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 a successful engineering run in spring of 2015 and physics run in winter of 2016. HPS is expected to take significantly more data during 2018. The experiment is composed of a six-layer silicon microstrip vertex tracker and a $PbWO_4$ crystal calorimeter. HPS is a very small experiment by modern standards but uses cutting edge detection and readout technologies. HPS offers prospective HEP thesis students all aspects of experimental work, from design and hardware construction on numerous upgrade possiblities, to data taking and analysis.

Motivation

A heavy photon would be theoretically favorable in the mass range of 0.1 to 1.0 GeV, couple weakly to electrons, and decay to e^+e^-. It would be produced by electron bremsstrahlung on a heavy target, and be identified as a narrow e^+e^- resonance. Weak couplings of this heavy photon to electrons account for it having not yet been discovered and can give rise to separated vertices in its decay, providing a secondary signature. Heavy photons have become a hot topic recently because they may provide an explanation to several recently observed astrophysical anomalies (e.g. gamma rays from the galactic center), and be intimately linked to dark matter annihilation.

Signals and Backgrounds

Heavy Photon Signal

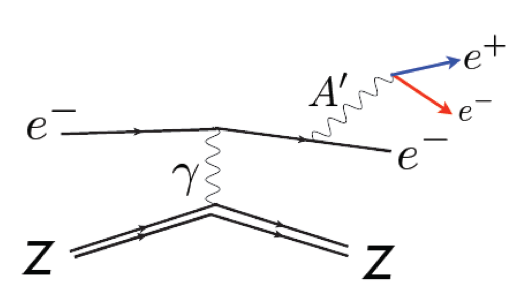

Figure 1: *A' production by bremsstrahlung off an incoming electron as it scatters on a nucleus with atomic number Z.*

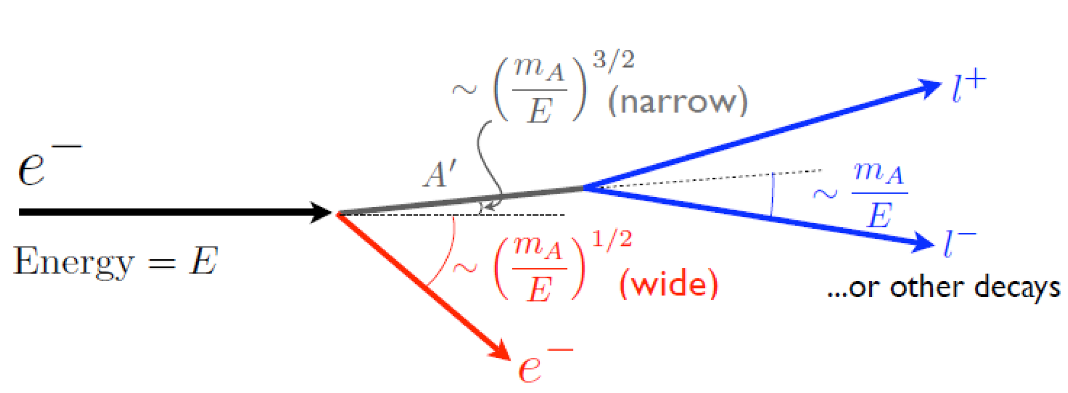

Figure 2: *A' production and decay kinematics.*

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

QED Trident Backgrounds

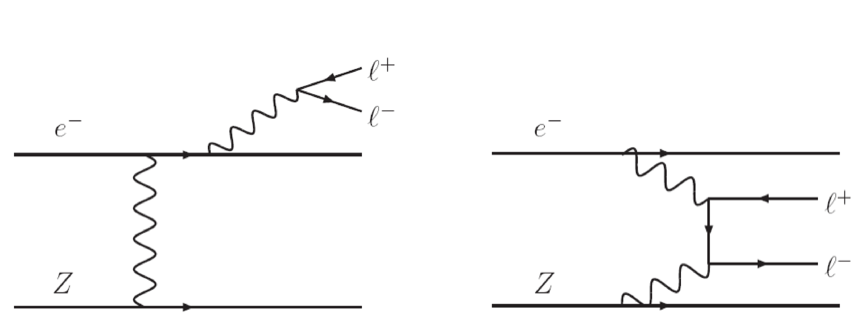

Figure 3: *Sample diagrams of (left) radiative trident (γ^*) and (right) Bethe-Heitler trident reactions that comprise the primary QED background to $A' \to l^+l^-$ search channels.*

QED tridents produce e^+e^- pairs with nonzero invariant mass. These events are the dominant background to the A' signal.

