EPJ Web of Conferences **81**, 03001 (2014)
DOI: 10.1051/epjconf/20148103001

Mixing and CP violation in the B_s system with ATLAS

Pavol Bartoš[1, a]
On behalf of the ATLAS Collaboration.

[1] *Department of nuclear physics and biophysics, Faculty of Mathematics, Physics and Informatics, Comenius University, Mlynská Dolina F1, 842 48 Bratislava, Slovakia*

Abstract. The different amplitudes contributing to the decay of B_s into $J/\psi\phi$ $(\mu^+\mu^- K^+K^-)$ can be studied with a combined analysis of the decay time and angular correlations. An analysis based on the LHC data collected by the ATLAS detector in 2011 and with initial B-meson flavour tagging is presented, improving the accuracy in the CP-violating phase ϕ_s compared to the untagged analysis.

1 Introduction

New phenomena beyond the Standard Model (SM) may alter CP violation in $B-$meson decays. The $B_s^0 \to J/\psi\phi$ decay channel is expected to be sensitive to a new physics contribution. The CP violation in this channel occurs due to interference between direct B_s^0 decays and decays following the $B_s^0 - \bar{B}_s^0$ mixing. The oscillation frequency of B_s^0 mixing is characterized by the mass difference Δm_s of the heavy (B_H) and light (B_L) mass eigenstates.

There are several quantities involved in $B_s^0 - \bar{B}_s^0$ mixing. The $CP-$violating phase ϕ_s is defined as the weak phase difference between amplitudes of $B_s^0 - \bar{B}_s^0$ mixing and direct decay. In the SM, the phase ϕ_s is small ($\phi_s = -0.0368 \pm 0.0018$ rad [1]) and can be related to CKM quark mixing matrix elements. Some new physics models predicts large values of ϕ_s while satisfying all existing constrains [2, 3]. The width difference $\Delta\Gamma_s = \Gamma_L - \Gamma_H$ of B_L and B_H is predicted to be $\Delta\Gamma_s = 0.087 \pm 0.021$ ps^{-1} [4]. Physics beyond the SM is not expected to affect $\Delta\Gamma_s$ as significantly as ϕ_s [5]. Nevertheless, it is useful to extract $\Delta\Gamma_s$ from data as it allows testing the theoretical predictions [5]. One can also define average decay width $\Gamma_s = (\Gamma_L + \Gamma_H)/2$. Among important parameters are also the amplitudes $A_0(0)$ and $A_\parallel(0)$ for the CP-even components of the B_s^0 decay, and $A_\perp(0)$ for the CP-odd component. The amplitudes have corresponding strong phases δ_0, $\delta_\parallel$ and $\delta_\perp$ (by convention, δ_0 is set to zero). The S-wave amplitude A_s describes the contribution of CP-odd $B_s \to J/\psi K^+K^-(f_0)$, where the non-resonant KK or f_0 meson is an S-wave state. The strong phase δ_s corresponds to the A_s.

The previous measurements of these quantities have been reported by the CDF [6], DØ [7], and LHCb [3] collaborations. In this paper, an update to the previous ATLAS measurement [8], using flavour tagging, is presented [9]. The analysis uses LHC pp data at $\sqrt{s} = 7$ TeV collected by the ATLAS detector [10] in 2011.

a. e-mail: Pavol.Bartos@cern.ch

2 Event selection

The candidate events have to pass trigger based on $J/\psi \to \mu^+\mu^-$ decay identification. In addition to that, events are required to contain at least one reconstructed primary vertex built from at least four Inner-detector tracks and at least one pair of oppositely charged muons. The pairs of muon tracks are refitted to a common vertex and accepted as a J/ψ candidate if the fit results in χ^2/d.o.f. < 10 and the invariant mass of the pair falls in a signal region. Taking into account varying mass resolution, the signal region is a mass range around J/ψ mass, which depends on the pseudorapidity of the muons. The mass range is defined so as to retain 99.8% of the J/ψ candidates identified in the fit.

The $\phi \to K^+K^-$ candidates are reconstructed from all pairs of oppositely charged tracks with transverse momentum $p_T > 0.5$ GeV and pseudorapidity $|\eta| < 2.5$, which are not identified as muons.

