b-flavour tagging in pp collisions

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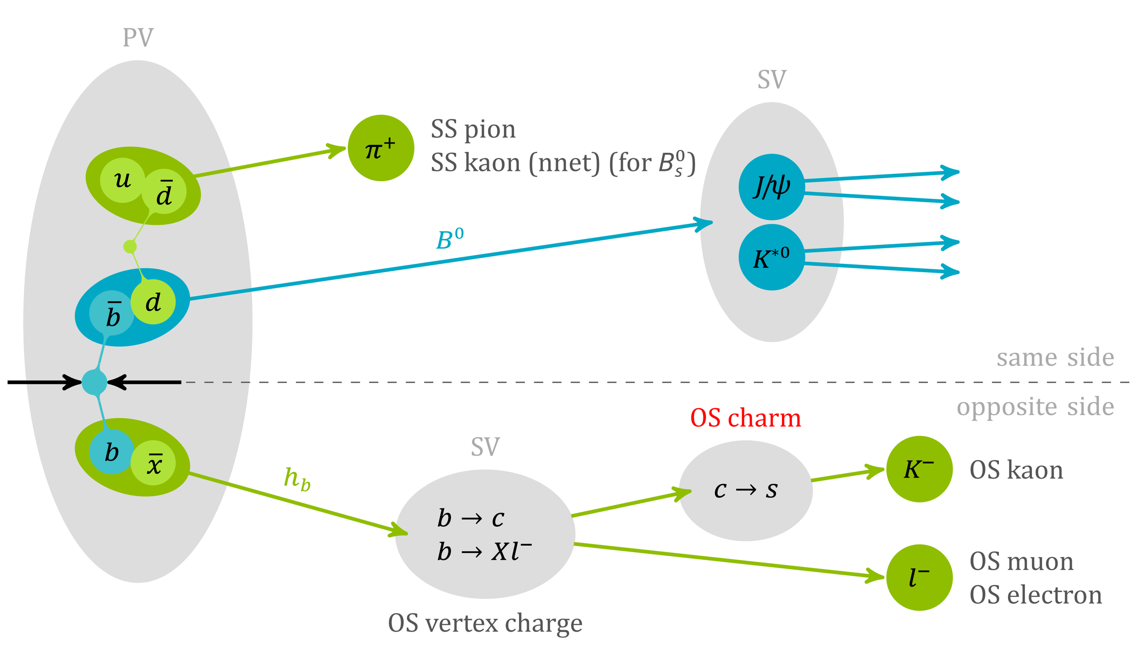
Basics

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 → SS kaon / SS kaon nnet
  - pion for B^0 → SS pion
  - proton for B^0 → 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) → OS vertex charge
  - lepton from semi-leptonic b hadron decays → OS muon / OS electron
  - kaon from the $b \to c \to s$ decay chain → OS kaon
  - D meson from the $b \to c$ decay chain → OS charm (New!)



Each tagger provides a decision d on the initial flavour ("tag") and a probability to be wrong, η.

Flavour Tagging characteristics

- **mistag**
  fraction of events with a wrong tagging decision
  $$\omega = \frac{N_\text{wrong}}{N_\text{right} + N_\text{wrong}}$$
- **tagging efficiency**
  fraction of events with a tagging decision
  $$\varepsilon_\text{tag} = \frac{N_\text{right} + N_\text{wrong}}{N_\text{all}}$$
- **effective tagging efficiency**
  represents the statistical reduction factor of a sample in a tagged analysis
  $$\varepsilon_\text{eff} = \varepsilon_\text{tag}\,(1 - 2\omega)^2$$

