

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. [1,2]

Two independent classes of algorithms

- same side taggers (SS)**

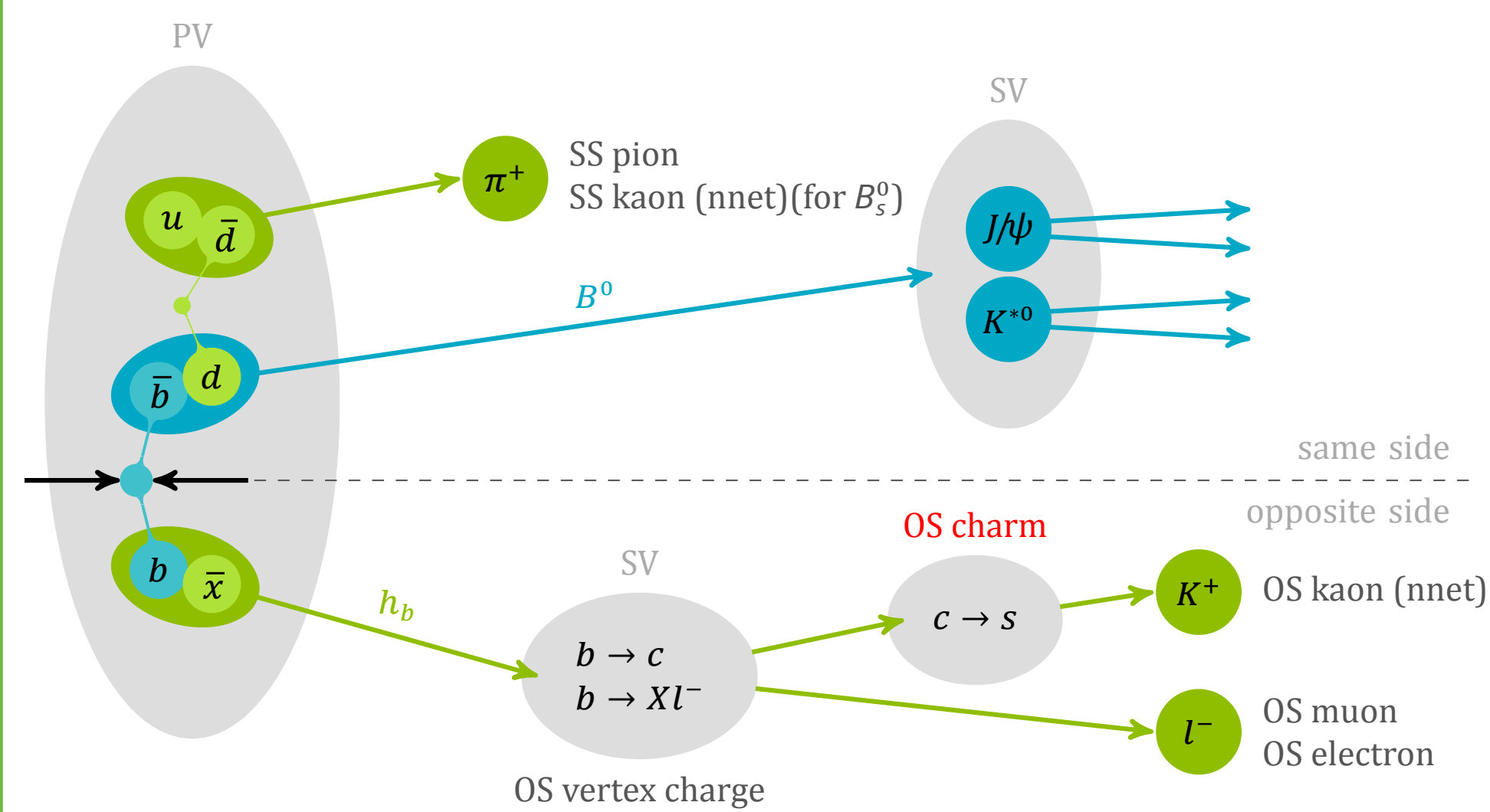
use charged particles created in the fragmentation process of the b quark of the signal B meson

