Searching for Heavy Photons in the HPS Experiment

Sho Uemura

SLAC

Reminder of review format

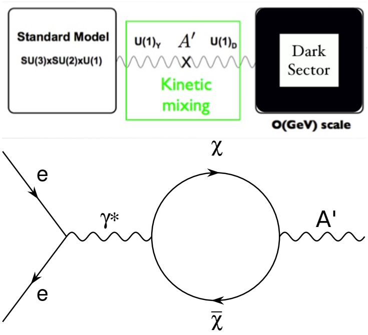
- Fourth-year students are required to give a 45-minute oral presentation to their Ph.D. reading committees.
- The purpose of the requirement is to increase contact between students and faculty members, to help students organize their thoughts, to give students practice in giving oral presentations, and most importantly to obtain feedback on the development of the thesis, approximate date of thesis completion and future plans.
- The sessions should consist of a half-hour presentation by the student, 15 minutes of discussion between the student, research advisors and readers, and then a closed door discussion by the committee.

Outline

- Background on HPS
- What I've been doing for HPS
- Plans for the analysis

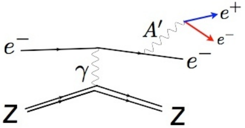
Motivation for heavy photon

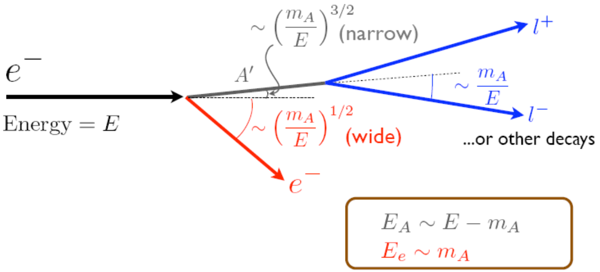
- A new massive $U(1)$ boson with no (direct) coupling to SM
  - Kinetic mixing with the photon $\rightarrow$ weak coupling to electric charge [Holdom 1986]
- One possible “portal” between SM and a dark sector
- Two relevant parameters: mass $m_{A'}$, relative coupling strength α'/α
- Useful in explaining PAMELA/Fermi/AMS positron excess, muon g-2 anomaly



Producing heavy photons

- Similar to bremsstrahlung: e^- (1.1, 2.2 and 6.6 GeV) on high-Z fixed target

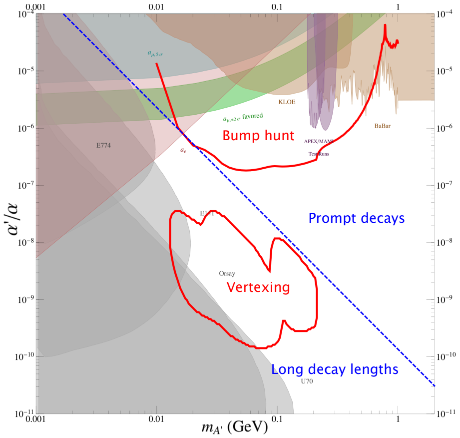




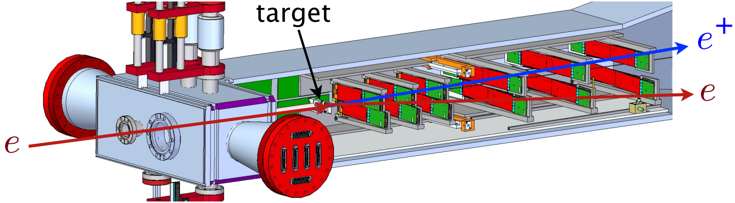
- A' carries most of incident e^- energy (unlike γ bremsstrahlung)
- Pairs from A' decay are produced along beam with some decay length and small opening angle

