The Heavy Photon Search Experiment

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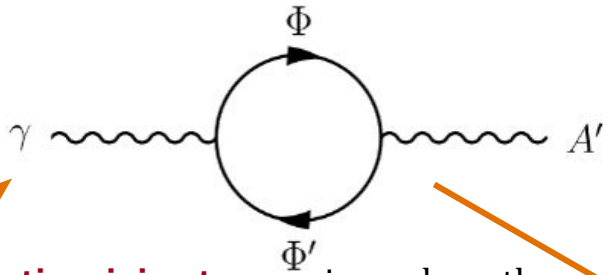
U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Introduction

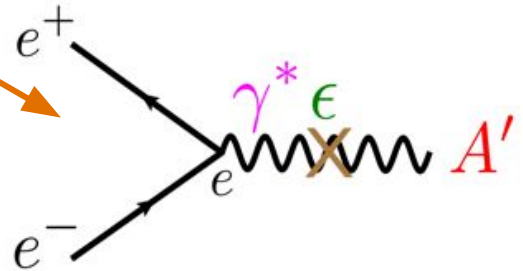
- A heavy photon (or dark photon, or A') is a **hypothetical vector boson** that couples weakly to electric charge
- The Heavy Photon Search (HPS) is a **fixed target experiment** at Jefferson Lab dedicated to searching for this hypothetical vector boson, an A'
- HPS uses two distinct methods to search for A's - a **resonance search** and a **displaced vertex search**

Suppose nature contains an **additional Abelian gauge symmetry** U'(1)



Kinetic mixing term arises where the SM photon mixes with an A' through interactions of massive fields

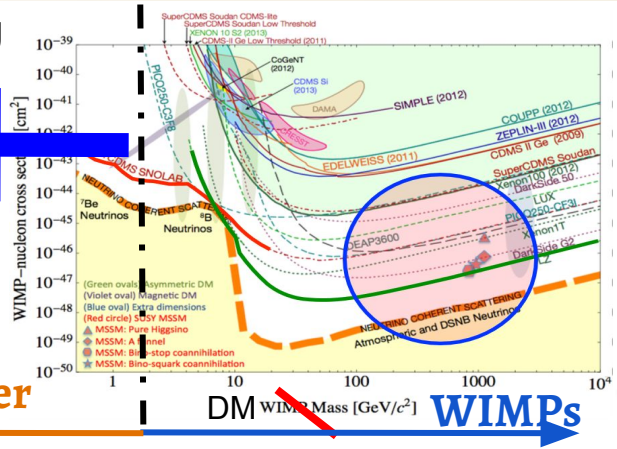
Induces a weak effective coupling of εe to SM fermions



$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \epsilon_Y F^{Y,\mu\nu} F'_{\mu\nu} + \frac{1}{4} F'^{,\mu\nu} F'_{\mu\nu} + m^2_{A'} A'^{\mu} A'_{\mu}$$

Heavy Photon as a New Light Force Carrier

WIMPs are running out of room!



arXiv:1310.8327

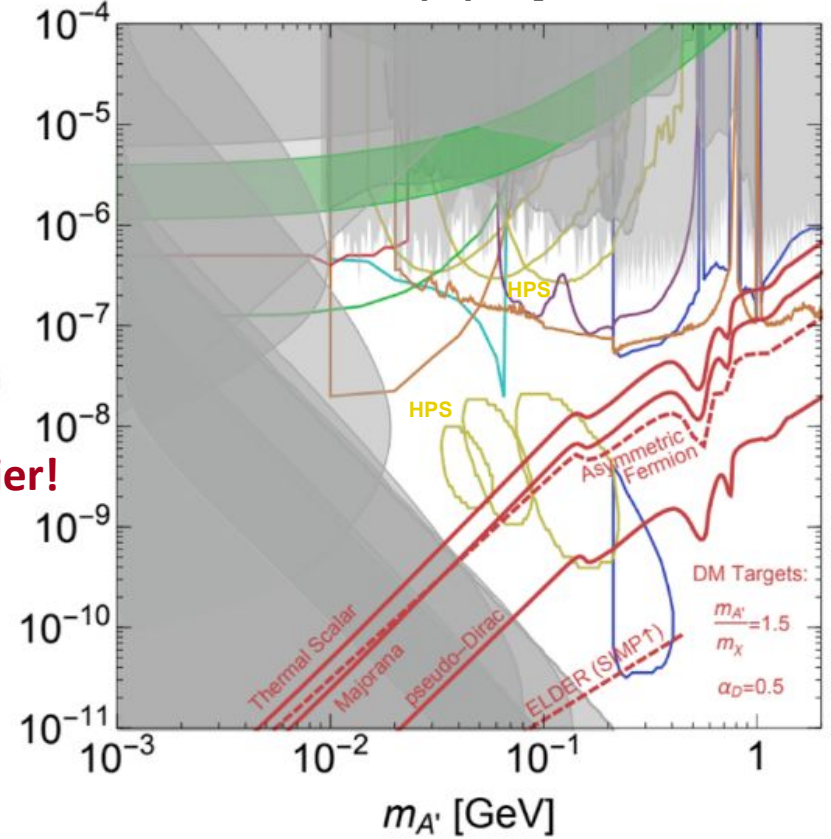
Light Dark Matter ← DM → **WIMPs**

Lighter dark matter requires a **new, light force carrier!**

$$\langle \sigma v \rangle \propto \frac{m_\chi^2}{m_Z^4} \Rightarrow m_\chi \geqslant 2\text{GeV}$$

"Lee-Weinberg Bound"

Cosmic Visions Whitepaper [arXiv:1707.04591]



Heavy Photon Signatures in HPS

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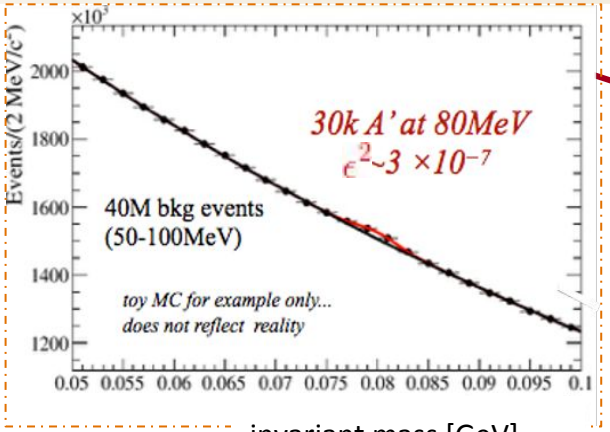
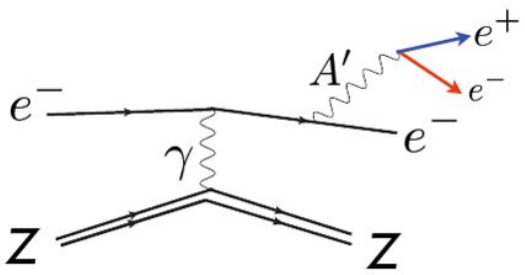
"Large" signal, huge QED background (**bump hunt**)





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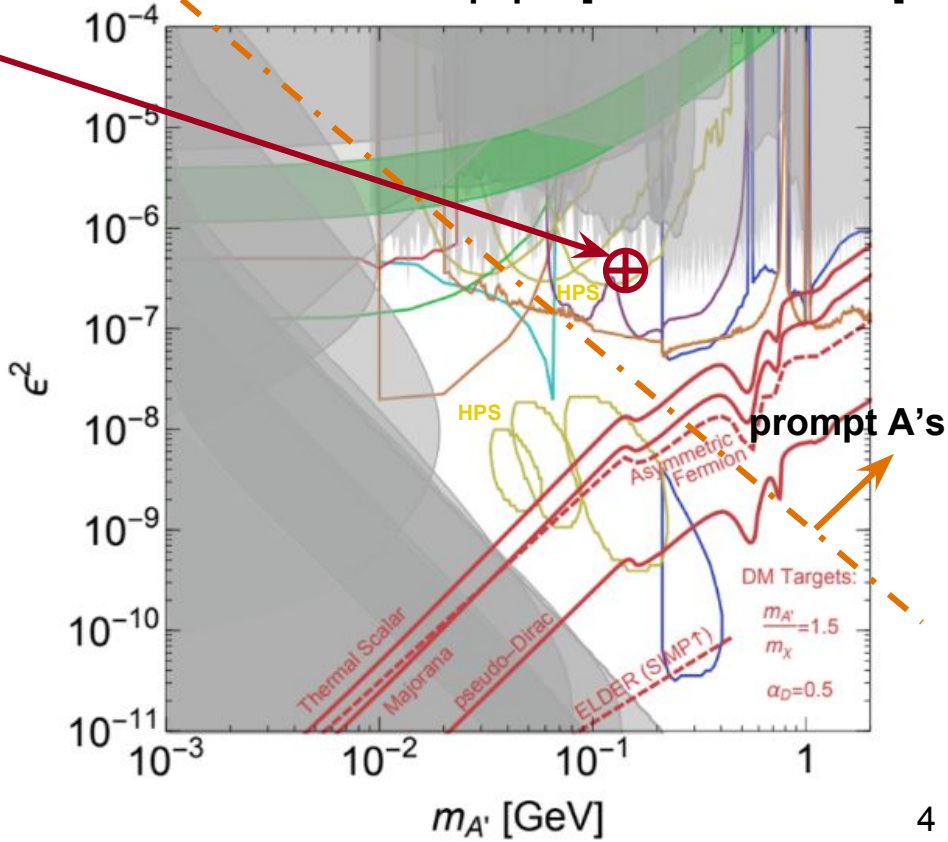
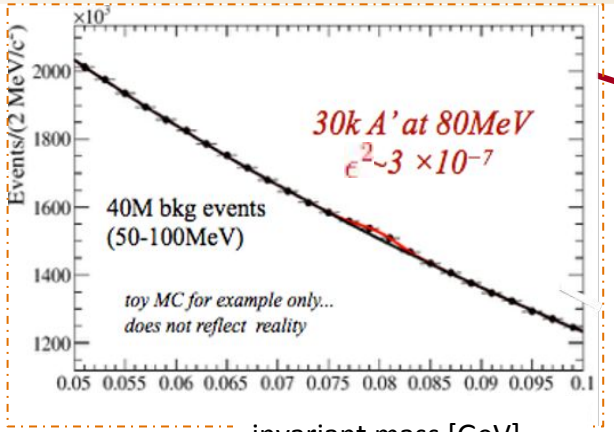


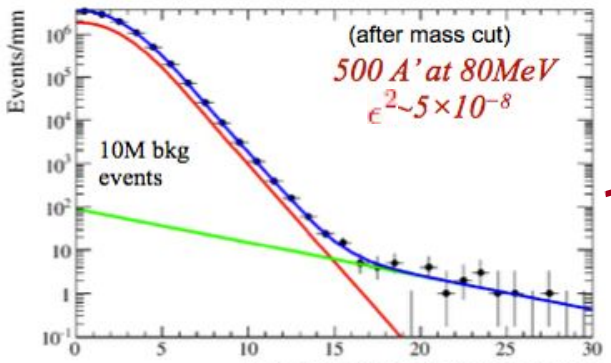
Heavy Photon Signatures in HPS

"Large" signal, huge QED background (**bump hunt**)

