# Searches for light Higgs/Axions at *BaBar*

*Alessandro Gaz*
University of Colorado, Boulder, Colorado 80309, USA
*representing the BaBar Collaboration*

**DOI:** http://dx.doi.org/10.3204/DESY-PROC-2009-05/gaz_alessandro

Searches for light Higgs bosons/axions have been performed by the *BaBar* Collaboration in their decays to the final states $\mu^+\mu^-$, $\tau^+\tau^-$ and *invisible*. The test of Lepton Universality from $\Upsilon(1S)$ decays allows also to set non trivial limits on the existence of exotic particles. No significant signal has been found and we get more stringent limits on the existence of those particles with respect to previously reported results.

## 1 Introduction

The Next to Minimal Super-Symmetric Standard Model (NMSSM) has been proposed in order to reduce the amount of fine tuning required in the MSSM. In such model a light CP-odd Higgs boson $A^0$ arises naturally and, if its mass is lower than $2m_b$, where $m_b$ is the mass of the $b$ quark, its existence is not constrained by the LEP experiments. The radiative decays of the $\Upsilon$ mesons ($\Upsilon(nS) \to \gamma A^0$) are a privileged place for searching for this particle [1]. Useful limits can be obtained at the current $B-$factories.

Moreover, the existence of an axion-like neutral light particle has been postulated to explain the positron excess seen by PAMELA [2]. According to [3], a particle $A^0$ with mass $m_K - m_\pi < m_{A^0} <\sim 800$ MeV/$c^2$ dominantly decaying to charged leptons would explain the experimental data.

Experimental motivation for searching for a light particle decaying into muon pairs comes from the HyperCP experiment [4], which observed the decay $\Sigma^+ \to p\,\mu^+\mu^-$. The invariant masses of the $\mu\mu$ pair for the three signal events observed cluster around 214 MeV/$c^2$, suggesting the existence of an intermediate state decaying to charged leptons.

## 2 The *BaBar* detector and dataset

The BaBar detector is described in detail elsewhere [5]. The data used for these searches have been collected at the PEP-II asymmetric $e^+e^-$ collider, located at the SLAC National Accelerator Laboratory. The relevant datasets are constituted by 30.2 fb$^{-1}$ (14.5 fb$^{-1}$) taken at a center of mass energy corresponding to the mass of the $\Upsilon(3S)$ ($\Upsilon(2S)$) resonance. This corresponds to a sample of 122 (99) million $\Upsilon(3S)$ ($\Upsilon(2S)$) decays. The non resonant background has been studied by collecting data at center of mass energies away from the resonances.

## 3 Search for light Higgs bosons/axions

Higgs bosons/axions have been searched through the radiative decays of $\Upsilon(2,3S)$ mesons $\Upsilon(2,3S) \to \gamma A^0$ and $A^0$ decaying to the final states: *invisible*, $\tau^+\tau^-$, and $\mu^+\mu^-$.

### 3.1 $A^0 \to$ *invisible*

We study the radiative decays of the $\Upsilon(3S)$ sample; the experimental signature of an $A^0$ decaying to invisible is a monochromatic peak of the photon energy in the center of mass (CM) frame. The energy of the peak is given by:

$$E_\gamma = \frac{m_\Upsilon^2 - m_{A^0}^2}{2m_\Upsilon}$$

The dominant backgrounds for this analysis arise from processes like $e^+e^- \to \gamma\gamma$ and $e^+e^- \to e^+e^-\gamma$. The selection is optimized in two different regions of the photon spectrum: the High Energy Region $3.2 < E_\gamma < 5.5$ GeV, dominated by the two-photon background, and the Low Energy Region $2.2 < E_\gamma < 3.7$ GeV, dominated by radiative Bhabha events. The signal is searched for by performing a scan (in steps of 0.025-0.1 GeV) over the photon spectrum. We find no significant signal and the 90% Confidence Level (CL) upper limits we establish on the product branching fraction $BF(\Upsilon(3S) \to \gamma A^0) \times BF(A^0 \to \textit{invisible})$ (see Fig. 1) are in the range $(0.7 - 31) \times 10^{-6}$ [6].

