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Search for Light Higgs and Dark Photons at BaBar and Belle

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From supersymmetry to dark matter, many extensions of the Standard Model include the possibility of light new physics. The ideal tools to explore such theories are low-energy high-luminosity collider experiments such as B factories. This report summarizes recent searches for light new physics by the BaBar and Belle experiments.

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$\sqrt{s}$	BaBar	Belle	Total
$\Upsilon(5S)$	-	121	121
$\Upsilon(4S)$	433	711	1,144
$\Upsilon(3S)$	30	3	33
$\Upsilon(2S)$	15	25	40
$\Upsilon(1S)$	-	6	6
Off-resonance	54	94	138

Table 1: Integrated luminosities(fb^{-1}) collected by the B factories at different center-of-mass energies. The off-resonance data were collected about 40 MeV below the $\Upsilon(4S)$ resonance at BABAR and at a similar offset for the $\Upsilon(4S)$ and $\Upsilon(5S)$ resonances in the case of Belle.

1. Introduction

During the last decade, the BaBar Collaboration at PEP-II [1] and the Belle Collaboration at KEKB [2][3] have respectively collected about 550 fb^{-1} and more than 1 ab^{-1} of data at several Υ resonances, mostly the $\Upsilon(4S)$ resonance(see Table 1).

2. Search for Light *CP*-Odd Higgs boson in Υ decays

The Higgs mechanism attempts to explain the origin of mass within the Standard Model (SM) [4]. Recently, experimental evidence suggests a Higgs-like states with the mass of about 125 GeV [5]. Several extensions of SM, such as the next-to-minimal supersymmetric Model (nMSSM) predicts more Higgs-like state [6].

The nMSSM suggests a Higgs sector contains seven states, two charged Higgs bosons, three neutral CP-even bosons, and two CP-odd bosons. The lightest CP-odd state, A^0, could be with the mass below the $b\bar{b}$ production threshold. Such a particle could be produced in $\Upsilon \to \gamma A^0$ decays [7] with a branching fraction as large as 10^{-4} for the narrow states $\Upsilon(nS)$ (where n$\leq$ 3). The predicted branching fraction depends on the A^0 mass and couplings [6]. The A^0 is accessible and well above the sensitivity of B-factories.

$e^+e^- \to \Upsilon(1S,2S,3S) \to \gamma A^0,\ A^0 \to \tau^+\tau^-$

The two taus of the $\Upsilon(nS) \to \gamma A^0$, $A^0 \to \tau^+\tau^-$ decays are identified through their leptonic decays, $\tau^+ \to \mu^+\nu_\tau\bar{\nu}_\mu$ and $\tau^- \to e^-\nu_\tau\bar{\nu}_e$. The signal event should consist of exactly two oppositely-charged tracks, identified as muons or electrons. The signal yield is extracted as a function of m_{A^0} by a simultaneous fit to the photon energy distribution of the $ee\gamma$, $\mu\mu\gamma$ and $e\mu\gamma$ samples. No excess is seen. The 90% CL limits on the branching fraction are listed in Table 2 [8]. The Belle results are preliminary.

$e^+e^- \to \Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-,\ \Upsilon(1S) \to \gamma A^0,\ A^0 \to \tau^+\tau^-$

In this analysis, the $\Upsilon(1S)$ resonance is produced from the $\Upsilon(2S)$ resonance with the emission of two charged pions. The $\Upsilon(1S)$ is identified by the dipion transition. The signal events are

Mode	Mass range (GeV)	BF upper limit (90% CL)	
		BaBar	Belle
$\Upsilon(1S) \to \gamma A^0,\ A^0 \to \tau^+\tau^-$	$3.6 < m_{A^0} < 9.3$	-	$(0.4-4.5)\times 10^{-5}$
$\Upsilon(2S) \to \gamma A^0,\ A^0 \to \tau^+\tau^-$	$4.16 < m_{A^0} < 9.19$	-	$(1.61-12.17)\times 10^{-5}$
$\Upsilon(3S) \to \gamma A^0,\ A^0 \to \tau^+\tau^-$	$4.03 < m_{A^0} < 10.1$	$(1.5-16)\times 10^{-5}$	-

Table 2: Results of light Higgs boson searches, $e^+e^- \to \Upsilon(1S,2S,3S) \to \gamma A^0$, $A^0 \to \tau^+\tau^-$, studied by the BaBar [8] and Belle Collaboration. The Belle results are preliminary.

Mode	Mass range (GeV)	BF upper limit (90% CL)	
		BaBar	Belle
$\Upsilon(1S) \to \gamma A^0,\ A^0 \to \tau^+\tau^-$	$3.5 < m_{A^0} < 9.2$	$(0.9-13)\times 10^{-5}$	-
$\Upsilon(1S) \to \gamma A^0,\ A^0 \to \tau^+\tau^-$	$3.84 < m_{A^0} < 9.16$	-	$(0.91-45.37)\times 10^{-5}$

Table 3: Results of light Higgs boson searches, $e^+e^- \to \Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$, $\Upsilon(1S) \to \gamma A^0$, $A^0 \to \tau^+\tau^-$, studied by the BaBar [9] and Belle Collaboration. The Belle result is preliminary.

