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A STUDY OF ISOSPIN 1 MESON STATES
USING 10 GeV/c K^-K^0 PRODUCTION DATA

A.D. Martin and E.N. Ozmütlu

University of Durham, Durham City, UK

R. Baldi, T. Böhringer, P.A. Dorsaz, V. Hungerbühler^{*)},

M.N. Kienzle-Focacci, M. Martin, A. Mermoud,

C. Nef and P. Siegrist

University of Geneva, Switzerland

ABSTRACT

We perform an amplitude analysis of 10 GeV/c $\pi^-p \rightarrow K^-K_S^0p$ data as a function of K^-K^0 mass from threshold up to 2 GeV. We find that the A_2 and g resonances are produced dominantly by natural and unnatural parity exchange, respectively, and we determine their resonance parameters. We present further evidence for the $I = 1, 4^+$ state $A_2^*(1900)$, in particular by isolating interference effects. The structure of S-wave K^-K^0 production suggests an $I = 1, 0^+$ state just below 1300 MeV of width about 250 MeV.

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^{*)} Present address: CERN, Geneva, Switzerland.

The high statistics data for the reaction $\pi^-p \rightarrow K^-K^0p$ allow a study of the meson spectrum that is more selective than that for K^+K^- production. The K^-K^0 channel has isospin 1 and is thus only accessible to even spin states of odd G-parity [such as the $\delta(0^+)$, $A_2(2^+)$] and to odd spin states of even G-parity [such as the $g(3^-)$]. The data that are available on $K^-K_S^0$ production therefore complement the information available^{*)} from the high statistics K^+K^- , $K_S^0K_S^0$, $\pi^+\pi^-$ and $\pi^0\pi^0$ production data.

The even and odd G-parity K^-K^0 states are produced by different exchange mechanisms. The allowed natural and unnatural parity exchanges (denoted by NPE and UPE) are shown in Table 1. From studies of the SU(3)-related reactions $KN \rightarrow (K\pi)N$ we expect isoscalar NPE (pomeron, f, and ω exchange) and isovector UPE to be dominant [3]. The possibility of pomeron exchange ($\mathbb{P}$) means that at high energies even L K^-K^0 states should be more copiously produced than those with odd L.

Here we analyse the 10 GeV/c $\pi^-p \rightarrow K^-K_S^0p$ data obtained using the University of Geneva two-arm spectrometer [4]. We use the moments $\text{Re} \langle Y_J^M \rangle$, of the K^- angular distribution in the t-channel K^-K^0 helicity frame in 50 MeV intervals over the mass range $1 < M(K^-K^0) < 2$ GeV, integrated over the t interval $0.07 < -t < 1$ (GeV/c)². Only the $J \leq 8$, $M \leq 2$ moments are found to be significantly different from zero^{**)}, and these are determined by the constrained linear fit described in the preceding letter [5]. The resulting mass spectra are shown in Fig. 1. These may be compared with the moments, shown in Ref. 5, obtained from the same data by a maximum likelihood method, but integrated over a somewhat smaller t interval.

The moments can be expressed [6] as the sum of bilinear products of amplitudes, $L_{\lambda\pm}$, describing, to leading order in the energy, the production of a K^-K^0 system of spin L, helicity λ by NPE and UPE, respectively. In terms of the helicity amplitudes $H_{L\lambda}$, we have $L_{\lambda\pm} \equiv [H_{L\lambda} \pm (-1)^{\lambda+1}H_{L,-\lambda}]/\sqrt{2}$ for $\lambda \neq 0$; and

*) Recent reviews are given, for example, by Petersen [1] and Cohen [2].

***) In the mass region of the A_2 resonance there is evidence for a small, but non-zero, $\langle Y_4^3 \rangle$ signal; we discuss the implication of this below.

$L_0 \equiv H_{L_0}$, that is only UPE for $\lambda = 0$. We will use the abbreviated notation $L_{\pm} \equiv L_{1\pm}$. A summation over helicity flip and non-flip at the nucleon vertex is implicit in each bilinear product, that is

$$|L|^2 = |L_f|^2 + |L_{nf}|^2.$$

The interference terms can be written in the form

$$\text{Re} (L'L^*) = |L'| \cdot |L| (\xi \cos \phi)_{L'L},$$

where ξ is the degree of nucleon spin coherence ($0 \leq \xi \leq 1$) and ϕ is the relative phase between amplitudes L and L' . We note that the observed moments do not contain interference terms between NPE and UPE amplitudes. That is, terms of the form $\text{Re} (L'_{\lambda+} L_{\lambda-}^*)$ do not occur.

