Searching for Long-Lived Dark Photons with the Heavy Photon Search Experiment

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Stanford University
Dissertation Defense Public Talk
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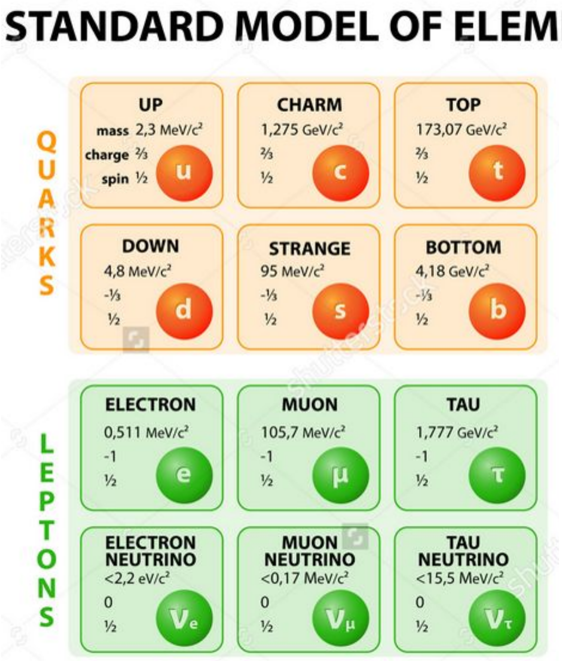
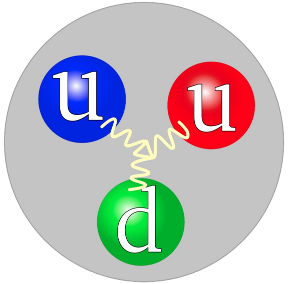
U.S. DEPARTMENT OF ENERGY
Office of Science

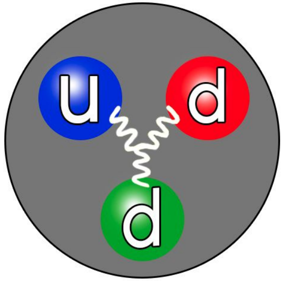
SLAC NATIONAL ACCELERATOR LABORATORY

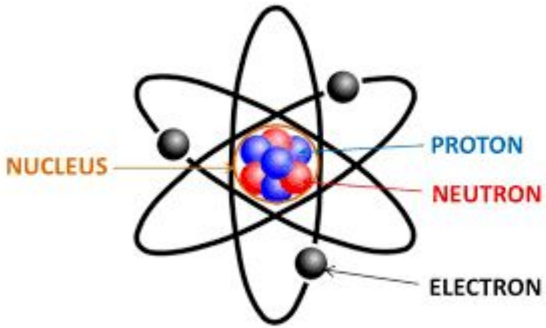
The Standard Model of Particle Physics

1. What fundamental particles exist in nature?



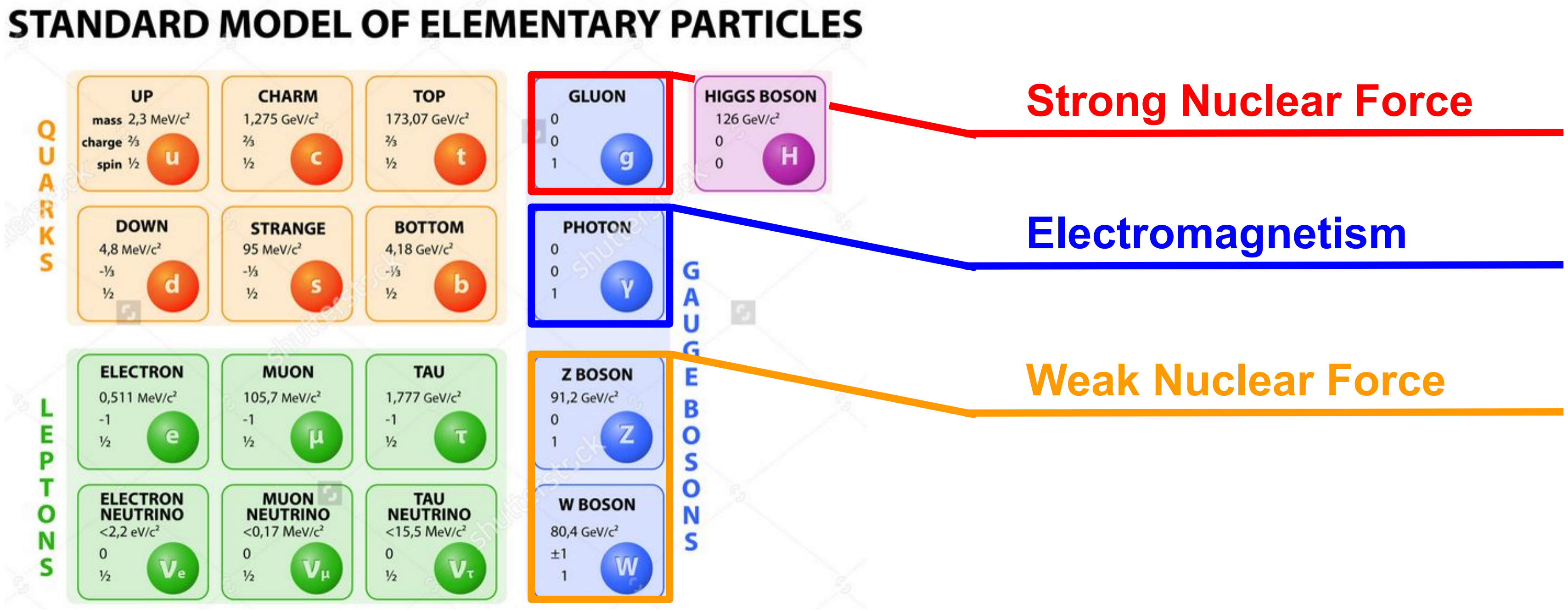






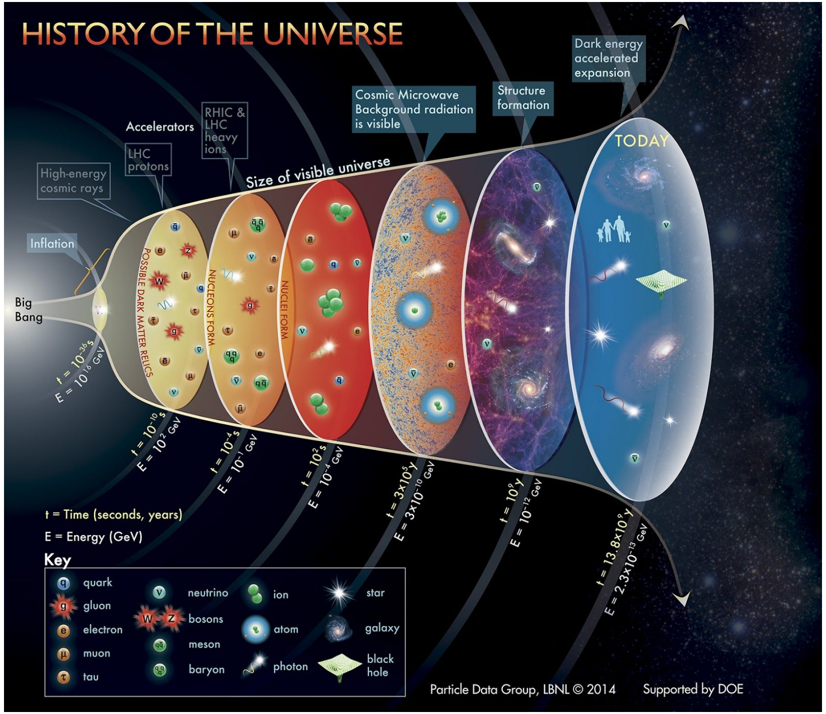
The Standard Model of Particle Physics

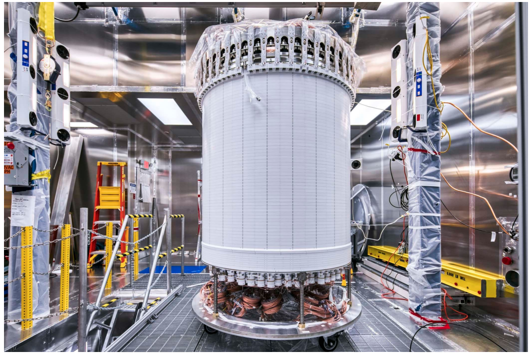
2. How do these particles interact?



The Standard Model of Cosmology (ΛCDM)

3. How did these particles get here?

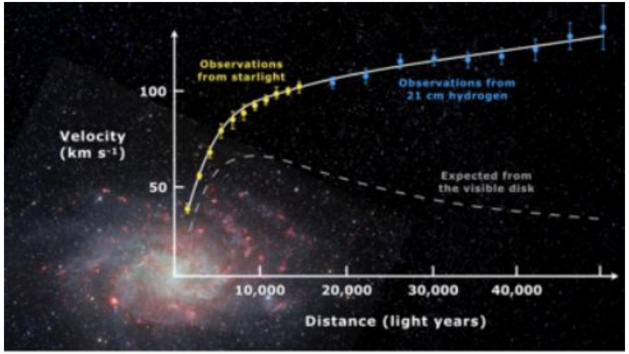




What kinds of experiments do we do?

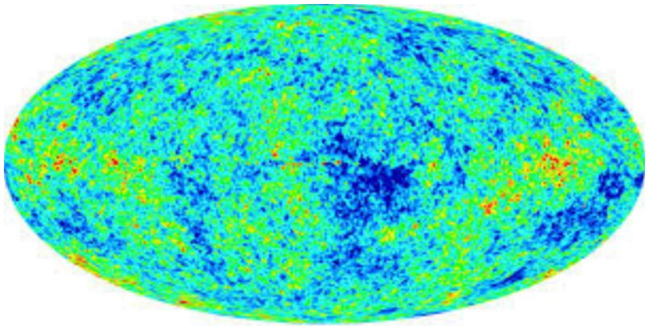
Evidence for Invisible (Dark) Matter

Galactic Rotation Curves

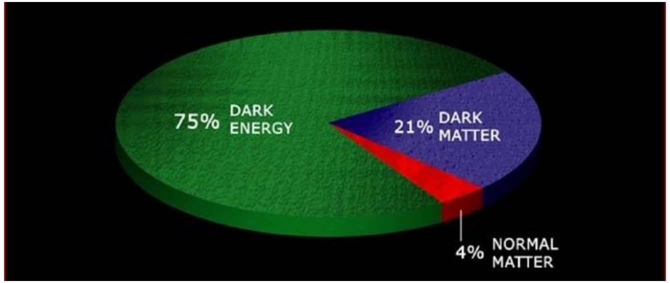


Gravitational Lensing

Cosmic Microwave Background



DM makes up ~85% of the total mass in the universe

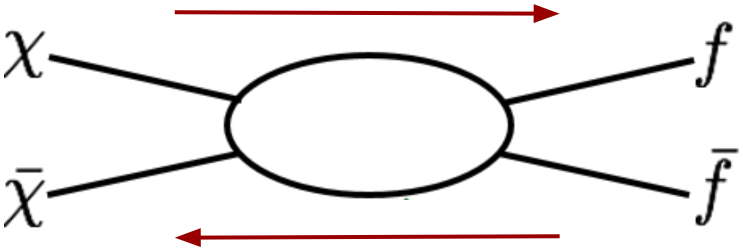


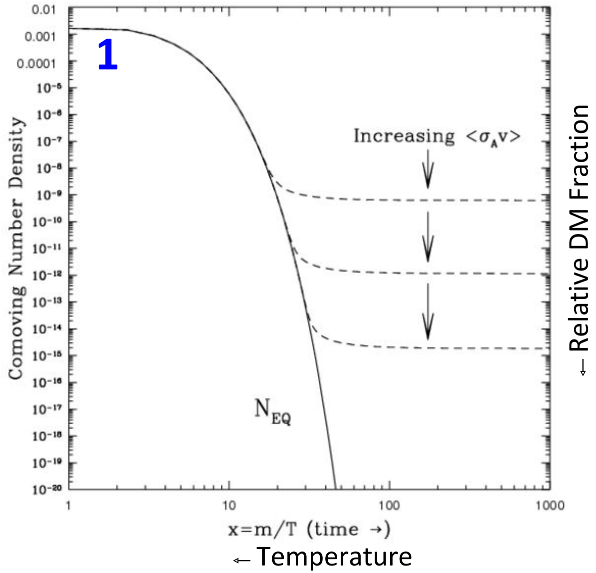
The SM provides no explanation of this missing (dark) matter:

1. What is it?
2. How does it interact?
3. Where did it come from?

Thermally Produced Dark Matter

- What is the origin of DM? Any proposed mechanism must yield 85% DM!
  - **1.** Assume DM was in thermal equilibrium with SM particles (a valid assumption)





Thermally Produced Dark Matter

- What is the origin of DM? Any proposed mechanism must yield 85% DM!
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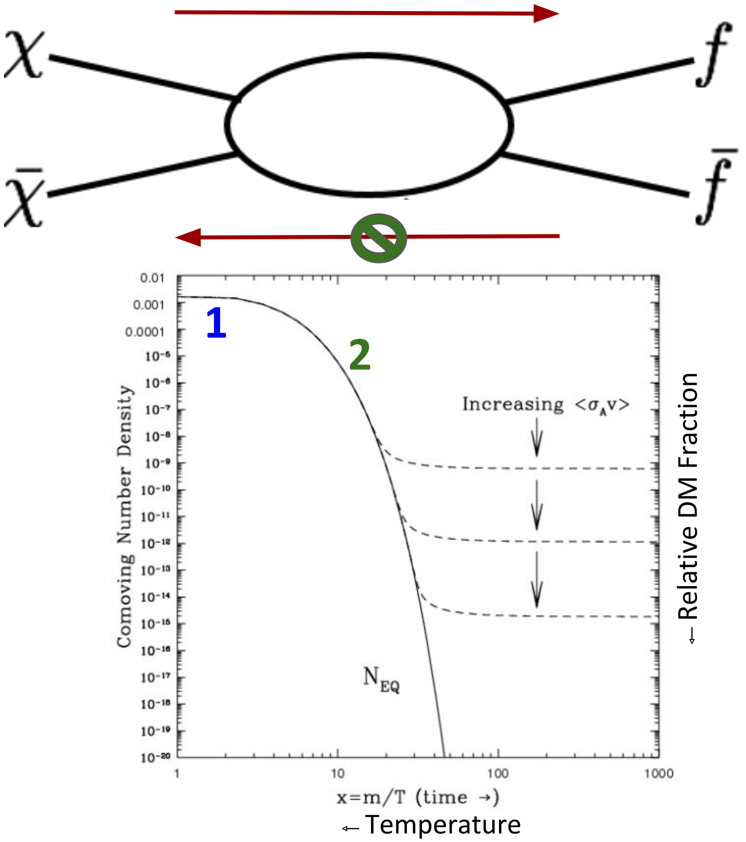
  - **2.** The universe expands and cools such that DM pairs are no longer produced



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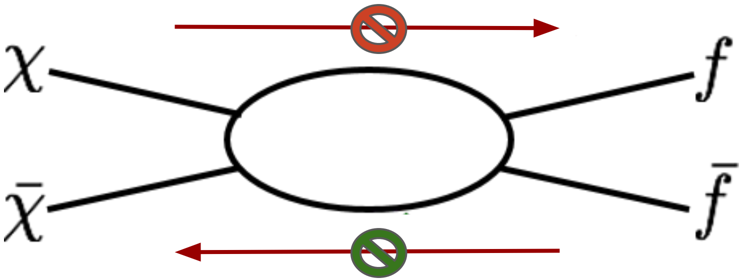

