

b -flavour tagging in pp collisions

Alex Birnkraut on behalf of the LHCb collaboration

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)

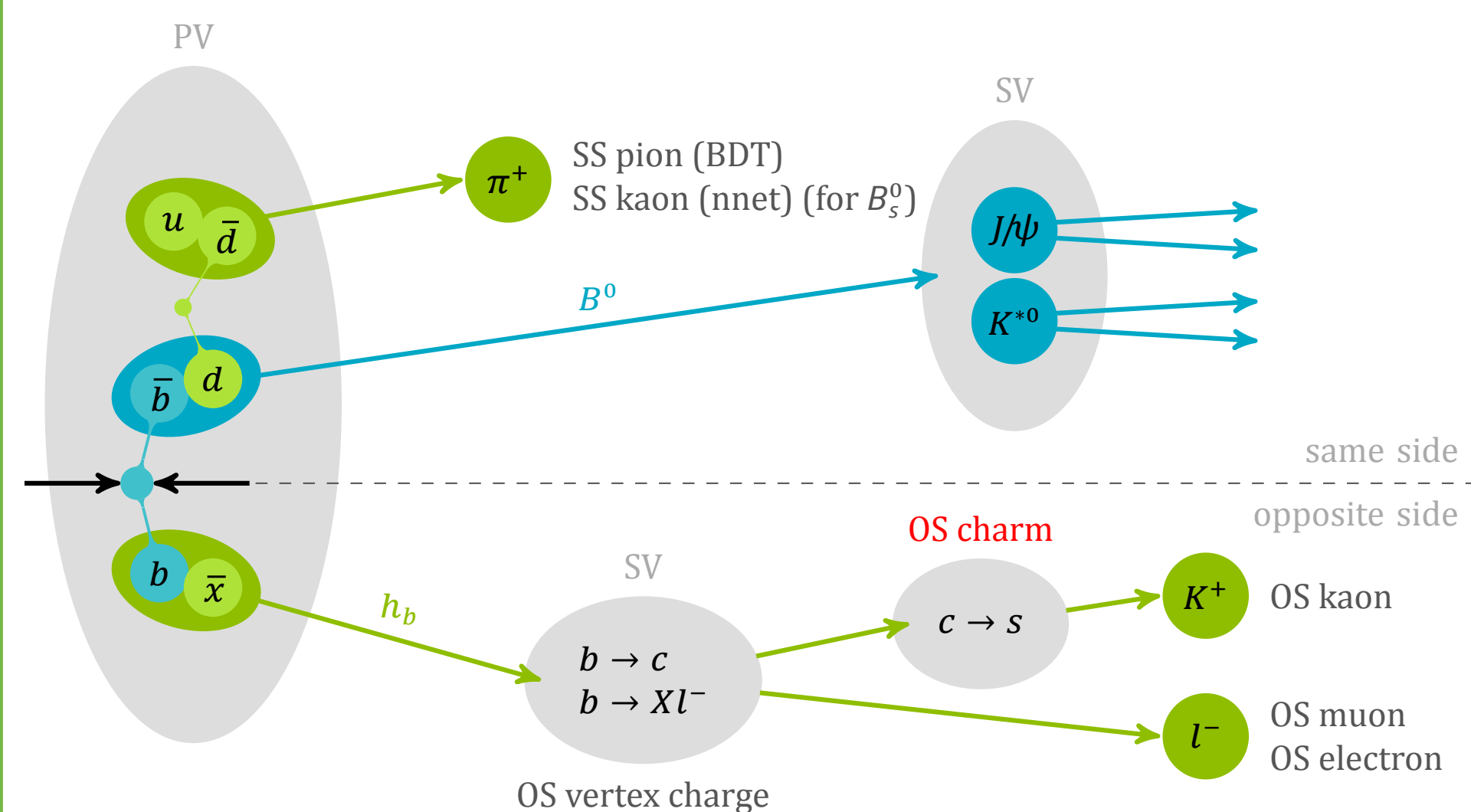
use charged particles created in the fragmentation process of the b quark of the signal B meson

