

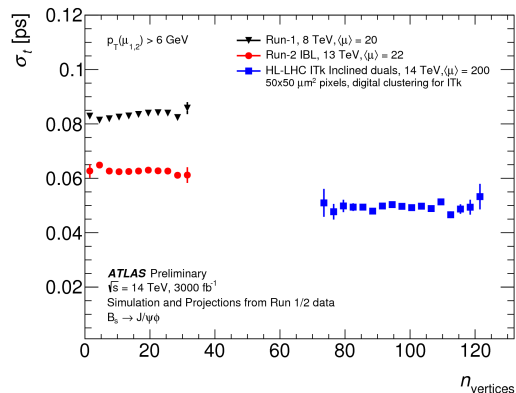
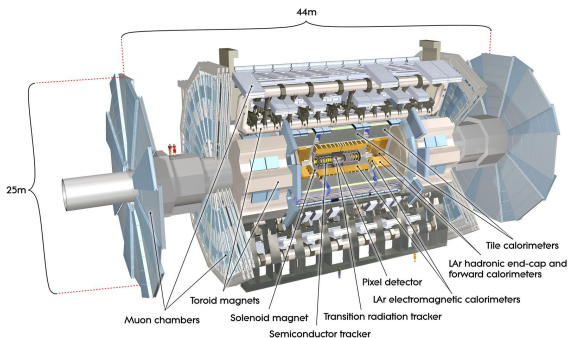
High-precision measurement of the B_d^0 lifetime and other lifetime measurements in ATLAS

Maria Smizanska,
Lancaster University
On behalf of the ATLAS collaboration

More than Lifetime, Siegen, 22-26 Sept 2025

- ATLAS detector and B-physics data
- Precision measurement of the B_d^0 meson lifetime performed at the ATLAS using Run2 data
[Eur. Phys. J. C \(2025\) 85:736](#). 
- Some other lifetime measurements in ATLAS
 - Measurement of the relative width difference $\Delta\Gamma_d/\Gamma_d$ of the $B_d^0-\overline{B}_d^0$ system with the ATLAS detector
[JHEP06\(2016\)081](#) 
 - Measurement of effective lifetime in $B_{(s)}^0 \rightarrow \mu^+ \mu^-$
[JHEP 09 \(2023\) 199](#) 
 - Measurement of the CP-violating phase, the width difference $\Delta\Gamma_s$ between the meson mass eigenstates and the average decay width Γ_s in the $B_s \rightarrow J/\psi\phi$ decay.
[Eur. Phys. J. C 81 \(2021\) 342](#) 
- HL-LHC and B-physics performance in ATLAS

ATLAS detector and features important for high precision B-physics measurements

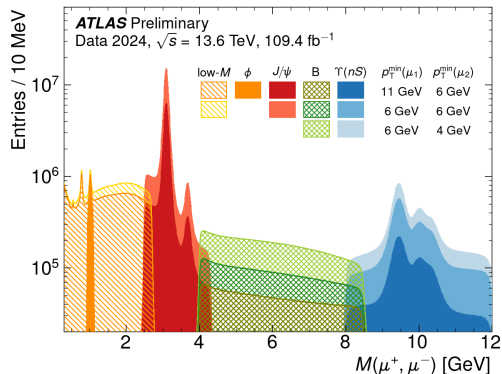
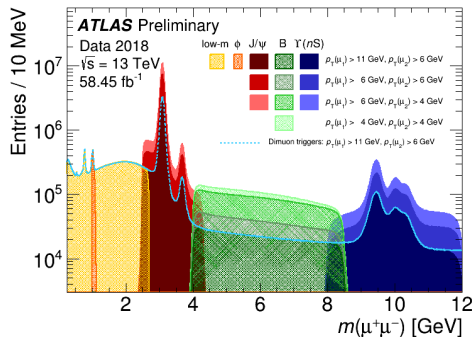


Time resolution of $B_s^0 \rightarrow J/\psi \phi$ for different numbers of reconstructed PV in the same bunch crossing [ATL-PHYS-PUB-2013-010](#)

- Inner Detector: PIX, SCT and TRT, $p_T > 0.5 \text{ GeV}$, $|\eta| < 2.5$
 - Run2: new IBL 25% improvement of time resolution with respect to Run1.
 - Time, mass resolutions remain stable within increasing pileup in Run 2
- Muon Spectrometer: triggering ($|\eta| < 2.4$), precision tracking ($|\eta| < 2.7$)

Data-taking conditions for di-muon final states

- ATLAS has collected 139 fb^{-1} of data in Run 2, and 25 fb^{-1} in Run 1
- Typical triggers di-muons with p_T thresholds of either 4 GeV or 6 GeV or 11 GeV (vary over run periods)
 - Low p_T thresholds were activated in the end of fills when the instantaneous luminosity decreases.
 - Additional trigger selections are applied, e.g. on di-muon masses, targeting different analyses, as shown in Fig.
- For Run2 events accepted for analysis, an average number of pp interactions per bunch crossing (pile-up) was 31.
- Trigger tracking: transverse impact parameter $d_0 < 10 \text{ mm}$ on all tracks, no trigger cuts from lower d_0 side.



