

Tests of the Standard Model with beauty meson rare decay processes and CP-violation measurements at ATLAS

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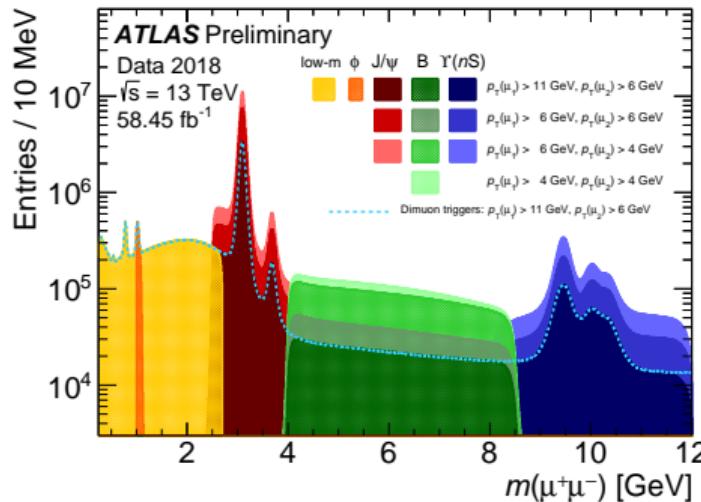
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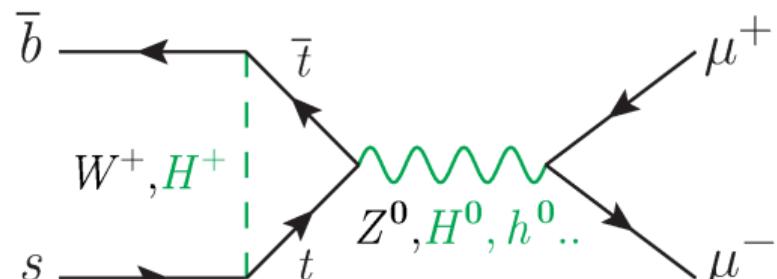
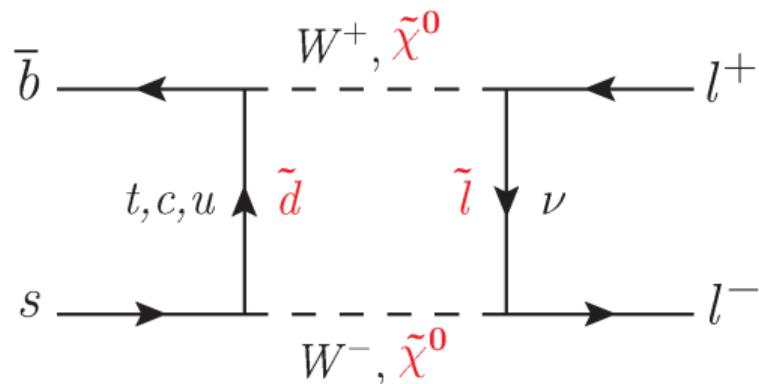
B Physics in ATLAS

- ATLAS has collected 25 fb^{-1} of data in Run 1, and 139 fb^{-1} in Run 2
- B physics in ATLAS mostly focus on final states with muons
- CP violation in $B_s^0 \rightarrow J/\psi \phi$ analysis (Run2, 2015-2017) and $B_{(s)} \rightarrow \mu\mu$ analysis (Run2, 2015-2016)
 - Events collected with a mixture of triggers based on $J/\psi \rightarrow \mu^+\mu^-$ identification, with muon p_T thresholds of either 4 GeV or 6 GeV (vary over run periods)