- 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

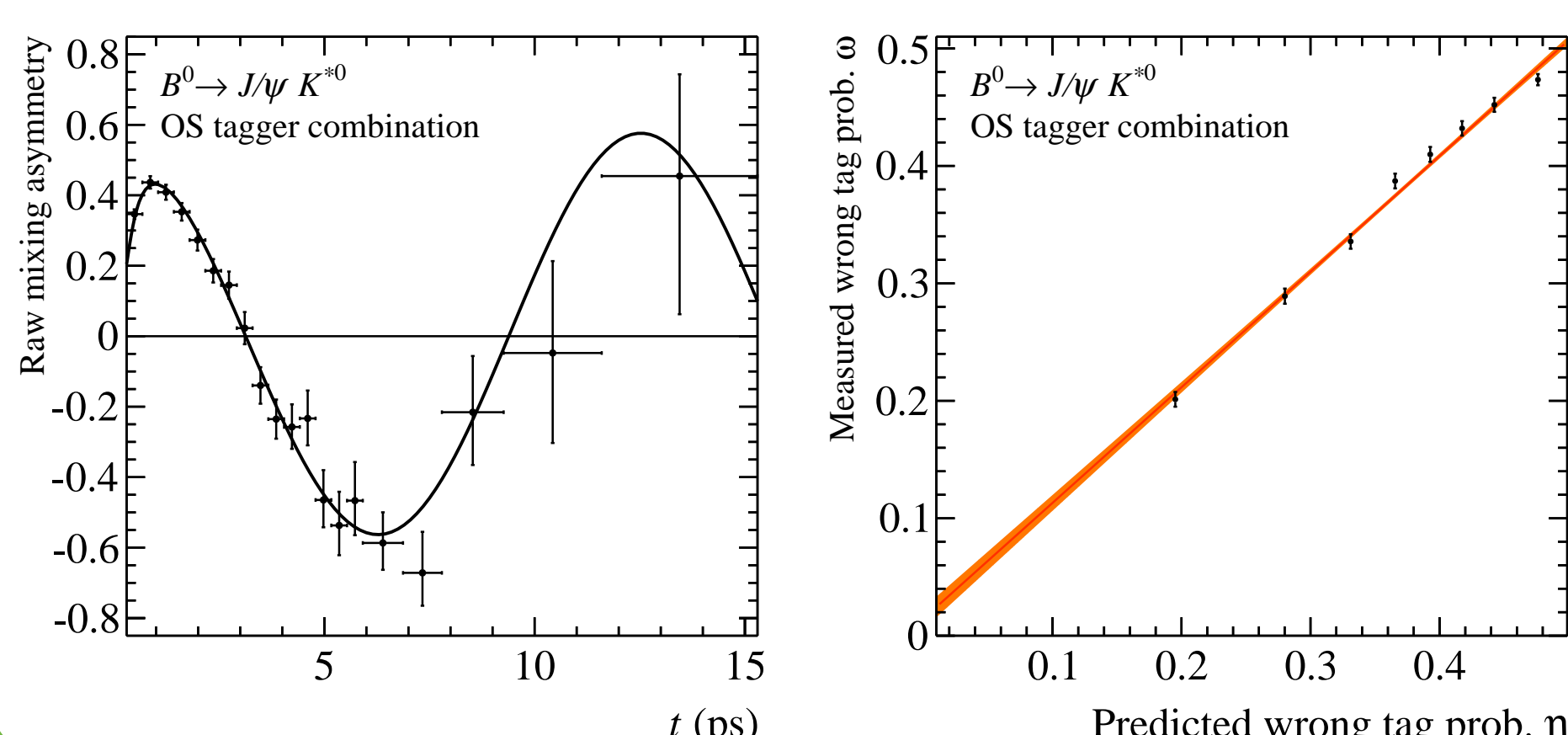
$$\omega(\eta) = p_0 + p_1(\eta - \langle \eta \rangle)$$

