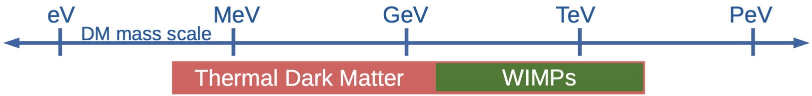
Searching for Visibly Decaying Displaced Dark Photons with the Heavy Photon Search Experiment

Sarah Gaiser (Stanford/SLAC),
on behalf of the HPS collaboration

APS April Meeting 2024

Low Mass Freeze-Out Thermal Relics

SLAC



- DM annihilation cross section from weak interaction: $\langle \sigma v \rangle \sim \frac{m_\chi^2}{M_Z^4}$
  - For $m_\chi \lesssim 2\,\mathrm{GeV}$: $\langle \sigma v \rangle$ too small for thermal DM (Lee-Weinberg bound)

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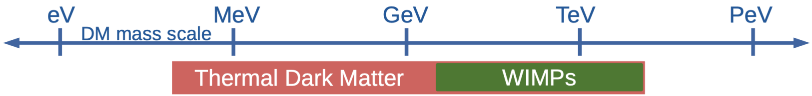

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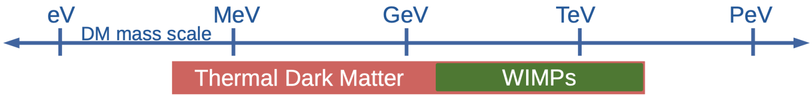

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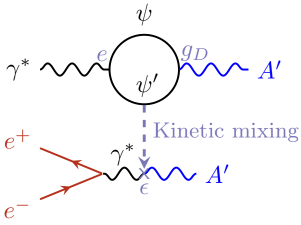
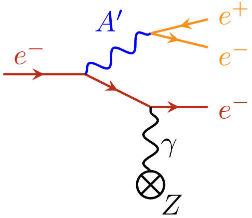
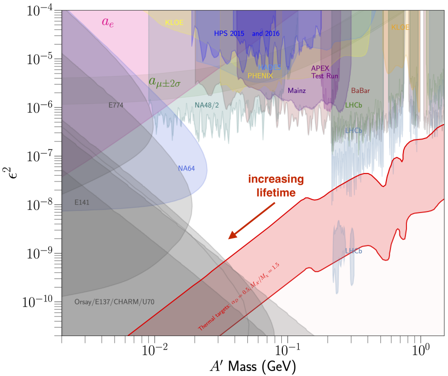
- Dark Sector with lighter mediator increases cross section
- Minimal Dark Sector: new U(1)'
  - Natural extension to SM
  - Heavy/Dark Photon A'
  - Kinetic mixing with SM
    - → small coupling: Dark Sector – SM
  - Can reproduce correct DM abundance



$$\mathcal{L} \supset -\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} F_Y^{\mu\nu}$$

HPS Search Strategy





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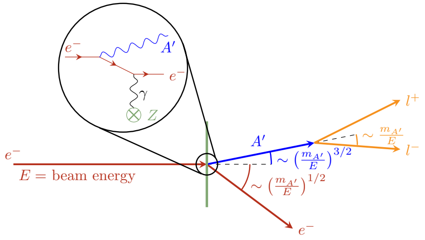
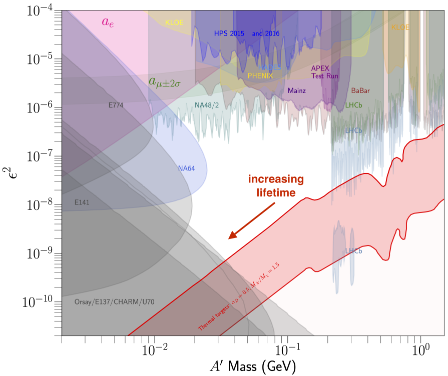
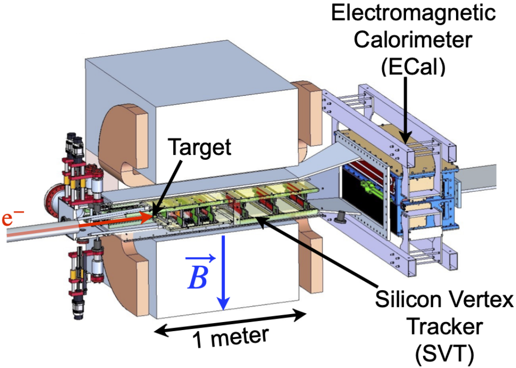




