First observation of the $\Xi^- \pi^+$ decay mode of the $\Xi^0(1690)$ hyperon

The WA89 Collaboration

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Abstract

We report the first observation of the $\Xi^- \pi^+$ decay mode of the $\Xi^0(1690)$, confirming the existence of this resonance. The $\Xi^0(1690)$ were produced by Σ^- of 345 GeV/c mean momentum in copper and carbon targets. The mass and width are close to those observed earlier for the $\Xi^-(1690)$ in the ΛK^- decay channel. The product of inclusive production cross section and branching ratio is given relative to that of the $\Xi^0(1530)$.

1   Introduction

More than three decades after the first observations of excited states of hyperons, the excited states of Ξ^- and Ω^- are still largely unexplored. Of the Ξ^* states, only the $\Xi(1530)$ rates four stars in the PDG ranking, while four other states, the $\Xi(1690)$, $\Xi(1820)$, $\Xi(1950)$ and $\Xi(2030)$ rate three stars [1].

First experimental evidence for the $\Xi(1690)$ came from a bubble chamber experiment using a K^- beam of 4.2 GeV/c. A strong threshold enhancement was observed in the $\Sigma\overline{K}$ mass spectra, with weaker evidence from the $\Lambda\overline{K}$ spectra [2]. The first direct observation of the $\Xi(1690)$ as a resonance resulted from a hyperon beam experiment at CERN. Here, a peak at 1690 MeV/c^2 in ΛK^- pairs produced diffractively in a Ξ^- beam of 116 GeV/c was observed [3]. In an earlier run of that experiment, a corresponding signal at around 1700 MeV/c^2 with poorer mass resolution was seen [4].

In the framework of the nonrelativistic quark potential model, a $\Xi(1/2^+)$ state was predicted with a mass around 1690 MeV/c^2, with dominating $\Xi\pi$ decay [5]. A relativistic version of this model, however, pushed the first excited $\Xi(1/2^+)$ to about 1800 MeV/c^2, and left no state to be identified with the observed $\Xi(1690)$ [6]. Also within a more recently developed chiral boson exchange interaction model the $\Xi(1/2^+)$ state is expected at an energy far above 1690 MeV/c^2 and close to 1800 MeV/c^2 [7].

In this paper, we report on a search for the $\Xi(1690)$ resonance in the $\Xi^-\pi^+$ channel. While in previous studies no statistically significant resonance signal around 1690 MeV/c^2 was observed in this decay mode [3], we find a clear resonant signal at a mass of 1686 MeV/c^2.

2   The experimental apparatus

The hyperon beam and the experimental setup were described in detail elsewhere [8, 9]. Here we give only a brief summary of the equipment important for this particular measurement.

The hyperon beamline selected Σ^- hyperons with a mean momentum of 345 GeV/c and a momentum spread of $\sigma(p)/p = 9\%$. Although the actual π^- to Σ^- ratio of the beam was about 2.3, high-momentum pions were strongly suppressed on the trigger level by a set of transition radiation detectors [10] resulting in a remaining pion contamination of about 12%. In addition the beam contained small admixtures of K^- and Ξ^- [9]. Σ^- decays upstream of the experimental target provided a background of neutrons and π^- at lower energy, which could be rejected by requiring that the beam track measured upstream of the target intercepted the interaction vertex and fulfilled the position/angle correlations given by the beam optics. The trajectories of incoming and outgoing particles were measured in silicon microstrip detectors upstream and downstream of the target. The experimental target itself consisted of one copper slab with a thickness of 0.025 λ_I in beam direction, followed by three carbon (diamond powder) slabs of 0.008 λ_I each.

The momenta of the decay particles were measured in a magnetic spectrometer equipped with MWPCs and drift chambers. The spectrometer magnet was placed with its center 13.6 m downstream of the target to allow hyperons and K_S^0 emerging from the target to decay in front of it.

Charged particles could be identified using a ring imaging Cherenkov (RICH) detector [11], which intercepted particles with momenta above about 12 GeV/c. In the analysis described below, particle identification was used for cross-check purposes only.

3   Event selection

The event selection for the decay chain $\Xi^* \to \Xi^- \pi^+$, $\Xi^- \to \Lambda^0 \pi^-$, $\Lambda^0 \to p\,\pi^-$ was done as follows:

Combinations of positive and negative particles were accepted as Λ^0 candidates if the distance of the two tracks at the decay point was smaller than 0.5 cm and if their reconstructed $p\pi^-$ mass was within $\pm 3\sigma_1$

of the Λ^0 mass. Here σ_1 is the uncertainty of the mass determination based on the track properties of the individual events. Typically, σ_1 is about 1.6 MeV/c^2.

