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LOW MASS NEW PHYSICS SEARCH FOR A CP-ODD HIGGS BOSON A^0 DECAYING TO $s\bar{s}$ OR GLUON GLUON AT *BABAR*

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We report on the search for the decay $\Upsilon(1S) \to \gamma A^0$, $A^0 \to gg$ or $s\bar{s}$, where A^0 is the pseudoscalar light Higgs boson predicted by the next-to-minimal supersymmetric standard model. A sample of $\sim 18 \times 10^6$ $\Upsilon(1S)$ resonances, produced in the *BABAR* experiment via $e^+e^- \to \Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$, is used for this search. No significant signal has been found, and upper limits at the 90% of confidence level are set on the product branching fraction of the process.

1 Introduction

The Next to Minimal Supersymmetric Standard Model (NMSSM) [1], one of the several extensions of the Standard Model, predicts a larger Higgs sector, with two charged, three neutral CP-even, and two neutral CP-odd Higgs bosons. In particular, the model includes the possibility that one of the pseudoscalar Higgs bosons, denoted as A^0 hereafter, can be lighter than two bottom quarks [2], therefore making its production accessible at the B-factories, via the radiative decay of an Υ resonance.

The A^0 is a superposition of a singlet and a non-singlet state, and the value of the branching fraction of the radiative decay $\Upsilon \to \gamma A^0$ actually depends on the non-singlet fraction. The final state to which the A^0 decays depends instead on various parameters, such as $\tan\beta$ and the mass of the CP-odd Higgs boson itself [3]. In order to be sensitive to as much parameter space as possible, *BABAR* has performed searches for different final states: A^0 decaying into $\mu^+\mu^-$ [4,5], into $\tau^+\tau^-$ [6,7], into invisible states [8], and into hadrons [9], without seeing any significant signal.

The search presented here [10] focuses on the decays $A^0 \to gg$ or $s\bar{s}$. For an A^0 mass smaller than $2m_\tau$, the light pseudoscalar Higgs boson is predicted to decay mostly into two gluons if $\tan\beta$ is of order 1, and into $s\bar{s}$ if $\tan\beta$ is of order 10. Despite being motivated by NMSSM, the results of this search can be applied to any CP-odd hadronic resonances produced in the radiative decays of $\Upsilon(1S)$.

2 Experimental technique

This analysis uses the data recorded by the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- collider at the SLAC National Accelerator Laboratory. The *BABAR* detector is described in detail elsewhere [11,12]. We use $\sim$14 fb^{-1} of data taken at the $\Upsilon(2S)$ resonance. Tagging the dipion in the $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$ transition allows to significantly reduce the otherwise dominant $e^+e^- \to q\bar{q}$ background, where q is a u, d, or s quark. We also use $\sim$ 1.4 fb^{-1} of data taken 30 MeV below the $\Upsilon(2S)$ resonance as a background estimate. Simulated signal events with various A^0 masses ranging from 0.5 to 9.0 GeV/c^2 are used in this analysis.

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Table 1: Decay modes for candidate $A^0 \to gg$ and $s\bar{s}$ decays, sorted by the total mass of the decay products.

#	Channel	#	Channel
1	$\pi^+\pi^-\pi^0$	14	$K^+K^-\pi^+\pi^-$
2	$\pi^+\pi^-2\pi^0$	15	$K^+K^-\pi^+\pi^-\pi^0$
3	$2\pi^+2\pi^-$	16	$K^\pm K^0_S\pi^\mp\pi^+\pi^-$
4	$2\pi^+2\pi^-\pi^0$	17	$K^+K^-\eta$
5	$\pi^+\pi^-\eta$	18	$K^+K^-2\pi^+2\pi^-$
6	$2\pi^+2\pi^-2\pi^0$	19	$K^\pm K^0_S\pi^\mp\pi^+\pi^-2\pi^0$
7	$3\pi^+3\pi^-$	20	$K^+K^-2\pi^+2\pi^-\pi^0$
8	$2\pi^+2\pi^-\eta$	21	$K^+K^-2\pi^+2\pi^-2\pi^0$
9	$3\pi^+3\pi^-2\pi^0$	22	$K^\pm K^0_S\pi^\mp 2\pi^+2\pi^-\pi^0$
10	$4\pi^+4\pi^-$	23	$K^+K^-3\pi^+3\pi^-$
11	$K^+K^-\pi^0$	24	$2K^+2K^-$
12	$K^\pm K^0_S\pi^\mp$	25	$p\bar{p}\pi^0$
13	$K^+K^-2\pi^0$	26	$p\bar{p}\pi^+\pi^-$

