arXiv:1603.00413, Submitted to JHEP

Observations of $\Lambda_b^0 \to \Lambda K^+ \pi^-$ and $\Lambda_b^0 \to \Lambda K^+ K^-$ decays

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On behalf of the LHCb collaboration

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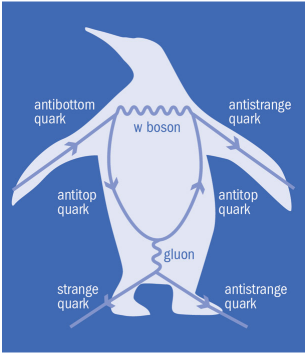
51st Recontres de Moriond, EW (YSF)

Charmless decays

- Suppressed: $b \to s$, $b \to d$ gluonic penguins and $b \to u$ tree
- New physics can appear in penguin loops
- Potential for large CP violation in penguin - tree process interference if similar magnitude
- Multi-body decays: CP asymmetry is a function of phase-space
  - See $B^+ \to h^+ h^+ h^-$ [Phys. Rev. D 90 (2014) 112004], huge CP asymmetries in specific phase-space regions
- CP violation is yet to be observed in baryon decays



Other measurements

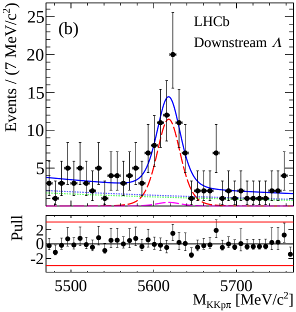
Few charmless Λ_b^0 decays studied so far:

- $\Lambda_b^0 \to K_{\rm S}^0 p\pi^-$: [JHEP 04 (2014) 087]
  - BF $(1.3 \pm 0.19 \pm 0.36) \times 10^{-5}$
  - $\mathcal{A}_{\rm CP}$: $-0.22 \pm 0.13 \pm 0.03$
- $\Lambda_b^0 \to \Lambda\eta$: [JHEP 09 (2015) 006]
  - Evidence at 3σ
- $\Lambda_b^0 \to ph^-$:

  CDF [Phys. Rev. Lett. 113, 242001 (2014)]
  - $\mathcal{A}_{\rm CP}(\Lambda_b^0 \to p\pi^-)$: $0.06 \pm 0.07 \pm 0.03$
  - $\mathcal{A}_{\rm CP}(\Lambda_b^0 \to pK^-)$: $-0.10 \pm 0.08 \pm 0.04$

- $\Lambda_b^0 \to \Lambda\phi$:

  [arXiv:1603.02870, submitted to PLB]
  - Observed at 5.9σ
  - BF $(5.18 \pm 1.10^{+0.67}_{-0.62}) \times 10^{-6}$
  - Triple product asymmetries consistent with zero

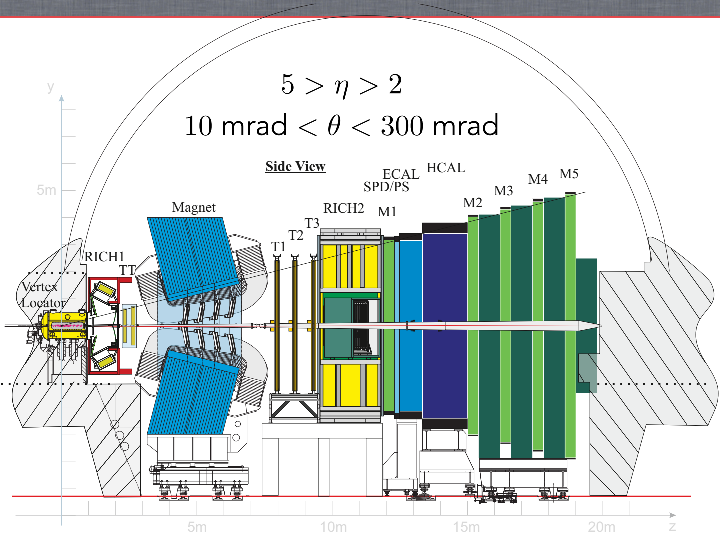


LHCb detector

- VELO: $\sim 20\mu m$ IP resolution
- RICH: Separation of $\pi/K/p$ via Cherenkov radiation
- Higher trigger efficiency for Λ in 2012

