First observation of $\Lambda\pi^+$ and $\Lambda\pi^-$ signals near the $\bar{K}N(I=1)$ mass threshold in $\Lambda^+_c \rightarrow \Lambda\pi^+\pi^+\pi^-$ decay

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Hyperon spectroscopy near the $\bar{K}N$ threshold has been a source of excitement for more than half a century. A typical example is the Λ(1405)(*I=0*) state[1], which is interpreted as an orbitally excited state with *uds* quarks in the naïve quark model, but an exotic interpretation as a $\bar{K}N$ bound state is considered to be more likely. On the other hand, the only known *I=1* state in this mass region is the Σ(1385), and the standard quark model does not predict any more states. So, if a Σ^* resonance is observed, it must be exotic. Here, the $\bar{K}N$(*I=1*) interaction is, most likely, not strong enough to produce a bound state, but a virtual state could exist [1] and could be observed as a threshold cusp. The shape of such a cusp reflects the scattering length of the $\bar{K}N$(*I=1*) interaction, which is particularly interesting in relation with kaon condensation in neutron stars, where K^-n interaction plays most important role.

In the present work, we have studied $\Lambda\pi^+$ and $\Lambda\pi^-$ invariant mass distributions in the decay $\Lambda_c^+ \rightarrow \Lambda\pi^+\pi^+\pi^-$, using the full data sample of the Belle experiment at the KEKB asymmetric-energy e^+e^- collider [2].

The reconstructed $\Lambda\pi^{\pm}$ invariant mass spectrum is shown in Fig. 1. Clear enhancements near the $\bar{K}N$ mass thresholds are observed in both of the $\Lambda\pi^+$ and $\Lambda\pi^-$ invariant mass spectra for the first time. We investigated the signals using two different parametrizations of the signal shape: a standard Breit-Wigner function which describes a Σ^* resonance, and the Dalitz model [3] which describes a $\bar{K}N$ cusp. For the background, we used a Breit-Wigner function for the Σ(1385) contribution and a second-order Chebyshev polynomial function for the high-mass background events.

With the fit to a Breit-Wigner function, we obtained the mass and width to be 1434.3±0.6(stat)±0.9(syst) [1438.5±0.9(stat) ±2.5(syst)] MeV/c^2 and 11.5±2.8(stat)±5.3(syst) [33.0± 7.5(stat)±23.6(syst)] MeV, respectively, for the $\Lambda\pi^+$ ($\Lambda\pi^-$) mode with the χ^2/NDF of 74.4/68 (92.3/68).

In the Dalitz model fit, we obtained the complex scattering length (a+ib) of the $\bar{K}^0p$ (K^-n) interaction to be a=0.48± 0.32(stat)±0.38(syst) [1.24±0.57(stat)±1.56(syst)] fm and b=1.22±0.83(stat)±2.54(syst) [0.18±0.13(stat)±0.20(syst)] fm with the χ^2/NDF of 68.9/68 (78.1/68). The scattering lengths derived in our data analysis are larger than the previous results [4–6]. This difference may be due to the neglected decay form factor of an order of 0.5 fm.

The significance for the observed signals is 7.5 σ (6.2 σ) for the $\Lambda\pi^+$ ($\Lambda\pi^-$) mode. Limited by the statistics and the shape of the background, we cannot distinguish between Σ^* resonances and $\bar{K}N$ threshold cusps, since both fits give similar χ^2s. On the theoretical side, both interpretations are discussed, but the cusp interpretation may be more favored. Oller and Meißner discussed the possibility of a resonance in the *I=1* channel and reported a pole at (1444.0 − i69.4) MeV in the second Riemann sheet [1]. However, the imaginary part is too large to explain the present structure. Many theories [5-7] predicted a threshold cusp in the *I=1* channel. In addition, Ref. [1] also reported another (virtual) pole in the third Riemann sheet below the threshold, which could produce a cusp at the threshold.

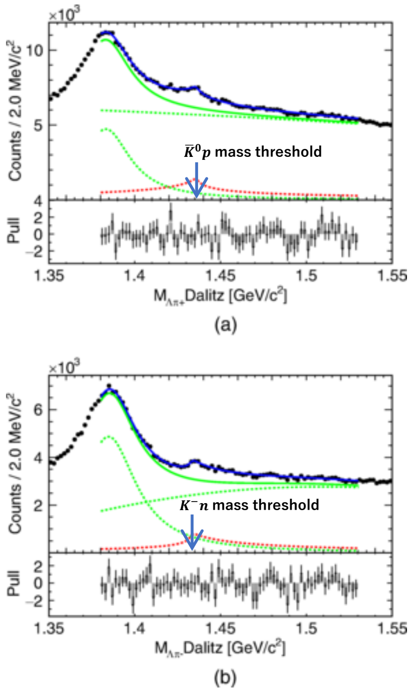

Fig. 1 $\Lambda\pi^+$ (a) and $\Lambda\pi^-$ (b) invariant mass distributions fitted with the Dalitz model [3] for the signal and a background function. The solid (dotted) green, red, and blue curves represent the (breakdown) background, signal, and total fit function, respectively.

References

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1 For the notation of hadrons, please refer to textbooks or Particle Data Group webpage (https://pdg.lbl.gov/).