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OBSERVATION OF A SPIN 4, ISOSPIN 1, MESON RESONANCE

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ABSTRACT

We present the observation of a $J^P = 4^+, I^G = 1^-$ state in the reaction $\pi^- p \rightarrow K_S^0 K^- p$ at 10 GeV/c measured with a non-magnetic spectrometer at the CERN Proton Synchrotron (PS).

A spherical harmonics moments analysis of the $K_S^0 K^-$ system shows a signal at ~ 1900 MeV in the $\langle Y_7^0 \rangle$ and $\langle Y_8^0 \rangle$ moments, indicative of a spin 4.

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The two-arm spectrometer of the University of Geneva was mainly designed for K^* studies in an unseparated hadron beam at 10 GeV/c at the CERN Proton Synchrotron (PS) [1]. Owing to its high data acquisition capability, this system simultaneously recorded π^- -induced reactions, among which we have identified 40,000 $\pi^-p \rightarrow K_S^0 K^- p$ events. In this paper we present results for the $K_S^0 K^-$ masses between 1.4 and 2.1 GeV. From the moment analysis we get evidence for a $J^P = 4^+$ state in the 1900 MeV mass region. This may be the $I = 1$ companion of the already-established $I = 0$ h-meson [2, 3] in the 4^+ octet.

The apparatus consisted of:

- a beam spectrometer to measure direction, momentum, and identity of the incident particle;
- a recoil proton arm to measure the proton direction by multiwire proportional chambers (MWPC) and its momentum by time of flight;
- a forward non-magnetic arm using MWPCs to determine the directions of the emitted particles with large solid angle acceptance.

We recorded 7.5×10^7 π induced triggers with at least three tracks in the forward spectrometer. This topological requirement was achieved by a hardware logic on the forward MWPC planes, requiring at least two tracks and less than five. The requirement of a reconstructed incident π track and a recoil p track reduced the set of events to about 3×10^7 .

Channel selection was then applied in two steps:

- i) a second vertex at least 30 mm downstream from the $p\pi$ vertex identifies the $K_S^0 \rightarrow \pi^+\pi^-$ candidates;
- ii) a 2C kinematical fit on twelve measured quantities (directions, incident pion and recoil proton momenta). The three unknown (moduli of the forward momenta) are determined by five equations (energy-momentum conservation at the production vertex and the K^0 mass).

The number of fitted events with $P(\chi^2) > 5\%$ was then about 40,000 in a momentum transfer range $0.07 \leq |t| \leq 1.0$ $(\text{GeV}/c)^2$ and $K_S^0 K^-$ effective mass $1.0 \leq M_{K_S^0 K^-} \leq 2.0$ GeV. A background of 4% was estimated by interpolation of the tails of the K^0 mass distribution under the K^0 mass peak and independently by inspection of the shape of the $P(\chi^2)$ distribution. An additional cut was made on the pK^- effective mass, requiring $M_{K^- p} > 1.9$ GeV to eliminate Y^* contributions and their kinematical reflections at high $K_S^0 K^-$ mass.

The Monte Carlo acceptance calculation took into account the geometry of the set-up, the various inefficiencies, the experimental resolutions of the detectors, and the absorption and decay of the incoming and outgoing particles. The same cuts and kinematical fit were applied to the simulated sample and to the data.

The $K_S^0 K^-$ decay mode selects states of the natural spin parity series, including the A_2 $J^P = 2^+$ and g $J^P = 3^-$ mesons. The raw data (histogram in Fig. 1) and the acceptance corrected data (cross points in Fig. 1) show clear A_2 and g signals in the $K_S^0 K^-$ effective mass spectrum in the t -interval $0.07 \leq |t| \leq 1.0$ $(\text{GeV}/c)^2$. The sensitivity is 7671 ± 300 corrected events per μb , corresponding to the reaction $\pi^- p \rightarrow K^0 K^- p$ corrected for $K^0 \rightarrow K_S^0 \rightarrow \pi^+ \pi^-$ and including all efficiency and acceptance correction factors (1 μb corresponds to 3383 measured events in the A_2 region).

