Study of Λ_b^0 decay properties with the ATLAS detector

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Overview and motivation on the Λ_b decay measurements

- Lightest baryon containing a *b* quark (*udb*)
- First observed by UA1 in 1991 in the decay channel $\Lambda_b \to J/\psi\, \Lambda^0$
- First lifetime measurement from LEP experiments (1992) using the semileptonic decays; first lifetime measurement in the fully reconstructed channel at the Tevatron experiments
- Hadron colliders are currently the only place to study b baryons
  - Produced with high statistics at LHC
- The final state $J/\psi(\mu^+\mu^-)\, \Lambda^0\, (p^+\pi^-)$ is an ideal decay mode for Λ_b baryon analysis, it is use to measure:
  - Λ_b mass and lifetime
  - Parity violating decay asymmetry parameter, α_b, and helicity amplitudes
  - Compare lifetime ratio $\tau\left(\Lambda_b^0\right) < \tau\left(B_d^0\right)$ and α_b with theory predictions
- Considerable physics motivation for studying the Λ_b sector
  - The lifetime ratio of Λ_b and B_d which is predicted HQET and perturbative QCD is of great theoretical interest
  - This data sample also offers the possibility of measuring the Λ_b helicity amplitudes and transverse polarization for the first time

ATLAS detector performance

- Inner Detector
  - 2 T solenoidal magnetic field strength
  - Pixel ($|\eta| < 2.5$): res. 10/115 μm in $R\phi/z$
  - SCT ($|\eta| < 2.5$): res. 17/580 μm in $R\phi/z$
  - TRT ($|\eta| < 2$): res. 130 μm in $R\phi$
  - $\sigma(p_t)/p_t \sim 0.05\% p_t$ (GeV) $\oplus$ 1%, $\sigma(d_0) \sim 10\mu m$
- ATLAS is a general purpose detector, designed to be sensitive to a wide range of physical phenom: SM rediscovery, Higgs, SUSY, BSM, also flavour physics: require high precision in tracking, muon and trigger systems

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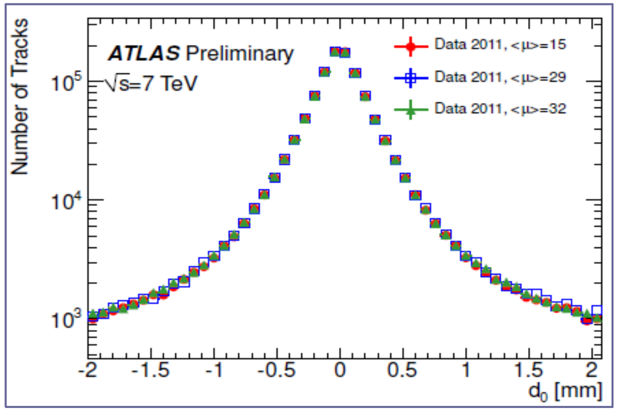

- Muon Spectrometer
  - Toroidal magnetic field: bending power 1.5-5.5 Tm (barrel) and 1-7.5 Tm (EC)
  - Precision chambers (MDT, CSC)
  - Triggers layers (RPC, TGC)
  - $|\eta| < 2.7$, $\sigma(p_t)/p_t \sim 10\%$ up to 1TeV
- Excellent mass resolution required for good S/B
- Transverse impact parameter of the reconstructed tracks with respect to the PV at three different pile-up conditions
- Muon reconstruction efficiency using J/ψ decays

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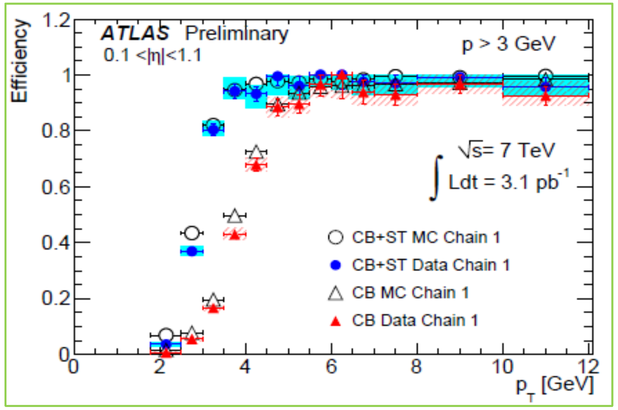
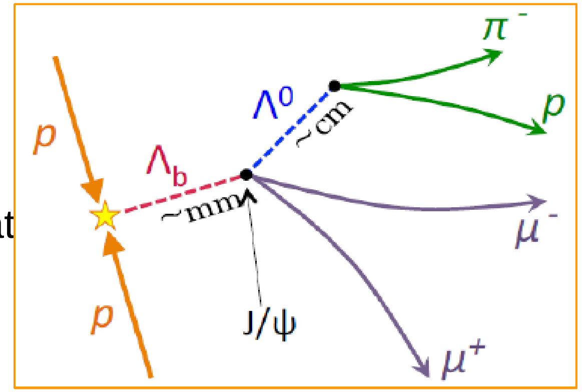
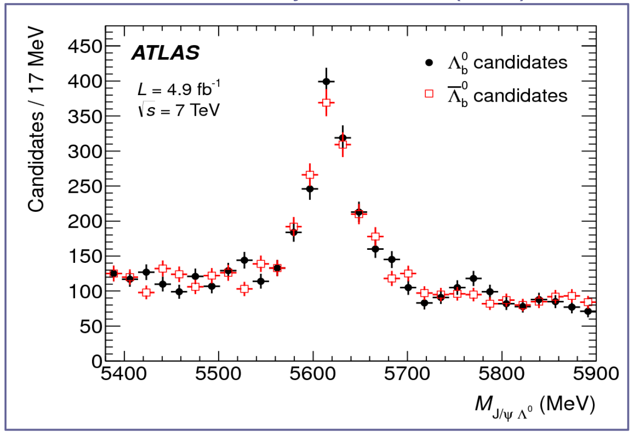


Λ_b selection and reconstruction

- Cascade topology: 2 vertices, 4 tracks
- Trigger:
  - single muon, di-muon J/ψ, $p_t(\mu) > 4$ GeV
- Dimuon and dihadron pairs are pre-selected by req.that their tracks are successfully fitted to a common vertex
  - Dimuon cand. acc. (J/ψ): 2.8 GeV < M(μμ) < 3.4 GeV
  - Dihadron cand acc. (Λ^0): 1.08 < M(hh) < 1.15 GeV
- The muon and hadron track pairs are then reffited with a constraint of a $\Lambda_b^0 \to J/\psi(\mu^+\mu^-)\Lambda^0(p^+\pi^-)$ topology
  - Cascade topology fit – constrain:
    - J/ψ and Λ^0 masses
    - $\vec{p}_{V^0}$ points to μμ vertex
  - Cascade topology fit requirements:
    - Fit $\chi^2 / N_{dof} < 3$ ($N_{dof} = 6$)
    - p_T of refitted $V^0 > 3.5$ GeV, $L_{xy,\Lambda} > 10$ mm
    - 5.38 < M(J/ψ Λ^0) < 5.90 GeV
    - If also B_d : $P_{\Lambda_b} - P_{B_d} > 0.05$



