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Measurement of $\psi(2S)$ Hadronic Decays into Vector plus Tensor Mesons

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Abstract

The $\psi(2S)$ decays into vector plus tensor mesons, ωf_2, ρa_2, $K^{*0}\overline{K_2}^{*0} + c.c.$ and $\phi f_2'(1525)$, have been first studied using a sample of 3.7×10^6 produced $\psi(2S)'s$. No convincing evidence for a signal in either of these decays is found. Upper limits on branching fractions are set. The ratio of $\psi(2S)$ to J/ψ decay rates is significantly in disagreement with the theoretical prediction of 15%.

There are outstanding puzzles in charmonium physics in which the experimental results reveal order-of-magnitude discrepancies with theoretical expectations, namely, the recently observed $\psi(2S)$ surplus problem [1] and the long-standing puzzle involving two-body decay modes of the J/ψ and $\psi(2S)$, the so-called $\rho\pi$ puzzle [2]. The existence of such dramatic discrepancies indicates that our understanding of charmonium production and decays is yet inadequate.

The $\rho\pi$ puzzle was first reported by the MARK II experiment at the SPEAR, which found that the J/ψ decays prominently to vector plus pseudoscalar meson (VP) channels, $\rho\pi$ and $K^*\overline{K} + c.c.$, whereas the $\psi(2S)$ decays to these same channels are highly suppressed [2]. According to perturbative QCD, for a given final hadronic state h, one expects

$$Q_h \equiv \frac{B(\psi(2S) \to h)}{B(J/\psi \to h)} \cong \frac{B(\psi(2S) \to e^+e^-)}{B(J/\psi \to e^+e^-)} = (14.6 \pm 2.2)\%,$$

referred to as the "15% *rule*". Such a ratio appears to hold approximetely for most J/ψ and $\psi(2S)$ decay modes measured so far. For $\rho\pi$ and $K^*\overline{K} + c.c.$ channels, Q_h is shown to be a factor of more than 19 and 6, respectively, below the predicted value. This anomaly has generated considerable interest; several theoretical explanations have been proposed [3]. However, over the past decade there has been meagre progress in experimental studies of $\psi(2S)$ physics [4]. As yet no further example of differences between J/ψ and $\psi(2S)$ is known. In order to conclusively clarify this puzzle, more experimental information concerning the pattern of the exclusive hadronic $\psi(2S)$ decays relative to the J/ψ is needed.

In this letter we extend the study of $\psi(2S)$ decays into non-VP final states and report on the first observation of anomalous suppressions of $\psi(2S)$ relative to J/ψ decays in vector plus tensor meson (VT) final states, ωf_2, ρa_2, $K^{*0}\overline{K_2}^{*0} + c.c.$, and $\phi f_2'(1525)$. The data were taken with the BES detector at the BEPC e^+e^- storage ring located at the IHEP, Beijing. The data sample corresponds to 3.7 million produced $\psi(2S)'s$. The BES detector has been described in detail elsewhere [5]. Charged particles are tracked using a 40-layer cylindrical drift chamber in a 0.4 Tesla magnetic field with a momentum resolution $\sigma_P/P = 2.1\%\sqrt{1+P^2(GeV/c)}$. The tracking chamber is surrounded by an array of 48 time-of-flight (TOF) counters with resolution of about 450 ps for hadrons. Radially outside of TOF are an electromagnetic calorimeter with resolution $\sigma_E/E = 0.22/\sqrt{E(GeV)}$, $\sigma_\phi = 4.5$ mrad, $\sigma_\theta = 12$ mrad, as well as an array of μ counters.

