ATLAS results on b hadrons weak decays

Alessandro Cerri on behalf of the ATLAS Collaboration

Introduction

- Broad flavour physics programme in ATLAS:
 – Rare decays, CP/LFU violations, precision measurements
  – Hadron spectroscopy and exotics
  – Heavy Flavour production measurements

- Competitive thanks to
  – high statistics
  – muon identification performance
  – detector acceptance
    • Muon reconstruction from $p_T > 2$ GeV
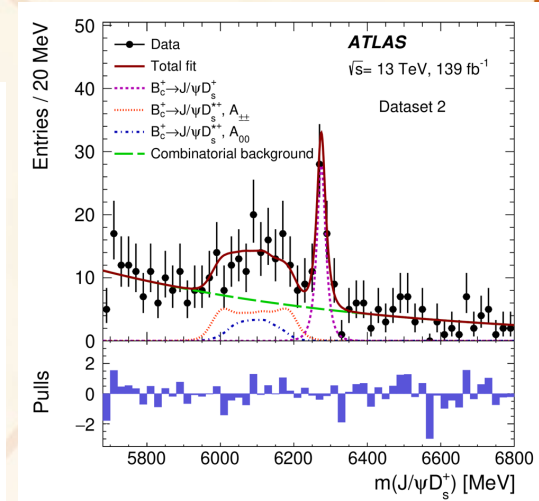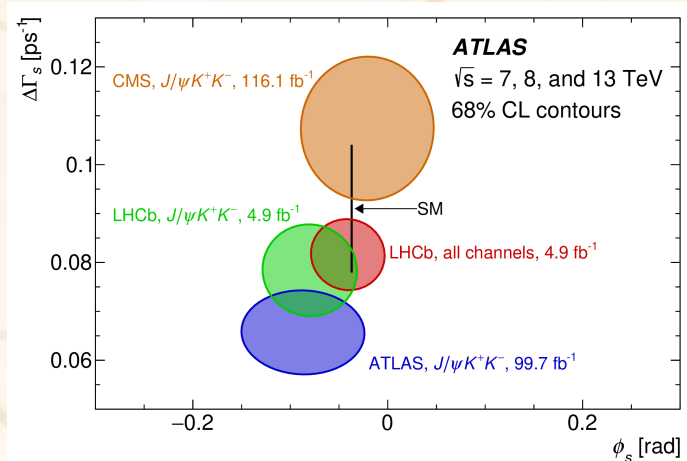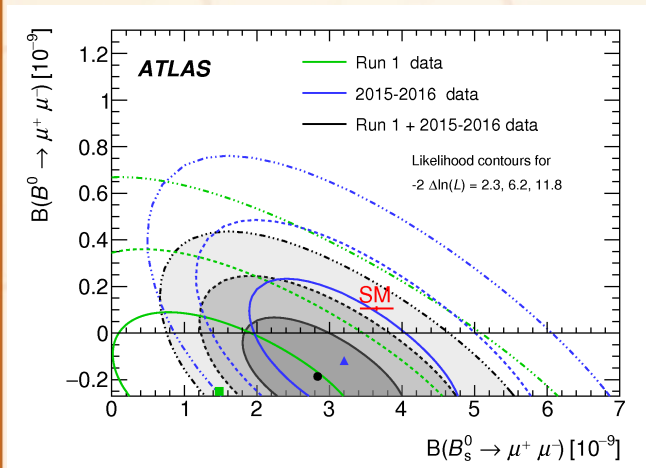   • Tracking $|\eta| < 2.5$, $p_T > 0.5$ GeV

