STUDY OF SCALAR MESONS AT BES

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Partial wave analyses have been performed on BES data to study scalar mesons. There is evidence for the κ near the $K\pi$ threshold and the pole position is $(760 \sim 840)-$i$(310 \sim 420)$ MeV. The σ peak is seen in $\omega\pi^+\pi^-$ and gives an accurate pole position, $(541 \pm 39)-$i(252 ± 42) MeV. The $f_0(980)$ is seen in both $\phi\pi^+\pi^-$ and ϕK^+K^- data. Parameters of the Flatté formula for $f_0(980)$ are: $M = 965\pm8(sta)\pm6(sys)$ MeV, $g_1 = 165\pm10(sta)\pm15(sys)$ MeV, $g_2/g_1 = 4.21\pm0.25(sta)\pm0.21(sys)$. The $J/\psi \to \phi\pi^+\pi^-$ data require $f_0(1790) \to \pi^+\pi^-$, distinct from $f_0(1710) \to K^+K^-$. Also $f_0(1370)$ is seen clearly in $\phi\pi^+\pi^-$ data.

1 Introduction

The scalar mesons are one of the most controversial subjects in hadron physics. Bellow 1.9 GeV, the Particle Data Group [1] lists the following $I = 0$ scalar states: $f_0(600)$(or σ), $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$ and two $I = 1/2$ scalar states: $K_0^*(800)$(or κ), $K_0^*(1430)$. Scalar mesons have been traditionally studied in scattering experiments. However, in these experiments the mesons can be difficult to disentangle from nonresonant background. Thus σ and κ are controversial; some $f_0(980)$ and $f_0(1370)$ have poorly determined parameters.

Recently, based on 58 million J/ψ events and 14 million $\psi(2S)$ events collected with the Beijing Spectrometer (BES II) detector [2], The scalar mesons have been studied by performing partial wave analysis on many channels of BES data. In this paper, we present some of the results from such study at BES.

2 Results from BES

2.1 κ in $J/\psi \to K^+K^-\pi^+\pi^-$

Events over all of the 4-body phase space for $J/\psi \to K^+K^-\pi^+\pi^-$ have been fitted. We find evidence for the κ in the process $J/\psi \to K^*(890)\kappa$, $\kappa \to (K\pi)_S$. We select a $K^+\pi^-$ pair in the K^* mass range 892 ± 100 MeV; Figure 1 then shows the projection of the mass of the other $K^-\pi^+$ pair.

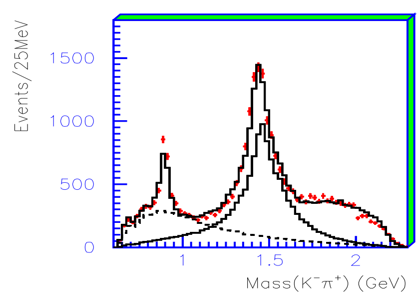

Figure 1. $K^+\pi^-$ combinations are selected in the mass range 892 ± 100 MeV from $J/\psi \to K^+K^-\pi^+\pi^-$ data. The figure shows the invariant mass distribution of accompanying $K^-\pi^+$ pairs (crosses). The upper full histogram shows the maximum likelihood fit, the lower one shows the $K_0^*(1430)$ contribution, and the dashed histogram the κ contribution.

The data are fitted with a form for the κ containing an Adler zero in the width. The pole position for κ is at $(760 \pm 20(sta) \pm 40(sys))-i(420 \pm 45(sta) \pm 60(sys))$ MeV.

In Figure 1, the upper full histogram shows the maximum likelihood fit, the lower full histogram shows the $K_0^*(1430)$ contribution and the dashed histogram the κ contribution. There are strong destructive interference between the κ and $K_0^*(1430)$. The pole for $K_0^*(1430)$ lies at $(1433 \pm 30(sta) \pm 10(sys))-\mathrm{i}(181 \pm 10(sta) \pm 12(sys))$ MeV.