Phys. Rev. D87 (2013) 032002



4074 Λ_b and anti-Λ_b 4081 candidates

Λ_b mass and lifetime fit

- For each Λ_b candidate the proper decay time is calculated as:

$$\tau = L_{xy} \frac{m^{PDG}(\Lambda_b)}{p_T(\Lambda_b)}$$

  - L_{xy} is a Λ_b transverse decay distance measured from the primary vertex
  - $m^{PDG}(\Lambda_b)$ = 5619.4 MeV
  - p_T is reconstructed Λ_b transverse momentum

- Measurement procedure consist of: select signal events, build p.d.f. for signal and background for mass and proper decay time, for signal and background
- The lifetime and mass are determined using a simultaneous unbinned maximum likelihood fit to the reconstructed mass and decay time of each selected candidate:

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

  - f_{sig} - fraction of signal candidates
  - m_i, τ_i - inv.mass, p.decay time of i-th cand.
  - δ_τ , δ_m - per-candidate errors of m and τ
  - M_s , M_b , τ_s , τ_b – PDFs descr. the signal and background mass/proper decay time depend.

- Background component: - prompt : J/ψ from pp + accidental Λ vertex,
  - nonprompt: J/ψ from b + accidental Λ
- Free parameters: $m_{\Lambda b}$, $\tau_{\Lambda b}$, f_{sig}, Sm, Sτ error scale factors, 7 parameters describing the background shapes
- Signal fit model: time - exponential., mass - Gaussian; Background fit model: time: prompt component - sum of two functions (Dirac, Laplace), nonprompt - exponential, mass: Polynomial

Fit results and systematics

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Parameter	Value
$m_{\Lambda b}$	5619.7 ± 0.7 MeV
$\tau_{\Lambda b}$	1.449 ± 0.036 ps
N_{sig}	2184 ± 57
N_{bkg}	5970 ± 160
σ_m (MeV)	31.1 ± 0.8 MeV
σ_τ	0.117 ± 0.003 ps
χ^2 / N_{dof}	1.09
f_{sig}	0.268 ± 0.007
S_m	1.18 ± 0.03
S_τ	1.05 ± 0.02

Selection: V0 reconstruction
82 ± 46 B_d candidates misidentified as Λ_b

Syst. Uncertainty	σ_τ (fs)	σ_m (GeV)
Selection/ reconstruction	12	0.9
Background fit models	9	0.2
B_d contamination	7	0.2
Misalignment	1	-
Extra material	3	0.2
Tracking p_T scale	-	0.5
Total systematics	17	1.1

$m(\Lambda_b) = 5619.7 \pm 0.7(stat) \pm 1.1(syst)$ MeV

$\tau(\Lambda_b) = 1.499 \pm 0.036(stat) \pm 0.017(syst)$ ps

$R = \tau(\Lambda_b)/\tau(B_d) = 0.960 \pm 0.025(stat) \pm 0.016(syst)$

Λ_b mass and lifetime measurement results

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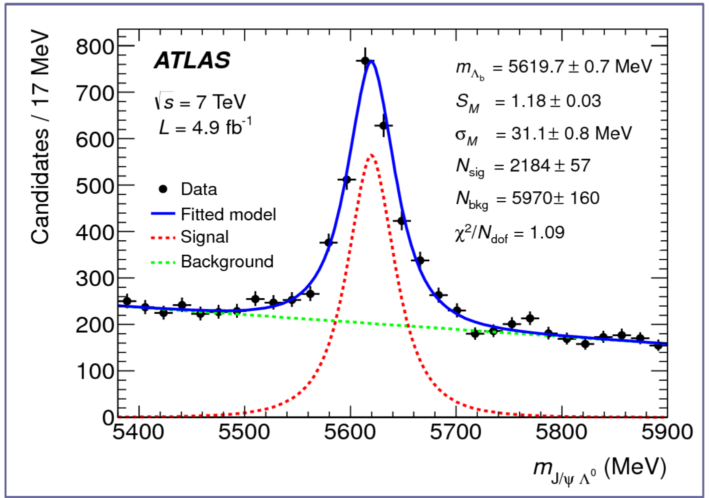
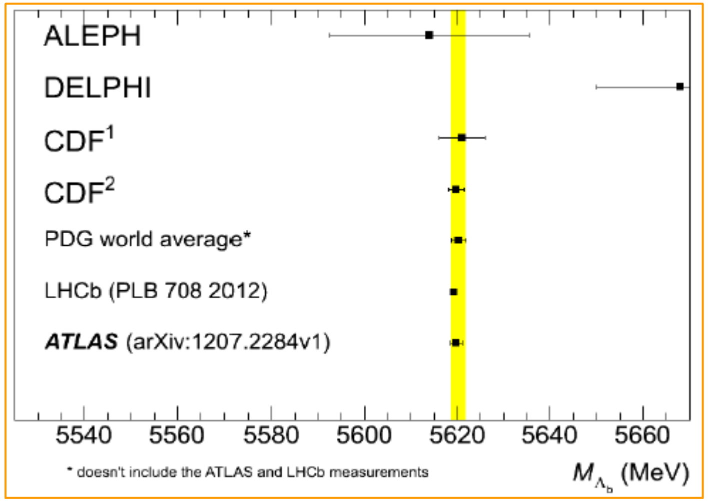
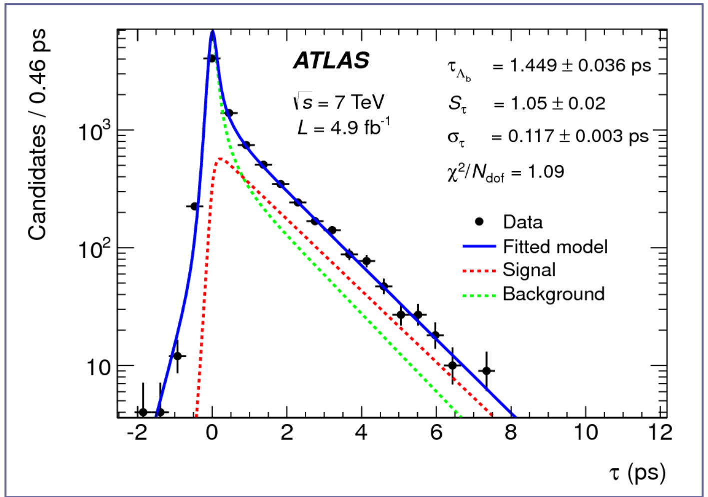


mass result

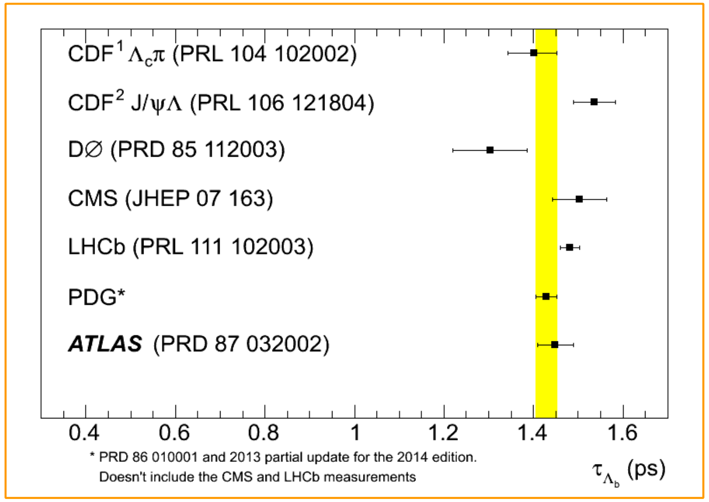
comp.





lifetime result

comp.