Beam Backgrounds

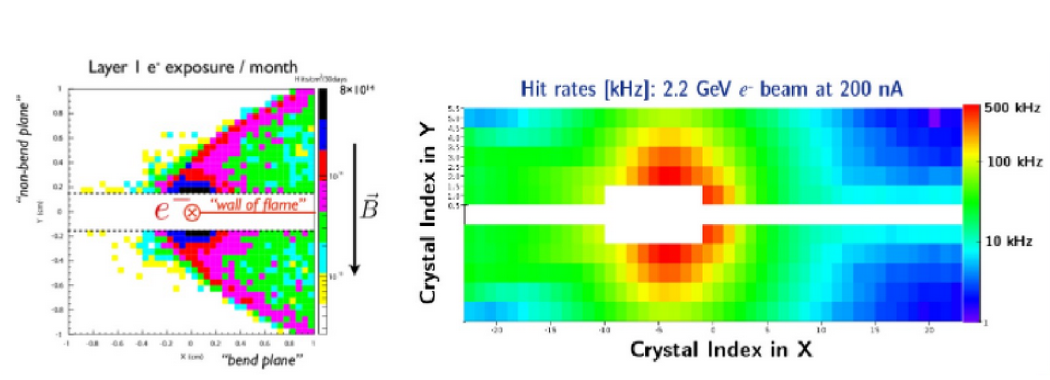

Figure 4: *Beam background rates in Layer 1 on the silicon tracker (left) and the electromagnetic calorimeter (right).*

Beam backgrounds are significant because of our high beam current and forward detector coverage.

Experimental Setup

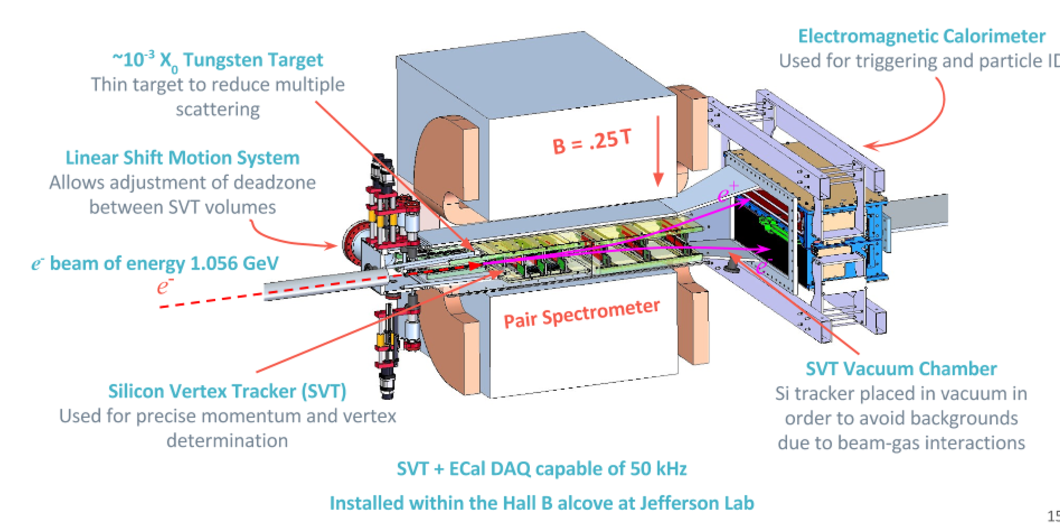

Figure 5: *Schematic view of the HPS detector.*

High luminosities and thin targets are needed to minimize beam background while maximizing A' production. 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

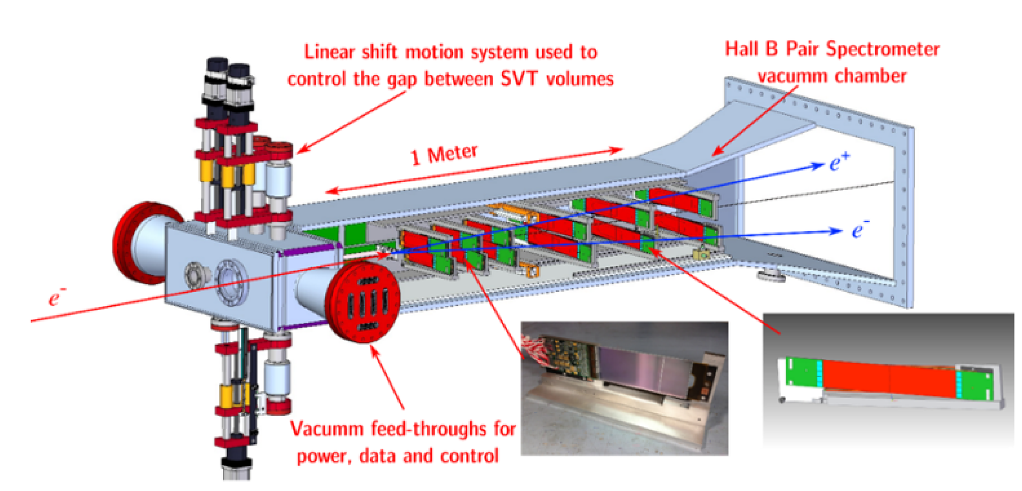

Figure 6: *Renderings of the target assembly and silicon planes inside their support box.*

The thickness of material in the tracker are minimized to reduce measurement uncertainties and backgrounds. The best choice is silicon microstrip sensors, which are simple, low-mass and fast. We use 4 cm $\times$ 10 cm silicon sensors left over from the cancelled Run IIb upgrades at the Tevatron, and the APV25 readout chip developed for the CMS tracker at the LHC, which can read out continuously at 40 MHz.

