Meeting of the Division of Particles & Fields of the American Physical Society
Northeastern University, July 29th, 2019

The Heavy Photon Search Experiment

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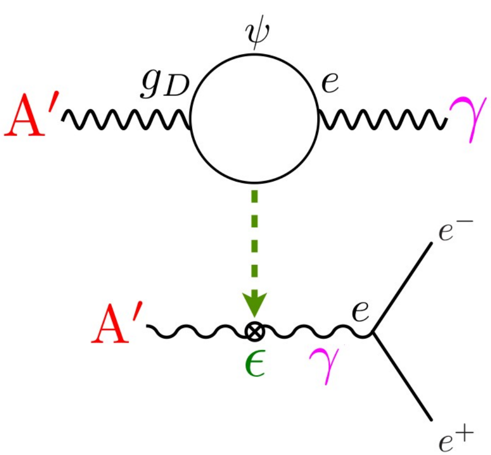
on behalf of the HPS collaboration

U.S. DEPARTMENT OF ENERGY
Office of Science

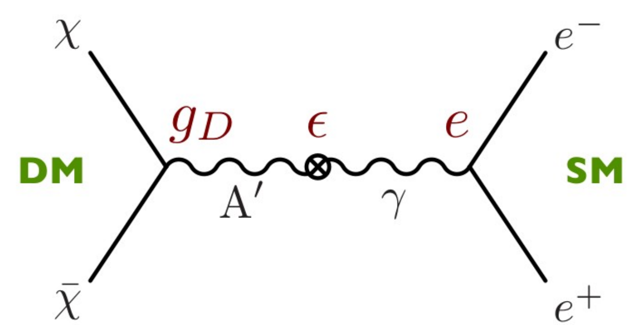
SLAC NATIONAL ACCELERATOR LABORATORY

Dark Photons

- Strong evidence for the existence of Dark Matter (DM)
  - We know nothing of it's 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



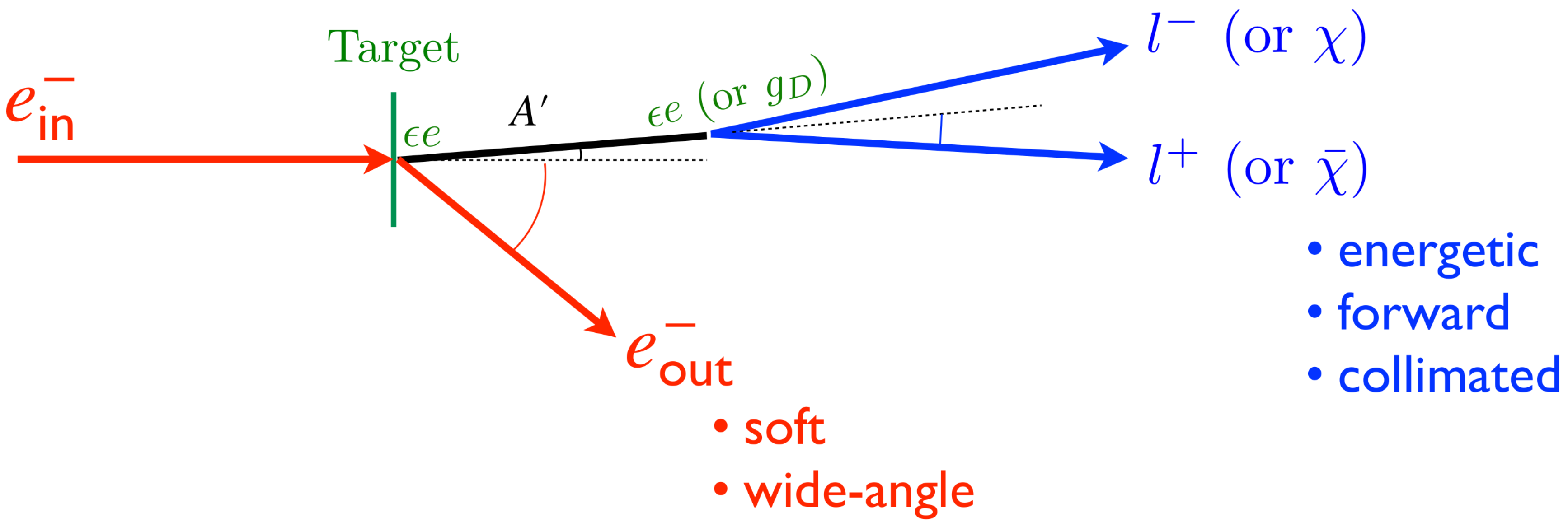
$$\alpha_D \equiv \frac{g_D^2}{4\pi}$$



$$\alpha \equiv \frac{e^2}{4\pi}$$

Dark Photons in Fixed Target Experiments

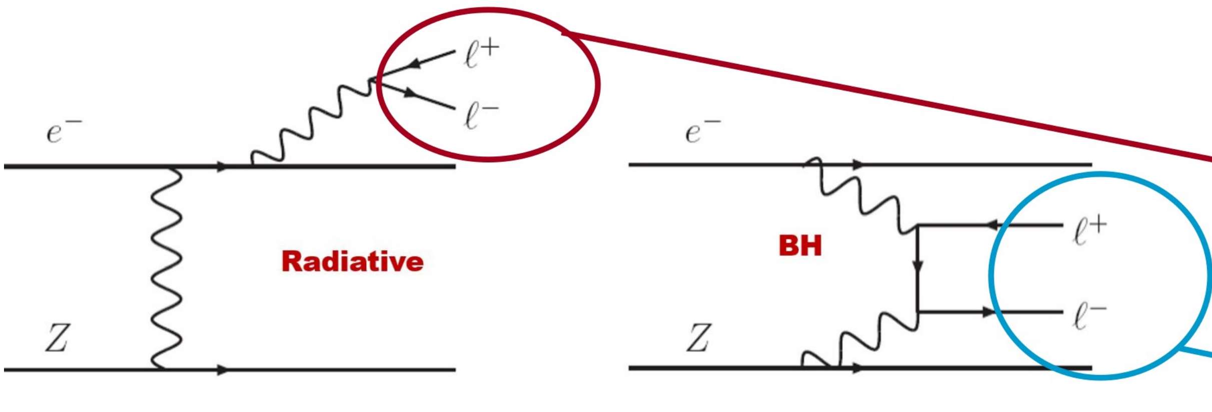
- Where there are photons, there can be dark photons aka "dark bremsstrahlung"
- Heavier product (A') takes most of the beam energy

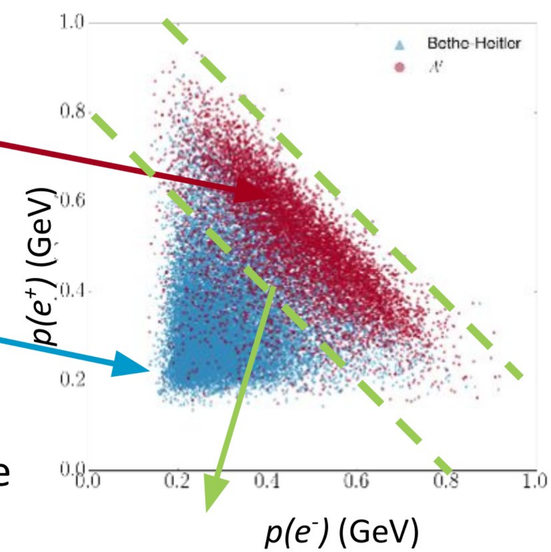


HPS results assume a mass hierarchy $m_{A'} < 2m_\chi$

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





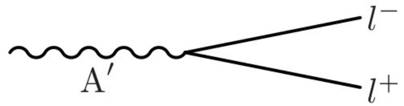
Require $0.8E_{beam} < p(e^+e^-) < 1.2E_{beam}$ greatly reduces fraction of BH background

