Flavour Tagging at the LHCb experiment

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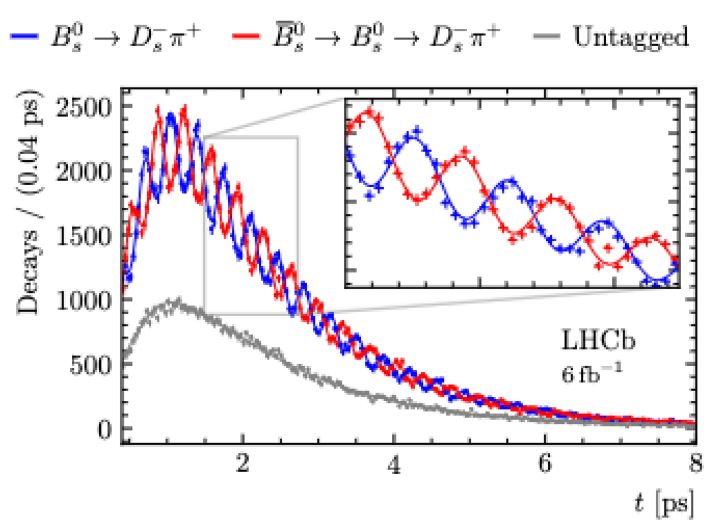
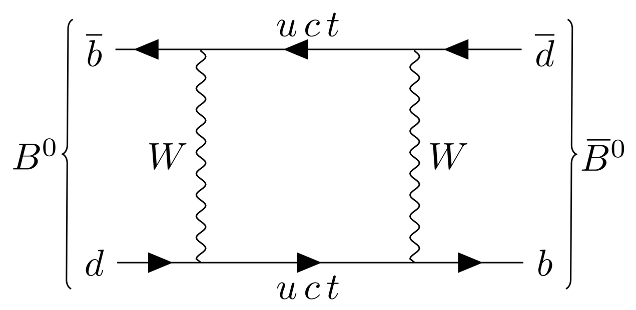
Introduction to Flavour Tagging

Flavour Oscillation

- The LHCb experiment has a diverse B physics program, including the measurement of time-dependent CP violation which is particularly challenging in the presence of $B-\bar{B}$ oscillations.
- By oscillating, the B meson flavour at production time might differ from the flavour at its decay time.

Flavour Tagging algorithms allow to access the initial B flavour.





[1]

Flavour Tagging characteristics

- **Tagging efficiency**

  Fraction of events with tagging decision:

$$\varepsilon_{\text{tag}} = \frac{N_{\text{right}} + N_{\text{wrong}}}{N_{\text{right}} + N_{\text{wrong}} + N_{\text{untagged}}}$$

- **Mistag probability**

  Fraction of events with wrong tagging decision:

$$\omega = \frac{N_{\text{wrong}}}{N_{\text{right}} + N_{\text{wrong}}}$$

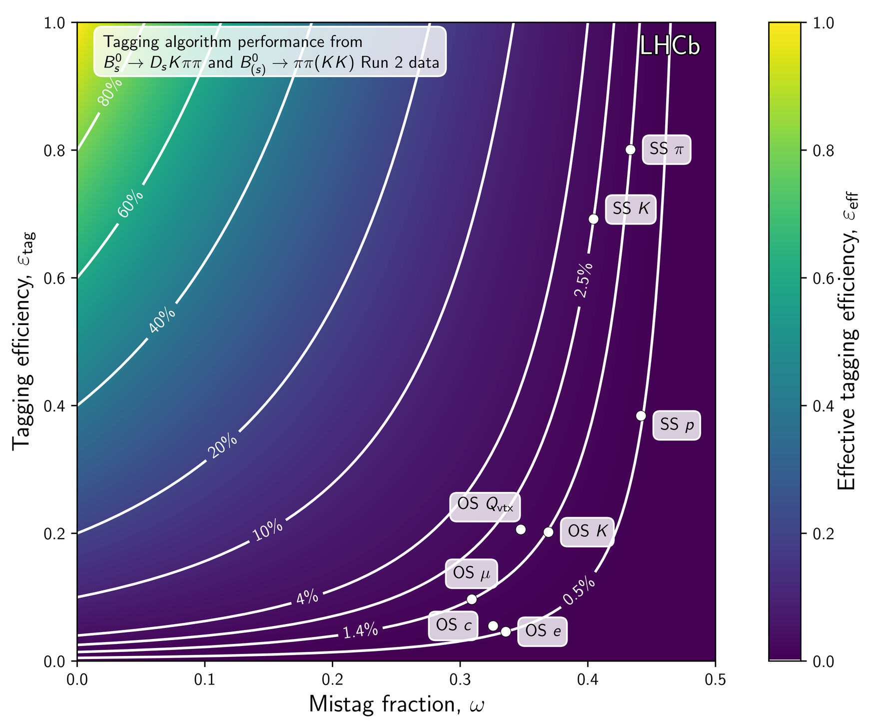
- **Effective tagging efficiency (tagging power)**

