ATLAS measurements of CP violation and rare decays processes with beauty mesons

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CP-violating phase ϕ_s in $B_s^0 \to J/\psi\phi$ decays in ATLAS

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Introduction

- $B_s^0 \to J/\psi\phi$ is used to measure the CP-violating phase ϕ_s which is potentially sensitive to New Physics (NP)
- The CP violation occurs due to interference between a direct decay and a decay with $B_s^0 - \overline{B}_s^0$ mixing
- In the SM, ϕ_s is related to the CKM elements and predicted with high precision: $\phi_s = -0.03696^{+0.00072}_{-0.00082}$ rad

Data and Selection

- pp collisions at $\sqrt{s} = 13$ TeV collected between years 2015 and 2017 corresponding to 80.5 fb^{-1}
- Data were collected with triggers based on the identification of a $J/\psi \to \mu^+\mu^-$ ($p_T > 4$ or 6 GeV)
- $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ selection criteria:
  - Vertex fit: χ^2/n.d.f. < 3
  - Muon pair vertex fit: χ^2/n.d.f. < 10
  - Only candidate with best χ^2/n.d.f. per event used
  - B_s^0 candidate mass in range 5.15–5.65 GeV
  - No lifetime cut
- 2 977 526 B_s^0 candidates used

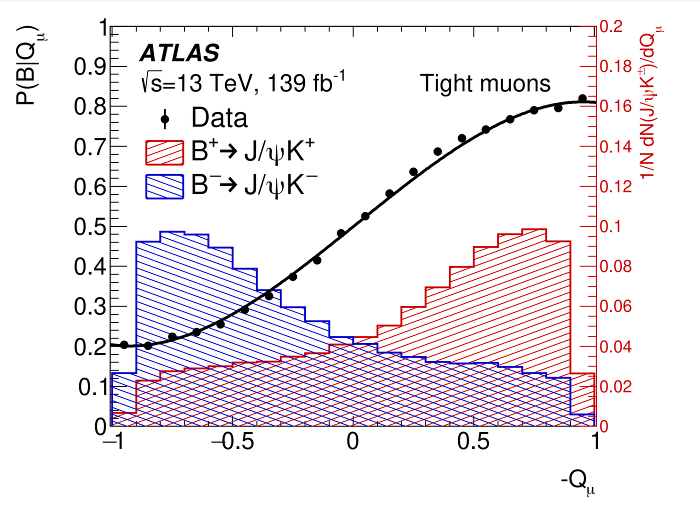
Mass Lifetime Angular Fit

- Unbinned maximum likelihood fit used

$$\mathcal{L} = \sum_{i=1}^{N}\{\underbrace{w_i}_{\text{tau weight}} \cdot \ln(\underbrace{f_s\mathcal{F}_s}_{\text{signal}} + \underbrace{f_s \cdot f_{B_d^0}\mathcal{F}_{B_d^0} + f_s f_{\Lambda_b}\mathcal{F}_{\Lambda_b}}_{\text{peaking background}} + \underbrace{(1-f_s)(1+f_{B_d^0}+f_{\Lambda_b})\mathcal{F}_{\text{bkg}}}_{\text{combinatorial background}})\}$$

- Main physics parameters of interest: ϕ_s, the average decay width Γ_s and the decay width difference $\Delta\Gamma_s$, the CP-state amplitudes with their phases
  - $B_s^0 \to J/\psi\phi$ is a decay of pseudoscalar into pair of vectors
  - Final state: admixture of CP-odd (L = 1) and CP-even (L = 0, 2) states and Non-resonant S-wave $B_s^0 \to J/\psi K^+K^-$
- Base observables: mass m, lifetime t, angles $\Omega(\psi_T, \phi_T, \theta_T)$
- Conditional observables per-candidate: mass and lifetime resolution, candidate p_T, tagging probability and method
- No direct CP violation assumed: $\lambda = 1$
- $\Delta m_s = |m_L - m_H|$ value fixed to PDG: $\Delta m_s = 17.77$ ps^{-1}

Flavour Tagging



- Opposite side tagging used
  - Infering initial signal flavour from $b - \overline{b}$ pair
- Tagging methods: tight and low-p_T muons, electron, jet
  - $b \to l$ is clean, $b \to c \to l$ dilutes tagging results
  - Information from tracks in b-tagged jets
- The probability to tag a B_s^0 meson is $P(B|Q) = \frac{P(Q|B^+)}{P(Q|B^+)+P(Q|B^-)}$

