Measurement of the masses and lifetimes of B-hadrons at ATLAS

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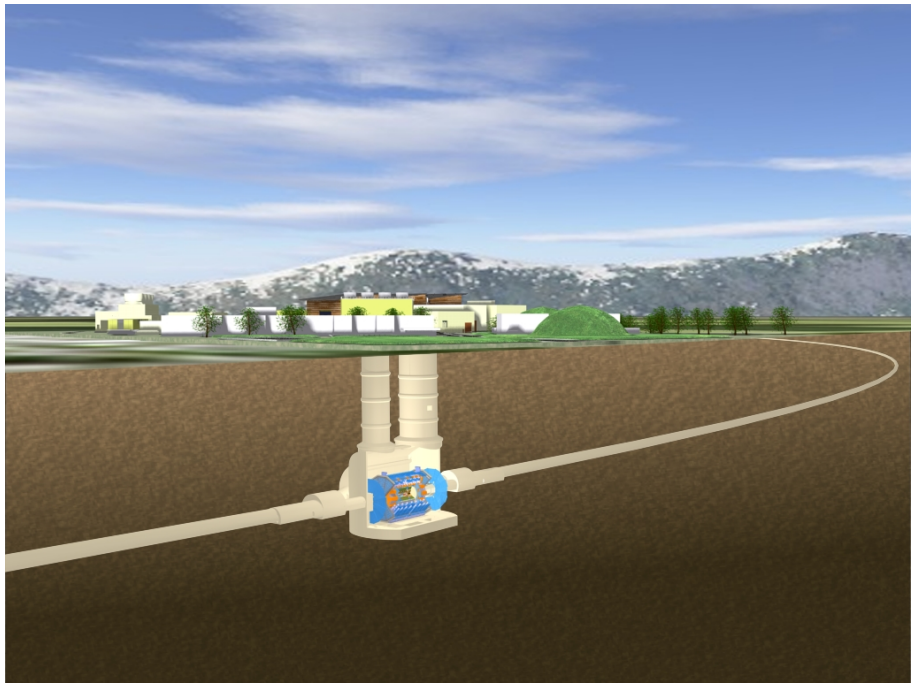
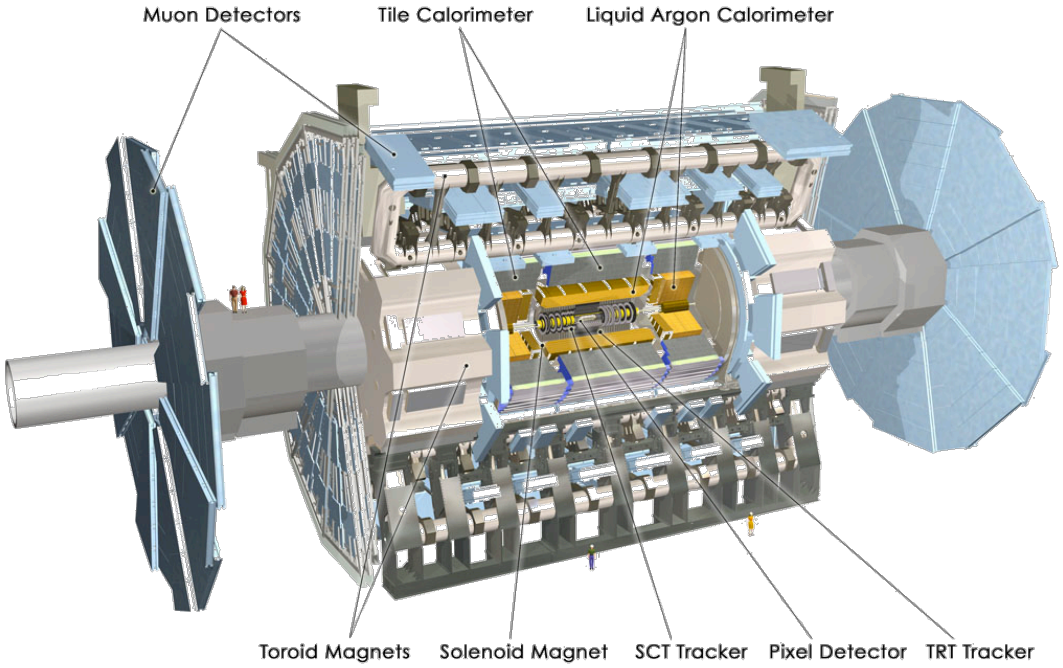
Outline

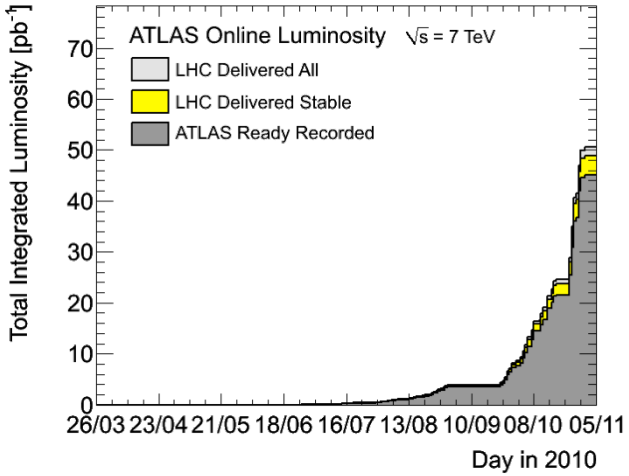
- Data collection with the ATLAS detector at the Large Hadron Collider.
- Triggers for B-physics.
- Average B lifetime in inclusive $B \rightarrow J/\psi(\mu^+\mu^-)\, X$.
- B_s and B_d mass and lifetime measurements.
- B_c observation.
- New result: Λ_b mass and lifetime measurements.
- First steps for Λ_b polarization studies.

