Study of $B_s^0 \to \eta_c(4h)\phi(K^+K^-)$ pre-selection at LHCb

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Abstract

The LHCb experiment [1] is designed to carry out precision measurements in beauty and charm sectors. One of the core physics programs at LHCb is the determination of CP-violating phase ϕ_s in the transition $b \to c\bar{c}s$. The $B_s^0 \to \eta_c\phi$ decay is such process, and has never been studied before. A multivariate analysis based pre-selection has been developed for $B_s^0 \to \eta_c\phi$, with $\eta_c \to 4h$, and $\phi \to K^+K^-$. The efficiency of pre-selection has been improved by a factor of 4, compared to previous work.

Introduction

The existence of the CP-Violation permits unambiguous discrimination between matter and antimatter. Sources of CP-violation in the Standard Model can not explain the matter/antimatter asymmetry in the universe. On the other hand, some new physics models predict additionnal sources of CP-violation. These can appear in loop processes. The interference between B_s^0 meson decay amplitudes to CP final state directly or via mixing gives rise to a measurable CP-violating phase ϕ_s, which is predicted to be $\phi_s^{SM} = (-0.0364 \pm 0.0017)\,\mathrm{rad}$ [2] in the Standard Model. However, such process may receive contributions from the new physics and change the value of ϕ_s.

At present, the most precise measurement of ϕ_s is given by the LHCb experiment, using the decay $B_s^0 \to J/\psi\,\phi$, with $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$. The measured ϕ_s is $\phi_s^{\mathrm{exp}} = (0.07\pm0.09\pm0.01)\mathrm{rad}$ [3], which is still dominated by the statistical uncertainty. Study of other decays that is sensitive to ϕ_s would be very useful.

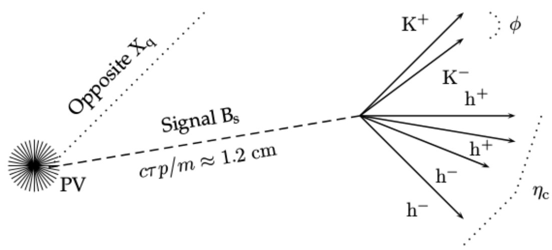

Fig 1: Schematic reconstruction of the event $B_s^0 \to \eta_c\phi$.

One of them, which has never been observed before, is the decay $B_s^0 \to \eta_c\phi$; where η_c is reconstruct in 4 hadrons and ϕ reconstruct in 2 kaons (Fig 1). The 4 hadrons which come from η_c can be $K^+K^-\pi^+\pi^-$ (53%), $\pi^+\pi^-\pi^+\pi^-$ (40%) or $K^+K^-K^+K^-$ (7%); with the $\eta_c \to$ 4h fraction in parenthesis. Since there are six hadrons in the final states, it is challenging to trigger and select such decay from the huge background at LHC. On the other hand, the total branching ratio of $B_s^0 \to \eta_c(4h)\phi(K^+K^-)$ is of the same order of magnitude as the decay $B_s^0 \to J/\psi\,(\mu^+\mu^-)\phi(K^+K^-)$. Furthermore, the final state $\eta_c\phi$ has a CP-eigenstate equal to $\eta_{CP,\eta_c} \times \eta_{CP,\phi} \times (-1)^l$; with l the relative orbital momentum between the resonance η_c and ϕ. It's only CP-even compare with the final state $J/\psi\,\phi$ which is a mixing CP-even and CP-odd state. As a result, the study of $B_s^0 \to \eta_c\phi$ doesn't need an angular analysis.

To have best sensitivity to the ϕ_s, we have to maximize the signal yields, N_S,

$$N_s = \mathcal{L}_{\text{int}} \times \sigma_{b\bar{b}} \times f_{B_s^0} \times 2 \times \mathcal{B}(B_s^0 \to \eta_c(4h)\phi(KK)) \times \epsilon_{\text{tot}}, \tag{1}$$

where $\mathcal{L}_{\text{int}}$ is the total luminosity (1 fb^{-1} in 2011 and 2 fb^{-1} in 2012), $\sigma_{b\bar{b}}$ is the cross section ((288 $\pm$ 4 $\pm$ 48)μb at 7 TeV [4] and (298 $\pm$ 3 $\pm$ 36)μb at 8 TeV [5]), $f_{B_s^0}$ is the fraction of b quark that hadronize to B_s^0 meson (about 10%), $\mathcal{B}(B_s^0 \to \eta_c(4h)\phi(KK))$ is the total branching fraction, and ϵ_{tot} is the total efficiency.

The total efficiency includes geometrical acceptance, trigger and reconstruction, and offline selections.

$$\epsilon_{\text{tot}} = \epsilon_{\text{acceptance}} \times \epsilon_{\text{reconstruction}} \times \epsilon_{\text{trigger}} \times \epsilon_{\text{selection}} \tag{2}$$

In this study, we try to optimize the offline preselection, called as Stripping in LHCb. This report is organized as follows. The first section presents the previous Stripping Line and its shortcomings. The second section describes the new Stripping Line and the BDT implementation.