- Radiative tridents provide reference for expected signal rate

$$\frac{d\sigma\left(e^-Z \to e^-Z(A' \to l^+l^-)\right)}{d\sigma\left(e^-Z \to e^-Z(\gamma^* \to l^+l^-)\right)} = \frac{3\pi\epsilon^2}{2N_{eff}\alpha}\frac{m_{A'}}{\delta m}$$

Parameter Space: Mediator Decays to SM

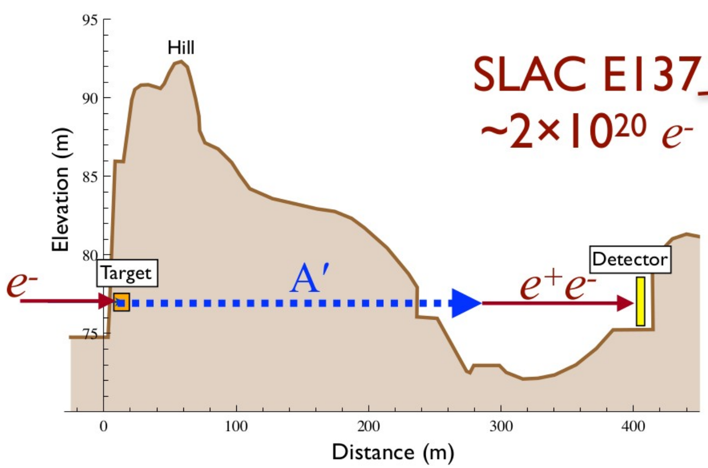
Generally, searches are "bump hunts" for $m(l^+l^-)$ resonances.



A′ becomes long lived at small couplings.

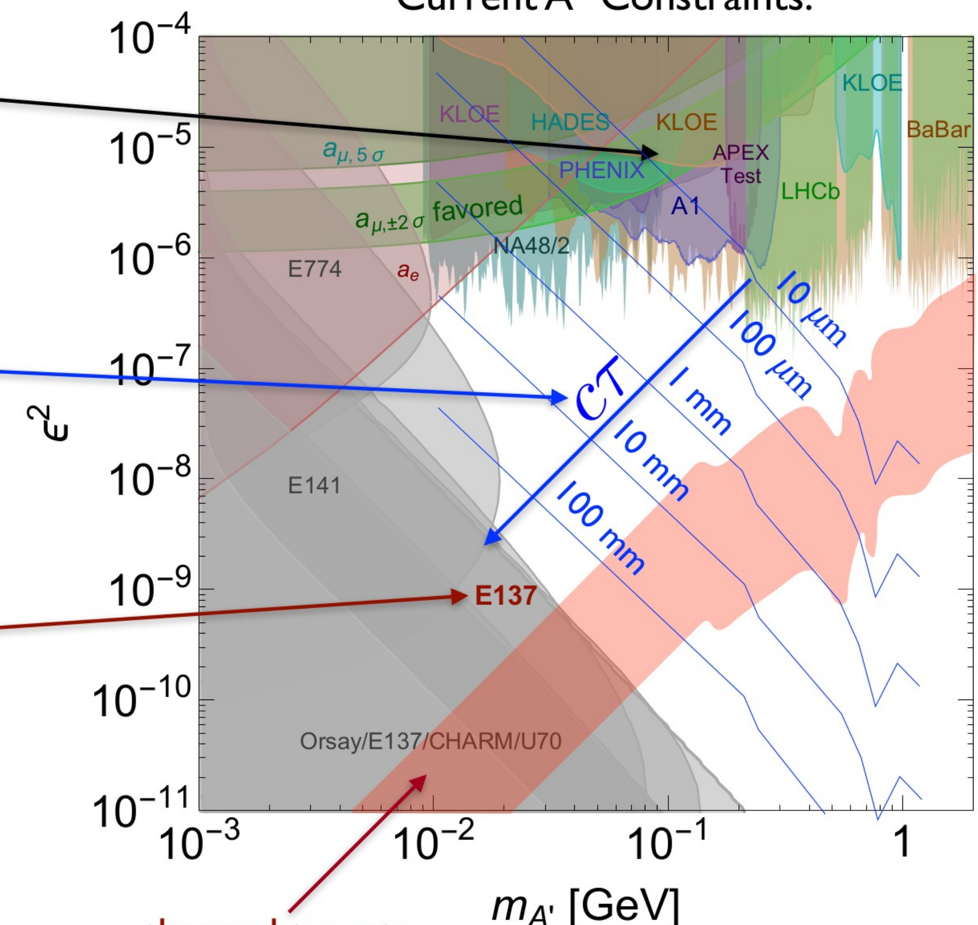
$$\gamma c\tau \propto \frac{1}{\epsilon^2 m^2_{A'}}$$

Leads to constraints from "beam dump experiments"



SLAC E137
~2×10^{20} e^-

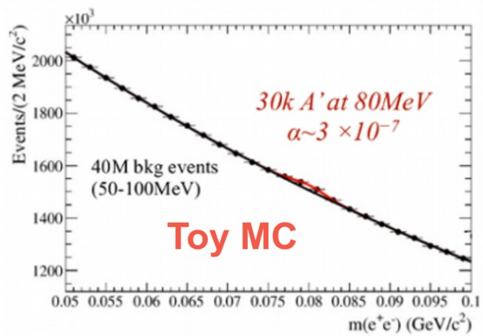
Current A′ Constraints:



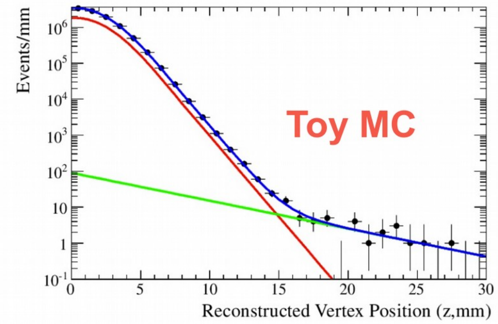
thermal targets
$\alpha_D = 0.5, M_{A'}/M_\chi = 1.5$