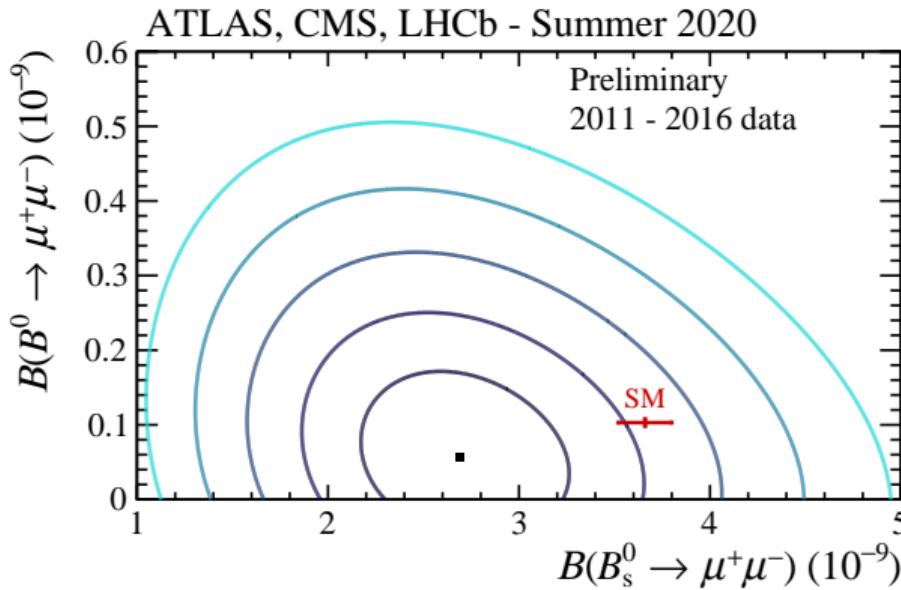
$B_{(s)}^0 \rightarrow \mu\mu$: Motivation

- Flavour-changing-neutral-current (FCNC) processes **highly suppressed in SM**, significant deviations predicted by theories beyond SM
- $B_s^0 \rightarrow \mu\mu$ and $B^0 \rightarrow \mu\mu$ highly sensitive to New Physics
- SM predictions: $\mathcal{B}(B_s^0 \rightarrow \mu\mu) = (3.66 \pm 0.14) \cdot 10^{-9}$ and $\mathcal{B}(B^0 \rightarrow \mu\mu) = (1.03 \pm 0.05) \cdot 10^{-10}$



- Any deviation of results from SM: hint for SUSY, dark matter,...?

$B_{(s)}^0 \rightarrow \mu\mu$: LHC Combination



- Combination from LHC experiments results calculated
- 2.1σ compatibility of LHC combination and SM

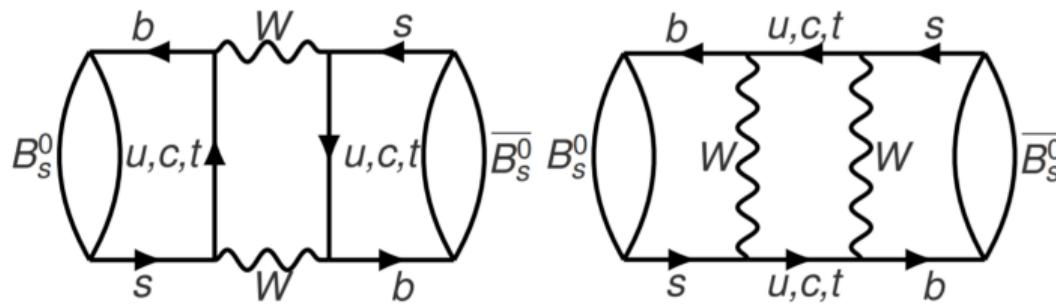
$$\mathcal{B}(B_s^0 \rightarrow \mu\mu) = (2.69^{+0.37}_{-0.35}) \cdot 10^{-9}$$

$$\mathcal{B}(B^0 \rightarrow \mu\mu) < 1.9 \cdot 10^{-10} \text{ at } 95\% \text{ CL}$$

