Heavy Photon Search

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The Heavy Photon Search Group at SLAC is performing an experiment aimed at discovering a hidden-sector heavy (or dark) photon - a $U(1)$ vector boson. Heavy photons (or A's) couple to electric charge through kinetic mixing with the Standard Model photon, with production analogous to bremsstrahlung radiation. They may also mediate dark matter interactions. The Heavy Photon Search experiment (HPS) has recently performed two successful engineering runs, first in spring of 2015 and later in the winter of 2016 with a higher beam energy. HPS is expected to take significantly more data during 2019. The experiment is composed of a six-layer silicon microstrip vertex tracker and a $PbWO_4$ crystal calorimeter.

Motivation

Anomalies from cosmic rays [1], as well as dark matter distributions in galactic haloes [2], provide theoretical motivation for a heavy photon in the 0.1 to 1.0 GeV range. Such a particle could be produced in a laboratory setting through electron-nucleus scattering via a process analogous to bremsstrahlung. It could then decay into an lepton-antilepton pair, which may be identified through its narrow resonance, and possibly also the displacement of the decay.

Signals and Backgrounds

Heavy Photon Signal

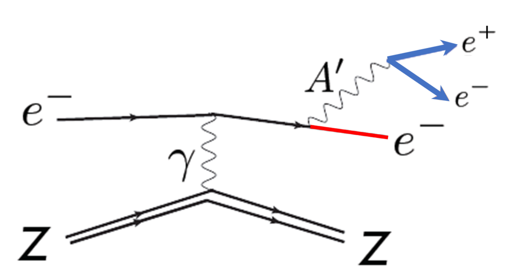

Figure 1: *A' production by bremsstrahlung off an incoming electron as it scatters on a nucleus with atomic number Z.*

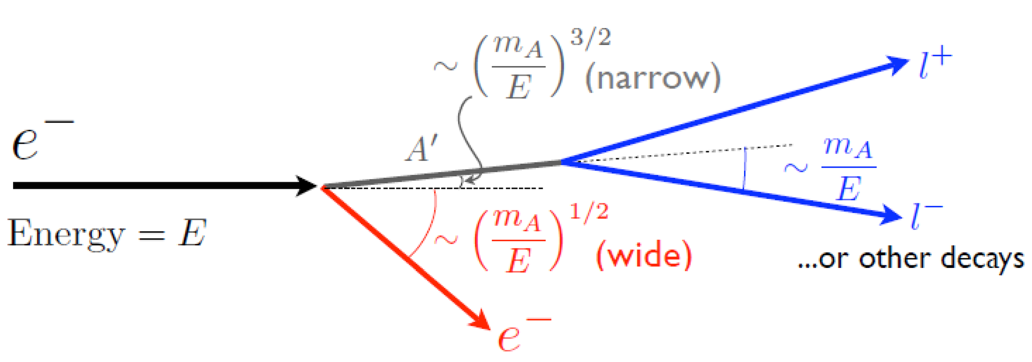

Figure 2: *A' production and decay kinematics.*

A' particles are generated in electron collisions on a fixed target by a process analogous to ordinary photon bremsstrahlung.