α_b Measurement

- The Λ_b decay, and subsequent Λ^0 and J/ψ decays, 2-body decays, can be parametrized by a polar and azimuthal angle in their respective rest frames
- $\Lambda_b^0 \to J/\psi(\mu^+\mu^-)\Lambda^0(p^+\pi^-)$ decay can be described by:
  - 4 helicity amplitudes (possible helicity combinations)
  - Dynamics described by 5 angles - sensitive to squared amplitudes
  - Parity violating decay asymmetry parameter:

$$\alpha_b = |a_+|^2 - |a_-|^2 + |b_+|^2 - |b_-|^2$$

Amplitude	$\lambda_{J/\psi}$	λ_Λ
a_+	0	1/2
a_-	0	- 1/2
b_+	-1	1/2
b_-	1	- 1/2

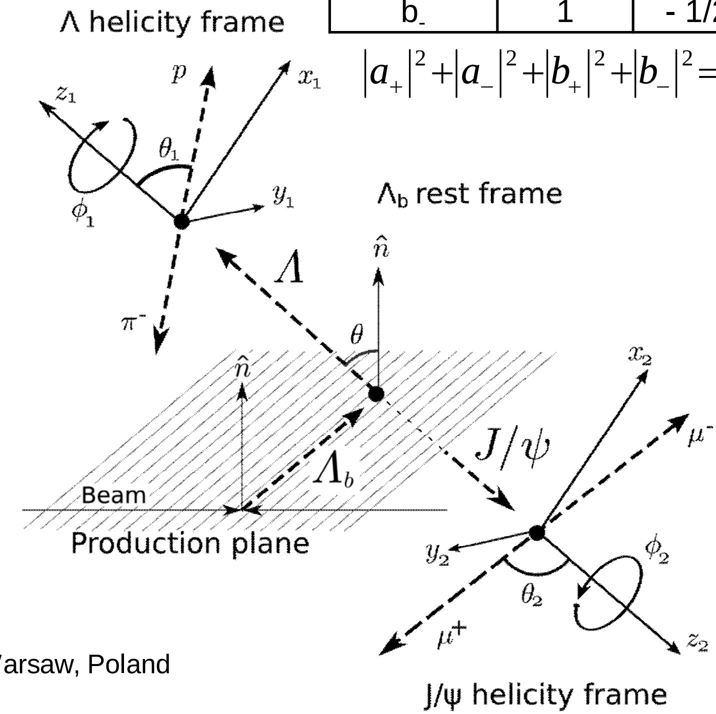
$$|a_+|^2 + |a_-|^2 + |b_+|^2 + |b_-|^2 = 1$$

- The full decay angular PDF[1]:
  - angular distributions described by 20 terms

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

  - helicity amplitudes are free parameters;
  - $F_i(\Omega)$ are the measurements $\Rightarrow$ Fit
  - PDF of the decay angle:

$$W_e(\theta) = \frac{1}{2}(1 + \alpha_b P \cos\theta)$$



[1] probability density function

Probability density function (PDF) parametrization

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

- $f_{1i}\left(\vec{A}\right)$: bilinear comb. of helicity ampl. $\vec{A}\equiv\left(a_+,a_-,b_+,b_-\right)$

$$a_+=\left|a_+\right|e^{i\rho_+},\ a_-=\left|a_-\right|e^{i\rho_-},\ b_+=\left|b_+\right|e^{i\omega_+},\ b_-=\left|b_-\right|e^{i\omega_-}$$

- $f_{2i}\left(P\alpha_\Lambda\right)$: has a values: $P\alpha_\Lambda$, P, α_Λ or 1
  - Asymmetry parameter α_Λ = 0.642 ± 0.013[1] for $\Lambda^0 \rightarrow p\pi^-$
- $F_i\left(\vec{\Omega}\right)$: orthogonal functions of decay angles
- Analysis uses method of moments:
  - α_b and h.a. are extracted from measured averages of each F_i (moments)
- There are 9 unknown parameters with a real value in the PDF: 4 h.a. each with a magnitude and phase, and polarization *P*.
- 7 of these 9 are independent, considering following constraints:
  - Normalization: $\left|a_+\right|^2+\left|a_-\right|^2+\left|b_+\right|^2+\left|b_-\right|^2=1$
  - Only the differences between the four phases are relevant

$$\alpha_b=\left|a_+\right|^2+\left|a_-\right|^2+\left|b_+\right|^2+\left|b_-\right|^2$$

$$k_0=\frac{\left|a_+\right|}{\sqrt{\left|a_+\right|^2+\left|b_+\right|^2}}$$

$$k_1=\frac{\left|b_-\right|}{\sqrt{\left|a_-\right|^2+\left|b_-\right|^2}}$$

$$\Delta_+=\rho_+-\omega_+$$

$$\Delta_-=\rho_--\omega_-$$

- Exploit ATLAS symmetry in η ⇒ Polarization = 0
- The PDF reduces to 6 terms, only two phase differences are accessible. Number of independent parameters reduced to 5: 3 magnitudes of h.a., 2 relative phases (P = 0)
- The parameters chosen to define the model are shown above

[1] PDG J. Phys. G 37 (2010)

Extraction of α_b and helicity amplitudes

- Selection and reconstruction of Λ_b dataset:
  - As for the mass & lifetime analysis plus specific requirements for this analysis aiming to reduce background (cleaner sample):
    - B_d veto cut: $P_{\Lambda_b} > P_{B_d}$ (removes most of B_d events)
    - Λ_b proper decay time $\tau > 0.35$ ps
    - Signal region: $5560 < m\,(J/\psi\,\Lambda^0) < 5680$ MeV
  - N_{sig}, N_{Bd} and N_{other} - from extended binned max. likelihood fit
- Extraction of α_b and helicity amplitudes:
- Perform χ^2 fit to measured moments $\langle F_i \rangle$:

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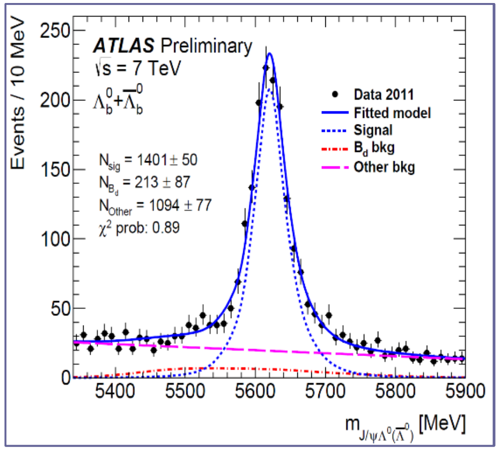


$$\chi^2 = \sum_i \sum_j (\langle F_i \rangle^{\text{expected}} - \langle F_i \rangle) V_{ij}^{-1} (\langle F_j \rangle^{\text{expected}} - \langle F_j \rangle)$$

