Resonances in $\Lambda_c^+ \rightarrow pK^-\pi^+$

Juan Medellin Z., Jürgen Engelfried, Antonio Morelos
For the SELEX Collaboration

Abstract. We report very preliminary results of a Dalitz-plot analysis [1] of $\Lambda_c^+$ in the decay to $pK^-\pi^+$ with the helicity formalism. We used the data from the fixed target experiment SELEX [2] (E781) in Fermilab. We report about branching-ratios of the resonant states involved, and a possible initial state polarization.

INTRODUCTION AND ANALYSIS METHOD

In our search for resonances in the 3-body decay of $\Lambda_c^+ \rightarrow pK^-\pi^+$ we are considering in addition to the non-resonant mode the following resonant decay modes: $\Lambda_c^+ \rightarrow K^{*0}p$, $K^{*0} \rightarrow K^-\pi^+$; $\Lambda_c^+ \rightarrow \Delta^{++}K^-$, $\Delta^{++} \rightarrow p\pi^+$; and $\Lambda_c^+ \rightarrow \Lambda(1520)\pi^+$, $\Lambda(1520) \rightarrow pK^-.$

As a search tool for the resonances we calculate the invariant masses of pairs of daughter particles $M_{ij}^2, M_{ik}^2$ and fill with them into a two-dimensional histogram (Dalitz plot). A Monte-Carlo simulation of what could be expected is shown in fig. 1 (right).

The data sample used for this analysis is the same as in a previous SELEX publication [3], where more details can be found. We applied the following cuts to get a clean $\Lambda_c^+$ signal: good fits for tracks and vertices; momentum > 8.0 GeV/c for all tracks; proton and kaon identified in the RICH [4]; secondary vertex outside material; separation $L$ of primary and secondary vertices $L > 8\sigma,$ where $\sigma$ denotes the combined error of the vertices; $\sigma < 1.7$ mm; at least two tracks with a miss distance to the primary vertex of more than $20\mu$m; the momentum vector of the reconstructed $\Lambda_c^+$ has to point back to the primary vertex. The obtained $pK^-\pi^+$ invariant mass distribution can be found in fig. 1 (left).

To eliminate the contribution of background under the $\Lambda_c^+$-peak, we produce a Dalitz-plot of the sidebands shown in fig. 1, with a proper mapping of the allowed phase space. After normalizing to the correct number of events, we subtract this contribution bin-by-bin.

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2 email: juan@ifisica.uaslp.mx
3 email: jurgen@ifisica.uaslp.mx
4 email: morelos@ifisica.uaslp.mx
FIGURE 1. Left: Invariant mass distribution for $pK^-\pi^+$. A signal of approximately 1500 $\Lambda_c^+$ can be clearly seen. The signal and the sideband regions used in this analysis are indicated. Right: Dalitz plot from Monte Carlo with a mixture of non-resonant and three resonant decay modes.

bin from a Dalitz plot of the signal region. We verified this procedure by comparing the plots obtained by different sideband regions on the left and right side of the signal region. In fig. 2 we show the Dalitz plots for the sideband and the signal regions. In the background subtracted signal region one can still see some enhancement on the lower left of the phase space, also present in the sideband; we are still investigating the nature of this.

FIGURE 2. Left: Dalitz plot for the sideband region indicated in fig. 1 with phase space mapping. Right: Dalitz plot of signal region after sideband subtraction.
To extract the information from the Dalitz plot, we used an helicity formalism \cite{5, 6}. We will describe the fit functions used in the following sections.

**HELICITY FORMALISM FOR TWO BODY DECAYS**

From Fermi’s Golden Rule the partial decay width is given by $d\Gamma = \frac{(2\pi)^4}{2m} |\Omega|^2 d\Phi_n$, with $d\Gamma \sim |\Omega|^2 = |<BC|T|A>|^2$, where $A$ and $BC$ denote the initial and final states. We are working in the eigenstate base $|M, S, p^\mu, \lambda> \equiv |\alpha>$ of the operators $M^2 = P_\mu P^\mu$, $S \equiv -\omega_\mu \omega^\mu$ with $\omega^\mu = \frac{i}{2} e^{\kappa_\mu\lambda} M_{\mu\nu} P_\lambda$, and $P^\mu, \omega^\mu = J_x P_x + J_y P_y + J_z P_z$; $\omega^\mu$ represents the helicity operator with eigenvalue $\lambda$. For simplicity we assume only $|p^\mu, \lambda>.$

In the rest frame of the mother particle $A$ we can express the spin states as $|j_A m_A>$ and the final state as $|\theta_B \phi B \lambda_B \lambda_C>$, with

$$|\theta_B \phi B \lambda_B \lambda_C> = \sum_{JM} \sqrt{\frac{2J+1}{4\pi}} D_{M\lambda_1}^J (\theta_B, \phi_B, -\phi_B) |JM \lambda_B \lambda_C>.$$

Applying angular momentum conservation, we can write the transition amplitude as

$$<BC|T|A> = \sqrt{\frac{2J_A + 1}{4\pi}} D_{m_A m_1}^{j_A} (\theta_B, \phi_B, -\phi_B) <\lambda_B \lambda_C|T|j_A m_A>$$

