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Optimization and calibration of the flavour tagging algorithms in the LHCb experiment

A. Falabella
Università di Ferrara - Ferrara and INFN, Sezione di Bologna - Bologna, Italy

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Summary. — In what follows the calibration and performances of the flavour tagging algorithms using the decays $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^{*0}$ and $B_s^0 \to D_s^- \pi^+$ are reported. The data sample used correspond to $1.0\,\mathrm{fb}^{-1}$ of data collected by the LHCb experiment during 2011 ($\sqrt{s} = 7\,\mathrm{TeV}$). The measured effective tagging efficiency is found to be $2.35 \pm 0.06\%$ for the opposite side tagging algorithms combination, while it is $1.5 \pm 0.4\%$ for same side kaon tagging algorithm.

PACS 13.85.Ni – Inclusive production with identified hadrons.
PACS 12.15.-y – Electroweak interactions.
PACS 14.40.Nd – Bottom mesons ($|B| > 0$).

1. – Flavour Tagging

One of the main goals of the LHCb experiment is to perform precise measurement of B meson decays, for instance studying CP violation and very rare decays. For these purposes the LHCb spectrometer is designed to provide a very selective and efficient trigger, excellent track and vertex resolutions, good mass resolution and excellent identification of particles (pions, protons, kaons, muons and electrons) in a wide range of momenta. For CP violation and time dependent asymmetry measurements it is necessary to know whether the reconstructed B meson initially contain a b or a $\bar{b}$ quark (*flavour tagging*). In LHCb several flavour tagging algorithms are used: same side (SS) and opposite side (OS) algorithms. The same side algorithms infer the flavour of the B using particles from the fragmentation of the b quark that produce the signal B. In LHCb proton-proton collisions produce $b/\bar{b}$ pairs, that hadronize independently giving the signal B meson and an opposite B. The decay products of this second B can be used to assert the flavour of the signal B. OS algorithms use leptons from semileptonic B decays(μ/e), a kaon from the $b \to c \to s$ chain and Q_{vtx} (weighted mean of track charges of the secondary inclusive vertex) of the opposite side B meson decay.

Each algorithm provide a tagging decision ($d = +1/1$) for the B containing a $\bar{b}$ or a b quark based on the charge of the tagging particle [1].

The tagging decision can be wrong if the particle selected to tag is not correct. Moreover OS algorithms decision can be wrong due to the oscillation if the opposite B is neutral. The sensitivity to a CP asymmetry is directly related to the effective tagging efficiency $\epsilon_{eff} = \epsilon_{tag}(1-2\omega)^2$ which depends on the mistag fraction ω, which is the fraction of tagged events with a wrong decision, and the tagging efficiency ϵ_{tag} which is the fraction of tagged events. The tagging algorithms have been developed using simulated events (MC). Their performance have been optimised on real data with the purpose of maximising ϵ_{eff}.

Each algorithm provides also an estimate of the per-event mistag probability (η) based on the output of a neural network that is trained on simulated events to identify the correct flavour of the signal B. The neural network uses as input geometrical and kinematic variables of the tagger particle and of the event as input. Due to differences between data and simulated events the neural network output must be calibrated in data in order to represent a correct mistag probability. The calibrated mistag estimation (η_c) can be used as a per-event mistag probability. The use of the per-event value is found to improve the effective tagging efficiency with respect to the mean value. Moreover the per-event value can be used in CP measurements to weigh each event.

The mistag ω can be measured on data using flavour-specific control channels, where the signal b-quark content is uniquely defined by its final state. The control channel used are $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^{*0}$ and $B_s^0 \to D_s^- \pi^+$.

For charged channels the mistag can be measured comparing the charge of the signal B with the tag decision. The mistag ω can then be measured from the number of rightly and wrongly tagged events. For neutral control channels the mistag is determined from a fit to the time-dependent mixing asymmetry.

2. – Optimization and calibration

The tagging performances were optimized using $1.0\,\mathrm{fb}^{-1}$ of data collected by LHCb during 2011 data taking. The aim of the optimization is to tune the cuts used to select the tagging particles in order to maximize the effective tagging efficiency.

The opposite side algorithms have been optimized using the decay channel $B^+ \to J/\psi K^+$. The optimization of the same side kaon algorithm is performed studying the $B_s^0 \to D_s^- \pi^+$ decay.

The effective tagging efficiency for the opposite side algorithms combination and same side kaon is found to be respectively $2.35 \pm 0.06\%$ and $1.5 \pm 0.4\%$.

