Heavy flavour spectroscopy at LHCb

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Outline

- Motivation and status
- The LHCb experiment at CERN
- Mass measurements of Λ_b^0, Ω_b^-, Ξ_b^- and Ξ_b^0
- First observation of excited Λ_b^0 baryons
- Observation of excited D_{sJ} mesons
- Summary and plans

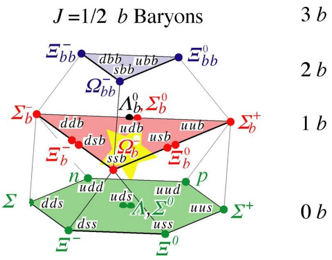
Motivations for heavy quark hadron spectroscopy

Different QCD models predict different 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

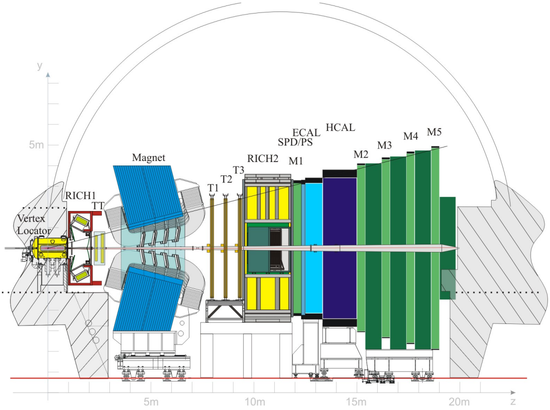
- Weakly decaying: Λ_b^0, Ξ_b^0, Ξ_b^- and Ω_b^- baryons observed
- Strongly decaying: only charged $\Sigma_b^\pm$ observed
- Some first excited states seen



c-meson status:

- Remaining puzzles in $c\bar{s}$ states

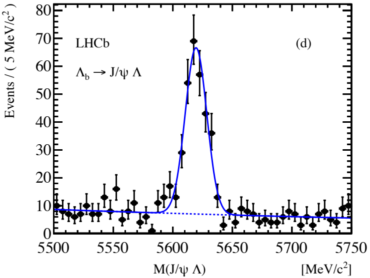
The LHCb experiment at CERN



- 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)

Mass measurements at LHCb

- Many mass measurements performed at LHCb
- Good mass resolution
- Example: currently world best Λ_b^0 mass measurement with 35 pb^{-1} of 2010 data[1].



LHCb Λ_b^0 mass measurement

$$M(\Lambda_b^0) = 5619.19 \pm 0.70\ (\text{stat}) \pm 0.30\ (\text{syst})\ \text{MeV/c}^2$$

Also recent ATLAS measurement[2]

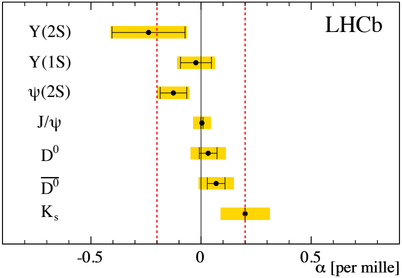
$$M(\Lambda_b^0) = 5619.7 \pm 0.7(\text{stat}) \pm 1.1(\text{syst})\ \text{MeV/c}^2$$

$\rightarrow$ Consistent with the LHCb value.

[1] Physics Letters B 708 (2012) 241
[2] ATLAS-CONF-2012-055

Momentum calibration at LHCb

- Crucial ingredient for mass measurements is momentum scale calibration.



- Momentum scaled by factor $1 - \alpha$ such that the invariant mass of $J/\psi \to \mu^+\mu^-$ is reconstructed at the PDG value.
- Systematics evaluated by the spread in calibration of other well known two-body decays (D^0, K_S^0, etc.).

Ξ_b^- and Ω_b^- mass measurements

Before the first LHCb measurement, both Ξ_b^- and Ω_b^- baryons have been observed but there was a very significant inconsistency regarding the Ω_b^- mass.

