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

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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 $\mathcal{BF}$ measurements are relative to the Cabibbo-favoured (CF) $\Lambda_c^+ \to p^+ K^- \pi^+$ mode, with uncertainty of 26%.
- Current PDG $\mathcal{BF}$s shown below, the doubly-Cabibbo Suppressed (DCS) decay $\Lambda_c^+ \to p^+ \pi^- K^+$ has not been observed.

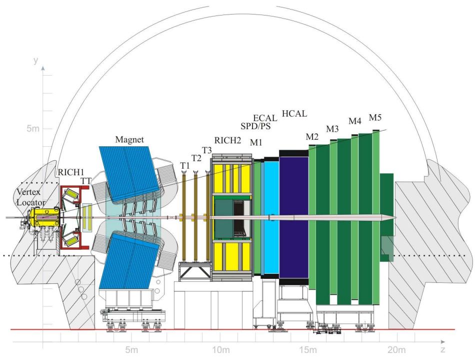
Decay Mode	**PDG Branching Fraction**
$\Lambda_c^+ \to p^+ K^- \pi^+$ (CF)	0.05 ± 0.013
$\Lambda_c^+ \to p^+ K^- K^+$ (SCS)	$(7.7 \pm 3.5) \times 10^{-4}$
$\Lambda_c^+ \to p^+ \pi^- \pi^+$ (SCS)	$(3.5 \pm 2.0) \times 10^{-3}$
$\Lambda_c^+ \to p^+ K^+ \pi^-$ (DCS)	$< 2.3 \times 10^{-4}$ @ 90% CL

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

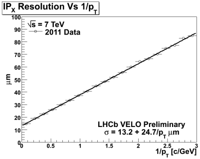
- Understanding these decays pivotal in analyses looking for doubly-charmed baryons and ΔA_{CP} in Λ_c^+.
- With its high statistics in charm LHCb can improve our understanding of these decays.

The LHCb Detector

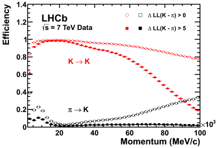
- LHCb is a forward arm spectrometer designed for precision flavour measurements.



Cross-section of the LHCb Detector.



IP Resolution vs $1/p_T$.

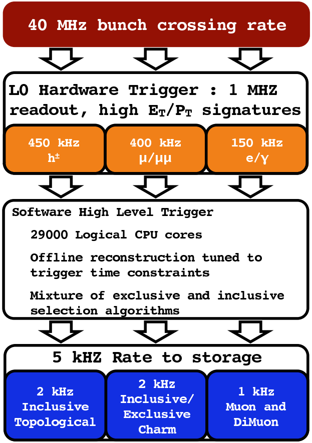


Kaon ID and $\pi - K$ misID rates.

- VELO and trackers give secondary vertex discrimination to trigger on decays of interest.
  Momentum resolution: $\Delta p/p = 0.4\%$ at $5 GeV/c$ to 0.6% at $100 GeV/c$.
- 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 *L*0 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 1*MHz* for HLT.
  - HLT1 rejects bulk of events with partial reconstruction, splits events into different "alleys".
  - HLT2 filters events using kinematic information for use in physics analyses. 5*kHz* rate written to tape.



Scheme of the LHCb trigger.

2011 Dataset and Measurements

- In 2011 LHCb gathered an integrated luminosity of $1.0 fb^{-1}$ 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 in LHCb acceptance in 2011.
- Utilise two sources of Λ_c^+ production: those produced promptly and those from semileptonic $\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}$ decays.
- Measuring $\mathcal{BF}$s of the modes relative to the CF $\Lambda_c^+ \to p^+ K^- \pi^+$ mode:

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

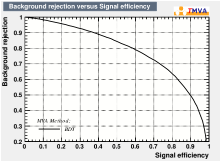
- Lack of suitable cross-check modes for these decays - keeping the unobserved DCS mode blind until we can demonstrate agreement between the ratios of the SCS/CF in the prompt and semileptonic samples.
- Aim to resolve some existing experimental tension regarding $\frac{\mathcal{BF}_{\Lambda_c^+ \to p^+ K^- K^+}}{\mathcal{BF}_{\Lambda_c^+ \to p^+ K^- \pi^+}}$:
  - Belle: $0.014 \pm 0.002(stat) \pm 0.002(syst)$.
  - CLEO II: $0.039 \pm 0.009(stat) \pm 0.007(syst)$.

Trigger and Stripping Selection

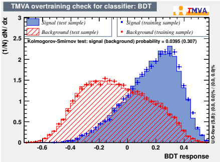
- Trigger:
  - Lack of prompt triggers in 2011 necessitates differing approaches to trigger chain (L0, HLT1, HLT2) in prompt and semileptonic.
  - In prompt require that events were triggered regardless of the inclusion of our signal event (trigger independently of signal) - same trigger efficiency across modes.
  - In semileptonic require that signal decay within the event fired the trigger (trigger on signal). Can measure well defined trigger efficiency for each mode.
- "Stripping" is the central processing of the data to extract interesting events. 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 can be calculated from MC.
- Full suite of cuts detailed in backup.

Offline Selection

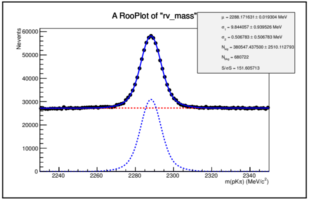
- In semileptonic very low combinatoric background. Minimal additional vertex quality cuts in offline. Not the case in prompt.
- Use a BDT to select prompt events, trained on 10% of the sWeighted CF data with a global signal weighting of $\frac{|V_{ud}|^2|V_{cs}|^2}{|V_{cd}|^2|V_{us}|^2} = 0.003$ for max sensitivity to DCS mode.