The final states analyzed must contain: two charged tracks as the dipion system candidate, a radiative photon with an energy greater than 200 MeV when calculated in its center-of-mass frame, and a hadronic system. An exclusive reconstruction of $A^0 \to gg$ is performed, using 26 channels as listed in Table 1, while disregarding two-body decay channels because a CP-odd Higgs boson cannot decay into two pseudoscalar mesons. The $A^0 \to s\bar{s}$ sample is defined as the subset of the 26 $A^0 \to gg$ decay channels that include two or four kaons (channels 11-24 in Table 1). Charged kaons, pions, and protons are required to be positively identified.

The A^0 mass resolution is improved by constraining the A^0 candidate and the photon to have an invariant mass equal to the $\Upsilon(1S)$ one, and a decay vertex at the beam spot. The main backgrounds to this search are:

- $\Upsilon(1S) \to \gamma gg$ events, with gluons hadronizing to more than one daughter; it is dominant at low masses, *i.e.* between 2 and 4 GeV/c^2;

- $\Upsilon(1S) \to ggg$ events, with a π^0 mistaken as a photon; it is dominant at higher masses, *i.e.* between 7 and 9 GeV/c^2.

This search relies on the hadronization modelling used in simulations; the agreement between data and Monte Carlo samples is checked on $\Upsilon(1S) \to \gamma gg$ events, resulting in a scaling factor and a global systematic uncertainty of 50% to be applied to the efficiency. This is the dominant contribution to the systematic uncertainties of this analysis.

3 Results

The candidate mass spectrum is shown in Fig. 1. The A^0 would appear as a narrow peak in the distribution. A scan of the mass spectrum has been performed in 10 MeV/c^2-steps, from 0.5 to 9 GeV/c^2, without finding any significant signal through the entire mass range analyzed. Bayesian upper limits at the 90% of confidence level are then set on the product of branching fractions $\mathcal{B}(\Upsilon(1S) \to \gamma A^0)\times$ $\mathcal{B}(A^0 \to gg)$ and $\mathcal{B}(\Upsilon(1S) \to \gamma A^0)\times$ $\mathcal{B}(A^0 \to s\bar{s})$, ranging between 10^{-6} and 10^{-2}, and between 10^{-5} and 10^{-3} for the two final states, respectively, as shown in Fig. 2. As a result, the low mass region for A^0 is excluded, and no evidence either for a light pseudoscalar Higgs boson, or for any narrow hadronic resonance is found through the entire mass spectrum.

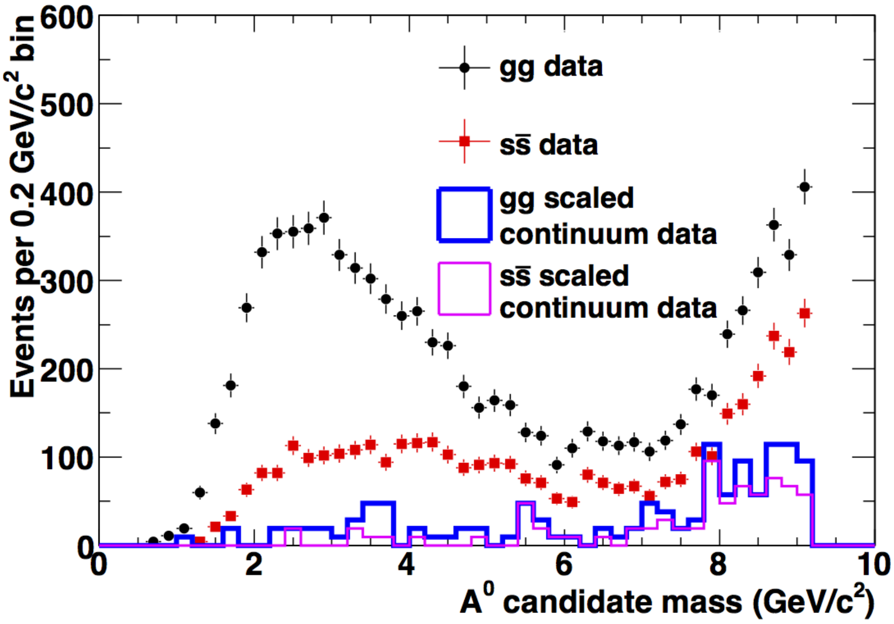

Figure 1: A^0 candidate mass spectra after applying all selection criteria. We reconstruct $A^0 \to gg$ using the 26 channels listed in Table 1 and $A^0 \to s\bar{s}$ using the subset of the same 26 channels that includes two or four kaons. The A^0 candidate mass is the invariant mass of the reconstructed hadrons in each channel. The black points with error bars are on-resonance data for $A^0 \to gg$. The red squares with error bars are on-resonance data for $A^0 \to s\bar{s}$. The thick blue histogram is $A^0 \to gg$ in off-resonance data normalized to the on-resonance integrated luminosity. The thin magenta histogram is $A^0 \to s\bar{s}$ in off-resonance data normalized to the on-resonance integrated luminosity.