- kaon for B_s^0 → SS kaon / SS kaon nnet
- pion for B^0 → SS pion / SS pion BDT
- 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 $b \rightarrow c \rightarrow s$ decay chain → OS kaon / OS kaon nnet
- D meson from the $b \rightarrow c$ decay chain → OS charm



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

$$\epsilon_{\text{tag}} = \frac{N_{\text{right}} + N_{\text{wrong}}}{N_{\text{all}}}$$

- effective tagging efficiency**

represents the statistical reduction factor of a sample in a tagged analysis

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

Calibration

Mistag calibration

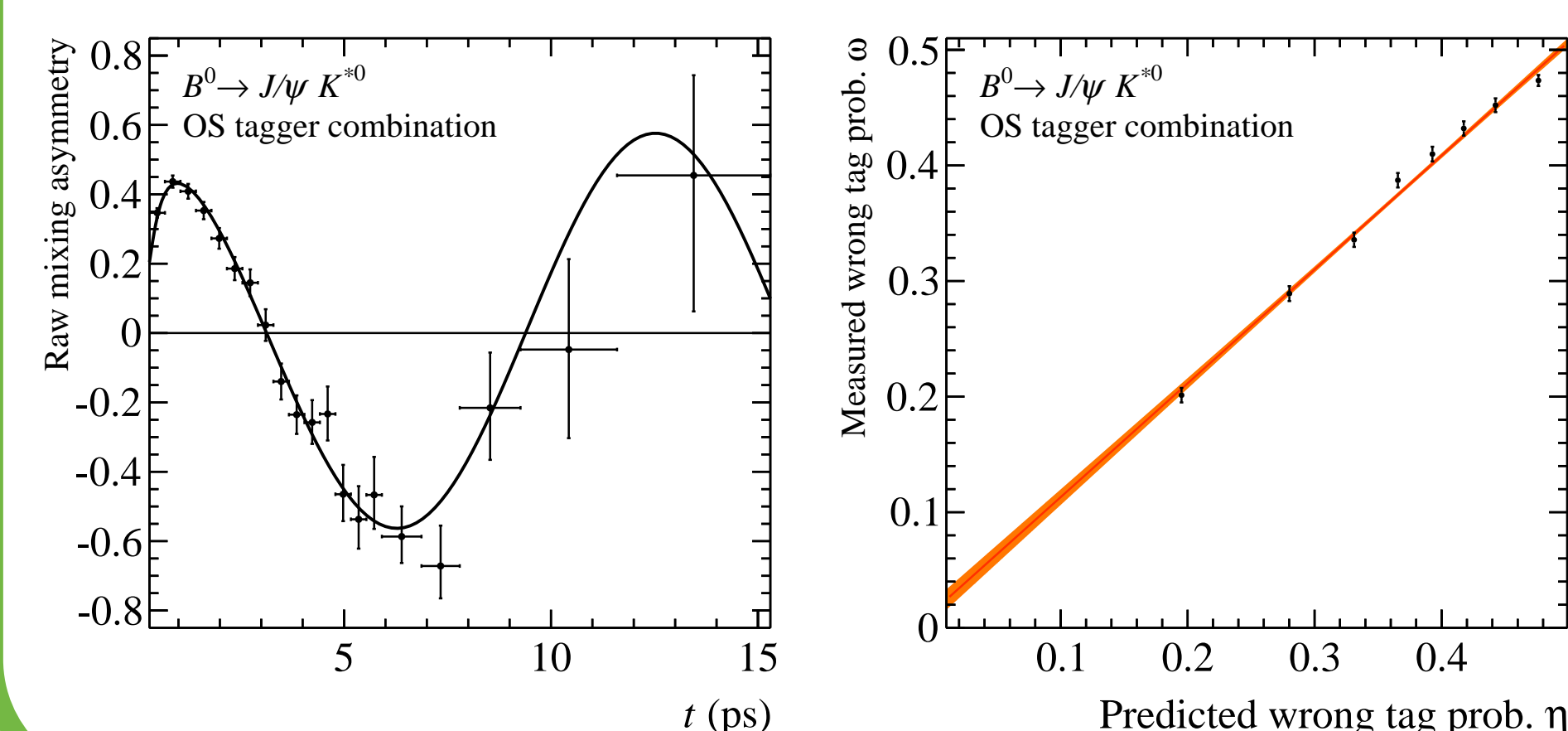
$$\omega(\eta) = p_0 + p_1(\eta - \langle \eta \rangle)$$

