Eur. Phys. J. C 5, 621–624 (1998)
DOI 10.1007/s100529800902

THE EUROPEAN
PHYSICAL JOURNAL C

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

WA89 Collaboration

M.I. Adamovich[8], Yu.A. Alexandrov[8], D. Barberis[3], M. Beck[5], C. Bérat[3], W. Beusch[2], M. Boss[6], S. Brons[5,a], W. Brückner[5], M. Buénerd[4], Ch. Busch[6], Ch. Büscher[5], F. Charignon[4], J. Chauvin[4], E.A. Chudakov[,6,b], U. Dersch[5], F. Dropmann[5], J. Engelfried[6, c], F. Faller[6,d], A. Fournier[4], S.G. Gerassimov[5,8], M. Godbersen[5], P. Grafström[2], Th. Haller[5], M. Heidrich[5], E. Hubbard[5], R.B. Hurst[3], K. Königsmann[5,e], I. Konorov[5], N. Keller[6], K. Martens[6,f], Ph. Martin[4], S. Masciocchi[5], R. Michaels[5,g], U. Müller[7], H. Neeb[5], D. Newbold[1], C. Newsom [h], S. Paul[5,i], J. Pochodzalla[5], I. Potashnikova[5], B. Povh[5], Z. Ren[5], M. Rey-Campagnolle[4], G. Rosner[7], L. Rossi[3], H. Rudolph[7], C. Scheel [j], L. Schmitt[7,i], H.-W. Siebert[6], A. Simon[6,e], V. Smith[1,k], O. Thilmann[6], A. Trombini[5], E. Vesin[4], B. Volkemer[7], K. Vorwalter[5], Th. Walcher[7], G. Wälder[6], R. Werding[5], E. Wittmann[5], and M.V. Zavertyaev[5,8]

[1] University of Bristol, Bristol, United Kingdom
[2] CERN, CH-1211 Genève 23, Switzerland
[3] Genoa Univ./INFN, Dipt. di Fisica,I-16146 Genova, Italy
[4] Grenoble ISN, F-38026 Grenoble, France
[5] Heidelberg Max-Planck-Inst. für Kernphysik, Postfach 103980, D-69029 Heidelberg, Germany
[6] Heidelberg Univ., Physikal. Inst., D-69120 Heidelberg Germany[l]
[7] Mainz Univ., Inst. für Kernphysik, D-55099 Mainz, Germany[k]
[8] Moscow Lebedev Physics Inst., RU-117924, Moscow, Russia

Received: 24 October 1997 / Published online: 21 September 1998

Abstract. We report the first observation of the $\Xi^-\pi^+$ scattering 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 of 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 $\Xi^0(1530)$.

[a] Now at TRIUMF, Vancouver, B.C., Canada V6T 2A3
[b] On leave of absence form Moscow State University, 119889 Moscow, Russia
[c] Now at FNAL, PO Box 500 Batavia, IL 60510, USA.
[d] Now at Fraunhofer Inst. für Solar Energiesysteme,D-79100 Freiburg, Germany
[e] Now at Fakultät für Physik, Univ. Freiburg, Germany
[f] Now at Institute for Cosmic Ray Research, University of Tokyo,Japan
[g] Now at Thomas Jefferson Lab, Newport News, VA 23606, USA
[h] University of Iowa, Iowa City, IA 52242, USA
[i] Now at Technische Universitaät München, Garching, Germany
[j] NIKEF, 1009 DB Amsterdam, The Netherlands
[k] supported by the UK PPARC
[l] supported by the Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie, Germany, under contract numbers 05 5HD15I, 06 HD524I and 06 MZ5265

1 Introduction

More than three decades after the first observation 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 was observed in ΛK^- pairs produced diffractively in a Ξ^- beam of 116 GeV/c [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 at 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 was 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 centre 13.6 m downstream of the target to allow hyperons and K^0_S 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 $\Xi^{*0} \to \Xi^- \pi^+$, $\Xi^- \to \Lambda^0 \pi^-$, $\Lambda^0 \to p \pi^-$ was done as follows:

Combinations of positive and negative particles were accepted as Λ^0 candidates if the distance between 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 vertex was defined as the space point with minimal distance between the tracks included in the vertex. 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. These cuts were optimised to reject safely background from neutron interactions while keeping a high efficiency for Σ^- induced interactions [9].

