Flavour Tagging of $B$ mesons in $pp$ collisions at LHCb
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**Basics**

Measurements of flavour oscillations and time-dependent CP asymmetries in neutral $B$ mesons require knowledge of the $b$ quark production flavour. This identification is performed by the Flavour Tagging. It is split into two independent classes of algorithms [1,2].

**Same side taggers (SS)**

use charged particles created in the fragmentation process of the $b$ quark of the signal $B$ meson
- kaon for $B^0$
- SS kaon
- pion for $B^0$
- SS pion
- proton for $B^0$
- SS proton

**Characteristics**

Each tagging algorithm provides a decision $(tag)$ on the initial flavour and a probability of the decision to be wrong (estimated mistag $\eta$).

- **tagging efficiency** fraction of events with a tagging decision $\epsilon_{tag} = \frac{N_{tagged}}{N_{tagged} + N_{misp}}$
- **mistag** fraction of events with a wrong tagging decision $\omega = \frac{N_{misp}}{N_{tagged} + N_{misp}}$
- **effective tagging efficiency** represents the statistical reduction factor of a sample in a tagged analysis (also called tagging power) $\epsilon_{eff} = \epsilon_{tag}(1 - 2\omega)^2$

**Calibration**

The calibrated event-by-event mistag $\omega(\eta)$ is parameterised as a linear function $\omega(\eta) = \rho_1 + \rho_2 \eta$ of the event-by-event estimated mistag $\eta$, where $\rho_1$ and $\rho_2$ are the average estimated mistag of the sample and $\rho_1$ and $\rho_2$ are calibration parameters. Several flavour-specific decay channels are used.
- charged channels: $B^0 \rightarrow J/\psi K^*, B^+ \rightarrow D^+\pi^+$
- extract $\omega$ by comparing the tag decision with the charge of the final state particle
- neutral channels: $B^0 \rightarrow J/\psi K_S, B^0 \rightarrow D^+\pi^-$

Full time-dependent analysis to extract $\omega$ from the mixing asymmetry $\Delta m_D = (1 - 2\epsilon) \cos(\Delta m_D/\tau)$

**Inside Flavour Tagging**

Selections ($S1$-$S3$) define the tagging efficiency and overlap between the different taggers.
- **S1**: per event, loose selection of tagging particles, reduce combinatorics
- **S2**: per $B$ candidate and associated PV, select suitable tagging particles (cut-based or multivariate analysis (MVA))
- **S3**: tagger specific, choose final tagging particle MVA is used to assign the final tag and mistag based on one best or multiple candidates.

**Flavour Tagging in Run I**

**Usage in analyses**

One overall calibration per tagger valid for all channels is provided by the Flavour Tagging group. Therefore systematics due to the calibration methods, i.e. the choice of the calibration model, and from differences between control and signal channels.
- general calibration is not always optimal for high statistic channels, ad-hoc calibration, when necessary

**Highlights of flavour-tagged analyses in Run I**

Measurements of $\beta_{c}$:
- $B^0 \rightarrow J/\psi K^*$, $\beta_{c} = 3.7 \%$ [4]
- $B^0 \rightarrow J/\psi K^*$, $\beta_{c} = 3.9 \%$ [5]
- $B^0 \rightarrow D^0\pi^*$, $\beta_{c} = 5.3 \%$ [6]
- $B^0 \rightarrow J/\psi K^*$, $\beta_{c} = 3.9 \%$ [7]

The latest analyses profited from
- including improved SS kaon
- re-optimisation of OS algorithms

Measurements of $\sin(2\phi)$ in $B^0 \rightarrow J/\psi K^*$:
- analysis on 2011 data: $\epsilon_{eff} = 2.4 \%$ [9]
- full Run I analysis: $\epsilon_{eff} = 3.0 \%$ [10]

Measurement of $CP$ violation in $B^0 \rightarrow J/\psi K^*$:
- not possible to exclude $B^0$ events in selection
- $B^0$ events: $\epsilon_{eff} = 4.0 \%$ [11]
- $B^0$ events: $\epsilon_{eff} = 2.6 \%$ [11]

Measurement of $CP$ violation in $B^0 \rightarrow D^+K^-$:
- analysis on 2011 data: $\epsilon_{eff} = 5.1 \%$
- SS kaon adds more than 1.3% to $\epsilon_{eff}$ [12]

**Analysis with new Flavour Tagging algorithms**

OS charm, SS pion and SS proton
- **OS charm** [13]:
  - reconstruct $D^+ D^- D^0$ decays related to the opposite side $b$ hadron
  - clean measurement of $B$ meson flavour (small mistag probability)
  - stand-alone tagging power of $\epsilon_{eff} = 0.3$ to 0.4% typically combined tagging power of the $OS$ combination (w/o OS charm) is around 2.5% (SS charm)
  - SS pion and SS proton
  - $B^0 \rightarrow D^+ D^-$ is used for development and calibration
  - combining both taggers with the OS tagging algorithms increases the total tagging power by 50.0% (OS charm)

Measurement of $CP$ violation in $B^0 \rightarrow D^+D^-$ [14]:
- analysis on full Run I dataset
- first analysis to use OS charm in the OS combination and SS proton as well as improved SS pion
- $\epsilon_{eff} = 87.6 \%$, $\epsilon_{eff} = 8.1 \%$

**References**


**Opposite side taggers (OS)**

- exploit the non-signal $b$ quark of the initial $B$ pair
- overall charge of the secondary vertex (SV)
- OS vertex change
- lepton from semi-leptonic $b$ hadron decay
- OS muon, OS electron
- kaon from the $b \rightarrow c \rightarrow s$ decay chain
- OS kaon
- $D$ meson from the $b \rightarrow c$ decay chain
- OS charm