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Λ_b exclusive decay

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Abstract

In a data sample of 3 million hadronic Z^0 decays collected with the ALEPH detector from 1991 to 1994, 4 Λ_b candidates are exclusively reconstructed in the $\Lambda_b \to \Lambda_c^+ \pi^-$ channel with the Λ_c decaying into $pK^-\pi^+$, $p\bar{K}^0$ and $\Lambda\pi^+\pi^-\pi^+$. Using a weighted mean of the 4 candidates that pass all the cuts, we measure the value of the Λ_b mass to be:

$$M_{\Lambda_b} = 5621 \pm 17(stat.) \pm 15(sys.)\ MeV/c^2$$

1 Introduction

From previous searches of Λ_b exclusive decays, the $\Lambda_b \to \Lambda_c^+\pi^-$ decay mode is expected to have a branching ratio of less than 1%. Using the whole sample of events collected by ALEPH up to now, corresponding to 3 million hadronic Z^0 decays, we have searched for this exclusive decay mode reconstructing the Λ_c^+ in three channels: $\Lambda_c^+ \to pK^-\pi^+$ $\Lambda_c^+ \to p\bar{K^0}$ and $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$. The underling idea of this analysis is to obtain evidence of an excess of events even on a non zero background level. We choose to apply tight cuts on the the b identification of events and on the decay length of the selected Λ_b candidates, while leaving loose the cuts on the other variables. To disentangle b events from the rest of the background, we select events with a large visible "lifetime" by using the QIPBTAG algorithm. This method combines information on the track impact-parameter and yields a probability that the event arises from (u, d, s) quark production [1].

2 The Λ_c^+ selection

The Λ_c^+ is selected using the following decay channels:

1. $\Lambda_c^+ \to pK^-\pi^+$ $(BR = 4.4 \pm 0.6\%)$
2. $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$ $(BR = 2.7 \pm 0.6\%)$
3. $\Lambda_c^+ \to p\bar{K^0}$ $(BR = 2.1 \pm 0.4\%)$

2.1 The $\Lambda_c^+ \to pK^-\pi^+$ decay reconstruction

This decay mode is reconstructed with three charged tracks, p, K^- and π^+ candidates, with the following conditions:

- $p_p > 2\ GeV/c$
- $p_K > 1.5\ GeV/c$
- $p_\pi > 1\ GeV/c$
- VDET hits for at least 2 of the 3 tracks
- $|dE/dx(\pi)| < 3\sigma$ if available for the pion candidate

- $|dE/dx(p)| < 3\sigma$ and $|dE/dx(\pi)| > 2\sigma$ for the proton candidate
- $|dE/dx(K)| < 3\sigma$ if available for the kaon candidate
- $|m_{pK\pi} - m_{\Lambda_c}| < 21\ MeV/c^2 \quad (\pm 3\sigma)$
- A YTOP vertex with the 3 tracks

In this channel there are two sources of reflection background:

1. $D_s^+ \to K^+ K^- \pi^+$
2. $D^+ \to \pi^+ K^- \pi^+$

For this reason all the combinations with invariant mass in 3σ around the nominal D_s^+ and D^+ mass (using the appropriate mass hypothesis) are rejected.

2.2 The $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$ decay reconstruction

The Λ is reconstructed in the decay channel $\Lambda \to p\pi$ using the YV0V package [2] with the additional cuts listed below:

- The Λ decay length must be greater than 3 cm.
- $dE/dx(p) < 3\sigma$ (if available) for the proton candidate
- $|dE/dx(\pi)| < 3\sigma$ (if available) for the pion candidate
- $M_{e^+e^-} > 15\ MeV$ in order to reject photon conversions
- $|M_{\pi\pi} - M_{K^0}| > 10\ MeV$ when $|dE/dx(\pi)| < 2\sigma$ for the proton candidate, to reject K^0's
- To select Λ's from Λ_b decays, a momentum cut $p_\Lambda > 3\ GeV/c$ is also required

The two tracks from V^0 are then refitted with the V^0 mass constraint in order to improve the momentum resolution. The $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$ vertex is reconstructed with the three charged tracks (pion candidates) that satisfy the following criteria:

- $P_\pi > 0.5\ GeV/c$ for each of the three pions
- A YTOP reconstructed vertex for the 3 pion system

- The correct charge value ($Q_{\pi\pi\pi} = 1$ for a Λ and -1 for a $\bar{\Lambda}$)
- $|m_{\Lambda 3\pi} - m_{\Lambda_c}| < 20\ MeV/c^2 \quad (\pm 3\sigma)$

In the reconstruction of the Λ_c^+ decay vertex we do not include the Λ neutral track, because the Λ typically decays outside the VDET and therefore the errors on its track are large. Thus the Λ_c^+ vertex is identified with the three pion vertex.

