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A study of the $K\overline{K}\pi$ channel produced centrally in pp interactions at 450 GeV/c

The WA102 Collaboration

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Abstract

Results are presented of an analysis of the reactions $pp \rightarrow p_f(K^0_S K^\pm \pi^\mp\ )p_s$ and $pp \rightarrow p_f(K^0_S K^0_S \pi^0)p_s$ at 450 GeV/c. Clear $f_1(1285)$ and $f_1(1420)$ signals are seen and a spin parity analysis shows that both have $I^G J^{PC} = 0^+1^{++}$. The $f_1(1285)$ decays to $a_0(980)\pi$ and the $f_1(1420)$ decays to $K^*\overline{K}$. Both states have a similar dependence as a function of dP_T consistent with what has been observed for other $q\overline{q}$ states. Evidence is also presented for a $K^*\overline{K}$ decay mode of the $\eta_2(1620)$.

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In previous analyses [1, 2, 3] of the centrally produced $K^0_S K^\pm \pi^\mp$ system the peaks observed at 1.28 and 1.42 GeV were found to have $J^{PG} = 1^{++}$ and hence were identified with the $f_1(1285)$ and $f_1(1420)$ respectively. However, due to the limited statistics a 10% 0^{-+} contribution could not be excluded [3].

Originally the $f_1(1420)$ was thought to be the $s\overline{s}$ isoscalar member of the ground state 1^{++} nonet, the other members being the $a_1(1260)$ triplet, the $K_1(1270/1400)$ and the $f_1(1285)$. The $f_1(1420)$ was found to decay dominantly to $K^*\overline{K}$ hence reinforcing its $s\overline{s}$ assignment. It is commonly accepted that $s\overline{s}$ objects should be preferentially produced in K^- incident experiments whereas in the study of the reaction

$$K^- p \rightarrow K^0_S K^\pm \pi^\mp \Lambda$$

two experiments [4, 5] observed only weak evidence for a $f_1(1420)$ signal. Instead they found evidence for a new $J^{PC} = 1^{++}$ state with a mass of 1.53 GeV and a width of 100 MeV, called the $D'/f_1(1510)$. It was suggested that this state is a better candidate for the $s\overline{s}$ member of the 1^{++} nonet based on its production.

Therefore, the 1^{++} nonet appears to have ten candidates with the $f_1(1420)$ thought to be the extra state. As a 1^{++} state its mass is considered to be too low to be a glueball or hybrid state, and it has been suggested that it could be either a hybrid [6], a four quark state [7] or a $K^*\overline{K}$ molecule [8, 9].

This paper presents a study of the centrally produced exclusive final states formed in the reactions

$$pp \rightarrow p_f (K^0_S K^\pm \pi^\mp) p_s \tag{1}$$

and

$$pp \rightarrow p_f (K^0_S K^0_S \pi^0) p_s \tag{2}$$

at 450 GeV/c, where the subscripts f and s indicate the fastest and slowest particles in the laboratory respectively. The data presented here represent a factor of ten increase compared to previously published data. In addition, in order to try to gain more information about the nature of the $f_1(1420)$, a study is performed as a function of dP_T. This variable is the difference in the transverse momentum vectors of the two exchanged particles [10] and has been proposed as a glueball-$q\overline{q}$ filter [11].

The data come from the 1995 and 1996 runs of experiment WA102 which has been performed using the CERN Omega Spectrometer. The layout of the Omega Spectrometer used in these runs is similar to that described in ref. [12] with the replacement of the OLGA calorimeter by GAMS 4000 [13]. In the 1996 run of the experiment the setup was augmented by the addition of a threshold Čerenkov counter for charged particle identification.

Reaction (1) has been isolated from the sample of events having four outgoing tracks plus a reconstructed V^0 by first imposing on the components of missing momentum the cuts $|\Delta P_x| \leq 14.0$ GeV/c, $|\Delta P_y| \leq 0.12$ GeV/c and $|\Delta P_z| \leq 0.08$ GeV/c, where the x axis is along the beam direction. The $\pi^+\pi^-$ mass distribution for the V^0s shows a clear K^0 signal which was selected by requiring $0.475 \leq m(\pi^+\pi^-) \leq 0.520$ GeV. Reaction (1) was then selected from this sample by using energy conservation. A cut of $|\Delta| \leq 1.6$ (GeV)^2 was used, where $\Delta = MM^2(p_f p_s) - M^2(K^0_S K^\pm \pi^\mp)$.