We calculated the acceptance corrected spherical harmonic moments $N \text{Re} \langle Y_J^M \rangle$ of the angular distribution of the K^- in the t -channel helicity frame of the $K_S^0 K^-$ system (the Y_J^M normalization used is $\int |Y_J^M|^2 d\Omega = 4\pi$). It was found that the only moments significantly different from zero were those with $0 \leq J \leq 8$, $0 \leq M \leq 2$. These 24 corrected moments were obtained from the overdetermined linear system of 66 equations for the uncorrected moments with $0 \leq J \leq 10$, $0 \leq M \leq 10$ [1]. The $J = 7$ moments characteristic of interference between spin 3 and spin 4, and the $J = 8$ moments indicative of a spin 4 object have significant non-zero values in the mass region greater than 1.8 GeV. These $J \leq 8$, $M \leq 2$ moments have been analysed as a function of the produced $K_S^0 K^-$ mass, and the

resulting $K^0 K^-$ production amplitudes are presented in the following letter [4]. Here we fix our attention on the data in the high mass region.

As the accepted mass range depends on t , we removed events with $|t| \leq 0.15 \text{ (GeV/c)}^2$ in order to eliminate data with too small acceptance. We have then fitted the angular distribution from 1.4 to 2.125 GeV in 50 MeV bins integrated over the $|t|$ interval $0.15 - 1.0 \text{ (GeV/c)}^2$, by the extended maximum likelihood method [5] with a set of 24 unnormalized moments $N \langle Y_J^M \rangle$, $0 \leq J \leq 8$, $0 \leq M \leq 2$ as shown in Figs. 2a and 2b. Results were consistent with the previous fit. Non-zero $J = 7$, $M = 0$ (4 st.dev.) and $J = 8$, $M = 0$ (5 st.dev.) moments show evidence for a spin 4 wave with positive parity, isospin 1 and G parity = -1. A χ^2 fit of a Breit-Wigner form to the $\langle Y_8^0 \rangle$ moment gave a mass of $1903 \pm 10 \text{ MeV}$ and a width of $166 \pm 43 \text{ MeV}$ (statistical errors only). A plot of the uncorrected $\cos \theta$ in the t -channel helicity frame of the data in $1.8 \leq M_{K^0 K^-} \leq 2.0 \text{ GeV}$ is shown in Fig. 3 (histogram). Using the moments obtained from fits with and without $J = 7, 8$ terms, we generate Monte Carlo distributions shown as curves in Fig. 3. A statistical test comparing real to simulated distribution gives $\chi^2 = 99.4/39$ degrees of freedom for fits with $J_{\max} = 6$ and $\chi^2 = 48.9/39$ d.e.f. for $J_{\max} = 8$ (CL = 13%).

Neglecting contributions from waves with higher L , we can express the moments in terms of amplitudes:

$$\langle Y_{2L}^0 \rangle \sim C_1 |L_0|^2 - C_2 (|L_-|^2 + |L_+|^2) ,$$

$$\langle Y_{2L}^2 \rangle \sim C_3 (|L_-|^2 - |L_+|^2) ,$$

where L_0 is the spin L helicity zero amplitude produced by unnatural parity exchange (UPE) in the t -channel; $L_{\pm}$ are the spin L helicity 1 amplitudes produced by NPE(+) and UPE(-) [6]; C_1, C_2, C_3 are positive Clebsch-Gordan coefficients. The negative signs of the moments $\langle Y_8^0 \rangle, \langle Y_8^2 \rangle$ then indicate that this spin 4 state is mainly produced via NPE, and the suppression of UPE (mainly π exchange) is compatible with negative G parity. Conversely, in the g -meson region $\langle Y_6^0 \rangle$ is

small and positive as expected for a positive G-parity state produced by π exchange but highly suppressed owing to our high $|t|$ interval. An amplitude analysis on the data shows confirmation for this spin 4 state [4].

In conclusion, in a high statistics and low background sample we get evidence for a $I^G = 1^-, J^P = 4^+ K_S^0 K^-$ meson resonance at 1900 MeV with a width of about 200 MeV.

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Figure captions

Fig. 1 : $K_S^0 K^-$ effective mass spectrum, for $0.07 \leq |t| \leq 1.0 \text{ (GeV/c)}^2$. The spectrum is shown before (histogram) and after (points with error bars) acceptance correction. A constant factor of 5.8 due to the azimuthal aperture of the proton detector is not included in the correction.

Fig. 2a and 2b : The unnormalized, acceptance-corrected, moments $N \langle Y_J^M \rangle$ of the angular distribution of the K^- in the t-channel helicity frame, as a function of $M(K_S^0 K^-)$. The data are in the t-range $0.15 \leq |t| \leq 1.0 \text{ (GeV/c)}^2$.

Fig. 3 : $\cos \theta$ projection in the t-channel helicity frame of the K^- . The fits include moments $\text{Re} \langle Y_J^M \rangle$ with $0 \leq L \leq L_{\text{max}}$ and $M = 0, 1, 2$.

Fig. 1

Fig. 2 a)

Fig. 2 b)

Fig. 3