Properties and spectroscopy of b-hadrons with the ATLAS detector

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Outline

- The ATLAS experiment at LHC
- Study of the properties of the Λ^0_b baryon.
  - Measurement of Λ^0_b lifetime and mass
  - Measurement of Λ^0_b helicity amplitudes and parity violating asymmetry parameter α_B
- Observation of a new χ_b state in radiative transitions to $\Upsilon(1S)$ and $\Upsilon(2S)$
- Summary and outlook

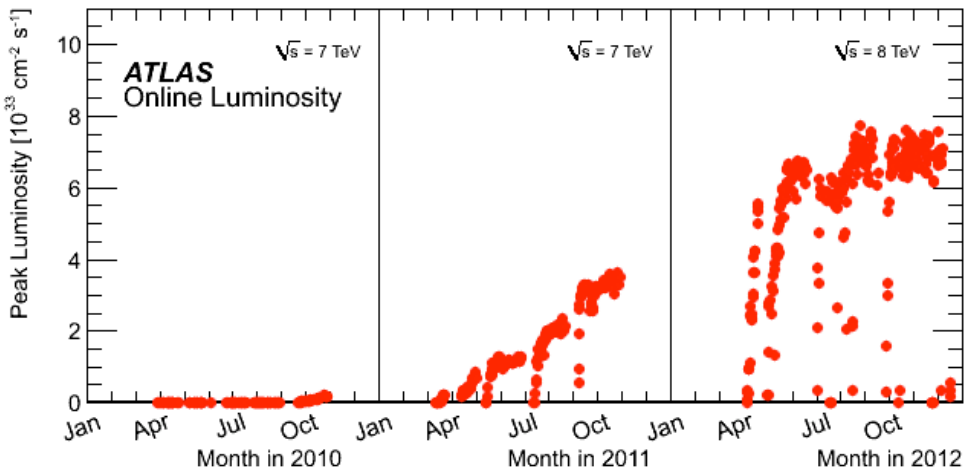
ATLAS collaboration: Phys.Rev.D **87**, 032002 (2013)

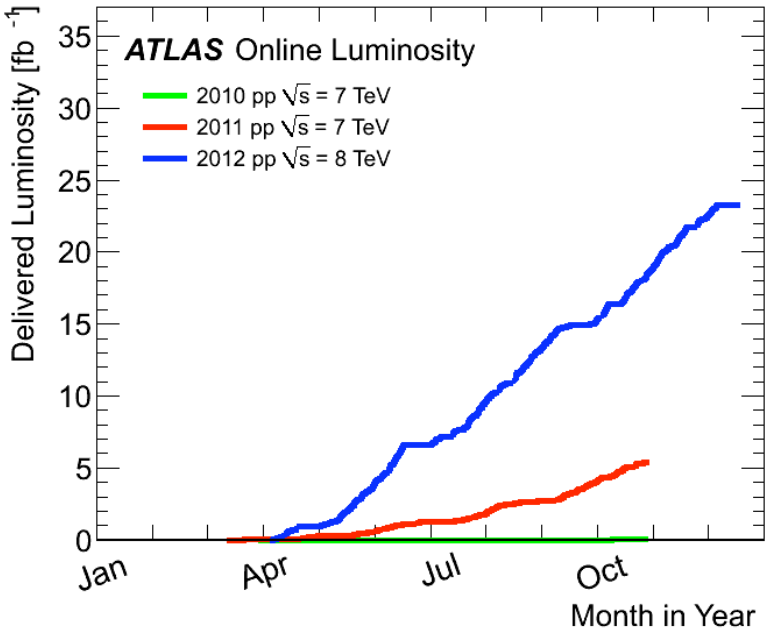
ATLAS collaboration: ATLAS-CONF-2013-071

ATLAS collaboration: Phys.Rev.Lett.**108**, 152001 (2012)

The ATLAS experiment at LHC - I

- The ATLAS experiment has been running at LHC from 2010 to 2013 collecting 26.4 fb^{-1} pp collisions at $\sqrt{s} = 7$ and 8 TeV.
- The data presented here are based on the 2011 data taking:
  - $\sqrt{s} = 7$ TeV, Luminosity up to $4 \times 10^{33} cm^{-2} s^{-1}$
  - $L_{int} = 4.4 \div 4.9\ fb^{-1}$, <pile-up> up to 15.