For the restricted region of phase space $\bar{K}^*(892)K^+\pi^-$ in $K^+K^-\pi^+\pi^-$ data, two other independent analyses have been performed. Both favor strongly that the low mass enhancement of the $K^+\pi^-$ system is a resonance. The 0^+ resonances κ is highly necessary in both fits. The average values of pole position for κ is determined to be $(841 \pm 78^{+81}_{-73})-\mathrm{i}(309 \pm 91^{+48}_{-72})$ MeV.

2.2 σ in $J/\psi \to \omega\pi^+\pi^-$

In $J/\psi \to \omega\pi^+\pi^-$, there are conspicuous $\omega f_2(1270)$ and $b_1(1235)\pi$ signals. At low $\pi\pi$ mass, a large, broad peak due to the σ is observed.

Figure 2 shows the $\pi^+\pi^-$ invariant mass distribution from $J/\psi \to \omega\pi^+\pi^-$. Partial wave analyses have been performed on this channel using two methods [3]. In the first method, the whole mass region of $M_{\pi^+\pi^-}$ which recoils against the ω is analyzed, the ω decay information is used, and the background is subtracted by sideband estimation. For the second method, the region $M_{\pi^+\pi^-} <$ 1.5 GeV is analyzed, and the background is fitted by 5π phase space.

The upper full histogram in Figure 2 shows the maximum likelihood fit from first method, the dashed histogram shows the σ contribution.

Different analysis methods and four parametrizations of the σ amplitude give consistent results for the σ pole. The average pole position is determined to be $(541 \pm 39)-\mathrm{i}(252 \pm 42))$ MeV.

Recently, an analysis of $\psi(2S) \to \pi^+\pi^- J/\psi$ has been performed to study the σ. The pole position of σ is consistent with that from $J/\psi \to \omega\pi^+\pi^-$.

2.3 Study of $J/\psi \to \omega K^+K^-$

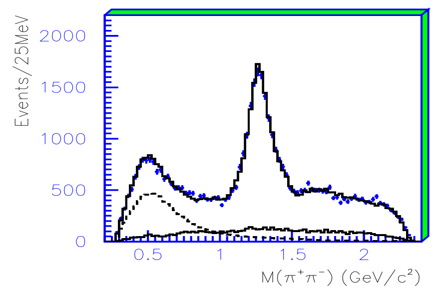

Figure 2. The $\pi^+\pi^-$ invariant mass distribution from $J/\psi \to \omega\pi^+\pi^-$ (crosses). The upper full histogram shows the maximum likelihood fit, the lower full histogram corresponds to the background estimated from ω sidebins, and the dashed histogram shows the σ contribution.

Figure 3 shows the K^+K^- invariant mass distribution from $J/\psi \to \omega K^+K^-$. The shaded area indicates background events from the sideband estimation. A partial wave analysis has been performed [4], the full histogram in Figure 3 shows the maximum likelihood fit.

A dominant feature of $J/\psi \to \omega K^+K^-$ is $f_0(1710)$, the present data are consistent with earlier studies which identify $J = 0$. The fitted $f_0(1710)$ optimises at $M = 1738 \pm 30$ MeV, $\Gamma = 125 \pm 20$ MeV.

In $J/\psi \to \omega\pi^+\pi^-$ [3], there is no definite evidence for the presence of $f_0(1710)$; if its mass is scanned, there is no optimum around 1710 MeV/c^2, and the fitted $f_0(1710)$ is only $0.43 \pm 0.21\%$ of $\omega\pi^+\pi^-$. In the ωK^+K^- data presented here, the $f_0(1710)$ intensity is $(38 \pm 6)\%$ of the data within the same acceptance as for $\omega\pi^+\pi^-$. The branching fraction for $J/\psi \to \omega f_0(1710)$, $f_0(1710) \to K^+K^-$ is $(6.6 \pm 1.3) \times 10^{-4}$. We find at the 95% confidence level

$$\frac{BR(f_0(1710) \to \pi\pi)}{BR(f_0(1710) \to K\bar{K})} < 0.11, \qquad (1)$$

where all charge states for decay are taken into account.

