

Review Article

Search for Light New Physics at B Factories

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Many extensions of the Standard Model include the possibility of light new particles, such as light Higgs bosons or dark matter candidates. These scenarios can be probed using the large datasets collected by B factories, complementing measurements performed at the LHC. This paper summarizes recent searches for light new physics conducted by the $BABAR$ and Belle experiments.

1. Introduction

From supersymmetry to dark matter, many extensions of the Standard Model (SM) include the possibility of light new physics. Thanks to their large luminosities, B factories offer an ideal environment to explore these theories. 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). These datasets have been exploited to explore many aspects of precision physics, including searches for light new particles. In the following, we review searches for light Higgs bosons, dark matter candidates, hidden sectors, sgoldstinos, and Majorana neutrinos.

2. Search for Light CP -Odd Higgs Boson in Υ Decays

A light Higgs boson is predicted by several extensions of the Standard Model, such as the Next-to-Minimal Supersymmetric Standard Model (NMSSM). The NMSSM Higgs sector contains a total of seven states, three CP -even, two CP -odd, and two charged Higgs bosons. A CP -odd Higgs boson (A^0) lighter than $2m_b$ can evade present experimental constraints [4], and could be detected through radiative $\Upsilon(nS) \rightarrow \gamma A^0$ decays [5]. The corresponding branching fraction could be as large as a few $\times 10^{-4}$, well above the sensitivity of B factories [4, 6].

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.

\sqrt{s}	BABAR	Belle	Total
$\Upsilon(5S)$	—	121	121
$\Upsilon(4S)$	433	711	1144
$\Upsilon(3S)$	30	3	33
$\Upsilon(2S)$	15	25	40
$\Upsilon(1S)$	—	6	6
Off-resonance	54	94	138

Table 2: Results of light Higgs boson searches performed by the BABAR Collaboration.

Mode	Mass range (GeV)	BF upper limit (90% CL)
$\Upsilon(2S, 3S) \rightarrow \gamma A^0, A^0 \rightarrow \mu^+ \mu^-$	$0.21 < m_A < 9.3$	$(0.3\text{--}8.3) \times 10^{-6}$
$\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow \tau^+ \tau^-$	$4.0 < m_A < 10.1$	$(1.5\text{--}16) \times 10^{-5}$
$\Upsilon(2S, 3S) \rightarrow \gamma A^0, A^0 \rightarrow \text{hadrons}$	$0.3 < m_A < 7.0$	$(0.1\text{--}8) \times 10^{-5}$
$\Upsilon(1S) \rightarrow \gamma A^0, A^0 \rightarrow \chi \bar{\chi}$	$m_\chi < 4.5 \text{ GeV}$	$(0.5\text{--}24) \times 10^{-5}$
$\Upsilon(1S) \rightarrow \gamma A^0, A^0 \rightarrow \text{invisible}$	$m_A < 9.2 \text{ GeV}$	$(1.9\text{--}37) \times 10^{-6}$
$\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow \text{invisible}$	$m_A < 9.2 \text{ GeV}$	$(0.7\text{--}31) \times 10^{-6}$

The Higgs boson decay pattern depends on its mass and couplings, as well as the NMSSM particle spectrum. In the absence of light neutralinos, the A^0 decays predominantly into a pair of muons below $2m_\tau$, while $\tau^+ \tau^-$ and hadronic final states become significant above this threshold. The branching fraction $A^0 \rightarrow \chi^0 \bar{\chi}^0$ may be dominant if the neutralino (χ^0) is the lightest stable particle with $m_{\chi^0} < m_{A^0}/2$ [7]. In this case, the neutralino is a natural dark matter candidate.

BABAR has performed searches for a light CP -odd Higgs boson in a variety of decay channels. These measurements are discussed in the next paragraphs, and the results are summarized in Table 2. They place stringent constraints on light CP -odd Higgs models.

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

The $\Upsilon(2S, 3S) \rightarrow \gamma A^0, A^0 \rightarrow \mu^+ \mu^-$ candidates are reconstructed by combining a photon with a pair of oppositely-charged tracks. The energy of the photon in the Υ center-of-mass (CM) frame is required to be greater than 0.5 GeV and one or both tracks must be identified as muons by particle identification algorithms. Events containing additional tracks and photons are rejected. The $\Upsilon(2, 3S)$ candidates are then fit, constraining their CM energies to the total beam energy, and imposing a common vertex for the tracks. A series of unbinned likelihood fits to the dimuon mass distribution is performed to extract the signal. No evidence of A^0 is observed; 90% confidence level (CL) limits on the branching fractions are established at the level of $(0.26\text{--}8.3) \times 10^{-6}$ for $0.212 < m_{A^0} < 9.3 \text{ GeV}$ [8]. The limits as a function of the A^0 mass are shown in Figure 1, together with limits on the product $B(A^0 \rightarrow \mu^+ \mu^-) f_Y^2$, where f_Y^2 denotes the effective coupling of the b quark to the Υ meson [5, 9]. Slightly more stringent constraints have been recently derived by the BES-III Collaboration for some A^0 mass hypotheses below 3 GeV using $J/\psi \rightarrow \gamma \mu^+ \mu^-$ decays [10].

