$\Lambda_c^+ \to p^+ h^+ h^-$ $\mathcal{BF}$ Measurements

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Charm Baryons on LHCb

- Several analyses within the Charm WG underway.
  - Ξ_{cc}^{+} search in 2011 $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ data. Will be followed by searches in a variety of Ξ_{cc}^{+} and Ξ_{cc}^{++} modes with 2011 and 2012 data (Glasgow, Tsinghua).
  - $D^0 p^+$ final state spectroscopy of excited charm baryons (INFN).
  - CPV searches in Cabibbo Suppressed Λ_c^{+}decays (Sajan et al).
- Today will present update on the $\Lambda_c^{+} \to p^{+} h^{-} h^{+} \mathcal{BF}$analysis (Glasgow, Heidelberg).

Physics Motivation

- $\Lambda_c^+ \rightarrow p^+ h^- h^+$ modes still poorly understood in terms of Branching Fractions ($\mathcal{BF}$), decay amplitudes and resonance structure.
- Current PDG $\mathcal{BF}$s shown below, the doubly-Cabibbo Suppressed decay $\Lambda_c^+ \rightarrow p^+ \pi^- K^+$ has not been observed.

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

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

- Work on $\Lambda_c^+ \rightarrow p^+ h^- h^+$ selections of utility to other analyses:
  - Ξ_{cc}^+ searches through decays to Λ_c^+.
  - CPV searches in Cabibbo Suppressed Λ_c^+ decays.

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Dataset Overview

- Have two sources of Λ_c^+decays: from prompt and from secondary semileptonic $\Lambda_b^0 \to \mu^- \Lambda_c^+$.
- Utilising Stripping 17b with full 2011 dataset.
- At present DCS mode kept blind.
- All $\mathcal{BF}$s measured relative to CF, current 26% uncertainty on absolute CF $\mathcal{BF}$.
- Lack of suitable control modes and large errors on PDG $\mathcal{BF}$s. Will unblind DCS mode when $\mathcal{BF}$measurements of the relative SCS/CF modes agree between prompt and semileptonic.

Trigger Chains

- All semileptonic modes utilise high the efficiency topological muon HLT2 lines, TOS chain
- No prompt dedicated triggers for SCS, DCS modes in 2011. CF trigger introduced in June 2011. Therefore use TIS chain.

- Semileptonic chain:
  - L0Muon TOS
  - Hlt1TrackMuon TOS
  - Hlt2TopoMuNBodyBBDT TOS
- Prompt Chain:
  - L0Hadron TIS
  - Hlt1TrackAllL0 TIS
  - Hlt2Phys TIS

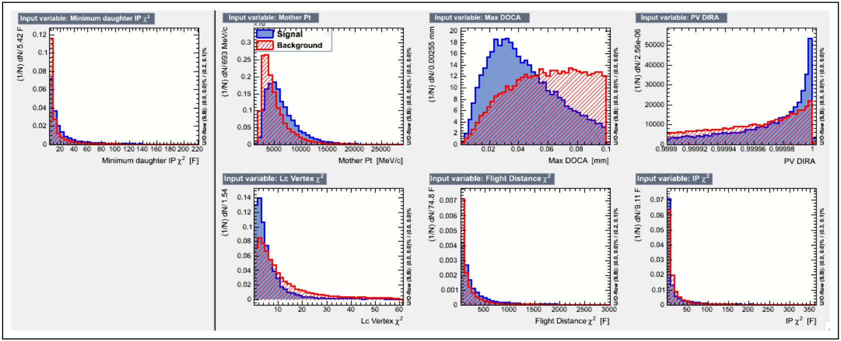
- Full suite of dedicated Hlt2 lines in place for full 2012.