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

Small signal, very little background (**vertex search**)





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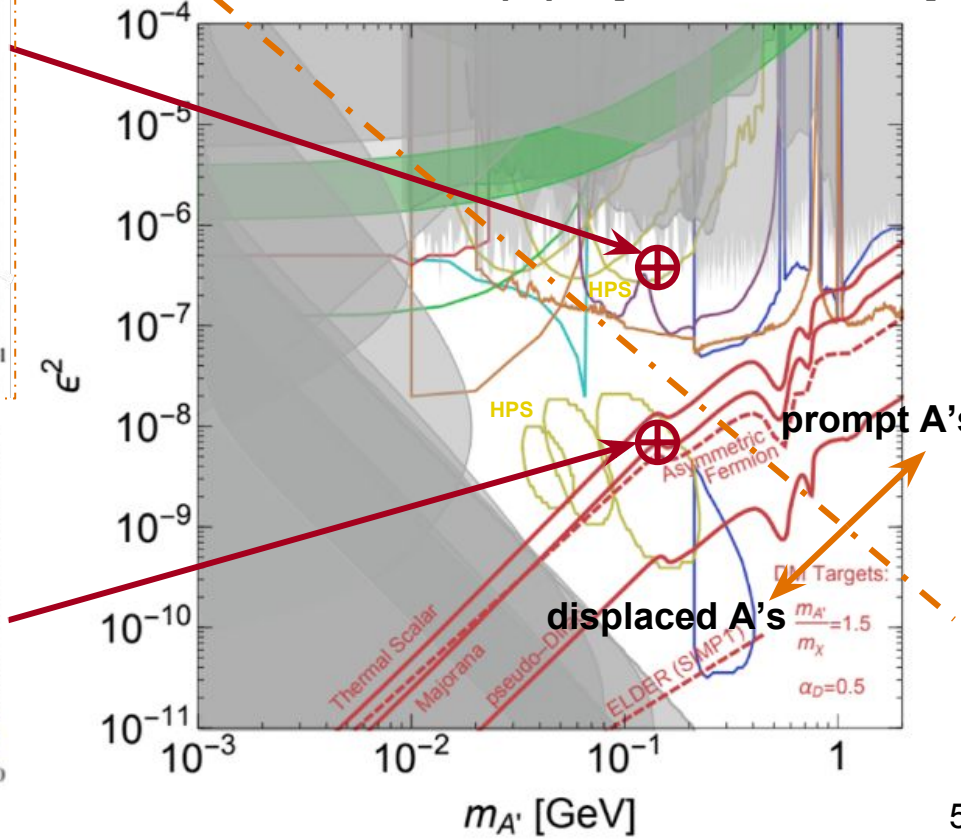

The Heavy Photon Search Experiment

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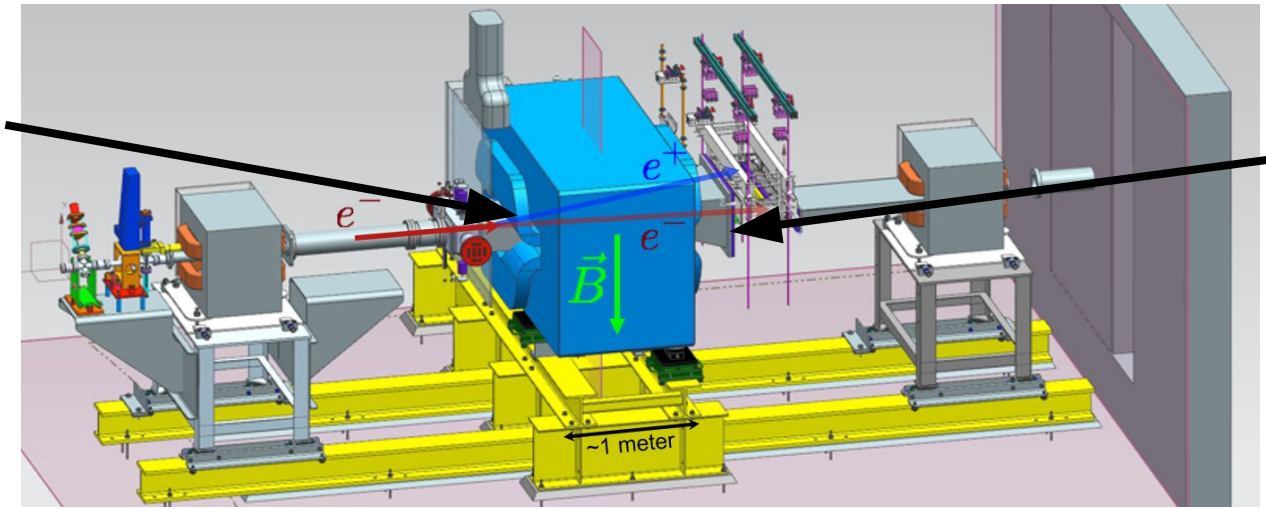
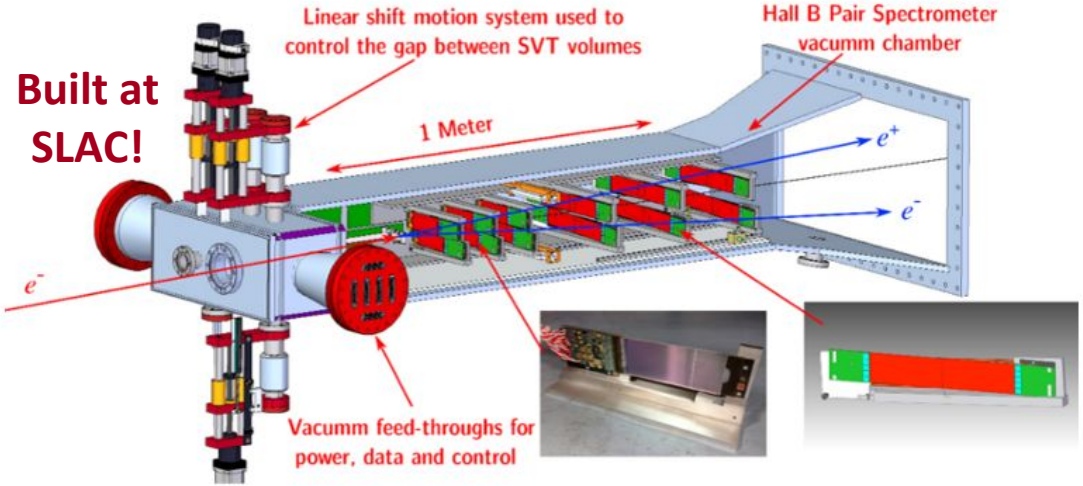
- HPS is a **fixed-target experiment** for **visibly decaying dark photons** using the CEBAF electron beam (1-12 GeV) in Hall B at Jefferson Lab
- Very forward A's can be produced in a process **analogous to Bremsstrahlung** in a thin W foil $x = \frac{E_{A'}}{E_{beam}} \sim 1$
- Large dipole magnet spreads e+e- pairs and provides momentum measurement

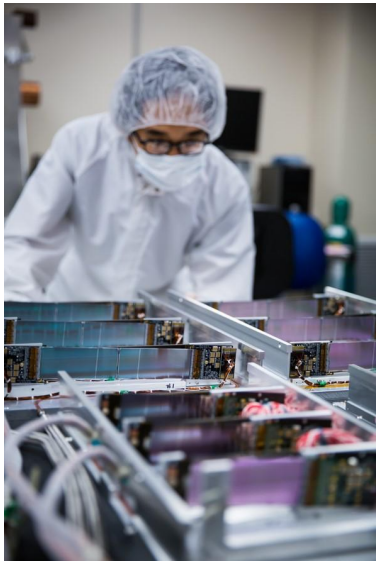


Silicon Vertex Tracker

- SVT measures trajectories of e+e- and **reconstructs mass and vertex position**
- 6 layers of silicon microstrips (~0.7% radiation length per layer)
- Each layer has axial/stereo strips for 3D hit position
- SVT is split to avoid “sheet of flame”; Also, very large scattered beam backgrounds!
- Silicon is very close to beam for good forward coverage

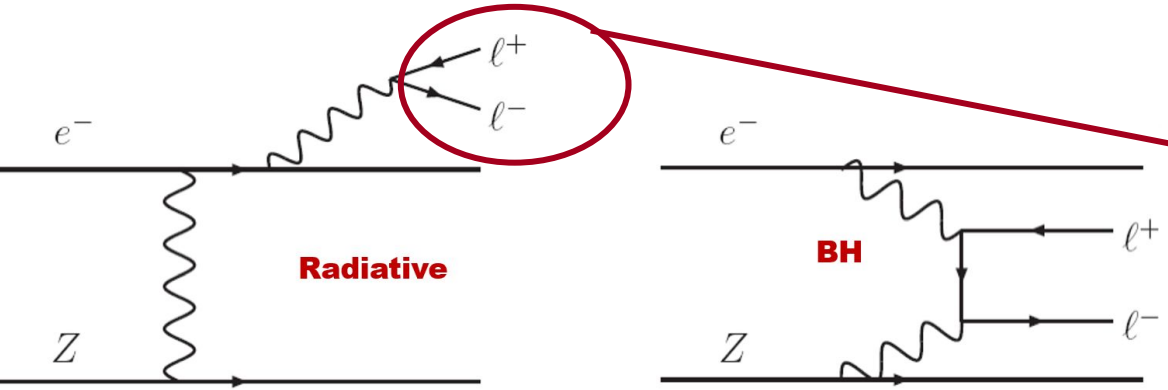
Built at SLAC!

