Observation of $\Lambda_c^+ \to n K_S^0 \pi^+$

Gu Shan

2017.9.8

JC 31 report

Introduction

- The charmed baryon Λ_c^+ decays eventually into a proton or a neutron, each taking about half of the total branching fraction (BF) . However, to date no direct measurement of the decay modes involving a neutron has been performed.
- Precise measurement of the BF for $\Lambda_c^+ \to \mathrm{n}K_S^0\pi^+$ provide stringent tests on the isospin symmetry in the charmed baryon decays by examining the triangle relation.
- A comparison to $\mathrm{B}(\Lambda_c^+ \to p(\bar{\mathrm{k}}\pi)^0)$ provides an important test of isospin symmetry and final state interactions.

Analysis method

- The data analyzed at $\sqrt{s}$ =4.599 GeV .
- $\Lambda_c^+\bar{\Lambda}_c^-$ are produced in pairs and no additional hadron is kinematically allowed .
- First, select a data sample of $\bar{\Lambda}_c^-$ baryons by reconstructing exclusive hadronic decays, called the single tag (ST) sample.
- Then, search for $\Lambda_c^+ \to nK_S^0\pi^+$ in the system recoiling against the ST $\bar{\Lambda}_c^-$ baryons, called the double tag (DT) sample.
- The neutron is not detected, its kinematics is deduced by four-momenta conservation.
- The absolute BF of $\Lambda_c^+ \to nK_S^0\pi^+$ is then determined from the probability of detecting the process $\Lambda_c^+ \to nK_S^0\pi^+$ in the ST sample.
- This method provides a clean and straightforward BF measurement independent of the total number of $\Lambda_c^+\bar{\Lambda}_c^-$ events produced.

Singly tagged $\bar{\Lambda}_c^-$

- The Singly tagged $\bar{\Lambda}_c^-$ are reconstructed by

$\Lambda_c^- \longrightarrow \bar{p}K_S^0$, $\Lambda_c^- \longrightarrow \bar{p}K^+\pi^-$
$\Lambda_c^- \longrightarrow \bar{p}K_S^0\pi^0$, $\Lambda_c^- \longrightarrow \bar{p}K^+\pi^-\pi^0$,
$\Lambda_c^- \longrightarrow \bar{p}K_S^0\pi^+\pi^-$, $\Lambda_c^- \longrightarrow \bar{\Lambda}\pi^-$,
$\Lambda_c^- \longrightarrow \bar{\Lambda}\pi^-\pi^0$, $\Lambda_c^- \longrightarrow \bar{\Lambda}\pi^-\pi^+\pi^-$,
$\Lambda_c^- \longrightarrow \bar{\Sigma}^0\pi^-$, $\Lambda_c^- \longrightarrow \bar{\Sigma}^-\pi^0$ and $\Lambda_c^- \longrightarrow \bar{\Sigma}^-\pi^+\pi^-$

where the intermediate resonances K_S^0, $\bar{\Lambda}$, $\bar{\Sigma}^0$, $\bar{\Sigma}^-$ and π^0 meson are reconstructed by

$K_S^0 \to \pi^+\pi^-$, $0.485 < M_{\pi^+\pi^-} < 0.510$ GeV/c^2; $L/\sigma_L > 0$;
$\bar{\Lambda} \to \bar{p}\pi^+$, $1.110 < M_{p\pi^-} < 1.121$ GeV/c^2; $L/\sigma_L > 0$;
$\bar{\Sigma}^0 \to \gamma\bar{\Lambda}$ with $\bar{\Lambda} \to \bar{p}\pi^+$, $1.179 < M_{\gamma\Lambda} < 1.205$ GeV/c^2;
$\bar{\Sigma}^- \to \bar{p}\pi^0$, $1.173 < M_{p\pi^0} < 1.200$ GeV/c^2;
$\pi^0 \to \gamma\gamma$. $0.10 < M_{\gamma\gamma} < 0.15$ GeV/c^2; 1-C Kinematic Fit $\chi_{\pi^0\to\gamma\gamma} < 20$;

Singly tagged $\bar{\Lambda}_c^-$

- The ST $\bar{\Lambda}_c^-$ signal candidates are identified using the variable of beam constrained mass ,

$$M_{bc} = \sqrt{E_{\rm beam}^2 - |\vec{p}_{\Lambda_c^-}|^2}$$

where E_{beam} is the beam energy, and $\vec{p}_{\Lambda_c^-}$ is the momentum of the $\bar{\Lambda}_c^-$ candidate.