$5 > \eta > 2$

10 mrad $< \theta <$ 300 mrad



- 2011: 1 fb^{-1} @ 7 TeV, 2012: 2 fb^{-1} @ 8 TeV

Analysis strategy

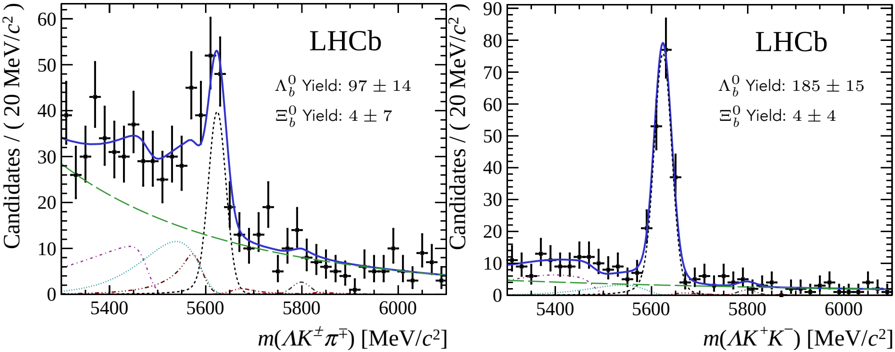
arXiv:1603.00413, Submitted to JHEP

- Search for $\Lambda_b^0(\Xi_b^0) \to \{\Lambda\pi^+\pi^-, \Lambda K^\pm\pi^\mp, \Lambda K^+K^-\}$
  - $\Lambda_b^0 \to (\Lambda\pi^+)_{\Lambda_c^+}\pi^-$ as control mode, selected from the $\Lambda_c^+\pi^-$ region of the $\Lambda_b^0 \to \Lambda\pi^+\pi^-$ phase-space
- Veto intermediate open charm: Ξ_c^+, D^0, Λ_c^+
- Apply boosted decision tree to remove combinatorial background and impose particle identification criteria on charged hadrons
- Fit b-baryon mass distributions simultaneously for all reconstruction categories, running periods and final states
  - Shared parameters give mis-ID contributions and stabilise fit
  - Shape parameters fixed to values from simulation
- Charmless signal regions were not inspected until the selection was finalised

Fit results

arXiv:1603.00413, Submitted to JHEP

- Observations of $\Lambda_b^0 \to \Lambda K^+ \pi^-$ at 8.1σ, and $\Lambda_b^0 \to \Lambda K^+ K^-$ at 15.8σ when systematics on the yield are taken into account (see later)



- Decays involving an un-reconstructed π^0 or photon as magenta and cyan lines, respectively

Fit results

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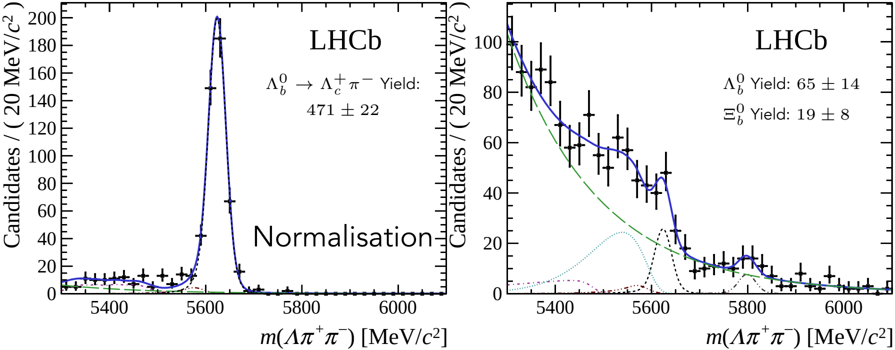
- $\Lambda_b^0 \to (\Lambda\pi^+)_{\Lambda_c^+}\pi^-$ normalisation, selected from $\Lambda_b^0 \to \Lambda\pi^+\pi^-$ phase-space
- Evidence for $\Lambda_b^0 \to \Lambda\pi^+\pi^-$ at 4.7σ, however no evidence for any Ξ_b^0 decays



Dalitz plot distributions

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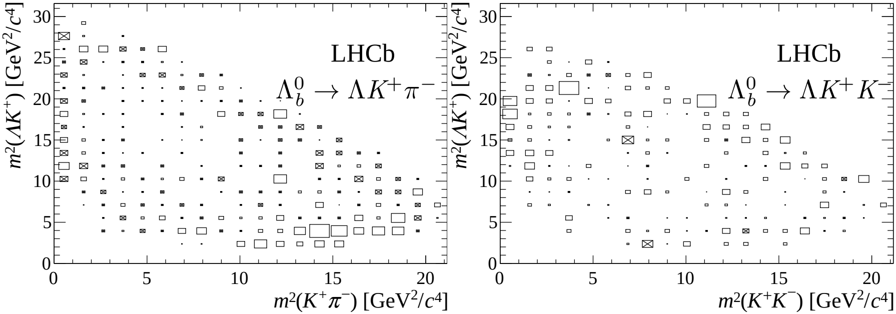

