HPS Update

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For the HPS Collaboration
JLab User Group Meeting June 2, 2015
Heavy Photons?

Old idea: Nature may have an additional $U(1)$ symmetry. If so there will be kinetic mixing between the photon and the new gauge boson.

$\mathcal{L}_{U(1)'} = -\frac{1}{4} V_{\mu\nu}^2 - \frac{\varepsilon}{2} V_{\mu\nu} F^\mu\nu + |D_\mu \phi|^2 - V(\phi)$

Kinetic Mixing term.

Holdom, Phys. Lett B166, 1986
Mixing

Photon mixing with $A'$ is equivalent to ordinary charged matter acquiring a milli-charge under the $A'$

$e^- \gamma^* \leftrightarrow e^- \leftrightarrow e^- e^+ \leftrightarrow A'$ will pair produce: $e^+e^-$, $\mu^+\mu^-$, $\pi^+\pi^-$, ...

$A' \\ A_\mu \rightarrow A_\mu + e\alpha_\mu$
Putting this in perspective

Venn Diagram
“DM Candidate Landscape”

We are here

T. Tait from arXiv:1401.6085v1 [hep-ex]
Putting this in perspective

We are here

"Light Shining Through Wall"

Jaeckel and Ringwald ('10)  
*Ann. Rev. of Nuclear and Particle Science, 60(1), 405–437*
“Natural*” Coupling and Mass

* Depends on the model

\[ m_{A'}^2 \sim \epsilon M_W^2 \]

or

\[ m_{A'}^2 \sim \frac{e g D}{16 \pi^2} M_W^2 \]

Stückelberg mechanism:

\[ m_{A'} \sim \text{meV} \]

Leading to:

\[ M_{A'} \sim \text{MeV} - \text{GeV} \]

Natural \( \epsilon \) could be \( \sim 1 \) (tree level)

Or \( 1 < \epsilon < 10^{-8} \) (loops)

or “anything”...

See: R. Essig et al, Intensity Frontier WS ’11 summary paper.
Search area of choice

\[ \log_{10} m_{\gamma'} \text{ (eV)} \]

\[ \frac{\alpha'}{\alpha} \]

\[ M_{A'} \text{ (GeV/c}^2) \]

- \( \alpha_e \)
- \( \alpha_M \)
- BaBar
- \( \alpha_{\mu, \pm, 2} \text{ favored} \)

- E774
- E141
- E137

- Rydberg
- Solar lifetime
- HB

- E137
- E141
- E774
- \( \gamma_{35} \text{ EW} \)
- \( \gamma_{35} \text{ LHC} \)
- \( \gamma_{35} \text{ LSW} \)

- Unified DM
- Lukewarm DM
- dDM

- 0.01
- 0.1
- 1

- \( 10^{-4} \)
- \( 10^{-5} \)
- \( 10^{-6} \)
- \( 10^{-7} \)
- \( 10^{-8} \)
- \( 10^{-9} \)
- \( 10^{-10} \)

\[ \alpha'/\alpha \pm 2 \]

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A lot of interest!

Since 2010, a lot of interest in this field.

Arkani-Hamed et al. PRD 79 015014 (2009)

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Exclusion areas in 2010

At the time of the HPS proposal, exclusion areas were mostly due to beam dump searches.
A lot of interest!

Since 2010, a lot of interest in this field.

Exclusion areas in 2015

At the time of the HPS proposal, exclusion areas were mostly due to beam dump searches.

Since then, a lot of existing data has been re-analyzed to set improved limits.
A lot of interest!

Since 2010, a lot of interest in this field.

Exclusion areas in 2015

Lots of places to look:
- Flavor Factories
- Rare Meson Decays
- Fixed target experiments.
- Precision Measurements
- Beam dump experiments.
Look for radiated $A'$ decay to $e^+e^-$, $(\mu^+\mu^-)$

Bump Hunt:
Look for signal over background.

Bump Hunt + Vertexing:
Look for signal over background, reduce background with vertexing.

Very high luminosities:
Intensity Frontier Physics.


$\sigma_{B-H}$ very large $\gg \sigma_{Rad}$. But kinematically distinct $\rightarrow$ Use clever trigger to separate.
## A' lifetime

\[ \gamma c \tau \approx 1 \; \text{mm} \left( \frac{\gamma}{10} \right) \left( 10^{-8} \frac{\alpha}{\alpha'} \right) \left( \frac{100 \; \text{MeV}}{m_{A'}} \right) \]

**Lower \( \alpha' \), lower mass \( \rightarrow \) longer lifetime**

**Background is all prompt \( \rightarrow \) Lower coupling can be reached using vertexing.**
Detecting A’ decays

\[ e^- \rightarrow A' \rightarrow l^- l^+ \]

Energy = \( E \)

\[ E_{A'} \approx E_{\text{beam}} \]
\[ \theta_{A'} \approx 0 \]
\[ \theta_{\text{decay}} = m_{A'}/E_{A'} \]

