CP Violation in $B^0 \to D^{*\pm}D^{\mp}$ decays at LHCb

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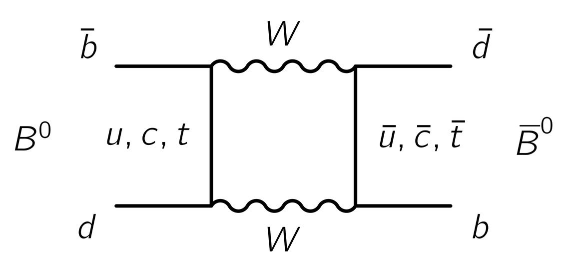
Introduction

B^0 Meson Mixing

Neutral B mesons oscillate between their matter and antimatter states.

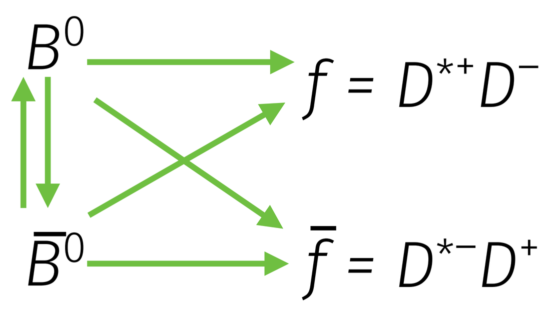


CP Violation

The decay of a neutral B meson into the final state f or $\bar{f}$ may occur directly or after oscillation. This leads to two decay-rate asymmetries that depend on the decay time t.

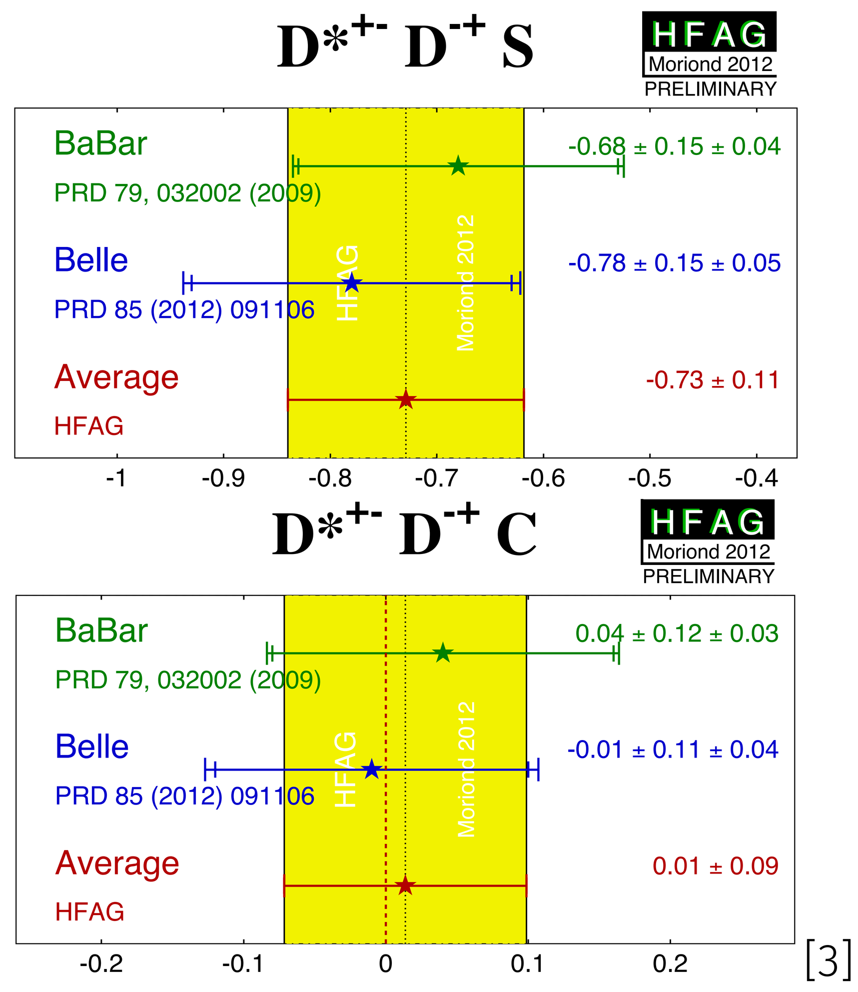
$$A_{CP,f}(t) = \frac{\Gamma(\bar{B}^0(t)\to f) - \Gamma(B^0(t)\to f)}{\Gamma(\bar{B}^0(t)\to f) + \Gamma(B^0(t)\to f)} \approx S_f \sin(\Delta m_d t) - C_f \cos(\Delta m_d t)$$

$$A_{CP,\bar{f}}(t) = \frac{\Gamma(\bar{B}^0(t)\to \bar{f}) - \Gamma(B^0(t)\to \bar{f})}{\Gamma(\bar{B}^0(t)\to \bar{f}) + \Gamma(B^0(t)\to \bar{f})} \approx S_{\bar{f}} \sin(\Delta m_d t) - C_{\bar{f}} \cos(\Delta m_d t)$$