	Value measured or predicted for $M_{\Omega_b^-}$			
DØ[3]	6165	$\pm$ 10	$\pm$ 13	MeV/c^2
CDF[4]	6054.4	$\pm$ 6.8	$\pm$ 0.9	MeV/c^2
Theory[5]	6052.1	$\pm$ 5.6		MeV/c^2

DØ measurement of Ω_b^- mass is more than 6 standard deviations away from the CDF one !

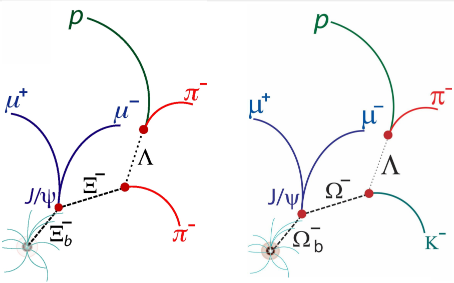
Also: only the CDF value is in agreement with main QCD models.

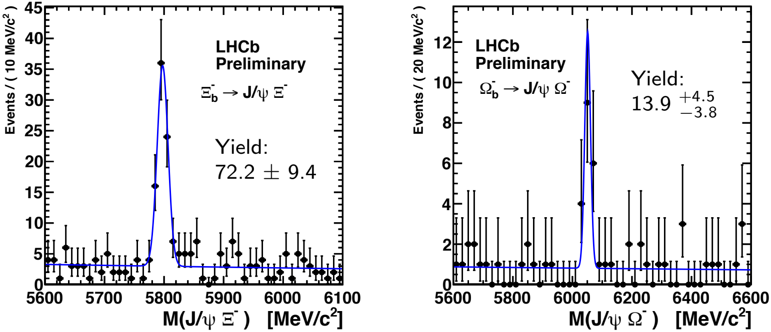
[3] Phys. Rev. Lett. 101:232002 (2008)

[4] Phys. Rev. D80:072003 (2009)

[5] Annals Phys. 324:2-15 (2009)

- Using 0.62 fb^{-1} of 2011 data
- Single gaussian fit
- Width fixed to MC





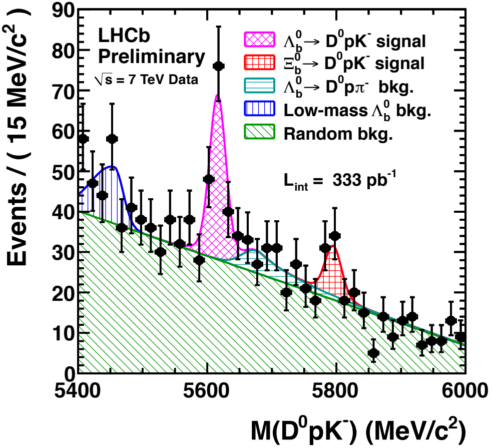
Source of uncertainty	$\Xi_b^- \to J/\psi\, \Xi^-$	$\Omega_b^- \to J/\psi\, \Omega^-$
Momentum calibration:		
Average momentum scale	1.2	2.1
η dependence of momentum scale	< 0.1	< 0.1
Detector description:		
Energy loss correction	< 0.1	< 0.1
Mass fitting:		
Signal model	0.1	0.1
Background model	< 0.1	0.7
Total systematic uncertainty	1.2	2.2

Biggest systematic uncertainty from momentum calibration

Final result [LHCb-CONF-2011-060]

$$M_{\Xi_b^-} = 5796.5 \pm 1.2\ (\text{stat.}) \pm 1.2\ (\text{syst.})\ \text{MeV}/c^2$$
$$M_{\Omega_b^-} = 6050.3 \pm 4.5\ (\text{stat.}) \pm 2.2\ (\text{syst.})\ \text{MeV}/c^2$$

$\to$ in agreement with CDF and not with DØ.

