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Observation of an isoscalar vector meson at $\simeq 1650\ \mathrm{MeV}/c^2$ in the $e^+e^- \to K\bar{K}\pi$ reaction

DM2 Collaboration

D. Bisello, G. Busetto, A. Castro, M. Nigro, L. Pescara, P. Sartori, L. Stanco

Dipartimento di Fisica dell'Università di Padova, e INFN, Sezione di Padova, I-35131 Padua, Italy

A. Antonelli, R. Baldini, M.E. Biagini, M. Schioppa

Laboratori Nazionali di Frascati dell'INFN, CP 13, I-00044 Frascati, Italy

J.E. Augustin, A. Calcaterra*, G. Cosme, F. Couchot, F. Fulda, G. Grosdidier, B. Jean-Marie, V. Lepeltier, F. Mane, G. Szklarz

Laboratoire de l'Accélérateur Linéaire, Université de Paris-Sud, F-91405 Orsay, France

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Abstract. The $e^+e^- \to K_s^0 K^\pm \pi^\mp$ and $K^+K^-\pi^0$ cross sections have been measured in the energy interval $1350 \leqq \sqrt{s} \leqq 2400$ MeV with the DM2 detector at DCI. The $K_s^0 K^\pm \pi^\mp$ cross section shows the contribution of an isoscalar vector meson at $\approx 1650\ \mathrm{MeV}/c^2$ in agreement with a previous experiment. The low statistics $K^+K^-\pi^0$ measurement is consistent with the above result.

Introduction

The important multihadron production observed above the ϕ in e^+e^- experiments is usually interpreted as the contribution of the recurrencies of the ρ, ω, ϕ mesons. Candidates for such new vector mesons have been found but their parameters and/or nature are still controversial.

In the isoscalar sector, a reported state is the ϕ (1680) found by the DM1 experiment [1] in the $K\bar{K}$, $\omega\pi^+\pi^-$ and $K_s^0 K^\pm \pi^\mp$ channels, but still not considered a well established resonance. In fact, photoproduction experiments have given a preferred ω' assignment for the state around 1670 MeV, and suggested the existence of a ϕ' at slightly higher masses [2]. On the other hand in a previous paper [3] DM2 confirmed that the charged kaon form factor is best fit if the ϕ (1680) contribution is assumed.

In this paper we present an improved measurement of the reaction $e^+e^- \to K_s^0 K^\pm \pi^\mp$ and the first measurement of the $e^+e^- \to K^+K^-\pi^0$ channel in the energy range $1350 \leqq \sqrt{s} \leqq 2400$ MeV. Data have been collected with the DM2 detector at the Orsay e^+e^- colliding beam facility DCI.

*Present address: Laboratori Nazionali di Frascati dell'INFN, CP 13, I-00044 Frascati, Italy

Detector and luminosity

The DM2 detector [4] is a large solid angle spectrometer. A 0.5 T field is produced by a solenoid 2 m in diameter and 3 m long. Inside the magnet, proportional and drift chambers measure track momenta over $87\% \times 4\pi$ sr with a resolution of 3.5% at 1 GeV/c. A system of 36 two cm thick scintillators covering 80% of the solid angle measures the time of flight with a total resolution $\sigma = 540$ ps and permits a 3σ π/K separation up to 420 MeV/c. The photon detector barrel ($6X_0$), divided into octants, is located outside the coil. It consists of planes of delay streamer tubes interleaved with lead and scintillators whose segmentation allows a separation between showering particles (γ, e) and muons and hadrons. It covers $70\% \times 4\pi$ sr and is fully efficient ($>96\%$) for $E_\gamma \geqq 100$ MeV. The resolution on the photon direction is 10 mrad in azimuth and 7 mrad in polar angle. The tracking capability and the TOF measurements permit identification of most of the fake photons thus reducing the amount of background events.

The total luminosity integrated by DM2 in the $1.35 \div 2.4$ GeV energy range amounts to $(1927 \pm 116)\ \mathrm{nb}^{-1}$. This value has been calculated from large angle Bhabha events. TOF measurements are practical for $\simeq 85\%$ of the whole luminosity.

