Charmless *b*-meson and *b*-baryon decays at LHCb

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on behalf of the LHCb Collaboration

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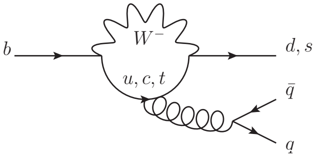
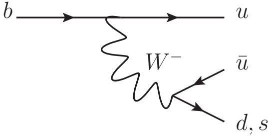
Charmless b-hadron decays

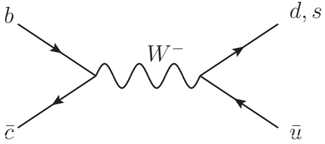
- Penguin $b \to d$ or $b \to s$
  - Sensitive to new particles in the loop



- Tree-level $b \to u$ suppressed by V_{ub}
  - Similar magnitude of tree & penguin contributions
  - Tree & penguin have relative weak phase γ
    Interference $\to$ CP violation



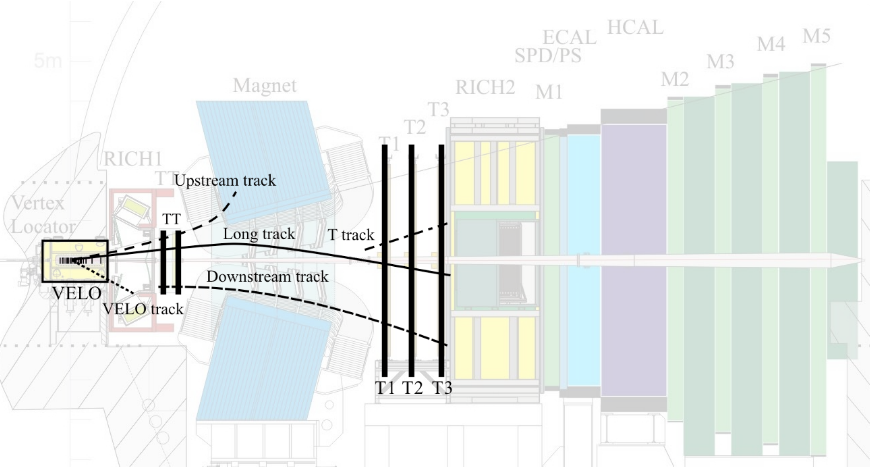
- $B_c \to$ annihilation diagrams
  - Sensitive to BSM charged propagators



Outline

1. Observations of $\Lambda_b \to \Lambda K^+\pi^-$ and $\Lambda_b \to \Lambda K^+K^-$ and searches for other Λ_b and Ξ_b^0 decays to $\Lambda h^+h'^-$
    - LHCb-PAPER-2016-004
    - arXiv:1603.00413
    - JHEP 05 (2016) 081
2. Observation of the $\Lambda_b \to \Lambda\phi$ decay
    - LHCb-PAPER-2016-002
    - arXiv:1603.02870
    - Submitted to PLB
3. Search for B_c^+ decays to the $p\bar{p}\pi^+$ final state
    - LHCb-PAPER-2016-001
    - arXiv:1603.07037
    - Submitted to PLB

Track types at LHCb



- Long tracks pass through all tracking stations
- Downstream tracks pass through the TT and T
  - Λ and K_S^0 can decay outside VELO

Performance paper:
LHCb-DP-2014-002

Event selection

- Full Run 1 dataset: 3 fb^{-1} of pp collisions at $\sqrt{s} = 7$ and 8 TeV
- Pre-selection using track quality, vertex quality, isolation criteria and kinematic information
- Multivariate Analysis to reduce combinatorial background
- Hadron PID requirements to suppress misidentified backgrounds

$$\Lambda_b/\Xi_b^0 \to \Lambda h^+ h'^-$$

Introduction

Motivation:

- Only a handful of observed charmless *b*-baryon decay modes
  - $\Lambda_b \to p\pi^-$ and $\Lambda_b \to pK^-$
  - $\Lambda_b \to K_S^0 p\pi^-$
  - Some evidence for $\Lambda_b \to \Lambda\eta$
- No charmless decays of the Ξ_b^0 have been observed
- Can be used to study hadronisation in *b*-baryons
- Complement *CP* violation studies performed in *b*-mesons

This analysis:

- Search for charmless Λ_b and Ξ_b^0 decays to $\Lambda\pi^+\pi^-$, $\Lambda K^\pm\pi^\mp$ and ΛK^+K^-
  - Veto open charm $\Lambda_c^+ \to \Lambda h^+, \Xi_c^+ \to \Lambda h^+$ and $D^0 \to h^+h'^-$
- Normalise to $\Lambda_b \to \Lambda_c^+(\to \Lambda\pi^+)\pi^-$
- Measure branching fractions and *CP* asymmetries of observed modes

