EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/84-65
May 24th, 1984

A STUDY OF THE $K\pi$ SYSTEM IN THE REACTION $K^-p \rightarrow \bar{K}^0\pi^-p$ AT 8.25 GeV/c

Birmingham^{1*}-CERN²-Glasgow^{3*}-Michigan State^{4**}-Paris VI (LPNHE)^{5***}
Collaboration

M. Baubillier⁵, I.J. Bloodworth¹, A.J. Burns², J.N. Carney¹,
G.F. Cox¹, U. Dore²⁺, J.B. Kinson¹, K. Knudson², F. Lévy⁵,
P.J. Negus³, B.Y. Oh⁴, E. Quercigh², J.M. Scarr³,
G.A. Smith⁴, O. Villalobos Baillie¹, M.F. Votruba¹,
J. Whitmore⁴ and R. Zitoun⁵

1 Dept. of Physics, University of Birmingham, Birmingham, UK.

2 CERN, Geneva, Switzerland.

3 Dept. of Natural Philosophy, University of Glasgow, Glasgow, UK.

4 Michigan State University, East Lansing, Michigan, USA.

5 LPNHE, University of Paris VI, Paris, France.

(Submitted to Zeitschrift für Physik C)

* Work supported by the Science and Engineering Research Council, UK.

** Work supported in part by the National Science Foundation, USA.

*** Laboratory associated to IN2P3.

+ Now at the University of Rome.

ABSTRACT

The production of K^* resonances has been studied in the reaction $K^-p \rightarrow \bar{K}^0 \pi^- p$ at 8.25 GeV/c. The data comes from a high statistics bubble chamber experiment (180 events/ μ b).

Masses, widths and production cross-sections have been determined for the first three K^* 's. The contributions from natural and unnatural parity exchange have been obtained for the $K^*(890)$ and the $K^*(1420)$.

A partial wave analysis of the $K\pi$ system from threshold to 1.9 GeV provides evidence for a 0^+ enhancement near 1.4 GeV which could be interpreted as the $\kappa(1350)$.

1. INTRODUCTION

A study of the $K\pi$ system produced in 8.25 GeV/c K^-p interactions has been carried out using the CERN 2 m bubble chamber. The data correspond to a sensitivity of ~ 180 events/ μ barn. The investigation is based on a study of the reaction

$$K^-p \rightarrow \bar{K}^0 \pi^- p \quad . \quad (1)$$

This reaction has been previously studied over a large energy range [1-7] and has provided information concerning the $K^*(890)$, $K^*(1420)$, $K^*(1780)$, and $K^*(2100)$. In a previous paper we presented evidence for production of $K^*(2100)$ at 8.25 GeV [4]. In this paper we determine the cross-section for the first three K^* 's and we study the production mechanism of the $K^*(890)$ and the $K^*(1420)$. Evidence is also reported for a 0^+ enhancement around 1.4 GeV, a region which has been confused for some time [5].

The analysis of the effective mass spectrum and the differential cross-sections for the first three K^* 's are given in Section 2. In Section 3 the density matrix elements are calculated for the first two K^* 's, and Section 4 presents the results of a partial wave analysis of the $\bar{K}^0 \pi^-$ system between 0.7 and 1.95 GeV.

2. TOTAL CROSS-SECTION, EFFECTIVE MASS SPECTRUM, AND DIFFERENTIAL CROSS-SECTIONS

Events fitting the four-constraint reaction (1) with a probability greater than 2% have been selected (14760 events). After corrections for losses, cuts and unseen K^0 decays, the cross-section for reaction (1) has been calculated to be

$$\sigma = (270 \pm 22) \mu\text{b}$$

in good agreement with a previous experiment at the same momentum [6].

