

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)**

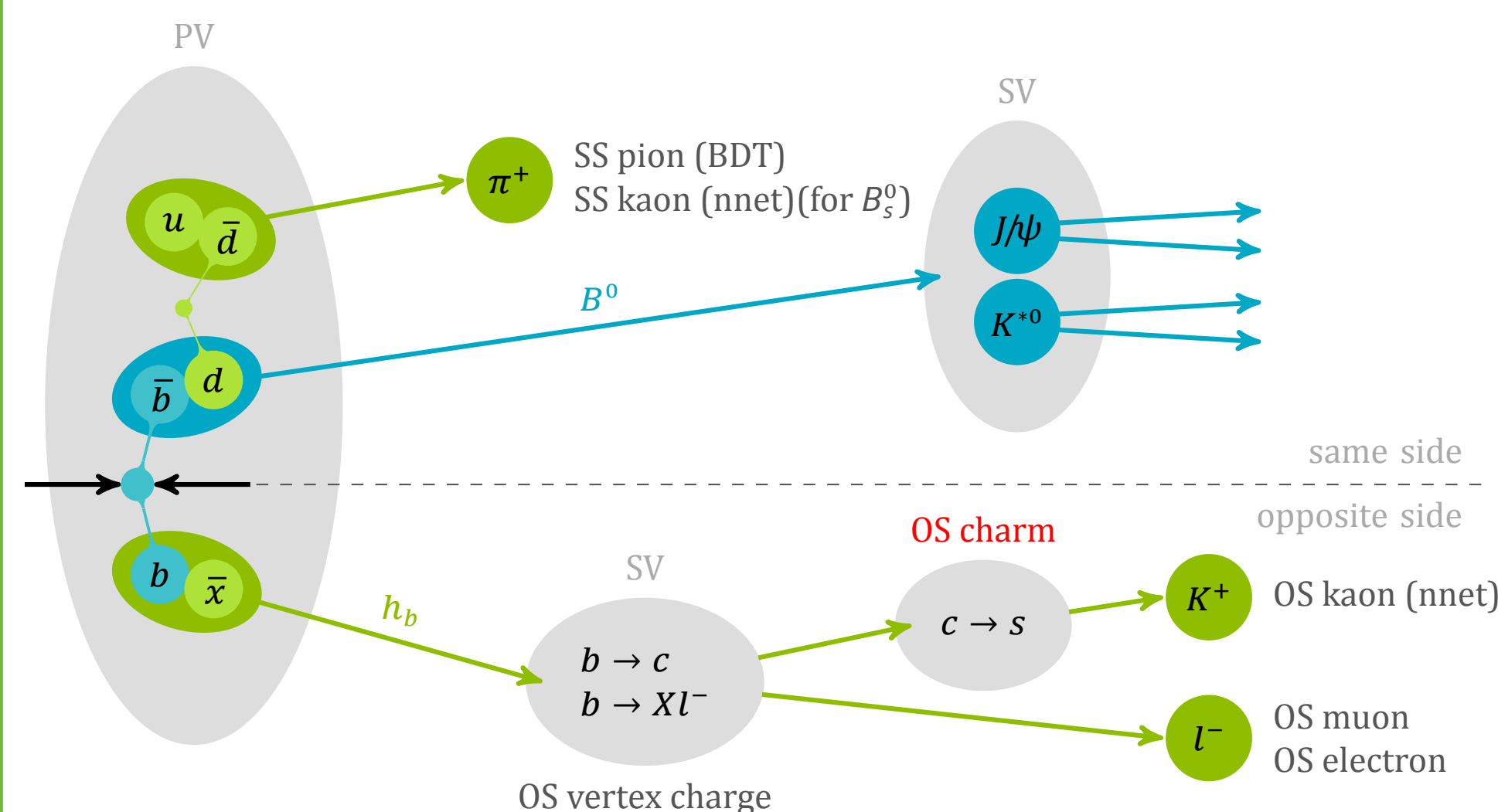
use charged particles created in the fragmentation process of the b quark of the signal B meson

