Heavy Photon Search

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The Heavy Photon Search Group at SLAC has two experiments aimed at discovering a hidden-sector, heavy photon. We have just submitted a proposal to Jefferson Lab and hope for approval this Fall. The experiment will use LHC style readout of silicon microstrip detectors for tracking and vertexing and a $PbWO_4$ crystal calorimeter to deal with the extremely high trigger rates expected. There are many opportunities for rotation students. Experimental design and simulation studies will continue, tracking pattern recognition and vertexing code is being developed, the data acquisition system for the experiment will be designed and tested, a silicon tracker/vertexer will be built, and the physics analysis techniques will be developed. This experiment is very small by modern standards, but exploits cutting edge detection and readout technologies to address a very fascinating piece of physics. It provides a perfect opportunity for a thesis student, offering all aspects of experimental work, from design to hardware implementation to data analysis.

Motivation

A heavy photon would have mass in the range 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 spectacular signature. Heavy photons have become a hot topic recently because they may explain high energy electrons and positrons in cosmic rays, and be intimately linked to dark matter annihilation.

True Muonium

This experiment has the potential to discover "true muonium" — a bound state of a $\mu^+\mu^-$ pair. Positronium (e^+e^-) and muonium (μ^+e^-) have been produced and studied, but true muonium, or dimuon, has not yet been detected.

Signals and Backgrounds

Heavy Photon Signal

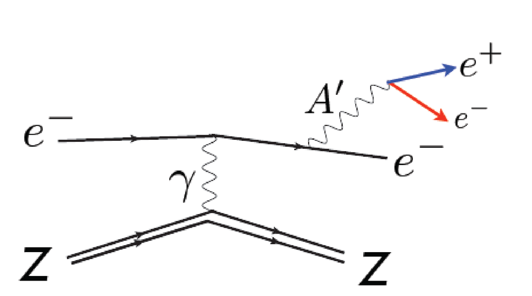

Figure 1: *A' production by bremsstrahlung off an incoming electron as it scatters on a nucleus with atomic number Z.*

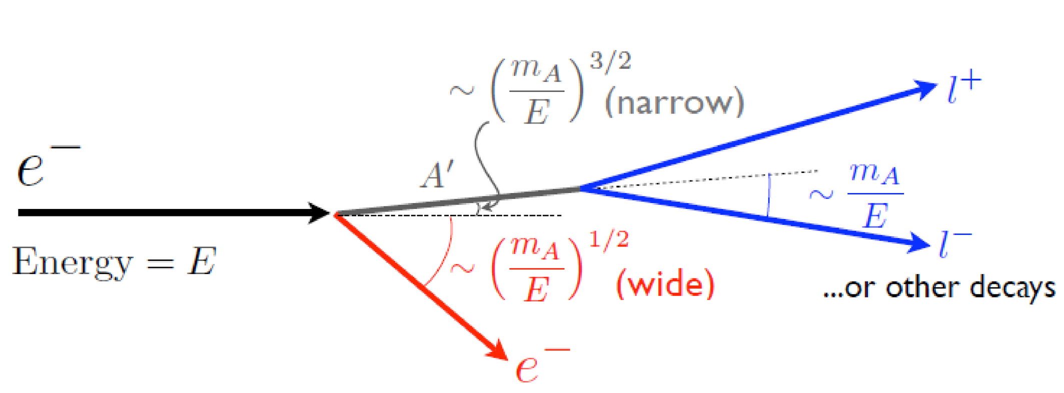

Figure 2: *A' production and decay kinematics.*

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

True Muonium Signal

The triplet states of true muonium decay to e^+e^- with a rest frame lifetime of 1.81n^3 ps. With a beam energy of 5.5 GeV, the typical decay length of the $n = 1$ state would be 1.4 cm. The kinematics of the true muonium signal is similar to that of A'.

