Научном већу Института за физику

Београд,
07. јул 2014.

ПРЕДМЕТ:

Молба за покретање поступка за реизбор у звање *истраживач-сарадник*

Молим Научно веће Института за физику да покрене поступак за мој реизбор у звање истраживач-сарадник.

У прилогу достављам:

- Стручну биографију
- Мишљење руководиоца пројекта
- Списак и копије објављених радова
- Одлуку о стицању истраживачког звања истраживач-сарадник
- Потврду о уписаним докторским студијама

За чланове Комисије за писање извештаја за реизбор Предрага Ћирковића у звање истраживач-сарадник предлажем:

1. др Љиљану Симић, научног саветника Института за физику (као првог референта),
2. др Марију Врањеш Милосављевић, научног сарадника Института за физику,
3. др Милоша Ђорђевића, научног сарадника Института за нуклеарне науке „Винча“.

С поштовањем,

Предраг Ћирковић
истраживач-сарадник

Биографија кандидата

Предраг Ћирковић рођен је 14. децембра 1984. године у Кикинди, Република Србија. Основне студије уписао је 2003. године на Електротехничком факултету, Универзитета у Београду. Дипломирао је на Одсеку за електронику са просечном оценом 8.07 и оценом 10 на дипломском раду на тему „Реализација асемблерског преводиоца за 16-битни RISC процесор Харвардске архитектуре“. Мастер студије завршио је 2009. године на истом факултету са просечном оценом 10, одбранивши мастер рад на тему „Софтверски контролисани дигитални FM модулатор за 100 стандардних станица“ са оценом 10. Од октобра 2010. године уписан је на програм Докторских академских студија на Физичком факултету, Универзитета у Београду, на смеру Физика језгра и честица. Тренутно је студент треће године и положио је све испите предвиђене програмом.

Од 1. априла 2010. године био је запослен у Институту за нуклеарне науке „Винча“. Звање истраживач сарадник стекао је 5. маја 2011. године. Од 15. марта 2011. године, учествује у ATLAS експерименту на Великом хадронском сударачу (LHC) у CERN-у. Радио је на квалификацији за ауторство на задацима у области b-физике и идентификације знака наелектрисања b-кварка. Од 15. марта 2012. године, квалификовао се за ауторство на радовима ATLAS колаборације развијајући алате за праћење квалитета података који користе алгоритми за „tagiranje“ b-џетова. У оквиру ATLAS експеримента, такође је радио на „тагирању“ флејвора B_s^0 мезона које омогућава уклањање нееднозначности у мерењу фазе нарушења CP симетрије у распадима $B_s^0 \to J/\psi\, \phi$. Ова активност је резултовала објављивањем рада „*Time-dependent angular analysis of the decay* $B_s^0 \to J/\psi\phi$ *and extraction of* $\Delta\Gamma_s$ *and the CP-violating weak phase* ϕ_s *by ATLAS*“ објављеног у часопису Journal of High Energy Physics и одговарајуће интерне (backup) ноте ATLAS колаборације (*ATL-COM-PHYS-2013-293*) која детаљно описује све техничке аспекте и читав поступак анализе.

Предраг Ћирковић је похађао следеће међународне школе физике честица:
- European School of High Energy Physics, од 5. до 18. јуна, 2013. Parádfürdő, Мађарска,
- Sarajevo School of High Energy Physics, од 9. до 13. маја, 2012. Сарајево, Босна и Херцеговина,
- Trans-European School of High Energy Physics, од 13. до 20. јула, 2012. Петница, Србија,
- AIDA Student Tutorial – Solid State Detectors, 27. марта 2012. Хамбург, Немачка.

Од 1. септембра 2013. године, запослен је у Институту за физику и учествује у CMS експерименту на Великом хадронском сударачу (LHC) у CERN-у. Тренутно је ангажован на квалификацији за ауторску листу CMS колаборације на задацима редизајнирања кода за валидацију података прикупљених помоћу Pixel детектора. Такође је започео и рад на анализи за докторску дисертацију која се бави темом распада Higgs бозона асоцираних са паром top кваркова, $t\bar{t}H$, где се Higgs бозон распада на парове ZZ^*, WW^* и $\tau\tau$, продукујући лептонска финална стања ($2lss$, $3l$ и $4l$).

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Мишљење руководиоца пројекта за реизбор
Предрага Ћирковића у звање истраживач-сарадник

Колега Предраг Ћирковић испуњава све услове предвиђене Правилником за реизбор у звање истраживач-сарадник и сматрам да Научно веће Института за физику треба да покрене поступак за његов реизбор у ово звање.

До 1. септембра 2013. године, Предраг Ћирковић је био сарадник на Пројекту ОИ171012 и запослен у Лабораторији за физику 010 ИНН ”Винча”. Од 1. септембра 2013. он је запослен у Лабораторији за физику високих енергија Института за физику као истраживач-сарадник и учествује на пројекту Министарства просвете, науке и технолошког развоја ОИ171019: „Физика високих енергија на детектору CMS“.

Докторске студије на Физичком факултету Универзитета у Београду је уписао 2010. године. Тренутно је студент треће године, а положио је све испите предвиђене статутом докторских студија на смеру “Физика језгра и честица”. Учествовао је и радио на ATLAS експерименту на Великом хадронском сударачу (LHC) у CERN-у и у марту 2012. године успешно је завршио квалификацију за ауторску листу ATLAS колаборације. Резултате свог рада представљао је на интерним састанцима радних група (Flavour Tagging Combined Performance и B-Physics).

С обзиром да је променио пројект и истраживачку тему, колега Ћирковић се брзо и врло успешно прилагодио новој истраживачкој околини. У протеклих шест месеци успешно је окончао свој обавезни сервисни и пробни рад на експерименту CMS, прошао кроз све тренинг курсеве неопходне за активно учествовање у том експерименту и под менторством др Милоша Ђорђевића убрзано ради на својој докторској дисертацији везаној за изучавање и анализу финалног стања канала са Хигс бозоном асоцираним пару топ кваркова добијеним у сударима протона на детектору CMS.

Колега Предраг Ћирковић је до сада вредно посећивао неколико међународних школа из физике високих енергија у земљи и иностранству. Два пута је презентирао и резултате својих радова на међународним конгресима у земљи и иностранству.

Као студент докторских студија, колега Ћирковић је врло успешно положио два курса које држим на докторским студијама, добивши при том максималне оцене. Као руководилац Пројекта 171019 и српског истраживачког тима на експерименту CMS, очекујем да колега Предраг Ћирковић настави убрзано да напредује и да своју докторску дисертацију комплетира релативно брзо, с обзиром да је био принуђен на промену пројекта и истраживачке теме.

Свакако да сматрам да је реизбор у звање истраживач-сарадник најмање што колега Предраг Ћирковић заслужује, уз уверење да неће протећи дуго времена кад ће он да конкурише за звање научни сарадник.

Београд, 11. јун 2014.

Руководилац пројекта 171019,

Проф. др Петар Аџић,
редовни професор Физичког факултета
Универзитета у Београду

Списак научних радова и саопштења са конференција

Радови у врхунским међународним часописима (M21)

- G. Aad, …, P. Cirkovic *et al.* [ATLAS Collaboration], "Time-dependent angular analysis of the decay $B_s^0 \to J/\psi\phi$ and extraction of $\Delta\Gamma_s$ and the CP-violating weak phase ϕ_s by ATLAS", JHEP 1212 (2012) 072, [arXiv:1208.0572 [hep-ex]]

Интерна (backup) нота

- A. Barton, …, P. Cirkovic *et al.*, Internal documentation for "Time-dependent angular analysis of $B_s^0 \to J/\psi\phi$ decay and extraction of $\Delta\Gamma_s$ and weak phase of B_s^0 meson in ATLAS", March 5, 2013, ATL-COM-PHYS-2013-293

Остале референтне публикације ATLAS колаборације доступне на CERN CDS серверу (cds.cern.ch)

- G. Aad, …, P. Cirkovic *et al.* [ATLAS Collaboration], "Flavour tagged time dependent angular analysis of the $B_s^0 \to J/\psi\phi$ decay and extraction of $\Delta\Gamma_s$ and the weak phase ϕ_s in ATLAS", Apr 12, 2013. 18 pp. ATLAS-CONF-2013-039

Саопштења са међународних скупова (M30)

- The 2013 European School of High-Energy Physics, Parádfürdő, Hungary 05-18.06.2013. (ESHEP2013), Predrag Cirkovic, "B-flavour Charge Tagging in CP Violation Measurements in ATLAS Experiment"

Саопштења на националним конференцијама (M63)

- XII Конгрес физичара Србије, 28.04–02.05.2013. (https://indico.cern.ch/event/248020), Предраг Ћирковић, *et al.*, XII Конгрес физичара Србије, "ИДЕНТИФИКАЦИЈА ЗНАКА НАЕЛЕКТРИСАЊА b-КВАРКА У МЕРЕЊУ НАРУШЕЊА CP СИМЕТРИЈЕ У ATLAS ЕКСПЕРИМЕНТУ"

Презентације на састанцима ATLAS колаборације

- Predrag Cirkovic, "Comparison of calibration curves generated from 2011 (left) and 2012 (right) data", BsJpsiphi, CPV and tagging meeting, 16.08.2013. (https://indico.cern.ch/event/267762)
- Predrag Cirkovic, "Tagging: MC origin of jets and where we loose b-jets", BsJpsiphi, CPV and tagging meeting, 12.02.2013. (https://indico.cern.ch/event/235396)
- Predrag Cirkovic, "Jet-tagger tuning", BsJpsiphi, CPV and tagging meeting, 28.01.2013. (https://indico.cern.ch/event/231091)
- Predrag Cirkovic, "Tasks in Progress and Plans on B-tagging", BTagging DQ meeting, 20.10.2011. (https://indico.cern.ch/event/159573)
- Predrag Cirkovic, "d0, Sd0, z0, Sz0 variables distributions", BTagging DQ meeting, 25.05.2011. (https://indico.cern.ch/event/140846)

Презентације на састанцима CMS колаборације

- Predrag Cirkovic, "Update on the Pixel Validation Code Redesign", Tracker DQM Meeting, 17.06.2014. (https://indico.cern.ch/event/305424)
- Predrag Cirkovic, "Pixel Validation Code Redesign Contribution", Tracker DQM Meeting, 22.04.2014. (https://indico.cern.ch/event/305420)

- Predrag Cirkovic, “Pixel Validation Code Redesign Progress Report”, Tracker DQM Meeting, 25.02.2014. (https://indico.cern.ch/event/298805)
- Predrag Cirkovic, “Tracker MC Validation Progress Report”, Tracker DQM Meeting, 04.02.2014. (https://indico.cern.ch/event/298802)
- Predrag Cirkovic, “Pixel RecHits Validation Code Redesign Status”, Tracker DQM Meeting, 14.01.2014. (https://indico.cern.ch/event/290195)
- Predrag Cirkovic, “Pixel RecHits Validation Status”, Tracker DQM Meeting, 17.12.2013. (https://indico.cern.ch/event/243965)
- Predrag Cirkovic, “Pixel Tracker Validation”, Tracker DQM Meeting, 26.11.2013. (https://indico.cern.ch/event/243945)
- Predrag Cirkovic, “Pixel Tracker Validation”, Tracker DQM Meeting, 12.11.2013. (https://indico.cern.ch/event/243944)

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Time-dependent angular analysis of the decay $B_s^0 \to J/\psi\phi$ and extraction of $\Delta\Gamma_s$ and the CP-violating weak phase ϕ_s by ATLAS

The ATLAS collaboration

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ABSTRACT: A measurement of $B_s^0 \to J/\psi\phi$ decay parameters, including the CP-violating weak phase ϕ_s and the decay width difference $\Delta\Gamma_s$ is reported, using 4.9 fb^{-1} of integrated luminosity collected in 2011 by the ATLAS detector from LHC pp collisions at a centre-of-mass energy $\sqrt{s} = 7$ TeV. The mean decay width Γ_s and the transversity amplitudes $|A_0(0)|^2$ and $|A_{\parallel}(0)|^2$ are also measured. The values reported for these parameters are:

$$\begin{aligned}
\phi_s &= 0.22 \ \pm 0.41 \ \text{(stat.)} \pm \ 0.10 \ \text{(syst.) rad} \\
\Delta\Gamma_s &= 0.053 \pm 0.021 \ \text{(stat.)} \pm \ 0.010 \ \text{(syst.) ps}^{-1} \\
\Gamma_s &= 0.677 \pm 0.007 \ \text{(stat.)} \pm \ 0.004 \ \text{(syst.) ps}^{-1} \\
|A_0(0)|^2 &= 0.528 \pm 0.006 \ \text{(stat.)} \pm \ 0.009 \ \text{(syst.)} \\
|A_{\parallel}(0)|^2 &= 0.220 \pm 0.008 \ \text{(stat.)} \pm \ 0.007 \ \text{(syst.)}
\end{aligned}$$

where the values quoted for ϕ_s and $\Delta\Gamma_s$ correspond to the solution compatible with the external measurements to which the strong phase $\delta_{\perp}$ is constrained and where $\Delta\Gamma_s$ is constrained to be positive. The fraction of S-wave KK or f_0 contamination through the decays $B_s^0 \to J/\psi K^+K^-(f_0)$ is measured as well and is found to be consistent with zero. Results for ϕ_s and $\Delta\Gamma_s$ are also presented as 68%, 90% and 95% likelihood contours, which show agreement with Standard Model expectations.

