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Study of the $\psi(2S)\pi^+\pi^-$ final state at BABAR

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Summary. — We present new results on the study of the $\psi(2S)\pi^+\pi^-$ final state from the *BABAR* experiment located at the PEP-II asymmetric energy e^+e^- storage ring at the SLAC National Accelerator Laboratory.

PACS 13.66.Bc – Hadron production in e^-e^+ interactions.
PACS 14.40.Lb – Charmed mesons ($|C| > 0, B = 0$).
PACS 14.40.Pq – Heavy quarkonia.

1. – Analysis overview

We utilize the Initial State Radiation (ISR) mechanism to study the reaction $e^+e^- \to \psi(2S)\pi^+\pi^-$ in the center-of-mass (c.m.) energy (E_{cm}) range 3.95–5.95 GeV, where the $\psi(2S)$ decays to $J/\psi\pi^+\pi^-$ or to l^+l^-; for the latter, l^+l^- represents either e^+e^- or $\mu^+\mu^-$. We use a data sample corresponding to an integrated luminosity of 520 fb^{-1}, recorded by the *BABAR* detector at the SLAC PEP-II asymmetric-energy e^+e^- collider operating at and near the c.m. energies of the $\Upsilon(nS)$ ($n = 2, 3, 4$) resonances. The detector is described elsewhere [1].

We reconstruct events corresponding to the reaction $e^+e^- \to \gamma_{ISR}\psi(2S)\pi^+\pi^-$, where γ_{ISR} represents a photon that is radiated from the initial state $e^\pm$, thus lowering the c.m. energy of the e^+e^- collision which produce the $\psi(2S)\pi^+\pi^-$ system. We do not require observation of the ISR photon, since it would be detectable in the EMC for only $\sim 15\%$ of the events.

We estimate the background for the decay mode $\psi(2S) \to J/\psi\pi^+\pi^-$ using events that have a $J/\psi\pi^+\pi^-$ mass in either of the $\psi(2S)$ sideband regions (3.566, 3.666) or (3.706, 3.806) GeV/c^2. For the decay mode $\psi(2S) \to e^+e^-$, the corresponding regions of e^+e^- mass are (3.476, 3.576) and (3.776, 3.876) GeV/c^2, while for $\psi(2S) \to \mu^+\mu^-$ the sideband regions of mass are (3.516, 3.596) and (3.776, 3.856) GeV/c^2.

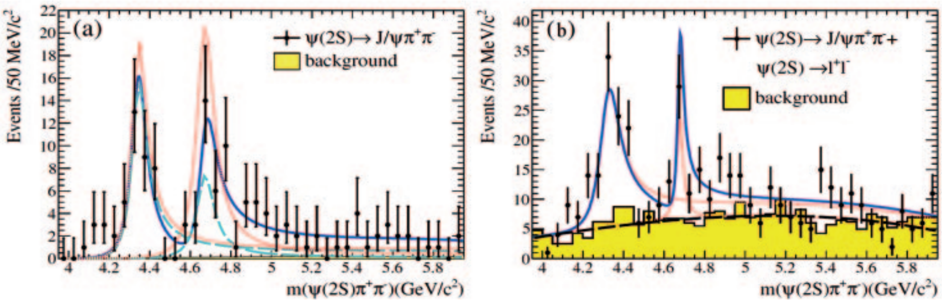

Fig. 1. – (a) The $\psi(2S)\pi^+\pi^-$ invariant-mass distribution from threshold to $5.95\,\mathrm{GeV}/c^2$ for $\psi(2S) \to J/\psi\pi^+\pi^-$; the points with error bars represent the data in the signal region, and the shaded histogram is the background estimated from the $\psi(2S)$ sideband regions. The solid curve shows the result of the fit described in the text. The dashed (dotted) curves indicate the individual resonant contributions for constructive (destructive) interference. (b) The combined $\psi(2S)\pi^+\pi^-$ invariant mass distribution for $\psi(2S) \to J/\psi\pi^+\pi^-$ and $\psi(2S) \to l^+l^-$. There is only one solution in this case.

2. – Results

Figure 1 shows the $\psi(2S)\pi^+\pi^-$ invariant mass distributions for the selected $\psi(2S)$ events corresponding to the decays (a) $\psi(2S) \to J/\psi\pi^+\pi^-$, and (b) the combined sample for $\psi(2S) \to J/\psi\pi^+\pi^-$ and $\psi(2S) \to l^+l^-$. The background is estimated from the $\psi(2S)$ mass sidebands as described above.

In fig. 1 two structures are evident, the first near $4.35\,\mathrm{GeV}/c^2$, and the second near $4.65\,\mathrm{GeV}/c^2$. We attribute these peaks to the Y (4360) [2] and to the Y (4660) [3], respectively. We first perform an unbinned, extended-maximum-likelihood fit to the distribution shown in fig. 1(a) in order to extract the parameter values of the resonances. We then perform a second fit to the combined $J/\psi\pi^+\pi^-$ and l^+l^- data of fig. 1(b), where the signal yields are larger, but where the presence of the large background associated with the dilepton channel may offset the impact of the statistical gain.