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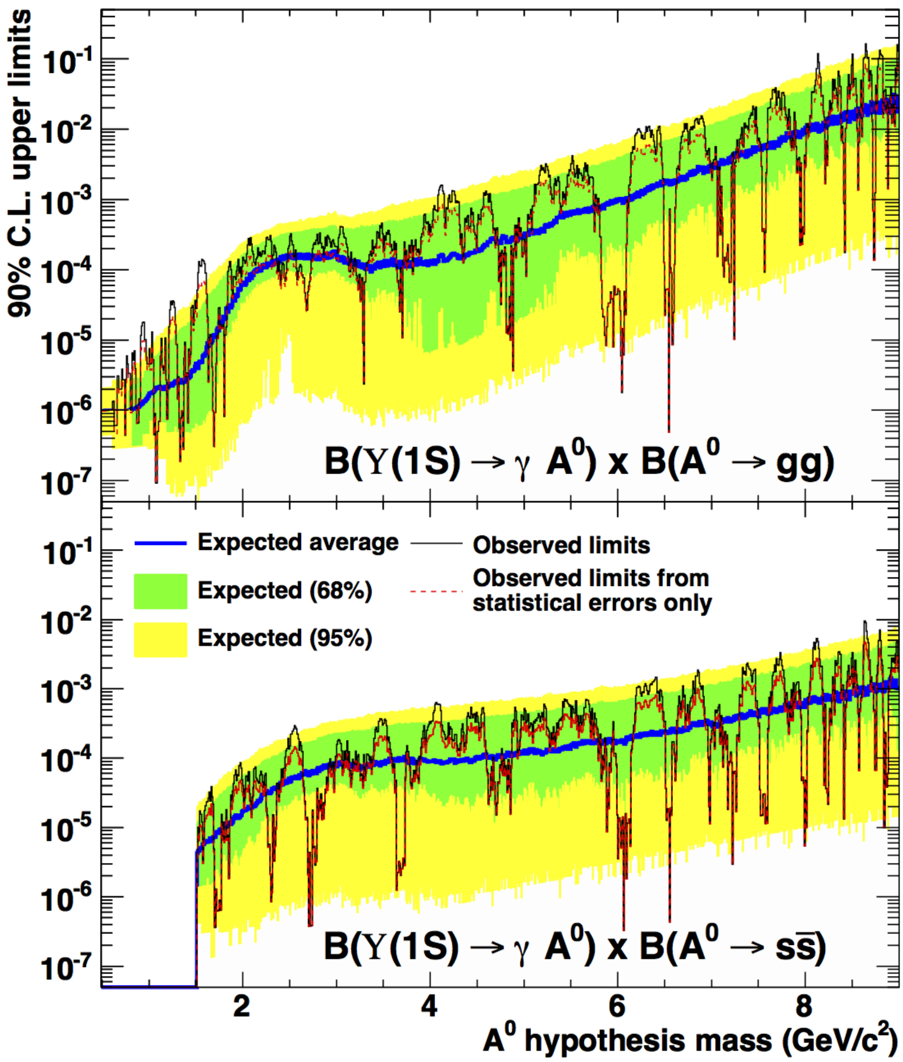

Figure 2: The 90% confidence level upper limits (thin solid line) on the product branching fractions $\mathcal{B}(\Upsilon(1S) \to \gamma A^0)\times\ \mathcal{B}(A^0 \to gg)$ (top) and $\mathcal{B}(\Upsilon(1S) \to \gamma A^0)\times\ \mathcal{B}(A^0 \to s\bar{s})$ (bottom). We overlay limits calculated using statistical uncertainties only (thin dashed line). The inner band is the expected region of upper limits in 68% of simulated experiments. The inner band plus the outer band is the expected region of upper limits in 95% of simulated experiments. The bands are calculated using all uncertainties. The thick line in the center of the inner band is the expected upper limits calculated using simulated experiments.