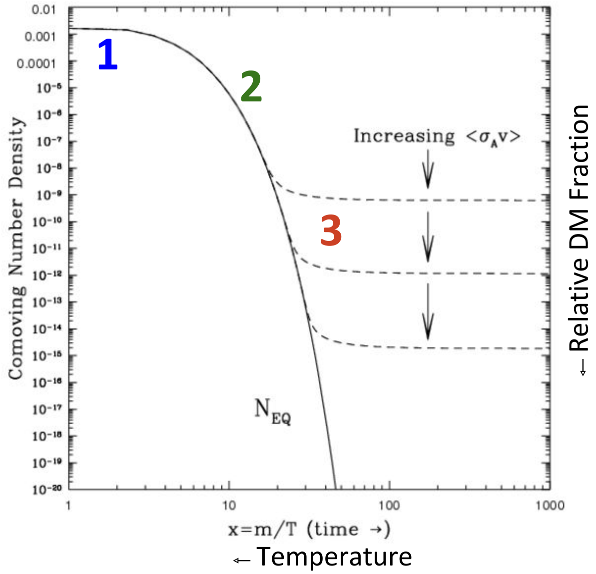

Thermally Produced Dark Matter

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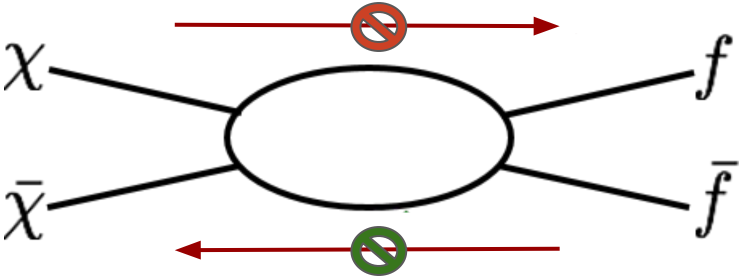
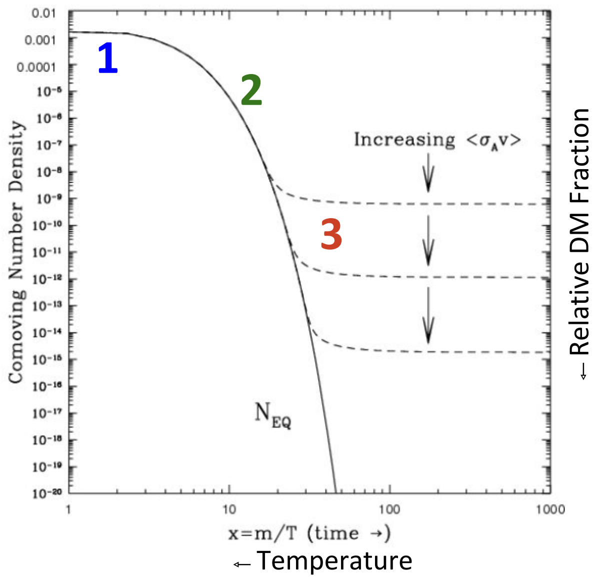
    - **1.** Assume DM was in thermal equilibrium with SM particles (a valid assumption)
    - **2.** The universe expands and cools such that DM pairs are no longer produced
    - **3.** The universe expands and cools such that DM annihilations cease.
- The present DM density Ω_χ is related to the DM annihilation cross-section $\langle \sigma v \rangle$





$$\Omega_\chi \propto \frac{1}{\langle \sigma v \rangle} \longrightarrow \langle \sigma v \rangle = 3 \times 10^{-26} \, \frac{\mathrm{cm}^3}{\mathrm{s}}$$

Weakly Interacting Massive Particles

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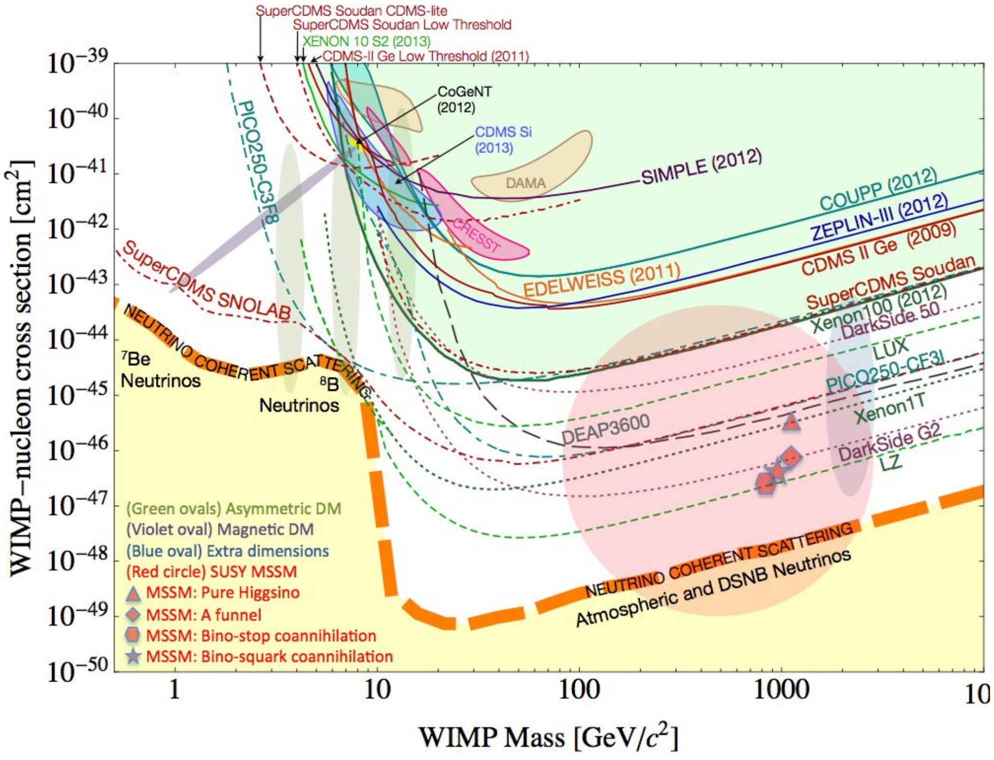
$$\langle \sigma v \rangle \propto \frac{m_\chi^2}{m_Z^4} \Rightarrow m_\chi \approx 100 \text{ GeV}$$

A weak-like particle works! Weakly interacting massive particles (WIMPs) remains the most popular model of DM.

WIMPs have yielded null results so far. Are there other places to look?



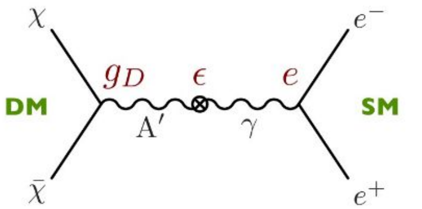
Light Dark Matter

"Lee-Weinberg Bound"

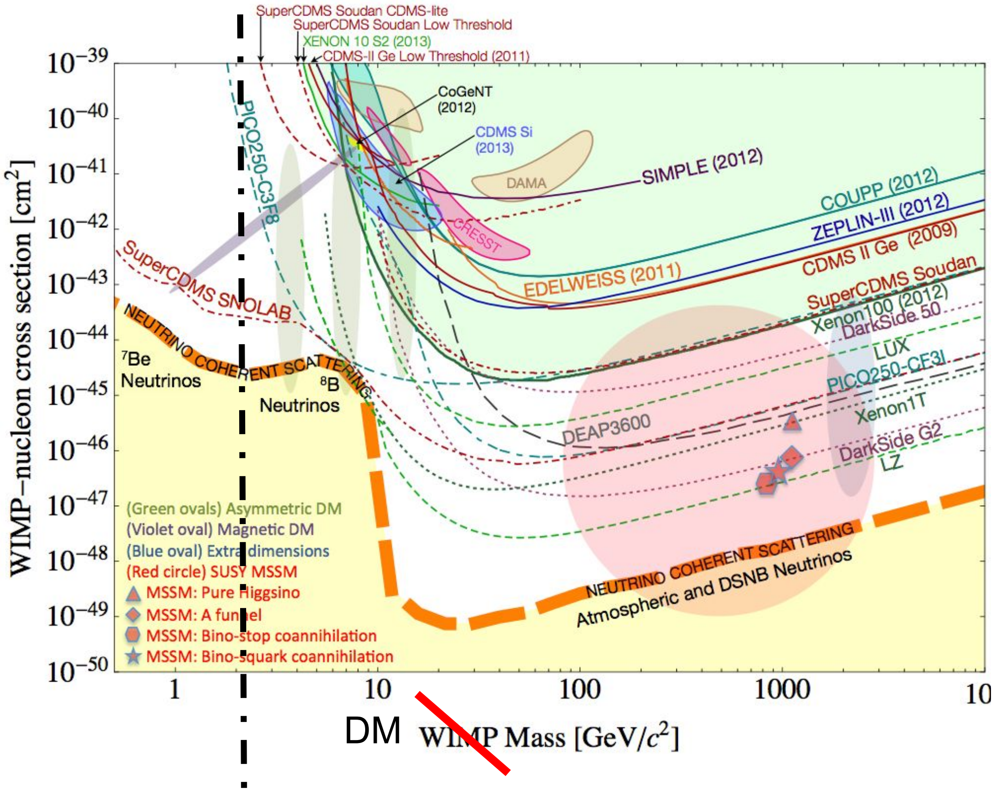
$$\langle \sigma v \rangle \propto \frac{m_\chi^2}{m_Z^4} \Rightarrow m_\chi \gtrsim 2\ \mathrm{GeV}$$

Lighter dark matter requires a **new, comparably light force carrier.**
A simple/natural candidate:
heavy/dark photon (A')

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



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



Light Dark Matter ← → **WIMPs**

Heavy Photon Primer

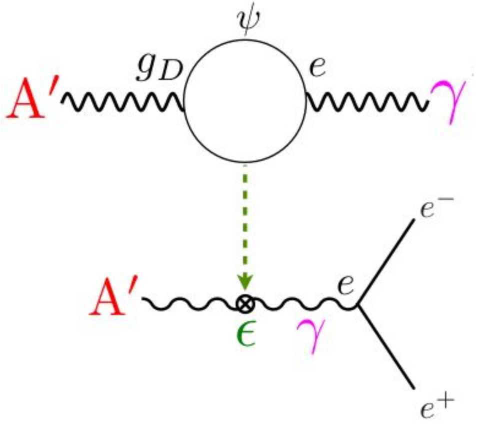
Suppose nature contains an **additional Abelian gauge symmetry** U’(1) (analogous to EM)

This gives rise to a **kinetic mixing term** where the SM photon mixes with a new gauge boson (an A’)

Induces a weak effective coupling of εe to SM fermions

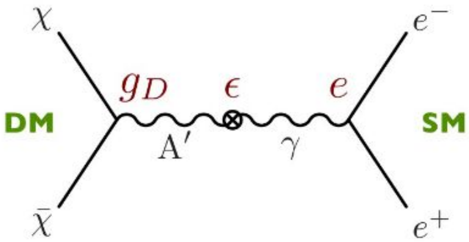
$$\epsilon \sim \frac{e g_D}{16\pi^2} log \frac{M_\psi}{\Lambda} \sim 10^{-4} - 10^{-2}$$

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



Two Parameter Model:
Mass of A’ and ε

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



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

A Dark Sector

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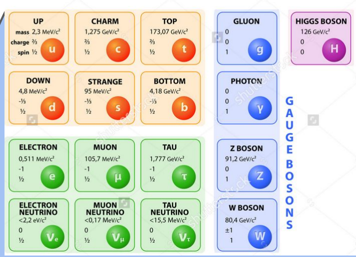
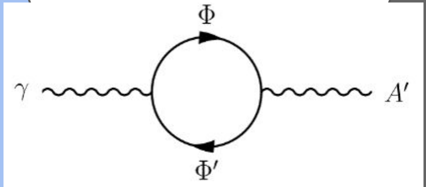
Regular Forces and Matter (Standard Model)



Dark Forces and Matter (Dark Sector)



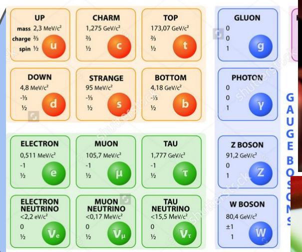
$$\epsilon F^{\mu\nu} F'_{\mu\nu}$$

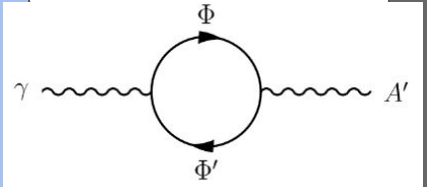
"Vector Portal"

What types of experiments can search for heavy photons?

A Dark Sector

Regular Forces and Matter (Standard Model)





$$\epsilon F^{\mu\nu} F'_{\mu\nu}$$

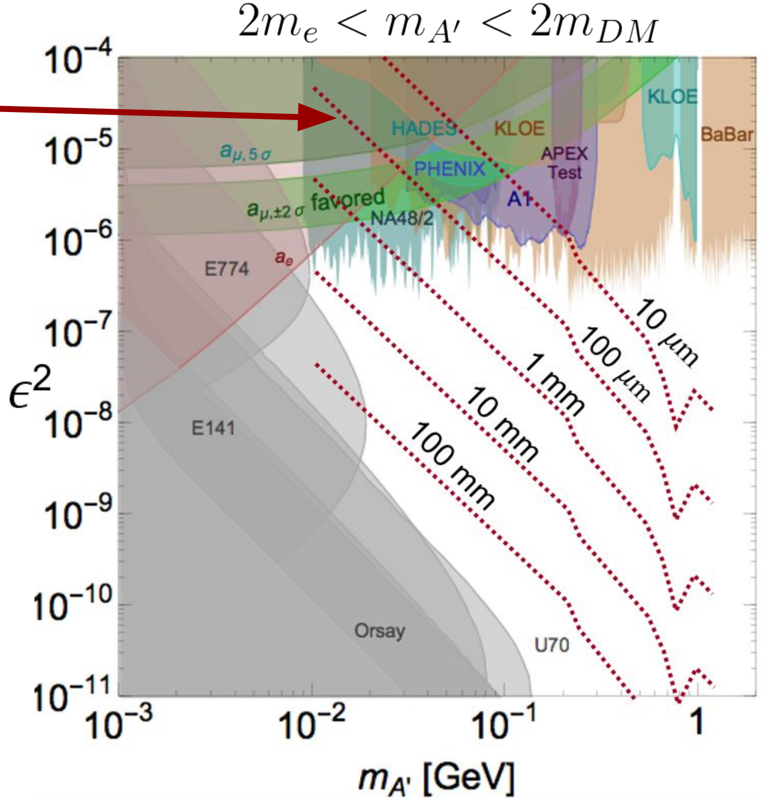
“Vector Portal”

Dark Forces and Matter (Dark Sector)

What types of experiments can search for heavy photons?