Backgrounds

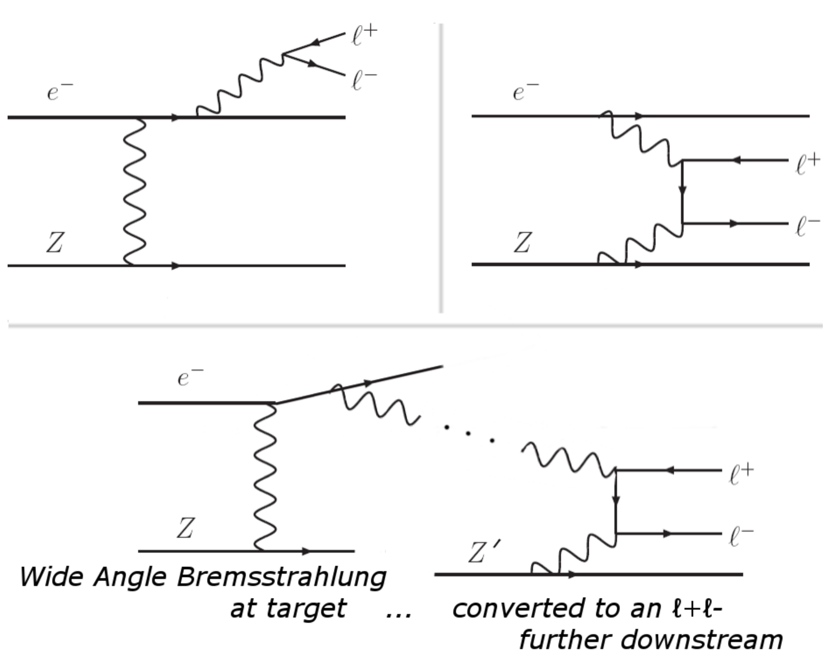

Figure 3: *Sample diagrams of (top left) radiative trident (γ^*), (top right) Bethe-Heitler trident, and (bottom) converted wide-angle bremsstrahlung reactions, that comprise the primary QED background to $A' \to l^+l^-$ search channels.*

There are three main sources of background in our detector. The first source are QED tridents, which produce e^+e^- pairs at the target. Secondly, photons produced via wide-angle bremsstrahlung are often converted to e^+e^- pairs either in the target or in one of the layers of the silicon tracker. Thirdly, beam background is non-negligible due to our high beam current.

Experimental Setup

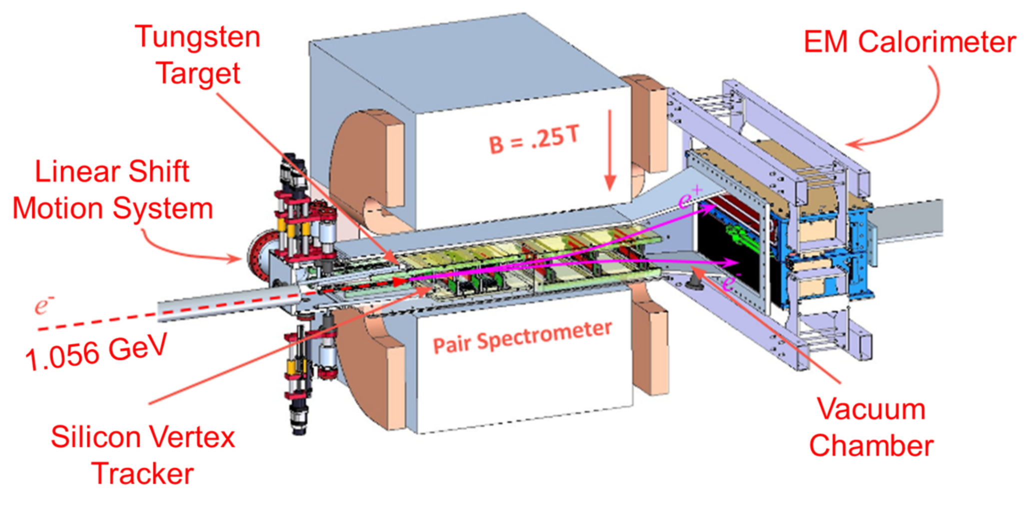

Figure 4: *Schematic view of the HPS detector.*

The near-continuous duty cycle of the CEBAF beam at Jefferson Lab, along with fast detectors and electronics, allows us to run with short time windows and reduce occupancies.

