A new high-precision measurement of the B_d^0 meson lifetime at the ATLAS experiment

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Outline

- Introduction, Physics motivation

- ATLAS detector and performance in Run2
- Data-taking conditions
- Data and event selection

- Maximum-likelihood fit
- Efficiencies and corrections
- Systematic uncertainties
- Results
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- Summary and Conclusions

- Precise measurements on B-lifetimes and their Ratios test our understanding of weak interactions.
- In Heavy Quark Expansion (HQE) theory the total decay rate $\Gamma = 1/\tau$ of a weekly decaying Heavy Hadron B_q is calculated by formula consisting of two terms:

$$\Gamma(\mathscr{B}_q) = \Gamma_3 + \delta\Gamma(\mathscr{B}_q)$$

leading

subleading

Free b-quark decay:

\+ free of non-perturbative uncertainties

0 Looks like the muon decay

$$\Gamma_3 \propto \frac{G_F^2 m_b^5}{192\pi^3} V_{cb}^2$$

\- Quark masses are difficult to define, huge dependence on definition can be reduced by higher order **perturbative corrections**

Power-suppressed terms on the HQE:

\+ suppressed with at least 2 powers of $1/m_b \Rightarrow$ small

0 Individual contributions are products of **perturbative** Wilson coefficients and **non-perturbative matrix elements** (determined with lattice-QCD, sum rules and/or from fits of experimental data of inclusive semi-leptonic decays - V_{cb})

- Overview of HQE calculations: historic development 1405.3601, and status quo 2402.04224, Feb 2024.

- The HQE prediction of decay rates suffers from huge theory uncertainties due to m_b^5 in Γ_3 term
  $\Gamma_d = 0.63^{+0.11}_{-0.07}\ \mathrm{ps}^{-1}$ Lenz, Piscopo, Rusov 2023
- In the lifetimes ratios - the free quark decay rate Γ_3 exactly cancels leading to smaller uncertainties:
  $\Gamma_d/\Gamma_s = 1.003 \pm 0.006$ Lenz, Piscopo, Rusov 2023

- Lifetimes measurements can also serve to test Theory models of New Physics (BSM):

$$\Gamma(\mathscr{B}_q) = \Gamma_3^{\mathrm{SM}} + \Gamma_3^{\mathrm{BSM}} + \delta\Gamma(\mathscr{B}_q)^{\mathrm{SM}} + \delta\Gamma(\mathscr{B}_q)^{\mathrm{BSM}}$$

- From theory considerations it would be very unlikely to have e.g. a 5% BSM contribution to the total decay rate, but it is also hard to exclude such a possibility at present.
- On the other hand excluding BSM effects to be larger than 5%, will already constrain many BSM scenarios
  Lenz2021
- In all scenarios: SM or BSM, the improvement in experimental measurements of lifetimes and their ratios, will serve to constrain theory models.

The lifetime we measured in $B^0 \to J/\psi K^{*0}$ 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–$\overline{B_d^0}$ system via: Fleischer et al, 2011

$$\tau_{B^0} = \frac{1}{\Gamma_d}\frac{1}{1-y^2}\left(\frac{1+2Ay+y^2}{1+Ay}\right), \tag{1}$$

$\Gamma_d = (\Gamma_\mathrm{L}+\Gamma_\mathrm{H})/2$; $y = \Delta\Gamma_d/(2\Gamma_d) = (\Gamma_\mathrm{L}-\Gamma_\mathrm{H})/(2\Gamma_d)$. The asymmetry A:

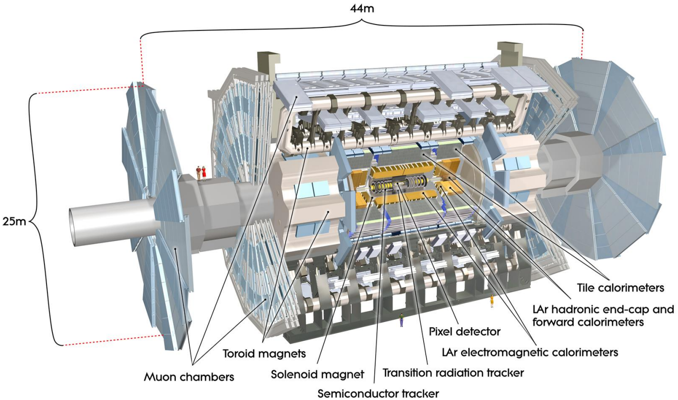
$$A = \frac{R_H^f - R_L^f}{R_H^f + R_L^f}.$$

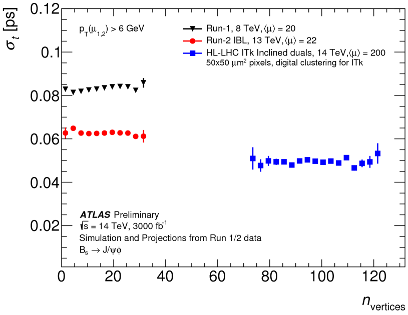
amplitudes R_L^f and R_H^f are defined via the summed decay rate of the members of the B_d^0–$\overline{B_d^0}$ system: Fleischer et al, 2011

$$\langle\Gamma(B^0(t))\rangle = \Gamma(B^0(t)) + \Gamma(\bar{B}^0(t)) = R_\mathrm{H}^f \exp\left(-\Gamma_\mathrm{H}\, t\right) + R_\mathrm{L}^f \exp\left(-\Gamma_\mathrm{L}\, t\right).$$

Using the values of y and A from Heavy Flavour Averaging group (HFLAV) Ref.HFLAV:2023, our $\tau_{B_d^0}$ value and Eg(1) allows Γ_d to be extracted.
ATLAS measured Γ_s = 0.6703$\pm$0.0014(stat.)$\pm$0.0018(syst.) ps^{-1} from $B_s^0 \to J/\psi\phi$ Eur. Phys. J. C 81 (2021) 342. This result combined with $B_d^0 \to J/\psi K^*$ allowed us to determine the ratio Γ_d/Γ_s.

ATLAS detector and feature important for this measurement



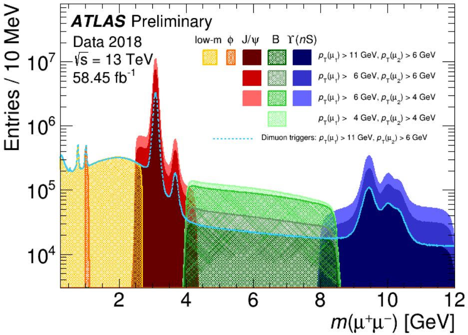


Time resolution of $B_s^0 \to J/\psi\phi$ for different numbers of reconstructed PV in the same bunch crossing ATL-PHYS-PUB-2013-010

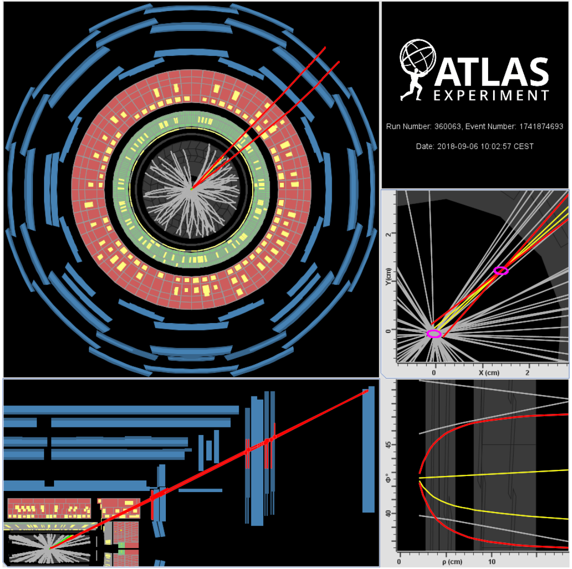
- Inner Detector: PIX, SCT and TRT, $p_{\mathrm{T}} > 0.5\,\mathrm{GeV}$, $|\eta| < 2.5$
  - Run2: new IBL 25% improvement of time resolution with respect to Run1.
  - Time, mass resolutions remain stable within increasing pileup in Run 2
- Muon Spectrometer: triggering ($|\eta| < 2.4$), precision tracking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