The final selection is done by fitting the tracks for each combination of $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$ to a common vertex. The fit is further constrained by fixing the calculated invariant mass from the two muon tracks to the world average J/ψ mass [11]. The quadruples of tracks are accepted as B_s^0 candidates if the fit results in χ^2/d.o.f. < 3, the fitted transverse momentum p_T of the tracks from $\phi \to K^+K^-$ is greater than 1 GeV and the invariant mass of the track pair (under assumption that they are kaons) falls within interval 1.0085 GeV $< m(K^+K^-) <$ 1.0305 GeV. In total, 131k B_s^0 candidates are collected within a mass range of $5.15 < m(B_s^0) < 5.65$ GeV.

In the selected events, there are 5.6 interactions per event in average. The primary vertex at which the B_s^0 meson is produced, is selected by requiring the smallest three-dimensional impact parameter [12]. Using the Monte Carlo simulation it is shown that the wrong assignment of B_s^0 to primary vertex occurs in less than 1% of cases.

3 Flavour tagging

To increase the sensitivity of the measurement, the opposite side flavour tagging is used. The initial flavour of neutral B-mesons is inferred from the other B-meson which is coming from the other b quark in the event. The method is studied and calibrated using $B^\pm \to J/\psi K^\pm$ events, where the charge of the B-meson at production is extracted from the kaon charge.

There are two possibilities to obtain the charge of the other B-meson in the event. In case of presence of an additional muon, which originates near the interaction point, one can define *muon cone charge* as a weighted sum of the charges of the tracks (with $p_T > 0.5$ GeV and $|\eta| < 2.5$), which are reconstructed within a cone of $\Delta R < 0.5$ around the muon momentum axis. In case of multiple muons, the one with the highest transverse momentum is selected. In the absence of an additional muon, a b-tagged jet [13] is required in the event, with tracks associated to the same primary vertex as the signal decay. The jet is reconstructed using the anti-k_t algorithm with a cone size of 0.6. In this case, a *jet charge* is defined as a weighted sum of the charges of the tracks associated to the jet. In case of multiple jets, the jet with the highest value of b-tag weight is used.

Using the calculated muon-cone charge or jet charge (in the absence of an additional muon), one can define per-B_s candidate probability that the B_s was born as B_s and not as $\bar{B}_s$. If it is not possible to provide tagging response for the event, the probability of 0.5 is assigned.

4 Likelihood fit

An unbinned likelihood fit is used to extract the B_s^0-decay parameters mentioned in section 1. The fit uses the information about reconstructed mass, the measured proper decay time together with their uncertainties, tag probability, and the transversity angles. The likelihood function is defined as a combination of the signal and background probability density functions as follows:

$$lnL = \sum_{i}^{N}\{w_i \cdot ln(f_s \cdot F_s(m_i, t_i, \Omega_i) + f_s \cdot f_{B^0} \cdot F_{B^0}(m_i, t_i, \Omega_i)) + (1 - f_s \cdot (1 + f_{B^0}))F_{\text{bkg}}(m_i, t_i, \Omega_i)\}\ , \quad (1)$$

where N is the number of selected candidates, w_i is a weighting factor to account for the trigger efficiency, f_s is the fraction of signal candidates, f_{B^0} is the fraction of peaking B^0-meson background events calculated relative to the number of signal events (this parameter is fixed in the likelihood fit). The mass m_i, the proper decay time t_i, and the decay angles Ω_i are the values measured from the data for each event i. F_s, F_{B^0}, and F_{bkg} are the probability density functions (PDF) modeling signal, the specific B^0 background and the other background distributions, respectively. A detailed description of the likelihood terms can be found in [9].

5 Results and conclusions

The PDF describing the $B_s^0 \to J/\psi\phi$ decay is invariant under the following simultaneous transformations:

$$\{\phi_s, \Delta\Gamma_s, \delta_\perp, \delta_{||}\} \to (\pi - \phi_s, -\Delta\Gamma_s, \pi - \delta_\perp, 2\pi - \delta_{||})\ .$$

$\Delta\Gamma_s$ has been defined to be positive [14]. Therefore, there is a unique solution.

Table 1. Fitted values for the physical parameters along with their statistical and systematic uncertainties [9].