Calibration

Mistag calibration

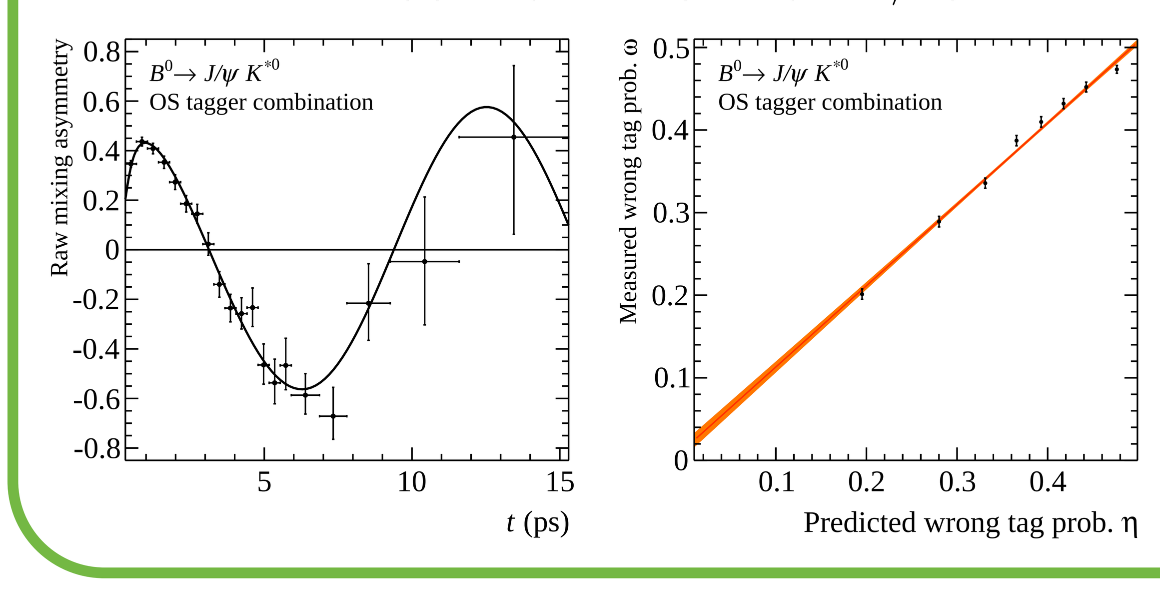
$$\omega(\eta) = p_0 + p_1\,(\eta - \langle\eta\rangle)$$

calibrated ev-by-ev mistag; estimated ev-by-ev mistag; mean estimated mistag

Several flavour-specific decay channels are used

- $B^+ \to J/\psi\, K^+$, $B^+ \to D^0\pi^+$
  charged channels: extract ω by comparing tag decision with charge of the final state
- $B^0 \to J/\psi\, K^{*0}$, $B^0 \to D^{*-}\mu^+\nu_\mu$, $B_s^0 \to D_s^-\pi^+$, ...
  neutral channels: full time-dependent analysis to extract ω from the mixing asymmetry

$$\mathcal{A}_\text{mix}(t) \propto (1 - 2\omega)\cos(\Delta m_{d/s}\, t)$$



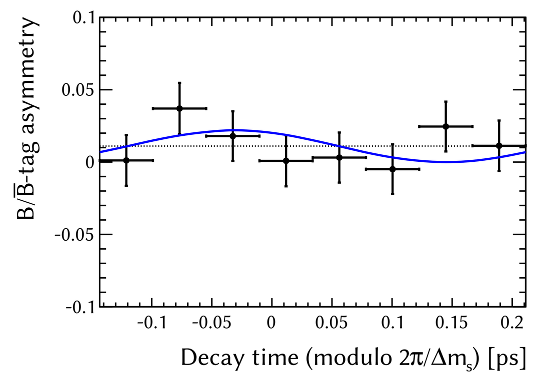
Flavour Tagging in Run I

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

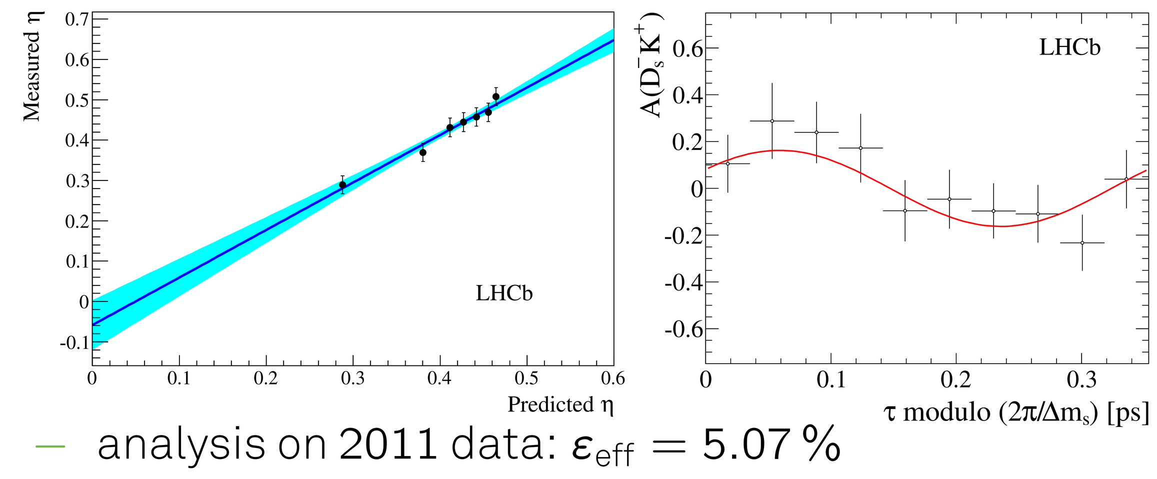
- Measurements of ϕ_s



Mode	$\varepsilon_{\text{eff},2011}$	$\varepsilon_{\text{eff, Run I}}$
$J/\psi K^+K^-$	3.13 [3]	3.73 [4]
$J/\psi\pi^+\pi^-$	2.43 [5]	3.89 [6]
$D_s^+D_s^-$	-	5.33 [7]

