ATLAS Λ_b^0 Baryon Studies

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on behalf of ATLAS Collaboration

Hadron2015, Jefferson Lab
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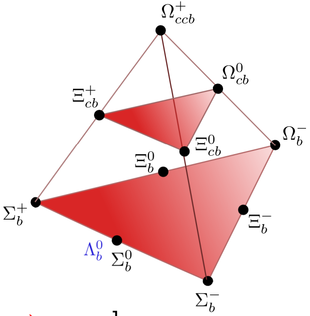
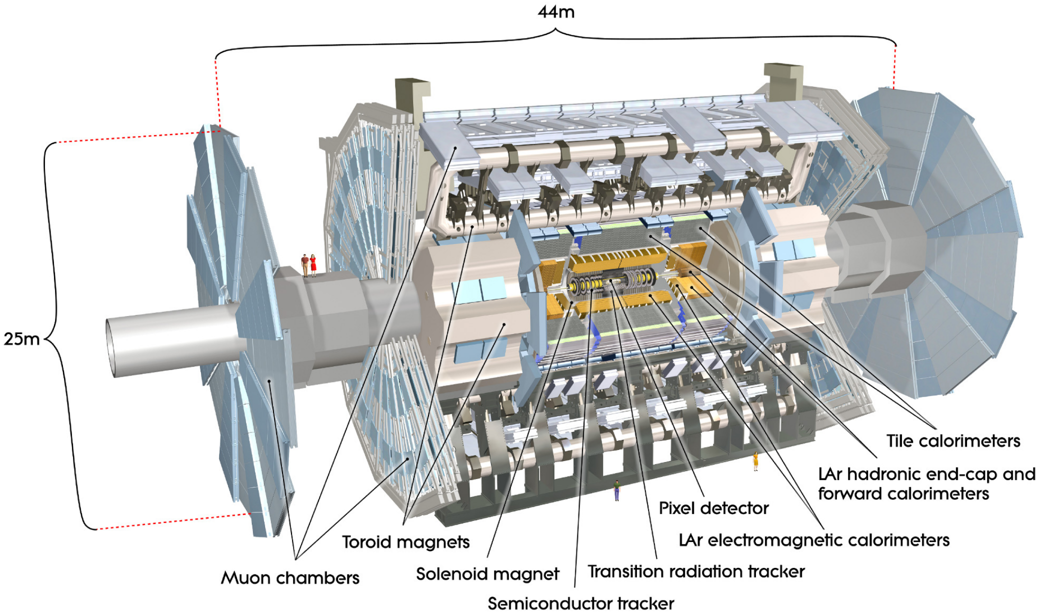
Λ_b^0 baryon



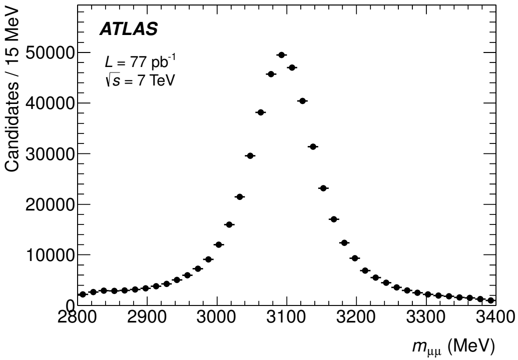
- Λ_b^0 is the lightest b-baryon
  - $m \sim 5620$ MeV
  - Beyond the reach of B-factories
  - Was less studied
    - Lifetime
    - Polarization
    - Decay properties
- Included in this talk:
  - Mass and lifetime measurement [Phys. Rev. D 87 (2013) 032002]
  - $\Lambda_b^0 \to J/\psi\Lambda^0$ decay asymmetry parameter and helicity amplitude measurement [Phys. Rev. D 89 (2014) 092009]
  - Observation of $\Lambda_b^0 \to \psi(2S)\Lambda^0$ decay and $\Gamma(\Lambda_b^0 \to \psi(2S)\Lambda^0)/\Gamma(\Lambda_b^0 \to J/\psi\Lambda^0)$ measurement [arXiv:1507.08202 [hep-ex], submitted to Phys. Lett. B.]

ATLAS detector

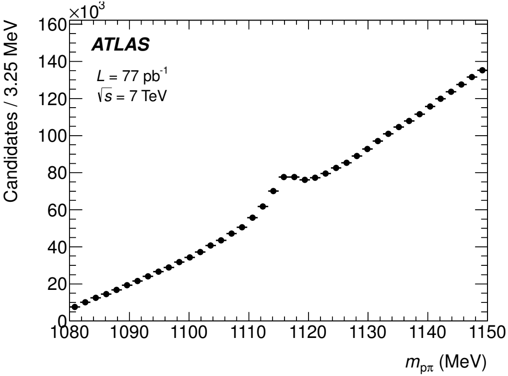


J/ψ and Λ^0 candidates

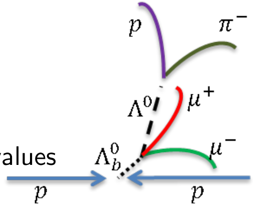
- J/ψ candidates
  - Two combined muons, $|\eta| < 2.5$
  - Sufficient Inner Detector hits
  - In J/ψ or $\psi(2S)$ mass window



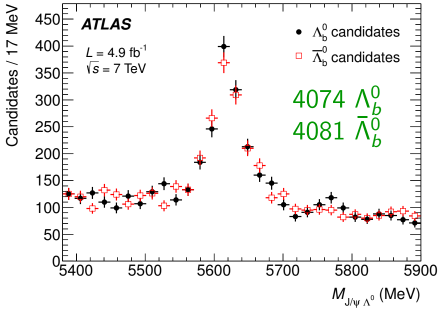
- Λ^0 candidates
  - Two good ID tracks, $p_T > 400$ MeV
  - $p\pi^-$ and $\bar{p}\pi^+$ combination, in Λ^0 mass window



