Search for a Vector Glueball by a Scan of the J/ψ Resonance

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Using the BES detector at BEPC, a search for a vector glueball hypothesized to explain the $\rho\pi$ puzzle in charmonium physics is presented. By analysing the data for $e^+e^- \to \rho\pi$ scan across the J/ψ resonance, no evidence is found to support the existence of such a state.

There is a well known mystery in charmonium physics, the so-called "$\rho\pi$ puzzle". While the prediction based on perturbative QCD,

$$Q_h \equiv \frac{B(\psi(2S) \to h)}{B(J/\psi \to h)} \cong \frac{B(\psi(2S) \to e^+e^-)}{B(J/\psi \to e^+e^-)} = 0.147 \pm 0.023, \quad (1)$$

appears to be satisfied for most hadronic channels, there are startling exceptions that occur for the $\rho\pi$ and $K^*\bar{K}$ final states. The present experimental limits[1] are given at 90% confidence level to be

$$Q_{\rho\pi} < 0.0028 \quad \text{and} \quad Q_{K^*\bar{K}} < 0.0064. \quad (2)$$

An intriguing possible explanation for this anomaly was provided by Ref.[2] based on a refinement of an idea in Ref.[3]. This assumes the general validity of the perturbative QCD theorem that total hadron helicity is conserved in high-momentum-transfer exclusive processes, in which case the decays to $\rho\pi$ and $K^*\bar{K}$ are forbidden for both the J/ψ and the $\psi(2S)$. The observed J/ψ decays to these channels are mediated by an intermediate gluonium state O with quantum number $J^{PC} = 1^{--}$ and a mass near that of the J/ψ.

A direct way to search for the O is to scan the $e^+e^- \to VP$ cross section across the J/ψ resonance[4]. The O, being close in mass to the J/ψ and having decay width Γ_O substantially larger than $\Gamma_{J/\psi}$, should interfere with the J/ψ, producing a distortion of the shape of the J/ψ obtained from the $e^+e^- \to VP$ cross section compared to that of the total hadronic or lepton pair cross section. We report on such a search based on an energy scan done with the BES detector[5] at the BEPC e^+e^- collider.

Cross section measurements were performed at 29 different energy points covering a 40 MeV interval spanning the J/ψ resonance. The data sample corresponds to a total integrated luminosity of 238 nb^{-1}. In this energy region the uncertainty in the c.m. energy of the BEPC collider is ± 0.07 MeV, and the rms c.m. energy spread is 1 MeV [5].

In this analysis, the candidate events for $e^+e^- \to \rho\pi$ are required to have exactly two, oppositely charged and well reconstructed tracks, and between two and six neutral energy clusters in the shower counters. Each charged track is identified as a pion using a combination of the time-of-flight and dE/dx information. "Good" photons are defined as neutral energy deposits that are larger than 80 MeV and are separated from the nearest charged track by more than 8°. The selected events are kinematically fitted to the $\pi^+\pi^-\gamma\gamma$ hypothesis by imposing the energy and momentum constraints corresponding to each scan point.

The $\rho\pi$ scan data are analyzed using a maximum likelihood method. The likelihood function is a product of Poission distributions, one for each center-of-mass energy W_i. At each scan point i, the number of expected events ν_i is given by

$$\nu_i = [\epsilon\sigma_{\rho\pi}(W_i) + \sigma_b(W_i)]\mathcal{L}_i; \tag{3}$$

ϵ is the overall efficiency for identifying $\rho\pi$ events; $\mathcal{L}_i$ is the integrated luminosity; $\sigma_{\rho\pi}(W_i)$ is the corresponding cross section for $\rho\pi$ production; and $\sigma_b(W_i)$ is the background cross section, mainly from $e^+e^- \to J/\psi \to \pi^+\pi^-\pi^0$(direct) and $K^+K^-\pi^0$.

The $\rho\pi$ cross section $\sigma_{\rho\pi}(W)$ is the sum of a nonresonant direct-channel contribution from nonresonant virtual photon annihilation and a resonant term of the Breit-Wigner cross section due to the J/ψ and O propagators for the process $e^+e^- \to \rho\pi$, $\sigma(W)$, that is convoluted with a Gaussian function describing the c.m. energy spread of the collider. Taking into account radiative corrections, $\sigma(W)$ can be expressed as a sum of two parts: the one which corresponds to the normal J/ψ resonance, $\sigma_{J/\psi}(W)$, and the other due to the O and its interference with the J/ψ, $\sigma_{O+I}(W)$.

In fitting the cross section $\sigma_{\rho\pi}$ in Eq.(3) to the data six parameters including the mass and total width of the O, M_O, Γ_O and θ, the possible relative complex phase are treated as free, independent parameters. M_O is limited to vary from $M_{J/\psi} - 80$ MeV to $M_{J/\psi} + 80$ MeV , and Γ_O up to 160 MeV. These ranges are suggested by Ref. [2]. The lower bound of Γ_O is set to 2 MeV. Although in the literature [3,6,2], Γ_O is proposed to be at least on the order of 10 MeV, here a more general search is pursued. In this experiment, 2 MeV is the limit of the sensitivity, due to the finite c.m. energy spread of the collider and the statistics of the data. The best fit values are at $M_O - M_{J/\psi} = 0.7 \pm 0.4$ MeV and $\Gamma_O = 2$ MeV. The fits yield an upper limit with the cross section ratio of

$$\frac{\sigma_{O+I}}{\sigma_{J/\psi}} < 0.098 \;\; (90\%\; C.L.) \tag{4}$$

at $W = M_{J/\psi}$.

However, for the model proposed in Ref.[2], the $\sigma_{J/\psi}$ contribution should observe the perturbative QCD relation of Eq.(1), while the anomalous $J/\psi \to \rho\pi$ decay mode is the contribution from σ_{O+I}. Thus we find, using the experimental limit of $Q_{\rho\pi}$ in Eq.(2), that

$$\frac{\sigma_{O+I}}{\sigma_{J/\psi}} > 51.5, \tag{5}$$

in clear contradiction with the obtained upper bound in Eq.(7).

Fig. 1a shows the measured $\rho\pi$ cross sections as a function of c.m. energy. The solid curve in this figure is the result of the likelihood fit to the null hypothesis (no contribution from O). For comparison, the measured total hadronic cross section and the fitted curve [7] are shown in Fig. 1b. Additional hypothesis testing further indicates that the fit with the null hypothesis is well acceptable.

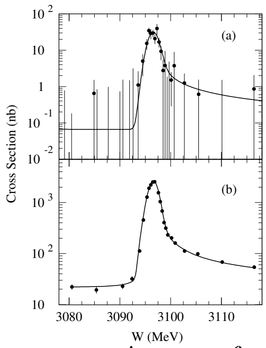

Figure 1: (a) The $\rho\pi$ cross section as a function of c.m. energy: solid curve – the likelihood fit. (b) The total cross section for $e^+e^- \to hadrons$.

In conclusion, the data from a scan of the $\rho\pi$ cross section spanning the J/ψ resonance have been used to search for the vector gluonium state O that was hypothesized to explain the $\rho\pi$ puzzle in J/ψ and $\psi(2S)$ physics. No evidence was found to support the existence of such a vector gluonium state. The shape of the $\rho\pi$ curve is found to be consistent with the shape of the total hadronic curve with no distortion observed within the experimental uncertainties. The $\rho\pi$ puzzle in charmonium physics remains a puzzle.

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