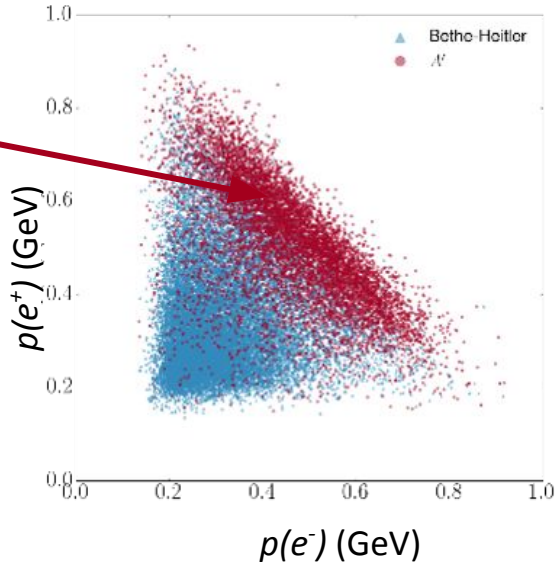




Trident Backgrounds

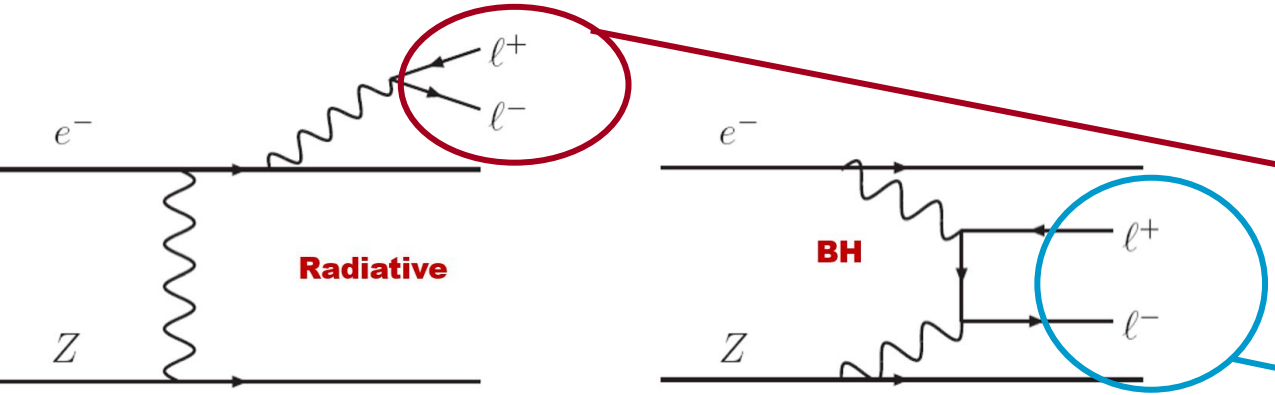
- **Radiative tridents** have identical kinematics to signal; constitute an irreducible background

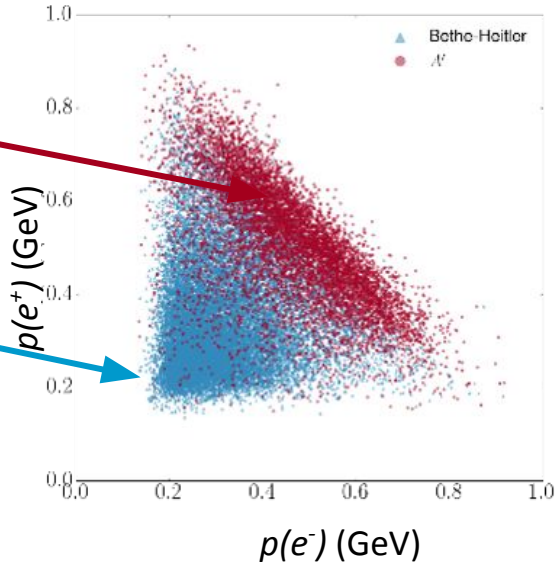




Trident Backgrounds

- **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





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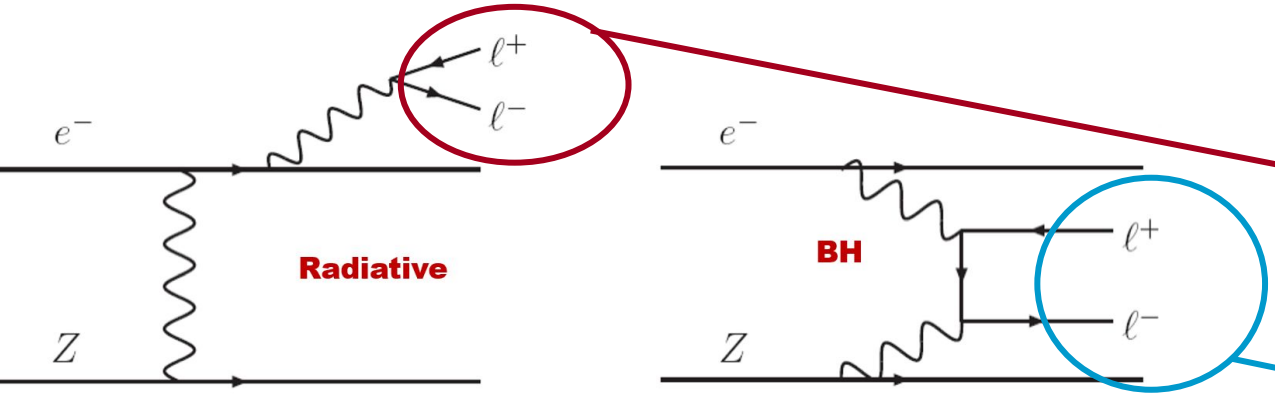
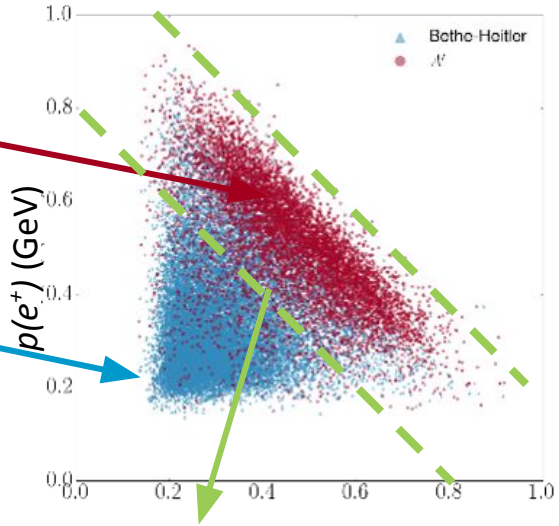




- Radiative tridents provide reference for expected signal rate

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

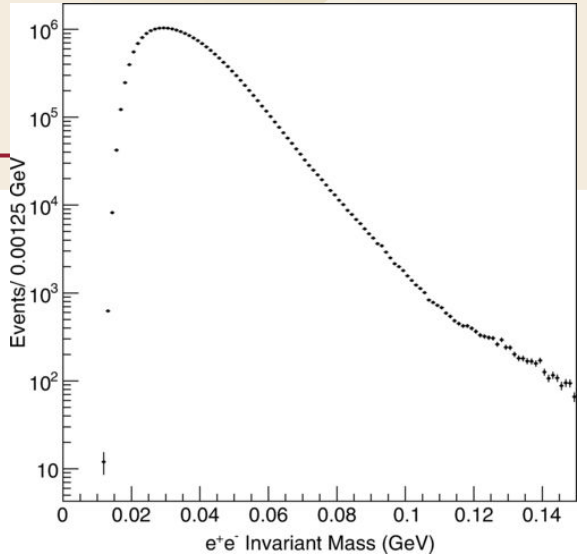
Require $0.8E_{beam} < p(e^+e^-) < 1.2E_{beam}$ greatly reduces fraction of BH background

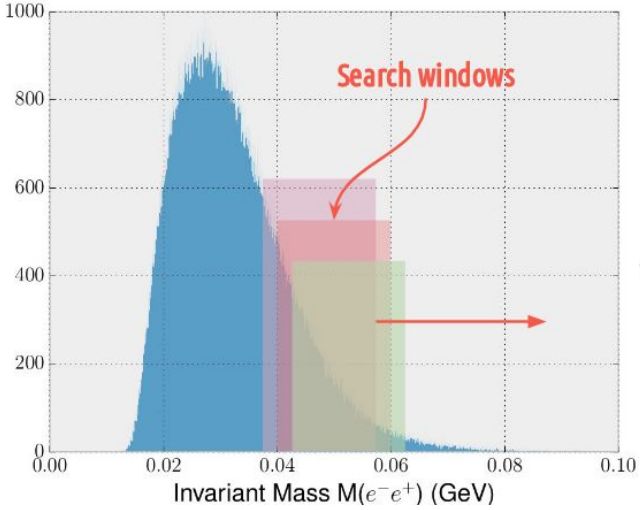
2015 & 2016 Engineering Runs

Data Run	Beam Energy (GeV)	Beam Current (nA)	Beam Time (days)	Total Charge (mC)	SVT Position (mm)
2015 Engineering Run	1.05	50	1.7	10	0.5
2016 Engineering Run	2.3	200	5.4	92.5	0.5

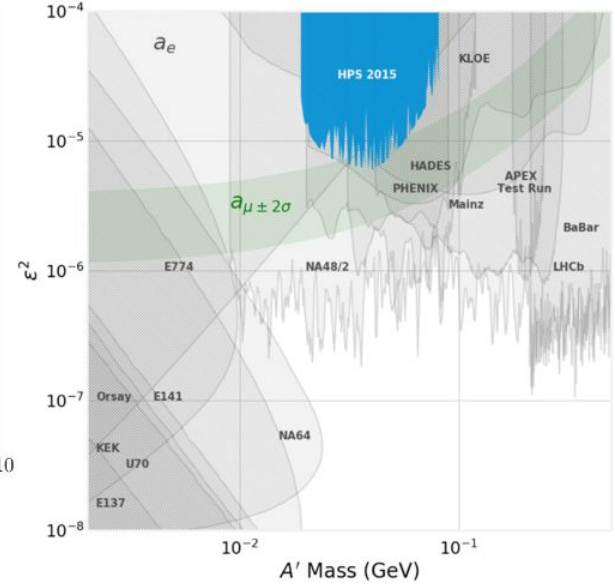
Resonance Search Results

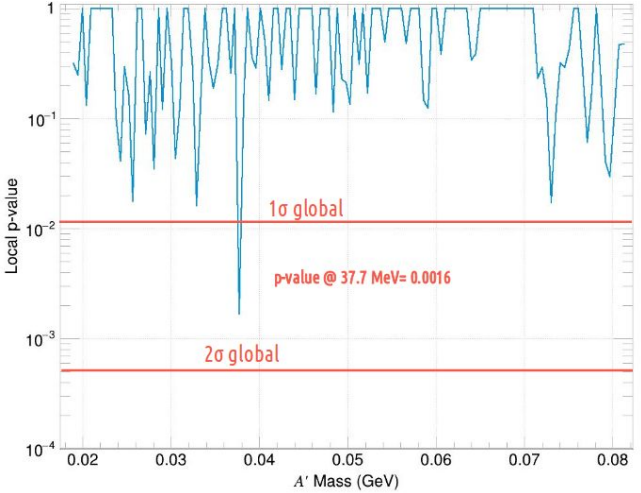
- 2015 Bump Hunt results are published
- No significant bumps found, consistent with other experiments excluded





