Charm Baryon Spectroscopy

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Charm Spectroscopy

Several analyses currently underway in Charm WG. Will cover three today.

- Branching fractions of $\Lambda_c^+ \to p^+ h^+ h^-$, $h = K, \pi$.
- Search for the doubly charmed baryons $\Xi_{cc}^{+(++)}$.
- Spectroscopy of $D^0 p$ final states.

Will focus today on Λ_c^+ BF analysis.

Lc Overview

- Physics Motivation
- Λ_c^+ Dataset.
- Mass Fits and Signal Yields
- Selections (cut based and MVA).
- Efficiencies
- Future Work

Physics Motivation

- $\Lambda_c^+ \rightarrow$ p h h modes still poorly understood in terms of Branching Fractions (BFs), decay amplitudes and resonance structure.
- Current PDG BFs shown below, the doubly-Cabibbo Suppressed decay $\Lambda_c^+ \rightarrow p^+ K^+ \pi^+$ 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)	$(3.5 \pm 2.0) \times 10-^3$
$\Lambda_c^+ \rightarrow p^+ K^+ \pi^-$ (DCS)	$< 2.3 \times 10^{-4}$ @ 90% CL

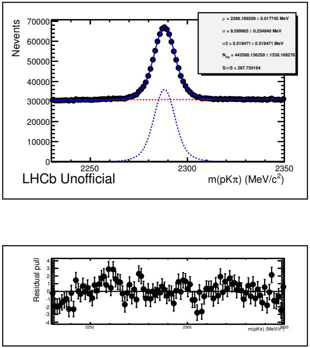
The $\Lambda_c^+ \rightarrow$ p h h decay modes and their branching fractions.

- Easy to get competitive measurements but makes cross checks more challenging.
- Work is ongoing with Rio to perform multi-dimensional resonance analysis with the CF and DCS modes.

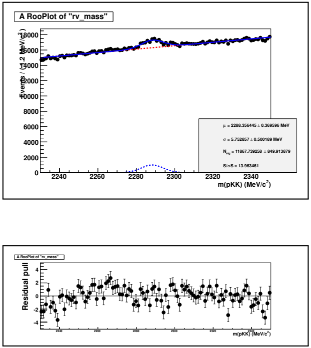
Λ_c^+ Stripping 17b 2011 Dataset

- Two sources of Λ_c^+ production: prompt and from semileptonic $\Lambda_b^0 \to \Lambda_c^+ \mu^- \nu_\mu$ secondary decays.
- Expect more prompt production but prompt charm baryon triggers are inefficient. Dedicated $\Lambda_c^+ \to p^+ \pi^+ K^-$ TOS is 8.1% efficient.
- Compared to topological muon semileptonic lines, typically 20-30% TOS efficient.
- This is partly due to the shorter time of flight for baryons than mesons. $\tau_{\Lambda_c} = 0.2$ps. $\tau_D = 0.4 - 1$ps.
- Both are important due to the lack of a suitable control mode for the decays. Treating both samples independently.
- Have chosen a TIS trigger chain as we have only had a prompt Cabibbo-Favoured dedicated trigger for half of 2011.
- We now have prompt dedicated triggers in place for all four modes.

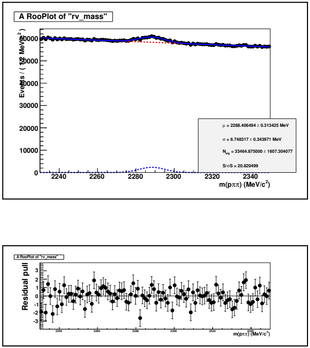
- Double (Single) Gaussian signal and linear background describe CF mode (DCS modes) well.



