HPS Update

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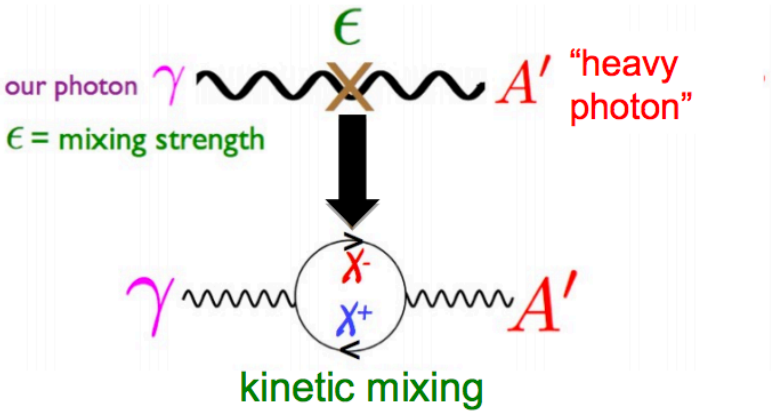
On behalf of the Heavy Photon Search Collaboration
June 14, 2017
CLAS Collaboration Meeting

Motivation

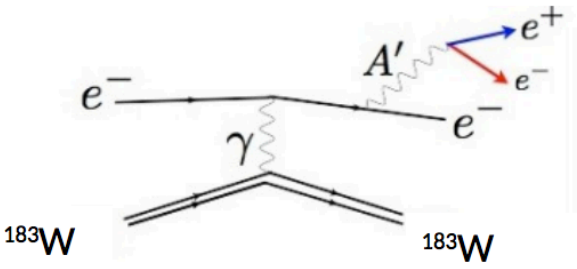
Large amounts of Dark Matter is the only existing coherent explanation for world's cosmological evidence …

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



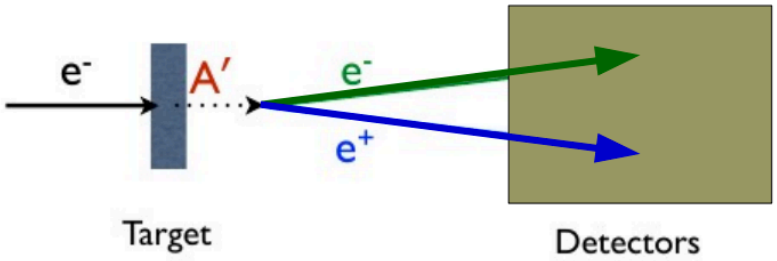
Kinetic mixing could be the leading interaction between the Standard Model and Dark Sector!

Experimental Signature



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

A' → Standard Model particles



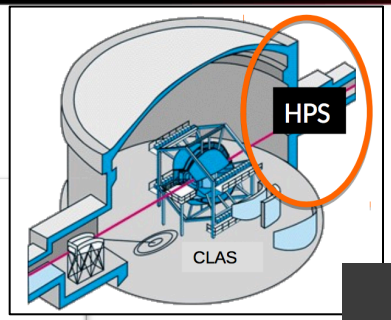
"Visible" Decay

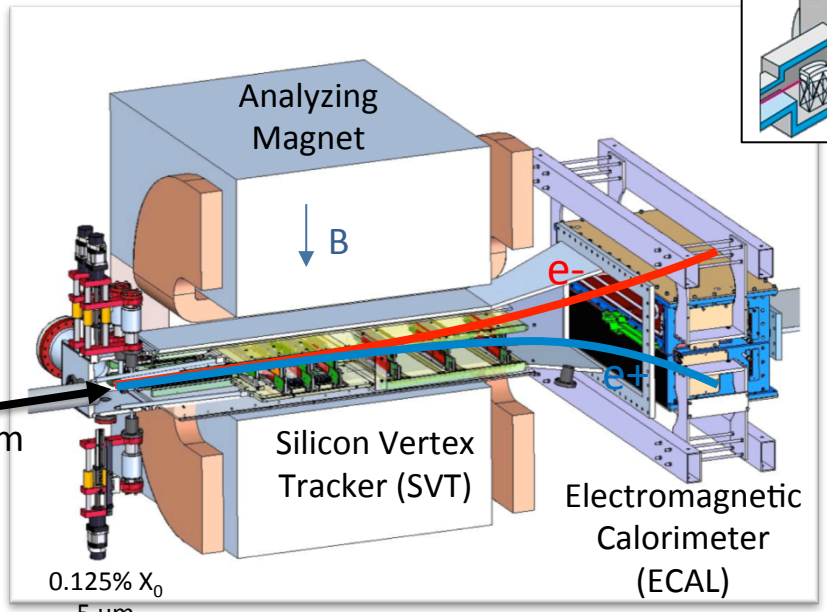
Heavy Photon?