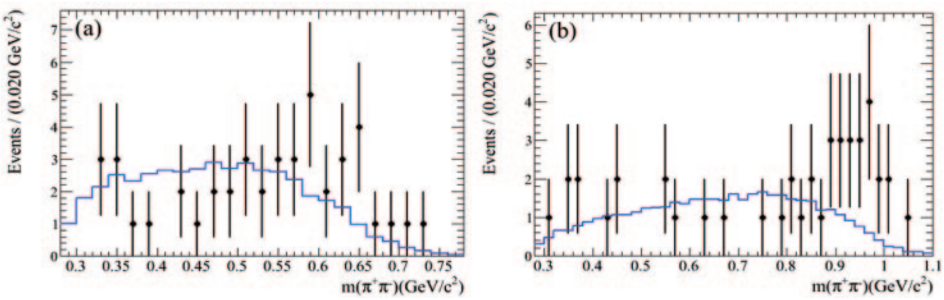

Fig. 2. – The $\pi^+\pi^-$ invariant-mass spectrum for the $\psi(2S) \to J/\psi\pi^+\pi^-$ channel in the $\psi(2S)\pi^+\pi^-$ mass regions (a) $4.0\,\mathrm{GeV}/c^2 < m(\psi(2S)\pi^+\pi^-) < 4.5\,\mathrm{GeV}/c^2$, and (b) $4.5\,\mathrm{GeV}/c^2 < m(\psi(2S)\pi^+\pi^-) < 4.9\,\mathrm{GeV}/c^2$. The histogram represents a MC distribution generated according to the phase space decay of (a) one resonance with a mass of $4.360\,\mathrm{GeV}/c^2$ and width 70 MeV, and (b) one resonance with a mass of $4.660\,\mathrm{GeV}/c^2$ and width 50 MeV.

We describe the background contribution by a fourth-order polynomial in $\psi(2S)\pi^+\pi^-$ mass, for the fit to the data of fig. 1(a), and by a third-order polynomial for the fit to the data of fig. 1(b). The signal lineshape is described by a function which includes two distint relativistic Breit Wigner, and allow the possibility of interference between the two resonant amplitudes, since they have the same quantum numbers ($J^{PC} = 1^{--}$); the mass-dependent selection efficiency is properly taken into account. Moreover, the signal lineshape is convolved with a Gaussian resolution function obtained from MC simulation. This function has r.m.s. deviation which increases linearly from $2\,\mathrm{MeV}/c^2$ at $3.95\,\mathrm{MeV}/c^2$ to $5\,\mathrm{MeV}/c^2$ at $5.95\,\mathrm{MeV}/c^2$.

The results of the fits are shown in fig. 1(a) and in fig. 1(b). The significance of the Y(4660) signal for both fits is greater than 5 σ. For the fit to the distribution in fig. 1(a), we obtain two solutions: one corresponding to constructive interference and one to destructive interference between the resonant amplitudes. The mass and the width values of the resonances are the same for each solution. For the fit to the distribution in fig. 1(b), the constructive and destructive interference solutions coalesce, and only a solution showing constructive interference remains.

We conclude that the inclusion of the $\psi(2S) \to l^+l^-$ events yields no significant improvement in our results, and because of the large associated background we confine our attention to the results from $\psi(2S) \to J/\psi\pi^+\pi^-$ decay in the remainder of the analysis.

For the decay mode $\psi(2S) \to J/\psi\pi^+\pi^-$, we calculate the $e^+e^- \to \psi(2S)\pi^+\pi^-$ cross section after background subtraction for each $\psi(2S)\pi^+\pi^-$ mass interval. We obtain a model-independent integrated cross section value of 311^{+76}_{-30} (stat) $\pm$ 11 (syst) pb for the region 3.95–5.95 GeV.

In fig. 2 we show the $\pi^+\pi^-$ invariant mass distributions for events in the $\psi(2S)\pi^+\pi^-$ invariant mass regions (a) $4.0\,\mathrm{GeV}/c^2 < m(\psi(2S)\pi^+\pi^-) < 4.5\,\mathrm{GeV}/c^2$, and (b) $4.5\,\mathrm{GeV}/c^2 < m(\psi(2S)\pi^+\pi^-) < 4.9\,\mathrm{GeV}/c^2$. The distributions are consistent with previous measurements [3]. In each case, the mass distribution appears to differ slightly from the phase space expectation, as shown by the corresponding histogram. For the higher mass resonance, there is some indication of an accumulation of events in the vicinity of the $f_0(980)$. The small number of events involved precludes the drawing of any definite conclusion about this.

3. – Summary

In summary, we have used ISR events to study the reaction $e^+e^- \to \psi(2S)\pi^+\pi^-$ in the c.m. energy range 3.95–5.95 GeV. We observe two resonant structures, which we interpret as the Y(4360) and the Y(4660), respectively. For the first resonance we obtain $m_{Y(4360)} = 4340 \pm 16$ (stat) $\pm$ 9 (syst) MeV/c^2 and $\Gamma_{Y(4360)} = 94 \pm 32$ (stat) $\pm$ 13 (syst) MeV/c^2, and for the second $m_{Y(4660)} = 4669 \pm 91$ (stat) $\pm$ 3 (syst) MeV/c^2 and $\Gamma_{Y(4660)} = 104 \pm 48$ (stat) $\pm$ 10 (syst) MeV/c^2. We thus confirm the report in ref. [3] of a structure near $4.65\,\mathrm{GeV}/c^2$, and obtain consistent parameter values for this state.

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