KEYWORDS: Hadron-Hadron Scattering

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JHEP12(2012)072

Contents

1 Introduction

New phenomena beyond the predictions of the Standard Model (SM) may alter CP violation in B-decays. A channel that is expected to be sensitive to new physics contributions is the decay $B_s^0 \to J/\psi\phi$. CP violation in the $B_s^0 \to J/\psi\phi$ decay occurs due to interference between direct decays and decays occurring through $B_s^0 - \overline{B_s^0}$ mixing. The oscillation frequency of B_s^0 meson mixing is characterized by the mass difference Δm_s of the heavy (B_H) and light (B_L) mass eigenstates. The CP-violating phase ϕ_s is defined as the weak phase difference between the $B_s^0 - \overline{B_s^0}$ mixing amplitude and the $b \to c\bar{c}s$ decay amplitude. In the absence of CP violation, the B_H state would correspond exactly to the CP-odd state and the B_L to the CP-even state. In the SM the phase ϕ_s is small and can be related to CKM quark mixing matrix elements via the relation $\phi_s \simeq -2\beta_s$, with $\beta_s = \arg[-(V_{ts}V_{tb}^*)/(V_{cs}V_{cb}^*)]$; a value of $\phi_s \simeq -2\beta_s = -0.0368 \pm 0.0018$ rad [1] is predicted in the SM. Many new physics models predict large ϕ_s values whilst satisfying all existing constraints, including the precisely measured value of Δm_s [2, 3].

Another physical quantity involved in $B_s^0 - \overline{B_s^0}$ mixing is the width difference $\Delta\Gamma_s = \Gamma_L - \Gamma_H$ of B_L and B_H. Physics beyond the SM is not expected to affect $\Delta\Gamma_s$ as significantly as ϕ_s [4]. Extracting $\Delta\Gamma_s$ from data is nevertheless useful as it allows theoretical predictions to be tested [4].

The decay of the pseudoscalar B_s^0 to the vector-vector final-state $J/\psi\phi$ results in an admixture of CP-odd and CP-even states, with orbital angular momentum $L = 0$, 1 or 2. The final states with orbital angular momentum $L = 0$ or 2 are CP-even while the state with $L = 1$ is CP-odd. No flavour tagging to distinguish between the initial B_s^0 and $\overline{B_s^0}$ states is used in this analysis; the CP states are separated statistically through the time-dependence of the decay and angular correlations amongst the final-state particles.

In this paper, measurements of ϕ_s, the average decay width $\Gamma_s = (\Gamma_L + \Gamma_H)/2$ and the value of $\Delta\Gamma_s$, using the fully reconstructed decay $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ are presented. Previous measurements of these quantities have been reported by the CDF and DØ collaborations [6, 5] and recently by the LHCb collaboration [7]. The analysis presented here uses data collected by the ATLAS detector from LHC pp collisions running at $\sqrt{s} = 7$ TeV in 2011, corresponding to an integrated luminosity of approximately 4.9 fb^{-1}.

2 ATLAS detector and Monte Carlo simulation

The ATLAS experiment [8] is a multipurpose particle physics detector with a forward-backward symmetric cylindrical geometry and near 4π coverage in solid angle. The inner tracking detector (ID) consists of a silicon pixel detector, a silicon microstrip detector and a transition radiation tracker. The ID is surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, and by high-granularity liquid-argon (LAr) sampling electromagnetic calorimeter. An iron/scintillator tile calorimeter provides hadronic coverage in the central rapidity range. The end-cap and forward regions are instrumented with LAr calorimeters for both electromagnetic and hadronic measurements. The muon spectrometer (MS) surrounds the calorimeters and consists of three large superconducting toroids with eight coils each, a system of tracking chambers, and detectors for triggering.

The muon and tracking systems are of particular importance in the reconstruction of B meson candidates. Only data where both systems were operating correctly and where the LHC beams were declared to be stable are used. The data were collected during a period of rising instantaneous luminosity at the LHC, and the trigger conditions varied over this time.

The triggers used to select events for this analysis are based on identification of a $J/\psi \to \mu^+\mu^-$ decay, with either a 4 GeV transverse momentum[1] (p_{T}) threshold for each muon or an asymmetric configuration that applies a higher p_{T} threshold ($4 - 10$ GeV) to one of the muons and a looser muon-identification requirement (p_{T} threshold below 4 GeV) to the second one.

Monte Carlo (MC) simulation is used to study the detector response, estimate backgrounds and model systematic effects. For this study, 12 million MC-simulated $B_s^0 \to J/\psi\phi$

[1] The ATLAS coordinate system and the definition of transverse momentum are described in reference [8].

events were generated using PYTHIA [9] tuned with recent ATLAS data [10]. No p_T cuts were applied at the generator level. Detector responses for these events were simulated using an ATLAS simulation package based on GEANT4 [11, 12]. In order to take into account the varying trigger configurations during data-taking, the MC events were weighted to have the same trigger composition as the collected collision data. Additional samples of the background decay $B^0 \to J/\psi K^{0*}$ as well as the more general $bb \to J/\psi X$ and $pp \to J/\psi X$ backgrounds were also simulated using PYTHIA.

3 Reconstruction and candidate selection

Events passing the trigger and the data quality selections described in section 2 are required to pass the following additional criteria: the event must contain at least one reconstructed primary vertex built from at least four ID tracks in order to be considered in the subsequent analysis; the event must contain at least one pair of oppositely charged muon candidates that are reconstructed using two algorithms that combine the information from the MS and the ID [13]. In this analysis the muon track parameters are taken from the ID measurement alone, since the precision of the measured track parameters for muons in the p_T range of interest for this analysis is dominated by the ID track reconstruction. The pairs of muon tracks are refitted to a common vertex and accepted for further consideration if the fit results in χ^2/d.o.f. < 10. The invariant mass of the muon pair is calculated from the refitted track parameters. To account for varying mass resolution, the J/ψ candidates are divided into three subsets according to the pseudorapidity η of the muons. A maximum likelihood fit is used to extract the J/ψ mass and the corresponding resolution for these three subsets. When both muons have $|\eta| < 1.05$, the di-muon invariant mass must fall in the range $(2.959 - 3.229)$ GeV to be accepted as a J/ψ candidate. When one muon has $1.05 < |\eta| < 2.5$ and the other muon $|\eta| < 1.05$, the corresponding signal region is $(2.913 - 3.273)$ GeV. For the third subset, where both muons have $1.05 < |\eta| < 2.5$, the signal region is $(2.852-3.332)$ GeV. In each case the signal region is defined so as to retain 99.8% of the J/ψ candidates identified in the fits.

The candidates for $\phi \to K^+K^-$ are reconstructed from all pairs of oppositely charged tracks with $p_T > 0.5$ GeV and $|\eta| < 2.5$ that are not identified as muons. Candidates for $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ are sought by fitting the tracks for each combination of $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$ to a common vertex. All four tracks are required to have at least one hit in the pixel detector and at least four hits in the silicon strip detector. The fit is further constrained by fixing the invariant mass calculated from the two muon tracks to the world average J/ψ mass [14]. These quadruplets of tracks are accepted for further analysis if the vertex fit has a χ^2/d.o.f. < 3, the fitted p_T of each track from $\phi \to K^+K^-$ is greater than 1 GeV and the invariant mass of the track pairs (under the assumption that they are kaons) falls within the 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 used in the fit.

For each B_s^0 meson candidate the proper decay time t is determined by the expression:

$$t = \frac{L_{xy}\, M_B}{c\, p_{\mathrm{T}_B}},$$

where p_{T_B} is the reconstructed transverse momentum of the B_s^0 meson candidate and M_B denotes the world average mass value [14] of the B_s^0 meson (5.3663 GeV). The transverse decay length L_{xy} is the displacement in the transverse plane of the B_s^0 meson decay vertex with respect to the primary vertex, projected onto the direction of B_s^0 transverse momentum. The position of the primary vertex used to calculate this quantity is refitted following the removal of the tracks used to reconstruct the B_s^0 meson candidate.

For the selected events the average number of pileup interactions is 5.6, necessitating a choice of the best candidate for the primary vertex at which the B_s^0 meson is produced. The variable used is a three-dimensional impact parameter d_0, which is calculated 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 each primary vertex candidate. The chosen primary vertex is the one with the smallest d_0. Using MC simulation it is shown that the fraction of B_s^0 candidates which are assigned the wrong primary vertex is less than 1% and that the corresponding effect on the final results is negligible. No B_s^0 meson lifetime cut is applied in the analysis.

4 Maximum likelihood fit

An unbinned maximum likelihood fit is performed on the selected events to extract the parameters of the $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ decay. The fit uses information about the reconstructed mass m, the measured proper decay time t, the measured mass and proper decay time uncertainties σ_m and σ_t, and the transversity angles Ω of each $B_s^0 \to J/\psi\phi$ decay candidate. There are three transversity angles; $\Omega = (\theta_T, \psi_T, \varphi_T)$ and these are defined in section 4.1.

The likelihood function is defined as a combination of the signal and background probability density functions as follows:

$$\ln\, \mathcal{L} = \sum_{i=1}^{N} \Big\{ w_i \cdot \ln\big(f_{\mathrm{s}} \cdot \mathcal{F}_{\mathrm{s}}(m_i, t_i, \Omega_i) + f_{\mathrm{s}} \cdot f_{B^0} \cdot \mathcal{F}_{B^0}(m_i, t_i, \Omega_i) + (1 - f_{\mathrm{s}} \cdot (1 + f_{B^0}))\mathcal{F}_{\mathrm{bkg}}(m_i, t_i, \Omega_i)\big) \Big\} + \ln P(\delta_\perp) \tag{4.1}$$

where N is the number of selected candidates, w_i is a weighting factor to account for the trigger efficiency (described in section 4.5), f_{s} is the fraction of signal candidates, f_{B^0} is the fraction of peaking B^0 meson background events (described in section 4.2) 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. $\mathcal{F}_{\mathrm{s}}$, $\mathcal{F}_{B^0}$ and $\mathcal{F}_{\mathrm{bkg}}$ are the probability density functions (PDF) modelling the signal, the specific B^0 background and the other background distributions, respectively. $P(\delta_\perp)$ is a constraint on the strong phase $\delta_\perp$. A detailed description of the PDF functions and other terms in the equation (4.1) is given in sections 4.1–4.5.

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4.1 Signal PDF

The PDF describing the signal events, $\mathcal{F}_{\rm s}$, has the form of a product of PDFs for each quantity measured from the data:

$$\mathcal{F}_{\rm s}(m_i, t_i, \Omega_i) = P_{\rm s}(m_i|\sigma_{m_i}) \cdot P_{\rm s}(\sigma_{m_i}) \cdot P_{\rm s}(\Omega_i, t_i|\sigma_{t_i}) \cdot P_{\rm s}(\sigma_{t_i}) \cdot A(\Omega_i, p_{{\rm T}i}) \cdot P_{\rm s}(p_{{\rm T}i}) \quad (4.2)$$

The terms $P_{\rm s}(m_i|\sigma_{m_i})$, $P_{\rm s}(\Omega_i, t_i|\sigma_{t_i})$ and $A(\Omega_i, p_{{\rm T}i})$ are explained in the current section, and the remaining per-candidate uncertainty terms $P_{\rm s}(\sigma_{m_i})$, $P_{\rm s}(\sigma_{t_i})$ and $P_{\rm s}(p_{{\rm T}i})$ are described in section 4.4. Ignoring detector effects, the joint distribution for the decay time t and the transversity angles Ω for the $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ decay is given by the differential decay rate [15]:

$$\frac{d^4\Gamma}{dt\, d\Omega} = \sum_{k=1}^{10} \mathcal{O}^{(k)}(t) g^{(k)}(\theta_T, \psi_T, \varphi_T), \quad (4.3)$$

where $\mathcal{O}^{(k)}(t)$ are the time-dependent amplitudes and $g^{(k)}(\theta_T, \psi_T, \varphi_T)$ are the angular functions, given in table 1. The time-dependent amplitudes are slightly different for decays of mesons that were initially $\overline{B_s^0}$. As an untagged analysis is performed here, all B_s^0 meson candidates are assumed to have had an equal chance of initially being either a particle or anti-particle. This leads to a significant simplification of the time-dependent amplitudes as any terms involving the mass splitting Δm_s cancel out. These simplified time-dependent amplitudes are given in table 1. $A_\perp(t)$ describes a CP-odd final-state configuration while both $A_0(t)$ and $A_\parallel(t)$ correspond to CP-even final-state configurations. 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 corresponding amplitudes are given in the last four lines of table 1 (k=7-10) and follow the convention used in previous analysis [7]. The likelihood is independent of the invariant KK mass distribution.

