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The buzz of $b \to sll$ decays and why it still matters

On behalf of LHCb collaboration, Alice Biolchini[a,*]

[a] *NIKHEF,*
Science Park, Amsterdam, NL

E-mail: alice.biolchini@cern.ch, abiolchi@nikhef.nl

Rare $b \to sll$ decays provide a valuable testing ground for probing the Standard Model flavour universality. These decays are potentially sensitive to indirect contributions from heavy mediators, otherwise inaccessible via direct searches. Additionally, comparing decays involving electrons and muons offers a unique opportunity to uncover potential differences between lepton families. The LHCb experiment plays a crucial role in this sector, as it is specifically designed to study hadrons containing b or c quarks, delivering high-precision measurements of branching ratios and angular distributions. This talk presents the first angular analysis of the rare decay $B^0 \to K^{*0}e^+e^-$ in the central q^2 region at the LHC. Using the full Run 1 and Run 2 datasets collected by LHCb (9 fb^{-1}), a multidimensional fit is performed to extract angular observables and compare them with SM predictions. While the angular observables show no significant deviations from the Standard Model prediction, the Wilson coefficients fit is consistent with that obtained from the same decay channel with muons, confirming a shift in C_9 with approximately 2σ significance. These findings mark an important step in testing the consistency of $b \to sll$ transitions and reinforce the necessity of further precision studies to probe potential new physics contributions.

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*Speaker

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1. Introduction and motivations

The $b \to s\ell\ell$ decays are flavor-changing neutral currents (FCNC). With branching fractions of the order $O(10^{-6})$, they are highly suppressed in the Standard Model (SM) and forbidden at tree level. Therefore, they are excellent laboratories for exploring physics at the TeV scale [1], as potential New Physics (NP) can affect their decay rates and angular distributions via modifications of the Wilson Coefficients (WCs) C_7, C_9, and C_{10}, which describe the short-distance dynamics of the process using the Effective Field Theory (EFT). A key observable for these decays is the di-lepton invariant mass, known as q^2, by studying the decays as a function of q^2 it is possible to access information about different Wilson Coefficients. The main types of measurements involving $b \to s\ell\ell$ transitions include the ratio of branching fractions between muons and electrons [2–8], angular analyses [9–14], and differential branching fraction studies [6, 15–19], listed in order of increasing theoretical uncertainties. Over the years, deviations from the SM predictions have been observed across several observables. While none of these deviations has reached statistical significance to claim a discovery, they are compelling enough to draw substantial attention. The consistency of these discrepancies across different measurements hints at the possible presence of NP.

The full spectrum of $b \to s\ell\ell$ observables can be analysed collectively through "global fits" within the framework of the EFT. This approach parametrises the angular observables in terms of WCs and performs maximum likelihood fits to extract potential NP contributions (C_i^{NP}). A