Existing Heavy Photon Constraints

Large coupling searches are generally **"bump hunts"** for $m(l^+l^-)$ resonances

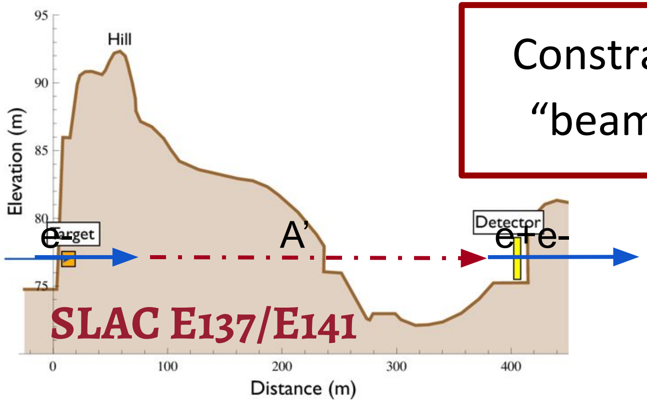


Existing Heavy Photon Constraints

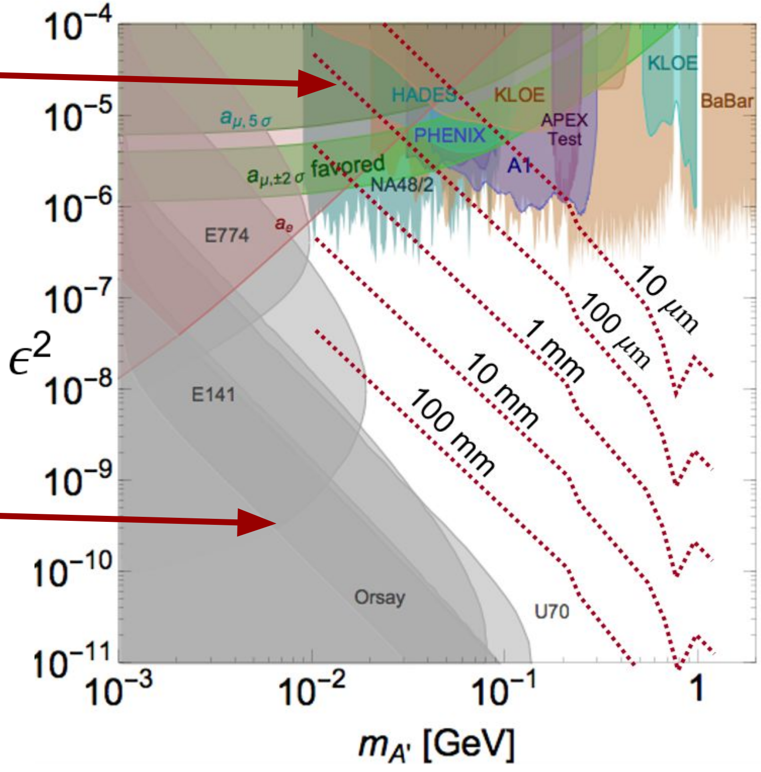
Large coupling searches are generally **"bump hunts"** for $m(l^+l^-)$ resonances

A's with small coupling are **long-lived**

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

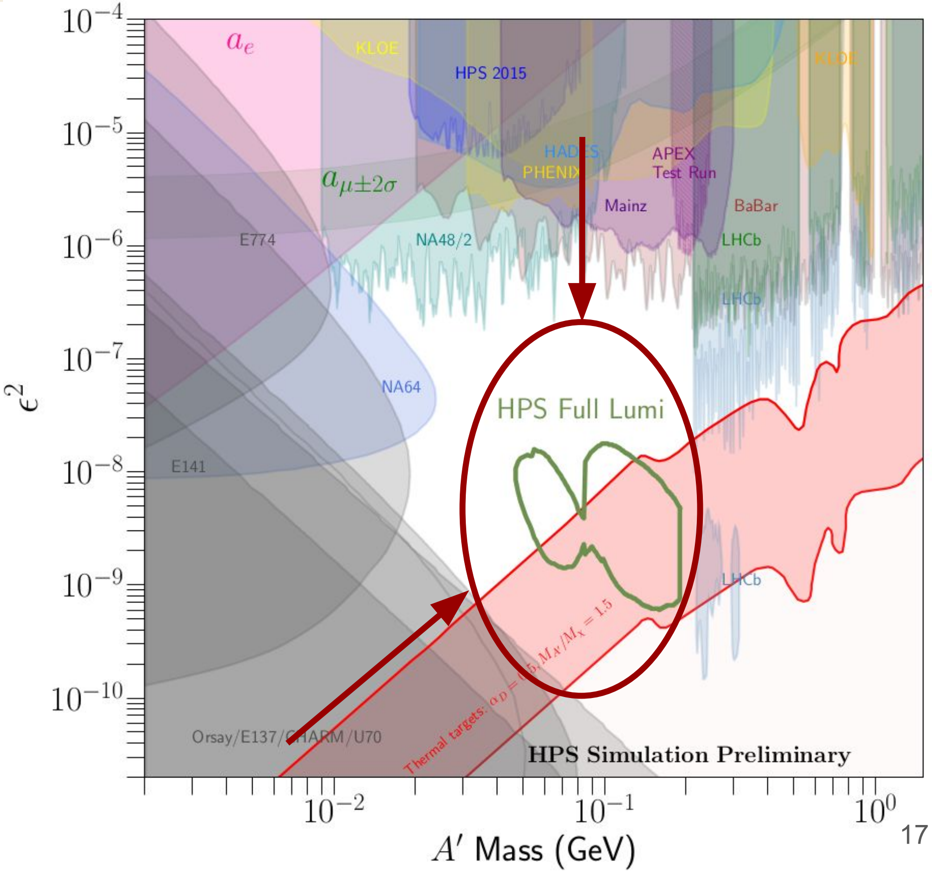


Constraints from "beam dumps"



Probing New Heavy Photon Territory

- How to probe the highly motivated untouched territory?
- “From above”
  - Resonance searches - need more data or improved mass resolution
- “From below”
  - Displaced vertex search - need to reconstruct particles with excellent vertex resolution. A very challenging task!



Heavy Photon Kinematics and Design Considerations

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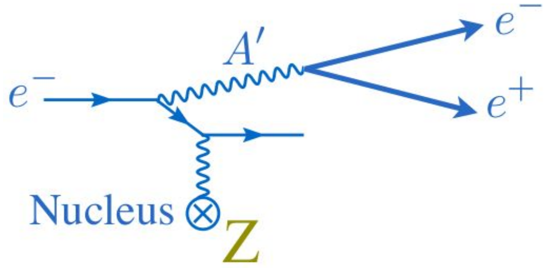
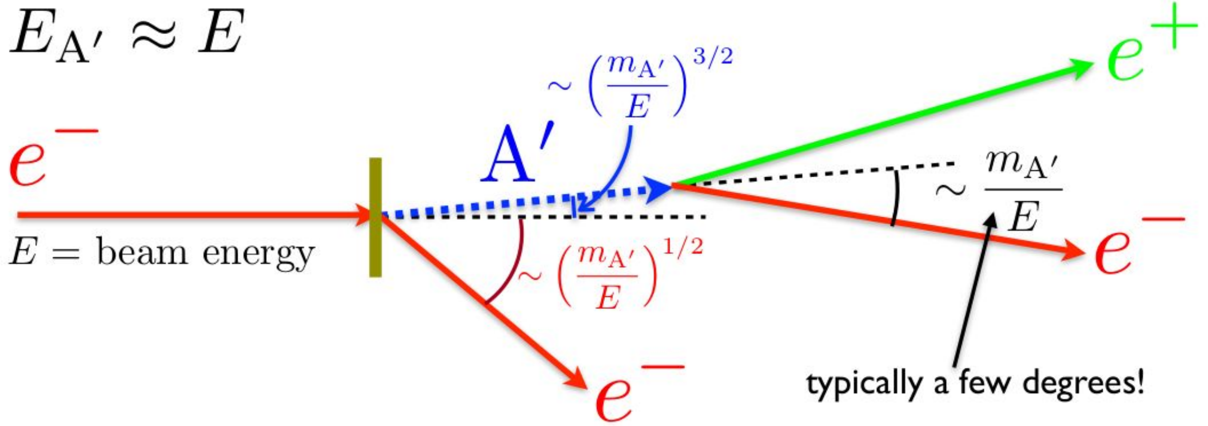
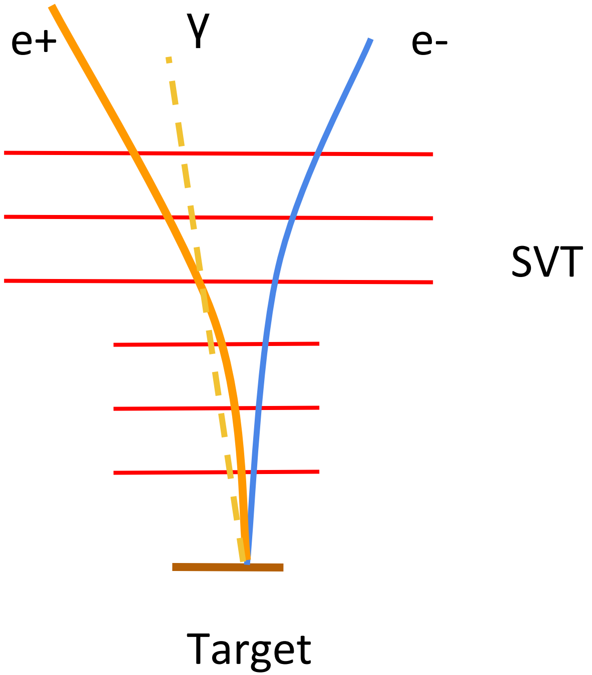
- A’s can be produced in a process **analogous to Bremsstrahlung** (dark Bremsstrahlung)
- A’s take most of beam energy - decay products are forward with small opening angle
- Detector **acceptance must be very forward** (very close to beam plane)





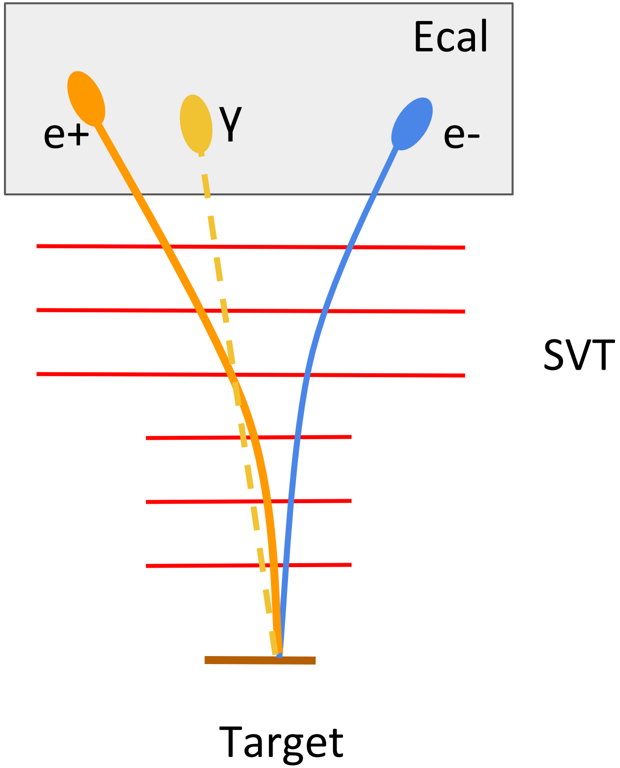
HPS Apparatus

- Silicon Vertex Tracker (SVT) measures trajectories of e+e- and **reconstructs mass and vertex position**



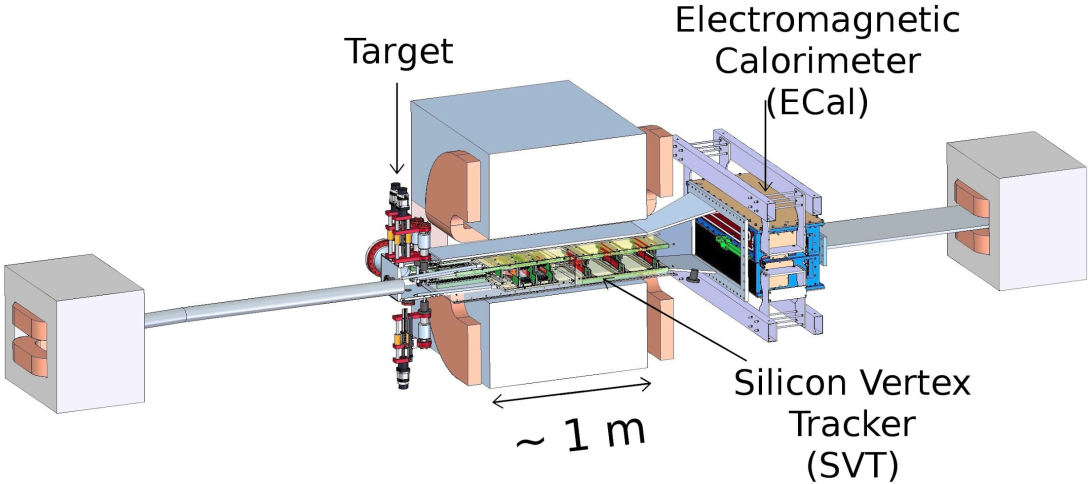
HPS Apparatus

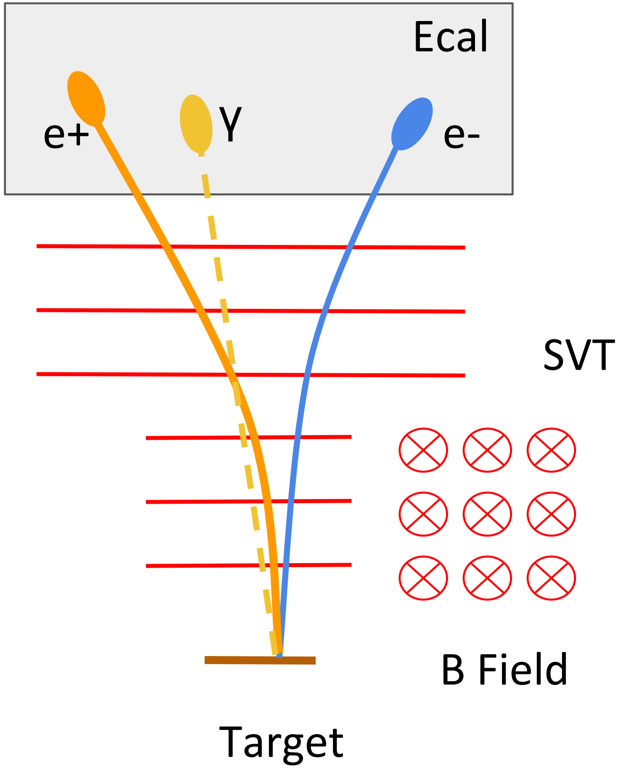
- Silicon Vertex Tracker (SVT) measures trajectories of e+e- and **reconstructs mass and vertex position**
- Electromagnetic Calorimeter (Ecal) provides **e+e- trigger with precision timing**



HPS Apparatus

- Silicon Vertex Tracker (SVT) measures trajectories of e+e- and **reconstructs mass and vertex position**
- Electromagnetic Calorimeter (Ecal) provides **e+e- trigger with precision timing**
- Dipole magnet spreads e+e- pairs and provides curvature for momentum measurement and PID