Λ_b^0 reconstruction



- Λ_b^0 fit
  - $m_{\mu^+\mu^-}$ and $m_{p\pi^-}$ ($m_{\bar{p}\pi^+}$) fixed to J/ψ and Λ^0 mass values
  - Dihadron vertex point to dimuon vertex
  - $\chi^2/N_{dof} < 3$
- Also fitted to $B_d^0 \to J/\psi(\mu^+\mu^-)K_S^0(\pi^+\pi^-)$ hypothesis for B_d^0 background rejection cuts
- In lifetime measurement
  - Refitted Λ^0
    - $p_T > 3.5$ GeV
    - $L_{xy} > 10$ mm
  - $\mathcal{P}_{\Lambda_b^0} - \mathcal{P}_{B_d^0} > 0.05$



Λ_b^0 lifetime measurement

- Proper decay time

$$\tau = \frac{L_{xy}\, m^{\mathrm{PDG}}}{p_{\mathrm{T}}}$$

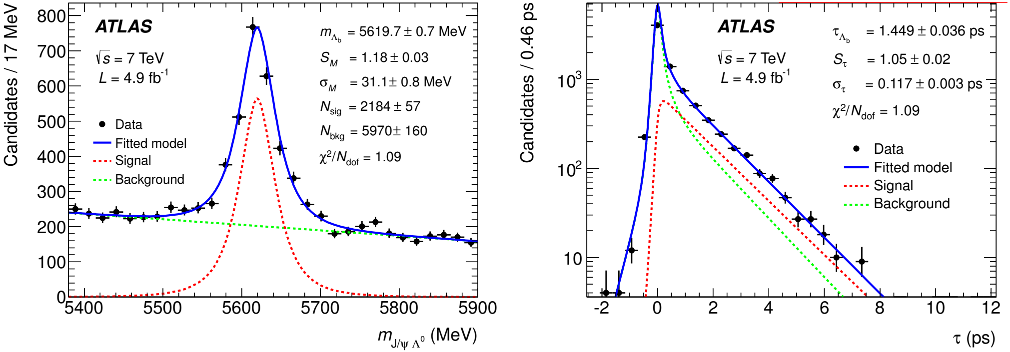
- Mass-lifetime unbinned likelihood fit

$$L = \prod_{i=1}^{N}[f_{\mathrm{sig}}\mathcal{M}_{\mathrm{s}}(m_i|\delta_{mi})\mathcal{T}_{\mathrm{s}}(\tau_i|\delta_{\tau i})w_{\mathrm{s}}(\delta_{mi},\delta_{\tau i}) + (1-f_{\mathrm{sig}})\mathcal{M}_{\mathrm{b}}(m_i|\delta_{mi})\mathcal{T}_{\mathrm{b}}(\tau_i|\delta_{\tau i})w_{\mathrm{b}}(\delta_{mi},\delta_{\tau i})]$$

  - Mass
    - $\mathcal{M}_{\mathrm{s}}(m_i|\delta_{mi})$: Gaussian
    - $\mathcal{M}_{\mathrm{b}}(m_i|\delta_{mi})$: 1st order polynomial
  - Proper decay time
    - $\mathcal{T}_{\mathrm{s}}(\tau_i|\delta_{\tau i})$: exponential with efficiency correction
    - $\mathcal{T}_{\mathrm{b}}(\tau_i|\delta_{\tau i})$:
      - prompt: Dirac delta + symmetric exponential
      - non-prompt: two exponential
  - $w_{\mathrm{s,b}}(\delta_{mi},\delta_{\tau i})$ is the PDF for δ_{mi} and $\delta_{\tau i}$, from data and same for signal and background

Λ_b^0 mass and lifetime

Phys. Rev. D 87 (2013) 032002

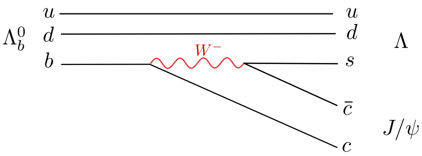


$$m_{\Lambda_b^0} = 5619.7 \pm 0.7(\text{stat}) \pm 1.1(\text{syst})\ \text{MeV}$$

$$\tau_{\Lambda_b^0} = 1.449 \pm 0.036(\text{stat}) \pm 0.017(\text{syst})\ \text{ps}$$

- Consistent with results from other experiments and theoretical predictions
- Main systematic uncertainty from muon trigger efficiency and Λ^0 reconstruction bias

$\Lambda_b^0 \to J/\psi(\mu^+\mu^-)\Lambda^0(p\pi^-)$ decay



- Asymmetric decay

$$\frac{dN}{d\cos\theta} = \frac{1}{2}(1 + P \cdot \alpha_b \cos\theta)$$

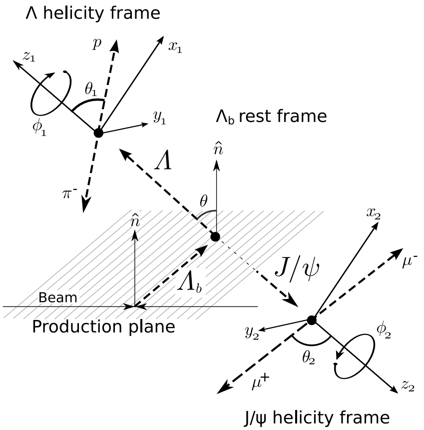
- In subsequent decay:
  - 4 helicity combination

Amplitude	λ_Λ	$\lambda_{J/\psi}$
$a_+ = \lvert a_+ \rvert e^{i\omega_+}$	1/2	0
$a_- = \lvert a_- \rvert e^{i\omega_-}$	-1/2	0
$b_+ = \lvert b_+ \rvert e^{i\rho_+}$	-1/2	-1
$b_- = \lvert b_- \rvert e^{i\rho_-}$	1/2	1