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

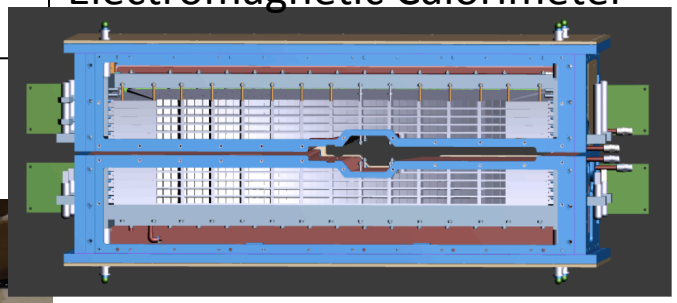
Experimental Setup

Heavy Photon Search in Hall-B at Jefferson Lab

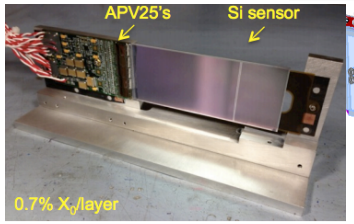




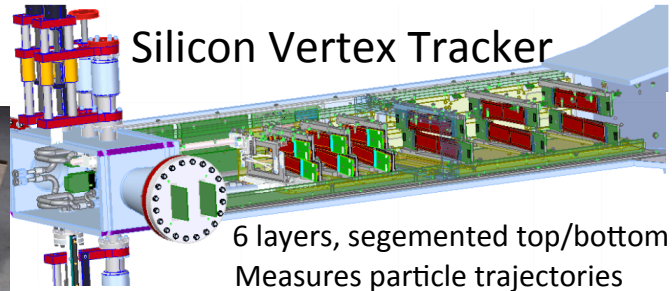
Electromagnetic Calorimeter



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



Silicon Vertex Tracker

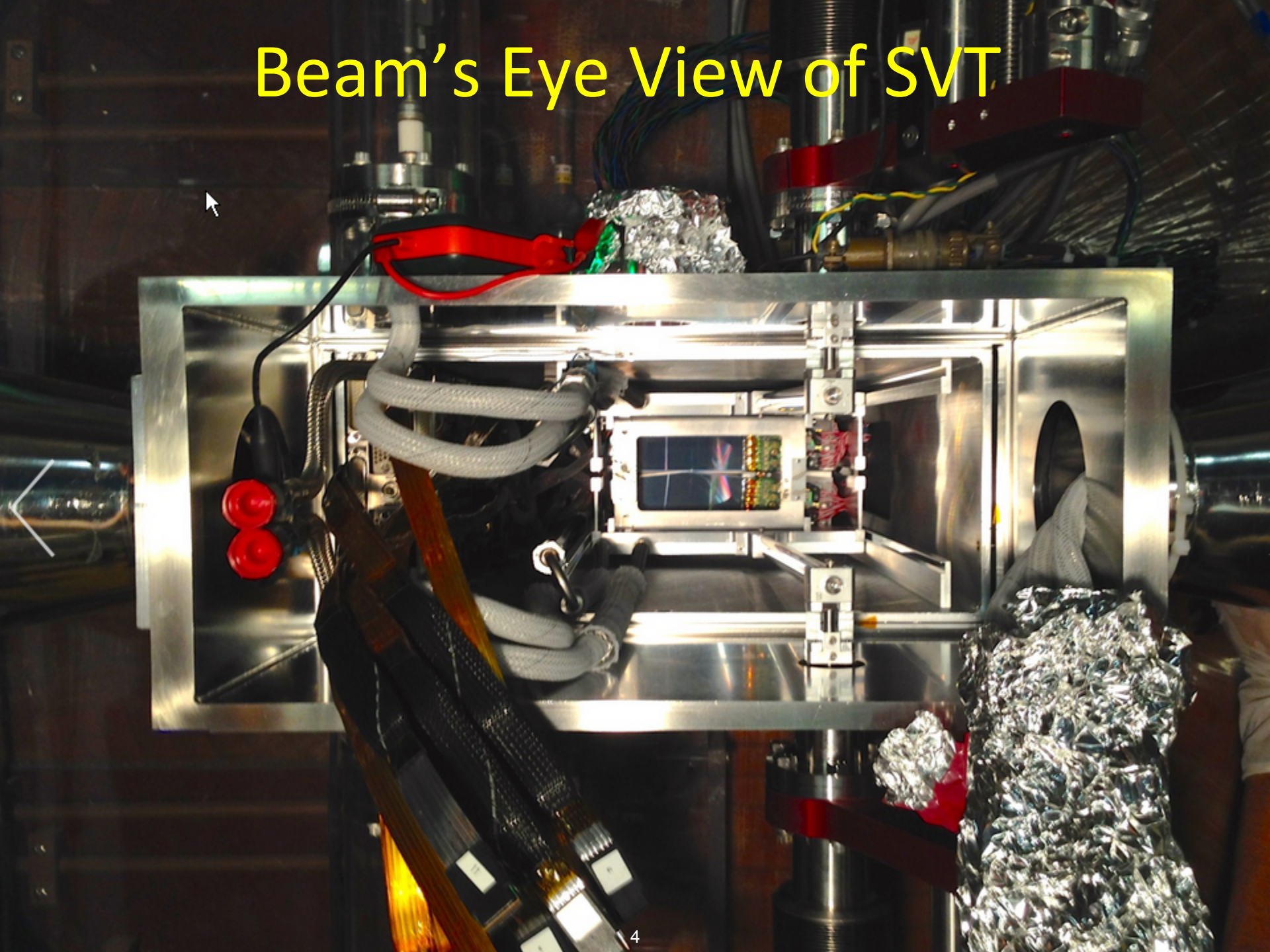


6 layers, segemented top/bottom
Measures particle trajectories
-Momentum, q, vertex

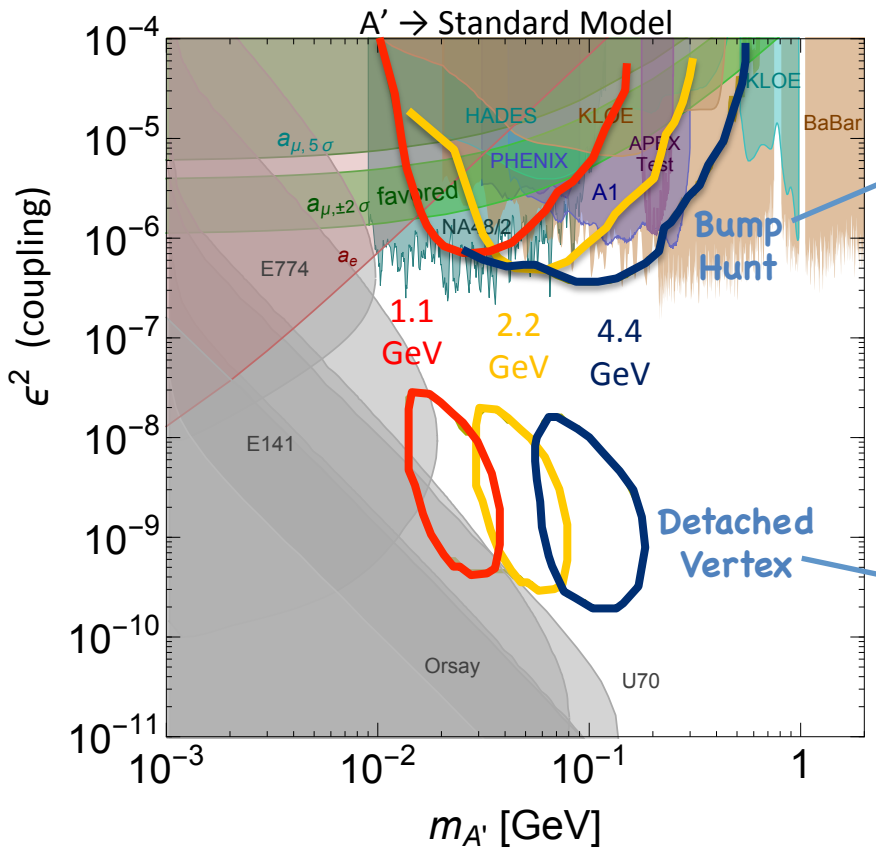
SVT active area 0.5 mm from beam!