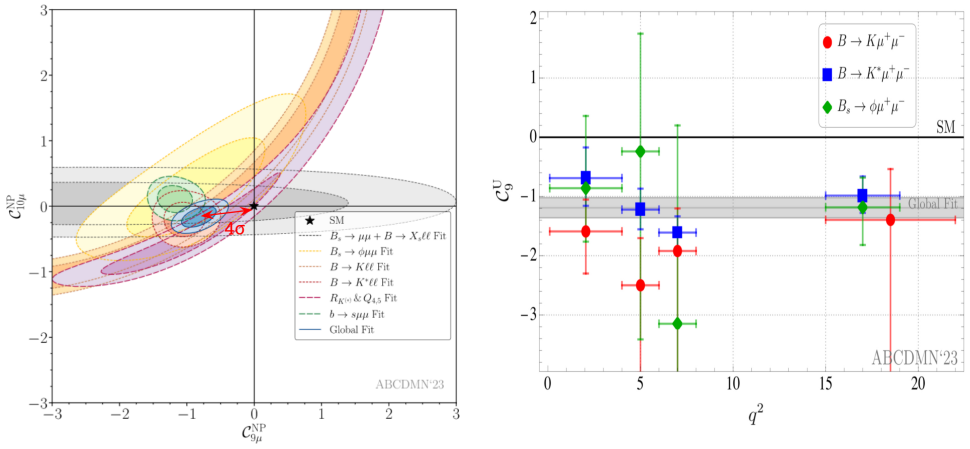

Figure 1: On the left, the comparison of WC fits results using different analysis results in the $C_{9\mu}^{NP} - C_{10\mu}^{NP}$ plane. In blue, the global fit using all the measurements [20]. On the right side, the preferred value of C_9^U for different bins of q^2 [21]. The data included in these fits correspond to the branching fractions for both the charged and neutral $B \to K^*\mu^+\mu^-$, the branching fractions for the $B_s \to \phi\mu^+\mu^-$ mode, and the angular observables for both the $B \to K^*\mu^+\mu^-$ and $B_s \to \phi\mu^+\mu^-$ modes. The grey band corresponds to the 1σ confidence interval for the global fit to C_9^U.

state-of-the-art global fit to the WCs is reported in Fig. 1 on the left: it shows a 4σ deviation on the $C_{9\mu}^{NP} - C_{10\mu}^{NP}$ plane from the SM value. Among the various NP scenarios, the most favoured represents a Lepton Flavour Universal (LFU) NP contribution [21]. Fig. 1 on the right, illustrates

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the preferred values of C_9^U for different bins of q^2 and various measurements performed in channels with muons. Notably absent from this plot are the analyses conducted on decays with electrons as charged leptons in the final state. This absence is mainly due to experimental challenges with electrons: they emit bremsstrahlung radiation in the detector, and the hardware trigger for electrons, performed in the electromagnetic calorimeter, requires higher thresholds than those applied to muons in the muon stations due to high occupancy. Although some of the emitted photons can be reconstructed and associated with the electrons, the energy resolution and reconstruction efficiency for electrons are significantly worse compared to muons. Nevertheless, the first angular analysis in a channel with electrons has been recently measured and will soon be published: the $B^0 \to K^{*0}e^+e^-$ channel, analysed for the first time in the central q^2 region at a hadronic machine [22].

2. $B^0 \to K^{*0}e^+e^-$ angular analysis in central q^2

2.1 Physics Goals

The $B^0 \to K^{*0}e^+e^-$ decay is described by three angles, θ_ℓ, θ_K, and ϕ, as well as q^2. The angular distribution can be expressed as:

$$\frac{d^4(\Gamma + \bar{\Gamma})}{dq^2\, d\cos\theta_\ell\, d\cos\theta_K\, d\phi}\,\frac{dq^2}{d^4(\Gamma + \bar{\Gamma})} \propto \sum_i S_i(q^2)\, f_i(\theta_\ell, \theta_K, \phi),$$

where S_i are the CP averaged angular coefficients, and f_i are known functions of the angles [23]. The goal is to measure the S_i coefficients and compare them with the SM prediction, as well as with their values in the same decay involving muons. This analysis specifically focuses on two q^2 regions: $[1.1 - 6]$ GeV$^2/c^4$ and a larger region, $[1.1 - 7]$ GeV$^2/c^4$. The angular parameters are measured in both the S and the theoretically optimized P' bases [24].

2.2 Analysis Methodology

The analysis [22] uses the full Run 1 and Run 2 datasets collected by the LHCb experiment, corresponding to an integrated luminosity of 9 fb^{-1}. An unbinned maximum likelihood fit is carried out in 4 dimensions (mass and angles). The following sections outline and elaborate on the main steps of the analysis.

Acceptance Parametrization Detector effects, such as reconstruction efficiency and resolution, distort the angular distributions. These are corrected by applying per-event weights, $w_i = 1/\epsilon(\vec{x})$, to the dataset, where $\epsilon(\vec{x})$ is a function that parametrizes the acceptance of the detector and it is computed using Legendre polynomials and Fourier terms, as follows:

$$\epsilon(\cos\theta_\ell, \cos\theta_K, \phi, q^2) = \sum_{k,l,m,n} c_{k,l,m,n} L_k(\cos\theta_K) L_l(\cos\theta_\ell) F_m(\phi) L_n(q^2).$$

The coefficients of the functions are determined via Monte Carlo simulations.

