$\Lambda_c^+ \to phh'$ yield stabilities and PID

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This document contains a series of cross checks pertaining to the prompt $\Lambda_c^+ \to phh'$ BR analysis. We focus mainly on the ratio $\mathcal{B}(\Lambda_c^+ \to pK^-K^+)/\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$ where we consider just the raw yields.

1 Studies with 20 % of data

These studies are carried out with a subset of the data roughly equal to 20 % of the stripping output for each mode. These are selected as follows:

Stripping17b - The full 17b dataset is processed by a DaVinci job. All subjob outputs are merged into a TChain and the first 20 % of these events is the dataset used, as rounded by an integer from float python comparison, so nearest integer lower than the float value.

Stripping21r1 - The first 20 % of the MDST files is taken as an input to the DaVinci job, with the 20 % calculated as for the Stripping17b output.

So we expect the integrated luminosities of the stripping versions to be not quite the same in this study. Accordingly the ratios of MagUp to MagDown should be different between the strippings. Will eventually give more info on the fits in Section 3, but for now make do with saying all fits were convergent with accurate error matrices.

1.1 Definitions of selections

The selections herein are the stripping selections, the TIS trigger requirement on the Λ_c^+ candidate, plus additional PID cuts. In Stripping21r1 where the maximum Λ_c lifetime cut is not present, I've added the maximum Λ_c lifetime cut of 1.2 ps from Stripping17b to make the selections identical.

In this document we use three different additional PID selections for sanity checks - loose, moderate and tight. These are defined in Table 1. I emphasise that these cuts apply to all particles in the Λ_c decay - so in the case of $\Lambda_c^+ \to pK^-K^+$ the kaon cuts apply to both kaons.

selection	$p \log(\mathcal{L}_p/\mathcal{L}_K)$	$p \log(\mathcal{L}_p/\mathcal{L}_\pi)$	$K \log(\mathcal{L}_K/\mathcal{L}_p)$	$K \log(\mathcal{L}_K/\mathcal{L}_\pi)$
loose	5	10	-12	8
moderate	8	15	-8	12
tight	11	21	-6	16

Table 1: The PID selection definitions. The values given are the minumum DLL required for the track to be accepted. Selection applies to all particles of that species in the Λ_c decay.

1.2 Stability of polarities

The first cross check is more of a sanity check that all the job processing and scripts are working correctly - are the raw yield ratios of MagUp and MagDown consistent? We first define the ratio:

$$R_P = \frac{N(\Lambda_c^+ \to pK^-\pi^+) \text{ MagDown}}{N(\Lambda_c^+ \to pK^-\pi^+) \text{ MagUp}} \tag{1}$$

where N is the total Λ_c^+ yield for that decay mode, as established from a fit to the Λ_c^+ mass. Therefore the yield is the union of the prompt and the secondary Λ_c^+ in the sample.

We give these ratios for $\Lambda_c^+ \to pK^-\pi^+$ for the highest precision of the $\Lambda_c^+ \to phh'$ modes. I also found it impossible to extract significant $\Lambda_c^+ \to pK^-K^+$ signals for this subset of the data using the loose selections, so I've done this for just the Cabibbo-favoured mode. The results are presented in Table 2. The ratios are consistent within the individual stripping processings.

Stripping	PID selection	R_P
17b	loose	1.49 ± 0.03
	moderate	1.49 ± 0.03
	tight	1.50 ± 0.03
21r1	loose	1.42 ± 0.03
	moderate	1.42 ± 0.03
	tight	1.44 ± 0.03

Table 2: The values of R_P for each stripping version and PID selection. The ratios are consistent.

1.3 Stability of CS/CF modes

Now I wanted to look at the yields of the $N(\Lambda_c^+ \to pK^-K^+)/N(\Lambda_c^+ \to pK^-\pi^+)$, to check they were consistent between MagUp and MagDown. Define these ratios of raw signal yields as R_{up} and R_{down} for MagUp and MagDown respectively. Statistically significant signals for the $\Lambda_c^+ \to pK^-K^+$ mode can be derived for the moderate and tight PID selections for this sample of the data, but not for the loose PID selections. As such we present these ratios for only the moderate and tight PID selections. They are given in Table 3.

Selection	Stripping	R_{down} [%]	R_{up} [%]
Moderate	17b	1.34 ± 0.20	1.24 ± 0.23
	21r1	1.42 ± 0.21	1.22 ± 0.23
Tight	17b	1.83 ± 0.28	1.69 ± 0.21
	21r1	1.30 ± 0.21	1.57 ± 0.23

Table 3: The values of R_{up} and R_{down} for the each stripping, polarity, and PID selection.