measured ev-by-ev mistag estimated ev-by-ev mistag estimated mean

Several flavour-specific decay channels are used

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

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



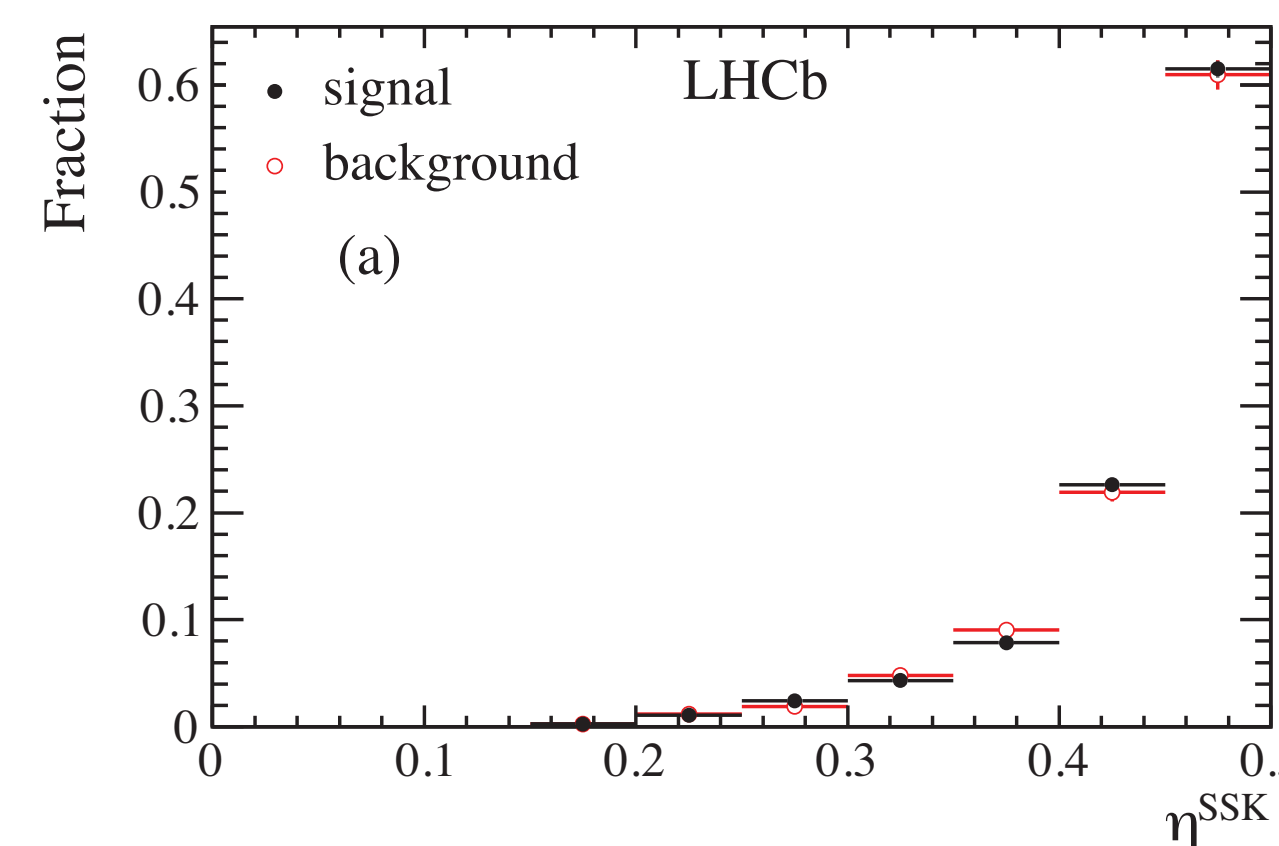