ATLAS-CONF-2020-049

CP violation measurement in $B_s^0 \rightarrow J/\psi\phi$

- $B_s^0 \rightarrow J/\psi\phi$ used to measure the CP -violating phase ϕ_s [Eur. Phys. J. C 81 \(2021\) 342](#)
 - Potentially sensitive to New Physics (NP)
- The CP violation due to interference between a direct decay and a decay with $B_s^0 - \bar{B}_s^0$ mixing
- In the Standard Model (SM), ϕ_s is related to the CKM elements and predicted with high precision: $\phi_s \simeq 2\arg[-(V_{ts} V_{tb}^*)/(V_{cs} V_{cb}^*)] = -0.03696^{+0.00072}_{-0.00082}$ rad [Phys. Rev. D 91 \(2015\), 073007](#)

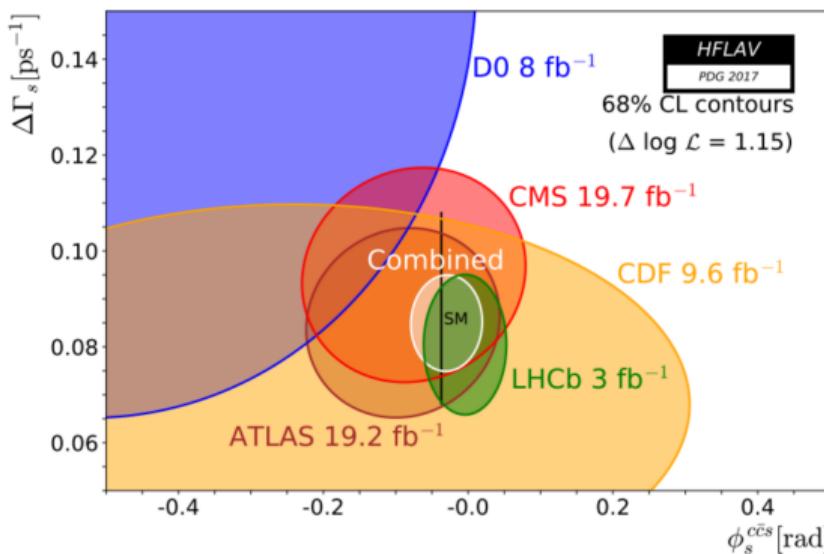


- Any deviations from SM: SUSY particles, Dark Matter, ... in the box diagram?

CP violation measurement in $B_s^0 \rightarrow J/\psi\phi$

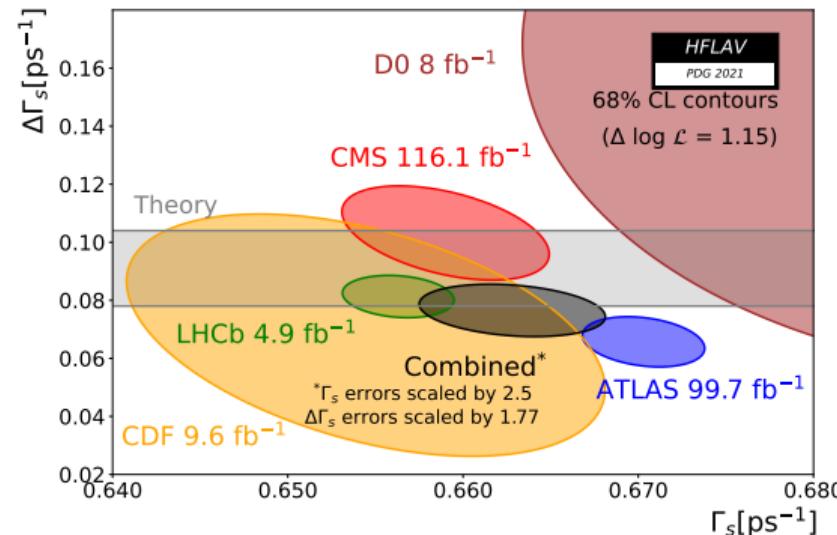
- The other quantities in B_s^0 mixing are $\Delta m_s = |m_L - m_H|$, $\Delta\Gamma_s = \Gamma_s^L - \Gamma_s^H$ and $\Gamma_s = (\Gamma_s^L + \Gamma_s^H)/2$

