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# SEARCH FOR DARK PHOTONS AND DARK HIGGS AT BABAR

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**Abstract**

We report on a search for dark photons $A'$ and dark Higgs $h'$ through the higgs-strahlung process $e^+e^- \to A'^*,\ A'^* \to A'h'$ using the BABAR detector at the PEP-II asymmetric energy $e^+e^-$ collider. This search is motivated by the results of astrophysical and terrestrial experiments. We analyze the full BABAR dataset (516 fb$^{-1}$) and find no significant signal, thus we proceed to set 90% confidence level upper limits on the product of the Standard Model-dark sector mixing angle and the dark sector coupling constant.

## 1 Introduction

While the evidence of the existence of dark matter has become overwhelming in the past decade, its nature still remains unclear. Among the different models that have been proposed, the scenario in which the dark matter is made of

Weakly Interacting Massive Particles (WIMPs) seems particularly appealing. The generic Lagrangian that incorporates the Standard Model (SM) and the dark sector can be written as:

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{WIMP} + \mathcal{L}_{mediator} \,, \tag{1}$$

where the mediator between the SM and the WIMP sector can be either a SM particle (gauge boson, Higgs), or a yet to be discovered kind of particle.

The models of *secluded* $U(1)_D$, in which the additional gauge field mixes kinetically with the SM hypercharge $U(1)_Y$ are particularly interesting for the investigation at colliders [1]. In such scenarios, WIMP particles can annihilate into the mediator particle $A'$ (which we will refer to as the dark photon), which then couples to the SM particles. If $m(A') \sim 1$ GeV $\ll m(WIMP)$, this naturally leads to an enhancement of the WIMP annihilation cross-section in the center of the galaxy, and a larger branching fraction to leptons, consistent with the observations of PAMELA [2], ATIC [3], and INTEGRAL [4]. In addition, this could also explain the annual modulation observed by the DAMA/LIBRA Collaboration [5].

In this search we focus on models in which a dark Higgs $h'$ is responsible for the spontaneous symmetry breaking of the secluded $U(1)_D$. In general the $A'$ and $h'$ states are predicted to be narrow, so the favored production mechanism at $e^+e^-$ colliders is the so called higgs-strahlung process: $e^+e^- \to A'^* \to A'h'$ [6, 7]. If $m(h') > 2m(A')$, as we will assume in this analysis, the $h'$ dominantly decays to a pair of dark photons, which always decay with sizable branching fraction to pairs of leptons. In the higgs-strahlung process, we would therefore expect a very clear signature of three pairs of leptons in the final state.

## 2 The BABAR experiment at the PEP-II $e^+e^-$ collider

The BABAR detector is described in detail elsewhere [8]. The tracking system is composed by a five-layer silicon vertex tracker (SVT) and a drift chamber (DCH) which operates using a mixture of helium and isobutane. The measurement of the energy loss through the silicon and the gaseous mixture provides useful information for particle identification, particularly at low momentum. A detector of internally reflected Cherenkov light (DIRC) is used for particle identification (PID) purposes, particularly for separating charged kaons from charged pions at high momentum. A tallium-doped CsI calorimeter (EMC) measures the energy deposited by electromagnetic showers and the interaction of neutral particles, while the detectors (resistive plate chambers or limited streamer tubes) of the instrumented flux return (IFR) provide the detection of muons and neutral kaons.

Particularly important, for this analysis, are the PID capabilities of the detector. The PID algorithms that have been developed in the last years of the experiment are based on Error Correcting Output Code (ECOC) [9], and combine all the relevant information from the five subdetectors. For this analysis, it is important to maximize the selection efficiency, rather than keeping the mis-identification rate low. With the selectors employed in this analysis we select electrons (muons) with an average efficiency of $\sim 98\%$ ($\sim 90\%$), with a pion mis-identification rate of $\sim 0.4\%$ ($\sim 4\%$).

The PEP-II $e^+e^-$ asymmetric energy collider has operated for a decade, mostly as a $\Upsilon(4s)$ factory. In the last months of data-taking runs at the energy of the $\Upsilon(3s)$ and $\Upsilon(2s)$ have been taken, and throughout the whole history of the experiment data at energies away from the resonances have been collected, in order to study the continuum $e^+e^- \to q\bar{q}$, $q = u, d, s, c$ background. For the purposes of this analysis, all data can be used: the total dataset has a corresponding integrated luminosity of 516 $\text{fb}^{-1}$.