Method	ϵ_x [%]	D_x [%]	T_x [%]
Tight μ	4.50 ± 0.01	43.8 ± 0.2	0.862 ± 0.009
e^-	1.57 ± 0.01	41.8 ± 0.2	0.274 ± 0.004
Low-p_T μ	3.12 ± 0.01	29.9 ± 0.2	0.278 ± 0.006
Jet	12.04 ± 0.02	16.6 ± 0.1	0.334 ± 0.006
Total	21.23 ± 0.03	28.7 ± 0.1	1.750 ± 0.010

- Calibration using $B^\pm \to J/\psi K^\pm$
  - Efficiency: fraction of tagged candidates
  - Dilution: correctly tag probability
  - Tag power: figure of merit of tagger performance $\to T_x = \epsilon_x D_x^2$

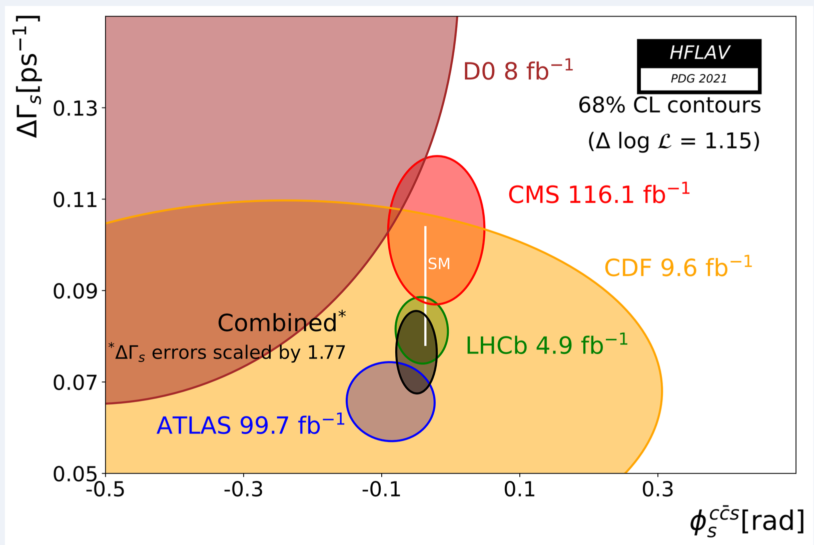
Fit Result Comparison

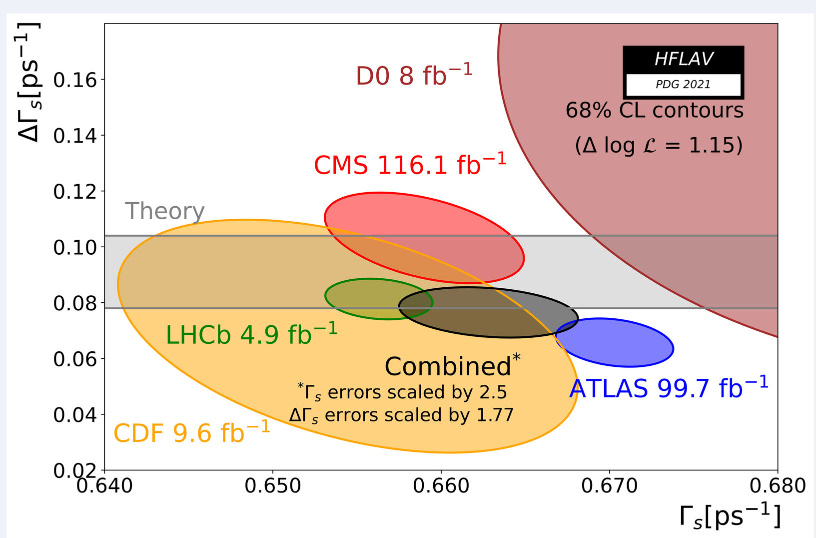
- Results combined with ATLAS Run1 using BLUE method

$$\phi_s = -87 \pm 36(\text{stat.}) \pm 21(\text{syst.})\ \text{mrad}$$

$$\Delta\Gamma_s = 65.7 \pm 4.3(\text{stat.}) \pm 3.7(\text{syst.})\ \text{ns}^{-1}$$