The tagging optimization requires the calibration of the mistag probability (η) to the measured mistag fraction (ω). In fact, when more than one tagging decision is available, these are combined according to η to provide a single combined decision and probability. Due to possible correlations among taggers, the combined mistag probability η has to be calibrated on data to match the measured mistag fraction.

The calibration model used is $\omega(\eta) = p_0 + p_1(\eta - \langle\eta\rangle)$, where p_0 and p_1 are free parameters and $\langle\eta\rangle$ is the average mistag probability. Deviations from $p_0 = \langle\eta\rangle$ and $p_1 = 1$ indicate that η must be corrected. The calibration is performed for each tagger and than for the combination.

The $B^0 \to J/\psi K^{*0}$ is used to cross-check the validity of the calibration. In table I the calibration results for $B^+ \to J/\psi K^+$ and $B_s^0 \to D_s^- \pi^+$ decay channels are reported. The errors are statistical and systematic.

The results show that for both channels the mistag is correctly calibrated within errors. The systematic uncertainty in the calibration parameters has been computed

TABLE I. – *Calibration results for $B^+ \to J/\psi K^+$ and $B_s^0 \to D_s^- \pi^+$ channels. Statistical and systematic errors are reported.*

Algorithm	Channel	p_0	p_1	η_c
OS [2]	$B^+ \to J/\psi K^+$	$0.392 \pm 0.002 \pm 0.009$	$1.035 \pm 0.021 \pm 0.012$	0.391
SS [3]	$B_s^0 \to D_s^- \pi^+$	$0.349 \pm 0.015 \pm 0.012$	$1.00 \pm 0.30 \pm 0.02$	0.350

taking into account of the possible differences of the parameters related to the data taking conditions (run period, magnet polarity), to the initial flavour of the B signal and to the control channel.

3. – Conclusions

The optimized and calibrated performances of flavour tagging algorithms with $1\,\mathrm{fb}^{-1}$ of data collected in 2011 have been reported. For the OS algorithms the $B^+ \to J/\psi K^+$ decay channel has been used. In this channel the effective tagging efficiency is $2.35 \pm 0.06\%$. The SS kaon algorithm has been optimized and calibrated on the $B_s^0 \to D_s^- \pi^+$ channel and the effective tagging efficiency is $1.5 \pm 0.4\%$.

Tagging algorithms have been used in several LHCb published results such as the measurement of the CP-violating phase ϕ_s in $B_s^0 \to J/\psi K^+ K^-$ and $B_s^0 \to J/\psi \pi^+ \pi^-$ decays [4] where the effective tagging efficiency using OS and SS kaon algorithms is $(3.13 \pm 0.12 \pm 0.20)\%$. For the measurement of $B_s^0 - \bar{B}_s^0$ oscillation frequency Δm_s [5] the OS and SS kaon algorithms have been used and the effective tagging efficiency is $(3.5 \pm 0.5)\%$. The measurement of time dependent CP-violation in $B_s^0 \to D_s^{\mp} K^{\pm}$ [6] used OS algorithms and the effective tagging efficiency is 1.9%. Flavour tagging algorithms have been used also in charmless two-body B decays studies [7] where the effective tagging efficiency with OS algorithms is $2.3 \pm 0.1\%$.

REFERENCES

[1] CALVI M. *et al.* (LHCb COLLABORATION), *Flavour Tagging Algorithms and Performances in LHCb*, [CERN-LHCB-2007-058].
[2] LHCb COLLABORATION, *Opposite-side flavour tagging of B mesons at the LHCb Performance of flavour tagging algorithms optimised for the analysis of $B_s^0 \to J/\psi\phi$*, [LHCB-CONF-2012-026].
[3] LHCb COLLABORATION, *Optimization and calibration of the same-side kaon tagging algorithm using B_s hadronic decays in 2011 data*, [LHCB-CONF-2012-033].
[4] LHCb COLLABORATION, *Measurement of CP -violation and the B_s^0 decay width difference with $B_s^0 \to J/\psi K^+ K^-$ and $B_s^0 \to J/\psi \pi^+ \pi^-$ decays*, [LHCB-PAPER-2013-002].
[5] LHCb COLLABORATION, *Measurement of the $B_s^0 - \hat{B}_s^0$ oscillation frequency Δm_s in $B_s^0 \to D_s^- \pi^+$*, [LHCB-PAPER-2013-006-001].
[6] LHCb COLLABORATION, *Measurement of time-dependent CP-violation observables in $B_s^0 \to D_s^{\mp} K^{\pm}$*, [LHCB-CONF-2012-029].
[7] LHCb COLLABORATION, *Measurement of time-dependent CP violation in charmless two-body B decays*, [LHCB-CONF-2012-007].