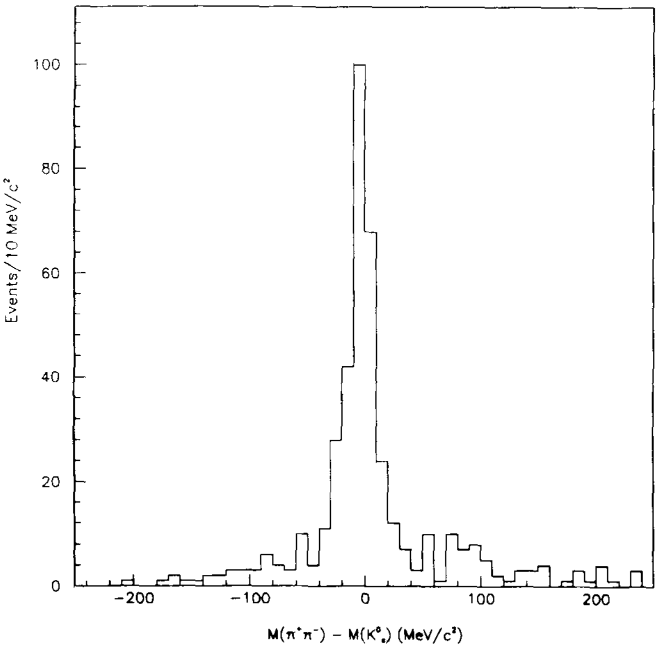

Fig. 1. Best K_s^0 invariant mass

$K_s^0 K^{\pm} \pi^{\mp}$ events selection

Candidates for the reaction $e^+e^- \to K_s^0 K^{\pm} \pi^{\mp}$ have been looked for among the four-prong events with zero total charge having, at least, two tracks belonging to a common vertex inside the fiducial volume (5 mm in the radial coordinate and ± 300 mm in the along-the-beam coordinate).

The K_s^0 decaying into $\pi^+\pi^-$ is selected either by demanding a secondary vertex with the appropriate mass or, if no secondary vertex is found, requiring two prongs with a K_s^0 invariant mass within 50 MeV/c^2 (Fig. 1).

A first kinematical separation of $K_s^0 K^{\pm} \pi^{\mp}$ events from the background is performed by a cut on missing momentum ($p_{\rm miss} \leqq 10\%\ p_{\rm beam}$) and on total energy: one of the two possible energies must be equal to $\sqrt{s}$ within 5%.

The background is small and is further reduced by discarding those events which are best fit to the 4π or $K^+K^-\pi^+\pi^-$ hypotheses (50 and 17 events respectively).

The final $K_s^0 K^{\pm} \pi^{\mp}$ sample amounts to 367 events. The residual contamination due to the 4π channel has been estimated at $\leqq 7$ events, all above 1.8 GeV, while that from $K^+K^-\pi^+\pi^-$ and 5π events has been found to be negligible. TOF measurements have not been used because of the very low background. Moreover they do not produce a significant improvement on the track signature performed by the kinematical fit.

$K^+K^-\pi^0$ events selection

The $K^+K^-\pi^0$ candidates have been selected among the two-prong events with zero total charge and at least two photons. The kinematical separation from other two-body decays is provided both by a $K^+K^-\pi^0$ $3C$ kinematical fit ($\chi^2 \leqq 20$), and by TOF information (at least one prong with measured TOF compatible with a kaon assignment within 2.5σ). For the events with more than two photons the pair which best satisfies the kinematical fit is choosen.

A final sample of 35 $K^+K^-\pi^0$ events has been found with negligible background.

Cross sections

Efficiencies for the two channels have been calculated by Monte Carlo simulations, applying radiative corrections for bremsstrahlung and soft and virtual photon emission. In the case $K_s^0 K^{\pm} \pi^{\mp}$ an isoscalar $K^*(892)K$ dynamics has been used as indicated by the Dalitz plot analysis. The efficiency linearly increases from 13.5% at $\sqrt{s} = 1400$ MeV to 15.5% at $\sqrt{s} = 1550$ MeV and stays almost constant above this energy. A maximum relative difference of about 5% is found with respect to different dynamics.*

In the $K^+K^-\pi^0$ case the efficiency increases slowly from 4% at $\sqrt{s} = 1400$ MeV to 7.5% at $\sqrt{s} = 2200$ MeV.

