PROCEEDINGS OF SCIENCE

Prospects for $\bar{B}_d \to \bar{K}^{*0}\mu^+\mu^-$ at LHC*b*

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$\bar{B}_d \to \bar{K}^{*0}\mu^+\mu^-$ is a rare electroweak $b \to s$ penguin decay that has excellent sensitivity to physics beyond the Standard Model. It is expected that LHC*b* will select around 7200 signal with 1100 background events for each nominal year of data–taking. This allows for a comprehensive and exciting physics programme, the plans for which are reviewed in this article.

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1. Introduction

As we enter the LHC era, we are confronted with the experimental fact that results from the Tevatron and the B–factories are, by and large, in agreement with Standard Model (SM) predictions. The working hypothesis of the LHC project is that there will be new physics (NP) at the TeV scale, however considerations from flavour physics imply that the NP scale is much larger, assuming its flavour structure is generic. If these two observations are to be reconciled then the study of flavour will be of great interest at the LHC. LHC*b* is a high precision experiment for the study of *CP* violation and rare decays at the LHC (1) and will play an invaluable role in these studies.

Of particular interest at LHC*b* will be the exclusive $b \to s$ decay mode $\bar{B}_d \to \bar{K}^{*0}\mu^+\mu^-$. It is dominated by the Wilson coefficients $\mathscr{C}_{7,9,10}$ all of which have right–handed versions, denoted with a prime, that are highly suppressed in the SM and in minimal flavour–violating models. In the presence of NP, the value of these coefficients will change due to new heavy degrees of freedom in the penguin loops. Measuring the Wilson coefficients then allows for entire classes of NP to be observed or excluded.

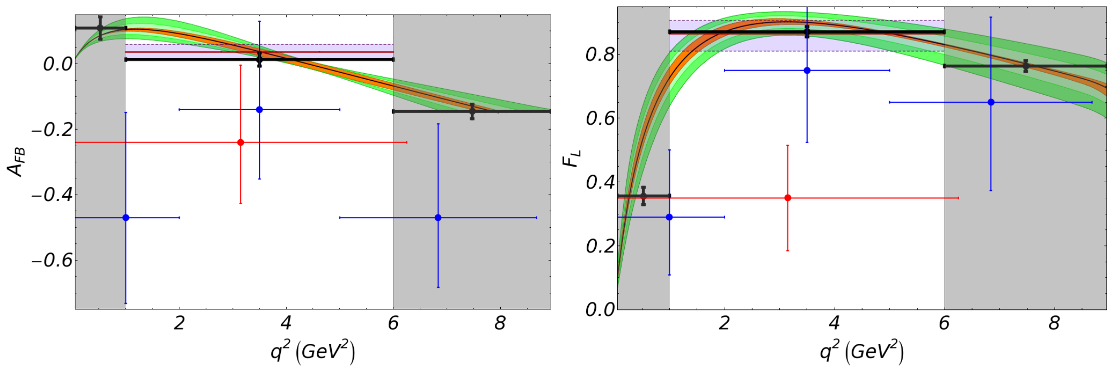

Figure 1: Recent results from *BABAR* (red) and BELLE (blue) for A_{FB} (left) and F_{L} (right). SM theoretical predictions are shown; the orange, light green, and dark green bands show the parametric, 5%, and 10% Λ/m_b corrections respectively (2). The light purple band shows the rate weighted SM average in the region $q^2 \in [1\,\mathrm{GeV}^2/c^4, 6\,\mathrm{GeV}^2/c^4]$, with all uncertainties. The black points show LHC*b* 2 fb^{-1} sensitivities using a simultaneous angular projection fit, assuming the SM, where the central values are taken from a single toy experiment (3).