  - Full PDF of $\Omega = (\cos\theta, \phi, \cos\theta_1, \phi_1, \cos\theta_2, \phi_2)$:

$$w(\Omega) = \frac{1}{(4\pi)^3} \sum_{i=0}^{19} f_{1i}(\vec{A}) f_{2i}(P, \alpha_\Lambda) F_i(\Omega)$$

  - 7 free parameters: P, 6 helicity parameters in $\vec{A}$



Parametrization

- For α_b measurement, using $P = 0$, reduced to 6 terms ($i = 0, 2, 4, 6, 18$, and 19)
- Parameters $\vec{A}$
  - $\alpha_b = |a_+|^2 - |a_-|^2 + |b_+|^2 - |b_-|^2$
  - $k_+ = \frac{|a_+|}{\sqrt{|a_+|^2+|b_+|^2}}$
  - $k_- = \frac{|b_-|}{\sqrt{|a_-|^2+|b_-|^2}}$
  - $\Delta_+ = \omega_+ - \rho_+$
  - $\Delta_- = \omega_- - \rho_-$

i	f_{1i}	F_i
0	1	1
2	$(k_+^2 + k_-^2 - 1) + \alpha_b(k_+^2 - k_-^2)$	$\cos\theta_1$
4	$\frac{1}{4}[(3k_-^2 - 3k_+^2 - 1) + 3\alpha_b(1 - k_-^2 - k_+^2)]$	$0.5(3\cos^2\theta_2 - 1)$
6	$-\frac{1}{4}[(k_+^2 + k_-^2 - 1) + \alpha_b(3 + k_+^2 - k_-^2)]$	$0.5(3\cos^2\theta_2 - 1)\cos\theta_1$
18	$\frac{3}{\sqrt{2}}[\frac{1-\alpha_b}{2}\sqrt{k_-^2(1-k_-^2)}\cos(-\Delta_-) - \frac{1+\alpha_b}{2}\sqrt{k_+^2(1-k_+^2)}\cos(\Delta_+)]$	$\sin\theta_1\sin\theta_2\cos\theta_2\cos(\phi_1+\phi_2)$
19	$-\frac{3}{\sqrt{2}}[\frac{1-\alpha_b}{2}\sqrt{k_-^2(1-k_-^2)}\sin(-\Delta_-) - \frac{1+\alpha_b}{2}\sqrt{k_+^2(1-k_+^2)}\sin(\Delta_+)]$	$\sin\theta_1\sin\theta_2\cos\theta_2\sin(\phi_1+\phi_2)$

Method of moments

- Least square fit

$$\chi^2 = \sum_i \sum_j (\langle F_i \rangle^{\text{expected}} - \langle F_i \rangle) V_{ij}^{-1} (\langle F_j \rangle^{\text{expected}} - \langle F_j \rangle)$$

  - $\langle F_j \rangle$ measured from data
  - V_{ij} is the covariance matrix
  - $\langle F_i \rangle^{\text{expected}}$ depends on the parameters $\vec{A}$

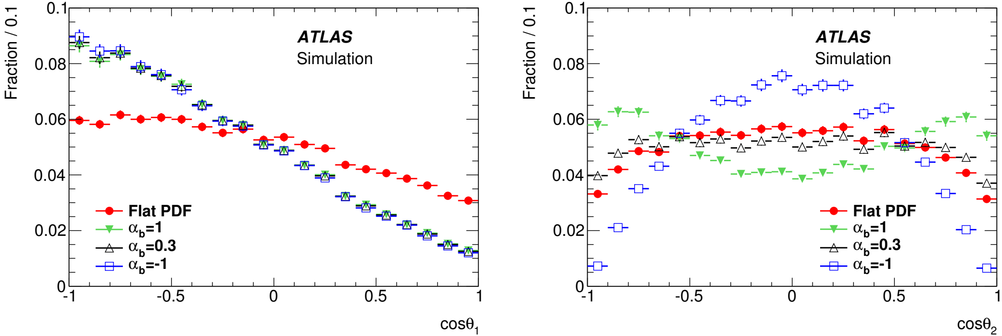
$$\begin{aligned}
\langle F_i \rangle^{\text{expected}}(\vec{A}) &= \int F_i(\Omega') \int T(\Omega', \Omega) w(\vec{A}, \Omega)\, d\Omega d\Omega' \\
&= \sum_j \frac{1}{(4\pi)^3} \iint f_{1j}(\vec{A}) f_{2j}(\alpha_\Lambda) F_i(\Omega') T(\Omega', \Omega) F_j(\Omega)\, d\Omega' d\Omega \\
&= \sum_j f_{1j}(\vec{A}) f_{2j}(\alpha_\Lambda) \mathbf{C}_{ij}
\end{aligned}$$

- The effects of detector are in $\mathbf{C}_{ij}$
- $T(\Omega', \Omega)$ is the resolution and efficiency function

Efficiency correction from MC

$$\mathbf{C}_{ij} = \frac{1}{(4\pi)^3} \iint F_i(\Omega') F_j(\Omega)\, T(\Omega', \Omega)\, \mathrm{d}\Omega' \mathrm{d}\Omega$$

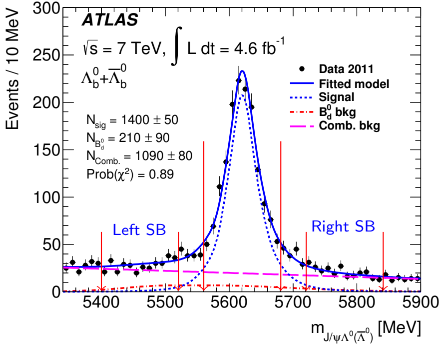
$$\approx \frac{\epsilon_{\mathrm{T}}}{N^{\mathrm{mc}}} \sum_{n=1}^{N^{\mathrm{mc}}} F_i(\Omega'_n) F_j(\Omega_n)$$