V_{ij} : covariance matrix of measured $\langle F_i \rangle$

- The helicity amplitudes and α_b are extracted from the expected value of each of the F_i variables in the PDF, given in the Table (backup slide no. 22). $\langle F_i \rangle^{expected}$ calculated from the PDF as follows:

$$\langle F_i \rangle^{\text{expected}} = \sum_j f_{1j}(\vec{A}) f_{2j}(\alpha_\Lambda) C_{ij}$$

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

Model: defined in terms of 5 free parameters (slide 12)

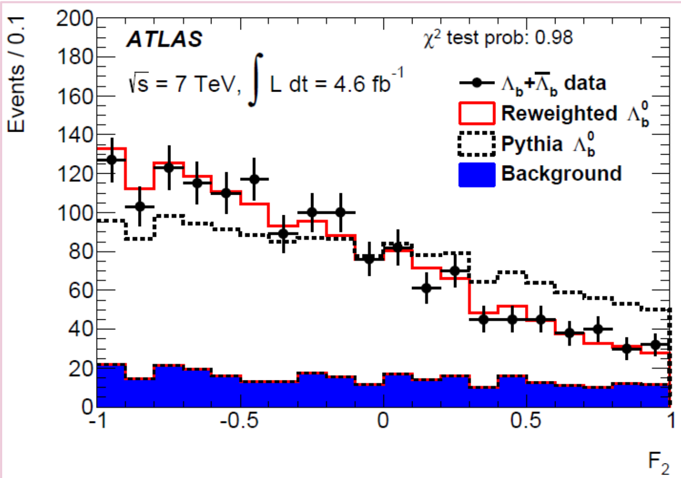
Detector effects: detector acceptance, efficiency, resolution encoded by C_{ij} :
- no dependence on helicity parameters
- determined from MC samples generated with flat angular distributions

Fit results

arXiv:1404.1071

- The χ^2 fit is applied to data and yields
- To check the fit results:
  - MC events are further weighted using the signal PDF with parameters determined from the fit
  - This weighted MC and sideband background distrib. of F_i are added and compared with data; fig. at the bottom
- Systematics mainly from:
  - Uncertainties in bkg. contrib. to measured $\langle F_i \rangle$ moments and calculation of correction matrix

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



- Λ_b decay has large $|a_-|$ and $|b_+|$ $\Rightarrow$ negative-helicity states for Λ^0 preferred; Λ^0 and J/ψ from Λ_b are highly polarized in the direction of their momenta;
- α_b value:
  - Consistent with LHCb: 0.05 ± 0.17(stat) ± 0.07(syst) — Phys. Letters **B 724** (2013) 27
  - Intermediate between pQCD and HQET predictions:
    - ~2.5σ c.f. pQCD expectation ~(−0.14 → −0.18)
      Chou et. al. Phys. Rev. D65 (2002) 074030
    - ~2.9σ c.f. HQET expectation (0.78)
      Leitner et al. Nucl. Phys. A755 (2005) 435,
      Ajaltouni et al. Phys. Let. B614 (2005) 165

Summary

- Λ_b mass & lifetime have been measured: ➡ Phys. Rev. D87 (2013) 032002

$$\tau(\Lambda_b) = 1.499 \pm 0.036(\text{stat}) \pm 0.017(\text{syst})\ \text{ps}$$
$$m(\Lambda_b) = 5619.7 \pm 0.7(\text{stat}) \pm 1.1(\text{syst})\ \text{MeV}$$
$$R = \tau(\Lambda_b)/\tau(B_d) = 0.960 \pm 0.025(\text{stat}) \pm 0.016(\text{syst})$$

Consistent with both pQCD and HQET predictions and other experimental measurements

- Λ_b parity violating asymmetry parameter, α_b, and helicity amplitudes have been measured: ➡ arXiv:1404.1071

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

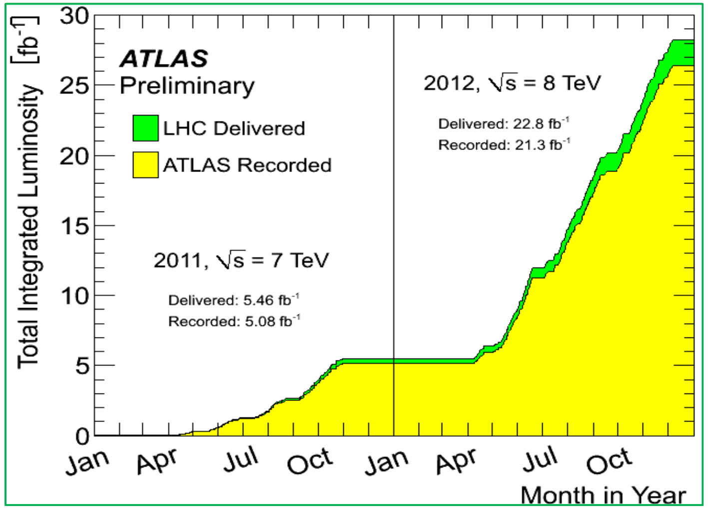
α_b differs from pQCD expectation –(0.14~0.18) by ~2.5σ and HQET expectation (0.78) by 2.9σ

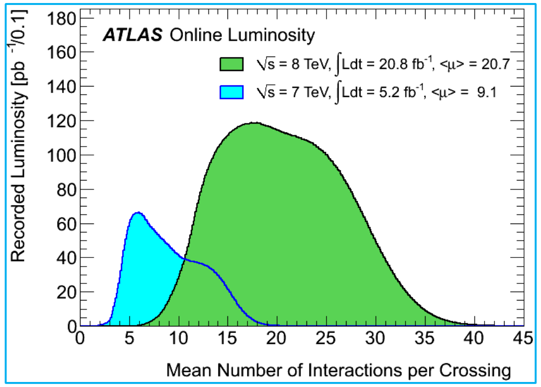
- More accurate measurements will be made with 2012 data (21.7 fb^{-1} rec.)