ATLAS

A new record for precision on B-meson lifetimes

As direct searches for physics beyond the Standard Model continue to push frontiers at the LHC, the b-hadron physics sector remains a crucial source of insight for testing established theoretical models.

The ATLAS collaboration recently published a new measurement of the B^0 lifetime using $B^0 \rightarrow J/\psi K^0$ decays from the entire Run-2 dataset it has recorded at 13 TeV. The result improves the precision of previous world-leading measurements by the CMS and LHCb collaborations by a factor of two.

Studies of b-hadron lifetimes probe our understanding of the weak interaction. The lifetimes of b-hadrons can be systematically computed within the heavy-quark expansion (HQE) framework, where b-hadron observables are expressed as a perturbative expansion in inverse powers of the b-quark mass.

ATLAS measures the “effective” B^0 lifetime, which represents the average decay time incorporating effects from mixing and CP contributions, as $\tau(B^0) = 1.5053 \pm 0.0012 (\text{stat.}) \pm 0.0035 (\text{syst.}) \text{ ps}$. The result is consistent with previous measurements published by ATLAS and other experiments, as summarised in figure 1. It also aligns with theoretical predictions from HQE and lattice QCD, as well as with the experimental world average.

The analysis benefitted from the large Run-2 dataset and a refined trigger selection, enabling the collection of an extensive sample of 2.5 million $B^0 \rightarrow J/\psi K^0$ decays. Events with a J/ψ meson decaying into two muons with sufficient transverse momentum are cleanly identified in the ATLAS Muon Spectrometer by the first-level hardware trigger. In the next-level software trigger, exploiting the full detector information, these muons are

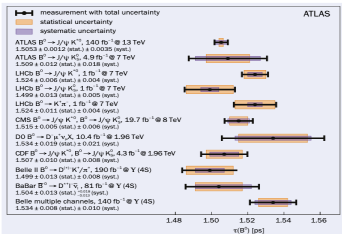


Fig. 1. A comparison of the current ATLAS result for the B^0 lifetime with the previous ATLAS result in the $B^0 \rightarrow J/\psi K^0$ channel, and with those from other experiments.

then combined with two tracks measured by the Inner Detector, ensuring they originate from the same vertex.

The B^0 -meson lifetime is determined through a two-dimensional unbinned maximum-likelihood fit, utilising the measured B^0 -candidate mass and decay time, and accounting for both signal and background components. The limited hadronic particle-identification capability of ATLAS requires careful modelling of the significant backgrounds from other processes that produce J/ψ mesons. The sensitivity of the fit is increased by estimating the uncertainty of the decay-time measurement provided by the ATLAS tracking and vertexing algorithms on a per-candidate basis. The resulting lifetime measurement is limited by sys-

tematic uncertainties, with the largest contributions arising from the correlation between B^0 mass and lifetime, and ambiguities in modelling the mass distribution.

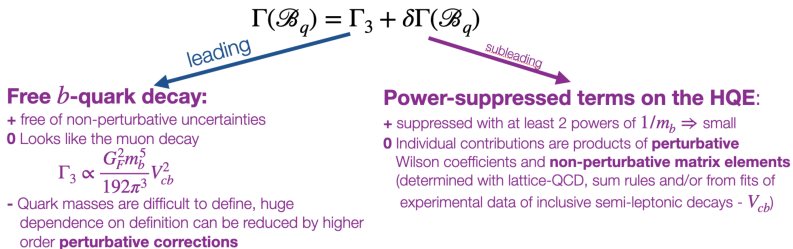
ATLAS combined its measurement with the average decay width (Γ_s) of the light and heavy B_s -meson mass eigenstates, also measured by ATLAS, to determine the ratio of decay widths as $\Gamma_d/\Gamma_s = 0.9905 \pm 0.0022 (\text{stat.}) \pm 0.0036 (\text{syst.}) \pm 0.0057 (\text{ext.})$. The result is consistent with unity and provides a stringent test of QCD predictions, which also support a value near unity.

Further reading

ATLAS Collab. 2024, arXiv:2411.09962.
 ATLAS Collab. 2021, Eur. Phys. J. C **81** 342.