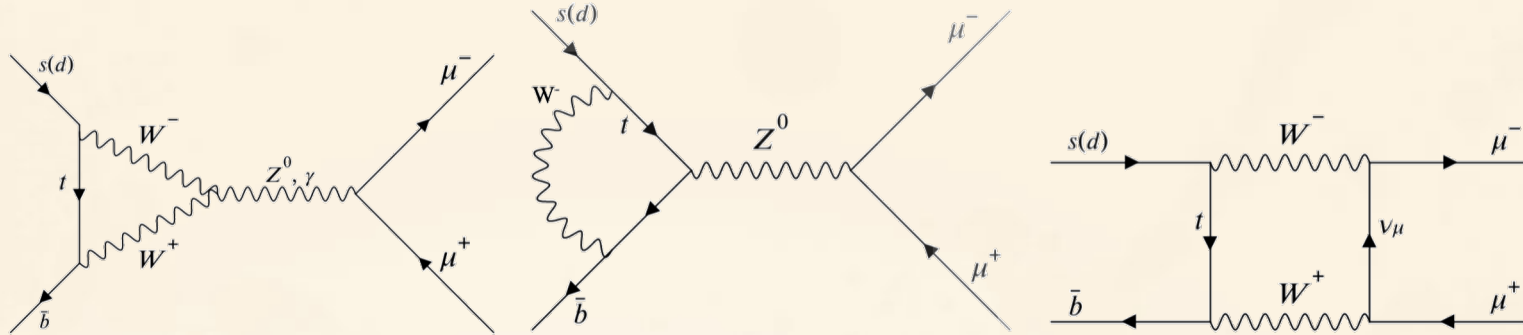- Studies predominantly based on leptonic selections, often with the inclusion of "topological" requirements
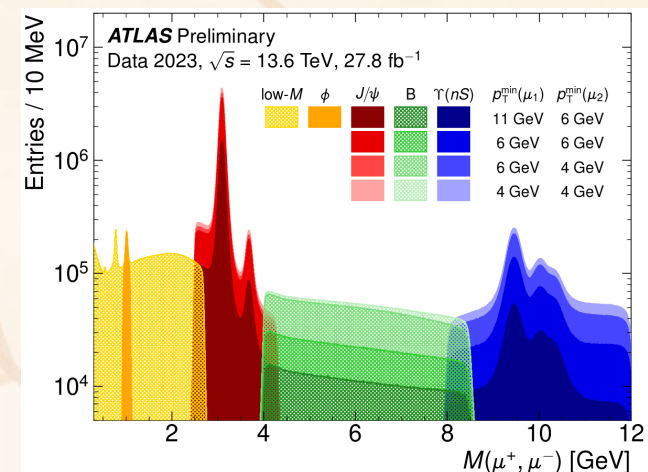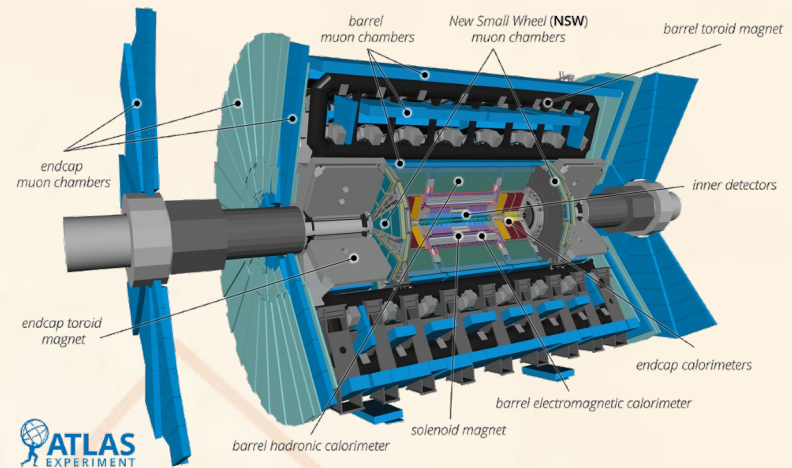
Weak decays of b hadrons

- $B_s \to \mu\mu$ lifetime [JHEP09(2023)199]

- $B_{(s)} \to \mu\mu$ Branching Ratios [JHEP04(2019)098]

- $B_c \to J/\psi D_s^{(*)+}$ [JHEP08(2022)087]

- Measurement of ϕ_s in $B_s \to J/\psi\phi$ [EPJC81(2021)342]