Backup

ATLAS data taking

- ~5.5 fb^{-1} integrated luminosity in 2011
- 3.65×10^{33} cm^{-2} s^{-1} max. inst. luminosity
  - up to 12 collisions/event on average
- Overall data taking efficiency: 93.5%
  - Subdetector efficiency > 90%
- 2011 ATLAS benefit from being able to collect data at increasing LHC instantaneous luminosity
  - Attention paid to B Physics triggers and stability of tracking
  - Vertexing performance with growing pile-up
- Results discussed based on
  - 2011 (~4.9 fb^{-1}) data





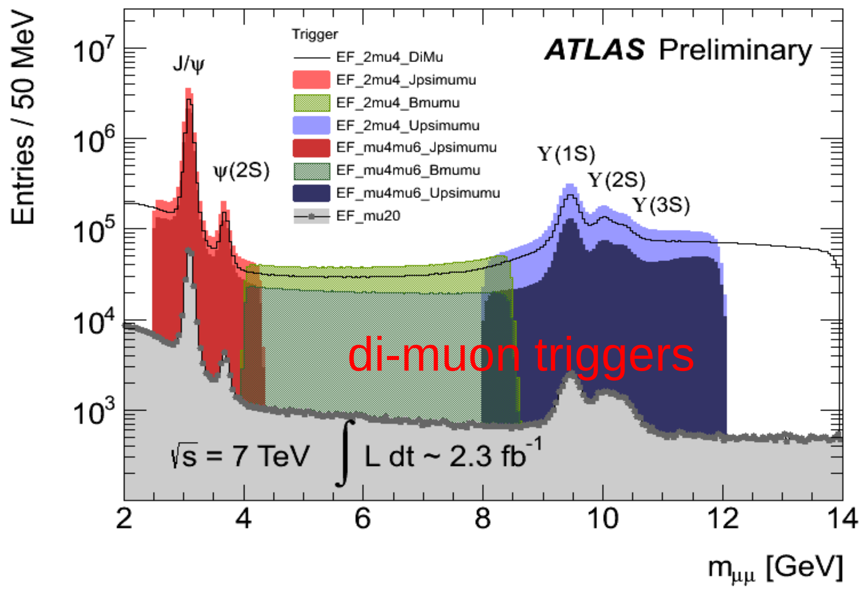
***ATLAS* 2011 p–p run**

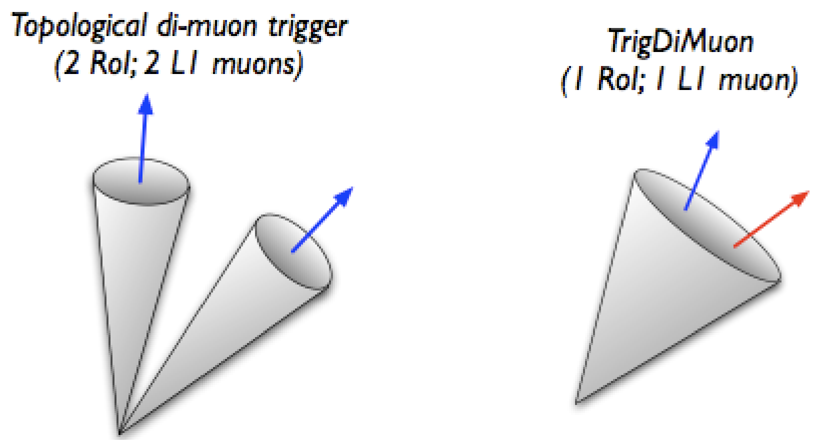
Inner Tracking			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.8	99.6	99.2	97.5	99.2	99.5	99.2	99.4	98.8	99.4	99.1	99.8	99.3

Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at √s=7 TeV between March 13th and October 30th (in %), after the summer 2011 reprocessing campaign

ATLAS B Triggers in 2011(I)

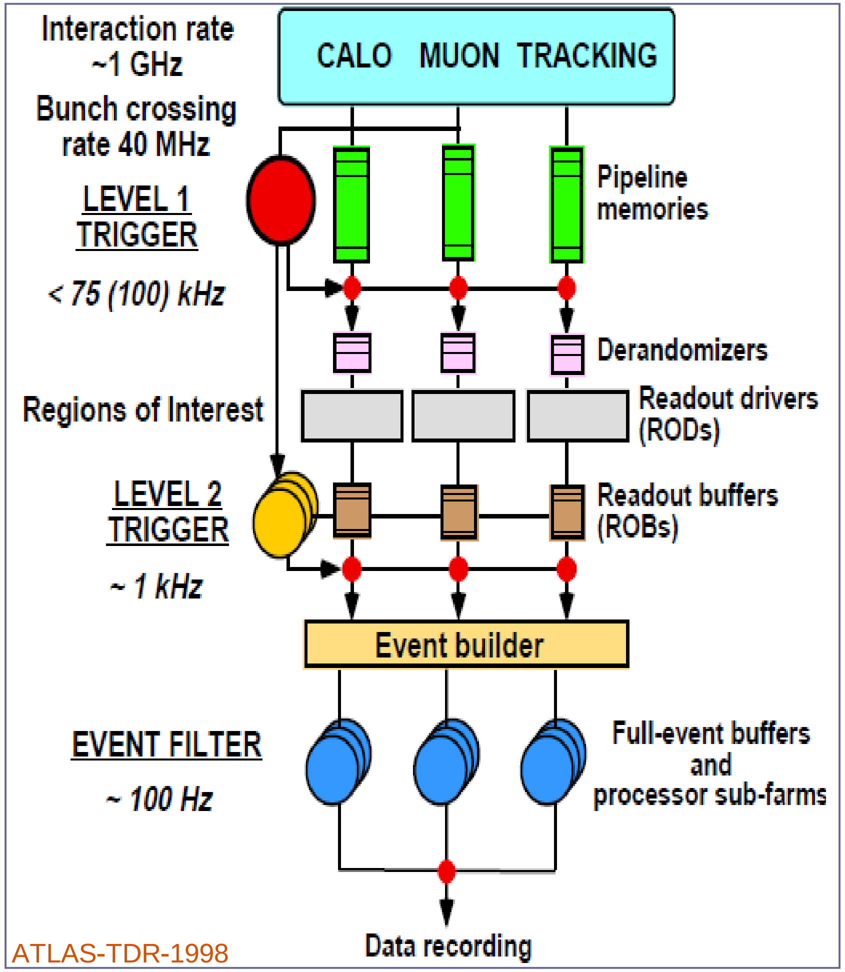
- In 2011 ATLAS di-muon triggers dominate B-trigger menus; single muon trigg.-prescaled
- p_T thresholds 4&4 GeV or 4&6 GeV with masses in J/ψ (2.5-4.3 GeV), B (4-8.5 GeV) and Υ (8-12 GeV); the combined range of all three (1.5-14 GeV)
- A higher p_T trigger (20 GeV) di-muon events over whole mass region
- ATLAS di-muon triggers performed online tracking & vertexing, accepting only a good quality vertices
- In ATLAS NO displaced vertex cuts applied at trigger level during whole 2011 in B-physics menu





ATLAS Trigger Operations

- ATLAS has 3 different trigger levels:
  - L1: hardware trigger → 50 kHz rate, decision time < 2.5 μs
  - L2: software selection on reduced granularity (ROI) → 4 kHz rate, ~10 ms
  - EF: based on offline reconstruction, full granularity → 200 Hz rate design with peak to 600 Hz, ~ few sec
- Physics rate is ~ 300 Hz



Measurement of Primary Vertex and Inner Detector Performance

- Select fully reconstructed tracks with small transverse & longitudinal impact parameter for primary vertex reconstruction
- Determine primary vertex with adaptive vertex fitting algorithm
- Remove tracks that are more than 7σ incompatible with PV and use as seed for new vertex
- Resolution of PV: $\sigma_x = 15.7\ \mu m$, $\sigma_y = 13.5\ \mu m$
- For precise measurements of secondary vertices, the performance of the Inner Detector is crucial, particulary that of silicon pixels
- In barrel measure σ = 25 μm for hits from tracks with $p_t > 2$ GeV
- In the EC meausure σ=20 μm for hits from tracks with $p_t > 2$ GeV

