PROCEEDINGS OF SCIENCE

Measurements of masses and lifetimes of b-hadrons at ATLAS

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Using data collected by the Large Hadron Collider in 2010–2011, the ATLAS Collaboration has measured the lifetimes and masses of the Λ_b baryon, B_d and B_s mesons, and the average lifetime for inclusive B production at 7 TeV center of mass energy in proton-proton collisions. The results are in agreement with previous measurements and demonstrate excellent detector performance.

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1. Introduction

By the end of 2011, the ATLAS detector [1] at the Large Hadron Collider (LHC) [2] had collected about 5 inverse femtobarns of pp-collisions at 7 TeV center of mass energy. Studies of hadrons containing the b-quark are an important part of the ATLAS program.

2. Triggers for B-physics at ATLAS

The ATLAS trigger system comprises the hardware-based Level 1 (L1) trigger and the software-based High Level Trigger (HLT). Selection of exclusive b-hadron decays is based on single or di-muon signatures. During the low luminosity period in 2010 it was possible to keep single-muon triggers unprescaled. In 2011, mostly the di-muon signatures were used due to the limited bandwidth [3]. Muons with transverse momentum (p_{T}) higher than 4 GeV must be first identified by the L1 trigger and then confirmed by the HLT. A fit to a common vertex with mass constraints is performed upon those that pass. Figure 1 shows the di-muon mass spectrum recorded with various B-triggers in the first half of 2011 and the corresponding mass constraints.

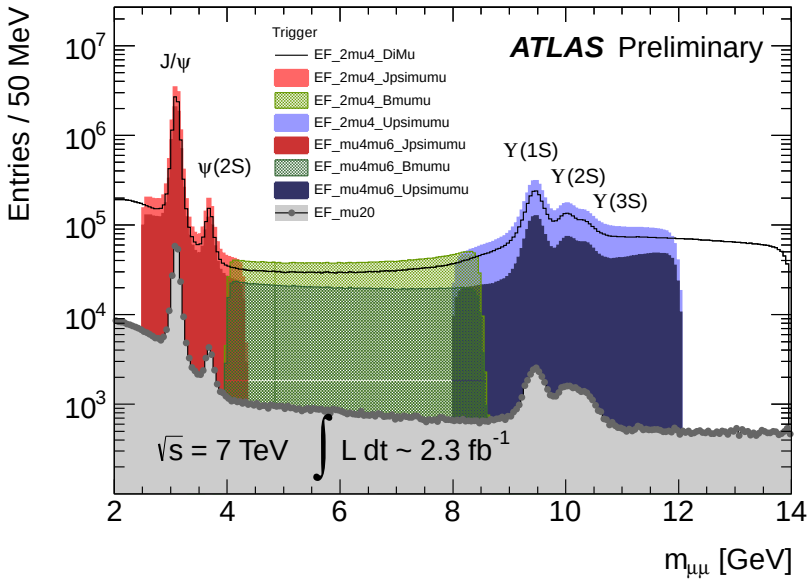

Figure 1: Distribution of the di-muon pairs' invariant mass [3]. The muons are selected by various ATLAS B-physics triggers. The single muon trigger is shown in gray for comparison. Different colors correspond to triggers with different mass constraints. Red: 2.5–4.3 GeV ("Jpsimumu"), green: 4–8.5 GeV ("Bmumu"), blue: 8–12 GeV ("Upsimumu").

3. Average B lifetime in $B \to J/\psi(\mu^+\mu^-)X$ transitions

As an important first step towards exclusive lifetime measurements, the average lifetime of b-hadrons was measured [4] using the full 2010 dataset, corresponding to an integrated luminosity of 35 pb^{-1} in transitions to final states containing the J/ψ. Since the b-hadron decay was not