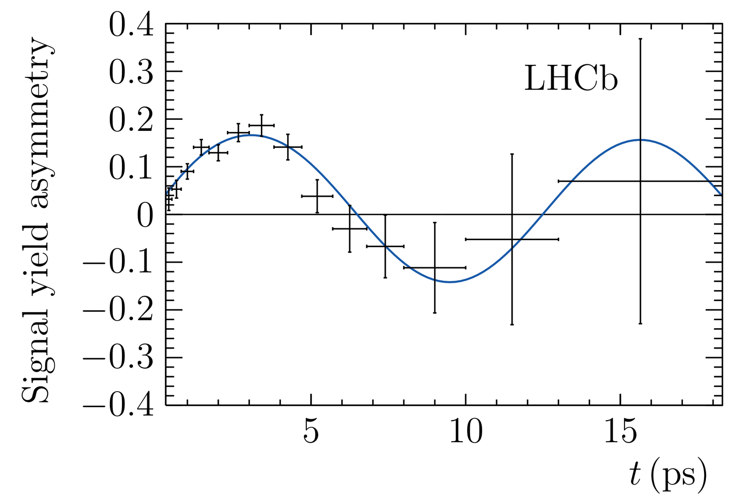
  - newest analyses profited from
    → including SS kaon nnet tagger
    → re-optimisation of OS algorithms

- CP violation in $B_s^0 \to D_s^\mp K^\pm$



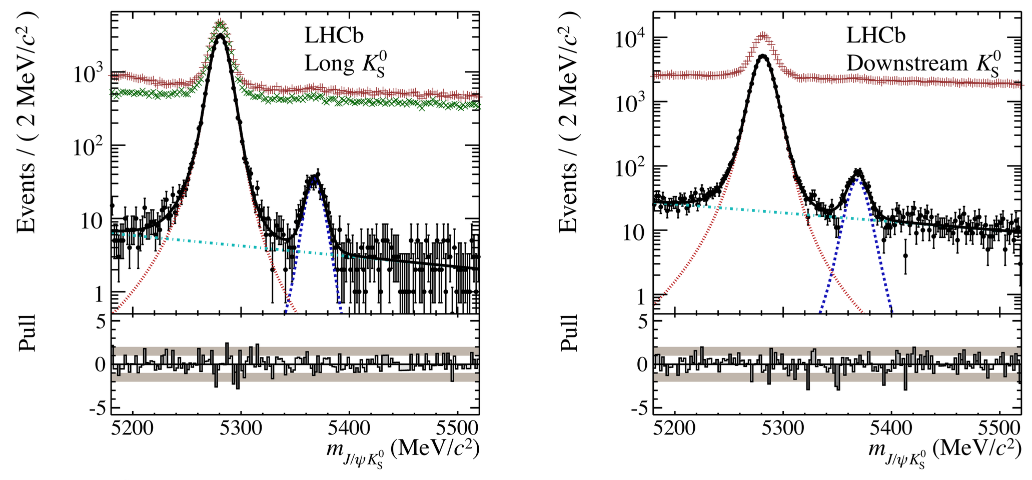
  - analysis on 2011 data: $\varepsilon_\text{eff} = 5.07\,\%$
  - SS kaon nnet adds more than 1.3 % to ε_eff [5]

- CP violation in $B^0 \to J/\psi\, K_S^0$ (sin 2β)
  - analysis on 2011 data: $\varepsilon_\text{eff} = 2.38\,\%$ [6]
  - full Run I analysis: $\varepsilon_\text{eff} = 3.02\,\%$ [7]
    → SS pion tagger adds more than 0.376 % to ε_eff



  - precision analysis → "ad-hoc" FT calibration
    → OS algorithms calibrated with $B^+ \to J/\psi\, K^+$
    → SS pion calibrated with $B^0 \to J/\psi\, K^{*0}$

