

# Measurements of $\Lambda_c^+ \rightarrow p^+ h^+ h^-$ $\mathcal{BF}$ s with LHCb 2011 Data

Stephen Ogilvy  
on behalf of the LHCb collaboration

University of Glasgow

# Overview

- 1 Existing Measurements
- 2 The LHCb Detector
- 3 Data Selection
- 4 Mass Fits and Signal Yields
- 5 Efficiencies and Systematic Uncertainties
- 6 Outlook

# Existing $\Lambda_c^+ \rightarrow p^+ h^- h^+$ Measurements

- $\Lambda_c^+$  decay modes currently poorly understood in terms of Branching Fractions ( $\mathcal{BF}$ s) and resonance structure.
- All  $\Lambda_c^+$   $\mathcal{BF}$  measurements made relative to Cabibbo-favoured (CF)  
 $\Lambda_c^+ \rightarrow p^+ K^- \pi^+$  mode - has absolute  $\mathcal{BF}$  uncertainty 26%.
- Doubly-Cabibbo Suppressed (DCS) decay  $\Lambda_c^+ \rightarrow p^+ \pi^- K^+$  not yet observed.

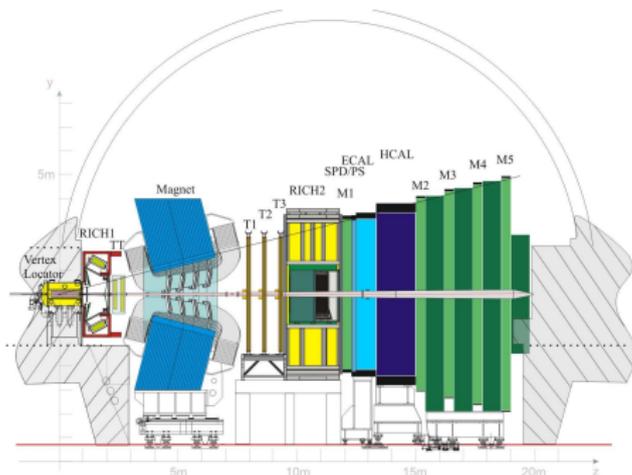
Decay Mode	PDG Branching Fraction
$\Lambda_c^+ \rightarrow p^+ K^- \pi^+$ (CF)	$0.05 \pm 0.013$
$\Lambda_c^+ \rightarrow p^+ K^- K^+$ (SCS)	$(7.7 \pm 3.5) \times 10^{-4}$
$\Lambda_c^+ \rightarrow p^+ \pi^- \pi^+$ (SCS)	$(3.5 \pm 2.0) \times 10^{-3}$
$\Lambda_c^+ \rightarrow p^+ K^+ \pi^-$ (DCS)	$< 2.3 \times 10^{-4}$ @ 90% CL

The  $\Lambda_c^+ \rightarrow p^+ h^- h^+$  decay modes and their branching fractions.

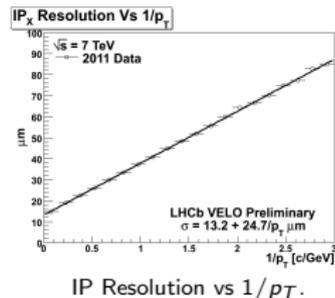
- Understanding these decays key to other analyses:
  - doubly-charmed baryon searches through  $\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+$ .
  - CPV searches in Cabibbo-suppressed  $\Lambda_c^+$  decays (see Alex Pearce's talk).
- **High statistics in charm - LHCb can improve our understanding of these decays.**

# The LHCb Detector

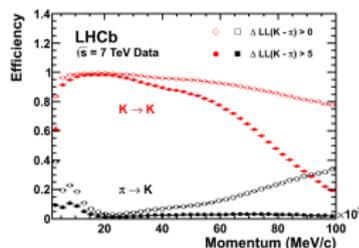
- Forward arm spectrometer designed for precision flavour measurements.



Cross-section of the LHCb Detector.



IP Resolution vs  $1/p_T$ .



Kaon ID and  $\pi - K$  misID rates.