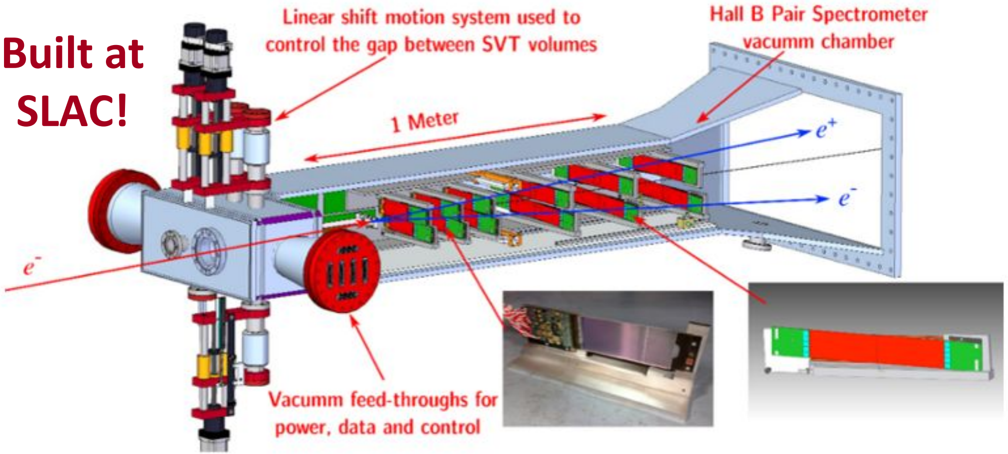


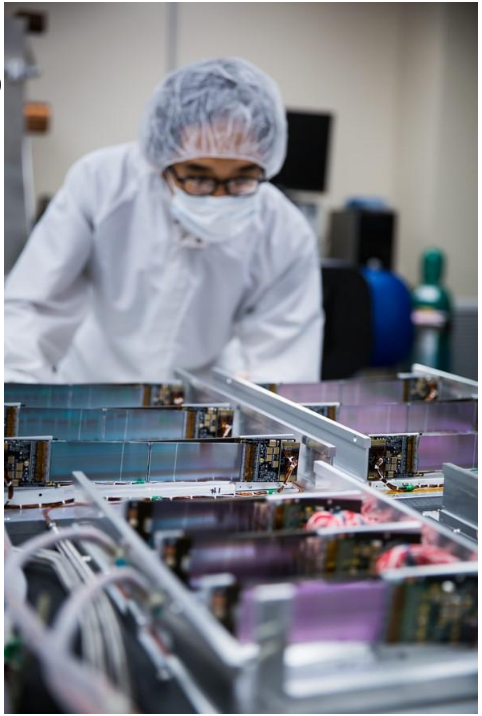


Silicon Vertex Tracker

- Detector (vertical) acceptance down to +/- 15 mrad (which means L1 of SVT is **0.5 mm from beam axis!**). Split into two top/bottom halves
- 6 layers of silicon microstrips (~0.7% radiation length per layer)
- Each layer has 2 sensors - axial/stereo strips for 3D hit position
- L1-L3 vertically retractable from beam
- L4-L6 are double wide for acceptance purposes

Built at SLAC!





HPS SVT

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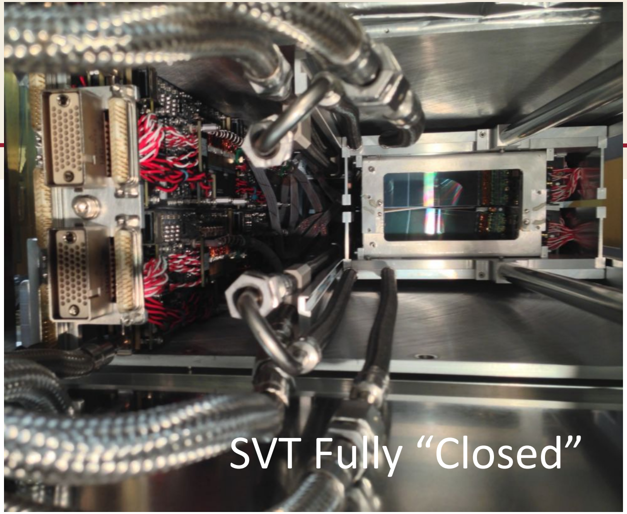
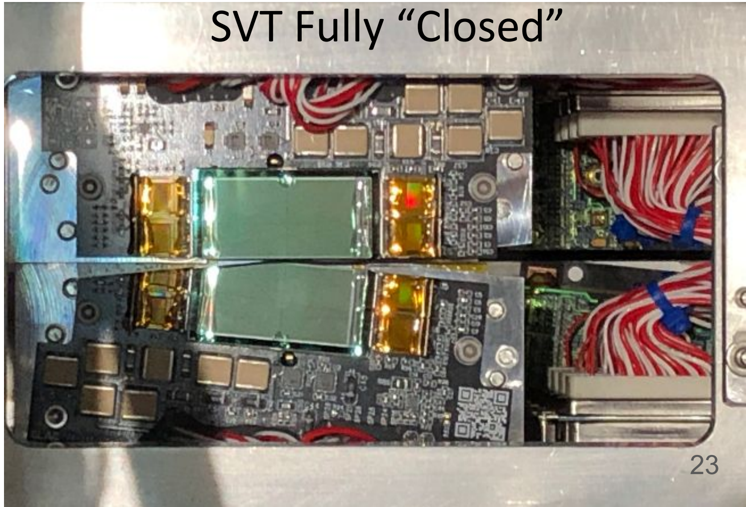
Top: Engineering Run Detector (focus of this talk)
Bottom: Upgraded Detector

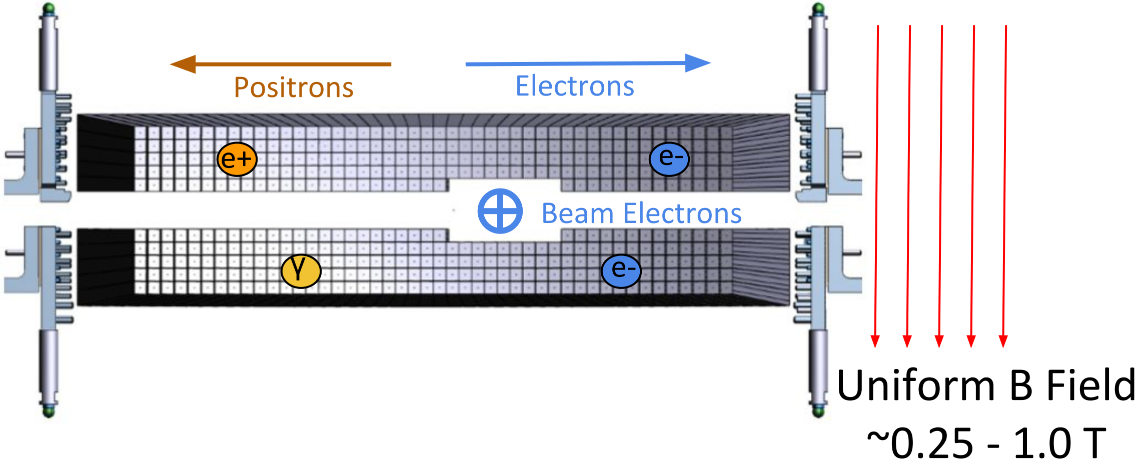


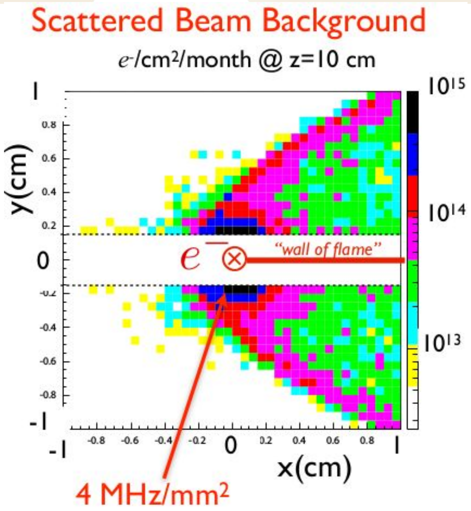
Open: configuration used for beam tuning
Closed: configuration used for operation. **0.5 mm from the beam!**



Electromagnetic Calorimeter and Trigger

- Ecal made out of 442 lead tungstate (PbWO4) crystals and built by JLab/Orsay/INFN
- >100 kHz max trigger rate with 8 ns trigger window
- Background is dominated by **electrons scattering in the target.** Trigger eliminates 10's MHz of these
- Split in top/bottom halves to avoid "wall of flame"



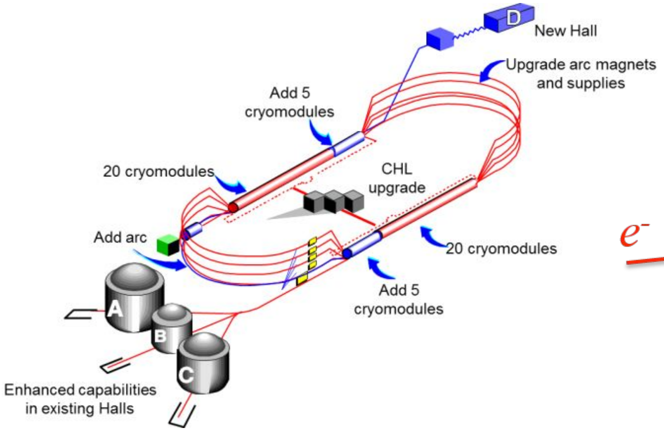


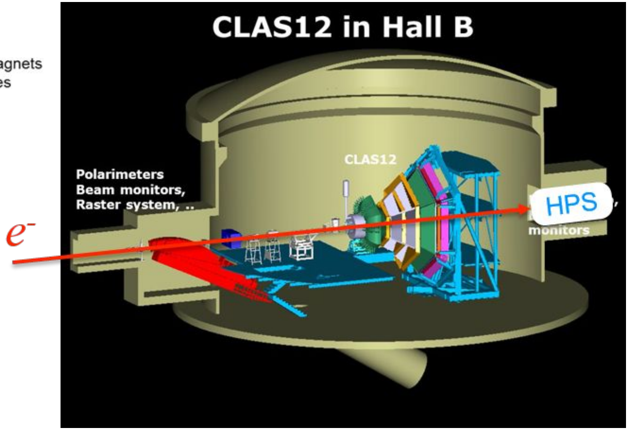
Trigger selects on opposite top/bottom clusters:

- Cluster Time Difference
- Cluster Energy
- Cluster Energy Sum
- Cluster Energy Difference
- Cluster Coplanarity

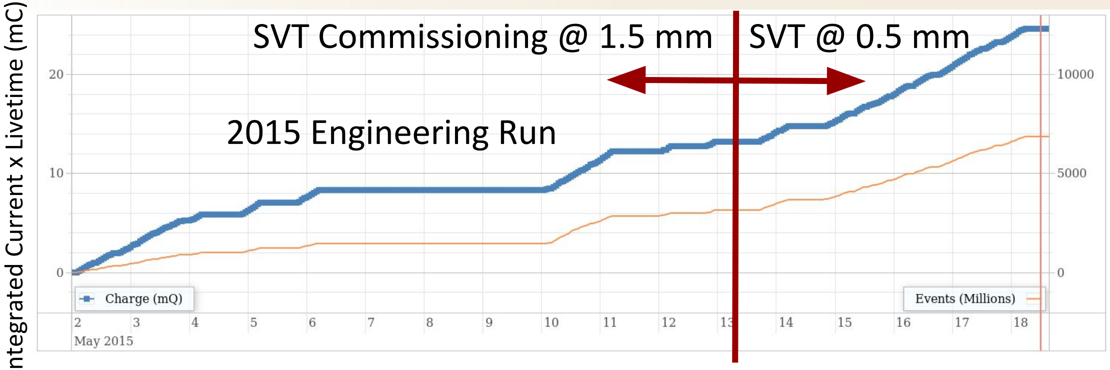
Jefferson Laboratory and CEBAF

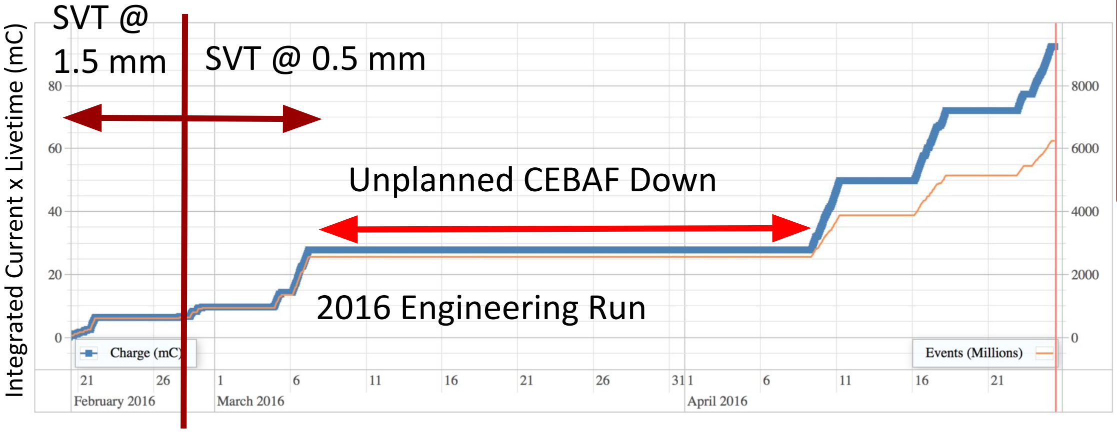
- JLab (Newport News, VA) has the Continuous Electron Beam Accelerator Facility (CEBAF) that can simultaneously deliver intense **continuous** electron beams of different energies to 4 experiment halls
- 2.2 GeV per pass up to 12 GeV and 2 ns bunch pulse
- **Provides small beam spot with small tails** (~10^{-6})





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!