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. Linear shift motion system allows SVT layers 1-3 to be moved within 15 mrad of the beam.

Electromagnetic Calorimeter

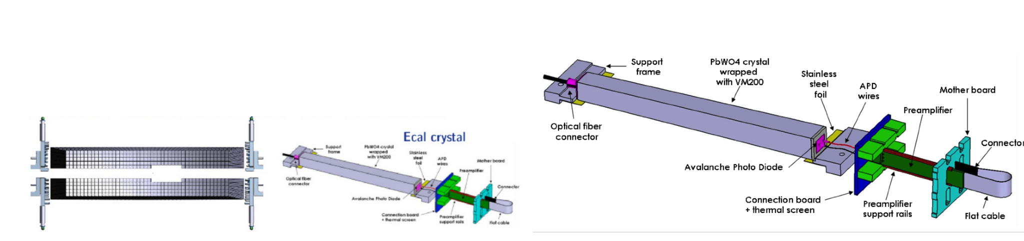

Figure 7: *A rendering of the electromagnetic calorimeter setup looking down the beam line (left) and a more detailed view of the Ecal crystal. The Ecal contains 442 lead tungstate crystals.*

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.

We use lead tungstate ($PbWO_4$) crystals read by Hamamatsu avalanche photodiodes.

Electronics and DAQ

A level 1 hardware trigger selects events to be read out. The triggered events are acquired and processed in the data acquisition and processing system. The DAQ system is designed for a maximum trigger rate of 50 kHz; simulations estimate that the ECal trigger rate due to background will be approximately 17 kHz.

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.

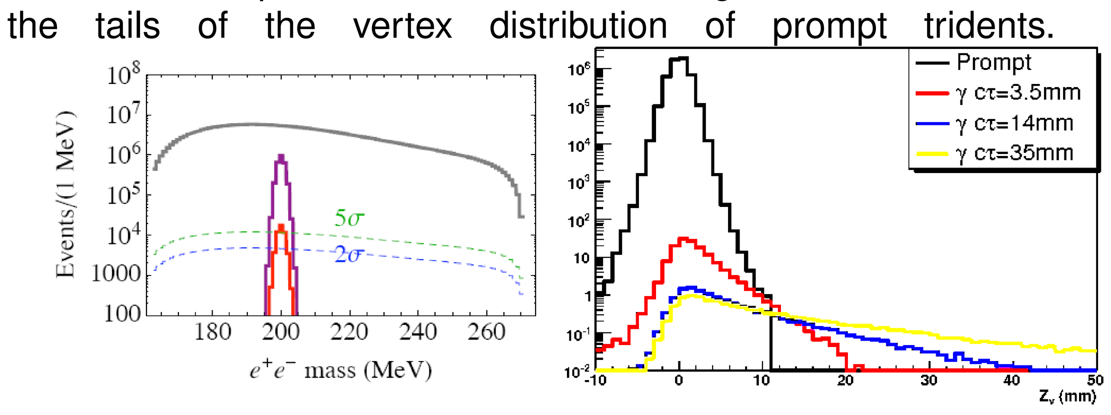

Figure 8: *Example signals and backgrounds for (left) a resonance search and (right) a vertexing search.*