Branching fractions

- The Λ_b branching fractions are calculated as:

$$\frac{\mathcal{B}(\Lambda_b \to \Lambda h^+ h'^-)}{\mathcal{B}(\Lambda_b \to \Lambda_c^+(\to \Lambda\pi^+)\pi^-)} = \frac{N_{\Lambda_b \to \Lambda h^+ h'^-}}{N_{\Lambda_b \to \Lambda_c^+(\to \Lambda\pi^+)\pi^-}} \frac{\varepsilon_{\Lambda_b \to \Lambda_c^+(\to \Lambda\pi^+)\pi^-}}{\varepsilon_{\Lambda_b \to \Lambda h^+ h'^-}}$$

- Since $f_{\Xi_b^0}$ is not known, we measure:

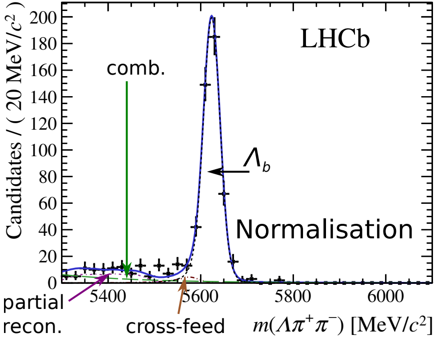
$$\frac{f_{\Xi_b^0}}{f_{\Lambda_b}} \frac{\mathcal{B}(\Xi_b^0 \to \Lambda h^+ h'^-)}{\mathcal{B}(\Lambda_b \to \Lambda_c^+(\to \Lambda\pi^+)\pi^-)} = \frac{N_{\Xi_b^0 \to \Lambda h^+ h'^-}}{N_{\Lambda_b \to \Lambda_c^+(\to \Lambda\pi^+)\pi^-}} \frac{\varepsilon_{\Lambda_b \to \Lambda_c^+(\to \Lambda\pi^+)\pi^-}}{\varepsilon_{\Xi_b \to \Lambda h^+ h'^-}}$$

- Yields are obtained by fitting mass distributions
- Efficiencies are found from simulation
  - Data-driven corrections

Fits to mass distributions

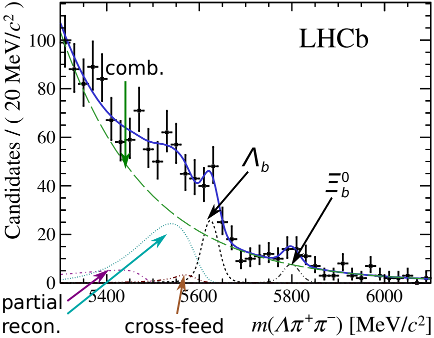
Components for $\Lambda_b/\Xi_b^0 \to \Lambda h^+ h'^-$ signal, cross-feed, partially reconstructed backgrounds (missing π^0 and missing γ) and combinatorial background

$\Lambda_b \to \Lambda_c^+(\to \Lambda\pi^+)\pi^-$



$N_{\Lambda_b} = 471 \pm 22$

$\Lambda_b/\Xi_b^0 \to \Lambda\pi^+\pi^-$



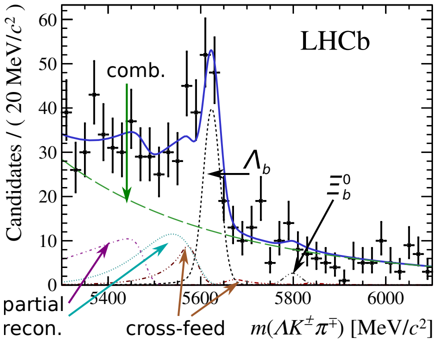
$N_{\Lambda_b} = 65 \pm 14$

$N_{\Xi_b^0} = 19 \pm 8$

Fits to mass distributions

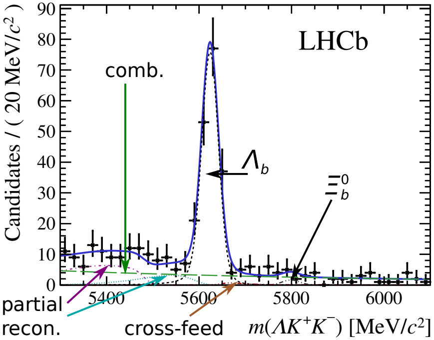
Components for $\Lambda_b/\Xi_b^0 \to \Lambda h^+ h'^-$ signal, cross-feed, partially reconstructed backgrounds (missing π^0 and missing γ) and combinatorial background