CP Violation in $B^0 \to D^{*\pm}D^{\mp}$

The aim of this analysis is the first measurement of CP violation in $B^0 \to D^{*\pm}D^{\mp}$ decays at LHCb. Former measurements exist from Belle and BaBar [1, 2].



[3]

Higher order contributions in decays that involve $b \to c\bar{c}d$ transitions are not further CKM suppressed. This implies a sensitivity to $\sin(\phi_d^{\rm eff})$ with

$$\phi_d^{\rm eff} = 2\beta + \Delta\phi_d \,,$$

where β is one angle of the CKM-triangle.

Four CP parameters can be determined by a measurement of the decay-time-dependent decay rates

$$\frac{d\Gamma(t,d,q,\omega)}{dt} \propto e^{-t/\tau}\Big[1 + d(1-2\omega)\Big((S + q\Delta S)\sin(\Delta m t) - (C + q\Delta C)\cos(\Delta m t)\Big)\Big] \,,$$

with $S = \frac{1}{2}(S_f + S_{\bar{f}})$ and $\Delta S = \frac{1}{2}(S_f - S_{\bar{f}})$ (analog for C and ΔC).

Dataset

The analysis uses data from the LHCb experiment corresponding to integrated luminosities of

- 1 $\rm fb^{-1}$ at 7 TeV,
- 2 $\rm fb^{-1}$ at 8 TeV,
- 2 $\rm fb^{-1}$ at 13 TeV.

The D^{*+} meson is reconstructed as $D^0\pi^+$, while the D^0 final states

- $K^-\pi^+$,
- $K^-\pi^-\pi^+\pi^+$

are considered. One kaon and two pions are combined to form the charged D meson.

References

[1] Belle collaboration, M. Röhrken et al., Measurements of branching fractions and time-dependent CP violating asymmetries in $B^0 \to D^{(*)\pm}D^{\mp}$ decays, Phys. Rev. Lett. 108 (2012) [arXiv:1201.4643]

[2] BaBar collaboration, B. Aubert et al., Measurements of time-dependent CP asymmetries in $B^0 \to D^{(*)+}D^{(*)-}$ decays, Phys. Rev. D79 (2009) [arXiv:0808.1866]

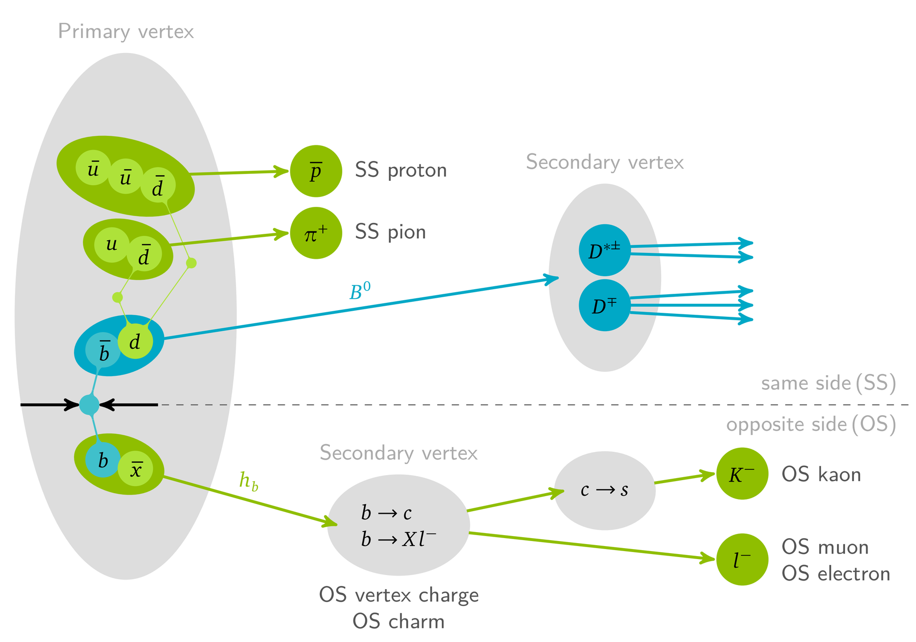
[3] Heavy Flavor Averaging Group, Y. Amhis et al., Averages of b-hadron, c-hadron, and τ-lepton properties as of summer 2016, updated results and plots available at http://www.slac.stanford.edu/xorg/hfag/ [arXiv:1612.07233]

