Physics with *b*-baryons at LHCb

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XI INTERNATIONAL CONFERENCE ON HYPERONS, CHARM AND BEAUTY HADRONS
UNIVERSITY OF BIRMINGHAM, UK, 21-26 JULY 2014

LHCb

XI International Conference on Hyperons, Charm and Beauty Hadrons
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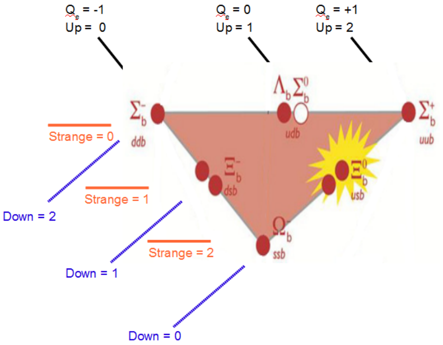
Introduction

- Physics with b-baryons relatively unexplored.
- Baryons have non-zero spin
  - Probe helicity structure of HQE Hamiltonian
- Need precision measurements of mass, lifetime and branching fractions.

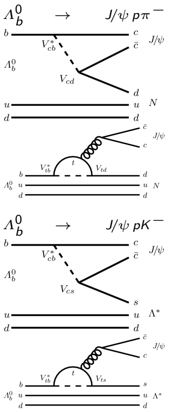


- *CP* measurements interesting.
  - Due interference between tree and loop diagrams.
  - Self tagging decays.
  - No *CP* asymmetries observed.
- Focus on results of baryon decays and Ξ_b^0 measurements.
  - Lifetime measurements by L. Anderlini in Tues session.

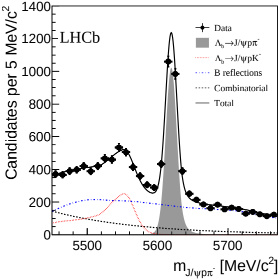
Contents

$\Lambda_b^0 \to J/\psi\, p\pi^-$ observation. arXiv: 1406.0755

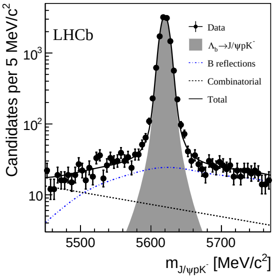
- Search for $\Lambda_b^0 \to J/\psi\, p\pi^-$ in $3\,\text{fb}^{-1}$ data.
- $\Lambda_b^0 \to J/\psi\, pK^-$ decay as control channel.
- Loose selection followed by PID and Neural Network.



$\Lambda_b^0 \to J/\psi\, p\pi^-$: 2102 ± 61



$\Lambda_b^0 \to J/\psi\, pK^-$: 11179 ± 109



$$\frac{\mathcal{B}(\Lambda_b^0 \to J/\psi\, p\pi^-)}{\mathcal{B}(\Lambda_b^0 \to J/\psi\, pK^-)} = \frac{N(\Lambda_b^0 \to J/\psi\, p\pi^-)}{N(\Lambda_b^0 \to J/\psi\, pK^-)} \times \frac{\eta(\Lambda_b^0 \to J/\psi\, pK^-)}{\eta(\Lambda_b^0 \to J/\psi\, p\pi^-)}$$

$$= 0.0824 \pm 0.0025\,(\text{stat}) \pm 0.0042\,(\text{syst})$$

$\mathcal{A}^{CP}$ measurements. arXiv: 1406.0755

- Measure raw asymmetries, $\mathcal{A}^{\rm raw} = \frac{N(\Lambda_b^0) - N(\overline{\Lambda}_b^0)}{N(\Lambda_b^0) + N(\overline{\Lambda}_b^0)}$

$$\mathcal{A}^{\rm raw}(\Lambda_b^0 \to J/\psi\, p\pi^-) = (+7.9 \pm 2.2)\%$$
$$\mathcal{A}^{\rm raw}(\Lambda_b^0 \to J/\psi\, pK^-) = (+1.1 \pm 0.7)\%$$