$\Lambda_b/\Xi_b^0 \to \Lambda K^+ \pi^-$



$$N_{\Lambda_b} = 97 \pm 14$$
$$N_{\Xi_b^0} = 4 \pm 7$$

$\Lambda_b/\Xi_b^0 \to \Lambda K^+ K^-$



$$N_{\Lambda_b} = 185 \pm 15$$
$$N_{\Xi_b^0} = 4 \pm 4$$

Branching fraction results

- Observation of $\Lambda_b \to \Lambda K^+ K^-$ with significance 15.8σ
- Observation of $\Lambda_b \to \Lambda K^+ \pi^-$ with significance 8.1σ
- Evidence for $\Lambda_b \to \Lambda \pi^+ \pi^-$ at 4.7σ

$$
\begin{aligned}
\mathcal{B}(\Lambda_b \to \Lambda \pi^+ \pi^-) &= (4.6 \pm 1.2 \pm 1.4 \pm 0.6) \times 10^{-6} \\
\mathcal{B}(\Lambda_b \to \Lambda K^+ \pi^-) &= (5.6 \pm 0.8 \pm 0.8 \pm 0.7) \times 10^{-6} \\
\mathcal{B}(\Lambda_b \to \Lambda K^+ K^-) &= (15.9 \pm 1.2 \pm 1.2 \pm 2.0) \times 10^{-6}
\end{aligned}
$$

  - Order of uncertainties: $\pm$ stat. $\pm$ syst. $\pm$ norm.

- No observation of any of the Ξ_b^0 decays

$$
\begin{aligned}
\frac{f_{\Xi_b^0}}{f_{\Lambda_b}} \times \mathcal{B}(\Xi_b^0 \to \Lambda \pi^+ \pi^-) &< 1.7 \times 10^{-6} \text{ at } 90\,\%\text{ CL} \\
\frac{f_{\Xi_b^0}}{f_{\Lambda_b}} \times \mathcal{B}(\Xi_b^0 \to \Lambda K^- \pi^+) &< 0.8 \times 10^{-6} \text{ at } 90\,\%\text{ CL} \\
\frac{f_{\Xi_b^0}}{f_{\Lambda_b}} \times \mathcal{B}(\Xi_b^0 \to \Lambda K^+ K^-) &< 0.3 \times 10^{-6} \text{ at } 90\,\%\text{ CL}
\end{aligned}
$$

CP asymmetries

- Fit separately for Λ_b and $\overline{\Lambda}_b$ in the $\Lambda K^+\pi^-$ and ΛK^+K^- samples
- Calculate efficiency-corrected yields, N^{corr}, using Dalitz plots

$$\mathcal{A}_{CP}^{\text{raw}} = \frac{N_f^{\text{corr}} - N_{\bar{f}}^{\text{corr}}}{N_f^{\text{corr}} + N_{\bar{f}}^{\text{corr}}}$$

- $\Lambda_b \to \Lambda_c^+(\to \Lambda\pi^+)\pi^-$ has the same b-hadron production asymmetry and similar detection asymmetry, therefore:

$$\Delta\mathcal{A}_{CP}(\Lambda_b \to \Lambda h^+ h'^-) = \mathcal{A}_{CP}^{\text{raw}}(\Lambda_b \to \Lambda h^+ h'^-) - \mathcal{A}_{CP}^{\text{raw}}(\Lambda_b \to \Lambda_c^+(\to \Lambda\pi^+)\pi^-)$$

$$\begin{aligned}\Delta\mathcal{A}_{CP}(\Lambda_b \to \Lambda K^+\pi^-) &= -0.53 \pm 0.23 \pm 0.11\\ \Delta\mathcal{A}_{CP}(\Lambda_b \to \Lambda K^+K^-) &= -0.28 \pm 0.10 \pm 0.07\end{aligned}$$

- Both consistent with zero

$\Lambda_b \to \Lambda\phi$

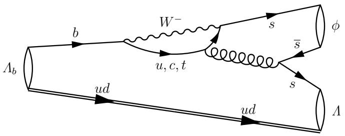
Introduction

Motivation:

- $\Lambda_b \to \Lambda K^+ K^-$ should contain significant $\Lambda_b \to \Lambda\phi$ component
- $b \to s\bar{s}s$ FCNC transition → penguin loop sensitive to new particles
- Of particular interest is non-SM *CP* violation
  - Previously studied in $B^0 \to \phi K^0_S$, $B^0 \to \phi K^{*0}$ and $B^0_s \to \phi\phi$
  - Results so far consistent with SM
- Measurements with Λ_b → look for direct *CP* violation
  - *CP* asymmetries
  - *T*-odd observables

This analysis:

- Measure $\Lambda_b \to \Lambda\phi$ branching fraction
- Normalise to $B^0 \to \phi K^0_S$
- Measure *T*-odd triple-product asymmetries
- $\phi \to K^+K^-$, $\Lambda \to p\pi^-$, $K^0_S \to \pi^+\pi^-$



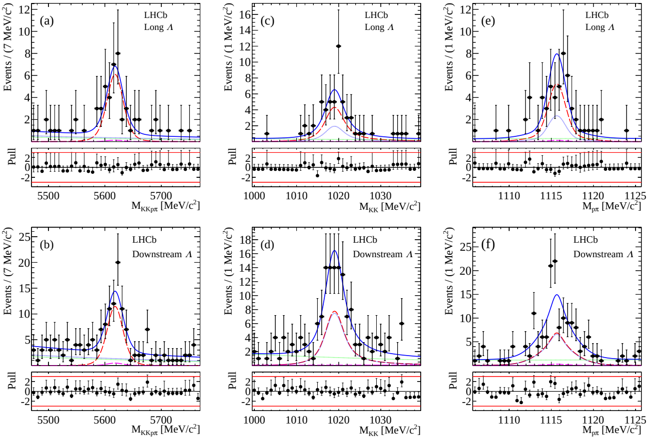
Fits to mass distributions for $\Lambda_b \to \Lambda\phi$