PhysRevD.98.091101



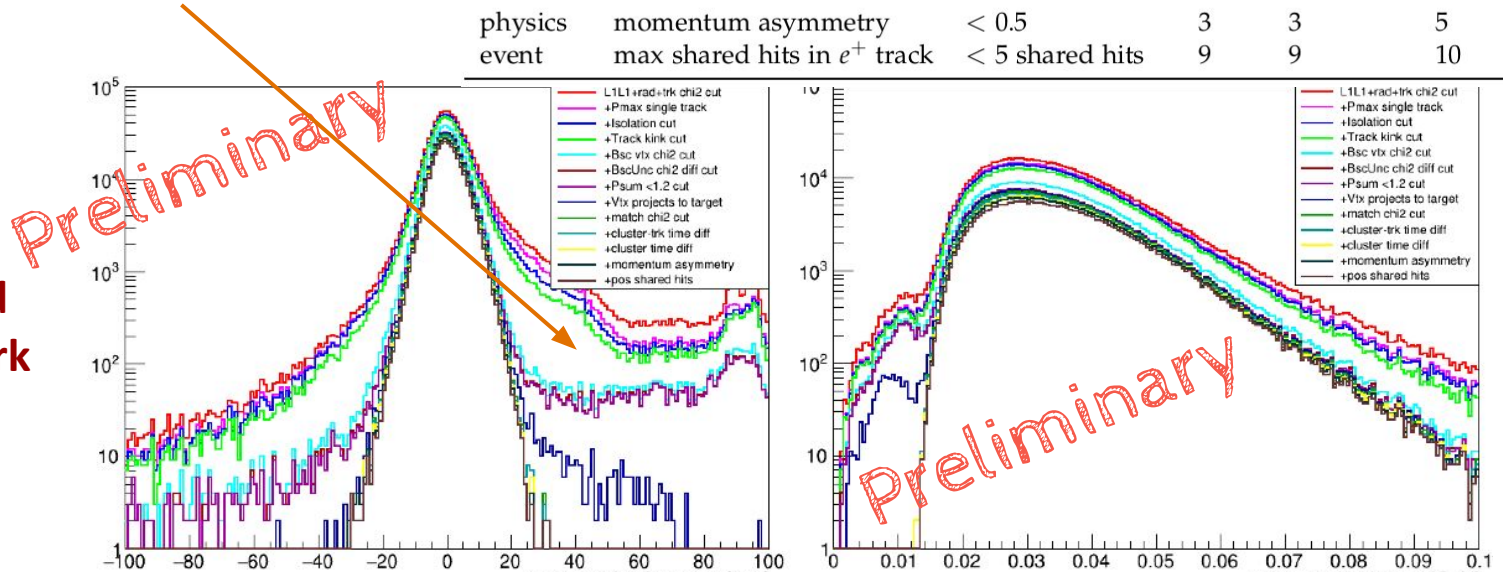


Vertex Event Selection

Cut type	Cut	Cut Value	%cut	%cut core	%cut tails
track	Fit quality	track $\chi^2/dof < 6$	24	–	–
track	Max track momentum	$P_{trk} < 75\%E_{beam}$	11	9	20
track	Isolation		4	1	14
track	kinks in L1 and L2	9	7	16	
vertex	beamspot constraint	bsc$\chi^2 < 10$	28	22	57
vertex	beamspot - unconstrained	bscχ^2-unc$\chi^2 < 5$	15	15	15
vertex	maximum P_{sum}	$< 115\%E_{beam}$	0.5	0.5	0.8
vertex	vertex projects to target	elliptical $3\sigma_{x,y}$	2	1	16
ecal	Ecal SVT matching	$\chi^2 < 10$	5	4	10
ecal	track Ecal timing	< 4ns	4	4	5
ecal	2 cluster time diff	< 2ns	6	6	9
physics	momentum asymmetry	< 0.5	3	3	5
event	max shared hits in e^+ track	< 5 shared hits	9	9	10

Goal is to reduce/eliminate backgrounds at large z

Tracking and vertexing work very well!



Vertex Analysis

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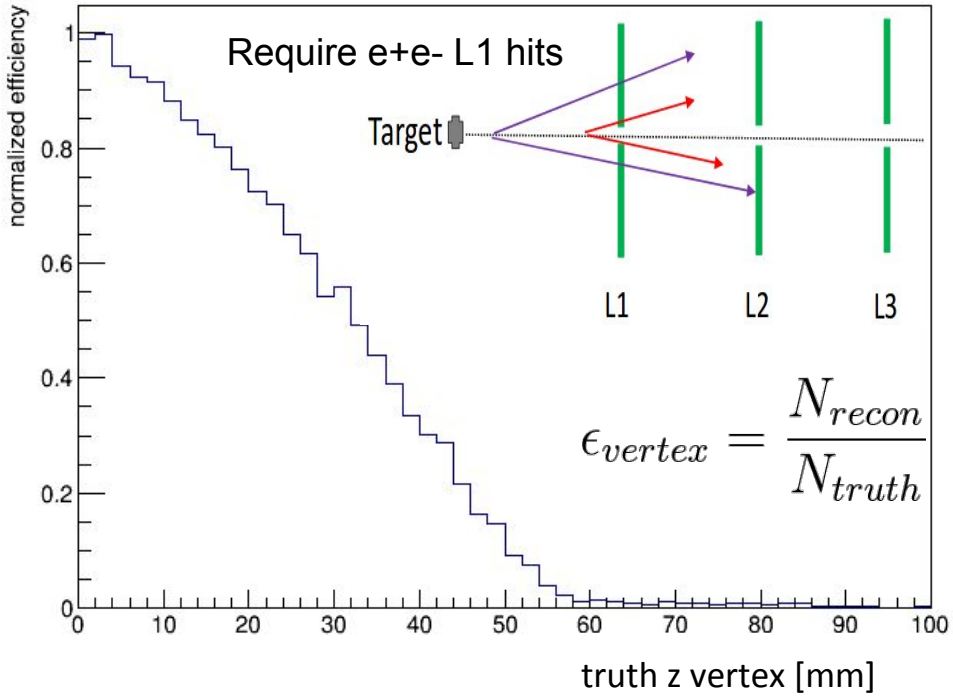
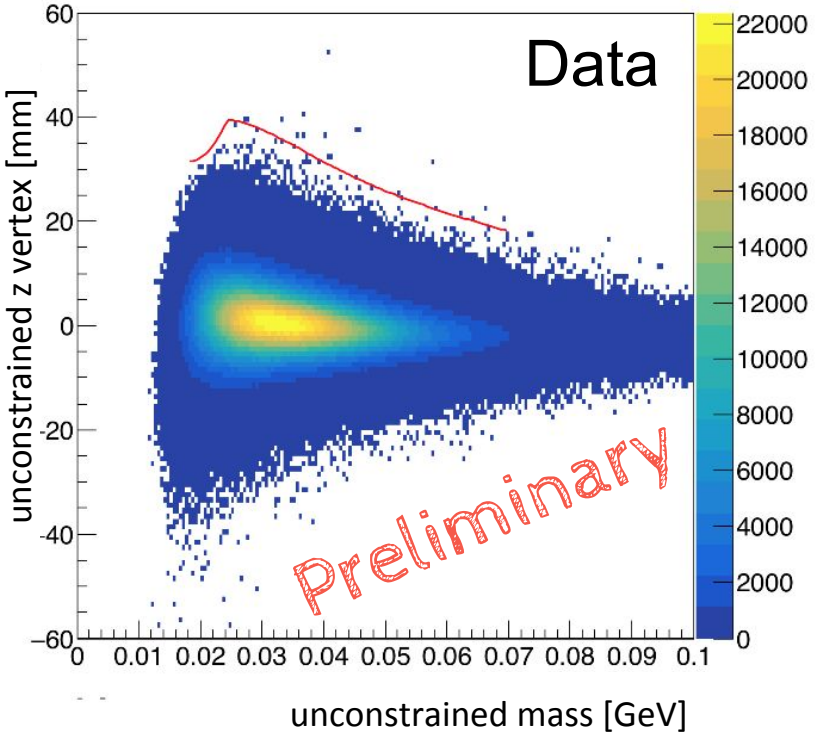
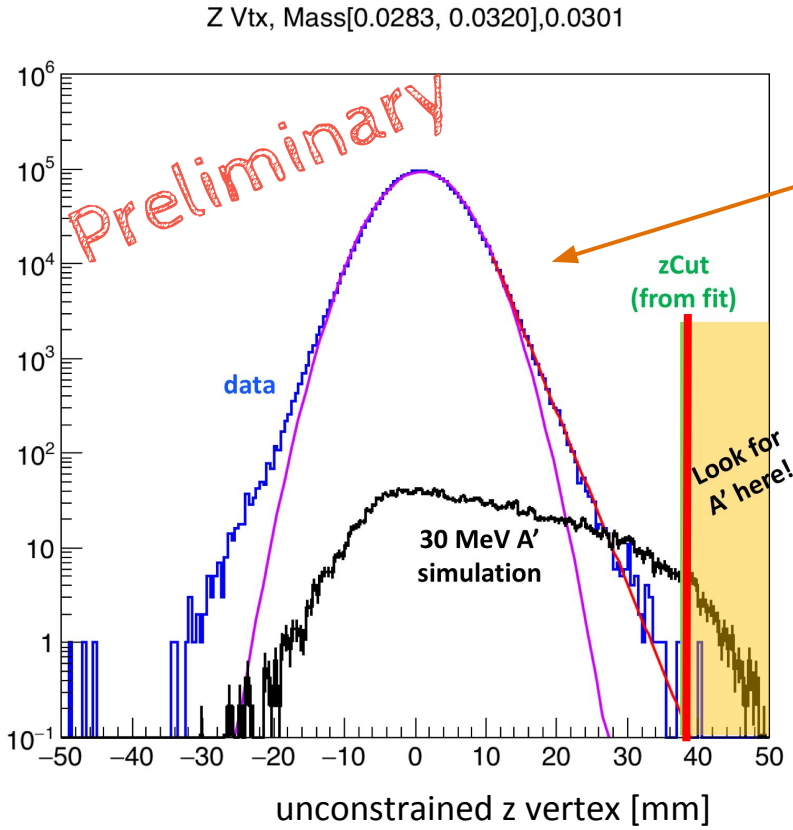
40 MeV A' Normalized Acceptance*Efficiency