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

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

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



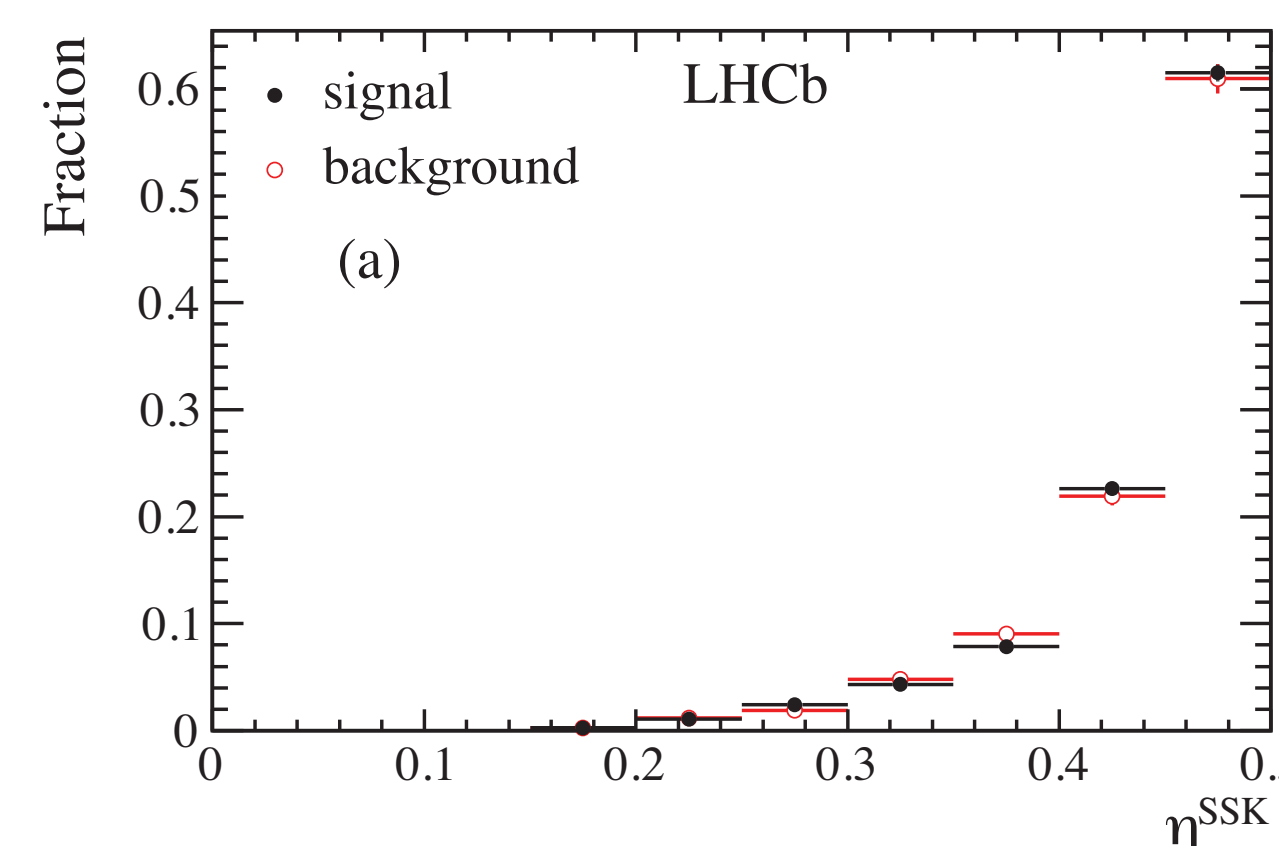
Flavour Tagging in Run I

Handling for analyses

- one calibration per tagger 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