Ξ^- candidates were accepted if their trajectory measured in the vertex detector downstream of the target agreed within errors with the Ξ^- momentum direction and the Ξ^- decay vertex which were constructed from the Λ^0 and π^- daughter particles. Furthermore, the reconstructed $\Lambda\pi^-$ mass had to be within $\pm 3\sigma_2$ of the Ξ^- mass where σ_2 is typically 2.7 MeV/c^2 .

The Ξ^- production vertex had to contain at least one more charged particle track besides the Ξ^- track. The reconstructed vertex position had to be inside a target block with an error margin of 3σ in each coordinate. The transverse distance between the Σ^- beam track and the reconstructed vertex position was required to be less than $6\sigma_3$, where $\sigma_3 \approx 25\mu$m typically. Furthermore events were rejected for which the beam track was connected to an outgoing track.

4   Results

The $\Xi^-\pi^+$ mass distribution for all combinations of Ξ^- candidates with positively charged particles from the interaction vertex is presented in Figure 1a. This plot is dominated by the peak from $\Xi^0(1530)$ decays. The mass of the $\Xi^0(1530)$ is measured to be $M = 1532.6 \pm 0.5$ MeV/c^2 where the error comes mainly from the uncertainty in the mass scale. It is in good agreement with the known value $M = 1531.8 \pm 0.3$ MeV/c^2 [1]. The observed width is consistent with the known value of the intrinsic width, $\Gamma = 9.1 \pm 0.5$ MeV/c^2 [1] and the mass resolution of our apparatus. The number of $\Xi^0(1530)$ decays is 63000 ± 6000, where the error is mainly due to the uncertainties in the shapes of the signal and background distributions.

Figure 1b shows the mass region between 1600 and 1800 MeV/c^2 in more detail. A resonance signal at about 1690 MeV/c^2 is visible above a large background. For a more quantitative analysis the background was fitted with a Legendre polynomial of second order in the mass range from 1610 to 1792 MeV/c^2 but excluding the resonance region. In figure 1c the resonance signal is shown after background subtraction. Its mass and intrinsic width are

$$M = 1686 \pm 4 \text{ MeV}/c^2 \,, \Gamma = 10 \pm 6 \text{ MeV}/c^2 \,.$$

The number of observed events above background is 1400 ± 300. Note that all quoted errors include uncertainties due to reasonable variations of the signal and background shapes.

Finally we checked whether the observed signal could be caused by a reflection from a Ξ^-K^+ state. We selected those combinations where the π^+ candidate was actually positively identified as a K^+ by the RICH detector. This sample contains about 4% of the total sample and shows no resonant structure in the $\Xi^-\pi^+$ mass spectrum.

To measure the product of the production cross section and branching ratio, $\sigma \cdot BR$, for $\Xi^0(1690)$ relative to $\Xi^0(1530)$, we determined the apparatus acceptances from a Monte Carlo calculation. Within the observable kinematic range, $0.1 < x_F < 1$, the ratio of acceptances r_A is very close to unity as expected from the similar decay kinematics: $r_A = A(\Xi^0(1690) \to \Xi^-\pi^+)/A(\Xi^0(1530) \to \Xi^-\pi^+) = 0.98 \pm 0.02$. Within the large statistical uncertainties, the x_F distribution of the $\Xi^0(1690)$ is consistent with that of the $\Xi^0(1530)$. We therefore assume them to be equal and obtain within the range of $0.1 < x_F < 1$ a ratio for the $\sigma \cdot BR$ values of

$$\frac{\sigma \cdot BR(\Xi^0(1690) \to \Xi^-\pi^+)}{\sigma \cdot BR(\Xi^0(1530) \to \Xi^-\pi^+)} = 0.022 \pm 0.005. \tag{1}$$

This number should be corrected for contributions from the Ξ^- admixture to the beam. The Ξ^- flux was measured to be $(1.3 \pm 0.1)\%$ of the Σ^- flux. The production rate of the $\Xi^-(1320)$ by Ξ^- is about equal to the production rate by Σ^- at $x_f \approx 0$ and enhanced by one order of magnitude at $x_F \approx 0.5$ [9]. The latter feature is related to the different numbers of common valence quarks in the projectiles and the produced

$\Xi^-(1320)$. As expected from the smaller difference in the quark-overlap between a Ξ^- and a $\Xi^0(1530)$ on one hand and a Σ^- and $\Xi^0(1530)$ on the other hand, a less pronounced enhancement is observed for the $\Xi^0(1530)$ production [13]. We, therefore, expect that contaminations from Ξ^- induced reactions to the observed $\sigma \cdot BR$ values are of the order of a few percent. Considering furthermore that contributions to the numerator and denominator in eq. 1 partially cancel, we neglect them here.

