STUDY OF $e^+e^- \to K^0_S K^\pm \pi^\mp$ IN THE 1.4–2.18 GeV ENERGY RANGE: A NEW OBSERVATION OF AN ISOSCALAR VECTOR MESON: ϕ' (1.65 GeV)

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First measurements of the $e^+e^- \to K^0_S K^\pm \pi^\mp$ reaction in the 1.4–2.18 GeV energy range have been performed with the magnetic detector DM1 at the Orsay storage rings DCI. The cross section is rather large. The production is mainly $K^{*0}K^0$ which reveals an interference between isovector and isoscalar amplitudes. These results show again the existence of an isoscalar vector at 1.65 GeV shown to be a ϕ' meson.

1. Introduction. The quark model predicts the existence of vector meson recurrences due to radial and orbital excitations and in the case of heavy quarks, a number of such states, recurrences of the ψ and of the Υ, have been observed. In the case of light quarks, up to now the only well-established excited state was the ρ' (1.6 GeV). The study of the $e^+e^- \to K\bar{K}\pi$ reaction is a way of looking for excited states of the strangonium ($s\bar{s}$), even if smaller contributions may come from other states like the ρ'.

We have performed the first measurement of the $K^0_S K^\pm \pi^\mp$ cross section between 1.4 and 2.18 GeV, which is part of the results [1–3] obtained with the magnetic detector DM1 at the Orsay storage rings DCI. The apparatus has been described in detail elsewhere [4]. Briefly, it consists of four cylindrical MWPC inside a solenoidal magnet (1.8 m diameter, 1.2 m long and 0.82 T magnetic field) detecting charged particles over a $0.6 \times 4\pi$ sr solid angle. The momentum resolution is proportional to momentum and $\sigma(p)/p = 2.5\%$ at 500 MeV/c. The total analysed luminosity amounts to about 1500 nb^{-1} and its measurement has been reported previously [5].

2. Selection of $K^0_S K^\pm \pi^\mp$ events (250 events). Event selection proceeds only through kinematic analysis as the experimental set-up provides no particle identification.

$K^0_S K^\pm \pi^\mp$ events are selected among three-track and four-track events with a K^0_S candidate, detected by its decay into $\pi^+\pi^-$. We call K^0_S candidate a pair of tracks of opposite charges, having at least three hits in the four MWPC and satisfying the same cuts as in ref. [2] on the opening angle, reconstructed momentum direction (depending on the flight distance) and invariant mass (fig. 1).

Four-track events with a K^0_S candidate should satisfy the following cuts:
– Missing momentum less than 9% of beam energy.
– One of the two possible total energies, assuming the two other tracks to be one a pion and the other a kaon, equal to the c.m. energy within ±2.5%. No flight distance is needed for the K^0_S candidate, as the background is negligible.

When only three tracks are detected, one of the two energies calculated as previously described, assigning the missing momentum to the missing particle, has to be equal to the c.m. energy within ±3%. In order to eliminate residual contamination, we require a 6 mm flight distance, projected on the plane transverse to the beam line.

The total reconstructed energy spectrum is shown in fig. 2.

The contamination by $\pi^+\pi^-\pi^+\pi^-$ events, either in the low-energy region where the production is abun-

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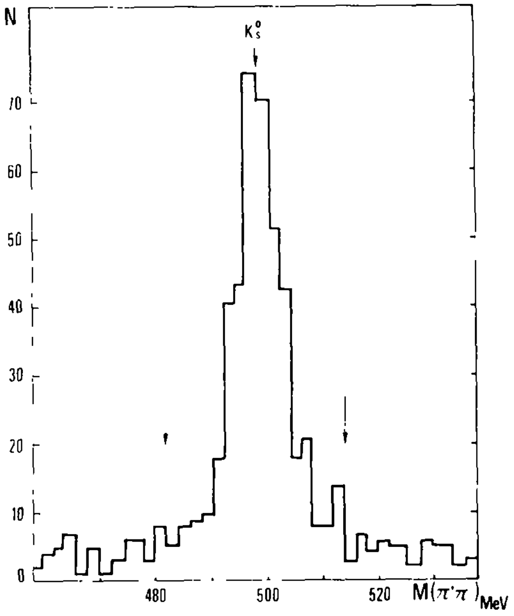