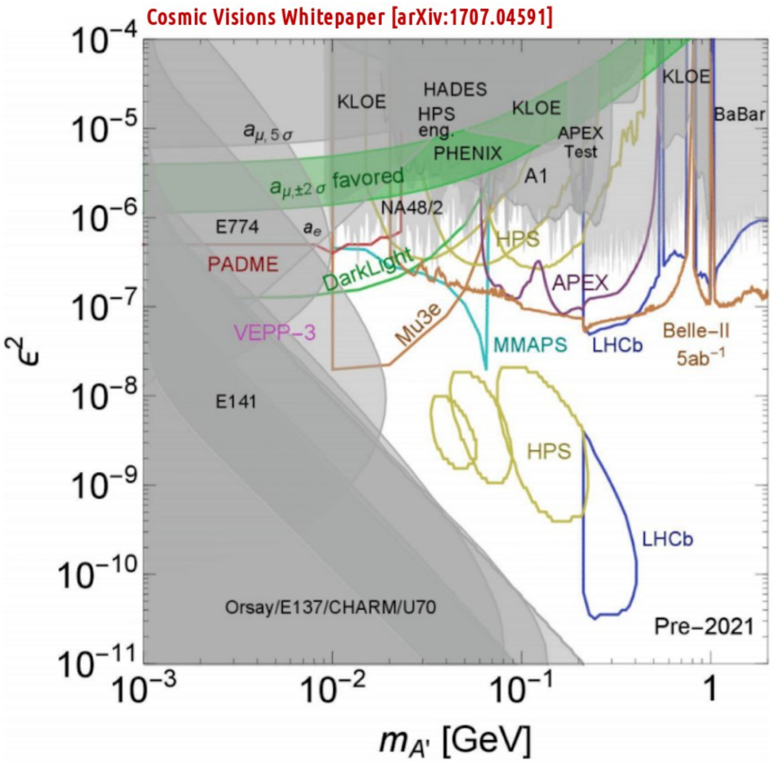
HPS Signatures and Reach

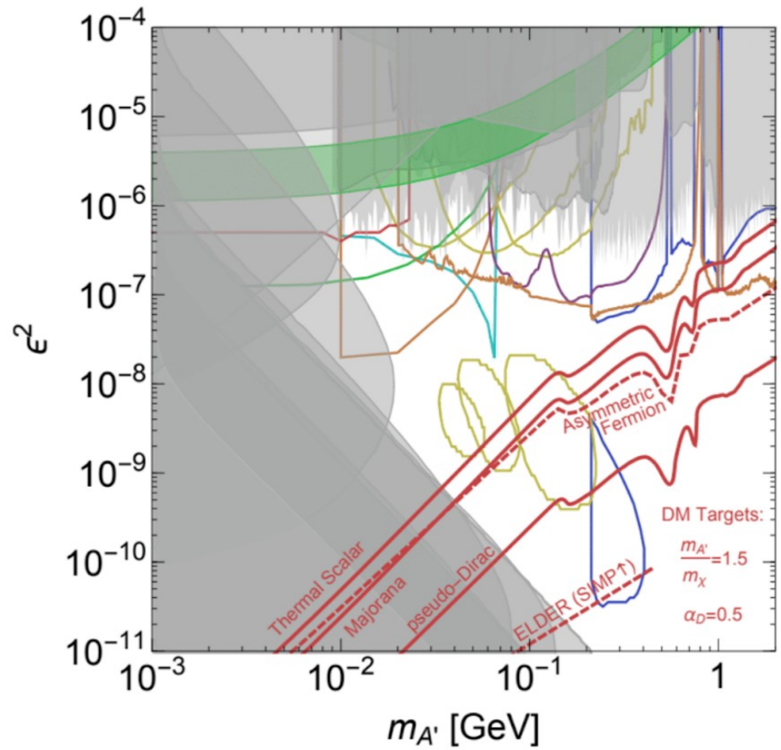
Resonance Search
(Bump Hunt)
High Coupling



Displaced Vertex
+ Bump Hunt
Low Coupling



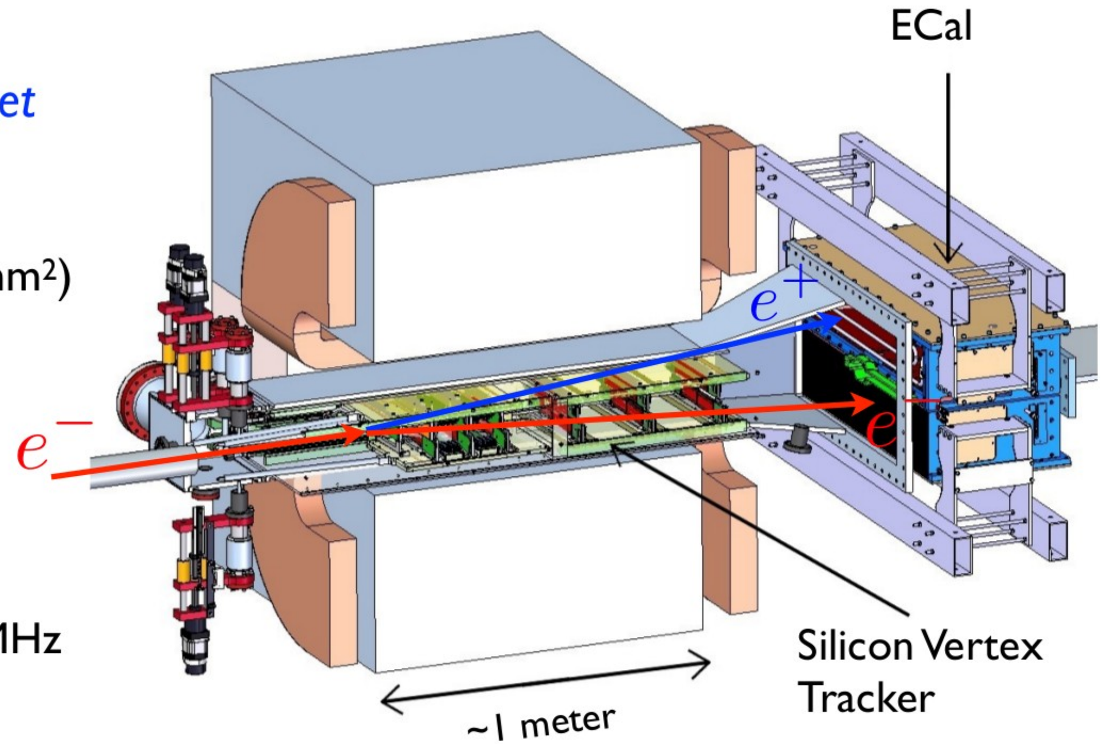


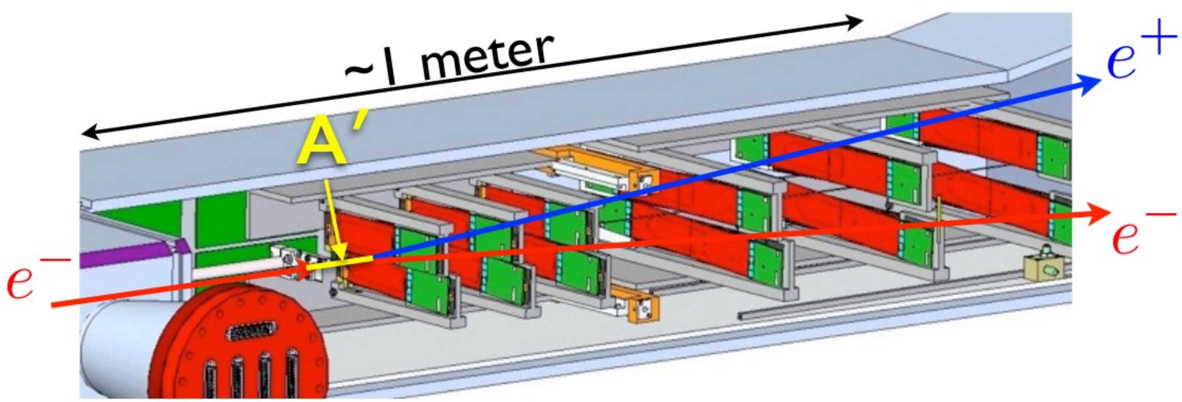


The HPS Apparatus @ JLab CEBAF

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 ~10^7
- $PbWO_4$ ECal trigger eliminates 10's MHz scattered single e^-