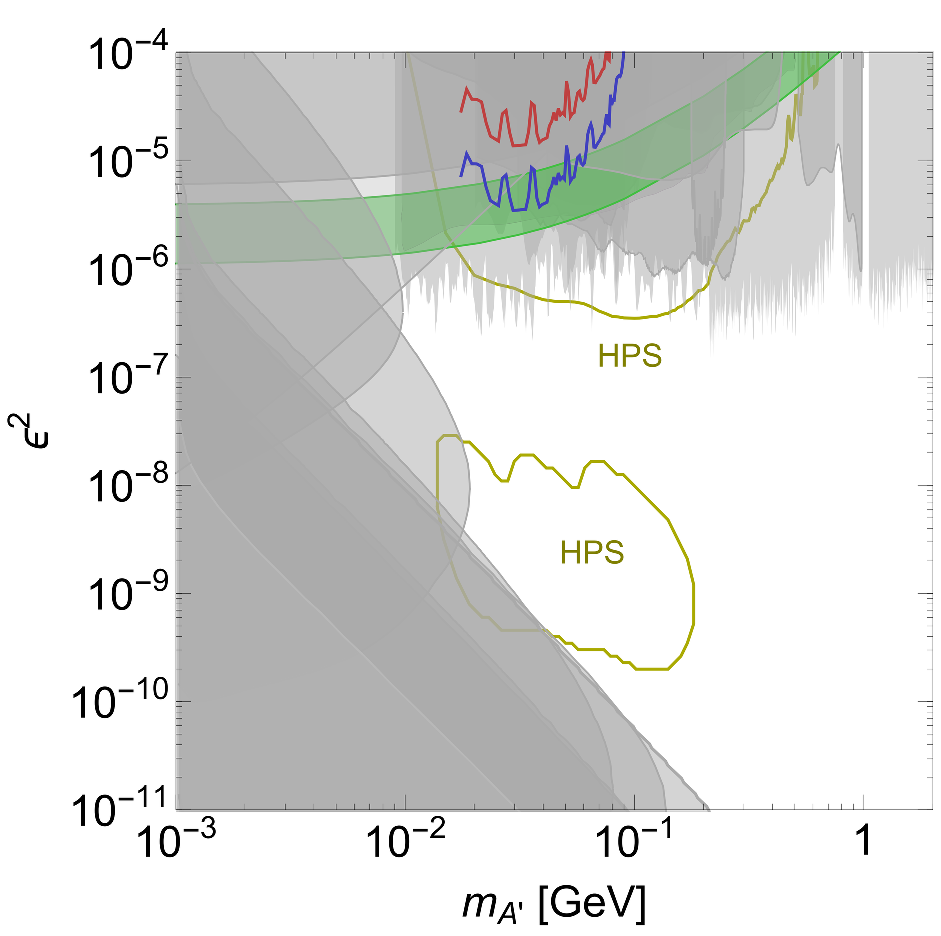

Figure 9: *Anticipated reach in $\alpha'/\alpha = \epsilon^2$ for the Heavy Photon Search (HPS) experiment at Hall B in JLab (brown lines) with existing constraints on an A' from electron and muon anomalous magnetic moment measurements (green), the BaBar search for $\gamma(3S) \to \gamma\mu^+\mu^-$, and several beam dump experiments. Red is the reach for the 2015 HPS engineering run and blue is the expected reach for the full data set.*

Future of HPS

Layer 0 Upgrade

HPS is planning an upgrade to the SVT by adding another silicon tracking layer (Layer 0) between the target and first layer. This is expected to significantly improve the tracking of HPS in two main ways. First, it will improve the vertex resolution and hence the upward reach in the vertex search of HPS (lower solid brown lines in Fig. 9). Second, the upgrade will improve the detection efficiency of the recoil electron that will result in higher invariant mass resolution. This improves the overall experiment and especially the bump hunt reach.

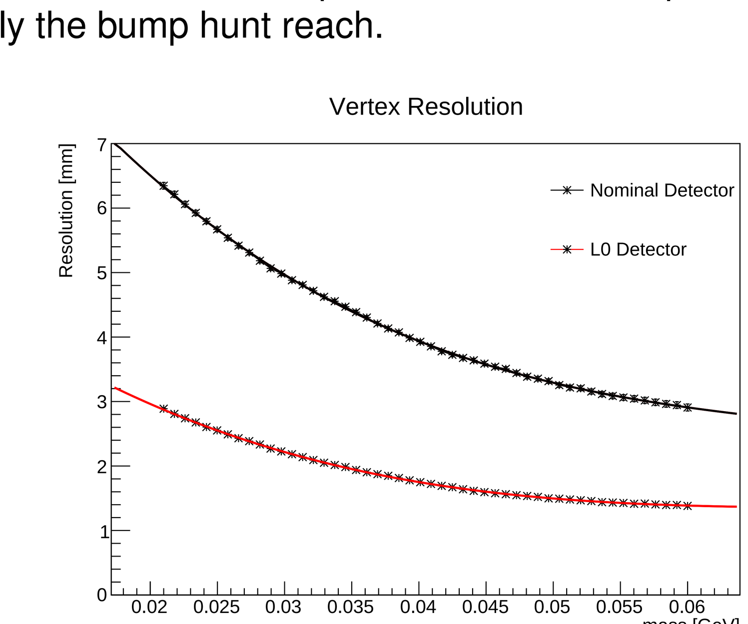

Figure 10: *A comparison of the vertex resolution between the nominal detector and the L0 upgrade detector shows an improvement of about a factor of about 2.*

2018 Data Taking

The major physics results of HPS will result from the 2018 running and will produce several theses. HPS is currently looking for students (both rotation and permanent) for upgrades, data taking, and data analysis.