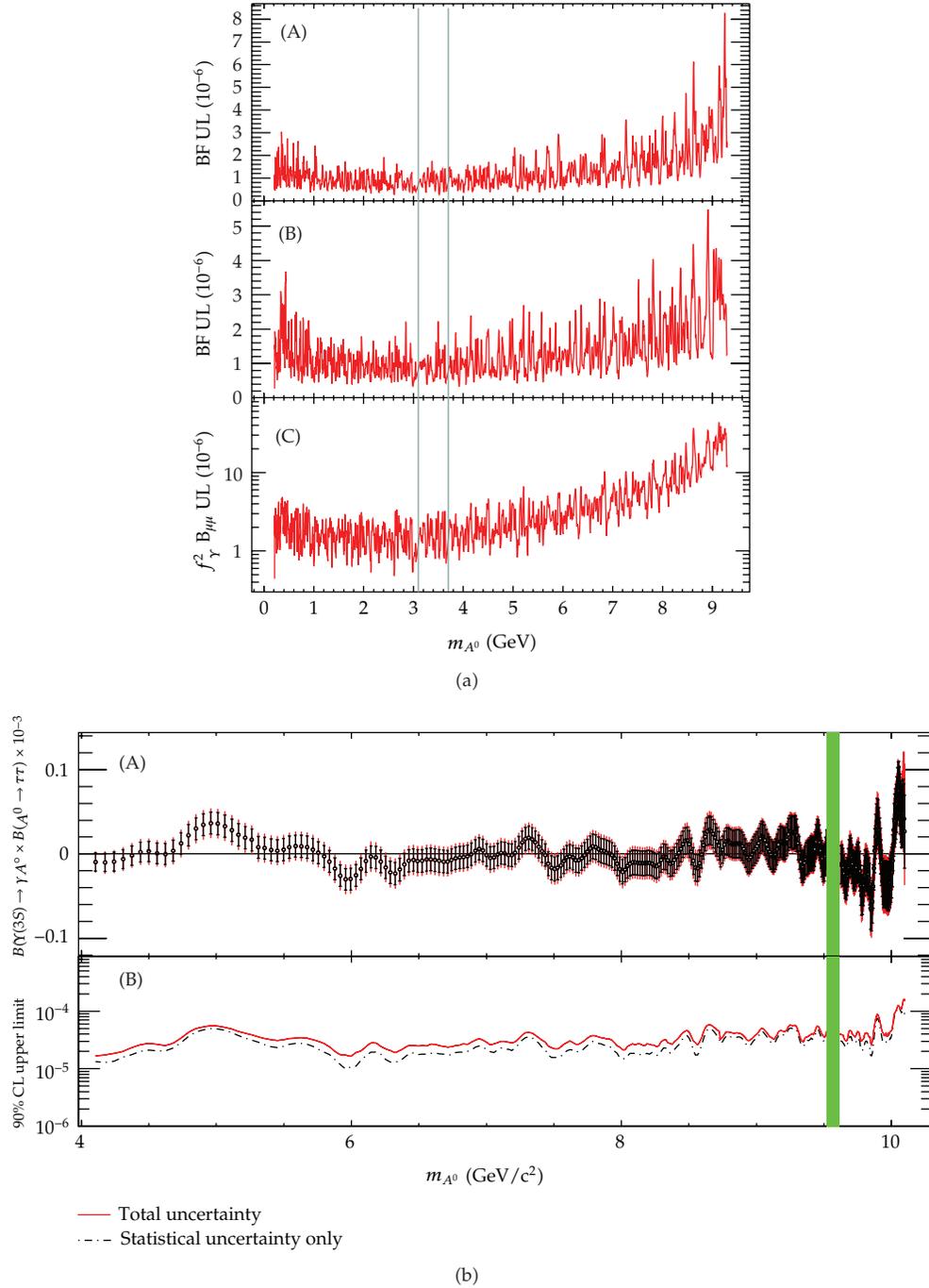


Figure 1: (a) 90% CL upper limit on the $Y(3S) \rightarrow \gamma A^0$, $A^0 \rightarrow \mu^+ \mu^-$ (top) and $Y(2S) \rightarrow \gamma A^0$, $A^0 \rightarrow \mu^+ \mu^-$ branching fractions (middle) as a function of the A^0 mass derived by *BABAR*. The limits on the product $B(A^0 \rightarrow \mu^+ \mu^-) f_\gamma^2$ are also shown (bottom). The J/ψ and $\psi(2S)$ regions (solid bands) are excluded from the search. (b) Product of branching fraction $Y(3S) \rightarrow \gamma A^0$, $A^0 \rightarrow \tau^+ \tau^-$ (top) and the corresponding 90% CL upper limit (bottom) as a function of the A^0 mass set by *BABAR*. The region corresponding to $\chi_{bJ}(2P) \rightarrow \gamma Y(1S)$ transitions (shaded band) is excluded.