Components for $\Lambda_b \to \Lambda\phi$ signal, non-resonant $\Lambda_b \to \Lambda K^+K^-$, Λ + random ϕ and pure combinatorial background

$m(\Lambda\phi)$ | $m(K^+K^-)$ | $m(p\pi^-)$

Long

Downstream



$N = 89 \pm 13$

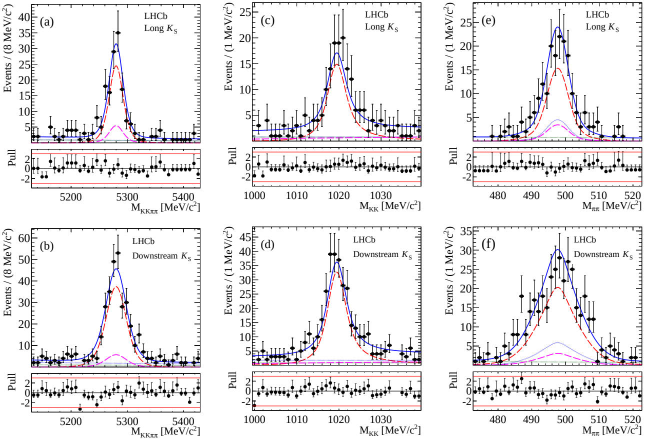
Fits to mass distributions for $B^0 \to \phi K^0_S$

Components for $B^0 \to \phi K^0_S$ signal, non-resonant $B^0 \to K^+K^-K^0_S$, K^0_S + random K^+K^- pair and pure combinatorial background

$m(\phi K^0_S)$ $m(K^+K^-)$ $m(\pi^+\pi^-)$

Long

Downstream



$N = 350 \pm 24$

Branching fraction result

- $\Lambda_b \to \Lambda\phi$ is observed with a significance of 5.9σ
- Branching fraction calculated as:

$$\mathcal{B}(\Lambda_b \to \Lambda\phi) = \frac{f_d}{f_{\Lambda_b}} \frac{N_{\Lambda_b \to \Lambda\phi}}{N_{B^0 \to \phi K^0_S}} \frac{\varepsilon_{B^0 \to \phi K^0_S}}{\varepsilon_{\Lambda_b \to \Lambda\phi}} \frac{\mathcal{B}(B^0 \to \phi K^0)}{2} \frac{\mathcal{B}(K^0_S \to \pi^+\pi^-)}{\mathcal{B}(\Lambda \to p\pi^-)}$$

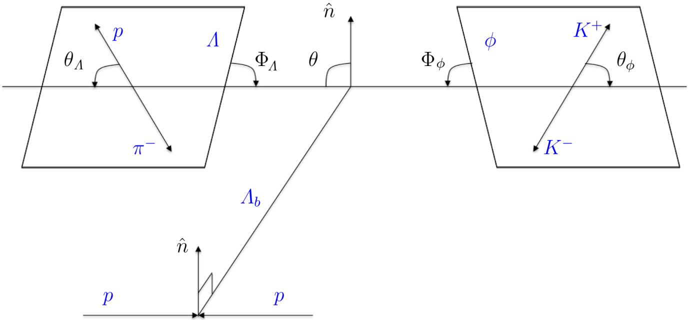
- Result:

$$\mathcal{B}(\Lambda_b \to \Lambda\phi) = (5.18 \pm 1.04 \pm 0.35\, ^{+0.50}_{-0.43} \pm 0.44) \times 10^{-6}$$

  - Order of uncertainties: $\pm$ stat. $\pm$ syst. $\pm$ norm. $\pm$ f_d/f_{Λ_b}

T-odd observables

- 5 angles needed to describe the angular distribution of $\Lambda_b \to \Lambda\phi$



T-odd observables:

- $\cos(\Phi_\Lambda)$
- $\sin(\Phi_\Lambda)$
- $\cos(\Phi_\phi)$
- $\sin(\Phi_\phi)$

DOI:10.1016/j.nuclphysbps.2007.08.117

T-odd observables results

- Datasets split by sign of observables $\to$ mass fits to obtain $N_D^{\pm,O}$
  - D is daughter: Λ or ϕ
  - O is observable: $\cos\Phi_D$ or $\sin\Phi_D$
  - $\pm$ denotes sign of O
- Asymmetries calculated as:

$$A_D^O = \frac{N_D^{+,O} - N_D^{-,O}}{N_D^{+,O} + N_D^{-,O}}$$

- Results:

$$\begin{aligned} A_\Lambda^c &= -0.22 \pm 0.12 \pm 0.06 \\ A_\Lambda^s &= +0.13 \pm 0.12 \pm 0.05 \\ A_\phi^c &= -0.01 \pm 0.12 \pm 0.03 \\ A_\phi^s &= -0.07 \pm 0.12 \pm 0.01 \end{aligned}$$