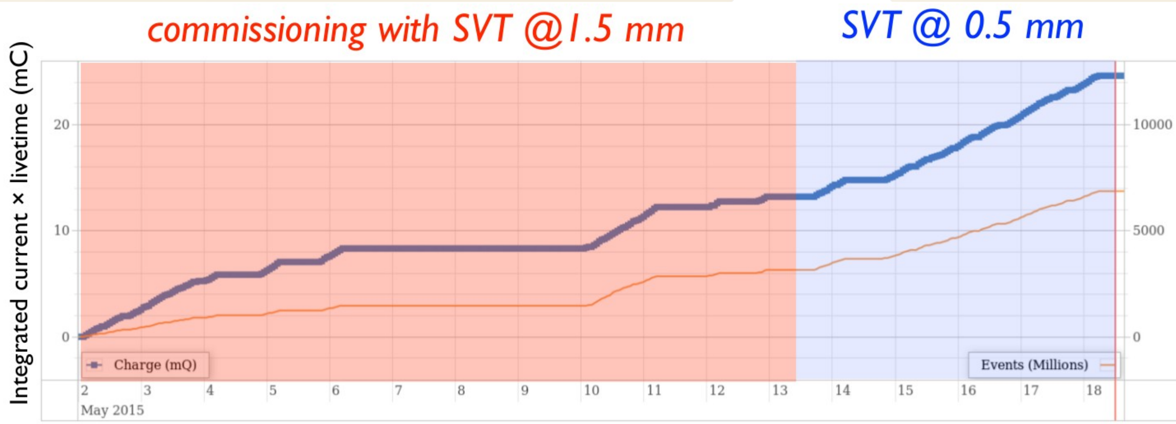


Engineering Runs

2015 Engineering Run

50 nA @ 1.06 GeV

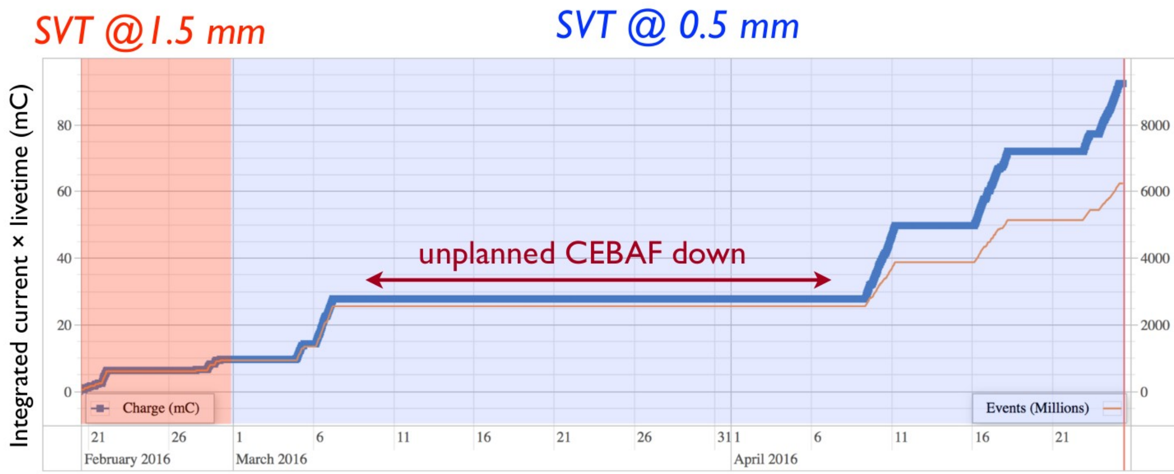
1.7 days (10 mC) of physics data



2016 Engineering Run

200 nA @ 2.3 GeV

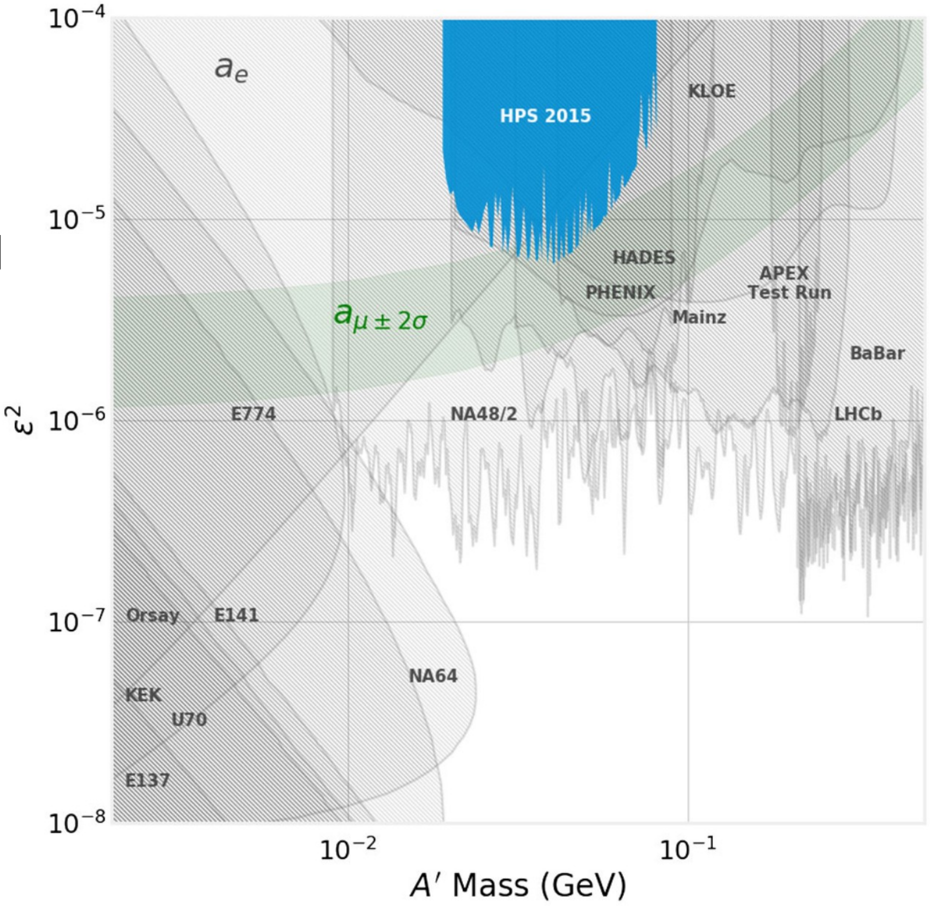
5.4 days (92.5 mC) of physics data



- 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

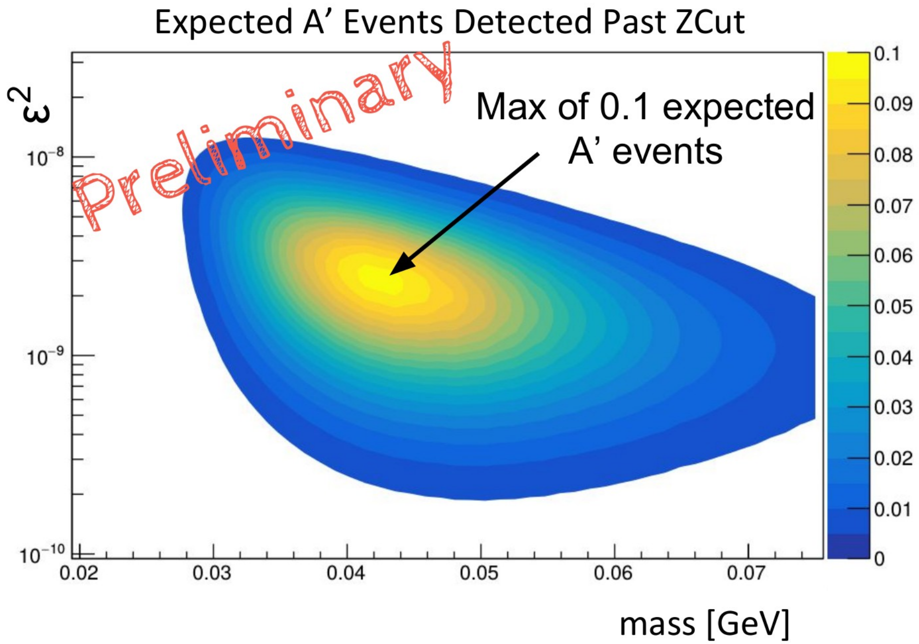
- Mass resolution measured in data using Møllers
- Tridents used to calibrate the expected signal rate
- 7th order Chebyshev polynomial used for background shape
- Likelihood ratio used to quantify significance of any excess
    - No signal observed
    - Invert likelihood ratio to determine 2σ upper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