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

The two taus of the $\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow \tau^+ \tau^-$ decays are identified through their leptonic decays, $\tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$ and $\tau^+ \rightarrow \mu^+ \nu_\mu \bar{\nu}_\tau$. The signal signature consists of exactly two oppositely-charged tracks, identified as muons or electrons, and at least one photon with an energy greater than 100 MeV in the CM frame. A set of eight kinematic and angular variables are used to further suppress the background, which arises mainly from radiative τ production and two-photon processes. 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; 90% CL limits on the branching fraction are set at the level of $(1.5\text{--}16) \times 10^{-5}$ in the interval $4.03 < m_{A^0} < 10.1$ GeV [11], as shown in Figure 1.

2.3. Search for $\Upsilon(2S, 3S) \rightarrow \gamma A^0, A^0 \rightarrow \text{Hadrons}$

The hadronic final states are selected from the fully reconstructed $A^0 \rightarrow \text{hadrons}$ decays. The highest energy photon of the event is identified as the radiative photon from the $\Upsilon(nS)$ decay; the A^0 candidate is then constructed by adding the four-momenta of the remaining particles, constraining the A^0 decays products to originate from the interaction point to improve the resolution. The signal yield is obtained by fitting the candidate mass spectrum in the range 0.3–7.0 GeV in steps of 1 MeV. The results are compatible with the null hypothesis; limits on the branching fraction are therefore set in the range $(0.1\text{--}8) \times 10^{-5}$ with 90% confidence level [12].

2.4. Search for $\Upsilon(2S) \rightarrow \pi^+ \pi^- \Upsilon(1S), \Upsilon(1S) \rightarrow \gamma A^0, A^0 \rightarrow \text{Invisible}$

This final state is characterized by a pair of low-momentum tracks, a single energetic photon, and large missing energy and momentum. Additional criteria on the photon and the extra neutral energy in the event are applied to further suppress contributions from electron bremsstrahlung, radiative hadronic $\Upsilon(1S)$ decays, and two-photon processes in which particles escape undetected. The signal is extracted by a series of bidimensional unbinned likelihood fits to the dipion recoil mass and the missing mass squared for both two-body decays, $\Upsilon(1S) \rightarrow \gamma A^0, A^0 \rightarrow \text{invisible}$, and nonresonant three-body processes, $\Upsilon(1S) \rightarrow \gamma A^0, A^0 \rightarrow \chi \bar{\chi}$. Values of m_{A^0} and m_{χ^0} are probed over $0 < m_A < 9.2$ GeV and $0 \leq m_{\chi^0} \leq 4.5$ GeV, respectively. No significant signal is found; 90% CL limits $B(\Upsilon(1S) \rightarrow \gamma A^0, A^0 \rightarrow \text{invisible}) < (1.9\text{--}37) \times 10^{-6}$ and $B(\Upsilon(1S) \rightarrow \gamma A^0, A^0 \rightarrow \chi^0 \bar{\chi}^0) < (1.9\text{--}37) \times 10^{-6}$ are set [13]. These limits are displayed in Figure 2 as a function of the A^0 and χ^0 masses.

2.5. Search for $\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow \text{Invisible}$

The $\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow \text{invisible}$ decays are also selected from events containing a single energetic photon with no additional activity in the detector. The background arises mainly from $e^+ e^- \rightarrow \gamma\gamma$, radiative Bhabha, and two-photon fusion events. The A^0 yield is extracted by a series of unbinned likelihood fits to the photon energy distribution for $0 < m_{A^0} < 7.8$ GeV. No excess is seen, and limits on the branching fraction at the level of $(0.7\text{--}31) \times 10^{-6}$ are derived with 90% confidence level [14].