Flavour Tagging in Run I

Strategy

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

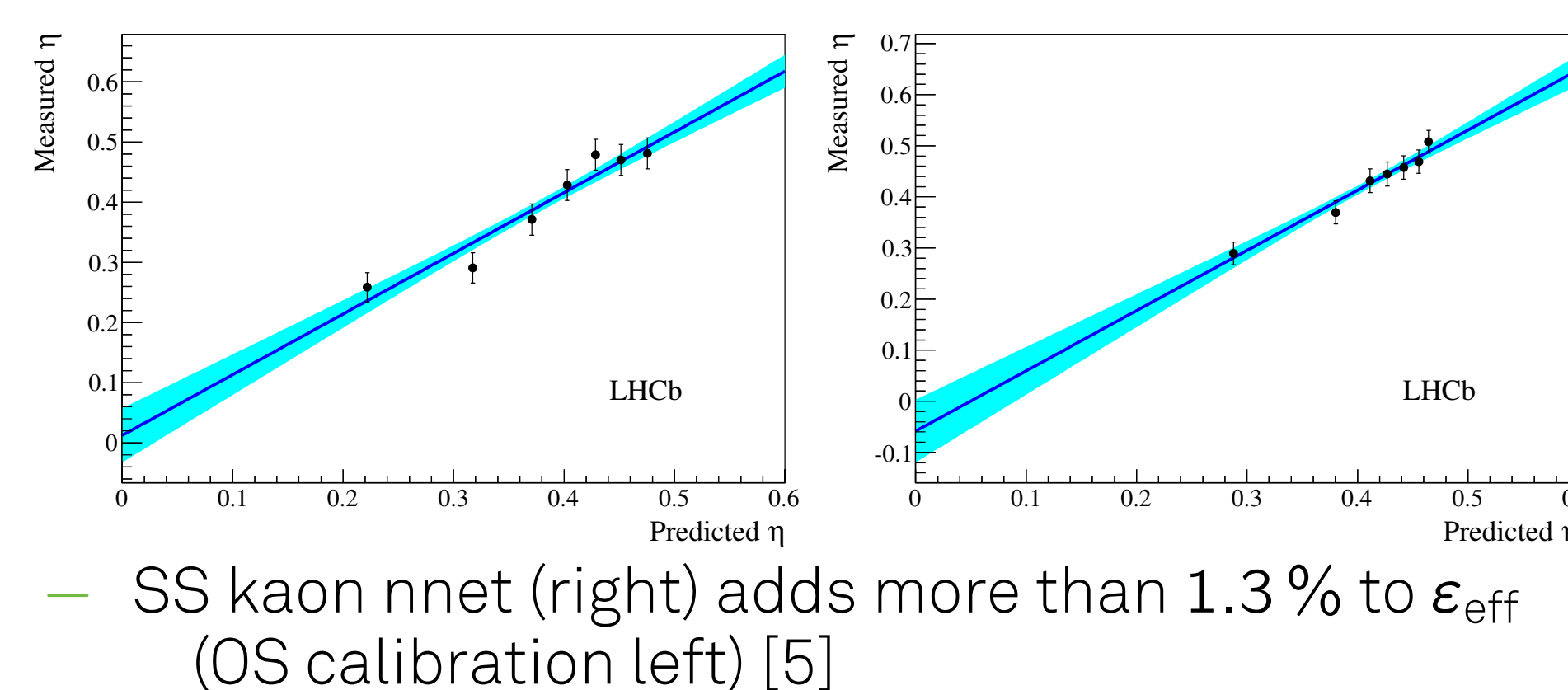
Performance in analyses

- CP violation in $\bar{B}_s^0 \rightarrow J/\psi \pi^+ \pi^-$**



- two analyses:
 - on 1 fb^{-1} : $\epsilon_{\text{eff}} = 2.43 \%$ [3]
 - on 3 fb^{-1} : $\epsilon_{\text{eff}} = 3.89 \%$ [4]
- second analysis included SS kaon nnet tagger
- OS algorithms have been re-optimised

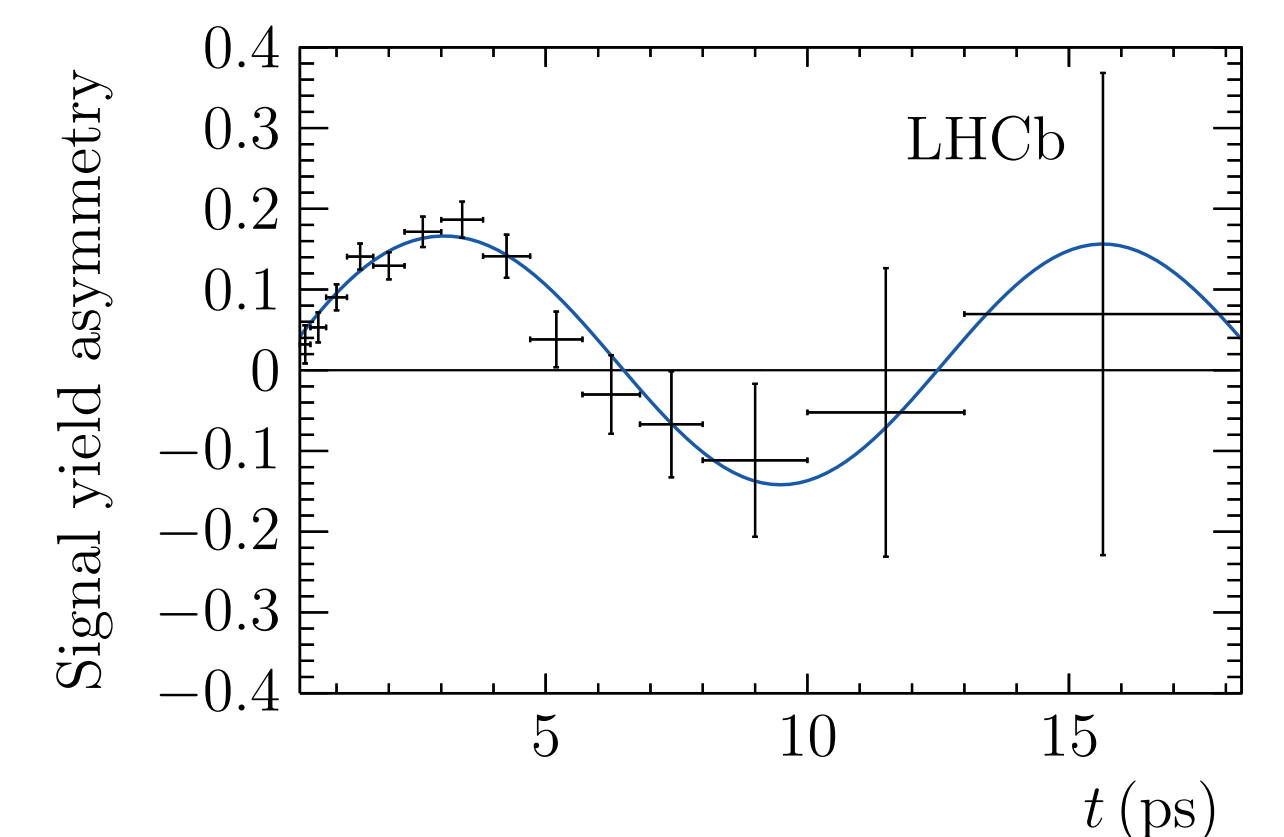
- CP violation in $B_s^0 \rightarrow D_s^\mp K^\pm$**



