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

Stephen Ogilvy[1], Thomas Ruf[2],Paul Soler[1], Patrick Spradlin[1]

1. University of Glasgow, UK 2. CERN

University of Glasgow | Experimental Particle Physics

Overview

Existing $\Lambda_c^+ \to p^+ h^- h^+$ Measurements

- Λ_c^+ decay modes currently poorly understood in terms of Branching Fractions ($\mathcal{BF}$s), decay amplitudes and resonance structure.
- All Λ_c^+ $\mathcal{BF}$ measurements are currently made relative to the Cabibbo-favoured (CF) $\Lambda_c^+ \to p^+ K^- \pi^+$ mode, which has absolute $\mathcal{BF}$ uncertainty 26%.
- Current PDG $\mathcal{BF}$s shown below, the doubly-Cabibbo Suppressed (DCS) decay $\Lambda_c^+ \to p^+ \pi^- K^+$ has not been observed.

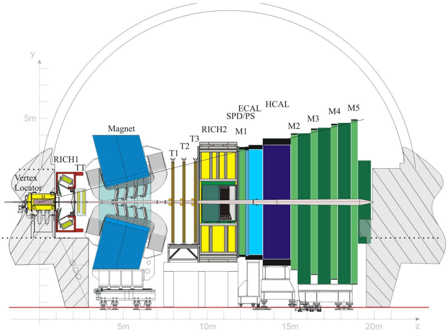
Decay Mode	**PDG Branching Fraction**
$\Lambda_c^+ \to p^+ K^- \pi^+$ (CF)	0.05 ± 0.013
$\Lambda_c^+ \to p^+ K^- K^+$ (SCS)	$(7.7 \pm 3.5) \times 10^{-4}$
$\Lambda_c^+ \to p^+ \pi^- \pi^+$ (SCS)	$(3.5 \pm 2.0) \times 10^{-3}$
$\Lambda_c^+ \to p^+ K^+ \pi^-$ (DCS)	$< 2.3 \times 10^{-4}$ @ 90% CL

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

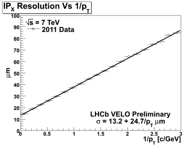
- Understanding these decays pivotal in analyses looking for doubly-charmed baryons and ΔA_{CP} in Λ_c^+.
- With its high statistics in charm LHCb can improve our understanding of these decays.

The LHCb Detector

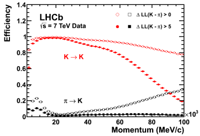
- LHCb is a forward arm spectrometer designed for precision flavour measurements.
- Requires powerful particle identification (PID), secondary vertex discrimination and high momentum and energy resolution.



Cross-section of the LHCb Detector.



IP Resolution vs $1/p_T$.

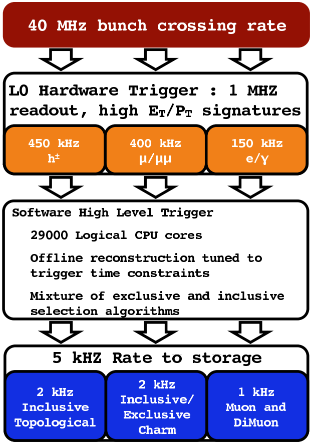


Kaon ID and $\pi - K$ misID rates.

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

The LHCb Trigger

- Trigger has multiple stages, hardware $L0$ and software HLT.
- L0 reconstructs:
  - the highest transverse energy (E_T) hadron, electron and photon clusters in the calorimeters.
  - the two highest transverse momentum (p_T) muons in the muon chambers.
- Reduces rate to $1MHz$ for HLT.
  - HLT1 rejects bulk of events with partial reconstruction.
  - HLT2 filters events using full event reconstruction for use in physics analyses. $5kHz$ rate written to tape.



Scheme of the LHCb trigger.