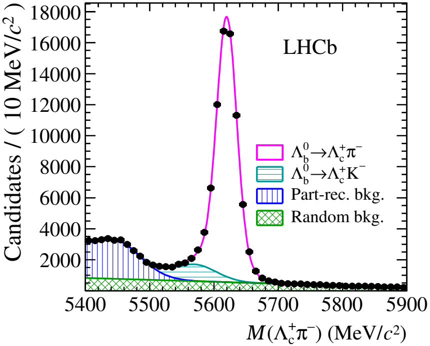


A signal has been observed for the first time in the $\Xi_b^0 \to D^0 p K^-$ channel with a significance of 2.6 standard deviations.

The fit gives [CERN-LHCb-CONF-2011-036]

$$M_{\Xi_b^0} = 5802.0 \pm 5.5\ (\text{stat}) \pm 1.7\ (\text{syst})\ \text{MeV}/\text{c}^2$$

$\Lambda_b^0 \to \Lambda_c^+ \pi^-$ at LHCb



Within the full 2011 statistics (1 fb^{-1}):

- Huge samples of hadronic decays of Λ_b^0 collected !
- 70'540 $\pm$ 330 signal events[6]
- Signal-to-background ($\pm$25 MeV/c^2 around the nominal Λ_b^0 mass) S/B = 11

[6] arXiv:1205.3452

Excited Λ_b^0-baryons

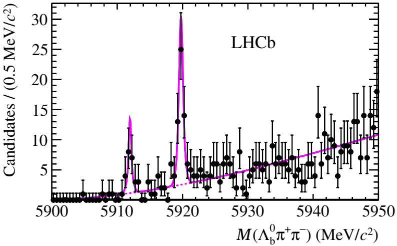
- Excited Λ_b^0 states: two states with $J^P = 1/2^-$ and $3/2^-$
- Orbital excitations with $L = 1$
- First observation at LHCb
- Predictions exist:

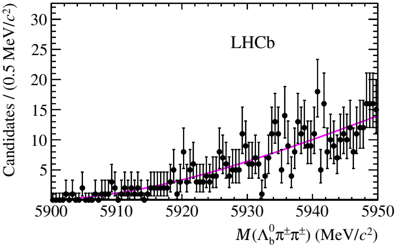
Reference	$M[\Lambda_b^{0*}(1/2^-)]$	$M[\Lambda_b^{0*}(3/2^-)]$
Capstick, Isgur [PRD 34 2809 (1986)]	5912	5920
Baccouche, et al. [hep-ph/0105148]	5920 (spin-averaged)	
Garcilazo, et al. [hep-ph/0703257]	5890	5890
Ebert, et al. [arXiv:0705.2957]	5930	5947
Karliner, et al. [arXiv:0804.1575]	5929 ± 2	5940 ± 2
Roberts, Pervin [arXiv:0711.2492]	5939	5941

Predicted mass above $\Lambda_b^0\pi^+\pi^-$ threshold (5900 MeV/c^2) but below the $\Sigma_b\pi$ one (around 5950 MeV/c^2).

First observation of excited Λ_b^0 baryons

Kinematic fit - Λ_b^0 and Λ_c^+ mass constraint



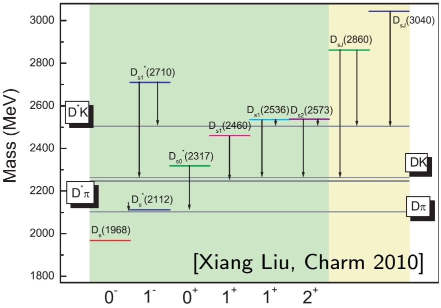


Left $\Lambda_b^0\pi^+\pi^-$ and right $\Lambda_b^0\pi^\pm\pi^\pm$ (WS) combinations[7]

$$M_{\Lambda_b^0(5912)} = 5911.95 \pm 0.12\ (\text{stat}) \pm 0.03\ (\text{syst}) \pm 0.66\ (\Lambda_b^0\ \text{mass})\ \text{MeV/c}^2$$
$$M_{\Lambda_b^0(5920)} = 5919.76 \pm 0.07\ (\text{stat}) \pm 0.02\ (\text{syst}) \pm 0.66\ (\Lambda_b^0\ \text{mass})\ \text{MeV/c}^2$$

The significances of the observations are 4.9 and 10.1 standard deviations, respectively.