[4] LHCb Collaboration, R. Aaij et. al., Opposite-side flavour tagging of B mesons at the LHCb experiment, Eur. Phys. J. C72 (2012) 2022 [arXiv:1202.4979]

[5] LHCb collaboration, R. Aaij et al., Measurement of CP violation in $B^0 \to D^+D^-$ decays, Phys. Rev. Lett. 117 (2016) [arXiv:1608.06620]

Flavour Tagging

The knowledge of the b quark flavour at production is essential for the measurement of a time-dependent CP asymmetry. This identification is performed by the Flavour Tagging.

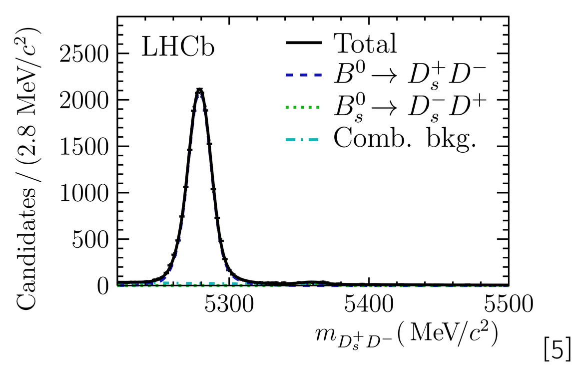


Utilised Tagging Algorithms

- OS standard combination (OSμ, e, K, vtx Charge) [4]
- Combination of SSp and SSπ

Calibration Channels

- $B^0 \to D_s^+ D^-$
- $B^0 \to D^{*-} D_s^+$



[5]

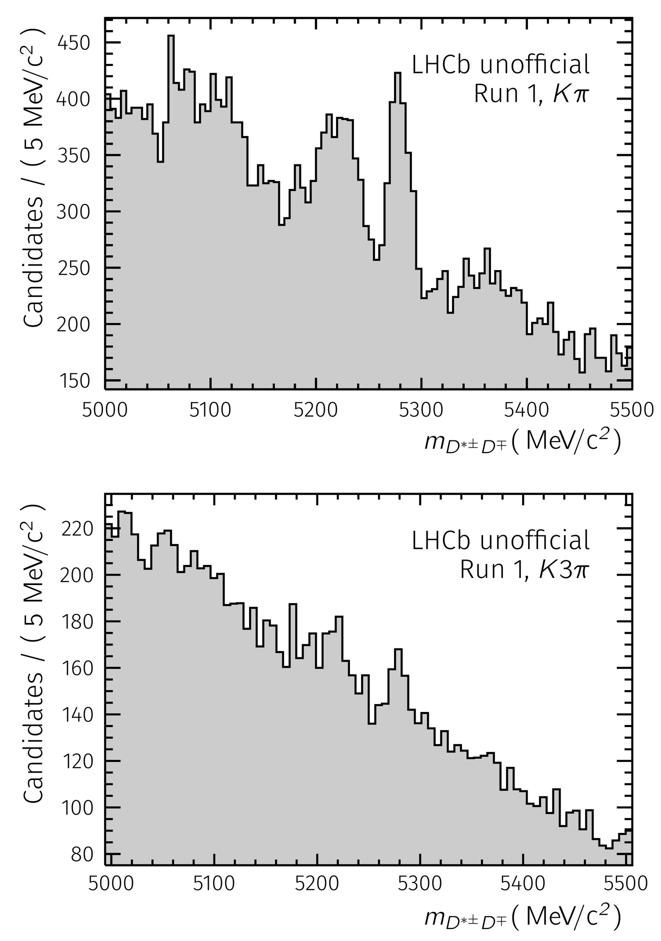
Tagging Power

Signal	Mode	OS combination	SS combination
Run 1	$D^0 \to K^-\pi^+$	$(4.14 \pm 0.34({\rm stat}))\%$	$(2.66 \pm 0.22({\rm stat}))\%$
	$D^0 \to K^-3\pi$	$(4.75 \pm 0.54({\rm stat}))\%$	$(2.39 \pm 0.22({\rm stat}))\%$
Run 2	$D^0 \to K^-\pi^+$	$(3.15 \pm 0.23({\rm stat}))\%$	$(2.72 \pm 0.13({\rm stat}))\%$
	$D^0 \to K^-3\pi$	$(3.66 \pm 0.41({\rm stat}))\%$	$(3.18 \pm 0.28({\rm stat}))\%$