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completely reconstructed, its transverse momentum is not known. The best approximation of this parameter is the transverse momentum of the J/ψ meson. A "pseudo-proper time" $t^\star$ is defined as $t^\star = [L_{xy} \times m_{PDG}^{J/\psi}]/p_{\rm T}(J/\psi)$. Here the L_{xy} is the signed projection of the flight distance of the J/ψ onto its transverse momentum $\vec{p}_{\rm T}$, and the $m_{PDG}^{J/\psi}$ is the world average [5] mass value of the J/ψ meson. A correction for the bias introduced by this substitution was obtained from a PYTHIA6 [6] Monte Carlo study. An unbinned maximum likelihood fit was performed simultaneously for the mass and pseudo-proper time, and the average lifetime $< \tau_b >$ was extracted at $< \tau_b >= 1.489 \pm 0.016({\rm stat}) \pm 0.043({\rm syst})$ ps. The systematic uncertainty is dominated by uncertainties in the background model and the detector misalignment effects. The measured value is in a good agreement with the recent CDF measurement [7] and with the world average [5].

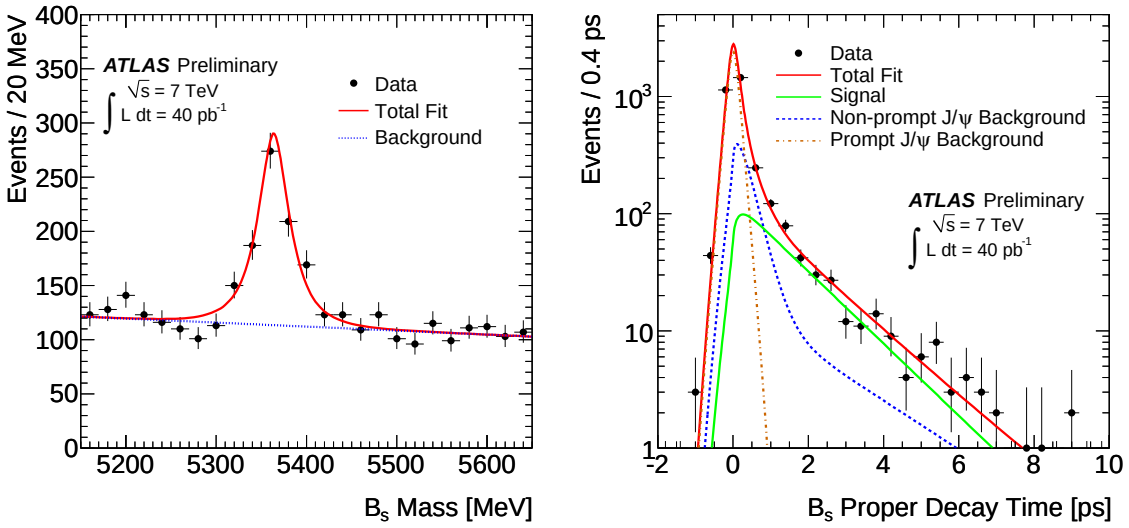

Figure 2: Distributions of invariant mass (left) and proper decay time (right) of reconstructed $B_s^0 \to J/\psi\phi$ decay candidates [8]. The points with error bars are data. The solid lines are the mass (left) and lifetime (right) projections of the simultaneous mass and lifetime fit. The dashed line in the left figure is the projection for the background of the same fit. The figure on the right side shows the proper decay time functions of the individual background components extracted from the fit: the background containing promptly produced J/ψ (dashed-dotted line), the background from non-prompt J/ψ production (dashed line), and the time function of the B_s^0 signal (lower solid line).

4. Masses and lifetimes of the $B_{d,s}$ mesons

The mass and lifetime of the B_s meson were measured in the $B_s \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ decay channel [8], which is important for the CP violation studies. Figure 2 shows the fitted mass and lifetime distributions for a data sample corresponding to an integrated luminosity of 40 pb^{-1}. The measured values of the B_s mass, $m(B_s) = 5363.7 \pm 1.2({\rm stat})$ MeV, and the lifetime, $\tau(B_s) = 1.41 \pm 0.08({\rm stat}) \pm 0.05({\rm syst})$ ps, are consistent with the world average values [5]. The lifetime of the B_s was also measured indirectly [9] with the same decay topology as a part of the ATLAS CP-violation studies. The mass and lifetime of the B_d meson were measured [10]

