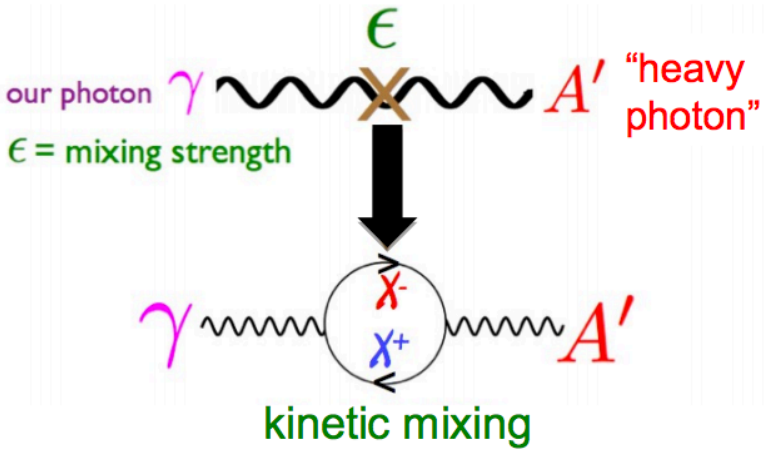
HPS Update

N. Baltzell
On behalf of the Heavy Photon Search Collaboration
March 29, 2017
CLAS Collaboration Meeting

Motivation

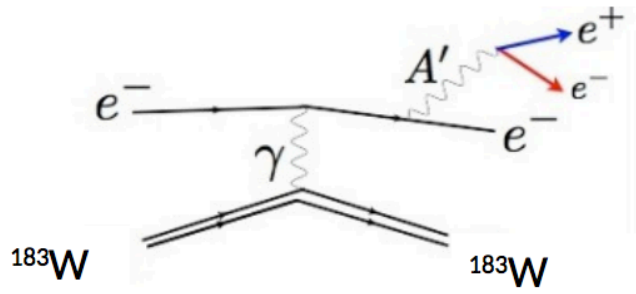
Additional U(1) symmetry in nature
-> new gauge boson! Holdom, Phys. Lett. B166, 1986



kinetic mixing

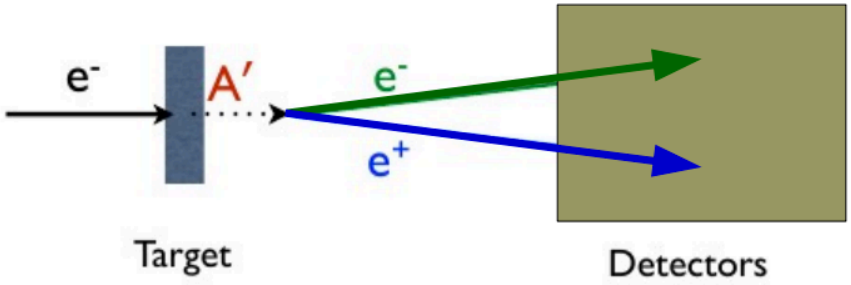
Kinetic mixing could be the leading interaction between the Standard Model and Dark Sector!

Experimental Signature



$e^- + {}^{183}W \rightarrow A' + X \rightarrow e^+ + e^- + X$

$A' \rightarrow$ Standard Model particles

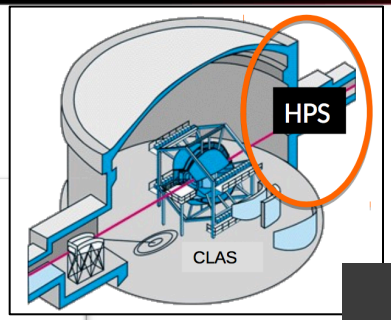


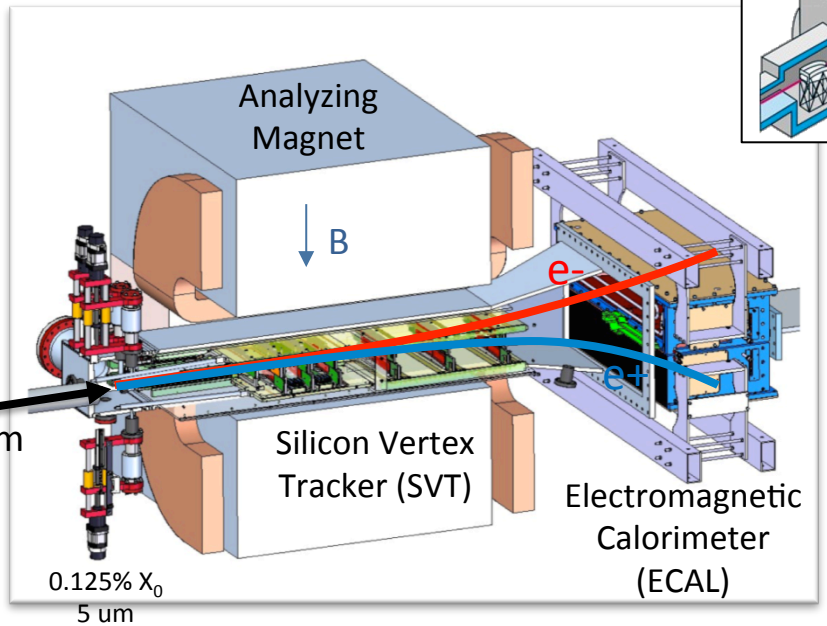
Heavy Photon?

Standard Model		Dark Sector
g $W^{\pm}, Z$ γ	⟷	forces + particles dark matter?