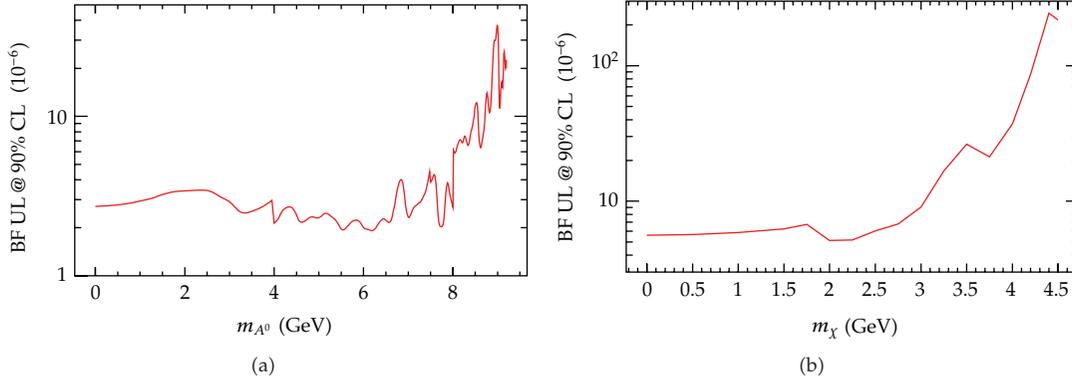


Figure 2: 90% CL upper limits on the $\Upsilon(1S) \rightarrow \gamma A^0$, $A^0 \rightarrow$ invisible (a) and $\Upsilon(1S) \rightarrow \gamma A^0$, $A^0 \rightarrow \chi\bar{\chi}$ (b) branching fractions as a function of the A^0 and χ masses set by *BABAR*.

3. Search for Dark Matter in Invisible $\Upsilon(1S)$ Decays

In a minimal model, a single dark matter particle (χ) is added to the SM content, together with a new boson mediating SM-dark matter interactions [15–17]. A light mediator could be produced in $b\bar{b}$ annihilation and decay into a $\chi\bar{\chi}$ pair, contributing to the invisible width of Υ mesons. In the SM, invisible $\Upsilon(1S)$ decays proceed via the production of a $\nu\bar{\nu}$ pair with a branching fraction $B(\Upsilon(1S) \rightarrow \nu\bar{\nu}) \sim (1 \times 10^{-5})$ [18], well below the current experimental sensitivity. The rate $\Upsilon(1S) \rightarrow \chi\bar{\chi}$ is predicted to be larger by one or two orders of magnitude than that of $\Upsilon(1S) \rightarrow \nu\bar{\nu}$, assuming no flavor changing currents [19].

A search for dark matter in invisible $\Upsilon(1S)$ decays has been performed by *BABAR* using a sample of 122×10^6 $\Upsilon(3S)$ mesons [20]. The $\Upsilon(1S)$ mesons are selected by reconstructing the $\Upsilon(3S) \rightarrow \pi^+\pi^-\Upsilon(1S)$ transitions. The dipion recoil mass peaks at the $\Upsilon(1S)$ for signal events, while backgrounds are broadly distributed. This strategy is common to several analyses, and provides a very clean $\Upsilon(1S)$ sample.

The event topology consists of exactly two oppositely-charged tracks without any additional activity. The selection is performed using a multivariate classifier based on variables describing the pions, the neutral energy deposited in the calorimeters, and the multiplicity of K_L^0 candidates.

The distribution of the resulting dipion recoil mass (Figure 3) shows a clear peak corresponding to $\Upsilon(1S)$ mesons on top of a nonresonant component. In addition to signal events, a background from $\Upsilon(1S)$ decays in which the decay products escape undetected, is also present. This component, kinematically indistinguishable from the signal, is evaluated using Monte Carlo simulations.

The sum of signal and peaking background yields is first extracted by an extended maximum likelihood fit to the dipion recoil mass. After subtracting the peaking background, a signal yield of $-118 \pm 105 \pm 124$ is measured, where the first uncertainty is statistical and the second systematic. No evidence for $\Upsilon(1S) \rightarrow$ invisible decays is observed and a 90% confidence level Bayesian upper limit on its branching fraction is set at 3.0×10^{-4} using a prior flat in branching fraction. This result improves the best previous measurement [21] by nearly an order of magnitude, and sets stringent constraints on minimal light dark matter models.

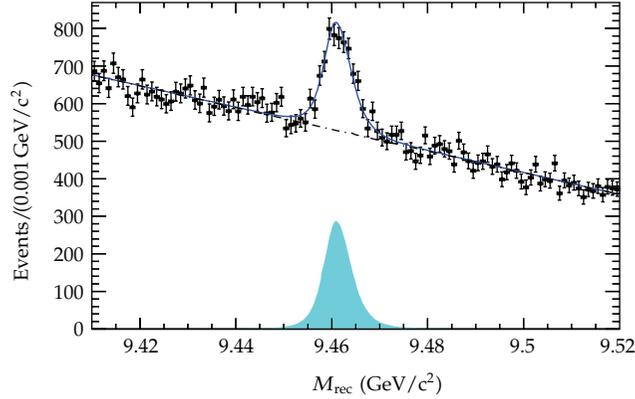


Figure 3: The distribution of the dipion recoil mass (M_{rec}) for *BABAR* data, together with the result of the maximum likelihood fit (full line). The nonresonant background (dashed line) and the sum of the signal and the peaking background (solid filled) are also shown.

