Search for the $\xi(2220)$ and Study of the $X(3872)$ at BaBar

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The BaBar Collaboration performed a search for $\xi(2220)$ production in the initial-state radiation process $e^+e^- \rightarrow \gamma J/\psi, J/\psi \rightarrow \gamma K^+K^-$ or $J/\psi \rightarrow \gamma K^0_SK^0_S$. No evidence for the $\xi(2220)$ resonance has been found. The 90% confidence level upper limits on the product of branching fractions are sensitive to the spin and helicity hypotheses. These upper limits are of the order $10^{-5}$, below the values reported in previous experiments. Also at BaBar, the decays $B \rightarrow J/\psi\pi^+\pi^-\pi^0K$ are studied to search for the decay $X(3872) \rightarrow J/\psi\omega$. This search yields a four standard deviation evidence for $X(3872) \rightarrow J/\psi\omega$, with product branching fractions of $\mathcal{B}(B^+ \rightarrow X(3872)K^+) \times \mathcal{B}(X(3872) \rightarrow J/\psi\omega) = [0.6 \pm 0.2(\text{stat}) \pm 0.1(\text{syst})] \times 10^{-5}$, and $\mathcal{B}(B^0 \rightarrow X(3872)K^0) \times \mathcal{B}(X(3872) \rightarrow J/\psi\omega) = [0.6 \pm 0.3(\text{stat}) \pm 0.1(\text{syst})] \times 10^{-5}$. A detailed study of the $\pi^+\pi^-\pi^0$ mass distribution from $X(3872)$ decay favors a negative-parity assignment but does not rule out the positive-parity hypothesis.

35th International Conference of High Energy Physics - ICHEP2010,
July 22-28, 2010
Paris France

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1. Introduction

The $\xi(2220)$ resonance is a glue-ball candidate whose existence is not yet established. The $X(3872)$ has been observed in several decay modes and by several Collaborations. However, the nature of the $X(3872)$ is still not yet understood. We present the BABAR results on the search for $\xi(2220)$ in radiative $J/\psi$ decays [1], and on the evidence for the decay $X(3872) \rightarrow J/\psi \omega$ [2].

2. Search for $\xi(2220)$ in Radiative $J/\psi$ Decays

In 1986, the Mark III Collaboration reported [3] a narrow resonance with a mass of $\sim 2.2$ GeV/$c^2$ in the radiative decay $J/\psi \rightarrow \gamma \xi(2220)$, $\xi(2220) \rightarrow K^+K^-$ and $\xi(2220) \rightarrow K_S^0K_S^0$. A 3.6 and 4.7 standard deviation significance for $J/\psi \rightarrow \gamma K^+K^-$ and $J/\psi \rightarrow \gamma K_S^0K_S^0$ modes were reported. The BES Collaboration also reported evidence for the $\xi(2220)$ in $J/\psi$ radiative decays at a comparable level of significance [4]. Moreover, there are indications for a similar structure in $\pi^-p$ and $K^-p$ collisions [5, 6, 7]. On the other hand, searches for $\xi(2220)$ in $p\bar{p}$ collisions [8, 9], or two photon production [10, 11], have been inconclusive.

In a recent BABAR search [12], the initial-state radiation (ISR) events $e^+e^- \rightarrow \gamma_{\text{ISR}}J/\psi$, $J/\psi \rightarrow \gamma KK$ ($KK$ indicates $K^+K^-$ or $K_S^0K_S^0$), were studied to search for the $\xi(2220)$. The BABAR data sample is equivalent to an integrated luminosity of 460 fb$^{-1}$, recorded at or slightly below 10.58 GeV.

The $\gamma K^+K^-$ and $\gamma K_S^0K_S^0$ mass distributions are shown in Fig. 1, where a large $J/\psi$ signal is observed in both decay modes. The background under the signal arises mainly from partially reconstructed $J/\psi \rightarrow KKK$ or $e^+e^- \rightarrow q\bar{q}_{\text{ISR}}$ events, where $X$ can be any final state system and $q = u, d, s, c$. The $\gamma \gamma K$ candidates are required to originate from a common vertex and are kinematically constrained to the $J/\psi$ nominal mass. Each $K_S^0$ candidate in the decay $J/\psi \rightarrow \gamma K_S^0K_S^0$ is reconstructed from two oppositely charged tracks identified as pions. The photon emitted from the $J/\psi$ has a minimum energy of 300 MeV.

The $K^+K^-$ and $K_S^0K_S^0$ mass distributions are shown in Fig. 3. The inclusive background and background events corresponding to $J/\psi \rightarrow \gamma J/\psi(1525)$ and $J/\psi \rightarrow \gamma f_0(1710)$, are present. The small data excess at $\sim 1.25$ GeV/$c^2$ in the charged mode may be due to the process $J/\psi \rightarrow \rho^0\pi^0$, with $\rho^0 \rightarrow \pi^+\pi^-$, where both pions are misidentified as kaons, and one of the photons from the $\pi^0$ is undetected. To extract the $\xi(2220)$ yield, unbinned-maximum likelihood fits in the range $1.9 \leq m_{KK} \leq 2.6$ GeV/$c^2$ are performed. The signal is described as a Breit-Wigner function convolved with a Gaussian resolution function. The background is parametrized as a second-order Chebychev polynomial. Both the mass and width of the $\xi(2220)$ are fixed. There is no evidence for $\xi(2220)$ state. The upper limits on the product of branching fractions depend on the spin and helicity assignment. For all hypotheses of spin and helicity, the 90% confidence level upper limits for the $J/\psi \rightarrow \gamma \xi(2220)$, $\xi(2220) \rightarrow KK$ product branching fractions are in the range $(1.2 - 3.6) \times 10^{-5}$, smaller or close to the values reported by the Mark III Collaboration.