The ωf_2, ρa_2, $K^{*0}\overline{K_2}^{*0} + c.c.$ and $\phi f_2'$ final states of the $\psi(2S)$ decays have been observed in the modes $\pi^+\pi^-\pi^+\pi^-\pi^0$, $\pi^+\pi^-K^+K^-$ and $K^+K^-K^+K^-$, respectively. Four charged track events with total charge zero and, in the case of $\pi^+\pi^-\pi^+\pi^-\pi^0$, at least two photons have been selected. Particle identification is accomplished by combining the specific ionization measurement from the drift chamber with TOF information, whenever available, to derive probabilites for each charged track to be consistent with the pion or kaon mass hypothesis. Tracks compatible with electron in electromagnetic calorimeter or muon in muon detector are discarded. A particle species dependent correction for energy loss in the beam pipe is made for all charged tracks. A correction of -0.42% is also applied to the momentum of each charged track to compensate for a shift in the BES magnetic field. Events are kinematically fitted to energy-momentum constraints and a cut on the probability > 0.01 is applied. A neutral pion candidate is formed from a pair of showers detected in the calorimeter which yields a $\gamma\gamma$ invariant mass within 2.5σ of the known π^0 mass ($\sigma \sim 14$MeV).

The background contribution to the $\pi^+\pi^-\pi^+\pi^-\pi^0$ final state from $\psi(2S) \to \eta J/\psi$ where η decays to $\pi^+\pi^-\pi^0$ and J/ψ decays to leptons is removed by a cut $M(\pi^+\pi^-) < 2.9\ GeV/c^2$. The contamination of $\psi(2S) \to \pi^+\pi^-J/\psi$ with J/ψ decays into $\pi^+\pi^-\pi^0$ (Figure 1) is rejected by requiring the $\pi^+\pi^-\pi^0$ mass not within $50MeV/c^2$ of known J/ψ mass. The $\pi^+\pi^-\pi^0$ mass distribution of the selected events (4 entries/event) shows a clean ω signal owing to the good mass resolution ($\sigma = 13.4\ MeV/c^2$) and the proximity of the phase space limit. The $\omega\pi^+\pi^-$ events are selected by requiring that $740 < m_{\pi^+\pi^-\pi^0} < 820\ MeV/c^2$. The decay $\psi(2S) \to \omega f_2$ is looked for in the spectrum of $\pi^+\pi^-$ mass recoiling against the ω (figure 3). Taking the expected mass resolution of f_2 about 12.3 MeV/c^2 into account, a fit to a Breit-Wigner function added to a linear background yields 8.8 ± 9.2 ωf_2 events. Using an isospin ratio 2:1 for f_2 decays into $\pi^+\pi^-$ to $\pi^0\pi^0$ and the efficiency of 0.074, one gets an upper limit on the branching fraction

$$B(\psi(2S) \to \omega f_2) < 1.8 \times 10^{-4} \qquad \text{(C.L.=90\%)}$$

The channel ρa_2 is analyzed in $\rho^0\rho^\pm\pi^\mp$ combination which decays to $\pi^+\pi^-\pi^+\pi^-\pi^0$ final state. The best $\rho^0\rho^\pm\pi^\mp$ combination is selected by minimizing the quantity [6]

$$\sqrt{(m_{\pi^+\pi^-} - m_{\rho^0})^2 + (m_{\pi^0\pi^\pm} - m_{\rho^\pm})^2}.$$

and a cut at 200 MeV/c^2 is applied to select $\rho^0\rho^\pm\pi^\mp$ candidates. Events dynamically compatible with the $\omega\pi^+\pi^-$ dynamics are already discarded. The combining $\rho^0\pi^\pm$ and $\rho^\pm\pi^\mp$ mass plot (fig. 4) is fitted to a Breit-Wigner line shape over a quadratic background and the number of ρa_2 events is 3.9 ± 15.7. The expected a_2 mass resolution is around 10.3 MeV/c^2. Using an isospin ratio of $\rho^+a_2^- : \rho^-a_2^+ : \rho^0a_2^0 = 1:1:1$ and the detection efficiency of 0.074, one calculates