- 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

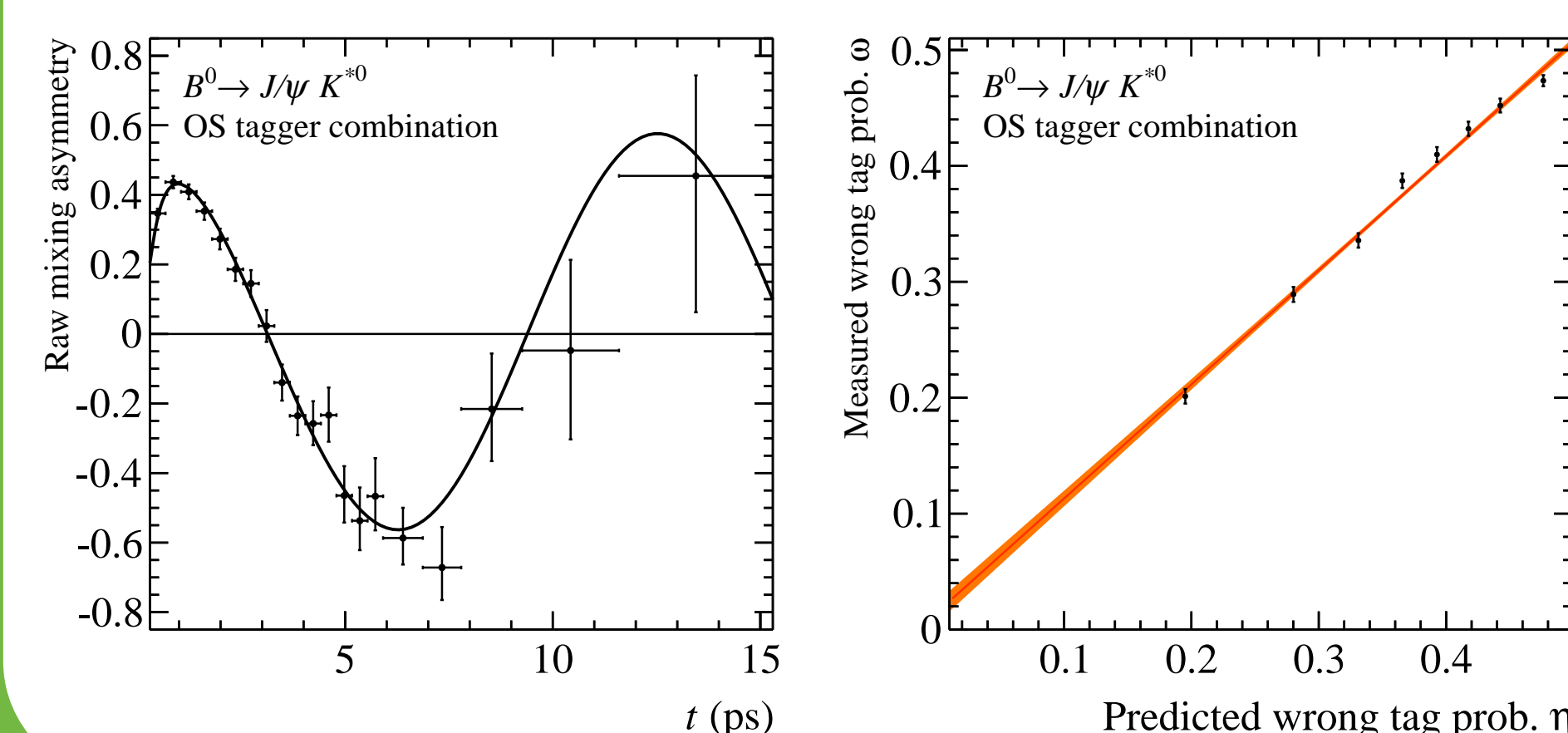
$$\omega(\eta) = p_0 + p_1(\eta - \langle \eta \rangle)$$