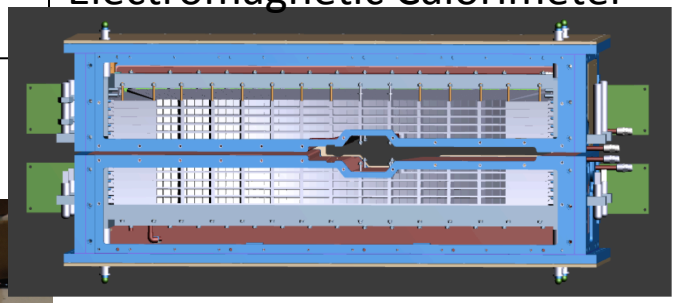
Experimental Setup

Heavy Photon Search in Hall-B at Jefferson Lab

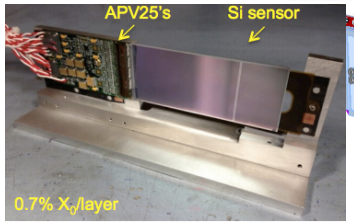




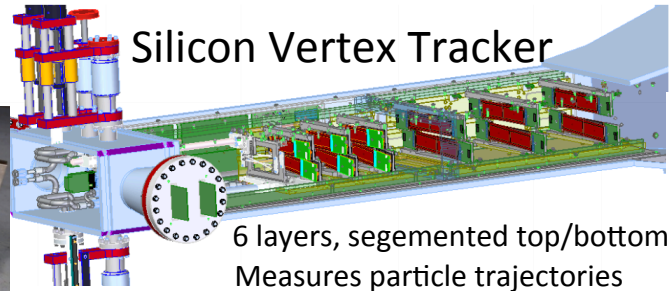
Electromagnetic Calorimeter



- 442 $PbWO_4$ Crystals
- Gap for "sheet of flame"
- HPS Trigger
- Measures particle energy ~4%/√E



Silicon Vertex Tracker

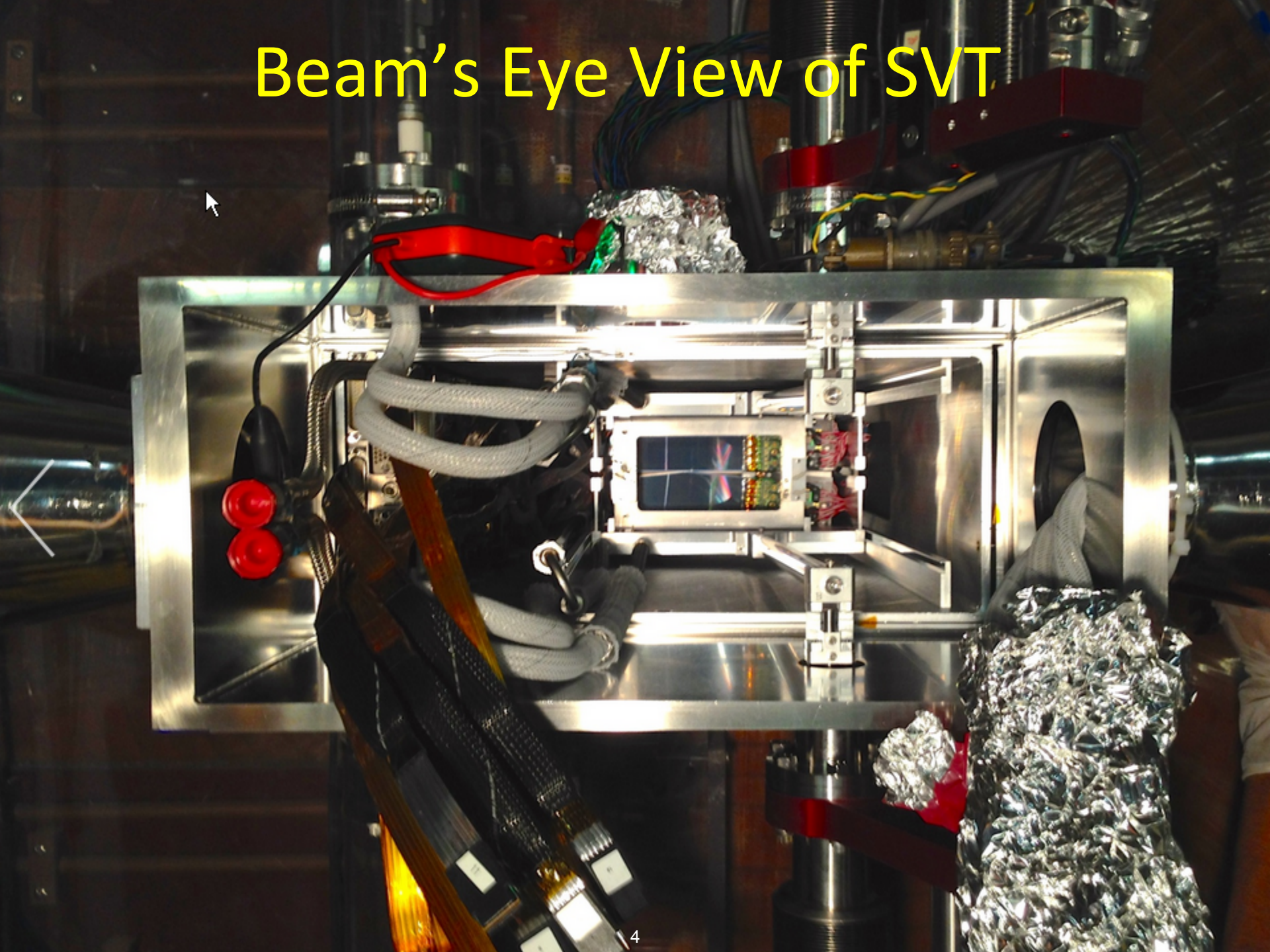


6 layers, segemented top/bottom
Measures particle trajectories
-Momentum, q, vertex