The kinematics of the decay is described by three angles, θ_l, θ_K, and ϕ, and q^2, the invariant mass squared of the $\mu\mu$ pair. To extract the maximal information from the decay we need observables that have small statistical uncertainties and at the same time small theoretical uncertainties. A widely studied observable is the di-lepton forward–backward asymmetry, A_{FB} (4), the zero–crossing point (q_0^2) of which has small theoretical uncertainties due to leading order form–factor (FF) cancellations (5). The SM distribution can be seen in Fig. 1, however the theoretical uncertainties are not well controlled outside of the $q^2 \in [1\,\mathrm{GeV}^2/c^4, 6\,\mathrm{GeV}^2/c^4]$ region, where QCD factorisation is no longer reliable (6; 7). New measurements from both *BABAR* and BELLE (8; 9) are shown in Fig. 1 for points that lie inside the theoretically clean region. Also shown is F_{L}, the longitudinal polarisation fraction of the $\bar{K}^*$. The current experimental uncertainties are still too large to make any definitive statements about deviations from the SM and any differences seen are greatest outside of the theoretically clean q^2 region (not shown). The large increase in statistics that LHC*b* will provide should clarify this situation. For comparison, the estimated sensitivities for LHC*b* with $2\,\mathrm{fb}^{-1}$ of integrated luminosity are shown in the same figure.

2. Physics Programme

Making precision *B*–physics measurements in the LHC environment will be challenging but LHC*b* has been carefully optimised to make this possible (1). The detector is expected to select ~ 7200 $B_d \to K^{*0}\mu^+\mu^-$ signal events across the complete q^2 range with ~ 1100 background events, for each nominal year of data–taking ($2\,\mathrm{fb}^{-1}$) (10). This is approximately a factor of ten more events per year than all previous experiments have found in their lifetimes when combined. This demonstrates the effects of the large *b* production cross–section at the LHC and the advantages of LHC*b*'s forward geometry.

The large increase in statistics of $\bar{B}_d \to \bar{K}^{*0}\mu^+\mu^-$ at LHC*b* allows for the planning of an ambitious physics programme. A selection of measurements of the angular distribution are discussed below. The first major analysis target is to map out the A_{FB} distribution and determine q_0^2. This can be done with relatively low integrated luminosity using a counting experiment in θ_l, as shown on the left of Fig. 2. Taking a particular FF model (11), this approach gives a projected uncertainty of $\sigma(q_0^2) = 0.46\,\mathrm{GeV}^2/c^4$ for $2\,\mathrm{fb}^{-1}$ of integrated luminosity (12). However the uncertainty is approximately proportional to the gradient of the A_{FB} distribution, which is in turn dependent on the FFs found in nature, meaning that the actual uncertainty found may differ significantly from this.

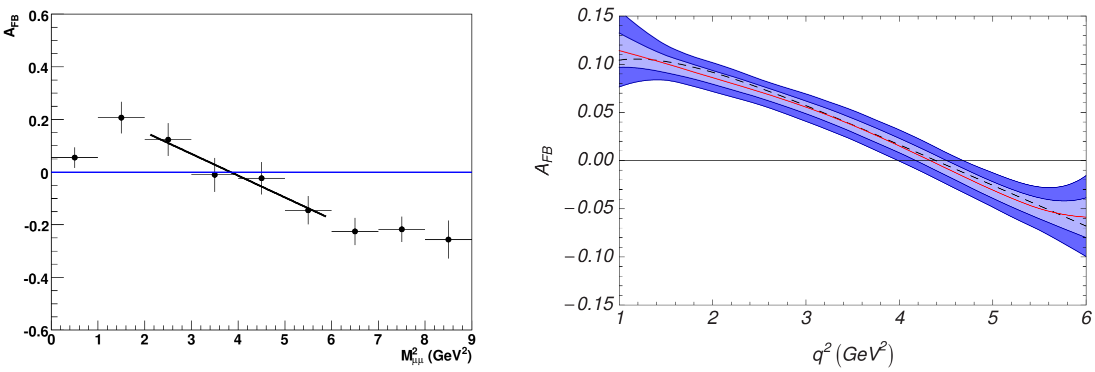

Figure 2: Left: A $2\,\mathrm{fb}^{-1}$ counting experiment, from Ref. (12), produced using the full LHC*b* detector simulation and a SM signal simulation following Ref. (11) ($M_{\mu\mu}^2 \equiv q^2$). A straight–line fit is used to extract q_0^2. **Right:** Estimated sensitivity to A_{FB} in the range $q^2 \in [1\,\mathrm{GeV}^2/c^4, 6\,\mathrm{GeV}^2/c^4]$ as extracted using a full angular analysis to $10\,\mathrm{fb}^{-1}$ of toy LHC*b* data, with the SM signal simulation following Refs. (6; 13; 2). The dashed black line shows the input SM distribution, while the solid red line is the median of a thousand toy fits. The 1σ and 2σ confidence levels are marked by the light and dark blue bands. The differing input calculations and FF distributions lead to the variations in gradient and q_0^2 between the two figures.