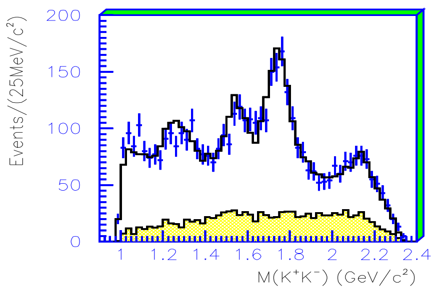

Figure 3. The K^+K^- invariant mass distribution from $J/\psi \to \omega K^+K^-$ (crosses). The full histogram shows the maximum likelihood fit and the shaded histogram the background estimated from ω sidebands.

2.4 Study of $J/\psi \to \phi\pi^+\pi^-$ and $J/\psi \to \phi K^+K^-$

Figure 4 shows the $\pi^+\pi^-$ invariant mass distribution from $J/\psi \to \phi\pi^+\pi^-$. Figure 5 shows thew K^+K^- invariant mass distribution from $J/\psi \to \phi K^+K^-$. In Figure 4 and 5, the shaded histogram corresponds to the the background estimated from ϕ sidebins.

The $\phi\pi^+\pi^-$ and ϕK^+K^- data are fitted simultaneously by using partial wave analysis [5], constraining resonance masses and widths to be the same in both sets of data. The full histogram in Figure 4 and 5 show the maximum likelihood fit.

The $f_0(980)$ is observed clearly in both sets of data. The Flatté form:

$$f = \frac{1}{M^2 - s - i(g_1\rho_{\pi\pi} + g_2\rho_{K\bar{K}})}. \qquad (2)$$

has been used to fit the $f_0(980)$ amplitude. Here ρ is Lorentz invariant phase space, $2k/\sqrt{s}$, where k refers to π or K momentum in the rest frame of the resonance. The present data offer the opportunity to determine the parameters of $f_0(980)$ accurately: $M = 965 \pm 8(sta) \pm 6(sys)$ MeV, $g_1 = 165 \pm 10(sta) \pm 15(sys)$ MeV, $g_2/g_1 = 4.21 \pm 0.25(sta) \pm 0.21(sys)$.

The $\phi\pi\pi$ data also exhibit a strong peak centred at $M = 1335$ MeV. It may be fitted with $f_2(1270)$ and a dominant 0^+ signal made from $f_0(1370)$ interfering with a smaller $f_0(1500)$ component. There is definite evidence that the $f_0(1370)$ signal is resonant, from interference with $f_2(1270)$. The Mass and width of $f_0(1370)$ are determined to be: $M = 1350 \pm 50$ MeV and $\Gamma = 265 \pm 40$ MeV.

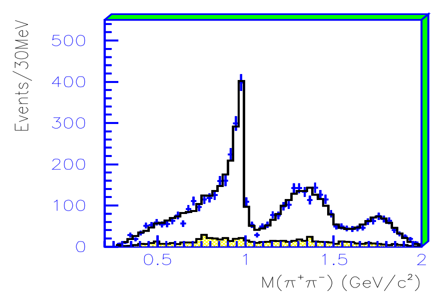

Figure 4. The $\pi^+\pi^-$ invariant mass distribution from $J/\psi \to \phi\pi^+\pi^-$ (crosses). The full histogram shows the maximum likelihood fit and the shaded histogram the background estimated from ϕ sidebins.

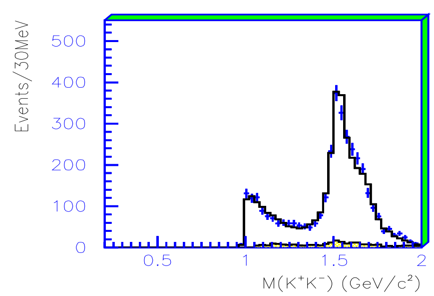

Figure 5. The K^+K^- invariant mass distribution from $J/\psi \to \phi K^+K^-$ (crosses). The full histogram shows the maximum likelihood fit and the shaded histogram the background estimated from ϕ sidebins.