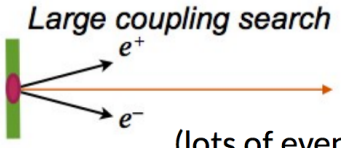
Layer	1	2	3	4	5	6
z position from target [cm]	10	20	30	50	70	90
Stereo angle [mrad]	100	100	100	50	50	50
Non-bend plane resolution [μm]	≈ 6	≈ 6	≈ 6	≈ 6	≈ 6	≈ 6
Bend-plane resolution [μm]	≈ 60	≈ 60	≈ 60	≈ 120	≈ 120	≈ 120

Beam's Eye View of SVT



HPS *Proposal* Reach



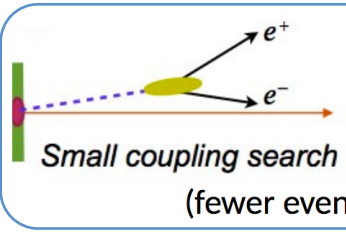


→ Requires good mass resolution

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



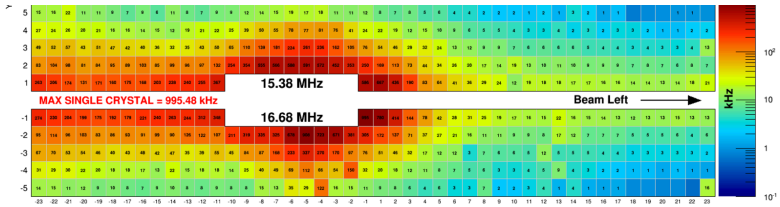
→ Requires good vertex resolution and high luminosity

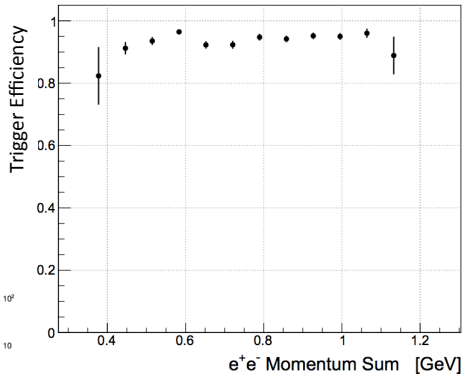
Engineering Runs – Performance (1)

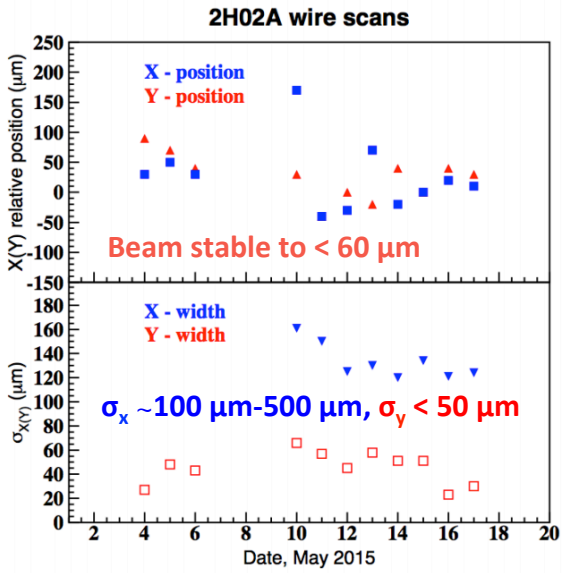
- All “opportunistic” running, nights and weekends only
- Beamline
  - Beam profile, stability, halo requirements met
  - Fast Shut Down tested & verified, for SVT protection
  - Calorimeter rates as simulated, < 1 MHz

See HPS beamline NIM - arXiv:1612.07821

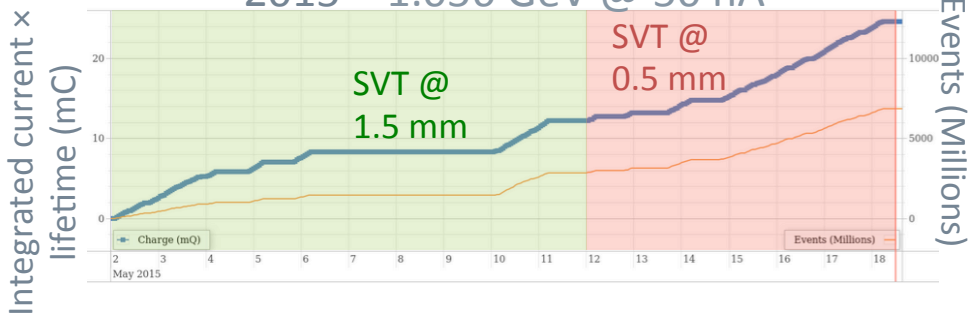
- Trigger/DAQ
  - Livetime > 85%
  - Trigger rate ~20 kHz
  - Trigger efficiency >> 90%



