b-baryon mass measurements at LHCb

La Thuile 2013

Les Rencontres de Physique de la Vallée d'Aoste

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Outline

- Motivations for heavy quark hadron spectroscopy
- Experimental status before LHCb

Mass measurements of Λ_b^0, Ω_b^- and Ξ_b^- at LHCb with 1 fb^{-1} reconstructing $\Lambda_b^0 \to J/\psi\,\Lambda$, $\Omega_b^- \to J/\psi\,\Omega^-$ and $\Xi_b^- \to J/\psi\,\Xi^-$

- Momentum scale calibration
- Candidate selection
- Fits
- Systematic uncertainties
- Results

[arXiv:1302.1072]
[LHCb-PAPER-2012-048]

- Summary and plans

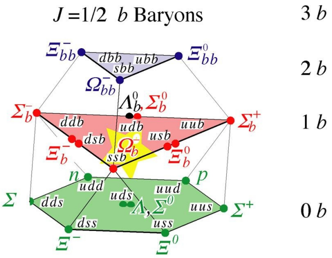
Motivations for heavy quark hadron spectroscopy

Different QCD models predict masses, lifetimes, branching ratios, spin-parity etc. for many c- and b-hadrons.

Further confirmation and testing of models of the heavy quark interactions is provided by c- and b-hadron spectroscopy

b-baryon status: 16 predicted ground states ($J = 1/2$ and $3/2$)

- Weakly decaying: Λ_b^0, Ξ_b^- and Ω_b^- baryons observed
- Strongly decaying: only charged $\Sigma_b^{\pm}$ observed
- Some first excited states seen: eg. Λ_b^{*0} at LHCb[1]



[1] Phys. Rev. Lett. 109:172003 (2012)

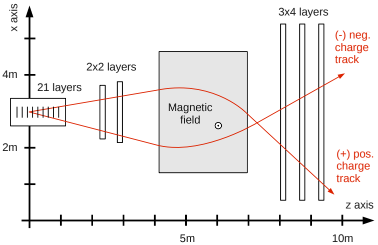
Previous Ξ_b^- and Ω_b^- mass measurements

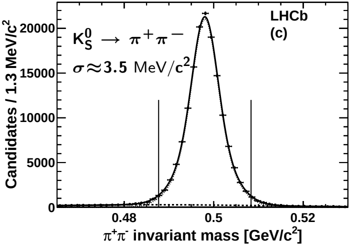
- CDF and D0 measured both Ξ_b^- and Ω_b^- baryon masses with a precision of several MeV/c^2.
- Agreement for Ξ_b^- but significant inconsistency regarding the Ω_b^- mass.

	Value measured or predicted for $M_{\Omega_b^-}$			
D0[2]	6165	$\pm$ 10	$\pm$ 13	MeV/c^2
CDF[3]	6054.4	$\pm$ 6.8	$\pm$ 0.9	MeV/c^2
Theory[4]	6052.1	$\pm$ 5.6		MeV/c^2

- D0 measurement of Ω_b^- mass is more than 6 standard deviations away from the CDF one and only the CDF value is in agreement with main QCD models !
- Today, LHCb can measure these masses with a precision at the MeV/c^2 level.

[2] Phys. Rev. Lett. 101:232002 (2008)
[3] Phys. Rev. D80:072003 (2009)
[4] Annals Phys. 324:2-15 (2009)



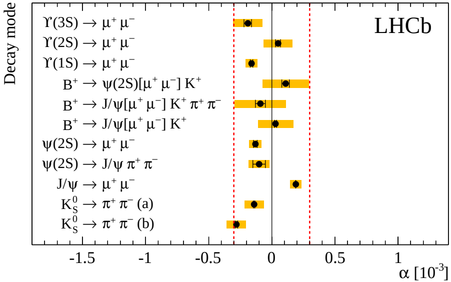


- High precision mass measurements require good momentum measurement of the final state tracks.
- Thanks to its geometry and the excellent tracking devices, the LHCb detector has a very good momentum resolution.
- The two limitations are
  - Field map of 4 Tm dipole magnet known with finite precision
  - Detector alignment is never perfect

→ The track momentum measurement needs to be calibrated and the residual bias evaluated.