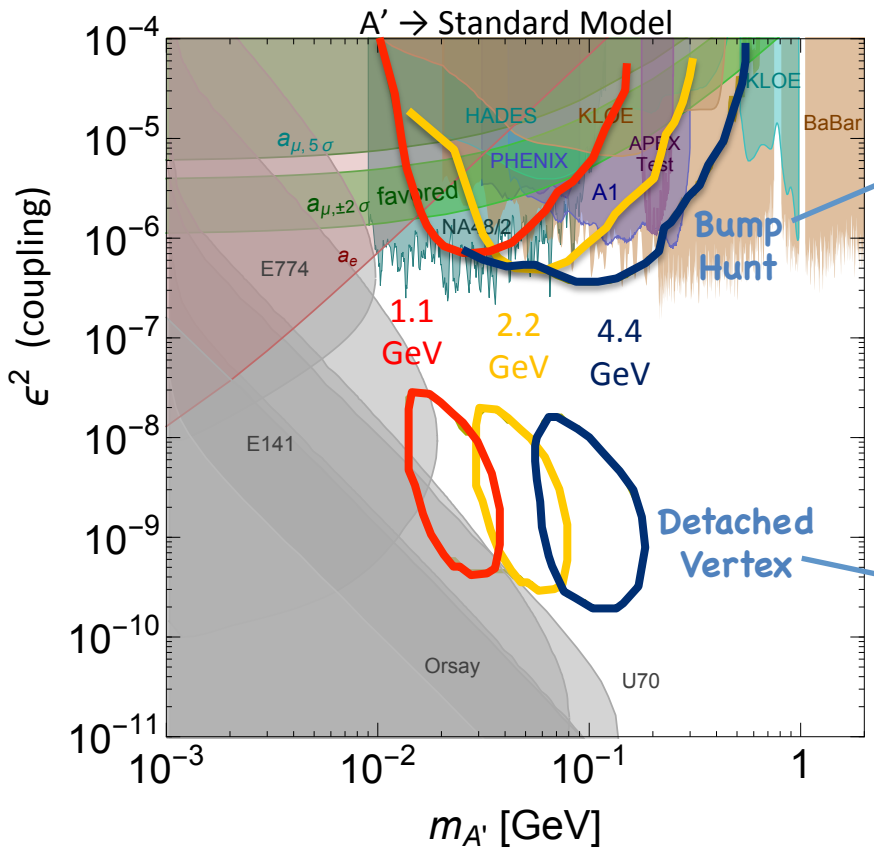
SVT active area 0.5 mm from beam!

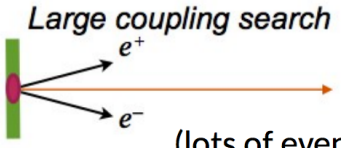
Layer	1	2	3	4	5	6
z position from target [cm]	10	20	30	50	70	90
Stereo angle [mrad]	100	100	100	50	50	50
Non-bend plane resolution [μm]	≈ 6	≈ 6	≈ 6	≈ 6	≈ 6	≈ 6
Bend-plane resolution [μm]	≈ 60	≈ 60	≈ 60	≈ 120	≈ 120	≈ 120

Beam's Eye View of SVT



HPS Proposed Reach



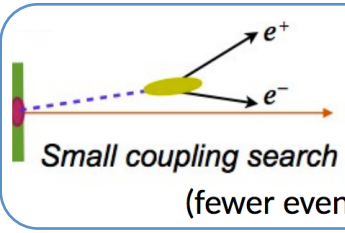


→ Requires good mass resolution

HPS Approved for 180 Days

- Spring 2015 "Engineering" Run: nights & weekends
  - 1.05 GeV, 50 nA, ~1.7 days (SVT @ 0.5 mm)
- Spring 2016 Run: weekends only
  - 2.3 GeV, 200 nA, ~5.2 days

Need more time to achieve the proposed reach



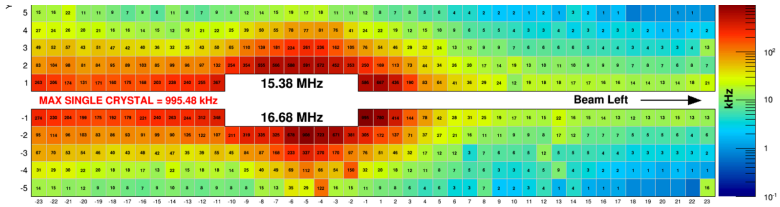
→ Requires good vertex resolution and high luminosity

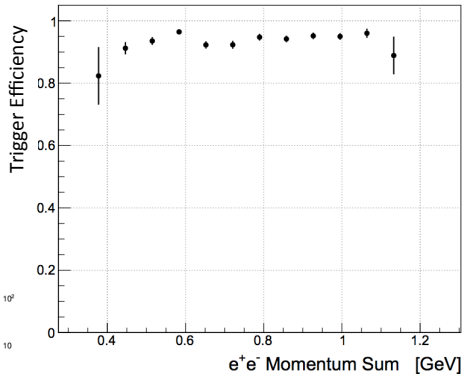
Engineering Runs – Performance (1)