LHC ATLAS detector and *pp* data collection in 2010—2012

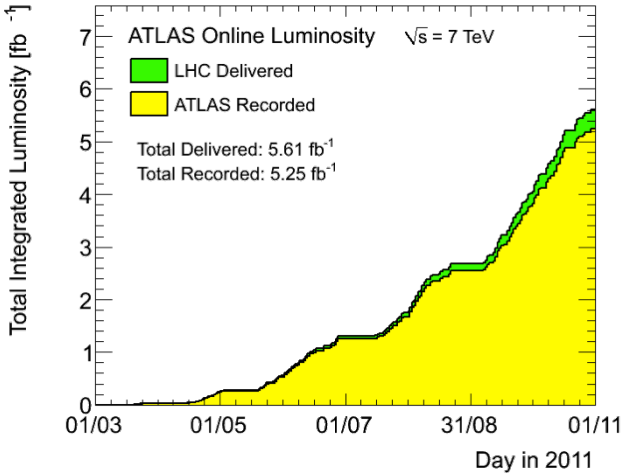




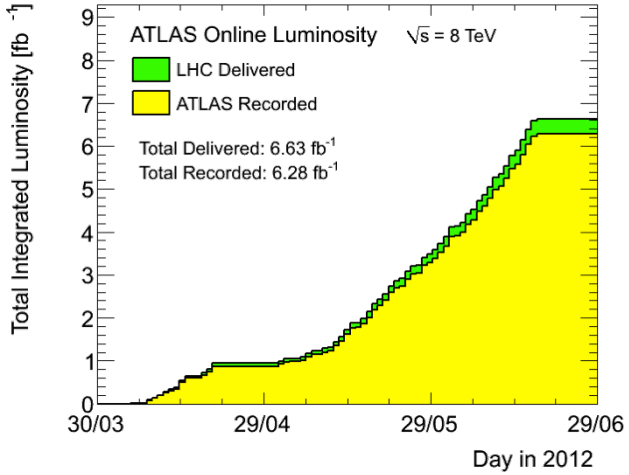
2010: > 40 pb^{-1} @ 7 TeV



2011: > 5 fb^{-1} @ 7 TeV

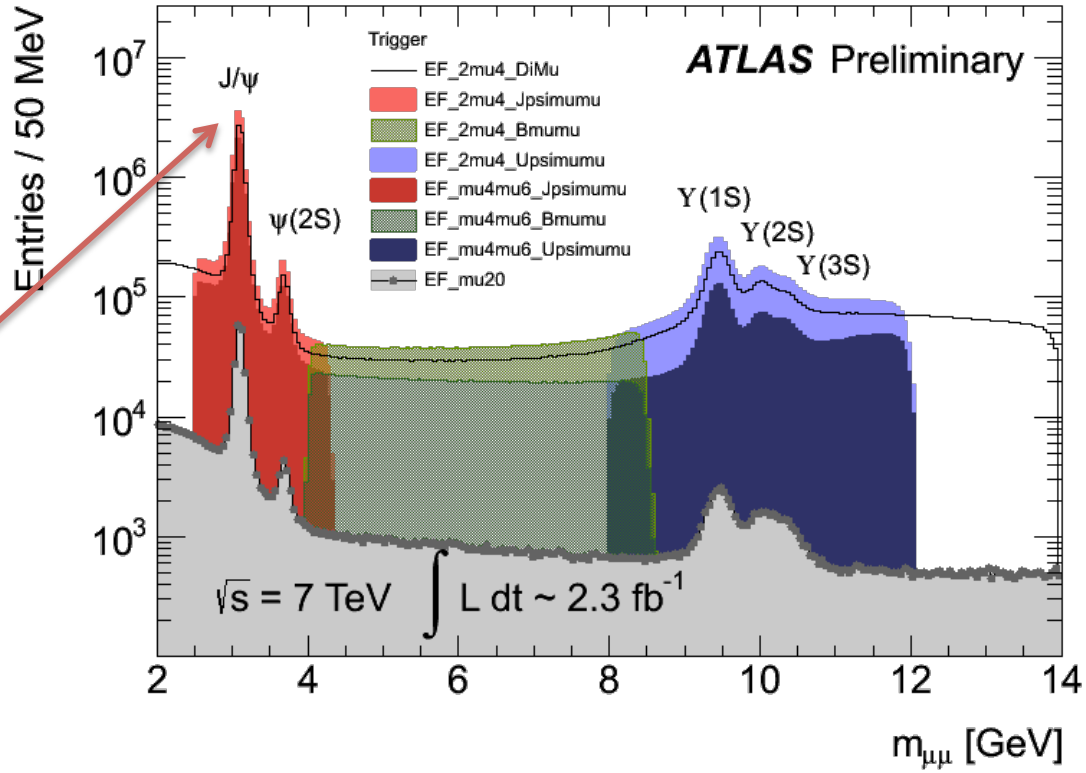


July 2012: > 6 fb^{-1} @ 8 TeV



Triggers for B-physics at ATLAS

- B-physics starts with single or di-muon triggers with various thresholds:
  - $p_T(\mu) > 6$ GeV
  - $p_T(\mu) > 18$ GeV
  - $p_T(\mu_1) > 4$ GeV & $p_T(\mu_2) > 4$ GeV
  - $p_T(\mu_1) > 6$ GeV & $p_T(\mu_2) > 4$ GeV
  - $p_T(\mu_1) > 6$ GeV & $p_T(\mu_2) > 6$ GeV

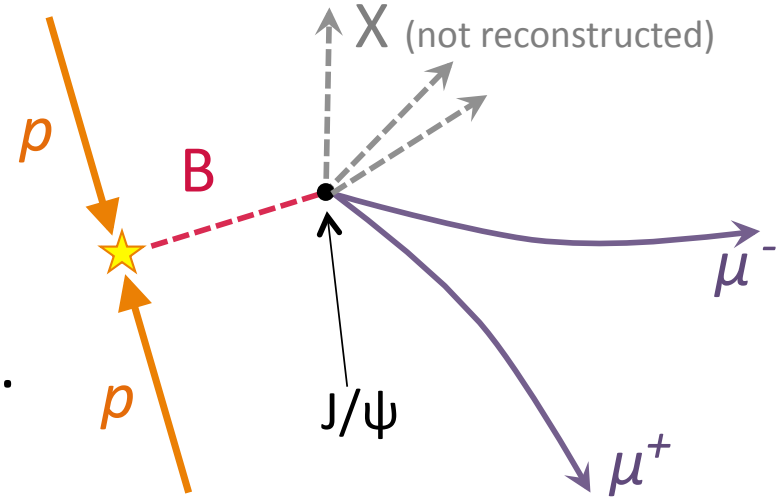


- Di-muon mass range: $m(\mu\mu) \in [2.5; 4.3]$ GeV (final states containing J/ψ) and $m(\mu\mu) \in [4.0; 8.5]$ GeV (B to μ transitions).
- No displaced vertex selection requirements: advantage for lifetime measurements.