Counting experiments in θ_l are attractive as they require a relatively modest understanding of the detector and backgrounds. However, there is much more information available in the decay which can be extracted at the price of a more challenging analysis. Projections over the full angular distribution can be used to perform a simultaneous fit to the decay angles (3). This gives additional sensitivity to A_{FB} and F_{L}, shown in Fig. 1, and to non–SM values of $\mathcal{C}_7'$ via a new observable,

$A_T^{(2)}$ (14). Finally, it is possible to perform the full angular analysis (15). In this case all four experimental observables are utilised to extract the underlying decay amplitudes. This allows for the measurement of additional observables which can not be accessed in other ways. Fig. 3 shows the estimated LHC*b* sensitivity to the theoretically clean observables $A_T^{(3)}$ and $A_T^{(4)}$ for a simulated $10\,\text{fb}^{-1}$ dataset (2). In addition, significant improvement can be gained on A_{FB} and q_0^2. The right–hand figure of Fig. 2 shows the expected sensitivity to A_{FB} with $10\,\text{fb}^{-1}$ of integrated luminosity, giving $\sigma(q_0^2) = {}^{+0.18}_{-0.16}\,\text{GeV}^2/c^4$. A further factor of ~ 2 improvement might be expected if the FF model from (4) had been used instead of that from (6; 13).

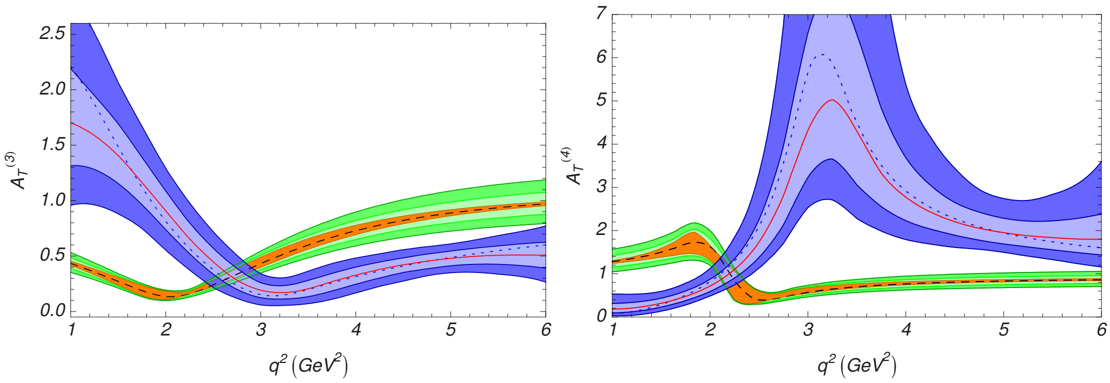

Figure 3: Experimental sensitivity bands (1σ and 2σ uncertainties are marked light and dark blue) compared to the theoretically clean observables $A_T^{(3)}$ and $A_T^{(4)}$ for $10\,\text{fb}^{-1}$ of LHC*b* data assuming the supersymmetric model 'b' from Ref. (16). The dashed blue line shows the model 'b' distribution taken as input, while the solid red line is the median of a thousand toy fits. The SM theoretical distributions are also shown with the same colour scheme as in Fig. 1. These two distributions must be statistically distinguishable if the observation of NP is to be claimed.

Within the currently allowed region of parameter space (17), these observables can show large differences from the SM. If the ansatz is made that any NP to be discovered only affects $\mathcal{C}_7^{(\prime)}$ and that the Wilson coefficients are real, then a naïve estimate indicates that with $10\,\text{fb}^{-1}$ of LHC*b* data an uncertainty on $\mathcal{C}_7^{(\prime)}$ of order ± 0.05 could be achieved with $\bar{B}_d \to \bar{K}^{*0}\mu^+\mu^-$ alone. This would allow for considerable model discrimination if NP is discovered at the LHC and could be further reduced if theoretical progress on the higher order Λ/m_b corrections can be made, or other $b \to s$ observables are included.