- Related to CP asymmetry: $\mathcal{A}^{\rm raw} = \mathcal{A}^{CP} + \mathcal{A}^{\rm prod}(\Lambda_b^0) - \mathcal{A}^{\rm det}(\pi/K) + \mathcal{A}^{\rm det}(p)$
- Calculate difference in decay modes:

$$\begin{aligned}\Delta\mathcal{A}^{CP} &= \mathcal{A}^{CP}(J/\psi\, p\pi^-) - \mathcal{A}^{CP}(J/\psi\, pK^-)\\ &= \mathcal{A}^{\rm raw}(J/\psi\, p\pi^-) - \mathcal{A}^{\rm raw}(J/\psi\, pK^-) + \mathcal{A}^{\rm det}(\pi) - \mathcal{A}^{\rm det}(K)\end{aligned}$$

- Find $\mathcal{A}^{\rm det}(\pi) - \mathcal{A}^{\rm det}(K)$ from $\overline{B}^0 \to J/\psi\, \overline{K}^{*0}$ decay.

$$\begin{aligned}\mathcal{A}^{\rm raw}(\overline{B}^0 \to J/\psi\, \overline{K}^{*0}) &= \mathcal{A}^{CP}(\overline{B}^0 \to J/\psi\, \overline{K}^{*0}) + \mathcal{A}^{\rm prod}(B^0) + \mathcal{A}^{\rm det}(\pi) - \mathcal{A}^{\rm det}(K)\\ &\approx \mathcal{A}^{\rm det}(\pi) - \mathcal{A}^{\rm det}(K)\end{aligned}$$

$$\Delta\mathcal{A}^{CP} = (+5.7 \pm 2.3\,(\rm stat) \pm 1.2\,(\rm syst))\%$$

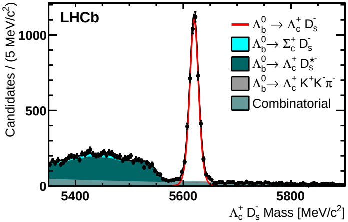
Contents

Beauty hadron decays into pairs of charm hadrons

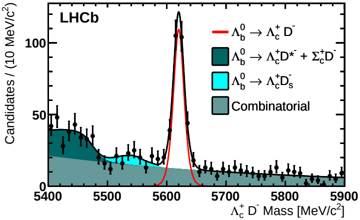
Phys. Rev. Lett. 112 (2014) 202001

- Search for $\Lambda_b^0 \to \Lambda_c^+ D_s^-$ and $\Lambda_b^0 \to \Lambda_c^+ D^-$ decays with $3\,\text{fb}^{-1}$.
- Reconstruct resonances: $D^+ \to K^-\pi^+\pi^+$, $D_s^+ \to K^-K^+\pi^+$, $\Lambda_c^+ \to pK^-\pi^+$
- First observation of these decays:

$\Lambda_b^0 \to \Lambda_c^+ D_s^-$: 4633 ± 69



$\Lambda_b^0 \to \Lambda_c^+ D^-$: 262 ± 19



$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ D^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ D_s^-)} = 0.042 \pm 0.003\,(\text{stat}) \pm 0.003\,(\text{syst})$$

Mass measurement Phys. Rev. Lett. 112 (2014) 202001

- Measure relative to high statistics channel $\overline{B}^0 \to D^+ D_s^-$
- Double ratio removes any dependence on production fractions.

$$\left[\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ D_s^-)}{\mathcal{B}(\overline{B}^0 \to D^+ D_s^-)}\right] / \left[\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^-)}{\mathcal{B}(\overline{B}^0 \to D^+ \pi^-)}\right] = 0.96 \pm 0.02\,(\mathrm{stat}) \pm 0.06\,(\mathrm{syst})$$

$$\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ D_s^-) = (1.1 \pm 0.1) \times 10^{-2}$$

$$\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ D^-) = (4.7 \pm 0.6) \times 10^{-4}$$

- Kinematics similar enough to measure mass difference
  - $[m(\Lambda_b^0) - m(\Lambda_c^+) - m(D_s^-)] - [m(B^0) - m(D^+) - m(D_s^-)]$ is small.
  - Small uncertainty on momentum scale ($\approx 0.03\%$).
  - Dominant uncertainty due to Λ_c^+ and D^+ lifetimes.

$$m(\Lambda_b^0) - m(B^0) = 339.72 \pm 0.24\,(\mathrm{stat}) \pm 0.18\,(\mathrm{syst})\,\mathrm{MeV}/c^2$$