- e^- beam on W target; production of A' through Dark Bremsstrahlung
- Search for visibly decaying Dark Photons: $2m_e < m_{A'} < 2m_\chi$
  - Depending on coupling strength: prompt or displaced decay
    - $\rightarrow$ This talk: focus on probing thermal target region

HPS experiment at JLab

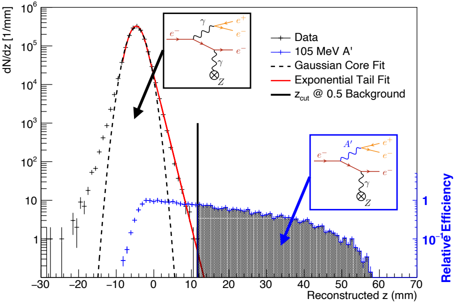
- HPS experiment in Hall B at JLab using electron beam from CEBAF
- ECal for trigger
- SVT: silicon strip tracker
  - $\sim$ 25000 channels
  - Close to beam: 500 µm, 15 mrad acceptance
- Four datasets:
  - Two engineering runs: 2015 (1.05 GeV), 2016 (2.3 GeV)
  - Two physics runs: 2019 (4.55 GeV), 2021 (3.74 GeV)



- Results published on 2016 data, other years coming up soon

Displaced vertex analysis

105 $\pm$ 4.7 MeV mass slice

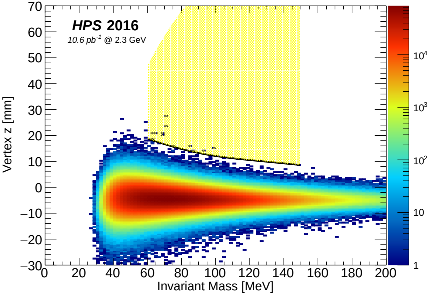


Plots from HPS Collaboration, PRD108, 012015 (2023)

- Long-lived A's: decaying 1-10 cm from target
- True displaced vertex:
  - Good vertex χ^2
  - Projects back to beam spot
  - Tracks with large vertical impact parameter
- Signal region: $0.5 = \int_{z_{\text{cut}}}^{\infty} F_{\text{bkg}}(z)\ \mathrm{d}z$

Displaced vertex analysis

Final selection, full dataset



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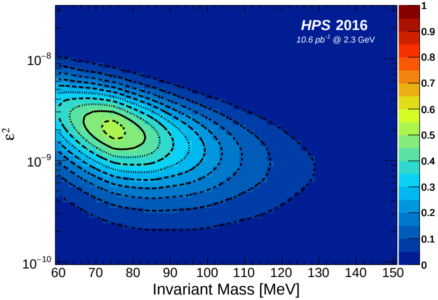
- Signal region: $0.5 = \int_{z_{\rm cut}}^{\infty} F_{\rm bkg}(z)\ dz$
- Repeated for overlapping mass slices
- Categorize events based on layer containing first hit

Results of the 2016 Engineering Run

Expected signal yield

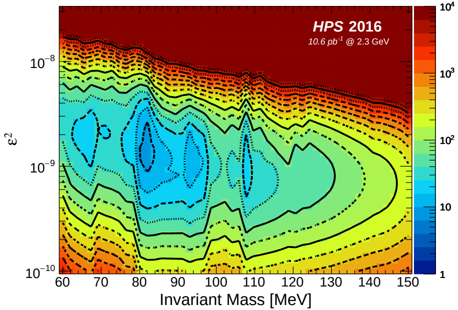


Plots from HPS Collaboration, PRD108, 012015 (2023)

- Calculating signal yield:
  - Decay length distribution
  - Detector acceptance and efficiency
- Peak at $m_{A'} = 75\,\text{MeV}$, $\epsilon^2 = 2.1 \times 10^{-9}$ $\rightarrow$ 0.52 events