  A measure for the statistical power of a flavour tagged sample:

$$\varepsilon_{\text{eff}} = \varepsilon_{\text{tag}} D^2 = \varepsilon_{\text{tag}}(1-2\omega)^2$$

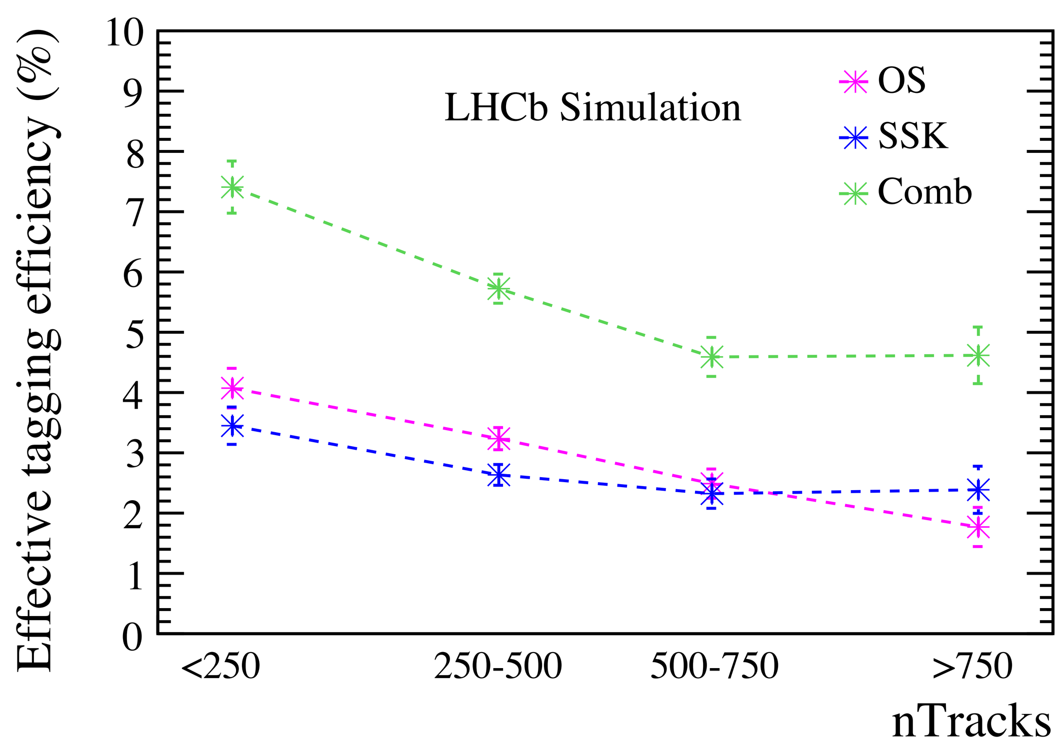
A trade-off between high tagging quality and high efficiency has to be made [2]

The uncertainty on measured mixing amplitudes scales with $\sigma_A \sim \frac{1}{\sqrt{N\varepsilon_{\text{eff}}}}$.



Higher luminosity at LHCb

In LHC Run 3 the luminosity at the LHCb experiment is increased by a factor of five with respect to Run 2, implying more pile-up vertices and a higher track multiplicity which affect Flavour Tagging performance [3]