The number of observed moments is insufficient to determine the magnitudes and phases of all the amplitudes $L_{\lambda\pm}$. Fortunately, for a given L , not all (t-channel) helicity components are important. The study of the t structure in the A_2 and g resonance regions [7] (as well as the amplitude structure in the SU(3)-related reactions [3] $K^{\pm}p \rightarrow (K\pi)^{\pm}p$) shows that the dominant NPE amplitudes are L_+ , and that UPE proceeds mainly via L_0 . This can also be inferred directly from the observed t-channel moments as a function of mass (Fig. 1); we see that the $\langle Y_J^{0,2} \rangle$ moments are, in general, larger than those with $M = 1$.

For other related meson production processes (such as $\pi^+\pi^-$ [8], $K^-\pi^+$ [9], K^+K^- [10], $K^0\pi^+$ [3], $\bar{K}^0\pi^-$ [3]), it is found that the t-channel moments with $M > 2$ are compatible with zero, indicating that the amplitudes with $\lambda \geq 2$ can be neglected. However, for $\pi^-p \rightarrow (K^-K^0)p$ in the A_2 mass region a definite signal is found [7] in the $\langle Y_4^3 \rangle$ t-channel moment. Owing to the dominance of D_+ in this mass region, this signal can be attributed to D_+D_{2+} interference. In fact an amplitude analysis [7] of A_2 production as a function of t shows that $|D_{2+}| \sim 0.1 |D_+|$, on an average over the relevant t range. We therefore conclude that the $L'_+L_{2+}^*$ interference terms will, in general, contribute to the $M = 1$ moments at least as strongly as the $L'_0L_-^*$ interference terms. The data are unable to determine both L_- and L_{2+} . However, these small amplitudes only contribute

quadratically to the $M = 0$ and 2 moments and so it should be reliable to use these moments to determine the more dominant L_0 and L_+ amplitudes.

For these reasons we use the $M = 0$ and 2 t -channel moments with $J \leq 8$ (Fig. 1) to determine the magnitudes and relative phases of the amplitudes in the NPE sector (P_+, D_+, F_+, G_+) and in the UPE sector (S_0, P_0, D_0, F_0, G_0) as a function of the produced K^-K^0 mass in the range $1 < M < 2$ GeV. For example, for each mass bin above 1.8 GeV, where amplitudes up to $L = 4$ are required, we use 16 moments to determine 9 amplitude magnitudes and 7 relative phases. In principle, this assumes that, within each sector, the amplitudes have a common coherence factor ξ . There is no certainty that this is correct. However, in practice, at a given mass, often only one interference term is important within each sector, and then the data give a reliable determination of the corresponding spin-phase coherence^{*)} $\xi \cos \phi$. For example, in the A_2 mass region the data determine $\xi \cos \phi$ for S_0D_0 and P_+D_+ interference.

Even then the amplitude determination is not unique. The data determine only $(\cos \phi)_{LL'}$, and not the relative phases $\phi_{LL'}$, and so there remain discrete ambiguities. At each K^-K^0 mass M we obtain all possible solutions by using a similar technique to that proposed by Gersten [11] and Barrelet [12]. We write the amplitudes, describing $\pi^-p \rightarrow K^-K^0p$ by UPE and NPE, in the form

$$A(\text{UPE}) = a(M) \prod_{i=1}^{\mathcal{L}} (z - z_i)$$

$$A(\text{NPE}) = a'(M) \sin \phi \sin \theta \prod_{i=1}^{\mathcal{L}-1} (z - z'_i),$$

with $z = \cos \theta$, where θ and ϕ are the angles specifying the direction of the K^- in the (t -channel) K^-K^0 rest frame. $\mathcal{L}$ is the maximum value of L included in the partial wave decomposition of $A(\text{UPE})$ and $A(\text{NPE})$ into the L_0 and L_+ amplitudes, respectively. The "Barrelet" zeros, $z_i(M)$ and $z'_i(M)$ are complex. The ambiguities arise because the data do not determine the signs of the $\text{Im } z_i$ or the $\text{Im } z'_i$.

*) The value represents the spin-phase coherence averaged over the t interval of the data, $0.07 < -t < 1$ (GeV/c)².

