Search for $\Xi_b^-(\Omega_b^-) \to \Lambda_c^+ h^- h'^-$ decays at the LHCb

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on behalf of LHCb collaboration

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Motivation

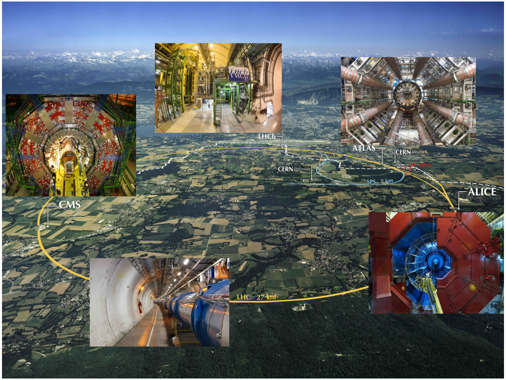
- CP asymmetry - observed in some weak processes involving mesons showing interference effects.
- Drives to look for other sources of CP violation.
- No such effects have been observed in b baryons yet, that might explain the baryogenesis process.
- Decays of heavier b-baryons are not well studied yet.
- Motivates us to investigate the sector.
- Large statistics can provide exciting possibilities for resonances.
- Aim to understand and search for their decay possibilities.

Why LHCb?

- The LHCb experiment at CERN provides platform to understand the unprecedented quantities of b baryons produced by the LHC collisions.
- A versatile online data selection capability.
- Excellent mass, vertex and proper time resolution.
- Precise particle identification.

The LHCb detector

- It is a single-arm forward spectrometer.
- Operates at the COM energy of 7, 8 and 13TeV of the LHC where the proton-proton collisions happen.



The LHCb sub-detectors

- VELO : Tracking device; beams collide; accurate measurement of the decay positions.
- RICH : provides particle identification; measure emissions of cherenkov radiation;
- Magnet : Track's curvature helps to measure the momentum of the charged particles.

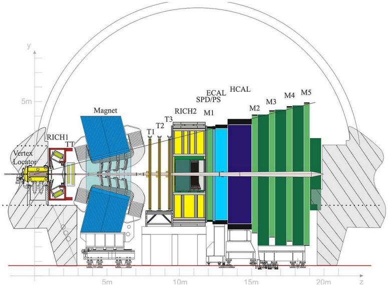
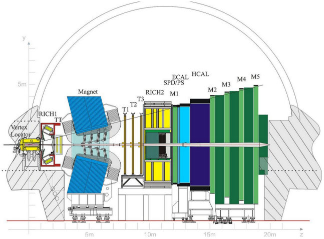


Figure: *Int. J. Mod. Phys. A 30, 1530022 (2015)*

The LHCb sub-detectors

- Tracking system (TT, T1,T2,T3) : picks up ionisation of charged particles; provide efficient reconstruction of tracks;
- Calorimeters : designed to stop particles; measure amount of energy lost; provide main method to identify neutrally charged particles.
- Muon systems : detects muons that are present in the final states of many B decays



- Upgraded detector will start taking data this year, providing further opportunities to explore the physics.

Introduction

- Search for $\Xi_b^-(\Omega_b^-) \to \Lambda_c^+ h^- h'^- decays$; $h, h' = KK, K\pi, \pi\pi$
- Cabibbo Favoured Decays: $\Xi_b^- \to \Lambda_c^+ K^- \pi^-$, $\Omega_b^- \to \Lambda_c^+ K^- K^-$
- Has an unmeasured branching fraction.
- Important to control systematics in future CP Violation studies with other modes.
- $B^- \to \Lambda_c^+ \bar{p} \pi^-$ and $B^- \to \Lambda_c^+ \bar{p} K^-$ are used as the normalisation modes.

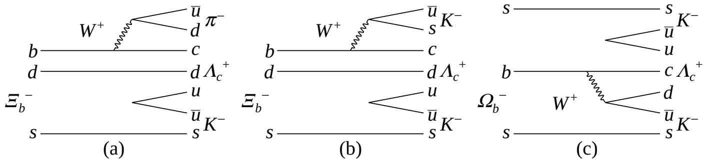


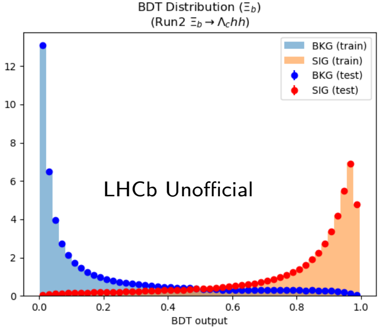
Figure: Decay diagrams for the (a) $\Xi_b^- \to \Lambda_c^+ K^- \pi^-$, (b) $\Xi_b^- \to \Lambda_c^+ K^- K^-$, (c) $\Omega_b^- \to \Lambda_c^+ K^- K^-$

Measurement Aim

- Branching fraction measurement of the decay modes relative to the control modes
- Relative branching fraction of the two control modes.
- Observe Dalitz plot projections.
- Production kinematics and production asymmetry of Ξ_b^- baryon.

