Flavour Tagging at LHCb

Miriam Calvo Gomez, on behalf of the LHCb Collaboration
Enginyeria La Salle
Universitat Ramon Llull
08022 Barcelona, SPAIN
miriam.calvo@cern.ch

1 Introduction

LHCb is a heavy flavour experiment, mainly focused on beauty and charm physics, which performs precision measurements of CP violation and rare decays. The results shown here correspond to data samples up to 1 fb^{-1} of proton proton collisions at $\sqrt{s} = 7\ TeV$ collected in 2011. As $b\overline{b}$ pairs are produced in the same forward (or backward) region, the LHCb detector [1] is fully instrumented in the forward direction, covering a pseudorapidity range $2 < \eta < 5$. The requirements for CP measurements in the B sector are: a flexible and efficient trigger, a good particle identification and an excellent tracking and vertexing, conditions that the detector fulfills.

Many LHCb measurements require the knowledge of the initial flavour (b or $\overline{b}$) of the reconstructed $B^0_{d,s}$ mesons, such as $B^0 - \overline{B}^0$ oscillations and time dependent CP asymmetries. The process of flavour identification is known as flavour tagging [2, 3, 4] and this will be detailed in the following sections. Some examples of LHCb published results that use flavour tagging are: measurement of the B_s oscillation frequency Δm_s in $B^0_s \to D_s\pi$ [5, 6]; CP violating mixing phase, ϕ_s [7, 8, 9, 10] and direct and mixing induced CP violation in $B \to hh$ [11].

2 Flavour tagging

Different type of taggers (algorithms) are used for the B flavour determination in LHCb. A schematic view of the possible sources of information are shown in Fig. 1. The one known as Same Side (SS) tagger exploits the particle produced at the fragmentation process of the signal B: a pion in the case of B^0 or B^+ signal (or from a B** decay) and a kaon for B^0_s. The rest of taggers are those called Opposite Side (OS) taggers. These exploit the decay products of the other b-hadron produced in the event: a lepton (electron or muon) from semileptonic B decays; a kaon from a $b \to c \to s$ chain and an overall charge of the secondary vertex. In any case, the charge of the tagger tags the flavour of the signal B.

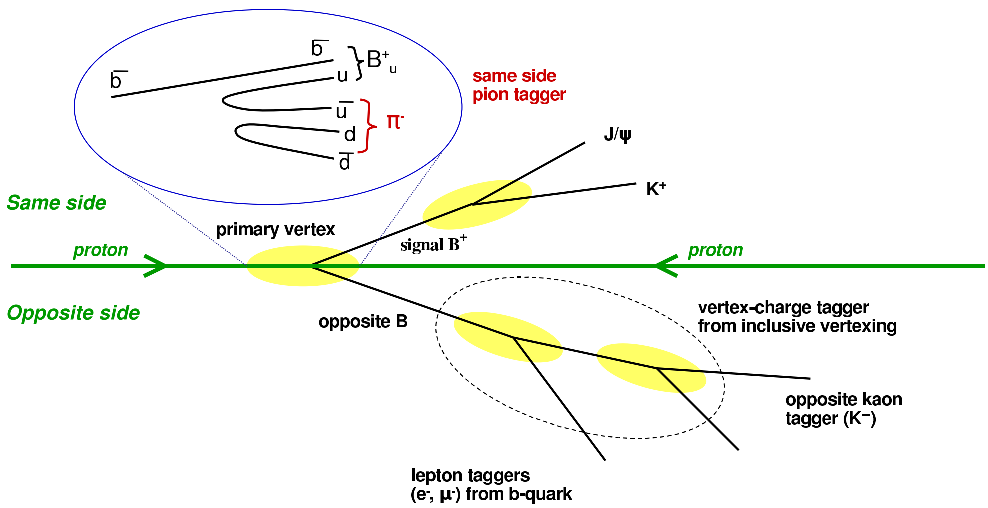

Figure 1: Schematic view of the different sources of information available to tag the initial flavour of a signal B candidate.