The equations are normalised such that the squares of the amplitudes sum to unity; three of the four amplitudes are fit parameters and $|A_\perp(0)|^2$ is determined according to this constraint.

The angles $(\theta_T, \psi_T, \varphi_T)$, are defined in the rest frames of the final-state particles. The x-axis is determined by the direction of the ϕ meson in the J/ψ rest frame, the K^+K^- system defines the xy plane, where $p_y(K^+) > 0$. The three angles are defined:

- θ, the angle between $p(\mu^+)$ and the xy plane, in the J/ψ meson rest frame
- φ, the angle between the x-axis and $p_{xy}(\mu^+)$, the projection of the μ^+ momentum in the xy plane, in the J/ψ meson rest frame
- ψ, the angle between $p(K^+)$ and $-p(J/\psi)$ in the ϕ meson rest frame

It can be seen from table 1, that in the untagged analysis used in this study the time-dependent amplitudes depending on $\delta_\perp$ ($\mathcal{O}^{(k)}(t), k = 5, 6$) are multiplied by $\sin\phi_s$. Previous measurement by LHCb ref. [7] showed that ϕ_s is close to zero $(0.15 \pm 0.18 \pm 0.06)$ rad. For such a small value of ϕ_s the untagged analysis is not sensitive to $\delta_\perp$. A Gaussian constraint

k	$\mathcal{O}^{(k)}(t)$	$g^{(k)}(\theta_T, \psi_T, \varphi_T)$
1	$\frac{1}{2}\lvert A_0(0)\rvert^2 \left[(1+\cos\phi_s)\, e^{-\Gamma_{\rm L}^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_{\rm H}^{(s)}t}\right]$	$2\cos^2\psi_T(1-\sin^2\theta_T\cos^2\varphi_T)$
2	$\frac{1}{2}\lvert A_\parallel(0)\rvert^2 \left[(1+\cos\phi_s)\, e^{-\Gamma_{\rm L}^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_{\rm H}^{(s)}t}\right]$	$\sin^2\psi_T(1-\sin^2\theta_T\sin^2\varphi_T)$
3	$\frac{1}{2}\lvert A_\perp(0)\rvert^2 \left[(1-\cos\phi_s)\, e^{-\Gamma_{\rm L}^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_{\rm H}^{(s)}t}\right]$	$\sin^2\psi_T\sin^2\theta_T$
4	$\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\parallel(0)\rvert\cos\delta_{\vert\vert}$ $\left[(1+\cos\phi_s)\, e^{-\Gamma_{\rm L}^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_{\rm H}^{(s)}t}\right]$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin^2\theta_T\sin 2\varphi_T$
5	$\frac{1}{2}\lvert A_\parallel(0)\rvert\lvert A_\perp(0)\rvert \left(e^{-\Gamma_{\rm H}^{(s)}t} - e^{-\Gamma_{\rm L}^{(s)}t}\right)\cos(\delta_\perp - \delta_{\vert\vert})\sin\phi_s$	$\sin^2\psi_T\sin 2\theta_T\sin\varphi_T$
6	$-\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\perp(0)\rvert \left(e^{-\Gamma_{\rm H}^{(s)}t} - e^{-\Gamma_{\rm L}^{(s)}t}\right)\cos\delta_\perp\sin\phi_s$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin 2\theta_T\cos\varphi_T$
7	$\frac{1}{2}\lvert A_S(0)\rvert^2 \left[(1-\cos\phi_s)\, e^{-\Gamma_{\rm L}^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_{\rm H}^{(s)}t}\right]$	$\frac{2}{3}\left(1-\sin^2\theta_T\cos^2\varphi_T\right)$
8	$-\frac{1}{2}\lvert A_S(0)\rvert\lvert A_\parallel(0)\rvert \left(e^{-\Gamma_{\rm H}^{(s)}t} - e^{-\Gamma_{\rm L}^{(s)}t}\right)\sin(\delta_\parallel - \delta_S)\sin\phi_s$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin^2\theta_T\sin 2\varphi_T$
9	$\frac{1}{2}\lvert A_S(0)\rvert\lvert A_\perp(0)\rvert$ $\left[(1-\cos\phi_s)\, e^{-\Gamma_{\rm L}^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_{\rm H}^{(s)}t}\right]\sin(\delta_\perp - \delta_S)$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin 2\theta_T\cos\varphi_T$
10	$-\frac{1}{2}\lvert A_0(0)\rvert\lvert A_S(0)\rvert\sin(-\delta_S) \left(e^{-\Gamma_{\rm H}^{(s)}t} - e^{-\Gamma_{\rm L}^{(s)}t}\right)\sin\phi_s$	$\frac{4}{3}\sqrt{3}\cos\psi_T\left(1-\sin^2\theta_T\cos^2\varphi_T\right)$

Table 1. Table showing the ten time-dependent amplitudes, $\mathcal{O}^{(k)}(t)$ and the functions of the transversity angles $g^{(k)}(\theta_T, \psi_T, \varphi_T)$. The amplitudes $|A_0(0)|^2$ and $|A_\parallel(0)|^2$ are for the CP-even components of the $B_s^0 \to J/\psi\phi$ decay. $|A(0)_\perp|^2$ is the CP-odd amplitude. They have corresponding strong phases δ_0, $\delta_\parallel$ and $\delta_\perp$; by convention δ_0 is set to be zero. The S-wave amplitude $|A_S(0)|^2$ gives the fraction of $B_s^0 \to J/\psi K^+K^-(f_0)$ and has a related strong phase δ_S.

to the best measured value, $\delta_\perp = (2.95 \pm 0.39)$ rad [7], is therefore applied by adding a Gaussian function term $P(\delta_\perp)$ into the likelihood fit.

The signal PDF, $P_{\rm s}(\Omega_i, t_i|\sigma_{t_i})$ must take into account the time resolution and thus each time-dependent element in table 1 is convoluted with a Gaussian function. This convolution is performed numerically on an event-by-event basis where the width of the Gaussian is the proper decay time uncertainty σ_{t_i}, multiplied by an overall scale factor to account for any mis-measurements.

The angular sculpting of the detector and kinematic cuts on the angular distributions is included in the likelihood function through $\mathcal{A}(\Omega_i, p_{{\rm T}i})$. This is calculated using a four-dimensional binned acceptance method, applying an event-by-event efficiency according to the transversity angles $(\theta_T, \psi_T, \varphi_T)$ and the $p_{\rm T}$ of the B_s^0. The acceptance was calculated from the $B_s^0 \to J/\psi\phi$ MC events. In the likelihood function, the acceptance is treated as an angular sculpting PDF, which is multiplied by the time- and angular-dependent PDF describing the $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ decays. Consequently, the complete angular function must be normalised as a whole as both the acceptance and the time-angular decay PDFs depend on the transversity angles. This normalisation is performed numerically in the likelihood fit.

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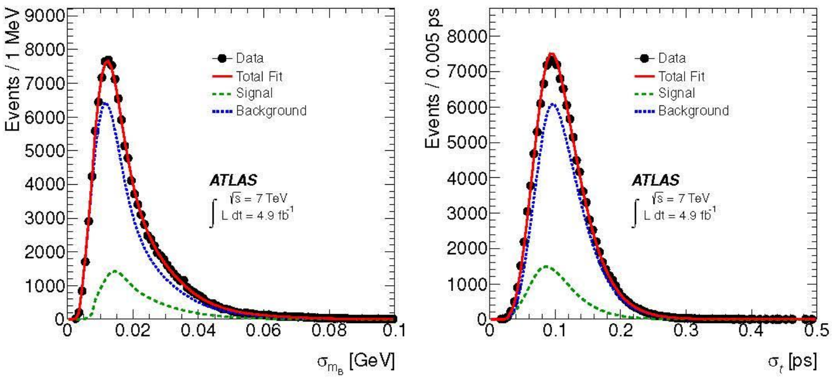

Figure 1. Left: mass uncertainty distribution for data, the fits to the background and the signal fractions and the sum of the two fits. Right: proper decay time uncertainty distribution for data, the fits to the background and the signal fractions and the sum of the two fits.

The signal mass PDF, $P_{\rm s}(m_i)$, is modelled as a single Gaussian function smeared with an event-by-event mass resolution σ_{m_i}, see figure 1, which is scaled using a factor to account for mis-estimation of the mass errors. The PDF is normalised over the range $5.15 < m(B_s^0) < 5.65$ GeV.

4.2 Specific B^0 background

The $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ sample is contaminated with mis-reconstructed $B^0 \to J/\psi K^*$ and $B^0 \to J/\psi K^+\pi^-$ (non-resonant) decays, where the final-state pion is mis-identified as a kaon. The two components of the background are referred to as B^0 reflections, since the B^0 is reconstructed as a B_s^0 meson and therefore lies within the B_s^0 meson mass window rather than in the usual B^0 mass range. The fractions of these components are fixed in the likelihood fit to values $(6.5 \pm 2.4)\%$ and $(4.5 \pm 2.8)\%$ respectively. These values are calculated from the relative production fractions of the B_s^0 and B^0 mesons and their decay probabilities taken from the PDG values [14] and from their selection efficiencies, which are determined from MC events. The corresponding uncertainties are dominated by uncertainties in the decay probabilities.

Mis-reconstructed B^0 decays are treated as part of the background and are described by a dedicated PDF:

$$\begin{aligned}\mathcal{F}_{B^0}(m_i, t_i, \Omega_i) = {} & P_{B^0}(m_i) \cdot P_{\rm s}(\sigma_{m_i}) \cdot P_{B^0}(t_i|\sigma_{t_i}) \\ & \cdot P_{B^0}(\theta_T) \cdot P_{B^0}(\varphi_T) \cdot P_{B^0}(\psi_T) \cdot P_{\rm s}(\sigma_{t_i}) \cdot P_{\rm s}(p_{{\rm T}i})\end{aligned} \tag{4.4}$$

The mass is described by the $P_{B^0}(m_i)$ term in the form of a Landau function due to the distortion caused by the incorrect mass assignment. The decay time is described in the term $P_{B^0}(t_i|\sigma_{t_i})$ by an exponential smeared with event-by-event Gaussian errors. The transversity angles are described using the same functions as the other backgrounds but with different values for the parameters obtained from the fit to MC data. The terms $P_s(\sigma_{m_i})$, $P_s(\sigma_{t_i})$ and $P_s(p_{\mathrm{T}i})$ are described in section 4.4. All the PDFs describing these B^0 reflections have fixed shapes determined from the MC studies.

4.3 Background PDF

The background PDF has the following composition:

$$\mathcal{F}_{\mathrm{bkg}}(m_i, t_i, \Omega_i) = P_{\mathrm{b}}(m_i) \cdot P_{\mathrm{b}}(\sigma_{m_i}) \cdot P_{\mathrm{b}}(t_i|\sigma_{t_i}) \\ \cdot P_{\mathrm{b}}(\theta_T) \cdot P_{\mathrm{b}}(\varphi_T) \cdot P_{\mathrm{b}}(\psi_T) \cdot P_{\mathrm{b}}(\sigma_{t_i}) \cdot P_{\mathrm{b}}(p_{\mathrm{T}i}) \quad (4.5)$$

The proper decay time function $P_{\mathrm{b}}(t_i|\sigma_{t_i})$ is parameterised as a prompt peak modelled by a Gaussian distribution, two positive exponentials and a negative exponential. This function is smeared with the same resolution function as the signal decay time-dependence. The prompt peak models the combinatorial background events, which are expected to have reconstructed lifetime distributed around zero. The two positive exponentials represent a fraction of longer-lived backgrounds with non-prompt J/ψ, combined with hadrons from the primary vertex or from a B/D hadron in the same event. The negative exponential takes into account events with poor vertex resolution.

The shape of the background angular distributions, $P_{\mathrm{b}}(\theta_T)$, $P_{\mathrm{b}}(\varphi_T)$, and $P_{\mathrm{b}}(\psi_T)$ arise primarily from detector and kinematic sculpting. These are described by the following empirically determined functions:

$$f(\cos\theta_T) = \frac{a_0 - a_1\cos^2(\theta_T) + a_2\cos^4(\theta_T)}{2a_0 - 2a_1/3 + 2a_2/5}$$

$$f(\varphi_T) = \frac{1 + b_1\cos(2\varphi_T + b_0)}{2\pi}$$

$$f(\cos\psi_T) = \frac{c_0 + c_1\cos^2(\psi_T)}{2c_0 + 2c_1/3}$$

They are initially fitted to data from the B_s^0 mass sidebands only, to find reasonable starting values for $a_{0,1,2}$, $b_{0,1}$ and $c_{0,1}$, then allowed to float freely in the full likelihood fit. The B_s^0 mass sidebands, $(5.150 - 5.317)$ GeV and $(5.417 - 5.650)$ GeV, are defined to retain 0.02% of signal events identified in the fit. The correlations between the background angular shapes are neglected, but a systematic error arising from this simplification is evaluated in section 5. The background mass model, $P_{\mathrm{b}}(m)$ is a linear function.

4.4 Time and mass uncertainties of signal and background

The event-by-event proper decay time and mass uncertainty distributions differ significantly for signal and background, as shown in figure 1. The background PDFs cannot be factorized and it is necessary to include extra PDF terms describing the error distributions in the likelihood function to avoid significant biases [16].