HPS Reconstruction

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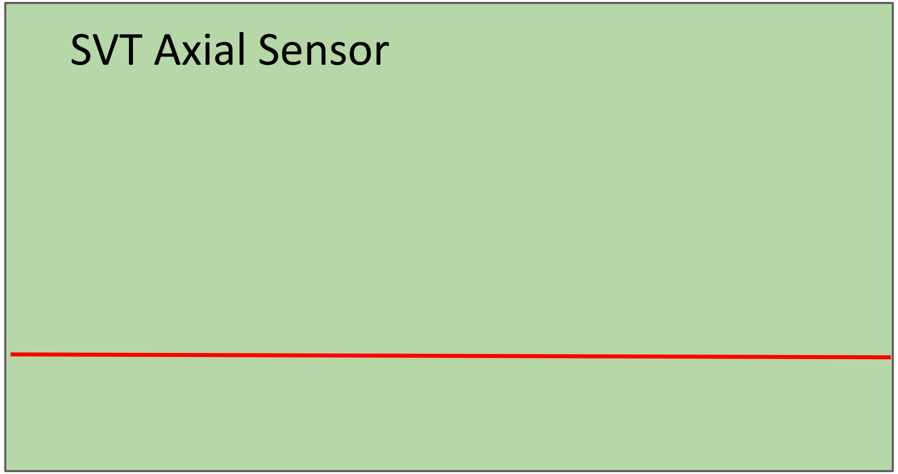
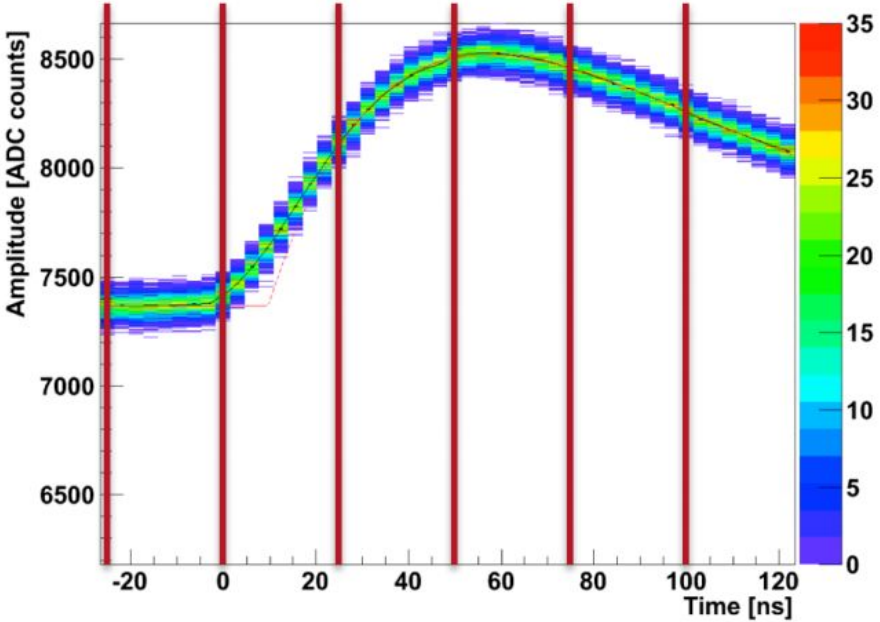
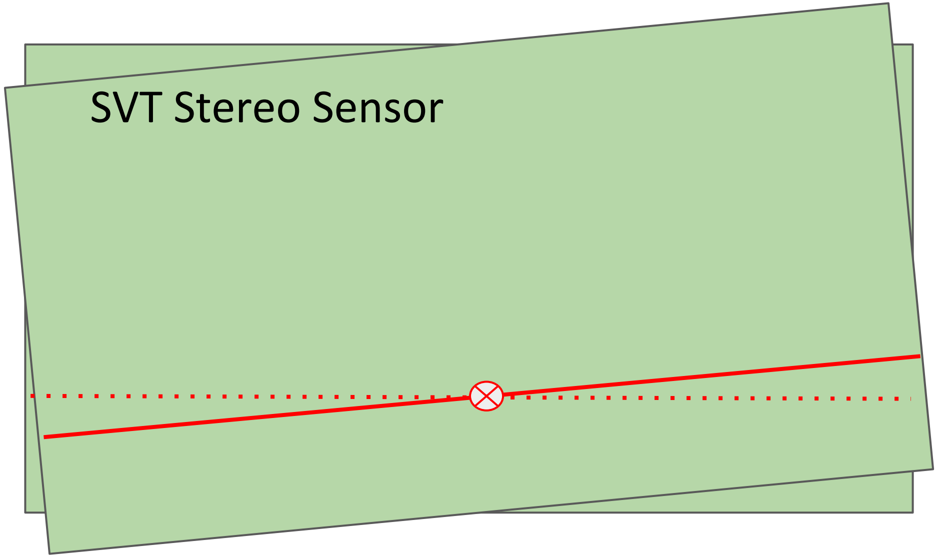


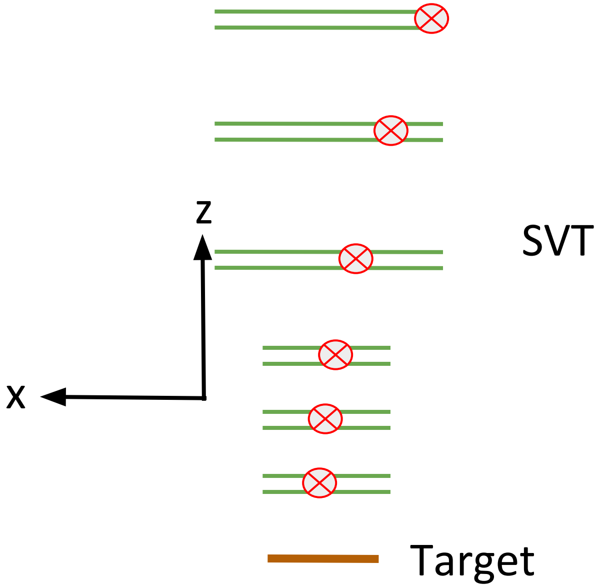
A typical pulse from an APV25 readout chip for a given silicon strip (channel)



Step 1: Form 1D Hits.
Fit pulses readout on individual strips in the SVT sensors. Cluster neighboring strips together.

HPS Reconstruction

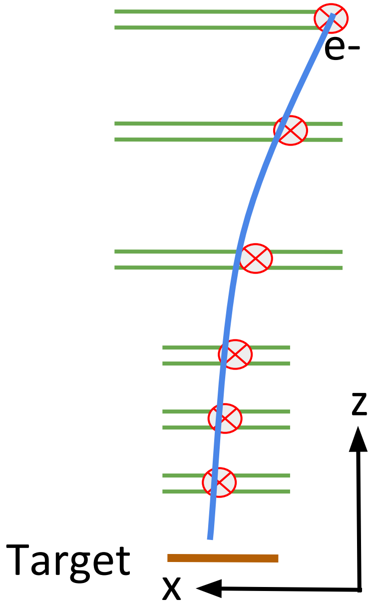


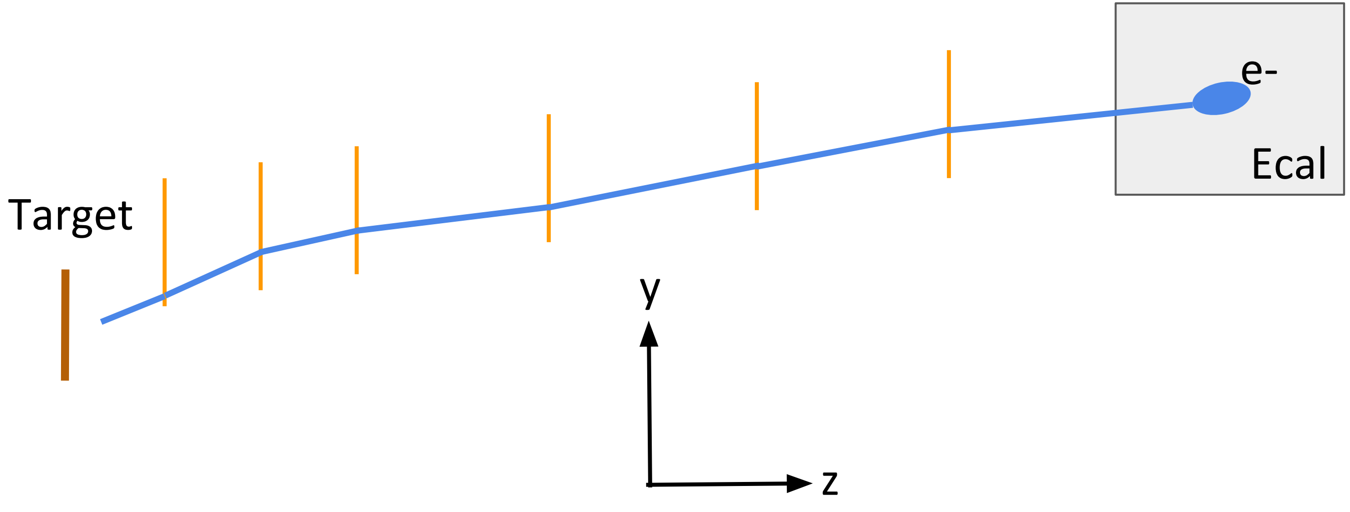


Step 2: Form 3D Hits.
Find axial/stereo pairs where strips cross in space.

Step 3: Repeat for each of 6 SVT layers.

HPS Reconstruction



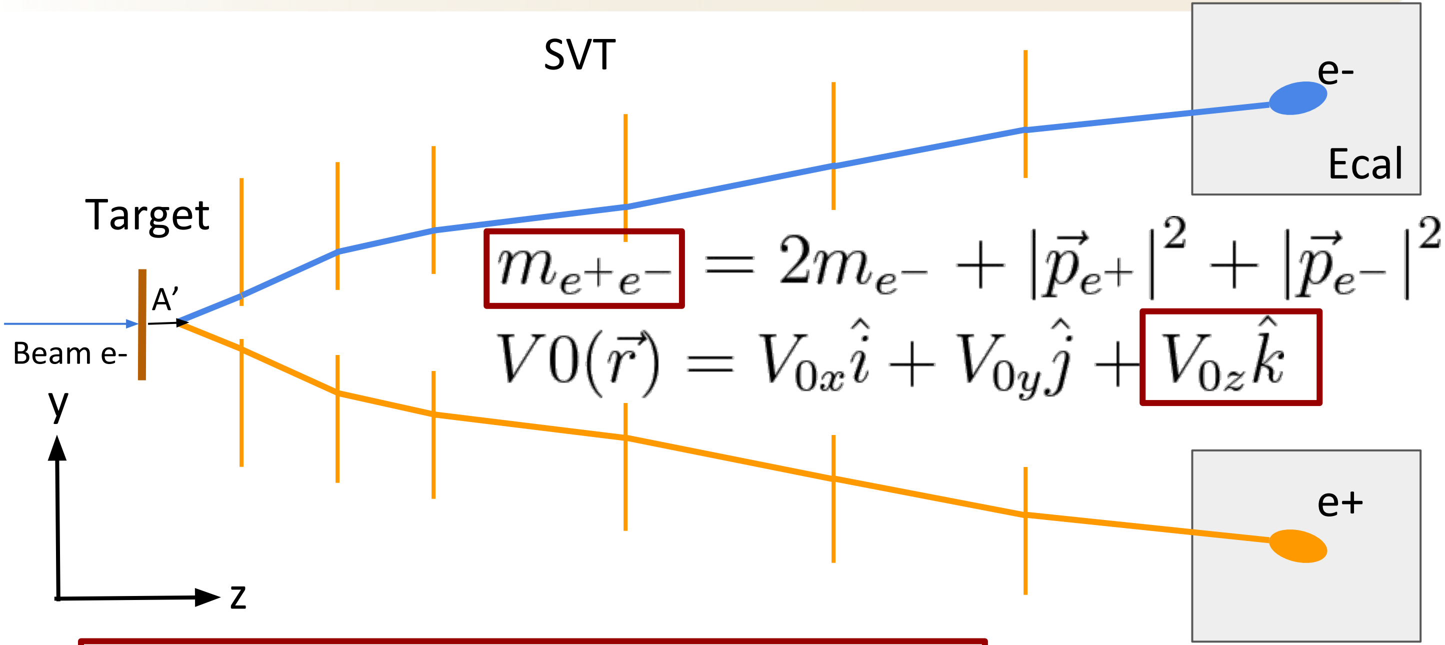


Step 4: Find Tracks (particle trajectories) with the SeedTracker algorithm.

Step 5: Account for multiple scattering with General Broken Lines (GBL) and match tracks to Ecal Clusters

HPS Reconstruction

SLAC



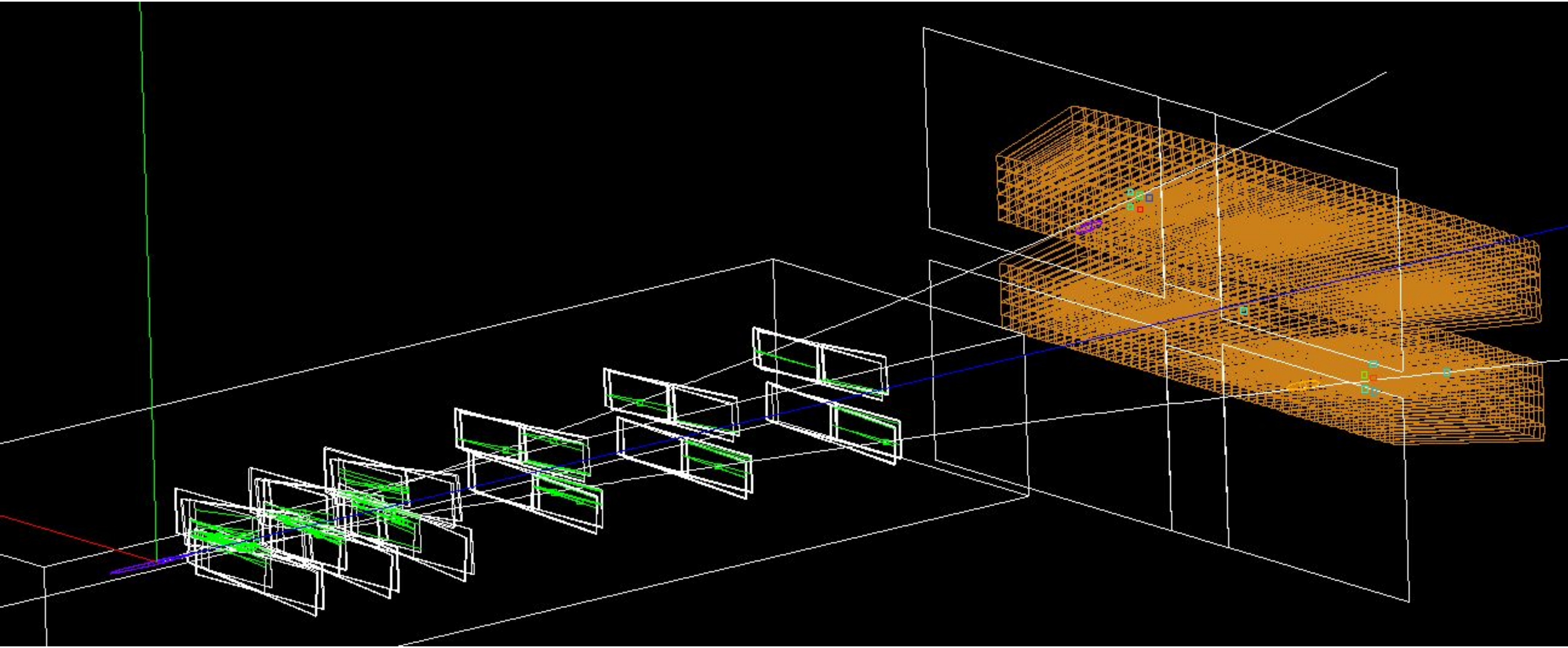
$$\boxed{m_{e^+e^-}} = 2m_{e^-} + |\vec{p}_{e^+}|^2 + |\vec{p}_{e^-}|^2 - |\vec{p}_{e^+} + \vec{p}_{e^-}|^2$$

$$V0(\vec{r}) = V_{0x}\hat{i} + V_{0y}\hat{j} + \boxed{V_{0z}\hat{k}}$$

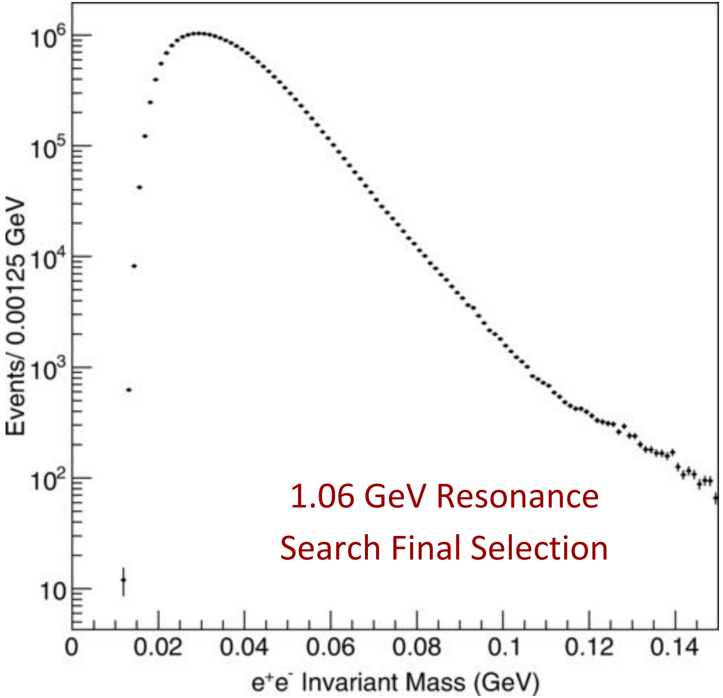
Step 6: Repeat for both halves of SVT. Form vertices (V0s) with top/bottom e+e- pairs. Reconstruct mass and vertex position.