For our study of the $\bar{K}^0 \pi^-$ effective mass spectrum the $\Lambda^0 [M(p\pi^-) < 1.34 \text{ GeV}]$ has been removed reducing the sample to 12878 events. A further requirement of $t' < 0.4 \text{ GeV}^2$ reduces the background and leaves us with 9410 events. This sample shows signals at 0.89 GeV (Fig. 1), 1.42, 1.78, and 2.10 GeV (Fig. 2). We have fitted the $\bar{K}^0 \pi^-$ effective mass spectrum over the range 0.64–2.44 GeV using four relativistic Breit-Wigner functions and a fourth order polynomial background. The parameters of the $K^*(2100)$ have been fixed to the values given in Ref. [4]. We used the following Breit-Wigner formula:

$$BW^{\ell}(M) = \frac{M\Gamma(M)/q}{[M^2 - M_0^2]^2 + [M_0\Gamma(M)]^2}$$

in which

$$\Gamma(M) = \Gamma_0 \times \left(\frac{q}{q_0}\right)^{2\ell+1} \times \left(\frac{M_0}{M}\right),$$

and M_0 , Γ_0 , and ℓ are the mass, width and spin of the resonances, M is the effective mass of the $\bar{K}^0 \pi^-$ system and q_0 and q are the c.m. momenta corresponding to the masses M_0 and M , respectively. The results of the fit are shown in Figs. 1 and 2, and the resonance parameters and cross-sections are given in Table 1.

Figure 3 shows the $|t'|$ distributions without removal of the $\Lambda(1236)$, for the first three K^* 's (t is the four momentum transfer between the incident K^- and the outgoing $\bar{K}^0 \pi^-$ system and $t' = t_{\min} - t$). A small correction ($\sim 10\%$) has been applied to the first three points for the $K^*(890)$ to account for the loss of protons parallel to the camera axis. The differential cross-sections were obtained by fitting the mass spectra for each t bin.

3. NATURAL AND UNNATURAL PARITY EXCHANGE MECHANISMS

A calculation of the cross-section for these exchange mechanisms has been carried out for the $K^*(890)$ and $K^*(1420)$.

Two main samples have been defined according to the effective mass of the $K\pi$ system: (0.84–0.94 GeV) and (1.34–1.52 GeV). Background subtraction for the $K^*(1420)$ has been performed using the side bands of the resonance.

The density matrix elements of the K^* 's have been calculated in the Gottfried-Jackson system according to the relation:

$$\text{Re } \rho_{mm}^J = \sum_{\text{even } L} \frac{2L+1}{2J+1} \frac{\langle Jm'LM|Jm \rangle}{\langle J0L0|J0 \rangle} H(LM)$$

where

$$0 \leq L \leq 2J$$

$$-L \leq M \leq L$$

$$H(LM) = 1/N \sum_i D_{M0}^L(\Omega_i)$$

and N is the number of events.

If a resonance of pure spin J is produced by meson exchange from a pseudoscalar incident particle, the fractions σ_m^+ and σ_m^- of the boson state produced with helicity m by natural and unnatural parity exchange, respectively, are given by

$$2\sigma_m^\pm = \rho_{mm} \mp v(-1)^m \rho_{m-m}$$

where $v = +1$ if the produced boson has natural parity and $v = -1$ if it has unnatural parity. Consequently, the natural and unnatural parity contributions can be defined for each final helicity state by taking the combinations:

$$\left. \frac{d\sigma}{dt} \right|_u (m=0) = \rho_{00} \frac{d\sigma}{dt}$$

$$\left. \frac{d\sigma}{dt} \right|_n (m=1) = (\rho_{11} + \rho_{1-1}) \frac{d\sigma}{dt}$$

$$\left. \frac{d\sigma}{dt} \right|_u (m=1) = (\rho_{11} - \rho_{1-1}) \frac{d\sigma}{dt}$$

$$\left. \frac{d\sigma}{dt} \right|_n (m=2) = (\rho_{22} - \rho_{2-2}) \frac{d\sigma}{dt}$$

$$\left. \frac{d\sigma}{dt} \right|_u (m=2) = (\rho_{22} + \rho_{2-2}) \frac{d\sigma}{dt}$$

The partial differential cross-sections are shown in Figs. 4 and 6 while the density matrix elements are shown in Figs. 5, 7, and 8.