2011 Dataset and Measurements

- In 2011 LHCb gathered an integrated luminosity of $1.0fb^{-1}$ at $\sqrt{s} = 7\,TeV$.
- Cross section of Λ_c^+ production in LHCb acceptance at $7\,TeV$ is $178.43\mu b$.
- $\sim 10^{11}$ Λ_c^+ produced promptly in LHCb acceptance in 2011 in alone.
- Utilise two sources of Λ_c^+ production: those produced promptly and those from semileptonic $\Lambda_b^0 \rightarrow \Lambda_c^+ \mu^- \bar{\nu}$ decays. Treat these independently.
- Measuring $\mathcal{BF}$s of the modes relative to the CF $\Lambda_c^+ \rightarrow p^+ K^- \pi^+$ mode:

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

- Lack of suitable cross-check modes for these decays - keeping the unobserved DCS mode blind until we can demonstrate agreement between the ratios of the SCS/CF in the prompt and semileptonic samples.
- Also look at $\Lambda_c^+ \rightarrow p^+ \phi$, as this is easy to isolate due to relatively low non-resonant production.
- Aim to resolve some existing experimental tension regarding $\frac{\mathcal{BF}_{\Lambda_c^+ \rightarrow p^+ K^- K^+}}{\mathcal{BF}_{\Lambda_c^+ \rightarrow p^+ K^- \pi^+}}$:
  - 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].

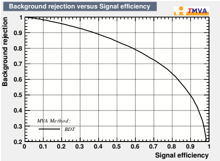
Trigger and Stripping Selection

- Trigger:
  - Lack of prompt trigger lines in HLT2 in 2011 necessitates differing approaches to trigger chain (L0, HLT1, HLT2) in prompt and semileptonic.
  - In prompt require that events were triggered regardless of the inclusion of our signal event (trigger independently of signal) - same trigger efficiency across modes.
  - In semileptonic require that signal decay within the event fired the trigger and not some other feature of the underlying event (trigger on signal). Therefore can measure well defined trigger efficiency for each mode.
- "Stripping" is the central processing of the data to extract interesting events from tape.

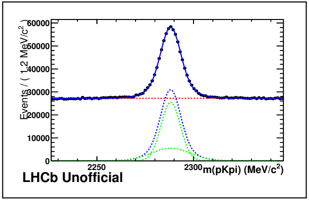
  Utilise rectangular cuts on a variety of quantities:
  - PID information from the RICH.
  - Kinematic cuts on mother and daughters.
  - Quality cuts on track reconstruction and vertexing.
- Efficiencies of trigger and stripping can be calculated from MC.

Offline Selection

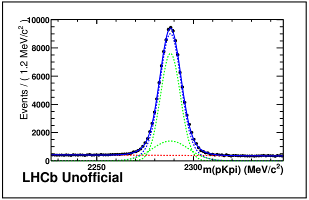
- In semileptonic very low combinatoric background. Minimal additional vertex quality cuts in offline. In prompt much higher combinatoric background.
- Use a BDT to select prompt events, trained on 10% of the CF data (weighted with the sPlots method - arXiv:physics/0402083) with additional global signal weighting of $\frac{|V_{ud}|^2|V_{cs}|^2}{|V_{cd}|^2|V_{us}|^2} = 0.003$ for max sensitivity to DCS mode.



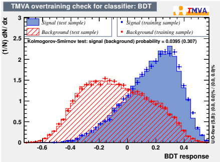
ROC curve for BDT.



Prompt sample before BDT.



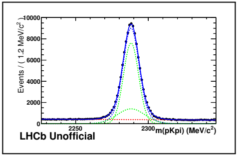
Prompt sample after BDT.



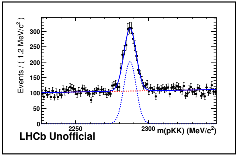
Overtraining check for BDT.

- BDT in conjunction with further PID cuts reduce the prompt CF combinatoric background by 98%.
- Projected signal significance $\frac{S}{\sqrt{S+B}}$ for prompt DCS $= 4.4\sigma$.
- Projected signal significance for semileptonic DCS $= 8.4\sigma$.