- “Precision measurement of the B_d^0 meson lifetime performed at the ATLAS using Run2 data ” **Eur. Phys. J. C (2025) 85:736**. [🔗](#).
- ATLAS B^0 lifetime is the most precise measurement to date
- Also measured the decay rate Γ_d of B^0
- Γ_d/Γ_s determined using ATLAS Γ_s measured in $B_s^0 \rightarrow J/\psi \phi$ **Eur. Phys. J. C 81 (2021) 342** [🔗](#)
- Recognised by ATLAS **ATLAS Briefing 25 November 2024** [🔗](#)
- Recognised by CERN **LHC CERN Seminar** [🔗](#) and Article in **CERN Courier** p. 15). [🔗](#)

- In the Heavy Quark Expansion (HQE) theory the decay rate $\Gamma = 1/\tau$ is calculated:



- Γ suffers from huge uncertainties of the leading term Γ_3 ; $\Gamma_d = 0.63_{-0.07}^{+0.11} \text{ ps}^{-1}$ [Lenz, et al. 2023](#)
- In rates ratios the leading term Γ_3 exactly cancels leaving just small uncertainties from sub-leading terms; $\Gamma_d/\Gamma_s = 1.003 \pm 0.006$ [Lenz, Piscopo, Rusov 2023](#)
- Lifetimes measurements also test models of New Physics (BSM) contributing to both leading and sub-leading terms. Excluding BSM effects larger than 5%, will already constrain many BSM scenarios [Lenz2021](#)
- Since the theory predictions are more precise for ratios - we also extracted Γ_d/Γ_s .

Derivation of decay rate Γ_d and ratio Γ_d/Γ_s from measured B_d^0 lifetime.

Γ_d

The lifetime we measured in $B^0 \rightarrow J/\psi K^{*0}$ is the effective lifetime $\tau_{B_d^0}$ related to decay widths: Γ_L, Γ_H of the light and heavy mass eigenstates of $B_d^0 - \bar{B}_d^0$ system via: [Dunietz, Fleischer, Nierste, 2000](#) 

$$\tau_{B^0} = \frac{1}{\Gamma_d} \frac{1 + y^2}{1 - y^2}, \quad (1)$$

where $\Gamma_d = (\Gamma_L + \Gamma_H)/2$; $y = \Delta\Gamma_d/(2\Gamma_d) = (\Gamma_L - \Gamma_H)/(2\Gamma_d)$.

Using the value of y from Heavy Flavour Averaging group (HFLAV) Ref. [HFLAV:2023](#) , our $\tau_{B_d^0}$ value and Eq(1) allows Γ_d to be extracted.

Γ_d/Γ_s

ATLAS measured $\Gamma_s = 0.6703 \pm 0.0014(\text{stat.}) \pm 0.0018(\text{syst.}) \text{ ps}^{-1}$ from $B_s^0 \rightarrow J/\psi \phi$ [Eur. Phys. J. C 81 \(2021\) 342](#) . This result combined with $B_d^0 \rightarrow J/\psi K^*$ allowed us to determine the ratio Γ_d/Γ_s .

2D unbinned maximum-likelihood fit applied simultaneously to mass and proper decay time of B_d^0 candidates. Likelihood Function formula:

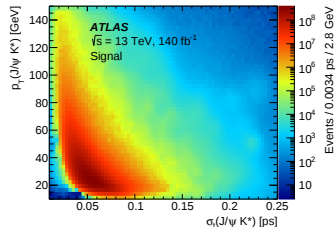
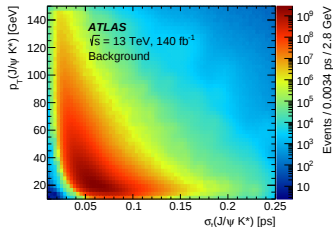
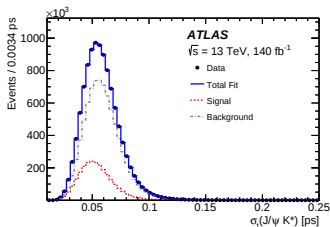
$$\ln L = \sum_{i=1}^N w(t_i) \ln [f_{\text{sig}} \mathcal{M}_{\text{sig}}(m_i) \mathcal{T}_{\text{sig}}(t_i, \sigma_{t_i}, p_{T_i}) + (1 - f_{\text{sig}}) \mathcal{M}_{\text{bkg}}(m_i) \mathcal{T}_{\text{bkg}}(t_i, \sigma_{t_i}, p_{T_i})].$$

- f_{sig} - fraction of signal events in the total number of events, N .
- $\mathcal{M}_{\text{sig}}, \mathcal{T}_{\text{sig}}$ mass and time signal PDFs
- $\mathcal{M}_{\text{bkg}}, \mathcal{T}_{\text{bkg}}$ mass and time Background PDFs
- The mass m_i , the proper decay time t_i , its uncertainty σ_i and the B_d^0 candidate transverse momentum p_{T_i} are the values measured from the data for each event i .
- Weight w_i accounts for event selection efficiency, based on MC.