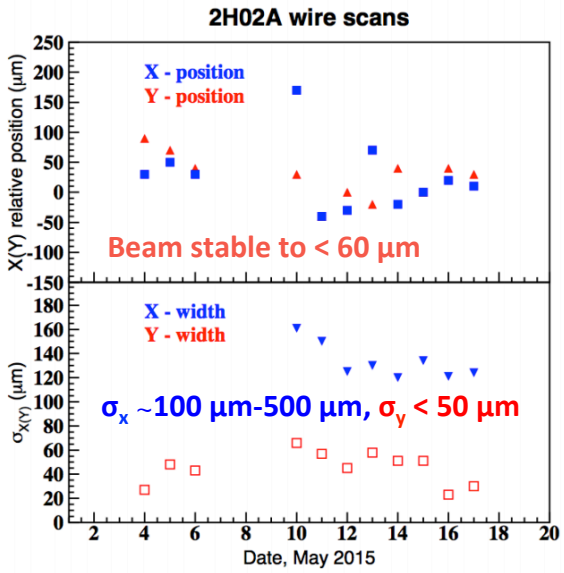
- Beamline
  - Beam profile & stability requirements met
  - Tested FSD for SVT protection
  - Calorimeter rates as simulated, < 1 MHz

See HPS beamline NIM - arXiv:1612.07821

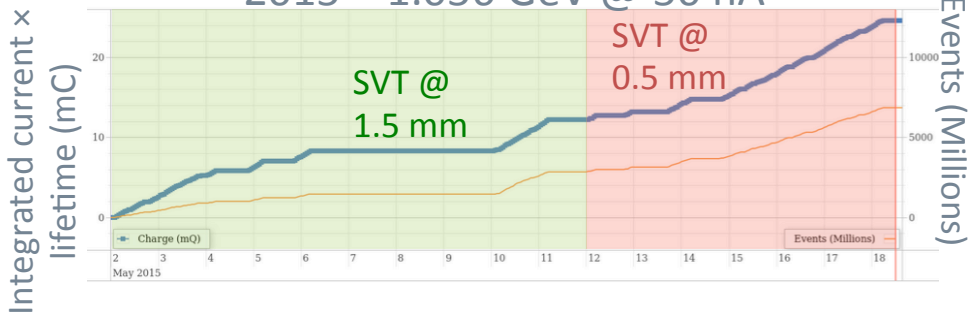
- Trigger/DAQ
  - Livetime > 85%
  - Trigger rate ~20 kHz
  - Trigger efficiency >> 90%



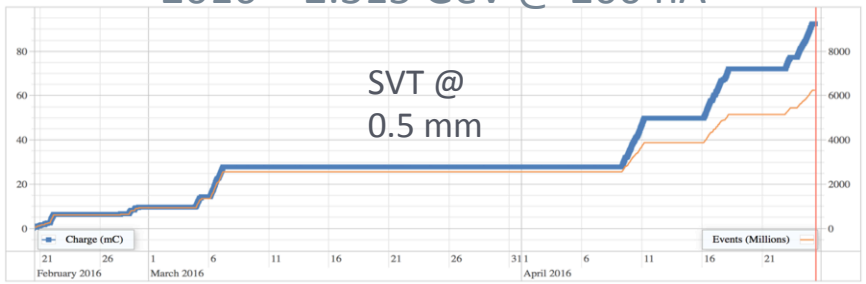




2015 – 1.056 GeV @ 50 nA



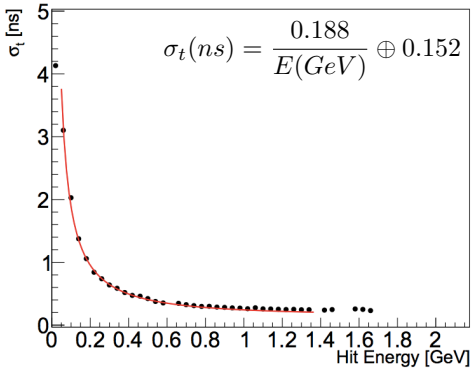
2016 – 2.315 GeV @ 200 nA

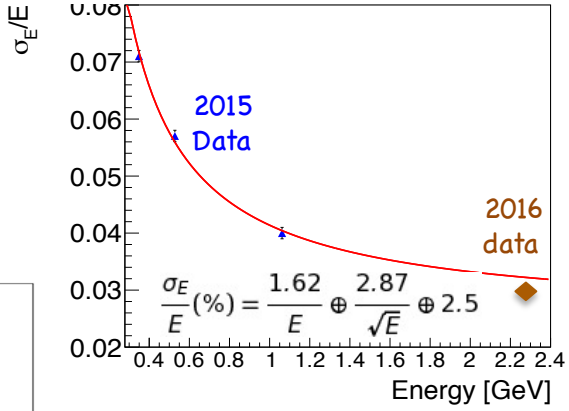


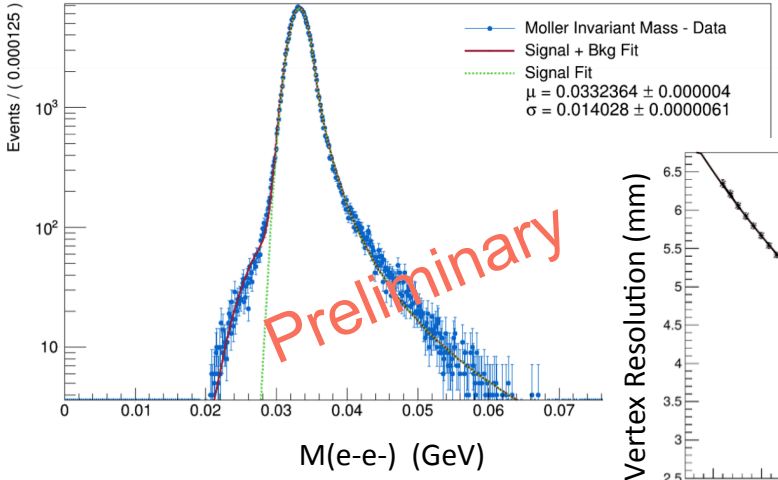
Engineering Runs – Performance (2)