Previous Stripping Line

Old Stripping Line reconstructing $B_s^0 \to \eta_c(\to K^+K^-\pi^+\pi^-)\phi(\to K^+K^-)$ is already present in the LHCb software. This Stripping uses a collection of kinematic, geometric and PID variables. The crucial variables and the cut-efficiency associated are quoted in the Tab 1. We estimated the efficiencies per cut using simulated $B_s^0 \to \eta_c\phi$ decays in LHCb detector. The total efficienty is only (8.63$\pm$0.13)%.

			%		
K^+ PT [MeV]	$>$	750.0	79.57	$\pm$	0.18
K^- PT [MeV]	$>$	750.0	79.45	$\pm$	0.19
π^+ PT [MeV]	$>$	750.0	66.05	$\pm$	0.23
π^- PT [MeV]	$>$	750.0	65.79	$\pm$	0.23
η_c			%		
ΣPT (K^+, K^-, π^+, π^-) [MeV]	$>$	4000.0	77.45	$\pm$	0.20
DOCA	$<$	0.1	65.02	$\pm$	0.23
Max(PT$_{K^+,K^-,\pi^+,\pi^-}$) [MeV]	$>$	1400.0	85.65	$\pm$	0.17
$\eta_c \to K^+K^-\pi^+\pi^-$			18.41	$\pm$	0.18
			%		
K^+ PIDK	$>$	-3.0	98.65	$\pm$	0.05
K^- PIDK	$>$	-3.0	98.63	$\pm$	0.06
ϕ			%		
PT [MeV]	$>$	1900.0	76.47	$\pm$	0.20
DIRA_OWNPV	$>$	0.95	86.52	$\pm$	0.16
$\phi \to K^+K^-$			55.66	$\pm$	0.24
B_s^0			%		
ENDVERTEX_Z	$>$	0.0	75.74	$\pm$	0.20
$B_s^0 \to \eta_c\phi$			8.63	$\pm$	0.13

Tab 1: Some efficiency of the previous Stripping Line.

New Stripping Line with BDT implementation

To improve efficiency of preselection (Stripping), the cuts need to be loosened. On the other hand, due to limited CPU and disk spaces, one Stripping line can not take more than 1 ms/event, and should have high background rejection power so that the retention rate is small (<0.05%). So for the new Stripping line, a cut-based pre-selection is used to reduce the number of combinations and CPU timing. Then a BDT-based selection is used to suppress background further while retaining high signal efficiency.

The new cuts and their efficiency are shown in Tab 2. The total efficiency of the cut-based preselection is (37.07$\pm$0.23)%.

		%		
K^+ PT [MeV]	$>$ 250.0	97.76	$\pm$	0.07
K^+ ProbNNk	$>$ 0.13	93.93	$\pm$	0.11
K^- PT [MeV]	$>$ 250.0	97.79	$\pm$	0.07
K^- ProbNNk	$>$ 0.13	93.91	$\pm$	0.11
π^+ PT [MeV]	$>$ 250.0	94.34	$\pm$	0.11
π^+ ProbNNpi	$>$ 0.2	97.90	$\pm$	0.07
π^- PT [MeV]	$>$ 250.0	94.40	$\pm$	0.11
π^- ProbNNpi	$>$ 0.2	97.97	$\pm$	0.07
η_c		%		
ΣPT (K^+, K^-, π^+, π^-) [MeV]	$>$ 2500.0	96.79	$\pm$	0.08
Σ IPCHI2_OWNPV (K^+, K^-, π^+, π^-)	$>$ 30.0	93.03	$\pm$	0.12
IPCHI2_OWNPV	$>$ 2.0	94.32	$\pm$	0.11
		%		
K^+ PT	$>$ 500.0	92.36	$\pm$	0.13
K^+ IPCHI2_OWNPV	$>$ 4.0	91.35	$\pm$	0.13
K^+ PIDK	$>$ 0.0	96.68	$\pm$	0.08
K^- PT	$>$ 500.0	92.20	$\pm$	0.13
K^- IPCHI2_OWNPV	$>$ 4.0	91.34	$\pm$	0.13
K^- PIDK	$>$ 0.0	96.73	$\pm$	0.08
ϕ		%		
PT [MeV]	$>$ 800.0	95.53	$\pm$	0.10
IPCHI2_OWNPV	$>$ 2.0	95.09	$\pm$	0.10
ENDVERTEX_CHI2	$<$ 9.0	95.81	$\pm$	0.09
B_s^0		%		
DIRA_OWNPV	$>$ 0.99	98.13	$\pm$	0.06
$B_s^0 \to \eta_c \phi$		37.07	$\pm$	0.23
$B_s^0 \to \eta_c \phi$ (previous)		8.63	$\pm$	0.13

Tab 2: Some cut-based preselection of the New Stripping.

