PROCEEDINGS OF SCIENCE

Recent Bottomonium Results from BABAR

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Preliminary results from spectroscopic bottomonium studies of the $\Upsilon(2S)$ and $\Upsilon(3S)$ datasets collected by BABAR are presented.

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1. Introduction

At the end of its operation, the *BABAR* experiment collected large datasets of approximately 122M $\Upsilon(3S)$ and 100M $\Upsilon(2S)$ events, creating renewed possibilities for spectroscopic research of the bottomonium system. Four new results are described herein: observation of the hadronic decay $\Upsilon(1D_2) \to \pi^+\pi^-\Upsilon(1S)$, a study of the $\Upsilon(2S)$ and $\Upsilon(3S)$ inclusive converted photon spectrum, and searches for $h_b(1P)$ in both $\Upsilon(3S) \to \pi^+\pi^+ h_b(1P)$ and $\Upsilon(3S) \to \pi^0 h_b(1P)$, $h_b(1P) \to \gamma\eta_b(1S)$.

2. $\Upsilon(1D_J)$ hadronic decays

The $\Upsilon(1D_J)$ was first observed by CLEO in the decay $\Upsilon(3S) \to \gamma\gamma\Upsilon(1D_J) \to \gamma\gamma\gamma\gamma\Upsilon(1S)$ [1], with a measured mass of $10161.1 \pm 0.6 \pm 1.6\,\mathrm{MeV}/c^2$ and an assumed value of $J = 2$. In the same analysis, CLEO set a 90% confidence level (C.L.) upper limit of $\mathscr{B}(\Upsilon(1D_J) \to \pi^+\pi^-\Upsilon(1S)) < 4\%$.

The *BABAR* analysis reconstructs the decay chain $\Upsilon(3S) \to \gamma\gamma\Upsilon(1D_J)$, $\Upsilon(1D_J) \to \pi^+\pi^-\ell^+\ell^-$. Exactly four tracks are required in the event, and the mass of the lepton pair is constrained to the nominal mass of the $\Upsilon(1S)$ [2]. In the case of multiple candidates, the best is chosen by minimizing a χ^2 value based on the energy of the candidate photons compared to the energy expected for the $\Upsilon(3S) \to \gamma\gamma\Upsilon(1D_J)$ transition. The $\Upsilon(1D_J)$ mass has an experimental resolution of $\sim 3\,\mathrm{MeV}/c^2$.

A maximum likelihood fit is performed to the $m_{\pi^+\pi^-\ell^+\ell^-}$ spectrum. The fit contains three $\Upsilon(1D_J)$ signal components and several Monte Carlo-determined backgrounds. The backgrounds are well-separated from the signal and small in size. They generally consist of known $\Upsilon(3S)$ decay chains resulting in a true $\Upsilon(1S)$ with misreconstructed intermediate photons and $\pi^0 \to \gamma\gamma$ decays.

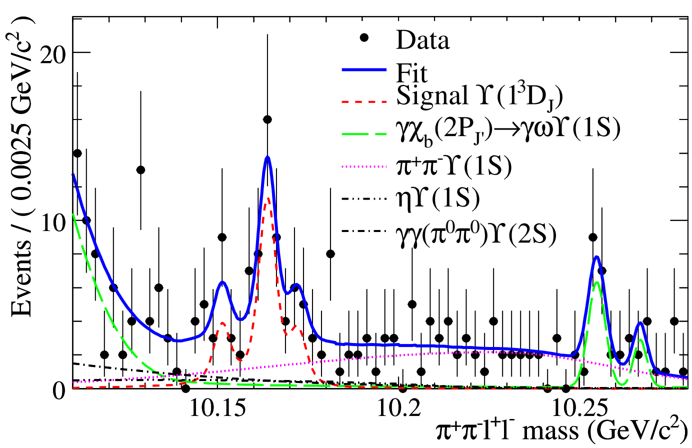

Figure 1: $\Upsilon(1D_J)$ results, with the fit components labeled in the legend.