Older results, not covered in this talk

$B_s \rightarrow \mu\mu$ lifetime: motivation

- Very rare decays: small accurately predicted SM amplitudes
- New Physics could manifest itself in BR and/or lifetime
  - BR and lifetime are independent tests of NP contributions
  - In SM only CP-odd (heavy) state decays to $\mu\mu$
  - NP could introduce CP-even amplitudes with significant effects on effective lifetime:
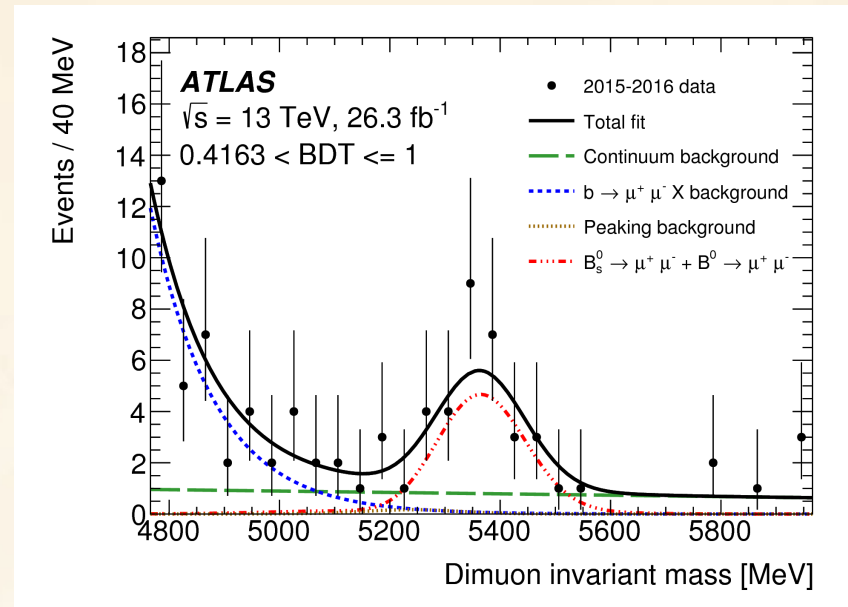 $\Delta\tau$=0.193 ps and τ_H=1.622 ps [PDG]

First ATLAS measurement of the $B_s \rightarrow \mu\mu$ effective lifetime, based on 2015-2016 data (26.3 fb^{-1})
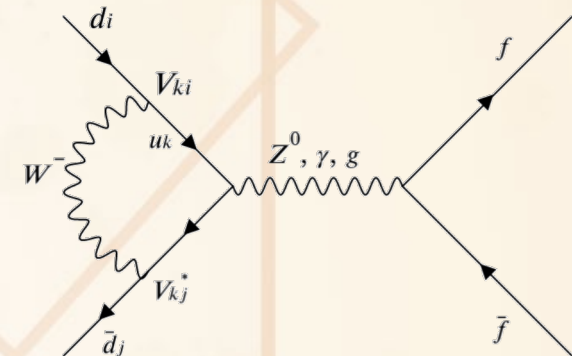
$B_s \to \mu\mu$ lifetime: datasets and selection

- **Same data already unblinded for the latest ATLAS BR measurement**

  – MVA (BDT) selection, reconstruction and simulated samples inherited from BR result

- Unbinned Extended ML fit to m($\mu\mu$) distribution
  - Limited statistics → selection simplified to single BDT bin
  - BDT selection re-optimised for best $\frac{S}{\sqrt{S+B}} \Rightarrow S:B \sim 2:1$
  - Signal and background models from BR measurement
  - Signal proper decay time extracted from m($\mu\mu$) fit using sPlot technique

$B_s \rightarrow \mu\mu$ lifetime: m($\mu\mu$) fit

- Di-muon dominated Background:

  – Combinatorial → linear

  – Partially reconstructed (SSSV) b-hadron decays → exponential

  – Models challenged as part of systematic uncertainty studies

- Unconstrained background parameters (shape & normalization)
- Signal shape constrained to MC model (+ mass scale/resolution effects)
- Additional contributions to m($\mu\mu$) not included but accounted as sources of systematic uncertainties
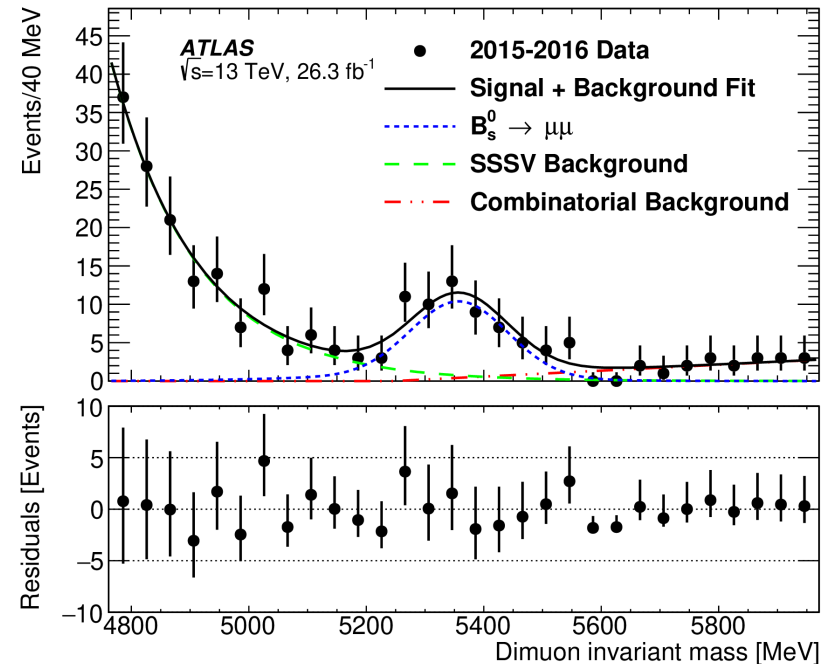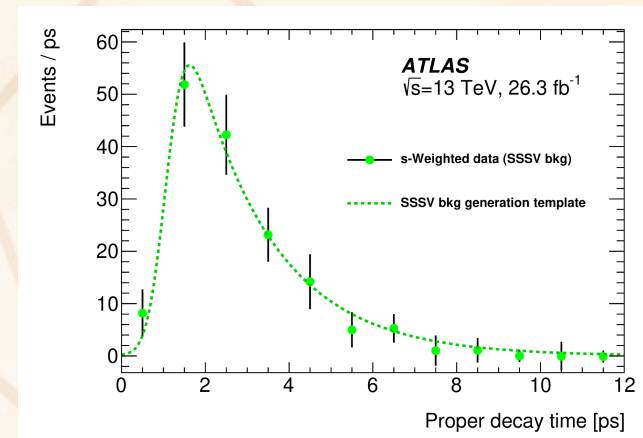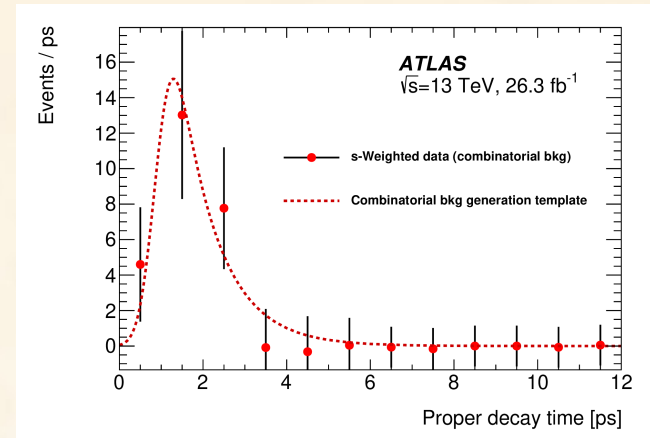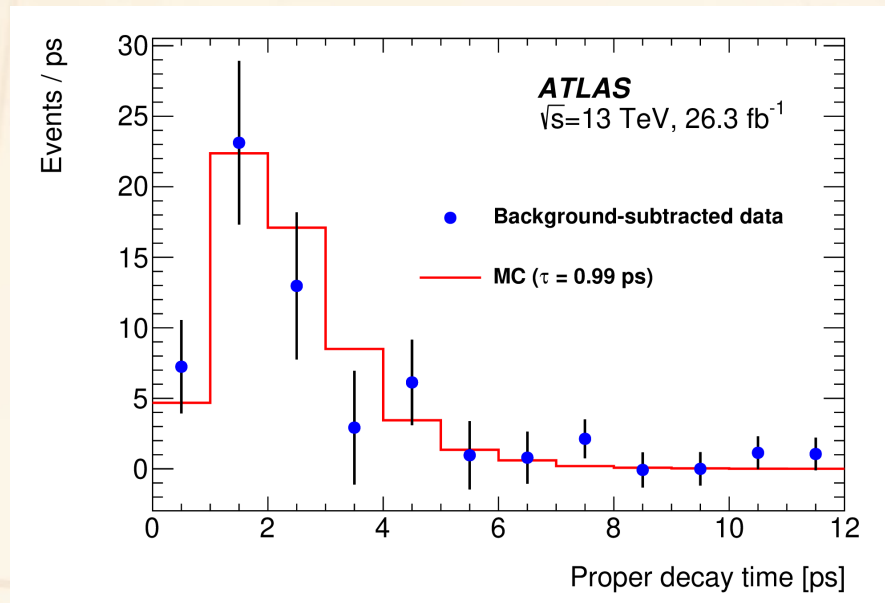

