PROCEEDINGS OF SCIENCE

Search for a low-mass Higgs boson (A^0) at BABAR

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The BABAR Collaboration has performed three searches for a light Higgs boson, A^0, in radiative Upsilon (Υ) decays: $\Upsilon(3S) \to \gamma A^0$, $A^0 \to \tau^+\tau^-$; $\Upsilon(nS) \to \gamma A^0$, $A^0 \to \mu^+\mu^-$ $(n = 2,3)$; and $\Upsilon(3S) \to \gamma A^0$, $A^0 \to$ invisible. Such a Higgs boson (A^0) appears in the Next-to-Minimal Supersymmetric extensions of the Standard Model, where a light *CP*-odd Higgs boson couples strongly to b-quarks. The searches are based on data samples that consist of 122×10^6 $\Upsilon(3S)$ and 99×10^6 $\Upsilon(2S)$ decays, collected by the BABAR detector at the SLAC National Accelerator Laboratory. The searches reveal no evidence for an A^0, and product of branching fractions upper limits, at 90% C.L., of $(1.5-16) \times 10^{-5}$, $(0.44-44) \times 10^{-6}$, and $(0.7-31) \times 10^{-6}$ were obtained for these searches, respectively. Also, we set the upper limits $\mathscr{B}(\eta_b \to \tau^+\tau^-) < 8\%$ and $\mathscr{B}(\eta_b \to \mu^+\mu^-) < 0.9\%$.

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PoS(EPS-HEP 2009)232

1. Introduction

The origin of mass in the Standard Model (SM) arises through the Higgs mechanism where an elementary scalar acquires a vacuum expectation value. The minimal SM has a single Higgs doublet model; however, in many theories beyond the SM there may be more elaborate Higgs sector. The minimal supersymmetric Standard Model (MSSM) requires two Higgs doublets to generate masses for all SM fermions [1] and in the next-to-minimal supersymmetric Standard Model (NMSSM), there is one additional complex singlet scalar in addition to the two Higgs doublets [2]. The NMSSM naturally addresses several over the problems of the MSSM such as the origin of the μ and B_μ terms and is considered one of the prime extensions to the Standard Model. Frequently in the NMSSM there is a very light pseudo-scalar state, A^0, with a mass less than 10 GeV and this state can couple weakly to the SM fermions with a coupling proportional to the mass of the fermion. This motivates a search for the decay of $\Upsilon \to \gamma A^0$ which occurs whenever the mass of the A^0 is less than the $b\bar{b}$ production threshold [3]. This search is presented in this proceeding at BABAR with 122×10^6 $\Upsilon(3S)$ and 99×10^6 $\Upsilon(2S)$ states.

2. Search for $\Upsilon(3S) \to \gamma A^0, A^0 \to \tau^+\tau^-$

We study the decays $\Upsilon(3S) \to \gamma\tau^+\tau^-$ [4] using 122×10^6 $\Upsilon(3S)$ decays. In this analysis the search for A^0 is extended for a wider mass range with respect to a previous CLEO Collaboration analysis [5]. We scan for peaks in the distribution of the photon energy, E_γ, corresponding to peaks in the $\tau\tau$ invariant mass $m^2_{\tau\tau} = m^2_{3S} - 2m_{3S}E_\gamma$, where m_{3S} is the $\Upsilon(3S)$ mass and E_γ is measured in the $\Upsilon(3S)$ rest frame. We quote branching fractions in the region $4.03 < m_{\tau\tau} < 10.10$ GeV/c^2, but we exclude the region $9.52 < m_{\tau\tau} < 9.61$ GeV/c^2, which corresponds to the expected irreducible background of photons in the decay chain $\Upsilon(3S) \to \gamma\chi_{bJ}(2P)$, $\chi_{bJ}(2P) \to \gamma\Upsilon(1S)$, where $J = 0,1,2$.

The product branching fractions are shown in Fig. 1(a). These results show no evidence for a narrow resonance in the mass range under study. Bayesian upper limits on the product of branching fractions, computed with a uniform prior at 90% C.L., are shown in Fig. 1(b). The upper limits on the product branching fraction $\mathscr{B}(\Upsilon(3S) \to \gamma A^0) \times \mathscr{B}(A^0 \to \tau^+\tau^-)$ vary between $(1.5-16) \times 10^{-5}$ at 90% C.L. We also set the upper limit $\mathscr{B}(\eta_b \to \tau\tau) < 8\%$ at $m_{\tau\tau} = 9.389$ GeV/c^2 using the $\mathscr{B}(\Upsilon(3S) \to \gamma\eta_b)$ from Ref. [6].

