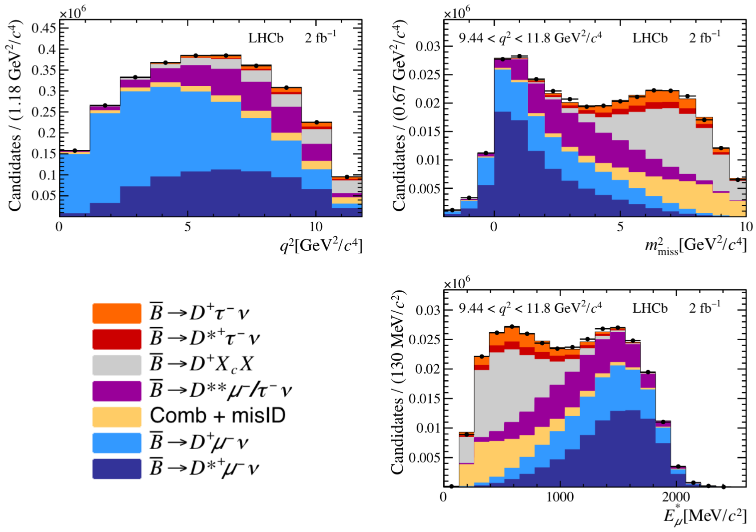


**Figure 2:** Distributions of the fit variables in the signal isolation region of the muonic $R(D^{(*)+})$ analysis, with the fit model overlaid. The $q^2$ distribution is shown over the full fit range, whereas $m^2_{\rm miss}$ and $E^*_\mu$ are only shown in the selected range.

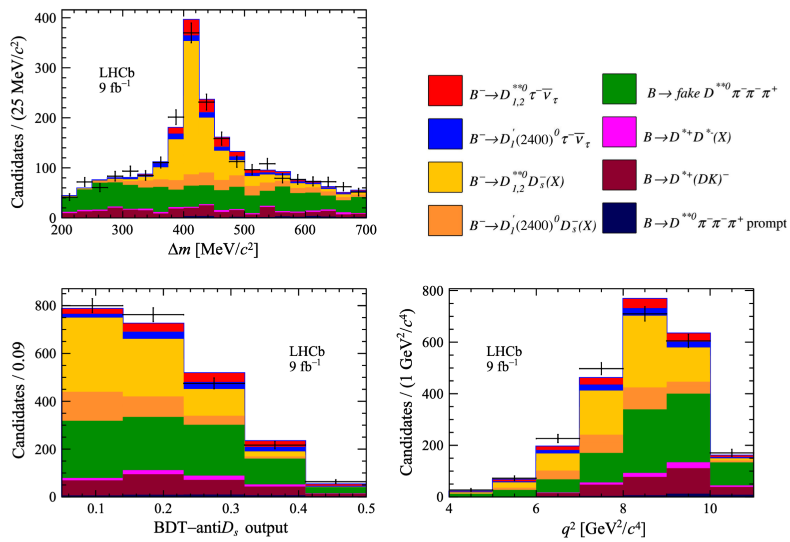


**Figure 3:** Projections of the three-dimensional fit for the $B^- \to D^{**0}\tau^-\bar{\nu}_\tau$ analysis, with the fit result overlaid on the data. The panels show (top) the mass difference between the $D^{**0}$ and $D^{*+}$ candidates, (bottom left) the anti-$D_s$ BDT output, and (bottom right) the squared four-momentum transfer to the lepton pair, $q^2$.

## 4. A Complementary Test in Baryon Decays

To provide a crucial cross-check of LFU in a different physical system, a measurement of the semileptonic hyperon decay $\Lambda \to p\mu^-\bar{\nu}_\mu$ was performed using 5.4 fb$^{-1}$ of data [10]. This $s \to u$ transition offers a valuable comparison to the $b \to c$ decays where the anomalies are observed. Furthermore, it provides a new baryonic channel to determine the CKM element $|V_{us}|$, offering an independent perspective on the "Cabibbo Anomaly" seen in $|V_{us}|$ measurements from kaon

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decays [12]. The branching fraction is measured relative to the abundant $\Lambda \to p\pi^-$ channel to minimize production-related uncertainties.

The main experimental challenge is a background from the normalization channel itself where the pion decays in-flight, $\pi^- \to \mu^-\bar{\nu}_\mu$, creating a final state identical to the signal. This background is powerfully suppressed using a novel "corrected mass" variable, $m_{\text{corr}}(p\pi)$. This variable is constructed by using the high-precision tracking information and the constraint that the reconstructed $\Lambda$ must point back to the primary vertex to estimate what the pion's momentum would have been before its decay. A 2D template fit to the standard reconstructed mass and this corrected mass variable is then used to extract the signal yield, which is found to be $16370 \pm 160$ events. This analysis provides the world's most precise measurement of the branching fraction:

$$\mathcal{B}(\Lambda \to p\mu^-\bar{\nu}_\mu) = (1.462 \pm 0.016(\text{stat}) \pm 0.100(\text{syst}) \pm 0.011(\text{ext})) \times 10^{-4}.$$

From this, the LFU ratio is found to be $R_{\mu e}(\Lambda) = 0.175 \pm 0.012$, which is consistent with the SM within $1.5\sigma$. The extracted value of $|V_{us}| = 0.253 \pm 0.011$ is also in agreement with the SM value of the CKM element. This result from the baryon sector shows no deviation from the SM, providing an important contrast to the tensions observed in $B$-meson decays.

## 5. Conclusion

This proceeding has presented a multi-faceted investigation into charged-current decays at LHCb, providing a significant update on the Lepton Flavour Universality puzzle. The results paint a compelling and increasingly clear picture.

In the $b$-hadron sector, a new precision measurement of $R(D^+)$ and $R(D^{*+})$ confirms that the long-standing anomaly in $b \to c$ transitions persists. Crucially, a potential explanation for this anomaly has been directly addressed. The first search for semitauonic decays to excited $D^{**}$ states has shown that the contribution from this key feed-down background is insufficient to explain the observed discrepancy in $R(D^{(*)})$. This finding closes an important experimental loophole and strengthens the hypothesis that the anomaly may have its origin in New Physics.

In contrast, a complementary test of LFU in a different physical system, the $s \to u$ transition of the $\Lambda$ baryon, finds results consistent with the Standard Model. This agreement in the baryon sector provides an important point of contrast, suggesting that if new physics is at play, it may have a non-trivial flavour structure, coupling preferentially to third-generation quarks and leptons.

Taken together, these results sharpen the focus of the flavour anomaly puzzle. The LHCb program for charged-current decays is ongoing, with many more analyses in the pipeline. With the high-statistics dataset currently being collected in Run 3, LHCb is pushing the precision of these measurements into a new regime, with the potential to turn the long-standing hints of New Physics in the flavour sector into a conclusive discovery.

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