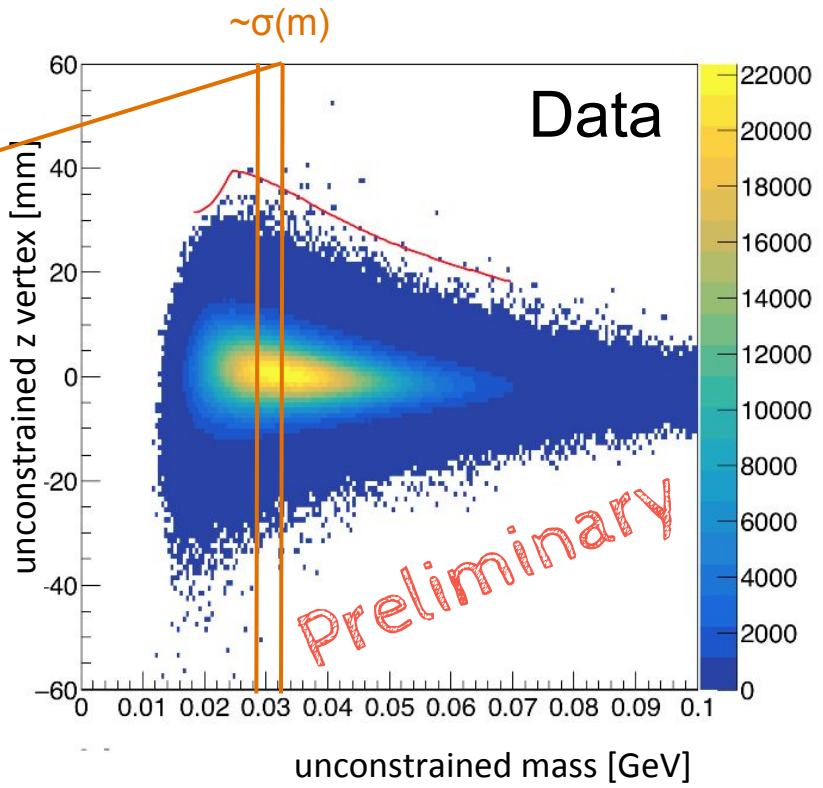


Vertex resolution is limited by multiple scattering

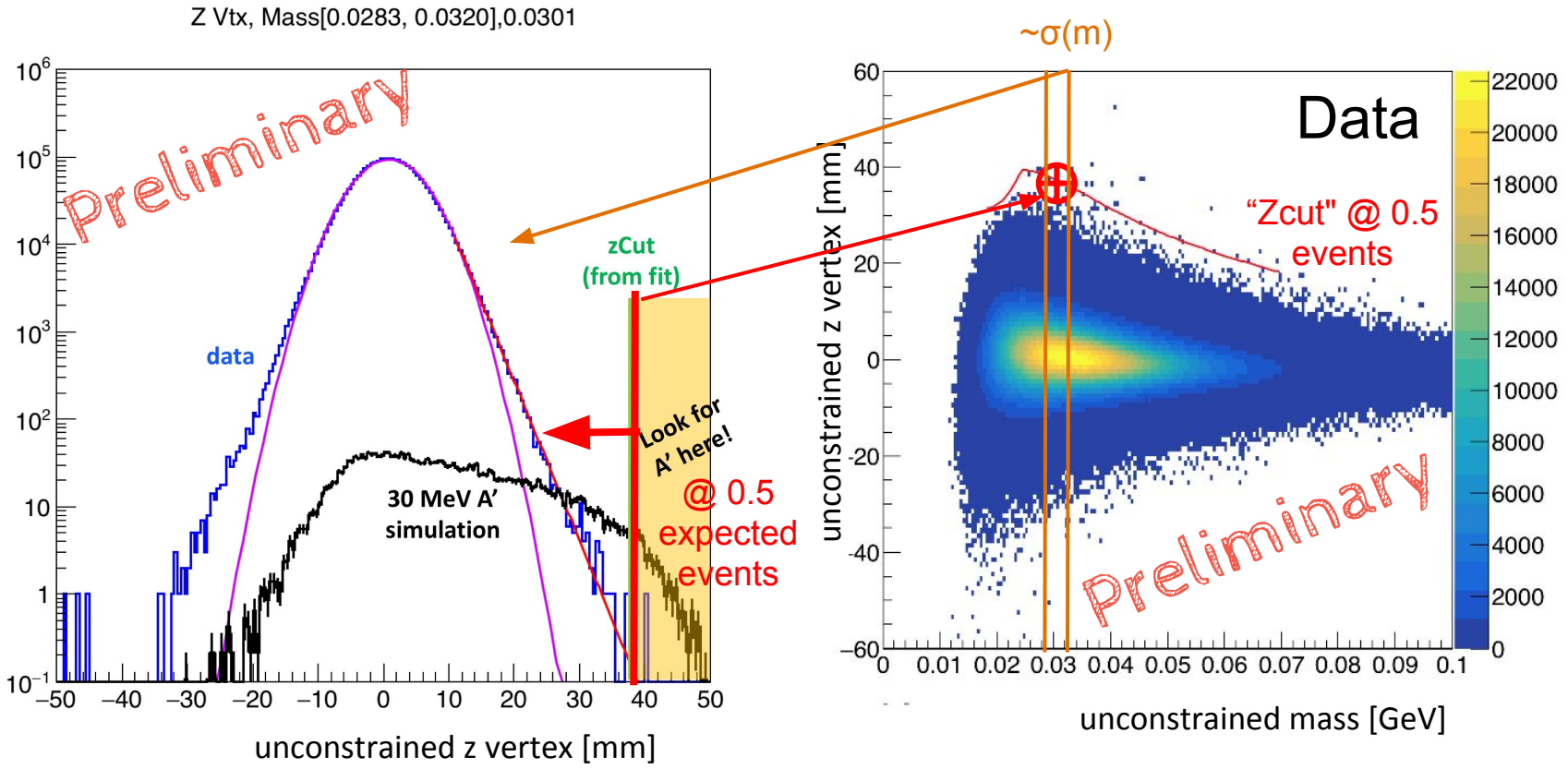


Vertex Analysis

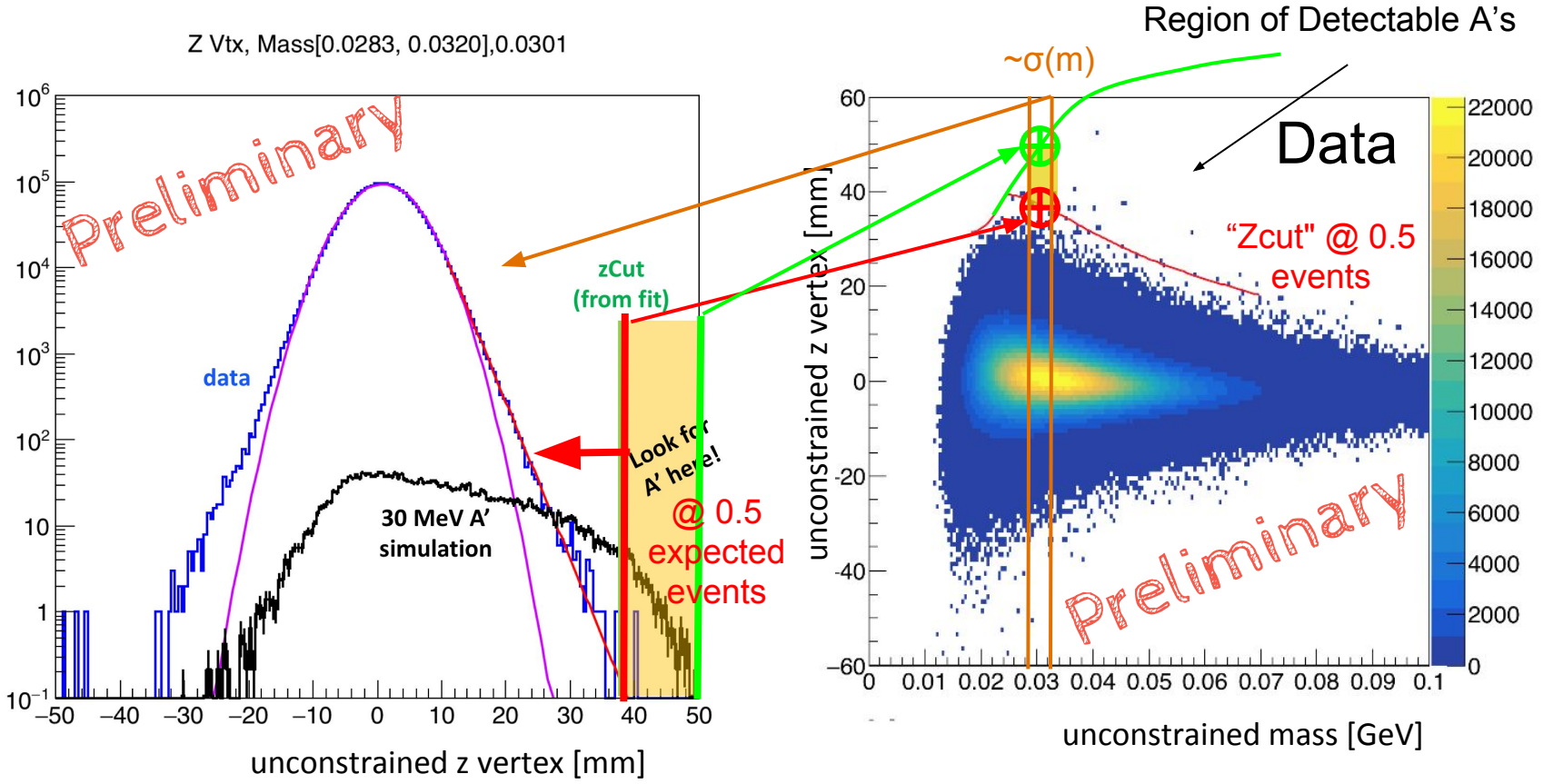




Vertex Analysis



Vertex Analysis



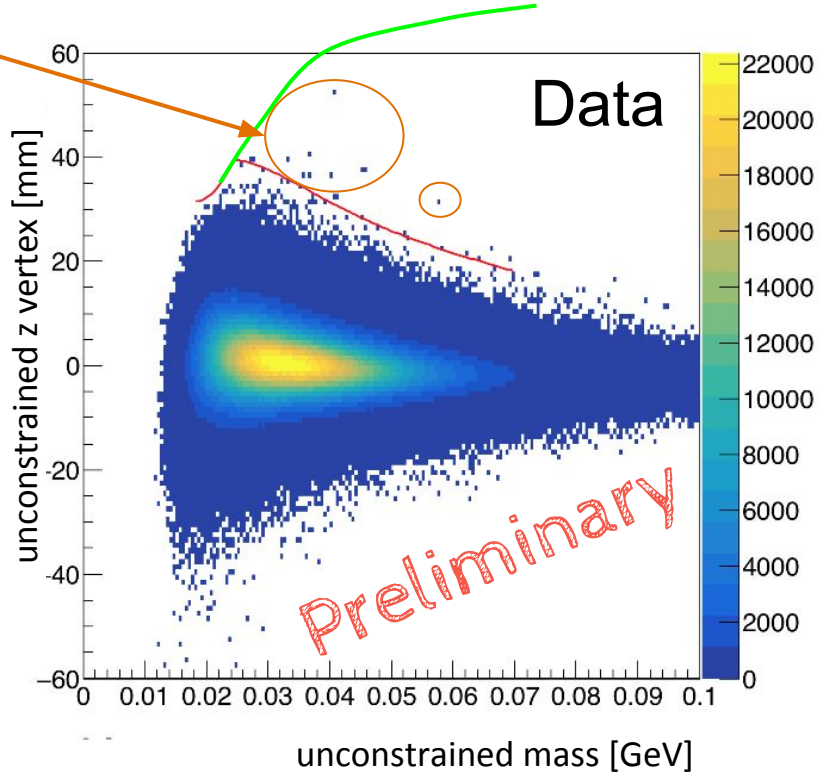
Additional Backgrounds Beyond Zcut

- We have vertices past zcut that are inconsistent with what we expect from our background fit (below)

$$F\left(\frac{z - z_{mean}}{\sigma_z} < b\right) = Ae^{-\frac{(z - z_{mean})^2}{2\sigma_z^2}}$$

$$F\left(\frac{z - z_{mean}}{\sigma_z} >= b\right) = e^{-\frac{b^2}{2} - b\frac{z - z_{mean}}{\sigma_z}}$$