The signal and background time and mass error distributions are described with Gamma functions:

$$P_{\mathrm{s,b}}(\sigma_{t(m)_i}) = \frac{(\sigma_{t(m)_i} - c)^{a_{\mathrm{s,b}}} e^{-(\sigma_{t(m)_i} - c)/b_{\mathrm{s,b}}}}{b_{\mathrm{s,b}}^{a_{\mathrm{s,b}}+1}\Gamma(a_{\mathrm{s,b}} + 1)} \quad (4.6)$$

where $a_{\mathrm{s,b}}$ and $b_{\mathrm{s,b}}$ are constants fitted from (b) sideband and (s) sideband-subtracted signal and fixed in the likelihood fit. Since $P_{\mathrm{s,b}}(\sigma_{t(m)_i})$ depend on transverse momentum of the B_s^0 meson, they were determined in six selected p_{T} bins, the choice of which is reflecting the natural p_{T} dependence of the detector resolution.

The same treatment is used for B_s^0 p_{T} signal and background, by introducing additional terms $P_{\mathrm{s}}(p_{\mathrm{T}i})$ and $P_{\mathrm{b}}(p_{\mathrm{T}i})$ into the PDF. These are described using the same functions as $P_{\mathrm{s,b}}(\sigma_{t(m)_i})$ but with different values for the parameters obtained from the fit to sideband and sideband-subtracted signal p_{T} distributions.

4.5 Muon trigger time-dependent efficiency

It has been observed that the muon trigger biases the transverse impact parameter of muons toward smaller values. The trigger selection efficiency was measured in data and MC simulation using a tag-and-probe method [17]. To account for this efficiency in the fit, the events are re-weighted by a factor w:

$$w = e^{-|t|/(\tau_{\mathrm{sing}}+\epsilon)}/e^{-|t|/\tau_{\mathrm{sing}}} \tag{4.7}$$

where the τ_{sing} is a single B_s^0 lifetime measured before the correction, using unbinned mass-lifetime maximum likelihood fit. The weight form and the factor $\epsilon = 0.013 \pm 0.004$ ps are determined using MC events by comparing the B_s^0 lifetime distribution of an unbiased sample with the lifetime distribution obtained after including the dependence of the trigger efficiency on the muon transverse impact parameter as measured from the data. The value of ϵ is determined as the difference of exponential fits to the two distributions. The uncertainty 0.004 ps, which reflects the precision of the tag-and-probe method, is used to assign a systematic error due to this time efficiency correction.

5 Systematic uncertainties

Systematic uncertainties are assigned by considering several effects that are not accounted for in the likelihood fit. These are described below.

- **Inner Detector Alignment:** residual misalignments of the ID affect the impact parameter distribution with respect to the primary vertex. The effect of this residual misalignment on the measurement is estimated using events simulated with perfect and distorted ID geometries. The distorted geometry is produced by moving detector components to match the observed small shifts in data. The observable of interest is the impact parameter distribution with respect to the primary vertex as a function of η and ϕ. The mean value of this impact parameter distribution for a perfectly aligned detector is expected to be zero and in data a maximum deviation of less than 10 μm is observed. The difference between the measurement using simulated events reconstructed with a perfect geometry compared to the distorted geometry is used to assess the systematic uncertainty.

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- **Angular acceptance method:** the angular acceptance is calculated from a binned fit to MC data. In the kinematical region used in this analysis, the angular acceptance varies with the transversity angles by about $\pm 10\%$. The statistical error in the acceptance is smaller than 1% in any bin, and data driven analyses show that systematic uncertainties in modelling detector and reconstruction are also at the level of 1% [18, 19]. Possible dependences of the results on the choice of the binning are tested by varying bin widths and central values. Taking all these arguments into consideration, the systematic uncertainties due to detector acceptance are found to be negligible.

- **Trigger efficiency:** to correct for the trigger lifetime bias the events are re-weighted according to equation (4.7). The uncertainty in the parameter ϵ is used to estimate the systematic uncertainty due to the time efficiency correction.

- **Fit model:** pseudo-experiments are used to estimate systematic uncertainties. In a first test, the results of 1000 pseudo-experiments are compared to the generated values, and the average of the differences are taken as systematic uncertainties. Additional sets of 1000 pseudo-experiments are generated with variations in the signal and background mass model, resolution model, background lifetime and background angles models, as discussed below. These sets are analysed with the default model, and average deviations in the results of the fit are taken as additional systematic errors. The following variations are considered:

  - The signal mass distribution is generated using a sum of two Gaussian functions. Their relative fractions and widths are determined from a likelihood fit to data. In the PDF for this fit, the mass of each event is modelled by two different Gaussians with widths equal to products of the scale factors multiplied by a per-candidate mass error.
  - The background mass is generated from an exponential function. The default fit uses a linear model for the mass of background events.
  - Two different scale factors instead of one are used to generate the lifetime uncertainty.
  - The values used for the background lifetime are generated by sampling data from the mass sidebands. The default fit uses a set of functions to describe the background lifetime.
  - Pseudo-experiments are performed using two methods of generating the background angles. The default method uses a set of functions describing the background angles of data without taking correlations between the angles into account. In the alternative fit the background angles are generated using a three dimensional histogram of the sideband-data angles.

- **B^0 contribution:** contamination from $B^0 \to J/\psi K^{*0}$ and $B^0 \to J/\psi K\pi$ events misreconstructed as $B_s^0 \to J/\psi\phi$ are accounted for in the default fit; the fractions of these contributions are fixed to values estimated from selection efficiencies in MC simulation and decay probabilities from ref. [14]. To estimate the systematic uncertainty arising from the precision of the fraction estimates, the data are fitted with these fractions increased and decreased by 1σ. The largest shift in the fitted values from the default case is taken as the systematic uncertainty for each parameter of interest.

The systematic uncertainties are summarised in table 4. In general, pseudo-experiments generated with the default model produce pull-distributions that show a negligible bias, and confirm that the uncertainties are correctly estimated by the fit. The largest average deviation in a residual divided by its fit uncertainty (or pull) is 0.32; the second largest is 0.26, while the remainder where much smaller. These two largest deviations were added in quadrature to those obtained by varying the model assumptions, resulting for each variable in a total systematic uncertainty shown in table 4.

6 Results

The full maximum likelihood fit contains 26 free parameters. This includes the eight physics parameters: $\Delta\Gamma_s$, ϕ_s, Γ_s, $|A_0(0)|^2$, $|A_{||}(0)|^2$, $\delta_{||}$, $|A_S(0)|^2$ and δ_S, and strong phase $\delta_\perp$ constrained by external data. The other free parameters in the likelihood function are the B_s^0 signal fraction f_{s}, the parameters describing the $J/\psi\phi$ mass distribution, the parameters describing the decay time and the angular distributions of the background, the parameters used to describe the estimated decay time uncertainty distributions for signal and background events, and the scale factors between the estimated decay-time and mass uncertainties and their true uncertainties, see equation (4.6).

As discussed in section 4.1, the strong phase $\delta_\perp$ is constrained to the value measured in ref. [7], as the fit in the absence of flavour tagging is not sufficiently sensitive to this value. The second strong phase, $\delta_{||}$, is fitted very close to its symmetry point at π. Pull studies, based on pseudo-experiments using input values determined from the fit to data, return a non-Gaussian pull distribution for this parameter. For this reason the result for the strong phase $\delta_{||}$ is given in the form of a 1σ confidence interval $[3.04, 3.24]$ rad. The strong phase of the S-wave component is fitted relative to $\delta_\perp$, as $\delta_\perp - \delta_S = (0.03 \pm 0.13)$ rad.

The number of signal B_s^0 meson candidates extracted from the fit is 22690 ± 160. The results and correlations for the measured physics parameters of the unbinned maximum likelihood fit are given in tables 2 and 3. Fit projections of the mass, proper decay time and angles are given in figures 2, 3 and 4 respectively.

7 Symmetries of the likelihood function and two-dimensional likelihood contours

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

$$\{\phi_s, \Delta\Gamma_s, \delta_\perp, \delta_{||}, \delta_S\} \to \{\pi - \phi_s, -\Delta\Gamma_s, \pi - \delta_\perp, -\delta_{||}, -\delta_S\}.$$

Parameter	Value	Statistical uncertainty	Systematic uncertainty
ϕ_s(rad)	0.22	0.41	0.10
$\Delta\Gamma_s$(ps^{-1})	0.053	0.021	0.010
Γ_s(ps^{-1})	0.677	0.007	0.004
$\lvert A_0(0)\rvert^2$	0.528	0.006	0.009
$\lvert A_{\parallel}(0)\rvert^2$	0.220	0.008	0.007
$\lvert A_S(0)\rvert^2$	0.02	0.02	0.02

Table 2. Fitted values for the physics parameters along with their statistical and systematic uncertainties.

	ϕ_s	$\Delta\Gamma_s$	Γ_s	$\lvert A_0(0)\rvert^2$	$\lvert A_{\parallel}(0)\rvert^2$	$\lvert A_S(0)\rvert^2$
ϕ_s	1.00	−0.13	0.38	−0.03	−0.04	0.02
$\Delta\Gamma_s$		1.00	−0.60	0.12	0.11	0.10
Γ_s			1.00	−0.06	−0.10	0.04
$\lvert A_0(0)\rvert^2$				1.00	−0.30	0.35
$\lvert A_{\parallel}(0)\rvert^2$					1.00	0.09
$\lvert A_S(0)\rvert^2$						1.00

Table 3. Correlations between the physics parameters.

Systematic Uncertainty	ϕ_s(rad)	$\Delta\Gamma_s$(ps^{-1})	Γ_s(ps^{-1})	$\lvert A_{\parallel}(0)\rvert^2$	$\lvert A_0(0)\rvert^2$	$\lvert A_S(0)\rvert^2$
Inner Detector alignment	0.04	< 0.001	0.001	< 0.001	< 0.001	< 0.01
Trigger efficiency	< 0.01	< 0.001	0.002	< 0.001	< 0.001	< 0.01
Default fit model	< 0.001	0.006	< 0.001	< 0.001	0.001	< 0.01
Signal mass model	0.02	0.002	< 0.001	< 0.001	< 0.001	< 0.01
Background mass model	0.03	0.001	< 0.001	0.001	< 0.001	< 0.01
Resolution model	0.05	< 0.001	0.001	< 0.001	< 0.001	< 0.01
Background lifetime model	0.02	0.002	< 0.001	< 0.001	< 0.001	< 0.01
Background angles model	0.05	0.007	0.003	0.007	0.008	0.02
B^0 contribution	0.05	< 0.001	< 0.001	< 0.001	0.005	< 0.01
Total	0.10	0.010	0.004	0.007	0.009	0.02

Table 4. Summary of systematic uncertainties assigned to parameters of interest.

In the absence of initial state flavour tagging the PDF is also invariant under

$$\{\phi_s, \Delta\Gamma_s, \delta_\perp, \delta_\parallel, \delta_S\} \to \{-\phi_s, \Delta\Gamma_s, \pi - \delta_\perp, -\delta_\parallel, -\delta_S\} \tag{7.1}$$

leading to a fourfold ambiguity.

The two-dimensional likelihood contours in the $\phi_s - \Delta\Gamma_s$ plane are calculated allowing all parameters to vary within their physical ranges. As discussed in section 6, the value for the Gaussian constraint on $\delta_\perp$ is taken from the LHCb measurement [7]. That paper quotes only two solutions with a positive ϕ_s and two $\Delta\Gamma_s$ values symmetric around zero, by using initial state flavour tagging to eliminate the symmetry defined in equation (7.1).

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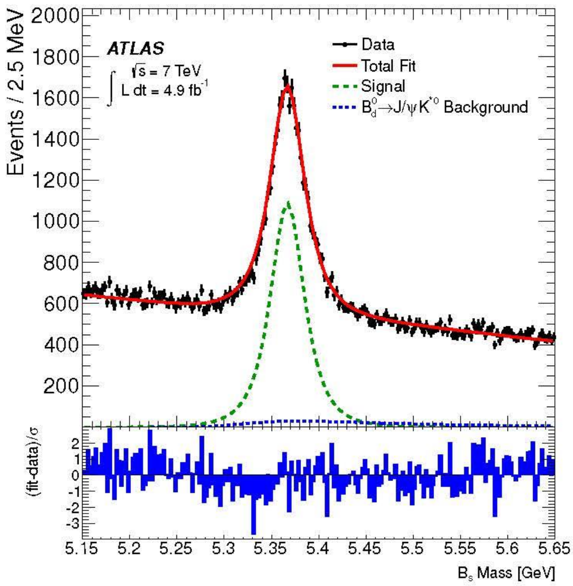

Figure 2. Mass fit projection for the B_s^0. The pull distribution at the bottom shows the difference between the data and fit value normalised to the data uncertainty.