5 Discussion

Our measured values for the mass and width of the $\Xi^0(1690)$ are in reasonable agreement with the result of a coupled channel analysis of $\Sigma^+ K^-$ and $\Lambda \bar{K}^0$ spectra measured in K$^-$p interactions [2]. That analysis provided first evidence for a Ξ^0 resonance with a mass of 1684±5 MeV/c^2 and a width of 20±4 MeV/c^2. Both measurements of the $\Xi^0(1690)$ mass are slightly below the most significant value available for the $\Xi^-(1690)$ mass, $m = 1691.1 \pm 1.9 \pm 2.0$ MeV/c^2 [3]. Such a difference is in line with the mass splittings observed in the $\Xi(1320)$ and $\Xi(1530)$ systems of 6.4±0.6 and 3.2±0.6 MeV/c^2 [1], respectively. We also note that the width of the $\Xi^0(1690)$ determined in the present experiment is comparable to that of the $\Xi^0(1530)$.

From fig. 7 of ref. [3], an upper limit on the diffractive production cross section and branching ratio relative to $\Xi^0(1530)$ can be estimated, $\sigma \cdot BR[\Xi^0(1690) \to \Xi^- \pi^+]/\sigma \cdot BR[\Xi^0(1530) \to \Xi^- \pi^+] < 0.03$. The suppression factor of 0.022 ± 0.005 observed in the present study is consistent with that upper limit. For comparison it is interesting to note that in Ξ^- induced interactions the ratio of $\Xi^0(1530)$ to $\Xi^0(1320)$ production was measured to be 0.25 at $x_F \approx 0.4$ and to increase with x_F [12]. It remains to be seen how much of the significantly stronger suppression found in the present experiment is due to the opening up of the $\Lambda \overline{K}$ and $\Sigma \overline{K}$ decay channels.

In conclusion we would like to point out that this is the first unambiguous observation of the neutral member of the $\Xi(1690)$ doublet, confirming the existence of this resonance at a mass of 1690 MeV/c^2.

Acknowledgements

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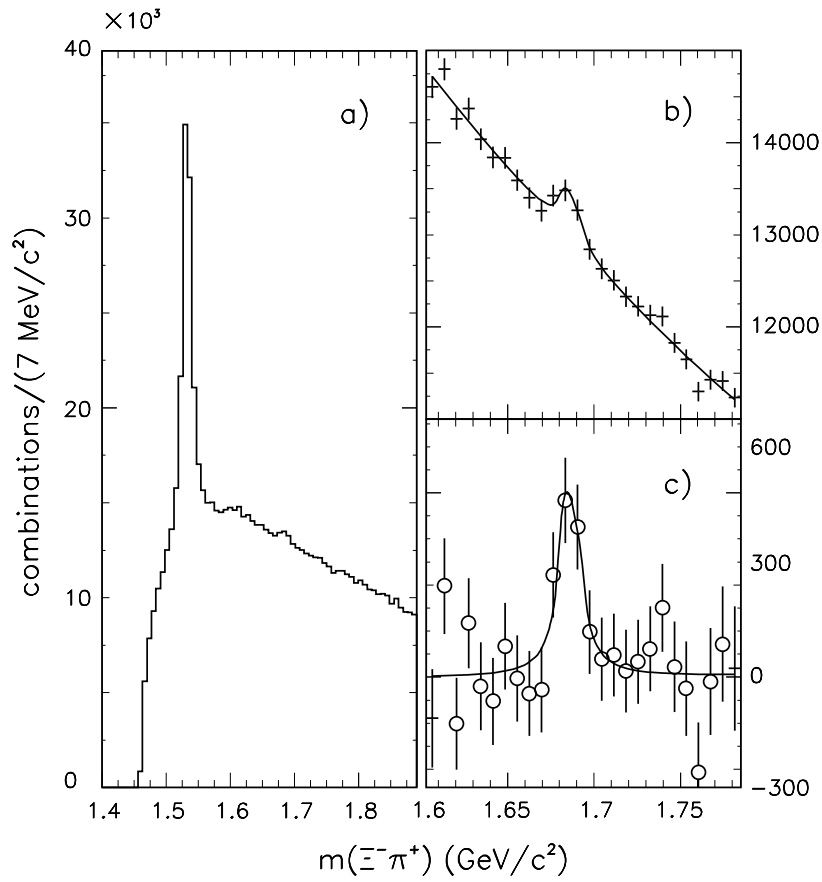[13] N. Keller, diploma thesis, Univ. Heidelberg 1996 (unpublished).

Figure 1: Invariant mass distribution of the $\Xi^- \pi^+$ combinations. a) the $\Xi^0(1530)$ and $\Xi^0(1690)$ mass region; b) the $\Xi^0(1690)$ mass region only; c) the $\Xi^0(1690)$ mass region after background subtraction.