Our results are in good agreement with a recent paper based on a similar analysis, but with less statistics, at 6.5 GeV/c [5].

For the $K^*(1420)$, helicities $m = 0$, $m = 1$ give important contributions to the total cross-section whereas the contribution from $m = 2$ is consistent with zero. For both K^* 's, the natural parity contribution is mainly $m = 1$ and the unnatural parity contribution mainly $m = 0$. The natural parity contribution dominates that from unnatural parity. Their ratio however is smaller for the $K^*(1420)$ than for the $K^*(890)$ — see Table 2. This result is compatible with the expectations of a dual triple Regge exchange model [8].

4. PARTIAL WAVE ANALYSIS

A partial wave analysis of the $K\pi$ system has been carried out in the mass region (0.70–1.95) GeV. A selection of events with $t' < 0.8 \text{ GeV}^2$ has been made in order to discard events coming from other possible two-body reactions (e.g. $K^-p \rightarrow K^0 N^{*0}$). We assume as in previous analyses [1,5] that the contribution to the unnatural parity exchange mechanism is due only to pion exchange, i.e. the generalized density matrix elements satisfy:

$$\rho_{mm'}^{JJ'} + (-1)^{m'} \rho_{m-m'}^{JJ'} = 0$$

unless $m' = m = 0$. This is in agreement with our observation that $m \geq 1$ contributions to the unnatural parity exchange are consistent with zero.

The partial cross-section $\sigma(J_m^P \eta)$ for the production of a $K\pi$ system in the J_m^P state [$P = (-1)^J$] by an exchange of naturality η can be obtained from the relation:

$$\sigma(J_m^P \eta) = [\rho_{mm}^{JJ} - \eta(-1)^{|m|} \rho_{m-m}^{JJ}] \frac{d\sigma}{dM}.$$

The relations for the states $|1^-1^+\rangle$, $|2^+0^-\rangle$, $|2^+1^+\rangle$, $|2^+2^-\rangle$ can be easily obtained from the Sekulin formalism [9]. However, the cross-sections for the states $|0^+0^-\rangle$ and $|1^-0^-\rangle$ cannot be separated unambiguously and we can only compute the combinations

$$[\sigma(0^+0^-) + \sigma(1^-0^-)] \quad \text{and} \quad [\sigma(1^-0^-) + \sqrt{5} \rho_{00}^{20} \frac{d\sigma}{dM}] .$$

The results are displayed in Fig. 9.

As expected from Fig. 4, the $|1^-1^+\rangle$ wave is very important in the $K^*(890)$ region. The $|2^+1^+\rangle$ wave exhibits a clear signal at the $K^*(1420)$ position, whereas the $|2^+0^-\rangle$ and the $|2^+2^-\rangle$ waves do not show any significant signal.

The most interesting results come from examination of Figs. 9c and 9f. The sum of the cross-sections for the waves $|0^+0^-\rangle$ and $|1^-0^-\rangle$ (Fig. 9c) shows two clear enhancements. The first one, around 0.89 GeV can obviously be assigned to the $K^*(890)$; the second one peaks around 1.4 GeV, with a width of the order of 0.2 GeV and could be assigned to a $|0^+0^-\rangle$ state if, as might be expected, the $|1^-0^-\rangle$ contribution is negligible above 1 GeV.

Another indication for the existence of a $|0^+0^-\rangle$ state comes from Fig. 9f which presents the cross-section for the combination $[(1^-0^-) + \sqrt{5} \rho_{00}^{20} d\sigma/dM]$. The production of the $K^*(890)$ is shown clearly in our data by a sharp peak together with a second peak having a maximum at ~ 1.4 GeV. This peak could represent the constructive interference between the $|0^+0^-\rangle$ state mentioned above and the $K^*(1420)$. These observations therefore suggest the production of $\kappa(1350)$ in this reaction.

5. CONCLUSIONS

We have studied K^* production in the channel $K^-p \rightarrow \bar{K}^0 \pi^- p$ at 8.25 GeV/c, and we give measurements of the mass, width and cross-section for the first three K^* s. The production mechanism of the first two K^* s has been studied and a partial wave analysis has been performed.