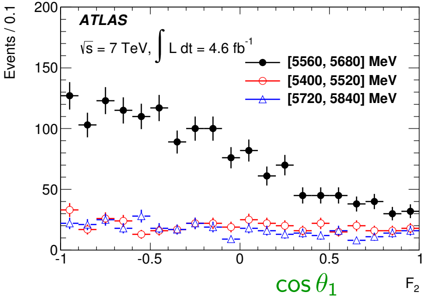


Event selection & Background

- 2011 7 TeV data
- Λ_b^0 selection
  - Exclude tracks from primary vertex
  - $\tau > 0.35$ ps
  - Loose B_d^0 veto: $\mathcal{P}_{\Lambda_b^0} > \mathcal{P}_{B_d^0}$
  - $5560 < m < 5680$ MeV
- Combinatorial background
  - Estimated from sidebands (SB)
- Peaking background
  - $B_d^0 \to J/\psi(\mu^+\mu^-)K_S^0(\pi^+\pi^-)$
  - Yield from the mass fit
  - $\langle F_i \rangle$ from Mont Carlo

Parameter	[5340, 5900] MeV	[5560, 5680] MeV
N_{sig}	1400 ± 50	1240 ± 40
N_{Comb}	1090 ± 80	234 ± 16
$N_{B_d^0}$	210 ± 90	73 ± 30





$\cos\theta_1$

Results

Phys. Rev. D 89 (2014) 092009

Fit results

$$\alpha_b = 0.30 \pm 0.16(\text{stat}) \pm 0.06(\text{syst})$$

$$k_+ = 0.21^{+0.14}_{-0.21}(\text{stat}) \pm 0.13(\text{syst})$$

$$k_- = 0.13^{+0.20}_{-0.13}(\text{stat}) \pm 0.15(\text{syst})$$

corresponding to

$$|A(1/2, 0)| = 0.17^{+0.12}_{-0.17} \pm 0.09$$

$$|A(-1/2, -1)| = 0.59^{+0.06}_{-0.07} \pm 0.03$$

$$|A(-1/2, 0)| = 0.79^{+0.04}_{-0.05} \pm 0.02$$

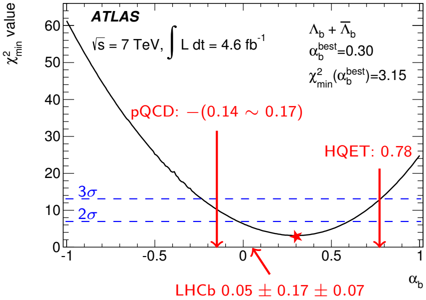
$$|A(1/2, 1)| = 0.08^{+0.13}_{-0.08} \pm 0.06$$

Main **systematic uncertainties**

- MC statistics
- Background shape modeling

Correlation

Parameter	α_b	k_+	k_-
α_b	1	0.41	−0.19
k_+		1	0.20
k_-			1



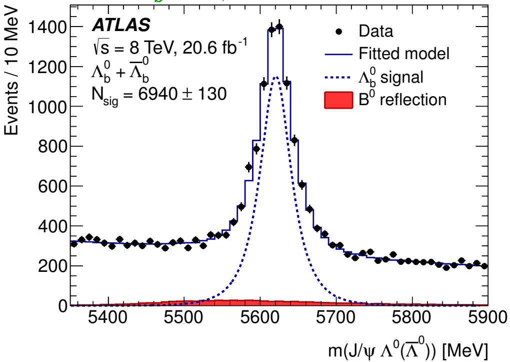
- Between two theory predictions
- Consistent with LHCb results

Ref: LHCb [Phys. Lett. B 724 (2013) 27]; pQCD [Phys. Rev. D 65 (2002) 074030]; HEQT [Phys. Lett. B 614 (2005) 165173];

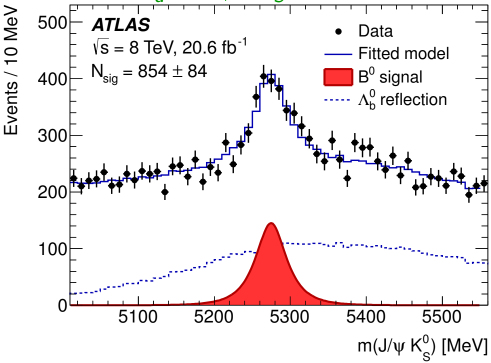
$\Lambda_b^0 \to \psi(2S)\Lambda^0$ selection

- Fiducial range
  - $p_T(\Lambda_b^0) > 10$ GeV, $|\eta(\Lambda_b^0)| < 2.1$ (Kinematic range)
  - $p_T(\mu^\pm) > 4$ GeV, $|\eta(\mu^\pm)| < 2.3$
  - $p_T(\Lambda^0) > 2.5$ GeV
- Other selectionc cuts
  - $p_T(\pi^-) > 0.45$ GeV
  - $\tau > 0.35$ ps, $\mathcal{P}(\Lambda_b^0) > \mathcal{P}(B_d^0)$