References

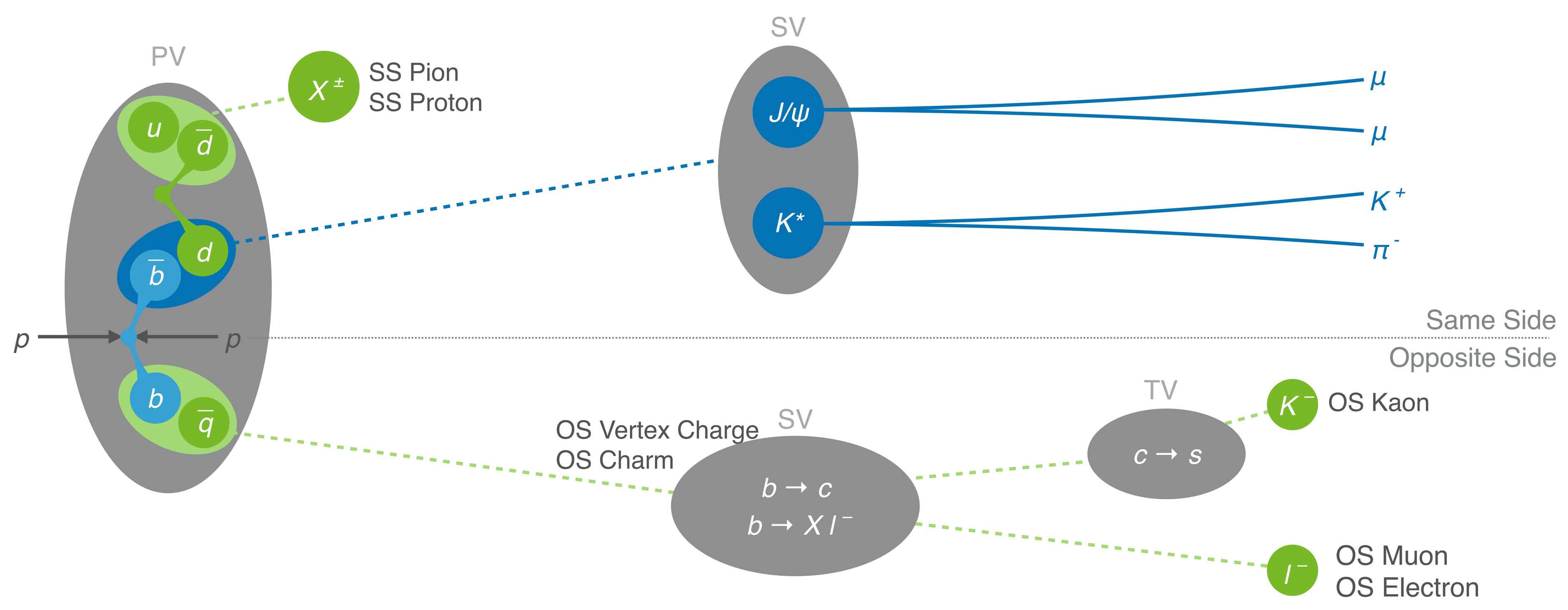
[1] LHCb Collaboration, R. Aaij et. al., *Precise determination of the B_s^0–$\overline{B}_s^0$ oscillation frequency*, LHCb-PAPER-2021-005

[2] LHCb Collaboration, R. Aaij et. al., *Comparison of Flavour Tagging performances displayed in the ω-ε_{tag}-plane*, LHCB-FIGURE-2020-002

[3] LHCb Collaboration, R. Aaij et. al., *Physics case for an LHCb Upgrade II - Opportunities in flavour physics, and beyond, in the HL-LHC era*, LHCB-PUB-2018-009

Flavour Tagging algorithms

Flavour Tagging algorithms exploit the **correlation** between the B **meson flavour at production time** and the **charge of specific particles** to **provide** a **tagging decision** (***d***).



- **Same side taggers (SS)**

  - use charged kaon, pion, proton created in the hadronization process of the signal B meson (SSKaon, SSPion, SSProton)

- **Opposite side taggers (OS)**

  - exploit the decay chain of non-signal b hadron originated by the b quark from the initial $b\bar{b}$ pair

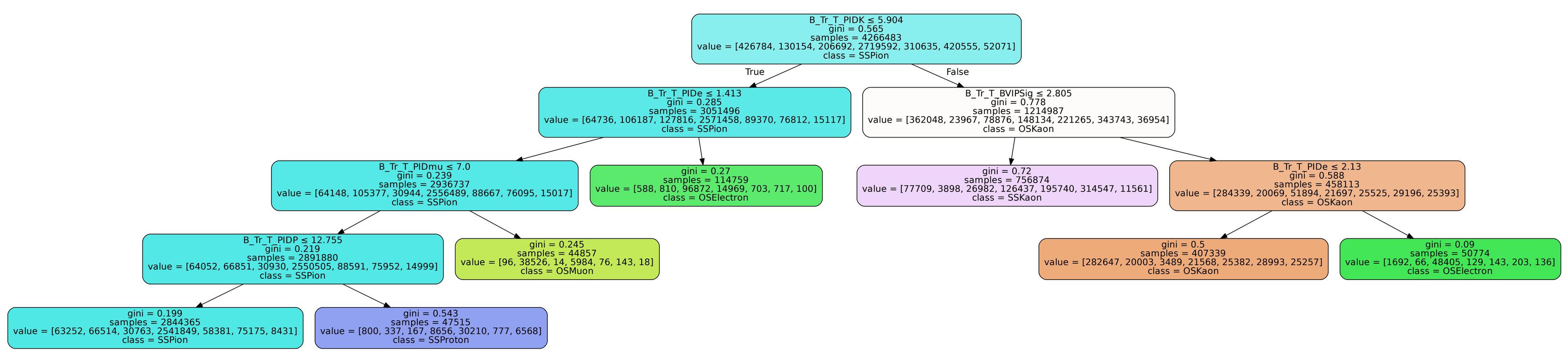
$$d_{predicted} = x * Q_{charge}$$

where $x = \pm 1$ depends on the particle type (OS/SS) and the decay used.