- VELO - secondary vertex discrimination to trigger on decays of interest. Momentum resolution:  $\Delta p/p = 0.4\%$  at  $5\text{GeV}/c$  to  $0.6\%$  at  $100\text{GeV}/c$ .
- RICH - daughter particle discrimination: Kaon ID efficiency  $\sim 95\%$  for  $\sim 5\%$   $\pi \rightarrow K$  mis-id probability.

- Measuring  $\mathcal{BF}$ s of the modes relative to the CF  $\Lambda_c^+ \rightarrow p^+ K^- \pi^+$  mode:

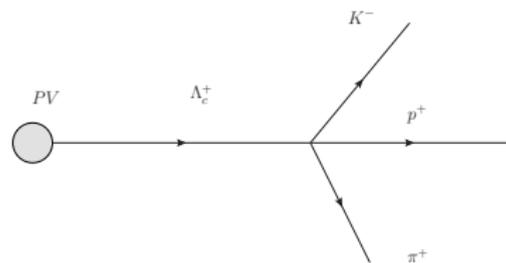
$$\frac{\mathcal{BF}_{\Lambda_c^+ \rightarrow p^+ K^- K^+}}{\mathcal{BF}_{\Lambda_c^+ \rightarrow p^+ K^- \pi^+}}, \frac{\mathcal{BF}_{\Lambda_c^+ \rightarrow p^+ \pi^- \pi^+}}{\mathcal{BF}_{\Lambda_c^+ \rightarrow p^+ K^- \pi^+}}, \frac{\mathcal{BF}_{\Lambda_c^+ \rightarrow p^+ \pi^- K^+}}{\mathcal{BF}_{\Lambda_c^+ \rightarrow p^+ K^- \pi^+}}.$$

- Also analyse  $\Lambda_c^+ \rightarrow p^+ \phi(K^+ K^-)$  decays: possible due to relatively low non-resonant production.
- Aim to resolve existing experimental tension:

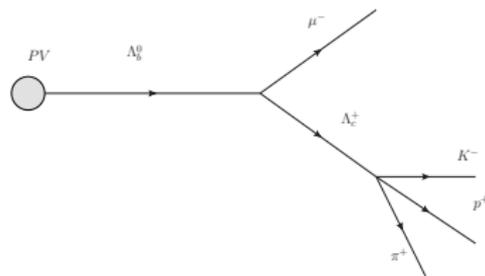
e.g.  $\frac{\mathcal{BF}_{\Lambda_c^+ \rightarrow p^+ K^- K^+}}{\mathcal{BF}_{\Lambda_c^+ \rightarrow p^+ K^- \pi^+}}:$

- Belle:  $0.014 \pm 0.002(stat) \pm 0.002(syst)$  [PL B524 33].
- CLEO II:  $0.039 \pm 0.009(stat) \pm 0.007(syst)$  [PR D53 R1013].

- In 2011 LHCb gathered integrated luminosity of  $1.0\text{fb}^{-1}$  at  $\sqrt{s} = 7\text{TeV}$ .
- Two sources of  $\Lambda_c^+$  production: produced promptly and from semileptonic  $\Lambda_b^0 \rightarrow \Lambda_c^+ \mu^- \bar{\nu}$  decays. Treat these independently.
- No good cross-check modes for these decays - DCS mode blinded until agreement between ratios of SCS/CF in prompt/semileptonic.



Prompt production.



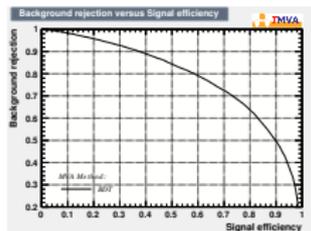
Semileptonic production

# Trigger and Stripping Selection

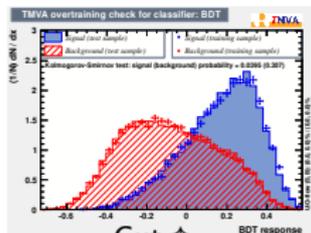
- Trigger:
  - No 2011 prompt triggers for  $\Lambda_c^+ \rightarrow p^+ h^- h^+$  - need different approaches to triggering in prompt and semileptonic.
  - In prompt require events triggered regardless of signal decay - same trigger efficiency across modes.
  - In semileptonic require signal decay within event fired trigger: well-defined trigger efficiencies for modes.
- Stripping - central processing of data to extract good events from tape. Use sequential cuts on a variety of quantities:
  - PID information from RICH.
  - Kinematic cuts on mother and daughters.
  - Quality cuts on track reconstruction and vertexing.