- Averaged with LHCb $\Lambda_b^0 \to J/\psi\,\Lambda$ result Phys. Rev. Lett. 110 (2013) 182001

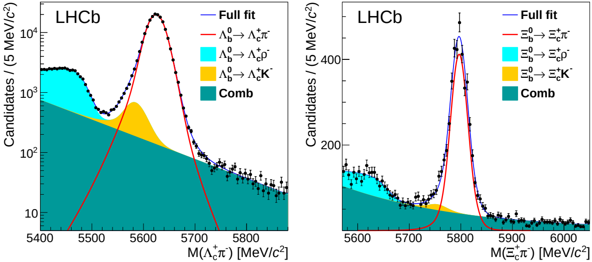
$$m(\Lambda_b^0) = 5619.36 \pm 0.26\,\mathrm{MeV}/c^2$$

Contents

Mass of Ξ_b^0 Phys. Rev. Lett. 113 (2014) 032001

- CDF measured $m(\Xi_b^0) = 5787.8 \pm 5.0 \pm 1.3\,\mathrm{MeV}/c^2$ Phys. Rev. Lett. 107 (2011) 102001
- Measured using full $3\,\mathrm{fb}^{-1}$ data.
- Using $\Xi_b^0 \to \Xi_c^+ \pi^-$ with $\Xi_c^+ \to pK^-\pi^+$
- Normalise with $\Lambda_b^0 \to \Lambda_c^+ \pi^-$ with $\Lambda_c^+ \to pK^-\pi^+$

$\Lambda_b^0 \to \Lambda_c^+ \pi^-$: $(180.8 \pm 0.5) \times 10^3$ $\Xi_b^0 \to \Xi_c^+ \pi^-$: 3775 ± 71

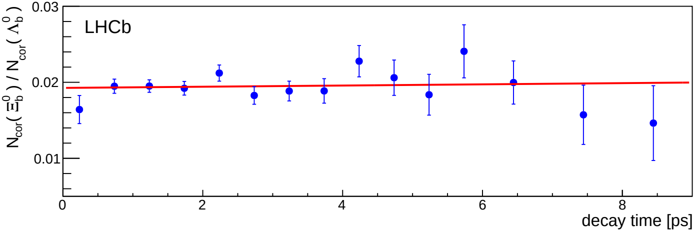


$$m(\Xi_b^0) - m(\Lambda_b^0) = 172.44 \pm 0.39\,(\mathrm{stat}) \pm 0.17\,(\mathrm{syst})\,\mathrm{MeV}/c^2$$

$$m(\Xi_b^0) = 5791.80 \pm 0.39\,(\mathrm{stat}) \pm 0.17\,(\mathrm{syst}) \pm 0.26(\Lambda_b^0)\,\mathrm{MeV}/c^2$$

Lifetime of Ξ_b^0 Phys. Rev. Lett. 113 (2014) 032001

- First measurement of Ξ_b^0 lifetime.
- Fit to ratio of yields and function of decay time.



- Exponential function, $e^{\beta t}$, where $\beta = \frac{1}{\tau(\Xi_b^0)} - \frac{1}{\tau(\Lambda_b^0)}$

$$\frac{\tau(\Xi_b^0)}{\tau(\Lambda_b^0)} = \frac{1}{1 - \beta\tau(\Lambda_b^0)}$$

$$= 1.006 \pm 0.018\,(\mathrm{stat}) \pm 0.010\,(\mathrm{syst})$$

$$\tau(\Xi_b^0) = 1.477 \pm 0.026\,(\mathrm{stat}) \pm 0.014\,(\mathrm{syst}) \pm 0.013(\Lambda_b^0)ps$$

