LHCC Poster Session - CERN, 2 March 2016

$B_s \to J/\psi\,\phi$ RUN-1 RESULTS AND STUDIES OF $B^{\pm}$ MASS WITH RUN-2 DATA AT ATLAS

A. $B_s \to J/\psi\phi$ in RUN-1

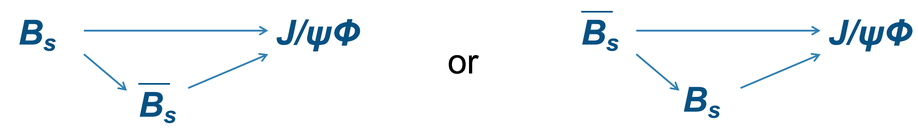
In the Standard Model *CP* violation (CPV) is described by a phase in the CKM matrix. One of the manifestations of this complex phase is a phase shift between direct and mixing-mediated B_s decays producing a common final state. In the case of $B_s \to J/\psi\phi$ this phase shift is predicted to be small: $\phi_s = 0.0368 \pm 0.0018$ rad. New physics can enhance ϕ_s whilst satisfying all existing constraints.

A1. *CP* violation in B_s system

Different *CP* violating effects:

- **CPV in decay:** decay amplitudes of *B*-meson and anti *B*-meson are different
- **CPV in mixing:** asymmetry in particle-antiparticle oscillations (*CP* eigenstates ≠ mass eigenstates)

In the $B_s \to J/\psi\phi$ channel the CPV occurs in **interference of mixing and decay**:



A2. Data and candidate selection

J/ψ

- Oppositely-charged muon pair
- $p_T(\mu) > 4$ GeV
- $|\eta|$ dependent mass cuts
- Vertex χ^2/ndf < 10

Φ

- Oppositely-charged track pair (no PID)
- $p_T(K) > 1$ GeV
- $|m(K^+K^-) - m_{PDG}(\phi)| < 11$ MeV

Used 2011+2012 *pp* data: 4.9 fb^{-1} of 7 + 14.3 fb^{-1} of 8 TeV.

B_s

- Coming from same vertex
- $\mu^+\mu^-K^+K^-$ vertex fit with J/ψ mass constraint
- Vertex χ^2/ndf < 3
- 5.15 GeV < $m(J/\psi K^+K^-)$ < 5.65 GeV

A3. Flavour tagging

Knowledge of the initial B_s meson flavour enhances the fit sensitivity to ϕ_s. It can be inferred using the other *B*-meson in the event (Opposite-Side Tagging).

Muon/electron tagging:

- Semi-leptonic decay of the *B*-meson
- Using *combined* muons (have full tracks in the MS and in the ID), *segment-tagged* muons (have full tracks in the ID matched to segment(s) in the MS) or electrons
- Momentum weighted charge of the lepton and tracks around
- Diluted through $b \to c \to l$, but even so it has good separation power

Jet-charge tagging:

- Used if the lepton is absent
- Momentum weighted track-charge in jet

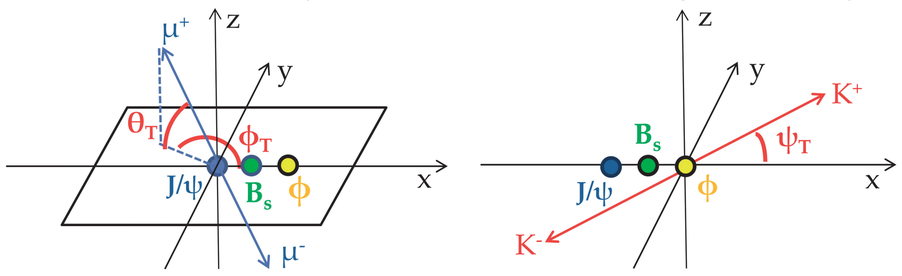
Initial flavour hypothesis is expressed as probability that an event has a signal decay containing a *b* quark.

Tagger	Efficiency [%]	Dilution [%]	Tagging Power [%]
Combined μ	4.12 ± 0.02	47.4 ± 0.2	0.92 ± 0.02
Electron	1.19 ± 0.01	49.2 ± 0.3	0.29 ± 0.01
Segment-tagged μ	1.20 ± 0.01	28.6 ± 0.2	0.10 ± 0.01
Jet-charge	13.15 ± 0.03	11.85 ± 0.03	0.19 ± 0.01
Total	19.66 ± 0.04	27.56 ± 0.06	1.49 ± 0.02

Tagging performance for the different tagging methods (statistical uncertainties only).