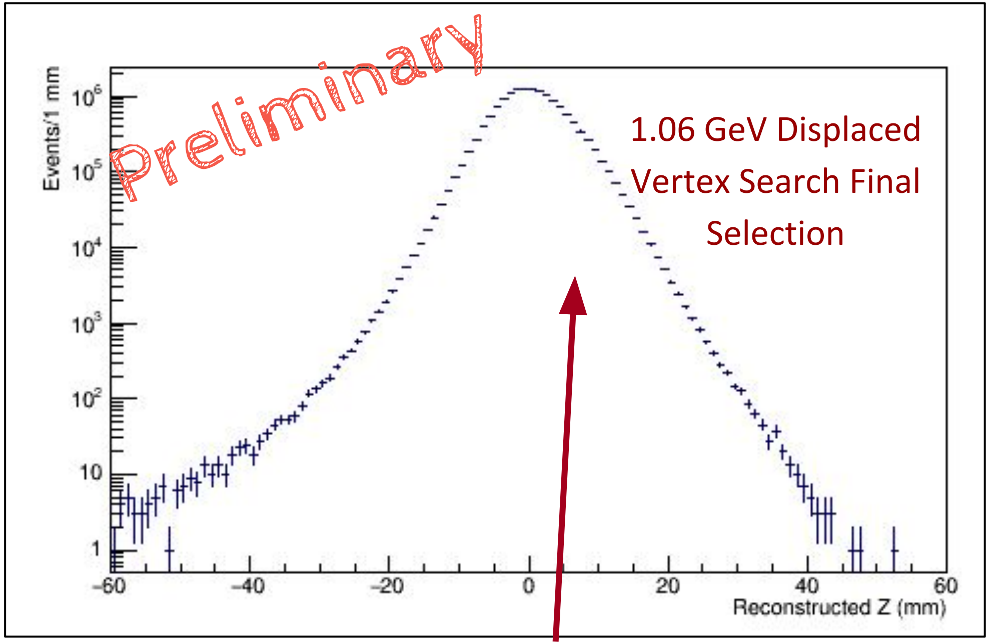
Mass and **decay length** are the most important measurements

HPS Reconstruction



e+e- Backgrounds





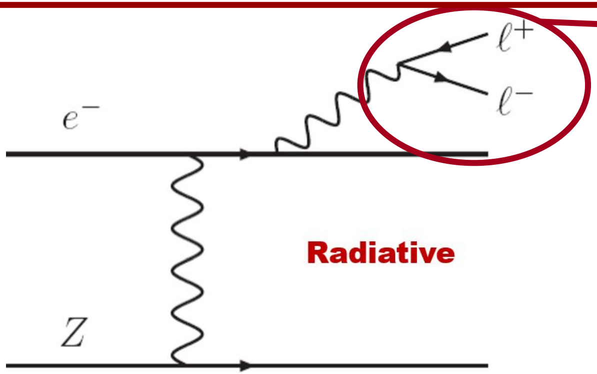
Large number of prompt e+e- pairs observed
What are these e+e- backgrounds?

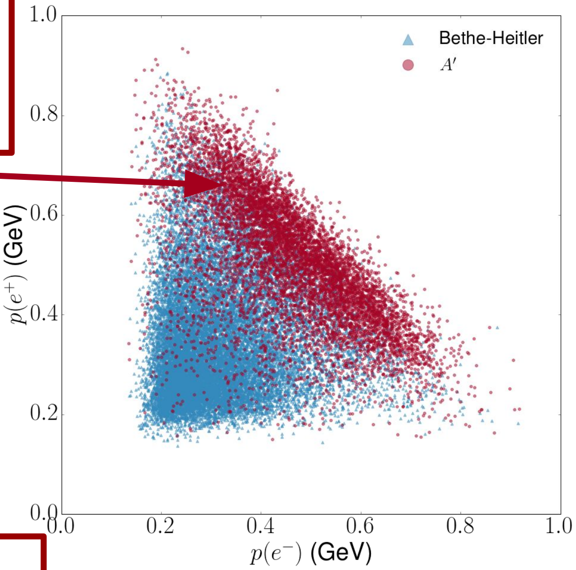
Vertex resolution + tails are dominated by multiple coulomb scattering in tracker

Trident Backgrounds

SLAC

Radiative tridents have identical kinematics to A's; constitute an irreducible prompt background





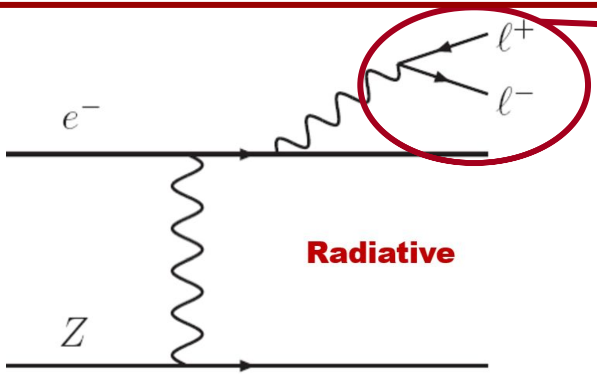
Radiative tridents provide reference for expected signal rate

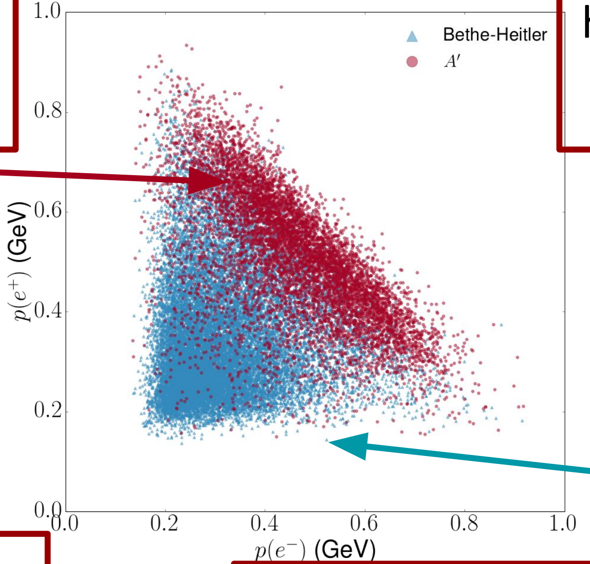
$$\frac{d\sigma(e^- Z \to e^- Z(A' \to l^+ l^-))}{d\sigma(e^- Z \to e^- Z(\gamma^* \to l^+ l^-))} = \frac{3\pi\epsilon^2}{2N_{eff}\alpha}\frac{m_{A'}}{\delta m}$$

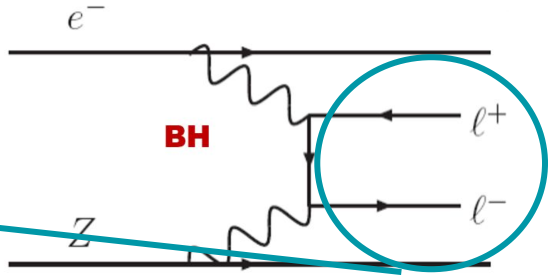
Trident Backgrounds

Radiative tridents have identical kinematics to A′s; constitute an irreducible prompt background

Bethe-Heitler (BH) tridents have softer e+e- pairs, but still dominates the signal region







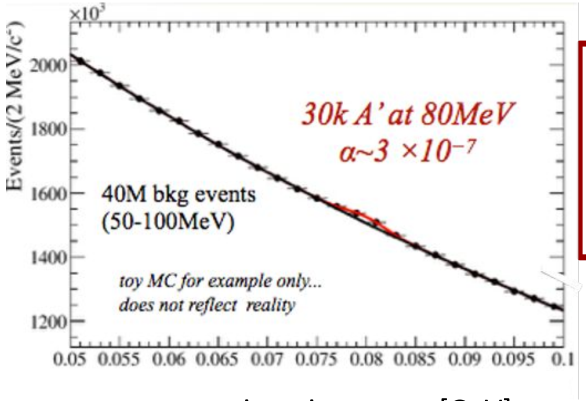
Radiative tridents provide reference for expected signal rate

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

Converted photons in tracker or target. Simple cuts eliminate about 80% of these e+e- pairs with minimal signal loss

Heavy Photon Signatures in HPS

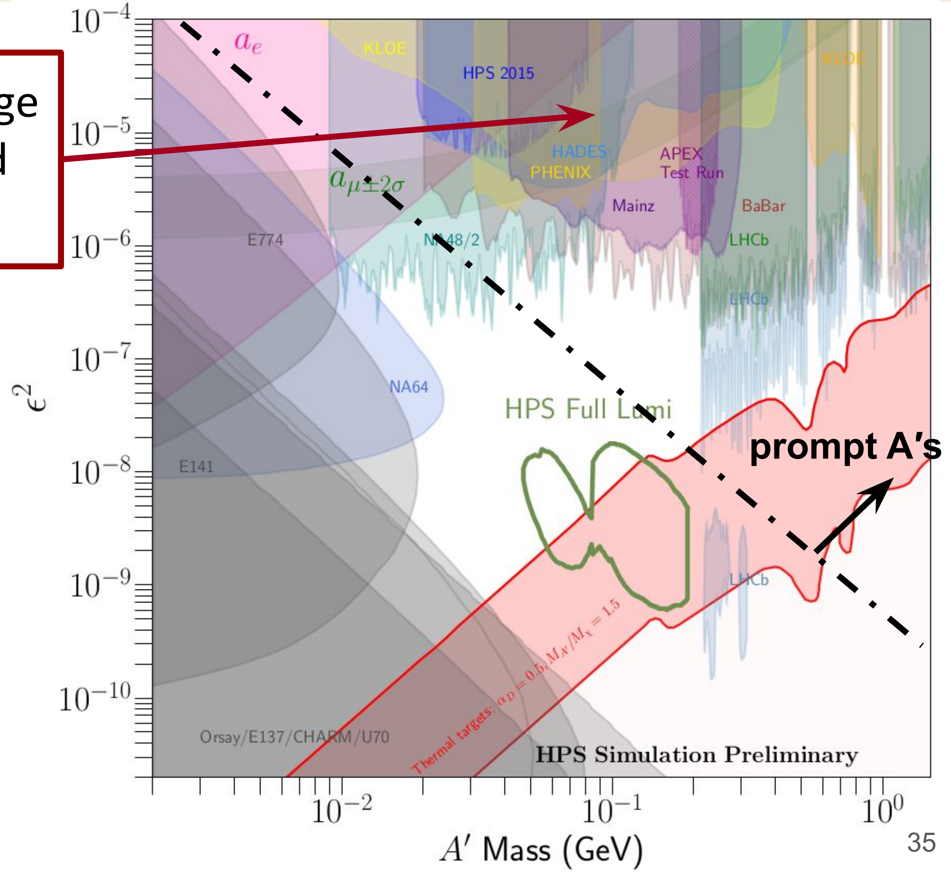
SLAC



invariant mass [GeV]

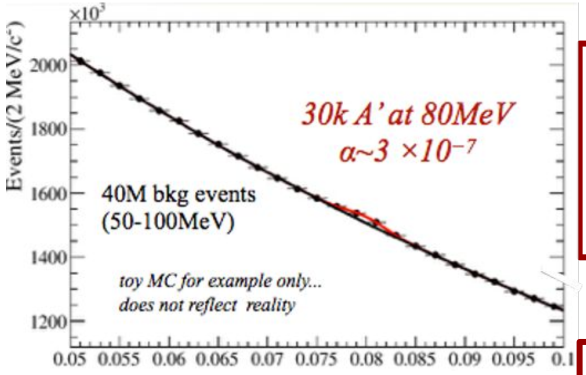
"Large" signal, huge QED background (**bump hunt**)

e+e- backgrounds are mostly prompt QED tridents

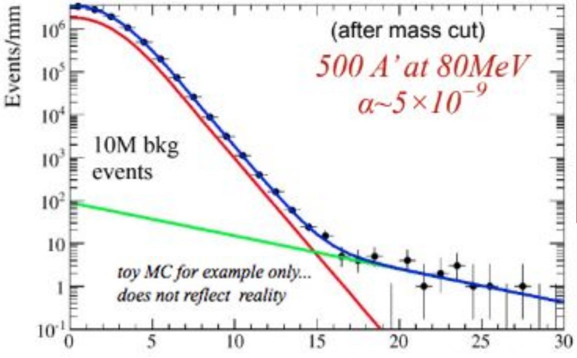


Heavy Photon Signatures in HPS

SLAC



invariant mass [GeV]

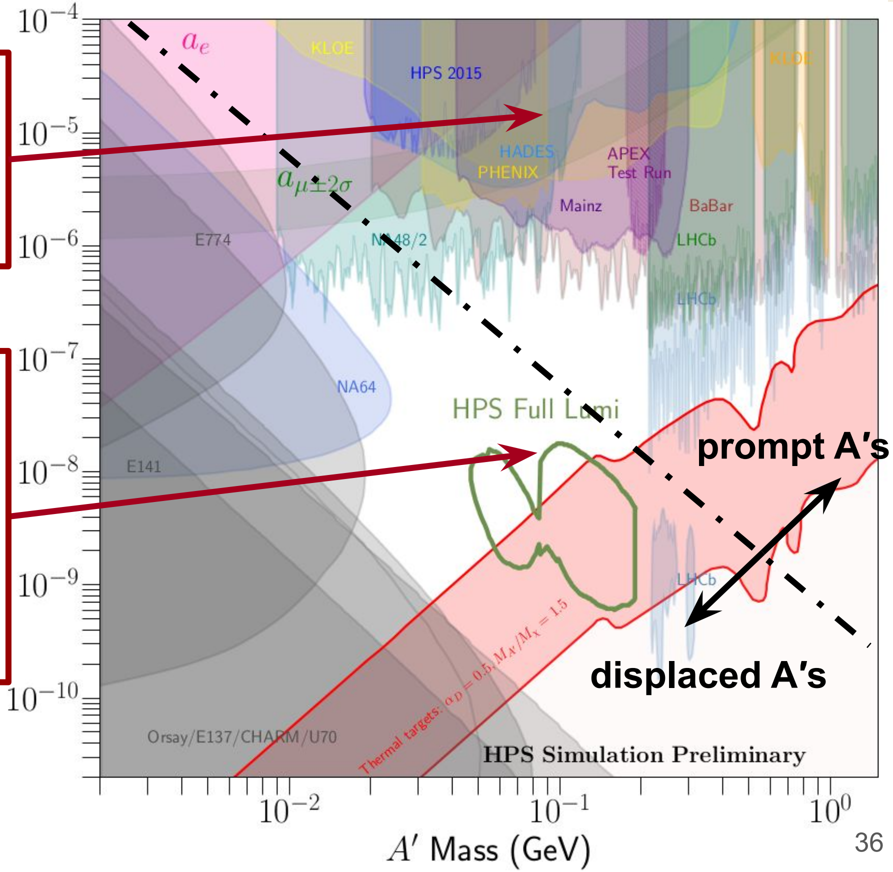


reconstructed z vertex [mm]