- Background subtracted - used to perform event-by-event efficiency correction
  - Efficiency calculated as a function of phase-space location using simulated events
- Excess at low $m(K^+K^-)$ consistent with separate LHCb analysis of $\Lambda_b^0 \to \Lambda\phi$ [arXiv:1603.02870, submitted to PLB]

Branching fraction systematics

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Systematic (10^{-3})	Fit	Efficiency	Phase space	PID	Vetoes	$\Lambda_c^+\pi^-$ yield	Total
$\Lambda_b^0 \to \Lambda\pi^+\pi^-$	8.4	2.0	19.7	0.4	2.2	3.5	21.9
$\Lambda_b^0 \to \Lambda K^+\pi^-$	1.7	11.7	—	2.9	1.3	4.6	13.1
$\Lambda_b^0 \to \Lambda K^+K^-$	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
$\Xi_b^0 \to \Lambda K^+\pi^-$	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

- Systematics on the fit model are obtained by fitting with an alternative model and fluctuating fixed parameters according to uncertainties
- Phase-space efficiency variation systematic calculated when no event-by-event correction can be performed
- Normalisation mode, $\Lambda_b^0 \to \Lambda_c^+\pi^-$, reconstructed via $\Lambda_c^+ \to \Lambda\pi^+$
  - Low yield as branching fraction $\mathcal{O}(10^{-5})$, but this will improve in future

Branching fraction results

- Normalisation: $\mathcal{B}(\Lambda_b^0 \to (\Lambda\pi^+)_{\Lambda_c^+}\pi^-) = (6.29 \pm 0.78) \times 10^{-5}$ [PDG]
- Observations:

$$\begin{aligned}\mathcal{B}(\Lambda_b^0 \to \Lambda K^+\pi^-) &= (5.6 \pm 0.8 \pm 0.8 \pm 0.7) \times 10^{-6}\,,\\ \mathcal{B}(\Lambda_b^0 \to \Lambda K^+K^-) &= (15.9 \pm 1.2 \pm 1.2 \pm 2.0) \times 10^{-6}\end{aligned}$$

- Evidence:

$$\mathcal{B}(\Lambda_b^0 \to \Lambda\pi^+\pi^-) = (4.6 \pm 1.2 \pm 1.4 \pm 0.6) \times 10^{-6}$$

- Limits:

$$\begin{aligned}f_{\Xi_b^0}/f_{\Lambda_b^0} \times \mathcal{B}(\Xi_b^0 \to \Lambda\pi^+\pi^-) &= (1.3 \pm 0.6 \pm 0.5 \pm 0.2) \times 10^{-6}\,,\\ &< 1.7\ (2.1) \times 10^{-6} \text{ at 90 (95) \% confidence level}\,,\\ f_{\Xi_b^0}/f_{\Lambda_b^0} \times \mathcal{B}(\Xi_b^0 \to \Lambda K^+\pi^-) &= (-0.6 \pm 0.5 \pm 0.3 \pm 0.1) \times 10^{-6}\,,\\ &< 0.8\ (1.0) \times 10^{-6} \text{ at 90 (95) \% confidence level}\,,\\ f_{\Xi_b^0}/f_{\Lambda_b^0} \times \mathcal{B}(\Xi_b^0 \to \Lambda K^+K^-) &< 0.3\ (0.4) \times 10^{-6} \text{ at 90 (95) \% confidence level}\end{aligned}$$

First uncertainty is statistical, second is systematic, and third is related to the uncertainty on the normalisation channel

$\mathcal{A}_{\mathrm{CP}}$ measurement

- Fit separately Λ_b^0 and $\overline{\Lambda}_b^0$ - same model as branching fraction measurement
- Raw yield asymmetry must be corrected for production ($\mathcal{A}_P$) and detection asymmetries ($\mathcal{A}_D$)
  - $\mathcal{A}_{CP} = \mathcal{A}_{CP}^{\mathrm{raw}} - (\mathcal{A}_P + \mathcal{A}_D)$
  - Use $\Lambda_b^0 \to (\Lambda\pi^+)_{\Lambda_c^+}\pi^-$ as a control mode : negligible CP asymmetry, final state differs only in particle identification requirements
- Measure:

$$\begin{aligned}\mathcal{A}_{CP}(\Lambda_b^0 \to \Lambda h^+ h'^-) &= \mathcal{A}_{CP}^{\mathrm{raw}}(\Lambda_b^0 \to \Lambda h^+ h'^-) - (\mathcal{A}_P + \mathcal{A}_D) \\ &= \mathcal{A}_{CP}^{\mathrm{raw}}(\Lambda_b^0 \to \Lambda h^+ h'^-) - \mathcal{A}_{CP}^{\mathrm{raw}}(\Lambda_b^0 \to (\Lambda\pi^+)_{\Lambda_c^+}\pi^-)\end{aligned}$$