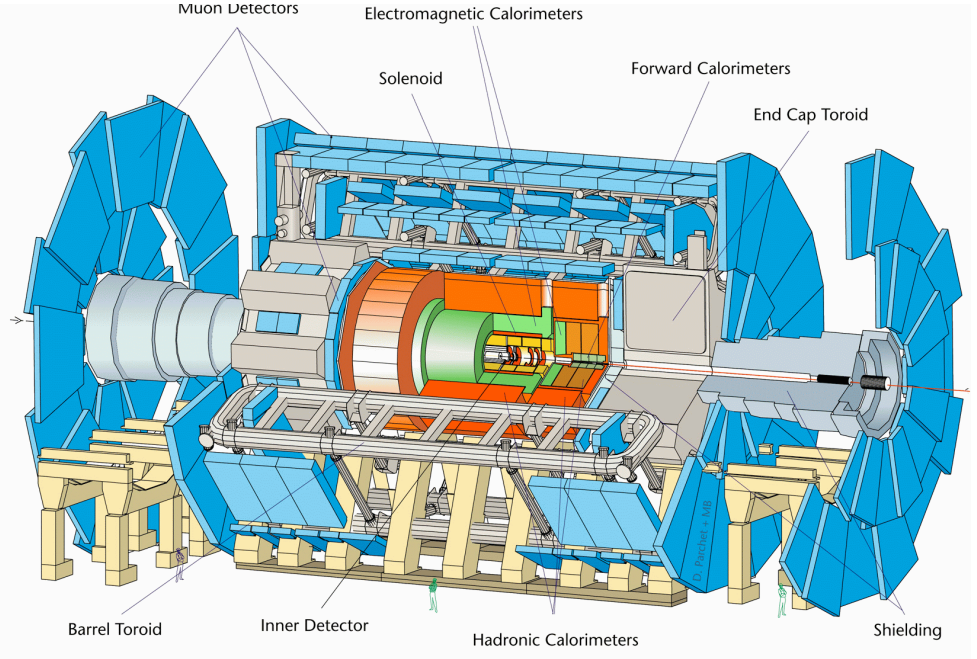


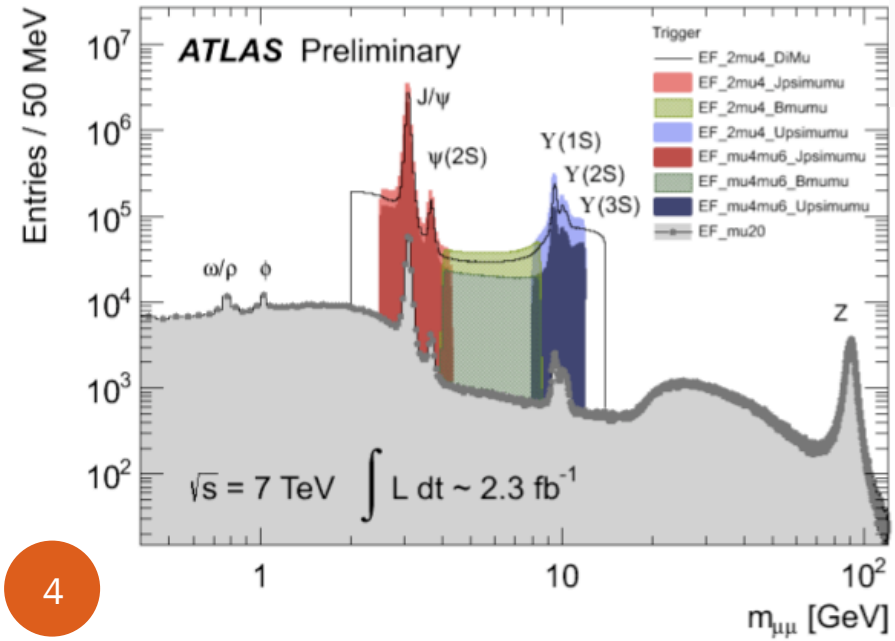


The ATLAS experiment at LHC - II

ATLAS is a general purpose detector.
For the results of this talk:

- Muon detection (MS + ID)
- Vertexing (ID)
- Photon reconstruction (ECAL)





B-physics triggers:

- SingleMuon & DiMuon (p_T thr. 4 ÷ 40 GeV)
- Opposite charge muons
- Loose Mass cuts:

J/ψ: $2.5 < M(\mu\mu) < 4.3$ GeV

B: $4.0 < M(\mu\mu) < 8.5$ GeV

Υ: $8.0 < M(\mu\mu) < 12$ GeV

Study of the properties of the Λ^0_b baryon

- Λ^0_b is the lightest b-baryon:
  - $I(J^P)=0(1/2^+)$
  - valence quark composition: ***u d b***
  - main decay mode (weak decay): $\Lambda^0_b \rightarrow J/\psi(1S)\ \Lambda^0$
- Produced in the fragmentation of the b-quark at hadron colliders ➔ measurement of properties:
  - Mass
  - Lifetime (including ratio $\tau_{\Lambda b}/\tau_{Bd}$)
  - helicity amplitudes ➔ parity violating asymmetry α_B.
- Comparison with several HF models
  - heavy quark expansion (predictions on $\tau_{\Lambda b}/\tau_{Bd}$)
  - pQCD vs. HQET (predictions on α_B)

Λ^0_b selection and reconstruction

Cascade topology → 2 vertices, 4 tracks.

Trigger:

single-muon, dimuon and J/ψ

mostly 2muons $p_T > 4$ GeV $M \approx M_{J/\psi}$

Pre-selection:

J/ψ and Λ vertices loosely selected

Reconstruction:

kinematic fit with mass and vertex constraints ($N_{dof} = 6$)

Final selection:

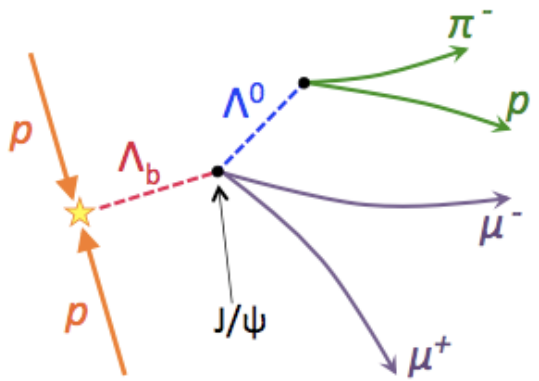
$\chi^2/N_{dof} < 3$

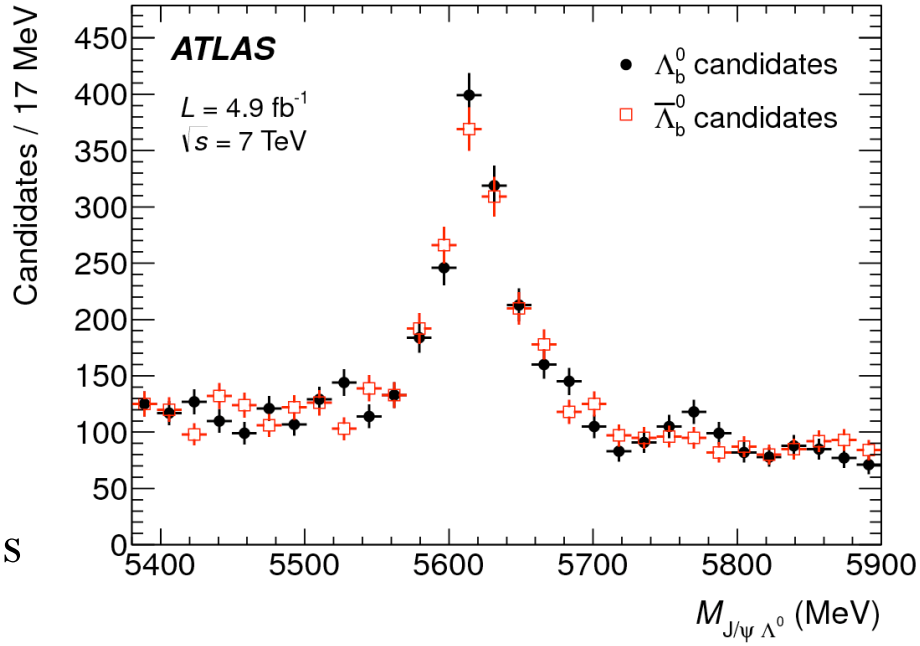
$p_{T,\Lambda} > 3.5$ GeV; $L_{xy,\Lambda} > 10$ mm

5.38 GeV $< m_{J/\psi\Lambda} <$ 5.90 GeV

$P_{\Lambda b} - P_{Bd} > 0.05$

→ 4074 Λ^0_b and 4081 $\overline{\Lambda}^0_b$ candidates





Λ^0_b mass and lifetime fit

For each event: $m_{J/\psi\Lambda}$ and τ

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

L_{xy} distance from PV (the one closest to Λ^0_b trajectory)

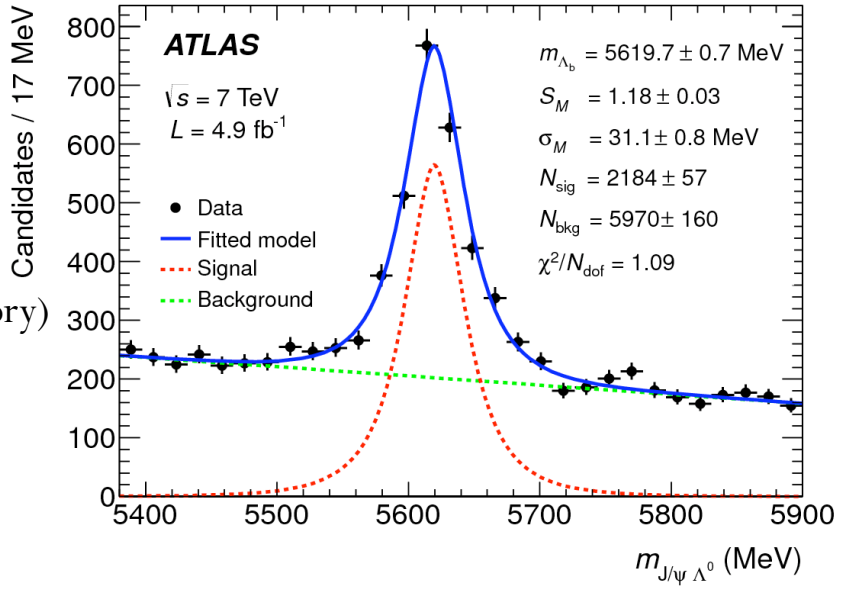
Unbinned maximum likelihood combined fit to the mass and lifetime distributions

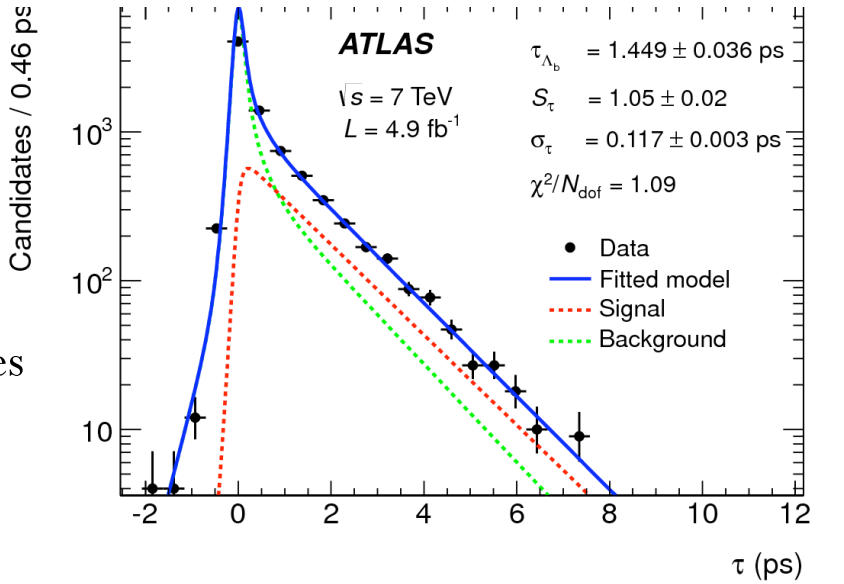
Background components:

- prompt (J/ψ from pp + accidental Λ vertex)
- nonprompt (J/ψ from b and K_S misidentified)

Free parameters:

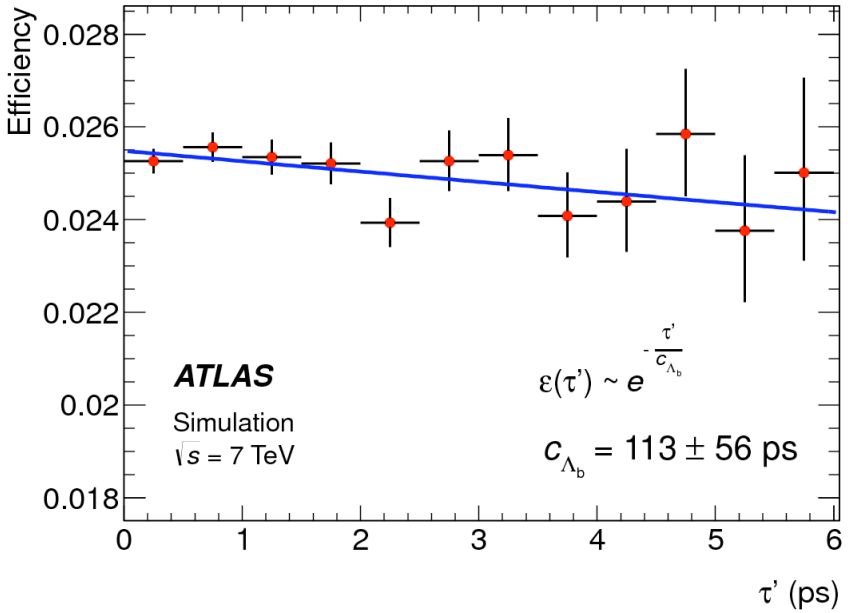
- $m_{\Lambda b}$, $t_{\Lambda b}$, f_{sig} for the signal
- S_m, S_τ error scale factors
- 7 parameters describing the background shapes





Fit results and systematics

Parameter	Value
$m_{\Lambda b}$ (MeV)	5619.7 ± 0.7
$\tau_{\Lambda b}$ (ps)	1.449 ± 0.036
N_{sig}	2184 ± 57
N_{bkg}	5970 ± 160
σ_m (MeV)	31.1 ± 0.8
χ^2/N_{dof}	$66.5 / 61$



Main sources of systematic errors:

Selection/reco. bias	12 fs	0.9 MeV
Background fit models	9	0.2
Bd contamination	7	0.2
Residual misalignment	1	-
Extra material	3	0.2
Tracking pT scale	-	0.5
➔ total (quadratic sum)	17 fs	1.1 MeV

B_d mass and lifetime fit results

Same analysis applied to B_d decay chains:

$B_d \rightarrow J/\psi(\mu^+\mu^-)\, K_S(\pi^+\pi^-)$

Cross-check of results and denominator for the lifetime ratio.

Results:

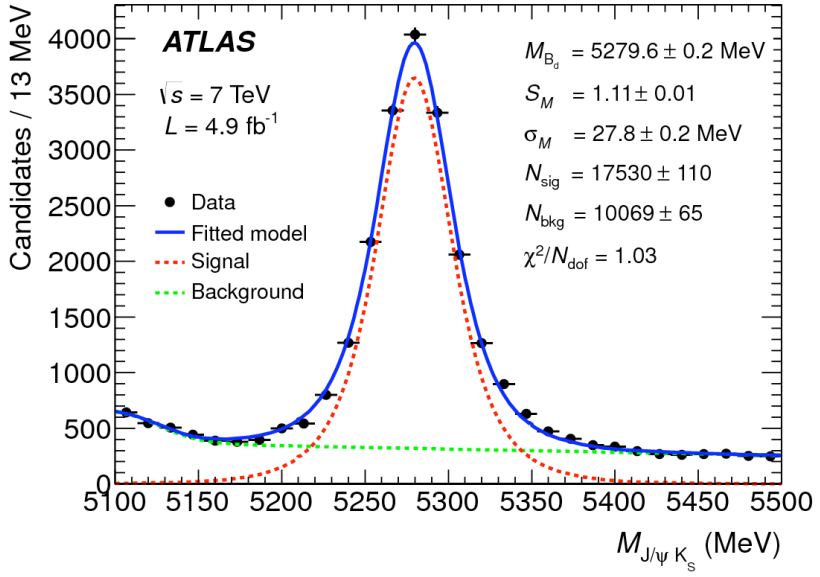
$m_{Bd} = 5279.6 \pm 0.2(\text{stat}) \pm 1.0(\text{syst})$ MeV