A4. Angular analysis

- $B_s \to J/\psi\phi \Rightarrow$ pseudoscalar $\to$ vector-vector $\Rightarrow$ admixture of *CP*-odd and *CP*-even final states
- *CP* states separated statistically in the combined lifetime-angular event-by-event fit



A5. Fitting model

Unbinned maximum likelihood fit uses per-candidate variables:

- B_s mass m_i and proper decay time t_i and its uncertainty
- 3 angles between final-state particles in transversity basis Ω_i
- B_s momentum p_{Ti}
- B_s tag probability and tagging method

Fit determines 9 physics variables that describe $B_s \to J/\psi\phi$ and S-wave ($B_s \to J/\psi K^+K^-$ or $B_s \to J/\psi\, f_0(K^+K^-)$) component: $\Delta\Gamma$, ϕ_s, Γ_s, $|A_0(0)|^2$, $|A_{||}(0)|^2$, $|A_S(0)|^2$, $\delta_{||}$, $\delta_\perp$, δ_S

Time dependent trigger efficiency

Background due to $B^0 \to J/\psi K^{*0}$ and $B^0 \to J/\psi K\pi$ (*)

$$\ln \mathcal{L} = \sum_{i=1}^{N} \{ w_i \cdot \ln(f_s \cdot \mathcal{F}_s(m_i, t_i, \sigma_{t_i}, \Omega_i, P(B|Q), p_{T_i}) + f_s \cdot f_{B^0} \cdot \mathcal{F}_{B^0}(m_i, t_i, \sigma_{t_i}, \Omega_i, P(B|Q), p_{T_i}) + (1 - f_s \cdot (1 + f_{B^0}))\mathcal{F}_{bkg}(m_i, t_i, \sigma_{t_i}, \Omega_i, P(B|Q), p_{T_i})) \},$$

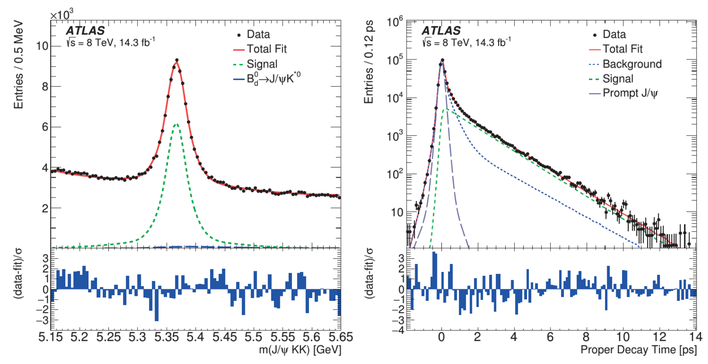
Signal Probability Density Function

Prompt and non-prompt combinatorial background

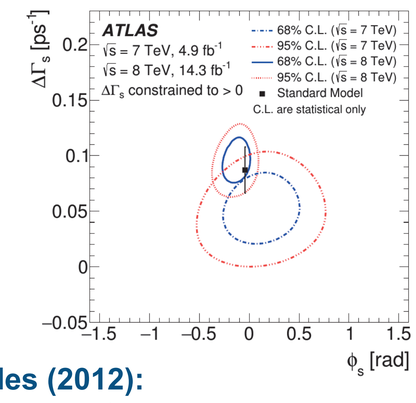
(*) f_{B0} constrained by known branching fractions and acceptance (11% of signal amplitude)

A6. Fit projections and ϕ_s - $\Delta\Gamma$ contour plot

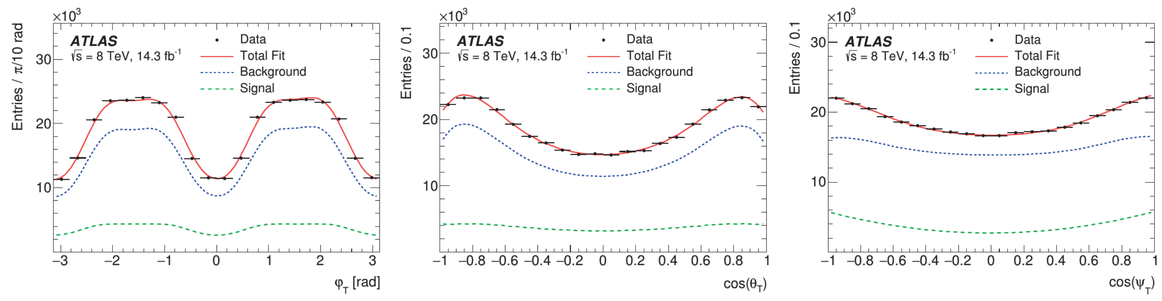
Mass and lifetime (2012):



$\Phi_s - \Delta\Gamma$ (2011 and 2012):



Transversity angles between final-state particles (2012):

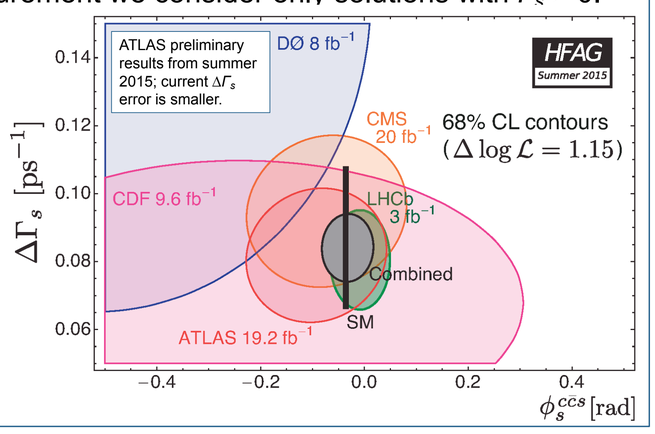


A7. Results

PDF describing the $B_s \to J/\psi\phi$ decay is invariant under (ϕ_s, $\Delta\Gamma_s$, $\delta_\perp$, $\delta_{||}$) $\to$ ($\pi-\phi_s$, $-\Delta\Gamma_s$, $\pi-\delta_\perp$, $2\pi-\delta_{||}$), based on the LHCb measurement we consider only solutions with $\Gamma_s > 0$.