Average B lifetime in B → J/ψ($\mu^+\mu^-$) X transitions

- ATLAS-CONF-2011-145

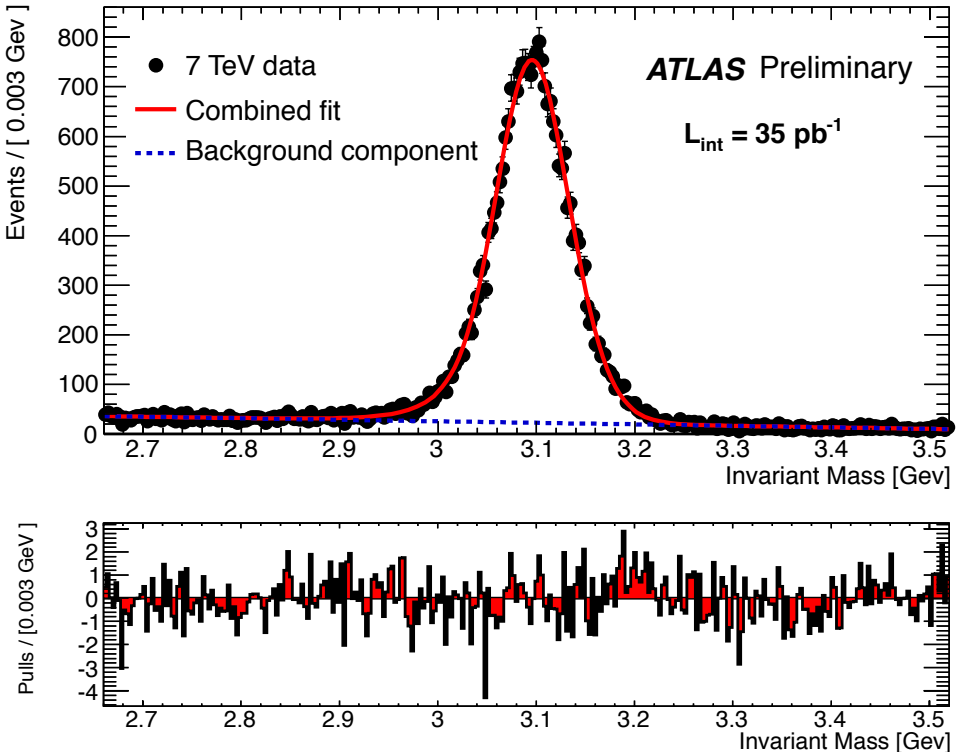
- Measurements of B-hadron lifetimes allow tests of theoretical predictions based on the Heavy Quark Expansion.

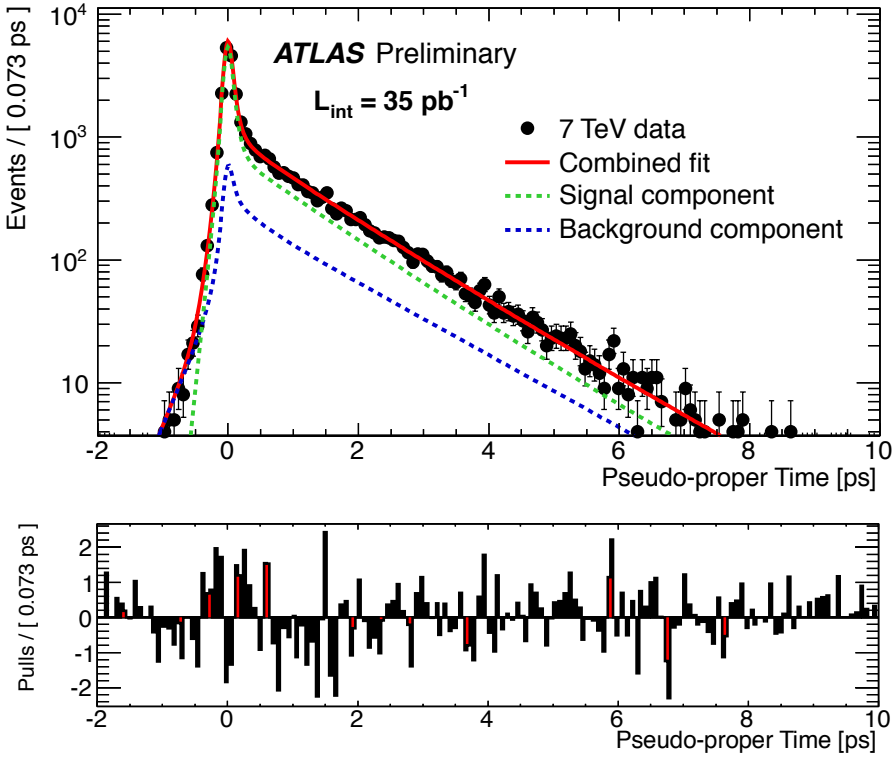


- Inclusive measurement: the final state is not fully reconstructed.

- J/ψ mesons from B-hadron decays are displaced relative to the primary vertex. Prompt J/ψ mesons originating at the primary vertex may be distinguished using the decay length.
- At large J/ψ p_T, most of the B-hadron's transverse momentum is carried by the J/ψ → approximation is possible.
- A correction factor determined from the Monte Carlo is used to account for the smearing introduced by this approximation.

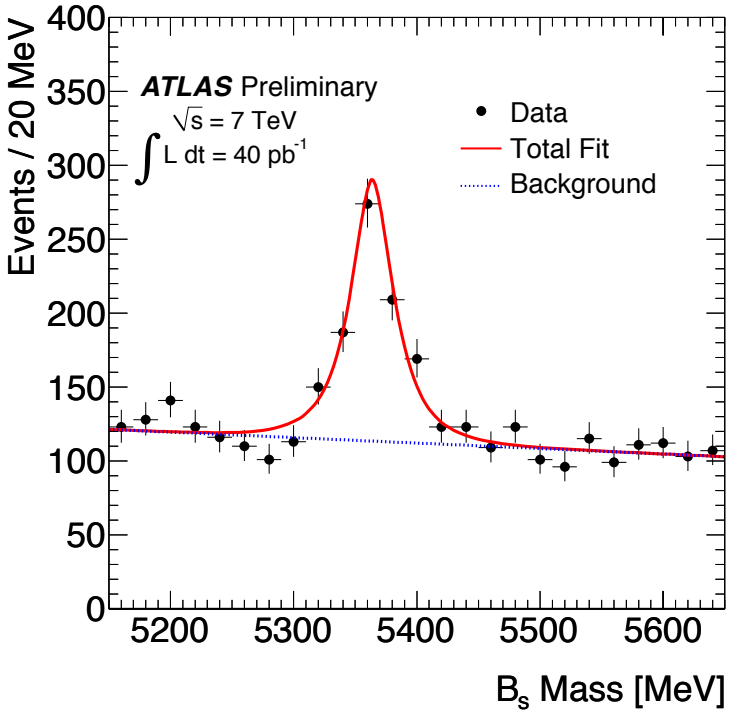
Average B lifetime in B → J/ψ($\mu^+\mu^-$) X transitions