Data-taking conditions for this analysis

- The measurement uses 2015-2018 *pp* collision data at sqrt(s) = 13 TeV.
- Triggers: $J/\psi \to \mu^+\mu^-$, the muon p_T thresholds varying: 4 GeV, 6 GeV and 11 GeV.
  - Low p_T thresholds were activated in the end of fills when the instantaneous luminosity decreases.
- For events accepted for this analysis, an average number of pp interactions per bunch crossing (pile-up) was 31.
- No displaced J/ψ vertex cuts applied. Trigger tracking: transverse parameter d0 $<$ 10mm on all tracks.



$B^0 \to J/\psi K^{*0}$ event display



Event reconstruction and selection

$B^0 \to J/\psi K^{*0}$ candidates

- At least one $J/\psi \to \mu^+\mu^-$ with χ^2ndof < 10; within mass window retaining 99.7% J/ψ candidates.
- K^*: Out of two hypothesis $K^+\pi^-$ / $K^-\pi^+$ the one closer to K^* PDG mass selected.
- J/ψ and K^* - fitted to a common vertex, constrained by fixing di-muon mass to J/ψ PDG. Only χ^2/ndof <3 retained.
- 10% events have multiple $J/\psi K^*$ candidates (in average 2.1); the one with smallest χ^2/ndof selected.

Primary vertex (PV) selection

- For selected events the average pileup is 31: need to choose the best PV candidate where B_d^0 is produced.
- PV positions are recalculated after removing any tracks used in the B_d^0.
- The PV candidate with the smallest 3D impact parameter, a_0 (min. distance between PV and the line extrapolated from the B_d^0 vertex in B_d^0 momentum direction), is used.

For each B_d^0 candidate, the proper decay time t is determined:

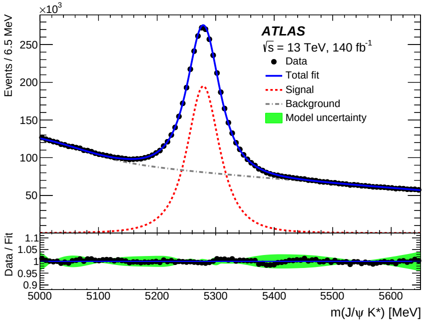
$$t = \frac{L_{xy}\ m_B}{p_{\mathrm{T}_B}}, \qquad (2)$$

p_{T_B} is transverse momentum of m_B = PDG B_d^0 mass. The transverse decay length, L_{xy}, is the distance in the transverse plane from PV to the B_d^0 decay vertex, projected onto p_{T_B}.

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

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

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



Signal mass is modelled with a Johnson S_U-distribution Johnson

$$\mathcal{M}_{\text{sig}}(m_i) = \frac{\delta}{\lambda\sqrt{2\pi}\sqrt{1+\left(\frac{m_i-\mu}{\lambda}\right)^2}} \exp\left[-\frac{1}{2}\left(\gamma+\delta\sinh^{-1}\left(\frac{m_i-\mu}{\lambda}\right)\right)^2\right]$$

where μ, γ, δ and λ are free parameters of fit.