Need:
- Small angle detection of e+ e-
- Very high luminosity
- Good invariant mass resolution
The HPS Experiment
A magnet chicane directs the CEBAF 12 electron beam onto a W foil, producing heavy photons. They decay to $e^+e^-$ pairs, which are measured by the Si vertex tracker inside an analyzing magnet. A PbWO$_4$ ECal provides a fast trigger.

https://confluence.slac.stanford.edu/display/hpsg/Heavy+Photon+Search+Experiment
Beam’s Eye View of SVT
Spring Engineering Run

- Installed SVT end of February
- Commissioned Hall B beamline March-April  
  * Calibrated bpms & established orbit locks  
  * Set up SVT Protection Collimator  
  * Checked beam position stability
- CEBAF down after power outage
- Commissioned Trigger and Integrated SVT DAQ late April
- Explored SVT backgrounds as moved SVT closer to beam
- Production running at 1.5 mm started May 1
- Production running at 0.5 mm started May 12
- Run ends May 18th.

Layer 1 silicon sensors are just 0.5 mm above and below beam. Min opening angle is \( \theta_y = 15 \text{ mrad.} \)
Beam Quality

HPS requires a very high quality beam, with very low halo.
\( \sigma_X \sim 300 \text{ to } 500 \, \mu \text{m} \) - To spread heat load.
\( \sigma_Y \sim 15 \text{ to } 50 \, \mu \text{m} \) - To help vertexing & tracking.

The beam also needs to be very stable over time. A Fast Shut-Down stops the beam in <10 ms, if halo counters register above threshold counts.

\( X, Y \) and 45 degree beam profiles. May 5th, 2015

Very stable beam on May 12th.
I GeV Run, Charge on target.

Proposal: 1 full week of 50 nA beam on target, 30mC
Achieved: ~10 mC with SVT at 1.5mm, 10 mC at 0.5 mm

Integrated current × lifetime (mC)

Millions of events.

Opportunistic running only
Nights + Weekends

SVT @
1.5 mm 0.5 mm
Online data quality

SVT Number of layers hit

Occupancy

HPS-EcalCommissioning : EcalHit : Hit Time

HPS-EcalCommissioning : EcalHit : Hit Count In Event

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Tracked Pairs at 1.5 mm

A' candidates have $P_{e^+} + P_{e^-} \approx P_{\text{beam}} = 1.05 \text{ GeV}$

Plots from M. Graham

Simulation (for 6GeV)

Black: BH  Red: Rad.
Detector is not yet fully calibrated! Alignment fine tuning needed, but close.
Gain calibrations need improvement.

PRELIMINARY
Pairs Vertex at the Target

- Z-vertex is critical for the experiment.
- Also the hardest @ 15 mrad.
- Requires very good SVT alignment (not yet done!)

Z RMS ~ 8.7 mm

Y RMS ~ 0.3 mm

X RMS ~ 0.7 mm

PRELIMINARY
Pairs Mass Distribution

Tiny fraction of all data. Very preliminary look!
To do: better calibrations, cuts, more data, …
Reach vs Runtime

For 1 GeV beam

Assumes coverage to 15 mrad

Contours:
- 1 PAC week
- 5/7 PAC week
- 3/7 PAC week

Measurement assured, but no new territory

Sample significance vs. mass here

1 GeV beam vertex reach.
Significance vs Mass (1.1 GeV; $\varepsilon=3 \times 10^{-9}$)

Plot from Matt Graham

Note:
Signif $\propto$ Time

HPS could cover 25 – 34 MeV in 3 PAC days
Much Worse at $\varepsilon = 10^{-9}$
Full HPS Reach

Near term Running (Yellow):
1 week with 50nA @ 1.1 GeV
1 week with 200nA @ 2.2 GeV
2 weeks with 300nA @ 4.4 GeV

Additional Running (Blue):
2 weeks with 200nA @ 2.2 GeV
2 weeks with 300nA @ 4.4 GeV
3 weeks with 450nA @ 6.6 GeV

Times are “PAC” times = Calendar time/2
Conclusions

- The HPS experiment has successfully completed its first physics data taking during the 2015 “Engineering Run”.
- Roughly 1/3 “PAC week” of data was gathered with the SVT at 0.5 mm from the beam. Enough data for several PhD theses.
- Initial look at the data looks very promising.
- Opportunistic running, with CLAS12 installation during the day, was challenging, but proved possible.
- We hope to take a lot more data in the next few years.
Some Extras
Hints from astrophysics?

PAMELA, FERMI, AMS
Energetic e+/e- cosmic rays from DM annihilation through $A'$?

10-100 MeV $A'$ could explain muon $g-2$ anomaly

Arkani-Hamed, Finkbeiner, Slatyer, Weiner. '09 PRD 79, 015014
Pospelov and Ritz '09 PLB, 671, 391–397
Cholis, Finkbeiner, Goodenough, Weiner '09 JCAP 09/2 (2009) 007


[Meade, Papucci, Strumia, Volansky 0905.0480]
More recent hints?

Excess of γ-rays from the galactic center is compatible with 50 GeV DM annihilating through a dark photon (“light mediator”)

Caveat: Astro-physics is complicated!
(and theorists are creative)

10.1103/PhysRevLett.114.211303 (May 2015)