b-flavour tagging in pp collisions

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Basics
Introduction
Measurements of flavour oscillations and time-dependent CP asymmetries in neutral B meson systems require knowledge of the b quark flavour at production. This identification is performed by the Flavour Tagging (FT) [1,2].

Two independent classes of algorithms

- same side taggers (SS)
  - use charged particles created in the fragmentation process of the b quark of the signal B meson
    - kaon for \( B_s^0 \) \rightarrow SS kaon / SS kaon net
    - pion for \( B^0 \) \rightarrow SS pion
    - proton for \( B^0 \) \rightarrow SS proton

- opposite side taggers (OS)
  - exploit the non-signal b quark of the initial \( b\bar{b} \) pair
    - overall charge of the secondary vertex (SV)
    - lepton from semi-leptonic b hadron decays
    - OS muon / OS electron
    - kaon from the \( b \rightarrow c \rightarrow d \) decay chain
    - OS (3) D meson from the \( b \rightarrow c \rightarrow d \) decay chain
    - OS charm (New!)

Each tagger provides a decision \( d \) on the initial flavour (“tag”) and a probability to be wrong, \( \eta \).

Flavour Tagging characteristics

- mistag fraction of events with a wrong tagging decision
  \[ \omega = \frac{N_{\text{mistag}}}{N_{\text{signal}} + N_{\text{mistag}}} \]

- tagging efficiency
  fraction of events with a tagging decision
  \[ \epsilon_{\text{tag}} = \epsilon = \frac{N_{\text{tag}}}{N_{\text{signal}}} \]

- effective tagging efficiency
  represents the statistical reduction factor of a sample in a tagged analysis
  \[ \epsilon_{\text{eff}} = \epsilon_{\text{tag}} (1 - 2 \omega)^2 \]

Flavour Tagging in Run I

Usage in analyses

- one calibration per tagger valid for all channels
- systematic uncertainties from
  - calibration methods
  - results in different control channels
- "ad-hoc" calibration using best-suited control channels for analyses dominated by FT uncertainty

Highlights of flavour-tagged measurements

- Measurements of \( \phi_5 \)
  - \( B_s^0 \rightarrow J/\psi K^0_s \) \( 18.88 \pm 0.32 \) \% [13]
  - \( B^0 \rightarrow \tau^+ \tau^- \) \( 0.54 \pm 0.54 \) % [8]
  - \( \epsilon_{\text{eff}} \) on 2011 data: \( \epsilon_{\text{eff}} = 5.07 \% \)
  - SS kaon net adds more than 1.3 % to \( \epsilon_{\text{eff}} \) [8]

CP violation in \( B_s^0 \rightarrow J/\psi K^0_s \) (sin \( 2\phi_5 \))

- analysis on 2011 data: \( \epsilon_{\text{eff}} = 2.38 \% \) [9]
- full Run I analysis: \( \epsilon_{\text{eff}} = 3.02 \% \) [10]

- SS pion tagger adds more than 0.376 % to \( \epsilon_{\text{eff}} \)

- precision analysis → "ad-hoc" FT calibration
  - OS algorithms calibrated with \( B^0 \rightarrow J/\psi K^0_s \)
  - SS pion calibrated with \( B^0 \rightarrow J/\psi K^0_s \)

- not possible to exclude \( B^0 \) events in selection

Developments

OS charm tagger (preliminary)

- reconstruct \( D^+D^0\bar{D}^0\bar{D}^0 \) decays related to OS b decay

  \[
  \begin{array}{c|c|c}
  \text{Decay mode} & \text{Relative } \epsilon_{\text{tag}} & \text{Relative } \epsilon_{\text{eff}} \\
  \hline
  D^+ \rightarrow K^+ \pi^+ & 1.00 & 24.0 \% \\
  D^0 \rightarrow K^- \pi^+ \pi^- & 5.9 \% & 8.4 \% \\
  D^0 \rightarrow K^- \pi^+ \pi^- X & 10.3 \% & 2.6 \% \\
  D^0 \rightarrow K^- \pi^+ \pi^- X & 69.7 \% & 0.5 \% \\
  D^0 \rightarrow K^- \pi^+ \pi^- X & 0.5 \% & 0.2 \% \\
  D^0 \rightarrow K^- \pi^+ X & 3.4 \% & 0.3 \% \\
  D^0 \rightarrow K^- X & 0.7 \% & 2.4 \% \\
  \end{array}
  \]

- one boosted decision tree (BDT) for each mode [12]
- clean measure of B meson flavour (low mistag)
- stand-alone tagging power of \( \epsilon_{\text{eff}} = 0.30 \% \) to 0.40 %

SS pion calibration

- calibration performed with \( B^0 \rightarrow J/\psi K^+ \),
- full evaluation of systematic uncertainties
- used for the first time in the measurements of
  \[ \sin(2\phi_5) \] with \( B^0 \rightarrow J/\psi K^+ \),
  \[ \epsilon_{\text{eff}} = 0.38 \% \]
  \[ \sin(2\phi_5) \] with \( B^0 \rightarrow J/\psi \pi^+ \pi^- \),
  \[ \epsilon_{\text{eff}} = 0.54 \% \]

SS kaon tagging using neural nets (NN)

- basic idea: use two NN
  - first NN distinguishes between: 1. fragmentation tracks; 2. underlying event tracks
  - assigns final tag and mistag based on multiple candidates [13]
  - second NN: SS kaon net adds more than 1.3 % to \( \epsilon_{\text{eff}} \)

Calibration

Mistag calibration

\[ \omega(\eta) = p_0 + p_1 (\eta - \eta_0) \]

Several flavour-specific decay channels are used

- \( B^+ \rightarrow J/\psi K^+ \), \( B^+ \rightarrow D^0 \pi^+ \)
- charged channels: extract \( \omega \) by comparing tag decision with charge of the final state
- \( B^+ \rightarrow J/\psi K^+ \), \( B^+ \rightarrow D^0 \pi^+ \), \( B^+ \rightarrow D^0 \pi^+ \), \( B^+ \rightarrow D^+ \pi^+ \), \( B^+ \rightarrow \pi^+ \pi^- \)
- neutral channels: full-time dependent analysis to extract \( \omega \) from the mixing asymmetry
  \[ \Delta A_{\text{mix}}(t) \propto (1 - 2\omega) \cos(\Delta m_{\text{mix}} t) \]

References