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.

Motivation

Anomalies from cosmic rays[**?**], as well as dark matter distributions[**?**], 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

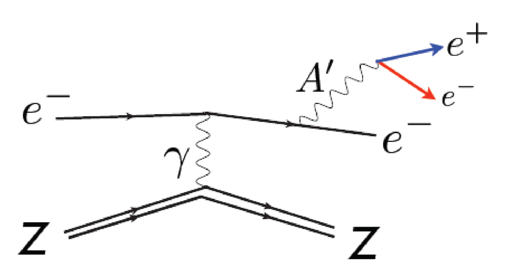

Figure 1: *A' production by bremsstrahlung off an incoming electron as it scatters on a nucleus with atomic number Z.*

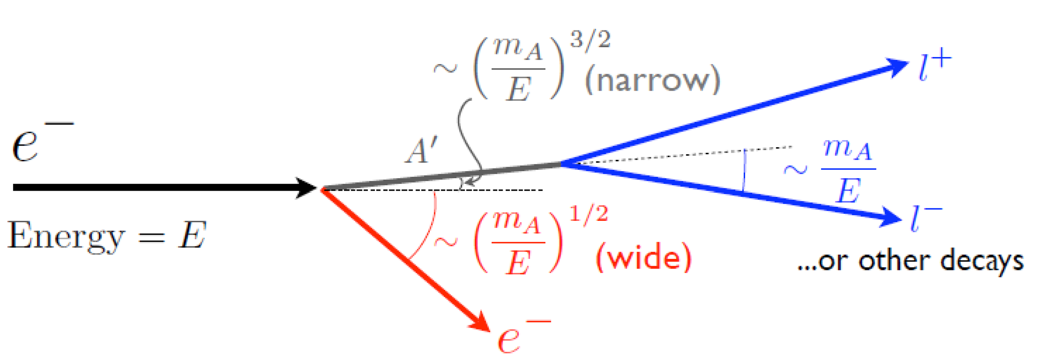

Figure 2: *A' production and decay kinematics.*

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

Backgrounds

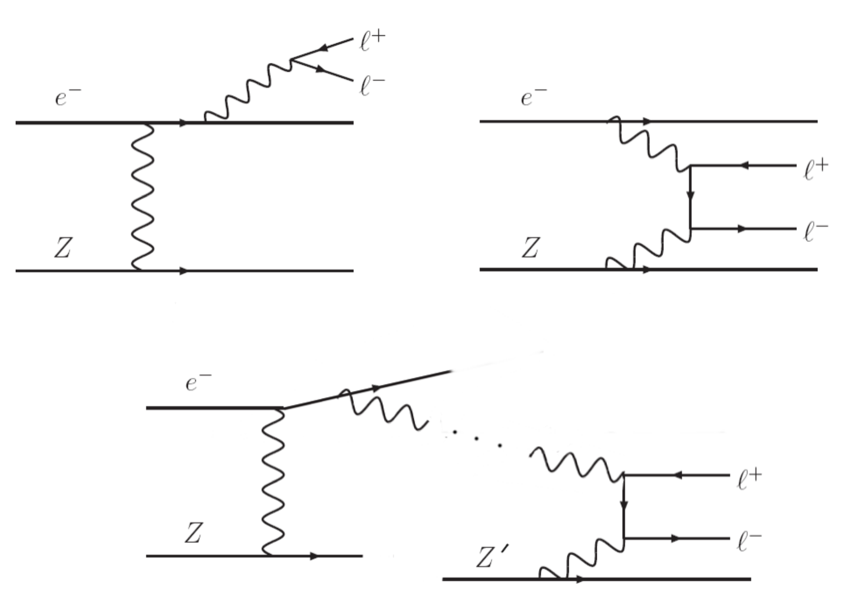

Figure 3: *Sample diagrams of (top left) radiative trident (γ^*), (top right) Bethe-Heitler trident, and (bottom) converted wide-angle bremsstrahlung reactions that comprise the primary QED background to $A' \to l^+l^-$ search channels.*

QED tridents produce e^+e^- pairs with nonzero invariant mass. Additionally, 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. These events are the dominant background to the A' signal. Beam background due to our high beam current also contributes to our background.