Silicon Vertex Tracker

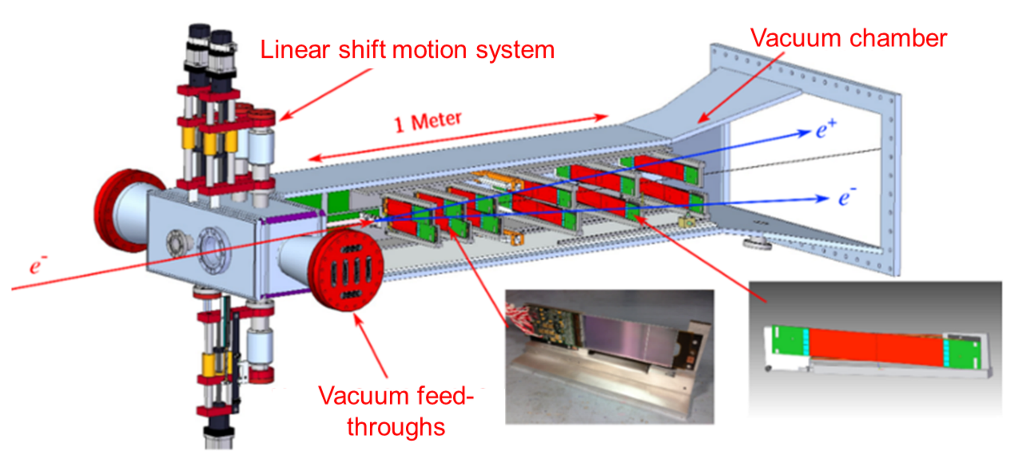

Figure 5: *Renderings of the target assembly and silicon planes inside their support box.*

The tracker is made up of six measurement layers. Each layer has two closely spaced planes of silicon microstrip sensors to measure both X and Y coordinates for momentum measurement and track identification. [3]

Electromagnetic Calorimeter

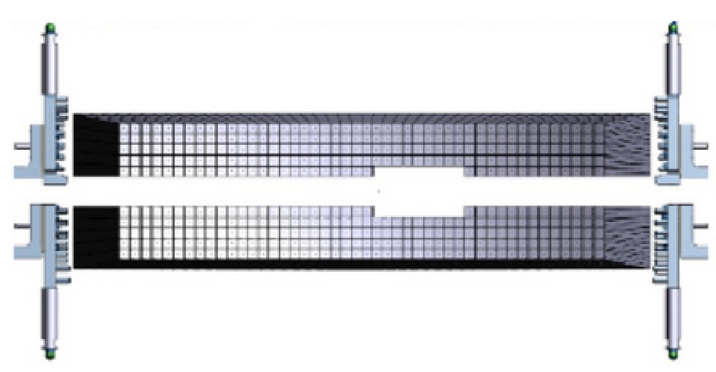

Figure 6: *A rendering of the electromagnetic calorimeter setup looking down the beam line. The Ecal contains 442 lead tungstate ($PbWO_4$) crystals.*

The electromagnetic calorimeter (ECal) covers the full acceptance region of the silicon tracker. It provides the trigger for data acquisition and also is used for electron identification during the data analysis. [4]

References

[1] D. P. Finkbeiner, L. Goodenough, T. R. Slatyer, M. Vogelsberger, and N. Weiner, JCAP **1105**, 002 (2011), 1011.3082.

[2] M. Vogelsberger, J. Zavala, and A. Loeb, Mon. Not. Roy. Astron. Soc. **423**, 3740 (2012), 1201.5892.

[3] P. Hansson Adrian (HPS), in *Proceedings, 2015 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC 2015): San Diego, California, United States* (2016), p. 7581862, 1511.07844.

[4] I. Balossino et al. (HPS), Nucl. Instrum. Meth. **A854**, 89 (2017), 1610.04319.

Experimental Reach

The search channel for this experiment is $A' \to e^+e^-$, with or without a displaced vertex, depending on the magnitude of the coupling α'.

In a resonance search, exclusion power is determined by the ratio of the signal within an invariant mass window to $\sqrt{N_{bin}}$, where N_{bin} is the total background statistics in the same window. A resonance search therefore is sensitive at large values of α'/α, where the A' production rate is high.

A displaced vertex resonance search is less subject to background, since only a signal event can create an actual displaced vertex; the background consists of the tails of the vertex distribution of prompt tridents.