QED Trident Backgrounds

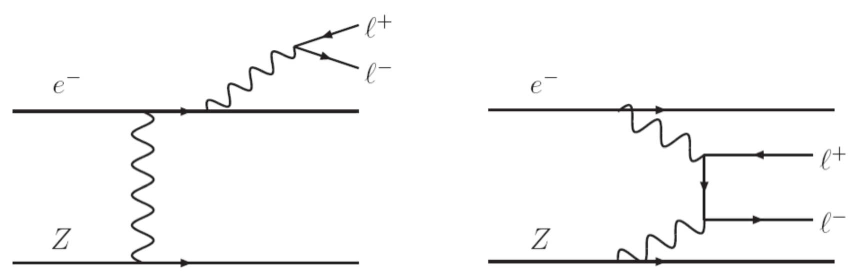

Figure 3: *Sample diagrams of (left) radiative trident (γ^*) and (right) Bethe-Heitler trident reactions that comprise the primary QED background to $A' \to l^+l^-$ search channels.*

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

Beam Backgrounds

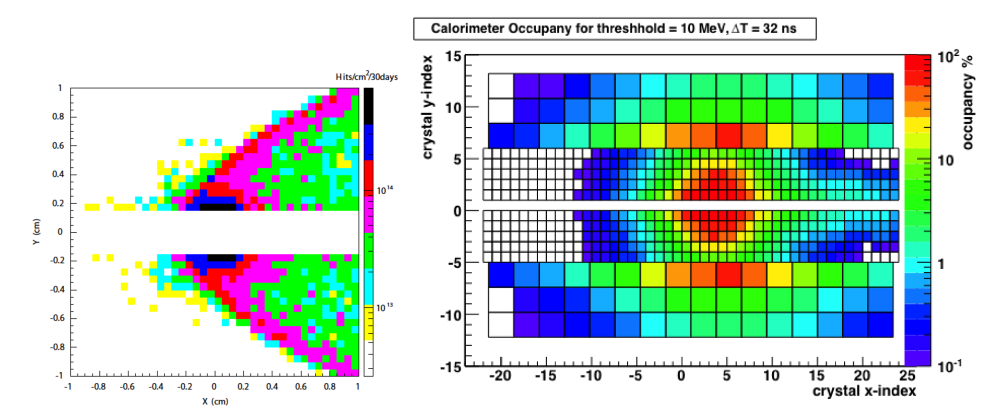

Figure 4: *Beam background rates in Layer 1 on the silicon tracker (left) and the electromagnetic calorimeter (right).*