Natural parity exchange largely dominates over unnatural parity exchange although this feature is more pronounced for the $K^*(1^-)$ than for the $K^*(2^+)$. The $m = 2$ amplitudes are negligible. These observations are all in agreement with similar studies at 6.5 GeV/c [5] and 50 GeV/c [2,3].

The partial wave analysis shows in addition to the $K^*(890)$ and $K^*(1420)$ a clear enhancement around 1.40 GeV with a width of 0.2 GeV which could be assigned to a $J^P = 0^+$ state and interpreted as the $\kappa(1350)$.

REFERENCES

- [1] M. Spiro et al., Phys. Lett. 60B, 389 (1976).
- [2] W.E. Cleland et al., Phys. Lett. 97B, 465 (1980).
- [3] W.E. Cleland et al., Nucl. Phys. B208, 189 (1982).
- [4] M. Baubillier et al., Phys. Lett. 118B, 447 (1982).
- [5] S. Toaff et al., Phys. Rev. D 23, 1500 (1981).
- [6] J.R. Fry et al., Nucl. Phys. B58, 408 (1973).
- [7] J.J. Engelen et al., Nucl. Phys. B167, 61 (1980).
- [8] P. Hoyer et al., Nucl. Phys. B56, 173 (1973).
- [9] R.L. Sekulin, Nucl. Phys. B56, 227 (1973).

Table 1

Fitted masses, widths, number of events, and cross-sections
for the $K^*(1^-)$, $K^*(2^+)$, $K^*(3^-)$

	Mass (MeV)	Width (MeV)	Fitted no. of events	Cross-section (μb)
K_1^{*-}	892.6 ± 0.5	49 ± 2	5840 ± 170	142 ± 12
K_2^{*+}	1420 ± 4	102 ± 10	1587 ± 80	37.2 ± 3.7
K_3^{*-}	1780 ± 9	99 ± 30	300 ± 45	8 ± 1.5

Table 2

Partial cross-sections due to natural and unnatural parity exchange
for the $K^*(890)$ and the $K^*(1420)$ decaying into $K^0\pi^-$

	σ_n (μb)	σ_u (μb)	σ_n/σ_u
$K^*(890)$	121 ± 20	21 ± 4	5.8 ± 0.8
$K^*(1420)$	24.5 ± 4	13 ± 2	1.8 ± 0.25

Figure captions

- Fig. 1 : Effective mass distribution of the $(K^0\pi^-)$ system. The solid line represents the fit described in the text.
- Fig. 2 : Same as Fig. 1, but for masses above 1.08 GeV.
- Fig. 3 : Differential cross-sections for the $K^*(890)$, $K^*(1420)$ and $K^*(1780)$.
- Fig. 4 : Natural (NAT) and unnatural (UN) parity cross-sections for $K^-p \rightarrow K^{*-}(890)p$.
- Fig. 5 : Density matrix elements of the $K^*(890)$ in the Gottfried-Jackson frame as a function of momentum transfer t' .
- Fig. 6 : Natural (NAT) and unnatural (UN) parity cross-sections for $K^-p \rightarrow K^{*-}(1420)p$.
- Fig. 7,8 : Density matrix elements of the $K^*(1420)$ in the Gottfried-Jackson frame as a function of momentum transfer t' .
- Fig. 9 : Partial wave cross-sections for $t' < 0.8 \text{ (GeV/c)}^2$ in the mass region $(0.7 < M(K^0\pi^-) < 1.95) \text{ GeV}$.
- a) $\sigma(1^-1^+)$.
 - b) $\sigma(2^+1^+)$.
 - c) $\sigma(0^+0^-) + \sigma(1^-0^-)$.
 - d) $\sigma(2^+0^-)$.
 - e) $\sigma(2^+2^-)$.
 - f) $\sigma(1^-0^-) + \sqrt{5} \rho_{00}^{20} d\sigma/dM$.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9