The results of the fit are shown in Figure 1. The decay of a state with $m_{\Upsilon(1D_J)} = 10164.5 \pm 0.8 \pm 0.6\,\mathrm{MeV}/c^2$ is observed with a total significance of 5.8σ. Comparing the $\pi^+\pi^-$ invariant mass with theoretical distributions [3], the χ^2 probability strongly prefers the $L = 2$. The π helicity angle is consistent with $J = 2$, and under this assumption, information from the angle between the $\pi^+\pi^-$ and $\ell^+\ell^-$ planes [4] is consistent with $J^P = 2^-$. Further details on this analysis can be found in [5].

3. $\Upsilon(2,3S)$ converted photon spectrum

The bottomonium ground state, $\eta_b(1S)$, was observed and confirmed in the decays $\Upsilon(3,2S) \rightarrow \gamma\eta_b(1S)$ [6]. The world average $\eta_b(1S)$ mass is found to be $m_{\eta_b(1S)} = 9390.9 \pm 2.8\,\text{MeV}/c^2$, a value smaller than theoretically predicted [7]. The experimental results are from the inclusive centre-of-mass photon energy (E^*_γ) spectrum as measured by electromagnetic calorimetry. The analysis presented here reconstructs the same spectrum using photons converted into e^+e^- pairs in the detector material, leading to a large improvement in E^*_γ resolution at the cost of a reduced event yield.

The converted photons are reconstructed by a dedicated vertexing algorithm with requirements on the e^+e^- pair mass, vertex radius, and topological consistency with a converted photon event. Selection criteria based on the number of tracks, $|cos(\theta_{thrust})|$, and vetoing π^0 decays are also applied. A binned χ^2 fit is performed simultaneously to the E^*_γ spectrum from the $\Upsilon(2S)$ and $\Upsilon(3S)$ data.

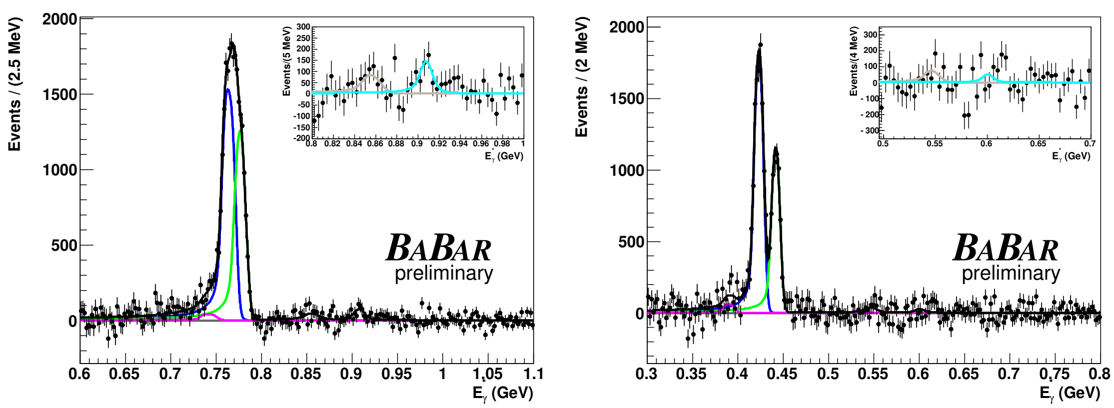

Figure 2: Fit results for the inclusive converted photon spectrum for $\Upsilon(3S)$ (left) and $\Upsilon(2S)$ (right). The purple, blue, green, gray, and cyan curves represent $\chi_{b0,1,2} \rightarrow \gamma\Upsilon(1S)$, initial state radiation (ISR), and $\Upsilon(nS) \rightarrow \gamma\eta_b(1S)$events, respectively.