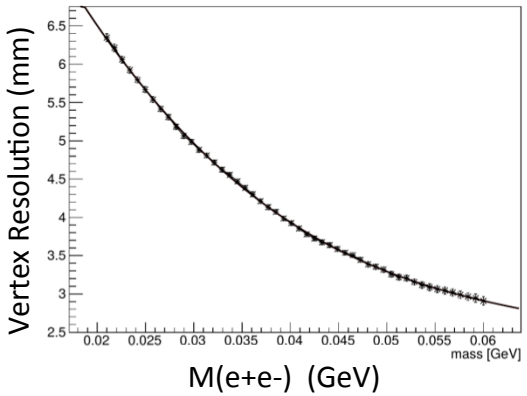
- ECAL
  - good energy/time resolution
    - 2-cluster time coincidence leaves <1% accidentals
  - efficiency measured ~100%
- SVT
  - occupancy < 1%
  - momentum resolution ~7%
  - mass resolution within 10% of simulation
    - Moller M(e^-e^-) used as benchmark
  - vertex resolution as expected
  - L1 hit efficiency >95%
  - small tracking efficiency loss at low-p, accounted for

See HPS ECAL NIM – arXiv:1610.04319





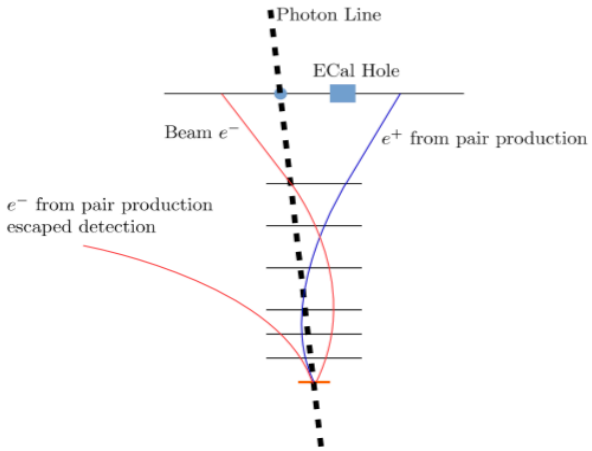




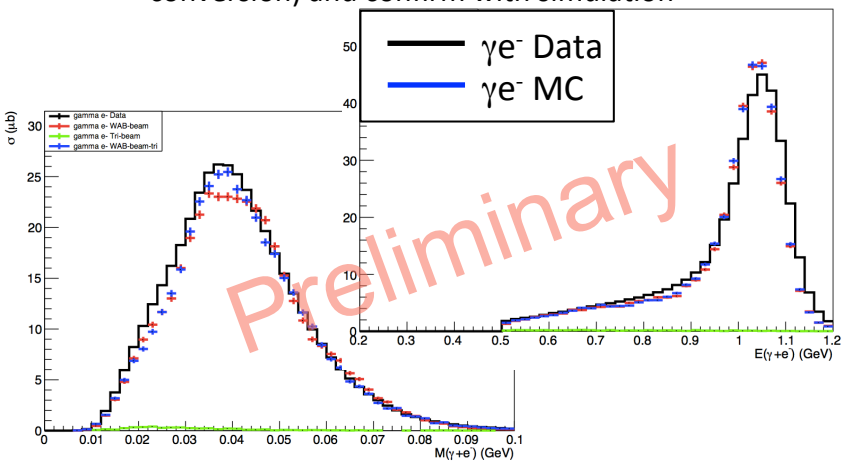
“Wide Angle” Bremssthrahlung Background

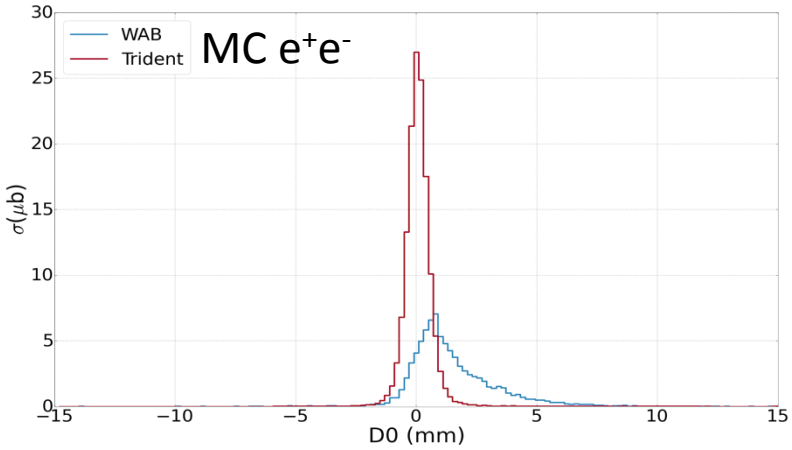
- A previously underestimated background
  - Bremsstrahlung in egs5 has approximate scattered electron kinematics (θ=0!)
    - artifically keeping this e^- out of HPS acceptance
  - After analyzing the data, we moved to a realistic generator for wide angle Bremsstrahlung, confirming this “new” background in our data