Development of Run 3 taggers

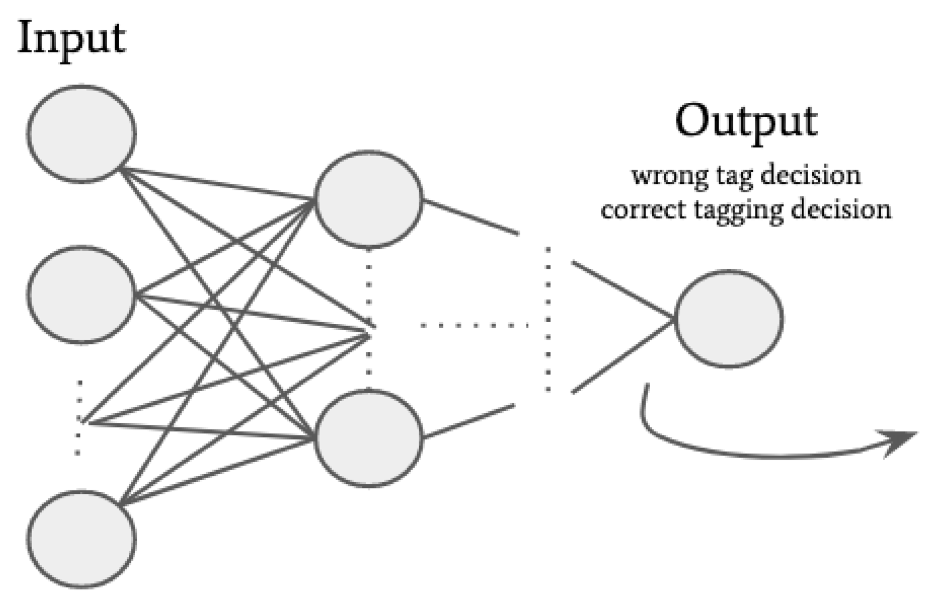
Strategy

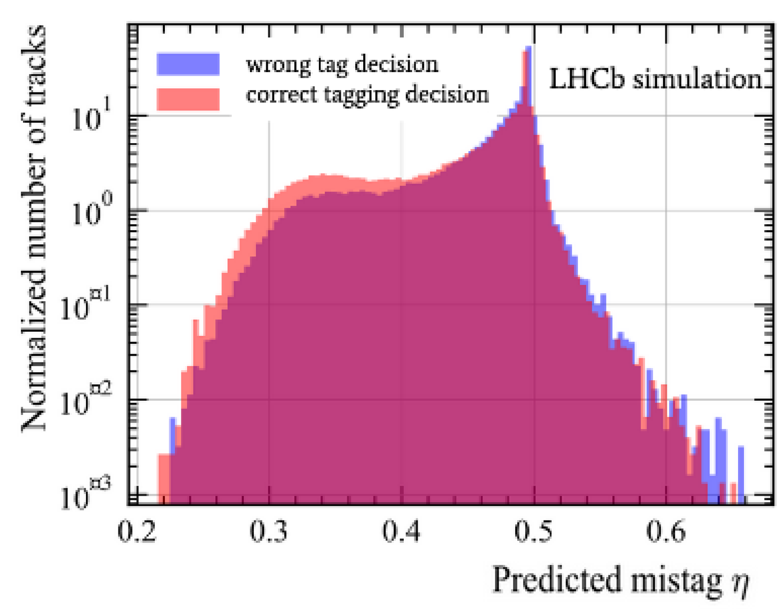
- **Pre-selections**: train a Decision Tree to distinguish the different tagging particles as exclusive classes (OSKaon, OSElectron, OSMuon, SSPion, SSProton, SSKaon).



- **Training**: Neural Network to predict the mistag probability η associated to a certain tagging decision. Labels are assigned by comparing the $d_{predicted}$ and the true B flavour (extracted from the Monte Carlo simulation).

  label = 0 $\rightarrow$wrong tagging decision   label = 1 $\rightarrow$correct tagging decision





- **Calibration**: to get **tagging efficiency, mistag probability, tagging power**.

  - If there are multiple tracks assigned to the same process in a single event, the tagging decision with the lowest mistag is taken.
  - To get a per event mistag probability, the predicted mistag η is calibrated on data with a linear calibration function of type:

$$\omega(\eta) = p_0 + p_1(\eta - \langle\eta\rangle)$$

  - The calibration recovers any harmful effects from overfitting (and underfitting) before the performance is evaluated.