The background-subtracted fit results are shown in Figure 2. $\chi_{b1,2} \rightarrow \gamma\Upsilon(1S)$ decays are clearly resolved, and the associated product of branching fractions $\mathscr{B}(\Upsilon(nS) \rightarrow \gamma\chi_{bJ}) \times \mathscr{B}(\chi_{bJ} \rightarrow \Upsilon(1S))$ are consistent with and improve upon the expected values [2]. In the $\Upsilon(3S)$ dataset, there is some evidence for both ISR and $\eta_b(1S)$ signal peaks. The best fit result for $m_{\eta_b(1S)}$ is $12.4^{+3.8}_{-4.0}\,\text{MeV}/c^2$ higher than the average of the previous values. However, the total significance of this measurement is less than 3σ. Similarly, if the $\eta_b(1S)$ mass is constrained to the nominal value in the fit, no evidence (2.3σ, statistical only) is found for an $\eta_b(1S)$ signal.

4. Search for $h_b(1P)$

The $h_b(1P)$ state has never been observed experimentally. Two possibly accessible production channels are $\Upsilon(3S) \rightarrow \pi^+\pi^- h_b(1P)$ and $\Upsilon(3S) \rightarrow \pi^0 h_b(1P)$, with expected branching fractions on the order of 10^{-3} [8]. Previous searches by CLEO set upper limits at this level [9]. *BABAR* analyses both production modes by performing fits to the distribution of the mass recoiling against the pion system, referred to here as m_R or $m.m.(\pi^0)$.

In the first case, a pair of oppositely-charged tracks are reconstructed as the dipion pair, and selection criteria based on the event energy and shape, number of tracks, and vetoing K_S^0 decays are applied. The binned χ^2 fit to m_R includes several components from known bottomonium transitions, shown in Figure 3. In the expected mass range for the $h_b(1P)$ near $9900\,\mathrm{MeV}/c^2$, no evidence for a signal is found, and a 90% C.L. upper limit of $\mathscr{B}(\Upsilon(3S) \to \pi^+\pi^- h_b(1P)) < 2.5 \times 10^{-4}$ is derived.

For the second search, the decay chain $\Upsilon(3S) \to \pi^0 h_b(1P)$, $h_b(1P) \to \gamma\eta_b(1S)$ is reconstructed by requiring a photon with an energy consistent with that for the $h_b(1P) \to \gamma\eta_b(1S)$ transition. Additional selection criteria are applied based on the number of tracks, event shape, and vetoing extraneous π^0 events. The number of π^0 events in $m.m.(\pi^0)$ is determined from a fit to the $m_{\gamma\gamma}$ distribution in each $m.m.(\pi^0)$ bin. The resulting distribution contains a broad peaking signal component above a smooth background, as seen in Figure 3. The fit to this distribution shows preliminary evidence (2.7σ) for a $h_b(1P)$ signal, leading to a branching fraction of $\mathscr{B}(\Upsilon(3S) \to \pi^0 h_b(1P)) = (3.1 \pm 1.1 \pm 0.4) \times 10^{-4}$ corresponding to limits of $1.5 \times 10^{-4} < \mathscr{B}(\Upsilon(3S) \to \pi^0 h_b(1P)) < 4.9 \times 10^{-4}$. Assuming $\mathscr{B}(h_b(1P) \to \gamma\eta_b(1S)) \sim 41\%$ [10], the BABAR measurements can be combined to produce a 90% C.L. upper limit on the ratio of branching fractions of $\frac{\mathscr{B}(\Upsilon(3S)\to\pi^0 h_b(1P))}{\mathscr{B}(\Upsilon(3S)\to\pi^+\pi^- h_b(1P))} > 3.2$.