4. Search for Dark Matter and Hidden Sectors

A new class of dark matter model has recently been proposed, following observation from satellite and ground-based experiments. These models introduce a new hidden sector with WIMP-like fermionic dark matter particles charged under a new Abelian gauge group [22–24]. The corresponding gauge boson, dubbed a hidden photon (A'), is constrained to have a mass at the GeV scale to explain the electron/positron excess observed by PAMELA [25] and FERMI [26], without a comparable antiproton signal. The hidden photon couples to the SM photon through kinetic mixing with a mixing strength ϵ , connecting the hidden sector to SM particles [27].

The Higgs mechanism generates the hidden boson masses, adding hidden Higgs bosons (h') to the theory. A minimal model includes a single hidden photon and a Higgs boson [28]. Additional gauge and Higgs bosons are considered in more complex variations [29, 30].

4.1. Search for a Hidden Photon

Hidden photons can be readily formed in $e^+e^- \rightarrow \gamma A'$ interactions, and be reconstructed via their leptonic decays as resonances in the $e^+e^- \rightarrow \gamma l^+l^-$ ($l = e, \mu$) spectrum. This signature is similar to that of light CP -odd Higgs production in $e^+e^- \rightarrow \Upsilon(2S, 3S) \rightarrow \gamma \mu^+\mu^-$ [8], and searches for this channel have therefore been reinterpreted as constraints on hidden photon production [31]. The limits are shown in Figure 4, together with bounds derived from measurements of $\phi \rightarrow \eta A'$, $A' \rightarrow e^+e^-$ decays at KLOE [32], and searches for direct production in fixed-target experiments [31, 33, 34]. A hidden photon could also contribute to the muon anomalous magnetic moment, and constraints from this measurement are shown as well. Values of the mixing strength down to $10^{-3} - 10^{-2}$ are probed for $0.212 < m_{A'} < 9.3 \text{ GeV}$.

Other measurements could be reinterpreted as bounds on hidden photon production, such as searches for peaks in $e^+e^- \rightarrow \gamma \tau^+\tau^-$ events [11] or inclusive $e^+e^- \rightarrow \gamma$ hadrons production [12]. Invisible decays, occurring if hidden bosons decay to long-lived states, could also be detected as a monoenergetic photon peaks in $e^+e^- \rightarrow \gamma + \text{invisible}$ events [14].

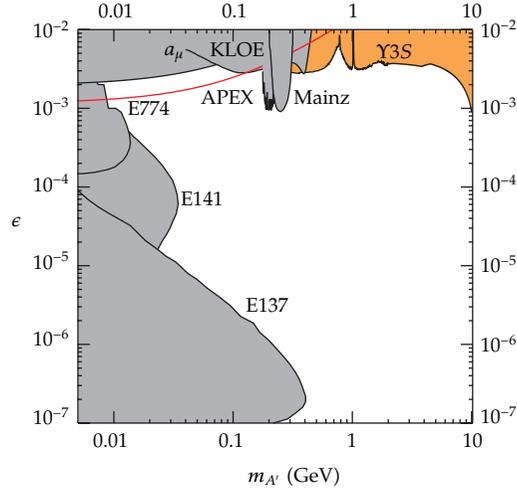


Figure 4: Constraints on the mixing strength, ϵ , as a function of the hidden photon mass derived from searches in $Y(2S, 3S)$ decays at *BABAR* (orange shading) and from other experiments (gray shading). The red line shows the value of the coupling required to explain the discrepancy between the calculated and measured anomalous magnetic moment of the muon [35].

4.2. Search for Hidden Sector Bosons

Non-Abelian extensions of hidden sectors introduce additional hidden gauge bosons, generically denoted W', W'', \dots . The phenomenology depends on the precise structure of the model, but heavy hidden bosons decay to lighter states if kinematically accessible, while the lightest bosons are metastable and decay to SM fermions via their mixing with the hidden photon [29, 30]. Non-Abelian hidden sectors could also accommodate inelastic dark matter [36] if the mass spectrum contains nearly degenerated states.

BABAR has performed a search for diboson production in $e^+e^- \rightarrow A'^* \rightarrow W'W''$, $W' \rightarrow l^+l^-$, $W'' \rightarrow l^+l^-$ ($l = e, u$) events, where the bosons are reconstructed via their decays into lepton pairs [37]. The study has been performed in the context of inelastic dark matter models, searching for two bosons with similar masses.

