Dark Sector Searches at Jefferson Lab

Ross Corliss

7th Workshop of the APS Topical Group on Hadronic Physics, Washington D.C. February 3, 2017
A' Searches at JLab

- effective dark charge: $\varepsilon q$
- tension for $g-2 +^8\text{Be} \Rightarrow \varepsilon_e \neq \varepsilon_d \neq \varepsilon_u$...? Or $a_e$ wrong?†
- Hadronic couplings: HADES, PHENIX, NA48/2
- Leptonic couplings: KLOE, BaBar, A1, HPS, DarkLight, APEX, BDX*

† John Ralston’s talk
LDM Search (BDX)

- Probes $m_{A'}$ through LDM interactions with detector
- Difficult to plot model independent limits
- Shown: slice with $\varepsilon(m_{A'})$ fixed at lower bound of $(g-2)_\mu$ 2σ band
# Experiments at Jefferson Lab

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- **DarkLight**
- **APEX**
- **HPS**
BDX at Jefferson Lab

"Beam Dump eXperiment"

• Generate LDM in beam dump

• Detect LDM through X-e scattering, possibly access X-N scattering

• GeV recoil easy to detect

• Parasitically operates with Hall A experiment
Beam Dump and Onward

- 11 GeV $e^-$ showers in dump
- LDM produced via $eN \rightarrow eN' \rightarrow eNXX$
- Primary background from neutrons, muon pair production
- (also produces neutrinos)
Shielding

- Iron shielding ranges out $\mu$
- Concrete shields $n$
BDX Detector

- \( \sim 1 \text{m}^3 \) of CsI(Tl) crystals from BaBar endcap EM calorimeter \( \sim 1 \text{k} \) channels

- Veto sandwich of Sci-Pb-Sci registers cosmic muons/showers

- Significant beam-off time to characterize cosmic neutrons
BDX Prototype

- Operating at INFN
- 3x3 BaBar crystals with SiPM
- 2-layer veto
$10^{22}$ EOT = 285 days of running:

**BDX expected reach**

**Elastic $\chi$-e$^-$ scattering - BDX reach**

Fermion DM, Above LSND Threshold, $m_\chi = 68$ MeV, $\sigma_D = 0.1$

Leptophilic DM, Most Conservative: $\sigma_D = 0.5$, $m_{A'} = 3 m_\chi$

**Inelastic $\chi$-N scattering**

Visible + Invisible decay

Viable Parameter Space Favored by $(g-2)_{\mu}$, $m_\chi \ll m_{A'}$
BDX Status

• Conditionally approved by JLab PAC (C2)
• Simulating muon backgrounds and planning to measure these in the near future
• Operating prototype at INFN
• Benchmark $10^{22}$ EOT (285 days)
• Hoping to run parasitically with MOLLER / PVDIS
DarkLight at Jefferson Lab

"Detecting A Resonance Kinematically with e\textsubscript{L}electrons Incident on a Gaseous Hydrogen Target"

- ISR/FSR A' production off e\textsuperscript{-} in ep scattering
- **LERF** (5mA, 100MeV) beam on ~5 Torr gas target to overcome small coupling (~ab\textsuperscript{-1}/mo)
- Detection of all final state particles to suppress backgrounds
DarkLight Concept
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- Si detector inside target to detect proton
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- Thin-walled, windowless target cell to minimize $e^\pm$ disruption and background
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- Cylindrical detectors for $e^\pm$ tracking
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- Si detector inside target to detect proton
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- Solenoidal magnet for Møllers and momentum
- Cylindrical detectors for $e^\pm$ tracking
- Streaming readout to accommodate high SM rate
DarkLight Concept

- Detect all final state particles (Access to visible and invisible decay modes)
- Search for $e^+e^-$ resonance or missing mass

**A' Signal**

**QED Background**
Target Commissioning

• Took place in Summer 2016

• Windowless gas target with multi-stage pumping achieved ~2.5 Torr in tests

• Prototype detector telescope operated parasitically
DarkLight Status

• Funded (DOE, NSF MRI award):
  1A: Operated LERF with Solenoid + Target, Summer 2016
  1B: Measure radiative Møller rates (spectrometer ready in 2017)
  1C: Proof-of-principle with partial coverage detector in solenoid

• Analyzing detector performance/rates from 1A
• Upgrading gas system/target
APEX at Jefferson Lab

"A Prime EXperiment"

- ISR A' production off e⁻ in electron-nucleus scattering
- Complex, multi-foil, high-Z targets
- Exploit boosted/most probably kinematics in A' decay
- **Hall A** High Resolution Spectrometers reconstruct narrow peak.
APEX Kinematics

- $A'$ carries large fraction of beam energy
- Dominant BH background suppressed via acceptance. (QED analog of $A'$ production remains)
Target Design

- Multiple scattering in target is significant background
- Thin, spaced elements so small angle clears next foil.

![Diagram of target design with beam, electrons, and positrons.](image)
APEX Design

- Septum magnet opens $e^+e^-$ decay into HRS reach
- Vertical Drift Chambers for tracking
- Gas Cherenkov for pion rejection (in trigger)
2010 Test Run

- Gaussian peak (width controlled by mass resolution studies) on 7th order polynomial
APEX Status

- Electronics upgrade to HRS can handle 5MHz in VDC
- SciFi hodoscope calibration of $e^+$ optics 0.5 $\Rightarrow$ 0.1 mrad
- Study of W target thermal cycling in progress
- Septum magnet testing in progress
- Vacuum system delivery to Hall A ~ February
- Most systems ready, testing this year
- Could run fall 2018, pending approval
HPS at Jefferson Lab

"Heavy Photon Search"

- ISR in W foil produces boosted $A'$ which decays to lepton pair
- Precision tracking near target/beam for angular resolution and displaced vertex
- Multiple beam energy settings to expand $m_{A'}$ reach
HPS Design

- Dipole for momentum, $e^+e^-$ separation
- Si Vertex Tracker at 1.5mm $\Rightarrow$ 0.5mm from beam ($<5$mm vertex, $<8\%$ mom.)
- ECAL opening for sheet of flame (4% ene.)
Beam Position Control

- Low frequency active feedback in steering
- High frequency motion small
- Fast Shut Down in case of large excursion ~1 per 16hrs
- Other trips ~ 10 per hr
Preliminary Result

- Gaussian peak (width controlled by Møller resolution studies) on 7th order polynomial

\[
\text{Mass hypothesis} = 27.525 \text{ MeV}
\]

\[
p\text{-value} = 0.04931
\]
• Lots more detail of this recent analysis: "Searching for a Resonance with HPS" Omar Moreno APS talk
HPS Status

- Detector performance in 2015-2016 very close to projections

- 6.7 beam days taken, bump hunt and vertex searches:
  - 1.1 GeV (1.7 days) analysis nearing completion (early 2017)
    17-90MeV search, 10% unblinded
  - 2.3 GeV (5 days) calibration underway

- 165 days left: 2018- run?
# Status Summary

- Variety of searches coming online in coming years:

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