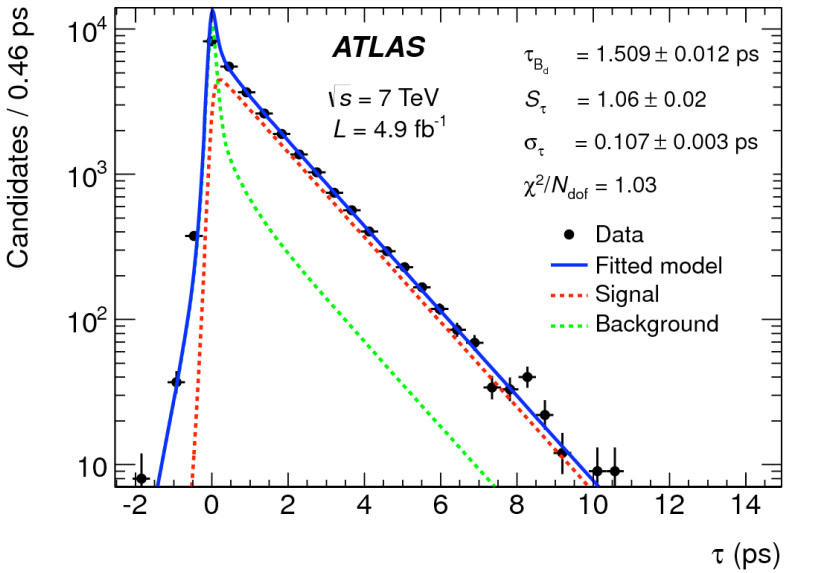
$\tau_{Bd} = 1.509 \pm 0.012(\text{stat}) \pm 0.018(\text{syst})$ ps

To be compared to PDG

$m_{Bd} = 5279.50 \pm 0.30(\text{stat})$ MeV

$\tau_{Bd} = 1.519 \pm 0.007(\text{stat})$ ps





Λ^0_b results on mass and lifetime

Parameter	ATLAS result	comparisons
$m_{\Lambda b}$ (MeV)	**5619.7 ± 0.7(stat) ± 1.1(syst)**	5619.4 ± 0.7 **(PDG)** 5619.19 ± 0.70(stat) ± 0.30(syst) **(LHCB)**
$\tau_{\Lambda b}$ (ps)	**1.449 ± 0.036(stat) ± 0.017(syst)**	1.425 ± 0.032 **(PDG)** 1.503 ± 0.052(stat) ± 0.031(syst) **(CMS)**
$R = \tau_{\Lambda b}/\tau_{Bd}$	**0.960 ± 0.025(stat) ± 0.016(syst)**	0.864 ± 0.052(stat) ± 0.033(syst) **(D0)** 1.020 ± 0.030(stat) ± 0.008(syst) **(CDF)** 0.88 ÷ 0.97 **(HQ expansion)** 0.86 ÷ 0.88 (±0.05) **(QCD – NLO)**

The ATLAS results on mass and lifetime are in good agreement with previous experiments;

The result on the ratio lies between D0 and CDF "conflicting" (2.3 σ) results and is in good agreement with Heavy Quark expansion models.

Parity violation in Λ^0_b decay - I

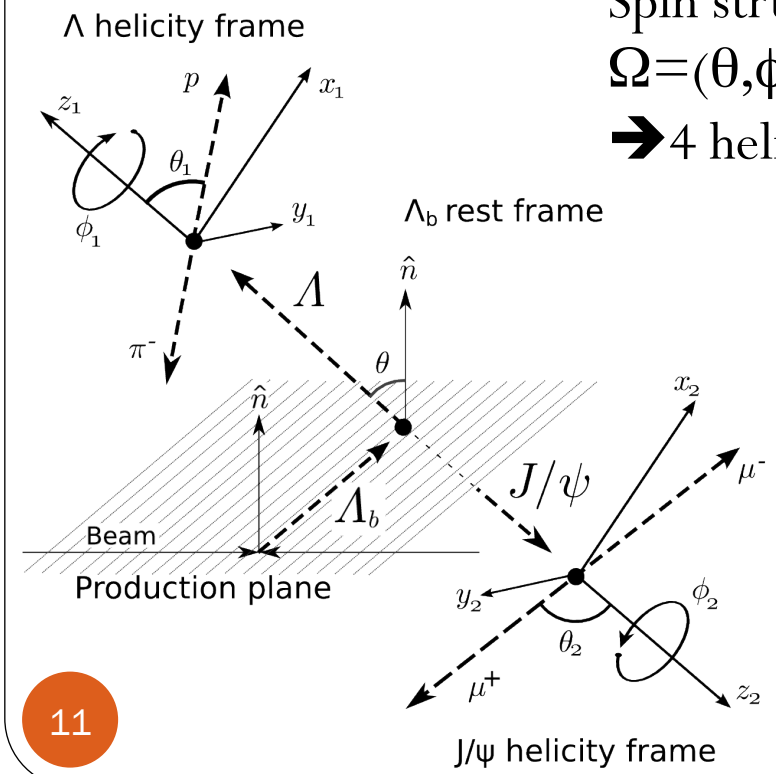
One of the first measurements of P-violation in weak decays was in the $\Lambda^0 \rightarrow p\pi^-$ decay

➔ α_Λ parameter ≈ 65% $[d\Gamma(\theta) \approx (1+\alpha_\Lambda \cos\theta) d\cos\theta]$

The same measurement can be done for Λ^0_b using the decay $\Lambda^0_b \rightarrow J/\psi \Lambda^0$

Predictions on α_b parameter easier due to the larger energy release in b-decay:

pQCD vs. HQET give different predictions.



Spin structure of decay:

$\Omega = (\theta, \phi, \theta_1, \phi_1, \theta_2, \phi_2)$

➔4 helicity amplitudes

	a_+	a_-	b_+	b_-
$h(J/\psi)$	0	0	-1	1
$h(\Lambda^0)$	1/2	-1/2	-1/2	1/2

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

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

Angular distributions described by 20 amplitudes

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

helicity amplitudes are free parameters,

$F_i(\Omega)$ are the measurements: ➔ Fit

Parity violation in Λ^0_b decay - II

Event selection: same as in the main Λ^0_b analysis plus specific requirements aiming to reduce background (cleaner sample):

B^0_d veto: $P(\Lambda^0_b) > P(B^0_d)$

$\tau(\Lambda^0_b) > 0.35$ ps

$5560 < M(J/\psi\Lambda^0) < 5680$ MeV

➔ 1548 Λ^0_b (and $\overline{\Lambda}^0_b$) candidates

Background components:

combinatorial: real or fake J/ψ and Λ^0

randomly combined to form a Λ^0_b topology

peaking: mainly B^0_d decays.