The signal signature consists of two narrow dileptonic resonances with similar masses carrying the full-beam energy. This topology is quite unique; the only backgrounds arise from QED processes. The signal is extracted as a function of the average dileptonic mass in the range 0.24–5.3 GeV. No significant signal is found; limits on the $e^+e^- \rightarrow A'^* \rightarrow W'W''$ cross-section are derived. The results are translated into limits on the product $\alpha_D e^2$, where $\alpha_D = g_D^2/4\pi$ and g_D is the hidden sector gauge coupling constant. Values down to 10^{-10} are probed, assuming nearly degenerate bosons.

4.3. Search for a Hidden Higgs Boson

The Higgsstrahlung process, $e^+e^- \rightarrow A'h'$, $h' \rightarrow A'A'$, offers another gateway to hidden sectors. 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 event topology is driven by the boson masses. While Higgs bosons heavier than two hidden photons decay promptly,

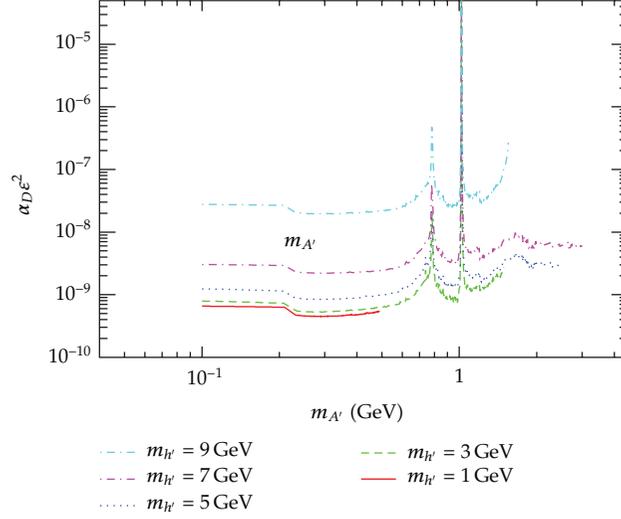


Figure 5: The 90% confidence level upper limit derived by *BABAR* on the product $\alpha_D \epsilon^2$ as a function of the hidden photon mass ($m_{A'}$) for selected values of hidden Higgs boson masses ($m_{h'}$).

they become metastable below this threshold and either produce displaced decays or escape undetected.

A search for hidden Higgs boson in Higgsstrahlung production in the prompt decay regime has been conducted at *BABAR*, based on a data sample of 521 fb^{-1} [38]. The measurement is performed in the range $0.8 < m_{h'} < 10.0 \text{ GeV}$ and $0.25 < m_{A'} < 3.0 \text{ GeV}$, with the constraint $m_{h'} > 2m_{A'}$. The signal is either fully reconstructed into lepton or pion pairs (exclusive mode), or partially reconstructed (inclusive mode). The exclusive modes contain of six tracks, forming three hidden photon candidates with equal masses and a total invariant mass close to the e^+e^- CM energy. The six pion final state has a significantly larger background than the other exclusive modes and is excluded from the search. Only two of the three hidden photons are reconstructed as dileptonic resonances for the inclusive modes. The remaining hidden photon, assigned to the recoiling system, must have a mass compatible with the Higgsstrahlung hypothesis.

No significant signal is observed, and upper limits on the $e^+e^- \rightarrow A'h', h' \rightarrow A'A'$ cross-section are set as a function of the hidden Higgs and hidden photon masses. These bounds are finally converted into limits on the product $\alpha_D \epsilon^2$. The results are displayed in Figure 5. Values down to 10^{-10} – 10^{-8} are excluded for a substantial fraction of the parameter space probed. These limits are translated into constraints on the mixing strength in the range 10^{-4} – 10^{-3} , assuming $\alpha_D = \alpha \simeq 1/137$.

5. Search for Dimuon Decays of Pseudoscalar Sgoldstinos

The observation of three $\Sigma^+ \rightarrow p\mu^+\mu^-$ events with a dimuon invariant mass clustered around 214 MeV by the HyperCP Collaboration [39] triggered much discussion about the possibility of a new light state X produced in $\Sigma^+ \rightarrow X$, $X \rightarrow \mu^+\mu^-$ decays. Speculations about the nature of this state included a pseudoscalar sgoldstino [40], a hidden sector photon [35, 41], or a light