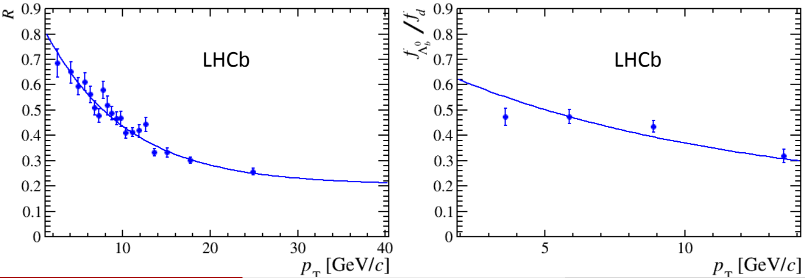
Contents

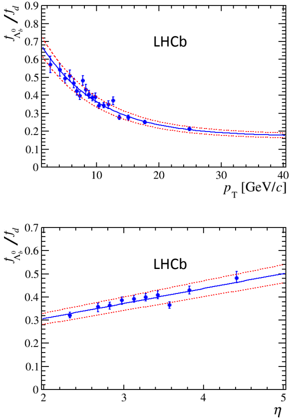
Λ_b^0 production fractions arXiv: 1405.6842

- $f_{\Lambda_b^0}$ varies as a function of p_T and η
- Measured by LHCb in semi-leptonic decays Phys. Rev. D85 (2012) 032008
- Updated measurement using $\Lambda_b^0 \to \Lambda_c^+\pi^-$ and $\bar{B}^0 \to D^+\pi^-$ decays in $1\,\mathrm{fb}^{-1}$.
- Fit exponential for p_T dependence, and linear η dependence.

$$\frac{f_{\Lambda_b^0}}{f_d}(X) = \frac{\mathcal{B}(B^0 \to D^+\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\pi^-)} \frac{\mathcal{B}(D^+ \to K^-\pi^+\pi^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} \times \frac{N_{\Lambda_b^0\to\Lambda_c^+\pi^-}(X)\epsilon_{B^0\to D^+\pi^-}(X)}{N_{B^0\to D^+\pi^-}(X)\epsilon_{\Lambda_b^0\to\Lambda_c^+\pi^-}(X)}$$

$$\equiv S \times R(X)$$





← 40 - 50%

$$\frac{f_{\Lambda_b^0}}{f_d}(p_{\mathrm{T}}) = a + exp(b + c \times p_{\mathrm{T}}[\,\mathrm{GeV}/c])$$

$$a = 0.151 \pm 0.016^{+0.024}_{-0.025}$$
$$b = -0.573 \pm 0.040^{+0.101}_{-0.097}$$
$$c = -0.095 \pm 0.007 \pm 0.014$$

$$\frac{f_{\Lambda_b^0}}{f_d}(\eta) = a + b \times (\eta - 3.198)$$

$$a = 0.387 \pm 0.013^{+0.028}_{-0.030}$$
$$b = 0.067 \pm 0.005^{+0.012}_{-0.009}$$

- From scale factor, S, extract absolute branching fraction:

$$\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^-) = (4.46 \pm 0.36) \times 10^{-3}$$

- Most precise measurement of a Λ_b^0 branching fraction.