Selection Outline

- Want to make selection agnostic to daughters for systematic cancellation.
- Use s-Weighted CF data to train BDT with variables pertaining to mother kinematics.
- Combine these with rectangular daughter PID cuts optimised with Conor Fitzpatrick's CROP recursive cut optimiser.
- Feed new PID cuts into BDT training and iterate until PID cuts converge to attain optimum pairing of tree and PID cuts.

Offline Prompt BDT I

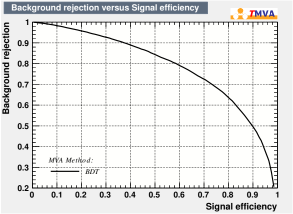
- Developed MVA selection to maximise sensitivity to DCS mode.
- Primary background is combinatoric, train with variables to reduce it.



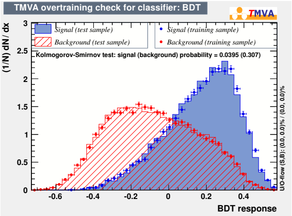
s-Weighted distributions of variables used in BDT training

Offline Prompt DBT II

- Examined a variety of forest construction/training parameters to maximise separation and suppress overtraining.
- Final training parameters:
  - Adaptive boosting used, ADABoost $\beta = 0.5$
  - Number of trees $= 150$
  - Tree max depth $= 3$
  - Number of steps during node optimisation $= 16$



ROC curve for final BDT



Overtraining check

- Currently training BDT for SL incorporating Λ_b^0 and μ^- variables.

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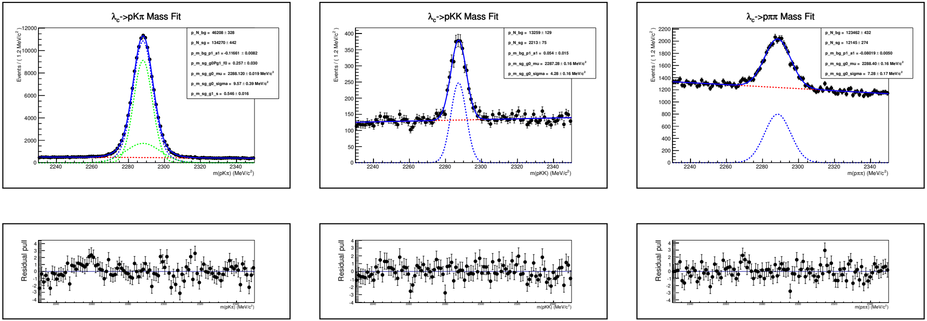
Stripping 17b Prompt Yields & Mass Plots

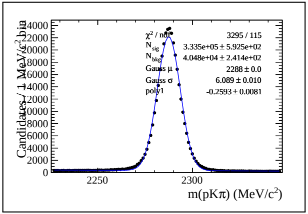
Data yields after offline BDT.

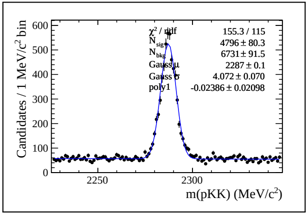


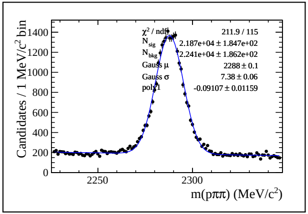
Mode	Yield	Measured fraction of CF	PDG fraction of CF
$pK\pi$	134270 ± 442	-	-
$p\pi\pi$	12145 ± 274	$(9.045 \pm 0.206) \times 10^{-2}$	$(7.0 \pm 4.3) \times 10^{-2}$
pKK	2213 ± 75	$(1.648 \pm 0.056) \times 10^{-2}$	$(1.5 \pm 0.8) \times 10^{-2}$

Stripping 17b Semileptonic Yields & Mass Plots

Yields after Stripping and offline PID cuts (no BDT, missing 20% of the data uniformly across all modes due to processing error).