2.3 The $\Lambda_c^+ \to p\bar{K}^0$ decays reconstruction

The $\Lambda_c^+ \to p\bar{K}^0$ decay channel is reconstructed with a K_s^0 and a proton with the following conditions. The K_s^0 decay is reconstructed in two charged pions, using the YV0V package, with the cuts listed below:

- A decay length greater than 1.5 cm
- $|dE/dx(\pi)| < 3\sigma$ (if available) for the pion candidates
- $M_{e^+e^-} > 15\ MeV$ to reject photon conversions
- $|M_{\pi p} - M_{\Lambda}| > 5\ MeV$ when $|dE/dx(p)| < 2\sigma$ for one of the two pion candidate, to reject the Λ 's
- Kaon momentum $p_{K_s^0} > 2\ GeV/c$

For the pK_s^0 system we require:

- Proton momentum $p_p > 3\ GeV/c$
- $|dE/dx(p)| < 3\sigma$ and $|dE/dx(\pi)| > 2\sigma$ for the proton candidate
- $cos\theta_p^* > -0.8$, where θ_p^* is the proton decay angle in the Λ_c^+ rest frame
- At least one VDET hit for the proton
- $\chi^2 < 10$ for the pK_s^0 vertex
- $|m_{pK_s^0} - m_{\Lambda_c^+}| < 24\ MeV/c^2 \quad (\pm 3\sigma)$

In this channel there are also two sources of reflection background:

1. $D_s^+ \to K^+\bar{K}^0$

2. $D^+ \rightarrow \pi^+ \bar{K}^0$

All the combinations with invariant mass within 3σ around the nominal D_s^+ and D^+ mass are rejected, as in the $\Lambda_c^+ \rightarrow pK^-\pi^+$ case.

3 Λ_b selection

The $\Lambda_b \rightarrow \Lambda_c^+ \pi^-$ decay is identified by selecting a Λ_c^+ with an associated π^-, with the criteria listed below:

- $Prob(QIPBTAG) < 0.01$ for uds probability of the event
- $p_{\Lambda_c} > 5\ GeV/c$ for the Λ_c^+ momentum
- $p_\pi > 5\ GeV/c$ for the π momentum
- $p_{\Lambda_c\pi} > 20\ GeV/c$
- $\cos\theta_{\Lambda_c\pi} > 0.9$ for the angle between the π^- and the Λ_c^+
- At least 1 VDET hit for the pion
- A reconstructed vertex for $\Lambda_c^+ \pi^-$
- $l/\sigma_l > 2$ or 4, depending on the Λ_c^+ channel, as described below.

The last cut on l/σ_l selects particles coming from a secondary vertex with a significant decay length. For the $\Lambda_c^+ \rightarrow pK^-\pi^+$ and the $\Lambda_c^+ \rightarrow p\bar{K}^0$ channels, l/σ_l is calculated from the projected Λ_b decay length and its error. The presence of a V^0 increases the error on the decay length. For this reason we prefer to use the distance of the three pion vertex from the primary vertex, to estimate the ratio l/σ_l in the $\Lambda_c^+ \rightarrow \Lambda\pi^+\pi^+\pi^-$ channel. For $\Lambda_c^+ \rightarrow pK^-\pi^+$ we cut at $l/\sigma_l > 4$, for the other two channels the background contamination is lower, and we cut at $l/\sigma_l > 2$. We require also that the Λ_c^+ vertex is in front of the Λ_b one, within the errors:

- $(l_{\Lambda_c} - l_{\Lambda_b})/\sqrt{\sigma_{\Lambda_c}^2 + \sigma_{\Lambda_b}^2} > -3$