Background has two components: 1. prompt - J/ψ produced in $\mathrm{pp} \to \mathrm{J}/\psi\mathrm{X}$, combined with random K^*. 2. combinatorial - J/ψ from any b-hadron decay combined with random K^*. They are modelled by sum of linear and sigmoid functions:

$$\mathcal{M}_{\text{bkg}}(m_i) = f_{\text{poly}}(1 + p_0 \cdot m_i) + (1 - f_{\text{poly}})\left(1 - \frac{s(m_i - m_0)}{\sqrt{1 + (s(m_i - m_0))^2}}\right)$$

where f_{poly} relative size of the two components and m_0, s and p_0 are parameters of the fit.

Signal PDF: exponential function convolved by Resolution function R.

$$P_{\rm sig}(t_i|\sigma_{t_i}, p_{{\rm T}_i}) = E(t', \tau_{B^0}) \otimes R(t' - t_i, \sigma_{t_i})$$

$E(t', \tau_{B^0}) = (1/\tau_{B^0})\exp(-t'/\tau_{B^0})$ for $t' \geq 0$, with τ_{B^0} - the fitted B^0_d lifetime.

Background PDF:

$$P_{\rm bkg}(t_i|\sigma_{t_i}, p_{{\rm T}_i}) = \left(f_{\rm prompt} \cdot \delta_{\rm Dirac}(t') + (1 - f_{\rm prompt}) \sum_{k=1}^{3} b_k \prod_{l=1}^{k-1} (1 - b_l) E(t', \tau_{{\rm bkg}_k})\right) \otimes R(t' - t_i, \sigma_{t_i})$$

Dirac function $\delta_{\rm Dirac}$: direct background; 3 exponentials $E(t', \tau_{{\rm bkg}_k})$: components of combinatorial background; $\tau_{{\rm bkg}_k}$, and fractions: $f_{\rm prompt}$ and b_k are free parameters of fit.

Resolution function *R*: modelled as a sum of three Gaussian distributions with widths: $S^{(k)}\ \sigma_{\tau_i}$

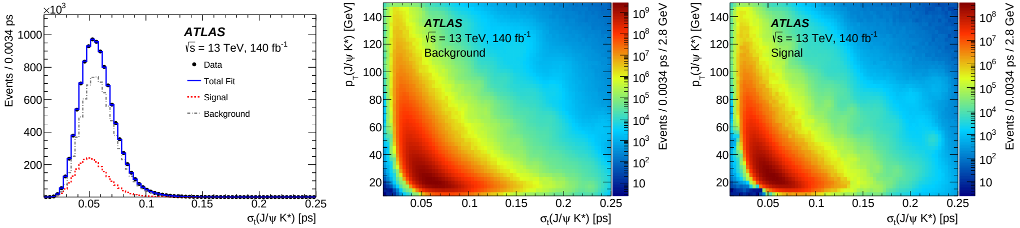
$$R(t' - t_i, \sigma_{t_i}) = \sum_{k=1}^{3} f_{\rm res}^{(k)} \frac{1}{\sqrt{2\pi}\ S^{(k)}\ \sigma_{t_i}} \exp\left(\frac{-(t' - t_i)^2}{2(S^{(k)}\ \sigma_{t_i})^2}\right)$$

three $f_{res}^{(k)}$ fractions and scale factors $S^{(k)}$ are free parameters of fit, σ_{τ_i} is the per-candidate time error, extracted from data in the vertex fit of each $B^0 \to J/\psi K^{*0}$.

Conditional probability of the time uncertainty σ_{τ_i} and $p_{\mathrm{T}_\mathrm{i}}$ of B_d^0

- Per-candidate time errors σ_{τ_i}, extracted from data in the vertex fit of each B_d^0 are used in the Resolution function R for deconvolution of proper decay times.
- σ_{τ_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 in the likelihood fit, the 2D probability terms $C_j(\sigma_{\tau_i}, p_{\mathrm{T}_i})$ are introduced into Time PDF terms $\mathcal{T}_j$ for Signal and Bg, j - stands for Signal or Bg. The method first used in G.Punzi

$$\mathcal{T}_j(\tau_i, \sigma_{\tau_i}, p_{\mathrm{T}_i}) = P_j(\tau_i, \sigma_{\tau_i}, p_{\mathrm{T}_i}) \cdot C_j(\sigma_{\tau_i}, p_{\mathrm{T}_i}), \quad (3)$$



Left: σ_{τ_i} for signal and Background. Middle and Right: 2D conditional probability distribution of the per-candidate σ_{τ_i} and $p_{\mathrm{T}_\mathrm{i}}$ of B_d^0 candidates, illustrating the strong dependence between these observables for both (a) signal and (b) background. The sPlot technique Pivk:2004ty is used to separate the signal and background distributions in data.