Mode	Mass range (GeV)	BF upper limit (90% CL)	
		BaBar	Belle
$\Upsilon(2S) \to \gamma A^0,\ A^0 \to \mu^+\mu^-$	$0.213 < m_{A^0} < 9.37$	-	$(0.19-8.26)\times 10^{-6}$
$\Upsilon(2S,3S) \to \gamma A^0,\ A^0 \to \mu^+\mu^-$	$0.21 < m_{A^0} < 9.3$	$(0.3-8.3)\times 10^{-6}$	-

Table 4: Results of light Higgs boson searches, $\Upsilon(2S,3S) \to \gamma A^0$, $A^0 \to \mu^+\mu^-$, studied by the BaBar [10] and Belle Collaboration. The Belle result is preliminary.

identified by the photon and two charged tracks from one-prong decays of the two tau leptons. No excess is seen. The 90% CL limits on the branching fraction are listed in Table 3 [9]. The Belle result is preliminary.

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

In this analysis, the signal events are reconstructed by combining a photon with a pair of oppositely-charged tracks. The charged tracks must be identified as muons by particle identification algorithms. A series of unbinned likelihood fits to the dimuon mass distribution is performed to extract the signal. No excess is seen. The 90% CL limits on the branching fraction are listed in Table 4 [10]. The Belle result is preliminary.

$e^+e^- \to \Upsilon(2S,3S) \to \Upsilon(1S)\pi^+\pi^-,\ \Upsilon(1S) \to \gamma A^0,\ A^0 \to \mu^+\mu^-$

In this analysis, the $\Upsilon(1S)$ resonance is produced from the $\Upsilon(2S,3S)$ resonance with the emission of two charged pions. The $\Upsilon(1S)$ is identified by the dipion transition. The signal events are identified by the photon and two charged tracks. The charged tracks must be identified as muons by particle identification algorithms. A series of unbinned likelihood fits to the dimuon mass dis-

Mode	Mass range (GeV)	BF upper limit (90% CL)	
		BaBar	Belle
$\Upsilon(1S) \to \gamma A^0,\, A^0 \to \mu^+\mu^-$	0.212<m_{A^0}< 9.20	$(0.28-9.7)\times 10^{-6}$	-
$\Upsilon(1S) \to \gamma A^0,\, A^0 \to \mu^+\mu^-$	0.212<m_{A^0}< 9.27	-	$(0.01-11.86)\times 10^{-6}$

Table 5: Results of light Higgs boson searches, $e^+e^- \to \Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$, $\Upsilon(1S) \to \gamma A^0$, $A^0 \to \mu^+\mu^-$, studied by the BaBar [11] and Belle Collaboration. The BaBar result is formed by combining the $\Upsilon(2S,3S)$ dataset. The Belle result is preliminary.

tribution is performed to extract the signal. No excess is seen. The 90% CL limits on the branching fraction are listed in Table 5 [11]. The Belle result is preliminary.

Summary

The selected searches of A^0 decays into $\mu^+\mu^-$ and $\tau^+\tau^-$ final states have been studied by BaBar and Belle Collaboration. All studies show null results.

3. Search for low-mass dark-sector Higgs bosons

Recent results from terrestrial and satellite experiments have motivated the proposal of a new, hidden gauge sector under which WIMP-like dark matter particles are charged [12].

An Abelian gauge field, the dark photon A, couples this dark sector to Standard Model (SM) particles through its kinetic mixing with the SM hypercharge fields [13]. In this framework dark matter particles can annihilate into pairs of dark photons, which subsequently decay to SM particles. The dark photon mass is constrained to be at most a few GeV to be compatible with astrophysical constraints [14]. In a minimal model [15], the dark photon mass is generated via the Higgs mechanism, adding a dark Higgs boson h′ to the theory. The mass hierarchy between these two particles is not constrained, and the dark Higgs boson could be light as well.

The Higgsstrahlung process, $e^+\ e^- \to$ Ah′, h′ $\to$ AA, offers a gateway to the hidden gauge sector. This process is one of the few suppressed by only a single power of the mixing strength, and the background is expected to be almost negligible.

The BaBar [16] measurement is performed in the range 0.8 $< m_{h'} <$10.0 GeV and 0.25$<$ m_A <3.0 GeV, with the constraint $m_{h'} > 2m_A$. The signal is either fully reconstructed into $3(\ell^+\ell^-)$, $2(\ell^+\ell^-)(\pi^+\pi^-)$, $\ell^+\ell^-2(\pi^+\pi^-)$ final states ($\ell = e,\ \mu$) or partially reconstructed in the $2(\mu^+\mu^- + X)$ and $\mu^+\mu^-e^+e^- + X$ channels, where X denotes any final state other than a pair of pions or leptons.

The Belle measurement is performed in the range 0.5 $< m_{h'} <$10.5 GeV and 0.25$<$ m_A <3.5 GeV, with the constraint $m_{h'} > 2m_A$. The signal is fully reconstructed into $3(\ell^+\ell^-)$, $(e^+e^-)2(\pi^+\pi^-)$, $2(\mu^+\mu^-)e^+e^-$ final states ($\ell = e,\ \mu$).

In both BaBar and Belle studies, no significant signal is observed. Upper limits on the $e^+\ e^-$ $\to$ Ah′, h′ $\to$ AA cross section are set as a function of the hidden Higgs and hidden photon masses. The limits on each channels are combined to extract 90% CL upper limits, which is at the level of 10 - 100 ab. Upper limits on the product of the mixing angle and the dark coupling constant in the case of a hidden sector with an Abelian Higgs boson have been set at the level of $10^{-10} - 10^{-8}$ [17]. The Belle results are preliminary.

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