- All consistent with zero

$B_c^+ \to p\bar{p}\pi^+$

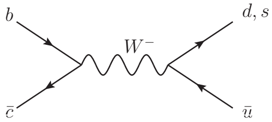
Introduction

Motivation:

- Charmless B_c^+ decays proceed via annihilation diagrams
- Probe BSM physics such as charged Higgs
- $\mathcal{A}(\bar{b}c \to W^+ \to \bar{q}u) \propto V_{cb}V_{uq}^*$ where $q = d, s$
- Cabibbo suppression $\to$ final states with zero strangeness dominate
- In B decays to states containing baryons, often enhancement at threshold
    - Poorly understood

This analysis:

- Search for $B_c^+ \to p\bar{p}\pi^+$
- Normalise to $B^+ \to p\bar{p}\pi^+$
- Focus on $B_c^+ \to p\bar{p}\pi^+$ with $m(p\bar{p}) < 2.85$ GeV$/c^2$
    - Below $c\bar{c}$ threshold
- Cross-check with $B_c^+ \to (J/\psi \to p\bar{p})\pi^+$



Analysis strategy

Since f_c is unknown, the measured quantites are:

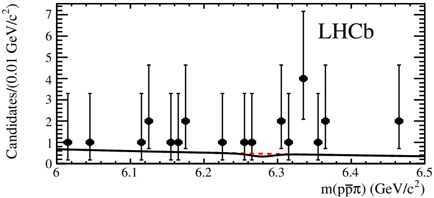
$$R_p \equiv \frac{f_c}{f_u}\mathcal{B}(B_c^+ \to p\bar{p}\pi^+) = \frac{N_{B_c^+\to p\bar{p}\pi^+}}{N_{B^+\to p\bar{p}\pi^+}}\frac{\varepsilon_u}{\varepsilon_c}\mathcal{B}(B^+ \to p\bar{p}\pi^+)$$

$$R_p^{J/\psi} \equiv \frac{f_c}{f_u}\mathcal{B}(B_c^+ \to J/\psi\pi^+) = \frac{N_{B_c^+\to J/\psi(\to p\bar{p})\pi^+}}{N_{B^+\to p\bar{p}\pi^+}}\frac{\varepsilon_u}{\varepsilon_c^{J/\psi}}\frac{\mathcal{B}(B^+ \to p\bar{p}\pi^+)}{\mathcal{B}(J/\psi \to p\bar{p})}$$

Mass fits: $B_c^+ \to p\bar{p}\pi^+$ signal

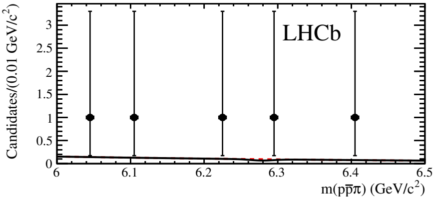
Fits to $m(p\bar{p}\pi^+)$ with components for $B_{(c)}^+$ signal, combinatorial background and partially reconstructed $B_{(c)}^+ \to p\bar{p}\rho^+(\to \pi^+\pi^0)$

Simultaneous fit to 3 bins in multivariate classifier output for B_c^+ region



$m(p\bar{p}) < 2.85$ GeV$/c^2$

$$N_{B_c^+ \to p\bar{p}\pi^+} = -2.7 \pm 6.3\,(\text{stat})$$

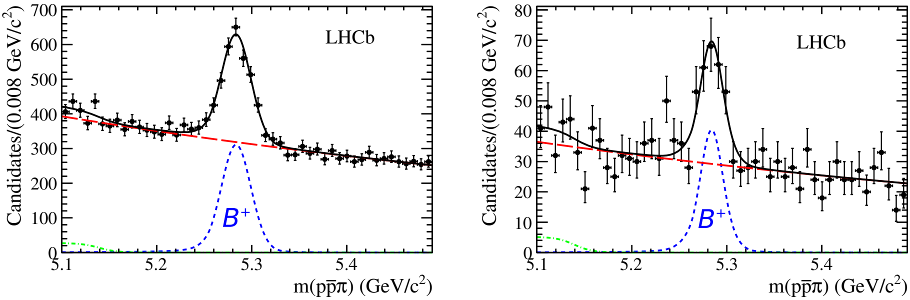


$2.85 < m(p\bar{p}) < 3.15$ GeV$/c^2$

$$N_{B_c^+ \to J/\psi(\to p\bar{p})\pi^+} = -0.1 \pm 3.0\,(\text{stat})$$

Mass fits: normalisation mode

Fits to $m(p\bar{p}\pi^+)$ with components for $B^+_{(c)}$ signal, combinatorial background and partially reconstructed $B^+_{(c)} \to p\bar{p}\rho^+(\to \pi^+\pi^0)$