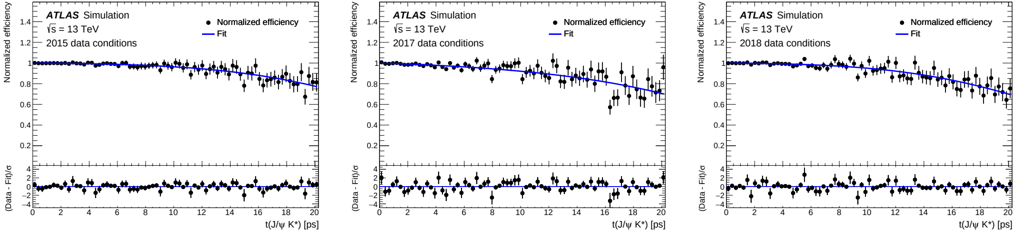
Efficiencies and corrections

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

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

$$1/w(t_i) = p_0 \cdot [1 - p_1 \cdot (\mathrm{Erf}((t_i - p_3)/p_2) + 1)] \quad (4)$$

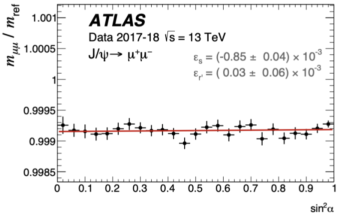
$w(t_i)$ are used to re-weight each event in Likelihood fit. The fit is applied individually for each year, due to their different trigger and data-taking conditions.



Systematic uncertainties

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

- 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. $J/\psi \to \mu^+\mu^-$ Eur. Phys. J. C 80 (2020) 1194.



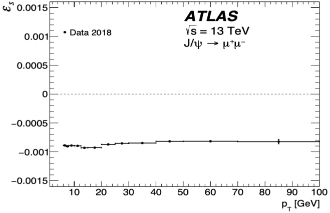


Fig left: Kinematic variable $sin^2_\alpha = E^+ \cdot E^- \cdot (p_T^+/E^+ - p_T^-/E^-)$ / m($\mu^+\mu^-$) introduced to allow differentiation between ϵ_r and ϵ_z.

Scale biases $\epsilon_S = \epsilon_z$ and $\epsilon' = \epsilon_r - \epsilon_z$ measured from fit. Difference between the radial and longitudinal biases negligible.

Fig right: ϵ_S as a function of 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 from the data. 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 σ

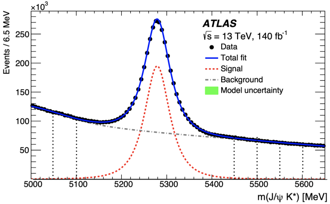
Kinematic reflections

- MC models of not negligible kinematic reflections $B^+ \to J/\psi K^+$, $B_s \to J/\psi K^+ K^-$ and $B^0 \to J/\psi \rho(\pi^+\pi^-)$, are included in the alternative fit to data with freely floating fractions.