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

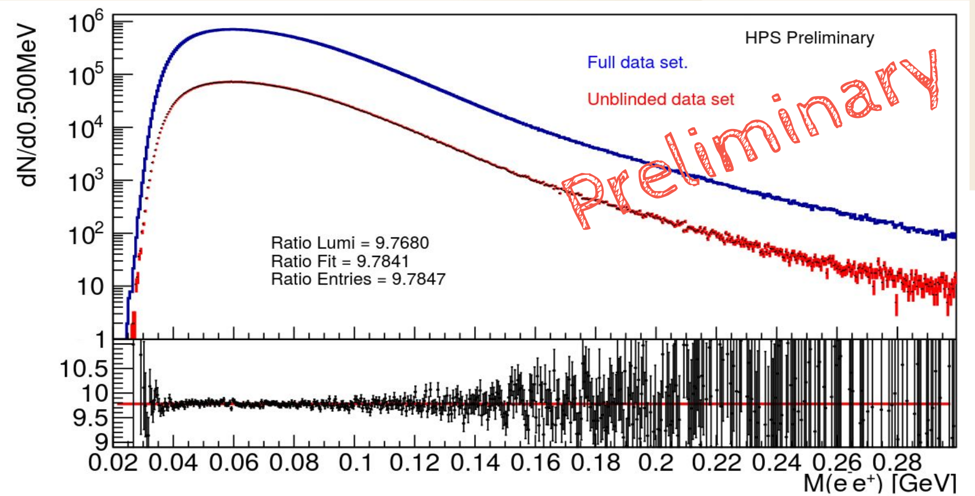
Small signal, very little background (**vertex search**). Must suppress background by ~10^9

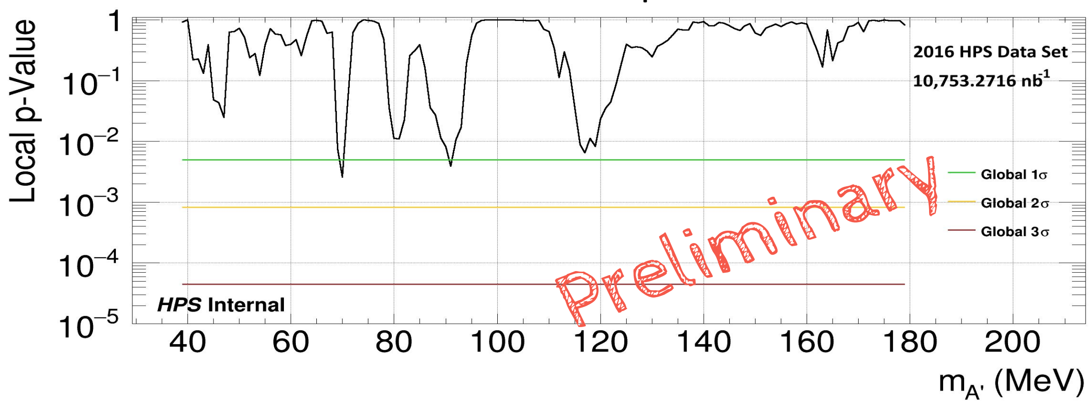
$$c\tau \propto \frac{1}{\epsilon^2 m_{A'}}$$

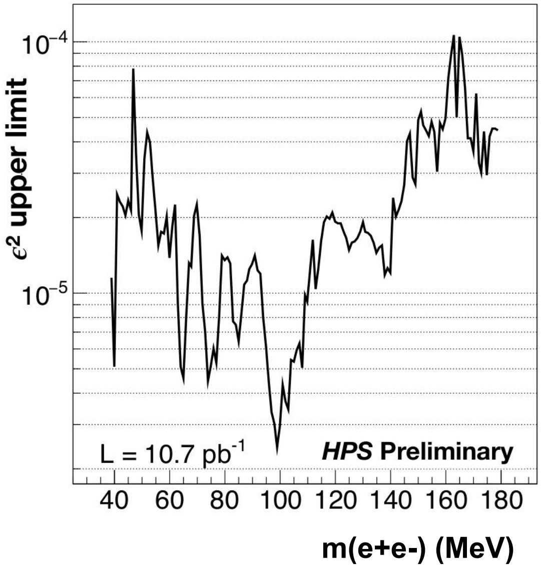


Resonance Search Results

- Preliminary results for the resonance search for the 2016 Engineering Run
  - Blinded analysis - event selection tuned on 10% of the full data set
  - No significant excess found
  - Preliminary limits are consistent with several other experiments

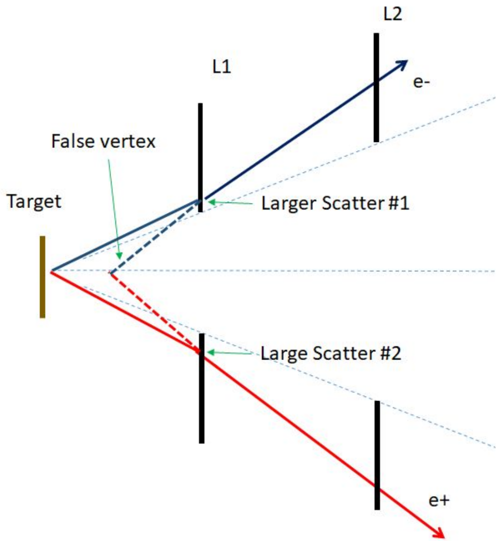


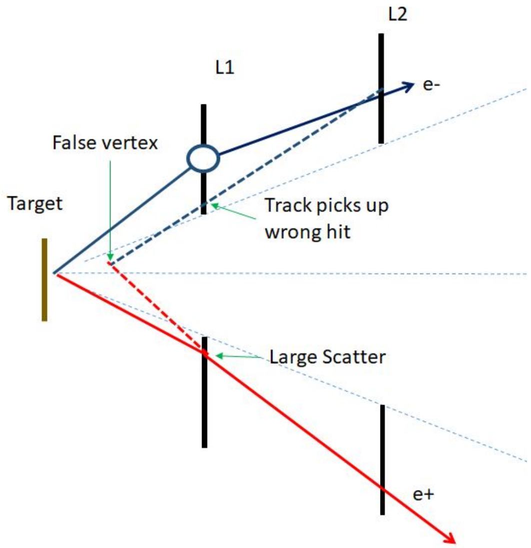


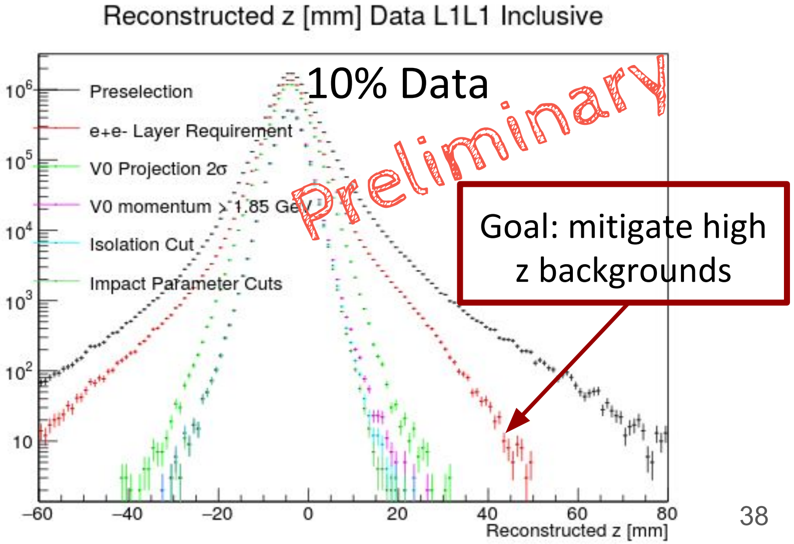


Displaced Vertex Search Event Selection

- In addition to bump hunt analysis, the displaced vertex analysis requires extra cleanup to reduce backgrounds at large z.
  - Two main backgrounds - large scatters in layer 1 of the tracker and mis-tracking
  - Require stricter selections on track quality and vertex quality & require layer 1 hits
  - Displaced vertex search is also blinded with the selection tuned on 10% of the data

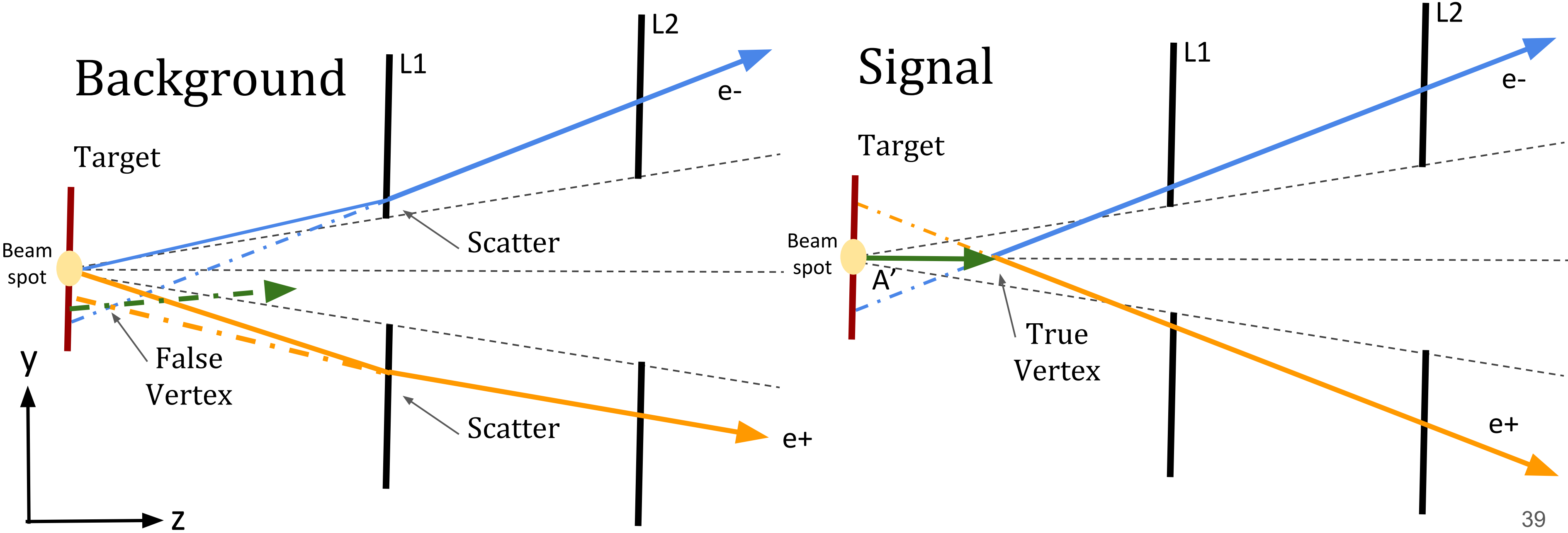






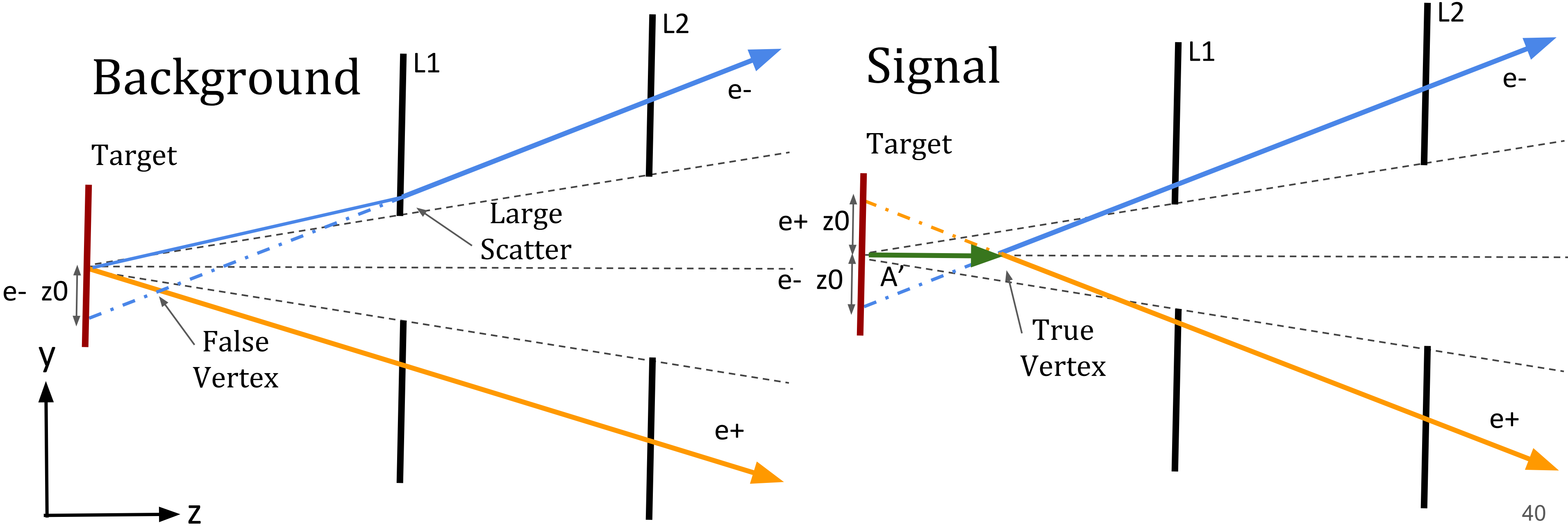
V0 Projection to the Target

- High Z background - scattering may cause momentum to project far from the beam spot at the target
- High Z signal - momentum will point back to the beam spot at the target



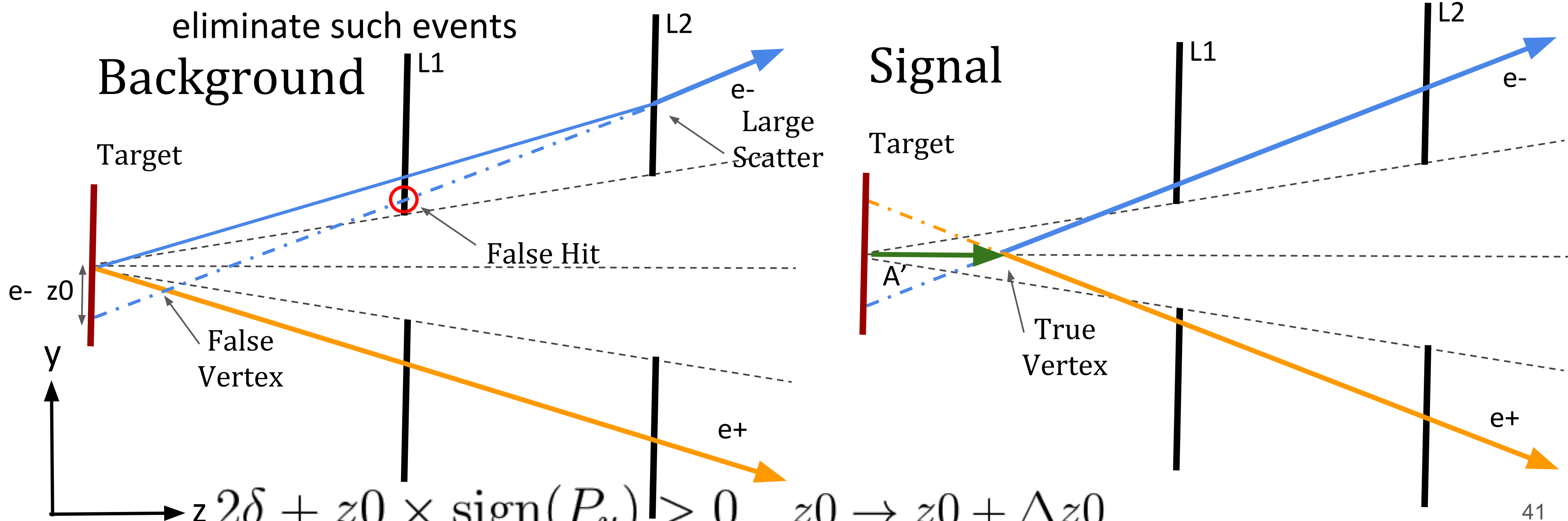
Track Impact Parameters

- High Z background - many events have only one large impact parameter
- High Z signal - large impact parameters for both e+e- tracks
- This is a new requirement for the 2016 Engineering Run