With $D_{m_A m_1}^{j_A} (\theta, \phi, -\phi) = e^{-i\phi(m_1 - \lambda)} d_{m_A m_1}^{j_A} (\theta)$, $\lambda_1 = \lambda_2 - \lambda_C (|\lambda_1| \leq m_A)$, and summing over all spin and helicity projections and we obtain

$$d\Gamma \sim \sum_{m_A \lambda_B \lambda_C} |\alpha_{\lambda_B \lambda_C} e^{i\phi_B (m_A - \lambda_1)} d_{m_A m_1}^{j_A} (\theta_B)|^2$$

**HELICITY FORMALISM FOR THREE BODY RESONANT DECAYS**

The decay width in this case is given by $d\Gamma \sim |<DE|T_2|B><BC|T_1|A>|^2$. In the rest frame of the resonance $B$, with the z-axes pointing into the direction of motion of the resonance $B$ in the rest system of the mother particle $A$, we can write

$$<DE|T_2|B> = \sqrt{\frac{2J_B + 1}{4\pi}} e^{i\phi_D (\lambda_B - \lambda_2)} d_{\lambda_B \lambda_2}^{j_B} (\theta_D) <\lambda_D \lambda_E|T_2|B>.$$

Summing over all resonances we obtain

$$d\Gamma \sim \sum_{m_A \lambda_C \lambda_D \lambda_E} \sum_{\lambda_B} \sum_{B} |BW (m_r) \alpha_{\lambda_B \lambda_C} \alpha_{\lambda_D \lambda_E} e^{i\phi_B (m_A - \lambda_1)} e^{i\phi_D (\lambda_B - \lambda_2)} d_{m_A \lambda_1}^{j_A} (\theta_B) d_{\lambda_B \lambda_2}^{j_B} (\theta_D)|^2$$

where we also consider the finite width of the resonance with a Breit-Wigner distribution $BW (m_r) \sim \frac{m_0 \Gamma_r}{m_r^2 - m_0^2 + im_r \Gamma_r}$. In the parity conserving decay of the resonance we can write

$$\alpha_{\lambda_D \lambda_E} = (-1)^{S_D + S_E - S_B} \eta_B \eta_D \eta_E \alpha_{-\lambda_D - \lambda_E}.$$
In this formalism we can naturally introduce an initial polarization of the mother particle $P_A$, given by

$$d\Gamma \sim \frac{1}{2} (1 + P_A) \sum_{\lambda_C, \lambda_D, \lambda_E} |\sum_{\lambda_B} B W (m_B) \xi_B, \lambda_B, \lambda_C, \lambda_D, \lambda_E|^2$$

$$+ \frac{1}{2} (1 - P_A) \sum_{\lambda_C, \lambda_D, \lambda_E} |\sum_{\lambda_B} B W (m_B) \xi_B, -\frac{1}{2}, \lambda_B, \lambda_C, \lambda_D, \lambda_E|^2.$$  

Integrating the contribution of a resonance over the phase space gives

$$F_r = \int \frac{\sum_{m_A, \lambda_B} B W (m_r) \xi_{r, m_A, \lambda_B}}{\sum_{m_B, \lambda_B} B W (m_B) \xi_{B, m_A, \lambda_B}} d\vec{x}$$

from where, after applying weight factors for isospin conservation, we can extract the branching ratio for the resonance.

### PRELIMINARY RESULTS

We performed an unbinned maximum likelihood fit with the functions described in the previous section, with 23 free parameters in the fit. The preliminary results are shown in the following tables. Only statistical errors are shown.

| Parameter | Amplitude | Phase |
|-----------|-----------|-------|
| $N_1$     | 1. fixed  | 0. fixed |
| $N_2$     | 320 ± 82  | 2 ± 1.9 |
| $N_3$     | 26 ± 56   | 4.7 ± 1.9 |
| $N_4$     | 200 ± 135 | 3.2 ± 0.2 |
| $A_1$     | 495 ± 143 | 5.6 ± 0.2 |
| $A_2$     | 70 ± 91   | 3.9 ± 10^3 |
| $A_3$     | 362 ± 91  | 3.3 ± 0.1 |
| $A_4$     | 95 ± 69   | 2.9 ± 481 |
| $B_1$     | 11 ± 23   | 3.3 ± 10^4 |
| $B_2$     | 196 ± 87  | 3.5 ± 9 |
| $C_1$     | 115 ± 142 | 2.6 ± 18 |
| $C_2$     | 644 ± 144 | 0.8 ± 2 |

The two most significant features in the Dalitz plot are not properly taken into account in this analysis method. The fit function does not include a resonance describing the feature seen in the lower left of the phase space, leading to an over-estimate of the non-resonant contribution, and the central region with a small number of entries is not taken into account in an unbinned fit. At this moment, we are finalizing the analysis procedure, by optimizing the cuts used for extracting the $\Lambda^{+}$ signal, a study if additional resonances have to be included, and on a binned fit to included the information about the center region. Also some systematic studies are under way to quantify the significance of the results. This work was supported by CONACyT Mexico under Grant 28435-E.

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