- Also correct for phase-space distribution of signal events

$\mathcal{A}_{\mathrm{CP}}$ results

Systematic	$\mathcal{A}_{\mathrm{CP}}(\Lambda_b^0 \to \Lambda K^+\pi^-)$ (10^{-3})	$\mathcal{A}_{\mathrm{CP}}(\Lambda_b^0 \to \Lambda K^+ K^-)$ (10^{-3})
Control mode	66	57
PID asymmetry	20	—
Fit model	27	32
Fit bias	14	4
Efficiency uncertainty	80	28
Total	110	71

- Systematics calculated similarly to branching fraction measurement

$$\mathcal{A}_{CP}(\Lambda_b^0 \to \Lambda K^+\pi^-) = -0.53 \pm 0.23\,(stat.) \pm 0.11\,(syst.)\,,$$
$$\mathcal{A}_{CP}(\Lambda_b^0 \to \Lambda K^+ K^-) = -0.28 \pm 0.10\,(stat.) \pm 0.07\,(syst.)$$

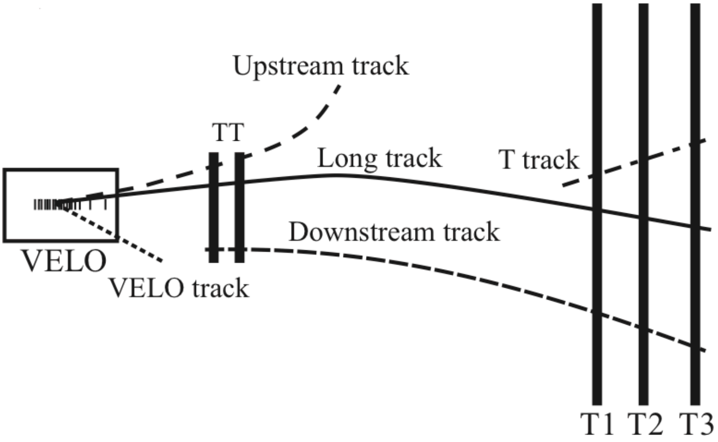
- Both consistent with CP symmetry

Summary

- Observations of $\Lambda_b^0 \to \Lambda K^+\pi^-$ at 8.1σ, and $\Lambda_b^0 \to \Lambda K^+ K^-$ at 15.8σ
  - Branching fractions $\mathcal{O}(10^{-5})$
  - Phase-space integrated CP asymmetries consistent with no CP violation at the level of 3σ
  - $\Lambda_b^0 \to \Lambda\phi$ subject of separate LHCb analysis (arXiv:1603.02870, Submitted to PLB)
- Evidence for $\Lambda_b^0 \to \Lambda\pi^+\pi^-$ at 4.7σ
- Upper limits set on all Ξ_b^0 decays to $\Lambda h^+ h'^-$
- Interesting to probe CP asymmetry and decay dynamics with more data in Run 2!

Backup

Track types


Upstream track
TT
Long track
T track
VELO
Downstream track
VELO track
T1
T2
T3

Theory predictions - $\Lambda_b^0 \to \Lambda\pi^+\pi^-$

- T-violating triple product asymmetries in $\Lambda_b^0 \to \Lambda\pi^+\pi^-$ decay
  S. Arunagiri and C. Q. Geng (hep-ph/0307307)
  - Predicts BF of $\Lambda_b^0 \to \Lambda\pi^+\pi^- \sim 10^{-8}$
- Direct CP Violation in $\Lambda_b^0 \to \Lambda(n)\pi^+\pi^-$ Decays via ρ - ω Mixing
  X.H. Guo and A.W. Thomas (hep-ph/9805332)
  - Predicts BF of $\Lambda_b^0 \to \Lambda\rho \sim 10^{-9}$
  - Possibility of CPV at a level of 70%
- Testing Fundamental Symmetries with $\Lambda_b^0 \to \Lambda\mathrm{Vector}$ Decay
  O. Leitner, Z.A. Ajaltouni and E. Conte (hep-ph/0602043)
  - Predicts BF of $\Lambda_b^0 \to \Lambda(\rho, \omega) \sim 10^{-7}$
- Hopefully recent experimental work by LHCb will inspire more theory interest

Upper limits

- Bayesian upper limits set via Markov chain Monte Carlo
  - No events in signal region for $\Xi_b^0 \to \Lambda K^+ K^-$ (long track) decays
  - Fit likelihood not evaluated in this region
- Assume region contains sum of Poisson distributed signal and background
  - Signal rate prior is flat, background rate prior Gaussian from likelihood fit (both truncated at 0)
  - Log-normal priors used for normalisation mode yield and efficiencies
- Used for all upper limits