- Converted Bremsstrahlung in our e^+e^- sample
  - only relevant when scattered e^- detected
  - beamline x-DOCA and P_t asymmetry are decent discriminators against real tridents
  - requiring e^+ L1 hit – removes ~70% of conversions in L1
  - → Achieve ~80% WAB rejection
    - optimized against signal loss for A’ reach



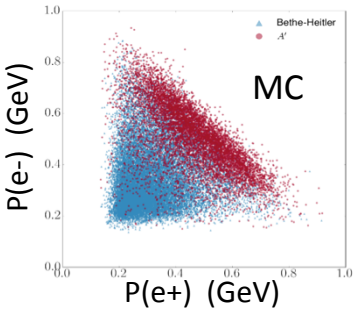
We also measure WAB directly (γe^-, no conversion) and confirm with simulation

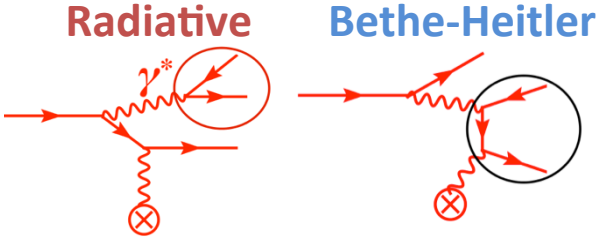




e^+e^- Trident "Background"

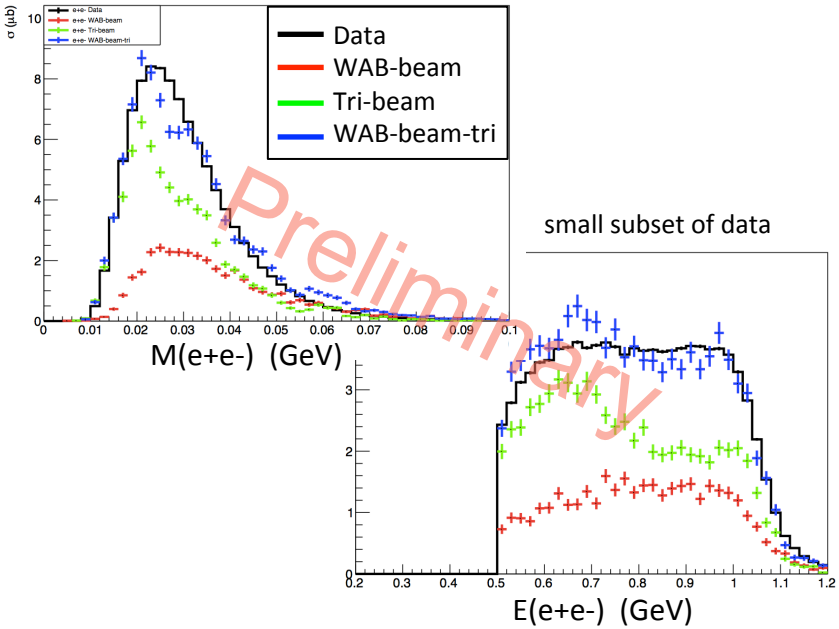
- Bethe-Heitler dominates at low energy
- Radiatives are kinematically identically to A'
  - except, of course, fixed mass / detached vertex
  - and used to understand expected A' rates / reach





- Madgraph4/5
  - For NLO full interference trident pair production
  - First look at data showed issues at low E(e+e-) vs MG4
  - We found significant shape difference between MG4 and MG5
    - MG4/5 agree at highest energy, but diverge towards low energy, and HPS covers the full range
    - Confirmed MG5 against independent calculations (i.e. Beranek's)
  - Default α factor in Madgraph was set to its running value at the Z_0 pole!
    - → 33% (15%) inflation of Trident (Bremsstrahlung)

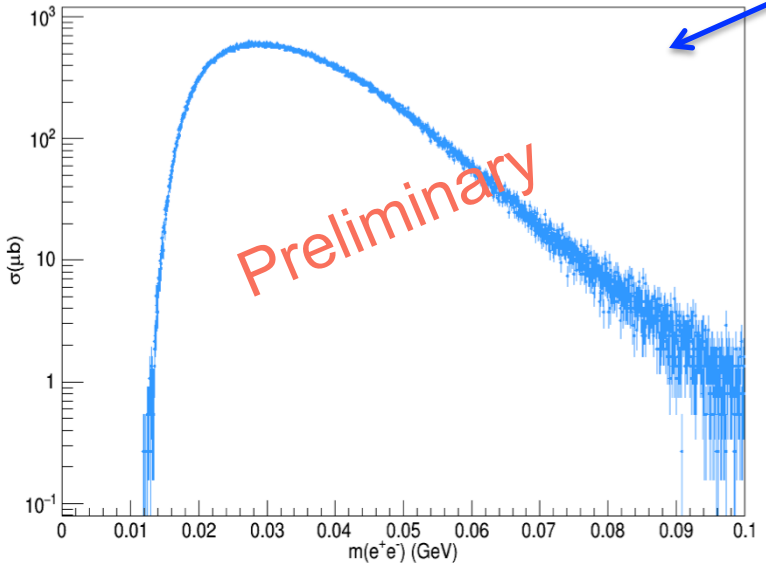
- Projected reach in proposal suffered from errors in simplified acceptance calculations
  - overestimate of small angle acceptance
  - no z-vertex dependence, flat out to first Si layer