These cuts gave an ambiguous $K^0_S K^\pm \pi^\mp$ assignment to 59% of the events. The Ehrlich mass [14] has been calculated for the V^0 and one of the charged particles, assuming the other to be a pion. A clear peak is observed in the Ehrlich mass spectrum (not shown) at the kaon mass squared and suitable cuts were applied to select out the $K^0_S K^+ \pi^-$ and $K^0_S K^- \pi^+$ channels.

Fig. 1a) shows the $K^0_S K^\pm \pi^\mp$ effective mass spectrum (52 141 events) where the events that still have an ambiguous mass assignment are plotted twice (18 % of the events). Fig. 2a) shows the $K^0_S K^\pm \pi^\mp$ effective mass spectrum where the kaon has been positively identified by the Čerenkov counter (5 647 events). A fit to these spectra, using two Breit-Wigners convoluted with Gaussians to account for the experimental resolution ($\sigma = 10$ MeV in the $f_1(1285)$ region and $\sigma = 13$ MeV in the $f_1(1420)$ region) and a background of the form $a(m - m_{th})^b exp(-cm - dm^2)$, where m is the $K^0_S K^\pm \pi^\mp$ mass, m_{th} is the threshold mass and a,b,c,d are fit parameters, yields masses and widths of

$$
\begin{array}{llllllll}
M_1 & = & 1281 \pm 1 & \text{MeV} & \Gamma_1 & = & 20 \pm 2 & \text{MeV} \\
M_2 & = & 1426 \pm 1 & \text{MeV} & \Gamma_2 & = & 58 \pm 4 & \text{MeV.}
\end{array}
$$

A Dalitz plot analysis of the $K^0_S K^\pm \pi^\mp$ final state has been performed using Zemach tensors and a standard isobar model [15]. The $K^0_S K^\pm \pi^\mp$ mass spectrum has been fitted in 20 MeV slices from 1.23 to 1.93 GeV. Different combinations of 22 waves, with J $\leq$ 2, decaying to $a_0(980)\pi$ and $K^*\overline{K}$ have been used, where the $a_0(980)$ has been described in terms of the Flatté formalism [16]. Full interference between waves having the same spin-parity has been allowed. Interference was also allowed between the 1^{++} and 1^{+-} $K^*\overline{K}$ waves.

The analysis has first been performed on the data without particle identification. This has the advantage of having the greatest statistics but has the disadvantage that 18 % of the events have a $K^\pm \pi^\mp$ ambiguity. This ambiguity does not affect the analysis of the 1.28 and 1.42 GeV regions but means that higher masses are contaminated from wrong sign reflections of the dominant peaks. The fit shows that the $J^{PG} = 1^{++}$ $a_0(980)\pi$ wave is the only wave required to describe the $f_1(1285)$ peak and that the $J^{PG} = 1^{++}$ $K^*\overline{K}$ wave is the only wave required to describe the $f_1(1420)$ peak. The addition of 0^{-+} or any other waves up to J equals 2 does not increase the likelihood significantly. The results of the fit are shown in fig.1 b),c) and d). It is interesting to note that there is no evidence for the $f_1(1510)$.

A spin analysis has also been performed on the sample where the K is identified by the Čerenkov system. This sample is lower in statistics but has the advantage that there are no ambiguities and hence the background at higher masses is reduced. The result of the analysis in the 1.28 and 1.42 GeV regions is the same as for the sample without kaon identification; only the $J^{PG} = 1^{++}$ waves are required in the fit. In addition, a $J^{PG} = 2^{-+}$ $K^*\overline{K}$ wave is found to be required in the 1.6 GeV region as shown in fig 2e). The addition of this wave increases the log likelihood by $\Delta\mathcal{L} = 15$ corresponding to $n = \sqrt{2\Delta\mathcal{L}} = 5.5$ standard deviations. Superimposed on fig 2e) is the Breit-Wigner found to describe the $\eta_2(1620)$ decaying to $a_2(1320)\pi$ in the analysis of the $\pi^+\pi^-\pi^+\pi^-$ final state of this experiment [17]. As can be seen the $J^{PG} = 2^{-+}$ $K^*\overline{K}$ wave is consistent with this in mass and width.