m($\mu\mu$) fit yields 58±13 signal events

Proper decay time extraction

- Calculated per-candidate using $\tilde{t}_{\mu^+\mu^-} = \dfrac{L_{xy} m_{B_s^0}^{\mathrm{PDG}}}{p_{\mathrm{T}}^{B_s^0}}$

- sPlot technique → lifetime-model independent extraction of signal and background $\tilde{t}_{\mu\mu}$ distributions:
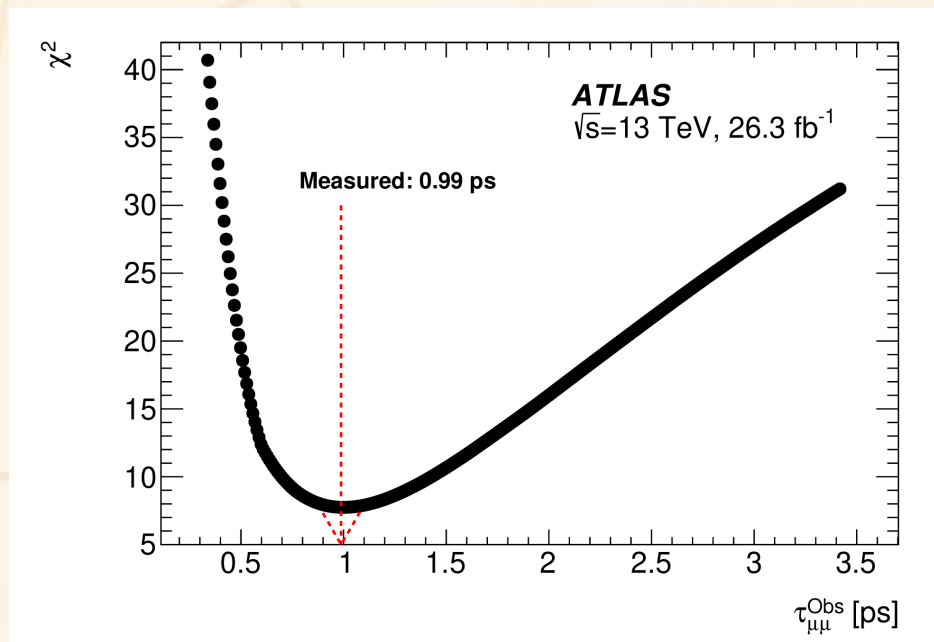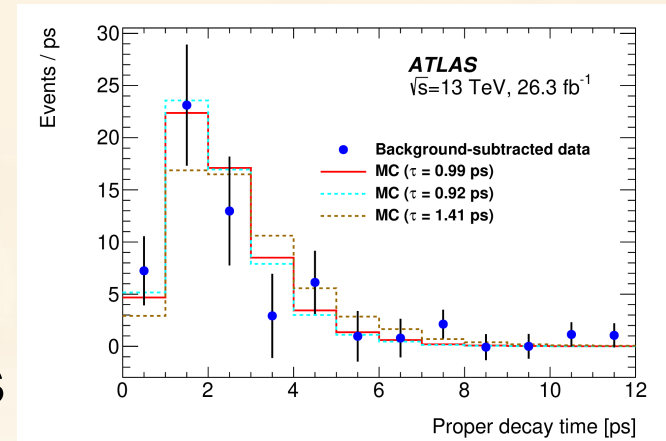