- CP violation in $B_s^0 \to J/\psi\, K_S^0$
  - not possible to exclude B^0 events in selection



  - B_s^0 events: $\varepsilon_{\text{eff},B_s^0} = 4.00\,\%$, $\varepsilon_{\text{eff},B^0} = 2.62\,\%$ [8]
    → small contribution of SS kaon for B^0 due to:
      - same-side protons misidentified as kaons
      - kaons from same-side K^* (892)
    ⇒ kaons have opposite charge: invert tag

Developments

OS charm tagger (preliminary)

- reconstruct $D^0/D^\pm/D^*$ decays related to OS b decay

Decay mode	Relative ε_tag	Relative ε_eff
$D^0 \to K^-\pi^+$	10.0 %	24.0 %
$D^0 \to K^-\pi^+\pi^+\pi^-$	5.9 %	8.4 %
$D^+ \to K^-\pi^+\pi^+$	10.3 %	2.6 %
$D^0, D^+ \to K^-\pi^+X$	69.7 %	61.5 %
$D^0, D^+ \to K^-e^+X$	0.5 %	0.2 %
$D^0, D^+ \to K^-\mu^+X$	3.4 %	0.3 %
$\Lambda_c^+ \to p^+K^-\pi^+$	0.2 %	2.4 %

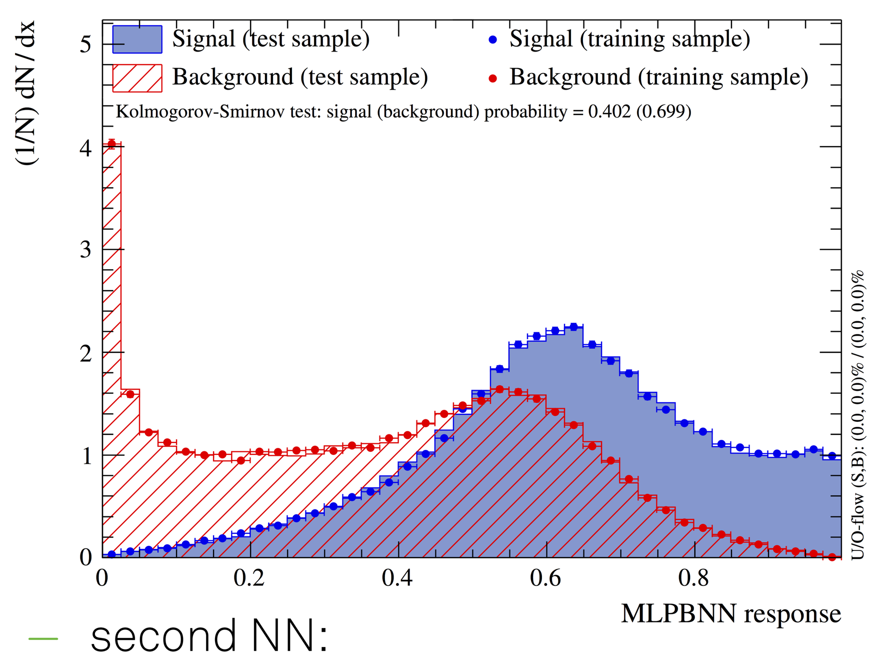
- one boosted decision tree (BDT) for each mode [9]
- clean measure of B meson flavour (low mistag)
- stand-alone tagging power of $\varepsilon_\text{eff} = 0.30\,\%$ to $0.40\,\%$

SS pion calibration

- calibration performed with $B^0 \to J/\psi\, K^{*0}$
- full evaluation of systematic uncertainties
- used for the first time in the measurements of
  - sin(2β) with $B^0 \to J/\psi\, K_S^0$
    ⇒ $\varepsilon_\text{eff}^{\text{SS}\pi} = 0.38\,\%$
  - sin(2β_eff) with $B^0 \to J/\psi\,\pi^+\pi^-$
    ⇒ $\varepsilon_\text{eff}^{\text{SS}\pi} = 0.54\,\%$

SS kaon tagging using neural nets (NN)

- basic idea: use two NN
  - first NN distinguishes between:
    1. fragmentation tracks
       ⇒ signal for SS kaon nnet
    2. underlying event tracks



  - second NN:
    - assigns final tag and mistag based on multiple candidates [10]
- SS kaon nnet tagger is a great success, compared to the previous cut-based SS kaon it gives
  - $B_s^0 \to D_s^-\pi^+$: 50 % relative improvement in ε_eff
  - $B_s^0 \to J/\psi\,\phi$: 41 % relative improvement in ε_eff

References

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