Fig. 1. Invariant mass $M(\pi^+\pi^-)$ distribution of two-track combinations among two-, three- and four-track events with a vertex-beam distance larger than 6 mm ($1.6 < \sqrt{s} < 1.7$ GeV). The arrows show the limits of the accepted mass values.

dant, or in the high-energy region where the energy resolution is worse, has been estimated from Monte Carlo simulation and found negligible ($\lesssim 2\%$). Other hadronic channels e.g. $\pi^+\pi^-\pi^+\pi^-\pi^0$, $K^+K^-\pi^+\pi^-$ have been studied and shown to give a low contamination. Contaminations from these annihilation channels as well as from beam–gas interaction can be globally evaluated from side bins in the K_S^0 invariant mass distribution and the results confirm estimates from Monte Carlo studies ($\lesssim 3\%$). Contamination from $K_S^0K\pi\pi$ events for three-track events is evaluated from those events which have a total energy less than 0.97 times the c.m. energy. The fraction of events in this channel satisfying the total energy cut is determined by Monte Carlo simulation. This contamination is negligible below 1800 MeV and lower than 10% above 1800 MeV.

3. Cross sections. Efficiencies (about 5.8% at 1.4 GeV to 8% at 2.18 GeV) were calculated by Monte Carlo simulation, taking account of the dynamics as determined by the Dalitz plot analysis (see section 4). Relative differences between different dynamics are about 10% at lower energies and at most 20% at 2150 MeV. As we have taken into account the Dalitz plot analysis, systematic errors related to dynamics are negligible.

The following radiative corrections have been applied to the cross sections:

(i) A correction of bremsstrahlung type calculated by Monte Carlo program, taking into account the apparatus acceptance and the selection cuts (about +15%).

(ii) A correction for soft and virtual photons and vacuum polarisation (−8%).

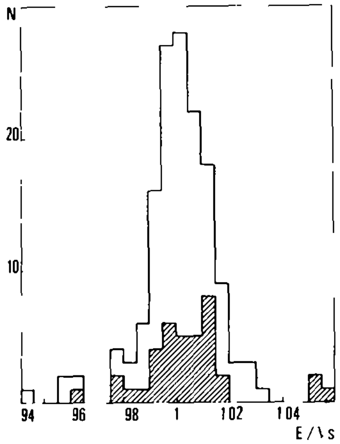

Fig. 2. Total reconstructed energy spectrum (solution closer to $\sqrt{s}$) for $K_S^0K^{\pm}\pi^{\mp}$ selected events (hatched area, four-track events).

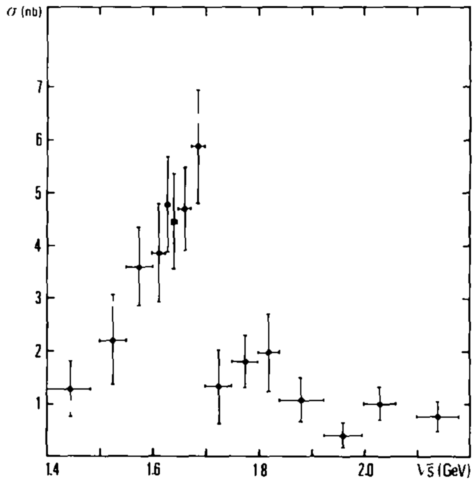

Fig. 3. $e^+e^- \to K_S^0K^{\pm}\pi^{\mp}$ cross section.

Table 1
$e^+e^- \to K_S^0K^\pm\pi^\mp$ cross section.

Energy range (MeV)	Cross section (nb)
1400–1483	1.27 ± 0.52
1500–1549	2.21 ± 0.84
1550–1599	3.61 ± 0.74
1600–1624	3.86 ± 0.94
1625–1634	4.77 ± 0.90
1635–1649	4.19 ± 0.62
1650–1674	4.69 ± 0.78
1675–1699	5.87 ± 1.07
1700–1749	1.34 ± 0.67
1750–1799	1.81 ± 0.50
1800–1839	1.97 ± 0.74
1840–1924	1.08 ± 0.44
1925–1998	0.40 ± 0 23
2002–2060	1.01 ± 0.32
2105–2175	0.76 ± 0.29

Systematic errors (luminosity, radiative corrections) are negligible compared to statistical ones.