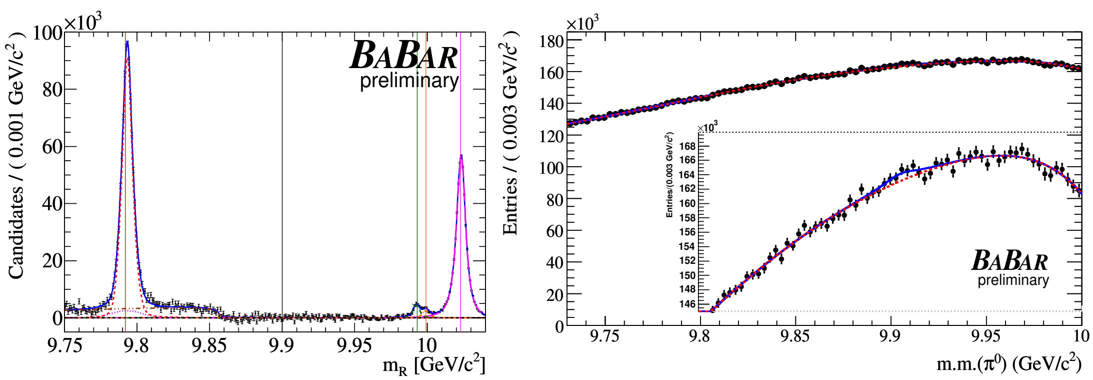

Figure 3: Results of the search for $\Upsilon(3S) \to \pi^+\pi^- h_b(1P)$ (left) and $\Upsilon(3S) \to \pi^0 h_b(1P)$ (right). In the leftmost figure, the red, brown, black, green, orange, and magenta lines indicate $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$, $K_S^0 \to \pi^+\pi^-$, $\Upsilon(3S) \to \pi^+\pi^- h_b(1P)$, $\chi_{b1,2}(2P) \to \pi^+\pi^-\chi_{b1,2}(1P)$, and $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(2S)$ decays, respectively. In the rightmost figure, the red line represents background while the blue denotes the presence $\Upsilon(3S) \to \pi^0 h_b(1P)$ signal events.

References

[1] G. Bonvicini *et al.* (CLEO Collaboration), Phys. Rev. D **70**, 032001 (2004).

[2] C. Amsler *et al.* (Particle Data Group), Phys. Lett. B **667**, 1 (2008) and 2009 partial update for the 2010 edition (URL: http://pdg.lbl.gov).

[3] T.M. Yan, Phys. Rev. D **22**, 1652 (1980); Y.P. Kuang, S.F. Tuan, and Y.M. Yan, Phys. Rev. D **37**, 1210 (1988).

[4] J.R. Dell'Aquila and C.A. Nelson, Phys. Rev. D **33**, 80 (1986).

[5] P. del Amo Sanchez *et al.* (BABAR Collaboration), submitted to Phys. Rev. Lett., arXiv:1004.0175, (2010).

[6] B. Aubert *et al.* (BABAR Collaboration), Phys. Rev. Lett. **101**, 071801 (2008); B. Aubert *et al.* (BABAR Collaboration), Phys. Rev. Lett. **103**, 161801 (2009); G. Bonvicini *et al.* (CLEO Collaboration), Phys. Rev. D **81**, 031104(R) (2010).

[7] B.A. Kniehl *et al.*, Phys. Rev. Lett. **92**, 242001 (2004); A. Gray *et al.* (HPQCD and UKQCD Collaborations), Phys. Rev. D **72**, 094507 (2005); T. Burch *et al.* (Fermilab Lattice and MILC Collaboration), Phys. Rev. D **81**, 034508 (2010); S. Meinel, arXiv:1007.3966, (2010).

[8] M.B. Voloshin, Sov. J. Nucl. Phys. **43**, 1011 (1986); S.F. Tuan, Mod. Phys. Lett. A **7**, 3527 (1992).

[9] I.C. Brock *et al.* (CLEO Collaboration), Phys. Rev. D **43**, 1448 (1991); F. Butler *et al.* (CLEO Collaboration), Phys. Rev. D **49**, 40 (1994).

[10] S. Godfrey and J.L. Rosner, Phys. Rev. D **66**, 014012 (2002).