$\Lambda_b^0 \to J/\psi\Lambda^0$

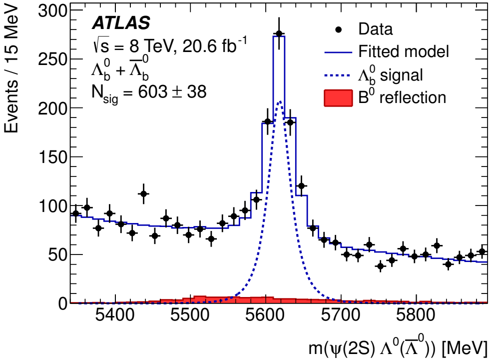


$B_d^0 \to J/\psi K_S^0$

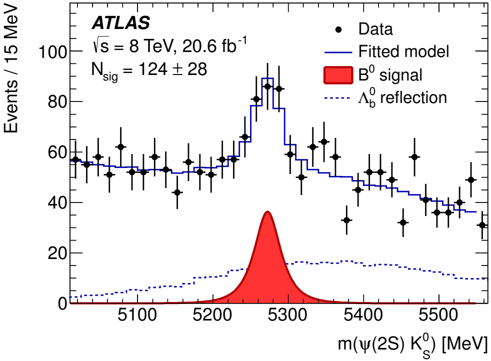


$\Lambda_b^0 \to \psi(2S)\Lambda^0$ selection

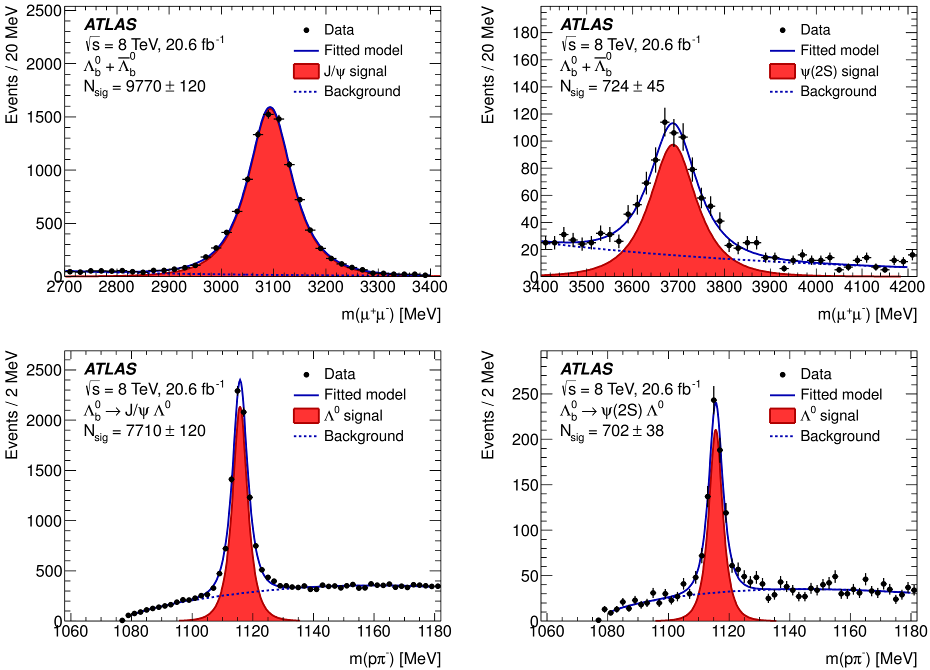
$\Lambda_b^0 \to \psi(2S)\Lambda^0$



$B_d^0 \to \psi(2S)K_S^0$



- Simultaneous Λ_b^0 and B_d^0 mass fit
  - Signal: modified Gaussian $p(x) = \exp[-0.5 \cdot x^{1+1/(1+0.5 \cdot x)}]$, $x = |(m - m_0)/\sigma|$
  - B_d^0 and Λ_b^0 reflection using MC templates
  - Non-resonant background: exponential functions


ATLAS
√s = 8 TeV, 20.6 fb-1
Λb0 + Λb0
Nsig = 9770 ± 120
Data
Fitted model
J/ψ signal
Background
Events / 20 MeV
m(μ+μ-) [MeV]
ATLAS
√s = 8 TeV, 20.6 fb-1
Λb0 + Λb0
Nsig = 724 ± 45
Data
Fitted model
ψ(2S) signal
Background
Events / 20 MeV
m(μ+μ-) [MeV]
ATLAS
√s = 8 TeV, 20.6 fb-1
Λb0 → J/ψ Λ0
Nsig = 7710 ± 120
Data
Fitted model
Λ0 signal
Background
Events / 2 MeV
m(pπ-) [MeV]
ATLAS
√s = 8 TeV, 20.6 fb-1
Λb0 → ψ(2S) Λ0
Nsig = 702 ± 38
Data
Fitted model
Λ0 signal
Background
Events / 2 MeV
m(pπ-) [MeV]

Branching ratio

- Yields from fits

	$\Lambda_b^0 \to J/\psi\Lambda^0$	$B^0 \to J/\psi K_S^0$	$\Lambda_b^0 \to \psi(2S)\Lambda^0$	$B^0 \to \psi(2S)K_S^0$
$N_{\rm sig}$	6940 ± 130	854 ± 84	603 ± 38	124 ± 28
$m_{\rm sig}$ [MeV]	5620.4 ± 0.4	5274.7 ± 2.3	5618.2 ± 1.2	5272.4 ± 4.9
$\sigma_{\rm sig}$ [MeV]	19.7 ± 0.5	19.2 ± 2.2	14.3 ± 1.1	16.7 ± 4.1

- Acceptance correction $N_{\rm cor} = N_{\rm sig}/\mathcal{A}$
- Efficiency ($\mathcal{A}_{\rm eff}$) and acceptance ($\mathcal{A}_{\rm kin}$) in fiducial range

$p_T(\Lambda_b^0) > 10$ GeV, $|\eta(\Lambda_b^0)| < 2.1$

$p_T(\mu^\pm) > 4$ GeV, $|\eta(\mu^\pm)| < 2.3$

$p_T(\Lambda^0) > 2.5$ GeV

Channel	$\mathcal{A}_{\rm eff}$ [%]	$\mathcal{A}_{\rm kin}$ [%]
$\Lambda_b^0 \to J/\psi\Lambda^0$	4.16 ± 0.02	7.57 ± 0.06
$\Lambda_b^0 \to \psi(2S)\Lambda^0$	4.30 ± 0.03	9.61 ± 0.07

arXiv:1507.08202 [hep-ex]