Due to the accurate local determination of ϕ_s and $\Delta\Gamma_s$ in both this measurement and in the LHCb measurement [7], the other two solutions seen in the ATLAS analysis are not compatible with the observations of the two experiments. As such, two of the four minima fitted in the present non-flavour tagged analysis are excluded from the results presented here. Additionally a solution with negative $\Delta\Gamma_s$ is excluded following the LHCb measurement [20] which determines the $\Delta\Gamma_s$ to be positive. Therefore, the two-dimensional contour plot for ϕ_s and $\Delta\Gamma_s$ has been computed only for the solution consistent with the previous measurements. The resulting contours for the 68%, 90% and 95% confidence intervals are produced using a profile likelihood method and are shown in figure 5.

The systematic errors are not included in figure 5 but as seen from table 2 they are small compared to the statistical errors. The confidence levels are obtained using the corresponding $\Delta \ln \mathcal{L}$ intervals. Pseudo-experiments are used to study the coverage of the likelihood contours. This test suggests that the statistical uncertainty of our result is overestimated by about 5%. No correction to compensate for this overestimation is applied.

8 Conclusion

A measurement of CP violation in $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ decays from a 4.9 fb^{-1} data sample of pp collisions collected with the ATLAS detector during the 2011 $\sqrt{s} = 7$ TeV run was presented. Several parameters describing the B_s^0 meson system are measured. These

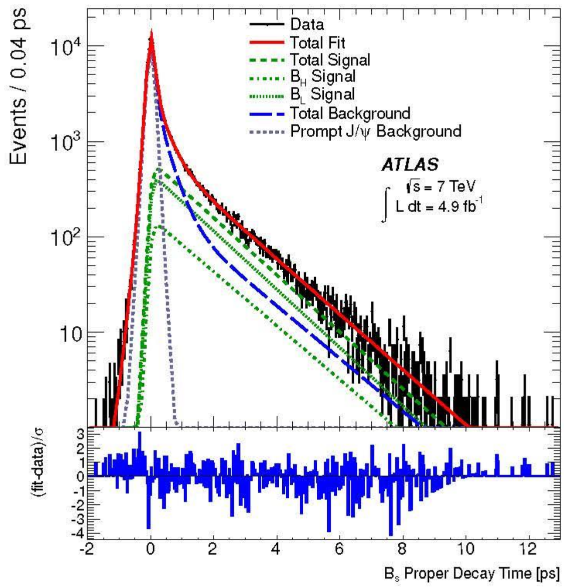

Figure 3. Proper decay time fit projection for the B_s^0. The pull distribution at the bottom shows the difference between the data and fit value normalised to the data uncertainty.

include the mean B_s^0 lifetime, the decay width difference $\Delta\Gamma_s$ between the heavy and light mass eigenstates, the transversity amplitudes $|A_0(0)|$ and $|A_{\parallel}(0)|$ and the CP-violating week phase ϕ_s. They are consistent with the world average values.

The measured values, for the minimum resulting from $\delta_{\perp}$ constrained to the LHCb value of 2.95 ± 0.39 rad [7] and $\Delta\Gamma_s$ being constrained to be positive following LHCb measurement [20], are:

$$\begin{aligned}
\phi_s &= 0.22 \ \ \pm 0.41 \ \ (\text{stat.}) \pm \ 0.10 \ \ (\text{syst.})\ \text{rad} \\
\Delta\Gamma_s &= 0.053 \pm 0.021\ (\text{stat.}) \pm \ 0.010\ (\text{syst.})\ \text{ps}^{-1} \\
\Gamma_s &= 0.677 \pm 0.007\ (\text{stat.}) \pm \ 0.004\ (\text{syst.})\ \text{ps}^{-1} \\
|A_0(0)|^2 &= 0.528 \pm 0.006\ (\text{stat.}) \pm \ 0.009\ (\text{syst.}) \\
|A_{\parallel}(0)|^2 &= 0.220 \pm 0.008\ (\text{stat.}) \pm \ 0.007\ (\text{syst.})
\end{aligned}$$

These values are consistent with theoretical expectations, in particular ϕ_s is within 1σ of the expected value in the Standard Model. A likelihood contour in the $\phi_s - \Delta\Gamma_s$ plane is also provided for the minimum compatible with the LHCb measurements [7, 20]. The fraction of S-wave KK or f_0 contamination is measured to be consistent with zero, at $|A_S(0)|^2 = 0.02 \pm 0.02$.

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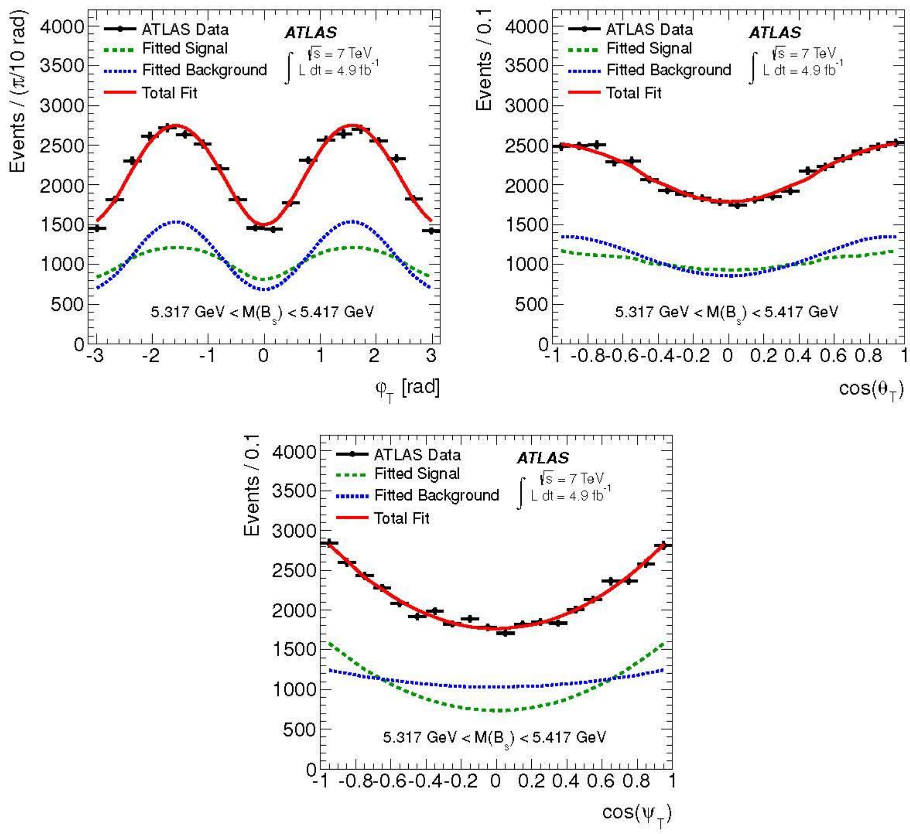

Figure 4. Fit projections for transversity angles. (Left): φ_T, (Right): $\cos\theta_T$, (Bottom): $\cos\psi_T$ for the events with B_s^0 mass from signal region (5.317–5.417) GeV.

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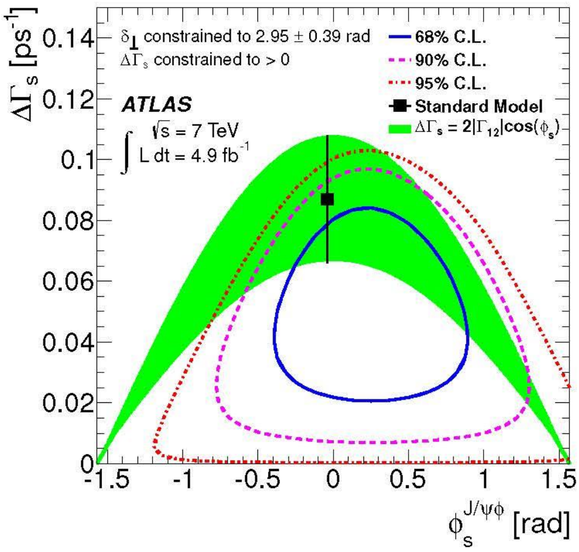

Figure 5. Likelihood contours in the $\phi_s - \Delta\Gamma_s$ plane. Three contours show the 68%, 90% and 95% confidence intervals (statistical errors only). The green band is the theoretical prediction of mixing- induced CP violation. The PDF contains a fourfold ambiguity. Three minima are excluded by applying the constraints from the LHCb measurements [7, 20].

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References

[1] UTFIT collaboration, M. Bona et al., *Constraints on new physics from the quark mixing unitarity triangle*, *Phys. Rev. Lett.* **97** (2006) 151803 [hep-ph/0605213] [INSPIRE].

JHEP12(2012)072

[2] CDF collaboration, A. Abulencia et al., *Observation of $B_s^0 - \bar{B}_s^0$ Oscillations*, *Phys. Rev. Lett.* **97** (2006) 242003 [hep-ex/0609040] [INSPIRE].

[3] LHCb collaboration, R. Aaij et al., *Measurement of the $B_s^0 - \bar{B}_s^0$ oscillation frequency Δm_s in $B_s^0 \to D_s^-(3)\pi$ decays*, *Phys. Lett.* **B 709** (2012) 177 [arXiv:1112.4311] [INSPIRE].

[4] A. Lenz and U. Nierste, *Theoretical update of $B_s - \bar{B}_s$ mixing*, *JHEP* **06** (2007) 072 [hep-ph/0612167] [INSPIRE].

[5] D0 collaboration, V.M. Abazov et al., *Measurement of the CP-violating phase $\phi_s^{J/\psi\phi}$ using the flavor-tagged decay $B_s^0 \to J/\psi\phi$ in 8 fb^{-1} of $p\bar{p}$ collisions*, *Phys. Rev.* **D 85** (2012) 032006 [arXiv:1109.3166] [INSPIRE].

[6] CDF collaboration, T. Aaltonen et al., *Measurement of the CP-Violating Phase $\beta_s^{J/\Psi\phi}$ in $B_s^0 \to J/\Psi\phi$ Decays with the CDF II Detector*, *Phys. Rev.* **D 85** (2012) 072002 [arXiv:1112.1726] [INSPIRE].

[7] LHCb collaboration, R. Aaij et al., *Measurement of the CP-violating phase ϕ_s in the decay $B_s^0 \to J/\psi\phi$*, *Phys. Rev. Lett.* **108** (2012) 101803 [arXiv:1112.3183] [INSPIRE].

[8] ATLAS collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, 2008 *JINST* **3** S08003 [INSPIRE].

[9] T. Sjöstrand, S. Mrenna and P.Z. Skands, *PYTHIA 6.4 Physics and Manual*, *JHEP* **05** (2006) 026 [hep-ph/0603175] [INSPIRE].

[10] ATLAS collaboration, *ATLAS tunes of PYTHIA 6 and PYTHIA 8 for MC11*, PHYS-PUB-2011-009 (2011).

[11] ATLAS collaboration, *The ATLAS Simulation Infrastructure*, *Eur. Phys. J.* **C 70** (2010) 823 [arXiv:1005.4568] [INSPIRE].

[12] GEANT4 collaboration, S. Agostinelli et al., *GEANT4: A Simulation toolkit*, *Nucl. Instrum. Meth.* **A 506** (2003) 250 [INSPIRE].

[13] ATLAS collaboration, *Measurement of the differential cross-sections of inclusive, prompt and non-prompt J/ψ production in proton-proton collisions at $\sqrt{s} = 7$ TeV*, *Nucl. Phys.* **B 850** (2011) 387 [arXiv:1104.3038] [INSPIRE].

[14] Particle Data Group collaboration, K. Nakamura et al., *Review of particle physics*, *J. Phys.* **G 37** (2010) 075021, and 2011 partial update for the 2012 edition [INSPIRE].

[15] A.S. Dighe, I. Dunietz and R. Fleischer, *Extracting CKM phases and $B_s - \bar{B}_s$ mixing parameters from angular distributions of nonleptonic B decays*, *Eur. Phys. J.* **C 6** (1999) 647 [hep-ph/9804253] [INSPIRE].

[16] G. Punzi, *Ordering algorithms and confidence intervals in the presence of nuisance parameters*, physics/0511202 [INSPIRE].

[17] ATLAS collaboration, *Measurement of the Λ_b lifetime and mass in the ATLAS experiment*, arXiv:1207.2284 [INSPIRE].

[18] ATLAS collaboration, *Charged-particle multiplicities in pp interactions measured with the ATLAS detector at the LHC*, *New J. Phys.* **13** (2011) S053033.

[19] ATLAS collaboration, *Measurement of Upsilon production in 7 TeV pp collisions at ATLAS*, arXiv:1211.7255 [INSPIRE].

[20] LHCb collaboration, R. Aaij et al., *Determination of the sign of the decay width difference in the B_s system*, *Phys. Rev. Lett.* **108** (2012) 241801 [arXiv:1202.4717] [INSPIRE].