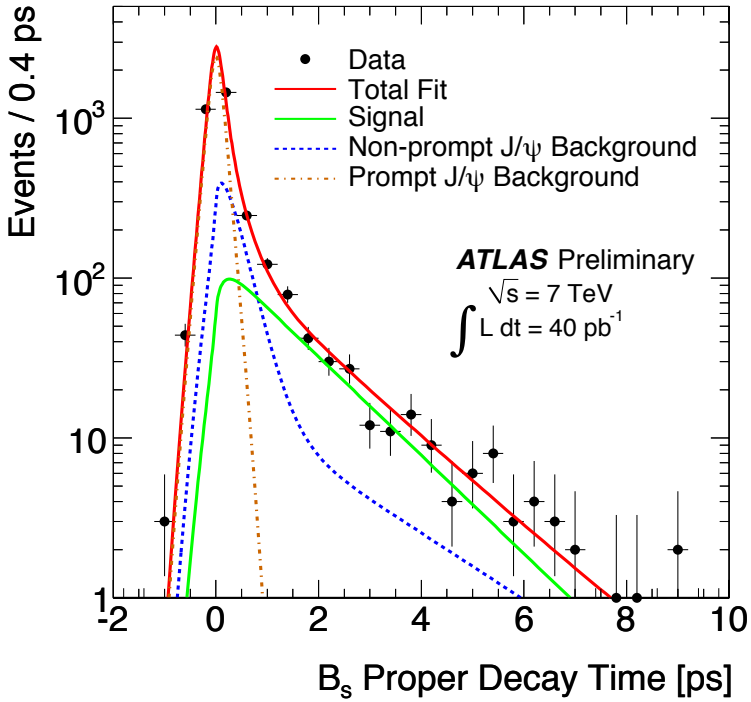




- Simultaneous unbinned ML fit of the J/ψ mass and lifetime.
- Result: $\langle\tau_b\rangle = 1.489 \pm 0.016_{stat} \pm 0.043_{syst}$ ps. The systematic error was based on early studies, and we have currently improved our understanding, in particular for the detector alignment.
- PDG $\langle\tau_b\rangle = 1.544 \pm 0.014$ ps

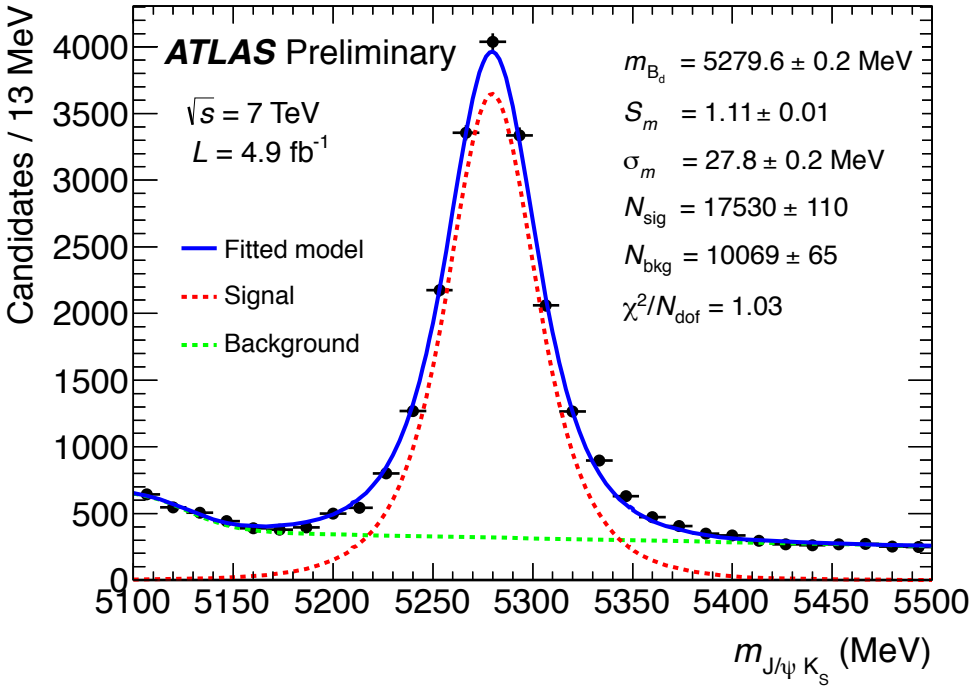
B_s mass and lifetime

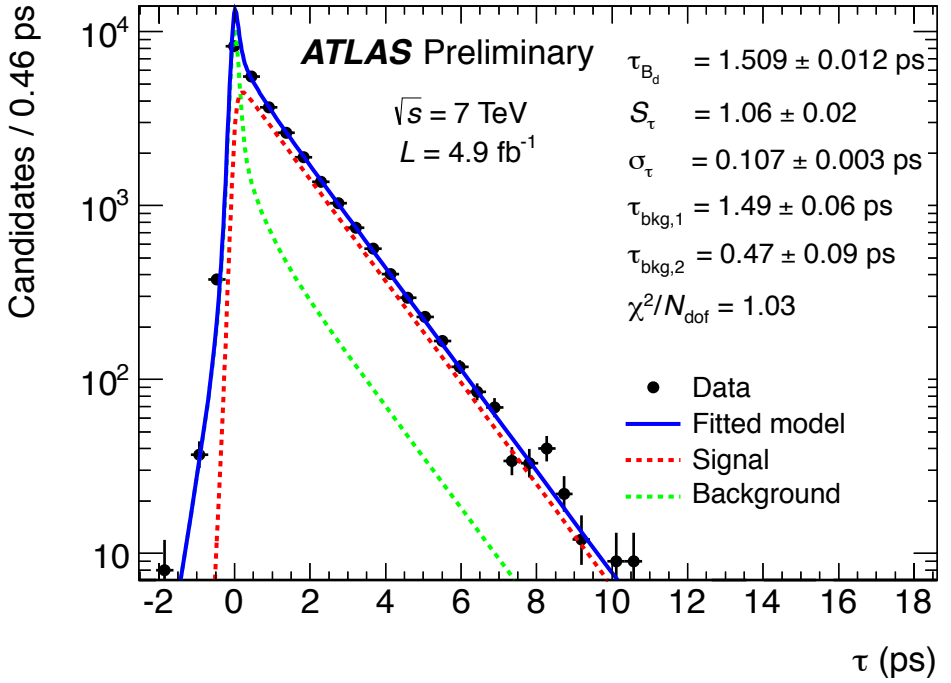




- ATLAS-CONF-2011-092
- Measured in $B_s \rightarrow J/\psi(\mu^+\mu^-)\,\phi(K^+K^-)$, important for CP violation studies.
- Results:
  - $m(B_s) = 5363.7 \pm 1.2_{stat}$ MeV (PDG value: 5366.3 ± 0.6 MeV)
  - $\tau(B_s) = 1.41 \pm 0.08 \pm 0.05$ ps (PDG value: 1.472 ± 0.026 ps)
- See also the talk "Determination of $\Delta\Gamma$ and ϕ_s from the decay B_s to $J/\psi\,\phi$ in ATLAS" by Sandro Palestini on July 7, with the most precise B_s lifetime measurements by ATLAS. The "average" lifetime of B_s obtained (2011 full data sample) is the inverse of $\Gamma_s = 0.677 \pm 0.007 \pm 0.004$ ps^{-1} ➔ total accuracy of 1.5%.