3. Search for $\Upsilon(2S,3S) \to \gamma A^0, A^0 \to \mu^+\mu^-$

We search for A^0 in the decays $\Upsilon(nS) \to \gamma A^0$, $A^0 \to \mu^+\mu^-$ ($n = 2,3$) using the BABAR data sample which contains 99×10^6 $\Upsilon(2S)$ and 122×10^6 $\Upsilon(3S)$ decays [7]. No significant excess of events above the background in the range $0.212 < m_{\mu\mu} < 9.3$ GeV/c^2 was observed. The 90% C.L. upper limits on the product branching fractions as a function of m_{A^0} for $\Upsilon(2S)$ and $\Upsilon(3S)$ are shown in Fig. 2(a) and Fig. 2(b), respectively, and span the range $(0.44-44) \times 10^{-6}$. We also compute the upper limit $\mathscr{B}(\eta_b \to \mu\mu) < 0.9\%$ at 90% C.L. The branching fractions $\mathscr{B}(\Upsilon(nS) \to \gamma A^0)$ are related to the effective coupling f_Υ of the bound b quark to the A^0 [3, 8, 9]. The effective coupling $f^2_\Upsilon \times \mathscr{B}_{\mu\mu}$ as a function of the m_{A^0} is shown in Fig. 2(c).

PoS(EPS-HEP 2009)232

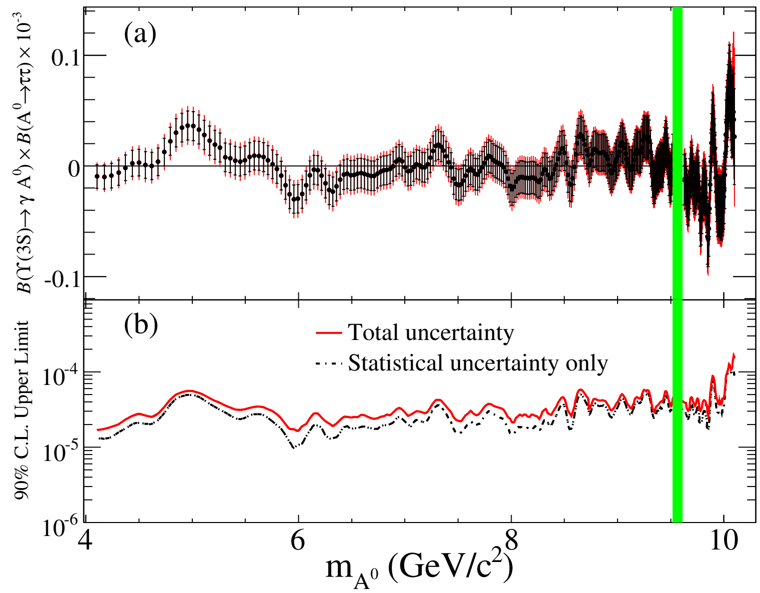

Figure 1: (a) The product of branching fractions ($\mathscr{B}(\Upsilon(3S) \to \gamma A^0) \times \mathscr{B}(A^0 \to \tau^+\tau^-)$) as a function of m_{A^0}. For each point, both the statistical uncertainty and the total uncertainty are shown. In (b), the corresponding 90% C.L. upper limits on the product of the branching fractions versus the Higgs mass values are shown, with total uncertainty (solid line) and statistical uncertainty only (dashed line). The shaded vertical region represents the excluded mass range corresponding to the $\chi_{bJ}(2P) \to \gamma\Upsilon(1S)$ states.

4. Search for $\Upsilon(3S) \to \gamma A^0$, $A^0 \to$ invisible

We search for A^0 produced in single-photon decays of the $\Upsilon(3S)$ resonance through the process $\Upsilon(3S) \to \gamma A^0$, $A^0 \to$ invisible [10]. The analysis is based on a BABAR dataset consisting of 122×10^6 $\Upsilon(3S)$ decays. We search for events with a high-energy photon and no other particles that are consistent with a two-body decay of the $\Upsilon(3S)$. We find no evidence for such a process and set 90% C.L. upper limits on the branching fraction $\mathscr{B}(\Upsilon(3S) \to \gamma A^0) \times \mathscr{B}(A^0 \to \text{invisible})$ at $(0.7-31) \times 10^{-6}$ in the mass range $m_{A^0} < 7.8$ GeV$/c^2$, as shown in Fig. 3.