Fig. 3 and table 1 show the obtained $e^+e^- \to K_S^0K^\pm\pi^\mp$ cross section. It shows a rapid rise above threshold followed by a steep decrease around 1.7 GeV. The total $K\bar{K}\pi$ cross section for all charge modes is about three times the measured one, depending on the dynamics. It means a cross section of about 15 nb around 1650 MeV, which is about a quarter of the total hadronic cross section. This suggests the presence of an $s\bar{s}$ state.

4. Dalitz plot analysis. The Dalitz plot exhibits a clear signal of K^*K production (fig. 4). In fact, our results are compatible with a pure K^*K production mechanism. Moreover, the K^{*0} production looks dominant above 1625 MeV compared to $K^{*\pm}$ production.

This reveals an interference between isovector and isoscalar amplitudes. If we assume these amplitudes to be due to vector mesons of the same nonet, the SU(3) relations between coupling constants:

$$g_{\rho'K^-K^{*+}}/g_{\rho'K^0K^{*0}}/g_{\omega'\bar{K}^0K^{*0}}/g_{\phi'\bar{K}^0K^{*0}}$$

$$= +1/-1/+1/-\sqrt{2}$$

imply for $K^{*0}K^0$ a constructive interference between ρ' and ϕ' and a destructive interference between ρ'

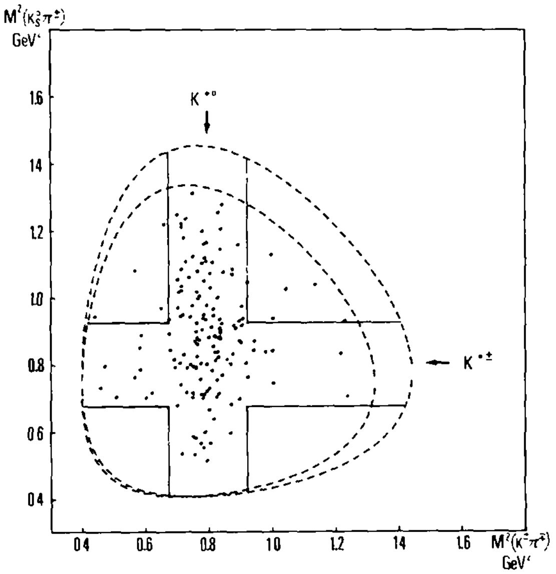

Fig. 4. $K\bar{K}\pi$ Dalitz-plot for $1.6 < \sqrt{s} < 1.7$ GeV. Dashed lines are the phase space limits for the two extreme energies. Full lines correspond to $M_{K^*}^2 \pm 3\,\Gamma M_{K^*}$.

and ω'. As the K^{*0} production is dominant, this isoscalar amplitude must be of the ϕ' type.

From the study of the Dalitz plot, one can derive the isoscalar amplitude $|A_0|$, the isovector amplitude $|A_1|$ and their relative phase $\Delta\phi = \phi_0 - \phi_1$. The population in the Dalitz plot can be 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 coefficients depending only on the area of the Dalitz plot where N is calculated and taking into account detection efficiencies, particle misidentification and integration on this area.

The coefficients C_1, C_2, C_3 and C_4 were determined from four different Monte Carlo generated types of events: pure isoscalar, pure isovector, $K_S^0K^{*0}$ ($A_0 = A_1, \Delta\phi = 0$) and $A_0 = A_1$ with $\Delta\phi = \pi/2$. We considered $|A_0|^2, |A_1|^2, X = |A_0A_1|\cos\Delta\phi$ and $Y = |A_0A_1|\sin\Delta\phi$ as independent parameters, which are determined by a linear least-square method (the constraint between these four parameters has been found, by Monte Carlo simulation, to lead to a biased estimate). The relative phase was calculated as $\Delta\phi = \tan^{-1}(Y/X)$. The results obtained for $|A_0|^2$, $|A_1|^2$