Varying Sig, Bg mass PDF

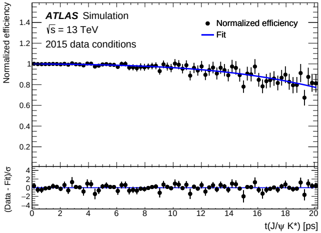
- Alternative signal mass models, the Johnson S_U-distribution is replaced by a double-sided Crystal Ball distribution or Student's t-distribution, giving systematics
- Alternative background mass models: the sigmoid component is replaced by $\arctan$ function
- Both items summed give systematics 1.3 σ

- Correlations between the invariant mass and the pseudo-proper decay time, and their potential impact on the fit results, are studied.
- No mass-time correlation in signal PDF proven by MC.
- For background the correlations are studied in data. First, applying the default time Background PDF $P_{\rm bkg}(t_i, \sigma_i, p_{\rm T_i})$ fit in each of the 6 mass sideband bins in data. Fractions $f_{\rm prompt}$ and b_1, b_2 determined in each bin were then fitted to extract their dependence on mass. The best description - achieved by linear functions.



- Based on this information, an alternative fit model, in which the background PDF term $P_{\rm bkg}(t_i, \sigma_i, p_{\rm T_i})$ is constructed with the parameters accounting for mass-dependence: $f_{\rm prompt}(m_i) = a + b(m_i - 5.279\text{ GeV})$, $b_1(m_i) = c_1 + d_1(m_i - 5.279\text{ GeV})$ and $b_2(m_i) = c_2 + d_2(m_i - 5.279\text{ GeV})$. a, b, c_1, d_1, c_2 and d_2 are free parameters of the fit. A difference of lifetime w.r.t default fit is 0.00228 ps (1.9 σ)

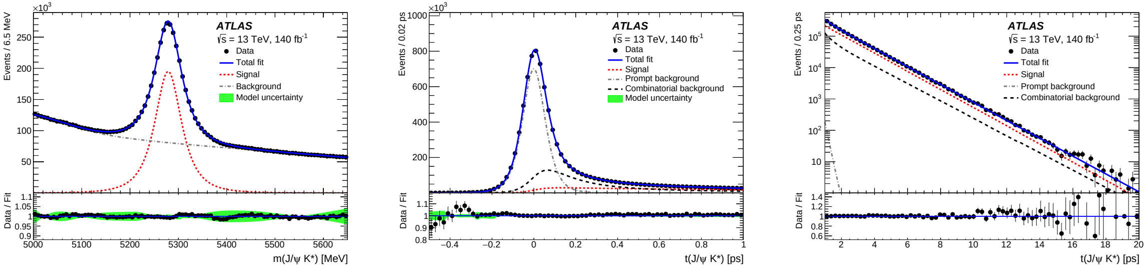
Time efficiency correction systematics



- Two alternative functions fitting the time efficiency histogram, replacing the default error function, were: hyperbolic tangent function or $(x^2+1)^{-1/2}$. The larger of the changes in the fitted lifetime, of size $0.6\sigma_{\rm stat}$ - taken as a systematic uncertainty.
- Systematic effects due to limited MC statistic, used to build the time efficiency histogram, was estimated by repeating the fit with a large number of alternative time efficiency functions, obtained by smearing the number of MC events in the time bins, leading to $0.8\sigma_{\rm stat}$.
- An alternative fit using data events with $t < 8$ ps, is performed to validate the modelling of the efficiency for high lifetimes, where the efficiency decrease is large, lead to small systematics $0.5\sigma_{\rm stat}$.

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

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



- 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.