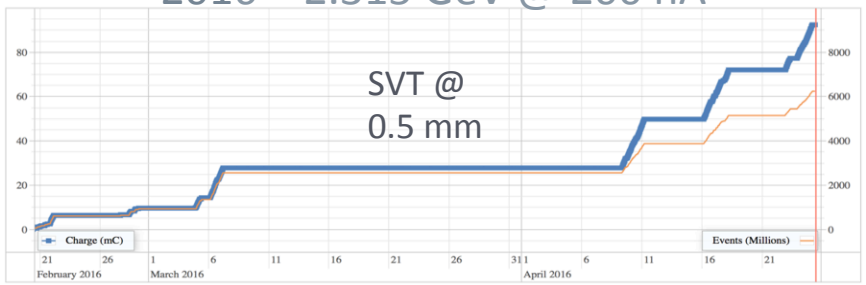




2015 – 1.056 GeV @ 50 nA



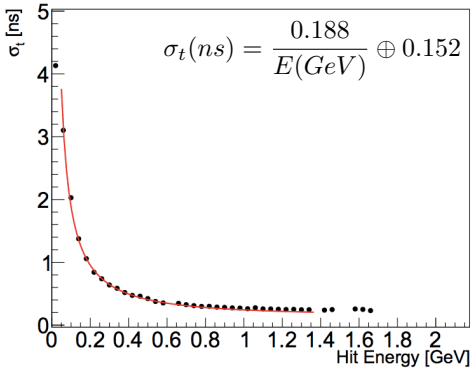
2016 – 2.315 GeV @ 200 nA

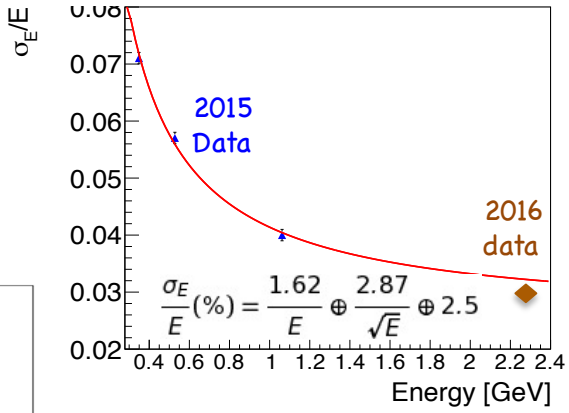


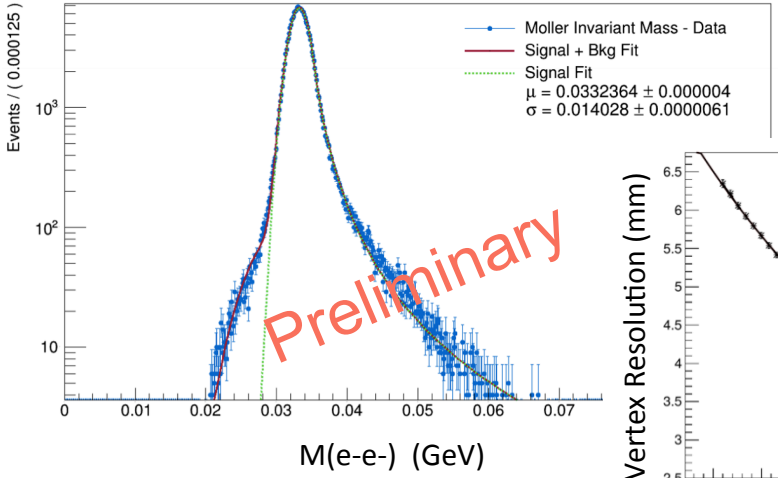
Engineering Runs – Performance (2)

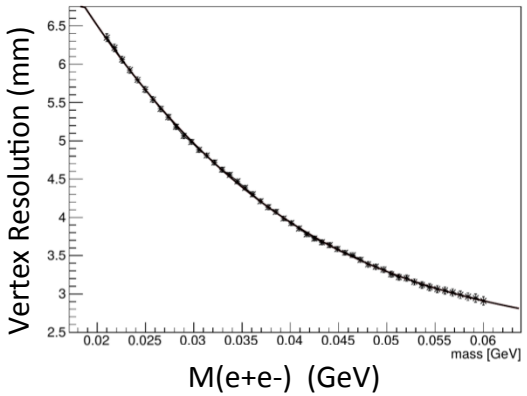
- ECAL
  - good energy/time resolution
    - 2-cluster time coincidence leaves <1% accidentals
  - efficiency measured ~100%
- SVT
  - occupancy < 1%
  - momentum resolution ~7%
  - mass resolution within 10% of simulation
    - Moller M(e^-e^-) used as benchmark
  - vertex resolution as expected
  -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

See HPS ECAL NIM – arXiv:1610.04319





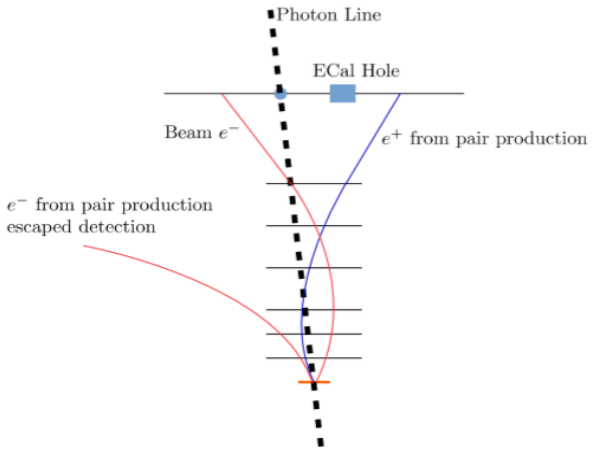




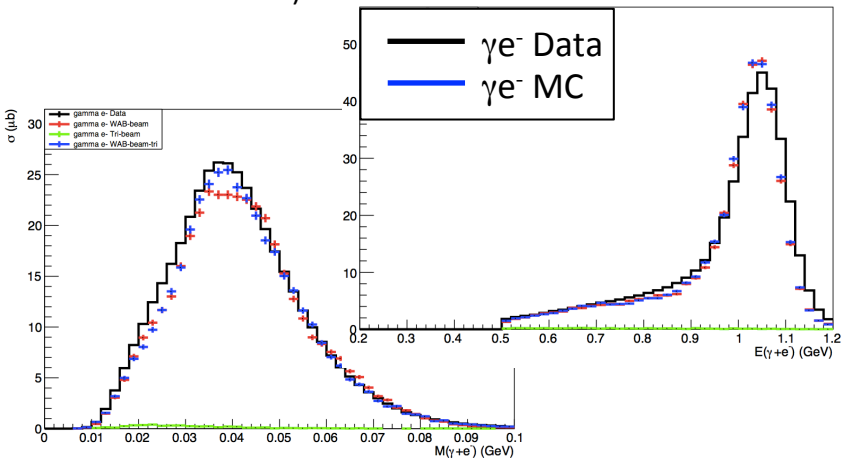
“Wide Angle” Bremssthrahlung Background

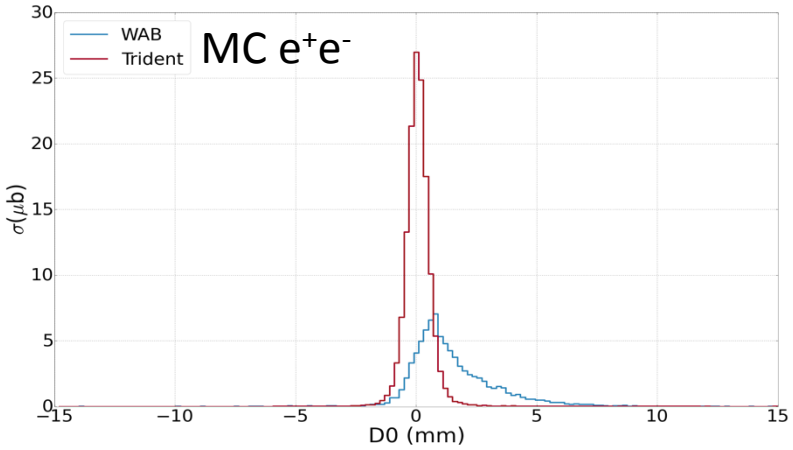
- A previously underestimated background
  - Bremsstrahlung in egs5 has approximate scattered electron kinematics (θ=0!)
    - artifically keeping this e^- out of HPS acceptance
  - After analyzing the data, we moved to a realistic generator for wide angle Bremsstrahlung, confirming this “new” background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