Figures 2 and 3 show the obtained $e^+e^- \to K_s^0 K^{\pm} \pi^{\mp}$ and $K^+K^-\pi^0$ cross sections. Systematic errors due to luminosity or radiative correction uncertainties are negligible compared to the statistical ones.

The $K_s^0 K^{\pm} \pi^{\mp}$ cross section shows an enhancement around 1650 MeV which cannot be reproduced by the VDM $\rho\omega\phi$ tail contributions**. The $K^+K^-\pi^0$ cross section is considerably suppressed with regard to that of $K_s^0 K^{\pm} \pi^{\mp}$.

* The choice of this particular dynamics and the different considered hypotheses are discussed in the Sect. below

** The ρ, ω, ϕ tail contribution has been calculated under the assumption of $K^{*0}(892)$ dominance. The values of $g_{\rho KK^*}$, $g_{\omega KK^*}$, and $g_{\phi KK^*}$ are inferred from [1]

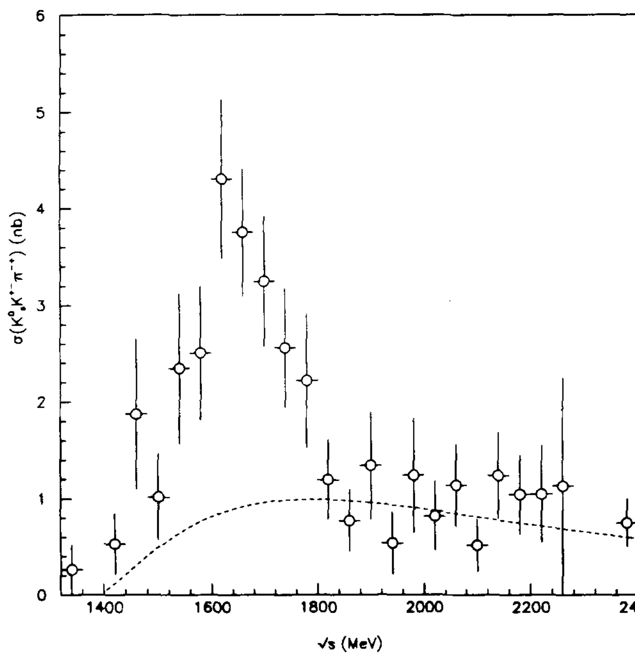

Fig. 2. $K_s^0 K^{\pm} \pi^{\mp}$ cross section. The dashed line shows the ρ, ω, ϕ tail contribution

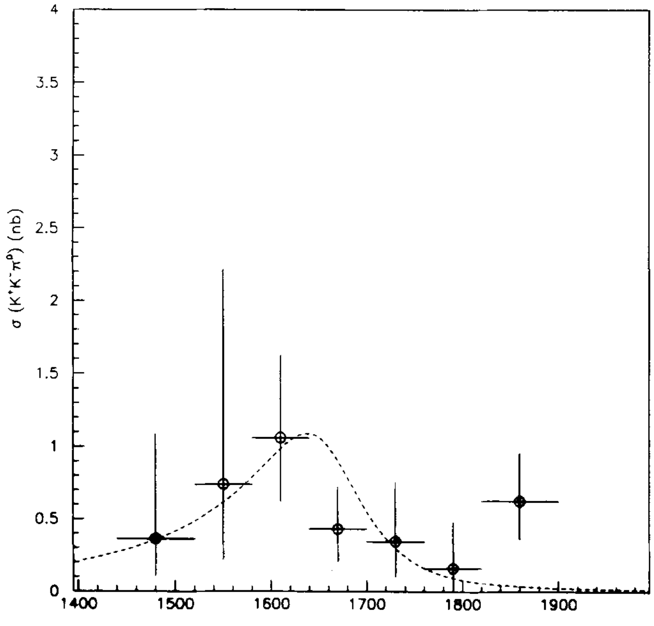

Fig. 3. $K^+K^-\pi^0$ cross section. The dashed line shows the expected behaviour.