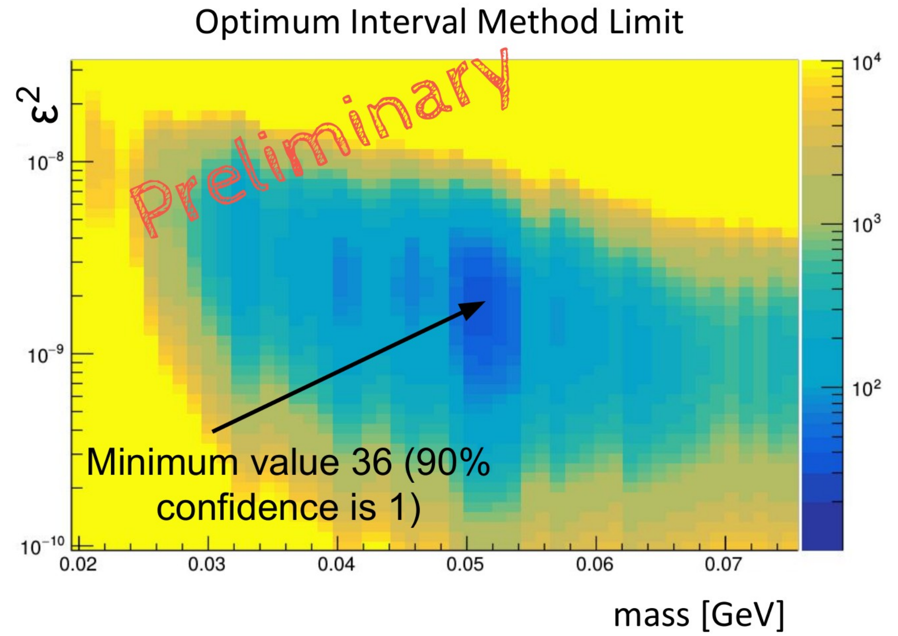


Displaced Vertex Search Preliminary Results

- 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



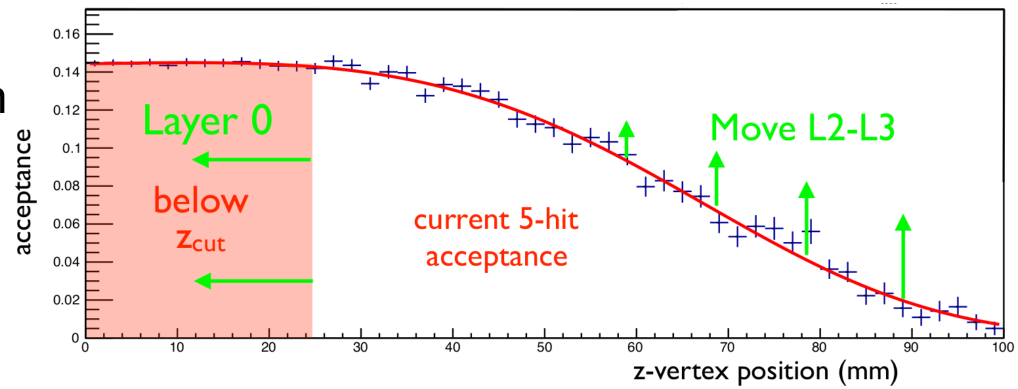


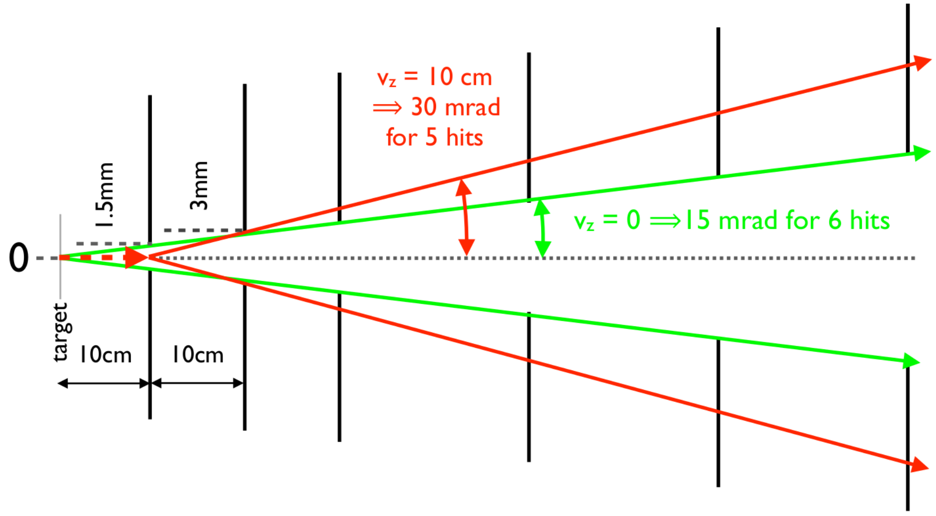
More detail in talk by Matthew Solt at APS April Meeting 2019

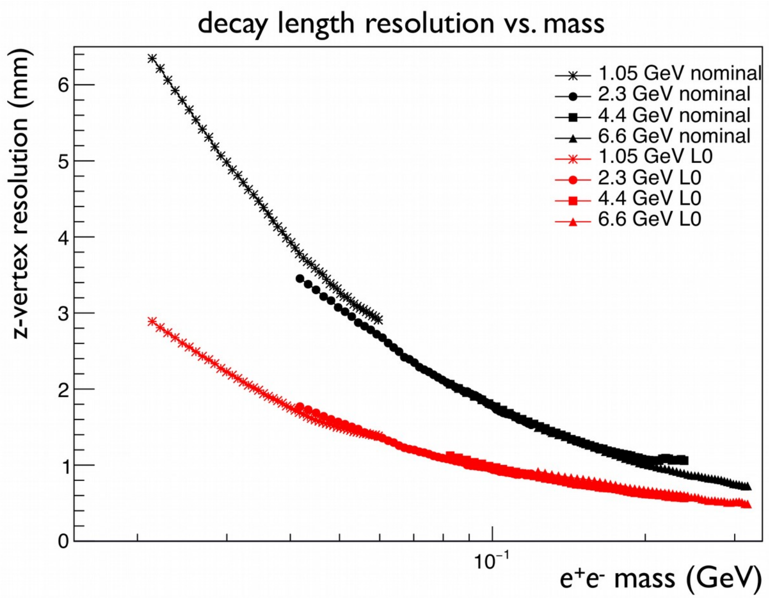
Not enough luminosity to be sensitive, longer run happening now!