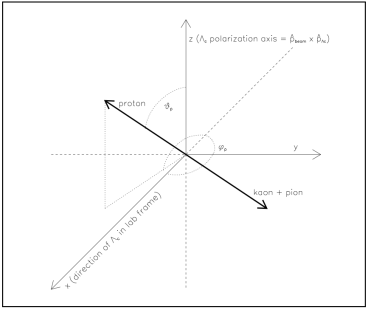


Mode	Yield	Measured fraction of CF	PDG fraction of CF
$pK\pi$	333500 ± 592	-	-
$p\pi\pi$	21870 ± 184	$(6.557 \pm 0.056) \times 10^{-2}$	$(7.0 \pm 4.3) \times 10^{-2}$
pKK	4796 ± 80	$(1.438 \pm 0.024) \times 10^{-2}$	$(1.5 \pm 0.8) \times 10^{-2}$

Treatment of Phase Space Acc. Variations

- Baryon decays - in resonant structure Λ_c^+ and proton spins must be considered.
- In addition to invariant masses of daughter pairs need 3 angular parameters to parameterise resonant structure of decays:

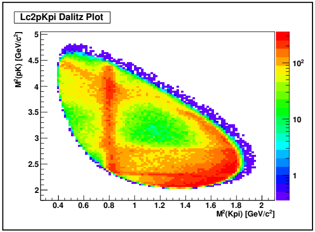
  - $\cos\theta_p$, angle between Λ_c^+ polarisation axis and daughter proton momentum.
  - ϕ_p, angle between Λ_c^+ momentum in lab frame and the production plane projection of the daughter proton momentum.
  - $\phi_{K\pi}$, orientation angle of $K\pi$ daughter plane relative to plane of daughter proton and Λ_c^+ polarisation axis.

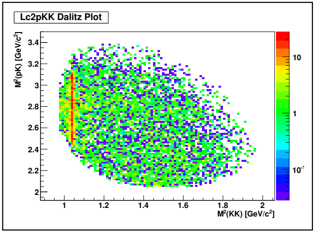


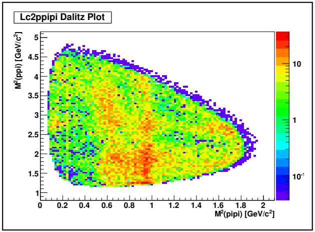
Angular parameters of 5D acceptance phase space in Λ_c^+ rest frame

Phase Space Variables

- Charge opposite daughter pairs from semileptonic modes (cleaner than prompt). s-Weighted for sideband subtraction.







- Variety of resonances can be clearly seen: $K^*(892)$, $\Lambda(1520)$, $\phi(1020)$, $f_0(980)$.

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Efficiencies Overview

Efficiencies to be determined:

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

- Trigger and stripping efficiencies taken from MC. Will eventually utilise a 5D binning in the quantities characterising the resonance structure of the decays, for now have average efficiencies.
- Offline (BDT) efficiency taken from data.
- PID efficiency derived using Andy Powell's data-driven method.
- Acceptance efficiency from differing MC generator level cuts between SL modes.

Stripping Efficiencies

- Attain efficiencies of stripping (without PID requirements) from MC. Require Reconstructed mass is $\pm 20\text{MeV}/c^2$ from Λ_c^+ mass and truth matching.