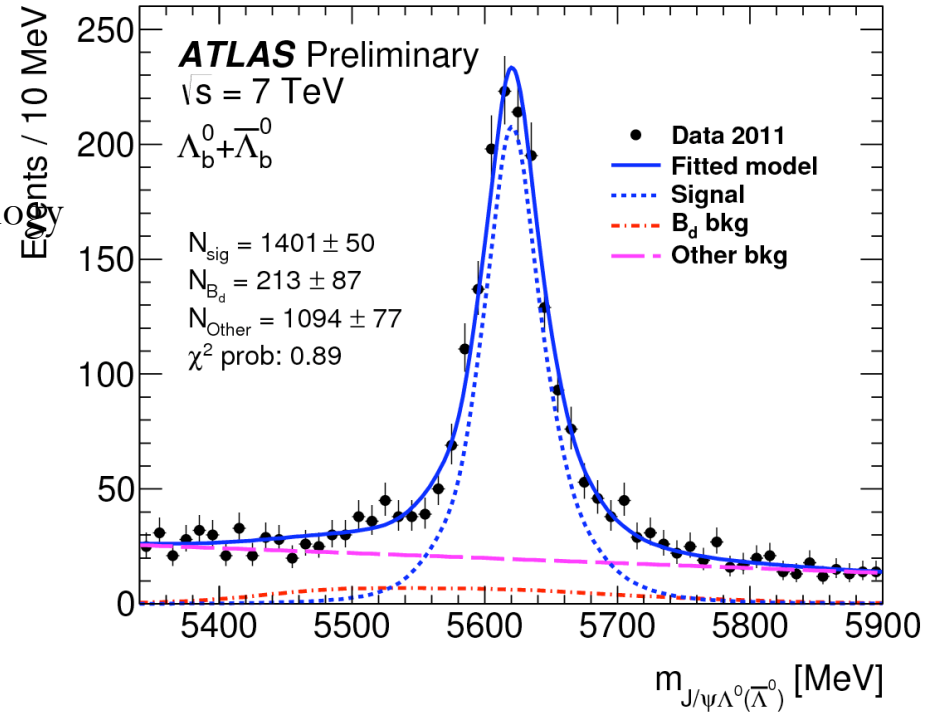
Fit:

evaluate the average $\langle F_i \rangle$ from the data;

evaluate the expected $\langle Fi \rangle$ based on

parameters and detector response;