Due to the possibility to select a wrong track to tag the event, the tagging performance is not perfect. Moreover, as the opposite B can be neutral and oscillate, OS tagging algorithms have an intrinsic dilution. In order to evaluate the performance, we define a tagging efficiency, ϵ_{tag}, which is the fraction of events with a tagging decision; a wrong tag fraction, ω, or mistag rate, which is the fraction of events with a wrong tagging decision and an effective efficiency, ϵ_{eff}, or tagging power, which indicates the statistical precision of the sample, given by $\epsilon_{tag}(1-2\omega)^2$.

The flavour tagging performance can be evaluated in data using flavour-specific decay channels, known as control channels, as the decays: $B^+ \to J/\psi K^+$, $B^0 \to D^{*-}\mu^+\nu$, $B^0 \to J/\psi K^{*0}$ and $B^0_s \to D^-_s\pi^+$. For B^+ the mistag can be estimated just comparing the flavour tagging decision with the observed (true) flavour. In case of neutral B, ω can be determined from a fit to the time dependent mixing asymmetry, whose amplitude is proportional to the dilution factor $(1-2\omega)$. Fig. 2 shows the mixing asymmetry fits for $B^0 \to D^{*-}\mu^+\nu$ and $B^0 \to J/\psi K^{*0}$ using OS tagged events.

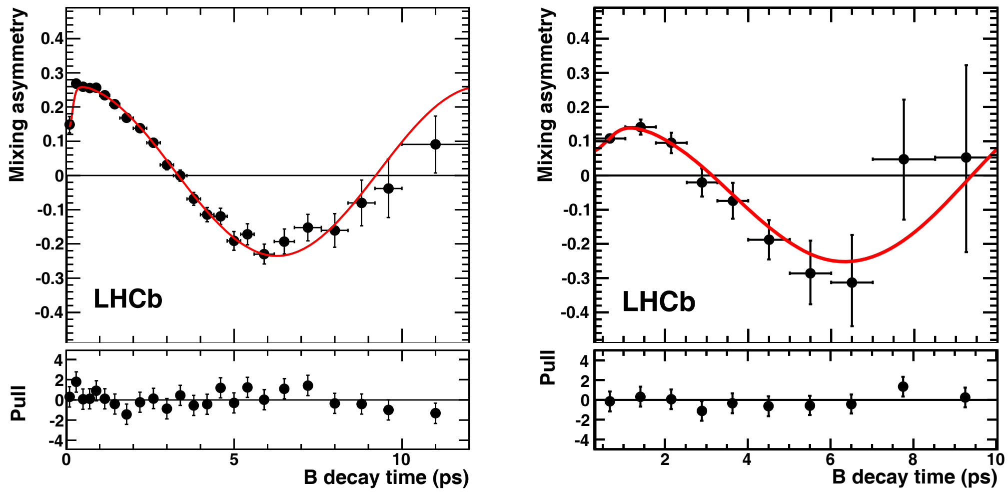

Figure 2: Raw mixing asymmetry of $B^0 \to D^{*-}\mu^+\nu$ (left) and $B^0 \to J/\psi K^{*0}$ (right) when using the combination of all OS taggers for 0.37 fb^{-1}. Black points are data and red line is the result of the fit. The lower plots show the pull of the residuals with respect to the fit.

3 Optimization and calibration

Flavour tagging algorithms were initially designed studying simulated events [2]. For each tagger, the tagging particle is selected requiring several cuts on kinematic and geometrical observables (such as $IP/\sigma, p, p_T$) and particle identification discriminators. In the case of SS taggers, also proximity to the signal B is required. If several candidates for the same tagger exist, the one with highest p_T is selected. An optimization of the selection cuts with real data has been performed using several control channels, in order to maximize the tagging power [3, 4]. For OS the main control channel used is $B^+ \to J/\psi K^+$ and the other channels are used as a cross check.

The taggers make individual decisions about the flavour with varying accuracy, which is evaluated by means of a Neural Net (NNet). The NNet uses as input some properties of the tagger and of the event (B p_T, number of interactions, ...), providing an estimate of the mistag probability (η) for each event. As this NNet was trained on MC samples, a calibration has to be performed on real data. The predicted mistag is calibrated with a linear fit using the measured ω in a control channel: $\omega = p_0 + p_1(\eta - < \eta >)$.