In the second step, the multivariate analysis is used to suppress background further [6]. This method uses the correlation between variables and gives a fonction which map the multivariate space. In order to train the MVA, we use signal simulation and we used Upper Side Band of the real data as background. We use two MVA methods (Boosted Decision Tree, Gradiant Boosted Decision Tree) for the training. These are algorithme with a binary structure which optimize the ratio $\frac{S}{\sqrt{S+B}}$ where S is the signal and B the background. Among the variables used there are the transverse momentum of all particles expect of B_s^0, the impact parameter of all particles, the decay time of B_s^0, primaris vertex constraint and angle direction. The Fig 2.a shows that the BDT method performs better than the BDTG method. The Fig 2.b shows the distribution of the BDT weights for the signal (blue) and the background (red). The efficiency of BDT-cut (BDT response > 0) is 95.54% which give a total Stripping efficiency is $37.07 \times 95.54 = 35.41\%$.

This New Stripping Line is now submited to the LHCb stripping software, it will be used to re-strip 3 fb^{-1} of data accumulated during Run1 phase. Two additionnal stripping lines for $B_s^0 \to \eta_c(\to \pi^+\pi^-\pi^+\pi^-)\phi(\to K^+K^-)$ and $B_s^0 \to \eta_c(\to K^+K^-K^+K^-)\phi(\to K^+K^-)$ were implemented.

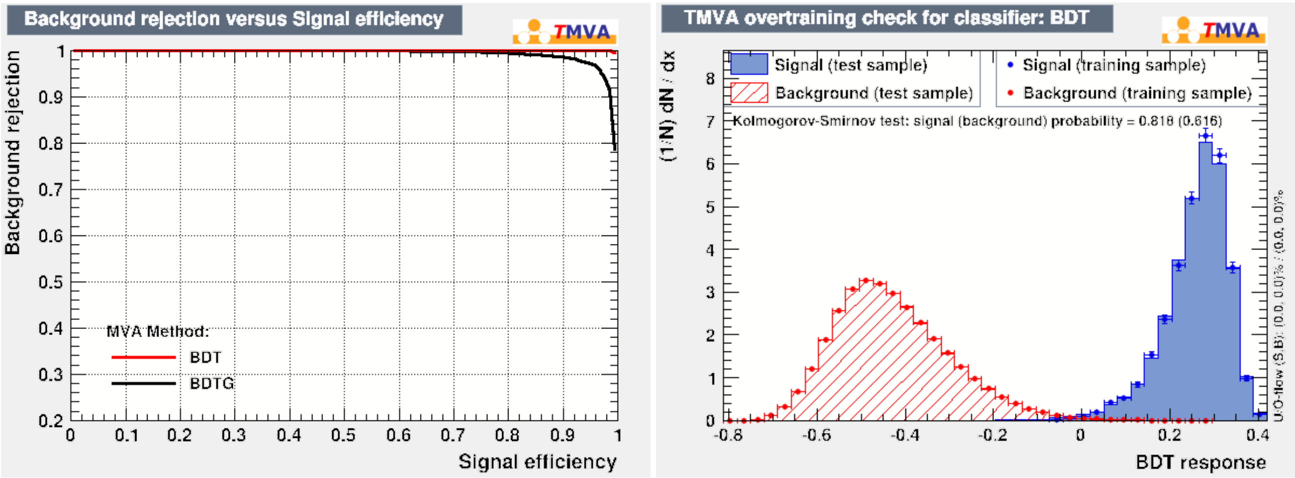

Fig 2: a) Background rejection versus the signal efficiency to BDT Method and BDTG Method. b) Background and signal separation with the BDT Method.

Conclusion and prospect

In this study we optimized the Stripping Line for the decay $B_s^0 \to \eta_c \phi$ reconstruct in 6 hadrons. A BDT is trained, the total selection efficiency obtained using the BDT approche increased by a factor 4. The retention rate is also improved. The expected signal yield with the new approche is about 1000 events per 3 fb^{-1} of data. Additionnaly we implemented the $B_s^0 \to J/\psi \phi$ for the signal, this will alow us to measure the relative branching ratio of $B_s^0 \to \eta_c \phi$.

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Bibliography

[1] Alves and all. The LHCb Detector at the LHC. *J. Instrum.*, 3(LHCb-DP-2008-001. CERN-LHCb-DP-2008-001):S08005, 2008. Also published by CERN Geneva in 2010.

[2] J. Charles et al. CP violation and the CKM matrix: Assessing the impact of the asymmetric B factories. *Eur.Phys.J.*, C41:1–131, 2005.

[3] R Aaij et al. Measurement of CP violation and the B_s^0 meson decay width difference with $B_s^0 \to J/\psi K^+K^-$ and $B_s^0 \to J/\psi \pi^+\pi^-$ decays. *Phys.Rev.*, D87(11):112010, 2013.

[4] R. Aaij et al. Measurement of J/ψ production in pp collisions at $\sqrt{s} = 7$ TeV. *Eur.Phys.J.*, C71:1645, 2011.

[5] R Aaij et al. Production of J/ψ and Υ mesons in pp collisions at $\sqrt{s} = 8$ TeV. *JHEP*, 1306:064, 2013.

[6] Andreas Hocker, J. Stelzer, F. Tegenfeldt, H. Voss, K. Voss, et al. TMVA - Toolkit for Multivariate Data Analysis. *PoS*, ACAT:040, 2007.