The ATLAS collaboration

G. Aad[48], T. Abajyan[21], B. Abbott[111], J. Abdallah[12], S. Abdel Khalek[115], A.A. Abdelalim[49], O. Abdinov[11], R. Aben[105], B. Abi[112], M. Abolins[88], O.S. AbouZeid[158], H. Abramowicz[153], H. Abreu[136], E. Acerbi[89a,89b], B.S. Acharya[164a,164b], L. Adamczyk[38], D.L. Adams[25], T.N. Addy[56], J. Adelman[176], S. Adomeit[98], P. Adragna[75], T. Adye[129], S. Aefsky[23], J.A. Aguilar-Saavedra[124b,a], M. Agustoni[17], M. Aharrouche[81], S.P. Ahlen[22], F. Ahles[48], A. Ahmad[148], M. Ahsan[41], G. Aielli[133a,133b], T. Akdogan[19a], T.P.A. Åkesson[79], G. Akimoto[155], A.V. Akimov[94], M.S. Alam[2], M.A. Alam[76], J. Albert[169], S. Albrand[55], M. Aleksa[30], I.N. Aleksandrov[64], F. Alessandria[89a], C. Alexa[26a], G. Alexander[153], G. Alexandre[49], T. Alexopoulos[10], M. Alhroob[164a,164c], M. Aliev[16], G. Alimonti[89a], J. Alison[120], B.M.M. Allbrooke[18], P.P. Allport[73], S.E. Allwood-Spiers[53], J. Almond[82], A. Aloisio[102a,102b], R. Alon[172], A. Alonso[79], F. Alonso[70], B. Alvarez Gonzalez[88], M.G. Alviggi[102a,102b], K. Amako[65], C. Amelung[23], V.V. Ammosov[128,*], A. Amorim[124a,b], N. Amram[153], C. Anastopoulos[30], L.S. Ancu[17], N. Andari[115], T. Andeen[35], C.F. Anders[58b], G. Anders[58a], K.J. Anderson[31], A. Andreazza[89a,89b], V. Andrei[58a], X.S. Anduaga[70], P. Anger[44], A. Angerami[35], F. Anghinolfi[30], A. Anisenkov[107], N. Anjos[124a], A. Annovi[47], A. Antonaki[9], M. Antonelli[47], A. Antonov[96], J. Antos[144b], F. Anulli[132a], M. Aoki[101], S. Aoun[83], L. Aperio Bella[5], R. Apolle[118,c], G. Arabidze[88], I. Aracena[143], Y. Arai[65], A.T.H. Arce[45], S. Arfaoui[148], J-F. Arguin[15], E. Arik[19a,*], M. Arik[19a], A.J. Armbruster[87], O. Arnaez[81], V. Arnal[80], C. Arnault[115], A. Artamonov[95], G. Artoni[132a,132b], D. Arutinov[21], S. Asai[155], R. Asfandiyarov[173], S. Ask[28], B. Åsman[146a,146b], L. Asquith[6], K. Assamagan[25], A. Astbury[169], M. Atkinson[165], B. Aubert[5], E. Auge[115], K. Augsten[127], M. Aurousseau[145a], G. Avolio[163], R. Avramidou[10], D. Axen[168], G. Azuelos[93,d], Y. Azuma[155], M.A. Baak[30], G. Baccaglioni[89a], C. Bacci[134a,134b], A.M. Bach[15], H. Bachacou[136], K. Bachas[30], M. Backes[49], M. Backhaus[21], E. Badescu[26a], P. Bagnaia[132a,132b], S. Bahinipati[3], Y. Bai[33a], D.C. Bailey[158], T. Bain[158], J.T. Baines[129], O.K. Baker[176], M.D. Baker[25], S. Baker[77], E. Banas[39], P. Banerjee[93], Sw. Banerjee[173], D. Banfi[30], A. Bangert[150], V. Bansal[169], H.S. Bansil[18], L. Barak[172], S.P. Baranov[94], A. Barbaro Galtieri[15], T. Barber[48], E.L. Barberio[86], D. Barberis[50a,50b], M. Barbero[21], D.Y. Bardin[64], T. Barillari[99], M. Barisonzi[175], T. Barklow[143], N. Barlow[28], B.M. Barnett[129], R.M. Barnett[15], A. Baroncelli[134a], G. Barone[49], A.J. Barr[118], F. Barreiro[80], J. Barreiro Guimarães da Costa[57], P. Barrillon[115], R. Bartoldus[143], A.E. Barton[71], V. Bartsch[149], A. Basye[165], R.L. Bates[53], L. Batkova[144a], J.R. Batley[28], A. Battaglia[17], M. Battistin[30], F. Bauer[136], H.S. Bawa[143,e], S. Beale[98], T. Beau[78], P.H. Beauchemin[161], R. Beccherle[50a], P. Bechtle[21], H.P. Beck[17], A.K. Becker[175], S. Becker[98], M. Beckingham[138], K.H. Becks[175], A.J. Beddall[19c], A. Beddall[19c], S. Bedikian[176], V.A. Bednyakov[64], C.P. Bee[83], L.J. Beemster[105], M. Begel[25], S. Behar Harpaz[152], M. Beimforde[99], C. Belanger-Champagne[85], P.J. Bell[49], W.H. Bell[49], G. Bella[153], L. Bellagamba[20a], F. Bellina[30], M. Bellomo[30], A. Belloni[57], O. Beloborodova[107,f], K. Belotskiy[96], O. Beltramello[30], O. Benary[153], D. Benchekroun[135a], K. Bendtz[146a,146b], N. Benekos[165], Y. Benhammou[153], E. Benhar Noccioli[49], J.A. Benitez Garcia[159b], D.P. Benjamin[45], M. Benoit[115], J.R. Bensinger[23], K. Benslama[130], S. Bentvelsen[105], D. Berge[30], E. Bergeaas Kuutmann[42], N. Berger[5], F. Berghaus[169], E. Berglund[105], J. Beringer[15], P. Bernat[77], R. Bernhard[48], C. Bernius[25], T. Berry[76], C. Bertella[83], A. Bertin[20a,20b], F. Bertolucci[122a,122b], M.I. Besana[89a,89b], G.J. Besjes[104], N. Besson[136], S. Bethke[99], W. Bhimji[46], R.M. Bianchi[30], M. Bianco[72a,72b], O. Biebel[98], S.P. Bieniek[77], K. Bierwagen[54], J. Biesiada[15], M. Biglietti[134a], H. Bilokon[47], M. Bindi[20a,20b], S. Binet[115], A. Bingul[19c], C. Bini[132a,132b], C. Biscarat[178], B. Bittner[99], K.M. Black[22], R.E. Blair[6], J.-B. Blanchard[136], G. Blanchot[30], T. Blazek[144a], C. Blocker[23], J. Blocki[39], A. Blondel[49], W. Blum[81], U. Blumenschein[54], G.J. Bobbink[105], V.B. Bobrovnikov[107], S.S. Bocchetta[79],

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A. Bocci[45], C.R. Boddy[118], M. Boehler[48], J. Boek[175], N. Boelaert[36], J.A. Bogaerts[30], A. Bogdanchikov[107], A. Bogouch[90,*], C. Bohm[146a], J. Bohm[125], V. Boisvert[76], T. Bold[38], V. Boldea[26a], N.M. Bolnet[136], M. Bomben[78], M. Bona[75], M. Boonekamp[136], C.N. Booth[139], S. Bordoni[78], C. Borer[17], A. Borisov[128], G. Borissov[71], I. Borjanovic[13a], M. Borri[82], S. Borroni[87], V. Bortolotto[134a,134b], K. Bos[105], D. Boscherini[20a], M. Bosman[12], H. Boterenbrood[105], J. Bouchami[93], J. Boudreau[123], E.V. Bouhova-Thacker[71], D. Boumediene[34], C. Bourdarios[115], N. Bousson[83], A. Boveia[31], J. Boyd[30], I.R. Boyko[64], I. Bozovic-Jelisavcic[13b], J. Bracinik[18], P. Branchini[134a], A. Brandt[8], G. Brandt[118], O. Brandt[54], U. Bratzler[156], B. Brau[84], J.E. Brau[114], H.M. Braun[175,*], S.F. Brazzale[164a,164c], B. Brelier[158], J. Bremer[30], K. Brendlinger[120], R. Brenner[166], S. Bressler[172], D. Britton[53], F.M. Brochu[28], I. Brock[21], R. Brock[88], F. Broggi[89a], C. Bromberg[88], J. Bronner[99], G. Brooijmans[35], T. Brooks[76], W.K. Brooks[32b], G. Brown[82], H. Brown[8], P.A. Bruckman de Renstrom[39], D. Bruncko[144b], R. Bruneliere[48], S. Brunet[60], A. Bruni[20a], G. Bruni[20a], M. Bruschi[20a], T. Buanes[14], Q. Buat[55], F. Bucci[49], J. Buchanan[118], P. Buchholz[141], R.M. Buckingham[118], A.G. Buckley[46], S.I. Buda[26a], I.A. Budagov[64], B. Budick[108], V. Büscher[81], L. Bugge[117], O. Bulekov[96], A.C. Bundock[73], M. Bunse[43], T. Buran[117], H. Burckhart[30], S. Burdin[73], T. Burgess[14], S. Burke[129], E. Busato[34], P. Bussey[53], C.P. Buszello[166], B. Butler[143], J.M. Butler[22], C.M. Buttar[53], J.M. Butterworth[77], W. Buttinger[28], S. Cabrera Urbán[167], D. Caforio[20a,20b], O. Cakir[4a], P. Calafiura[15], G. Calderini[78], P. Calfayan[98], R. Calkins[106], L.P. Caloba[24a], R. Caloi[132a,132b], D. Calvet[34], S. Calvet[34], R. Camacho Toro[34], P. Camarri[133a,133b], D. Cameron[117], L.M. Caminada[15], R. Caminal Armadans[12], S. Campana[30], M. Campanelli[77], V. Canale[102a,102b], F. Canelli[31,g], A. Canepa[159a], J. Cantero[80], R. Cantrill[76], L. Capasso[102a,102b], M.D.M. Capeans Garrido[30], I. Caprini[26a], M. Caprini[26a], D. Capriotti[99], M. Capua[37a,37b], R. Caputo[81], R. Cardarelli[133a], T. Carli[30], G. Carlino[102a], L. Carminati[89a,89b], B. Caron[85], S. Caron[104], E. Carquin[32b], G.D. Carrillo Montoya[173], A.A. Carter[75], J.R. Carter[28], J. Carvalho[124a,h], D. Casadei[108], M.P. Casado[12], M. Cascella[122a,122b], C. Caso[50a,50b,*], A.M. Castaneda Hernandez[173,i], E. Castaneda-Miranda[173], V. Castillo Gimenez[167], N.F. Castro[124a], G. Cataldi[72a], P. Catastini[57], A. Catinaccio[30], J.R. Catmore[30], A. Cattai[30], G. Cattani[133a,133b], S. Caughron[88], V. Cavaliere[165], P. Cavalleri[78], D. Cavalli[89a], M. Cavalli-Sforza[12], V. Cavasinni[122a,122b], F. Ceradini[134a,134b], A.S. Cerqueira[24b], A. Cerri[30], L. Cerrito[75], F. Cerutti[47], S.A. Cetin[19b], A. Chafaq[135a], D. Chakraborty[106], I. Chalupkova[126], K. Chan[3], P. Chang[165], B. Chapleau[85], J.D. Chapman[28], J.W. Chapman[87], E. Chareyre[78], D.G. Charlton[18], V. Chavda[82], C.A. Chavez Barajas[30], S. Cheatham[85], S. Chekanov[6], S.V. Chekulaev[159a], G.A. Chelkov[64], M.A. Chelstowska[104], C. Chen[63], H. Chen[25], S. Chen[33c], X. Chen[173], Y. Chen[35], A. Cheplakov[64], R. Cherkaoui El Moursli[135e], V. Chernyatin[25], E. Cheu[7], S.L. Cheung[158], L. Chevalier[136], G. Chiefari[102a,102b], L. Chikovani[51a,*], J.T. Childers[30], A. Chilingarov[71], G. Chiodini[72a], A.S. Chisholm[18], R.T. Chislett[77], A. Chitan[26a], M.V. Chizhov[64], G. Choudalakis[31], S. Chouridou[137], I.A. Christidi[77], A. Christov[48], D. Chromek-Burckhart[30], M.L. Chu[151], J. Chudoba[125], G. Ciapetti[132a,132b], A.K. Ciftci[4a], R. Ciftci[4a], D. Cinca[34], V. Cindro[74], C. Ciocca[20a,20b], A. Ciocio[15], M. Cirilli[87], P. Cirkovic[13b], M. Citterio[89a], M. Ciubancan[26a], A. Clark[49], P.J. Clark[46], R.N. Clarke[15], W. Cleland[123], J.C. Clemens[83], B. Clement[55], C. Clement[146a,146b], Y. Coadou[83], M. Cobal[164a,164c], A. Coccaro[138], J. Cochran[63], J.G. Cogan[143], J. Coggeshall[165], E. Cogneras[178], J. Colas[5], S. Cole[106], A.P. Colijn[105], N.J. Collins[18], C. Collins-Tooth[53], J. Collot[55], T. Colombo[119a,119b], G. Colon[84], P. Conde Muiño[124a], E. Coniavitis[118], M.C. Conidi[12], S.M. Consonni[89a,89b], V. Consorti[48], S. Constantinescu[26a], C. Conta[119a,119b], G. Conti[57], F. Conventi[102a,j], M. Cooke[15], B.D. Cooper[77], A.M. Cooper-Sarkar[118], K. Copic[15], T. Cornelissen[175], M. Corradi[20a], F. Corriveau[85,k], A. Cortes-Gonzalez[165], G. Cortiana[99], G. Costa[89a], M.J. Costa[167], D. Costanzo[139], D. Côté[30], L. Courneyea[169], G. Cowan[76], C. Cowden[28], B.E. Cox[82],

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ATLAS NOTE

March 5, 2013

Internal documentation for "Time dependent angular analysis of $B_s^0 \to J/\psi\phi$ decay and extraction of $\Delta\Gamma_s$ and weak phase of B_s^0meson in ATLAS".