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

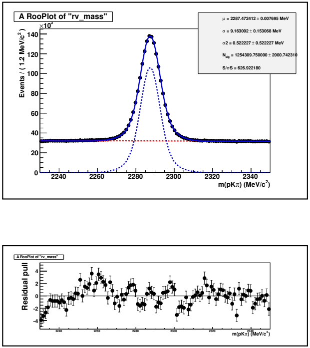


$\Lambda_c^+ \rightarrow p^+ K^- K^+$

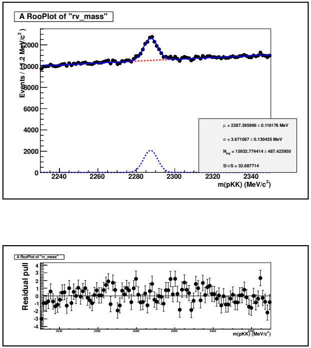


$\Lambda_c^+ \rightarrow p^+ \pi^- \pi^+$

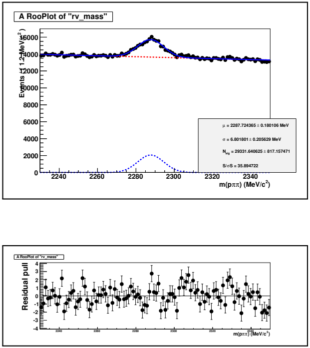
- Much higher raw yields from stripping than in prompt for CF, SCS modes comparible.
- Both datasets are being analysed in parallel.



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



$\Lambda_c^+ \rightarrow p^+ K^- K^+$



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

Mass Fits and Signal Yields III - Overall

- The DCS prompt mode is being kept blind. Peaking backgrounds likely to be more important for DCS mode due to much lower expected yield.
- Main sources likely to be from D reflections and double mis-ID from CF. Currently under investigation.

-	Decay Mode	Signal Yield
Prompt	$\Lambda_c^+ \to p^+ K^- \pi^+$	442 k
	$\Lambda_c^+ \to p^+ K^- K^+$	11.8 k
	$\Lambda_c^+ \to p^+ \pi^- \pi^+$	33.4 k
Semileptonic	$\Lambda_c^+ \to p^+ K^- \pi^+$	1.25 M
	$\Lambda_c^+ \to p^+ K^- K^+$	15.9 k
	$\Lambda_c^+ \to p^+ \pi^- \pi^+$	29.3 k

The signal yields of the Λ_c^+ unblinded modes.

- From here on in will discuss only the prompt sample.

Offline Selections I - Outline

- Main strategy: make the selection as agnostic to the daughter properties as possible. This will make the application to a relative BF measurement much more amenable.
- Have trained 2 cut-based and two MLP selections for each channel. One for the CF mode and one for the DCS mode.
- For DCS mode use a global weighting on signal events of $\frac{|V_{ud}|^2|V_{cs}|^2}{|V_{cd}|^2|V_{us}|^2} = 0.003$.
- Variables utlised:
  - Λ_c^+:
    - Pt , MAXDOCA, Vertex χ^2 , IPχ^2, FD χ^2, DIRA
  - PID:
    - $p_{PIDp}, K_{PIDK}, K_{PIDp}, (p_{PIDp} - p_{PIDK})$
- Aware that discrimination achieved with PID may be in effect daughter Pt cuts which makes the selection less agnostic to daughters under investigation.

Offline Selections I - Cut Based

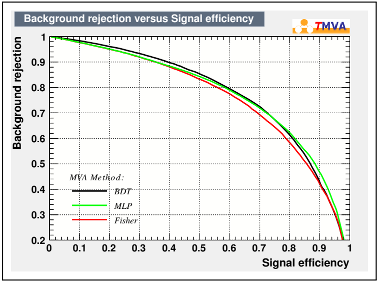
- Implement TIS trigger chain: L0, HLT1, HLT2Phys TIS.
- Conor Fitzpatrick's Cut Recursive Optimiser (CROP) used to acquire optimum $\frac{S}{\sqrt{S+B}}$ with rectangular cuts.
- Final yields for the CF mode shown below.