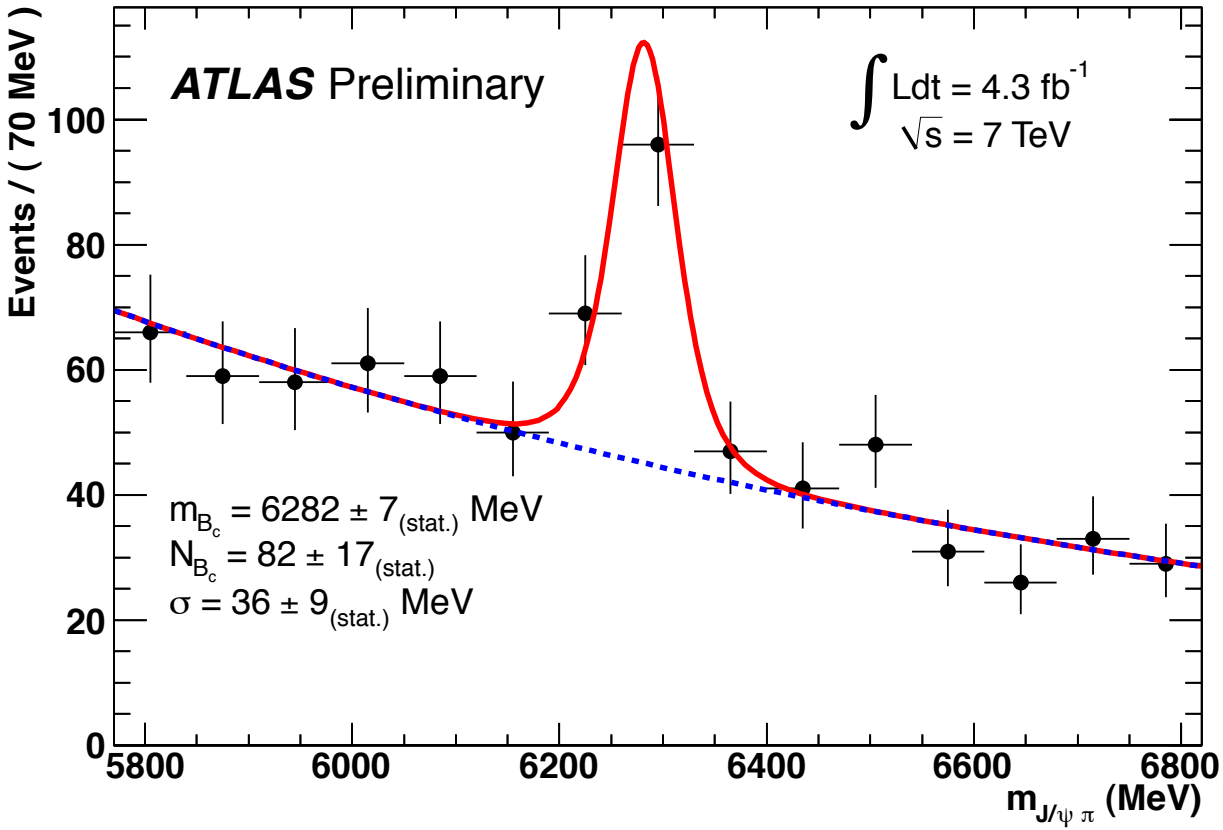
B_d mass and lifetime





- ATLAS-CONF-2012-055 (accompanying the Λ_b study).
- Measured in $B_d \rightarrow J/\psi(\mu^+\mu^-)\, K_s^0(\pi^+\pi^-)$.
- Results:
  - $m(B_d) = 5279.6 \pm 0.2_{stat} \pm 1.0_{syst}$ MeV (PDG value: 5279.5 ± 0.3 MeV)
  - $\tau(B_d) = 1.509 \pm 0.012_{stat} \pm 0.018_{syst}$ ps (PDG value: 1.519 ± 0.007 ps)

B_c observation

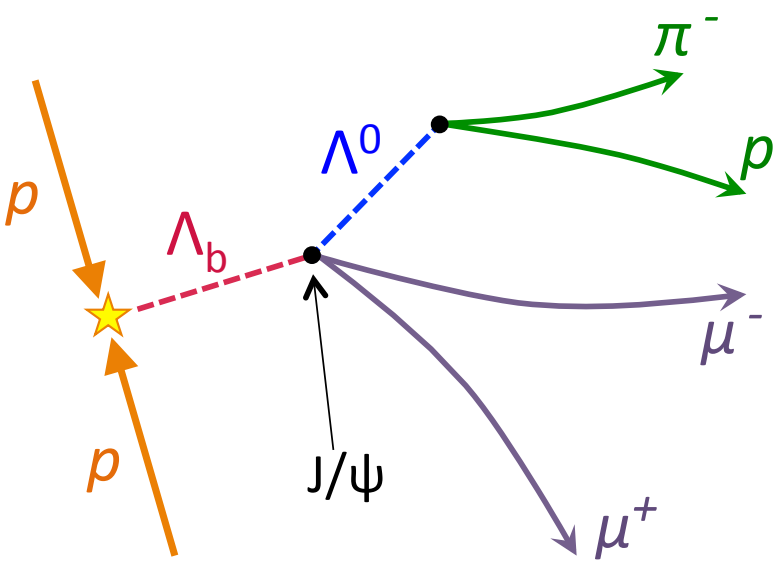


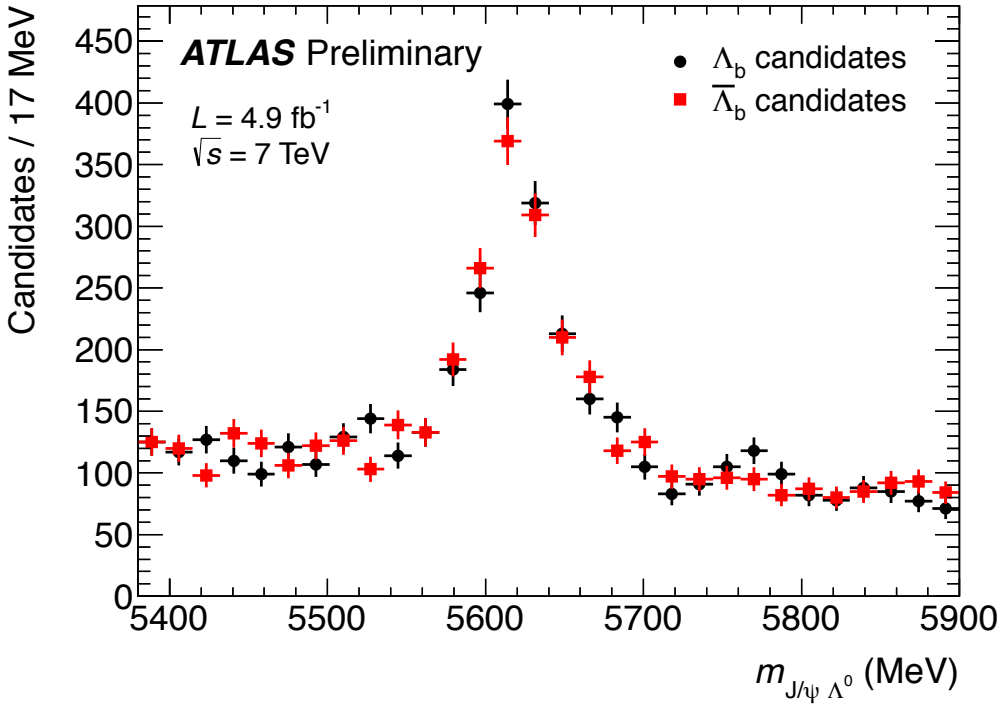
- ATLAS-CONF-2012-028
- B_c is observed in $B_c \rightarrow J/\psi(\mu^+\mu^-)\,\pi$.
- Result: $m(B_c) = 6282 \pm 7_{stat}$ MeV (PDG value: 6277 ± 6 MeV)

