The Heavy Photon Search Experiment

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What is a "Dark Photon"?

- Consider a theory in which nature contains an additional Abelian gauge symmetry, $U(1)_D$ (Holdom, Phys. Lett. 166, 1986)

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{\varepsilon}{2} F_{\mu\nu}^Y F_{\mu\nu}^{I'\prime} + \frac{1}{4} F_{\mu\nu}^I F_{\mu\nu}^I + m_{A'}^2 A_{\mu}^I A_{\mu}^{I'}$$

- This gives rise to a kinetic mixing term where the photon mixes with a new gauge boson ("dark/heavy photon" or $A'$) through the interactions of massive fields $\rightarrow$ induces a weak coupling to electric charge

- Since dark photons couple to electric charge, they will be produced through a process analogous to bremsstrahlung off heavy targets subsequently decaying to $l^+ l^-$
Where Do You Search for a Dark Photon?

- Lack of signals at LHC and direct detection experiments implies thinking of other type of DM, possibly light, which is compatible with dark photons
- New astrophysical anomalies (INTEGRAL, GC) can be explained by a light Dark Matter (~GeV) candidate decaying to an MeV - GeV $A'$ ($\varepsilon^2 \sim 10^{-6} - 10^{-12}$)

**Present limits**

- Fixed target with $e^-$ beam
  - APEX test run (JLab), Mainz (A1)
  - E774, E141, u70, Orsay

- Fixed target with $p$ beam
  - Fermilab
  - Annihilation
    - BABAR, BELLE, KLOE

- Meson decay
  - KLOE, BES-3, WASA-COSY, NA48/2 (CERN SPS), PHENIX

- Arkani-Hamed et. al., Pospelov, Ritz, Finkbeiner + Weiner, Nomura + Thaler

- Hooper, Weiner, Xue
Even though $A'$ particles are produced by a process analogous to ordinary photon bremsstrahlung, the rate and kinematics differ in several key ways:

- The $A'$ productions cross section is suppressed relative to photon bremsstrahlung by a factor of $\frac{m_e^2 \varepsilon^2}{m_{A'}^2}$.
- The $A'$ is produced very forward → opening angle of its decay products is $\sim \frac{m_{A'}}{E_{\text{beam}}}$.
- The $A'$ will take most of the incident beam energy.
- Long lived $A'$ will have a displaced vertex → Will help cut down prompt backgrounds.
A’ Fixed Target Backgrounds

Two physics backgrounds collectively known as “tridents”

Radiative

Irreducible. Kinematically identical to A’.

Bethe-Heitler

Dominant but is also kinematically distinct to the A’. Even after kinematic cuts, Bethe-Heitler dominates.

Beam Backgrounds

- Coulomb scattering in the target
- Secondary particle production: bremsstrahlung and delta-rays
- Pair conversion of bremsstrahlung photon
Maximizing the acceptance to low mass A’ decays and precise vertexing requires placement of the detector as close to the beam as possible.

**Bump Hunt**

Requires good mass (momentum) resolution to fight high backgrounds.

**Displaced Vertex + Bump Hunt**

Distinguishing A’ decay vertices as Non-prompt requires good vertex resolution.

- Both will require a tracking system and magnet that are placed as close to the target as possible.
- Mass and vertex resolution will be dominated by multiple scattering so tracker material needs to be minimized.

Small coupling $\rightarrow$ small cross section $\rightarrow$ requires high intensity beam.

- High occupancy will require fast readout and trigger system.
The HPS Apparatus

-10^3 X_0 Tungsten Target
Thin target to reduce multiple scattering

Linear Shift Motion System
Allows adjustment of deadzone between SVT volumes

Silicon Vertex Tracker (SVT)
Used for precise momentum and vertex determination

Electromagnetic Calorimeter
Used for triggering and particle ID

SVT Vacuum Chamber
Si tracker placed in vacuum in order to avoid backgrounds due to beam-gas interactions

Pair Spectrometer

B = 0.25 - 1.5 T

SVT + ECAL DAQ capable of 50 kHz

Omar Moreno (SCIPP)
2015 American Physical Society April Meeting
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**Continuous Electron Beam Accelerator Facility**

Simultaneous delivery of intense electron beams of different energies to four experimental halls.

- Hall A, C: $I_{beam} < 100 \, \mu A$, Hall D: $I_{beam} < 90 \, \mu A$, Hall B: $I_{beam} < 800 \, nA$
- With energy upgrade, $E_{beam} = n \times 2.2 \, GeV$, $n < 6$ up to a maximum of 11 GeV (12 GeV for Hall D)
- Beam delivery is nearly continuous $\rightarrow$ 2 ns bunch structure
- Capable of providing small beam spot with small tails which will help improve vertexing

HPS will run in experimental Hall B at a beam energy ranging from 1.1 - 4.4 GeV and current of 50 nA to 200 nA
Silicon Vertex Tracker

Design
- Six layers of pairs of Si microstrip sensors → One axial and the other at small angle stereo (50 or 100 mrad)
- Layers 4-6 are double width in order to match calorimeter acceptance
- Thin layers in order to reduce multiple scattering (0.7% X 0 /layer)
- Total of 36 sensors and 23004 channels

Readout
- Makes use of APV25 readout chip
- 40 MHz six sample readout helps achieve a 2 ns t0 resolution and fight pileup
- Low noise → S/N > 25
- High radiation tolerance

See Sho Uemura’s talk for details
Electromagnetic Calorimeter

- Comprised of 442 PbW04 crystals
- FADC readout at 250 MHz → allows for a narrow trigger window (8ns)
- FPGA based trigger selection (Two clusters along with some constraints on their energy and geometry) reduces background trigger rate from 3 MHz to 27 kHz
- Trigger and DAQ capable of a rate > 50 kHz

See Holly Vance’s talk for details
HPS Experimental Reach

Spring of 2015
1 Week @ 1.1 GeV

Fall of 2015
1 Week @ 2.2 GeV

Beyond...
2 Weeks @ 4.4 GeV
Running at other energies also possible

Beyond...

Bump Hunt
Displayed Vertex + Bump Hunt
**Current Status**

- Installation of the ECAL was completed in Fall in time for a December commissioning run.
- Installation of the SVT was completed in February 2015.
- Both systems have been commissioned and are ready for electrons.

1.1 GeV beam expected any day now!

**Test Run**

Demonstrated HPS is ready for electrons!

**December 2014 Run**

Analysis of data is ongoing.

See Nathan Baltzell’s talk for details.
STAY TUNED

Tracking and Vertexing for the Heavy Photon Search
Sho Uemura

Heavy Photon Search Commissioning Run and Performance of the Electromagnetic Calorimeter
Holly Szumila-Vance

Results from the HPS Commissioning Run
Nathan Baltzell
Demonstrated HPS is ready for electrons!

- 98% of 12780 SVT channels were operational
- $t_0$ resolution was found 2.6 ns
- SVT aligned to within 300 um
- Signal to noise ~23
- Hit efficiencies > 99%
- Trigger rates are well understood