# The HPS experiment: searching for a dark photon at Jefferson Lab

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**Abstract.** The Heavy Photon Search (HPS) experiment at Jefferson Laboratory will search for heavy U(1) vector bosons, called 'heavy photons' or 'dark photons'. Heavy photons are expected on very general theoretical grounds, and recent astrophysical evidence suggesting they might mediate dark matter annihilations and/or interactions with ordinary matter has motivated the search for a heavy photon in the mass range $m_{A'} \sim 20$ to 1000 MeV/c$^2$. Heavy photons couple to ordinary photons through kinetic mixing, which induces their weak coupling to electrons. Since they couple to electrons, heavy photons are radiated in electron scattering and can subsequently decay into narrow $e^+e^-$ resonances which can be observed above the background. Using the high luminosity, precision electron beam available from Jefferson Lab and a combination of a silicon microstrip vertex tracker with a lead tungstate calorimeter, HPS will explore a large and unexplored domain in the mass/coupling plane with extraordinary sensitivity. This talk will review the motivations for the search for dark photons, and will present the experimental set-up and goals of the HPS experiment.

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## THE MOTIVATION FOR HEAVY PHOTONS

Heavy photons, or $A'$ particles, are hypothetical massive vector bosons that weakly couple to electrically charged particles by kinetic mixing with the photon [1, 2], where the interaction is suppressed relative to the electron charge $e$ by the parameter $\varepsilon$, which can be in the range $10^{-12} - 10^{-2}$ [3]. The $A'$ allows ordinary matter to have a small coupling to new particles in a hidden sector, hitherto undetected, that do not interact with the Standard Model's strong, weak, or electromagnetic forces. The existence of heavy photons could explain several intriguing dark matter-related anomalies, and explain the discrepancy between the measured and calculated value of the anomalous magnetic moment of the muon $(a_\mu = g2)$ [4].

The possible role of heavy photons in dark matter physics [5, 6] has generated interest to directly search for the $A'$. Results from indirect and direct dark matter searches have been interpreted as potential signals of dark matter interacting through a heavy photon. In particular, recent measurements reporting an excess in the cosmic-ray flux of electrons and/or positrons above backgrounds expected from normal astrophysical processes, such as PAMELA [7] and FERMI [8], have motivated the existence of an $A'$.

If the excess arises from dark matter annihilation, two features conflict with the annihilation of WIMP dark matter charged under the Standard Model weak interactions, but

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are compatible with dark matter charged under a new $U(1)$ that annihilates into $A'$ pairs, which decay directly into electrons and positrons, and/or into muons that decay into electrons and positrons [5, 6]. The first is that the annihilation cross-section required to explain the electron signal is 50–1000 times larger than the cross-section favored for the "WIMP miracle". This can be explained if dark matter interacts with an $\mathscr{O}$(GeV)-mass $A'$, which mediates a new moderate range force and enhances the annihilation rate at low velocities. The second is that the PAMELA satellite did not observe any anti-proton excess [9], implying that if dark matter annihilation is responsible for the positron/electron signals, it does not produce baryons. This is contradictory to expectations for dark matter annihilating through Standard Model interactions, but is expected if dark matter decays into light $A'$s, which (for $m_{A'} \leq$ GeV) are kinematically unable to decay into protons and anti-protons.

The Heavy Photon Search experiment (HPS) will search for dark photons with mass $m_{A'} \sim 100$ MeV and $\alpha/\alpha \leq 10^{-5}$, which can be produced by a reaction analogous to photon bremsstrahlung, and which then decay promptly to $e^+e^-$ and/or $\mu^+\mu^-$ pairs. HPS is not the only experiment searching for heavy photons; other proposed experiments include APEX [10], MAMI [11], and DarkLight [12].

## THE HEAVY PHOTON SEARCH AT JEFFERSON LAB

HPS will search for heavy photons in the mass range from 20 MeV to 1000 MeV using two beam energies of 2.2 GeV and 6.6 GeV. Detection of heavy photons depends on precisely measuring the invariant mass of the $A'$ decay particles and the position of the decay vertex. To do this, HPS will use a compact, large acceptance forward spectrometer, a silicon microstrip vertex tracker, an electromagnetic calorimeter, and a muon system that will be positioned behind the CLAS detector in Hall B at Jefferson Lab. The experiment will take advantage of the clean electron beam available at Jefferson Lab and will run with 200–500 nA beam currents at 2.2 and 6.6 GeV on 0.15%–0.25% $X_0$ tungsten targets. By positioning the tracker immediately downstream of the tungsten target inside an analyzing magnet, the complete kinematic information required for $A'$ reconstruction can be obtained from the system. The proximity to the target maximizes the acceptance of the compact detector and provides excellent momentum and vertexing resolution.

The estimated reach for the full HPS experiment is shown in Figure 1, along with the estimated reach for a test run, and some existing constraints. The solid red line shows the projected $2\sigma$ limits from the full HPS experiment, assuming 3 months of running time at both 2.2 GeV (at 200 nA) and 6.6 GeV (at 450 nA). The upper region corresponds to a resonance search, while the lower corresponds to a combined resonance plus vertexing search. Several projected sensitivities are shown for HPS. The dashed red line shows the projected sensitivity from 1 week of running in the HPS test run configuration at 2.2 GeV (200 nA), while the dashed blue limits correspond to 1 week of running the in the test run configuration at 1.1 GeV (200 nA). Existing constraints shown are the 90% confidence level limits from the beam dump experiments E137, E141, and E774 [13, 14, 15, 16], the muon anomalous magnetic moment $a_\mu$ [4], KLOE [17], test run results from APEX [10] and MAMI [11], and an estimate using a BaBar result [13, 18, 19]. In addition, the green

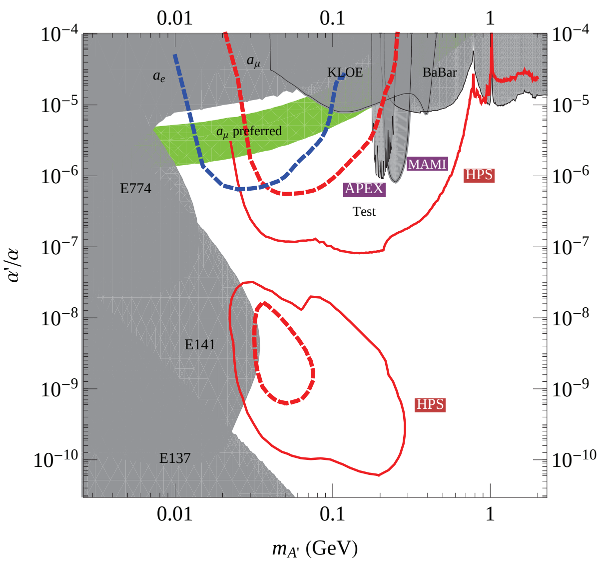


**FIGURE 1.** The estimated reach for the full HPS run (solid red) and test run (dashed red and blue), along with existing constraints and reach estimates from other proposed measurements (see text for details).

band shows the range where the $A'$ can explain the observed discrepancy between the calculated and measured muon anomalous magnetic moment [4] at the 90% confidence level.

The Heavy Photon Search will explore a large and unexplored domain in the mass/coupling plane with great enough sensitivity to exclude or observe a heavy photon decaying to $e^+e^-$ conclusively.

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