Λ_b mass and lifetime measurement: motivation

- Λ_b is reconstructed in the decay $\Lambda_b \rightarrow J/\psi(\mu^+\mu^-)\,\Lambda^0(p^+\pi^-)$
- The lifetime of the Λ_b was measured at LEP, the Tevatron and the LHC.
- There is a >2σ discrepancy between the CDF and DØ results:
  - Phys. Rev. Lett. 106 (2011) 121804
  - arXiv:1204.2340 [hep-ex]
- The ratio of Λ_b to B_d lifetimes is predicted by HQET and pQCD:
  - Eur. Phys. J. C 33 (2004) S895–S899: $\tau(\Lambda_b) / \tau(B_d) = 0.88 \pm 0.05$
  - Phys. Rev. D 70 (2004) 094031: $\tau(\Lambda_b) / \tau(B_d) = 0.86 \pm 0.05$

Λ_b mass and lifetime measurement: signal reconstruction





- Cascade decay topology: secondary ($\Lambda_b \rightarrow J/\psi\Lambda^0$) and tertiary ($\Lambda^0 \rightarrow p\,\pi^-$) vertices.
- Reconstruction efficiency oft he Λ^0 decreases with distance from the primary vertex, so a study of the selection biases is needed.
- 4075 Λ^0 and 4081 $\overline{\Lambda}^0$ candidates are selected in 4.9 fb^{-1} of 2011 data.

Λ_b mass and lifetime measurement: proper decay time

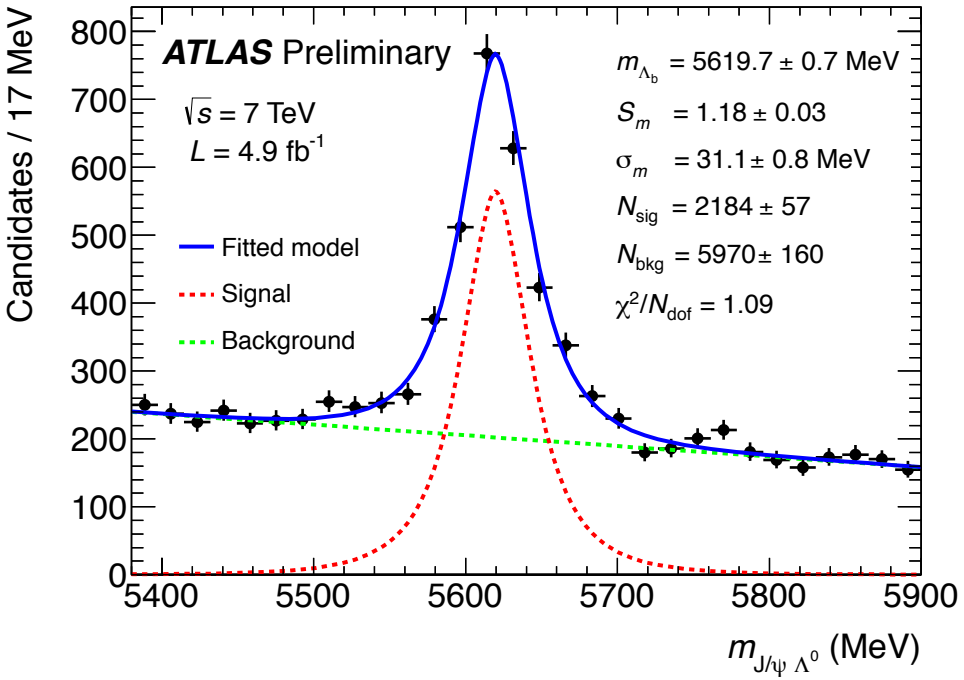
- The proper decay time is calculated for each candidate as:

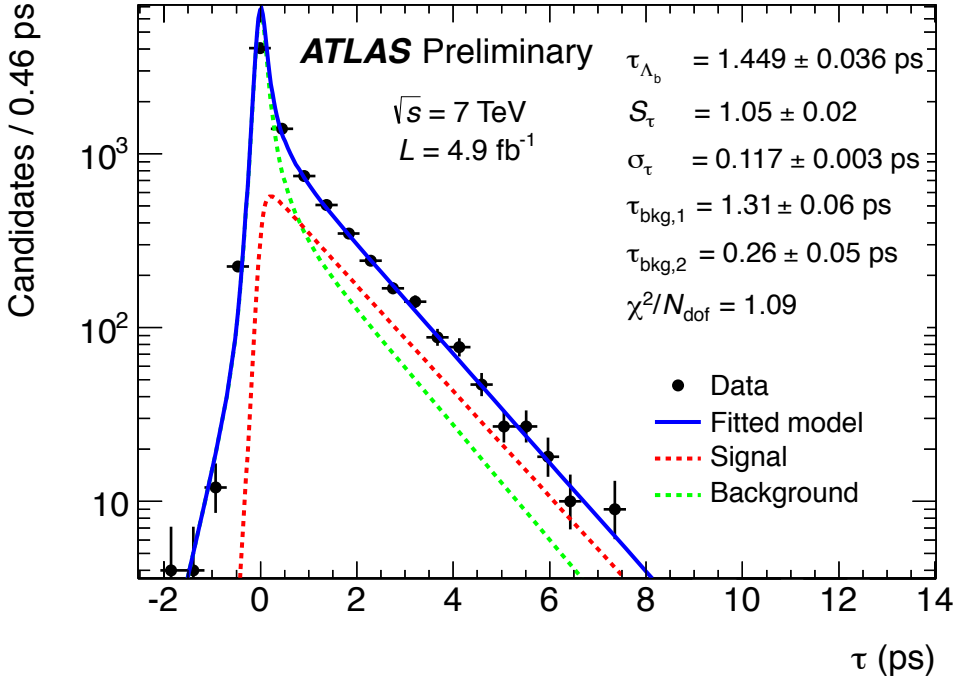
$$\tau = \frac{L_{xy}\, m^{PDG}}{p_T}$$

  - L_{xy} is the measured transverse decay length
  - m^{PDG} is the world average value of the Λ_b mass
  - p_T is the Λ_b transverse momentum