Situation after LHC Run2:



Eur. Phys. J. C 81 (2021) 226

Situation before LHC Run2:



- Where is $\phi_s - \Delta\Gamma$ plane after the Run2?
See my poster :)

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

JHEP 04 (2019) 098

Introduction

- FCNC processes highly suppressed in SM, significant deviations predicted by theories beyond SM
- $B_s^0 \rightarrow \mu\bar{\mu}$ and $B^0 \rightarrow \mu\bar{\mu}$ highly sensitive to New Physics in the decays via loop diagrams
- SM predictions: $\mathcal{B}(B_s^0 \rightarrow \mu\bar{\mu}) = (3.66 \pm 0.14) \cdot 10^{-6}$ and $\mathcal{B}(B^0 \rightarrow \mu\bar{\mu}) = (1.03 \pm 0.09) \cdot 10^{-12}$

Measurement

- Branching fractions are measured relative to the reference decay mode $B^0 \rightarrow J/\psi K^0$:
- $B(B_s^0 \rightarrow \mu\bar{\mu}) = N_{B_s^0} \frac{\mathcal{B}(B^0 \rightarrow J/\psi K^0) \times \epsilon(J/\psi \rightarrow \mu\bar{\mu}) f_{B_s^0}}{N_{B^0} f_{B^0} f_{J/\psi}}$
- $B_s^0 \rightarrow J/\psi \phi$ used as control channel
- Branching ratios known from PDG, f_0/f_{B^0} from HF-LW, Eur.Phys.J.C 77 (2017) 12, 895
- Relative reconstruction efficiencies estimated from MC (corrected for data-MC differences): $\epsilon_{\mu\bar{\mu}}/f_{B_s^0} = 0.3176 \pm 0.0008(\text{stat.}) \pm 0.0047(\text{syst.})$
- Yields $N_{B_s^0}$ and N_{B^0} extracted from unbinned ML fit

Fit Results and Comparison

- Results combined with ATLAS Run I:

$$\mathcal{B}(B_s^0 \rightarrow \mu\bar{\mu}) = (2.8^{+0.6}_{-0.5} \pm 10^{-6}$$

$$\mathcal{B}(B^0 \rightarrow \mu\bar{\mu}) < 2.1 \cdot 10^{-11} (95\% \text{ CL})$$

- Combined measurement compatible with SM at 2.4 σ

- Statistical uncertainties dominate total precision

- 2.1 σ compatibility of the LHC combination and SM

Introduction

- $B_s^0 \rightarrow J/\psi \phi$ is used to measure the CP-violating phase ϕ_b which is potentially sensitive to New Physics (NP)
- The CP violation occurs due to interference between a direct decay and a decay with $B_s^0 \rightarrow \bar{B}_s^0$ mixing
- In the SM, ϕ_b is related to the CKM elements and predicted with high precision: $\phi_b = -0.080(4) \pm 0.002$ 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 $J/\psi \rightarrow \mu^+\mu^-$ ($p_T > 40$ GeV)

- 2 977 526 B_s^0 candidates used passing the selection criteria:
 - $|y| < 2.4$
 - $\Delta E < 3$
 - $E_T^{\text{miss}} \in [15, 540]$ GeV
 - No lifetime cut

Flavour Tagging

- Opposite side tagging used
 - Inferring flavour from $b \rightarrow \bar{b}$
- Tagging methods: light and low-p T muons, electron, jet
 - $b \rightarrow \ell \nu$ lepton, $b \rightarrow c \bar{c}$ dijet
 - Tagging efficiency ϵ_T
- Figure of merit of tagger performance: tag power $T = 1.75 \pm 0.05$
- **HL-LHC prospects**
 - ATL-PHYS-PUB-2018-041
 - Lifetime resolution improved by 21% (Tk)
 - ϕ_b uncertainty improved by 9–20%
 - Δt uncertainty improved by 10%
 - Δt_{tag} and σ_t scale with statistics, tag power not scaled
 - The ATLAS Run2 results not included in this study