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

Experimental Setup

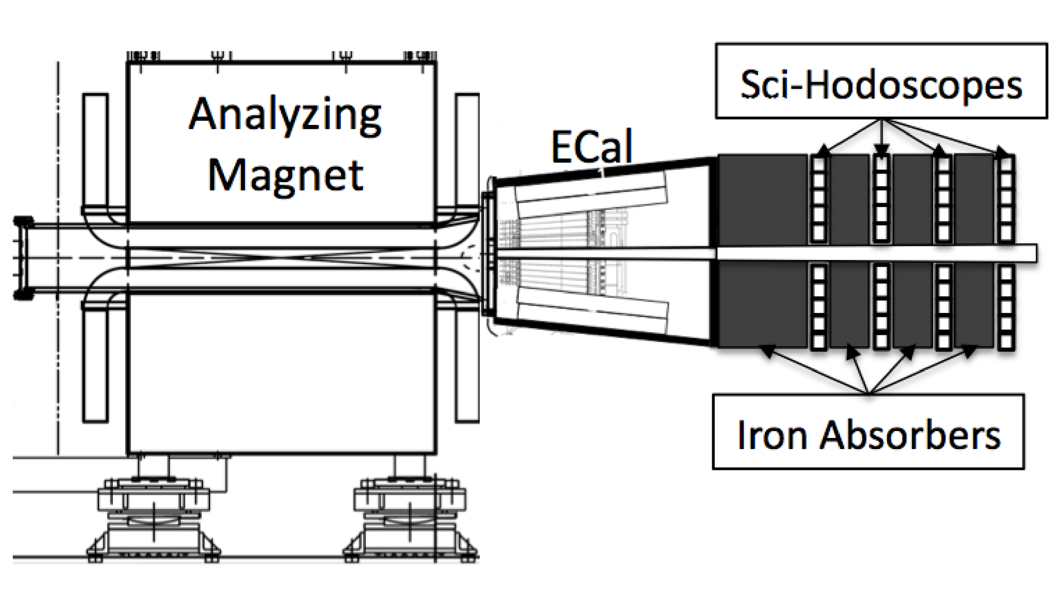

Figure 5: *Schematic view of the HPS detector with muon detection system.*

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

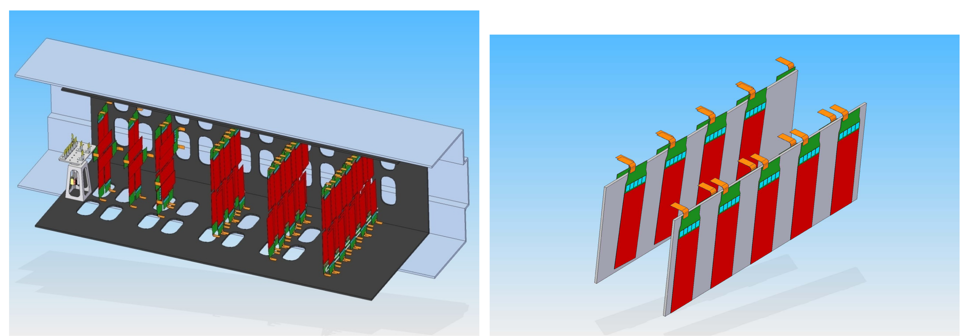

Figure 6: *Renderings of (left) the target assembly and silicon planes inside their carbon fiber support box and (right) the pair of modules comprising the top half of Layer 6.*

The thickness of material in the tracker must be minimized to reduce measurement uncertainties and backgrounds. The best choice is silicon microstrip sensors, which are simple, low-mass and fast. We will 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.

Electromagnetic Calorimeter

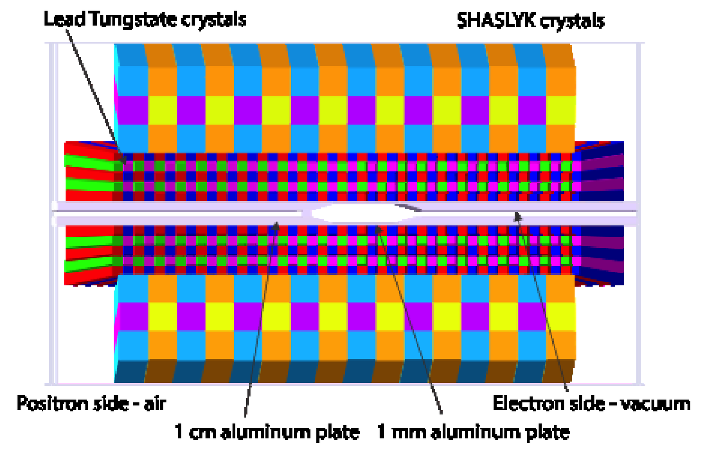

Figure 7: *A rendering of the electromagnetic calorimeter setup looking down the beam line.*

The electromagnetic calorimeter (ECal) will cover the full acceptance region of the silicon tracker. It will provide the trigger for data acquisition and will also be used for electron identification during the data analysis.
We will use lead tungstate ($PbWO_4$) crystals read by avalanche photodiodes in the inner region, and larger, lead-glass or "shashlyk" type modules read by conventional PMT photodetectors in the outer region.

Muon System

Searching for the A' in its di-muon decay mode has the advantage of having greatly reduced electromagnetic backgrounds for triggering. The muon detection system will be installed behind the ECal and consists of four iron absorbers and four scintillator planes positioned after each absorber layer.

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 events are down-selected in a Level 3 filter processing farm and the remaining events are transferred to the offline storage. 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.

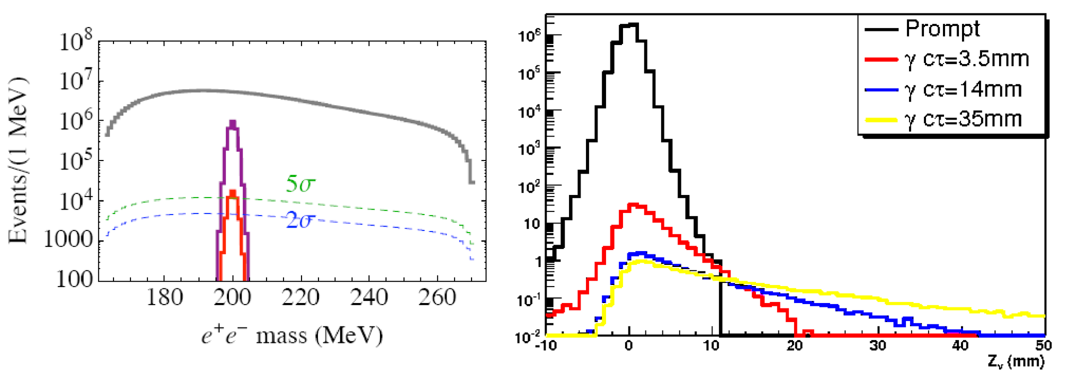

Figure 8: *Example signals and backgrounds for (left) a resonance search and (right) a vertexing search.*