$$B(\psi(2S) \to \rho a_2) < 2.5 \times 10^{-4} \qquad \text{(C.L.=90\%)}.$$

In the selection of $\pi^+\pi^-K^+K^-$ final state, each event has four assignments of π^+, π^-, K^+, K^- tracks. The TOF, dE/dx measurement and kinematic fit quality are combined to get a combined probability for an assignment. The combined χ^2 is calculated as:

$$\chi^2 = \sum_i \chi^2(TOF) + \sum_i \chi^2(dE/dx) + \chi^2(4C\_fits).$$

Similarly are the combined degrees of freedom calculated. The track assignment with the highest combined probability is selected for a $\pi^+\pi^-K^+K^-$ candidate. The contamination of $\psi(2S) \to \pi^+\pi^-J/\psi$ is discarded by a cut on the $\pi^+\pi^-$ recoiling mass. The $K^{*0}K^\pm\pi^\mp$ events are selected by requiring that $800 < m(K^\pm\pi^\mp) < 1000\ MeV/c^2$. The contamination of $\psi(2S) \to \phi\pi^+\pi^-$ with $\phi \to K^+K^-$ is negligible. The plot of $K^\pm\pi^\mp$ mass recoiling against the K^{*0} is fitted with two Breit-Wigner curves of K^{*0} and K_2^{*0} over a quadratic background (figure 6). With the expected mass resolution 4.9 MeV/c^2 for the K^{*0} and 6.7 MeV/c^2 for the K_2^{*0}, respectively, the fit yields 1.4 ± 8.6 $K^{*0}K_2^{*0}$ events. Applying $K^\pm\pi^\mp : K^0\pi^0 = 2:1$ for both K^{*0} and K_2^{*0} decay and using the efficiency of 0.171, one gets

$$B(\psi(2S) \to K^{*0}\overline{K_2}^{*0} + c.c.) < 1.4 \times 10^{-4} \qquad (C.L. = 90\%).$$

There are 41 events selected as $K^+K^-K^+K^-$ states. The K^+K^- mass spectrum (4 entries/event) shows the ϕ signal with mass resolution σ =4.1 MeV/c^2. The ϕK^+K^- candidates are selected requiring that $m_{K^+K^-} < 1040\ MeV/c^2$. Fig. 8 shows the spectrum of the K^+K^- mass pair recoiling against the ϕ where no clear evidence for enhancement at the mass of the f_2' resonance is found. The mass resolution of f_2' is expected to be about 6 MeV/c^2. There are 3 events on figure 8 that fall into one width region around the f_2' mass. Taken all of them as f_2' candidates, at the 90% confidence level the number is less than 6.68. The branching fraction is calculated by using the efficiency of 0.181 to be

$$B(\psi(2S) \to \phi f_2'(1525)) < 4.7 \times 10^{-5} \qquad \text{(C.L.=90\%)}.$$

Table I summarizes the results of branching fraction measurements for four decay modes of the $\psi(2S)$. The table includes the Particle Data Group (PDG) values for the corresponding J/ψ decays [7] as well as the ratios of branching fractions of the $\psi(2S)$ to the J/ψ. As can be seen, all these decay channels analyzed are suppressed in $\psi(2S)$ decays. The ratio of $\psi(2S)$ to J/ψ branching fractions deviate substantially from the theoretically predicted value 15%. As VT pair combinations, these decay modes are first examples of non-VP decays of the $\psi(2S)$ which are suppressed anomalously relative to the J/ψ. It is also noted that these VT decays are allowed, in a perturbative QCD quark scheme, by the hadron helicity conservation (HHC) theorem [8], unlike the VP decays which are forbidden by the same theorem [9]. It thus seems even more puzzling why J/ψ decays are enhanced in HHC forbidden channels while $\psi(2S)$ decays are missing in HHC allowed channels. This new anomalous suppression poses a new challenge to the present theoretical understanding of the charmonium decay mechanism.

