# Dark photon search and the Higgs-strahlung channel at Belle

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Preliminary individual limits of Belle are reported for the Dark Photon, $A$, and Dark Higgs, $h'$ searches, for mass ranges, respectively of $0.25 < m_A < 3.5$ GeV/c$^2$ and $0.5 < m_{h'} < 10.5$ GeV/c$^2$. The Dark Photon and Dark Higgs were searched for in the Higgs-strahlung channels: $e^+e^- \to Ah'$, with $h' \to AA$ and $A \to l^+l^-$ (with $l = e$ or $\mu$) or $A \to \pi^+\pi^-$.

## 1 Introduction

Dark gauge bosons are postulated to have low masses; of order MeV to GeV due to astrophysical constraints [1, 2, 3]. These astrophysical observations include: excesses in the cosmic-ray flux of electrons and/or positrons above expected background beyond normal astrophysical processes and the expected flux of protons and/or anti-protons. Dark matter could be charged under the dark $U(1)$ symmetry group and then the observed excess might correspond to dark matter annihilating into a Dark Photon $A$, which in turn decays into $l^+l^-$ (with $l = e$ or $\mu$ or possibly $\tau$ if energetically allowed).

The ideal tools to discover such particles are therefore not the highest energy hadron collider experiments, but lower-energy electron-positron high-luminosity collider experiments such as Belle/BelleII and BaBar, or dedicated fixed target experiments, several of which are planned or already under construction at JLAB (Newport News, USA) or at MAMI (Mainz, Germany), for example. In Belle, work on dark gauge boson searches was started only recently, and has focused on the strategies proposed by [4, 5, 6, 7, 8]. The dark $U(1)$ symmetry group could be spontaneously broken, often by a Higgs mechanism, adding a dark Higgs $h'$ (or dark Higgses) to these models. These proceedings will focus on the so-called Higgs-strahlung channel, where the electron-positron annihilation would produce a Dark Photon and a Dark Higgs, $e^+e^- \to Ah'$ and $h' \to AA$; and in particular the prompt decay modes with $3e^+3e^-$, $3\mu^+3\mu^-$, $2\mu^+2\mu^-e^+e^-$ and $2\pi^+2\pi^-e^+e^-$ final states; using the entire data set collected by Belle.

CLOE [9] and BaBar [10] reported their searches on the Dark Photon and the Dark Higgs (see also contribution of W. Gradl to these proceedings). CLOE focused their search on $m_{h'} < m_A$ (where $A$ and $h'$ are not prompt) and BaBar on $m_{h'} > 2m_A$ (where $A$ and $h'$ are prompt), but no signal was found.

## 2 Experimental setup

The Belle detector is a large-solid-angle magnetic spectrometer, which consists of a silicon vertex detector (SVD), a central drift chamber (CDC), an array of aerogel threshold Cerenkov counters (ACC), a barrel-like arrangement of time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter (ECL) composed of CsI(Tl) crystals located inside a super-conducting solenoid that provides a 1.5 T magnetic field. An iron flux-return (KLM) located outside the coil is optimized to detect $K_L^0$ mesons and to identify muons. A detailed description can be found in [11]. Belle is currently being upgraded to Belle II, an upgraded detector for operation at SuperKEKB, which will have 40 times higher luminosity than KEKB [12]. The KEKB collider [13], located in Tsukuba, Japan, is the world's highest-luminosity electron-position collider. KEKB has produced more than one ab$^{-1}$ of data at center-of-mass energies corresponding to the $\Upsilon$(1S) to $\Upsilon$(5S) resonances, and in the nearby continuum.

## 3 Analysis strategy

Events with six charged tracks final states from $e^+e^- \to Ah' \to AAA$ are reconstructed. Energy and momentum conservation are required. The invariant mass for each combination of leptons is required to be consistent with three distinct $A \to l^+l^-$ (or $\pi^+\pi^-$). Combinations with three "equal" masses eg, ($m_{ll}^1$, $m_{ll}^2$ and $m_{ll}^3$) and $m_{llll} > 2m_{ll}$ are kept. The "equality" is defined as follows: $m_{ll}^{mean} - 3.\sigma(m_{ll}^{mean}) < m_{ll}^{1,2,3} < m_{mean} + 3.\sigma(m_{ll}^{mean})$, with $m_{ll}^{mean}$ the mean mass of the three dark photon candidates and the width ($\sigma$) of the signal as function of the Dark Photon mass which is taken from Monte Carlo (MC) simulation. The detection efficiency of Belle was modeled with MC simulations based on the GEANT4 package [14]. Belle can achieve, on average, a detection efficiency of 20 % and 40 % respectively for six electrons and six muons final states and of 15 % and 30 % respectively for 4e2$\mu$ and 4$\pi$2e.