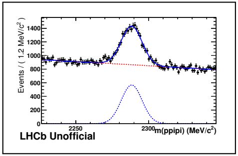
Mass Fits and Signal Yields



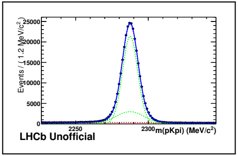
Prompt $\Lambda_c^+ \to p^+ K^- \pi^+$.



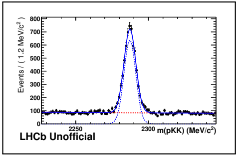
Prompt $\Lambda_c^+ \to p^+ K^- K^+$.



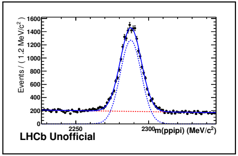
Prompt $\Lambda_c^+ \to p^+ \pi^- \pi^+$.



SL $\Lambda_c^+ \to p^+ K^- \pi^+$.



SL $\Lambda_c^+ \to p^+ K^- K^+$.



SL $\Lambda_c^+ \to p^+ \pi^- \pi^+$.

- 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
$\Lambda_c^+ \to p^+ K^- \pi^+$	109779 ± 397	292499 ± 578
$\Lambda_c^+ \to p^+ K^- K^+$	1773 ± 067	5390 ± 087
$\Lambda_c^+ \to p^+ \pi^- \pi^+$	8465 ± 225	19125 ± 175

Efficiencies and Systematics Overview

Efficiencies to be determined:

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

- Trigger and stripping efficiencies taken from MC.
- Offline (BDT in prompt, cut-based in SL) 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 from stripping and offline efficiencies.
- All efficiencies have been calculated.

Systematics:

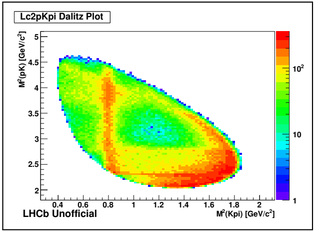
- Dominant systematic is associated with our PID calibration - $\sim 3\%$.
- Some sources of systematic uncertainty still to be evaluated, e.g. fit model, but expected to be small.

Outlook

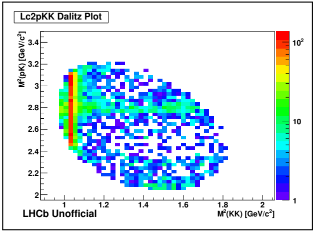
- Results in prompt and semileptonic:
  - agreement in $\frac{\mathcal{BF}_{\Lambda_c^+ \to p^+ \pi^- \pi^+}}{\mathcal{BF}_{\Lambda_c^+ \to p^+ K^- \pi^+}}$.
  - $\sim 4\sigma$ disagreement in $\frac{\mathcal{BF}_{\Lambda_c^+ \to p^+ K^- K^+}}{\mathcal{BF}_{\Lambda_c^+ \to p^+ K^- \pi^+}}$.
- Working to find this source of disagreement before unblinding $\Lambda_c^+ \to p^+ \pi^- K^+$and presenting results to public.
- Should have lower final systematics than previous measurements: Belle 14%, CLEO II 18% for $\frac{\mathcal{BF}_{\Lambda_c^+ \to p^+ K^- K^+}}{\mathcal{BF}_{\Lambda_c^+ \to p^+ K^- \pi^+}}$.
- After this result have another $2fb^{-1}$ at $\sqrt{s} = 8\,TeV$ of data to analyse.

Resonance Structure

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



$\Lambda_c^+ \rightarrow p^+ K^- \pi^+$ Dalitz Plot



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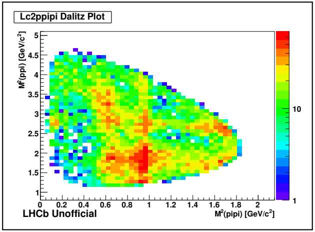

$\Lambda_c^+ \rightarrow p^+ \pi^- \pi^+$ Dalitz Plot

- Variety of resonances can be clearly seen: $K^*(892)$, $\Lambda(1520)$, $\phi(1020)$, $f_0(980)$.
- LHCb has the expertise, high statistics and low backgrounds for a comprehensive amplitude analysis of these poorly understood decays.