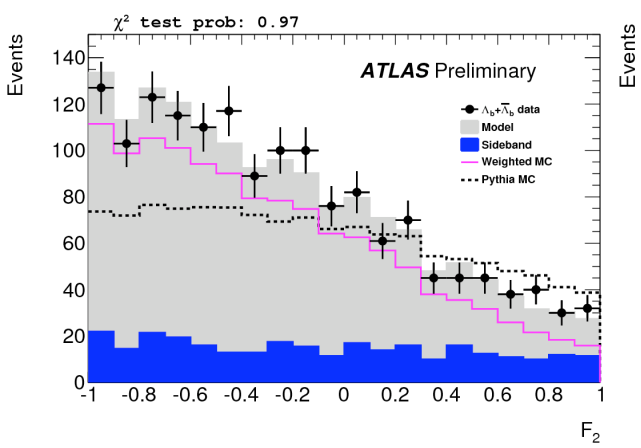
Least square fit ➔ amplitudes

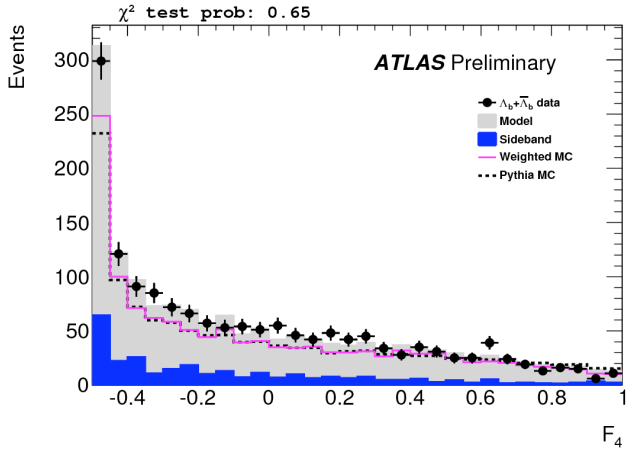


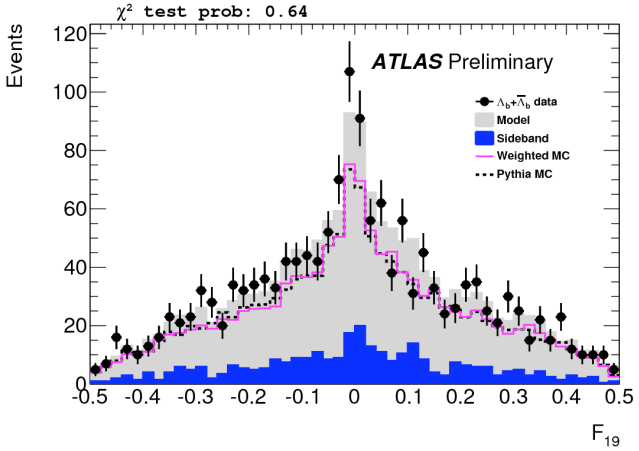
Results on parity violation - I

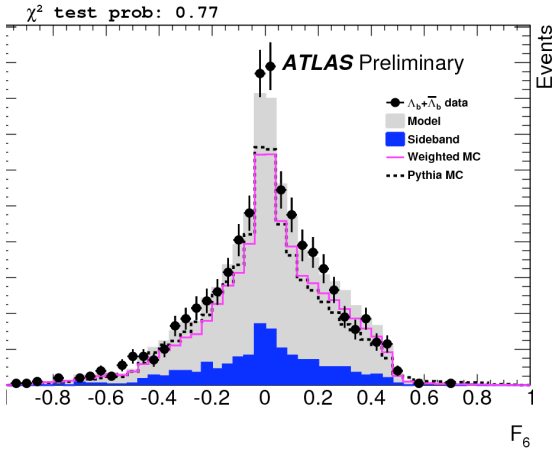
P=0 in pp collisions ➔ only 5 amplitudes survive: F_i, i=1,5
Distributions of these functions from data compared to results of the fit.

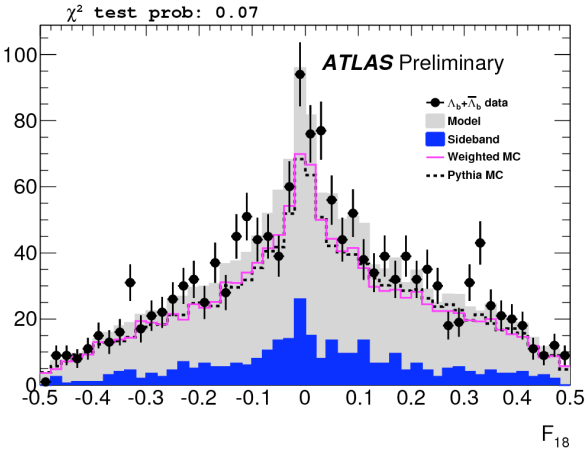
(points) data
(magenta line) weighted MC
using fitted amplitudes
(blue histo) background
(gray histo) signal + bkg
the "model"











Results on parity violation - II

- Fit results:

$$\alpha_b = 0.28 \pm 0.16 \pm 0.06$$
$$|a_+| = 0.17^{+0.12}_{-0.17} \pm 0.06$$
$$|a_-| = 0.59^{+0.06}_{-0.07} \pm 0.04$$
$$|b_+| = 0.79^{+0.04}_{-0.05} \pm 0.02$$
$$|b_-| = 0.08^{+0.13}_{-0.08} \pm 0.05$$

- A parity violation of 28% is observed (less than 2 σ from 0)
- Decay dominated by the a_- and b_+ amplitudes (h(Λ^0)=-1/2)
- Comparison with theory:
  - pQCD ➔ α_b =-(0.14÷0.18) $\approx$2.5 σ discrepancy
  - HQET ➔ α_b = 0.78 $\approx$2.9 σ discrepancy
- Agreement with recent LHCb result: $\alpha_b = 0.05 \pm 0.17 \pm 0.07$

Observation of a New χ_b state - I

- $\chi_b = b\bar{b}$ states with parallel spins and P-wave → J=0,1,2.
- The first two radial excitations χ_b(1P) and χ_b(2P) well identified.
- A third radial excitation χ_b(3P) expected to be close to the $B\bar{B}$ threshold ($M_{exp} \approx 10.52$ GeV)
- Unique insight into the nature of QCD close to the strong decay threshold.
- Search of χ_b(nP) in radiative transitions:
  - χ_b(nP) → Υ(1S)γ
  - χ_b(nP) → Υ(2S)γ

  looking for Υ(1S) → $\mu^+\mu^-$ and a photon (converted or not).

Observation of a New χ_b state - II

Event selection:

Muon and diMuon triggers;