Conditional probability of the time uncertainty σ_{t_i} and p_{T_i} of B_d^0

- Per-candidate time errors σ_{t_i} , extracted from data in the vertex fit of each B_d^0 are used for deconvolution of proper decay times t_i .
- σ_{t_i} are different for signal and background, see fig Left. Same it true for p_T of B_d^0 .
- To account for these differences, the 2D probability terms $C_j(\sigma_{t_i}, p_{T_i})$ are introduced into Signal and Bg Time PDF terms $\mathcal{T}$. Method first used in [G.Punzi](#)

$$\mathcal{T}_j(t_i, \sigma_{t_i}, p_{T_i}) = P_j(t_i, \sigma_{t_i}, p_{T_i}) \cdot C_j(\sigma_{t_i}, p_{T_i}), \quad (2)$$



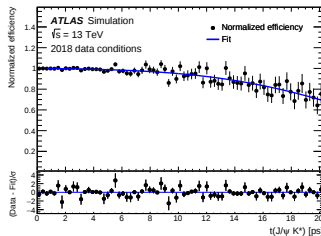
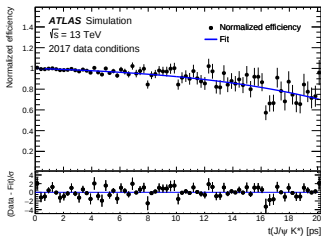
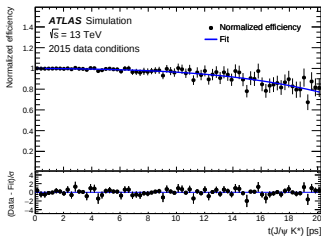
Left: σ_{t_i} for Signal and Bg. Middle and Right: 2D probability terms $C_j(\sigma_{t_i}, p_{T_i})$ for Bg. and Signal. The sPlot technique [Pivk:2004ty](#) is used to separate Signal and Bg.

- Trigger, offline reconstruction, event selections bias the reconstructed proper-decay time distribution.
- Trigger and offline tracking impose $|d_0| < 10$ mm, for all four final-state tracks of $B^0 \rightarrow J/\psi K^{*0}$, resulting in inefficiency at large times.
- Inefficiencies determined by signal MC, passed through simulation of detector response & triggers, offline tracking and event selections - as data.

Ratio of proper decay time distributions before and after the whole chain, were fitted by:

$$1/w(t_i) = p_0 \cdot [1 - p_1 \cdot (\text{Erf}((t_i - p_3)/p_2) + 1)] \quad (3)$$

Erf is error function, p_0 , p_1 , p_2 , p_3 determined in the fit. Weights $w(t_i)$ are used to re-weight each event in Likelihood fit.



Source of uncertainty	Systematic uncertainty [ps]
ID alignment	0.00108
Choice of mass window	0.00104
Time efficiency	0.00130
Best-candidate selection	0.00041
Mass fit model	0.00152
Mass-time correlation	0.00229
Proper decay time fit model	0.00010
Conditional probability model	0.00070
Fit model test with pseudo-experiments	0.00002
Total	0.0035

- The statistical error of this B_d^0 lifetime measurement is 0.0012 (stat.) ps.

- ID misalignment effects: dominated by global length scale biases originating from ID geometry radial and longitudinal distortions along track trajectory.
- These manifest themselves as a shift in the reconstructed masses of known resonances, e.g. $J/\psi \rightarrow \mu^+ \mu^-$ [Eur. Phys. J. C 80 \(2020\) 1194](#) .

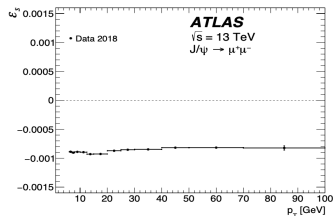


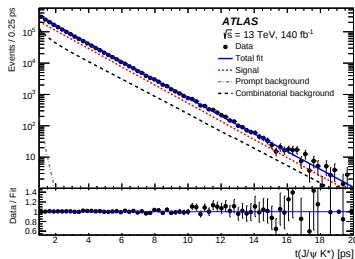
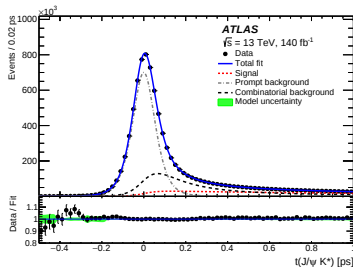
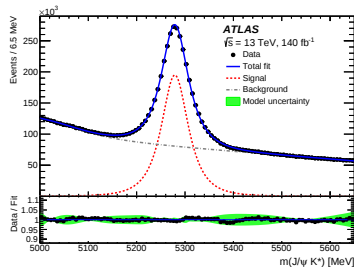
Fig showing a bias of the $J/\psi \rightarrow \mu^+ \mu^-$ mass, measured as a relative difference from PDG value, as a function of a muon track p_T .