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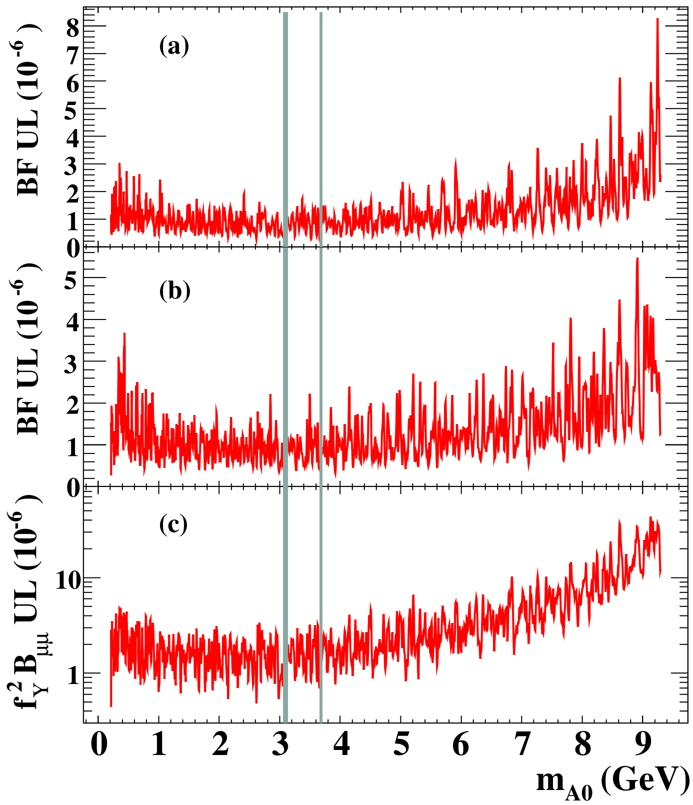

Figure 2: 90% C.L. upper limits on (a) $\mathscr{B}(\Upsilon(2S) \to \gamma A^0) \times \mathscr{B}_{\mu\mu}$ where $\mathscr{B}_{\mu\mu} \equiv \mathscr{B}(A^0 \to \mu\mu)$, (b) $\mathscr{B}(\Upsilon(3S) \to \gamma A^0) \times \mathscr{B}_{\mu\mu}$, and (c) effective coupling $f^2_{\Upsilon} \times \mathscr{B}_{\mu\mu}$ as a function of m_{A^0}. The shaded areas represent the J/ψ and $\psi(2S)$ regions, excluded from this search.

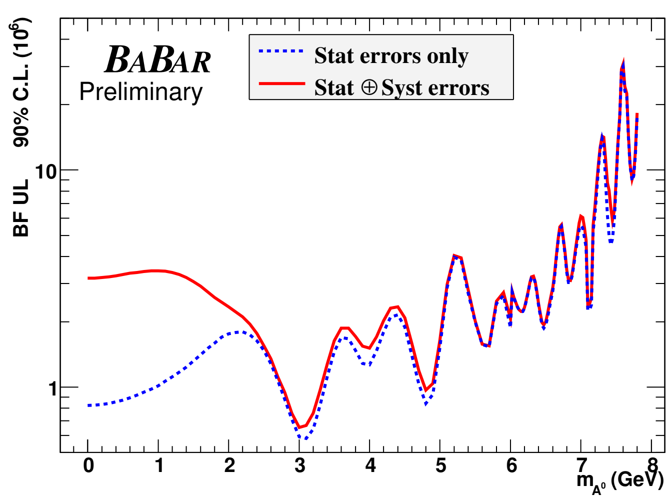

Figure 3: 90% C.L. upper limits on $\mathscr{B}(\Upsilon(3S) \to \gamma A^0) \times \mathscr{B}(A^0 \to \text{invisible})$ as a function of m_{A^0}. The limits are shown with the statistical uncertainties only (dashed line) and the total uncertainties (solid line).

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