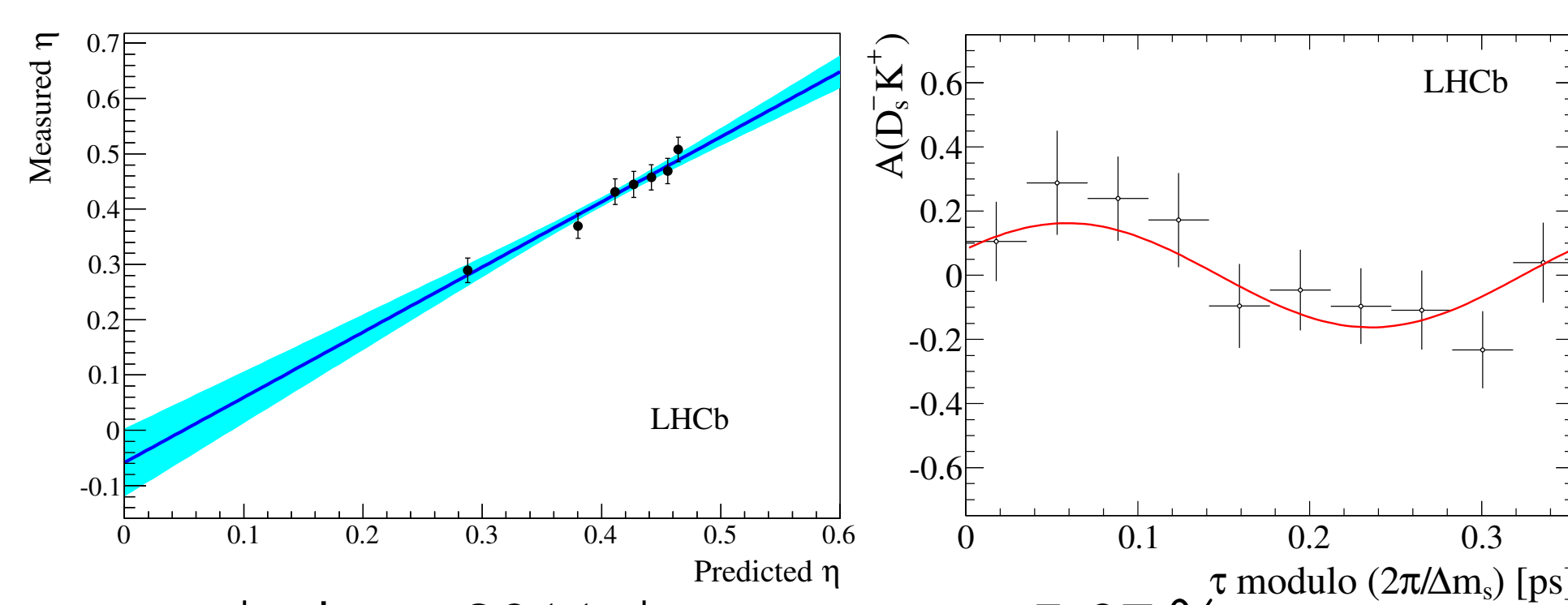
Highlights of successful FT uses

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



- analysis on 2011 data: $\epsilon_{\text{eff}} = 2.43\%$ [3]
- full Run I analysis: $\epsilon_{\text{eff}} = 3.89\%$ [4]
- newest analysis profited from
 - including SS kaon nnet tagger
 - re-optimisation of OS algorithms

