Investigation of resonance structure in the system of two $K_S$-mesons in the mass region around 1450 MeV

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Abstract. Results are presented that were obtained by studying the narrow resonance of mass about 1450 MeV. This state was discovered in the system of two $K_S$-mesons. The experimental data subjected to the analysis here come from the 6-m spectrometer (MIS ITEP) created at the Institute of Experimental and Theoretical Physics (ITEP, Moscow) and irradiated with a 40-GeV beam of negatively charged pions from the U-70 accelerator at the Institute for High Energy Physics (IHEP, Serpukhov) with the aim of studying $\pi^- p$ and $\pi^- C$ interactions. The statistical significance is better than six standard deviations. The mass and width of the observed meson are $M = 1449.5 \pm 2.0 \pm 3.0$ MeV and $\sigma = 7.5 \pm 1.5$ MeV, respectively, the product of the cross section for its formation and the relevant branching ratio $25^{+25}_{-5}(\text{stat.}) \pm 4(\text{syst.})$ nb. The spin-parity $J^{PC}$ is $0^{++}$ or $2^{++}$. Seeing its very narrow width this resonance is likely to be cryptoexotics (see [1],[2] for details).

1. Introduction
The experimental data employed in the present analysis were obtained by using the ITEP 6-m spectrometer. A detailed description of the spectrometer was given elsewhere [3]. The spectrometer records, with a high efficiency, $K_S$-mesons travelling in the forward direction and decaying to two charged pions. A large volume covered by a magnetic field and filled with detectors makes it possible to identify $K_S$-mesons reliably and to measure the effective mass of the $K_SK_S$-system in the region around 1450 MeV to a high precision. The data analyzed in the present study come from exposures where we employed liquid-hydrogen target. The $K_SK_S$-system recorded under experimental conditions of the 6-m spectrometer is produced in the following two reactions on a hydrogen target:

$$\pi^- p \rightarrow K_SK_S n,$$

$$\pi^- p \rightarrow K_SK_S + (n + m\pi^0, p + \pi^-, ...).$$

Reaction (1) is separated with a trigger facility based on veto counters surrounding the liquid-hydrogen target. Due to imperfect trigger operation, some fraction of events of the reaction (2) is recorded by the setup.

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The precision of the measurement of the effective mass of the $K_S K_S$-system is better than 3 MeV in mass region around 1450 MeV. The recording efficiency is about 45% for the system of the two $K_S$-mesons in the mass region around 1450 MeV. It depends on the $K_S$-meson momenta.

The effective mass $M_{KK}$ of a pair of two $K_S$-mesons, the missing mass squared $M M^2$, the 4-momentum transfer $-t$ from the beam to the system being studied, the cosine $\cos \theta_{GJ}$ of the Gottfried-Jackson angle, and the Treiman-Yang angle $\phi_{TY}$ are kinematical variables used in analyzing the $K_S K_S$ system. The angles are calculated in the rest frame of the $K_S$-meson pair, and the beam-axis direction in this reference frame is taken for the polar axis. The plane from which the Treiman-Yang angle is reckoned is spanned by the momenta of a beam particle and a target proton.

2. Resonance $X(1450)$

The Figure (1) shows the mass spectrum of the $K_S K_S$-system from 1380 to 1520 MeV with the bin width being 5 MeV. The resonance feature manifests itself as a maximum in the vicinity of 1450 MeV.

In comparison with our previous paper [4] now we observe resonance phenomena $X(1450)$ using the following experimental cut on transferred momentum ($0.0 < -t < 0.6$ GeV$^2$). In addition $X(1450)$ is produced in both reactions (1) and (2).

![Figure 1. Effective-mass spectrum of two $K_S$-mesons. The curve is the result of a fit by the maximum-likelihood method.](image)

In order to determine the parameters of the observed resonance feature and its statistical significance, the experimental data in the $K_S K_S$-mass range 1300-1600 MeV (about 500 events) were fitted by the Maximum-likelihood method. Describing the experimental data, we used the probability-density function $F(P; \Omega)$, where $P$ is the set of the parameters (the amplitude, the mass $M$, the width $\sigma$ appearing in the Gauss function and the coefficients of the squared amplitudes of the angular distributions). Elements of the phase space $\Omega$ are effective mass of two $K_S$-mesons, the cosine of the Gottfried-Jackson angle $\cos \theta_{GJ}$, the Treiman-Yang angle $\phi_{TY}$.

In order to obtain the most probable values of the parameters we minimized the functional:

$$L = \int_{\Omega} \epsilon(\Omega) F(P; \Omega) d\Omega - \sum_{i=1}^{N} \ln F(P; \Omega_i). \quad (3)$$

where $\epsilon(\Omega)$ is the event-detection recording, $N$ being the number of events and $L = \prod_{i=1}^{N} F(P; \Omega_i)$ $N$ being the number of events. To compare the probabilities of experimental-data description with different parameter set, we calculated $\chi^2$ by the formula:

$$\chi^2 = -2 \ln L + \text{const}. \quad (4)$$
A mass dependence in the form of a polynomial of second degree and the Gauss function were used here to describe the background and the resonance, respectively. The squares of the amplitudes of the $S$-, $D_0$- and $D_+$-waves proved to be sufficient for describing the angular distribution of the background. As the result of fitting of resonance, it was found that the $S$- and the $D_0$- waves both yielded a considerably lower $\chi^2$ value than each of the remaining waves. We have described the resonance by only $S$-wave or only $D_0$-wave. Since the $\chi^2$ values of these results of fitting are close, we cannot give preference to either the $S$- or the $D_0$-wave.

3. Comparison with other results

Comparison with other results is presented in Table 1. In the last line is given the result of present study.

| TECN  | Comment                | Mass, MeV | Width, MeV |
|-------|------------------------|-----------|------------|
| DM2   | $J/\psi \to \gamma \pi^+ \pi^-$ | 1421 ±5   | 30 ±9      |
| SPEC  | $pp \to pp\pi^+ \pi^-$ | 1480 ±50  | 150 ±50    |
| CNTR  | $17-18 \pi^- p \to K^+K^-n$ | 1436 ±26  | 81 ±56     |
| CNTR  | $63 \pi^- p \to K^0_SK^0_sn, K^+K^-n$ | 1412 ±3   | 14 ±6      |
| OSPK  | $5, 7, 12 \pi^- p \to K^0_SK^0_sn$ | 1439 ±5   | 43 ±17     |
| SPEC  | $40 \pi^- p \to K_SK_Sn$ | 1453.0 ±4 ±3 | 13.0 ±5.0 |
| SPEC  | $40 \pi^- p \to K_SK_Sn$ | 1449.5 ±2 ±3 | 7.5 ±1.5  |

4. Conclusion

Let us summarize results. Strong evidence of the existence of a narrow resonance in the $K_SK_S-$system has been obtained. The statistical significance is better than six standard deviations. The distinguishing feature of this resonance is the following— it has a very narrow width.

The parameters of the $X$ (1450) resonance are: mass $M = 1449.5 \pm 2.0 \pm 3.0$ MeV and width $\sigma = 7.5 \pm 1.5$ MeV. Number of events in the resonance region is 67 ± 10. The spin-parity of this resonance is $J^{PC} = 0^{++}$ or $2^{++}$. The product of the cross section for $X$(1450) formation and the relevant branching ratio $\sigma Br(K_SK_S)$ is estimated at about $25^{+25}_{-5}$(stat.) ± 4(syst.) nb.

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