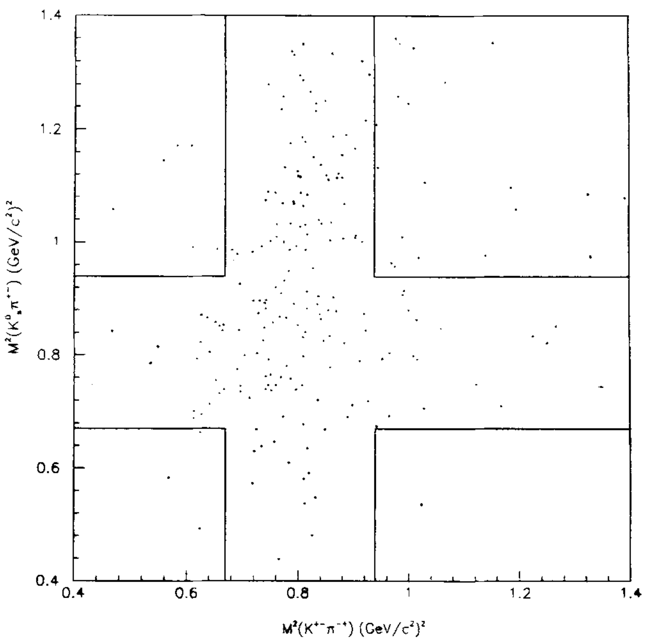

Fig. 4. Dalitz plot of $K_s^0 K^\pm \pi^\mp$ events for $1500 \leq \sqrt{s} \leq 1850$ MeV. The lines evidentiate the $0.67 \div 0.94\ (\mathrm{GeV/c^2})^2$ regions

Interpretation

The $K_s^0 K^\pm \pi^\mp$ Dalitz plot (Fig. 4) shows a clear $K^*(892)K$ dynamics with $K^{*0}(892)$ dominance*. This effect indicates an interference between isovector (ρ-like) and isoscalar (ϕ-like) amplitudes. In fact, assuming the $SU(3)$ relations for the coupling constants:

$$g_{\rho K^{*\pm} K^\mp}/g_{\rho K^{*0} K^0}/g_{\phi K^{*\pm} K^\mp}/g_{\phi K^{*0} K^0} = +1/-1/-\sqrt{2}/-\sqrt{2},$$

the $K^{*0}(892)K^0$ dominance is directly obtained from the constructive interference between the ρ-like meson and the ϕ-like one.

Isoscalar and isovector events populate the Dalitz plot in a different way providing an algorithm to disentangle the isoscalar $|A_0|$ from the isovector $|A_1|$ amplitude and evaluate the relative phase $\Delta\phi$.

The Dalitz plot has been divided into 9 adequate areas [5] where the population has been written as:

$$N = C_1|A_0|^2 + C_2|A_1|^2 + |A_0A_1|(C_3\cos\Delta\phi + C_4\sin\Delta\phi),$$

where C_1, C_2, C_3 and C_4 are normalisation and efficiency coefficients depending only on the particular area of the Dalitz plot where the population is calculated. These coefficients have been estimated using 4 different Monte Carlo simulations (pure isoscalar, pure isovector, $A_0 = A_1$ with $\Delta\phi = 0$, and $A_0 = A_1$ with $\Delta\phi = \pi/2$) at several center-of-mass energies. Then, $|A_0|^2$, $|A_1|^2$, $X = |A_0A_1|\cos\Delta\phi$ and $Y = |A_0A_1|\sin\Delta\phi$ have been determined as independent parameters by a linear least-squares method.

The results obtained show (Fig. 5) a resonant behaviour for the isoscalar cross section. A fit to a single Breit Wigner function provides the following parameters:

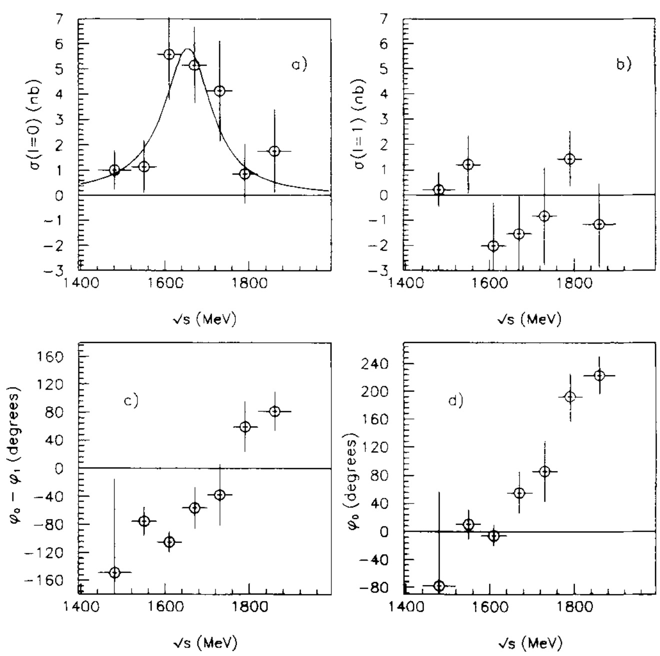

Fig. 5a–d. $K_s^0 K^\pm \pi^\mp$ isoscalar **a** and isovector **b** cross sections, and the difference between isoscalar and isovector phase **c** and the absolute isoscalar phase **d**. The overplotted curve in **a** refers to the fit described in the text

* No evidence of $K^*(892)K$ dynamics is observed in the $K^+K^-\pi^0$ channel which can proceed only through $K^{*\pm}(892)K^\mp$

$m = (1657 \pm 27)\ \mathrm{MeV/c^2}$,

$\Gamma = (146 \pm 55)\ \mathrm{MeV/c^2}$,

$\Gamma_{ee} B = (0.48 \pm 0.14)\ \mathrm{keV/c^2}$.

Γ_{ee} represents the electronic width and B the branching ratio into $K^*(892)K$ including all charge modes. These values are in close agreement with those obtained by DM1 [6] in the same channel and by both experiments on the $e^+e^- \to K^+K^-$ reaction [3, 7].

On the contrary the isovector cross section is largely suppressed, and no behaviour can be inferred from it. In particular we cannot disentangle the contributions of the ρ' (1450) and ρ' (1700) [2] which are expected to contribute to this cross section along with the ρ-tail. Moreover no estimate can be made of the isovector phase and thus the absolute isoscalar phase has been calculated by assuming the ρ' [8] ($m = 1.57, \Gamma = 0.51\ \mathrm{GeV/c^2}$) to be the isovector one. In this hypothesis the isoscalar phase crosses 90^0 at $\simeq 1700$ MeV.

Finally, $SU(3)$ relations for the coupling constants imply a destructive interference between ρ-like and ϕ-like resonances for the $K^+K^-\pi^0$ channel. The measured cross section is well compatible with the one expected (Fig. 3). We still assumed a single ρ' with the above parameters [8] to be the isovector amplitude. We note that this hypothesis is equivalent to assuming that the isovector $K_s^0 K^\pm \pi^\mp$ cross section has a behaviour compatible with the $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ one.

Conclusions

The $e^+e^- \to K_s^0 K^\pm \pi^\mp$ and $K^+K^-\pi^0$ cross sections have been measured in the energy interval $1350 \leqq \sqrt{s} \leqq 2400$ MeV from a final sample of 367 and 35 events respectively.

The $K_s^0 K^\pm \pi^\mp$ cross section shows a peak at $\sqrt{s} \simeq 1650$ MeV with a dominant $K^{*0}(892)K^0$ dynamics. This result is interpreted as the interference between a resonant isoscalar amplitude with $m = (1657 \pm 27)$, $\Gamma = (146 \pm 55)\ \mathrm{MeV/c^2}$ and a largely depressed isovector one. The low statistics $K^+K^-\pi^0$ measurement is consistent with this interpretation. Under reasonable hypotheses for the isovector phase the isoscalar one is found to cross 90^0 in the same mass range so supporting a resonant nature of the observed signal.

The above results and the important $K^*(892)K$ production are in close agreement with measurements made in the DM1 experiment which have supported the identification of the observed isoscalar vector meson with the ϕ (1680) resonance.

Nevertheless a firm attribution of this new vector meson requires a comparison with the results of the isoscalar $e^+e^- \to \pi^+\pi^-\pi^0$ and $\pi^+\pi^-\pi^+\pi^-\pi^0$ processes whose analyses are in progress.

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