- Experiments are consistent with each other
  - Except Γ_s: $\sim 3\sigma$ tension





Decays of B_s^0 and B^0 mesons into muon pairs in ATLAS

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Introduction

- FCNC processes highly supressed in SM, significant deviations predicted by theories beyond SM
- $B_s^0 \to \mu\mu$ and $B^0 \to \mu\mu$ highly sensitive to New Physics in the decays via loop diagrams
- SM predictions: $\mathcal{B}(B_s^0 \to \mu\mu) = (3.66 \pm 0.14) \cdot 10^{-9}$ and $\mathcal{B}(B^0 \to \mu\mu) = (1.03 \pm 0.05) \cdot 10^{-10}$

Measurement

- Branching fractions are measured relative to the reference decay mode $B^\pm \to J/\psi K^\pm$:

$$\mathcal{B}\left(B_{(s)}^0 \to \mu\mu\right) = N_{d(s)} \frac{\mathcal{B}(B^\pm \to J/\psi K^\pm) \times \mathcal{B}(J/\psi \to \mu\mu)}{N_{J/\psi K^\pm}\frac{\varepsilon_{\mu\mu}}{\varepsilon_{J/\psi K^\pm}}} \frac{f_u}{f_{d(s)}}$$

- $B_s^0 \to J/\psi\phi$ used as control channel
- Branching ratios known from PDG, $f_u/f_{d(s)}$ from HFLAV
- Relative reconstruction efficiencies estimated from MC (corrected for data-MC differences): $\varepsilon_{\mu\mu}/\varepsilon_{J/\psi K^\pm} = 0.1176 \pm 0.0009(\text{stat.}) \pm 0.0047(\text{syst.})$
- Yields $N_{d(s)}$ and $N_{J/\psi K^\pm}$ exctracted from unbinned ML fit

Data and Selection

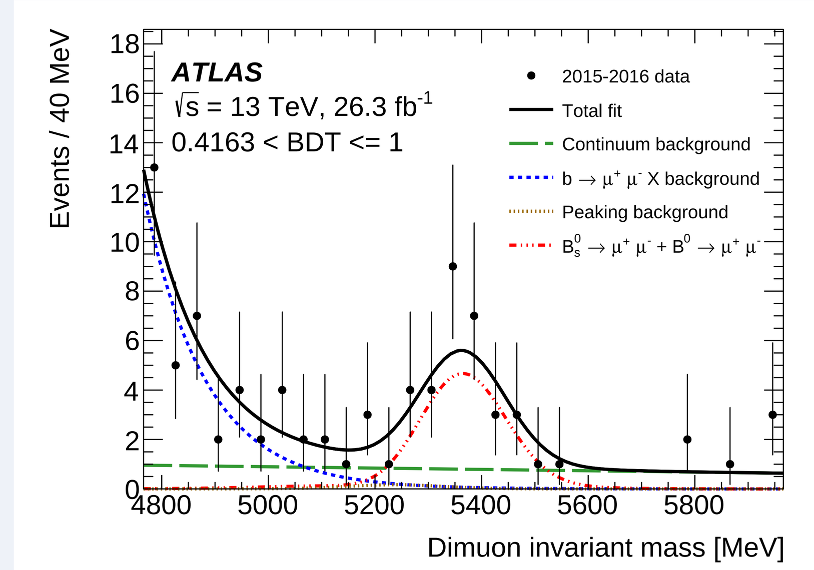
- pp collisions at $\sqrt{s} = 13$ TeV collected between years 2015 and 2016 corresponding to 36.2 fb^{-1}
- Data were collected with triggers based on the identification of a $J/\psi \to \mu^+\mu^-$ ($p_T > 4$ or 6 GeV)
- Signal sample :
  - Di-muon candidate in 4.0–8.5 GeV
- Reference and control channel
  - two, three or four track vertex fit: χ/n.d.f. < 6
  - J/ψ vertex: χ^2/n.d.f. < 10
  - Mass ranges: 5050–5650 MeV (B_s^0) and 4930–5630 $B^p m$
- $B_{(s)}^0 \to \mu\mu$ mass range: 4766–5966 MeV