Parameter	Value	Statistical uncertainty	Systematic uncertainty
ϕ_s (rad)	0.12	0.25	0.05
$\Delta\Gamma_s$ (ps^{-1})	0.053	0.021	0.010
Γ_s (ps^{-1})	0.677	0.007	0.004
$\|A_{\|\|}(0)\|^2$	0.220	0.008	0.009
$\|A_0(0)\|^2$	0.529	0.006	0.012
$\|A_S\|^2$	0.024	0.014	0.028
$\delta_\perp$	3.89	0.47	0.11
$\delta_{\|\|}$	[3.04 – 3.23]		0.09
$\delta_\perp - \delta_S$	[3.02 – 3.25]		0.04

The results of the measurement are summarized in table 1. The values are consistent with those obtained in the untagged analysis [8], while the overall uncertainty of ϕ_s is significantly improved. The results are consistent with theoretical expectations, in particular ϕ_s and $\Delta\Gamma_s$ are in good agreement with the values predicted by the Standard Model. Figure 1 shows the likelihood contour in $\phi_s - \Delta\Gamma_s$ plane. The fraction of S-wave KK of f_0 contamination is measured to be consistent with zero. The results of $\delta_{||}$ and $\delta_\perp - \delta_s$ are given in the form of a 1σ confidence interval. The $|A_\perp(0)|^2$ can be determined from a constrain that the squares of the amplitudes sum to unity.

For all of the measured parameters except ϕ_s, the main source of the systematics uncertainty comes from assumptions made for the transversity angles in case of background events. The main source of the systematics uncertainty for the ϕ_s is flavour tagging.

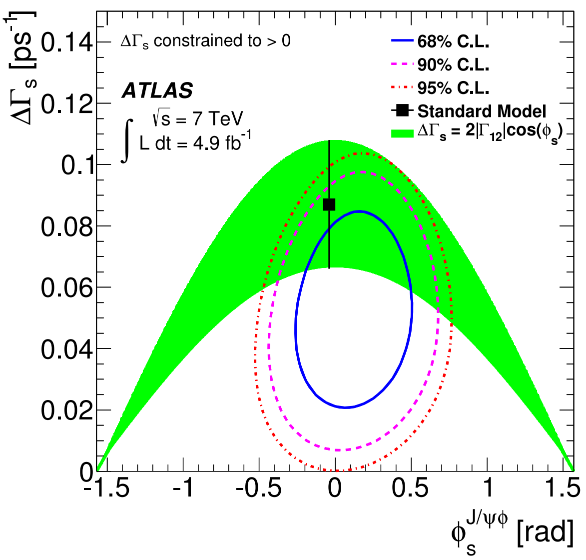

Figure 1. Likelihood contours in $\phi_s - \Delta\Gamma_s$ plane. The blue line shows the 68% likelihood contour, the dashed pink line shows the 90% likelihood contour, and the red dotted line shows the 95% likelihood contour (statistical errors only). The green band is the theoretical prediction of mixing-induced CP violation [9].

Acknowledgements

It is a pleasure to thank the ATLAS collaborators for their well-done work, the conveners of the B-physics working group for their help and the organizers of the Meson 2014 for a very interesting conference. This work was supported by Ministry of Education, Science, Research and Sport of the Slovak Republic.

References

[1] UTfit Collaboration, M. Bona *et al.*, Phys. Rev. Lett. **97**, 151803 (2006).
[2] CDF Collaboration, A. Abulencia *et al.*, Phys. Rev. Lett. **97**, 242003 (2006).
[3] LHCb Collaboration, R. Aaij *et al.*, Phys. Lett. B **709**, 177-184 (2012).
[4] A. Lenz and U. Nierste, arXiv: 1102.4274 [hep-ph].
[5] A. Lenz and U. Nierste, JHEP **0706**, 072 (2007).
[6] CDF Collaboration, T. Aaltonen *et al.*, Phys. Rev. D **85**, 072002 (2012).
[7] DØ Collaboration, V. M. Abazov *et al.*, Phys. Rev. Lett. **108**, 101803 (2012).
[8] ATLAS Collaboration, JHEP **1212**, 072 (2012).
[9] ATLAS Collaboration, Phys. Rev. D **90**, 052007 (2014).
[10] ATLAS Collaboration, JINST 3, S08003 (2008).
[11] Particle Data Group Collaboration, J. Beringer *et al.*, Phys. Rev. D **86**, 010001 (2012), (and 2013 partial update for the 2014 edition).
[12] Three-dimensional impact parameter is defined as the distance between the line extrapolated from the reconstructed B_s^0 meson vertex in the direction of the B_s^0 momentum and a primary vertex.
[13] ATLAS Collaboration, ATLAS-CONF-2011-102, http://cds.cern.ch/record/1369219.
[14] LHCb Collaboration, R. Aaij *et al.*, Phys. Rev. Lett. **108**, 241801 (2012).