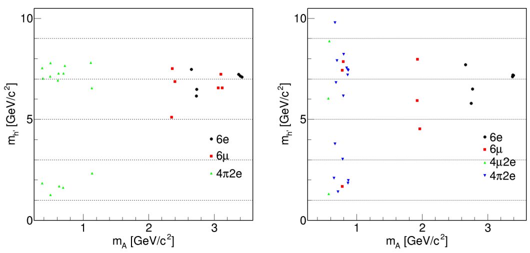


Figure 1: Dark Higgs mass as function of the Dark Photon mass. Left, background estimation. Right, events observed.

## 4 Results

Figure 1-right shows the preliminary results. Each event observed makes three entries in the plot Dark Higgs mass versus Darh Photon mass since there are three possible combination to form a Dark Higgs from two Dark Photons out of three Dark Photons. The events observed are consistent with the background estimation Figure 1-left. The background estimation is based on a data driven method. In this method, all combinations are combined with their wrong-sign

Table 1: Comparison between predicted Belle background, Belle number of events observed and BaBar number of events observed.

| Final state | 6e | $6\mu$ | $4\mu 2$e | $4\pi 2$e |
|---|---|---|---|---|
| Belle expected | $3.60 \pm 1.31$ | $1.64 \pm 1.12$ | 0 | $6.81 \pm 3.64$ |
| Belle observed | 2 | 2 | 1 | 5 |
| BaBar observed | 0 | 0 | 0 | 2 |

partner, eg $(l^-l^-)(l^+l^+)(l^+l^+)$, are kept. Table 1 summarizes the results. Contribution of $\rho \to \pi^+\pi^-$ or $\omega \to \pi^+\pi^-$ decays for $0.7 < m_A < 0.9$ GeV/c$^2$ is observed;produced most likely by two photon processes.

## 5 Preliminary individual upper limits

A statistical method based on Bayesian inference with the use of Markov Chain Monte Carlo [16] is used to then calculate preliminary upper limits, 90% Confidence Level (CL), for the full luminosity. Figure 2 (left to right - six electron, right six muons, $4\mu 2e$ and $4\pi 2e$ final states) shows the preliminary individual upper limits for different Dark Higgs mass hypotheses compared to the BaBar upper limits[10]. The preliminary individual upper limits scale nearly linearly with the integrated luminosity as one would expect in presence of almost no background.

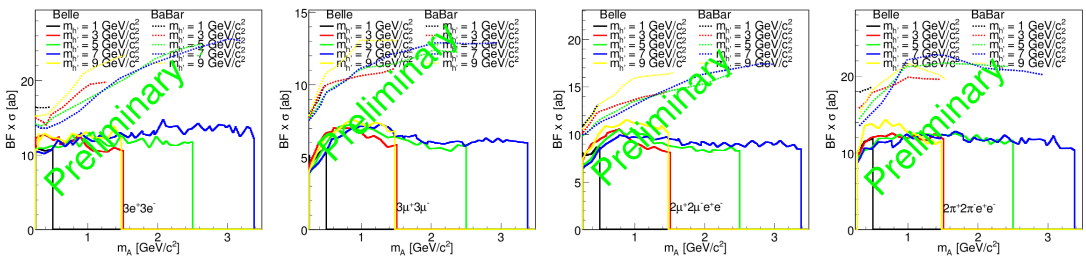


Figure 2: Preliminary individual limits as a function of the Dark Photon mass for different Dark Higgs mass hypotheses. From left to right: $6e$, $6\mu$, $2\mu^+2\mu^-e^+e^-$ and $2\pi^+2\pi^-e^+e^-$ final states. Full line this Belle analysis. Dashed line BaBar upper limit[10].

## 6 Conclusions

The Dark Photon and the Dark Higgs are searched for in the mass ranges: $0.25 < m_A < 3.5$ GeV/c$^2$ and $0.5 < m_{h'} < 10.5$ GeV/c$^2$. No signal was observed. It was found that the background is small and is consistent with the background estimation. The preliminary individual limits of Belle have been shown. The individual limit scales nearly linearly with the integrated luminosity. In the coming years, Belle2 will take 40 times more statistics. Altough the instantaneous luminosity will be much smaller than for the fixed target experiment instantaneous luminosity, Belle2 can cross-check with no extra cost any fixed target results avobe 20 MeV/c$^2$ and can extract limit up to 10.5 GeV/c$^2$.

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