Thus there is a $2^{\mathcal{L}}$ -fold ambiguity within the UPE sector and a $2^{\mathcal{L}-1}$ -fold ambiguity with the NPE sector. From a given solution we generate the other solutions by first determining the z_i (z'_i) and then making substitutions $z_i \rightarrow z_i^*$ ($z'_i \rightarrow z'^{*}_i$) for the various combinations of the zeros.

We find that the amplitude G_0 , describing $L = 4$ K^-K^0 production by UPE, is compatible with zero. This can be anticipated by inspection of the $J = 8$, $M = 0, 2$ moments. In the results presented below we have therefore set $G_0 \equiv 0$. For K^-K^0 masses below 1.7 GeV we fix G_+ to be given by the tail of a spin 4 resonance and fit only moments with $J \leq 7$. For K^-K^0 masses below 1.5 GeV we fix the $L = 3$ amplitudes, F_0 and F_+ , to be given by the tail of the g resonance and fit only moments with $J \leq 5$. The resonance forms are normalized to fit the amplitude determinations in the higher mass bins.

We tabulate all the allowed solutions in each mass bin. In the majority of mass bins these solutions give an essentially exact description of the data. In all but the mass bin about 1.325 GeV (see the data fluctuations in Fig. 1) and those above 1.85 GeV the fits have an acceptable χ^2 . In Figs. 2 and 3 we present the solution that is selected at each mass by requiring

- i) the dominance of S_0 just above the K^-K^0 threshold,
 - ii) the continuity of $\text{Im } z_i$ and $\text{Im } z'_i$ as a function of the K^-K^0 mass,
 - iii) amplitude behaviour consistent with the presence of the A_2 and g resonances.
- Leading resonant waves are essentially unchanged in magnitude by Barrelet transformations and the third criterion is mainly helpful off resonance. The first two criteria eliminate an alternative solution with P_0 similar in magnitude and structure to that shown for S_0 below 1.4 GeV (see Fig. 3) and with S_0 smaller and structureless.

From the results, we see that the A_2 resonance is dominantly produced by NPE, whereas g resonance production proceeds mainly by UPE. This is consistent with the exchange expectations of Table 1. The curves shown through the A_2 and g amplitudes correspond to Breit-Wigner fits and lead to the resonance production cross-sections given in Table 2.

Above 1.8 GeV we see the emergence of $L = 4$ K^-K^0 production. Unfortunately, the data do not allow reliable partial-wave analysis above 2 GeV so as to establish a resonance shape for G_+ . However, support for resonance identification comes from the behaviour of the D_+G_+ interference contribution. This is the dominant interference term in this mass range and, moreover, both $L = 2$ and $L = 4$ K^-K^0 states have similar production mechanisms. The behaviour of $(\xi \cos \phi)_{D_+G_+}$ should therefore reproduce $\cos(\delta_2 - \delta_4)$, where δ_L are the $I = 1$ $K\bar{K}$ phases. Assuming δ_2 is given by the tail of the A_2 , we see that the behaviour of $\xi \cos \phi$, as a function of mass, gives further confirmation of the spin 4 resonance of mass $M \sim 1.9$ GeV reported in the preceding letter [5].

Another new and surprising feature of the results is the importance of S-wave K^-K^0 production in the A_2 mass region. The 0^{++} states are an outstanding problem in meson spectroscopy, and this result has crucial implications. It is true that lower partial waves are, in general, less constrained than leading waves, and moreover that S_0 is dominated by D_+ . However, another place where such structure should manifest itself is in K^+K^- and $K_S^0K_S^0$ production. There the problem is not the dominance of NPE, but the separation of $I = 0$ and $I = 1$ $K\bar{K}$ effects. We recall that the S-wave spectrum obtained from K^+K^- and $K_S^0K_S^0$ production data [10,13] do in fact show, besides the S^* threshold enhancement, a significant bump at 1.3 GeV. This has been attributed to an $\epsilon(1300)$ state in the $I = 0$ $\pi\pi \rightarrow K\bar{K}$ channel [2]. The present analysis suggests that the S-wave structure just below 1300 MeV should be attributed to the $I = 1$, and not the $I = 0$, $K\bar{K}$ channel.