Branching ratio

In kinematic range $p_{\mathrm{T}}(\Lambda_b^0) > 10$ GeV, $|\eta(\Lambda_b^0)| < 2.1$:

$$\frac{\Gamma(\Lambda_b^0 \to \psi(2S)\Lambda^0)}{\Gamma(\Lambda_b^0 \to J/\psi\Lambda^0)} = \frac{N_{\mathrm{cor}}(\Lambda_b^0 \to \psi(\mu^+\mu^-)\Lambda^0)}{N_{\mathrm{cor}}(\Lambda_b^0 \to J/\psi(\mu^+\mu^-)\Lambda^0)} \cdot \frac{\mathcal{B}(J/\psi \to \ell^+\ell^-)}{\mathcal{B}(\psi(2S) \to \ell^+\ell^-)}$$
$$= 0.501 \pm 0.033(\mathrm{stat}) \pm 0.016(\mathrm{syst}) \pm 0.011(\mathcal{B})$$

- $\mathcal{B}(J/\psi \to \mu^+\mu^-) = 0.05961 \pm 0.00033$ [PDG]
- $\mathcal{B}(\psi(2S) \to \mu^+\mu^-) = \mathcal{B}(\psi(2S) \to e^+e^-) = 0.00789 \pm 0.00017$ [PDG]
- Systematic uncertainties
  - Signal extraction fits (2.8%)
  - MC statistics (1.3%)
  - Λ_b^0 polarization model (1.1%)
- In the range 0.5–0.8 for B meson decays; smaller than calculation 0.8 ± 0.1 [Phys. Rev. D 88 (2013) 114018]

Summary

- Studying Λ_b^0 production and decay using ATLAS data
- Lifetime measurement

$$m_{\Lambda_b^0} = 5619.7 \pm 0.7(\text{stat}) \pm 1.1(\text{syst})\ \text{MeV}$$
$$\tau_{\Lambda_b^0} = 1.449 \pm 0.036(\text{stat}) \pm 0.017(\text{syst})\ \text{ps}$$

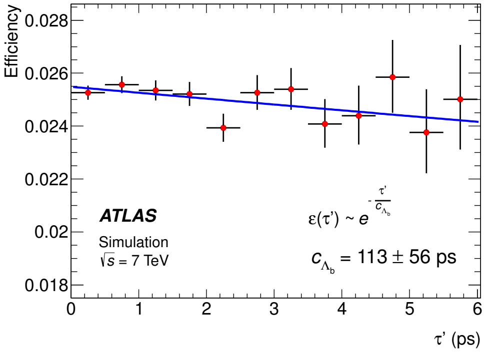
- α_b measurement

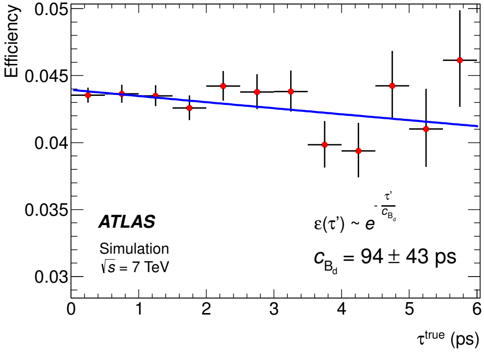
$$\alpha_b = 0.30 \pm 0.16(\text{stat}) \pm 0.06(\text{syst})$$
$$|a_+| = 0.17^{+0.12}_{-0.17}(\text{stat}) \pm 0.09(\text{syst})$$
$$|a_-| = 0.59^{+0.06}_{-0.07}(\text{stat}) \pm 0.03(\text{syst})$$
$$|b_+| = 0.79^{+0.04}_{-0.05}(\text{stat}) \pm 0.02(\text{syst})$$
$$|b_-| = 0.08^{+0.13}_{-0.08}(\text{stat}) \pm 0.06(\text{syst})$$

- Observation of $\Lambda_b^0 \to \psi(2S)\Lambda^0$ and the measured branching ratio

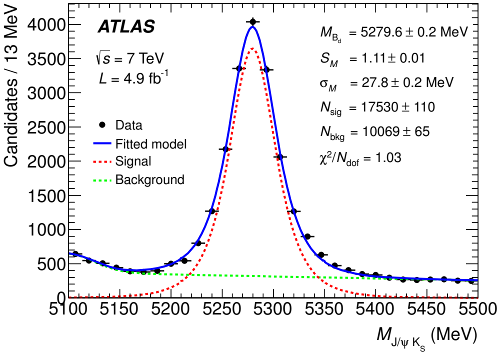
$$\frac{\Gamma(\Lambda_b^0 \to \psi(2S)\Lambda^0)}{\Gamma(\Lambda_b^0 \to J/\psi\Lambda^0)} = 0.501 \pm 0.033(\text{stat}) \pm 0.016(\text{syst}) \pm 0.011(\mathcal{B})$$

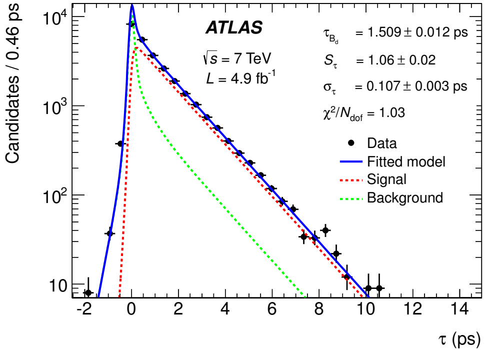
Backup: Efficiency correction of lifetime measurement