In conclusion, we have presented first measurements of $\psi(2S)$ decays into ωf_2, ρa_2, $K^{*0}\overline{K_2}^{*0} + c.c.$, and $\phi f_2'(1525)$. Upper limits are set on branching fractions for these decay modes, the ratio of which to the corresponding J/ψ branching fractions is substantially smaller than the theoretical expectation. The puzzle of the hadronic decays of the J/ψ and $\psi(2S)$ extends beyond the VP decay to the VT decay.

Table I. Results on branching fraction measurement for $\psi(2S)$ decays into vector plus tensor mesons. The data of corresponding J/ψ branching fractions [7] are also given for calculating the ratio of $\psi(2S)$ to J/ψ branching fractions. All limits are set at 90% confidence level.

Final state	$B(\psi(2S))$	$B(J/\psi)$	$B(\psi(2S))/B(J/\psi)$
ωf_2	$< 1.8 \times 10^{-4}$	$(4.3 \pm 0.6) \times 10^{-3}$	< 0.042
ρa_2	$< 2.5 \times 10^{-4}$	$(10.9 \pm 2.2) \times 10^{-3}$	< 0.023
$K^{*0}\overline{K_2}^{*0} + c.c.$	$< 1.4 \times 10^{-4}$	$(6.7 \pm 2.6) \times 10^{-3}$	< 0.022
$\phi f_2'$	$< 4.7 \times 10^{-5}$	$(12.3 \pm 0.6 \pm 2.0) \times 10^{-4}$	< 0.038

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FIGURES

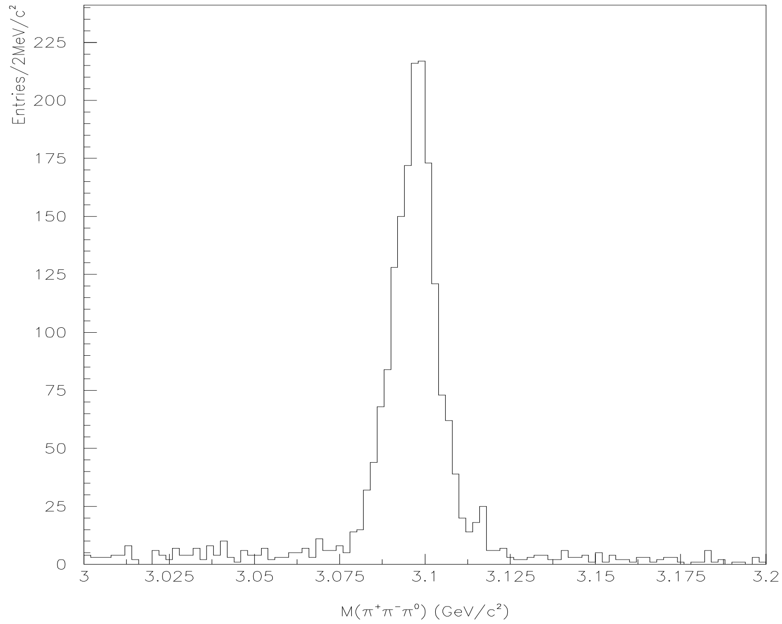

FIG. 1. The $\pi^+\pi^-\pi^0$ mass (4 entries/event) in the $\pi^+\pi^-\pi^+\pi^-\pi^0$ mode shows a significant production of $\psi(2S) \to \pi^+\pi^- J/\psi$ with $J/\psi \to \pi^+\pi^-\pi^0$.