Post...	N_{sig}	% of raw
Raw	$442k \pm 1538$	-
TIS	$361k \pm 1935$	81.6 ± 0.9
Offline	$229k \pm 756$	51.86 ± 0.35

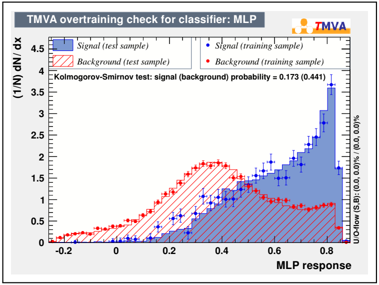
- With this selection we would expect in the signal region ($\pm 15 MeV$) a significance of $\frac{S}{\sqrt{S+B}} = 3.27$.
- To gain sensitivity we approached a full MVA selection.

Offline Selections II - MVA

- Investigated the use of a BDT, MLP and Fisher discriminant.
- BDT and MLP display the expected superior discrimination to the Fisher.
- However, MLP displays more robustness against overtraining.



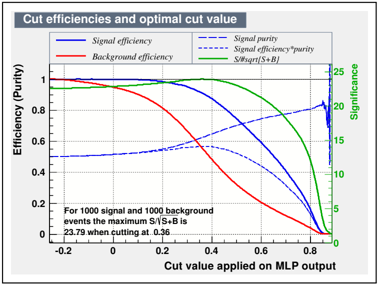
ROC curve for the $\Lambda_c^+ \to p^+ K^- \pi^+$ mode.



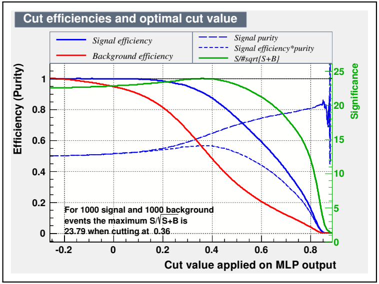
Overtraining check for the MLP. The Kolmogorov-Smirnov values display good agreement between the training and testing phases.

Offline Selections II - MLP Performance

- High signal purity can be attained with an MLP.



MLP performance curves.



Mass plot for CF prompt after MLP goes here.

- Final signal yield with MLP: $x \pm y$ ($z\% \pm a$ retained).
- Final projected DCS $\frac{S}{\sqrt{S+B}}$: .
- Would/would not expect a discovery of this mode.

Efficiencies I

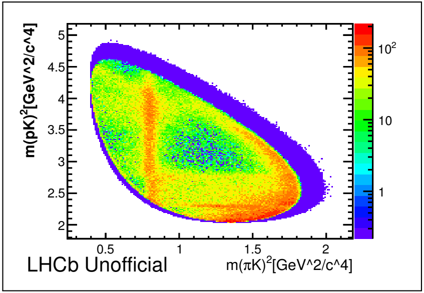
- Efficiencies composed of reconstruction and the full selection, incorporating the efficiencies of the trigger, stripping and offline.
- As usual, separate our PID efficiencies from our selection efficiencies to utilise Andrew Powell's PID reweighting. This prohibits the use of PID variables in MVA training.
- Relative BF between CF and other phh mode given by:

$$\frac{\mathcal{B}_{\Lambda_c^+ \to p^+ K^- \pi^-}}{\mathcal{B}_{\Lambda_c^+ \to p^+ h^- h^-}} = r \times \epsilon_{reco} \times \epsilon_{trigger} \quad (1)$$

- All decay modes of interest have a rich resonance structure. It therefore becomes necessary to consider the Dalitz space when calculating our efficiencies. But baryons have spin!
- The extension of the 2D Dalitz space in the meson sector to particles with spin incorporates an additional 3 angular parameters to make a 5D phase space.

Efficiencies II

- Strong resonance structures demonstrated in the sWeighted CF charge-opposite daughter pair invariant masses, below. Strong $K^*(892)$ and $\Lambda(1520)$ contributions can be seen.



CF prompt resonance structure for the TIS dataset.

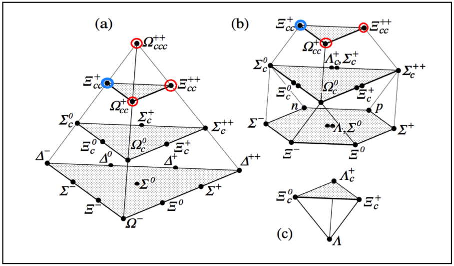
- Take our reconstruction efficiency from MC with a binning in the 5D phase space such should be no strong variation of the resonance structure within each bin.
- Then calculate a bin by bin efficiency to apply to the data.
- Work ongoing in this area.