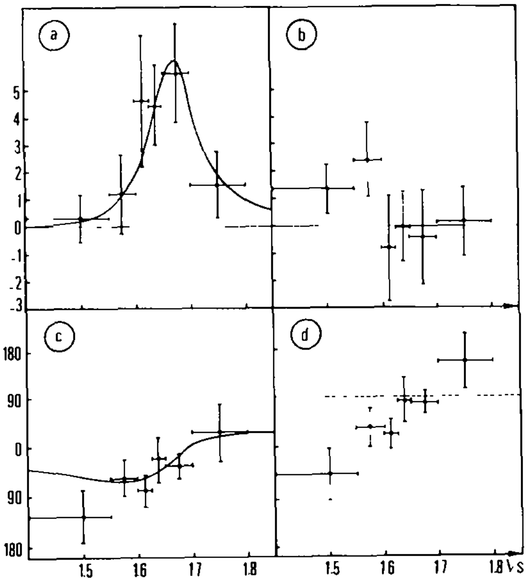

Fig. 5. (a) Isoscalar cross section in nb. (b) Isovector cross section in nb. (c) Relative phase between isovector and isoscalar amplitudes $\Delta\phi = \phi_0 - \phi_1$ in degrees. (d) Absolute phase of the isoscalar amplitude (the ρ'(1.57 GeV) is assumed to be the isovector one). Full lines: fit of $|A_0|^2$ and $\Delta\phi$ by the $\rho'\phi'$ model.

and $\Delta\phi$ as well as for the absolute phase of the isoscalar amplitude, assuming the ρ' (M = 1.57, Γ = 0.51 GeV) to be the isovector one, are shown in fig. 5. The isoscalar amplitude shows an enhancement and simultaneously a fast variation of the absolute phase crossing 90° around 1.65 GeV.

5. Interpretation of results. First of all, we can compare our results with what can be calculated for the $\rho\omega\phi$ tail. The coupling constants $g_{\rho KK^*}$, $g_{\omega KK^*}$, $g_{\phi KK^*}$ and $g_{\omega\rho\pi}$ are assumed to be related by SU(3) symmetry and $g_{\omega\rho\pi}$ is evaluated either from $\omega \to \rho\pi$ or from $\omega \to \pi^0\gamma$ [6]. The $\rho\omega\phi$ tail does not reproduce the experimental values of $|A_0|^2$ and $\Delta\phi$ (χ^2/dof = 47/12). Adding a contribution from the ρ' does not improve the fit (χ^2/dof: 46/11). Another contribution is needed to explain our data: a new isoscalar amplitude of the ϕ' type is needed.

If we fit $|A_0|^2$ alone with an isoscalar resonant amplitude, we obtain the following parameters: $M_{\phi'}$ = 1.653 ± 0.018 GeV, $\Gamma_{\phi'}$ = 113 ± 55 MeV and $\Gamma_{ee}B$ = 0.40 ± 0.14 keV with χ^2/dof = 0.6/3 (Γ_{ee} is the electronic width, B the branching ratio into KK^* including all charge modes). The relative phase can also be fitted alone, assuming the isovector amplitude dominated by the ρ', with a mass (1.57 GeV) and a width (0.51 GeV) determined by the $\pi^+\pi^-\pi^+\pi^-$ channel [7]. Then we obtain $M_{\phi'}$ = 1.693 ± 0.025 GeV, $\Gamma_{\phi'}$ = 61 ± 65 MeV and χ^2/dof = 4.6/4. If we assume that the ρ' width is only 300 MeV [8], these results do not vary significantly.

The best determination is obtained from a fit of both $|A_0|^2$ and $\Delta\phi$. With the same $\rho'\phi'$ model neglecting the $\rho\omega\phi$ tail, the fitted parameters are:

$$M_{\phi'} = 1.677 \pm 0.012 \text{ GeV},$$

$$\Gamma_{\phi'} = 102 \pm 36 \text{ MeV}, \quad \Gamma_{ee}B = 0.39 \pm 0.11 \text{ keV}.$$

$$\chi^2/\text{dof} = 5.5/9.$$

Here again the mass and width of the ϕ' are almost independent of the ρ' width. Moreover the $\rho\omega\phi$ tail gives only a small effect. On the contrary, the $\Gamma_{ee}B$ and the $e^+e^- \to KK^*$ cross section depend on the ρ' width. It should be noted that a presumed ω' in this energy range could rise significantly the value of $\Gamma_{ee}B$ (+30% for an ω' degenerate with the ρ').

In conclusion, our results in $K^0_S K^\pm \pi^\mp$ show again the existence of a new isoscalar vector meson around 1.65 GeV as our previous results on K^+K^- [5], $K^0_S K^0_L$ [2] and $\omega\pi^+\pi^-$ [1] production in e^+e^- annihilation. We determine the mass and width of this new isoscalar amplitude and get a first determination of its $\Gamma_{ee}B_{KK^*}$ The analysis of the $K\bar{K}\pi$ Dalitz plot shows that we are dealing with a ϕ' meson which explains the rather important production of the KK^* final state near threshold.

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