toy-MC models for fit closure and systematic studies

$B_s \rightarrow \mu\mu$ lifetime measurement

Signal MC templates from full simulation

– Single MC sample, re-weighted for different values of $\tau_{\mu\mu}$

– $\tau_{\mu\mu}$ fit minimising binned χ^2

– χ^2 includes data and MC uncertainties

Toy-based closure test yields 82 ps bias at $\tau_{\mu\mu}^{SM}$ included as a correction

Statistical Uncertainty

- Toy MC: signal and background analytical templates
  - verified against sPlots
- Neyman construction: $\tau_{\mu\mu}^{OBS} \rightarrow \tau_{\mu\mu}^{True}$ CL bands
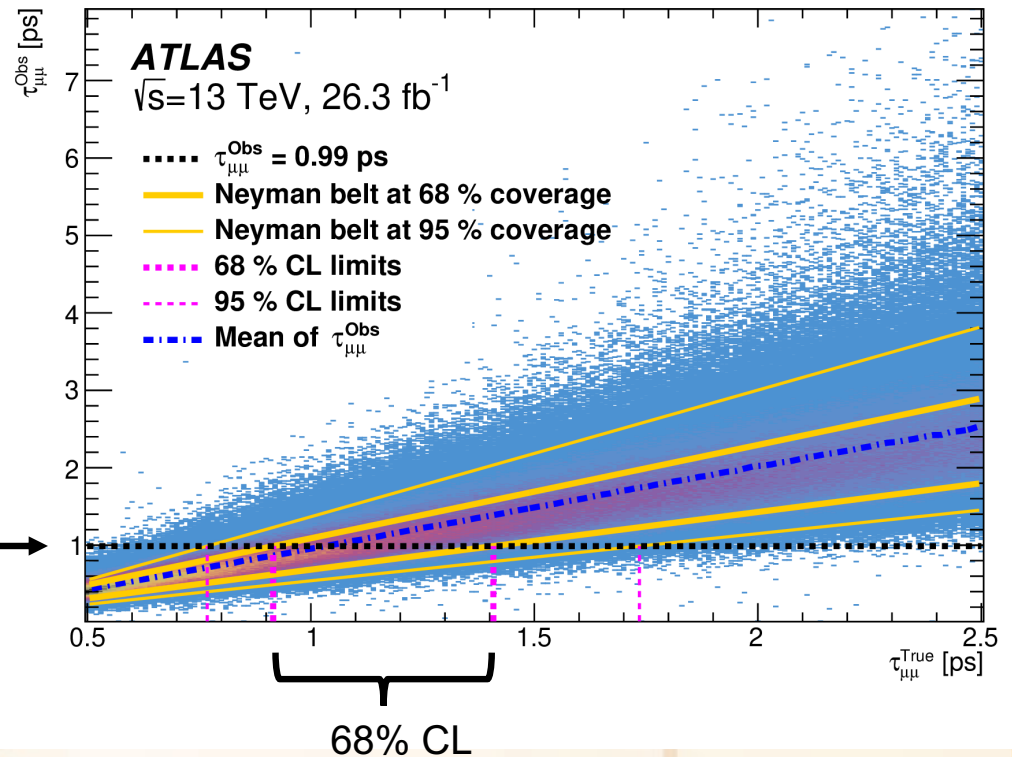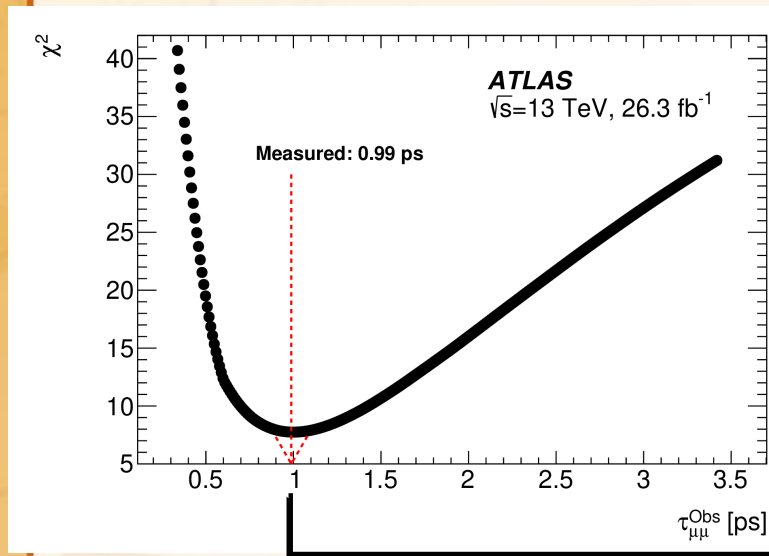
Systematic Uncertainties