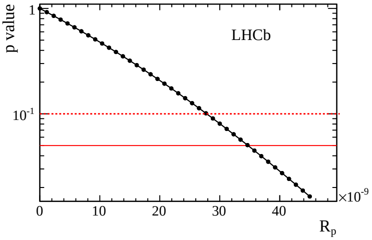


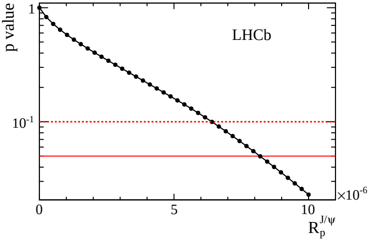
$m(p\bar{p}) < 2.85\ \text{GeV}/c^2$ $2.85 < m(p\bar{p}) < 3.15\ \text{GeV}/c^2$

$$N_{B^+\to p\bar{p}\pi^+} = 1644 \pm 83(\text{stat})$$

Upper limits

- Profile likelihood ratio scans for S+B and B-only hypotheses
- Signal *p*-value profiles calculated by dividing S+B by B





$R_p < 2.8 \times 10^{-8}$ (90% CL)

$R_p^{J/\psi} < 6.5 \times 10^{-6}$ (90% CL)

Summary

$\Lambda_b/\Xi_b^0 \to \Lambda h^+ h'^-$

- Observations of $\Lambda_b \to \Lambda K^+ K^-$ and $\Lambda_b \to \Lambda K^+ \pi^-$
  - Branching fractions: $(15.9 \pm 2.6) \times 10^{-6}$ and $(5.6 \pm 1.3) \times 10^{-6}$
  - *CP* asymmetries consistent with zero
- Evidence for $\Lambda_b \to \Lambda \pi^+ \pi^-$ at 4.7σ
- New upper limits on $\Xi_b^0 \to \Lambda h^+ h'^-$ branching fractions

$\Lambda_b \to \Lambda \phi$

- Observation of $\Lambda_b \to \Lambda \phi$
- Branching fraction: $(5.2 \pm 1.3) \times 10^{-6}$
- T-odd triple product asymmetries consistent with zero

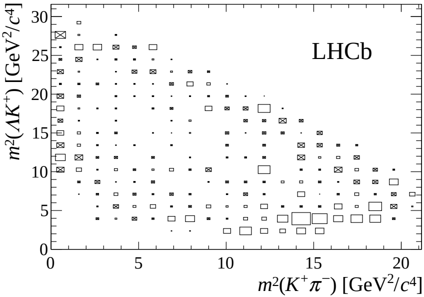
$B_c^+ \to p\bar{p}\pi^+$

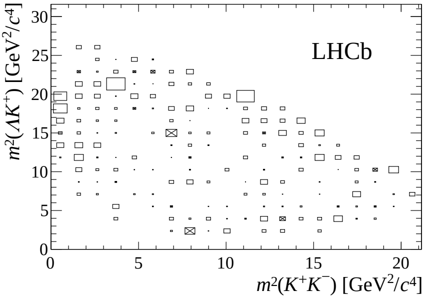
- No evidence for this decay $\to$ upper limits on $\frac{f_c}{f_u}\mathcal{B}(B_c^+ \to p\bar{p}\pi^+)$

Many more analyses in progress with Run I data and soon with Run II data.
Stay tuned...

Backup slides

$\Lambda_b \to \Lambda K^+ h^-$ Dalitz plots





$\Lambda_b/\Xi_b^0 \to \Lambda h^+ h'^-$ signal yields

Mode	Run period	Yield			
		Λ_b		Ξ_b^0	
		downstream	long	downstream	long
$\Lambda\pi^+\pi^-$	2011	10.2 ± 5.5	8.7 ± 4.7	-0.6 ± 2.4	4.9 ± 3.2
	2012a	9.1 ± 5.2	13.6 ± 5.7	5.3 ± 3.6	1.0 ± 2.6
	2012b	17.2 ± 7.1	6.2 ± 4.6	3.9 ± 4.0	4.1 ± 2.7
	Total	65 ± 14		19 ± 8	
$\Lambda K^+\pi^-$	2011	20.9 ± 6.4	8.2 ± 3.5	3.5 ± 3.7	-0.7 ± 2.4
	2012a	9.3 ± 3.7	1.7 ± 3.6	-0.1 ± 1.7	0.3 ± 1.5
	2012b	39.7 ± 8.9	16.9 ± 5.1	2.9 ± 4.5	-1.8 ± 1.5
	Total	97 ± 14		4 ± 7	
ΛK^+K^-	2011	32.3 ± 6.4	20.1 ± 4.6	0.6 ± 2.3	0.0 ± 0.6
	2012a	22.2 ± 5.3	15.9 ± 4.2	0.5 ± 2.4	0.0 ± 0.5
	2012b	60.5 ± 8.5	34.4 ± 6.1	3.0 ± 2.7	0.0 ± 0.6
	Total	185 ± 15		4 ± 4	
$(\Lambda\pi^+)_{\Lambda_c^+}\pi^-$	2011	78.1 ± 9.1	78.9 ± 9.2		
	2012a	45.0 ± 7.0	63.0 ± 8.3		
	2012b	115.3 ± 11.1	90.7 ± 9.8		
	Total	471 ± 22			