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REFERENCES

- [1] J.L. Petersen, The $\pi\pi$ interaction, CERN 77-04 (1977).
- [2] D. Cohen, $K\bar{K}$ amplitude analyses, ANL-HEP-CP-77-37, to be published in Proc. 5th Experimental Meson Spectroscopy Conference, Boston, 1977.
- [3] R. Baldi et al., Phys. Letters 70B (1977) 377.
A.D. Martin et al., Amplitude and natural-parity-exchange analysis of $K^\pm p \rightarrow (K\pi)^\pm p$ data at 10 GeV/c, submitted to Nuclear Phys. B, October 1977.
P. Estabrooks et al., SLAC-PUB-2011, 1977.
- [4] R. Baldi et al., Systematic study of $K\pi$ production in the reaction $K^\pm p \rightarrow K_S^0 \pi^\pm p$: technique and measurements at 10 GeV/c, submitted to Nuclear Phys. B, October 1977.
- [5] R. Baldi et al., Observation of a spin 4, isospin 1, meson resonance, submitted to Phys. Letters B.
- [6] A.D. Martin and C. Michael, Nuclear Phys. B84 (1975) 83.
- [7] A.D. Martin et al., A study of A_2 and g resonance production in $\pi^- p \rightarrow K^- K^0 p$, to be submitted to Nuclear Phys. B.
- [8] G. Grayer et al., Nuclear Phys. B75 (1974) 189.
- [9] P. Estabrooks et al., Phys. Letters 60B (1976) 473.
- [10] A.J. Pawlicki et al., Phys. Rev. D 15 (1977) 3196.
- [11] A. Gersten, Nuclear Phys. B12 (1969) 537.
- [12] E. Barrelet, Nuovo Cimento 8A (1972) 331.
- [13] N.M. Cason et al., Phys. Rev. Letters 36 (1976) 1485.

Table 1

Allowed exchanges for
spin L K^-K^0 production

	L even	L odd
NPE	$\mathbb{P}, f, \rho$	ω, A_2
UPE	B, Z a)	π, A_1

a) Z is used to denote
the possible 2^{--} ex-
change trajectory.

Table 2

A_2 and g resonance parameters and cross-sections^{a)}

Quantity fitted		Mass interval fitted (GeV)	Mass (MeV)	Width (MeV)	σ b) (μb)
A_2	Mass spectrum	1.0-2.0	1316 ± 1	104 ± 2	5.00 ± 0.04
	$ D_+ ^2$	1.15-1.45	1318 ± 1	113 ± 4	4.62 ± 0.06
	$ D_0 ^2$				0.20 ± 0.06
g	Mass spectrum	1.0-2.0	1697 ± 4	177 ± 11	0.93 ± 0.06
	$ F_+ ^2$				0.08 ± 0.03
	$ F_0 ^2$	1.50-1.95	1698 ± 12	199 ± 40	0.51 ± 0.06

a) All errors are statistical only. The systematic error of the mass scale is 4 MeV (st. dev.) and the uncertainty of the cross-section normalization 8%. The interaction radius in the centrifugal barrier factor of the Breit-Wigner shape is taken to be $R = 3.5 \text{ GeV}^{-1}$.

b) σ is the production cross-section times the branching ratio for decay into K^0K^- , corrected for the unseen K^0 decays. The cross-section is calculated in the t interval $0.07 < -t < 1.0 \text{ (GeV/c)}^2$, and mass interval $1.2 < M < 1.4 \text{ GeV}$ and $1.55 < M < 1.85 \text{ GeV}$ for the A_2 and g, respectively.

Figure captions

- Fig. 1 : The mass spectra of the t-channel acceptance corrected moments for 10 GeV/c $\pi^- p \rightarrow K^- K^0 p$ data, after allowance for the observed $K^0 \rightarrow K_S^0 \rightarrow \pi^+ \pi^-$ decay. The data are integrated over the t interval $0.07 < -t < 1 \text{ (GeV/c)}^2$. The sensitivity of the data is 7671 corrected events per μb .
- Fig. 2 : The (t-channel) amplitudes describing $K^- K^0$ production by NPE obtained by analysing the moments of Fig. 1. Representative errors are shown. The curves through the $L \geq 2$ amplitudes correspond to the Breit-Wigner resonant fits of Table 2. Only the coherences between significant amplitudes are shown.
- Fig. 3 : The same as Fig. 2, but for UPE $K^- K^0$ production.

$N \langle Y_J^M \rangle$ [Events / 50 MeV]

Fig. 1 a)

Fig. 1 b)

Fig. 2

Fig. 3