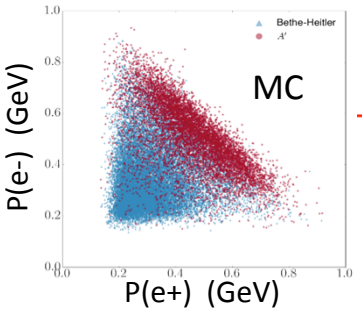
We also measure WAB directly (γe^-, no conversion) and confirm with simulation

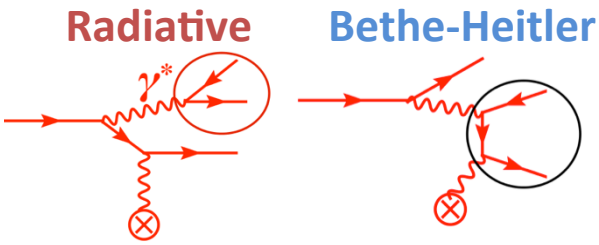




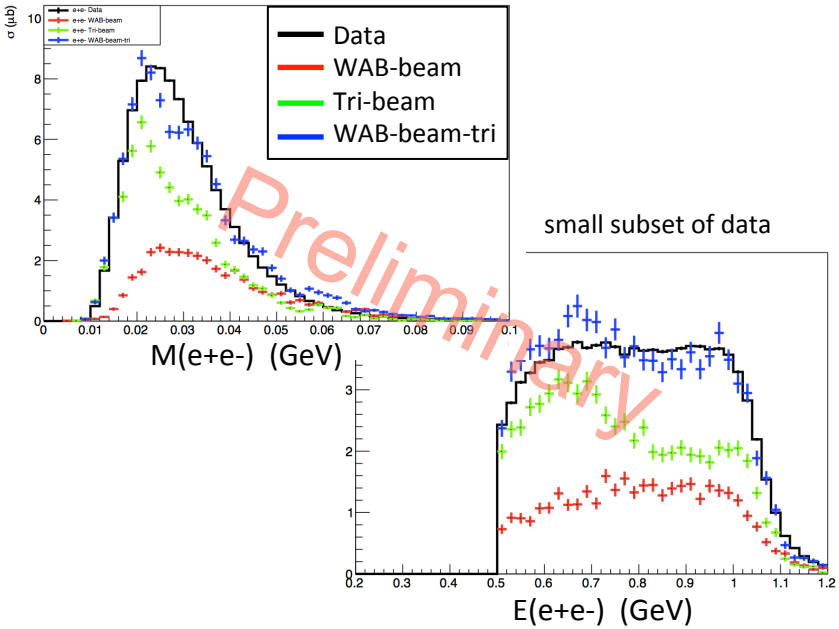
e^+e^- Trident "Background"

- 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!
    - → ~20% inflation of Trident cross section

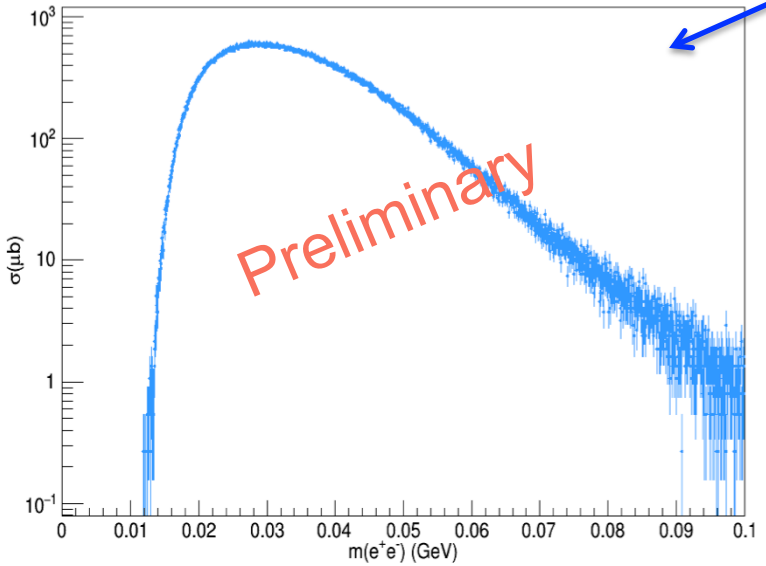


- *Projected reach in proposal suffered from errors in simplified acceptance calculations*
  - *overestimate of small angle trigger (i.e. did not account for 9x2-crystal hole in ECAL near beamline)*
  - *no z-vertex dependence, flat out to first Si layer*

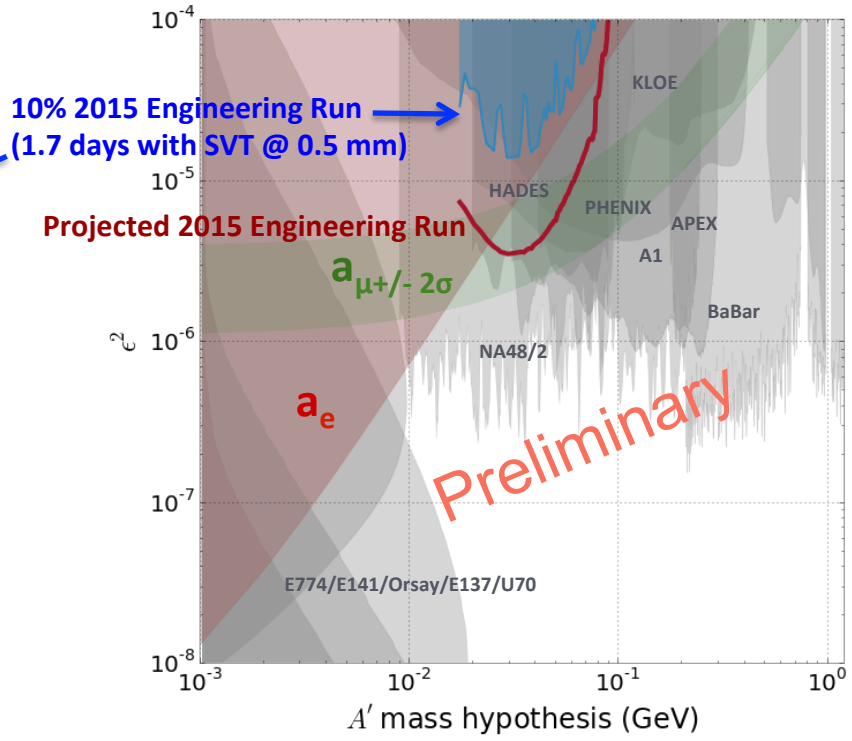
After sorting out the event generator issues, and correcting for low-momentum tracking ineffeciencies, our data lines up with MC to ~10%