- In our analysis B_d^0 tracks are re-fitted with the J/ψ mass constrained to PDG, effectively removing the misalignment effect. The impact of misalignment - estimated by alternative fit: B_d^0 vertex re-fitted without PDG constrain.
- Additionally, to account for the momentum bias affecting hadrons from K^{*0} - their p_T are altered by -0.085% [Eur. Phys. J. C 80 \(2020\) 1194](#) .
- The two effects summed in quadrature, give the systematics: $0.9 \sigma_{stat}$

Results: The B^0 effective lifetime and the mass and time projections of the likelihood fit

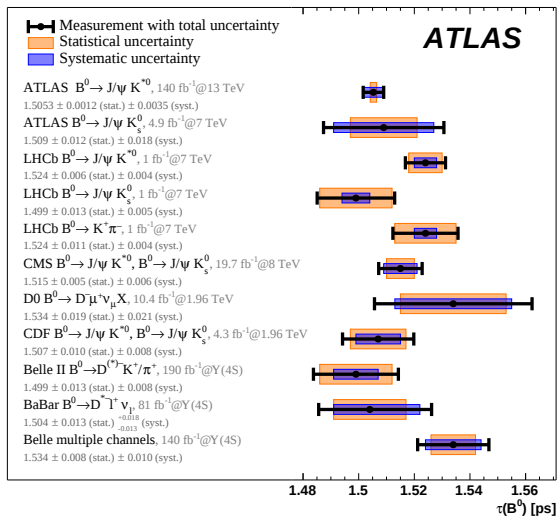
The B^0 effective lifetime value measured with a total of $2\,450\,500 \pm 2400$ $B^0 \rightarrow J/\psi K^{*0}$ signal events. The measured effective lifetime is

$$\tau = 1.5053 \pm 0.0012 \text{ (stat.)} \pm 0.0035 \text{ (syst.) ps.}$$



- Mass fit projection (left). Proper decay time fit projections in two different ranges: $(-0.5; 1.0)$ ps (Middle) and $(1; 20)$ ps (Right).
- Solid blue line - total fit, dashed red line - signal.
- The lower panels: ratio of data point to the fit value. The green band - the envelope of model variations included in the systematic uncertainty, the bars on the data points indicate statistical uncertainties. Plot -right - the model variation band too small to be visible.

A comparison ATLAS B^0 lifetime with the latest results of other experiments.



- The current ATLAS result in $B^0 \rightarrow J/\psi K^{*0}$ channel.
- The previous ATLAS result [Phys. Rev. D 87 \(2013\) 032002](#) in the $B^0 \rightarrow J/\psi K_S^0$ channel.
- Latest LHCb results [JHEP 04 \(2014\) 114](#) in $B^0 \rightarrow J/\psi K^{*0}$ and $B^0 \rightarrow J/\psi K_S^0$ decays and [Phys. Lett. B 736 \(2014\) 446](#) in the $B^0 \rightarrow K^+ \pi^-$.
- Latest CMS [Eur. Phys. J. C 78 \(2018\) 457](#) combined result for $B^0 \rightarrow J/\psi K^{*0}$ and $B^0 \rightarrow J/\psi K_S^0$ decays.
- Tevatron experiments: D0 [Phys. Rev. Lett. 114 \(2015\) 062001](#) in the $B^0 \rightarrow D^{*-} \mu^+ \nu_\mu$ channel, and CDF [Phys. Rev. Lett. 106 \(2011\) 121804](#) with a combined result for $B^0 \rightarrow J/\psi K^{*0}$ and $B^0 \rightarrow J/\psi K_S^0$.
- $e^+ e^-$ colliders: Belle II [Phys. Rev. D 107 \(2023\) L091102](#) in the $B^0 \rightarrow D^{(*)-} K^+ / \pi^+$ channel and the last result from BaBar [Phys. Rev. D 73 \(2006\) 012004](#) in the $B^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\ell$. Belle [PhysRevD.71.07990, 2005](#) this combination includes B_d^0 decays to $D^{*-} \ell^+ \nu$, $D^{*-} \pi^+$, $D^- \pi^+$, $D^{*-} \rho^+$, $J/\psi K^{*0}$, $J/\psi K_S^0$.

Results: Determination of the B_d^0 average decay width Γ_d and the ratio Γ_d/Γ_s

Γ_d

- We determine Γ_d from our measured effective lifetime τ_{B^0} , using Eq (1) and input values $2y = \Delta\Gamma_d/\Gamma_d = 0.001 \pm 0.010$ from [HFLAV:2023](#) :

$$\Gamma_d = 0.6639 \pm 0.0005 \text{ (stat.)} \pm 0.0016 \text{ (syst.)} \pm 0.0038 \text{ (ext.) ps}^{-1}$$

The uncertainty denoted 'ext.' originates from the HFLAV.

- The value Γ_d is in agreement with HQE theory of $0.63_{-0.07}^{+0.11} \text{ ps}^{-1}$ [Lenz et al. 2023](#) 

Γ_d/Γ_s

- Using $\Gamma_s = 0.6703 \pm 0.0014 \text{ (stat.)} \pm 0.0018 \text{ (syst.) ps}^{-1}$ measured by the ATLAS [Eur. Phys. J. C 81 \(2021\) 342](#)  the resulting Γ_d/Γ_s ratio is

$$\Gamma_d/\Gamma_s = 0.9905 \pm 0.0022 \text{ (stat.)} \pm 0.0036 \text{ (syst.)} \pm 0.0057 \text{ (ext.)}$$

- The statistical, systematic and external uncertainties are propagated from the quantities above. In Γ_d/Γ_s - systematic uncertainties of the ATLAS measurements of τ_{B^0} and Γ_s primarily come from different sources. They are therefore treated as uncorrelated.
- Γ_d/Γ_s agrees with theory HQE and lattice QCD models prediction.