- SS kaon nnet (right) adds more than 1.3 % to ϵ_{eff} (OS calibration left) [5]

- CP violation in $B^0 \rightarrow J/\psi K_s^0 (\sin 2\beta)$**

- compared to the 1 fb^{-1} analysis the SS pion tagger adds more than 0.376 % to ϵ_{eff} in the 3 fb^{-1} analysis
- precision analysis → "ad-hoc" calibration with $B^+ \rightarrow J/\psi K^+$ (OS) and $B^0 \rightarrow J/\psi K^{*0}$ (SS pion) leads to smaller uncertainties from FT [6]



- CP violation in $B_s^0 \rightarrow J/\psi K_s^0$**

- B_s^0 and B^0 events not separable in analysis
- B_s^0 events: $\epsilon_{\text{eff}} = 4.00 \%$ [7]
- B^0 events: also small contribution of SS kaon to ϵ_{eff}
 - same-side protons misidentified as kaons
 - kaons from K^* (892) produced in correlation with the B^0
 - kaons have charge opposite: tag decision has to be inverted

Overall performance improvements in Run I

- OS tagging improved $\mathcal{O}(15\%)$
- SS kaon tagging improved $\mathcal{O}(40\%)$
- ⇒ Flavour Tagging has been a success in Run I

Developments

OS charm tagger

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

Decay mode	Relative rate	Relative power
$D^0 \rightarrow K^- \pi^+$	10.0%	24.0%
$D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$	5.9%	8.4%
$D^+ \rightarrow K^- \pi^+ \pi^+$	10.3%	2.6%
$D^0, D^+ \rightarrow K^- \pi^+ X$	69.7%	61.5%
$D^0, D^+ \rightarrow K^- e^+ X$	0.5%	0.2%
$D^0, D^+ \rightarrow K^- \mu^+ X$	3.4%	0.3%
$A_c^+ \rightarrow p^+ K^- \pi^+$	0.2%	2.4%