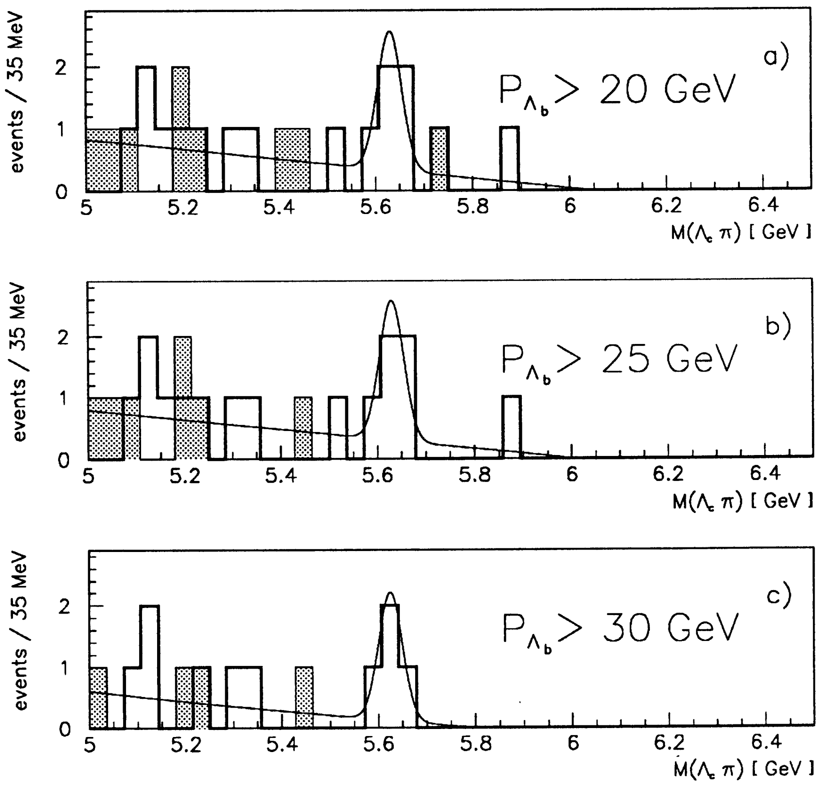

Figure 1: $\Lambda_c\pi$ invariant mass distribution. The histogram shows the right sign combinations while the shaded histogram represents the wrong sign combinations. The solid line shows the result of a fit to a flat distribution between 5.2 and 5.8 GeV/c^2 for the background and a gaussian for the signal. Figures a), b) and c) show the distributions for Λ_b momentum greater than 20, 25 and 30 GeV/c respectively.

4 Monte Carlo studies

To determine the cuts and calculate the efficiencies of our analysis we have used 3000 Monte Carlo signal events for each channel. The values of the efficiencies for the various Λ_b momentum cuts are reported in table 1. Two specific Monte Carlo simulations have been used to estimate the reflection background level. In the first one there are 5000 $B^o \to D^- \pi^+$ events and 5000 $B^o \to D^{*-}\pi^+$ with the $D^{(*)-}$ decaying in all the possible channels. This sample corresponds to 6 times the statistics of thereal data. In the second Monte Carlo there are 2500 $B_s^o \to D_s^- \pi^+$ events and 2500 $B_s^o \to D_s^{*-}\pi^+$ events with the $D_s^{(*)-}$ decaying in all the possible channels, corresponding to 12 times the statistics collected up to now.

Λ_c^+ *decay mode*	*Cut*	N_{ev}	$\epsilon(\%)$
$\Lambda_c^+ \to pK^-\pi^+$	$p_{\Lambda_b} > 20$	2	5
	$p_{\Lambda_b} > 30$	2	4
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	$p_{\Lambda_b} > 20$	2	4
	$p_{\Lambda_b} > 30$	1	3.2
$\Lambda_c^+ \to p\bar{K}^0$	$p_{\Lambda_b} > 20$	1	7.1
	$p_{\Lambda_b} > 30$	1	6

Table 1: Number of events found in the real data and variation of the efficiencies for the three channels with the Λ_b momentum cut.

After applying the pK_s^o and $pK^-\pi^+$ selections described above on these Monte Carlo, no events pass our cuts. Taking $\mathrm{BR}(B_s^o \to D_s^{(*)-}\pi^+) = 2\ \mathrm{BR}(B^o \to D^{(*)-}\pi^+)$ to be conservative when estimating the limit on the number of reflection events expected, we find:

$$N_{B_d} + N_{B_s} < 0.5 \ @\ 95\% \ C.L. \quad (1)$$

We have applied our selections also on 440000 $b\bar{b}$, which is the equivalent of 2 million hadronic events, to check if there are other significant sources of background. From this Monte Carlo study, looking at the Λ_c side band events as well as at the wrong sign combinations, we established that both distributions correctly reproduce the shape of the combinatorial background. In the following we will use the wrong sign combinations to estimate shape of the background distribution.