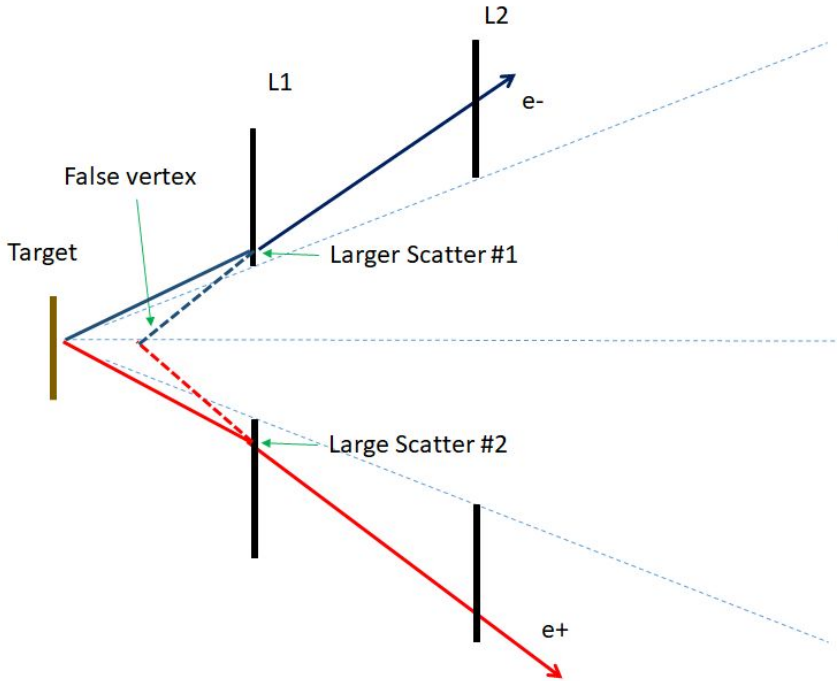
Gaussian Core + Exponential Tail

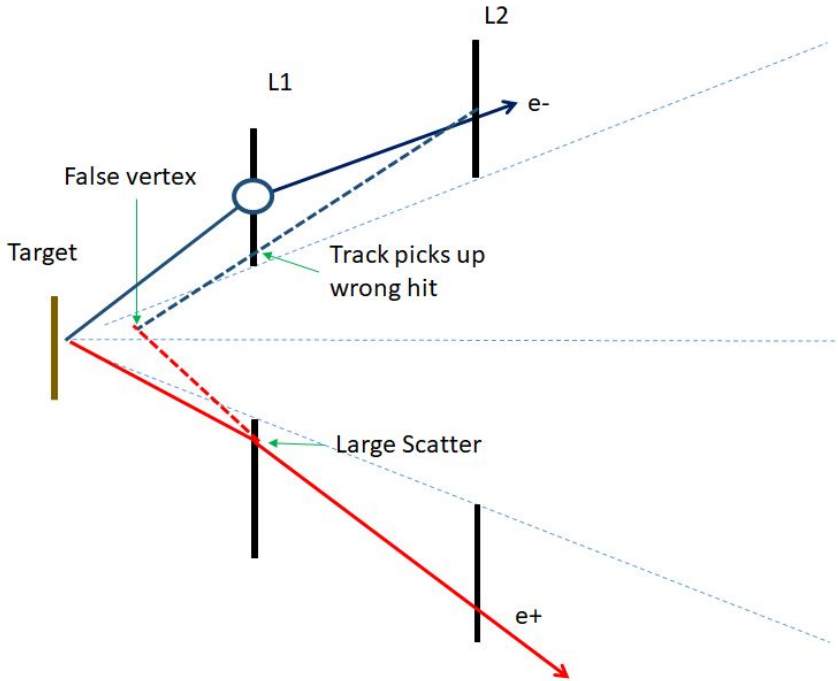


- MC sees roughly a similar number and pattern of such backgrounds
- **MC lets us see the source of these backgrounds**

Additional Backgrounds Beyond Zcut

- Measurement is limited by multiple scattering, but events past zcut are mainly due to rare double **large Coulomb scatters** (left) and picking up the **wrong L1 hit**



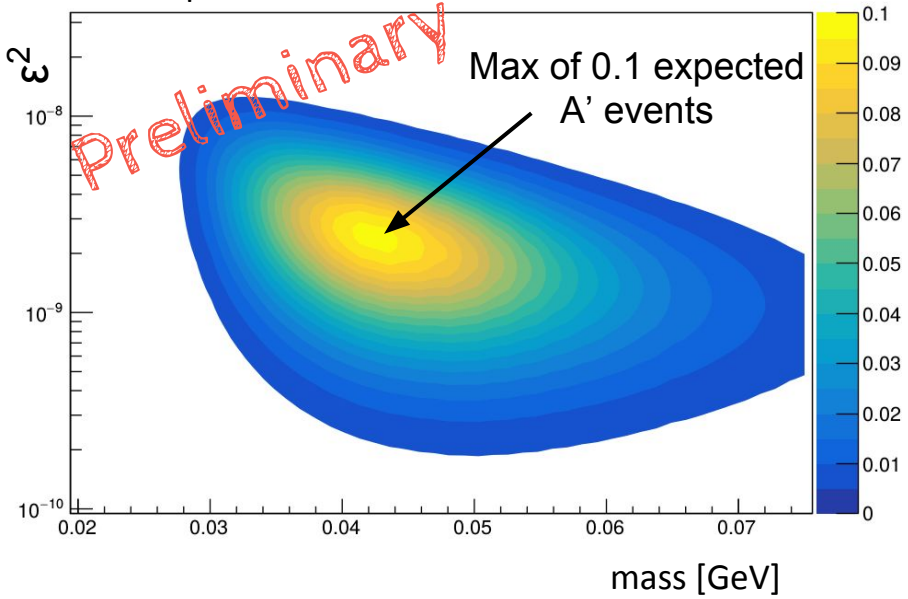


Vertex Analysis Final Results

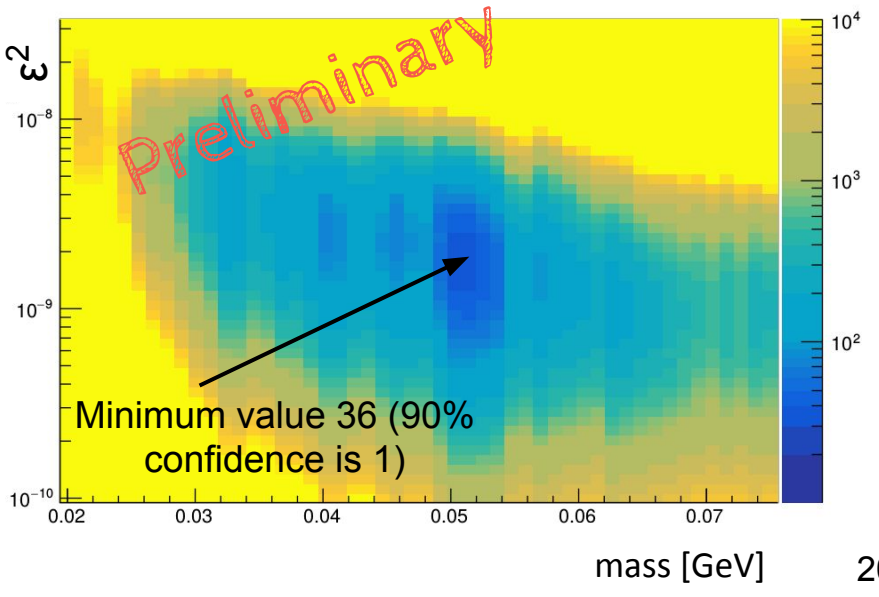
- Optimum Interval Method is ideally used for small signal where signal shapes are known, but background is not sufficiently known (HPS, direct DM detection, etc.)

arXiv:physics/0203002v2

Expected A' Events Detected Past ZCut



Optimum Interval Method Limit



Upgraded HPS for Future Running

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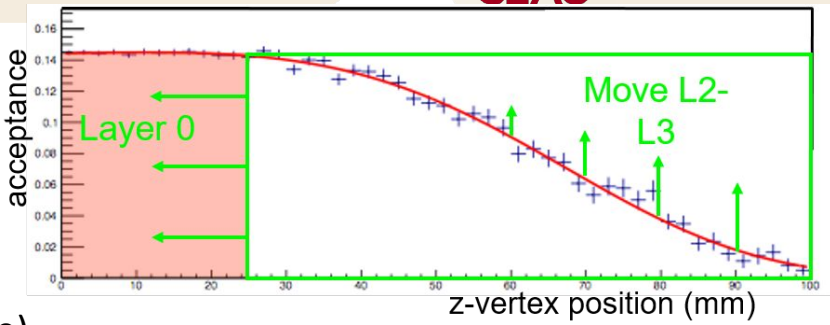
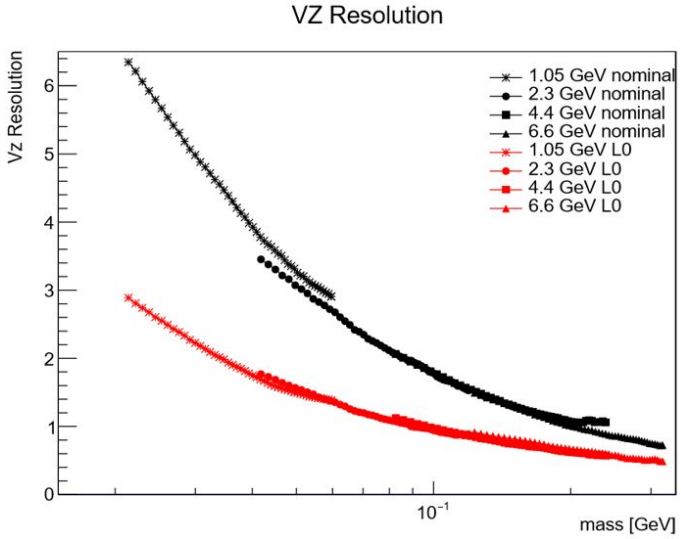
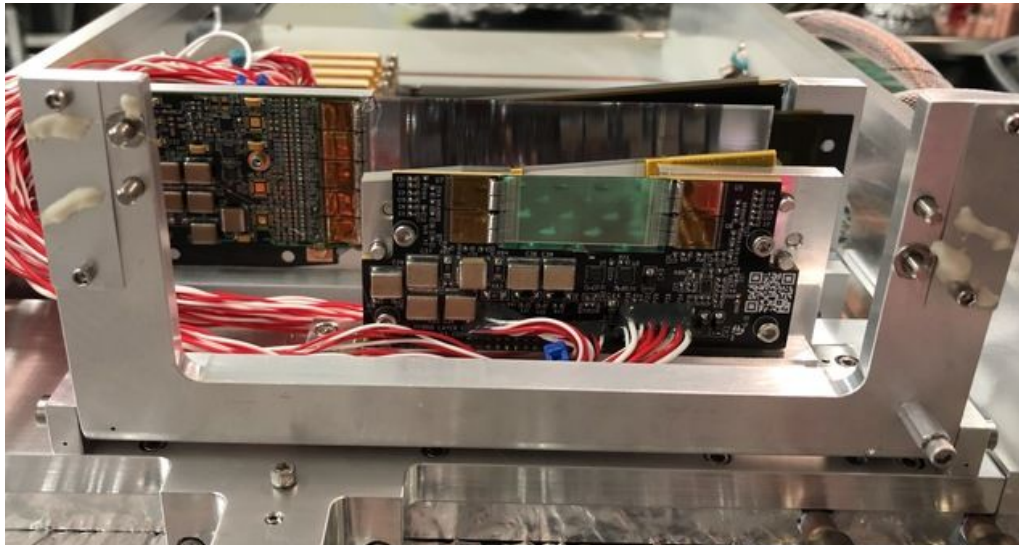
- **Small upgrade projects** will be installed at start of 2019
  - new tracking layer (improved vertex resolution)
  - upgraded trigger (improved signal acceptance)