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Abstract

An updated measurement including tagging of $B_s^0 \to J/\psi\phi$ decay parameters, including ϕ_s and $\Delta\Gamma_s$ is reported using $4.9\,\mathrm{fb}^{-1}$of integrated luminosity collected by the ATLAS detector from pp collisions recorded in 2011. The other measured parameters of interest are the mean decay width Γ_s and the transversity amplitudes $|A_0(0)|^2$ and $|A_\parallel(0)|^2$. The values reported for these parameters are:

$$\phi_s = 0.11 \pm 0.25 \text{ (stat.)} \pm 0.10 \text{ (syst.) rad}$$
$$\Delta\Gamma_s = 0.053 \pm 0.021 \text{ (stat.)} \pm 0.010 \text{ (syst.) ps}^{-1}$$
$$\Gamma_s = 0.678 \pm 0.007 \text{ (stat.)} \pm 0.004 \text{ (syst.) ps}^{-1}$$
$$|A_0(0)|^2 = 0.529 \pm 0.006\text{(stat.)} \pm 0.009 \text{ (syst.)}$$
$$|A_\parallel(0)|^2 = 0.220 \pm 0.008\text{(stat.)} \pm 0.007 \text{ (syst.)}$$

Where $\Delta\Gamma_s$ is constrained to be positive. The fraction of S-wave KK or f_0 contamination through the decays $B_s^0 \to J/\psi K^+K^-(f_0)$ is also measured and is found to be within 2 σ consistent with zero. Results for ϕ_s and $\Delta\Gamma_s$ are also presented as 68% and 95% likelihood contours, which show agreement with SM expectations.

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Author(s)	Barton, A (Lancaster University UK) ; Borissov, G (Lancaster University UK) ; Bozovic-Jelisavcic, I (Vinca Institute of Nuclear Sciences, Belgrade) ; Catmore, J (CERN) ; Cirkovic, P (Vinca Institute of Nuclear Sciences, Belgrade) ; Dearnaley, W (Lancaster University UK) ; Dewhurst, A (Rutherford Appleton Laboratory) ; Heller, C (Ludwig-Maximilians-Universitat Munchen) ; Jakoubek, T (Prague Institute of Physics) ; Jones, R (Lancaster University UK) ; Jovin, T (Vinca Institute of Nuclear Sciences, Belgrade) ; Kirk, J (Rutherford Appleton Laboratory) ; Reznicek, P (Ludwig-Maximilians-Universitat Munchen) ; Schieck, J (Ludwig-Maximilians-Universitat Munchen) ; Skinner, M (Lancaster University UK) ; Smizanska, M (Lancaster University UK) ; Walder, J (Lancaster University UK) *Hide*
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Abstract	An updated measurement including tagging of $B_s \to J/\psi\phi$ decay parameters, including ϕ_s and $\Delta\Gamma$ is reported using $4.9\mathrm{fb}^{-1}$ of integrated luminosity collected by the ATLAS detector from pp collisions recorded in 2011. The other measured parameters of interest are the mean decay width Γ_s and the transversity amplitudes $\lvert A_0(0)\rvert^2$ and $\lvert A_\parallel(0)\rvert^2$. The values reported for these parameters are: $\phi_s = 0.11 \pm 0.25\ (\mathrm{stat.}) \pm 0.10\ (\mathrm{syst.})\ \mathrm{rad}$; $\Delta\Gamma = 0.053 \pm 0.021\ (\mathrm{stat.}) \pm 0.010\ (\mathrm{syst.})\ \mathrm{ps}^{-1}$; $\Gamma_s = 0.678 \pm 0.007\ (\mathrm{stat.}) \pm 0.004\ (\mathrm{syst.})\ \mathrm{ps}^{-1}$; $\lvert A_0(0)\rvert^2 = 0.529 \pm 0.006(\mathrm{stat.}) \pm 0.009\ (\mathrm{syst.})$; $\lvert A_\parallel(0)\rvert^2 = 0.220 \pm 0.008(\mathrm{stat.}) \pm 0.007\ (\mathrm{syst.})$. Where $\Delta\Gamma$ is constrained to be positive. The fraction of S-wave KK or f_0 contamination through the decays $B_s \to J/\psi KK$ is also measured and is found to be within 2σ consistent with zero. Results for ϕ_s and $\Delta\Gamma$ are also presented as 68% and 95% likelihood contours, which show agreement with SM expectations.

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B-flavour Charge Tagging in CP Violation Measurements in ATLAS Experiment

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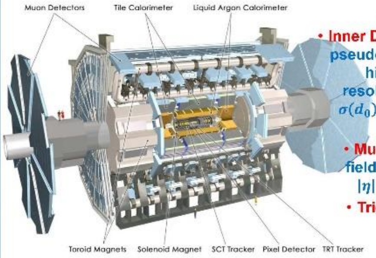
INTRODUCTION

- The **charge identification of the b-flavour** of reconstructed B_s^0 mesons is of relevance for the measurements of **oscillations** and **time-dependent CP asymmetries**
- b-quark charge identification ($b - \bar{b}$ separation) also known as **charge tagging** removes the ambiguity ($\phi_s, \pi - \phi_s$) of the measured CP violating phase ϕ_s

ATLAS DETECTOR

- A **large sample** of 10^{12} $b\bar{b}$ pairs/year is provided by
  - **Large cross section** for the $b\bar{b}$ production ($\sim 10^5$ nb) in pp collisions at $\sqrt{s} = 7$ TeV and
  - **High luminosity** ($3.6 \cdot 10^{33}$ $cm^{-2}s^{-1}$ was the peak luminosity in 2011)

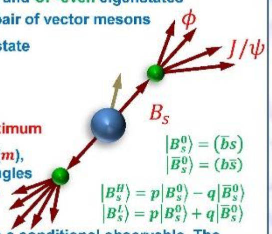


DETECTOR COMPONENTS:

- **Inner Detector** – magnetic field $2\,T$, pseudorapidity coverage $|\eta| < 2.5$, high p_T and impact parameter resolutions ($\sigma(1/p_T) \sim 1.5\,\%$ and $\sigma(d_0) \sim 10\,\mu m$), precise track and vertex reconstruction
- **Muon Spectrometer** – magnetic field $0.5\,T$, pseudorapidity range $|\eta| < 2.7$, fast response $\sim 25\,ns$
- **Trigger** for B-phyiscs based on muon reconstruction

METHOD OF CPV MEASUREMENTS AT ATLAS

- **Indirect CPV** is observed in $B_s^0 \to J/\psi\,\phi$ ($J/\psi \to \mu^+\mu^-$, $\phi \to K^+K^-$) decays
- Due to **flavour oscillations** ($B_s^0 - \bar{B}_s^0$), B_s meson is found in the quantum superposition states B_s^H and B_s^L, i.e. CP-odd and CP-even eigenstates
- $B_s^0 \to J/\psi\phi$ is a pseudo-scalar going into a pair of vector mesons
- Polarization of the two-meson ($J/\psi\,\phi$) final state ($L = \{0,\ 1,\ 2\}$) corresponds to CP-odd ($L = \{0,\ 2\}$) or CP-even ($L = 1$) final state
- CP violating phase ϕ_s ($\phi_s \approx 2\beta_s$, $\beta_s = \arg\left[-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right]$) is extracted from the **maximum likelihood fit** of the reconstructed B_s^0 mass (m), its proper decay time (t) and transversity angles ($\Omega = (\theta_T, \psi_T, \varphi_T)$) describing the $B_s^0 \to J/\psi\,\phi$ decay in the vector mesons rest frames



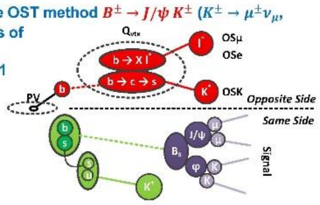
$|B_s^0\rangle = (\bar{b}s)$
$|\bar{B}_s^0\rangle = (b\bar{s})$

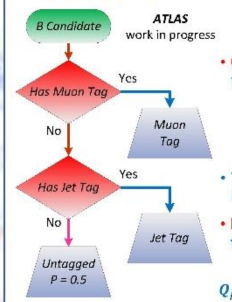
$|B_s^H\rangle = p|B_s^0\rangle - q|\bar{B}_s^0\rangle$
$|B_s^L\rangle = p|B_s^0\rangle + q|\bar{B}_s^0\rangle$

- The tag-probability enters the signal PDF as a conditional observable. The additional PDF is included to account for the differences between the signal (S) and background (B) tag probability distributions

OPPOSITE SIDE TAGGING

- To estimate the performance of the OST method $B^{\pm} \to J/\psi\,K^{\pm}$ ($K^{\pm} \to \mu^{\pm}\nu_{\mu}$, BR $\approx 63\,\%$) are studied on samples of
  - $4.9\,fb^{-1}$ for the MC events and
  - $4.5\,fb^{-1}$ for data collected in 2011 at $\sqrt{s} = 7\,TeV$
- **b-charge tagging** applied to the **opposite side** of the signal $B_s^0 \to J/\psi\phi$ (**OST**)



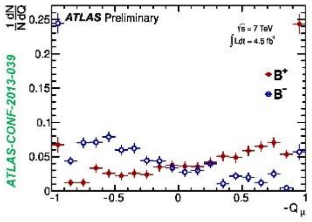


- **Current OST-techniques** are based on the following b-quark charge taggers:
  - Segment-tagged muon
  - Combined muon
  - Jet-charge
  - SV-charge
- The **hierarchical algorithm** of combining the individual taggers is employed
- **Muon (cone)–charge** (and similarly for the b-tagged jet-**jet charge**) is calculated as:

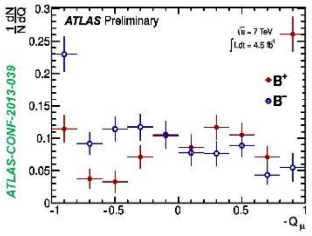
$$Q_{\mu,jet} = \frac{\sum_i^{N_{tracks}} q^i \cdot (p_T^i)^{\kappa}}{\sum_i^{N_{tracks}} (p_T^i)^{\kappa}}$$

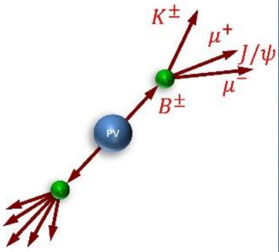
- where parameter $\kappa = 1.1$ is tuned to optimize the tagging power (TP),
- q^i is the charge of the track, p_T is the transverse momentum of the track and
- the sum is over the reconstructed ID tracks within a cone of $\Delta R < 0.5$ around the muon which $p_T < 0.5\,GeV$ and $|\eta| < 2.5$ or over the tracks associated to the jet

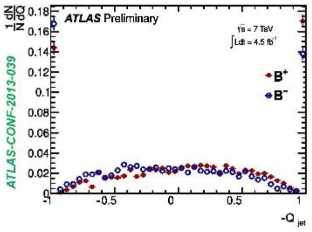
RESULTS



- The **charge distributions** of the B^+ and B^- candidates, taken from the MC sample are given for the different taggers at the following three plots:
  - **Muon-charge** distributions of the $B^{\pm}$ for the **combined** (first plot) and **segment-tagged muon** tagger (second plot)







  - The third plot shows the **jet-charge** distributions of the $B^{\pm}$ for the jet-charge tagger:
    - AntiKt6TopoEM jet collection
    - B-tagging applied with the IP3D+SV1 weight > -0.5
- The probability of tagging an event is described by the **tagging efficiency**:

$$\varepsilon = \frac{R + W}{R + W + U}$$

- The quantity defined to characterize the mistag rate for a particular algorithm is called **dilution**:

$$\mathcal{D} = 2P_W - 1 = \frac{W - R}{W + R}$$

- The dilution is constructed in a way that $\mathcal{D} = 1$ means that all tagging decisions are wrong
- The measure of the statistical power of a flavour tagging method is called **tagging power** or effective tagging efficiency, and is defined as $\varepsilon\mathcal{D}^2$, where $\mathcal{D}$ is the average dilution:

$$TP = \varepsilon\mathcal{D}^2 = \sum \varepsilon(2P_W - 1)^2$$

- Efficiency, dilution and tagging power describe robustness of the applied tagger
- Charge-tagging performance for the different taggers are given in the table below

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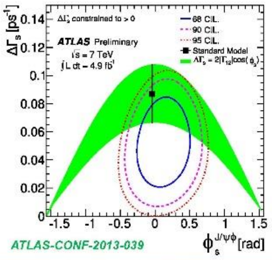
ATLAS	ε [%]	$\mathcal{D}$ [%]	TP [%]
Tagged muon	1.08±0.02	36.7±0.7	0.15±0.02
Combined muon	3.37±0.04	50.6±0.5	0.86±0.04
Jet charge	27.7±0.1	12.68±0.06	0.45±0.03
Total	32.1±0.1	21.3±0.08	1.45±0.05

- The table shows **comparable results with similar experiments** for individual taggers (i.e. combined + tagged muons) with comparable efficiency and slightly poorer separation of right and wrong tags (higher dilution)

CONCLUSIONS

- CPV measurement in $B_s \to J/\psi\phi$ decays relies on b-flavour charge tagging in order to remove sign ambiguity of the measured CPV phase (ϕ_s)
- OST method is studied on the $B^{\pm} \to J/\psi K^{\pm}$ decay sample
- Performance of the OST method is comparable to other experiments with further possible improvement like introduction of other tagger (i.e. SV charge) or combination of taggers in a more refined way (i.e. using MVA tools)



ATLAS-CONF-2013-039

ИДЕНТИФИКАЦИЈА ЗНАКА НАЕЛЕКТРИСАЊА *b*-КВАРКА У МЕРЕЊУ НАРУШЕЊА CP СИМЕТРИЈЕ У ATLAS ЕКСПЕРИМЕНТУ

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Апстракт. У овом раду биће представљен принцип и перформансе алгоритма за идентификацију знака наелектрисања *b*-кварка који је конституент B_s мезона од значаја у мерењу нарушења CP симетрије у ATLAS експерименту на сударачу LHC. Идентификација знака наелектрисања валентног *b*-кварка ($b,\bar{b}$ сепарација) је од посебне важности у уклањању неједнозначности (ϕ_s, $\pi-\phi_s$) у мерењу ϕ_s фазе нарушења CP симетрије у процесу $B_s \to J/\psi\phi$.

