The Heavy Photon Search Experiment

Cameron Bravo (SLAC) on behalf of the HPS collaboration
- Strong evidence for the existence of Dark Matter (DM)
  - We know nothing of its particle nature
  - WIMPs are a well motivated candidate but searches for them have yielded nothing, we have looked nearly everywhere we can for them. Limited by Lee-Weinberg bound Phys. Rev. Lett. 39, 165
  - Light Dark Matter (sub-GeV range) is a good candidate but requires a new force to achieve the correct thermal relic
- We consider the case where DM interacts via a vector mediator Holdom, Phys. Lett. B 166, 1986
Dark Photons in Fixed Target Experiments

- Where there are photons, there can be dark photons aka “dark bremsstrahlung”
- Heavier product (A’) takes most of the beam energy

HPS results assume a mass hierarchy $m_{A’} < 2m_\chi$
Visible Decay Backgrounds

- **Radiative tridents** have identical kinematics to signal; constitute an irreducible background
- **Bethe-Heitler (BH) tridents** have softer e+e- pairs, but still dominant in signal region

\[
\frac{d\sigma (e^- Z \rightarrow e^- Z (\ell^+ \rightarrow \ell^+ \ell^-))}{d\sigma (e^- Z \rightarrow e^- Z (\gamma^* \rightarrow \ell^+ \ell^-))} = \frac{3\pi e^2}{2N_{eff} \alpha} \frac{m_{\ell^+}}{\delta m}
\]

Require \(0.8E_{beam} < p(e^+ e^-) < 1.2E_{beam}\) greatly reduces fraction of BH background
Parameter Space: Mediator Decays to SM

Generally, searches are “bump hunts” for $m(l^+l^-)$ resonances.

$A'$ becomes long lived at small couplings.

$$\gamma_{CT} \propto \frac{1}{\epsilon^2 m_{A'}^2}$$

Leads to constraints from “beam dump experiments”

SLAC E137

$\sim 2 \times 10^{20} e^-$

$\alpha_D = 0.5, M_{A'}/M_X = 1.5$
HPS Signatures and Reach

Resonance Search (Bump Hunt)
High Coupling

Displaced Vertex + Bump Hunt
Low Coupling

Cosmic Visions Whitepaper [arXiv:1707.04591]
Compact $e^+e^-$ spectrometer, immediately downstream of thin target in multi-GeV beam in Hall B.

- Low-mass, high-rate (up to 4 MHz/mm$^2$) silicon tracker (SVT) allows vertexing long-lived $A'$. SVT must suppress SM tridents from target by factor $\sim 10^7$
- PbWO$_4$ ECal trigger eliminates 10’s MHz scattered single $e^-$
Engineering Runs

2015 Engineering Run
50 nA @ 1.06 GeV
1.7 days (10 mC) of physics data

2016 Engineering Run
200 nA @ 2.3 GeV
5.4 days (92.5 mC) of physics data

- The HPS apparatus, including the SVT, has performed exceptionally well.
- HPS still approved for 165 more days of beam time: a long way to go!
Resonance Search Results with 2015 Data

- Mass resolution measured in data using Møllers
- Tridents used to calibrate the expected signal rate
- 7th order Chebyshev polynomial used for background shape
- Likelihood ratio used to quantify significance of any excess
  - No signal observed
  - Invert likelihood ratio to determine 2σ upper limit for each mass
- Only used ~1% of approved run time
- Link to paper: Phys. Rev. D 98, 091101(R)
Displaced Vertex Search Preliminary Results

- Optimum Interval Method is ideally used for small signal where signal shapes are known, but background is not sufficiently known (HPS, direct DM detection, etc.)

[arXiv:physics/0203002v2]

More detail in talk by Matthew Solt at APS April Meeting 2019
Not enough luminosity to be sensitive, longer run happening now!
SVT Upgrade Motivations

- Adding a new “Layer 0” closer to the target allows access to shorter decay lengths → Large multiplier on acceptance for exponential decays
- Moving Layers 2 and 3 as close to the beam as occupancy allows → Gain acceptance at longer decay lengths
SVT Upgrade Concept

- Layer 0 is similar in concept to other layers
  - Closer to target, 5 cm vs. 10 cm for L1
  - ~Half the material (0.4 % $X_0$)
  - Same acceptance requires being proportionally closer to the beam
- Moving L2 and L3 closer by about 700 microns is as simple as adding shims under the modules
Layer 0 Sensor Design

- 200 micron thick p+-in-n bulk Si
- 55 micron readout pitch
- Split into two 15 mm by 14 mm active areas, with short strips read out from both ends
- 510 channels (2x255)
- 250 micron slim inactive edge allows placement closer to beam (scribe-cleave-passivate process)
- Around 500 V maximum bias voltage
SVT Upgrade Production

- Production of Layer 0 modules was successful!
- Produced enough to replace L1 with new modules as well
- Inactive Si in L1 creates some difficult backgrounds
  - Conversion of wide-angle brems
  - Tridents from scattered e⁻
Hodoscope Upgrade

- Original HPS trigger uses a pair of clusters in ECal
  - Hole in Ecal for beam passage
- Trigger on only positrons can increase acceptance
  - Fake rate from photons must be controlled

Built, installed, and commissioned in time for running in summer 2019!
Challenging the CEBAF

- Require beam spot to be less than 50 microns RMS perpendicular to beam plane
  - Use wires attached to SVT uchannel to measure beam profile near target
  - CEBAF capable of delivering adequate beam
- Squeezing beam spot on our target can take many hours of tuning work
Projected 2019 Reach

We are currently running at 4.5 GeV

4.4 GeV is for 300 nA and 8 $\mu$m W target

2.2 GeV is for 200 nA and 4 $\mu$m W target
Conclusions

- Detector performed great for 2015 and 2016 engineering runs
- HPS recently published first result on bump hunt analysis of 2015 engineering run
- Preliminary vertex analysis shows sensitivity should be possible with enough data
- Successful upgrade program for summer 2019 physics run
- Challenging experiment for CEBAF to deliver beam
- We are excited to get our first full physics run
  - Still in the middle of the run
  - Possibility of extending run is being discussed
- Thanks for your attention!