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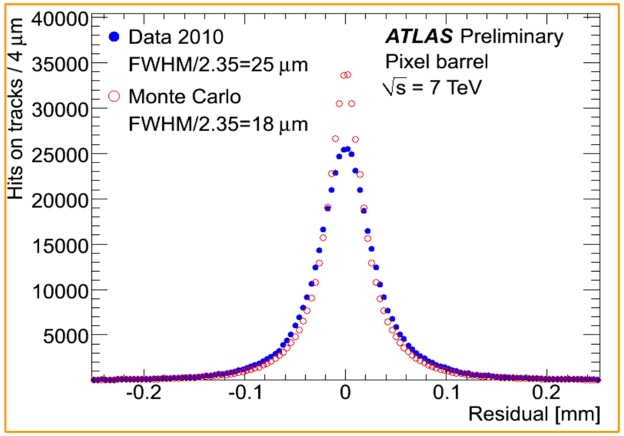

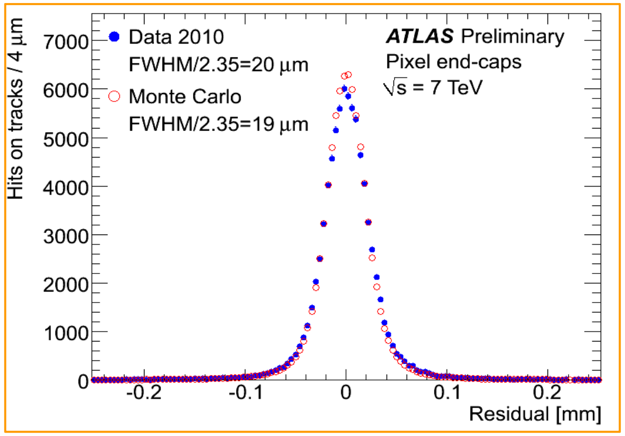

α_b Lifetime measurement

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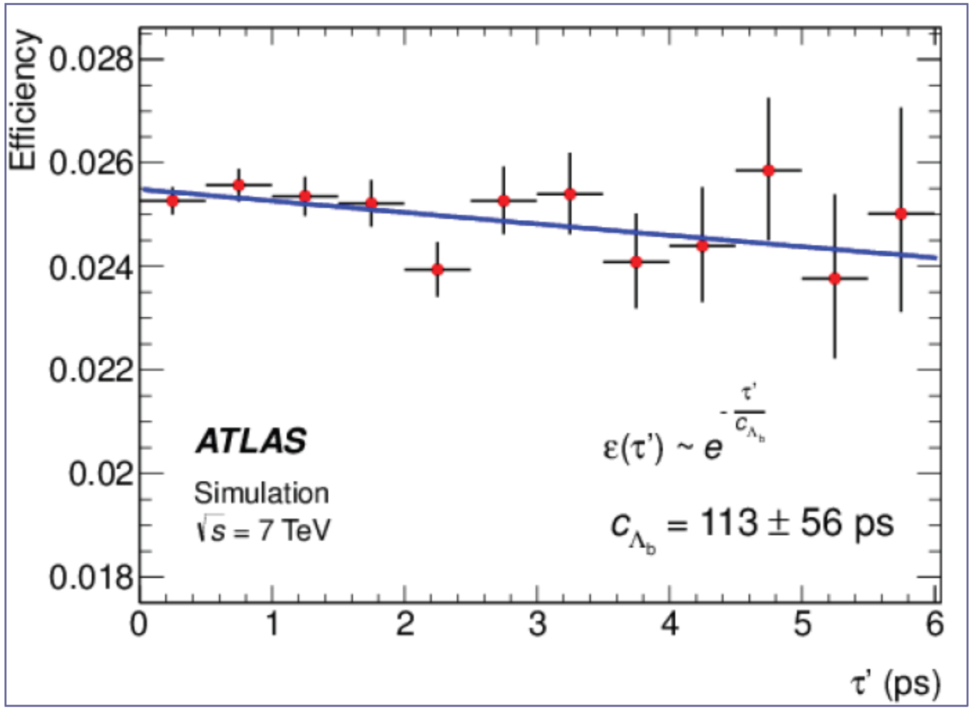
- Efficiency correction as a function of MC decay time
- The slope of the exponential, c_{Λ_b} , is extracted from a fit to the MC decay time efficiency plot shown in Fig.



Parity violation

- E. Wigner 1927 – formalized the principle of the *P*-conservation
- Lee and Yang 1956 – originated the idea of parity nonconservation and proposed the experiment; Nobel Prize in physics 1957
- Wu et al. 1957 - parity violation detection in nuclear beta decay (^{60}Co)
- Parity violation – maximal form in decays of leptons (e.g. muons), observable as well in weak decays of hadrons (not maximal, dependence on the hadron's constituents); e.g. the well-known process of $\Lambda^0 \rightarrow p\pi^-$ has an asymmetry parameter, α_Λ, of over 60%
- In case of heavy baryons, such as Λ_b^0, hard scattering function can be accurately calculated in pQCD – suggest a value of $\alpha_b \approx -0.2$ (HQET models give a value $\alpha_b \approx -0.8$)
- Recently, the LHCb experiment reported a measurement of α_b value, which is compatible with the pQCD prediction, but is not consistent with the HQET prediction – additional measurements are warranted
- The ATLAS exp. performed measurement of α_b in $\Lambda_b^0 \rightarrow J/\psi(\mu^+\mu^-)\Lambda^0(p^+\pi^-)$