Background Description

- Partially reconstructed b-hadrons
  - one or more of the final-state particles (X) in a b-hadron decay is not reconstructed
  - Mostly in the low di-muon mass region
- Peaking backgrounds
  - $B_{(s)}^0 \to hh'$ decays, both hadrons misreconstructed as muons
  - Simulated and fixed in the mass fit
- Continuum background
  - Muons originating from uncorrelated hadron decays
  - Reduced by BDT (15 variables)

Signal Yield Extraction

- BDT with 15 variables used (kinematics, isolation)
- BDT output validated on reference and control channels
- Signal region divided into four BDT bins
- B_s^0 and B^0 yields extracted from simultaneous unbinned ML fit



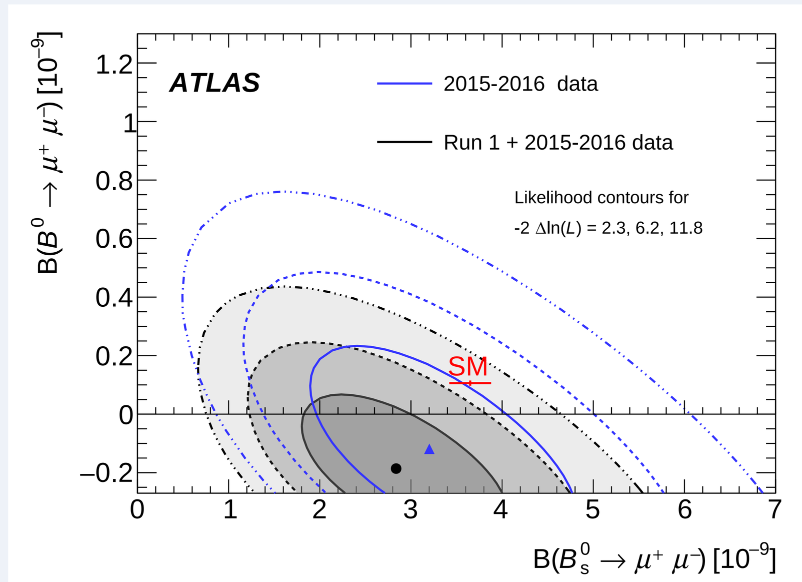
Fit Results and Comparison

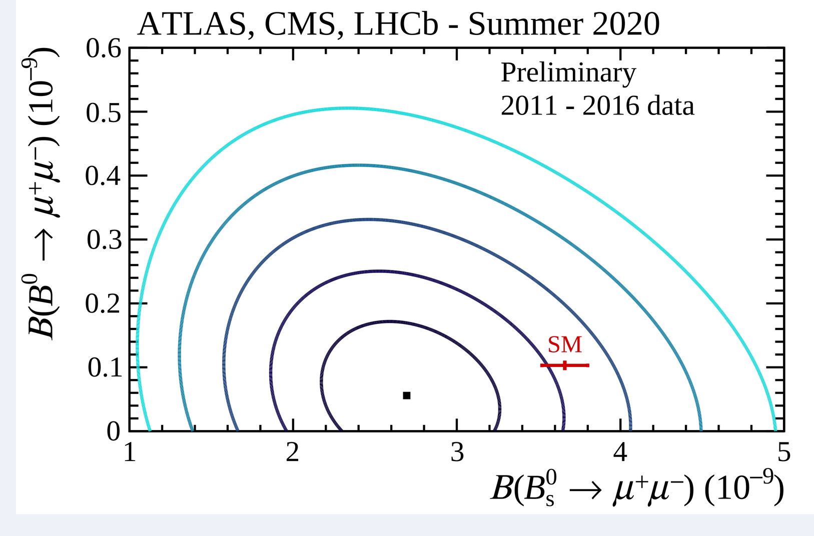
- Results combined with ATLAS Run1:

$$\mathcal{B}\left(B_s^0 \to \mu\mu\right) = \left(2.8^{+0.8}_{-0.7}\right) \cdot 10^{-9}$$

$$\mathcal{B}\left(B^0 \to \mu\mu\right) < 2.1 \cdot 10^{-10} \text{at 95\% CL}$$

- Combined measurement compatible with SM at 2.4σ
- Statistic uncertainties dominate
- 2.1σ compatibility of LHC combination and SM





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