In case more than one tagger give a response, the final decision and predicted mistag are obtained combining the individual decisions and calibrated predicted mistag (η_c). Due to the correlation among taggers (mainly between secondary vertex charge and other OS taggers) the OS predicted mistag needs to be calibrated in data.

The OS calibration is performed with $B^+ \to J/\psi K^+$ and validated using other control channels [10] (as $B^0 \to J/\psi K^{*0}$ and $B^0 \to D^-\pi^+$), as shown in Fig. 3. This calibrated per-event mistag can be used directly in the time-dependent CP fits.

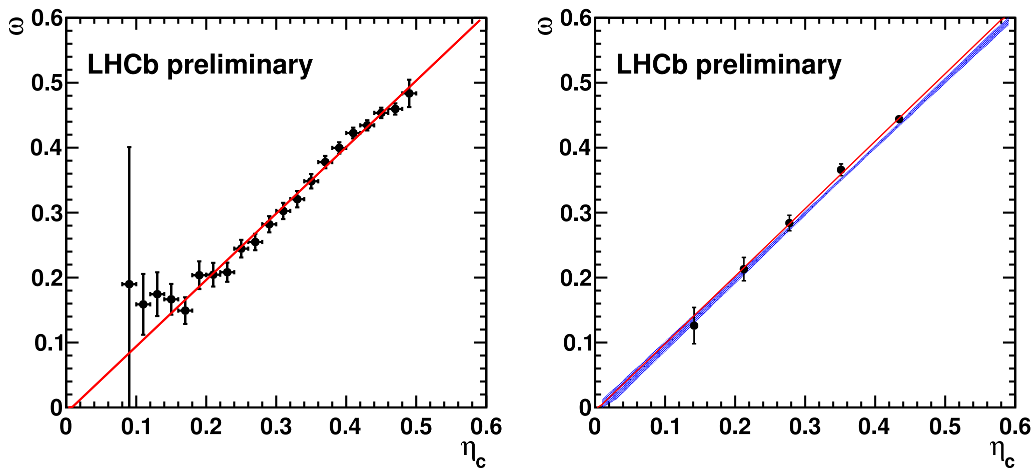

Figure 3: Measured OS mistag as a function of the predicted mistag probability, η_c, for $B^+ \to J/\psi K^+$ (left) and $B^0 \to J/\psi K^{*0}$ (right) with 1 fb^{-1} data sample. The solid red line corresponds to a linear fit. In the right plot the calibration obtained from the $B^+ \to J/\psi K^+$ sample is superimposed as a blue shaded area, corresponding to a $\pm 1\sigma$ variation.

4 Performances

After the optimization and calibration performed with the control channels, Table 1 shows the tagging power using OS taggers and the event-per-event mistags in some control channels with 0.37 fb^{-1} [4] and Table 2 the performance in some CP-channels with 1.0 fb^{-1} 2011 data [8, 9, 10]. Some differences in performance among channels are expected due to different trigger and selection requirements.

The SSπ tagger was already used together with OS taggers in 2010 measurements as Δm_d with $B^0 \to D^-\pi^+$ [12] and $\sin(2\beta)$ with $B^0 \to J/\psi K^0_s$ [13]. The tagging power for SSπ is around 1%.

The performance of SSK was initially optimized using prompt $D_s^+ \to \phi\pi^+$, due to the low event yield of the main control channel $B_s^0 \to D_s^-\pi^+$. The SSK has been used in the Δm_s measurement with $B_s^0 \to D_s^-\pi^+$ [6], where a clear oscillation is seen with only this tagger, as seen in Fig. 4 and obtaining a tagging power of $(1.3 \pm 0.4)\%$. The corresponding ϵ_{eff} is $(4.3 \pm 1.0)\%$ when using both OS and SSK. A new optimization and calibration has been performed with $B_s^0 \to D_s^- \pi^+$ and the whole 2011 data sample, 1 fb^{-1}, to be used for next updates.