Cut	N_{ev}	N_{sig}	N_{bkg}
$p_{\Lambda_b} > 20$	5	4.3 ± 2.3	1.3 ± 0.7
$p_{\Lambda_b} > 25$	5	4.2 ± 2.2	1.3 ± 0.7
$p_{\Lambda_b} > 30$	4	3.3 ± 2.0	0.6 ± 0.3

Table 2: Variation of the number of selected events with the Λ_b momentum cut. Also included are the fitted values for the number of signal and background events.

5 Λ_b mass

Looking either at table 2 or figure 1 we can see the behaviour of the number of signal and background events varying the Λ_b momentum cut. The number of events has been calculated by fitting the signal with a gaussian and the background with a flat distribution between 5.2 and 5.8 GeV/c^2. The last step (Λ_b momentum > 30 GeV/c) has been choosen to measure the mass since the background level is the lowest. Performing a weighted mean (see figure 2) of the mass values of the four events in the peak we find:

$$M_{\Lambda_b} = 5621 \pm 17 \quad MeV/c^2 \tag{2}$$

Since the number of expected background events is compatible with 1, to evaluate the systematic error we recalculate the mass for all the possible combinations of three events among our four candidates. As a systematic error we take the overall spread of these values. At the end the measured value of the Λ_b mass is:

$$M_{\Lambda_b} = 5621 \pm 17(stat.) \pm 15(sys.)\ MeV/c^2 \tag{3}$$

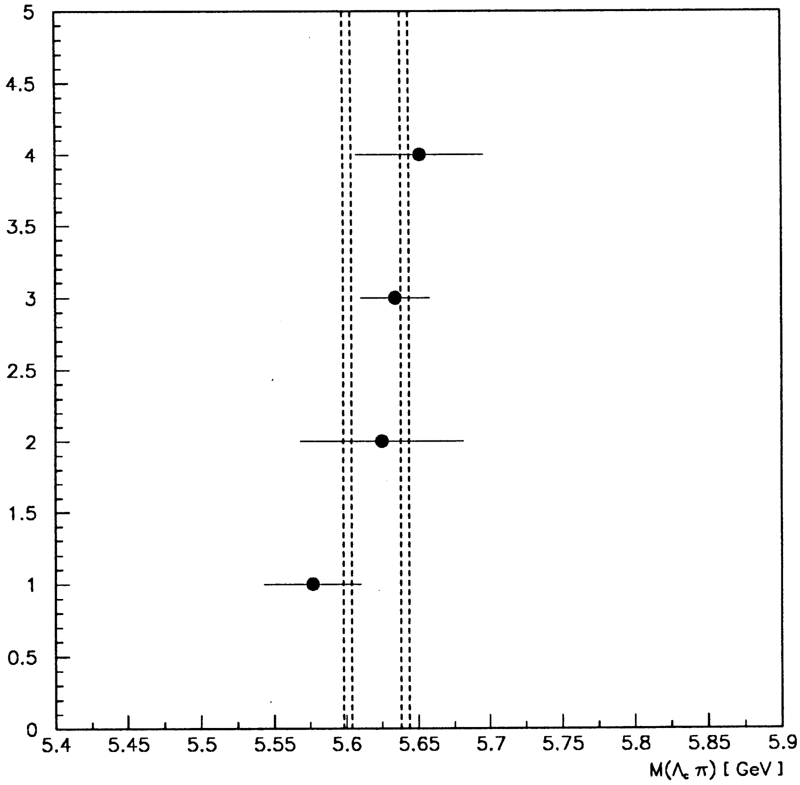

Figure 2: $\Lambda_c\pi$ invariant mass spread for the four selected candidates. The dotted lines show the statistical and the total error.

6 Conclusions

A signal of 4 events attributed to $\Lambda_b \to \Lambda_c^+\pi^-$ has been observed. From this number we evaluate a branching ratio of 1.0 $\pm$ 0.5 % which is consistent, within the errors, with the corresponding neutral B meson measurement (BR($B \to D^-\pi^+$) = 0.3 $\pm$ 0.4 %) [3]. The statistical signifcance of this excess is between 2 and 3 sigmas, depending on the way one takes into account the reflection background. With these 4 candidates we have measured the mass of the Λ_b to be 5621 $\pm$ 17 (stat.) $\pm$ 15 (syst.) MeV.

References

[1] D. Brown and M. Frank, "Tagging b Hadrons Using Track Impact Parameters", ALEPH Note 92-135, PHYSIC 92-124

[2] J.Knoblock, P.Norton, "V^0 reconstruction" in Status of reconstruction algoruthms for ALEPH, ALEPH note 88-46 (3 may, 1988)

[3] Particle Data Group: Phys. Review D50 Part I (August 1994)