4 Results

The $\Xi^-\pi^+$ mass distribution for all combinations of Ξ^- candidates with positively charged particles from the interaction vertex is presented in Fig. 1a. This plot is dominated by the peak from $\Xi^0(1530)$ decays. The mass distribution in the region of the Ξ_{1530} was fitted by a Breit-Wigner distribution convoluted with a Gaussian to describe the signal :

$$f_{BWG}(m, M, \Gamma, \sigma) = \frac{1}{\sqrt{2\pi^3}\sigma} \int_{-\infty}^{+\infty} \frac{2\Gamma}{4(\mu - M)^2 + (\Gamma)^2} e^{-\frac{1}{2}\left(\frac{m-\mu}{\sigma}\right)^2} d\mu. \quad (1)$$

the parameters M,Γ,σ are the mass of the resonance, its width and the experimental resolution. A Legendre polynomial of second order was used to describe the background. The width of the Breit Wigner was fixed to $\Gamma =$ 9.1 MeV/c^2 [1]. The fit result for the central mass is in good agreement with the known value $M = 1531.8 \pm 0.3$ MeV/c^2 [1]. The value obtained for the experimental resolution is $\sigma_{\Xi^0(1530)} = 3.7$ 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.

We further checked the uncertainty in the mass scale and the mass resolution on the signals of Λ^0, Ξ^-, and Ω^-. Since these particle decay weakly, their measured widths are entirely dominated by the detector resolution. Therefore the mass distributions were fit by Gaussian functions plus Legendre polynomials of second order. The same procedure was applied to Monte Carlo data. Table 1 shows

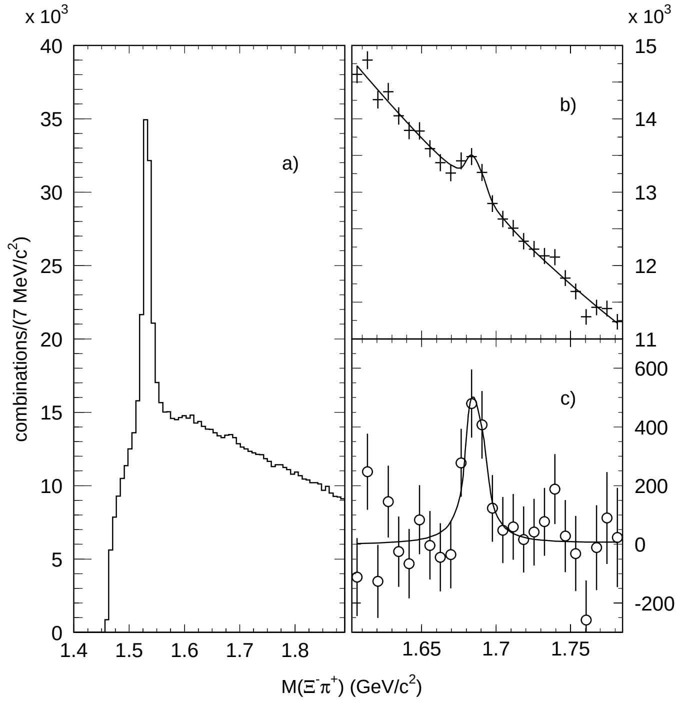

Fig. 1. Invariant mass destribution of the $\Xi^-\pi^+$ combinations. **a** the $\Xi^0(1530)$ and $\Xi^0(1690)$ mass region; **b** the $\Xi^0(1690)$ mass region only; **c** the $\Xi^0(1690)$ mass region after background subtraction

Table 1. Fitted mass value for Λ^0, Ξ^-, Ω^-, $\Xi^0(1530)$, and $\Xi^0(1690)$ and mass resolutions obtained in data and in Monte Carlo

particle	reconst. Mass	σ_{Data}	σ_{MC}
	MeV/c^2	MeV/c^2	MeV/c^2
$\Lambda \to p\pi^-$	1115.7 ± 0.1	1.93	1.62
$\Xi^- \to \Lambda\pi^-$	1321.0 ± 0.1	2.68	2.32
$\Omega^- \to \Lambda K^-$	1672.5 ± 0.9	2.4	2.1
$\Xi^0(1530)$	1532.2 ± 0.5	3.7	3.21
$\Xi^0(1690)$	1686 ± 4		3.28

the result of the fits together with the results obtained for the $\Xi^0(1530)$ and the $\Xi^0(1690)$. The mass scale up to the mass of the Ω^- shows no bias. The measured width the data is in general 10–15% larger than the one obtained in Monte Carlo. We accounted for that effect by taking the measured resolution at the $\Xi^0(1530)$ in the fit of the $\Xi^0(1690)$

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 Fig. 1c the resonance signal is shown after background subtraction. Its mass and intrinsic width obtained in a fit of the function defined in (1) are

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

For this fit the resolution was fixed to $\sigma_{\Xi^0(1530)}$ obtained in the fit of the $\Xi^0(1530)$. 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.