Event type	Mode	Polarity	Generated	Cheated	Stripped	$\epsilon_{\text{strip}\mid\text{acc}}$ (%)
25103000	$\Lambda_c^+ \to p^+K^-\pi^+$	MagDown	1,151,778	229,705	6,072	0.527 ± 0.013
		MagUp	1,157,023	231,051	6,100	0.527 ± 0.013
		Combined	2,308,801	460,756	12,172	0.527 ± 0.009
25103001	$\Lambda_c^+ \to p^+K^-K^+$	MagDown	1,140,547	229,215	4,453	0.390 ± 0.012
		MagUp	1,148,718	230,621	4,513	0.393 ± 0.012
		Combined	2,289,265	459,836	8,966	0.392 ± 0.008
25103002	$\Lambda_c^+ \to p^+\pi^-\pi^+$	MagDown	1,142,048	234,458	6,939	0.608 ± 0.015
		MagUp	1,163,634	239,673	7,016	0.603 ± 0.014
		Combined	2,305,682	474,131	13,955	0.605 ± 0.010
25103003	$\Lambda_c^+ \to p^+\pi^-K^+$	MagDown	1,152,303	231,581	6,069	0.527 ± 0.013
		MagUp	1,169,000	234,670	5,949	0.509 ± 0.013
		Combined	2,321,303	466,251	12,018	0.518 ± 0.009
15874000	$\Lambda_c^+ \to p^+K^-\pi^+$	MagDown	4,615,083	477,868	111,347	2.413 ± 0.014
		MagUp	4,549,564	472,553	110,526	2.429 ± 0.014
		Combined	9,164,647	950,421	221,873	2.421 ± 0.010
15874010	$\Lambda_c^+ \to p^+K^-\pi^+$	MagDown	5,012,578	497,053	106,657	2.128 ± 0.013
		MagUp	5,039,637	498,772	107,268	2.128 ± 0.013
		Combined	10,052,215	995,825	213,925	2.128 ± 0.009
15874020	$\Lambda_c^+ \to p^+K^-\pi^+$	MagDown	5,003,148	501,049	108,510	2.169 ± 0.013
		MagUp	5,015,649	501,203	108,309	2.159 ± 0.013
		Combined	10,018,797	1,002,252	216,819	2.164 ± 0.009
15674000	$\Lambda_c^+ \to p^+K^-K^+$	MagDown	26,979	5,729	1,320	4.893 ± 0.263
		MagUp	7,995	1,704	390	4.878 ± 0.482
		Combined	34,974	7,433	1,710	4.889 ± 0.231
15674010	$\Lambda_c^+ \to p^+\pi^-\pi^+$	MagDown	32,461	6,615	1,764	5.434 ± 0.252
		MagUp	18,982	3,954	1,036	5.458 ± 0.330
		Combined	51,443	10,569	2,800	5.443 ± 0.200

- SL efficiencies are more varied due to different generator level cuts

PID Efficiencies

- Utilise PIDCalib package to get effs. Have a fine binning (28 in P $\times$ 20 in PT) to minimise systematic.
- Limited kinematic ranges of proton calibration tracks leads to holes in our kinematic phase space where we cannot derive valid efficiencies.
- Veto these kinematic regions from selection.
- Systematics uncertainty in all modes is approx. 9%.

	Mode	Average PID Efficiency
Prompt	$pK\pi$	0.3144 ± 0.0014
	$p\pi\pi$	0.3474 ± 0.0021
	pKK	0.3455 ± 0.0015
Semileptonic	$pK\pi$	0.2809 ± 0.0004
	$p\pi\pi$	0.2875 ± 0.00063
	pKK	0.2909 ± 0.00066

Current Results and Future Work

Mode	Prompt fraction of CF	SL fraction of CF
$p\pi\pi$	$(7.09 \pm 0.084) \times 10^{-2}$	$(2.84 \pm 0.102) \times 10^{-2}$
pKK	$(2.02 \pm 0.036) \times 10^{-2}$	$(0.684 \pm 0.013) \times 10^{-2}$

Latest ratios of SCS w.r.t. CF, errors statistical only

- Different generator-level cuts having huge effect on SL relative BFs; should change drastically after taken into account.
- Efficiencies to be included:
  - Full treatment of phase space acceptance variations in trigger and stripping.
  - Data-driven efficiencies for offline BDT.
  - Generator level efficiencies for semileptonic MC.
  - Incorporation of vetoed kinematic regions (from invalid PID effs) into selection.
- Finalisation of BDT for SL.
- Analysis note under construction.