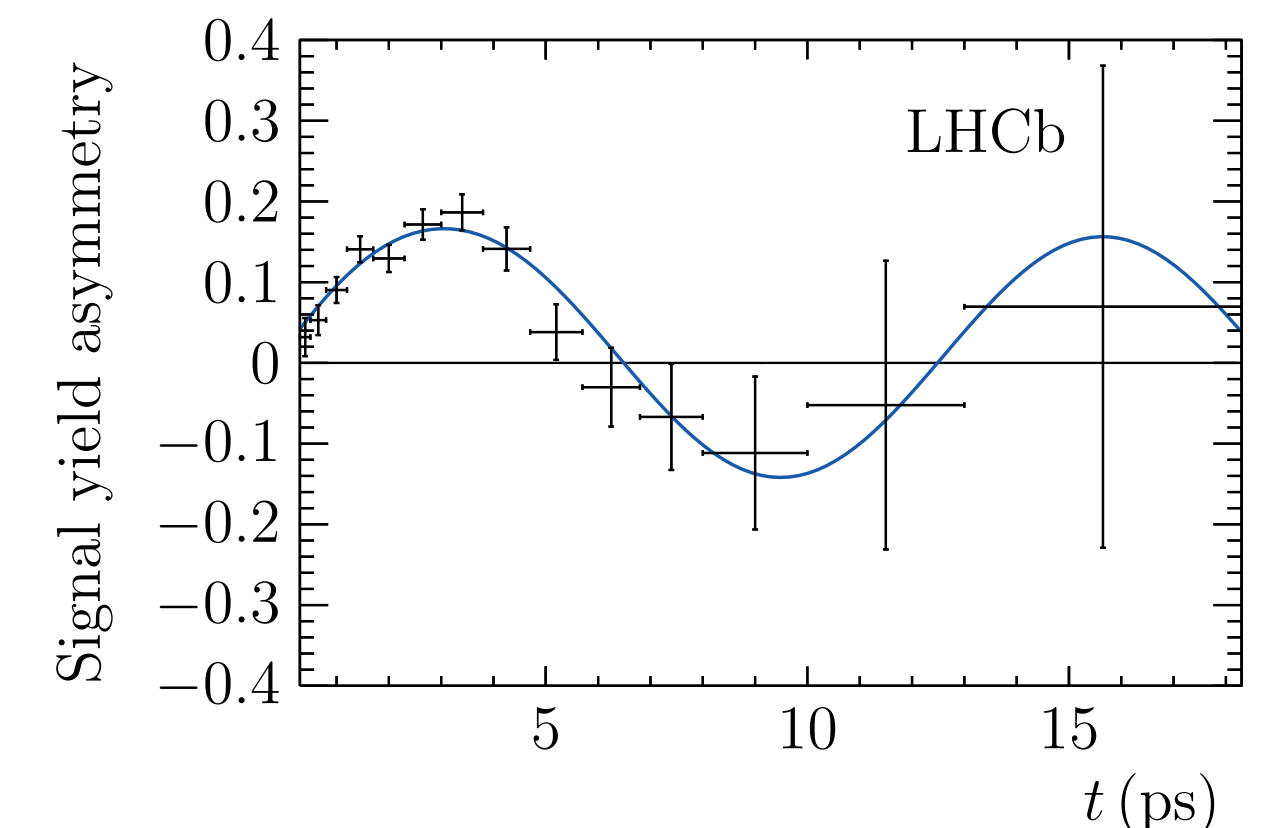
- CP violation in $B_s^0 \rightarrow D_s^\mp K^\pm$



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

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