- To improve the signal purity, the energy difference

$$\Delta E = E_{\rm beam} - E_{\Lambda_c^-}$$

for each candidate is required to be within approximately $\pm 3\sigma_{\Delta E}$ around the ΔE peak, where $\sigma_{\Delta E}$ is the ΔE resolution. And $E_{\Lambda_c^-}$ is the reconstructed $\bar{\Lambda}_c^-$ energy.

TABLE I. ST modes, ΔE requirements and ST yields $N_{\bar{\Lambda}_c^-}$ in data. The errors are statistical only.

Mode	ΔE (GeV)	$N_{\bar{\Lambda}_c^-}$
$\bar{p}K_S^0$	[−0.025, 0.028]	1066 ± 33
$\bar{p}K^+\pi^-$	[−0.019, 0.023]	5692 ± 88
$\bar{p}K_S^0\pi^0$	[−0.035, 0.049]	593 ± 41
$\bar{p}K^+\pi^-\pi^0$	[−0.044, 0.052]	1547 ± 61
$\bar{p}K_S^0\pi^+\pi^-$	[−0.029, 0.032]	516 ± 34
$\bar{\Lambda}\pi^-$	[−0.033, 0.035]	593 ± 25
$\bar{\Lambda}\pi^-\pi^0$	[−0.037, 0.052]	1864 ± 56
$\bar{\Lambda}\pi^-\pi^+\pi^-$	[−0.028, 0.030]	674 ± 36
$\bar{\Sigma}^0\pi^-$	[−0.029, 0.032]	532 ± 30
$\bar{\Sigma}^-\pi^0$	[−0.038, 0.062]	329 ± 28
$\bar{\Sigma}^-\pi^+\pi^-$	[−0.049, 0.054]	1009 ± 57
All tags		14415 ± 159

The yield of each tag mode is obtained from fits to the M_{bc} distributions in the signal region.

Search for $\Lambda_c^+ \to n K_S^0 \pi^+$

Candidates for the decay $\Lambda_c^+ \to nK_S^0\pi^+$ are selected from the remaining tracks recoiling against the ST $\bar{\Lambda}_c^-$ candidates.

- pion reconstruction:

  A pion with charge >0 is selected.

- K_S^0 reconstruction:

  1. At least two oppositely charged tracks are reconstructed in recoil side, one is assumed as π^+ and the other one is assumed as π^-;
  2. no |Vxy| cut, no |Vz| cut;
  3. $L/\sigma L > 0$;

Search for $\Lambda_c^+ \to n K_S^0 \pi^+$

$M^2_{\rm miss}$ is calculated to extract the information of missing neutron

$$M^2_{\rm miss} = (p_{\Lambda_c^+} - p_{K_S^0} - p_{\pi^+})^2 = E^2_{\rm miss} - c^2|\overrightarrow{p}_{\rm miss}|^2.$$

In analysis,

$$E_{\rm miss} = E_{\rm beam} - E_{K_S^0} - E_{\pi^+},$$

$$\vec{p}_{\rm miss} = \vec{p}_{\Lambda_c^+} - \vec{p}_{K_S^0} - \vec{p}_{\pi^+},$$

$$\vec{p}_{\Lambda_c^+} = -\hat{p}_{\rm tag}\sqrt{E^2_{\rm beam} - m^2_{\Lambda_c^+}},$$

where $\hat{p}_{\rm tag}$ is the direction of the momentum of singly tagged Λ_c^-;