Three main categories:

- Fit-related
  - Variations to fit models
  - Lifetime dependency of lifetime bias

- Neglected backgrounds

- Data-MC discrepancies
  - MC kinematics
  - BDT input variables consistency

| Uncertainty source	$\Delta\tau_{\mu\mu}^{\mathrm{Obs}}$ [fs]
Data - MC discrepancies	134
SSSV lifetime model	60
Combinatorial lifetime model	56
B kinematic reweighting	55
B isolation reweighting	32
SSSV mass model	22
B_d background	16
Fit bias lifetime dependency and B_s^0 eigenstates admixture	15
Combinatorial mass model	14
Pileup reweighting	13
B_c background	10
Muon Δ_η correction	6
$B \rightarrow hh'$ background	3
Muon reconstruction SF reweighting	2
Semileptonic background	2
Trigger reweighting	1
Total	**174**

Dominant Systematic: Data-MC

Data-driven assessment, based on $B^{\pm} \to J/\psi K^{\pm}$ signal

- Full extraction procedure repeated with comparable statistics
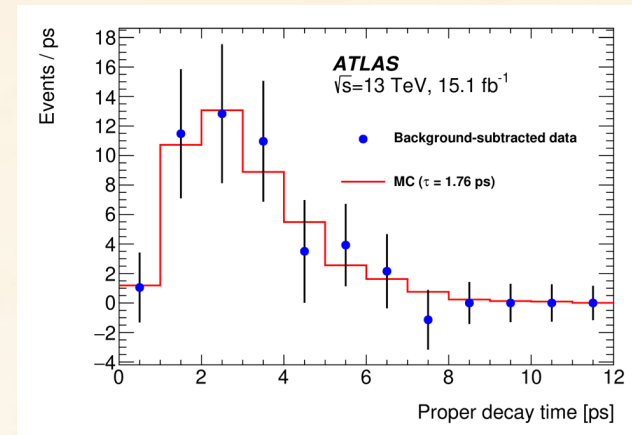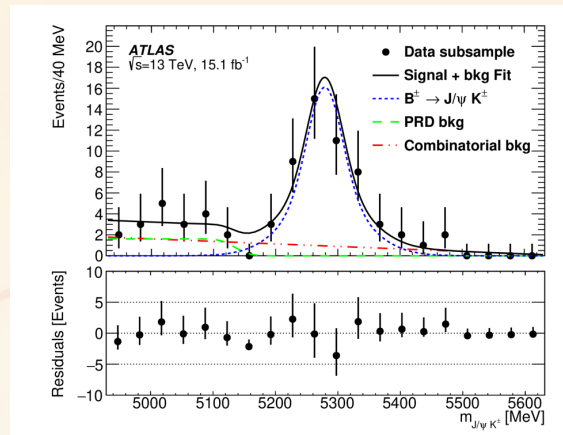
Comparison against PDG average reveals σ_{Lxy} dependent bias Yielding a 134fs effect for $B_s \to \mu\mu$
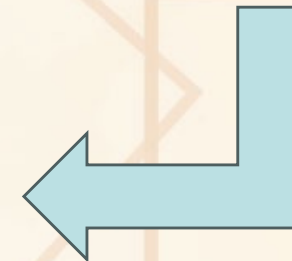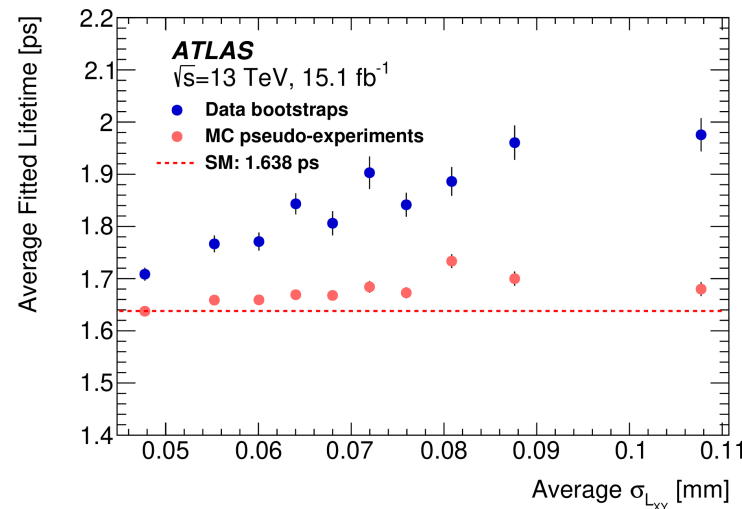
Result