Momentum scale calibration for 2011 data at LHCb

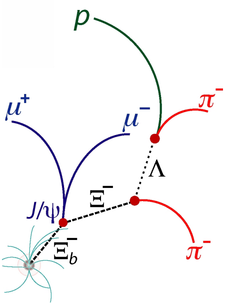
- Time dependence from $J/\psi \to \mu^+\mu^-$ (12 periods)
- Absolute momentum scale calibrated on $B^+ \to J/\psi K^+$ (high statistics, J/ψ mass constraint $\to$ main dependence on K^+)
- In bins of track slopes (p_x/p_z and p_y/p_z) of the K^+ track

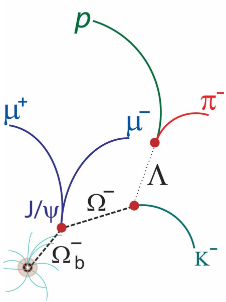


- Figure: residual bias evaluated with other resonances (multiplying the momentum of every final state track by $(1-\alpha)$ shifts the reconstructed invariant mass to the PDG 2012 mass)
- Assigned error on momentum scale: $\alpha_{max} = \pm 0.3 \times 10^{-3}$

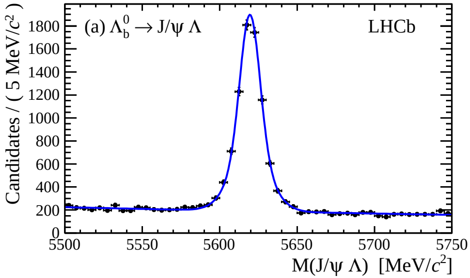
Cut based selection

- Λ_b^0 selection based on selection with 2010 data
- Other two selections optimized using relative yield estimate from CDF and D0
- Ξ_b^- and Ω_b^- selections almost identical
- Take advantage of decay topology and cut on flight distance





- In all three cases use tracks with and without vertex detector information



Signal: two Gaussian functions with common mean

Yield: 6870 ± 110 (stat)

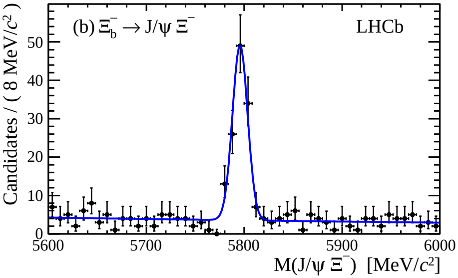
Widths: $\sigma_1 = 6.4 \pm 0.5$ (stat) MeV/c^2

$\sigma_2 = 12.5 \pm 1.3$ (stat) MeV/c^2

Mass: 5619.53 ± 0.13 (stat) MeV/c^2

Background: exponential function

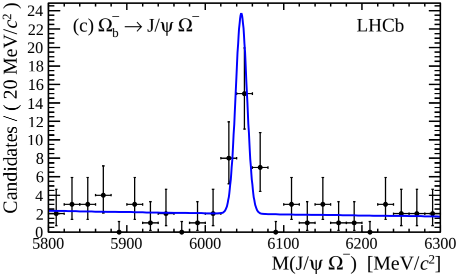
$\Xi_b^- \to J/\psi\, \Xi^-$ mass measurement - fit



Signal: single Gaussian function

Yield: 111 ± 12 (stat)
Width: 7.8 ± 0.7 (stat) MeV/c^2
Mass: 5795.8 ± 0.9 (stat) MeV/c^2

Background: exponential function



Signal: single Gaussian function with fixed width

Significance: $> 6\sigma$

Yield: 19 ± 5 (stat)

Width: $7.2\ \mathrm{MeV}/c^2$ (fixed to Ξ_b^- width scaled by MC ratio)

Mass: 6046.0 ± 2.2 (stat) MeV/c^2

Background: exponential function

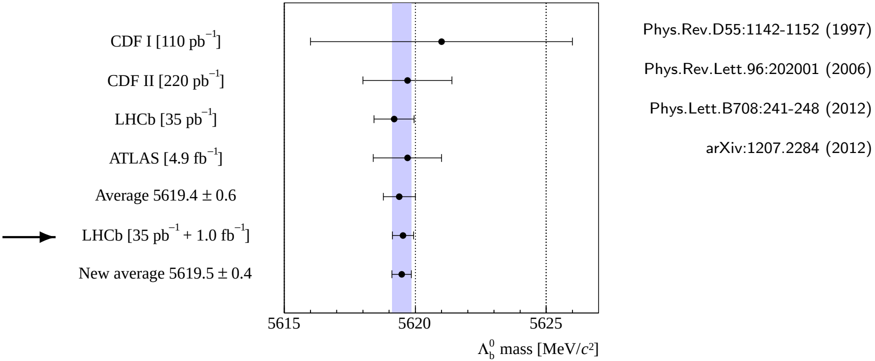
Systematic uncertainties

- Fits and candidate reconstruction repeated with different conditions (momentum scale, energy loss correction, fit parameters, etc.)
- Difference with respect to nominal fit taken as systematic uncertainty
- Summary table in MeV/c^2 :