From a Dalitz plot analysis of the $K^0_S K^\pm \pi^\mp$ system only the J^{PG} of the final state can be determined. In order to determine the C parity, and hence the isospin of the final states, a study of the $K^0_S K^0_S \pi^0$ system is required since only C parity positive states can be observed in this channel.

Reaction (2) has been isolated from the sample of events having two outgoing tracks together with two reconstructed V^0s and a π^0 decaying to 2γs which were detected in the GAMS calorimeter by first imposing the cuts on the components of missing momentum described above. The $\pi^+\pi^-$ mass distributions for the V^0s show clear K^0 signals which were selected by requiring $0.475 \leq m(\pi^+\pi^-) \leq 0.520$ GeV.

Fig. 3a) shows the $K^0_S K^0_S \pi^0$ effective mass spectrum (949 events) where clear peaks at 1.28 and 1.42 GeV can be seen. A spin analysis has been performed on this sample in 40 MeV slices from 1.21 to 1.69 GeV and shows that the peaks at 1.28 and 1.42 GeV have $J^{PC} = 1^{++}$. The small number of events does not allow a statistically significant signal in the $J^{PC} = 2^{-+}$ wave to be extracted.

Therefore, we have clearly identified both the $f_1(1285)$ and the $f_1(1420)$ to have $I^G J^{PC} = 0^+ 1^{++}$. The $f_1(1285)$ is found to decay only to $a_0(980)\pi$ while the $f_1(1420)$ is found to decay only to $K^*\overline{K}$. There is also evidence for a $J^{PG} = 2^{-+}$ $K^*\overline{K}$ signal consistent with the $\eta_2(1620)$.

The $f_1(1285)$ has also been observed in the $\pi^+\pi^-\pi^+\pi^-$ channel of this experiment [17] and its branching ratio to $K\overline{K}\pi$ and 4π has been calculated taking into account the unseen decay modes and gives

$$\frac{f_1(1285) \to K\overline{K}\pi}{f_1(1285) \to 4\pi} = 0.265 \pm 0.01 \pm 0.01. \tag{3}$$

This is a considerable improvement in accuracy on our previous determination [18].

Assuming the signal in the $J^{PC} = 2^{-+}$ $K^*\overline{K}$ wave to be due to the $\eta_2(1620)$ observed decaying to $a_2(1320)\pi$ in the $\pi^+\pi^-\pi^+\pi^-$ channel [17] the branching ratio for the $\eta_2(1620)$ to $K\overline{K}\pi$ and $a_2(1320)\pi$ has been calculated taking into account the unseen decay modes and gives

$$\frac{\eta_2(1620) \to K\overline{K}\pi}{\eta_2(1620) \to a_2(1320)\pi} = 0.07 \pm 0.02 \pm 0.02. \tag{4}$$

Since no signal is observed for the $f_1(1510)$ in the 1^{++} $K^*\overline{K}$ wave, an upper limit for its production in central collisions relative to the $f_1(1420)$ has been calculated and gives

$$\frac{f_1(1510) \to K^*\overline{K}}{f_1(1420) \to K^*\overline{K}} < 0.03 \qquad at\ 90\%\ CL. \tag{5}$$

Close and Kirk [11] have proposed that when the centrally produced system is analysed as a function of the parameter dP_T, which is the difference in the transverse momentum vectors of the two exchange particles [10], states with large (small) internal angular momentum will be enhanced at large (small) dP_T. A study of the $K^0_S K^\pm \pi^\mp$ mass spectrum as a function of dP_T is presented in fig. 4a), b) and c) for $dP_T \leq 0.2$ GeV, $0.2 \leq dP_T \leq 0.5$ GeV and $dP_T \geq 0.5$ GeV respectively. As can be seen both the $f_1(1285)$ and $f_1(1420)$ signals behave similarly, which is consistent with both states having the same underlying dynamical structure. Table 1 gives the percentage of each resonance in the three dP_T regions considered and shows a strong suppression of both resonances at small dP_T similar to that found for other $q\overline{q}$ states [10].

In conclusion, clear $f_1(1285)$ and $f_1(1420)$ signals are observed. A spin parity analysis shows that both are $I^G J^{PC} = 0^+ 1^{++}$ states. The $f_1(1285)$ is found to decay via $a_0(980)\pi$ while the

$f_1(1420)$ is found to decay only to $K^*\overline{K}$; no 0^{-+} or 1^{+-} waves are required to describe the data. The dP_T dependence of both states is similar and is consistent with both states having a $q\overline{q}$ nature. There is also evidence for a $K^*\overline{K}$ decay mode of the $\eta_2(1620)$.