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

Strategy

- universal calibration for each tagger
- systematic uncertainties from
 - calibration methods
 - portability
- mode-specific calibration if FT becomes leading systematic uncertainty in precision analyses

Performance in analyses

| Analysis | ϵ_{eff} on data [%] | | ratio | references |
|--------------------------------------|-------------------------------------|--------|-------|--|
| | previous | latest | | |
| $B_s \rightarrow J/\psi \pi^+ \pi^-$ | 2.43 | 3.89 | 1.60 | Phys. Lett. B 713 (2012) 378-386 Phys. Lett. B 736 (2014) 186 |
| $B_s \rightarrow J/\psi K^+ K^-$ | 3.13 | 3.73 | 1.19 | Phys. Rev. D87 (2013) 11, 112010 Phys. Rev. Lett. 114 (2015) 041801 |
| $B_s \rightarrow J/\psi K_s$ | - | 4.00 | | JHEP 1506 (2015) 131 |
| $B_s \rightarrow \phi \phi$ | 3.29 | 5.38 | 1.64 | Phys. Rev. Lett. 110 (2013) 241802 Phys. Rev. D90 (2014) 5, 052011 |
| $B_s \rightarrow D_s K$ | 1.9 | 5.07 | 2.67 | LHCb-CONF-2012-029 JHEP 1411 (2014) 060 |
| $B_s \rightarrow D_s D_s$ | - | 5.33 | | Phys. Rev. Lett. 113 (2014) 211801 |
| $B^0 \rightarrow J/\psi K_s$ | 2.38 | 3.02 | 1.27 | Phys. Lett. B 721 (2013) 24-31 Phys. Rev. Lett. 115 (2015) 031601 |
| $B^0 \rightarrow J/\psi \pi^+ \pi^-$ | - | 3.26 | | Phys. Lett. B 742 (2015) 38-49 |

Performance improvements in Run I

- OS tagging improved $\mathcal{O}(15\%)$
- SS kaon tagging improved $\mathcal{O}(40\%)$

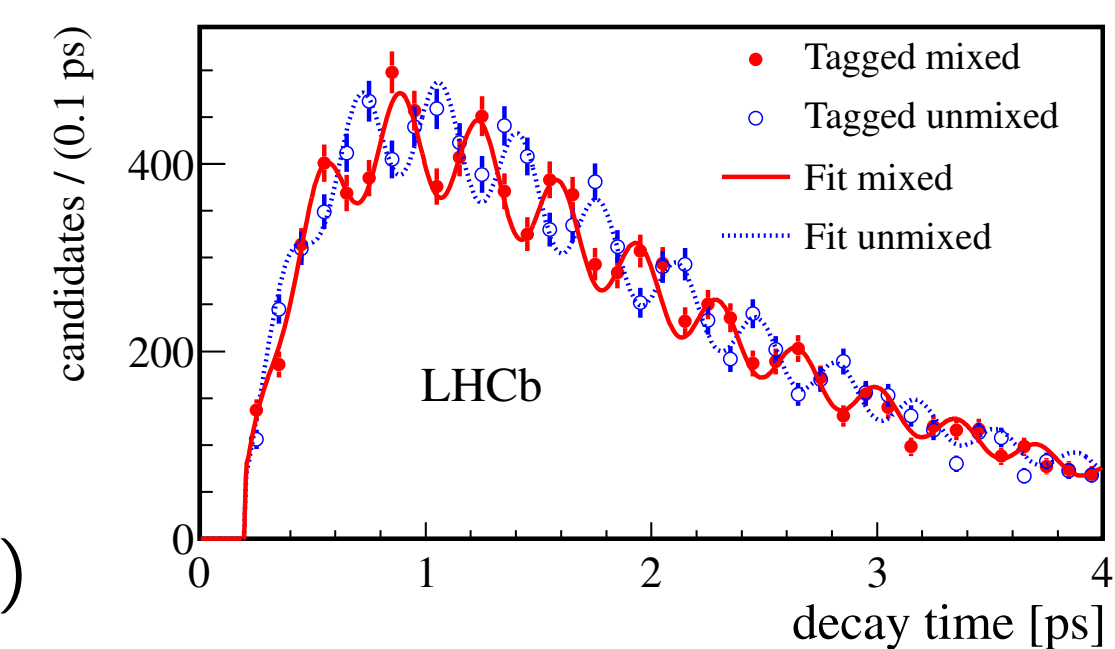
⇒ Flavour Tagging has been a success in Run I