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

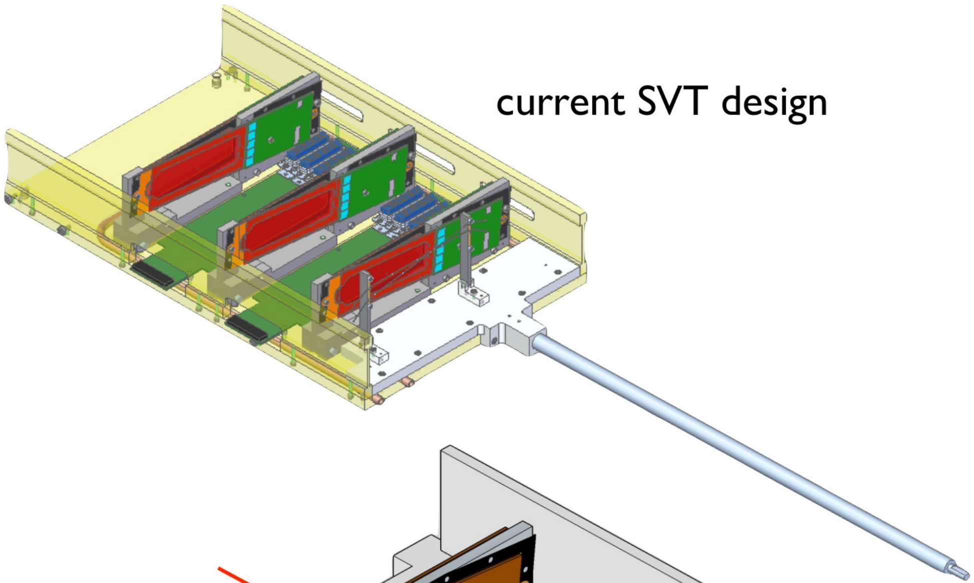


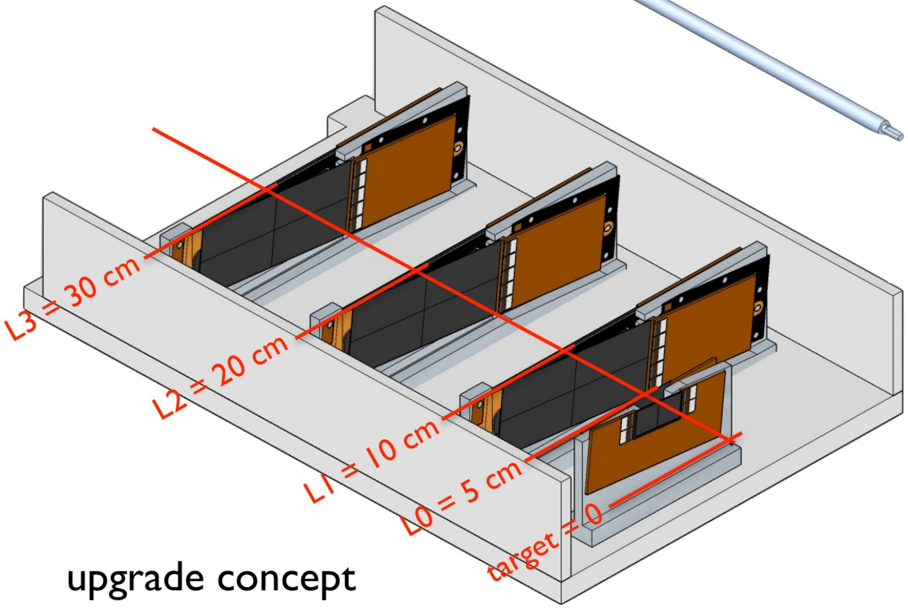




SVT Upgrade Concept

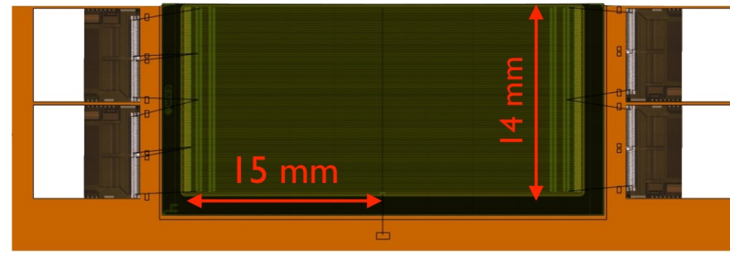
- Layer 0 is similar in concept to other layers
    - Closer to target, 5 cm vs. 10 cm for L1
    - ~Half the material (0.4 % X_0)
    - Same acceptance requires being proportionally closer to the beam
- Moving L2 and L3 closer by about 700 microns is as simple as adding shims under the modules