References

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Tables

Table 1: Resonance production as a function of dP_T expressed as a percentage of its total contribution.

	$dP_T \leq 0.2$ GeV	$0.2 \leq dP_T \leq 0.5$ GeV	$dP_T \geq 0.5$ GeV
$f_1(1285)$	7.2 ± 1.2	53.4 ± 2.7	39.4 ± 2.0
$f_1(1420)$	4.5 ± 1.2	51.3 ± 2.0	44.2 ± 1.5

Figures

Figure 1: The full $K^0_S K^\pm \pi^\mp$ sample. a) Mass spectrum with fit described in the text, b) the $K^0_S K^\pm \pi^\mp$ mass spectrum used in the spin analysis and the resulting phase space contribution, c) the $J^{PG} = 1^{++}$ $a_0(980)\pi$ wave and d) the $J^{PG} = 1^{++}$ $K^* \overline{K}$ wave.

Figure 2: The $K^0_S K^\pm \pi^\mp$ data with the $K^\pm$ identified by the Čerenkov counter. a) Mass spectrum with fit described in the text, b) the $K^0_S K^\pm \pi^\mp$ mass spectrum used in the spin analysis and the resulting phase space contribution, c) the $J^{PG} = 1^{++}$ $a_0(980)\pi$ wave, d) the $J^{PG} = 1^{++}$ $K^* \overline{K}$ wave and e) the $J^{PG} = 2^{-+}$ $K^* \overline{K}$ wave.

Figure 3: The $K^0_S K^0_S \pi^0$ sample. a) Mass spectrum, b) the $K^0_S K^0_S \pi^0$ mass spectrum used in the spin analysis and the resulting phase space contribution, c) the $J^{PC} = 1^{++}$ $a_0(980)\pi$ wave and d) the $J^{PC} = 1^{++}$ $K^* \overline{K}$ wave.

Figure 4: The $K^0_S K^\pm \pi^\mp$ mass spectrum as a function of dP_T for a) $dP_T \leq 0.2$, b) $0.2 \leq dP_T \leq 0.5$ and c) $dP_T \geq 0.5$ GeV.

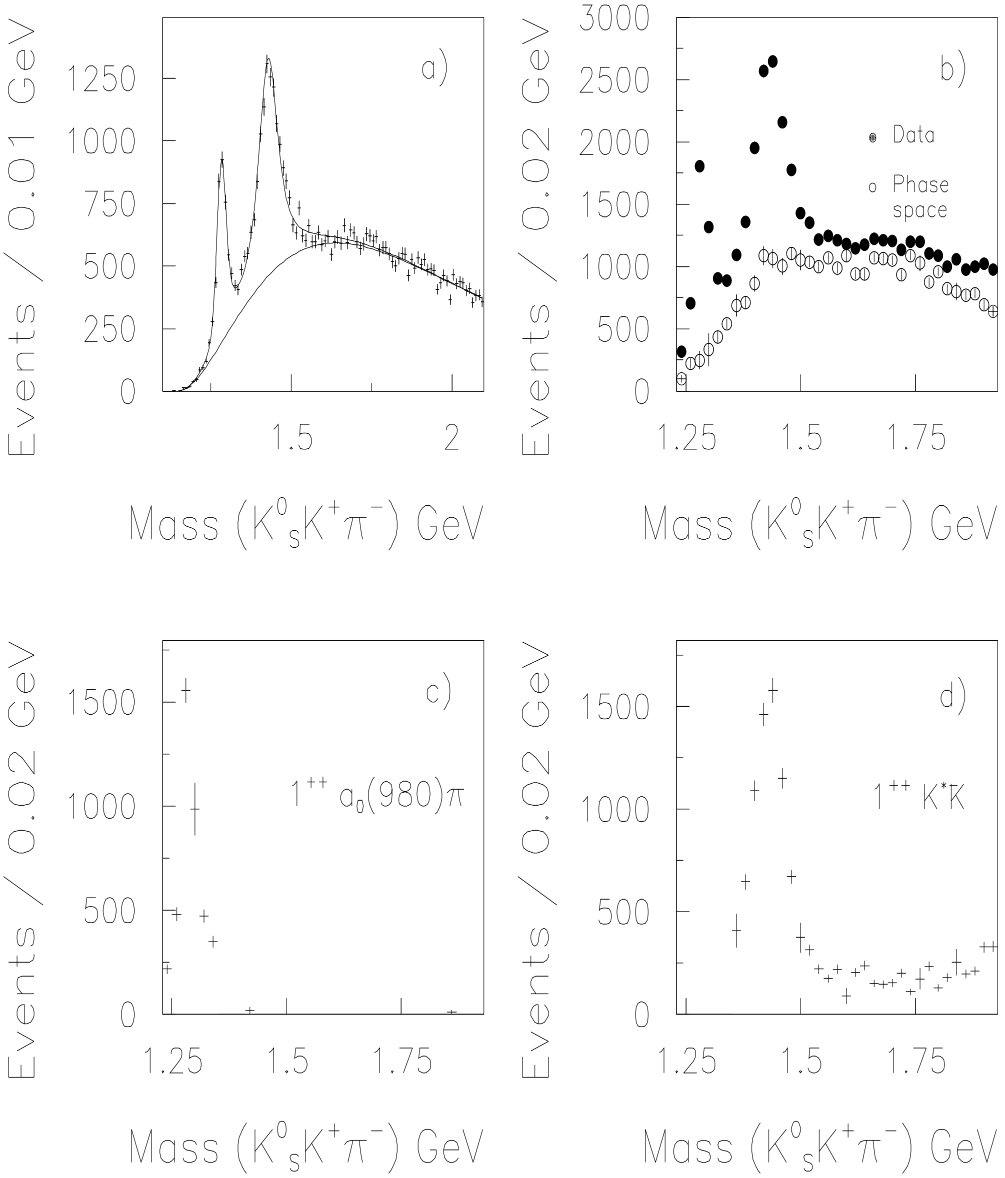
a)
b)
Data
Phase space
c)
1^{++} $a_0(980)\pi$
d)
1^{++} $K^*\bar{K}$
Events / 0.01 GeV
Events / 0.02 GeV
Mass ($K^0_S K^+ \pi^-$) GeV