- The value of $\Delta\Gamma_d/\Gamma_d$ is obtained by comparing the decay-time distributions of $B^0 \rightarrow J/\psi K^{*0}$ and $B^0 \rightarrow J/\psi K_S^0$ decays.
- Ratio of measured Proper-decay lengths distributions of the two processes is fitted using corresponding decay rate functions, with $\Delta\Gamma_d/\Gamma_d$ as a free parameter of the fit and using inputs values from $1/\Gamma_d$, Δm_s and $\sin 2\beta$ available at that time 2014.
- Using 25.1 fb^{-1} of 2011 and 2012 data the result is $\Delta\Gamma_d/\Gamma_d = (-0.1 \pm 1.1 \text{ (stat.)} \pm 0.9 \text{ (syst.)}) \times 10^{-2}$.
- This is in agreement with theory SM value: $(0.42 \pm 0.08) \times 10^{-2}$ JHEP06(2016)081  Lenz, Nierste.
- The word average measurement is currently (2025) $\Delta\Gamma_d/\Gamma_d = (-0.1 \pm 1.0) \times 10^{-2}$. The list of individual measurements with ATLAS result still leading in precision.

$3.4 \pm 2.3 \pm 2.4$	¹ SIRUNYAN	2018BY	CMS	pp at 8 TeV
$-0.1 \pm 1.1 \pm 0.9$	² AABOUD	2016G	ATLS	pp at 7, 8 TeV
$-4.4 \pm 2.5 \pm 1.1$	³ AAIJ	2014E	LHCB	pp at 7 TeV
$1.7 \pm 1.8 \pm 1.1$	⁴ HIGUCHI	2012	BELL	$e^+ e^- \rightarrow \Upsilon(4S)$
$0.8 \pm 3.7 \pm 1.8$	⁵ AUBERT,B	2004C	BABR	$e^+ e^- \rightarrow \Upsilon(4S)$

- In Standard Model (SM) only the CP -odd heavy-mass eigenstate in the $B_s^0 - \bar{B}_s^0$ pair decays into $\mu^+ \mu^-$
M. Beneke JHEP 10 (2019) 232 and errata JHEP 11 (2022) 099.
- Beyond the Standard Model (BSM) such as minimal supersymmetric Standard Model extensions D. M. Straub Il Nuovo Cimento C 35 (2012) 249 can potentially perturb the effective lifetime in $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ decays. These perturbations can be significant also in absence of measurable BSM effects on the $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ branching fraction (BR).

- The effective $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ lifetime is defined as

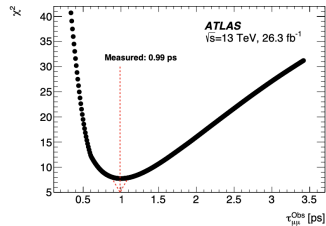
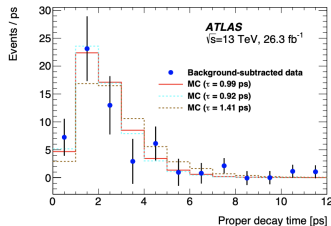
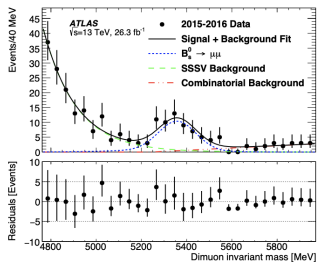
$$\tau_{\mu\mu} = \frac{\int_0^\infty t \Gamma(B_s^0(t) \rightarrow \mu\mu) dt}{\int_0^\infty \Gamma(B_s^0(t) \rightarrow \mu\mu) dt}, \text{ where: } \Gamma(B_s(t) \rightarrow \mu\mu) = \Gamma(B_s^0(t) \rightarrow \mu\mu) + \Gamma(\bar{B}_s^0(t) \rightarrow \mu\mu)$$

and t is the proper decay time of the B_s^0 and $\bar{B}_s^0$ mesons.

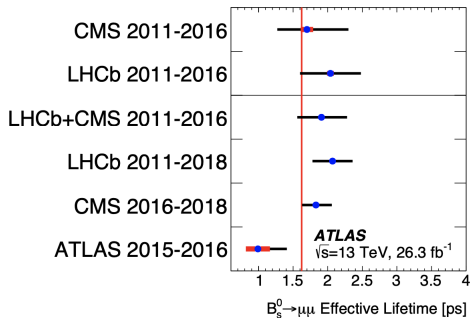
- In the SM hypothesis $\tau_{\mu\mu}$ coincides with the lifetime of the heavy B_s^0 eigenstate $\tau_{B_s^H}$.
- The experimental average of the $B_s^0 - \bar{B}_s^0$ lifetimes and their difference Phys. Rev. D 107 (2023) 052008 yields the prediction $\tau_{\mu\mu}^{SM} = (1.624 \pm 0.009)$ ps, with new physics effects perturbing it at most by the difference between the heavy and light eigenstate lifetimes (0.193 ps).