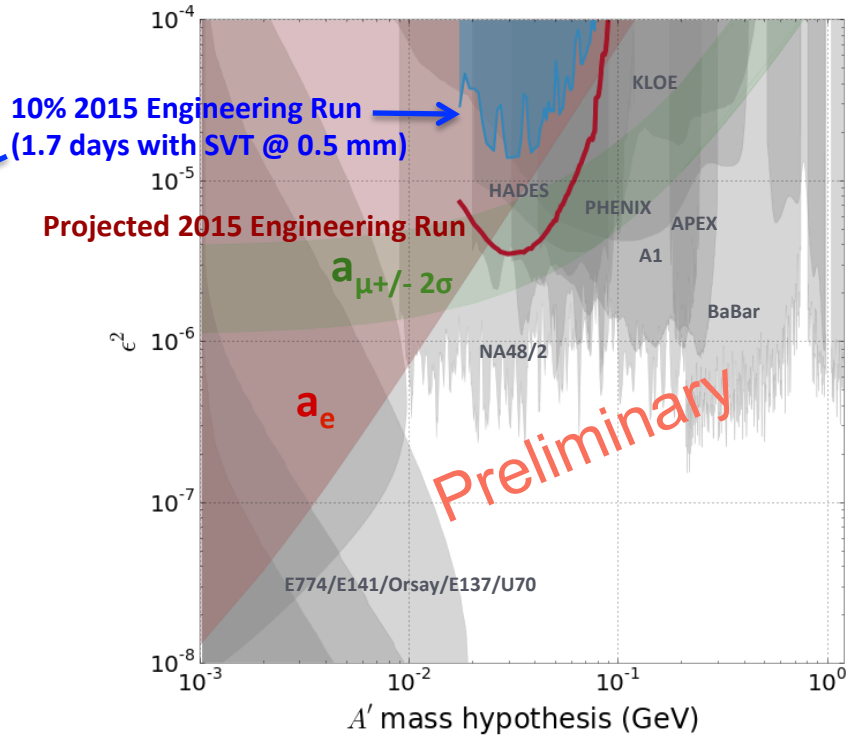
After sorting out the event generator issues, and correcting for low-momentum tracking ineffeciencies, our data lines up with MC to ~10%

2015 Bump Hunt Search

- Search for A' mass bump has been performed with rigorous statistical methods
  - Blinded on 10% of the data (shown)
  - Masses between 17 and 90 MeV
  - Use MC to tune the extraction method (bin sizes, polynomial order, fit window) by optimizing pulls and sensitivity
  - Account for "look-elsewhere effect" (via simulated global/local p-values) and use "power-constrainted" limit (cannot be stronger than expected sensetivity)



- No new territory is expected to be covered using the limited Engineering run data
- Review of the full result is underway and will be unblinded and released this Spring.



See O.Moreno's talk at Cosmic Visions workshop for details

2015 Vertexing Search

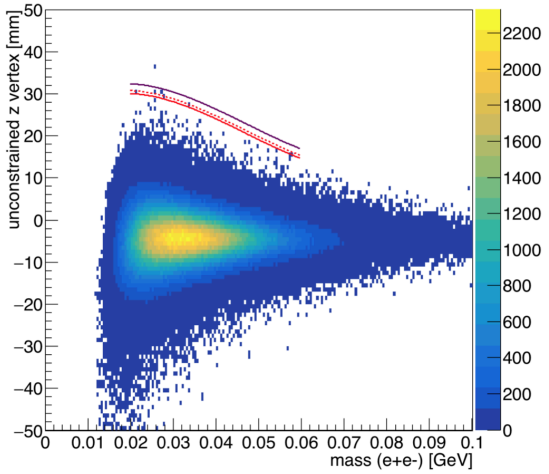
Requires understanding of vertex resolutions, tails, and elimination of any high-z backgrounds. Large efforts have

- nailed down the procedure and understanding of the data
- rejected high-z backgrounds
- quantified the HPS 2015 vertex reach
- including using tracks with missing 1st layer and SVT @ 1.5 mm to maximize reach
- Analysis note largely complete, in preparation for unblinding and release

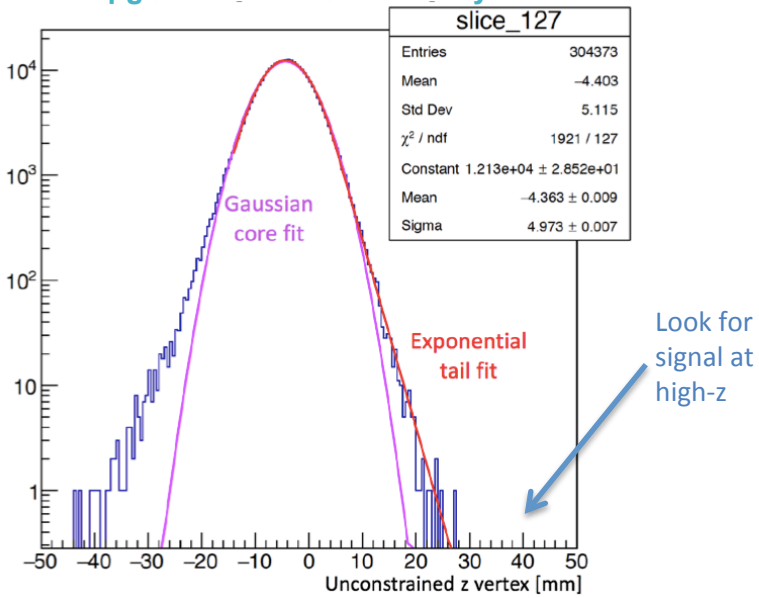
But reach is worse than we had projected