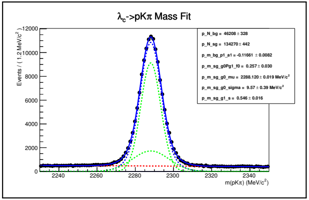
ROC curve for BDT.



Overtraining check for BDT.



Prompt sample before BDT

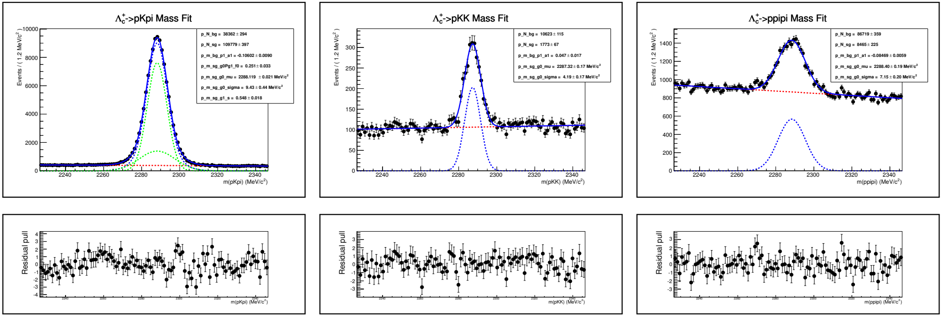


Prompt sample after BDT

- BDT and further PID cuts reduce the prompt combinatoric background by 94%.
- Projected signal significance $\frac{S}{\sqrt{S+B}}$ for prompt DCS $= 4.4\sigma$.
- Projected signal significance for semileptonic DCS $= 8.4\sigma$.

Prompt Yields & Mass Plots

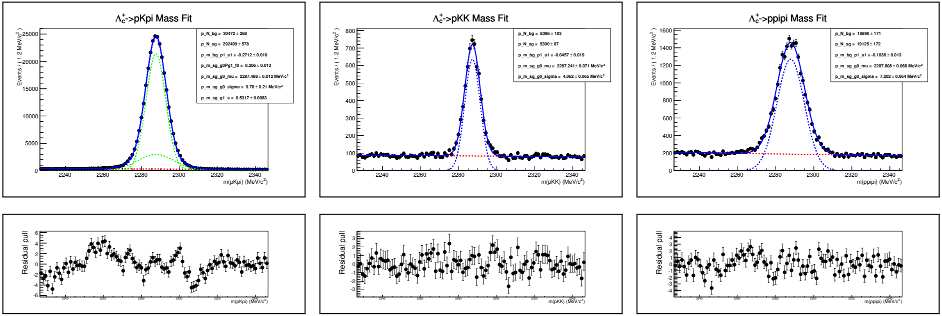
- Data yields after offline BDT.
- Signal models: double gaussian with shared mean for CF, single gaussian for CS.
- All backgrounds linear (1st order Chebychev).



Mode	Yield
$\Lambda_c^+ \to p^+ K^- \pi^+$	109779 ± 397
$\Lambda_c^+ \to p^+ K^- K^+$	1773 ± 067
$\Lambda_c^+ \to p^+ \pi^- \pi^+$	8465 ± 225

Semileptonic Yields & Mass Plots

- Data yields after offline selection.
- Signal models: double gaussian with shared mean for CF, single gaussian for CS. All backgrounds linear.



Mode	Yield
$\Lambda_c^+ \to p^+ K^- \pi^+$	292499 ± 578
$\Lambda_c^+ \to p^+ K^- K^+$	5390 ± 087
$\Lambda_c^+ \to p^+ \pi^- \pi^+$	19125 ± 175

Efficiencies 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.

Systematic Uncertainties

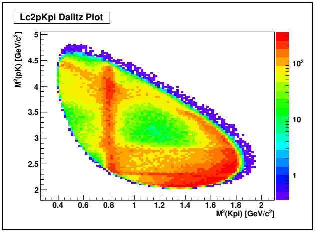
Systematic table goes here.

Outlook

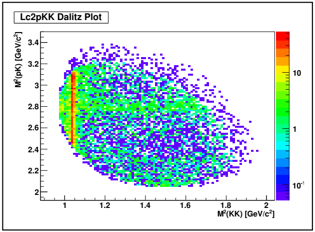
- Currently have agreement between prompt and semileptonic for $\frac{\mathcal{BF}_{\Lambda_c^+ \to p^+ \pi^- \pi^+}}{\mathcal{BF}_{\Lambda_c^+ \to p^+ K^- \pi^+}}$.
- $\sim 4\sigma$ disagreement in $\frac{\mathcal{BF}_{\Lambda_c^+ \to p^+ K^- K^+}}{\mathcal{BF}_{\Lambda_c^+ \to p^+ K^- \pi^+}}$
- Working to find this source of disagreement before unblinding $\Lambda_c^+ \to p^+ \pi^- K^+$ and presenting results to public.
- Until then...

First Look at Dalitz Plots

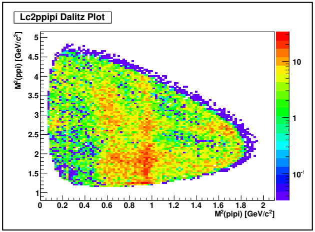
- Shown below: charge opposite daughter pairs from semileptonic modes (cleaner than prompt). s-Weighted for sideband subtraction.



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



$\Lambda_c^+ \to p^+ K^- K^+$ Dalitz Plot



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

- Variety of resonances can be clearly seen: $K^*(892)$, $\Lambda(1520)$, $\phi(1020)$, $f_0(980)$.
- LHCb has the statistics for the most comprehensive amplitude analysis of these decays to date.