Measurement of effective lifetime in $B_{(s)}^0 \rightarrow \mu^+ \mu^-$, cont 1

- Data from 2015-2016 are used in this measurement.
- Un-binned maximum likelihood fit to candidates in the [4766 – 5966] MeV mass region (Left Fig), yielding 58 ± 13 (stat. only) $B_{(s)}^0 \rightarrow \mu^+ \mu^-$ signal events.
- Signal and backgrounds weights calculated from the result of the mass fit are used to construct the proper decay time histogram - background-subtracted employing per-event weights calculated according to the *sPlot* technique (Middle Fig).
- The lifetime measurement is obtained by minimising the binned χ^2 between the data histogram and lifetime-dependent pure signal MC templates extracted from MC simulated samples, as illustrated in the Middle and Right Fig.



- The result using 2015-2016 data is $\tau_{\mu\mu} = 0.99_{-0.07}^{+0.42}$ (stat.) ± 0.17 (syst.) ps. It is consistent with the SM prediction $\tau_{\mu\mu}^{\text{SM}} = (1.624 \pm 0.009)$ ps [Phys. Rev. D 107 \(2023\) 052008](#)  as well as with the other available experimental results.
- The systematic errors are dominated by data-MC discrepancies, followed by uncertainties in backgrounds lifetime modelling.



Measurement of the CPV phase, width difference $\Delta\Gamma_s$ and the average decay width Γ_s in $B_s \rightarrow J/\psi\phi$. Eur. Phys. J. C 81 (2021) 342

Physics motivation

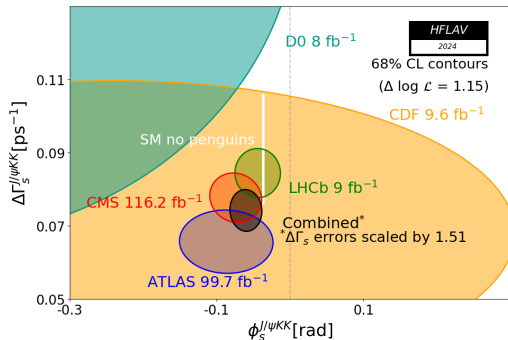
- $B_s^0 \rightarrow J/\psi\phi$ is used to measure CP-violation phase ϕ_s potentially sensitive to New Physics (NP)
 - In SM ϕ_s is related to the CKM elements $\phi_s \simeq 2 \arg[-(V_{ts}V_{tb}^*)/(V_{cs}V_{cb}^*)]$ and predicted with high precision PhysRevD.91.073007
- The same analysis also measure Γ_s^L and Γ_s^H the decay widths of B_s^0 mass eigenstates and $\Delta\Gamma_s = \Gamma_s^L - \Gamma_s^H$. $\Delta\Gamma_s$ was calculated in SM Lenz-et-al 2020 and new experimental results are needed to eventually get sensitivity to NP models that predict smaller $\Delta\Gamma_s$ than SM LenzOct2021

More analysis in preparation

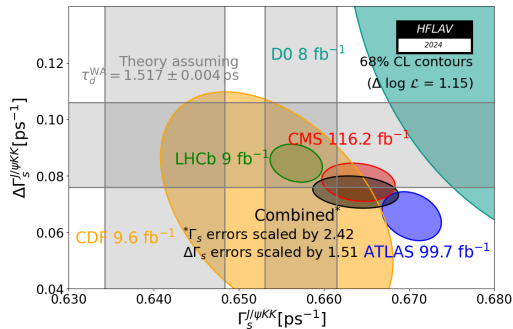
- Total Run2 data - including remaning 58.5 fb⁻¹
- Followed by Run3 analysis and Run2+Run3 comb.

ATLAS result with partial Run2 data 80.5 fb⁻¹ combined with 19.2 fb⁻¹ of Run1 data

Parameter	Value	Solution (a)	
		Statistical uncertainty	Systematic uncertainty
ϕ_s [rad]	-0.087	0.036	0.021
$\Delta\Gamma_s$ [ps ⁻¹]	0.0657	0.0043	0.0037
Γ_s [ps ⁻¹]	0.6703	0.0014	0.0018
$ A_{ }(0) ^2$	0.2220	0.0017	0.0021
$ A_0(0) ^2$	0.5152	0.0012	0.0034
$ A_S ^2$	0.0343	0.0031	0.0045
$\delta_{\perp}$ [rad]	3.22	0.10	0.05
$\delta_{ }$ [rad]	3.36	0.05	0.09
$\delta_{\perp} - \delta_S$ [rad]	-0.24	0.05	0.04



White narrow Ellipse: SM predictions.