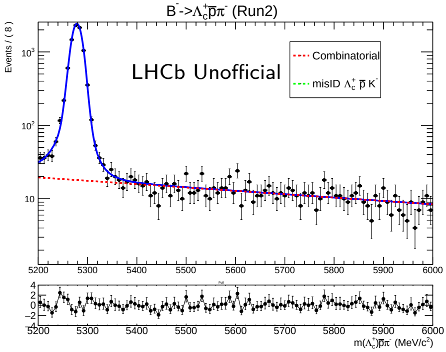
Analysis strategy

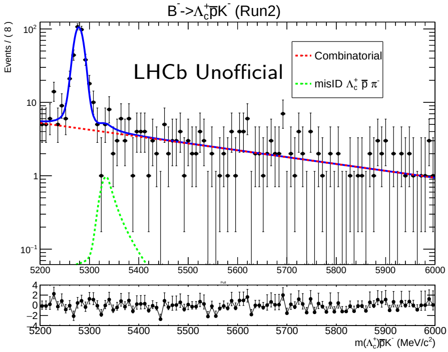
- Decay is reconstructed from the final state tracks for both data and MC simulation of the proton-proton collision.
- Signal-like and background-like events are separated using BDT.
- The BDT receives topological, vertex and kinematic information.
- Optimum working point is chosen for the analysis.



Mass fits of the control mode $B^- \to \Lambda_c^+ \bar{p} h^-$

- The invariant mass distribution is modelled from the MC and used to fit the shape to data.
- Study and model various possible backgrounds in the decay.





Signal yield $= 2019 \pm 46$

Signal yield $= 8407 \pm 93$

Results - Branching fraction measurement

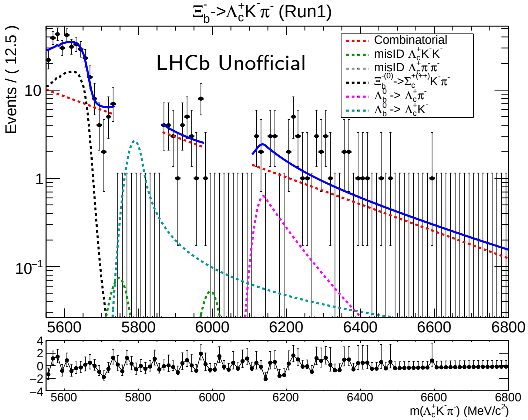
- The total efficiency of reconstruction, selection etc, is estimated from MC simulation.
- The corrected yields take into account the fitted yields and efficiency as N_{corr} = fit yields / efficiency.
- Branching fraction of the two decays will be ratio of their corrected yields.

Table: Branching fraction with statistical and systematic uncertainties.

	Run I	Run II
$\frac{(\mathcal{B}B^- \to \Lambda_c^+ \bar{p} K^-)}{(\mathcal{B}B^- \to \Lambda_c^+ \bar{p} \pi^-)}$	$0.043 \pm 0.006 \pm 0.002$	$0.040 \pm 0.003 \pm 0.001$
combined	$0.0406 \pm 0.0023 \pm 0.0015$	

Mass fit of the signal mode $\Xi_b^-(\Omega_b^-) \to \Lambda_c^+ K^- \pi^-$

- Signal modes are blinded in order to ensure that the modelling is unbiased.
- Blind mass window : $(5735–5865 MeV/c^2)$ and $(5977–6107 MeV/c^2)$