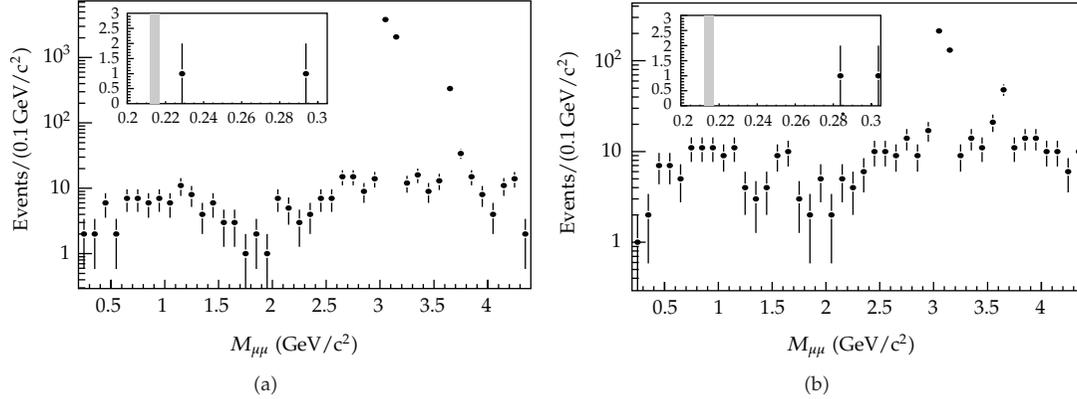


Figure 6: Distribution of the dimuon invariant mass for $B \rightarrow K^{*0}\mu^+\mu^-$ (a) and $B \rightarrow \rho^0\mu^+\mu^-$ (b) signal events for Belle data. The signal regions are shown as dashed bands in the inserts.

Higgs boson [42]. Subsequent measurements in e^+e^- collisions [8, 33] and $p\bar{p}$ interactions [43] excluded the light Higgs boson and hidden photon hypotheses.

The Belle Collaboration performed a search for this state in $B \rightarrow K^{*0}X$, $K^{*0} \rightarrow K^+\pi^-$, $X \rightarrow \mu^+\mu^-$ ($B_{K^{*0}X}$) and $B \rightarrow \rho^0X$, $\rho^0 \rightarrow \pi^+\pi^-$, $X \rightarrow \mu^+\mu^-$ (B_{ρ^0X}) decays using a sample of 675 million $B^0\bar{B}^0$ pairs [44]. The B mesons are reconstructed by combining two well-identified muons with a $K^+\pi^-$ or $\pi^+\pi^-$ pair. The signal candidates are identified using the beam-energy constrained mass $M_{bc} = \sqrt{E_{\text{beam}}^2 - p_B^2}$ and the energy difference $\Delta E = E_{\text{beam}} - E_B$, where E_{beam} denotes the beam energy and p_B (E_b) the momentum (energy) of the B candidate in the e^+e^- center-of-mass frame. Signal $B_{K^{*0}X}$ (B_{ρ^0X}) events are selected in the region $5.27 < M_{bc} < 5.29$ GeV and $-0.03 < \Delta E < 0.04$ GeV ($-0.04 < \Delta E < 0.04$ GeV). The corresponding dimuon mass distributions are shown in Figure 6. No events are observed in the signal region.

Lacking evidence for a pseudoscalar dimuon resonance at 214.3 MeV, 90% C.L. upper limits on the branching fraction $B \rightarrow K^{*0}X$, and $B \rightarrow \rho^0X$ are set at the level of 2.26×10^{-8} and 1.73×10^{-8} , respectively. They rule out models II and III of the sgoldstino interpretation of the HyperCP observation [45].

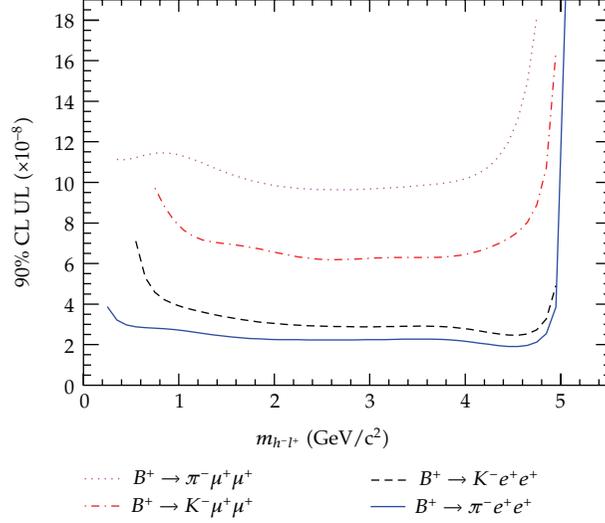
6. Search for Lepton Number Violation and a Majorana neutrino

Lepton number is conserved in low-energy processes in the SM model, but can be violated in a number of new physics scenarios, such as models containing Majorana neutrinos. In this case, the neutrino is its own antiparticle, and reactions changing the lepton number by two units become possible. The most sensitive searches have so far been based on neutrinoless nuclear double-beta decays $0\nu\beta\beta$ [46], but the nuclear environment complicates the extraction of the neutrino mass scale. Processes involving meson decays, such as $B \rightarrow h^-l^+l^+$ ($h = \pi, K, D$, and $l = e, \mu$), have been proposed as a possible alternative. The presence of a Majorana neutrino could mediate such a reaction, and would appear as an enhanced peak in the mass spectrum of the hadron and one of the leptons [47, 48].