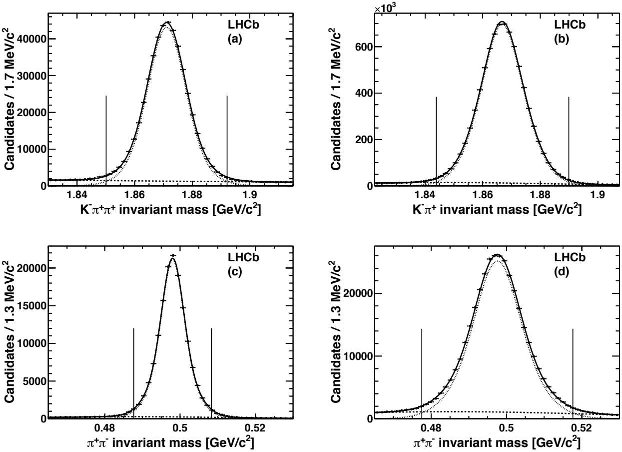
[7] arXiv:1205.3452



- $D_{s0}^*(2317)^+$ and $D_{s1}(2460)^+$ states discovered in the $D_s^+\pi^0$ channel in 2003 but were predicted to have much higher masses

- $D_{s1}^*(2700)^+$, $D_{sJ}^*(2860)^+$ and $D_{sJ}(3040)^+$ excited states observed in DK and D^*K decay modes and in three-body b-hadron decays at the B-factories between 2006 and 2009
- Quantum numbers of $D_{s1}^*(2700)^+$ need further confirmation
- Existence of the $D_{sJ}^*(2860)^+$ resonance still unclear and its spin-parity unknown

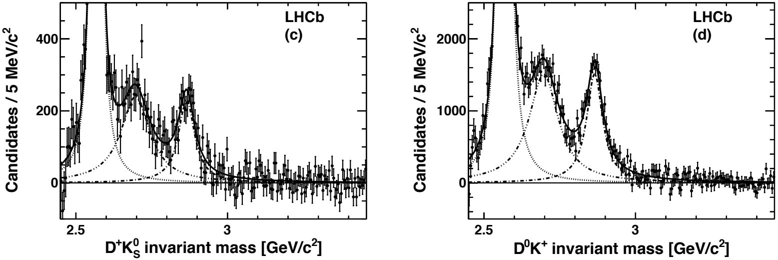
Very clean samples of D^0, D^+ and K_S^0 at LHCb



(a) D^+, (b) D^0 , (c) K_S^0 decaying inside and (d) outside the vertex detector

$K_S^0 \to \pi^+\pi^-$ mass resolution down to 3.5 MeV/c^2 !

Combined fit[8] - background subtracted (first peak is $D^*_{s2}(2573)^+$)



$$m(D^*_{s1}(2700)^+) = 2709.4 \pm 1.9 \text{ (stat)} \pm 4.5 \text{ (syst) MeV/c}^2$$
$$\Gamma(D^*_{s1}(2700)^+) = 121.7 \pm 7.3 \text{ (stat)} \pm 12.1 \text{ (syst) MeV}$$
$$m(D^*_{sJ}(2860)^+) = 2866.7 \pm 1.0 \text{ (stat)} \pm 6.3 \text{ (syst) MeV/c}^2$$
$$\Gamma(D^*_{sJ}(2860)^+) = 64.5 \pm 3.2 \text{ (stat)} \pm 6.6 \text{ (syst) MeV}$$