$\Lambda_b/\Xi_b^0 \to \Lambda h^+ h'^-$ systematics

Systematic uncertainties ($\times 10^{-3}$)

	Fit	Eff.	Ph. sp.	PID	Vetoes	$N_{\Lambda_c^+\pi^-}$	Total
$\Lambda_b \to \Lambda\pi^+\pi^-$	8.4	2.0	19.7	0.4	2.2	3.5	21.9
$\Lambda_b \to \Lambda K^+\pi^-$	1.7	11.7	–	2.9	1.3	4.6	13.1
$\Lambda_b \to \Lambda K^+K^-$	6.7	5.4	–	4.2	2.2	15.9	18.7
$\Xi_b^0 \to \Lambda\pi^+\pi^-$	4.1	0.7	7.0	0.1	–	1.2	8.2
$\Xi_b^0 \to \Lambda\pi^+K^-$	1.5	0.4	3.5	0.1	–	0.7	4.0
$\Xi_b^0 \to \Lambda K^+K^-$	0.1	0.1	0.8	0.0	–	0.2	0.8

$\Lambda_b/\Xi_b^0 \to \Lambda h^+ h'^-$ *CP* asymmetries

Systematic uncertainties ($\times 10^{-3}$)

	$\Delta\mathcal{A}_{CP}(\Lambda_b \to \Lambda K^+\pi^-)$	$\Delta\mathcal{A}_{CP}(\Lambda_b \to \Lambda K^+K^-)$
Control mode	66	57
PID asymmetry	20	–
Fit model	27	32
Fit bias	14	4
Efficiency uncertainty	80	28
Total	110	71

$\Lambda_b \to \Lambda\phi$ efficiencies

Combination of efficiencies for reconstruction, offline selection, trigger requirements and detector acceptance, ε^{tot}, taken from simulation.

Difference in detector-material interaction cross section determined from simulation

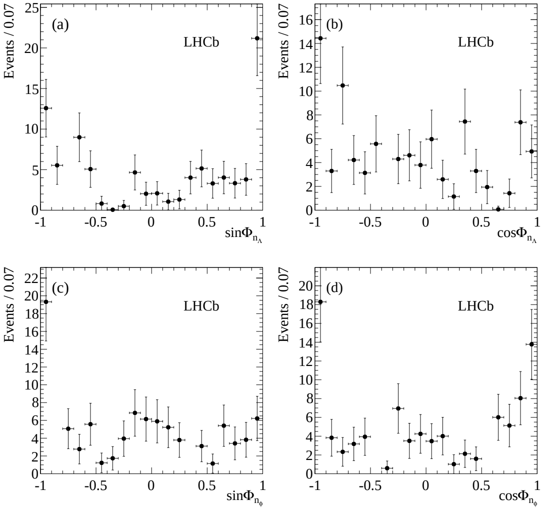
Data-driven corrections applied where necessary

- Hardware-level hadron trigger corrected with calibration samples from charm decays
- Reconstruction efficiency for long tracks corrected with tag-and-probe method with J/ψ calibration samples
- $D^0 \to \phi K^0_S$ samples used to correct vertexing efficiency

$\Lambda_b \to \Lambda\phi$ branching fraction systematics

Source	Uncertainty (%)
Mass model	3.0
Simulation sample size	2.2
Tracking efficiency	0.5
Vertex efficiency	2.6
Hardware trigger	2.8
Selection efficiency	4.1
Peaking background	0.1
Total	6.7

$\Lambda_b \to \Lambda\phi$ T-odd observables



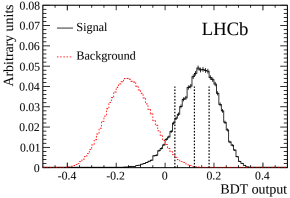
$\Lambda_b \to \Lambda\phi$ T-odd observables

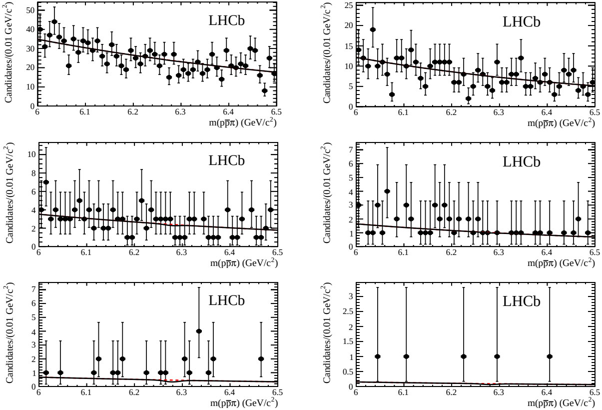
Systematic uncertainties

Source	A^c_Λ	A^s_Λ	A^c_ϕ	A^s_ϕ
Mass model	0.061	0.051	0.026	0.009
Angular acceptance	0.010	0.010	0.010	0.010
Angular resolution	0.008	0.008	0.005	0.005
Total	0.062	0.053	0.028	0.014