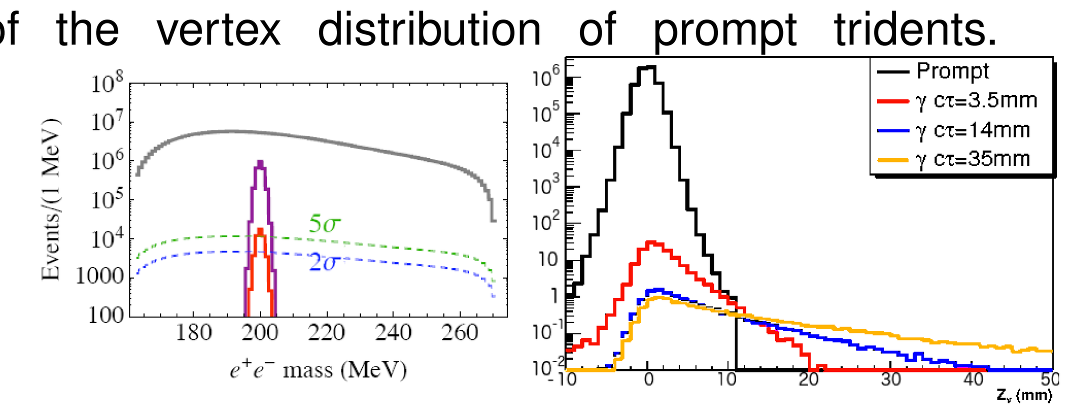

Figure 7: *Example signals and backgrounds for (left) a resonance search and (right) a vertexing search.*

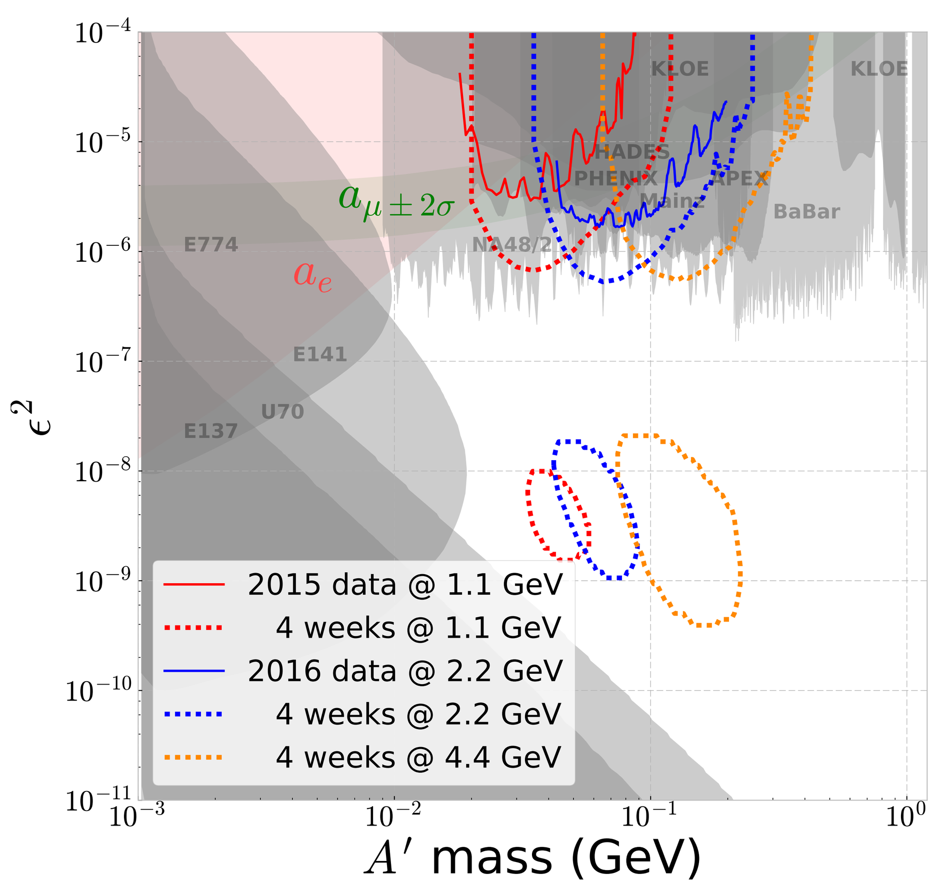

Figure 8: *Anticipated reach in $\alpha'/\alpha = \epsilon^2$ for the Heavy Photon Search (HPS) experiment at Hall B in JLab from data already taken (solid lines) and larger future data samples (dashed) with existing constraints on an A' from electron and muon anomalous magnetic moment measurements and several beam dump and resonance-search experiments.*

Future of HPS

The major physics results of HPS will result from the 2019 running. Several upgrades have been proposed in order to improve the reach of the experiment through improved resolution and acceptance:

- Including an additional layer to the Silicon Vertex Tracker, halfway between the target and the existing first layer of the tracker.
- Adding a hodoscope for an additional positron-only trigger.