BABAR has performed a search for the lepton number violating $B^+ \rightarrow h^-l^+l^+$ decays with $h = \pi, K$ and $l = e, \mu$, based on a sample of 471 ± 3 million $B\bar{B}$ pairs [49]. The B meson

Table 3: Results of lepton number violation searches performed by the *BABAR* (left column) and Belle Collaborations (right column). The limits are given at 90% confidence level.

Mode	BF UL (10^{-8})	Mode	BF UL (10^{-6})
$B^+ \rightarrow \pi^- e^+ e^+$	3.0	$B^+ \rightarrow D^- e^+ e^+$	2.6
$B^+ \rightarrow K^- e^+ e^+$	2.3	$B^+ \rightarrow D^- e^+ \mu^+$	1.8
$B^+ \rightarrow \pi^- \mu^+ \mu^+$	10.7	$B^+ \rightarrow D^- \mu^+ \mu^+$	1.0
$B^+ \rightarrow K^- \mu^+ \mu^+$	6.7		

**Figure 7:** 90% CL upper limits (UL) on the branching fraction $B(B^+ \rightarrow h^- l^+ l^+)$ as a function of the $h^- l^+ l^+$ mass ($m_{h^- l^+ l^+}$) derived by *BABAR*.

candidates are reconstructed by combining a hadron with a pair of tracks identified as leptons from particle identification algorithms. The background is suppressed through boosted decision trees (BDTs) using variables describing the event shape and the B meson candidate. The number of $B \rightarrow h^- l^+ l^+$ events is extracted by a multidimensional likelihood fit of the BDTs response and the beam-energy constrained mass $m_{ES} = \sqrt{s/4 - p_B^{*2}}$, where p_B^* is the momentum of the $e^+ e^-$ CM frame. No evidence for such decays is observed, and limits on the corresponding branching fractions are set.

A similar analysis has been conducted by Belle in $B^+ \rightarrow D^- e^+ e^+$, $B^+ \rightarrow D^- e^+ \mu^+$, and $B^+ \rightarrow D^- \mu^+ \mu^+$ decays, followed by a subsequent $D^- \rightarrow K^+ \pi^- \pi^-$ decay [50]. The analysis is based on a data sample of 772 million $B\bar{B}$ pairs collected at the $\Upsilon(4S)$ resonance. The B candidates are identified using the energy difference, $\Delta E = E_B - E_{\text{beam}}$ and m_{ES} . The signal region is defined as $5.27 < m_{ES} < 5.29$ GeV and $-0.055 < \Delta E < 0.035$ GeV for the $e^+ e^+$ and $e^+ \mu^+$ ($\mu^+ \mu^+$) final states. No signal events are observed and 90% CL limits on the branching fractions are set, assuming uniform three-body phase space distributions for $B^+ \rightarrow D^- l^+ l^+$ decays.

The results are reported in Table 3, and the limits on $B^+ \rightarrow h^- l^+ l^+$ decays as a function of the Majorana neutrino mass $m_\nu = m_{h^- l^+ l^+}$ are also displayed in Figure 7. The sensitivities of the $B \rightarrow h^- \mu^+ \mu^+$ channels are similar to that of recent measurements from LHCb in the same

channel [51, 52] and are an order of magnitude more stringent than the previous results for $B^+ \rightarrow h^- e^+ e^+$ decays [53].

7. Conclusion

B factories have proved to be versatile machines, ideally suited to search for light new physics over a wide range of processes. The next generation of flavor factories are expected to improve the sensitivity of these searches by one-to-two orders of magnitude, further constraining the parameter space of these theories. Many more results are to come in the near future, and will hopefully contribute to elucidate the nature of physics beyond the Standard Model.

Acknowledgments

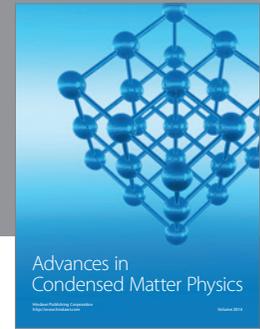
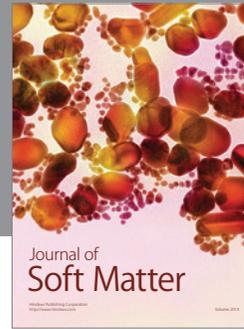
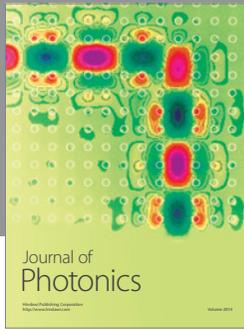
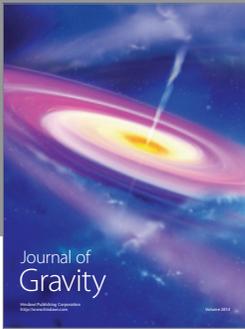
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