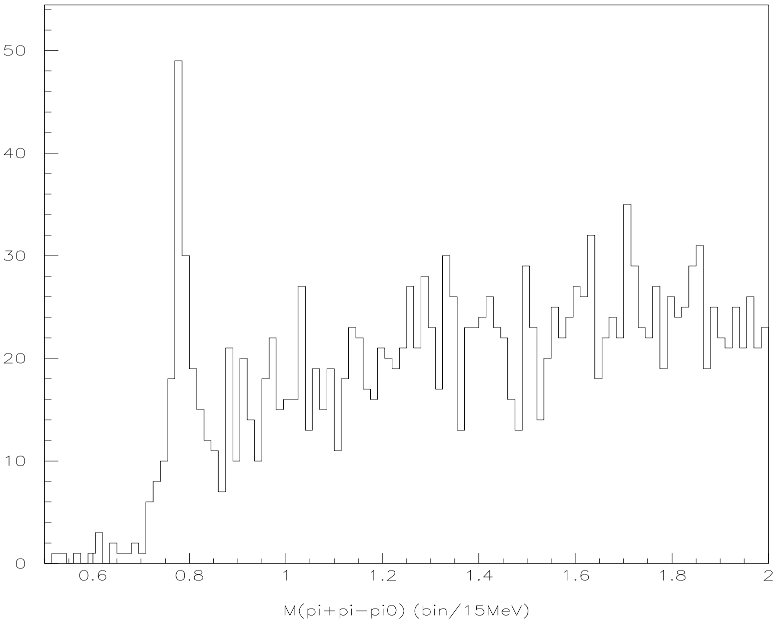

FIG. 2. Mass plot of $\pi^+\pi^-\pi^0$ in $\psi' \to \pi^+\pi^-\pi^+\pi^-\pi^0$

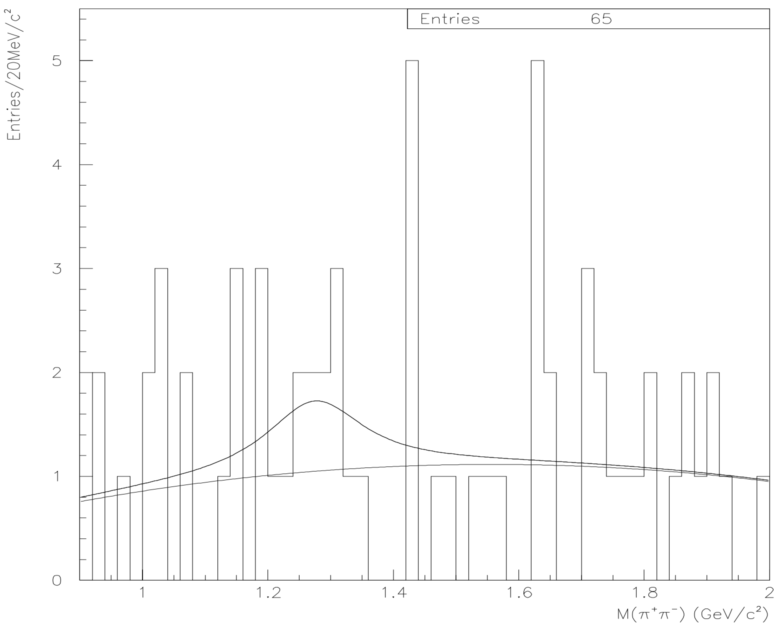

FIG. 3. Fit to plot of $m(\pi^+\pi^-)$ recoiling against the ω.