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References

[1] **LHC*b*** Collaboration, A. A. Alves *et. al.*, *The LHCb Detector at the LHC, JINST* **3** (2008) S08005.

[2] U. Egede, T. Hurth, J. Matias, M. Ramon and W. Reece, *New observables in the decay mode* $\bar{B}_d \to \bar{K}^{*0}\mu^+\mu^-$, *JHEP* **11** (2008) 032 [0807.2589].

[3] U. Egede, "Angular correlations in the $\bar{B}_d \to \bar{K}^{*0}\mu^+\mu^-$ decay." CERN-LHCb-2007-057.

[4] A. Ali, T. Mannel and T. Morozumi, *Forward backward asymmetry of dilepton angular distribution in the decay* $b \to sl^+l^-$, *Phys. Lett.* **B273** (1991) 505–512.

[5] G. Burdman, *Short distance coefficients and the vanishing of the lepton asymmetry in* $B \to Vl^+l^-$, *Phys. Rev.* **D57** (1998) 4254–4257 [hep-ph/9710550].

[6] M. Beneke, T. Feldmann and D. Seidel, *Systematic approach to exclusive* $B \to Vl^+l^-, V\gamma$ *decays*, *Nucl. Phys.* **B612** (2001) 25–58 [hep-ph/0106067].

[7] W. Altmannshofer *et. al.*, *Symmetries and asymmetries of* $B \to K^{*0}\mu^+\mu^-$ *decays in the Standard Model and beyond*, 0811.1214.

[8] ***BABAR*** Collaboration, B. Aubert *et. al.*, *Angular distributions in the decays* $B \to K^*l^+l^-$, 0804.4412.

[9] BELLE Collaboration, I. Adachi *et. al.*, *Measurement of the differential branching fraction and forward-backward asymmetry for* $B \to K^{(*)}l^+l^-$, 0810.0335.

[10] J. Dickens, V. Gibson, C. Lazzeroni and M. Patel, "Selection of the decay $B_d \to K^{*0}\mu^+\mu^-$ at LHC*b*." CERN-LHCb-2007-038.

[11] A. Ali, P. Ball, L. T. Handoko and G. Hiller, *A comparative study of the decays* $B \to (K, K^*)l^+l^-$ *in Standard Model and supersymmetric theories*, *Phys. Rev.* **D61** (2000) 074024 [hep-ph/9910221].

[12] J. Dickens, V. Gibson, C. Lazzeroni and M. Patel, "A study of the sensitivity to the forward-backward asymmetry in $B_d \to K^{*0}\mu^+\mu^-$ decays at LHC*b*." CERN-LHCb-2007-039.

[13] M. Beneke, T. Feldmann and D. Seidel, *Exclusive radiative and electroweak* $b \to d$ *and* $b \to s$ *penguin decays at NLO*, *Eur. Phys. J.* **C41** (2005) 173–188 [hep-ph/0412400].

[14] F. Kruger and J. Matias, *Probing new physics via the transverse amplitudes of* $B^0 \to K^{*0}(\to K^-\pi^+)l^+l^-$ *at large recoil*, *Phys. Rev.* **D71** (2005) 094009 [hep-ph/0502060].

[15] W. Reece and U. Egede, "Performing the full angular analysis of $\bar{B}_d \to \bar{K}^{*0}\mu^+\mu^-$ at LHC*b*." CERN-LHCb-2008-041.

[16] T. Feldmann and J. Matias, *Forward-backward and isospin asymmetry for* $B_d \to K^{*0}\mu^+\mu^-$ *decay in the Standard Model and in supersymmetry*, *JHEP* **01** (2003) 074 [hep-ph/0212158].

[17] C. Bobeth, G. Hiller and G. Piranishvili, *CP asymmetries in* $\bar{B} \to \bar{K}^{*0}(\to \bar{K}\pi)l^+l^-$ *and untagged* $\bar{B}_s, B_s \to \phi(\to K^-K^+)l^+l^-$ *decays at NLO*, *JHEP* **07** (2008) 106 [0805.2525].