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 covered using the limited Engineering runs' data*
- *Review of the full result with 0.5 mm data is finished, analysis unblinded and to be published*



Subject of JLab seminar on May 3 by O. Moreno

2015 Vertexing Search

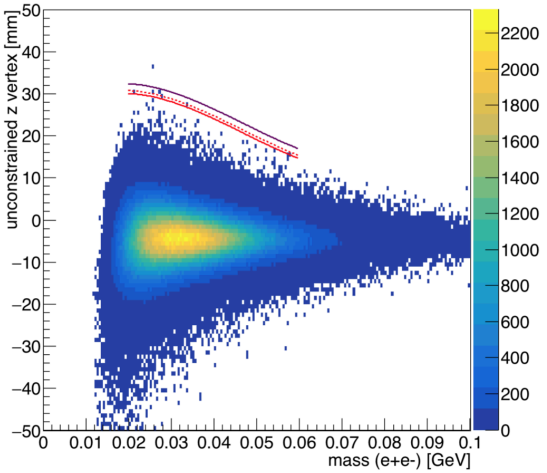
Requires understanding of vertex resolutions, tails, and elimination of high-z backgrounds. Large efforts have

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

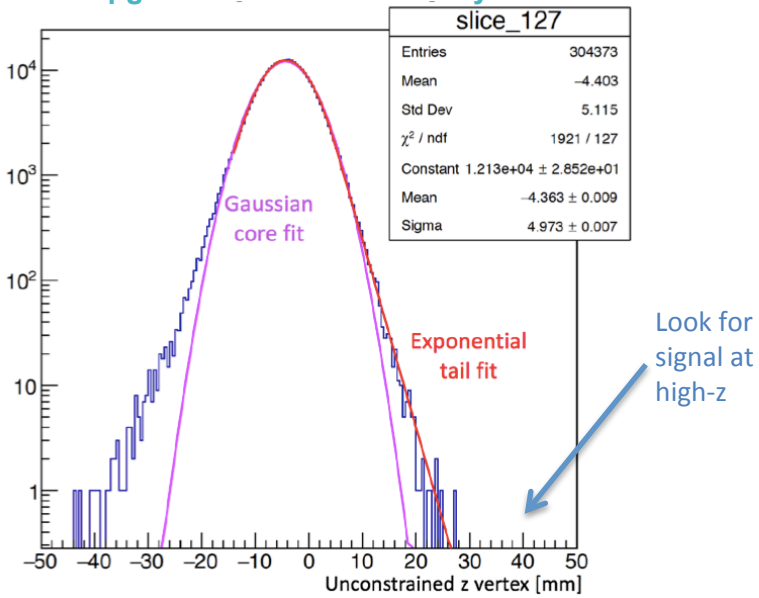
But reach is worse than we had projected

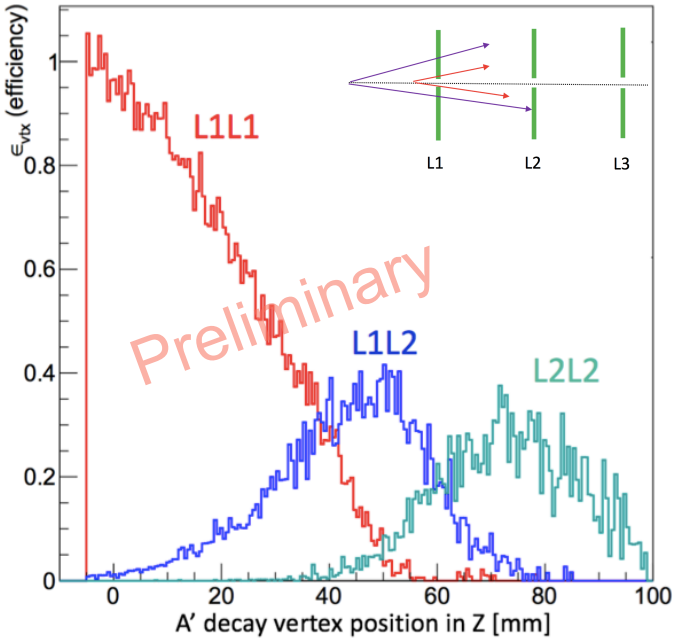
→ *No vertex reach expected using 2015's 1.7 days of data*

- 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)

HPS Upgrades

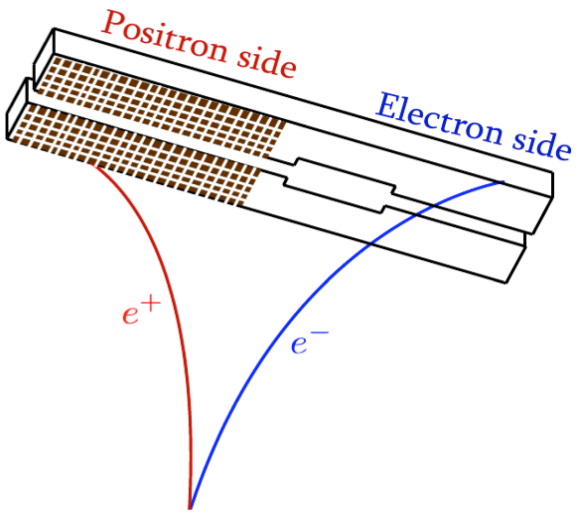
Modest upgrades will allow expanded reach for future runs

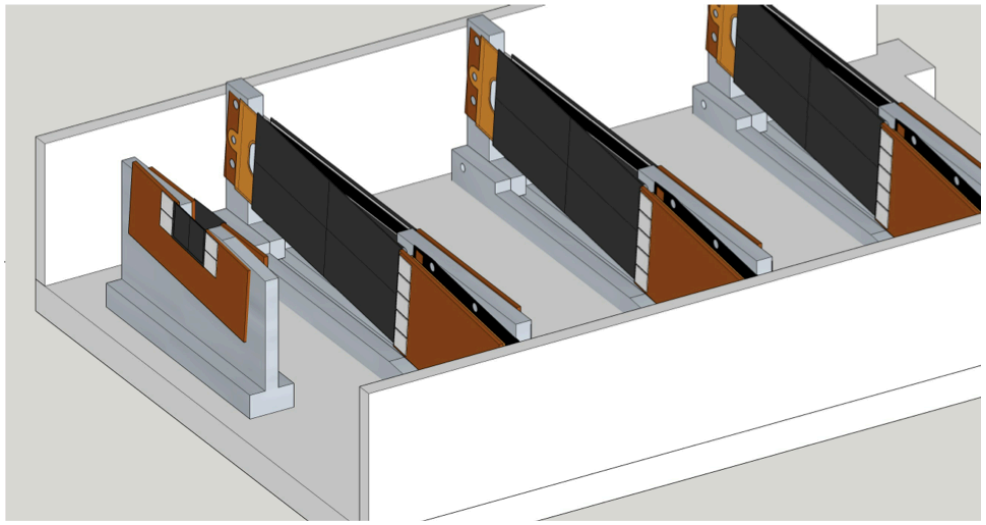
- The layers of the SVT can easily be moved closer to the beam
  → Increase acceptance for detached vertices. Only L2 and L3 to move.