Highlight analyses using flavour tagging

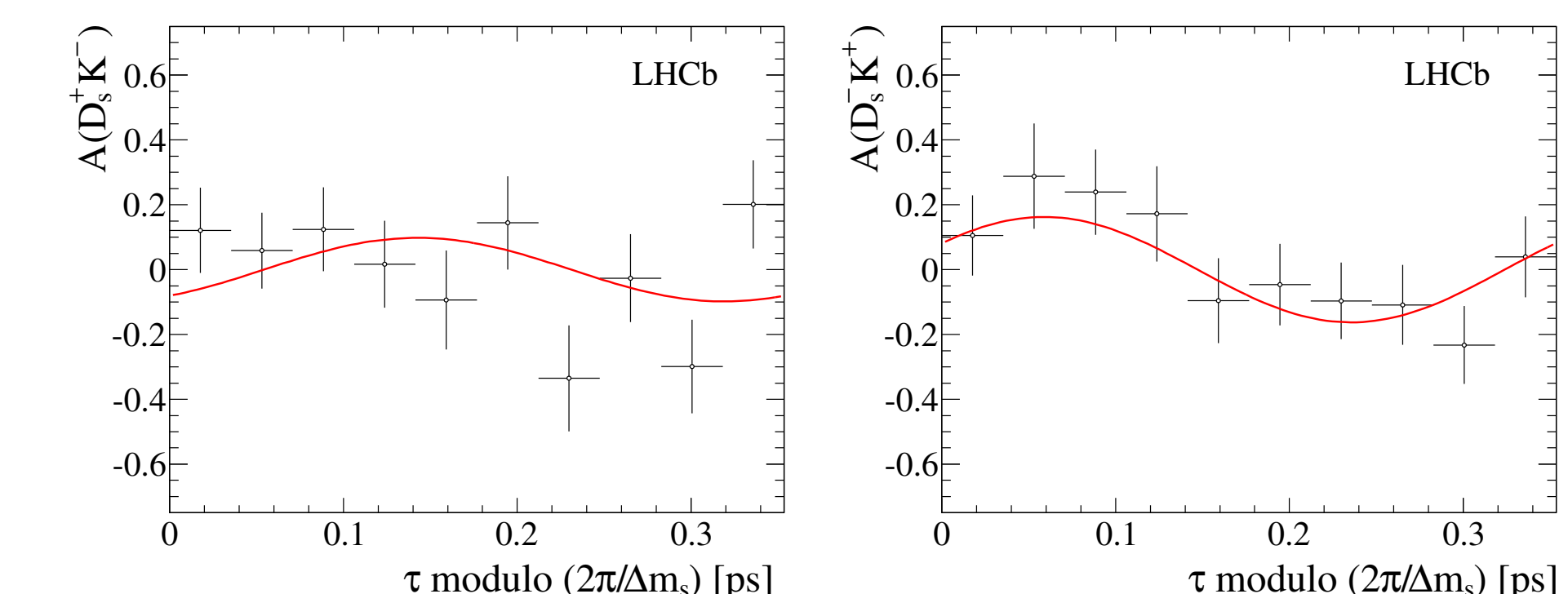
Measurement of Δm_s

Determination of the $B_s^0 - \bar{B}_s^0$ oscillation frequency with $B_s^0 \rightarrow D_s^- \pi^+$ [3].