# Offline Selection

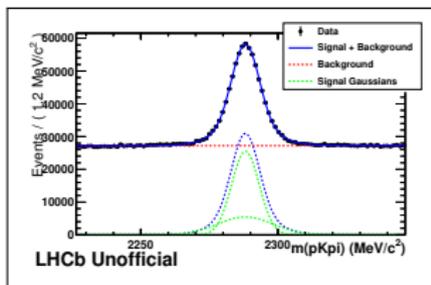
- Semileptonic: low combinatoric background. Minimal additional vertex quality cuts offline. Prompt: much higher combinatorics.
- Use BDT to select prompt events, trained on CF data (weighted with sPlots method - [arXiv:physics/0402083](https://arxiv.org/abs/physics/0402083)).
- Also global signal weighting of  $\frac{|V_{ud}|^2 |V_{cs}|^2}{|V_{cd}|^2 |V_{us}|^2} = 0.003$  for max sensitivity to DCS.



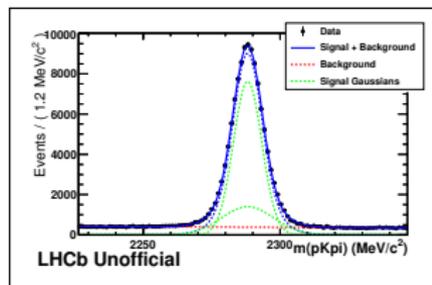
ROC curve for BDT.



Overtraining check for BDT.



Prompt sample before BDT.

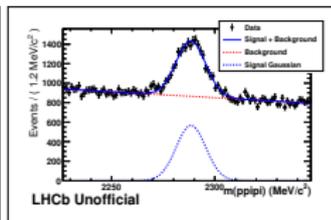
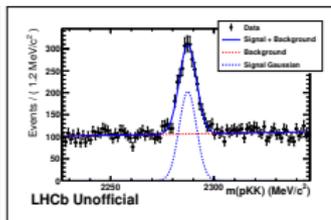
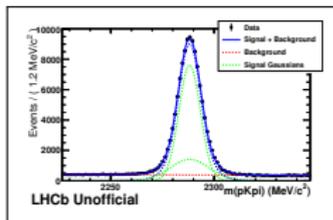


Prompt sample after BDT.

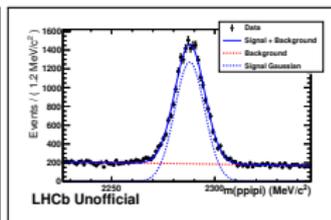
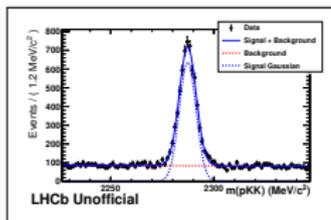
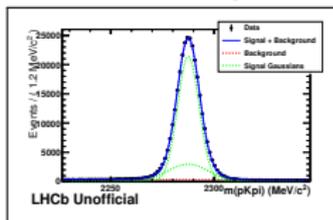
- BDT and further PID cuts reduce combinatorics by 98%.
- Projected signal significance  $\frac{S}{\sqrt{S+B}}$  for prompt DCS =  $4.4\sigma$ .
- Projected signal significance for semileptonic DCS =  $8.4\sigma$ .