Reach

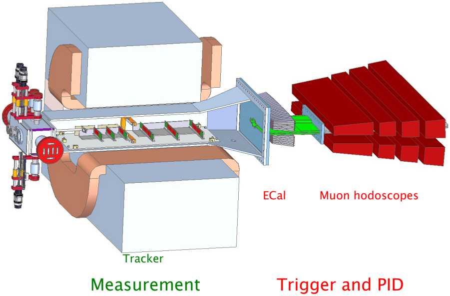
- Bump hunt: look for a peak in pair invariant mass
- Vertexing (my thesis topic): look for pairs originating downstream of the target
  - Requires a tracker close to the target for $\sim$mm vertex resolution
- HPS probes a large unexplored region of the parameter space
  - Bump-hunt region is under pressure (Babar result not shown in plot); vertexing is our strength



The HPS detector



- Thin (0.125% or 0.25% X_0) tungsten target
- Silicon microstrip tracker in dipole magnet for measurement
- $PbWO_4$ calorimeter for trigger



HPS schedule

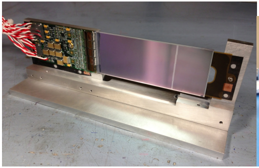
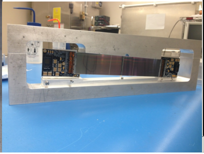
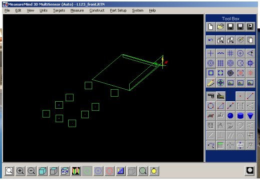
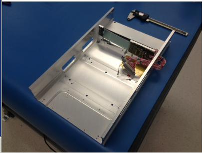
- Schedule has been controlled by CEBAF schedule:
  - Test run in May 2012 before shutdown for 12 GeV upgrade: photon beam only, good for testing detector performance but no physics
  - Commissioning November-December 2014, physics running in spring 2015
  - Further running planned, but thesis will be written on 2015 data
- We are pushing to publish a result within a year after we get data

My role in HPS

- SVT mechanics
  - Testing, disassembly and re-QA of test run SVT
  - Assembly and survey of new SVT
- Software
  - Readout simulation for ECal and SVT
  - Trigger studies and simulation
  - Hit time reconstruction in SVT
  - Bulk production of MC for mock data challenge
- Taking shifts

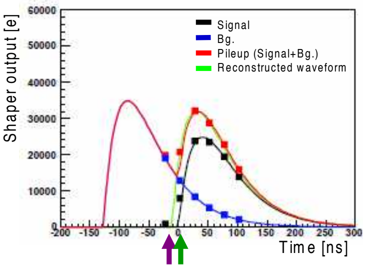
Assembly and survey of new SVT

- Pair half-modules onto support structure at 50/100 mrad stereo angle
- Survey assembled modules using optical/touch-probe CMM: get sensor positions and curvature
- Modules (in sets of 3) mount onto U-channels; survey U-channels to relate sensors to each other and beamline survey

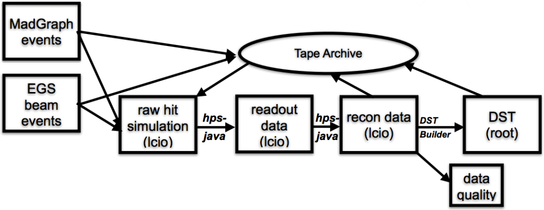
SVT timing

- SVT hit occupancies are very high; reject hits outside a time window defined by the ECal event time
- HPS is designed for a maximum occupancy of 1% (L1 next to the beam gap) in 8 ns window; to run at planned current with good tracking efficiency, hit time recon must be good within 8 ns
- Use APV25 readout chip to take 6 samples at 24 ns spacing; fit the pulse coming out of the preamp to get hit time resolution $\sim$2 ns
  - Minimize effect of pulse pileup on the time fit
- Use fitted hit times in track finding



MC production

- Mock data challenge: 1 week equivalent of simulated data with secret A' signals mixed in
- Run on JLab compute farm
- Set up and exercise all our MC, data handling and recon tools



Analysis!