Figure 1

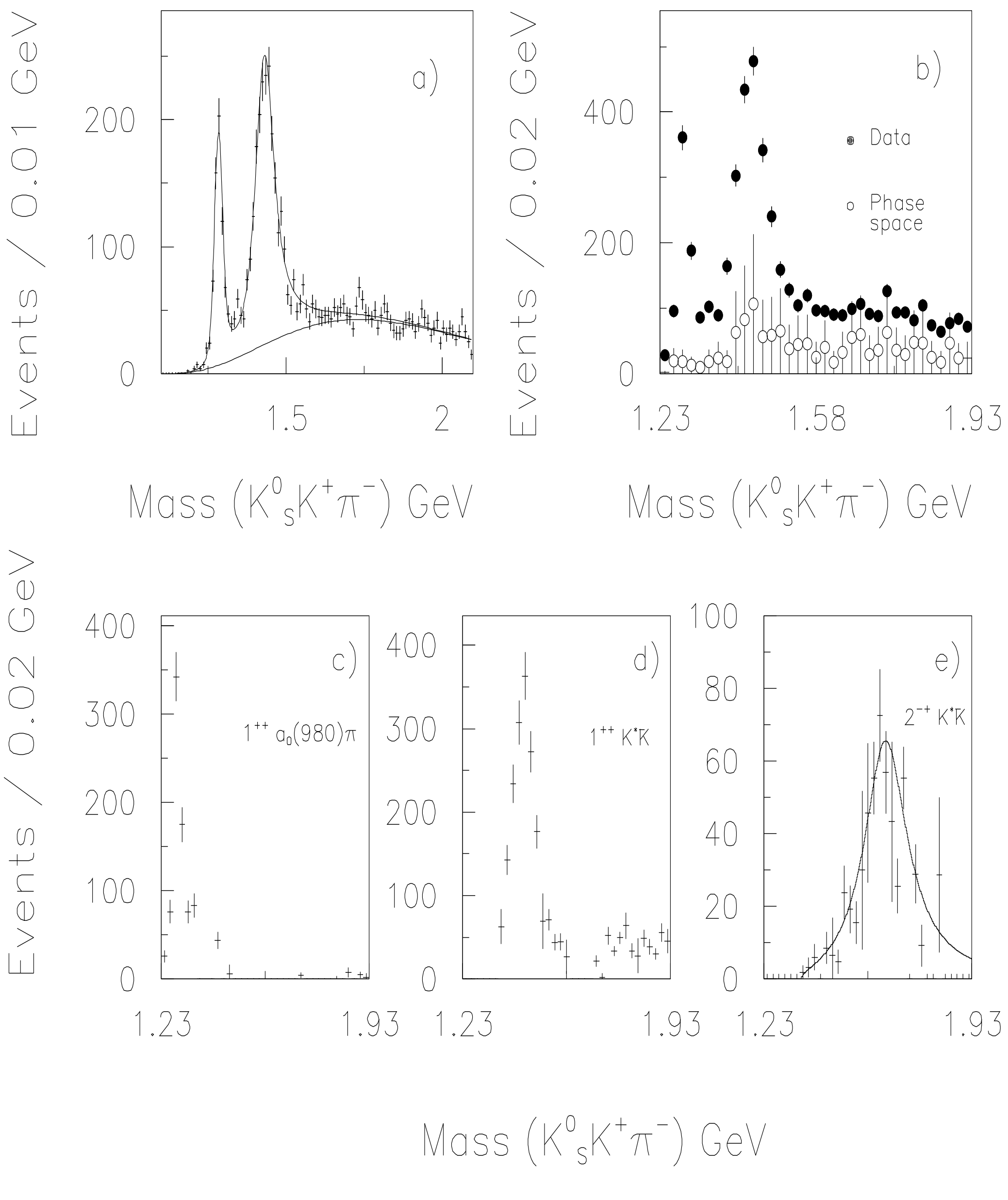
a)
b)
Data
Phase space
Events / 0.01 GeV
Events / 0.02 GeV
Mass (K⁰sK⁺π⁻) GeV
c)
1⁺⁺ a₀(980)π
d)
1⁺⁺ K*K̄
e)
2⁻⁺ K*K̄
1.23
1.58
1.93
1.5
2