Fit

A two-dimensional unbinned maximum likelihood fit to the $M^2_{\rm miss}$ and $M_{\pi^+\pi^-}$ is performed.

$$N^{\rm obs}_{nK^0_S\pi^+} = 83.2 \pm 10.6$$

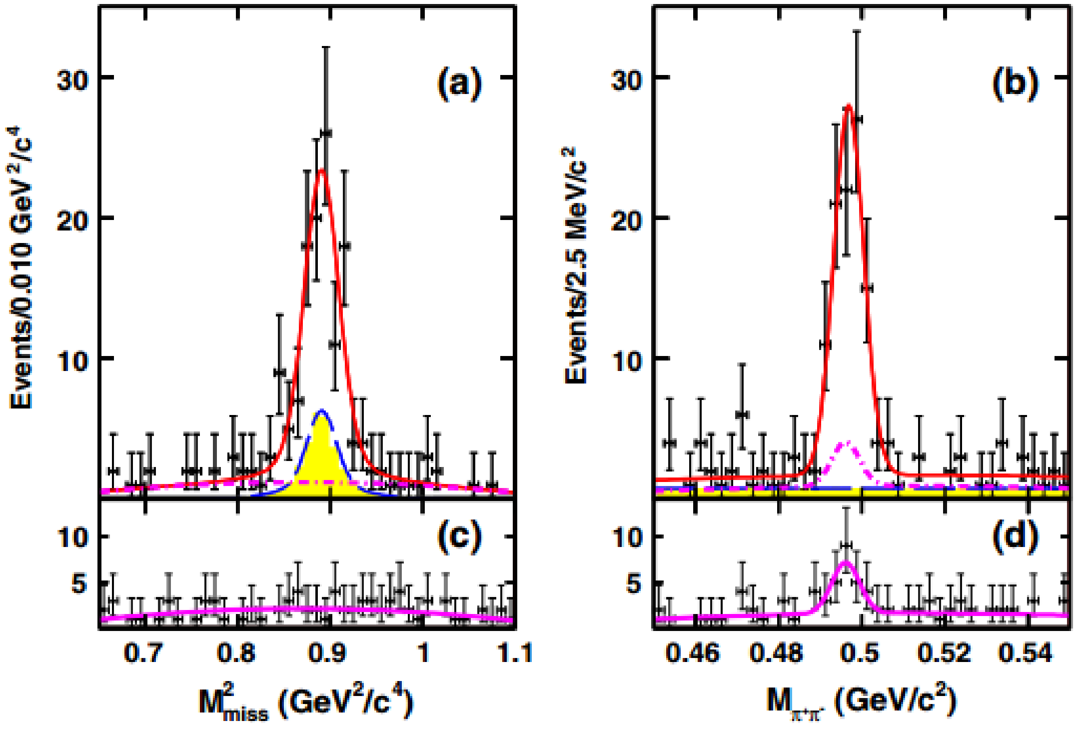

FIG. 2. Simultaneous fit to $M^2_{\rm miss}$ and $M_{\pi^+\pi^-}$ of events in (a),(b) the $\bar{\Lambda}_c^-$ signal region and (c),(d) sideband regions. Data are shown as the dots with error bars. The long-dashed lines (blue) show the Λ_c^+ backgrounds while the dot-dashed curves (pink) show the non-Λ_c^+ backgrounds. The (red) solid curves show the total fit. The (yellow) shaded area show the MC simulated backgrounds from Λ_c^+ decay.

Summary

- This is the first direct measurement of a Λ_c^+ decay involving the neutron in the final state since the discovery of the Λ_c^+ more than 30 years ago.
- Quoting $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$ and $\mathcal{B}(\Lambda_c^+ \to pK_S^0\pi^0)$, the amplitudes of the above three decay processes satisfy the triangle relation and validate the isospin symmetry .
- The analysis method used in this work can also be extended to study more decay modes involving a neutron.