There is also a definite signal from $f_0(1790) \to \pi^+\pi^-$ with $M = 1790^{+40}_{-30}$ MeV, $\Gamma = 270^{+60}_{-30}$ MeV. It cannot arise from $f_0(1710)$, since the branching fraction ratio $K\bar{K}/\pi\pi$ for $f_0(1790)$ is a factor 14 lower than that reported in Ref. 4 for $f_0(1710)$. The large discrepancy in branching fractions implies the existence of two distinct states $f_0(1790)$ and $f_0(1710)$, the $f_0(1790)$ decaying dominantly to $\pi\pi$ and the $f_0(1710)$ dominantly to $K\bar{K}$. The $f_0(1790)$ is a natural candidate for the radial excitation of $f_0(1370)$ and behaves like $f_0(1370)$.

For ϕK^+K^- data, there is a conspicuous peak due to $f_2'(1525)$, but there is a shoulder on its upper side. This shoulder is fitted mostly by $f_0(1710)$ interfering with $f_0(1500)$; there is also a possible small contribution from $f_0(1790)$ interfering with $f_0(1500)$.

2.5 Study of $J/\psi \to \gamma\pi\pi$

Figure 6 shows the $\pi^+\pi^-$ invariant mass distribution from $J/\psi \to \gamma\pi^+\pi^-$. A partial wave analysis is carried out in the 1.0-2.3 MeV $\pi\pi$ mass range. There are two 0^{++} states in the 1.45 and 1.75 GeV respectively. One 0^{++} state peaks at a mass of $1466\pm6\pm16$ MeV with a width of $108^{+14}_{-11}\pm21$ MeV, which is approximately consistent with $f_0(1500)$. However, due to the large interference between S-wave states, a possibility contribution from $f_0(1370)$ cannot be excluded.

A strong production of the $f_0(1710)$ signal was observed in the partial wave analysis of $J/\psi \to \gamma K\bar{K}$ [6], with a mass of $1740 \pm 4^{+10}_{-25}$ MeV and a width of 166^{+5+15}_{-8-10} MeV. If the 0^{++} state at $\sim$ 1.75 GeV observed here is interpreted as coming from $f_0(1710)$, we obtain the $\pi\pi$ to $K\bar{K}$ branching ratio as $\frac{\Gamma(f_0(1710)\to\pi\pi)}{\Gamma(f_0(1710)\to K\bar{K})} = 0.41^{+0.22}_{-0.18}$. This value is slightly higher than in $\omega\pi^+\pi^-$ and ωK^+K^- [4]. Hence, an alternative interpretation for this 0^{++} state is the $f_0(1790)$.

3 Summary

Partial wave analyses have been performed of BES data to study the scalar mesons. The κ near the $K\pi$ threshold is needed and the pole position is $(760 \sim 840)-$i$(310 \sim 420)$ MeV. The σ is seen clearly in $\omega\pi^+\pi^-$ and gives an accurate pole position, $(541\pm39)-$i(252 ± 42) MeV. The $f_0(980)$ is observed in both $\phi\pi^+\pi^-$ and ϕK^+K^- data with $M = 965 \pm 8(sta) \pm 6(sys)$ MeV, $g_1 = 165 \pm 10(sta) \pm 15(sys)$ MeV, $g_2/g_1 = 4.21 \pm 0.25(sta) \pm 0.21(sys)$. The $J/\psi \to \phi\pi^+\pi^-$ data require $f_0(1790) \to \pi^+\pi^-$, distinct from $f_0(1710) \to K^+K^-$. Also a peak due to $f_0(1370)$ is seen clearly in $\phi\pi^+\pi^-$ data.

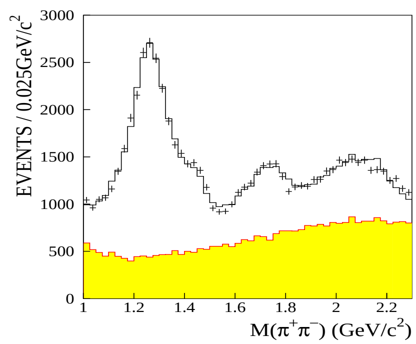

Figure 6. The $\pi^+\pi^-$ invariant mass distribution from $J/\psi \to \gamma\pi^+\pi^-$ (crosses). The full histogram shows the maximum likelihood fit and the shaded histogram corresponds to the $\pi^+\pi^-\pi^0$ background.

References

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