- Reconstruction overview
- Event sample: e^+e^- pairs with 2-track vertex and invariant mass
- Basic event selection
- Bump hunt, ref. APEX
- Blinding

Reconstruction, in brief (SVT only)

- Hit time reconstruction of individual strip hits
- Clustering to form strip clusters
- Track finding to form tracks with 5 or 6 stereo hits
- Track refit using GBL
- Vertexing using Billoir algorithm
- Result: e^+e^- pairs with 2-track vertex and invariant mass

Vertex search

- Signal: small number of events with detached vertices and a single mass
  - Parameters: mass, production cross-section, lifetime
  - In minimal model (100% branching ratio to e^+e^-), cross-section and lifetime are both determined by α'/α
- Background: QED tridents with finite vertex resolution (with non-Gaussian tails) and smooth mass distribution
  - Mix of Bethe-Heitler and radiative tridents
  - Beam-gas interactions possible but expected to be rare

Resolutions and tails

- We care about mass resolution and vertex resolution
- Mass resolution depends on angular and momentum resolution
  - Position resolution at target tells us about angular resolution
  - e-W elastic scattering gives momentum resolution near beam energy
  - Møller scattering gives angular and momentum resolution across momentum range
- Vertex resolution depends on angular resolution, but non-Gaussian tails of the distribution are a big deal
  - Mishits: wrong L1 hit is added to the track (MS makes the "'bad" hit a better fit than the "good" one), pulls track
  - Kinks: large-angle scatter in early layer

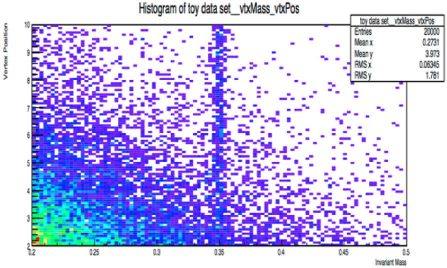
Event cuts

- Basic event cuts:
  - Track quality (track fit and time χ^2, ECal track match)
  - Pair quality: (vertex fit χ^2, $E_+ + E_- \approx E_{beam}$)
  - Kinematic cuts to reduce Bethe-Heitler tridents
- Important to reduce vertex tails (may or may not be useful for other analyses):
  - Track quality: layer 1 isolation cut (mishits), kink cut (large-angle scatters)

Blinding

- Hidden signal box: cut out events with vertex Z above some limit
  - Box should be looser than expected signal region, but tight enough that background and resolutions can be characterized before unblinding
  - Must be able to kill most backgrounds without looking in the box
- Subsample: develop analysis on a fraction of the data
  - Bump hunt will probably use this approach

Analysis



- Moving mass window
- Profile likelihood
- Discovery/setting limits

Fitting the signal

- A complete fit of the background is hard and unnecessary; use a scanning window
- Scan through the signal parameters (mass, lifetime); only fit data within a mass window and above some cutoff Z
- Signal shape is completely determined by mass, lifetime, and the known mass resolution; background distribution can be fit with an ansatz
- Use a mass window larger than mass resolution (to capture all signal events), but small enough that background (i.e. trident rate and vertex resolution as function of mass) can be fit well
- Use unbinned likelihood fit to use full event-by-event vertex resolution information

Profile likelihood

$$\lambda(\mu) = \frac{L(\mu, \hat{\hat{\theta}})}{L(\hat{\mu}, \hat{\theta})}$$

- Do a likelihood fit to the data in the scanning window, optimizing the background parameters θ as a function of the signal strength (production rate) parameter μ
- Profile likelihood ratio: ratio of the likelihood at each μ to the likelihood at the best fit $\hat{\mu}$
- $\lambda(0)$ gives the local p-value for discovery (correct for look-elsewhere effect to get global p-value)
- Setting limits: we can calculate the p-value for the μ corresponding to 100% branching ratio