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 $J/\psi \rightarrow \mu^+\mu^-$ ($p_T > 4$ or 6 GeV)
- $B_s^0 \rightarrow \mu\bar{\mu}$ mass range: 4766–5965 MeV
- Control ($B_s^0 \rightarrow J/\psi \phi$) and reference ($B^0 \rightarrow J/\psi K^0$) channels
 - Two, three or four-track vertex fit ($\chi^2/\text{d.o.f.} < 4$)
 - $\Delta p_T < 0.1$ GeV

Background Description

- Partially reconstructed b-hadrons
- Peaking background
 - $B_s^0 \rightarrow K\bar{K}$ decays left hadron reconstructed as mesons
 - $K\bar{K} \rightarrow \pi\pi$ decays reconstructed as mesons
- Continuum background
- Unresolved b-hadron events induced by BDT

Signal Yield Extraction

- BDT with 15 variables used (kinematics, isolation)
- BDT output validated on reference and control channels
- Signal yield fixed into four BDT bins
- \mathcal{B} and \mathcal{B}' yields extracted from simultaneous unbinned ML fit

CP-violating phase ϕ_b in $B_s^0 \rightarrow J/\psi \phi$ decays at ATLAS

Eur. Phys. J. C 81 (2021) 342

Mass Lifetime Angular Fit

- Unbinned maximum likelihood fit used

$$\mathcal{L} = \prod_{i=1}^N \left[\frac{w_i}{\sigma_i} \cdot \ln \left(\frac{f_i}{\sigma_i} \right) + \frac{1}{\sigma_i} \left(\frac{f_i}{\sigma_i} - 1 \right)^2 + f_i \sigma_i \left(\frac{1}{\sigma_i} - \frac{1}{\sigma_i^2} \right) + \frac{1}{\sigma_i^2} \left(1 + \frac{1}{\sigma_i} \right) \left(1 + \frac{1}{\sigma_i} \right) \right]$$

- Main physics parameters of interest: ϕ_b , the average decay width λ , and the decay width difference $\Delta\lambda$, the CP-odd amplitude with T , and the decay width difference ΔT , the CP-odd amplitude with T .

$$J/\psi \rightarrow \mu^+\mu^- \text{ is a decay of pseudoscalar into pair of vectors}$$

$$B_s^0 \rightarrow J/\psi \phi \text{ is a decay of pseudoscalar into } (1-\lambda) \text{ states and Non-resonant 3-wave } B_s^0 \rightarrow J/\psi K^0.$$

$$\text{Basis observables: mass } m, \text{ lifetime } \tau, \text{ tagger } \epsilon_T(\phi_b, \phi_c, \phi_d)$$

$$\text{Conditional observables per candidate: mass and lifetime resolution, candidate } p_T, \text{ tagging probability and method}$$

$$\text{No direct CP violation assumed: } \lambda = 1$$

$$\Delta m_s = |\tau_s - \tau_{\text{ref}}| \text{ value fixed to PDG: } \Delta m_s = 17.77 \text{ ps}^{-1}$$

Fit Result Comparison

- Results combined with ATLAS RunI using BLUE method
 - $\phi_b = -0.7 \pm 0.36(\text{stat.}) \pm 2.1(\text{syst.})$ mrad
 - $\Delta m_s = 65.7 \pm 4.3(\text{stat.}) \pm 3.7(\text{syst.}) \text{ ps}^{-1}$
- Experiments are consistent with each other: Eur. Phys. J. C 81 (2021) 226
 - Except $T_c \sim 3\sigma$ tension