$$e^{-\Gamma t} (\dots + d \cos(\Delta m t))$$



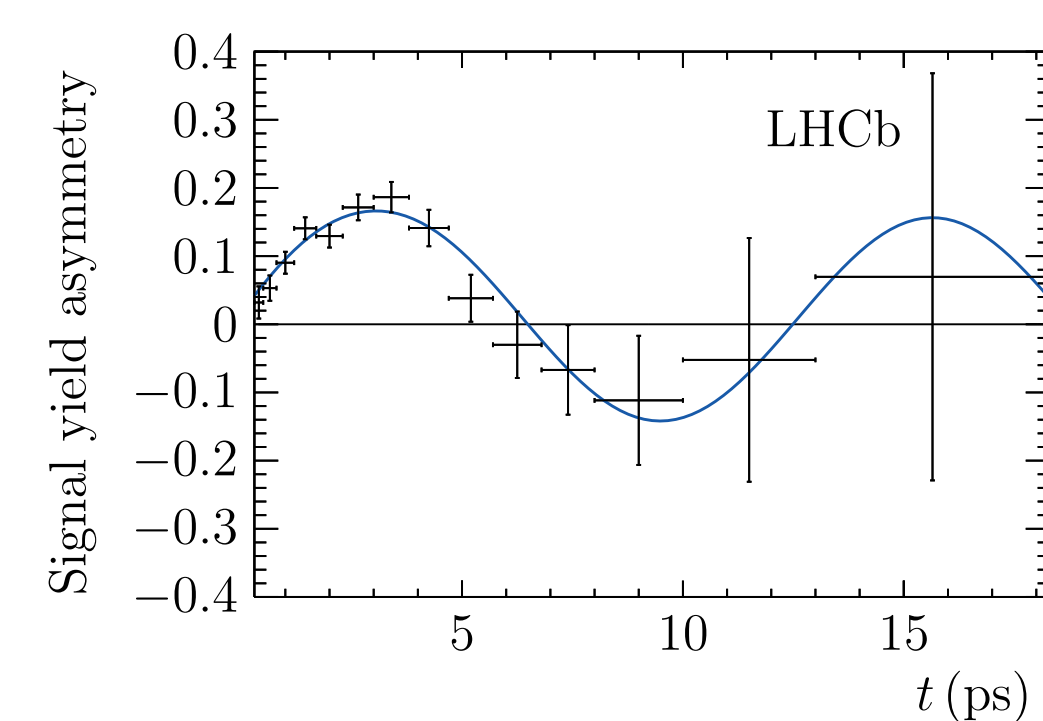
CP analysis of $B_s^0 \rightarrow D_s^\mp K^\pm$ decays



→ SS kaon nnet adds more than 1.3 % to ϵ_{eff} [4]