Figure 2

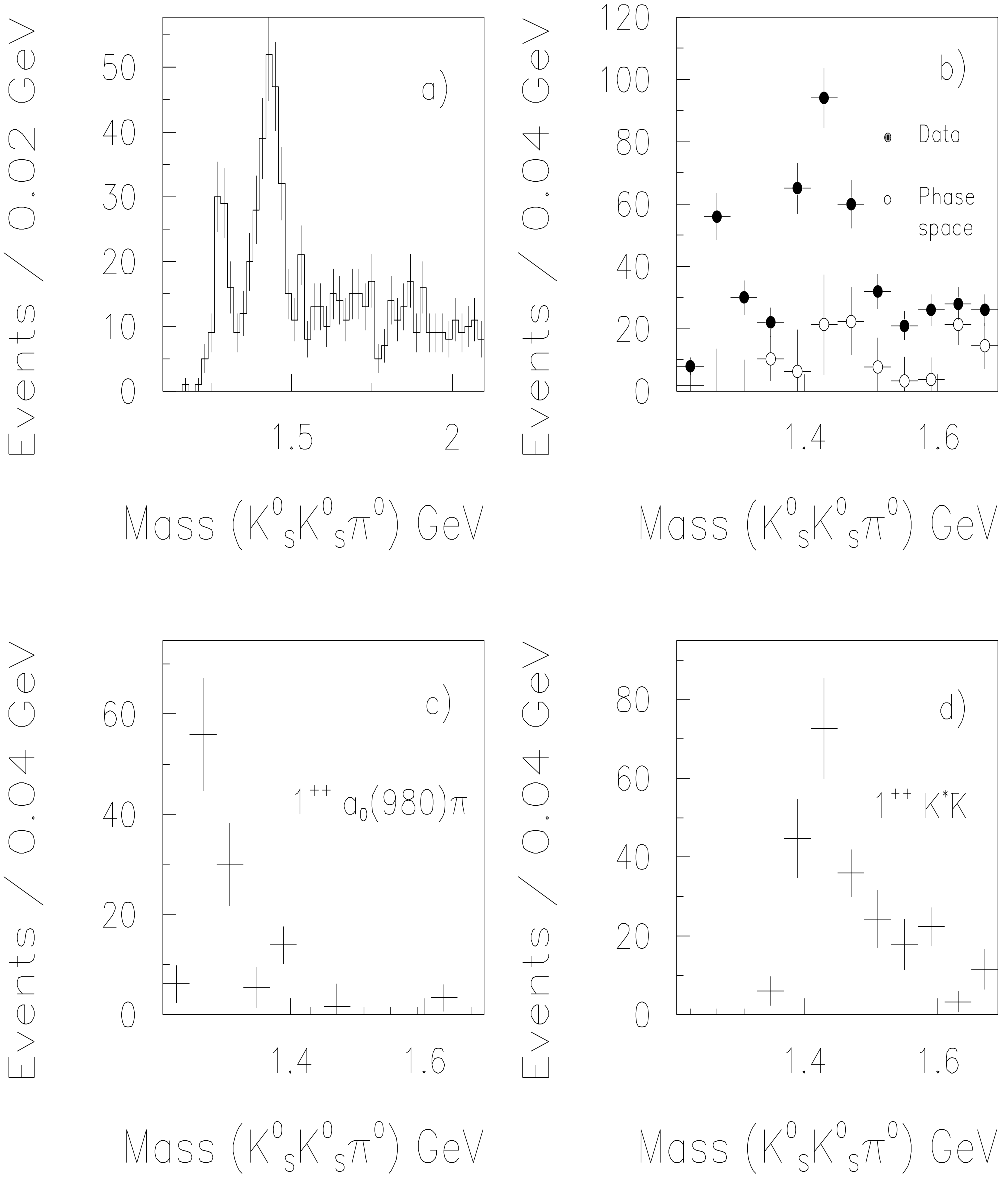
a)
b)
Data
Phase space
c)
1^{++} $a_0(980)\pi$
d)
1^{++} $K^*\bar{K}$
Events / 0.02 GeV
Events / 0.04 GeV
Mass ($K^0_S K^0_S \pi^0$) GeV