Results of the 2016 Engineering Run

Limit from OIM/expect signal



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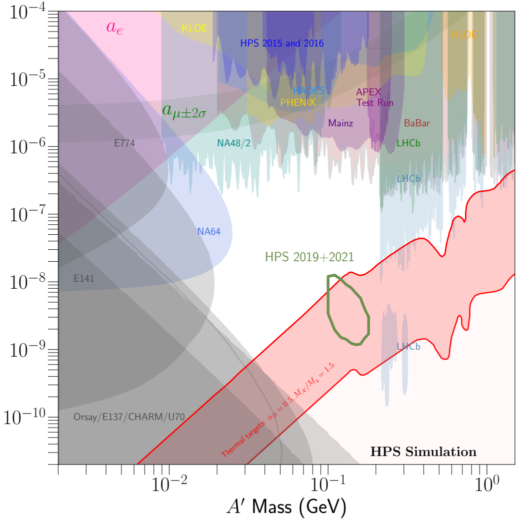
- Calculating signal yield:
  - Decay length distribution
  - Detector acceptance and efficiency
- Peak at $m_{A'} = 75\,\text{MeV}$, $\epsilon^2 = 2.1 \times 10^{-9}$ $\rightarrow$ 0.52 events
- Strongest exclusion at $m_{A'} = 82\,\text{MeV}$, $\epsilon^2 = 1.7 \times 10^{-9}$ $\rightarrow 7.9 \times \sigma_{A' exp}$
- No sensitivity to minimal A' model yet ($L = 10.6\,\text{pb}^{-1}$) $\rightarrow$ Sensitive to unique phase space given higher luminosity

Current Status and Plans

- Looking into other DM models that HPS is sensitive to
- Analysis of 2019 and 2021 datasets is currently in progress, results expected soon
  - 2019: $L = 110\,\text{pb}^{-1}$,
  - 2021: $L = 160\,\text{pb}^{-1}$
  - Improved SVT setup
- Further running planned in 2025/26 at JLab



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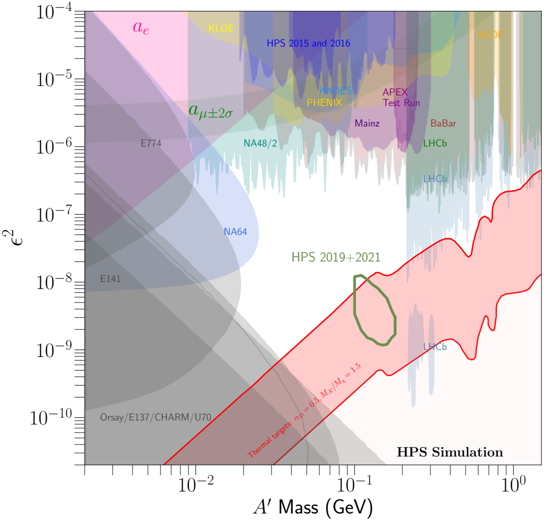
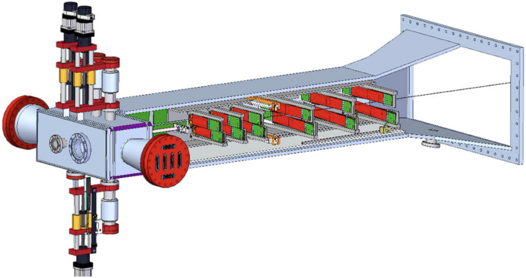


Thank you!

Silicon Vertex Tracker

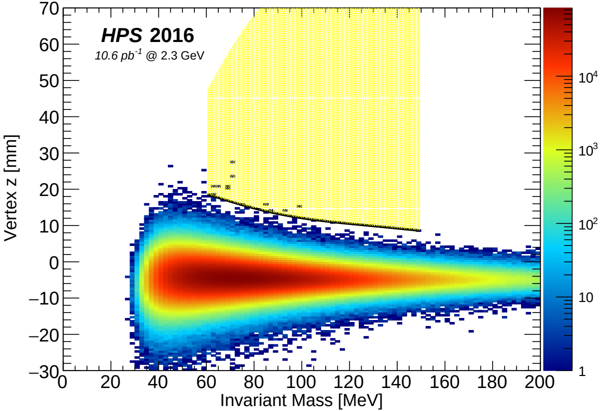
- 15 mrad acceptance above/below beam spot
  - Active edge of first sensor 1.5 mm from beam center
  - First three layers moveable: retract for beam tuning
- Enclosed in 0.24 T downward-pointing dipole field

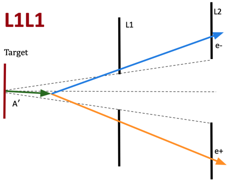
SVT inside its vacuum box



- Readout using APV25 chips: 'multipeak mode' recording six samples of signal development
  - → Hit time reconstruction ~ 2 ns

Distribution of vertex position





- Signal region for < 0.5 bkg events
- Analysis depends on event category: L1L1, L1L2, L2L2