- Add an additional, thinner layer (L0) to the SVT at 5 cm
  → Improve vertex resolution ~2x (by halving the distance between target and first layer)

- Single-arm (positron-only) trigger
  → Recover most of the proposed reach lost due to electrons in the ECal hole.

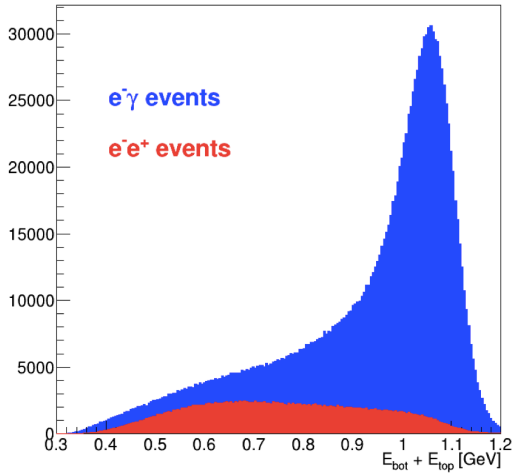
Experimental Readiness Review was this Monday for 2018 HPS Run with these upgrades



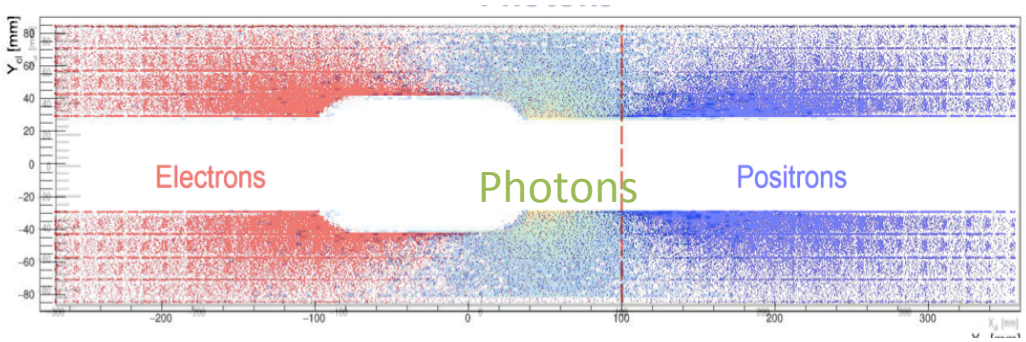


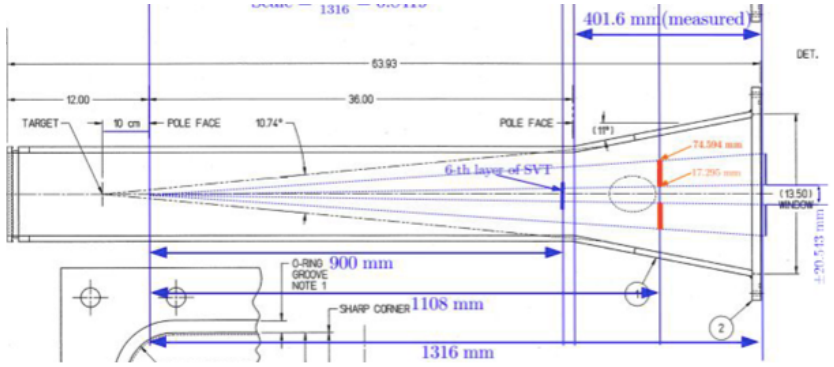
Trigger Upgrade

- Add hodoscope in trigger in coincidence with ECAL
  - single charged particle on positron side of acceptance
  - recovers e+e- where e- was lost to ECAL hole but still in SVT accteptance
  - Full simulations developed, confirmed with random triggers from 2015 data
  - Rates comprable to e+e- trigger, ~ 16 kHz
    - which has large contributions from converted WABs



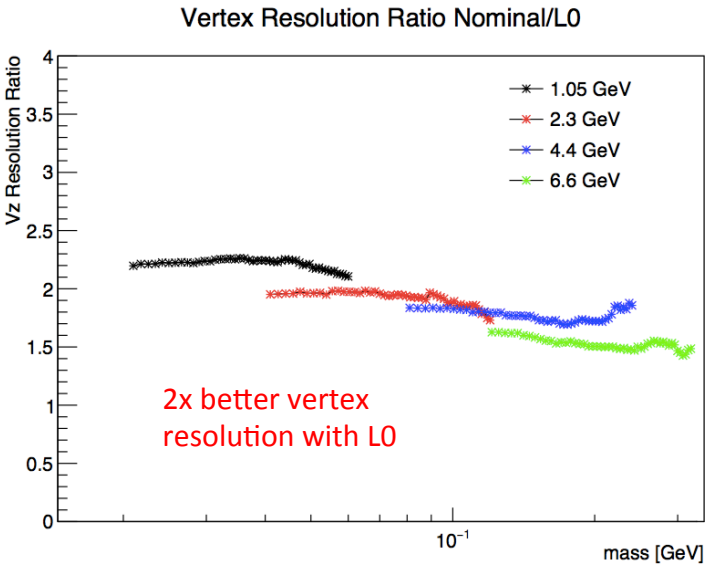
- Hodoscope Design
  - Mounted inside the vacuum chamber, halfway between last layer of SVT and ECAL,
  - Modified flange for readout/support
  - Scintillator strips (15-30 mm wide, oriented vertically) and fibers leftover from CLAS12 PCAL
  - Vacuum feedthrough and PMT housing same design as for CLAS12 BOM
  - Readout with leftover Hamamatsu H7811 MAPMT (16-channel) and an FADC250