Backup: B_d^0 lifetime measurement

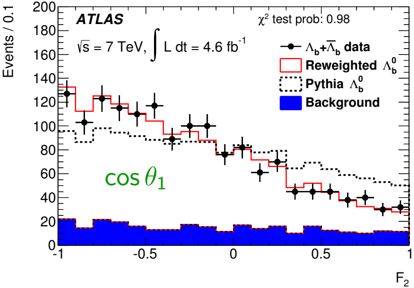


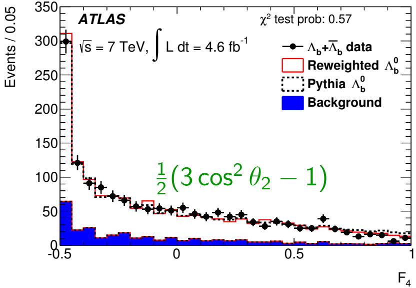


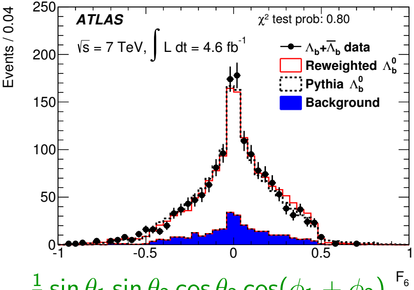
Backup: full PDF

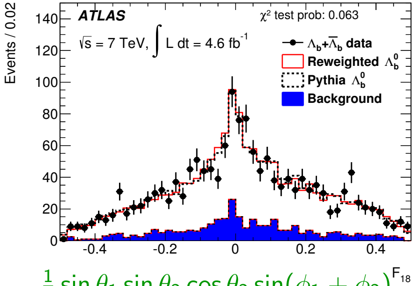
i	f_{1i}	f_{2i}	F_i
0	$a_+a_+^* + a_-a_-^* + b_+b_+^* + b_-b_-^*$	1	1
1	$a_+a_+^* - a_-a_-^* + b_+b_+^* - b_-b_-^*$	P	$\cos\theta$
2	$a_+a_+^* - a_-a_-^* - b_+b_+^* + b_-b_-^*$	α_Λ	$\cos\theta_1$
3	$a_+a_+^* + a_-a_-^* - b_+b_+^* - b_-b_-^*$	$P\,\alpha_\Lambda$	$\cos\theta\ \cos\theta_1$
4	$-a_+a_+^* - a_-a_-^* + \frac{1}{2}b_+b_+^* + \frac{1}{2}b_-b_-^*$	1	$\frac{1}{2}\left(3\cos^2\theta_2 - 1\right)$
5	$-a_+a_+^* + a_-a_-^* + \frac{1}{2}b_+b_+^* - \frac{1}{2}b_-b_-^*$	P	$\frac{1}{2}\left(3\cos^2\theta_2 - 1\right)\ \cos\theta$
6	$-a_+a_+^* + a_-a_-^* - \frac{1}{2}b_+b_+^* + \frac{1}{2}b_-b_-^*$	α_Λ	$\frac{1}{2}\left(3\cos^2\theta_2 - 1\right)\ \cos\theta_1$
7	$-a_+a_+^* - a_-a_-^* - \frac{1}{2}b_+b_+^* - \frac{1}{2}b_-b_-^*$	$P\,\alpha_\Lambda$	$\frac{1}{2}\left(3\cos^2\theta_2 - 1\right)\ \cos\theta\cos\theta_1$
8	$-3Re(a_+a_-^*)$	$P\,\alpha_\Lambda$	$\sin\theta\ \sin\theta_1\ \sin^2\theta_2\ \cos\phi_1$
9	$3Im(a_+a_-^*)$	$P\,\alpha_\Lambda$	$\sin\theta\ \sin\theta_1\ \sin^2\theta_2\ \sin\phi_1$
10	$-\frac{3}{2}Re(b_-b_+^*)$	$P\,\alpha_\Lambda$	$\sin\theta\ \sin\theta_1\ \sin^2\theta_2\ \cos(\phi_1 + 2\,\phi_2)$
11	$\frac{3}{2}Im(b_-b_+^*)$	$P\,\alpha_\Lambda$	$\sin\theta\ \sin\theta_1\ \sin^2\theta_2\ \sin(\phi_1 + 2\,\phi_2)$
12	$-\frac{3}{\sqrt{2}}Re(b_-a_+^* + a_-b_+^*)$	$P\,\alpha_\Lambda$	$\sin\theta\ \cos\theta_1\ \sin\theta_2\ \cos\theta_2\ \cos\phi_2$
13	$\frac{3}{\sqrt{2}}Im(b_-a_+^* + a_-b_+^*)$	$P\,\alpha_\Lambda$	$\sin\theta\ \cos\theta_1\ \sin\theta_2\ \cos\theta_2\ \sin\phi_2$
14	$-\frac{3}{\sqrt{2}}Re(b_-a_-^* + a_+b_+^*)$	$P\,\alpha_\Lambda$	$\cos\theta\ \sin\theta_1\ \sin\theta_2\ \cos\theta_2\ \cos(\phi_1 + \phi_2)$
15	$\frac{3}{\sqrt{2}}Im(b_-a_-^* + a_+b_+^*)$	$P\,\alpha_\Lambda$	$\cos\theta\ \sin\theta_1\ \sin\theta_2\ \cos\theta_2\ \sin(\phi_1 + \phi_2)$
16	$\frac{3}{\sqrt{2}}Re(a_-b_+^* - b_-a_+^*)$	P	$\sin\theta\ \sin\theta_2\ \cos\theta_2\ \cos\phi_2$
17	$-\frac{3}{\sqrt{2}}Im(a_-b_+^* - b_-a_+^*)$	P	$\sin\theta\ \sin\theta_2\ \cos\theta_2\ \sin\phi_2$
18	$\frac{3}{\sqrt{2}}Re(b_-a_-^* - a_+b_+^*)$	α_Λ	$\sin\theta_1\ \sin\theta_2\ \cos\theta_2\ \cos(\phi_1 + \phi_2)$
19	$-\frac{3}{\sqrt{2}}Im(b_-a_-^* - a_+b_+^*)$	α_Λ	$\sin\theta_1\ \sin\theta_2\ \cos\theta_2\ \sin(\phi_1 + \phi_2)$