Several things are noticeable here - in the moderate PID selection, the ratios of up and down agree within errors, as do the various stripping versions. Everything seems consistent there. When we go to the tight selection, two things are immediately obvious:

- In the tight selection, there is a marked disagreement between MagUp and MagDown in Stripping21r1.
- R_{down} disagrees strongly between Stripping17b and Stripping21r1.
- The most striking observation to be made - *when we tighten the cuts on kaons, the ratio $N(\Lambda_c^+ \to pK^-K^+)/N(\Lambda_c^+ \to pK^-\pi^+)$ increases in all cases.* Three of the four tight selection samples display statistically significant increases relative to the equivalent moderate selection values.

Naively, we would expect this ratio to be reduced the tighter we cut on kaons, by virtue of there being two kaons in the suppressed final state and one in the favoured final state. There are no tighter PID requirements being made on the pion in any of these selections.

We would like to see some more info here, and the first step is by repeating the studies using the full dataset so we have enough precision to analyse the signal components with the ${}_s\mathcal{P}lots$ technique. We can also see if these discrepancies hold up with greater precision.

2 Studies with full dataset

So now I want to measure the ratios R_{up} and R_{down} for the full datasets to get greater precision on the results, so verify these are significant differences. So we do this with the identical selections described previously. They are given in Table 4.

Selection	Stripping	R_{down} [%]	R_{up} [%]
Moderate	17b	1.91 ± 0.11	1.84 ± 0.12
	21r1	1.58 ± 0.14	1.34 ± 0.14
Tight	17b	1.49 ± 0.10	1.63 ± 0.09
	21r1	1.40 ± 0.11	1.62 ± 0.11

Table 4: The values of R_{up} and R_{down} for the each stripping, polarity, and PID selection.

So now, for the full dataset, we begin to observe some of the expected beahviour with Stripping17b, although the ratios in 17b still seem suspiciously high to me. Why are these so far from the subsets I ran? I'm also worried how the only section where MagUp and MagDown are compatible are in 17b. In all other cases the raw yields are not stable with respect to magnet polarity. Something very odd is happening here - is it to do with the data processing? Or is this to do with the fit itself?

2.1 Including fits to combined polarities

Let's compare the individual polarity fits to the combined fit. Let's call the total ratio R_{total}. Now the full results are replicated with the total ratios in Table 5.

Selection	Stripping	R_{down} [%]	R_{up} [%]	R_{total} [%]
Moderate	17b	1.91 ± 0.11	1.84 ± 0.12	1.89 ± 0.08
	21r1	1.58 ± 0.14	1.34 ± 0.14	1.47 ± 0.10
Tight	17b	1.49 ± 0.10	1.63 ± 0.09	1.57 ± 0.07
	21r1	1.40 ± 0.11	1.62 ± 0.11	1.52 ± 0.08

Table 5: The values of R_{up}, R_{down}, R_{total} for the each stripping, polarity, and PID selection.

Now let's check the totals are compatible between the combined fit signal yield and the individual polarity fits. These are given in Table 6.

These all look quite convincing - the fit seems stable enough between the statistics of the individual polarity samples and the statistics of the full samples. This still raises the qestion - why are the ratios of R_{down} and R_{up} so different in Stripping21r1?

3 Fits to the data

In this section I will provide plots of the fits for the subset studies and the full data, along with pull distributions, to indicate that the results are stable.

Selection	Stripping	Mode	N_{down}	N_{up}	$N_{\text{up}} + N_{\text{down}}$	N_{total}
Moderate	17b	$\Lambda_c^+ \to pK^-K^+$	1783 ± 103	1381 ± 89	3164 ± 136	3174 ± 137
		$\Lambda_c^+ \to pK^-\pi^+$	93149 ± 500	74951 ± 463	168100 ± 681	168088 ± 696
	21r1	$\Lambda_c^+ \to pK^-K^+$	1530 ± 134	944 ± 99	2474 ± 167	2456 ± 165
		$\Lambda_c^+ \to pK^-\pi^+$	96622 ± 465	70288 ± 520	166910 ± 698	167054 ± 842
Tight	17b	$\Lambda_c^+ \to pK^-K^+$	1009 ± 58	743 ± 50	1752 ± 82	1750 ± 77
		$\Lambda_c^+ \to pK^-\pi^+$	61736 ± 345	49891 ± 251	111627 ± 427	11597 ± 478
	21r1	$\Lambda_c^+ \to pK^-K^+$	1039 ± 68	662 ± 54	1701 ± 87	1699 ± 87
		$\Lambda_c^+ \to pK^-\pi^+$	64176 ± 371	47231 ± 303	111407 ± 728	111450 ± 549

Table 6: The yields from the fits by polarity and the fit to the union of the polarities.