Electromagnetic calorimetry requirements from b-flavoured hadrons radiative decays physics for application at FCC-ee

Stéphane Monteil[†], Lars Röhrig[*†]

[*] *Department of Physics, TU Dortmund University, Dortmund, Germany,* [†] *Université Clermont-Auvergne, CNRS, LPCA, Clermont-Ferrand, France,* [‡] *CERN, EP Department, Geneva, Switzerland*

This note reports an academic exercise to assess the electromagnetic (EM) calorimeter energy resolution performance that would be needed in order to separate candidates of the radiative quark transitions $b \to s\gamma$ and $b \to d\gamma$. The specific measurement considered in this work, the relative branching fractions of the decays $\overline{B}^0 \to K^{*0}(892)\gamma$ and $B_s^0 \to K^{*0}(892)\gamma$ can only be performed with a stochastic term of the electromagnetic calorimeter energy-resolution well-below 10%.

Contents

1 Physics motivations

The study of radiative decays, such as $B_d^0 \to K^*\gamma$ ($b \to s\gamma$) and $B_s^0 \to K^*\gamma$ ($b \to d\gamma$), serves as an important test of the Standard Model of Particle Physics (SM). It is a sensitive probe for potential Beyond the SM (BSM) effects in one-loop penguin diagrams [1–3], as the flavour-changing neutral current (FCNC) processes are forbidden at tree level in the SM. New heavy particles can enter the loop diagrams, altering the decay amplitudes and observables such as branching fractions, mixing-induced charge-parity (CP) asymmetries, and polarisation fractions. Examples of $b \to s\gamma$ and $b \to d\gamma$ transitions for both decays are shown in Fig. 1.

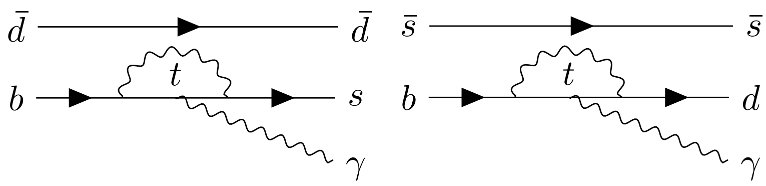

Figure 1: $b \to s\gamma$ and $b \to d\gamma$ at quark level in the SM.

Beyond the search for BSM amplitudes in these decays, they can be used to place constraints to the unitarity triangle profile complementary to those of the oscillation frequencies. This study considers the branching fraction ratio of the $B_d^0 \to K^*\gamma$ and $B_s^0 \to K^*\gamma$ transitions. The $B_s^0 \to K^*\gamma$ decay, unobserved to date, is one example of $b \to d$ transitions that a high-luminosity Z-factory can probably uniquely study, if it can benefit from an accurate photon-energy measurement complementing the already established exquisite reconstruction of displaced vertices.

2 Analysis

This study is based on about 10^6 simulated event samples, where the $B_d^0 \to K^*\gamma$ decay has been exclusively generated with `EvtGen` [4] and showered with `PYTHIA8` [5]. The detector response has been modelled using the IDEA card from the `DELPHES` [6] software package. The K^* are reconstructed from reconstructed charged kaon and pion, while the photon energy E_γ^{MC} is taken from the corresponding MC photon. Its energy response is modelled later via

$$E_\gamma^{\mathrm{smeared}} = r \cdot \sqrt{E_\gamma^{\mathrm{MC}}}\,, \tag{1}$$

with the resolution of the stochastic term r given in percentage units. It has been validated that a value of $r \approx 0.12$ corresponds to the energy resolution of the IDEA dual-readout calorimeter. For any emulated $E_\gamma^{\mathrm{smeared}}$, the momentum components of the photon are recalculated.