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in the decay channel $B_d \to J/\psi(\mu^+\mu^-)K^0_S(\pi^+\pi^-)$. Figure 3 shows the fitted mass and lifetime distributions for a data sample corresponding to an integrated luminosity of 4.9 fb^{-1}. The measured values of the B_d mass, $m(B_d) = 5279.6 \pm 0.2(\text{stat}) \pm 1.0(\text{syst})$ MeV, and the lifetime, $\tau(B_d) = 1.509 \pm 0.012(\text{stat}) \pm 0.018(\text{syst})$ ps, are consistent with the world average values [5]. This study is complementary to the Λ_b analysis described below.

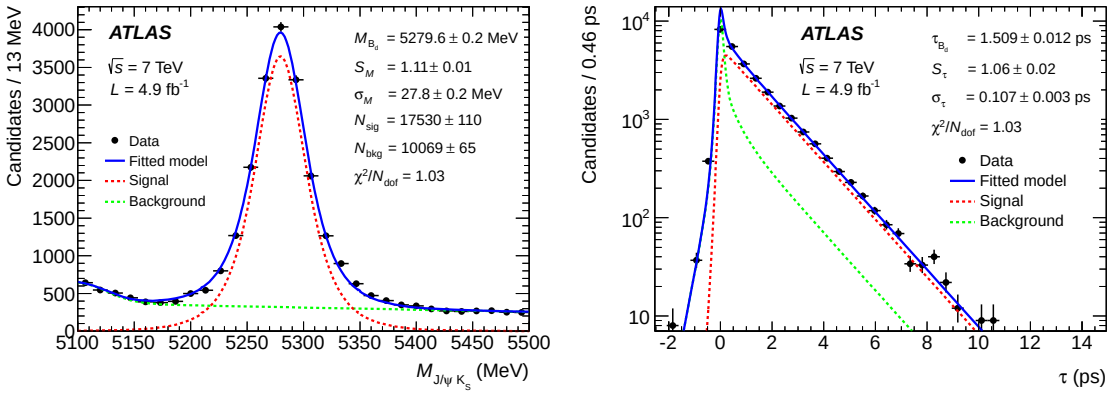

Figure 3: Projection of the fitted probability density function onto the mass axis (left) and the proper decay time (right) for B_d candidates [10]. The points with error bars are data. The displayed errors are statistical only. The χ^2/Ndof value is calculated from the dataset binned in mass and decay time with the number of degrees of freedom Ndof = 92 (left) and Ndof = 61 (right).

5. Observation of the B_c meson

The B_c meson is a bound state of the two heaviest distinct quarks able to form a stable state. Weak decays of the B_c provide a unique probe of quark dynamics that is inaccessible to $b\bar{b}$ or $c\bar{c}$ bound states. The B_c ground state was initially observed by CDF [11] and D0 [12], first through semileptonic and subsequently through hadronic decays. Recently the $B_c^\pm$ meson has been observed by the LHCb [13] and CMS [14] collaborations as well. The mass spectrum of the B_c family is predicted by non-relativistic potential models, perturbative QCD, and lattice calculations (see [15] for references). The B_c meson was observed with 4.3 fb^{-1} of 2011 data in the decay mode $B_c^\pm \to J/\psi(\mu^+\mu^-)\pi^\pm$ [15]. Figure 4 shows the fit of the invariant mass distribution of the $B_c^\pm$ candidates.

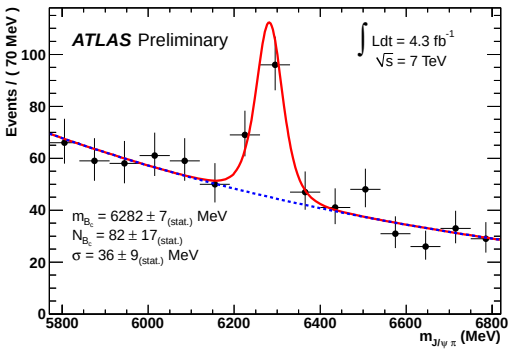

Figure 4: Invariant mass distribution of reconstructed $B_c^\pm \to J/\psi\pi^\pm$ candidates [15]. The points with error bars are the data. The solid line is the projection of the results of the unbinned maximum likelihood fit to all candidates in the mass range 5770–6820 MeV. The dashed line is the projection for the background component of the same fit.