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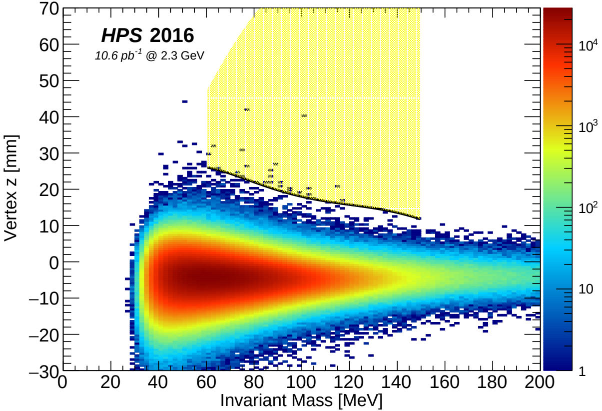

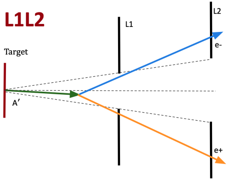

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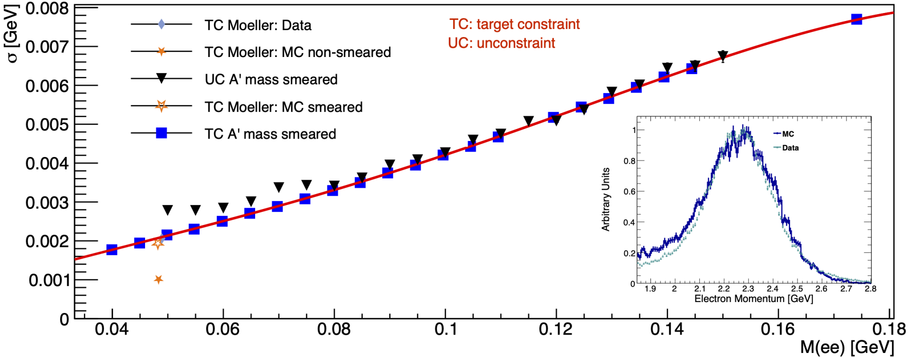
2016 Engineering Run – Mass resolution



- 2016 mass resolution:
  - Elastically scattered electrons have $E \sim E_{\text{beam}}$
  - Smear MC momenta to match data resolution
  - Compare Møller pairs in data and smeared MC

Systematic and statistical uncertainties

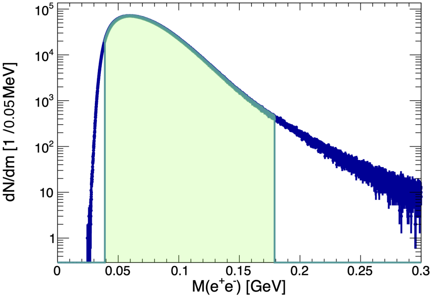
TABLE I. A summary of systematic uncertainties that impact the final result of the displaced vertex search. Where there is a single number, the systematic effect is the same for L1L1 and L1L2.

Systematic description	L1L1 value	L1L2 value
e^+e^- composition	$\sim$7%	
Mass resolution	$\sim$3%	
Analysis cuts	$\sim$8%	$\sim$13%
A' efficiency	$\sim$5%	
Total in quadrature	12%	16%
Target position	$\sim$5%–10% (m/ϵ dep)	

Table from HPS Collaboration, PRD108, 012015 (2023)

- Systematic uncertainties from careful investigation of data and MC
- Optimum interval method (OIM) with 90 % confidence interval C_0
  - OIM is an extension of maximum gap method allowing for small (unknown) background
  - Find optimum interval to set limit on smallest cross section at given C_0

Resonance Search



Plot from HPS Collaboration, PRD108, 012015 (2023)

- Resonance search over mass range 39-179 MeV in 1 MeV steps
- Using 95 % CL_s limit
- Trying to get better sensitivity by improving background model for future analyses

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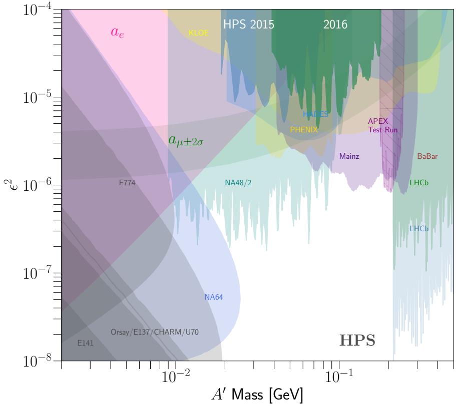

Exclusion plot combining 2015 (HPS Collaboration, PRD98, 091101 (2018)) and 2016 (HPS Collaboration, PRD108, 012015 (2023)) results

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