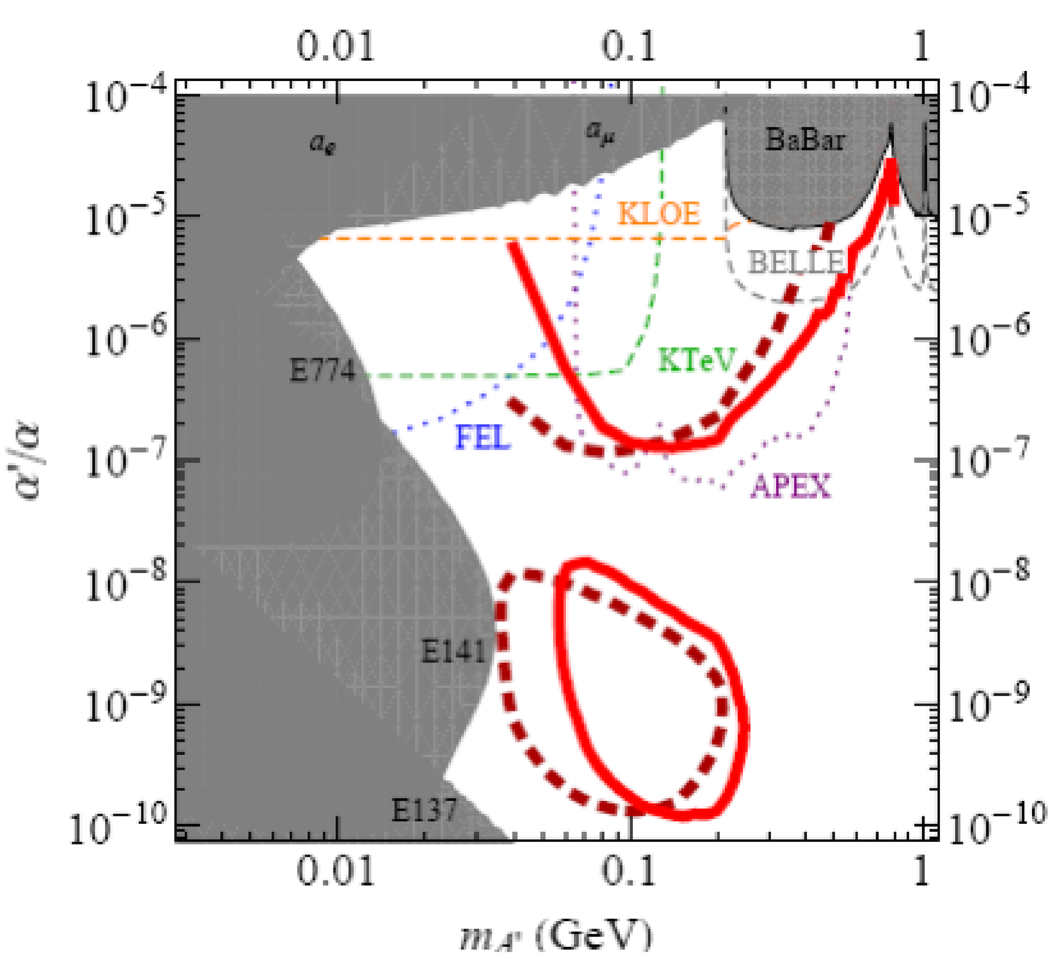

Figure 9: *Anticipated reach in α'/α and $m_{A'}$ for the Heavy Photon Search (HPS) experiment (red and maroon lines), with existing constraints on an A' and potential sensitivities of A' searches in both existing data and other proposed experiments. Curves correspond to 2σ sensitivity of a search run for 3×10^6 s at 400 nA, with (red) 5.5 GeV beam energy and 0.25% X_0 target or (dashed maroon) 3.3 GeV beam energy and 0.125% X_0 target.*