Experimental Setup

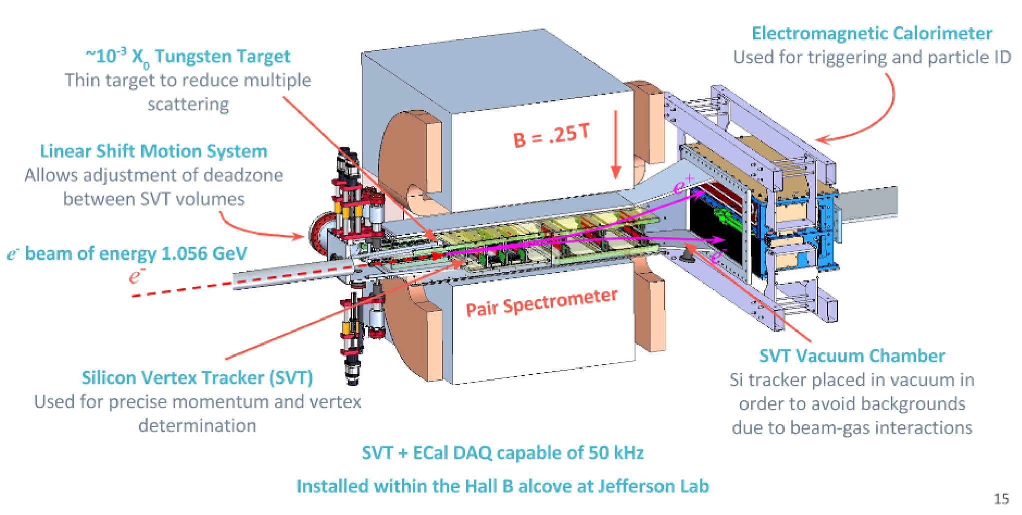

Figure 4: *Schematic view of the HPS detector.*

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

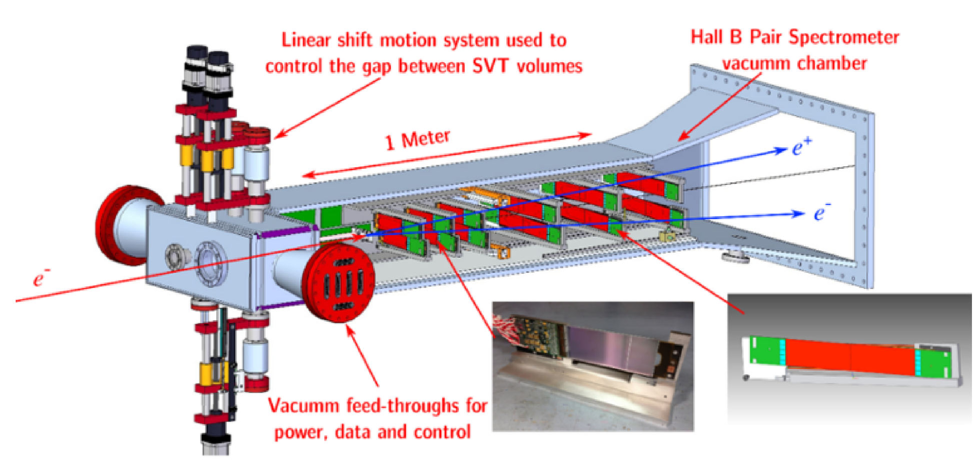

Figure 5: *Renderings of the target assembly and silicon planes inside their support box.*

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

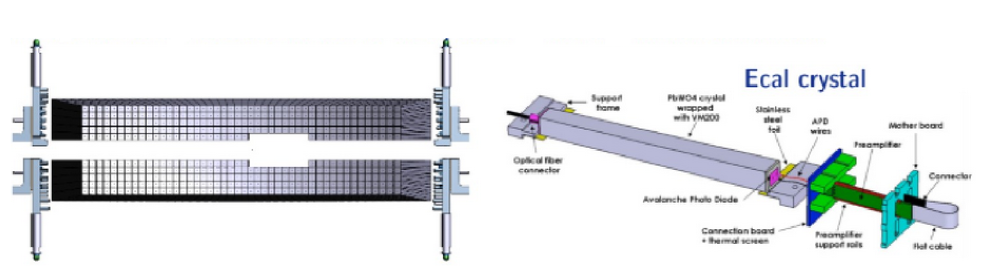

Figure 6: *A rendering of the electromagnetic calorimeter setup looking down the beam line (left) and a more detailed view of the Ecal crystal. The Ecal contains 442 lead tungstate crystals.*

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.

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.