Measurement of $\sin 2\beta$

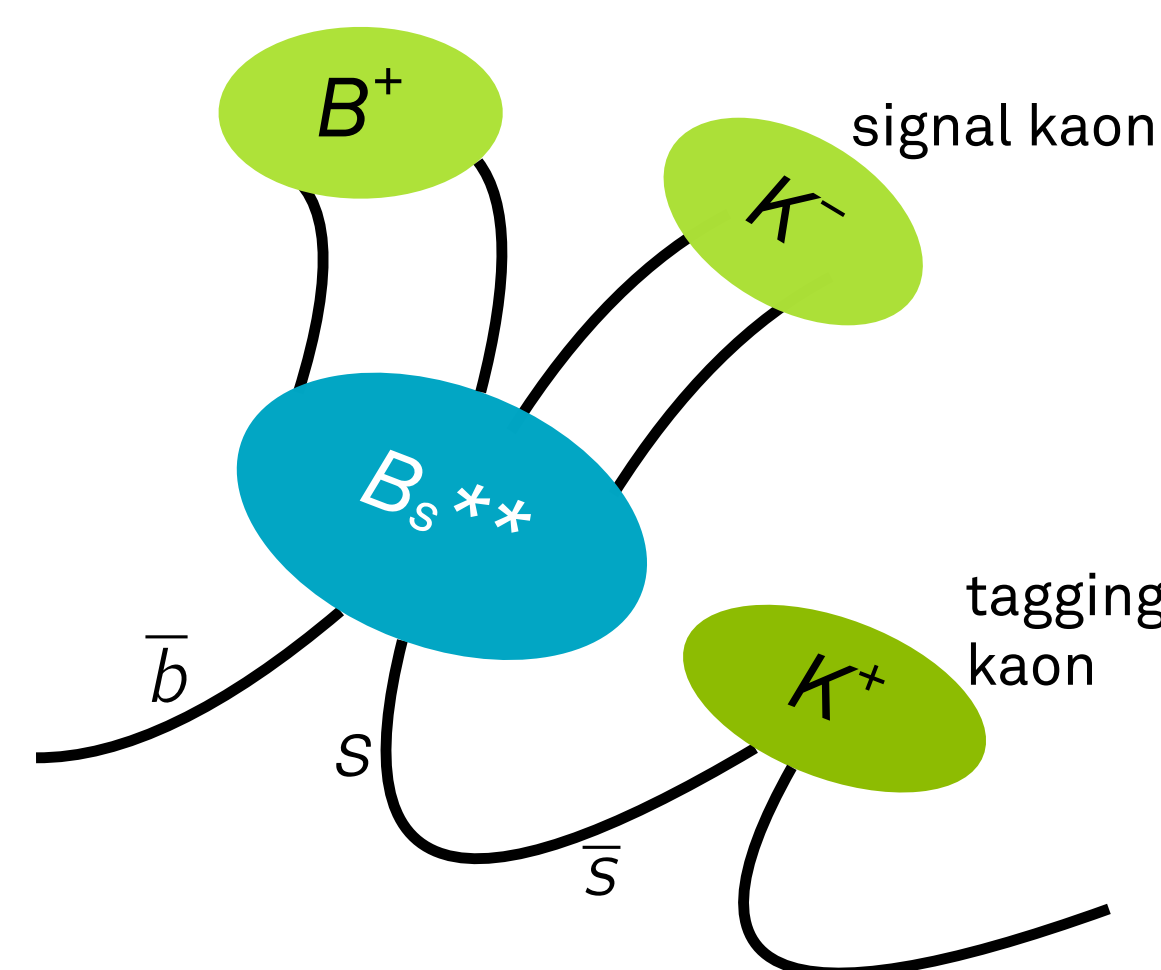
→ precision analysis
→ mode-specific calibration with $B^+ \rightarrow J/\psi K^+$ and $B^0 \rightarrow J/\psi K^{*0}$ [5]



Developments

SS kaon calibration with excited B_s^{*0} states

- SS kaon taggers calibrated with $B_s^{*0} \rightarrow D_s^- \pi^+$ only
 - limited statistics
 - time-dependent analysis required
- new idea: calibrate with B_s^{*0} decays
 - narrow states
 - reconstruct in $B_s^{*0} \rightarrow B^+ K^-$ decays
 - calibrate by counting, as in other charged modes