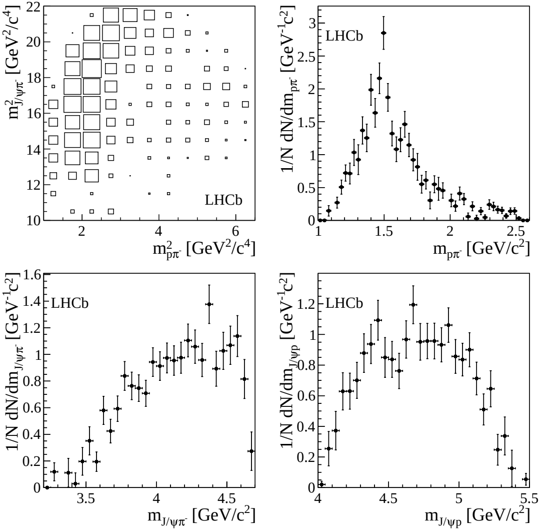
Summary

- First observation of $\Lambda_b^0 \to J/\psi\, p\pi^-$
- $\Delta\mathcal{A}^{CP} = \mathcal{A}^{CP}(J/\psi\, p\pi^-) - \mathcal{A}^{CP}(J/\psi\, pK^-) = (+5.7 \pm 2.3\,(\mathrm{stat}) \pm 1.2\,(\mathrm{syst}))\%$
- First observation of $\Lambda_b^0 \to \Lambda_c^+ D^-$ and $\Lambda_b^0 \to \Lambda_c^+ D_s^-$ decays.
- Used to measure $m(\Lambda_b^0) = 5619.36 \pm 0.26\,\mathrm{MeV}/c^2$
- Most precise measurements of Ξ_b^0 baryon.
  - $m(\Xi_b^0) = 5791.80 \pm 0.39\,(\mathrm{stat}) \pm 0.17\,(\mathrm{syst}) \pm 0.26\,\mathrm{MeV}/c^2$
  - $\tau(\Xi_b^0) = 1.477 \pm 0.026\,(\mathrm{stat}) \pm 0.014\,(\mathrm{syst}) \pm 0.013(\Lambda_b^0) ps$
- Measured Λ_b^0 production fractions as a function of p_T and η
- Measured $\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^-)$
  - Most precise Λ_b^0 branching fraction measurement to date.

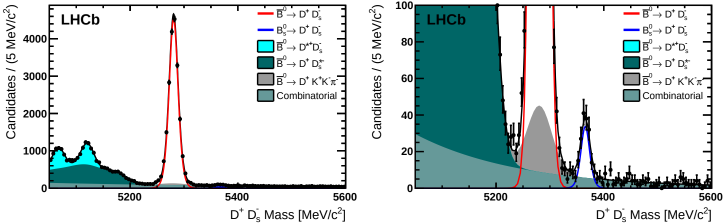
- Many new observations of baryonic decays shown.
- Expect many more in the years to come!

Back-Up Slides

$\Lambda_b^0 \to J/\psi\, p\pi^-$ Dalitz distributions



$\overline{B}^0 \to D^+ D_s^-$ and $B_s^0 \to D^+ D_s^-$ invariant mass distributions

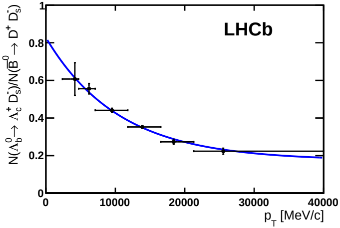


$$\frac{\mathcal{B}(B_s^0 \to D^+ D_s^-)}{\mathcal{B}(\overline{B}^0 \to D^+ D_s^-)} = 0.038 \pm 0.004 \pm 0.003$$

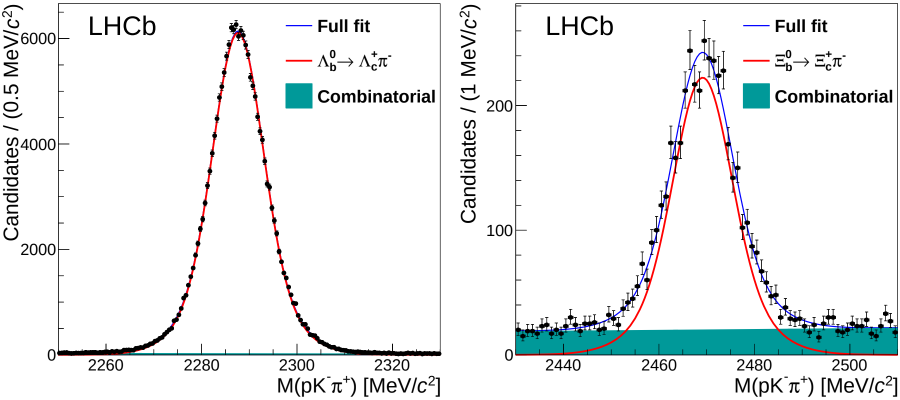
$$\frac{\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{\Lambda}_c^-)}{\mathcal{B}(\overline{B}^0 \to D^+ D_s^-)} < 0.0022 \; at \; 95\% \; C.L.$$

$$\frac{\mathcal{B}(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-)}{\mathcal{B}(B_s^0 \to D^+ D_s^-)} < 0.30 \; at \; 95\% \; C.L$$

Efficiency corrected ratio of yields as a function of p_{T}



Ξ_c^+ mass.



$$m(\Xi_c^+) - m(\Lambda_c^+) = 181.51 \pm 0.14\,(\mathrm{stat}) \pm 0.17\,(\mathrm{syst})\,\mathrm{MeV}/c^2$$

$$m(\Xi_c^+) = 2467.97 \pm 0.14\,(\mathrm{stat}) \pm 0.09\,(\mathrm{syst}) \pm 0.14\,\mathrm{MeV}/c^2$$