Parameters fitted in mass-time Likelihood fit

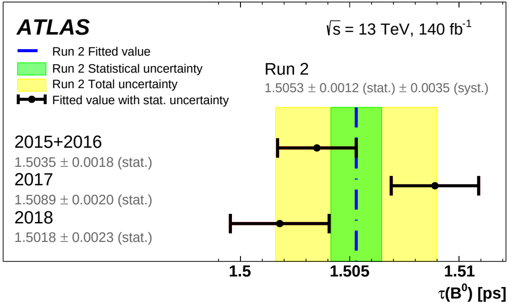
Parameter	Starting Value	Fitted Value	Error
p_0	-0.00015	-0.00015	1.8018e-07
m_0	4755.77315	5067.68398	2.2599
s	0.00940	0.00990	0.00028
δ_{sig}	1.26524	1.10875	0.00388
γ_{sig}	-0.05542	-0.00000	2e-05
λ_{sig}	40.57214	36.27316	0.13244
m_0	5277.87937	5278.96001	0.0285
f_{prompt}	0.60000	0.93427	0.00138
f_{prompt}	0.60000	0.63547	0.00048
$f_{\text{res;1}}$	0.82000	0.83456	0.00099
$f_{\text{res;2}}$	0.16000	0.15896	0.00096
f_{sig}	0.22000	0.23175	0.00022
$f_{\text{bkg;1}}$	0.19891	0.29218	0.00387
$f_{\text{bkg;2}}$	0.41310	0.41696	0.00376
$\tau_{\text{bkg;1}}$	0.50000	0.41574	0.00589
$\tau_{\text{bkg;2}}$	1.54400	1.57023	0.00483
$\tau_{\text{bkg;3}}$	0.13970	0.12932	0.00128
SF_1R	1.00000	0.99267	0.00068
SF_2R	1.70000	1.74252	0.00438
SF_3R	5.40000	5.35241	0.04473
$\tau(B^0)$	1.51600	1.50529	0.00116

There are no high correlations of the fitted B_d^0 lifetime with other parameters. The highest ones are:

- 18% with f_{sig} fraction of signal events
- 12% with τ_{bkg_2} - the lifetime of one of three components of Combinatorial Background, that has the fitted value $\tau_{\text{bkg}_2} = 1.5702$ ps rather close to the signal one.

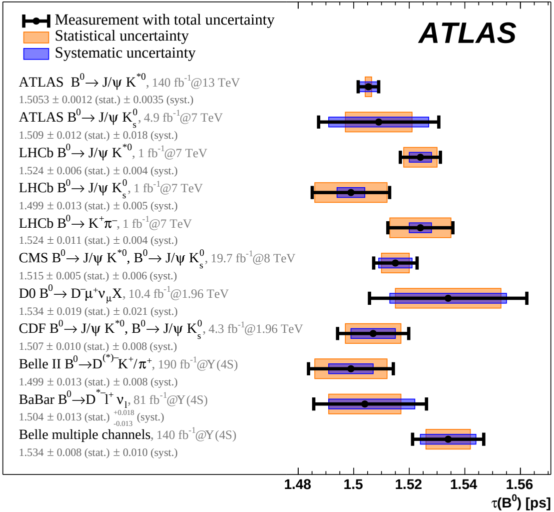
Results: A consistency and stability test over data taking periods

As a consistency and stability test, the B^0 lifetime value was fitted separately for each data-taking period (2015+2016, 2017 and 2018). Figure shows the degree of stability over time. The p-value for consistency of the three individual results, accounting for just statistical uncertainties is 0.038.



The fitted values of the B^0 lifetime, measured with $B^0 \to J/\psi K^{*0}$ decays, for the 2015+2016, 2017 and 2018 subsamples compared to the value for the whole sample. The B^0 lifetime value for each subsample is shown by a black point, with the error bar indicating the statistical uncertainty.

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



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

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 $2y = \Delta\Gamma_d/\Gamma_d = 0.001 \pm 0.010$ and asymmetry $A = -0.578 \pm 0.136$ from HFLAV:2023:

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

  The uncertainty denoted 'ext.' originates from the HFLAV.
- The value Γ_d is in agreement with HQE theory of $0.63^{+0.11}_{-0.07}\,\text{ps}^{-1}$ Lenz et al. 2023

Γ_d/Γ_s

- Using $\Gamma_s = 0.6703 \pm 0.0014\,(\text{stat.}) \pm 0.0018\,(\text{syst.})\,\text{ps}^{-1}$ 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.