$B_c^+ \to p\bar{p}\pi^+$ mass fits: signal

Simultaneous fit to 3 bins in BDT output for B_c^+ region





$m(p\bar{p}) < 2.85\ \mathrm{GeV}/c^2$ $\qquad$ $2.85 < m(p\bar{p}) < 3.15\ \mathrm{GeV}/c^2$

$$N_{B_c^+ \to p\bar{p}\pi^+} = -2.7 \pm 6.3\,(\text{stat})$$

$$N_{B_c^+ \to J/\psi(\to p\bar{p})\pi^+} = -0.1 \pm 3.0\,(\text{stat})$$

$B_c^+ \to p\bar{p}\pi^+$ efficiencies

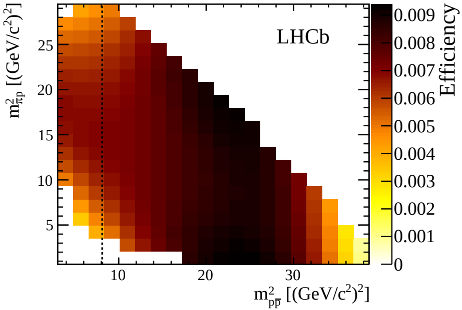
Detector acceptance efficiency, ε^{acc}, taken from simulation.
Selection efficiency, ε^{sel}:

- Acceptance maps in the $m^2(p\bar{p})$ vs $m^2(p\pi)$ plane
- Account for reconstruction, triggers, preselection, BDT, PID
- All but PID calculated from simulation
- PID part calculated using calibration samples from charm decays
- Use s-weights to calculate average ε^{sel} for B^+
- No B_c^+ signal $\to$ simple average over phase space region $\to$ large systematic
- Ratio $\varepsilon_u^{\text{sel}}/\varepsilon_c^{\text{sel}}$ corrected for differences in data and simulation

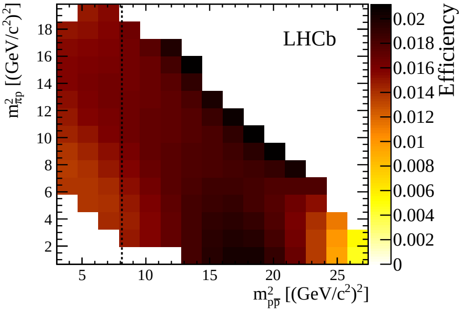
$$\frac{\varepsilon_u^{\text{sel}}}{\varepsilon_c^{\text{sel}}} = 2.495 \pm 0.028 \qquad \frac{\varepsilon_u^{\text{sel}}}{\varepsilon_c^{J/\psi,\text{sel}}} = 2.513 \pm 0.032$$

$$\frac{\varepsilon_u^{\text{acc}}}{\varepsilon_c^{\text{acc}}} = 1.195 \pm 0.007 \qquad \frac{\varepsilon_u^{\text{acc}}}{\varepsilon_c^{J/\psi,\text{acc}}} = 1.186 \pm 0.007$$

$B_c^+ \to p\bar{p}\pi^+$ efficiencies



Acceptance map for $B_c^+ \to p\bar{p}\pi^+$



Acceptance map for $B^+ \to p\bar{p}\pi^+$

$B_c^+ \to p\bar{p}\pi^+$ systematics

Relative systematic uncertainties on $\varepsilon_u/\varepsilon_c$ and input $\mathcal{B}$s

Source	$m(p\bar{p}) < 2.85\ \mathrm{GeV}/c^2$	$B_c^+ \to J/\psi(\to p\bar{p})\pi^+$
PID	3.0 %	3.0 %
B_c^+ lifetime	2.0 %	2.0 %
Simulation	0.8 %	0.9 %
Detector acceptance	0.6 %	0.6 %
BDT shape	1.5 %	1.5 %
Hardware trigger correction	0.8 %	0.9 %
Fiducial cut	0.1 %	0.1 %
Modelling	15 %	–
$\mathcal{B}(B^+ \to p\bar{p}\pi^+)$	15 %	15 %
$\mathcal{B}(J/\psi \to p\bar{p})$	–	1.4 %

- PID uncertainty dominated by proton calibration sample size
- B_c^+ lifetime $= 0.507 \pm 0.009$ ps
- "Modelling": variation in efficiency over phase space
- $\mathcal{B}(B^+ \to p\bar{p}\pi^+) = (1.07 \pm 0.16) \times 10^{-6}$
- $\mathcal{B}(J/\psi \to p\bar{p}) = (2.120 \pm 0.029) \times 10^{-3}$