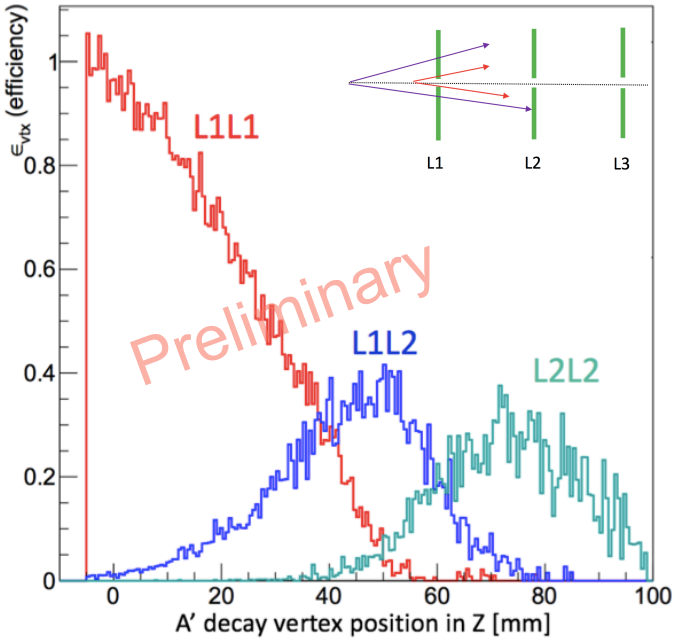
→ No vertex reach expected using 2015's 1.7 days of data

– again, contributions from proposal's overestimated acceptance and generator trident rates



Modest upgrades will allow recovery of reach for future runs (next slide)



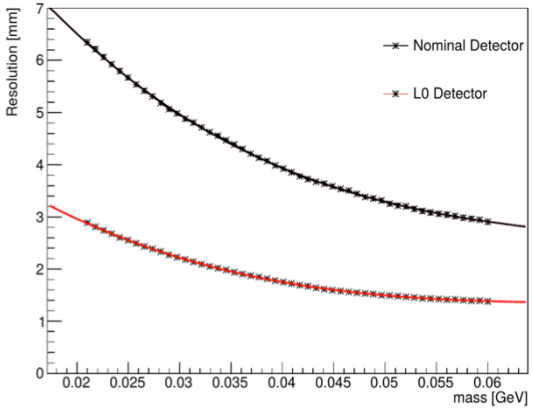


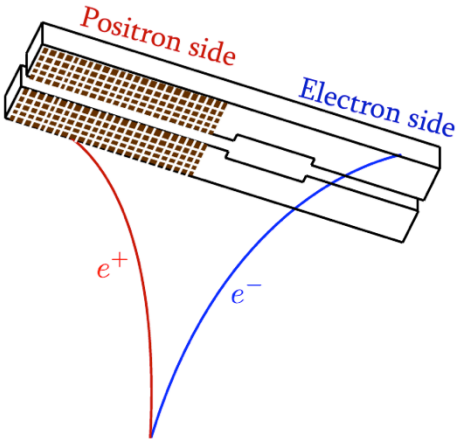
Holly Szumila-Vance (ODU)

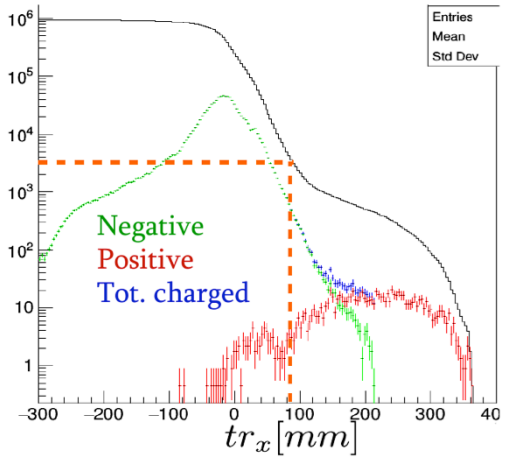
Potential Upgrades

Modest upgrades will allow expanded reach for future runs

- The layers of the SVT can easily be moved closer to the beam
  → Increase acceptance
- Add an additional thin layer (L0) to the SVT at 5 cm
  → Improve vertex resolution and vertex efficiency
- Implement a positron only trigger – simulations in progress
  → Will allow recovery of some of the proposed reach lost due to the ECal hole.







Summary / Outlook

- Successful HPS Engineering Runs in 2015 and 2016
  - Experimental performance excellent and fully validated to be within design
    - Beamline, Trigger, DAQ, ECAL, SVT
    - Effecincies and resolutions all measured and confirmed
  - Additional source of background (wide angle Bremsstrahlung) identified and mitigated
  - HPS is fully approved for 180 PAC days (15 already used)
  - Expecting a longer run in summer 2018
  - Modest upgrades in development to extend reach

- Several Analyses are ongoing
  - 2015 Bump hunt analysis is currently under review and will be unblinded very soon
  - 2015 Vertexing analysis following shortly
  - 2016 (2 GeV) analyses in progress -- calibrations being finalized followed by full reconstruction pass

- 2 PhD theses complete, 3rd expected this year
  - S. Uemura (Stanford), O. Moreno (UCSC), H. Szumila-Vance (ODU)
- NIM papers published / in progress
  - Calorimeter and Beamline accepted
    - arXiv: 1610.04319 and 1612.07821
  - SVT in progress