Par	Value	Stat	Syst	
ϕ_s[rad]	0.12	0.25	0.05	7 TeV data
$\Delta\Gamma_s$[ps^{-1}]	0.053	0.021	0.010	
ϕ_s[rad]	−0.123	0.089	0.041	8 TeV data
$\Delta\Gamma_s$[ps^{-1}]	0.096	0.013	0.007	
ϕ_s[rad]	−0.098	0.084	0.040	Run1 combined
$\Delta\Gamma_s$[ps^{-1}]	0.083	0.011	0.007	

- 2011 and 2012 results statistically combined into the final RUN-1 result
- ϕ_s and other parameters consistent with the Standard Model prediction



A8. Systematic uncertainties (2012)

Uncertainty in the calibration of the tag probability

Effect of residual misalignment (studied in signal MC)

Uncertainty in the relative fraction of B_d background (contaminations from $B_d \to J/\psi K^{0*}$ and $B_d \to J/\psi K\pi$ events misreconstructed as $B_s \to J/\psi\phi$)

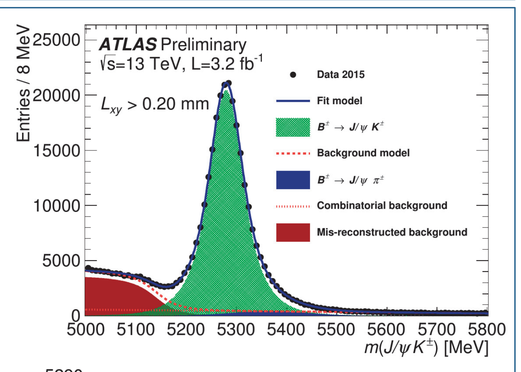
Uncertainties of fit model derived in pseudo-experiment studies

	ϕ_s [rad]	$\Delta\Gamma_s$ [ps^{-1}]
Tagging	0.025	0.003
Acceptance	<10^{-3}	<10^{-3}
Inner detector alignment	0.004	<10^{-3}
Background angles model:		
Choice of p_T bins	0.020	0.006
Choice of mass interval	0.008	0.001
B_d^0 background model	0.023	0.001
Fit model:		
Mass signal model	0.004	<10^{-3}
Mass background model	<10^{-3}	0.002
Time resolution model	0.003	<10^{-3}
Default fit model	0.001	0.002
Total	0.041	0.007

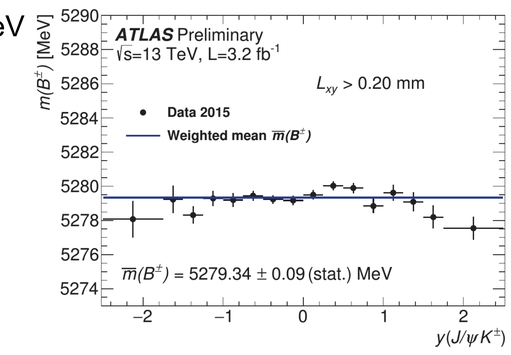
B. $B^{\pm}$ mass in RUN-2

Performance needed for the future $B_s \to J/\psi\phi$ and other *B*-measurements with the new data is tested using reconstructed $B^{\pm}$ in 2015 data (3.2 fb^{-1} of 13 TeV *pp* collisions).

- ATLAS has a new Pixel layer (IBL) in RUN-2, better ID performance
- Independent unbinned maximum likelihood fits to reconstructed $B^{\pm} \to J/\psi(\mu^+\mu^-)K^{\pm}$ candidates in 16 rapidity bins
- Weighted mean of the obtained mass values $m(B^{\pm})$ = 5279.34 ± 0.09 (stat.) ± 0.25 (syst.) MeV
- Good uniformity over the full *y*-range is visible



Source	Syst. Error [MeV]
y-Dependence	0.11
Signal Mass Model	0.09
Background Mass Model	0.17
Mass Fit Window	0.14
$B^{\pm} \to J/\psi\pi^{\pm}$ Background:	
Fraction	0.02
Line Shape	0.04
MC Reweighting	0.04



References: [1] Phys. Rev. D 90 (2014) 052007, [2] arXiv:1601.03297 [hep-ex] (submitted to JHEP), [3] ATLAS-CONF-2015-064

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ATLAS EXPERIMENT