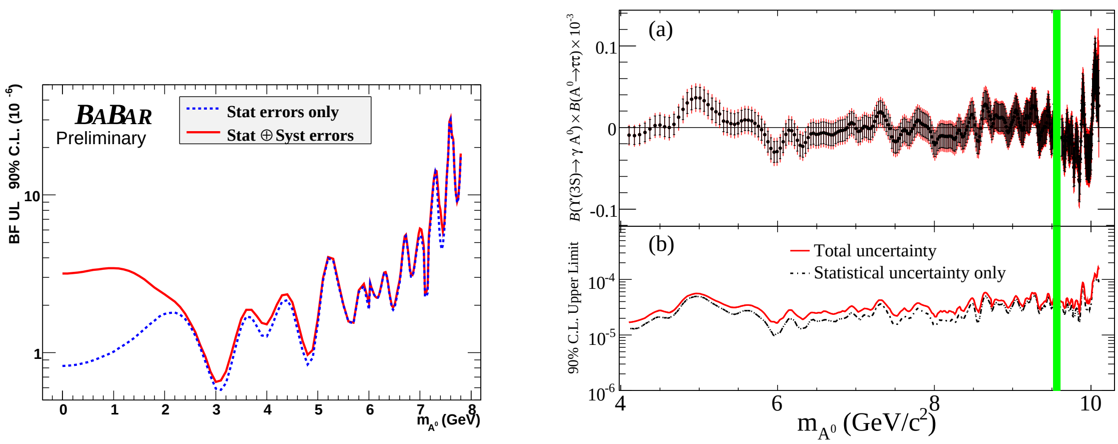


Figure 1: Left: results for the $A^0 \to$ *invisible* analysis: the 90% CL upper limit on $BF(\Upsilon(3S) \to \gamma A^0) \times BF(A^0 \to \textit{invisible})$ is shown as a function of the photon energy. Right: results for the $A^0 \to \tau^+\tau^-$ analysis. Top: fitted product branching fraction $BF(\Upsilon(3S) \to \gamma A^0) \times BF(A^0 \to \tau^+\tau^-)$; bottom: 90% CL upper limits.

### 3.2 $A^0 \to \tau^+\tau^-$

The $\Upsilon(3S)$ sample is also used in the search for $\Upsilon(3S) \to \gamma A^0$, with $A^0 \to \tau^+\tau^-$. The $\tau$ leptons are requested to decay to either $e\nu\bar{\nu}$ or $\mu\nu\bar{\nu}$. Events with one energetic photon, two identified leptons and missing energy consistent with the $\tau$ decays are selected. The selection is optimized in 5 different regions of the photon spectrum and the efficiency for signal events varies in the range $10-26\%$. Backgrounds arise from irreducible $e^+e^- \to \tau^+\tau^-$ events and higher order QED processes.

We look for a signal performing a scan on the photon energy spectrum ($0.2 < E_\gamma < 5.0$ GeV), fitting simultaneously the three final states ($ee$, $e\mu$, and $\mu\mu$). The region where $\chi_{bJ}(2P) \to \gamma\Upsilon(1S)$ is excluded from the scan. No significant signal is found and we set 90% CL upper limits (see Fig. 1) on the product branching fraction $BF(\Upsilon(3S) \to \gamma A^0) \times BF(A^0 \to \tau^+\tau^-)$ in the range $(1.5-16)\times 10^{-5}$ [7]. We also obtain an upper limit on the branching fraction of $\eta_b$ decaying to $\tau$ pairs: $BF(\eta_b \to \tau^+\tau^-) < 8\%$.

### 3.3 $A^0 \to \mu^+\mu^-$

Both the $\Upsilon(2S)$ and $\Upsilon(3S)$ data samples are used in the search for $\Upsilon \to \gamma A^0$, $A^0 \to \mu^+\mu^-$. The final state is fully reconstructed by requesting one energetic photon and two charged tracks kinematically compatible with the decay of the $\Upsilon$.

The signal is searched for by looking for a peak in the distribution of the *reduced mass* $m_R = \sqrt{m_{A^0}^2 - 4m_\mu^2}$. The dominant backgrounds arise from $e^+e^- \to \mu^+\mu^-\gamma$ events and by the Initial State Radiation production of the $\rho$, $\phi$, $\psi(nS)$ and $\Upsilon(1S)$ mesons.

We perform a scan consisting of $\sim 2000$ points over the range $0.212 < m_{A^0} < 9.3$ GeV on the two datasets; the regions of the $J/\psi$ and $\psi(2S)$ are excluded from the scan. We then extract the effective Yukawa coupling $f_\Upsilon$ of the bound $b\bar{b}$ state to the $A^0$ and combine the results (see Fig. 2). $f_\Upsilon$ is defined by:

$$\frac{BF(\Upsilon(nS) \to \gamma A^0)}{BF(\Upsilon(nS) \to \ell^+\ell^-)} = \frac{f_\Upsilon^2}{2\pi\alpha}\left(1 - \frac{m_{A^0}^2}{m_{\Upsilon(nS)}^2}\right),$$