Results - DP projections

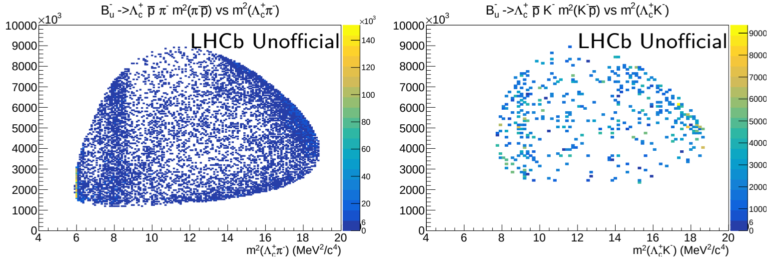
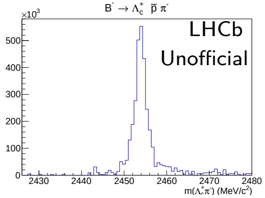
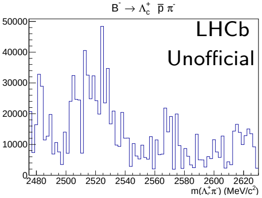
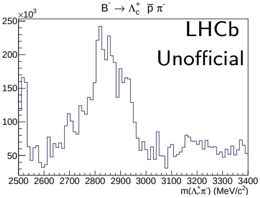


Figure: Background-subtracted and efficiency-corrected DP projections of (top) $B^- \to \Lambda_c^+ \bar{p}\pi^-$ and (bottom) $B^- \to \Lambda_c^+ \bar{p} K^-$ decays.

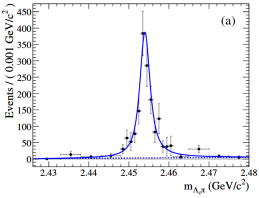
Results - Invariant Mass Projections



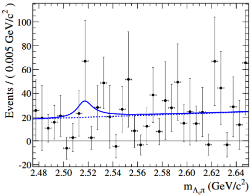




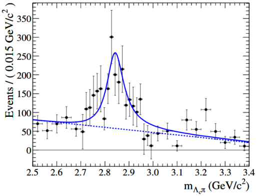
LHCb result



(a) $\Sigma_c(2455)$



(b) $\Sigma_c(2520)$



(c) $\Sigma_c(2840)$

Babar result : Phys. Rev. D, 78(2008),112003

We observe the three resonances seen in Babar results for the $B^- \to \Lambda_c^+ \bar{p}\pi^-$

Analysis Strategy - Production Asymmetry

- Production asymmetry of Ξ_b^- baryon.

$$A_{prod} = \frac{\sigma(pp \to XbY) - \sigma(pp \to \bar{X}bY)}{\sigma(pp \to XbY) + \sigma(pp \to \bar{X}bY)}$$

- According to the Standard Model $A_{CP} = 0$

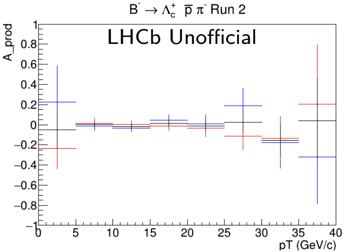
$$A_{meas} = A_{prod} + A_{CP}$$

$$A_{meas} = \frac{N(X_b^- \to \Lambda_c^+ h^- h`^-) - N(\bar{X}_b \to \bar{\Lambda}_c h^+ h`^+)}{N(X_b^- \to \Lambda_c^+ h^- h`^-) + N(\bar{X}_b \to \bar{\Lambda}_c h^+ h`^+)}$$

where, X_b is a b hadron and h,h‘ are p, K, π and N is background subtracted and efficiency corrected yields

- Hence $A_{prod} \approx A_{meas}$

- Variation of production asymmetry for the control mode.
- Studied in the bins of transverse momentum and acceptance range of the detector (pseudorapidity).



- A_prod = -0.00507 $\pm$ 0.0015 (Average over polarity - black)
- A_prod = -0.0052 $\pm$ 0.0019 (LHCb Average)

Summary and Conclusion

- Branching fraction measurements have been performed for the control modes along with systematics.
- Dalitz plot projection were studied for the control modes.
- Production asymmetry was evaluated for the control modes.
- Blind fits are performed for the signal modes.
- Efficiencies are computed for the signal modes

Future Work

- Unblind the fits for the signal and calculate the branching fraction ratios.
- Measure the production kinematics and asymmetries for the signal modes.
- Look for any resonances in the DP of the signal channel.

Backup slides

Analysis Strategy - Efficiency estimation

- The total efficiency estimated from MC :
  $\epsilon_{tot} = \epsilon_{Trig,Strip,Geom,Reco} \times \epsilon_{sel} \times \epsilon_{PID}$
- The lifetime corrections have been applied for the Ω_b decays, since the simulated value and world average value differ from each other.
- However, we use DP efficiency maps to apply an event by event efficiency correction.