Λ_b Asymmetry measurement

The coefficients f_{1i}, f_{2i}, F_i of the 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	$\frac{1}{2}(3\cos^2\theta_2 - 1)$
5	$-a_+a_+^* + a_-a_-^* + \frac{1}{2}b_+b_+^* - \frac{1}{2}b_-b_-^*$	P	$\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta$
6	$-a_+a_+^* + a_-a_-^* - \frac{1}{2}b_+b_+^* + \frac{1}{2}b_-b_-^*$	α_Λ	$\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta_1$
7	$-a_+a_+^* - a_-a_-^* - \frac{1}{2}b_+b_+^* - \frac{1}{2}b_-b_-^*$	$P\,\alpha_\Lambda$	$\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta\cos\theta_1$
8	$-3Re(a_+a_-^*)$	$P\,\alpha_\Lambda$	$\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\cos\varphi_1$
9	$3Im(a_+a_-^*)$	$P\,\alpha_\Lambda$	$\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\sin\varphi_1$
10	$-\frac{3}{2}Re(b_-b_+^*)$	$P\,\alpha_\Lambda$	$\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\cos(\varphi_1 + 2\varphi_2)$
11	$\frac{3}{2}Im(b_-b_+^*)$	$P\,\alpha_\Lambda$	$\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\sin(\varphi_1 + 2\varphi_2)$
12	$-\frac{3}{\sqrt{2}}Re(b_-a_+^* + a_-b_+^*)$	$P\,\alpha_\Lambda$	$\sin\theta\,\cos\theta_1\,\sin\theta_2\,\cos\theta_2\,\cos\varphi_2$
13	$\frac{3}{\sqrt{2}}Im(b_-a_+^* + a_-b_+^*)$	$P\,\alpha_\Lambda$	$\sin\theta\,\cos\theta_1\,\sin\theta_2\,\cos\theta_2\,\sin\varphi_2$
14	$-\frac{3}{\sqrt{2}}Re(b_-a_-^* + a_+b_+^*)$	$P\,\alpha_\Lambda$	$\cos\theta\,\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\cos(\varphi_1 + \varphi_2)$
15	$\frac{3}{\sqrt{2}}Im(b_-a_-^* + a_+b_+^*)$	$P\,\alpha_\Lambda$	$\cos\theta\,\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\sin(\varphi_1 + \varphi_2)$
16	$\frac{3}{\sqrt{2}}Re(a_-b_+^* - b_-a_+^*)$	P	$\sin\theta\,\sin\theta_2\,\cos\theta_2\,\cos\varphi_2$
17	$-\frac{3}{\sqrt{2}}Im(a_-b_+^* - b_-a_+^*)$	P	$\sin\theta\,\sin\theta_2\,\cos\theta_2\,\sin\varphi_2$
18	$\frac{3}{\sqrt{2}}Re(b_-a_-^* - a_+b_+^*)$	α_Λ	$\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\cos(\varphi_1 + \varphi_2)$
19	$-\frac{3}{\sqrt{2}}Im(b_-a_-^* - a_+b_+^*)$	α_Λ	$\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\sin(\varphi_1 + \varphi_2)$

α_b Measurement

- Polarization P=0: due to symmetry of initial state & ATLAS symmetry in pseudo-rapidity
- The coefficients f_{1i} of the remaining 6 terms of PDF for P=0 (from 20)
- Using the 5 free parameters to define the model

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

$$\alpha_b = |a_+|^2 - |a_-|^2 + |b_+|^2 - |b_-|^2$$

$$k_+ = \frac{|a_+|}{\sqrt{|a_+|^2 + |b_+|^2}},$$

$$k_- = \frac{|b_-|}{\sqrt{|a_-|^2 + |b_-|^2}},$$

$$\Delta_+ = \rho_+ - \omega_+,$$

$$\Delta_- = \rho_- - \omega_-.$$

α_b Measurement - Data set

- All 2011 7 TeV data
- Single muon and Jpsimumu triggers
  - EF_mu18, EF_mu18_medium
  - EF_mu6_Jpsimumu_tight, EF_mu10_Jpsimumu, EF_mu4_Jpsimumu, EF_2mu4_Jpsimumu, EF_2mu4T_Jpsimumu
- Total integrated luminosity: 4.59 ± 0.08 fb^{-1}
- MC
  - MC11 Pythia sample, 5M events. All angle variables are flat in generation level
  - Background MC: $B_d^0 \to J/\psi(\mu^+\mu^-)K_S^0(\pi^+\pi^-), b\bar{b} \to J/\psi + X$

α_b Measurement
Reconstruction and selection of Λ_b sample

- The decay $\Lambda_b^0 \to J/\psi(\mu^+\mu^-)\Lambda^0(p^+\pi^-)$ has a cascade topology
- Λ^0, J/ψ pre-selection: $1.08 < m_{p\pi} < 1.15$ GeV, $2.8 < m_{\mu\mu} < 3.4$ GeV
- J/ψ and Λ^0 mass are fixed to PDG value in Λ_b fitting
- Λ_b vertex is constrained to the di-muon vertex
- The four tracks are fitted simultaneously
- Fit quality $\chi^2/N_{dof} < 3.0$ ($N_{dof} = 6$)
- B_d veto cut: $P_{\Lambda_b} > P_{B_d}$ (removes most of B_d events)
- Refitted Λ^0 $p_T > 3.5$ GeV, $L_{xy} > 10$ mm (from Λ_b vertex)
- Λ_b proper decay time $\tau > 0.35$ ps
- Signal region: $5560 < m < 5680$ MeV
- In total 1548 Λ_b^0 and $\overline{\Lambda}_b^0$ candidates selected in the signal region

Λ_b^0 and $\overline{\Lambda}_b^0$ candidates

- Fit Λ_b^0 and $\overline{\Lambda}_b^0$ separately
- There is no overlap between candidates Λ_b^0 and $\overline{\Lambda}_b^0$
- The invariant mass distribution of Λ_b^0 and $\overline{\Lambda}_b^0$ candidates, fitted with three-component PDF, consisting of signal, combinatorial and B_d background
- Binned maximum likelihood fit is used

Parameter	Value	SR
N_{sig}	1401 ± 50	1243 ± 44
N_{Other}	1094 ± 77	234 ± 16
N_{Bd}	213 ± 87	73 ± 30