Future Work

- Have finalised an MVA selection for use in searching for the DCS mode.
- Would expect to see this mode in the prompt charm dataset.
- BF analysis progressing, moving onto efficiency techniques and calculations.
- Still requires a thorough consideration of physics backgrounds for the DCS mode and systematics for all modes.
- Analysis note currently under construction.
- When finished much of the groundwork for further analyses with Λ_c^+ will already be there.

Double Charm Baryon Searches - Motivation

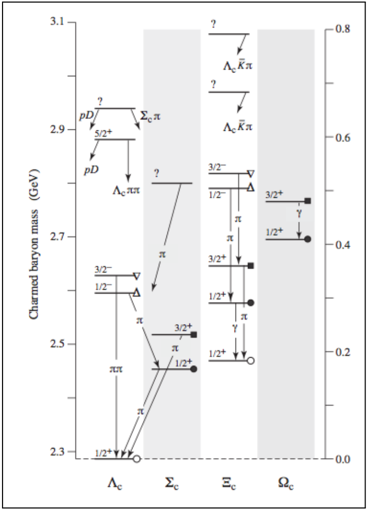
- Baryons containing u,d,c,s form an SU(4) group, below.



The SU(4) generated multiplets of charm baryons. Circled in blue indicates observed only by SELEX, red not observed. From PDG [1].

- SELEX [2] measurements of the Ξ^+_{cc} properties disagree strongly with theory.
  - SELEX
    - $m = 3518.7 \pm 1.7 MeV/c^2$.
    - $\tau < 0.33 ps$ at $90\% CL$.
  - Theory
    - $m = 3610 MeV/c^2$.
    - $\tau < 0.07 - 0.20 ps$.
- B factories [3] and FOCUS [4] have searched for but have not observed doubly charmed baryon production.

pD Final State Spectroscopy - Motivation



The spectrum of singly charmed baryons.

- Spectroscopy of excited charm baryons offers tests of HQET.
- Approximate the heavy baryon as a stationary heavy quark interacting with a light quark dipole.
- $\Lambda_c(2880, 2940) \rightarrow D^0 p$ first observed by BaBar.

pD Final State Spectroscopy - Initial cuts and selection

- Using Stripping 17b prompt $D^0 p$ production.
- Standard set of offline cuts using variables with negligible correlations.
  - Maybe we include
  - some cuts here
  - with a brief description of why they're used
- Could we perhaps comment on the size of our sample w.r.t. BaBar?
- All cuts are going to be optimised in the future, using the signal significance of the $\Lambda_c(2880)$.
- Vital to eliminate mis-ID crossfeed, eg. $D(s2)(2572) -> D^0 K$

pD Final State Spectroscopy - Mass Spectrum

It would make sense to me to show and explain the plots on pages 14/15 of the presentation Diego linked, but I need the plots to do so. Basically I want to cover points 3 and 4 in your email here.

pD Final State Spectroscopy - Future Work

- Selection Optimisation is underway.
- The auxiliary D*p decay mode requires further study to establish the possibility of crossfeed.
- This will enable us to find out the source of the new structure in the $D^0 p$ mass spectra.
- Note is being written, plans to release it to the Charm WG by the end of September.

Concluding Remarks

- Variety of work in progress with charmed baryons at LHCb.
- $\Lambda_c^+ \to p^+ h^- h^+$ BF measurement has finalised a selection. Now dealing with a thorough calculation of the relative efficiencies between the modes. Systematics and background studies for the DCS mode to follow.
- $\Xi_{cc}^{+(++)}$ search is continuing to refine an MVA selection for maximum sensitivity to the modes of interest. Background studies are in progress.
- $D^0 p$ final state spectroscopy is working with larger statistics than previous efforts at BaBar. Investigations into potential crossfeed from $D^* p$ decays are underway to establish the source of the new structure in the spectra observed.

Backup