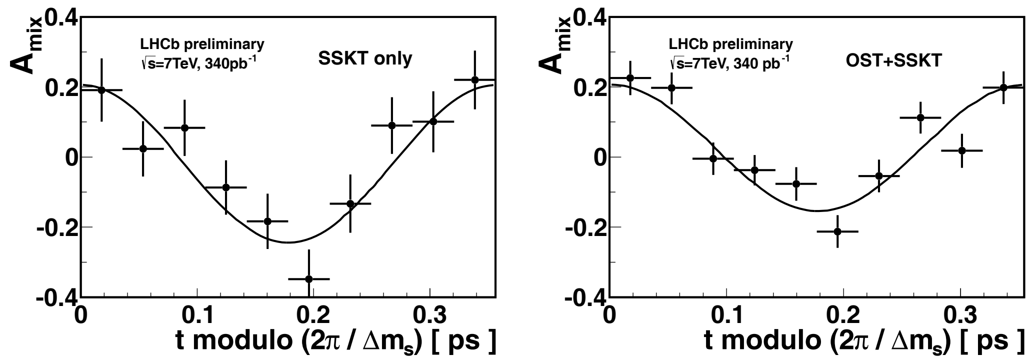

Figure 4: Mixing asymmetry for $B_s^0 \to D_s^- \pi^+$ candidates as a function of decay time, modulo $(\frac{2\pi}{\Delta m_s})$, for a fit using only the SSK tagger (left) and the combination of OS and SS taggers (right).

5 Summary

Flavour tagging is a fundamental ingredient for B physics measurements in LHCb. An optimization and calibration of the OS and SSπ tagging algorithms have been performed with $B^+ \to J/\psi K^+$ data and validated with other control channels. The SSK optimization and calibration with $B_s^0 \to D_s^- \pi^+$ required the whole 1 fb^{-1} and is going to be used in next updated measurements.

OS taggers have been already used in several published LHCb results, with an effective efficiency that goes from 2.1% to 3.5%, depending on the decay. SS taggers have also been used in a few measurements. The SSπ effective efficiency is approximately 1% and the SSK effective efficiency is 1.3% (with a preliminary optimization).

Channel	$\epsilon_{tag}(1-2\omega)^2(\%)$
$B^+ \to J/\psi K^+$	$2.10 \pm 0.08 \pm 0.24$
$B^0 \to J/\psi K^{*0}$	$2.09 \pm 0.09 \pm 0.24$
$B^0 \to D^{*-}\mu^+\mu$	$2.53 \pm 0.10 \pm 0.27$

Table 1: OS effective efficiency for some control channels measured with 0.37 fb^{-1}.

Channel	$\epsilon_{tag}(1-2\omega)^2(\%)$
$B_s^0 \to J/\psi\phi$	$2.29 \pm 0.07 \pm 0.26$
$B_s^0 \to J/\psi f_0(980)$	2.12 ± 0.26
$B_s^0 \to J/\psi\pi\pi$	$2.43 \pm 0.08 \pm 0.26$

Table 2: OS effective efficiency for some CP-channels, used for several measurements of ϕ_s in LHCb with 1 fb^{-1}.

References

[1] A. A. Alves, Jr. *et al.* [LHCb Collaboration], JINST **3** (2008) S08005.

[2] M. Calvi et. al., CERN-LHCb-2007-058.

[3] LHCb Collaboration, LHCb-CONF-2011-003.

[4] R. Aaij *et al.* [LHCb Collaboration], Eur. Phys. J. C **72** (2012) 2022 [arXiv:1202.4979 [hep-ex]].

[5] R. Aaij *et al.* [LHCb Collaboration], Phys. Lett. B **709** (2012) 177 [arXiv:1112.4311 [hep-ex]].

[6] LHCb Collaboration, LHCb-CONF-2011-050.

[7] R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **108** (2012) 101803 [arXiv:1112.3183 [hep-ex]].

[8] R. Aaij *et al.* [LHCb Collaboration], Phys. Lett. B **707** (2012) 497 [arXiv:1112.3056 [hep-ex]].

[9] R. Aaij *et al.* [LHCb Collaboration], LHCb-PAPER-2012-006 [arXiv:1204.5675v2 [hep-ex]].

[10] LHCb Collaboration, LHCb-CONF-2012-002.

[11] LHCb Collaboration, LHCb-CONF-2012-007.

[12] LHCb Collaboration, LHCb-CONF-2011-010.

[13] LHCb Collaboration, LHCb-CONF-2011-004.