Summary

- ATLAS preformed a measurement of B_d^0 effective lifetime and the average decay width Γ_d using $B^0 \to J/\psi K^{*0}$ events reconstructed from a 140 fb^{-1} data sample of pp collisions collected with the ATLAS detector during the $\sqrt{s}$=13 TeV LHC run.
- The B^0 effective lifetime is measured to be $1.5053 \pm 0.0012(\text{stat}) \pm 0.0035(\text{syst})$ ps. This results is compatible with other experimental measurements and is the most precise measurement to date.
- The measured average decay width of the heavy and light B^0 mass eigenstates is $\Gamma_d = 0.6639 \pm 0.0005\ (\text{stat.}) \pm 0.0016\ (\text{syst.}) \pm 0.0038\ (\text{ext.})\ \text{ps}^{-1}$ This value is in good agreement with the theory prediction.
- The measured average decay width Γ_d is combined with the average decay width Γ_s measured previously by ATLAS to obtain the ratio $\Gamma_d/\Gamma_s = 0.9905 \pm 0.0022\ (\text{stat.}) \pm 0.0036\ (\text{syst.}) \pm 0.0057\ (\text{ext.})$ This result is compatible with the theory predictions from HQE and lattice QCD calculations as well as with the experimental average.

Backup Slides

Detailed Comparison of B^0 lifetime, Γ_d and Γ_d/Γ_s with others

- ATLAS B^0 lifetime 1.5053 ± 0.0012(stat) $\pm$ 0.0035(syst) ps, is the most precise measurement to date.
  - Comparing to latest LHC measurements
    - LHCb $B^0 \to J/\psi K_S^0$ lifetime is smaller than ATLAS and well compatible within 0.4 σ. The other two LHCb results $B^0 \to J/\psi K^{*0}$ and $B^0 \to K^+\pi^-$ have lifetimes larger than ATLAS by 2.3 σ and 1.5 σ. The CMS combining $B^0 \to J/\psi K_S^0$ $B^0 \to J/\psi K^{*0}$ is within 1.1 σ from ATLAS.
  - Comparing to non LHC experiments
    - CDF and Belle II results combining the $B^0 \to J/\psi K_S^0$ $B^0 \to J/\psi K^{*0}$ are compatible with ATLAS within 0.1σ and 0.4σ respectively, while the older Belle result, combining six channels, has lifetime larger than ATLAS by 2.1σ.
  - The latest world average
    - 1.517 ± 0.004 ps PDG2024 differs from ATLAS by 2.1 σ.
- ATLAS $\Gamma_d = 0.6639 \pm 0.0005$ (stat.) $\pm$ 0.0016 (syst.)$\pm$ 0.0038 (ext.) ps^{-1} value
  - is compatible with the HQE theory of $0.63^{+0.11}_{-0.07}$ ps^{-1} Lenz et al. 2023 within 0.3 σ, σ combining both sources.
- ATLAS $\Gamma_d/\Gamma_s = 0.9905 \pm 0.0022$ (stat.) $\pm$ 0.0036 (syst.)$\pm$ 0.0057 (ext.)
  - is compatible with the theory HQE and lattice QCD models Lenz et al. 2023 . within 1.4 σ and 0.4 σ, respectively, and with the experimental average (1.001 ± 0.004) HFLAV:2023 within 1.3σ

Earlier ATLAS B-hadron lifetime measurements

- Measurement of effective lifetime in $B^0_{(s)} \to \mu^+\mu^-$
  JHEP 09 (2023) 199 W
- Measurement of Λ^0_b lifetime in $\Lambda^0_b \to J/\psi\Lambda^0$ and B^0_d lifetime in $B^0_d \to J/\psi K^0_S$ decays
  PhysRevD.87.032002, 2013
- Measurement of the relative width difference $\Delta\Gamma_d/\Gamma_d$ of the B^0_d-$\overline{B^0_d}$ system with the ATLAS detector
  JHEP06(2016)081
- 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 $B_s \to J/\psi\phi$ decay.
  Eur. Phys. J. C 81 (2021) 342