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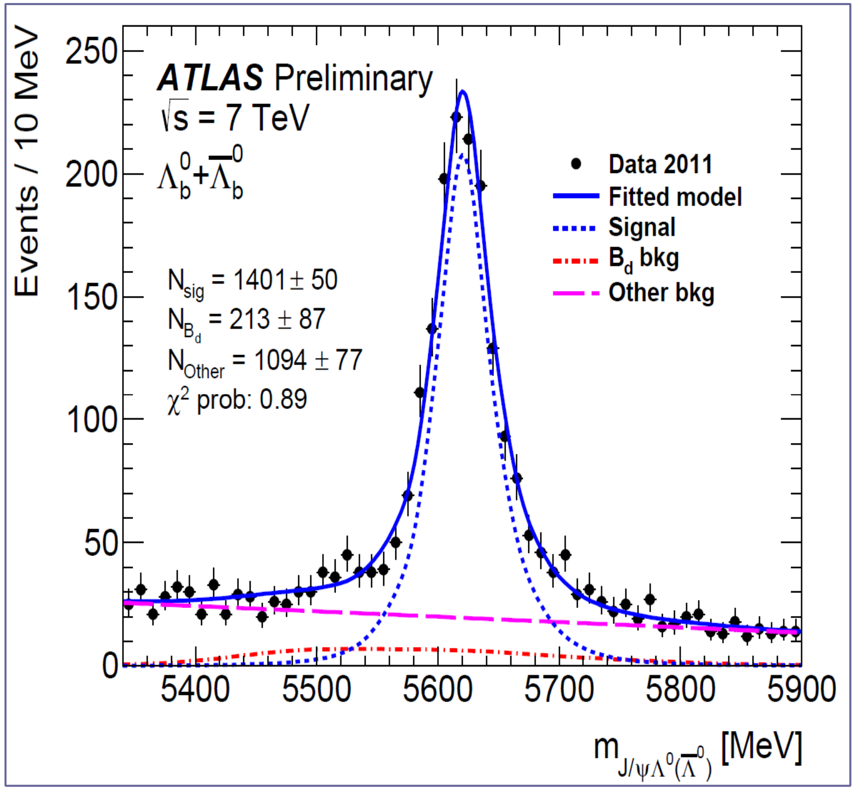
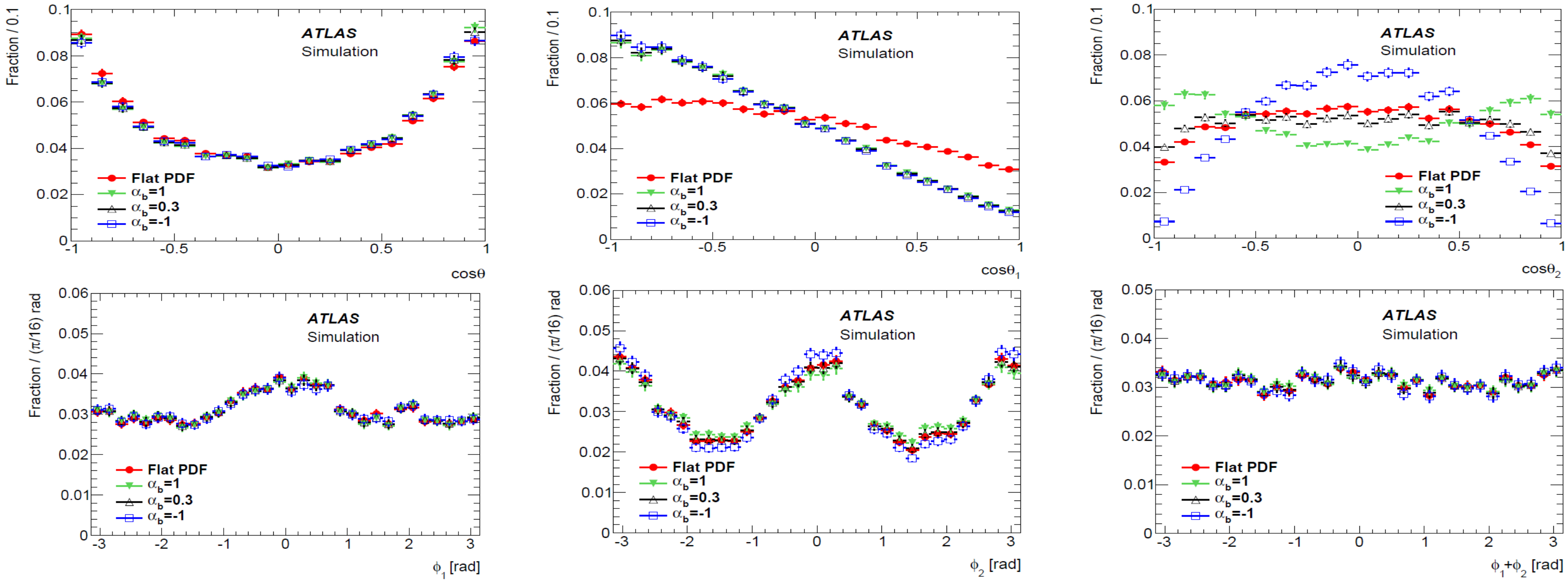


Efficiency Correction



$$\mathbf{C} = \begin{pmatrix} 1 & -0.113 & -0.033 & 0.0074 & 0.0223 & -0.0028 \\ -0.112 & 0.3091 & 0.0071 & -0.0133 & 0.0029 & -0.0010 \\ -0.033 & 0.0074 & 0.1775 & -0.0186 & 0.0041 & -0.0001 \\ 0.0071 & -0.0133 & -0.0185 & 0.0545 & 0.00013 & 0.00029 \\ 0.0221 & 0.0026 & 0.0040 & 0.00015 & 0.0465 & 0.0005 \\ -0.0031 & -0.0008 & -0.0003 & 0.00034 & 0.0005 & 0.0450 \end{pmatrix}$$

Ideal case, no detector effects - C is diagonal matrix D with elements

$$\mathrm{D}_{ij} = \frac{1}{(4\pi)^3} \int F_i(\Omega) F_j(\Omega)\, \mathrm{d}\Omega.$$

$$\mathbf{D} = \mathrm{diag}\{1, 1/3, 1/5, 1/15, 2/45, 2/45\}$$

Fit Results

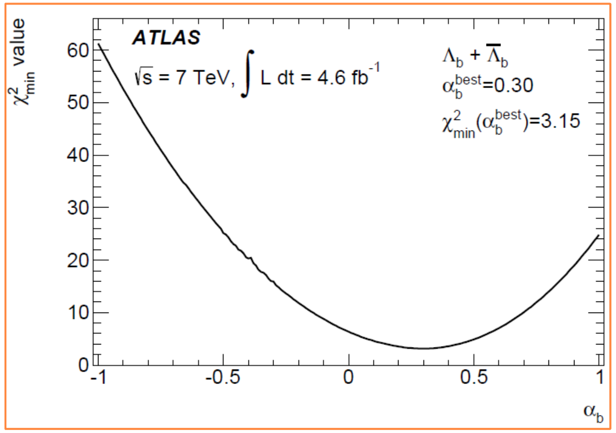
- Measured $\langle F_i \rangle$ values:
  - $\langle F_2 \rangle = -0.282 \pm 0.021$,
  - $\langle F_4 \rangle = -0.044 \pm 0.017$,
  - $\langle F_6 \rangle = 0.001 \pm 0.010$,
  - $\langle F_{18} \rangle = 0.019 \pm 0.009$,
  - $\langle F_{19} \rangle = -0.002 \pm 0.009$.

$\langle F_i \rangle$	$\langle F_2 \rangle$	$\langle F_4 \rangle$	$\langle F_6 \rangle$	$\langle F_{18} \rangle$	$\langle F_{19} \rangle$
$\langle F_2 \rangle$	1	-0.066	-0.121	0.028	0.003
$\langle F_4 \rangle$		1	-0.503	0.088	0.000
$\langle F_6 \rangle$			1	-0.025	-0.008
$\langle F_{18} \rangle$				1	0.048
$\langle F_{19} \rangle$					1

Correlation matrix of $\langle F_i \rangle$ measurements

- Values obtained from fit:
  - $\alpha_b = 0.30 \pm 0.16,\ k_+ = 0.21^{+0.14}_{-0.21}\quad k_- = 0.13^{+0.20}_{-0.13}$.
  - Correlation matrix of the fitted parameters

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



The conditional χ^2_{min} as a function of α_b

α_b Measurement Systematic uncertainties

Source	α_b	k_+	k_-	$\|a_+\|$	$\|a_-\|$	$\|b_+\|$	$\|b_-\|$
Background shape	0.034	0.020	0.042	0.018	0.017	0.010	0.024
B_d^0 background	0.011	0.085	0.061	0.069	0.008	0.008	0.036
Angles resolution	0.005	0.017	0.026	0.014	0.004	0.002	0.015
MC mass resolution modeling	0.020	0.004	0.004	0.002	0.008	0.007	0.002
MC kin. weighting (MC parameterization)	0.007	0.010	0.008	0.008	0.007	0.002	0.005
MC kin. weighting (data sample size)	0.011	0.017	0.014	0.014	0.005	0.003	0.008
MC sample size	0.047	0.090	0.121	0.039	0.016	0.013	0.037
Value of α_Λ	0.009	0.023	0.023	0.019	0.005	0.001	0.014
Total	0.064	0.130	0.147	0.086	0.028	0.020	0.061

Comparison between MC and data