Selection

Cut-based Preselection

variable	cut
$D^{*\pm}$, D^0 mass	$m_{D^{*\pm}} - m_{D^0} < 150$ MeV/c^2
D^0 mass	$\lvert m_{D^0} - m_{D^0,\rm PDG}\rvert < 40$ MeV/c^2
$D^\pm$ mass	$\lvert m_{D^\pm} - m_{D^\pm,\rm PDG}\rvert < 50$ MeV/c^2



Vetoes

Physical backgrounds occur due to misidentifications of pions and kaons.
Such backgrounds are suppressed by cuts on the invariant mass distributions in combination with requirements on Particle Identification (PID) variables.

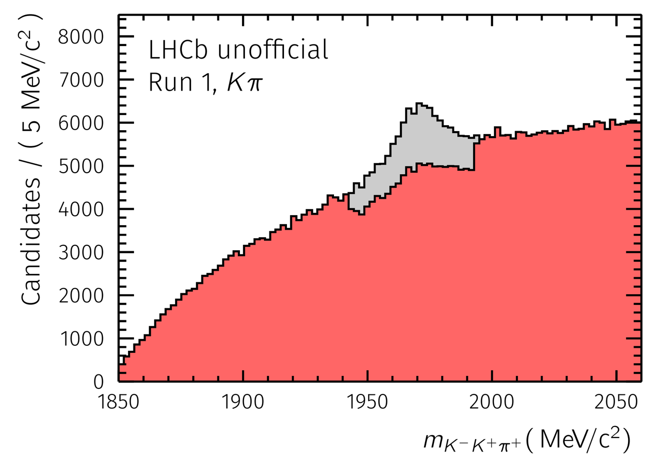
Example: D_s^+ Veto

Reject candidates, if

- $\lvert m_{KK\pi} - m_{D_s^+}\rvert < 25$ MeV/c^2

and

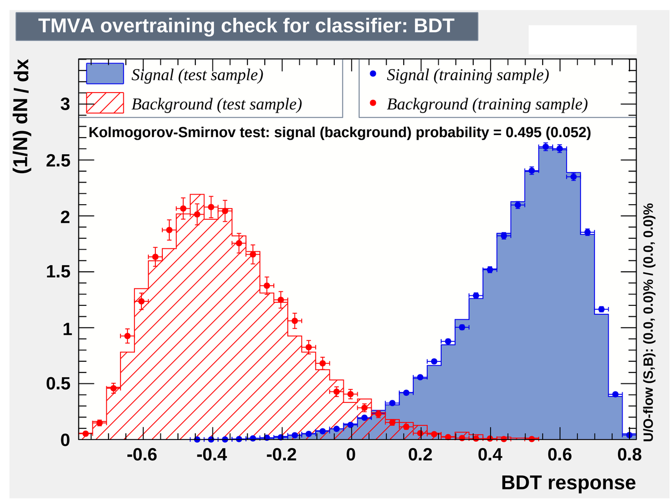
- if the pion is more likely a kaon.