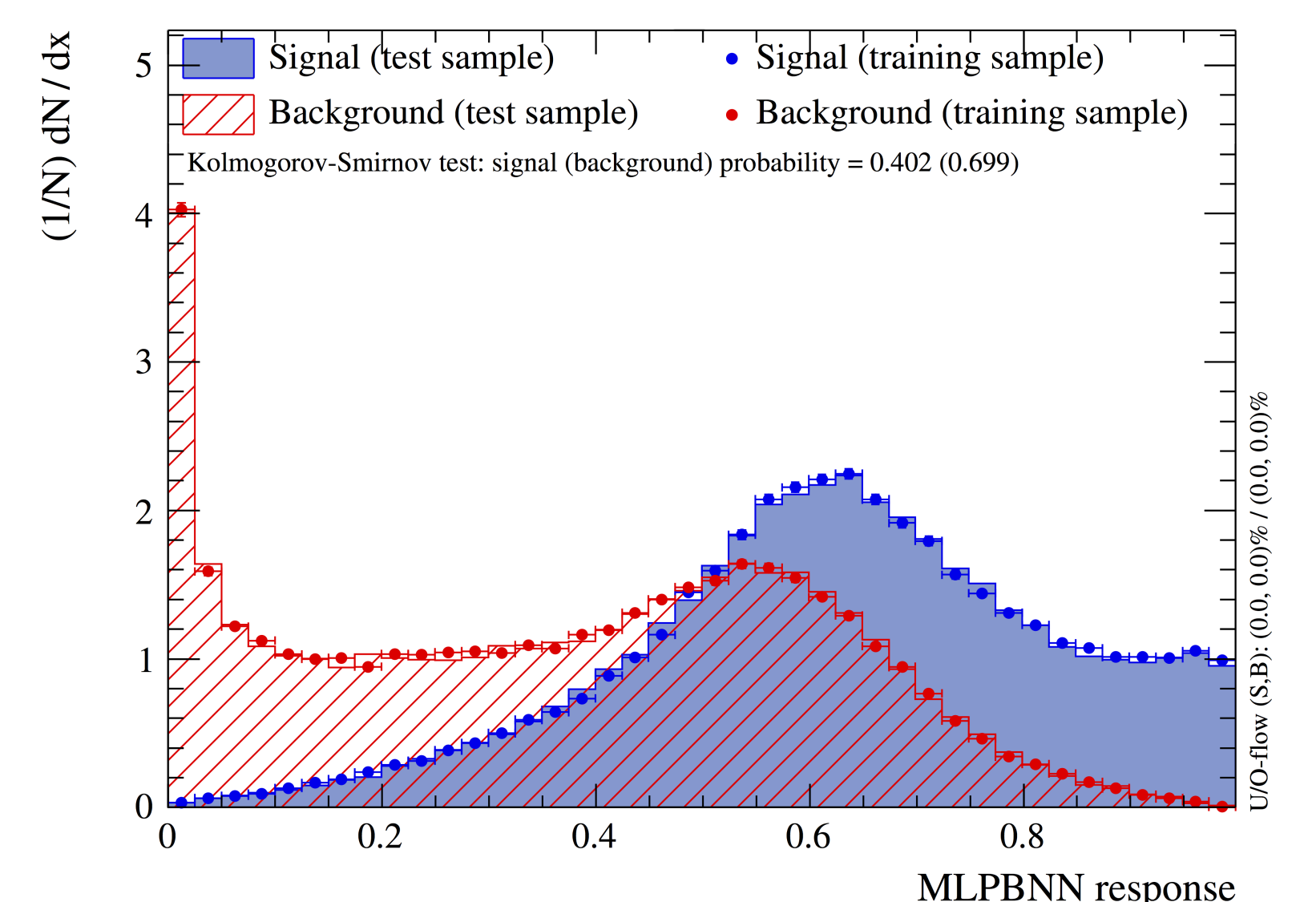
- one boosted decision tree (BDT) for each mode [8]
- clean measure of B meson flavour (low mistag)
- stand-alone tagging power of $\epsilon_{\text{eff}} = 0.30 \%$ to 0.40%

SS pion calibration

- calibration performed with $B^0 \rightarrow J/\psi K^{*0}$
- full evaluation of systematic uncertainties
- used for the first time in the measurements of
 - $\sin(2\beta)$ with $B^0 \rightarrow J/\psi K_s^0$
 - ⇒ precision comparable to B -factories
 - ⇒ $\epsilon_{\text{eff}}^{\text{SS}\pi} = 0.38 \%$
 - $\sin(2\beta_{\text{eff}})$ with $B^0 \rightarrow J/\psi \pi^+ \pi^-$
 - ⇒ $\epsilon_{\text{eff}}^{\text{SS}\pi} = 0.54 \%$

SS kaon tagging using neural nets (NN)

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



- second NN:
 - receives up to 3 candidates
 - assigns final tag and mistag [9]

- SS kaon nnet tagger is a great success, compared to the previous cut-based SS kaon it gives
 - $B_s^0 \rightarrow D_s^- \pi^+$: 50 % relative improvement in ϵ_{eff}
 - $B_s^0 \rightarrow J/\psi \phi$: 41 % relative improvement in ϵ_{eff}

References

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- [5] LHCb Collaboration, R. Aaij et. al., *Measurement of CP asymmetry in $B_s^0 \rightarrow D_s^\mp K^\pm$ decays*, JHEP 1411 (2014) 060
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