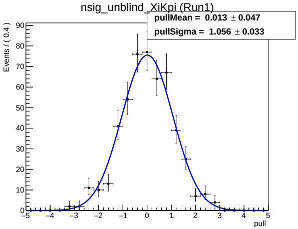
	Polarity	2011(%)	2012(%)	2015(%)	2016(%)	2017(%)	2018(%)
$B^- \to \Lambda_c^+ \bar{p} \pi^-$	Up	0.039	0.033	0.059	0.067	0.069	0.061
$B^- \to \Lambda_c^+ \bar{p} \pi^-$	Down	0.039	0.034	0.059	0.066	0.071	0.062
$B^- \to \Lambda_c^+ \bar{p} K^-$	Up	0.033	0.027	0.050	0.057	0.065	0.054
$B^- \to \Lambda_c^+ \bar{p} K^-$	Down	0.034	0.028	0.052	0.056	0.064	0.056
$\Xi_b^- \to \Lambda_c^+ K^- K^-$	Up	0.035	0.029	0.046	0.052	0.061	0.052
$\Xi_b^- \to \Lambda_c^+ K^- K^-$	Down	0.037	0.029	0.049	0.052	0.061	0.053
$\Xi_b^- \to \Lambda_c^+ K^- \pi^-$	Up	0.045	0.037	0.057	0.061	0.067	0.056
$\Xi_b^- \to \Lambda_c^+ K^- \pi^-$	Down	0.045	0.038	0.059	0.062	0.068	0.057
$\Xi_b^- \to \Lambda_c^+ \pi^- \pi^-$	Up	0.057	0.049	0.072	0.079	0.080	0.069
$\Xi_b^- \to \Lambda_c^+ \pi^- \pi^-$	Down	0.056	0.053	0.073	0.075	0.079	0.069
$\Omega_b^- \to \Lambda_c^+ K^- K^-$	Up	0.035	0.027	0.043	0.047	0.054	0.046
$\Omega_b^- \to \Lambda_c^+ K^- K^-$	Down	0.036	0.028	0.045	0.045	0.055	0.048
$\Omega_b^- \to \Lambda_c^+ K^- \pi^-$	Up	0.043	0.032	0.051	0.055	0.060	0.059
$\Omega_b^- \to \Lambda_c^+ K^- \pi^-$	Down	0.042	0.035	0.052	0.057	0.061	0.059
$\Omega_b^- \to \Lambda_c^+ \pi^- \pi^-$	Up	0.054	0.044	0.064	0.069	0.070	0.059
$\Omega_b^- \to \Lambda_c^+ \pi^- \pi^-$	Down	0.052	0.045	0.068	0.071	0.070	0.060

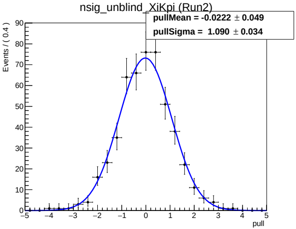
Systematic effects

	Run I	Run II
Fit model	0.153	0.532
Fixed parameters	0.797	0.485
Fit bias	1.081	0.478
Multiple candidates	0.047	0.412
Finite MC statistics	1.980	0.774
Data-MC mismatch	2.341	0.274
Square Dalitz plot binning	0.596	0.229
PID resampling	0.962	0.308
Tracking correction	0.838	0.018
`L0Hadron`	2.521	2.521
Subtotal (uncorrelated)	2.558	1.031
Subtotal (correlated)	3.625	2.652
Total (relative)	4.424	2.845
Total systematic (absolute)	0.0019	0.0011
Total statistical (absolute)	0.0057	0.0025

Analysis Strategy - Toy studies for blind fits

- The blind fits are validated by performing pseudoexperiments to ensure the stability of the fits and unbiasing of the fit parameters.
- Generate toy samples corresponding to the model and fit them while fixing the signal yields to values of 500(1000), 25(50), 50(100), for $\Xi_b^- \to \Lambda_c^+ K^- \pi^-$ Run I(Run II), $\Xi_b^- \to \Lambda_c^+ K^- K^-$ Run I(Run II) and $\Omega_b^- \to \Lambda_c^+ K^- K^-$ Run I(Run II).





Pull Distributions of toys for the $\Xi_b^- \to \Lambda_c^+ K^- \pi^-$ signal yield parameter