PROCEEDINGS OF SCIENCE

Flavour tagging of B mesons in pp collisions at LHCb

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Flavour tagging, i.e. the inference of the production flavour of reconstructed B hadrons, is essential for precision measurements of decay-time-dependent *CP* violation and of mixing parameters in the neutral B meson systems. At the LHC hadronic events create a challenging environment for flavour tagging and demand for new and improved strategies. We present recent progress and new developments in terms of the flavour tagging at the LHCb experiment, which will allow for a further improvement of *CP* violation measurements in neutral B meson decays.

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1. Introduction

Measurements of flavour oscillations and time-dependent *CP* asymmetries in neutral B meson decays require knowledge of the b quark production flavour. This identification is performed by the flavour tagging. It is split in two independent classes of algorithms (see Fig. 1). [1], [2], [3] The same side tagging algorithms (SS) use charged particles created in the fragmentation process of the b quark of the signal B meson. On the same side currently three different algorithms exist, which use the charge of kaons in the case of a B_s^0 meson, pions, and protons in the case of a B^0 meson to infer the production flavour of the signal B meson. The opposite side (OS) algorithms exploit the decay of the non-signal b quark of the initial $b\bar{b}$ pair. The opposite side consists of four algorithms, which use the charge of kaons, leptons, the secondary vertices, and charm hadrons to identify the flavour of the signal B.

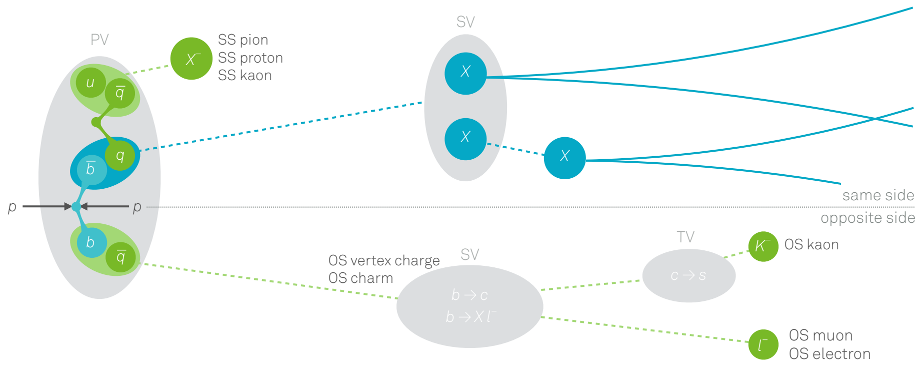

Figure 1: Schema of the current flavour tagging algorithms at LHCb. The blue shaded particles symbolize the signal decay.

Each tagging algorithm provides a decision (tag) d on the initial flavour and an estimation on the probability that the tag decision is wrong, called predicted mistag probability η, which is the number of events with a wrongly assigned tag over all tagged events. The flavour tagging algorithms are not always successful, which is described by the tagging efficiency ε_{tag}, which is the number of tagged events over the sum of all events, with and without an assigned tag. The effective tagging efficiency, the so-called tagging power, is the figure of merit for the development and optimisation of flavour tagging algorithms, because it represents the statistical reduction factor of a used sample in a tagged analysis and is defined as

$$\varepsilon_{\text{eff}} = \varepsilon_{\text{tag}} D^2 = \varepsilon_{\text{tag}}(1-2\omega)^2, \tag{1.1}$$

where ω is the true mistag. The predicted mistag probability η needs to be calibrated. The calibrated mistag $\omega(\eta)$ is parameterised as a linear function

$$\omega(\eta) = p_0 + p_1(\eta - \langle\eta\rangle) \tag{1.2}$$

of the predicted mistag probability η, where $\langle\eta\rangle$ is the average predicted mistag probability of the sample and p_0 and p_1 are calibration parameters. Several flavour specific decay channels are used for calibration.

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In Fig. 2 the functionality of a tagging algorithm in general is depicted. The queue of selections S1 to S3 define the tagging efficiency and the overlap between the different tagging algorithms. While the selections S1 and S2 are loose per-event selections to reduce combinatorics and to select suitable tagging candidates, selection S3 is custom-built for each tagging algorithm, which chooses the final set of tagging particles. In the end, multivariate classifiers are used to assign the tag decision and estimated mistag on one best or on multiple candidates given by the selection methods used before.