Step-1: $\Upsilon(1S) \rightarrow \mu^+\mu^-$ selection

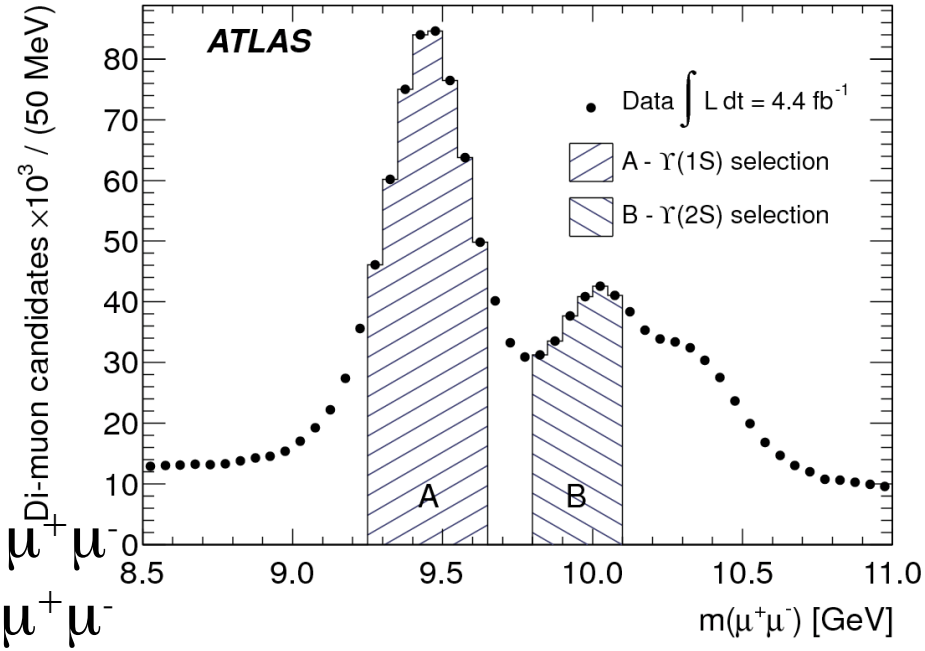
pair of opposite charge muons

$p_T > 4$ GeV, $|\eta| < 2.3$

$p_T(\mu\mu) > 12$ GeV, $|\eta_{\mu\mu}| < 2.0$

A) $9.25 < m_{\mu\mu} < 9.65$ GeV $\rightarrow \Upsilon(1S) \rightarrow \mu^+\mu^-$

B) $9.80 < m_{\mu\mu} < 10.10$ GeV $\rightarrow \Upsilon(2S) \rightarrow \mu^+\mu^-$



Step-2: photon reconstruction

→ converted photons ($|\eta| < 2.30$):

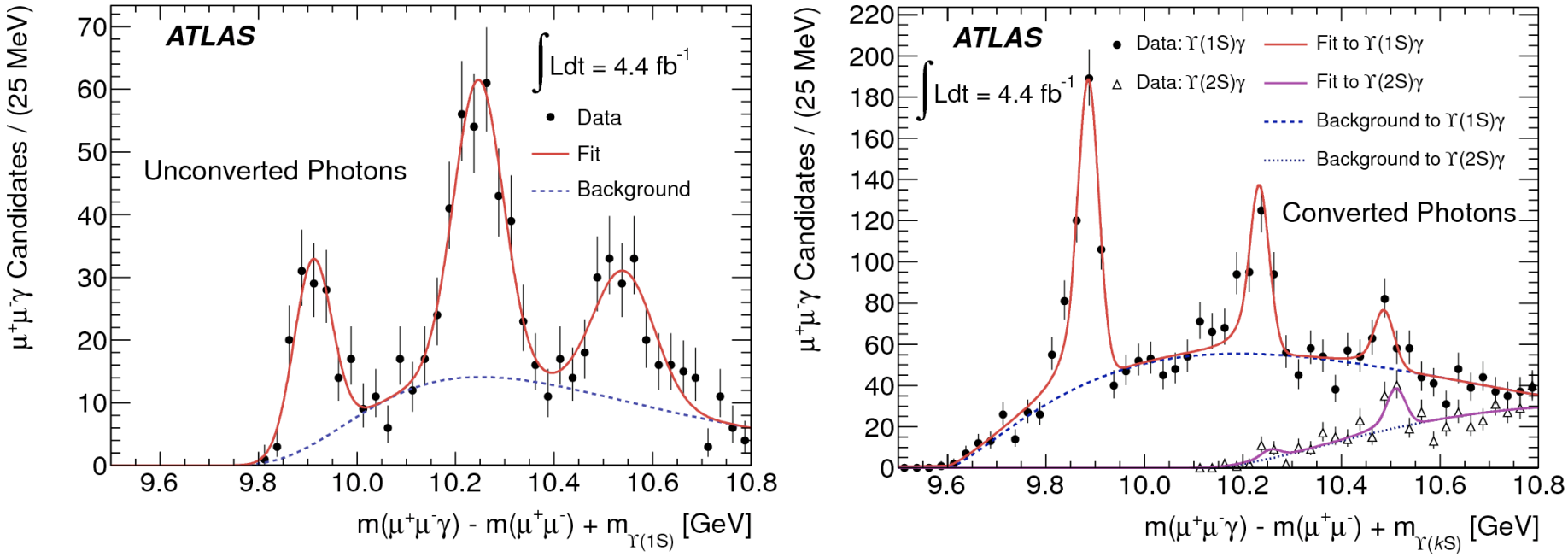
2 ID oppositely charged tracks with a vertex constrained to have 0 angle.

→ unconverted photons ($|\eta| < 2.36$):

deposits in the ECAL not matched to any track; vertex constraint.

For each candidate event: $\Delta m = m(\mu^+\mu^+\gamma) - m(\mu^+\mu^-)$

Observation of a New χ_b state - III



Separate fits of the unconverted and converted photon mass distributions.

state	Fitted mass (unconverted)	Fitted mass (converted)
χ_b (1P)	9910 ± 6(stat) ± 11(syst)	fixed: χ_{b1} =9892.78; χ_{b2} =9912.21
χ_b (2P)	10246 ± 5(stat) ± 18(syst)	fixed: χ_{b1} =10255.46; χ_{b2} =10268.65
χ_b (3P)	**10541 ± 11(stat) ± 30(syst)**	**10530 ± 5(stat) ± 8(syst)**

Summary and outlook

Λ^0_b physics:

mass and lifetime aligned with PDG values and HQET predictions

parity violation parameter α_b interesting

new analysis on higher statistics to reduce error

Study of exclusive decays in progress

χ_b physics:

New state $\chi_b(3P)$ observed

production cross-section measurement in progress

extension to 2012 data to improve error on mass

and discriminate J=0,1,2 states.

Several other published/ongoing analyses:

b-hadrons production cross-section from $D^*\mu X$ final states

Inclusive B^+ production cross-section @ $\sqrt{s}$=7 TeV

Excited B meson spectroscopy