Multivariate Selection

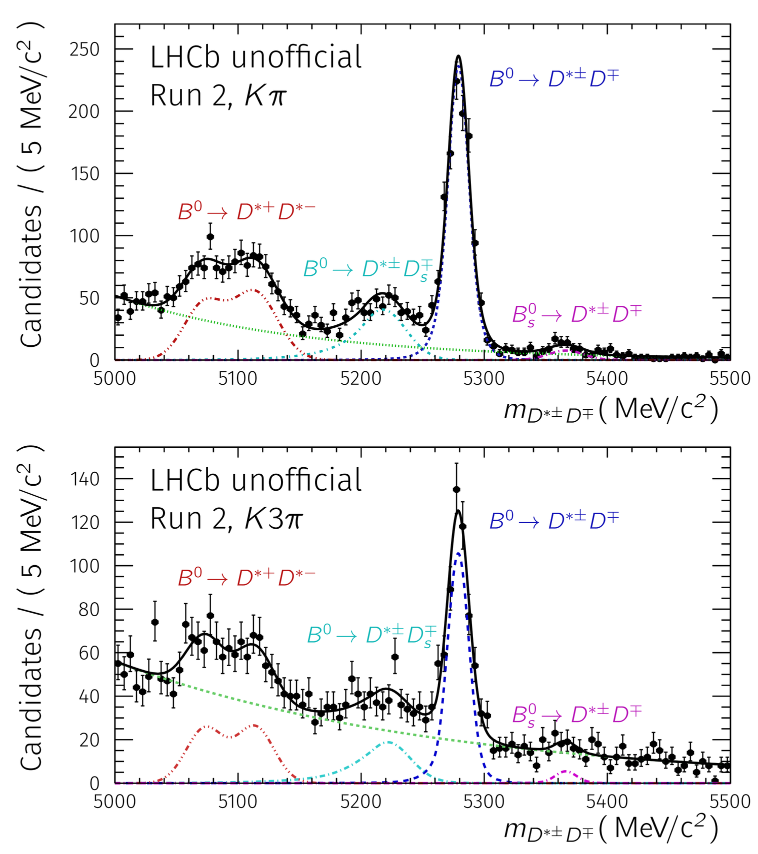
To reduce combinatorial background a multivariate selection is developed:

- Boosted Decision Tree (BDT)
- Signal proxy: signal MC
- Background proxy: upper mass sideband from data
- Training variables: kinematic, topological and PID variables
- BDT cut point: minimises uncertainties of CP parameters



Mass Fit

A mass fit is performed to disentangle signal from remaining background candidates.
The shape of the signal and background components is based on simulated data.



Signal Candidates (preliminary)

$D^0 \to K^-\pi^+$

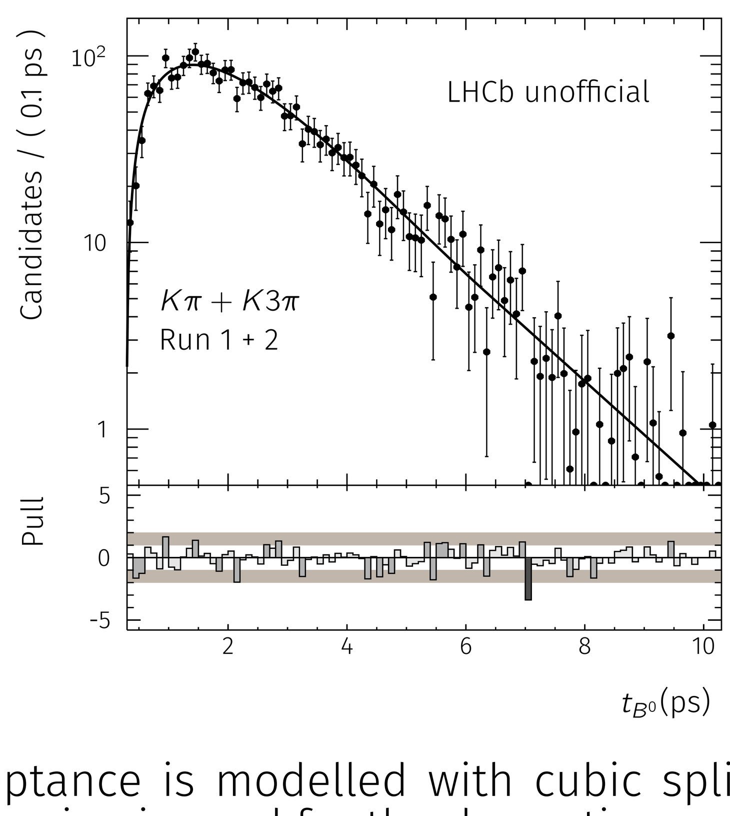
- Run 1: 893 ± 33
- Run 2: 1116 ± 36

$D^0 \to K^-\pi^-\pi^+\pi^+$

- Run 1: 475 ± 29
- Run 2: 494 ± 27

Decay-time Fit

A fit to the reconstructed decay time is performed to extract the CP parameters.



The acceptance is modelled with cubic splines and a triple Gaussian is used for the decay-time resolution.

Preliminary Result

$$\sigma(S) = \sigma(\Delta S) \approx 0.11$$
$$\sigma(C) = \sigma(\Delta C) \approx 0.13$$

This analysis is still blinded.