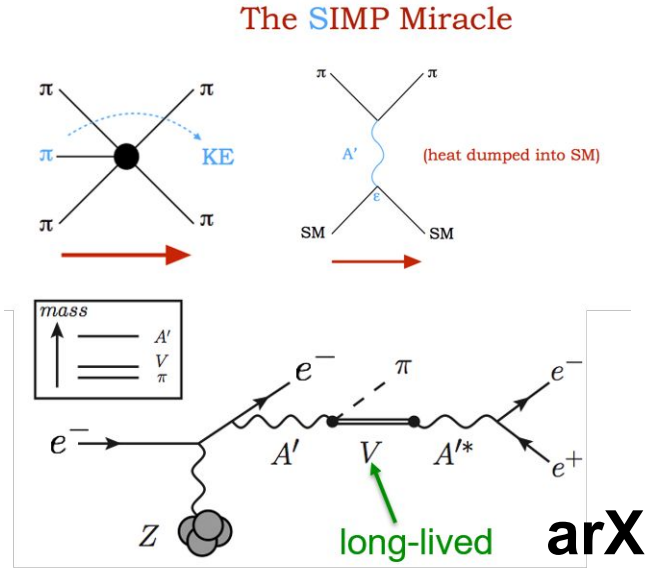




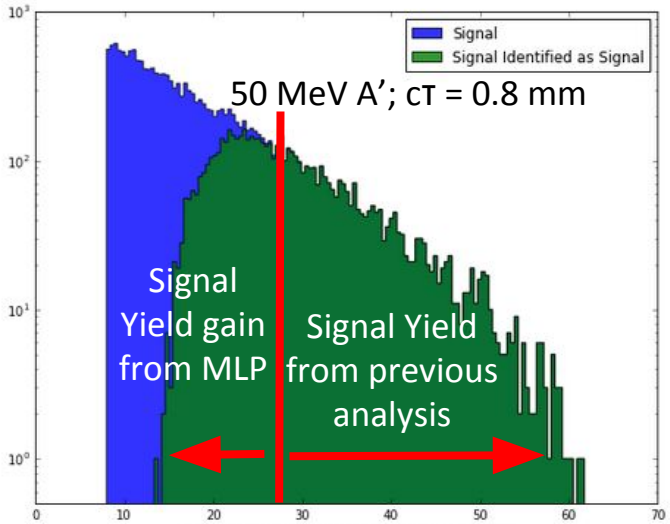


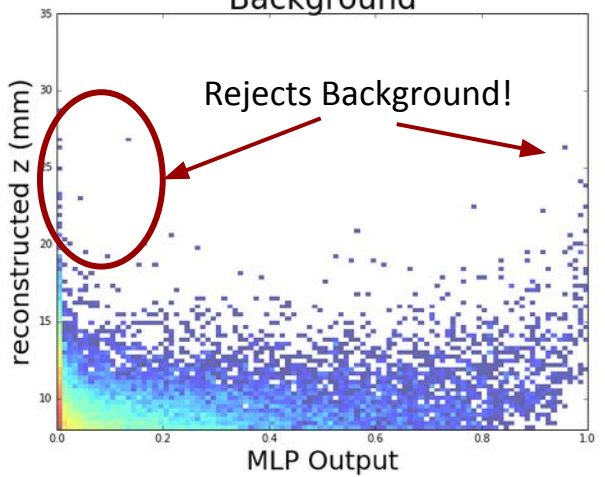
Vertexing Analysis Future

- Preliminary results using a neural network show rejection of high z backgrounds and improved signal yield!
- **Possibly sensitive to Strongly Interacting Massive Particles** (SIMPs) in both 2015 and 2016 datasets



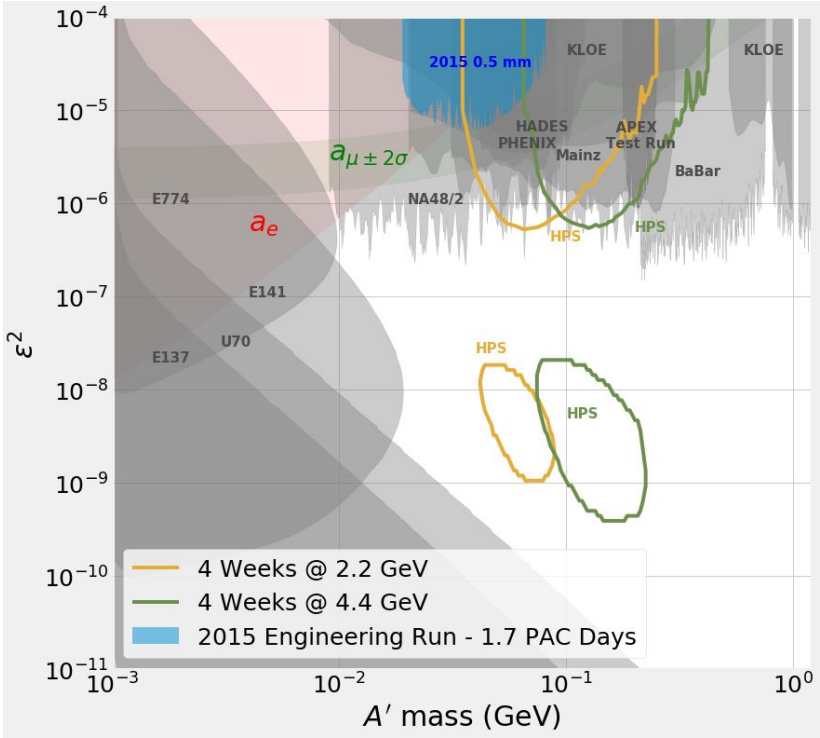
arXiv:1402.5143





Conclusion

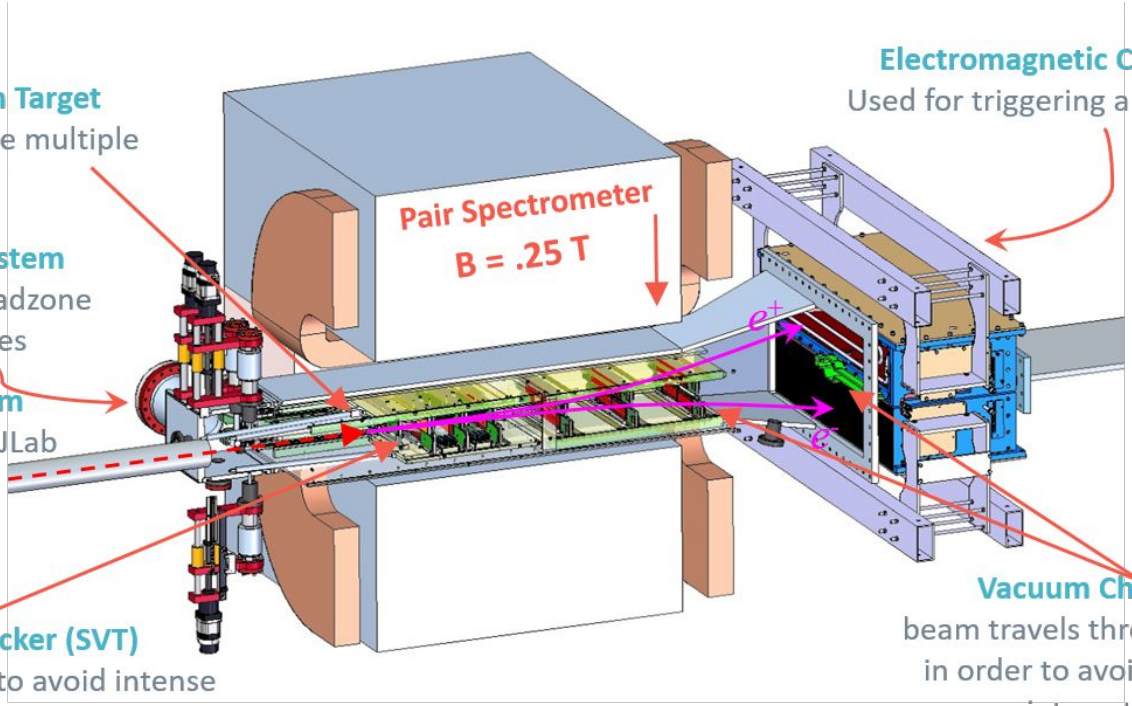
- Heavy photons are well-motivated as a force which mediates LDM-LDM and LDM-SM interactions
- **HPS has successfully completed** two engineering runs at two different beam energies (1.06 GeV in 2015 and 2.3 GeV in 2016)
- **Displaced vertex search technique works for HPS!**
  - Resonance search also shown to be successful
  - More results coming soon for 2016 data
- HPS upgrades are small projects but provide dramatic improvements (construction/installation underway). **HPS is on the JLab run schedule for 9 weeks at 4.4 GeV in 2019 with upgrades!**



Thank You!