3. Evidence for $X(3872) \rightarrow J/\psi \omega$

With the discovery [13] of the $X(3872)$ by the Belle Collaboration in 2003, interest in charmonium spectroscopy has been renewed. Confirmation of this state was obtained by CDF, D0, and...
In this analysis, \( \omega \rightarrow \pi^+ \pi^- \pi^0 \) candidates were required to satisfy \( 0.7695 \leq m_{3\pi} \leq 0.7965 \text{ GeV}/c^2 \), and no evidence for the decay \( X(3872) \rightarrow J/\psi \omega \) was found.
In a more recent B\(\text{A}\)\(\text{B}\)\(\text{A}\)\(\text{R}\) analysis [2] the same decay mode \(B \to J/\psi \omega K\) has been revisited using a slightly larger dataset and extending the range of the \(\omega\)-mass region to \(0.74 \leq m_{3\pi} \leq 0.7965\) GeV/c\(^2\). All other selection criteria are the same as in the previous analysis [23]. The efficiency as a function of \(m_{J/\psi \omega}\) varies between 5 and 7%, and the mass resolution degrades from 6.5 MeV/c\(^2\) to 9 MeV/c\(^2\), over the accessible mass range. The \(J/\psi \omega\) mass \((m_{J/\psi \omega})\) distribution, after background subtraction, shows a clear signal corresponding to \(Y(3940) \to J/\psi \omega\), and evidence for \(X(3872) \to J/\psi \omega\). These signals are present in both \(B^+\) and \(B^0\) samples [25] as shown in Fig. 3. The \(m_{J/\psi \omega}\) distributions are fitted simultaneously after correcting for efficiency and branching fractions. The function used in the fit has three components: an \(X(3872)\) component which is a Gaussian function with fixed \(\sigma = 6.7\) MeV/c\(^2\); a \(Y(3940)\) contribution described by a relativistic \(S\)-wave Bei-Wigner function; and a nonresonant contribution given by a broad Gaussian function multiplied by \(m_{J/\psi \omega}\). The \(Y(3940)\) and nonresonant components are multiplied by the phase space factor \(pq\), where \(p\) is the kaon momentum in the \(B\) rest frame and \(q\) is the \(J/\psi\) momentum in the \(J/\psi 3\pi\) system. A good fit is obtained \((\chi^2/NDF = 54.7/51)\). The fit results are summarized in Table 1.

When combined with the product branching fraction for \(B \to X(3872) K\), \(X(3872) \to J/\psi \pi^+ \pi^-\) [17], the B\(\text{A}\)\(\text{B}\)\(\text{A}\)\(\text{R}\) ratio of branching fractions \(\mathcal{B}(X(3872) \to J/\psi \omega)/\mathcal{B}(X(3872) \to J/\psi \pi^+ \pi^-)\) has the value 0.7 ± 0.3 and 1.7 ± 1.3 (combined uncertainties) for \(B^+\) and \(B^0\), respectively. These results provide an average ratio of 0.8 ± 0.3, which is in agreement with the Belle result [19] of 1.0 ± 0.4 ± 0.3.

To judge whether the 3\(\pi\) originate from \(\omega\) decays or not, 3\(\pi\) events in the mass range of \(\omega\) and \(\eta\) signals are selected. The sum of the \(\omega\)-Dalitz-plot weights [23] is consistent with the number of 3\(\pi\) events around the \(\omega\) signal. The same sum for the events around \(\eta\) signal is consistent with zero. The sum for the weighted 3\(\pi\) mass distribution associated with the \(X(3872)\) is consistent with the number of events observed. This justifies the \(\omega\) interpretation of the events in the \(X(3872)\) region.
The events with $3.8625 \leq m_{J/\psi\omega} \leq 3.8825$ GeV/$c^2$ are selected for further investigation of the $X(3872)$ parity. For those events, the $m_{3\pi}$ distributions are shown in Fig. 4 and compared with the Monte Carlo simulation for different spin assignment. The $P$-wave assignment is favored ($\chi^2/NDF = 3.53/5$) over the $S$-wave ($\chi^2/NDF = 10.17/5$), hence $J^P = 2^-$ is favored over $J^P = 1^+$, but the latter cannot be ruled out. Clearly this analysis would benefit greatly from the much larger datasets available from future facilities such as the Super $B$-factories.
4. Acknowledgments

I would like to thank my \textsc{BaBar} Collaborators, especially Vera Lüth, Bill Dunwoodie, and Bryan Fulsom, for their contributions to the presentation at the ICHEP meeting, and to these proceedings.

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