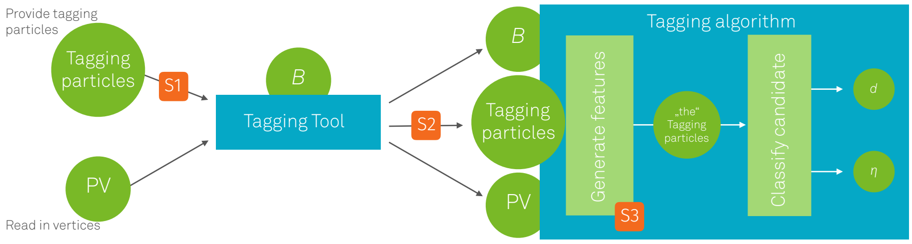

Figure 2: Schema of the current flavour tagging software at LHCb.

2. Flavour tagging in Run 1 at LHCb

LHCb has published world leading measurements in the sector of *CP* violation in $\mathrm{b} \to \mathrm{c\bar{c}s}$ transitions for example in the measurements of ϕ_S and $\sin(2\beta)$ on Run 1 data.
The latest analyses of ϕ_S in $\mathrm{B_S^0} \to \mathrm{J}/\psi\phi$ profited from including improved same side and re-optimised opposite side tagging algorithms and yields a tagging power of 3.7% [4]. The decay time and angular distributions are shown in Fig. 3. The measurement of $\sin(2\beta)$ in $\mathrm{B}^0 \to \mathrm{J}/\psi\mathrm{K_S^0}$ has an overall tagging power of 3.0% [5].

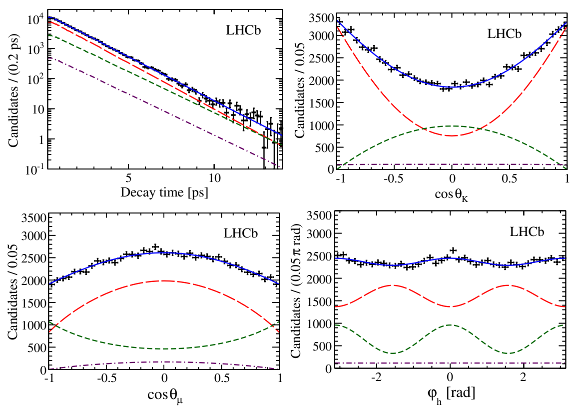

Figure 3: Decay time and angular distributions for $\mathrm{B_S^0} \to \mathrm{J}/\psi\mathrm{K^+K^-}$ [4].

Many recent improvements on the same side and an additional new flavour tagging algorithm on the opposite side cleared the way for new *CP* violation measurements. The new same side algorithms for identifying the flavor of B^0 mesons use protons and pions [3]. Besides this a multivariate classifier is now used to select tagging particles and to calculate the estimated mistag probability.

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And the new opposite side algorithm uses secondary charm hadron decays from the decay chain of the opposite side B hadron [6] to infer the production flavour of the signal B meson. These algorithms were used for the first time in the measurement of *CP* violation in $B^0 \to D^+D^-$ with an overall tagging power of around 8% and a tagging efficiency of 87.6% [7]. In Fig. 4 the decay-time-dependent signal yield asymmetry is shown.

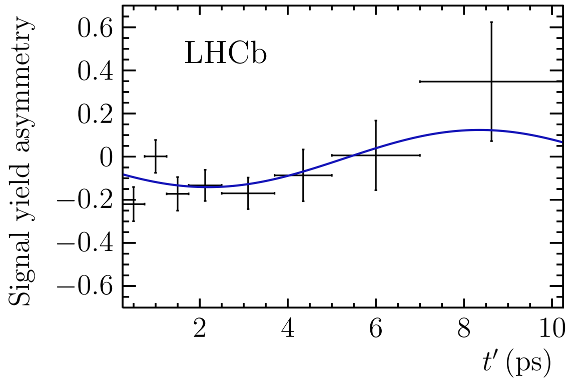

Figure 4: Decay-time-dependent signal yield asymmetry for $B^0 \to D^+D^-$ [7].

3. Conclusion

Flavour tagging at LHCb is playing a key role in obtaining world leading results in the field of flavour oscillations and time-dependent *CP* violation measurements. The improvements are resulting from a deeper understanding of the detector and the underlying physics as well as from improved know-how in statistics and machine learning. The future tasks are to optimise the existing flavour tagging algorithms and to develop new ones.

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