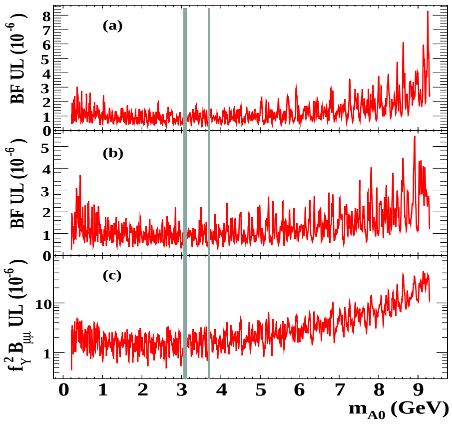


Figure 2: 90% CL upper limits on the product branching fractions of $\Upsilon \to \gamma A^0$, $A^0 \to \mu\mu$ for the $\Upsilon(2S)$ sample (top) and the $\Upsilon(3S)$ (middle). The bottom plot shows the combination of the above results in terms of the Yukawa coupling $f_\Upsilon$.

where $\alpha$ is the fine structure constant. We find no significant signal [8]; we limit $f_\Upsilon$ to be at most 12% of the Standard Model coupling of the $b$ quark to the Higgs boson. We also rule out the existence of a particle of 214 MeV mass suggested by the HyperCP results.

## 4 Test of Lepton Universality

In the Standard Model, the coupling of leptons with gauge bosons is independent of the lepton flavor. The existence of non-SM particles can be inferred from deviations from the predictions of the branching fractions of the $\Upsilon(1S)$ meson to lepton pairs.

The quantity:

$$R_{\tau\mu} = \frac{\Gamma_{\Upsilon(1S)\to\tau^+\tau^-}}{\Gamma_{\Upsilon(1S)\to\mu^+\mu^-}}$$

is predicted to be 1 in the Standard Model, neglecting very small corrections due to the mass difference between the two lepton species.

We study the events $\Upsilon(3S) \to \Upsilon(1S)\,\pi^+\pi^-$, $\Upsilon(1S) \to \mu^+\mu^-$, $\tau^+\tau^-$. The $\mu\mu$ sample is selected by fully reconstructing the event; the discriminant variables are the invariant mass of the muon pair $M(\mu^+\mu^-)$, and $\Delta M = M(\pi^+\pi^-\mu^+\mu^-) - M(\mu^+\mu^-)$. The $\tau\tau$ sample is selected requesting that the visible energy of the event is 5 GeV smaller than the collision energy, to account for the presence of the undetected neutrinos. The discriminating variable is the invariant mass of the recoiling $\pi^+\pi^-$ pair $M_{\pi^+\pi^-}$.

$R_{\tau\mu}$ is extracted from a simultaneous fit to the yields of the $\mu\mu$ and $\tau\tau$ samples. The result [9] is in agreement with the Standard Model expectations:

$$R_{\tau\mu} = 1.009 \pm 0.010 \pm 0.024\,,$$

where the first error is statistical and the second systematic.

## 5 Conclusions

The *BABAR* Collaboration performed searches for a light Higgs boson or an axion-like particle decaying to *invisible*, $\tau^+\tau^-$, and $\mu^+\mu^-$ final states in the radiative decays of $\Upsilon(ns)$ mesons. No significant signals have been found and sizable improvement over the previous upper limits set by the CLEO collaboration has been reached.

These measurements are still statistically limited; a very significant improvement in these searches could be obtained at one of the proposed *Super B-Factories*, particularly in the region around 10 GeV/$c^2$, where mixing with the $\eta_b$ states can occur [10].

A significant improvement in the test of Lepton Universality has been obtained from which more stringent limits on the existence of exotic particles can be set.

## References

[1] R. Dermisek, J. F. Gunion, and B. McElrath, Phys. Rev. **D76** 051105 (2007).

[2] O. Adriani et al., arXiv:0810.4995 [astro-ph]; arXiv:0810.4994 [astrp-ph].

[3] Y. Nomura and J. Thaler, Phys. Rev. **D79** 075008 (2009).

[4] HyperCP Collaboration: H. Park et al., Phys. Rev. Lett. **93** 021801 (2005).

[5] *BABAR* Collaboration: B. Aubert et al., Nucl. Instrum. Methods Phys. Res., Sect A479, 1 (2002).

[6] *BABAR* Collaboration: B. Aubert et al., arXiv:0808.0017 [hep-ex].

[7] *BABAR* Collaboration: B. Aubert et al., arXiv:0906.2219 [hep-ex].

[8] *BABAR* Collaboration: B. Aubert et al., Phys. Rev. Lett. **103** 081803 (2009).

[9] G. Bonneaud, representing the *BABAR* Collaboration, Talk given at FPCP 2009, Lake Placid, NY, USA.

[10] F. Domingo, U. Ellwanger, M.-A. Sanchis-Lozano, arXiv:0907.0348 [hep-ph].