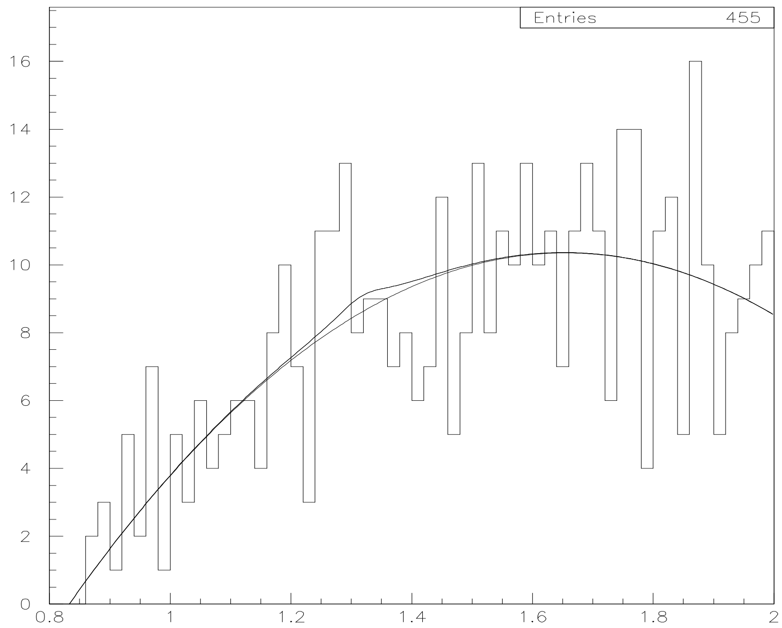

FIG. 4. Fit to plot of $m(\rho\pi)$ in $\psi' \to \rho^0\rho^{\mp}\pi^{\pm}$

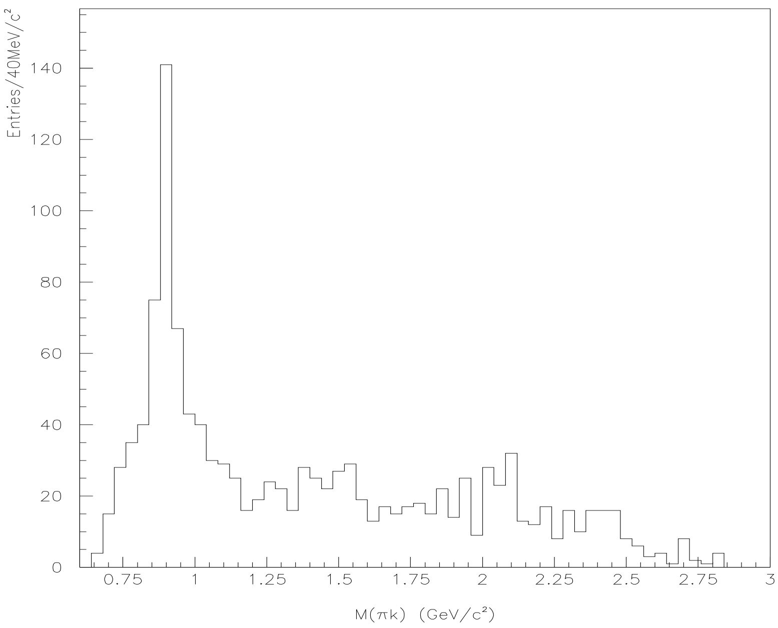

FIG. 5. Spectrum of $\pi^{\pm}k^{\mp}$ mass in the $\pi^{+}\pi^{-}K^{+}K^{-}$ mode.

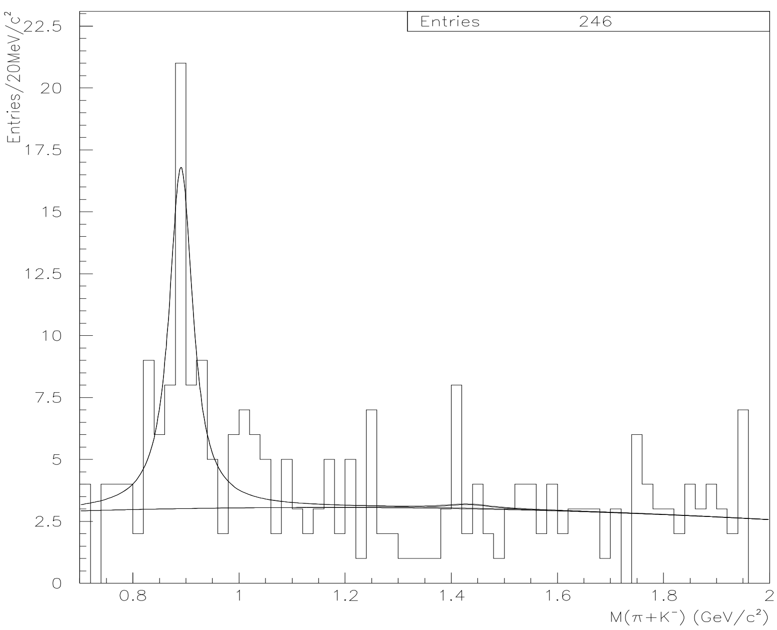

FIG. 6. Fit plot of $m(K^{\pm}\pi^{\mp})$ recoiling against the K^{*0}.