The assignment of strangeness -1 to the observed resonance depends on the assumption that the positive particle emitted in the decay is a π^+ and not a K^+ (we neglect the very unlikely proton hypothesis). This assumption cannot be verified by requiring pion identification with the RICH, since only half of the π^+ candidates have momenta large enough (greater than about 12 GeV/c) to be within the geometric acceptance of the RICH. We have no clear evidence for a $\Xi^-\pi^+$ signal in this reduced sample, which is explained by the fact, that anyway the major part of all particles in the relevant momentum range are pions. Positive identification of K^+ requires momenta above 25 GeV/c, and we do not observe a significant $\Xi^-\pi^+$ signal with this momentum requirement. We also do not observe a Ξ^-K^+ signal in the sample with RICH-identified K^+.

Kinematics provide strong arguments against the hypothesis of a reflection from a narrow Ξ^-K^+ state. A narrow state at 1900 MeV/c^2, decaying to Ξ^-K^+ and erroneously reconstructed as $\Xi^-\pi^+$, would extend from 1485 to 1755 MeV/c^2 and would therefore have to decay extremely anisotropically to produce a narrow reflection. Moreover, this state would be still close to the $\Xi^-\pi^+$ threshold and its decay to $\Xi^-\pi^+$ would be suppressed. Finally, $\varLambda$ and $\varSigma$ hyperons are well explored around and above 2 GeV and all states found have widths of about 100 MeV/c^2 or more.

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 $0.1 < x_F < 1$ [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

$$\frac{\sigma \cdot BR(\Xi^0(1690) \to \Xi^-\pi^+)}{\sigma \cdot BR(\Xi^0(1530) \to \Xi^-\pi^+)} = 0.022 \pm 0.005. \quad (2)$$

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 $\varSigma^-$ flux. The production rate of the $\Xi^-(1320)$ by Ξ^- is about equal to the production rate by $\varSigma^-$ 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^-

[1] x_F is defined as $x_F = p_z/p_{zmax} \approx 2p_{zcms}/\sqrt{s}$, and measures the momentum transfer in forward direction

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 (2) partially cancel, we neglect them here.

5 Discussion

Our measured values $M = 1686 \pm 4$ MeV/c^2 , $\Gamma = 10 \pm 6$ MeV/c^2 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 [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. We are indebted to J. Zimmer and the late Z. Kenesei for their help during all moments of detector construction and setup. We are grateful to the staff of CERN's EBS group for providing an excellent hyperon beam channel, to the staff of CERN's Omega group for their help in running the Ω-spectrometer and also to the staff of the SPS for providing very good beam conditions. We thank D.M. Jansen, B. Kopeliovich, O. Piskounova and R. Ransome for many helpful discussions.

References

1. R.M. Barnett *et al.*, The Particle Data Group, Phys. Rev. D **54** (1996)
2. C.Dionisi *et al.*, Phys. Lett. B **80**, (1978) 145
3. S.F.Biagi *et al.*, Z. Phys. C **34**, (1987) 15
4. S.F.Biagi *et al.*, Z. Phys. C **9**, (1981) 305
5. K.T. Chao, N. Isgur and G. Karl, Phys. Rev. D **23**, (1981) 155
6. S. Capstick and N. Isgur, Phys. Rev. D **34** (1986) 2809
7. L. Ya. Glozman and D.O. Riska, Phys. Rep. **268**, (1996) 263
8. P. Grafström, CERN/SPSC 88-4, CERN/SL/90-104, Yu. A. Alexandrov et al., CERN/SL/97-060
9. M.I.Adamovich *et al.*, Z. Phys. C **76**, (1997) 35
10. W. Brückner *et al.*, Nucl. Instrum. Methods A **378**, (1996) 451
11. W. Beusch *et al.*, Nucl. Instrum. Methods A **323**, (1992) 373 ; H.-W. Siebert *et al.*, Nucl. Instrum. Methods A **343**, (1994) 60 ; U. Müller *et al.*, Nucl. Instrum. Methods A **371**,(1996) 27
12. O. Schneider *et al.*, Z. Phys. C **46**, (1990) 341
13. N. Keller, diploma thesis, Univ. Heidelberg 1996 (unpublished)