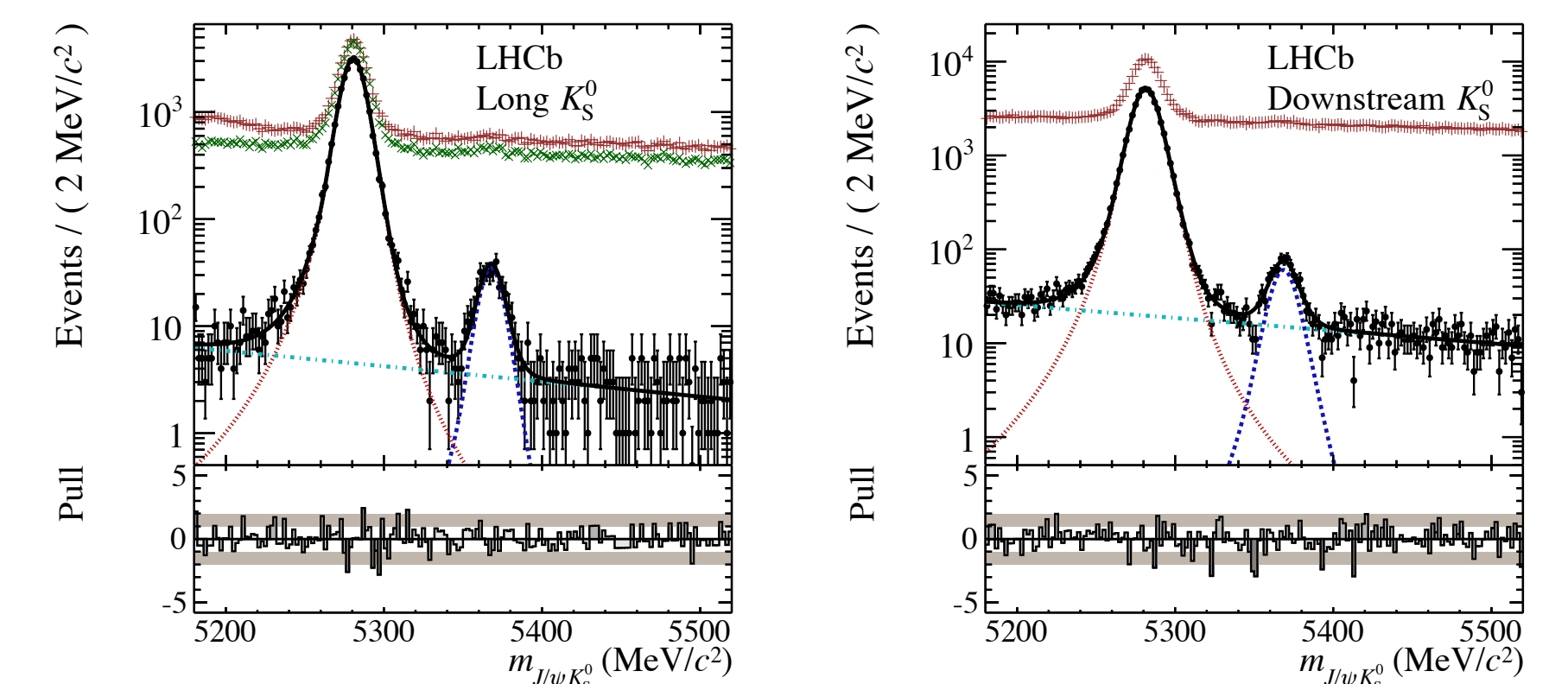
- analysis on 2011 data: $\epsilon_{\text{eff}} = 2.38\%$ [6]
- full Run I analysis: $\epsilon_{\text{eff}} = 3.02\%$ [7]
- SS pion tagger adds more than 0.376 % to ϵ_{eff}