Source	Λ_b^0	Ξ_b^-	Ω_b^-	$\Xi_b^- - \Lambda_b^0$	$\Omega_b^- - \Lambda_b^0$
Momentum scale	0.43	0.43	0.31	0.01	0.12
dE/dx correction	0.09	0.09	0.09	0.01	0.01
Hyperon mass	0.01	0.07	0.25	0.07	0.25
Signal model	0.07	0.01	0.24	0.07	0.25
Background model	0.01	0.01	0.02	0.01	0.02
Total	0.45	0.45	0.47	0.10	0.37

- Biggest systematic uncertainty from momentum calibration
- In mass differences, the hyperon mass constraint and signal model become important

Λ_b^0 final result



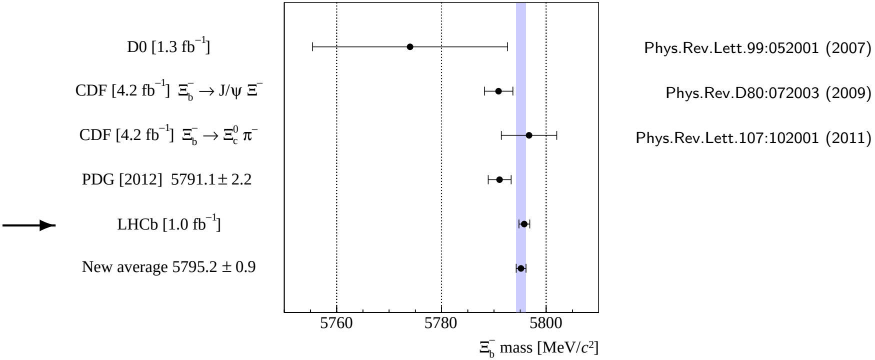
LHCb measurement (1 fb^{-1})

$$M(\Lambda_b^0) = 5619.53 \pm 0.13\ (\text{stat}) \pm 0.45\ (\text{syst})\ \text{MeV}/c^2$$

Combining with previous LHCb result (35 pb^{-1})

$$M(\Lambda_b^0) = 5619.44 \pm 0.13\ (\text{stat}) \pm 0.38\ (\text{syst})\ \text{MeV}/c^2$$

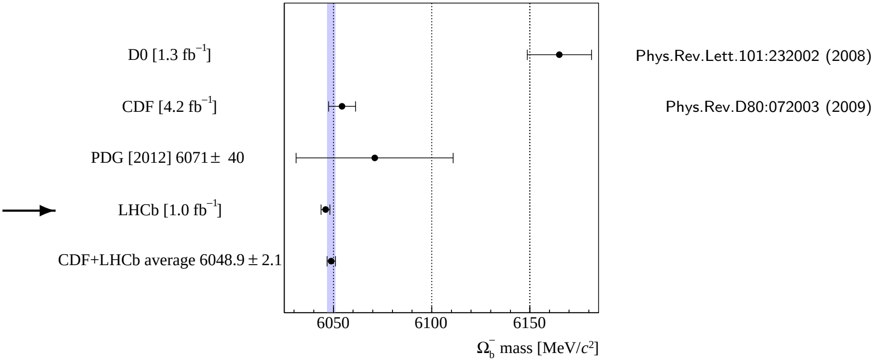
Ξ_b^- final result



LHCb measurement (1 fb^{-1})

$$M(\Xi_b^-) = 5795.8 \pm 0.9\ (\mathrm{stat}) \pm 0.4\ (\mathrm{syst})\ \mathrm{MeV}/c^2$$
$$M(\Xi_b^-) - M(\Lambda_b^0) = 176.2 \pm 0.9\ (\mathrm{stat}) \pm 0.1\ (\mathrm{syst})\ \mathrm{MeV}/c^2$$

Ω_b^- final result



LHCb measurement (1 fb^{-1})

$$M(\Omega_b^-) = 6046.0 \pm 2.2\,(\text{stat}) \pm 0.5\,(\text{syst})\ \text{MeV}/c^2$$
$$M(\Omega_b^-) - M(\Lambda_b^0) = 426.4 \pm 2.2\,(\text{stat}) \pm 0.4\,(\text{syst})\ \text{MeV}/c^2$$

Summary and plans

- LHCb gives the most precise Λ_b^0, Ξ_b^- and Ω_b^- mass measurements to date.
- Λ_b^0 and Ξ_b^- results in agreement with previous measurements.
- Ω_b^- result in agreement with CDF measurement, but in disagreement with D0 measurement.
- LHCb has also performed high precision mass measurements of other long-lived b-hadrons like B^+, B^0, B_s[5] and B_c[6].
- Soon new measurements with b-baryons including 2011+2012 data (1 fb^{-1}+2 fb^{-1}): Λ_b^0, Ξ_b^- and Ω_b^- lifetimes.
- Excellent prospects for further spectroscopy at LHCb in the years to come: expect additional 5 fb^{-1} at least by 2017 with a b-hadron production cross section twice as large.