For the sake of this study, the B_s^0 signal yield is estimated from the CKM matrix elements and the corresponding hadronisation fractions $f_{b\to B_d^0} = 0.4$ and $f_{b\to B_s^0} = 0.1$ via

$$\frac{N_{B_d^0}}{N_{B_s^0}} \sim \frac{f_{b\to B_d^0}}{f_{b\to B_s^0}} \cdot \left|\frac{V_{ts}}{V_{td}}\right|^2 \approx 92\,. \tag{2}$$

The left and right panels of Fig. 2 show the case for $r = 0.12$ (corresponding to roughly the IDEA baseline resolution) and $r = 0.02$ (high photon-energy resolution from crystals; see also Ref. [7]). Only with a sufficiently high photon-energy resolution, the peak of the B_s^0 signal becomes visible and distinguishable from the

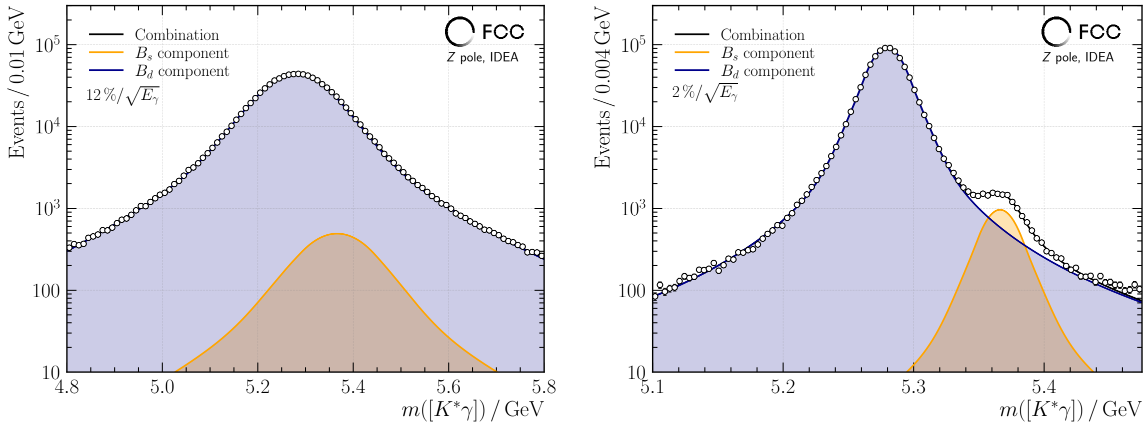

Figure 2: (Left) IDEA baseline scenario with a dual-readout calorimeter, $r = 0.12$. (Right) High photon-energy resolution from crystals, $r = 0.02$.

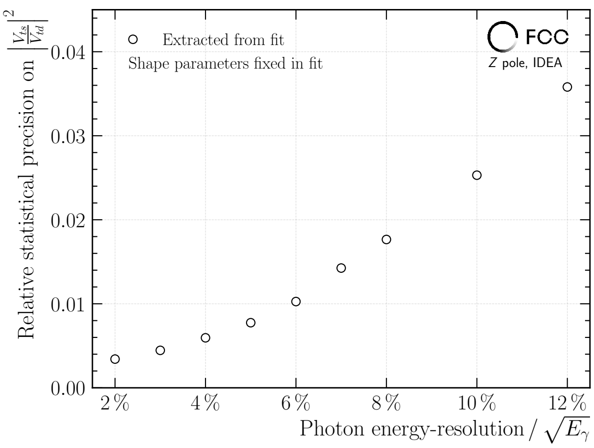

Figure 3: The photon energy-resolution is the driving impact on the measurement statistical precision of $\left|\frac{V_{ts}}{V_{td}}\right|^2$.

overwhelming B_d^0 counterpart spectrum. The relative uncertainty is highlighted in the figure Fig. 3, indicating that a statistical precision better than 0.5% is in reach with the highest energy resolution assumed in this study.

Several words of caution are in order when it comes to the interpretation of this academic exercise. The focus of the study is centred onto the separation power of the two transitions $b \to s, d\gamma$. The study hence assumed perfect charged hadron particle and photon identifications. Moreover, the physical backgrounds (*e.g.* the charmless transition $B^0 \to K\pi\pi^0$ with the π^0 is misidentified as a photon) are neglected. A single pseudo-experiment has been performed for the different fits and the actual convergence rate of the fits was not assessed. The uncertainties on the ratio of the form factors of the two decays must be as well assessed. It is expected that the next stage of the study will address these shortcomings.

3 References

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