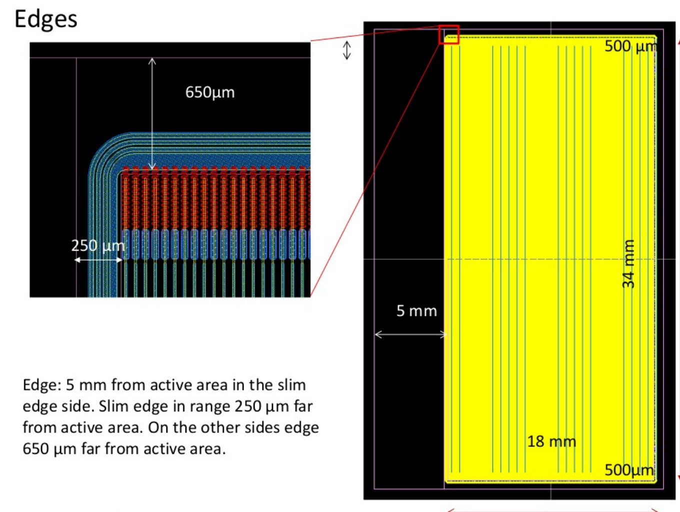


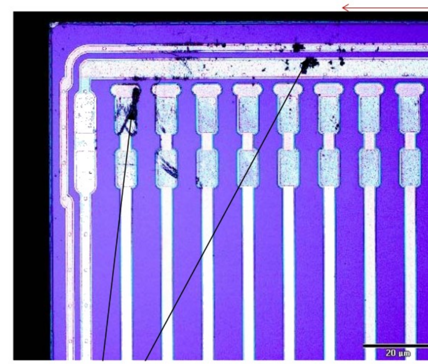


Layer 0 Sensor Design

- 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

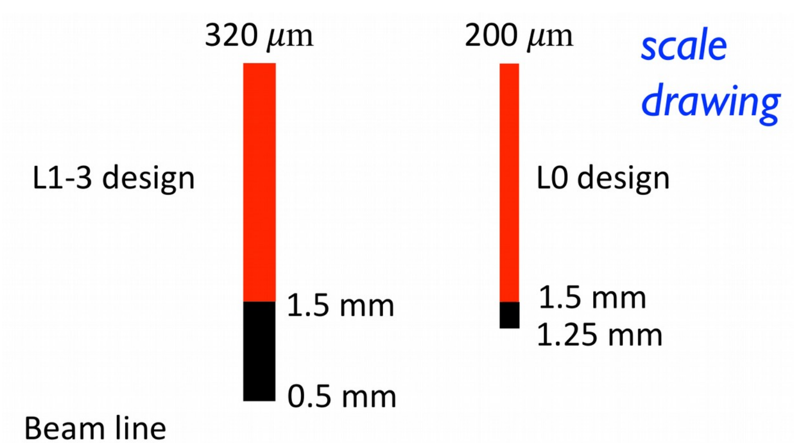


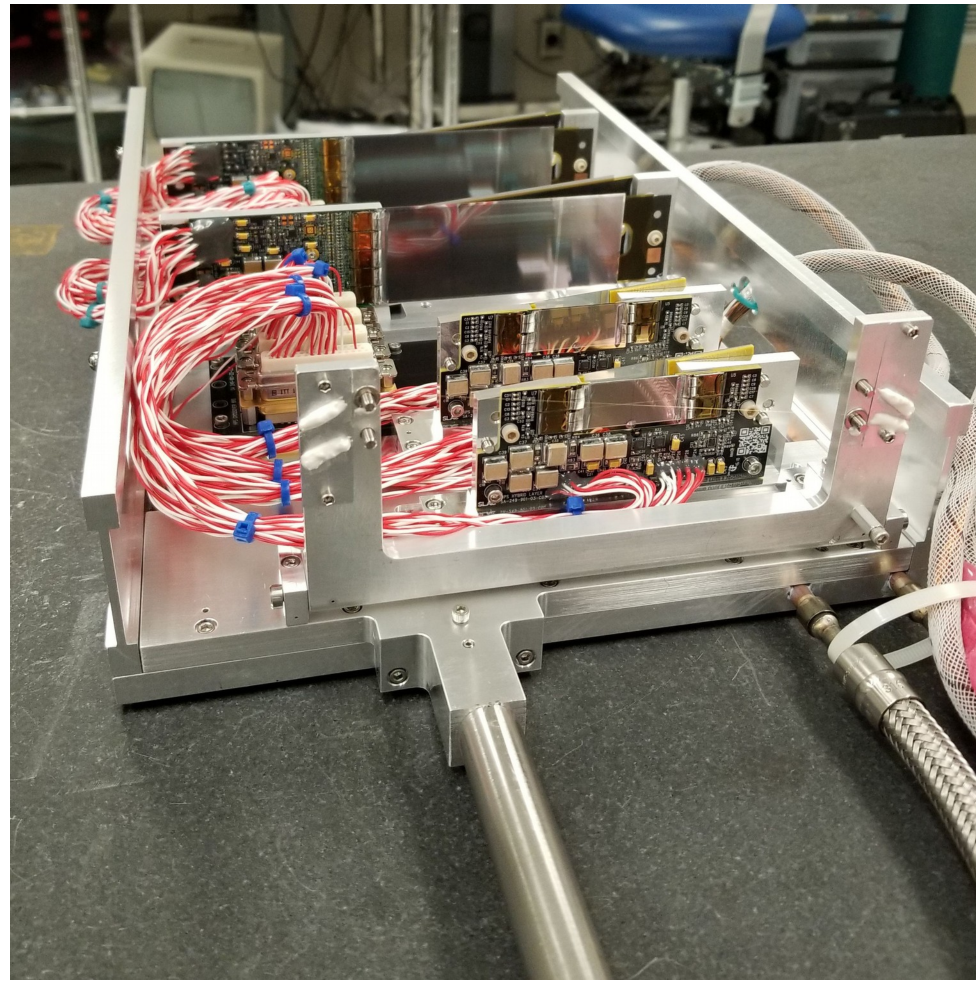




SVT Upgrade Production

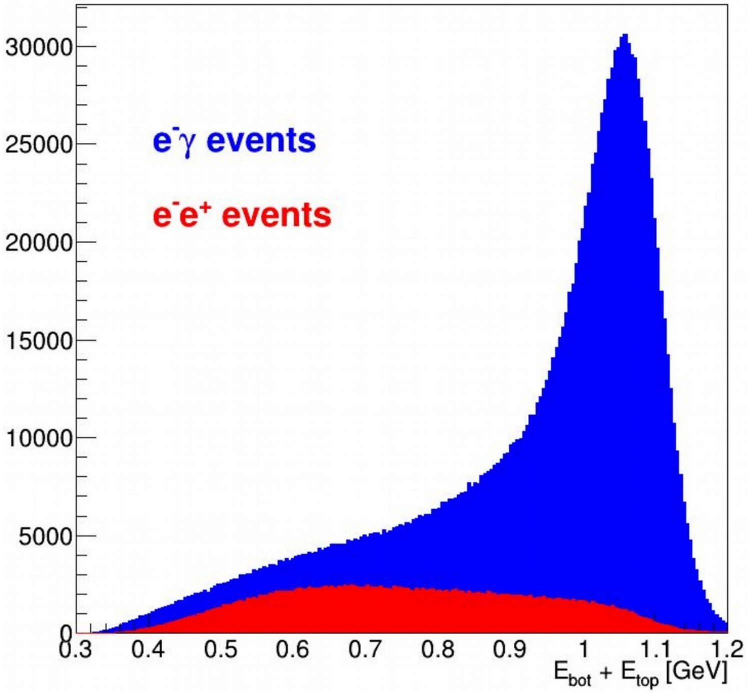
- Production of Layer 0 modules was successful!
- Produced enough to replace L1 with new modules as well
- Inactive Si in L1 creates some difficult backgrounds
  - Conversion of wide-angle brems
  - Tridents from scattered e^-