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

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

- B_s^0 events: $\epsilon_{\text{eff}} = 4.00\%$ [8]
- B^0 events: $\epsilon_{\text{eff}} = 2.62\%$ [8]
- also small contribution of SS kaon for B^0
- origins of this effect:
 - same-side protons misidentified as kaons
 - kaons from same-side K^* (892)
- kaons have opposite charge for B^0 : tagging decision has to be inverted



Developments

OS charm tagger

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

Decay mode	Relative ϵ_{tag}	Relative ϵ_{eff}
$D^0 \rightarrow K^- \pi^+$	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 %
$\Lambda_c^+ \rightarrow p^+ K^- \pi^+$	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 $\epsilon_{\text{eff}} = 0.30\%$ to 0.40%

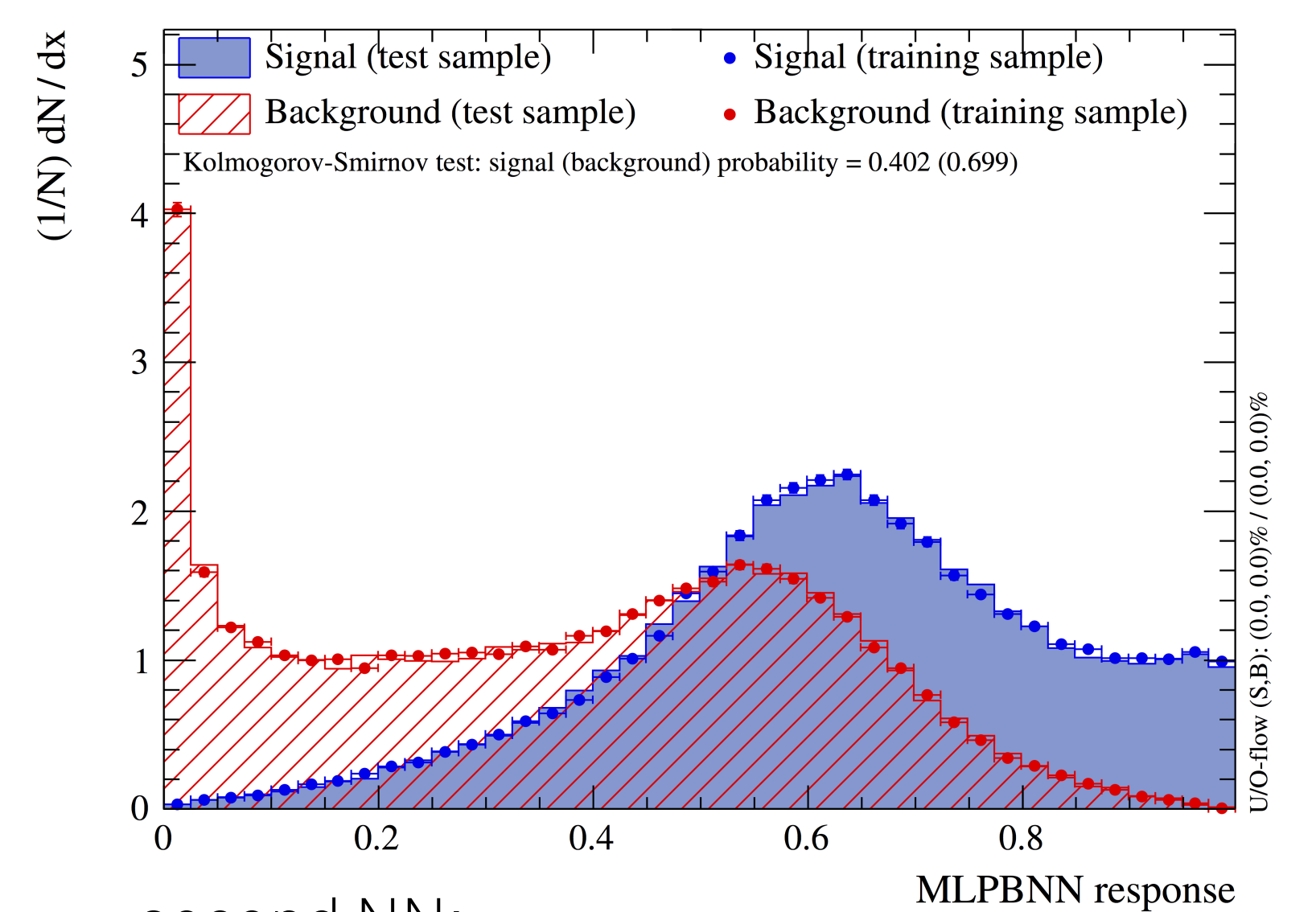
SS pion calibration

- 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 [10]

- 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

- [1] LHCb Collaboration, R. Aaij et. al., *Opposite-side flavour tagging of B mesons at the LHCb experiment*, Eur.Phys.J. C72 (2012) 2022
- [2] LHCb Collaboration, R. Aaij et. al., *Optimization and calibration of the same-side kaon tagging algorithm using hadronic B_s^0 decays in 2011 data*, LHCb-CONF-2012-033
- [3] LHCb Collaboration, R. Aaij et. al., *Measurement of the CP-violating phase ϕ_s in $\bar{B}_s^0 \rightarrow J/\psi \pi^+ \pi^-$ decays*, Phys.Lett. B713 (2012) 378-386
- [4] LHCb Collaboration, R. Aaij et. al., *Measurement of the CP-violating phase ϕ_s in $\bar{B}_s^0 \rightarrow J/\psi \pi^+ \pi^-$ decays*, Phys.Lett. B736 (2014) 186
- [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
- [6] LHCb Collaboration, R. Aaij et. al., *Measurement of the time-dependent CP asymmetry in $B^0 \rightarrow J/\psi K_S^0$ decays*, Phys.Lett. B721 (2013) 24-31
- [7] LHCb Collaboration, R. Aaij et. al., *Measurement of CP violation in $B^0 \rightarrow J/\psi K_S^0$ decays*, Phys.Rev.Lett. 115 (2015) 031601
- [8] LHCb Collaboration, R. Aaij et. al., *Measurement of the time-dependent CP asymmetries in $B_s^0 \rightarrow J/\psi K_S^0$* , JHEP 1506 (2015) 131
- [9] LHCb Collaboration, R. Aaij et. al., *B flavor tagging using reconstructed charm decays at the LHCb experiment*, LHCb-PAPER-2015.027
- [10] G. A. Krocker, *Development and calibration of a same side kaon tagging algorithm and measurement of the $B_s^0 - \bar{B}_s^0$ oscillation frequency Δm_s at the LHCb experiment*, PhD thesis, Heidelberg U., Sep, 2013, CERN-THESIS-2013-213