Introduction to Flavour Tagging

Flavour Oscillation

Decay-time-dependent measurements of the oscillation of neutral B mesons allow us to determine the Standard Model CP violation parameters — and possible deviations from it. These measurements require the knowledge of the initial B flavour which is provided by different Flavour Tagging algorithms.

Flavour Tagging characteristics

There are three major quantities characterising Flavour Tagging algorithms:

- **Tagging efficiency**
  - fraction of events with tagging decision:
  \[ \varepsilon_{\text{tag}} = \frac{N_{\text{tag}}}{N_{\text{tag}} + N_{\text{wrong}}} \]

- **Mistag probability**
  - fraction of events with wrong tagging decision:
  \[ \omega = \frac{N_{\text{wrong}}}{N_{\text{tag}} + N_{\text{wrong}}} \]

  Effective tagging efficiency
  
  a measure for the statistical power of a flavour tagged sample:
  \[ \varepsilon_{\text{eff}} = \varepsilon_{\text{tag}} \cdot (1 - 2\omega)^2 \]

  The uncertainty on measured mixing amplitudes \( \sigma_{\alpha} \) scales with an effective sample size.

Flavour Tagging at the LHCb experiment

LHC Run 3 challenges

Higher luminosities at LHCb

In LHC Run 3 the design luminosity at the LHCb experiment will be increased by a factor of five:

- correct selection of particles correlated to the signal B are crucial for Flavour Tagging
- Flavour Tagging performance depends on track multiplicity
- OS tagger performance depends on pile-up
- Run 2 strategy requires modification to cope with the more challenging environment

Development of an inclusive flavour tagger

Concept

The inclusive flavour tagging is a new approach at LHCb which uses the latest developments in machine learning and neural networks. It could replace the current ensemble of taggers and increase the performance.

- use (almost) all non-signal tracks in event
- use recurrent neural network to adapt to variable number of tracks
- use recurrent layer to combine evaluation of all available tracks
- only loose sanity cuts applied to tracks
- tagging efficiency close to 100%

First implementation

Neural network trained on simulated \( B^+ \to J/\psi K^+ \) events.

- shows good \( B^+ - B^- \) separation

Plans

- Currently the implementation is work in progress and there are many tasks and ideas in the pipeline.

- validation and calibration on data and different decay channels
- fine tuning of network architecture
- use within Run 3 software trigger
- investigation of two-network design with additional track type classification
  - tracks from common side fragmentation
  - tracks from opposite side fragmentation
  - opposite side decay products
  - underlying tracks

- used to understand behaviour
- first standalone implementation integrated in LHCb software stack

Current Flavour Tagging at LHCb

Flavour Tagging algorithms

At LHCb several Flavour Tagging algorithms are used. These taggers can be divided by their strategy into two classes:

- **Same side (SS) tagger**
  - identify charged particles created in the fragmentation process of the signal B meson
    - kaon for \( B_d^0 \) (5S kaon)
    - pion for \( B_s^0 \) (5S pion)
    - proton for \( B_s^0 \) (5S proton)

- **Opposite side (OS) tagger**
  - exploit (quasi-) flavour-specific decay chain of non initial B quark from initial \( B \) pair
    - charge of secondary vertex (OS vertex charge)
    - leptons from semi-leptonic B decay (OS muon / OS electron)
    - \( \Lambda_c \), baryon or D meson from B decay (OS charm)
    - kaon from from \( B \to s \to c \) decay chain (OS kaon)

Performance

Every tagger has its own characteristics. Multiple algorithms are combined into single tag decisions and mistag predictions.

Generally, a trade-off between high tag quality and high efficiency has to be made. Different experiments use different strategies to estimate the initial flavour.

References

[1] LHCb Collaboration, R. Aaij et al., Precision measurement of the B → D:\( \pi, K \) oscillation frequency with the decay \( B \) to \( D, \psi \), LHCb-PAPER-2013-006
[2] LHCb Collaboration, R. Aaij et al., Comparison of Flavour Tagging performances displayed in the \( \omega - \varepsilon_{\text{tag}} \)-plane, LHCb-Figure 2020-002