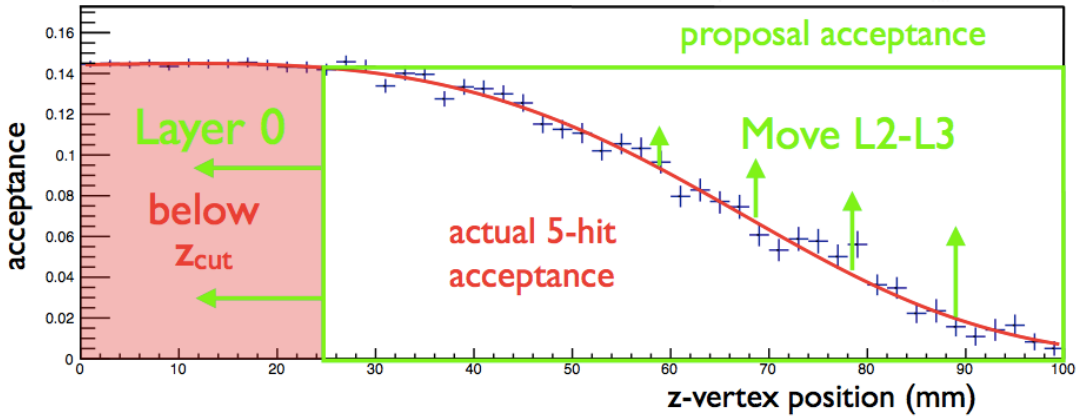


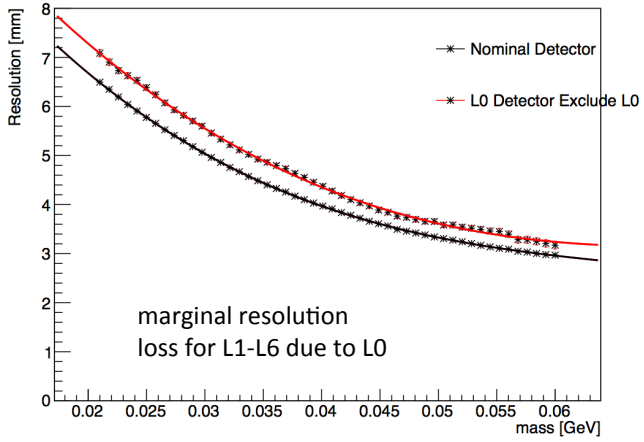


SVT Upgrade

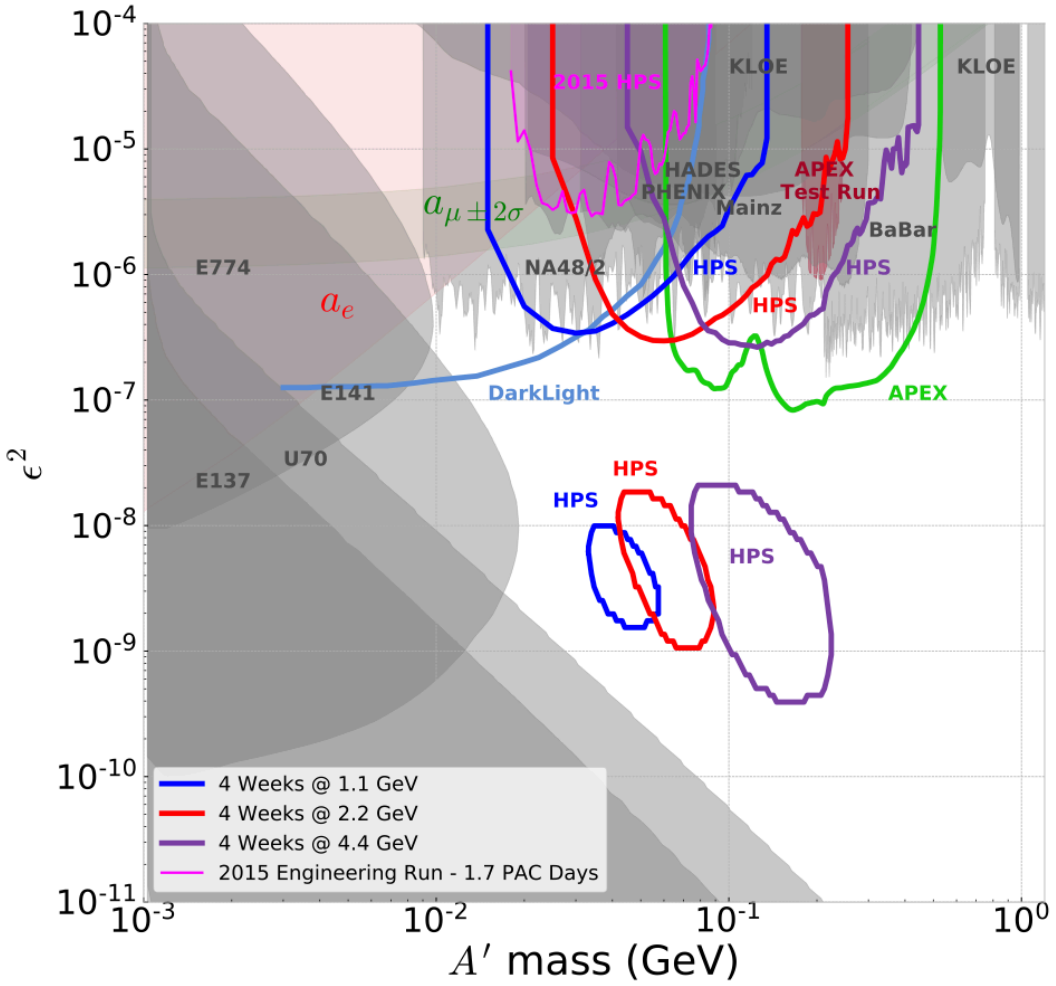
- Move layers 2 and 3 closer to beam
  - simple shims
  - increase occupancy, but no more than existing L1
  - → increase detached vertex acceptance
- Add additional layer L0
  - 5 cm from target, halfway between target and L1
  - 55 um pitch, thinner 150 um (vs 320 um)
  - slim edge sensors (<200 um vs 1 mm) already produced at UCSC
    - → Silicon no closer to beam than L1
  - new hybrid, but data acquistion requires no hardware modification
  - → increase vertex resolution ~2x
- Full simulations confirm expected resolution and acceptance improvements







Updated Reach Projections, after Upgrade



(requiring all-layer tracking)

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, occupancies, resolutions all measured and agree with simulation
  - Additional source of background identified and mitigated, simulation event generator issues addressed
  - Proposal's reach calculations updated to account for acceptance errors, now agrees with measured data for bump hunt and vertexing analyses
- HPS is fully approved for 180 PAC days (15 already used), planning for a longer run in 2018
- Modest upgrades in development to recover propsed reach, with corresponding ERR this week
- Several Analyses are ongoing
  - 2015 Bump hunt analysis is reviewed and now unblinded, to be moved towards publication this summer
  - 2015 Vertexing analysis following shortly
  - 2016 (2 GeV) analyses in progress – calibrations finalized, starting full reconstruction pass soon
- 2 PhD theses complete, 3rd imminent
  - 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