- MC weighted using the fit results



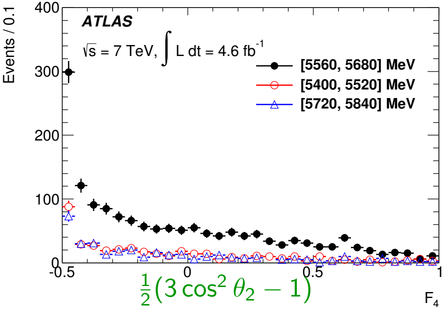




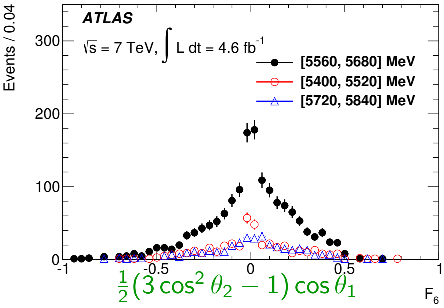


$\frac{1}{2}\sin\theta_1\sin\theta_2\cos\theta_2\cos(\phi_1+\phi_2)$ $\frac{1}{2}\sin\theta_1\sin\theta_2\cos\theta_2\sin(\phi_1+\phi_2)$

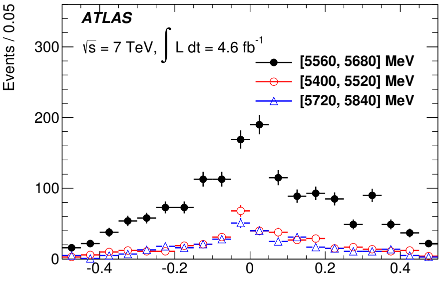
Sidebands comparison



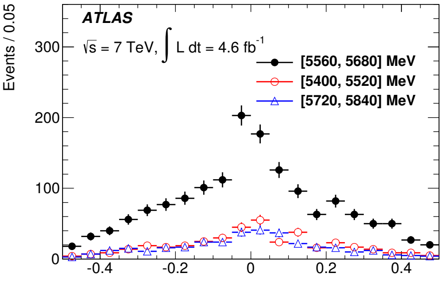
$\frac{1}{2}(3\cos^2\theta_2 - 1)$



$\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta_1$

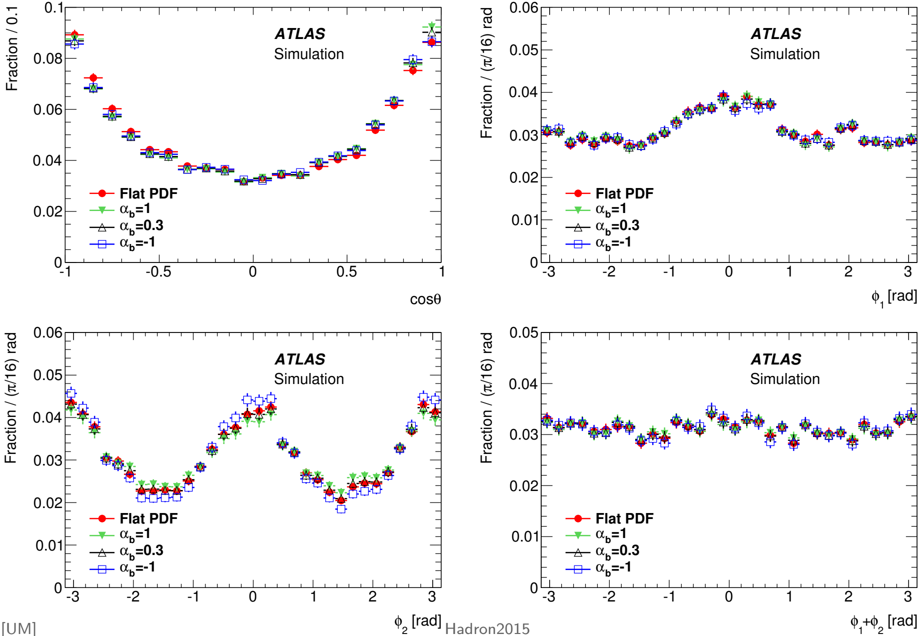


$\frac{1}{2}(\sin\theta_1 \sin\theta_2 \cos\theta_2 \cos(\phi_1 + \phi_2))$



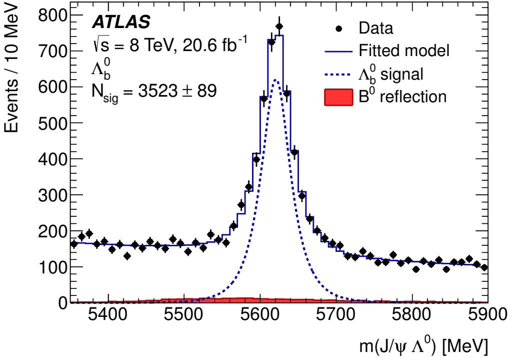
$\frac{1}{2}(\sin\theta_1 \sin\theta_2 \cos\theta_2 \sin(\phi_1 + \phi_2))$

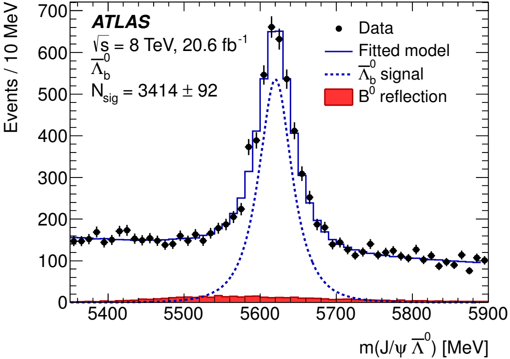
❑ Other angular variables



Backup: $\Lambda_b^0 \to \psi(2S)\Lambda^0$ selection

Λ_b^0 and $\bar{\Lambda}_b^0$





Threshold function

$$A \cdot (m - m_p - m_{\pi^-})^B \cdot \exp[C \cdot (m - m_p - m_{\pi^-}) + D \cdot (m - m_p - m_{\pi^-})^2]$$