- Lifetime and mass are simultaneously extracted with an unbinned maximum likelihood fit

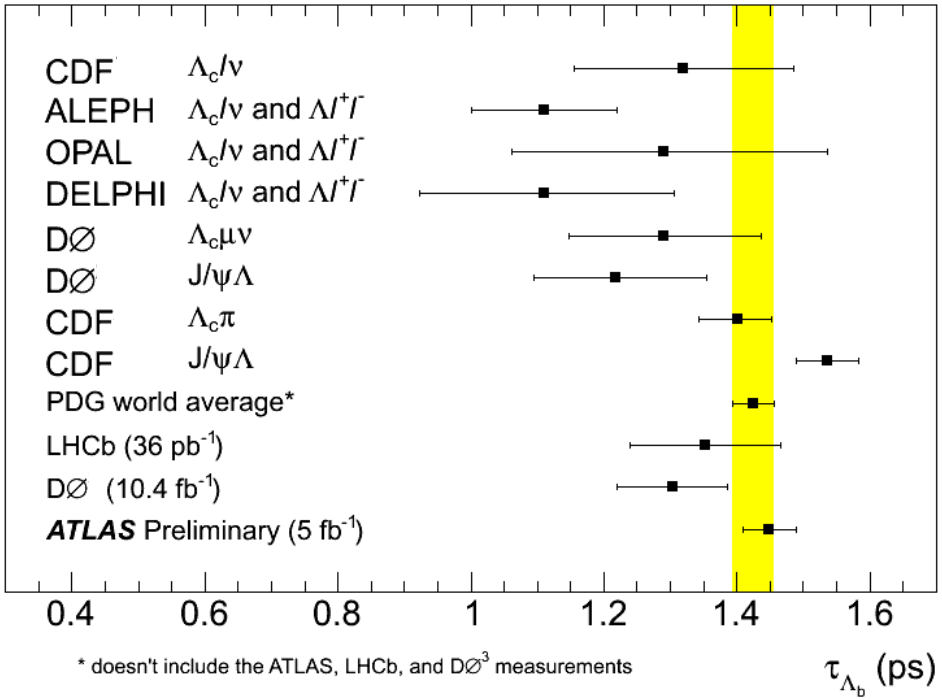
Λ_b mass and lifetime measurement: results

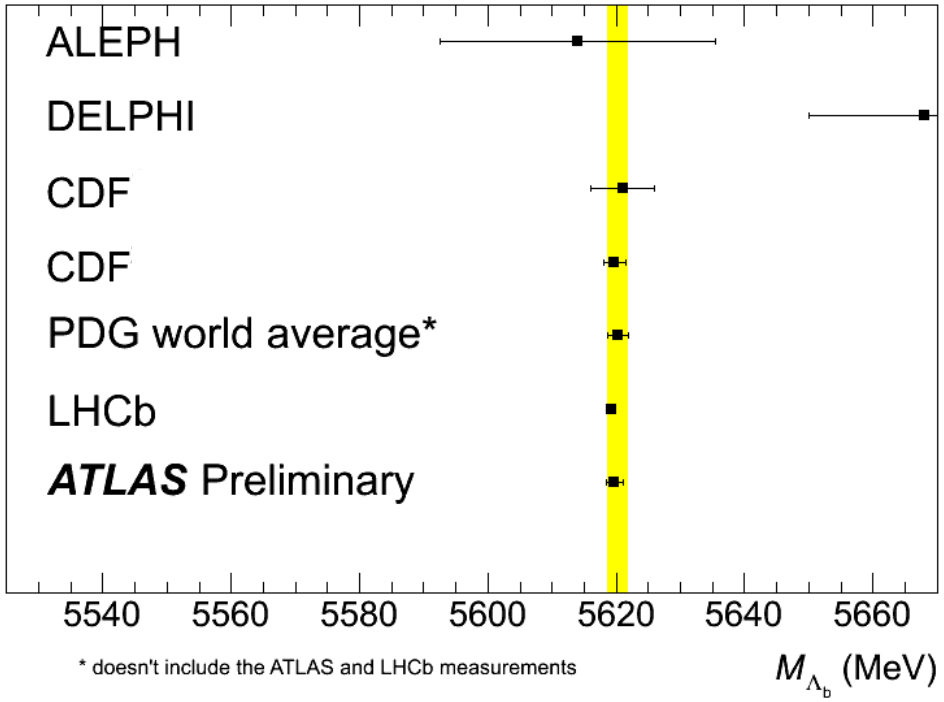




- ATLAS-CONF-2012-055; journal publication in preparation
- $m(\Lambda_b) = 5619.7 \pm 0.7_{stat} \pm 1.1_{syst}$ MeV
- $\tau(\Lambda_b) = 1.499 \pm 0.036_{stat} \pm 0.017_{syst}$ ps

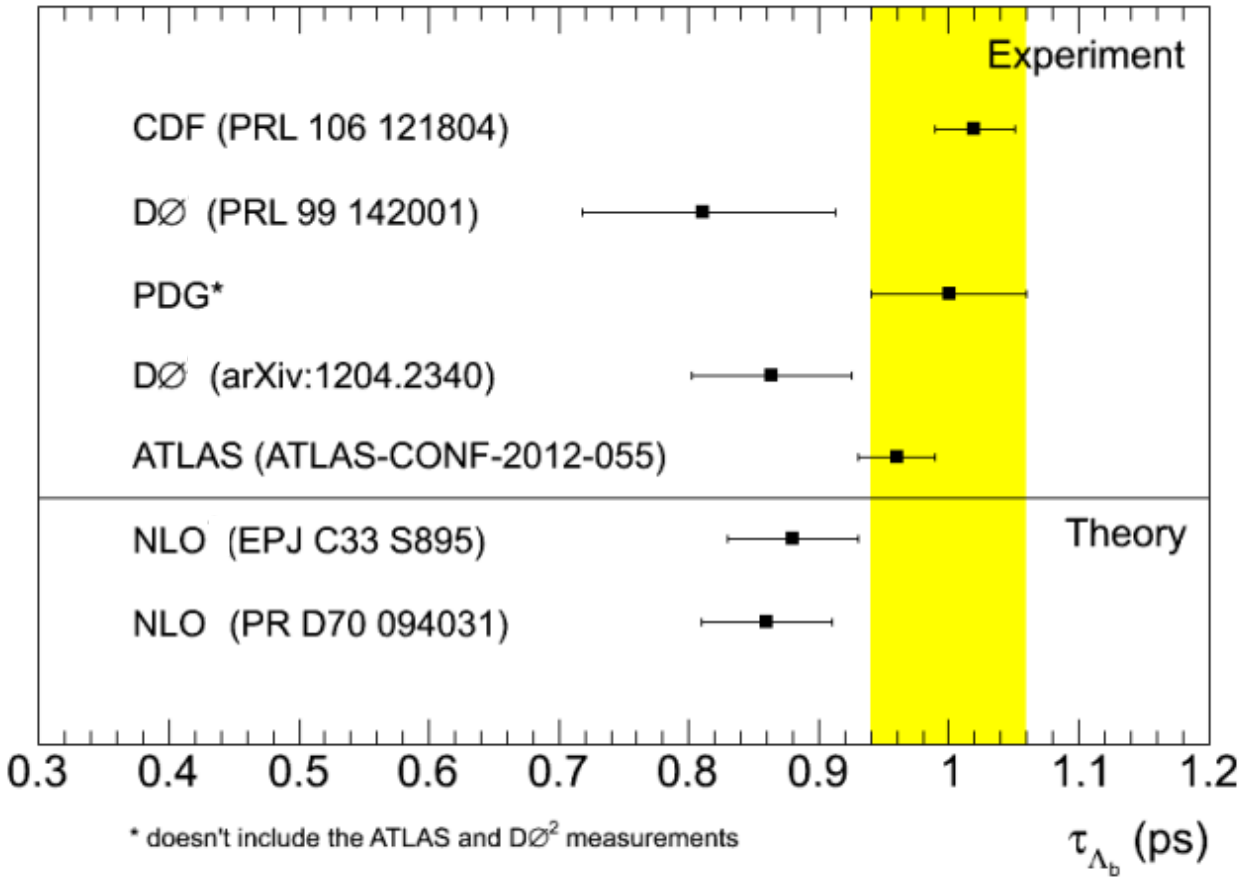
Λ_b mass and lifetime measurement: comparison to other measurements