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Background Modeling After the first stage of selection, residual backgrounds are left in the fit region and need to be modelled in the 4D fit. The *combinatorial background* arises with random associations of particles from multiple unrelated decays, resulting in a final state that mimics the signal. While, the so-called *double semileptonic (DSL)* background is composed of B^0 decays with the same detectable final state, but involves an intermediate a $D^{*\pm}$ ($e.g.$ $B^0 \to D^{*-}(\to K^{*0}e^-\bar{\nu}_e)e^+\nu_e$). These two backgrounds are modelled using a lepton flavour violating (LFV) dataset, reconstructed as $B^0 \to K^{*0}e^\pm\mu^\mp$ decay (where the search window has been kept blind), in which both backgrounds contribute. A tight cut on the boosted decision tree (BDT), targeting the combinatorial background in the LFV sample, allows for the creation of a DSL-enriched sample. A 4D fit of this sample provides the shape of this specific background. A second fit to the LFV sample, with the BDT cut relaxed and the shapes of the DSL background fixed, allows for the extraction of the shape of the combinatorial background. A *partially reconstructed background* is composed of decays such as $B^+ \to K\pi\pi e^+e^-$, where some particles escape detection. It is modelled using a $B^+ \to K\pi\pi e^+e^-$ Monte Carlo simulation. Finally, a *misidentified background* is composed of hadronic decays with single and double misidentified electrons ($e.g.$ kaons or pions reconstructed as electrons). This background is estimated using a data-driven method based on sideband extrapolation, specifically adopting the strategy developed by the analysis in Ref. [4, 5].

Angles and mass fit The 1D projections of the full 9 fb^{-1} dataset are shown in Fig. 2. Given that this is a 4D fit involving both mass and angular variables, special care was required in the background parametrization.

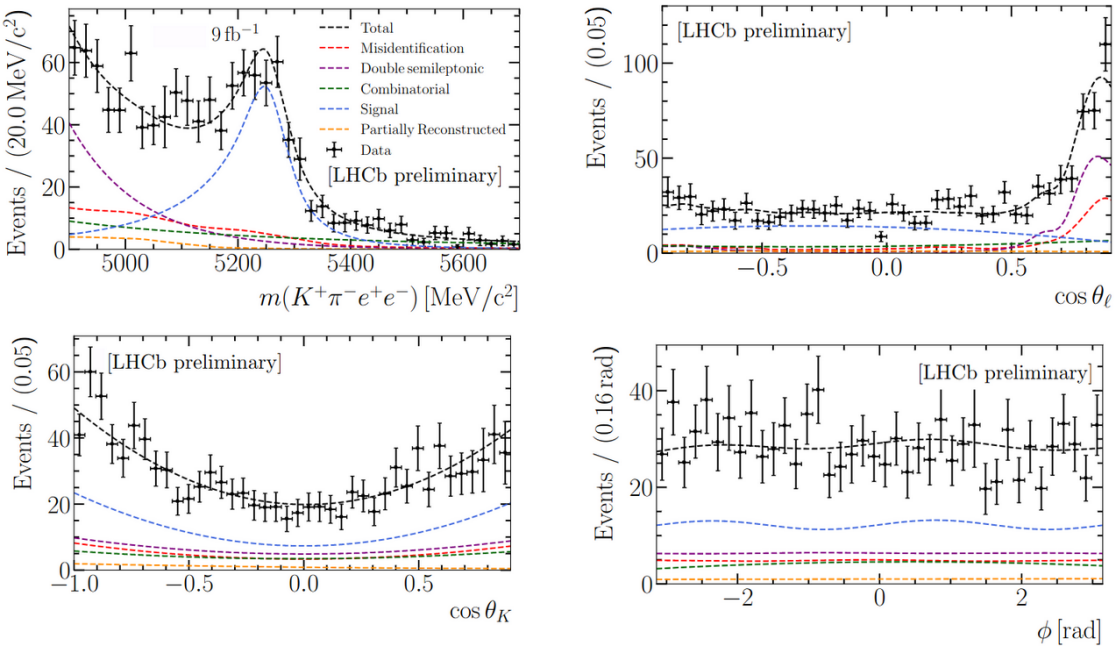

Figure 2: 1D projections of the full fit to the reconstructed mass and the three angles from which the CP averaged angular coefficients are extracted.