1. УВОД

Мерење нарушења CP симетрије у системима *B*-мезона мотивисано је двојаким разлозима: потрагом за неусаглашеностима у односу на Стандардни модел у физици честица, а које би указале на физику изван Стандардног модела, као и успостављањем везе између нарушења CP симетрије измереног у системима неутралних мезона (K^0, B^0) и космолошког нарушења потребног да објасни барионску асиметрију опсервабилну у Универзуму. У ATLAS експерименту на Великом хадронском сударачу (LHC), мерење фазе нарушења (ϕ_s) CP симетрије врши се у распадима $B_s^0 \to J/\psi\phi$ [5], у којима се CP симетрија индиректно нарушава распадом почетног стања које се, услед осцилација $B_s^0 - \overline{B_s^0}$, јавља као квантна суперпозиција стања B_s^0 и $\overline{B_s^0}$ и које се, у малом броју случајева, распада на поларизационо стање векторских мезона ($J/\psi\phi$) супротне CP парности.

Одређивање знака наелектрисања *b*-кварка у B_s мезону уклања неједнозначност (ϕ_s, $\pi-\phi_s$) у мерењу ϕ_s фазе нарушења CP симетрије присутну у претходним мерењима [1]. Узевши у обзир да *B*-мезони настају хадронизацијом из иницијалног пара $b\bar{b}$, довољно је утврдити знак *b*-кварка у мезону на супротној хемисфери од сигнала $B_s^0 \to J/\psi\phi$ и тај метод (*Opposite-Side Tagging* или OST) ће бити представљен у овом раду.

2. РЕКОНСТРУКЦИЈА НАЕЛЕКТРИСАЊА *b*-КВАРКА

У циљу калибрације и утврђивања перформанси OST метода преференцијално се користе распади попут $B^{\pm} \to J/\psi K^{\pm}$, код којих су наелектрисање, односно кварковски састав *B*-мезона једнозначно одређени наелектрисањем каона који се доминантно (у 63.55% случајева) распада на мион истог знака наелектрисања [2]. У анализи је коришћен целокупни узорак од $4.9\,fb^{-1}$ података прикупљених ATLAS детектором током 2011. године, на енергији у систему центра масе $7\,TeV$ и узорак величине $4.5\,fb^{-1}$добијен *Monte Carlo* симулацијом.

У смислу одређивања ефективног наелектрисања млаза, млаз (или *jet*) може представљати како експериментално реконструисани млаз честица, тако и мион. У принципу, за трагове који се налазе у просторном углу одређеном конусом димензије ΔR, могуће је дефинисати величину Q_{jet} (и аналогно њој Q_{μ}) коју називамо *наелектрисање млаза*, независно од тога да ли је (или није) у конусу реконструисан физички млаз честица, по чијим се траговима врши сумирање:

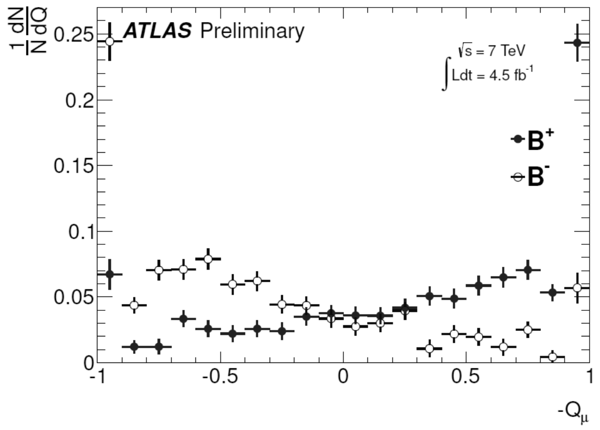
$$Q_{jet,\mu} = \frac{\sum_i^{N_{tracks}} q_i \cdot {p_T}^{\kappa}}{\sum_i^{N_{tracks}} {p_T}^{\kappa}}.$$

Отежињавање трагова наелектрисаних честица у зависности од њиховог трансверзалног импулса оптимизовано је коефицијентом κ ($\kappa = 1.1$), а величина конуса описаног око осе млаза (вектора импулса миона) износи $\Delta R < 0.5$. Трансверзални импулс (p_T) и псеудорапидитет (η) идентификованих миона задовољавају услове: $p_T > 0.5GeV$ и $|\eta| < 2.5$. Уколико је реконструисано више од једног миона или млаза на страни супротној сигналу, узима се мион (или млаз) са највећом вредношћу трансверзалног импулса.

Перформансе метода описују се величинама које се називају *ефикасност*, *разређеност* и *идентификациона моћ* [3]. Ефикасност ε индентификације се дефинише као однос броја исправно (R) или погрешно (W) идентификованих *b*-кваркова (догађаја) према укупном броју кандидата који укључује и неидентификоване догађаје (U). Разређеност (D) показује колико износи ефективно присуство погрешно идентификованих догађаја, узимајући вредности из опсега од -1 (ако нема погрешних идентификација) до 1 (ако су сви догађаји погрешно идентификовани).

$$\varepsilon = \frac{R+W}{R+W+U}, \quad D = \frac{W-R}{W+R}$$

Величина εD^2 представља идентификациону моћ метода. Алгоритам комбиновања тренутно расположивих идентификатора (ефективног наелектрисања миона и ефективног наелектрисања млаза) је хијерархијски: уколико је селектован мион који задовољава услове у погледу трансверзалног импулса и псеудорапидитета, као идентификатор се користи ефективно наелектрисање миона Q_μ; у противном користи се наелектрисање реконструисаног млаза који је идентификован да потиче од *b*-кварка (*flavour tagging*) Q_{jet}, или се догађај третира као неидентификован. На слици 1. приказане су расподеле ефективног наелектрисања миона за кандидате из распада B^+ и B^- мезона [4].



СЛИКА 1. Расподела ефективног наелектрисања миона за кандидате из распада B^+ и B^- мезона добијене *Monte Carlo* симулацијом.

3. РЕЗУЛТАТИ И ДИСКУСИЈА

Перформансе метода за идентификацију знака наелектрисања *b*-кварка на супротној страни од сигнала, израчунате за различите идентификационе величине, дате су у табели 1 [4]. Наведене грешке су статистичке. Метода OST показује упоредиве резултате са онима добијеним у сличним мерењима, иако је, услед ограниченог броја идентификатора као и релативно једноставног алгоритма за њихово комбиновање, ефикасност идентификације знака наелектрисања *b*-кварка мања, а фракција погрешних идентификација већа него у сличним експериментима (нпр. LHCb [3]).

ТАБЕЛА. Преглед перформанси идентификације за различите индентификаторе.

Идентификатор	Ефикасност [%]	Разређеност [%]	Идентификациона моћ [%]
Еф. наелектрисање сегм. идент. миона	1.08±0.02	36.7±0.7	0.15±0.02
Еф. наелектрисање комб. миона	3.37±0.04	50.6±0.5	0.86±0.04
Ефективно наелектрисање млаза	27.7±0.1	12.68±0.06	0.45±0.03
Укупно	32.1±0.1	21.3±0.08	1.45±0.05

За сваки догађај, окарактерисан неком вредношћу идентификатора Q, може се дефинисати вероватноћа $P(Q\,|\,B^-)$ (или $P(Q\,|\,B^+)$) да је одлука – да је на страни супротној сигналу произведен b (или $\bar{b}$) кварк – исправна. Ова вероватноћа се даље користи у математичком опису фита експериментално измерених величина (масе и времена живота B_s мезона, као и углова који описују распад $B_s^0 \to J/\psi\phi$ у формализму трансверзалитета) у мерењу фазе нарушења CP симетрије. Увођење идентификације знака наелектрисања валентног b-кварка у B_s мезону, као што је већ речено, уклања једну од нееднозначности у мерењу фазе нарушења CP симетрије ϕ_s

ЗАКЉУЧАК

У мерење фазе нарушења CP симетрије у ATLAS експерименту у распаду B_s мезона $B_s^0 \to J/\psi\phi$ уведена је идентификација валентног b-кварка, користећи идентификацију знака наелектрисања b-кварка у хемисфери насупрот сигналу (OST). Иако се тренутно користе само две идентификационе варијабле (ефективно наелектрисање миона и млаза) у хијерархијском алгоритму, увођење OST метода омогућава уклањање нееднозначности у мерењу фазе нарушења CP симетрије ϕ_s и даје у погледу перформанси метода упоредиве резултате са сличним експериментима.

ЗАХВАЛНИЦА

Овај рад је реализован уз подршку Министарства за просвету, науку и технолошки развој Републике Србије, у оквиру пројекта ОИ171012. Такође, истраживање на ову тему спроводи се уз помоћ и у сарадњи са групом за изучавање B_s мезона у ATLAS експерименту у CERN.

ЛИТЕРАТУРА

[1] Aad G., Bozovic-Jelisavcic I., Cirkovic P., Jovin T. et.al. [ATLAS Collaboration], *Time dependent angular analysis of the decay Bs->J/psi phi and extraction of Delta Gamma s and the CP-violating weak phase phi s by ATLAS*, JHEP12 (2012) 072, 34 pp, December 2012.

[2] J. Beringer et al. [Particle Data Group], *Review of Particle Physics*, Phys. Rev. D86, 010001 (2012).

[3] R. Aaij et al. [The LHCb Collaboration], *Opposite-side flavour tagging of B mesons at the LHCb experiment*, LHCB-PAPER-2011-027, March 6, 2012.

[4] Aad G., Bozovic-Jelisavcic I., Cirkovic P., Jovin T. et.al. [ATLAS Collaboration], *Flavour tagged time dependent angular analysis of the Bs->J/psi phi and extraction of Delta Gamma_s and the weak phase phi_s in ATLAS*, ATLAS-CONF-2013-039, 18 pp, April 9, 2013.

[5] Jovin T. [On behalf of the ATLAS collaboration], *CP Violation in ATLAS*, The XI International Conference on Heavy Quarks and Leptons, June 2012, Prague, Czech Republic, 11-15 June 2012, PoS (HQL 2012) 038.

ИНСТИТУТ ЗА НУКЛЕАРНЕ НАУКЕ
"ВИНЧА"
НАУЧНО ВЕЋЕ
Број: 718/16
05. 05. 2011. године
БЕОГРАД

На основу чл. 59., чл. 70. и чл. 82. Закона о научноистраживачкој делатности (**"Службени гласник РС", бр. 110/05)**, на седници ***Научног већа Института за нуклеарне науке "Винча"*** одржаној 05. 05. 2011. године, донета је

ОДЛУКА
О СТИЦАЊУ ИСТРАЖИВАЧКОГ ЗВАЊА

Предраг Ћирковић, дипл. инж. електротехнике и рачунарства

стиче истраживачко звање

ИСТРАЖИВАЧ САРАДНИК

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ПРЕДСЕДНИК НАУЧНОГ ВЕЋА
ИНСТИТУТА "ВИНЧА"

Др Зоран Марковић, научни саветник

Република Србија
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УВЕРЕЊЕ

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Рок за завршетак студија: у двоструком трајању студија.

Ово се уверење може употребити за регулисање војне обавезе, издавање визе, права на дечији додатак, породичне пензије, инвалидског додатка, добијања здравствене књижице, легитимације за повлашћену вожњу и стипендије.

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