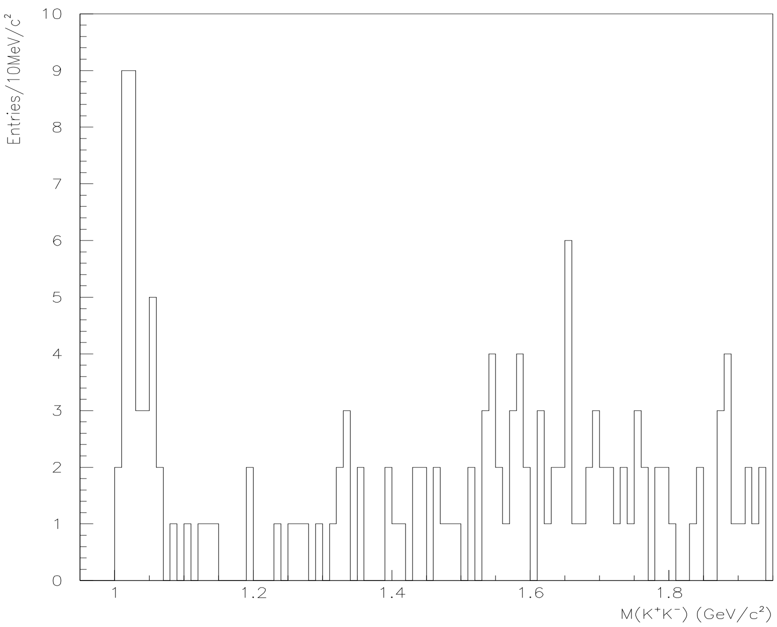

FIG. 7. K^+K^- mass in the $K^+K^-K^+K^-$ mode.

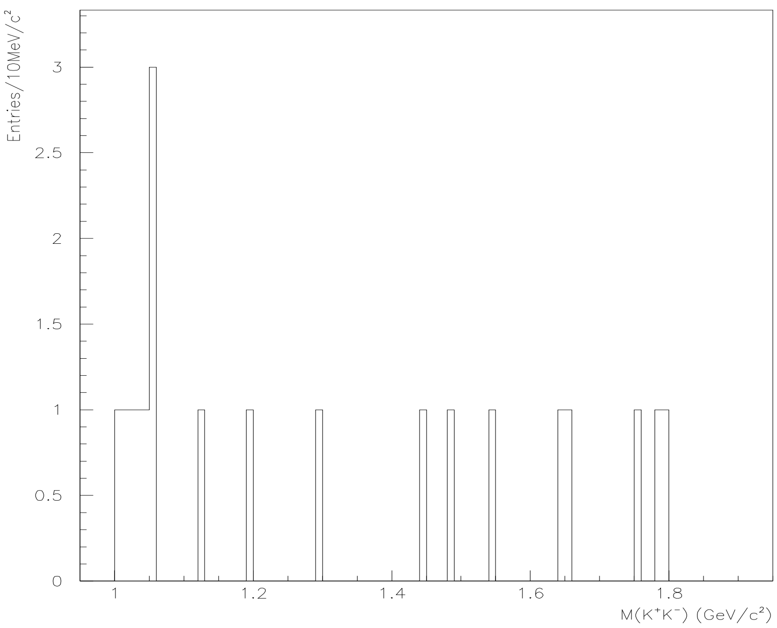

FIG. 8. Spectrum of K^+K^- mass recoiling against the ϕ in the $K^+K^-K^+K^-$ mode.