Systematic Uncertainties A comprehensive study has been conducted to assess all relevant sources of systematic uncertainties. The largest sources of systematic uncertainty arise from the

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modelling of combinatorial and DSL backgrounds, as well as acceptance determination, with some angular observables exhibiting systematic uncertainties exceeding 50% of the corresponding statistical uncertainty. For a detailed list, please refer to the paper [22].

2.3 Results and Discussion

The analysis extracts the CP-averaged angular observables S_i and their optimised counterparts P_i' [22]. The results are consistent with the SM predictions within the uncertainties. Very similar results are obtained in the q^2 $[1.1-7]$ GeV$^2/c^4$. The plot in Fig. 3 on the left shows the difference between the P_i observables measured for the muon and electron modes, defined as $Q_i = P_i^\mu - P_i^e$. As ratios of branching fractions, these variables are also very clean from the theoretical point of view. These results show no significant deviations from Lepton Flavour Universality (LFU) SM predictions. With these new results, a WCs fit is performed and compared to the corresponding fit obtained using the angular parameters from the same decay channel with muons [9]. The likelihood profile, expressed in terms of $\Delta C_9 = C_9^{(\mu)} - C_9^{(e)}$, is shown in Fig. 3 on the right. With ΔC_9 being compatible with zero within 1σ, it confirms a shift in C_9 consistent with that from the muons channel, with a significance of approximately 2σ. This is particularly remarkable since the systematic uncertainties of electrons and muons are quite different and uncorrelated. These results lend further support to the favoured LFU-NP scenario.

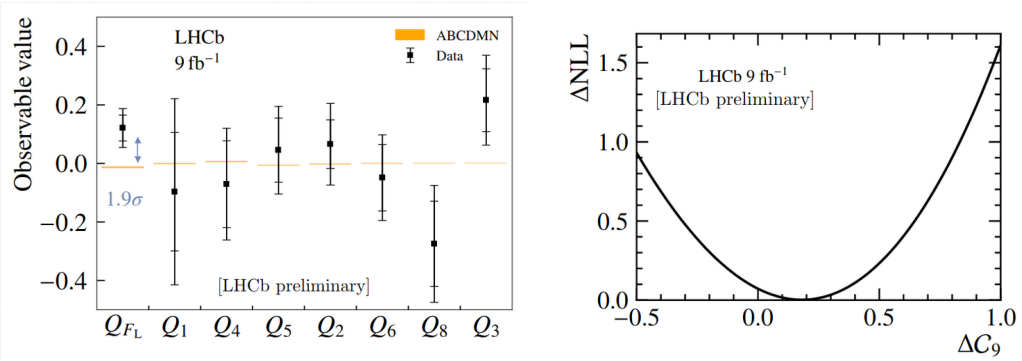

Figure 3: On the left, the plot shows the LFU observables $Q_i = P_i^\mu - P_i^e$. The SM predictions (orange boxes) are based on Ref. [21]. On the right, the likelihood profile obtained by performing global fits to the $B^0 \to K^{*0}\ell^+\ell^-$ angular observables, expressed in terms of $\Delta C_9 = C_9^{(\mu)} - C_9^{(e)}$.

3. Conclusion and Future Prospects

This study represents the first angular analysis of $B^0 \to K^{*0}e^+e^-$ decays at a hadronic machine in the central q^2 region. The sensitivity achieved is comparable to the first P_5' measurements in $B^0 \to K^{*0}\mu^+\mu^-$ decays, marking a significant milestone and highlighting the LHCb's capability to perform precise measurements in channels with electrons. The results are consistent with the SM. However, the compatibility of ΔC_9 with zero confirms the shift in C_9 obtained using the results from the analysis with muons [9], and emphasizes the need for further precision measurements to probe the $b \to s\ell\ell$ transitions. This underscores why $b \to s\ell\ell$ decays remain an essential window into physics beyond SM, offering valuable insights into potential NP contributions.

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