Figure 3

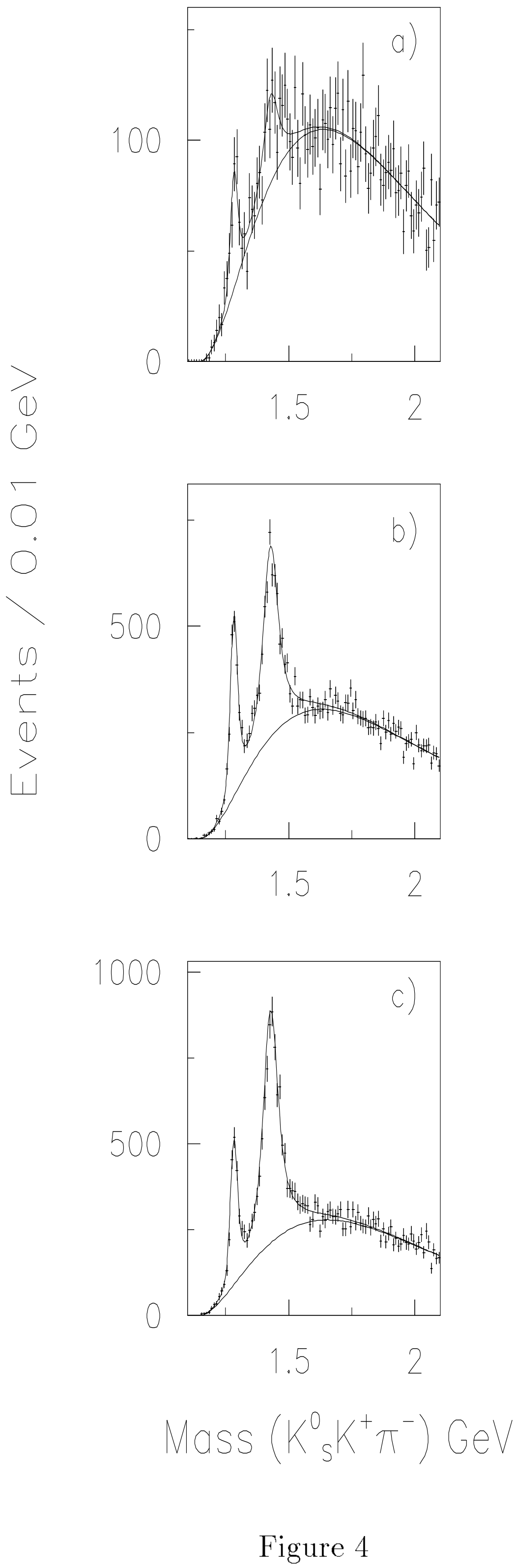

Figure 4