- All compatible with previous results from the B-factories, $D^*_{sJ}(2860)^+$ confirmed
- Precision dominated by systematic effects
- No statistically significant D_{sJ} resonance above 3 GeV/c^2 observed
- Spin-parity assignment still need angular analysis of D^*K

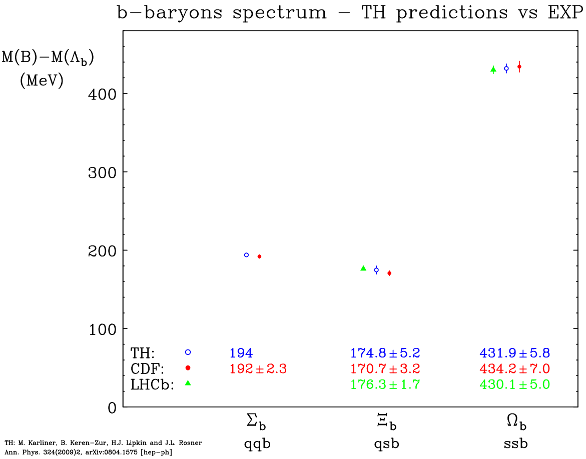
[8] LHCb-PAPER-2012-016

Summary and plans

- LHCb gives most precise Λ_b^0 mass measurement
- Ξ_b^- and Ω_b^- masses measured at LHCb and CDF observation of Ω_b^- confirmed
- Excited Λ_b^0 state observed and measured for the first time at LHCb
- LHCb confirms existence of $D_{sJ}^*(2860)^+$ and $D_{s1}^*(2700)^+$, mass + decay width measured
- New measurements are soon to come with 2011 data (1 fb^{-1}): Λ_b^0, Ξ_b^- and Ω_b^- lifetimes
- Excellent prospects for further spectroscopy at LHCb in the years to come: expect 2.5 fb^{-1} by end of 2012 + additional 5 fb^{-1} at least by 2017 with a b-hadron production cross section twice as large.

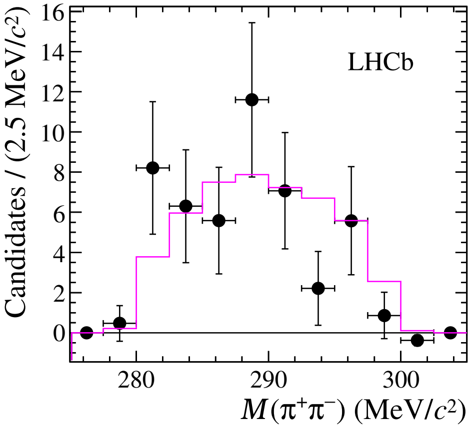
Thank you for your attention

BACKUP SLIDES



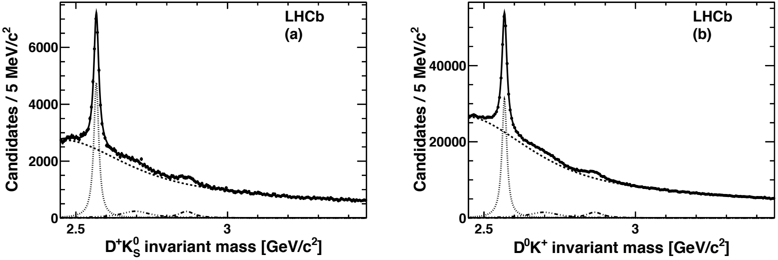
- Theory, CDF and LHCb agree but DØ does not.
- Measurements and prediction still have large uncertainties.

$M(\pi^+\pi^-)$ spectrum in $\Lambda_b^{0*} \to \Lambda_b^0 \pi^+\pi^-$



- $M(\pi^+\pi^-)$ spectrum is consistent with the result of phase-space decay simulation ($\chi^2/\text{ndf} = 1.6$ for ndf $= 9$)

D_{sJ} states observations



- $D^+K^0_S$ and D^0K^+ mass distributions without background subtraction
- The low signal-to-background ratio is responsible for the large systematic uncertainties