Grey areas: SM predictions

Because of tensions between the measurements, the errors on Γ_s and $\Delta\Gamma_s$ have been scaled (the ellipses representing the results of each experiment are shown before scaling, while the combined ellipses include the scale factors).

CP violation phase ϕ_s potentially sensitive to New Physics

- SM prediction $\phi_s = -0.0367^{+0.00072}_{-0.00082}$ rad M. Bona et al. (UTfit), Rend. Lincei Sci. Fis. Nat. 34, 27 (2023) is cca 17 more precise than World combined 2024 $\phi_s = -0.060 \pm 0.014$ rad. [HFLAV 2024](#) 
- There is a room for New physics. An answer is on experimental side: Run3 LHC and HL-LHC

Case of $\Delta\Gamma_s$ and Γ_s

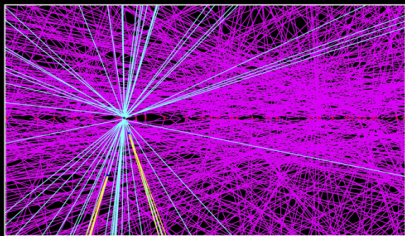
- SM prediction $\Delta\Gamma_s = +0.091 \pm 0.015 \text{ ps}^{-1}$ [Albrecht, Bernlochner, Lenz, Rusov 2023](#)  slightly higher than World Combined value.
- A potential New Physics enhancement of ϕ_s would also decrease $\Delta\Gamma_s$, [Lenz1 et al.](#) 
- "Precise experimental knowledge on B-lifetimes and their Ratios, will provide bounds on New Physics [LenzOct2021](#) 
- Currently tensions at level 2σ in $\Delta\Gamma_s$ between ATLAS - CMS and 5σ in Γ_s between ATLAS - LHCb. More data to be used to improve lifetime measurement precision and control of systematic effects.
- All experiments still to add Run3 and HL-LHC in preparations.

ATLAS B-decays and lifetimes at HL-LHC

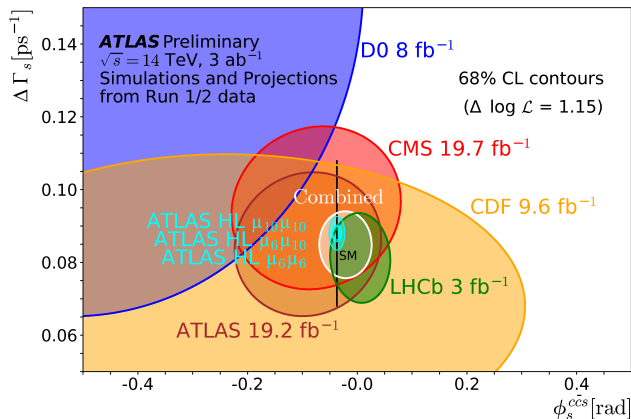


- Increase $> 10 \times \int L dt$ of LHC $\rightarrow 3000-4000 \text{ fb}^{-1}$
- Peak luminosity $5 - 7.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- Average amount of pp interactions 140-200 per BX with a time space 25 ns
- These conditions require Detector Upgrades.

 **ATLAS**
EXPERIMENT
HL-LHC $t\bar{t}$ event in ATLAS ITK
at $\langle\mu\rangle=200$



- ATL-PHYS-PUB-2018-041
- Inner Detector upgrade: proper decay time resolution improved by 21% w.r.t. Run 2
- Three trigger scenarios for muon momenta thresholds
- ϕ_s precision improves (9 - 20) times w.r.t. Run1, or (4 - 9) times w.r.t. current result combining Run1 and Run2 99.7 fb^{-1}



3 trigger scenarios for thresholds $p_T(\mu_1), p_T(\mu_2)$

Quantity	$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) [10^{-9}]$			$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) [10^{-10}]$			$\tau_{\mu\mu} [\text{ps}]$		
SM value	3.66 ± 0.14 [1]			1.03 ± 0.05 [1]			1.624 ± 0.009 [7]		
ATLAS 2015–2016 measurements	$3.21^{+0.96+0.49}_{-0.91-0.30}$ [2]			< 4.3 at 95% CL. [2]			$0.99^{+0.42}_{-0.07} \pm 0.17$ [8]		
Projected uncertainty	Stat.	Syst.	Total	Stat.	Syst.	Total	Stat.	Syst.	Total
$\mu 10 \mu 10$	0.17	0.36	0.40	0.36	0.32	0.48	+0.09 −0.06	0.06	+0.11 −0.08
$\mu 10 \mu 6$	0.11	0.32	0.34	0.23	0.26	0.35	+0.06 −0.03	0.05	+0.08 −0.06
$\mu 6 \mu 6$	0.09	0.32	0.33	0.19	0.26	0.32	+0.05 −0.03	0.05	+0.07 −0.05