## 3 Search for dark Higgs and dark photons with the Higgs-strahlung mechanism

We search for the higgs-strahlung process in the full BABAR dataset [10]. We limit ourselves to the ranges $0.8 < m(h') < 10$ GeV and $0.25 < m(A') < 3.0$ GeV, requiring $m(h') > 2m(A')$. For these masses and kinetical mixing strength $\varepsilon \geq 10^{-4}$, these particles are expected to decay promptly. We consider the $A'$ decaying to pairs of electrons, muons, and pions. We search for the higgs-strahlung process either in the *exclusive modes*, in the order: $6\mu$, $4\mu 2e$, $2\mu 6e$, $4\mu 2\pi$, $2\mu 2e 2\pi$, $4e2\pi$, $2\mu 4\pi$, $2e4\pi$, or the *inclusive modes*: $4\mu + X$, $2\mu 2e + X$. The order is chosen to minimize the cross-feed between channels and the loss of efficiency due to mis-classification. The remaining possible final states are neglected because their contribution to the final result is expected to be marginal.

We optimize the selection using $\sim 10\%$ of the data; these data are then discarded for the actual analysis. For the exclusive modes, we require the event to contain exactly 6 tracks, accounting for at least 95% of the colliding $e^+e^-$ energy. The tracks are also required to originate from the same vertex (the vertex probability has to be $\geq 10^{-5}$), and the largest mass difference $\Delta M$ between two $A'$ candidates has to be less than 10-240 MeV, depending on the final state. For the inclusive modes we require the four tracks to originate from the same vertex (probability $\geq 10^{-5}$) and the masses of the $A'$ candidates have to be compatible within uncertainties. Moreover, the knowledge of the beam energies allows us to derive the mass of the recoiling system $X$ (and require it to be compatible with the mass of the other $A'$ candidates). Figure 1 shows the $\Delta M$ distribution for signal Monte Carlo (MC) and the data. To increase the data statistics, we also consider the *same-sign* sample, obtained by requiring the presence of two pairs of particles having the same electric charge (e.g. $(\mu^+\mu^+)(e^-e^-)$). The signal is clearly peaking at low values of $\Delta M$, while the background has a much broader distribution. Opposite-sign and same-sign data give compatible predictions for the amount of background expected in the analysis.

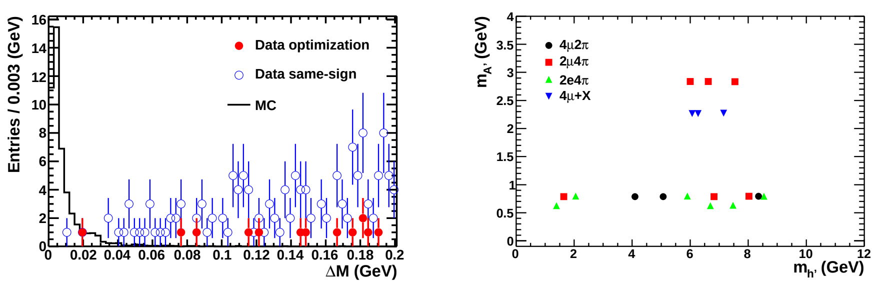


Figure 1: Left plot: $\Delta M$ distributions for (black histogram) signal MC ($m(h') = 3.0$ GeV, $m(A') = 0.5$ GeV), (red filled circles) data used for the optimization, (open blue circles) same-sign data. Right plot: distribution in the ($m(h')$, $m(A')$) plane of the six events observed in the dataset used in the analysis. For each event there are three different combinations of $A'$ candidates than can be assigned as daughters of the $h'$ candidate.

Six events pass our selection in the dataset used in the analysis, four of which lie on the band $m(A') \sim 0.7 - 0.8$ GeV, consistent with the decay of $\rho$ and $\omega$ mesons. This is fully compatible with our SM background predictions.

In order to establish 90% confidence level (CL) upper limits on the cross-sections of the higgs-strahlung process, we conservatively assume that each event is a potential signal event. We scan the $(m(h'), m(A'))$ plane at steps of 10 MeV along each axis, defining as signal region the interval $m(X) - 5\sigma_{m(X)} < m(X) < m(X) + 3\sigma_{m(X)}$, where $X$ is either $A'$ or $h'$. The signal efficiency (accounting for acceptance, trigger, and selection) is determined from MC for several signal points and then interpolated through the plane. The results of this scan are presented in Fig. 2.