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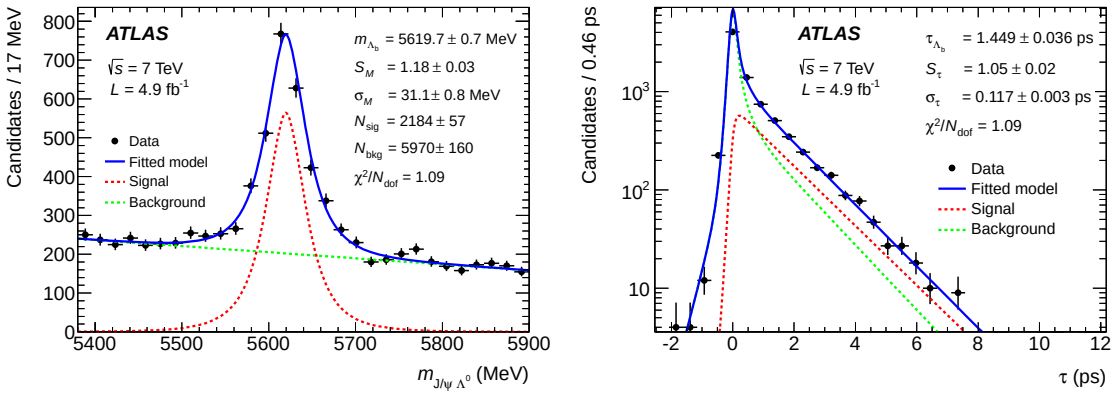

Figure 5: The projection of the fitted probability density function onto the mass axis (left) and the proper decay time (right) for Λ_b^0 candidates [10]. The points with error bars are data. The displayed errors are statistical only. The χ^2/Ndof value is calculated from the dataset binned in mass and decay time with the number of degrees of freedom Ndof = 61.

6. Λ_b mass and lifetime

The Λ_b is the lightest baryon containing a *b*-quark. It has been of great theoretical interest since its discovery. The Λ_b was studied [10] in the decay $\Lambda_b \to J/\psi(\mu^+\mu^-)\Lambda^0(p\pi^-)$ and c.c. The decay $B_d \to J/\psi(\mu^+\mu^-)K_S^0(\pi^+\pi^-)$ has the same topology and similar systematic uncertainties. It was used as a reference channel for this measurement. The lifetime ratio of the Λ_b relative to that of the B_d, $\tau_{\Lambda_b}/\tau_{B_d}$, is of interest, as it is predicted by Heavy Quark Effective Theory and perturbative QCD [16, 17]. Figure 5 shows fitted invariant mass and proper lifetime distributions of the Λ_b candidates. The Λ_b lifetime and mass were measured to be $\tau_{\Lambda_b} = 1.449 \pm 0.036(\text{stat}) \pm 0.017(\text{syst})$ ps and $m_{\Lambda_b} = 5619.7 \pm 0.7(\text{stat}) \pm 1.1(\text{syst})$ MeV. These values agree with the world average [5]. The ratio of the Λ_b and B_d lifetimes was measured to be $R = \tau_{\Lambda_b}/\tau_{B_d} = 0.960 \pm 0.025(\text{stat}) \pm 0.016(\text{syst})$. This is compatible with next-to-leading order theoretical predictions [16, 17].

7. Conclusions

The measurements of lifetimes and masses of the Λ_b baryon, B_d and B_s mesons performed by the ATLAS Collaboration have been presented here as well as the observation of the B_c meson. The results are in agreement with previous measurements and demonstrate excellent detector performance.

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