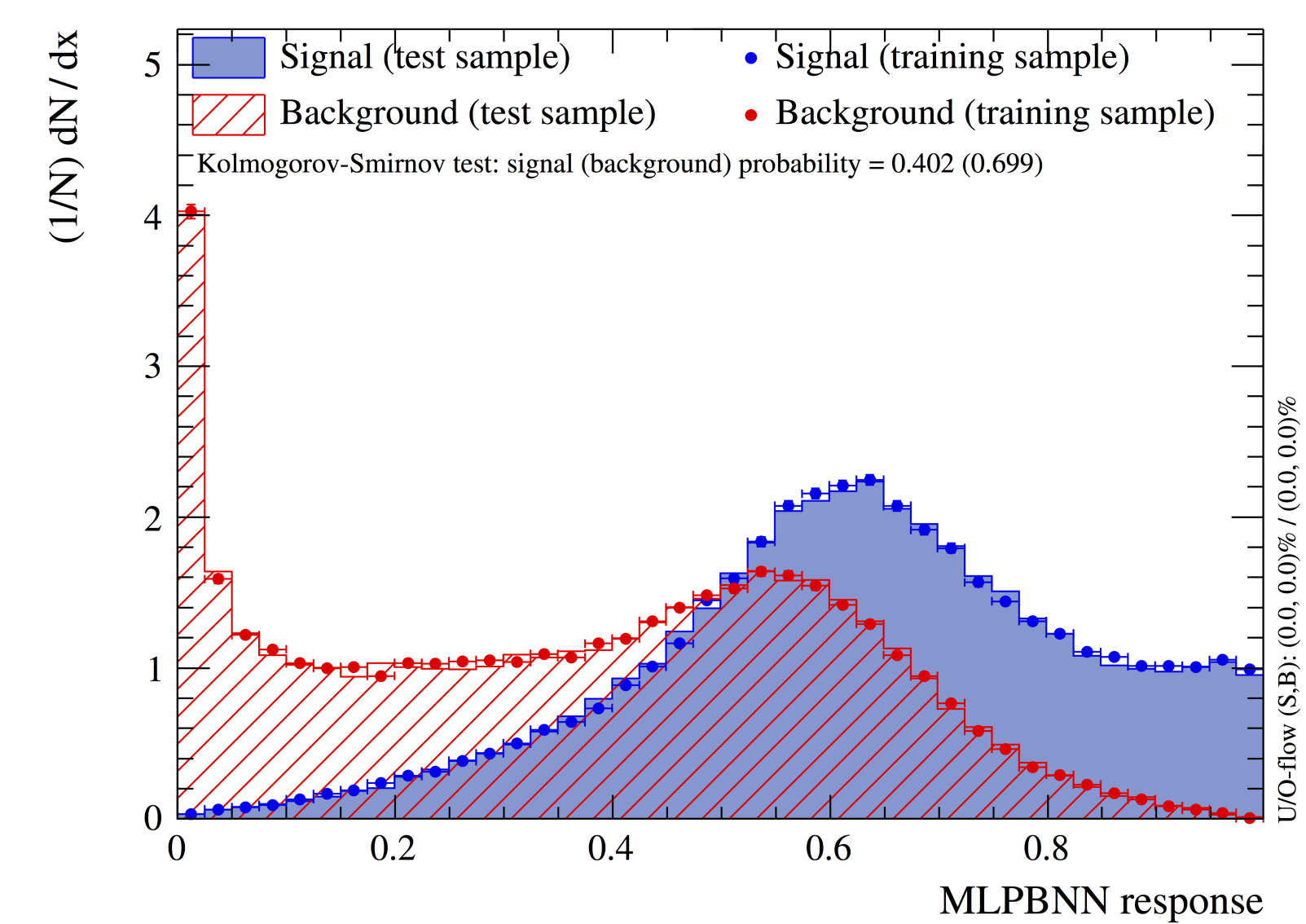
- true independent crosscheck for $B_s^0 \rightarrow D_s^- \pi^+$
- results in agreement with $B_s^0 \rightarrow D_s^- \pi^+$ channel

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 $B^0 \rightarrow J/\psi \pi^+ \pi^-$
⇒ $\epsilon_{\text{eff}}^{\text{SS}\pi} = 0.54\%$

OS and SS Kaon tagging using neural nets (NN)

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



→ second NN:

- receives up to 3 candidates
- assigns final tag and mistag
- 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}

OS charm tagger

- reconstruct $D^0/D^\pm/D^*$ decays related to OS b decay
- one boosted decision tree (BDT) for each mode
- clean measure of B meson flavour (low mistag)
- adds about 0.37 % to ϵ_{eff}

SS pion BDT and SS proton

- promising new taggers based on BDT's
- development ongoing

References

- LHCb Collaboration, R. Aaij et. al., *Opposite-side flavour tagging of B mesons at the LHCb experiment*, Eur.Phys.J. C72 (2012) 2022
- 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
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- LHCb Collaboration, R. Aaij et. al., *Measurement of CP violation in $B^0 \rightarrow J/\psi K_S$ decays*, LHCb-PAPER-2015-004