

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

Sarah K. Phillips¹

The University of New Hampshire, Durham, NH 03824

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 $1000 \text{ MeV}/c^2$. 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.

Keywords: dark photon, heavy photon, dark matter, Jefferson Lab

PACS: 14.70.Pw, 25.30.Rw

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 ε , 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 ($a_\mu = g - 2$) [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

¹ for the Heavy Photon Search Collaboration.

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 $\mathcal{O}(\text{GeV})$ -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 $m_{A'} \leq \text{GeV}$) are kinematically unable to decay into protons and anti-protons.

The Heavy Photon Search experiment (HPS) will search for dark photons with mass $m_{A'} \sim 100\text{s MeV}$ and $\alpha'/\alpha \equiv \varepsilon^2 \leq 10^{-5}$, 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 precise measurements 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, composed of a silicon microstrip vertex tracker, an electromagnetic calorimeter, and a muon system. The apparatus will be located behind the CLAS12 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 Fig. 1, along some existing constraints. The solid red line shows the projected 2σ exclusion 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 bump hunt search, while the lower corresponds to a combined bump hunt plus vertexing search. 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_μ [4], and an estimate using a BaBar result [13, 17, 18]. Other constraints have been reported by KLOE [19], as well as commissioning run results from APEX [10] and MAMI [11].

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.

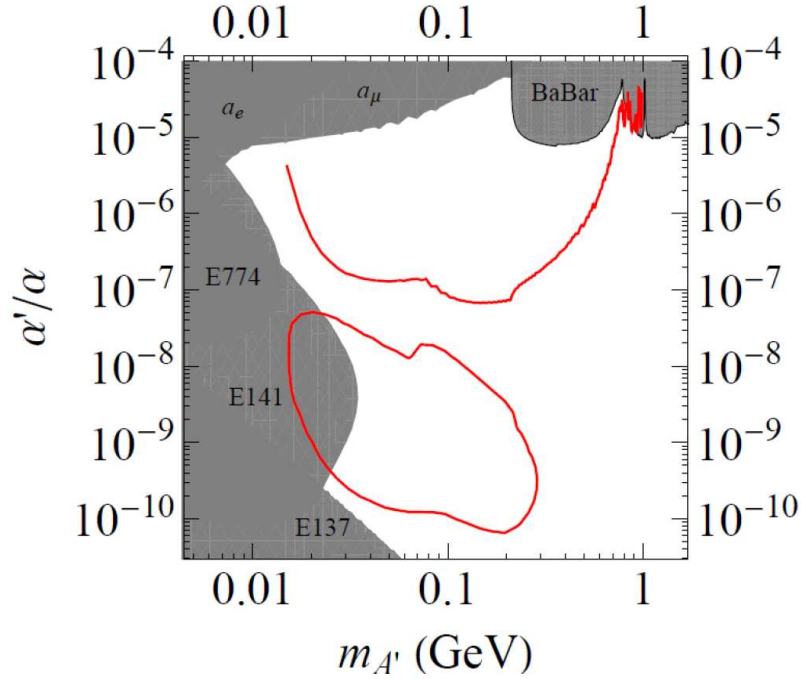


FIGURE 1. The estimated reach for the HPS experiment for two three-month runs at beam energies of 3.3 GeV and 6.6 GeV (solid red) [20], along with some existing constraints from other measurements (see text for details).

REFERENCES

1. B. Holdom, *Phys. Lett.* **B 166**, 196 (1986).
2. P. Galison, and A. Manohar, *Phys. Lett.* **B 136**, 279 (1984).
3. R. Essig, P. Schuster, and N. Toro, *Phys. Rev.* **D 80**, 015003 (2009), 0903.3941.
4. M. Pospelov, *Phys. Rev.* **D 80**, 095002 (2009), 0811.1030.
5. N. Arkani-Hamed, D. P. Finkbeiner, T. Slatyer, and N. Weiner, *Phys. Rev.* **D 79**, 015014 (2009), 0810.0713.
6. M. Pospelov, and A. Ritz, *Phys. Lett.* **B 671**, 391 (2009), 0810.1502.
7. O. Adriani, et al., *Phys. Rev. Lett.* **106**, 201101 (2011), 1103.2880.
8. M. Ackermann, et al., *Phys. Rev. Lett.* **108**, 011103 (2012), 1109.0521.
9. O. Adriani, et al., *Phys. Rev. Lett.* **102**, 051101 (2009), 0810.4994.
10. S. Abrahamyan, et al., *Phys. Rev. Lett.* **107**, 191804 (2011).
11. H. Merkel, et al., *Phys. Rev. Lett.* **106**, 251802 (2011), 1101.4091.
12. M. Freytsis, G. Ovanessian, and J. Thaler, *JHEP* **1001**, 111 (2010), 0909.2862.
13. J. D. Bjorken, R. Essig, P. Schuster, and N. Toro, *Phys. Rev.* **D 80**, 075018 (2009), 0906.0580.
14. J. D. Bjorken, et al., *Phys. Rev.* **D 38**, 3375 (1988).
15. E. M. Riordan, et al., *Phys. Rev. Lett.* **59**, 755 (1987).
16. A. Bross, et al., *Phys. Rev. Lett.* **67**, 2942 (1991).
17. M. Reece, and L. T. Wang, *JHEP* **0907**, 051 (2009), 0904.1743.
18. B. Aubert, et al., *Phys. Rev. Lett.* **103**, 081803 (2009), 0905.4539.
19. KLOE-2 Collaboration, *Phys. Lett.* **B 706**, 251 (2012), 1110.0411.
20. A. Grillo, et al., "HPS Heavy Photon Search" (Dec. 1, 2010), Jefferson Lab Proposal PR12-11-006, https://confluence.slac.stanford.edu/download/attachments/86676777/HPSProposal-FINAL_Rev2.pdf.