HPS Collaboration
May 3 - 5, 2017
Jefferson Lab • Newport News, VA

HPS Detector



~10^{-3} X_0 Tungsten Target
Thin target to reduce multiple scattering

Linear Shift Motion System
Allows adjustment of deadzone between SVT volumes

High intesity e^- beam
Courtesy of CEBAF @ JLab

Silicon Vertex Tracker (SVT)
Split into two volumes to avoid intense flux of scattered beam electrons. Measures momentum and vertex precisely.

Electromagnetic Calorimeter
Used for triggering and particle ID

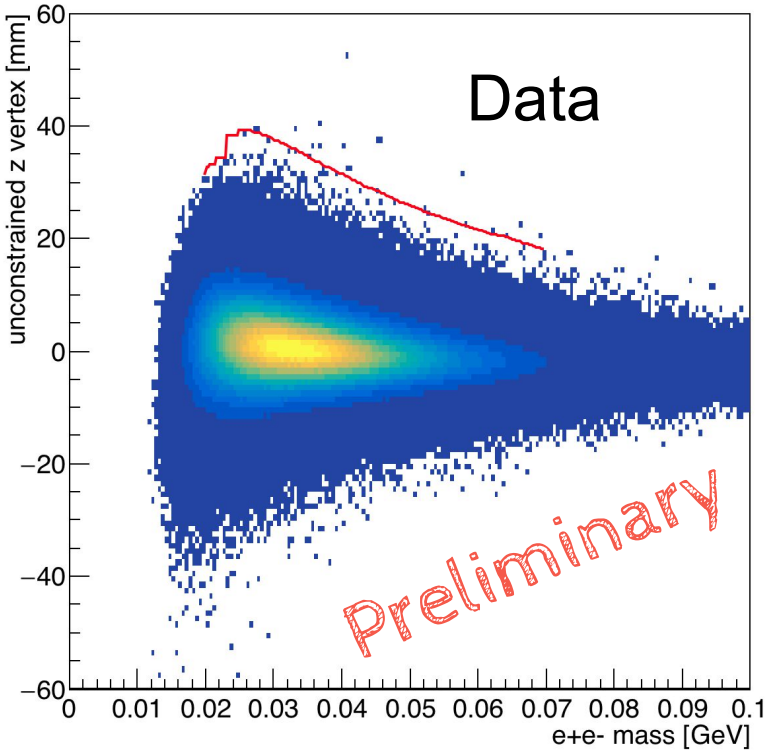
Vacuum Chambers
beam travels through vacuum in order to avoid beam-gas interactions

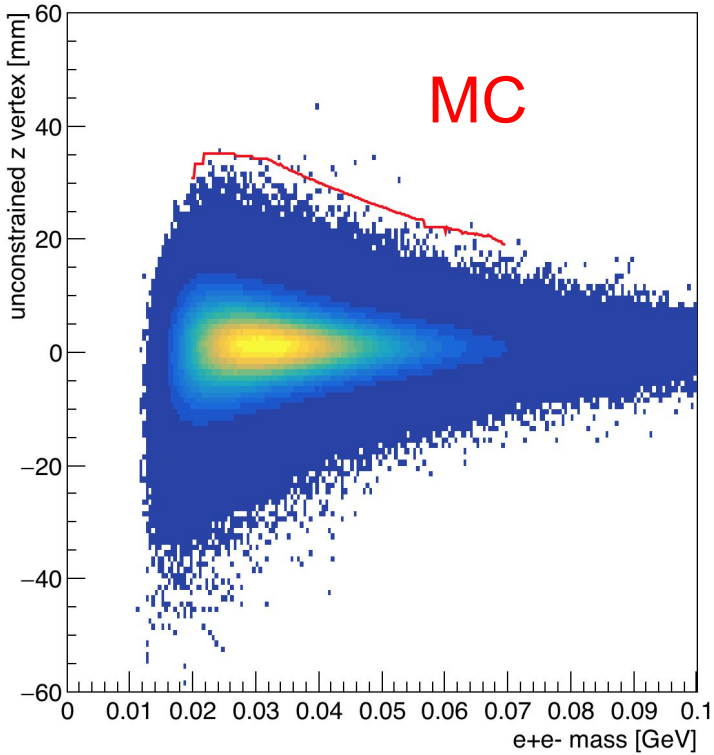
SVT + ECal DAQ capable of 50 kHz

Installed within the Hall B alcove at Jefferson Lab downstream of the CLAS12 detector

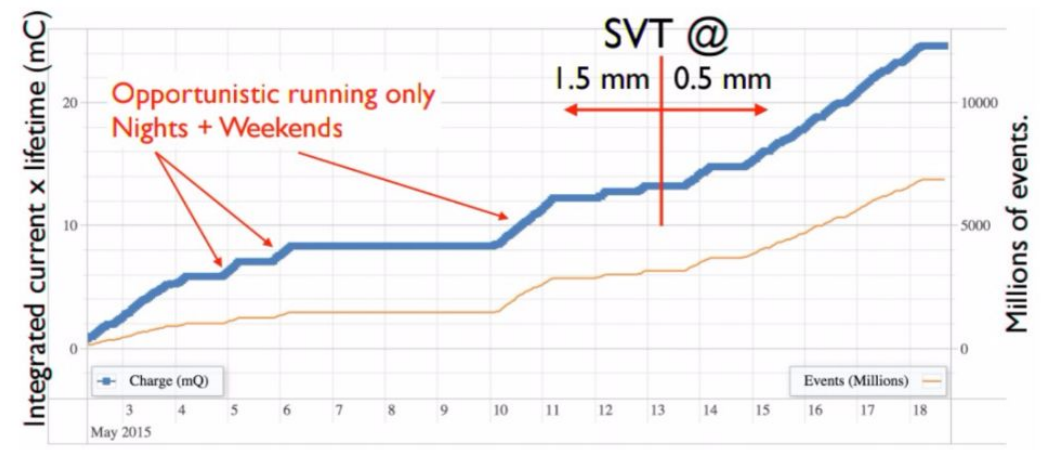
Comparison with MC

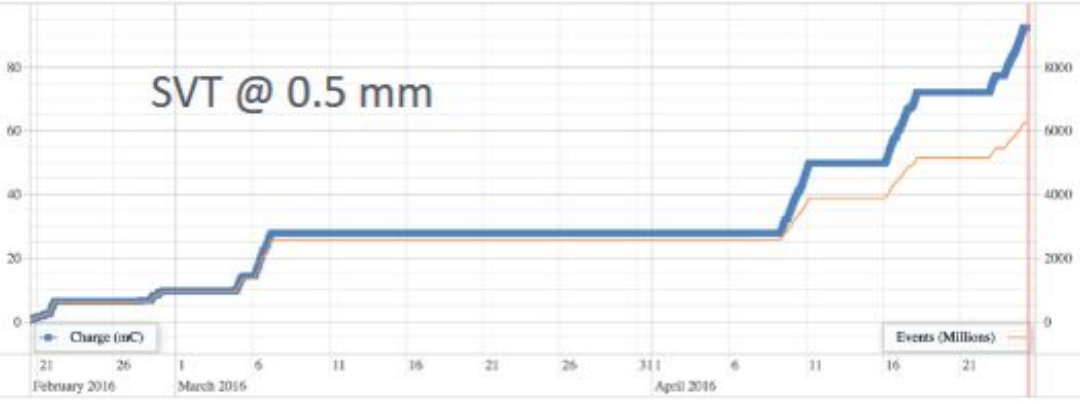
- Data (left) and MC (right) have reasonable agreement at equivalent luminosity





2015 & 2016 Engineering Runs





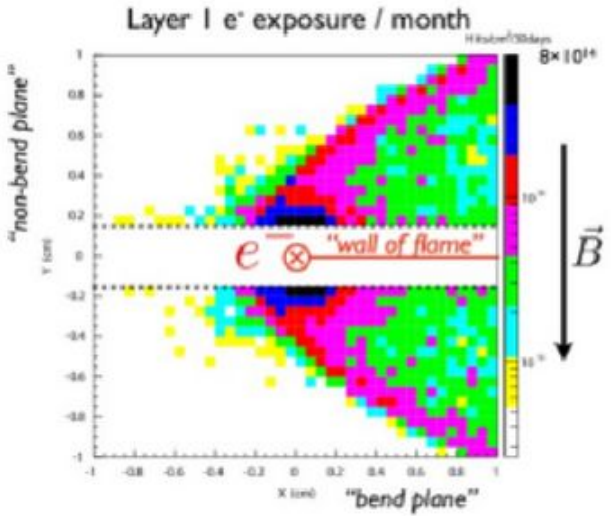
2015 Engineering Run
50 nA at 1.06 GeV
1.7 days (10 mC) of physics data

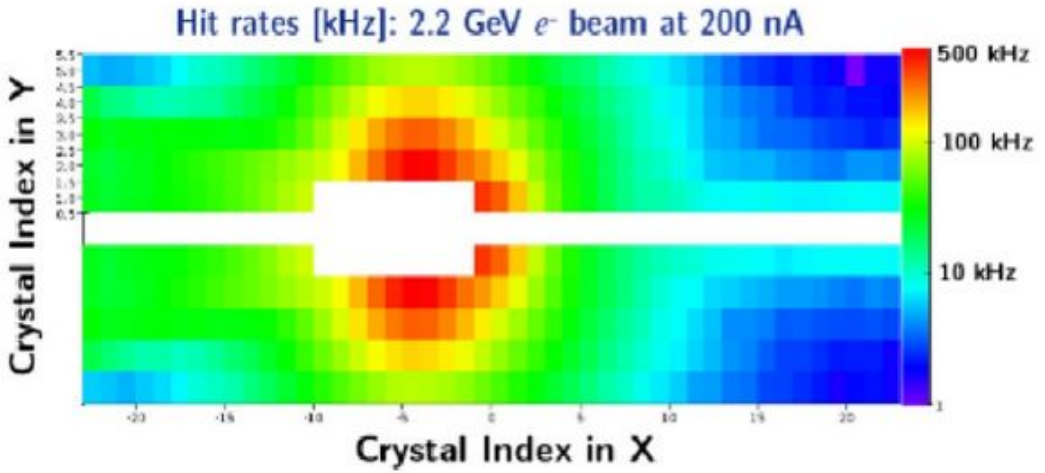
2016 Engineering Run
200 nA at 2.3 GeV
5.4 days (92.5 mC) of physics data

180 days of data taking approved by JLab PAC!

Beam Backgrounds

- Background is dominated by **electron scattering in the target**
- Detector (vertical) acceptance down to +/- 15 mrad (which means L1 of SVT is **0.5 mm from beam axis!**)
- This provides challenges for occupancies, data rates, and radiation tolerances





Jefferson Laboratory and CEBAF

SLAC

- JLab (Newport News, VA) has the Continuous Electron Beam Accelerator Facility (CEBAF) that can simultaneously deliver intense electron beams of different energies to 4 experiment halls
- 1.1 or 2.2 GeV per pass up to 12 GeV and 2 ns bunch pulse
- **Provides small, stable beam spot with minimal halo**