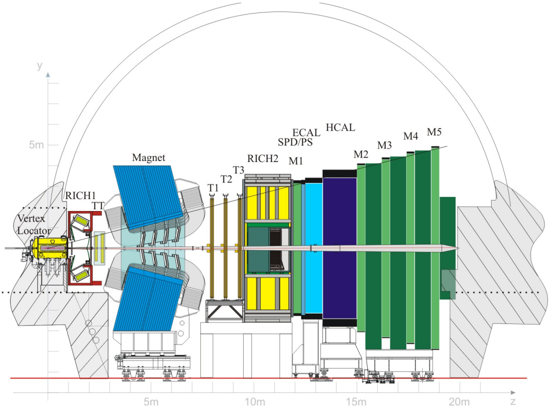
[5] Phys.Lett.B708:241-248,2012

[6] Phys.Rev.Lett.109:232001,2012, presented in Lucio Anderlini's talk

Thank you for your attention

BACKUP SLIDES

The LHCb experiment at CERN



- LHCb - single-arm forward spectrometer at the LHC
- Recording *pp* collisions with $\sqrt{s} = 7$ TeV (in 2011) and 8 TeV (in 2012)
- Optimized for measurements in heavy-flavour physics
- Comprizes tracking detectors, RICH detectors, calorimeters and muon chambers.
- The tracking system: Vertex Locator (VeLo), Tracker Turicensis (TT), Inner-Tracker (IT) and Outer Tracker (OT)

Theoretical predictions I

Modelling color hyperfine (HF) interactions (Annals Phys.324:2-15,2009)

- $\mathrm{M}(\Xi_b^-) = 5795 \pm 5\ \mathrm{MeV}/c^2$
- $\mathrm{M}(\Omega_b^-) = 6052.1 \pm 5.6\ \mathrm{MeV}/c^2$

QCD sum rule approach in the Heavy Quark Effective Theory (HQET) framework (Phys.Rev.D77:014031,2008)

- $\mathrm{M}(\Lambda_b^0) = 5637^{+68}_{-56}\ \mathrm{MeV}/c^2$
- $\mathrm{M}(\Xi_b^-) = 5780^{+73}_{-68}\ \mathrm{MeV}/c^2$
- $\mathrm{M}(\Omega_b^-) = 6036 \pm 81\ \mathrm{MeV}/c^2$

Sum rule approach in full QCD (Phys.Rev.D78:094015,2008)

- $\mathrm{M}(\Lambda_b^0) = 5690 \pm 130\ \mathrm{MeV}/c^2$
- $\mathrm{M}(\Xi_b^-) = 5750 \pm 130\ \mathrm{MeV}/c^2$
- $\mathrm{M}(\Omega_b^-) = 5890 \pm 180\ \mathrm{MeV}/c^2$

Theoretical predictions II

$1/N_c$ expansion (Phys.Rev.D77:034012,2008)

- $\mathrm{M}(\Omega_b^-) = 6039.1 \pm 8.3\ \mathrm{MeV}/c^2$

Lattice Non-Relativistic QCD (NRQCD) (Phys.Rev.D66:014502,2002)

- $\mathrm{M}(\Lambda_b^0) = 5680 \pm 110\ \mathrm{MeV}/c^2$
- $\mathrm{M}(\Xi_b^-) = 5780 \pm 100\ \mathrm{MeV}/c^2$
- $\mathrm{M}(\Omega_b^-) = 6030 \pm 90\ \mathrm{MeV}/c^2$

Heavy-quark–light-diquark approximation within the constituent quark model (Phys.Rev.D72:034026,2005)

- $\mathrm{M}(\Lambda_b^0) = 5622 \pm 100\ \mathrm{MeV}/c^2$
- $\mathrm{M}(\Xi_b^-) = 5812 \pm 100\ \mathrm{MeV}/c^2$
- $\mathrm{M}(\Omega_b^-) = 6065 \pm 100\ \mathrm{MeV}/c^2$

(Universal) quark-constituent model (arXiv:1205.6918)

Results only given in figure.