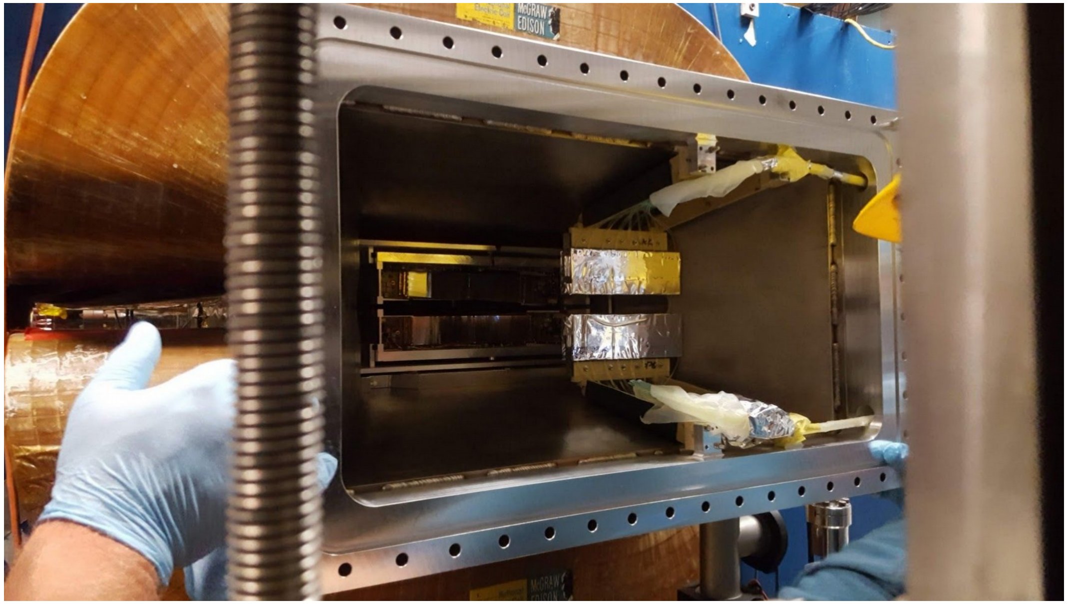




Hodoscope Upgrade

- 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

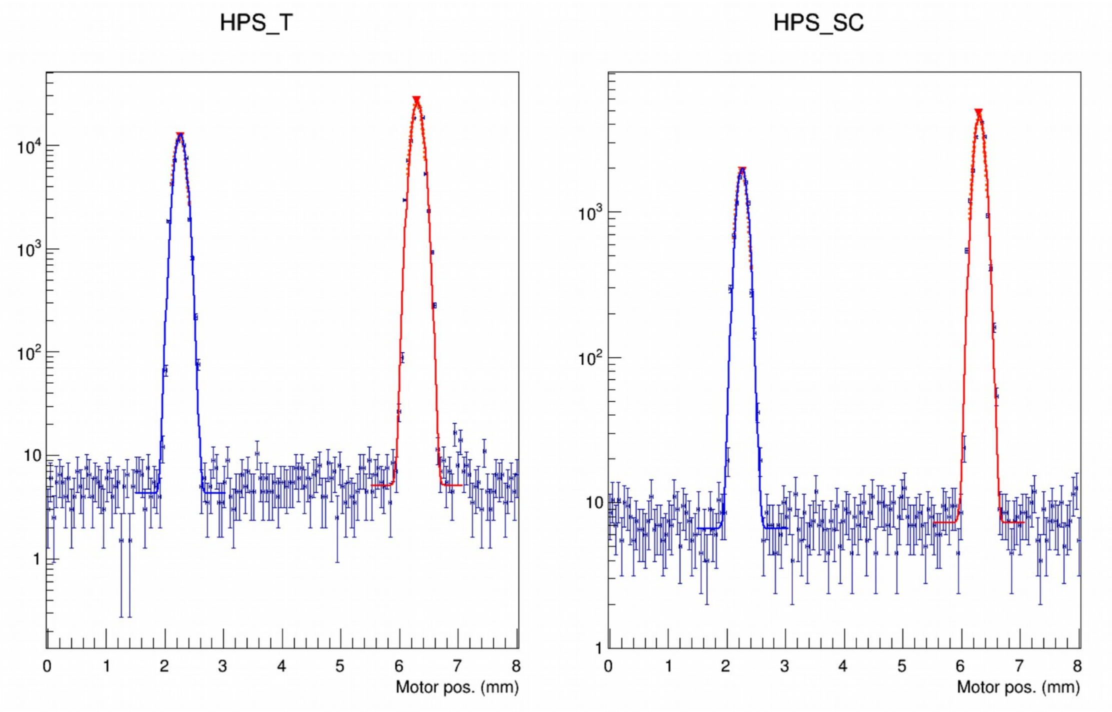




Built, installed, and commissioned in time for running in summer 2019!

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



Analyze from HPS_t counter

top_mot_pos1 = 2.259 mm
top_mot_pos2 = 6.301 mm
top_wire_dist = 1.946 mm
top_beam_Y = -0.036 mm
top_beam_X = -0.023 mm
top_beam_σ_Y = 0.0416 mm

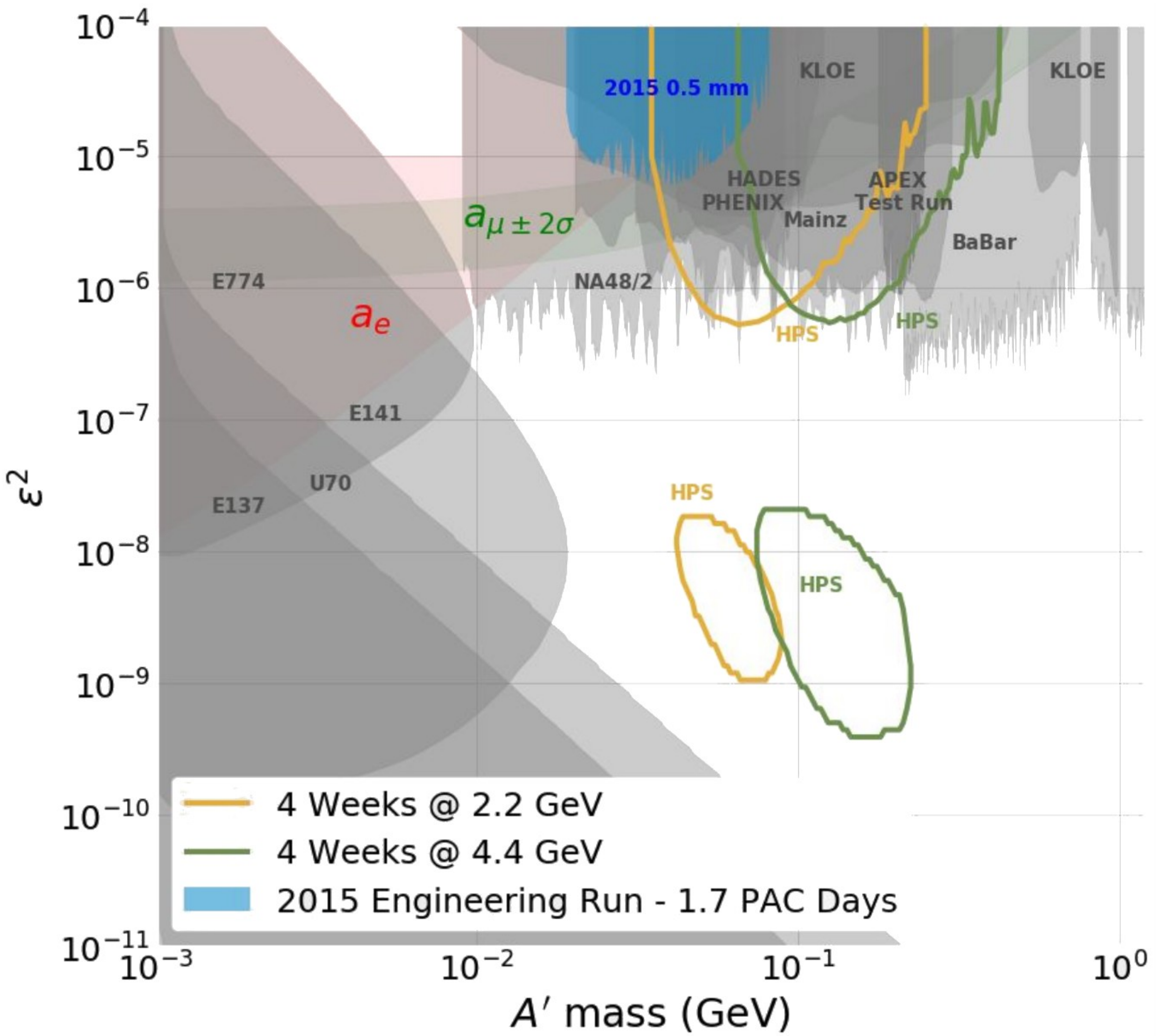
top_mot_pos1 = 2.255 mm
top_mot_pos2 = 6.300 mm
top_wire_dist = 1.948 mm
top_beam_Y = -0.035 mm
top_beam_X = -0.015 mm
top_beam_σ_Y = 0.0437 mm

Analyze from HPS_SC counter

top_mot_pos1 = 2.256 mm
top_mot_pos2 = 6.301 mm
top_wire_dist = 1.948 mm
top_beam_Y = -0.035 mm
top_beam_X = -0.015 mm
top_beam_σ_Y = 0.0424 mm

top_mot_pos1 = 2.254 mm
top_mot_pos2 = 6.300 mm
top_wire_dist = 1.949 mm
top_beam_Y = -0.034 mm
top_beam_X = -0.007 mm
top_beam_σ_Y = 0.0433 mm

Projected 2019 Reach



We are currently running at 4.5 GeV

4.4 GeV is for 300 nA and 8 μm W target

2.2 GeV is for 200 nA and 4 μm W target

Conclusions

SLAC

- 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 you attention!