# Mass Fits and Signal Yields

## Prompt



## Semileptonic

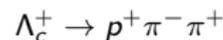
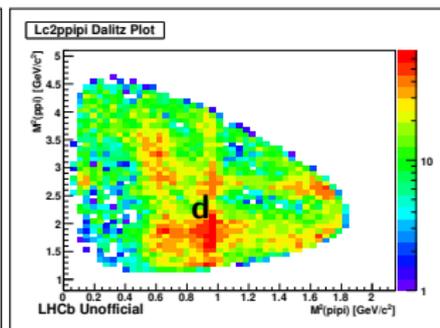
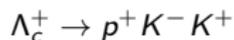
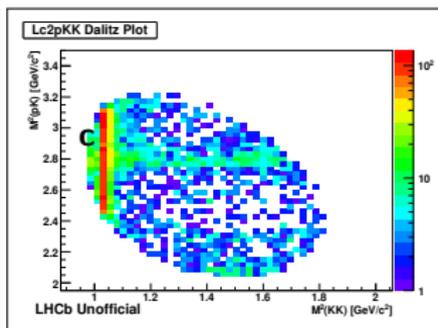
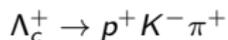
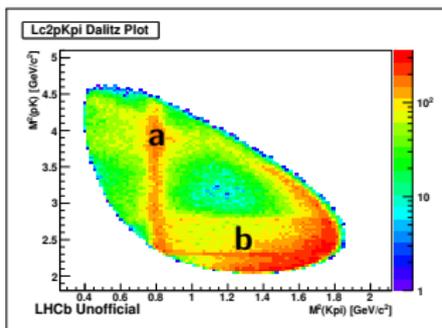


- Data yields after final selection.
- All fits unbinned extended likelihood fits.
- Signal models: double gaussian with shared mean for CF, single gaussian for CS.
- All backgrounds linear.

Mode	Prompt Yield	SL Yield
$\Lambda_C^+ \rightarrow p^+ K^- \pi^+$	$109779 \pm 397$	$292499 \pm 578$
$\Lambda_C^+ \rightarrow p^+ K^+ K^-$	$1773 \pm 67$	$5390 \pm 87$
$\Lambda_C^+ \rightarrow p^+ \pi^- \pi^+$	$8465 \pm 225$	$19125 \pm 175$

# Resonance Structure

- Shown below: charge opposite daughter pairs from semileptonic modes.
- s-Weighted for sideband subtraction.



- Variety of resonances clearly seen:  $K^*(892)$  (a),  $\Lambda(1520)$  (b),  $\phi(1020)$  (c),  $f_0(980)$  (d).
- LHCb can perform comprehensive amplitude analysis of these poorly understood decays.

# Efficiencies and Systematics Overview

Efficiency corrections:

$$\frac{BF_{phh}}{BF_{pK\pi}} = \frac{N_{phh\text{measured}}}{N_{pK\pi\text{measured}}} \times \frac{\epsilon_{\text{trig}|pK\pi}}{\epsilon_{\text{trig}|phh}} \times \frac{\epsilon_{\text{strip}|pK\pi}}{\epsilon_{\text{strip}|phh}} \times \frac{\epsilon_{\text{offline}|pK\pi}}{\epsilon_{\text{offline}|phh}} \times \frac{\epsilon_{\text{PID}|pK\pi}}{\epsilon_{\text{PID}|phh}}$$

- Trigger and stripping efficiencies taken from MC.
- Offline efficiency taken from data.
- PID cuts used in stripping, but badly modelled in MC. Use a data-driven calibration to evaluate the PID efficiency separately.
- All efficiencies have been calculated.

Systematics:

- Dominant systematic associated with PID calibration -  $\sim 3\%$ . Evaluated with MC, limited by MC stats.
- Some sources of systematic uncertainty still to be evaluated, e.g. fit model, but expected to be small.

- Working to ensure CS/CF results consistent before unblinding  $\Lambda_c^+ \rightarrow p^+ \pi^- K^+$  and presenting results to public.
- Significance projections indicate we should make first observation of  $\Lambda_c^+ \rightarrow p^+ \pi^- K^+$ .
- Should have lower final systematics than previous measurements:  
e.g. Belle 14%, CLEO II 18% for  $\frac{\mathcal{BF}_{\Lambda_c^+ \rightarrow p^+ K^- K^+}}{\mathcal{BF}_{\Lambda_c^+ \rightarrow p^+ K^- \pi^+}}$ .
- After this result - another  $2fb^{-1}$  at  $\sqrt{s} = 8 TeV$  to analyse!