- Lifetime is consistent with the PDG, CDF and LHCb values:
  - arXiv:1204.2340 [hep-ex] and Phys. Lett. B 708 (2012) 241—248
  - Phys. Rev. Lett. 104 (2010) 102002
  - LHCb-CONF-2011-001
- ATLAS Λ_b mass measurement is more precise than the world average.

Ratio of Λ_b and B_d lifetime



- Theoretical predictions at NLO: 0.86 ± 0.5 ps and 0.88 ± 0.5 ps
- ATLAS measurement: $R = \tau(\Lambda_b)/\tau(B_d^{PDG}) = 0.960 \pm 0.025 \pm 0.016$ ps
- Consistent with PDG, compatible with the latest CDF and DØ measurements and theoretical predictions.

Plans for Λ_b polarization studies

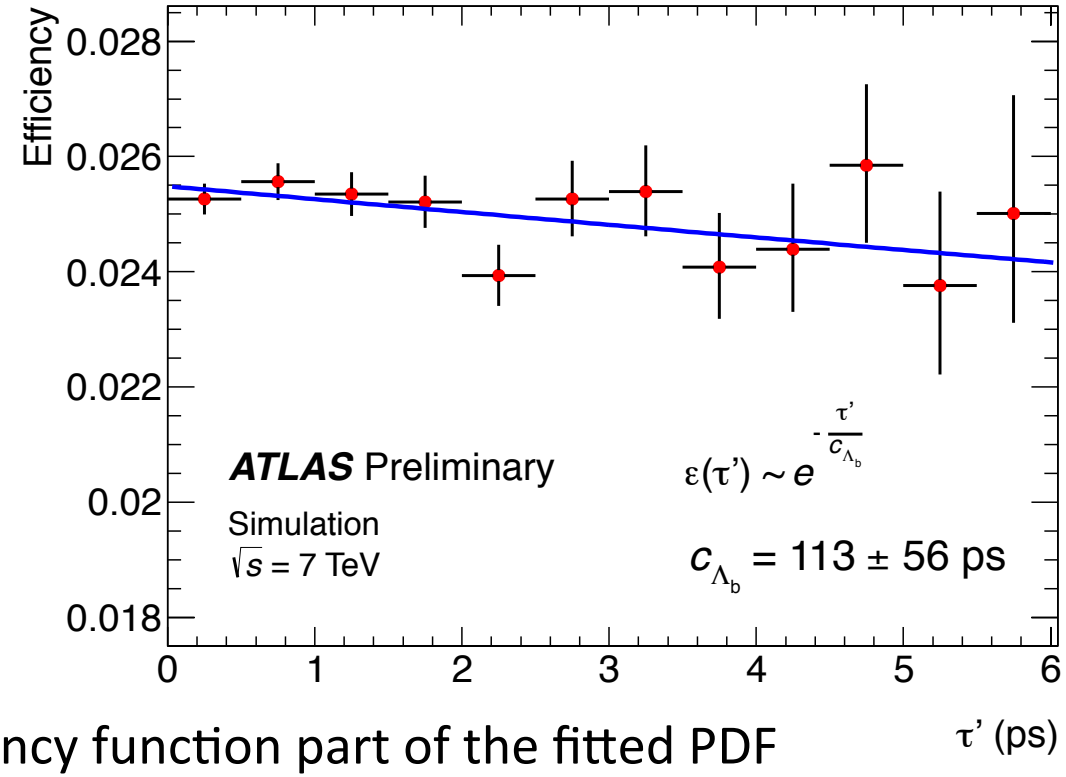
- Motivation: the Λ^0 polarization predicted by QCD is about one order of magnitude smaller than the observed value. The Λ^0 polarization p_T dependence (the plateau) is not yet satisfactorily explained. Is it the dynamics of qq production? What to expect for the Λ_b? The b-quark polarization is predicted to be an order of magnitude greater than the s-quark polarization.
- Planning details outlined in ATLAS CSC Book:arXiv:0901.0512
- MC study of polarized Λ_b with the full detector simulation demonstrated that the Λ_b polarization can be measured at level of a few percent with 30fb^{-1} of data. Looking toward 2014 run.
- Work is now ongoing to extract the parity violation parameter for Λ_b.
- Studies are also underway on Λ^0 polarization in jets to learn more about spin behavior in the hadronization process.

Conclusions

- LHC and ATLAS are performing very well.
- ATLAS has already delivered many important B-physics measurements, and more are on the way.
- Measured B-hadron masses and lifetimes are consistent with PDG. ATLAS has excellent p_T scale calibration, vertexing, and alignment.
- Λ_b lifetime is measured with good precision. The precision of the Λ_b mass measurement is now the second-best, and together with the LHCb we shall contribute to the world average.
- Measured Λ_b lifetime is consistent with PDG, CDF, and LHCb results.
- Preparations to measure the Λ^0 and Λ_b polarization are underway.

BACKUP

Efficiency corrections for Λ_b



- The efficiency function part of the fitted PDF
- Lifetime:
  - selection bias correction $c(\Lambda_b) = 113 \pm 56$, corresponding to 19 fs in total
  - $V(\Lambda^0)$ reconstruction bias estimated from the MC
  - trigger bias measured with tag-and-probe method
  - propagation of $c(\Lambda_b)$ uncertainty to the $\tau \sim 9$ fs
- Mass:
  - $\Delta M = M - M^{MC} = 0.9$ MeV