Measured value: $\tau_{\mu\mu} = 0.99^{+0.42}_{-0.07}(\text{stat.}) \pm 0.17(\text{syst.})$ ps

- Consistent with SM prediction of 1.624±0.009 ps

- Consistent with other LHC measurements

  – Competitive precision at same statistics

- Full Run 2 analysis (BR and lifetime) under way
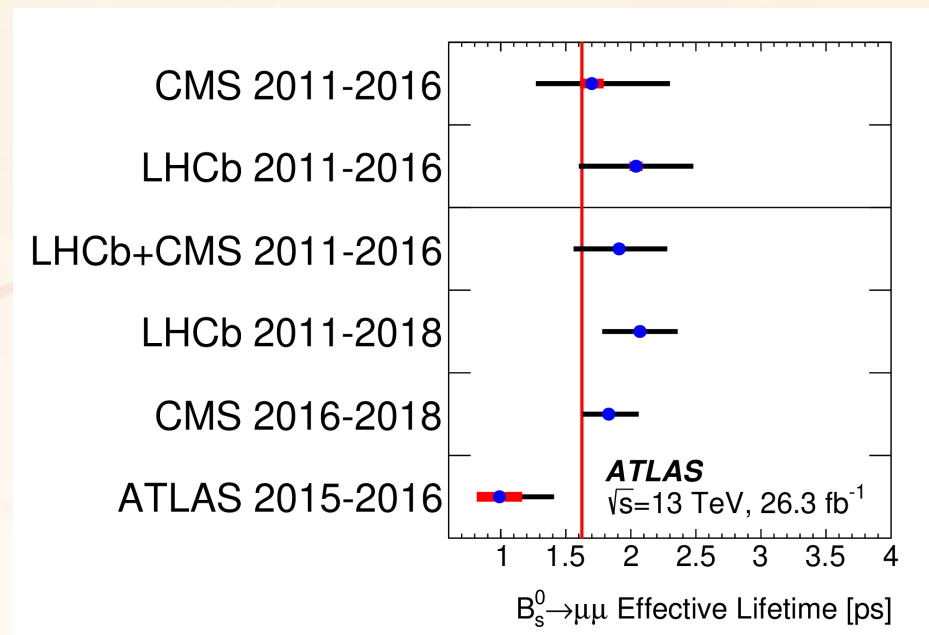
Conclusions and Outlook

- b-hadron weak decays results from ATLAS based on partial Run 2 data

- Competitive at comparable statistics

- Further studies to come:

    – Full Run 2 statistics

    – Run 3 and beyond!

Backup Material