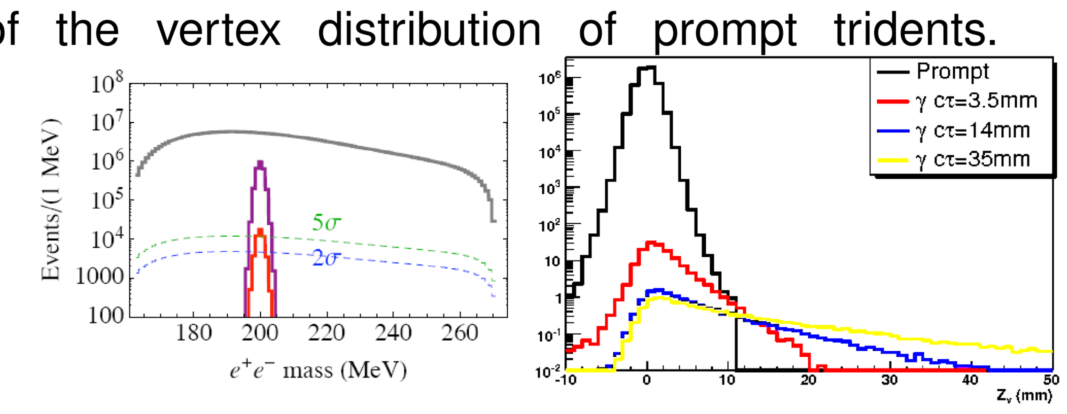

Figure 7: *Example signals and backgrounds for (left) a resonance search and (right) a vertexing search.*

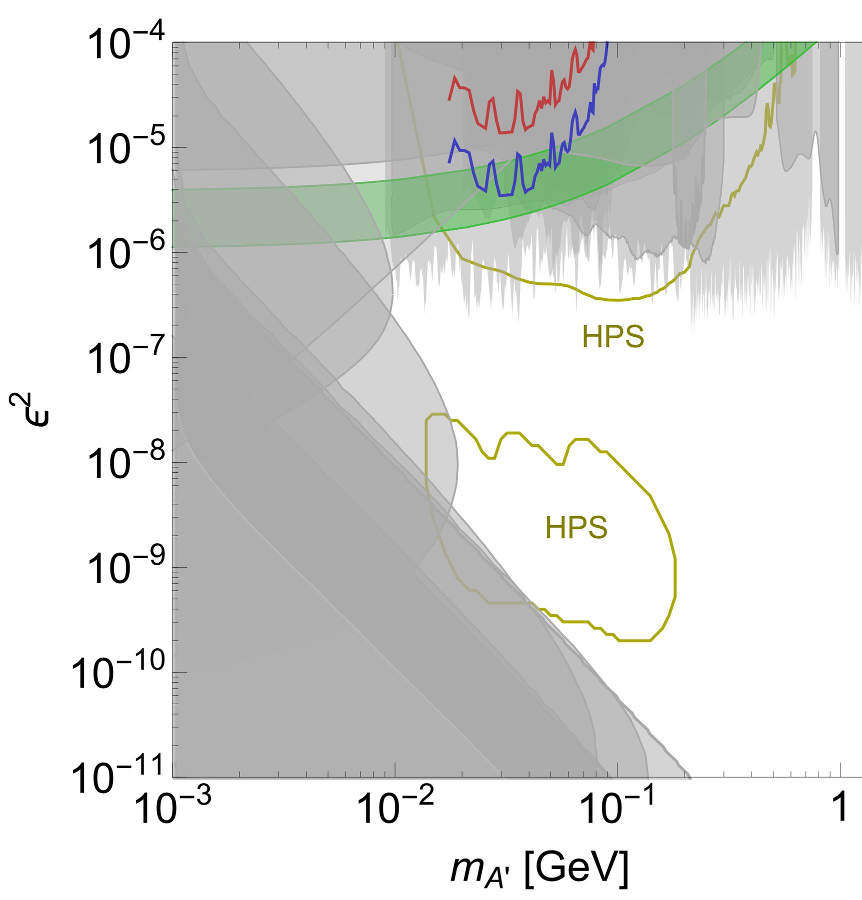

Figure 8: *Anticipated reach in $\alpha'/\alpha = \epsilon^2$ for the Heavy Photon Search (HPS) experiment at Hall B in JLab (brown lines) with existing constraints on an A' from electron and muon anomalous magnetic moment measurements (green), the BaBar search for $\gamma(3S) \to \gamma\mu^+\mu^-$, 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

2018 Data Taking

The major physics results of HPS will result from the 2018 running. Several upgrades have been proposed in order to improve the reach of the experiment:

- Including an additional layer to the Silicon Vertex Tracker, halfway between the target and the existing first layer of the tracker. This would improve both the vertex position resolution and the mass resolution.
- Adding a hodoscope on the side where the positrons curve towards, which would be used

for an additional positron-only trigger. This upgrade would increase the geometric acceptance of the detector.

1. Citations

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