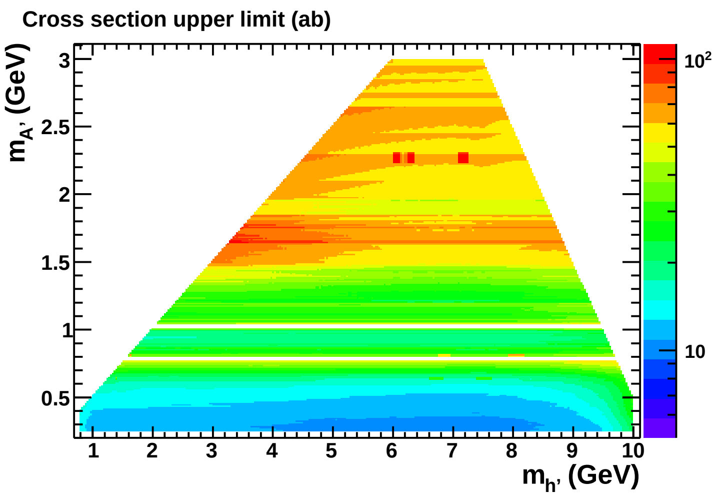


Figure 2: Cross section upper limits (in ab) for the higgs-strahlung process. We conservatively assume that each event is a potential signal event.

The dominant systematic uncertainty comes from the interpolation procedure of the signal efficiency (1-8%); other major contributions arise from PID (1.5-4.5%) and the modeling of $A'$ decays to hadrons (4%).

We translate these cross-section upper limits into upper limits on the product $\alpha_D \varepsilon^2$, where $\alpha_D = g_D^2/4\pi$ is the gauge coupling of the dark sector. These upper limits are displayed on Fig. 3. Assuming $\alpha_D = \alpha$, these limits translate into upper limits on the kinetic mixing $\varepsilon$, which are in the range $10^{-3} - 10^{-4}$, significantly tighter than those previously presented.

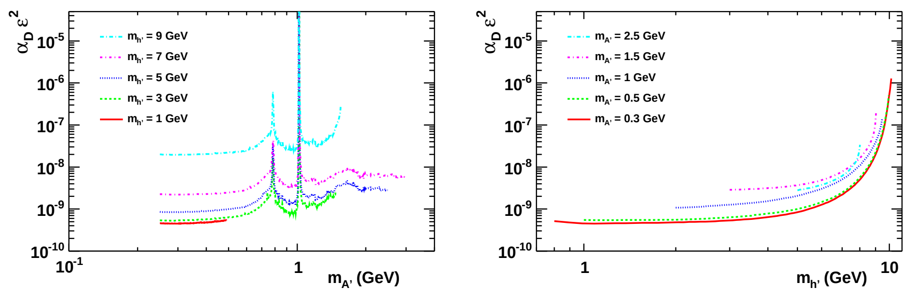


Figure 3: 90% CL upper limits on the product $\alpha_D\varepsilon^2$. On the left plot we show the exclusion curves as a function of $m(A')$ for different $m(h')$ hypotheses, whereas on the right plot the curves are as a function of $m(h')$ for different values of $m(A')$.

## 4 Conclusions

In conclusion, we have performed a search for the higgs-strahlung process $e^+e^- \to A'h'$, with the dark Higgs $h'$ decaying to a pair of dark photons $A'$. Using the full BABAR dataset, we found no signal and set upper limits on the dark coupling constant that are significantly tighter than corresponding limits previously presented by other experiments.

## References


1. M. Pospelov, A. Ritz, M. Voloshin, Phys. Lett. B **662**, 53 (2008).
2. O. Adriani *et al.*, Nature **458**, 607 (2009).
3. J. Chang *et al.*, Nature **456**, 362 (2008).
4. A.W. Strong *et al.*, Astron. Astrophys. **444**, 495 (2005).
5. R. Bernabei *et al.*, Eur. Phys. J. C **56**, 333 (2008).
6. B. Batell, M. Pospelov, A. Ritz, Phys. Rev. D **79**, 115008 (2009).
7. R. Essig, P. Shuster, N. Toro, Phys. Rev. D **80**, 115003 (2009).
8. BABAR Collaboration, Nucl. Instrum. Meth. A, **479**, 1 (2002).

9. T.G. Dietterich and G. Bakiri, J. Artif. Intell. Res., **2**, 263 (1995).

10. BABAR Collaboration, Phys. Rev. Lett, **108** 211801 (2012).