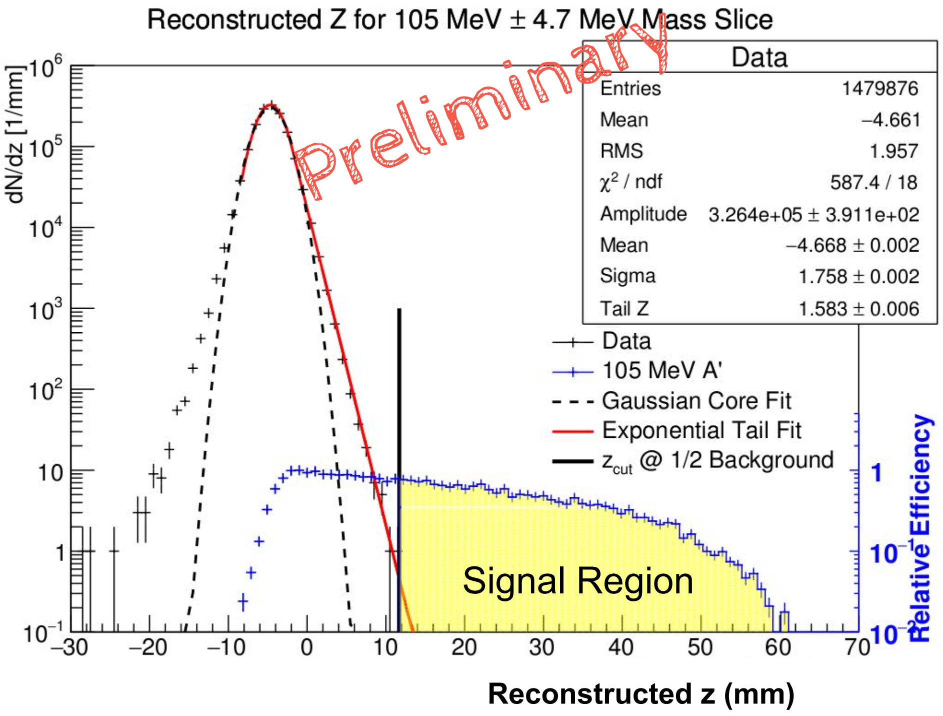
Mis-tracking

- High Z background - mis-tracking in layer 1, where a track picks up an incorrect hit (from beam particle, noise, etc.), can pull a vertex downstream of the target
- The isolation cut is geometrically designed (with multiple scattering) to eliminate such events



$2\delta + z0 \times \mathrm{sign}(P_y) > 0$ $\quad z0 \rightarrow z0 + \Delta z0$

Displaced Vertex Search Signal Region



- Start with a single mass slice and fit the background spectrum

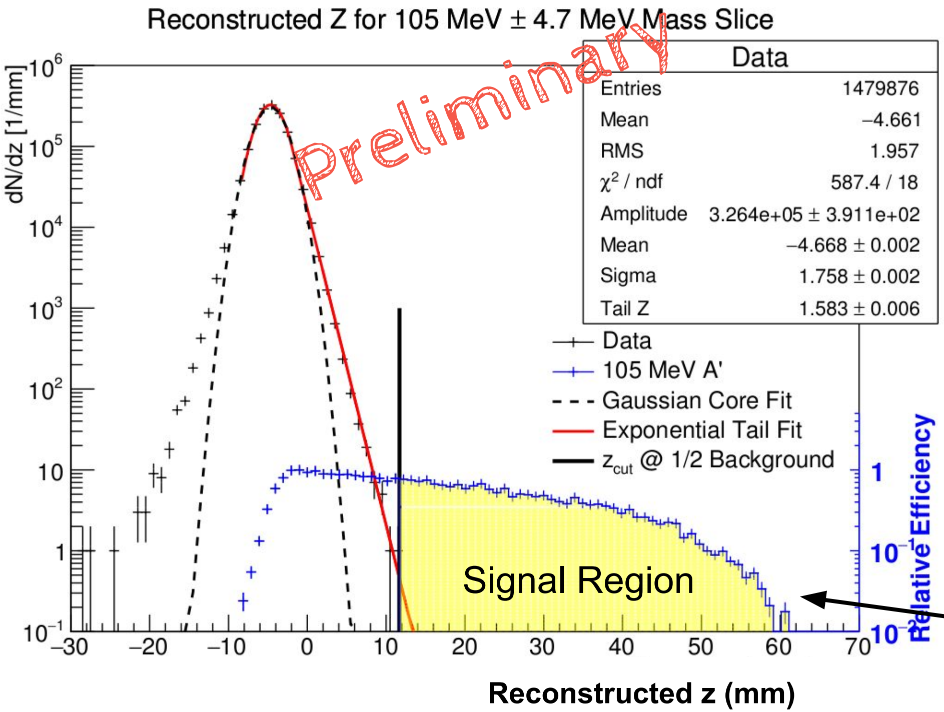
$$F\left(\frac{z - z_{mean}}{\sigma_z} < b\right) = Ae^{-\frac{(z - z_{mean})^2}{2\sigma_z^2}}$$

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

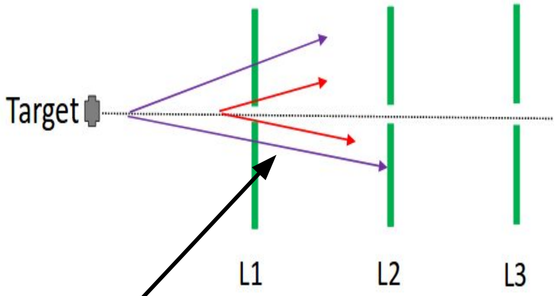
Gaussian Core + Exponential Tail

- Select the *z* position ("zcut") where the background model predicts 0.5 background events and cut away everything upstream
- This defines signal region. Events remaining are candidates for a signal

Displaced Vertex Search Signal Region

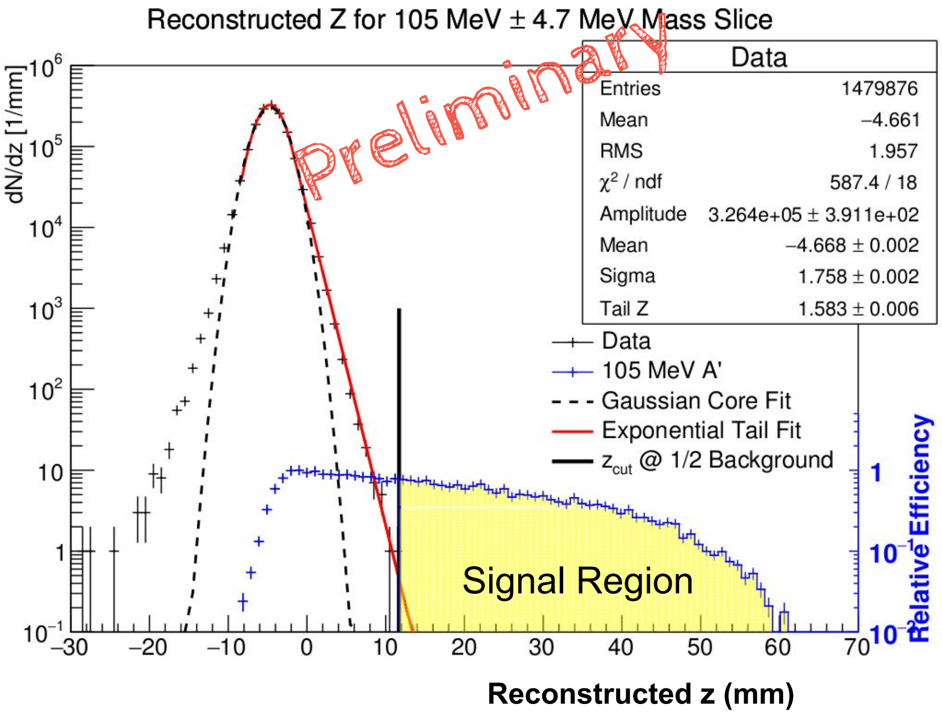


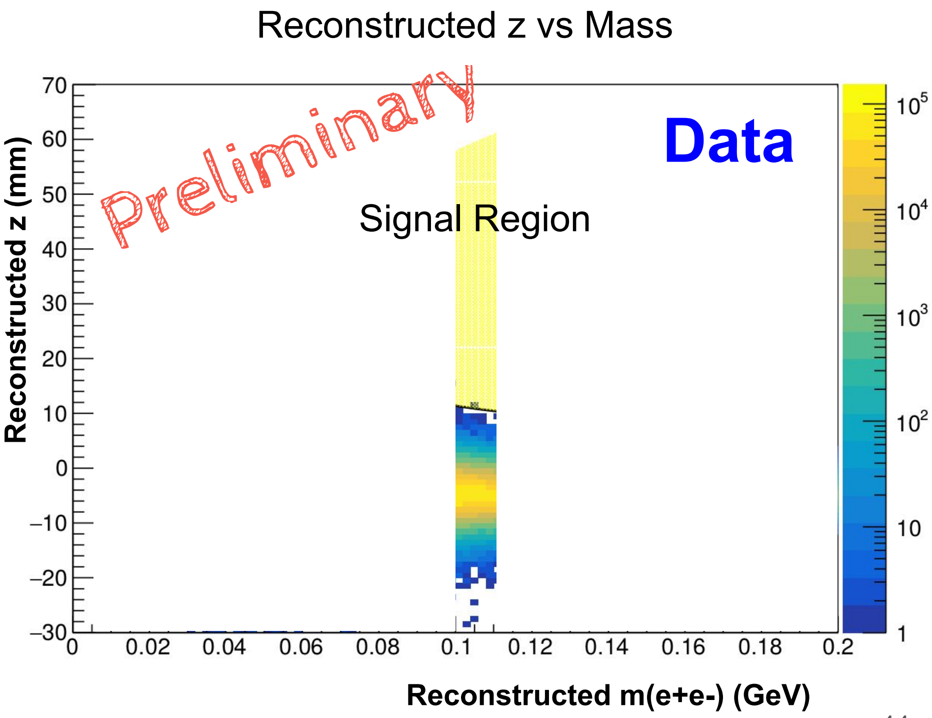
We require layer 1 hits. Relaxing this restriction is discussed later.



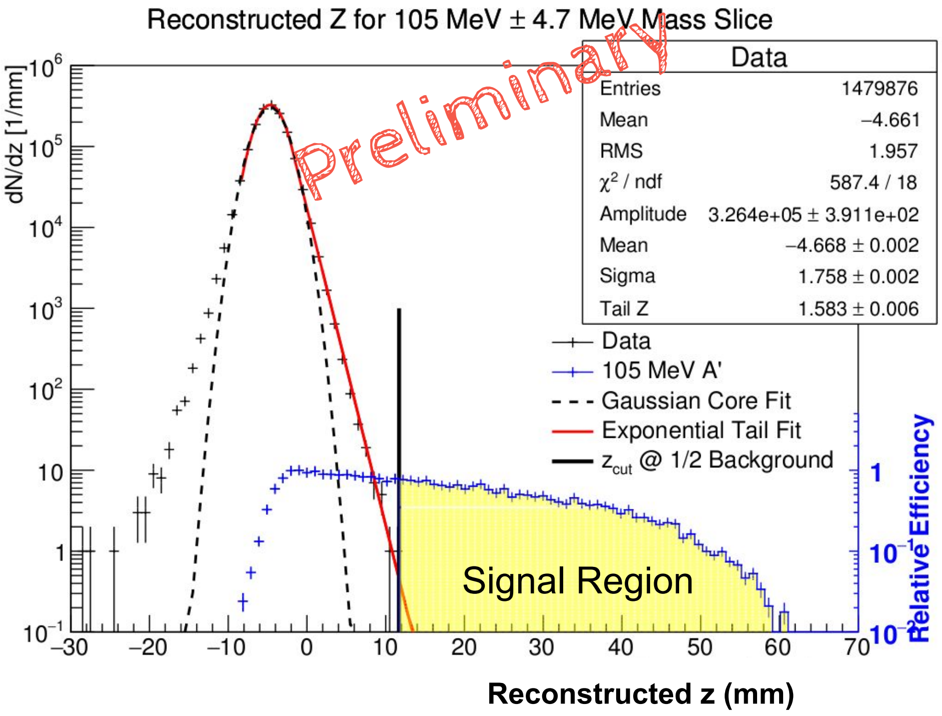
Signal falls off rapidly due to **geometrical acceptance**

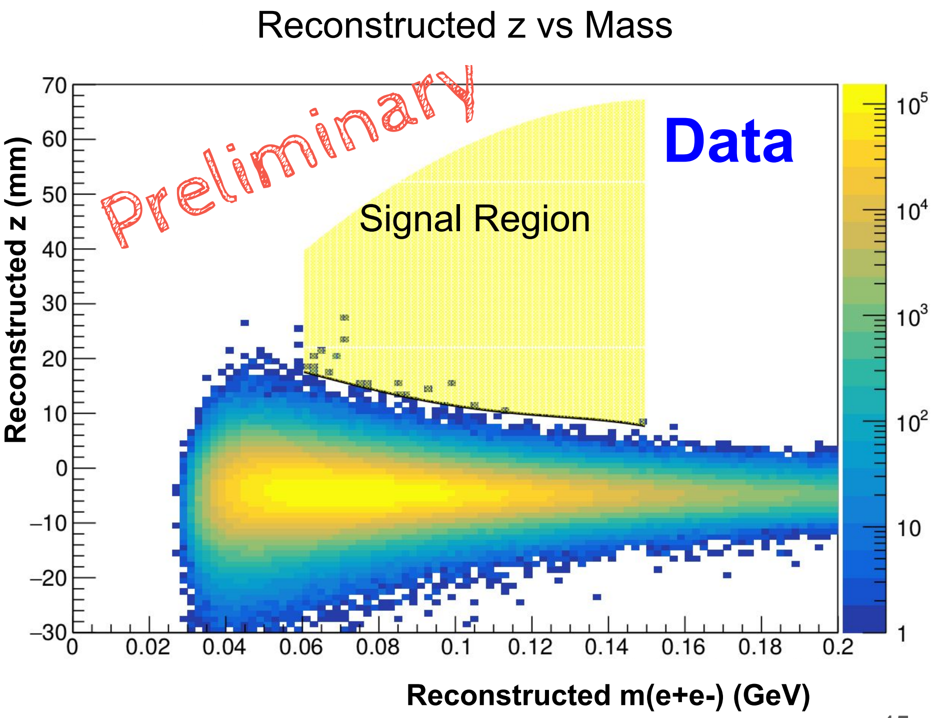
Displaced Vertex Search Signal Region





Displaced Vertex Search Signal Region





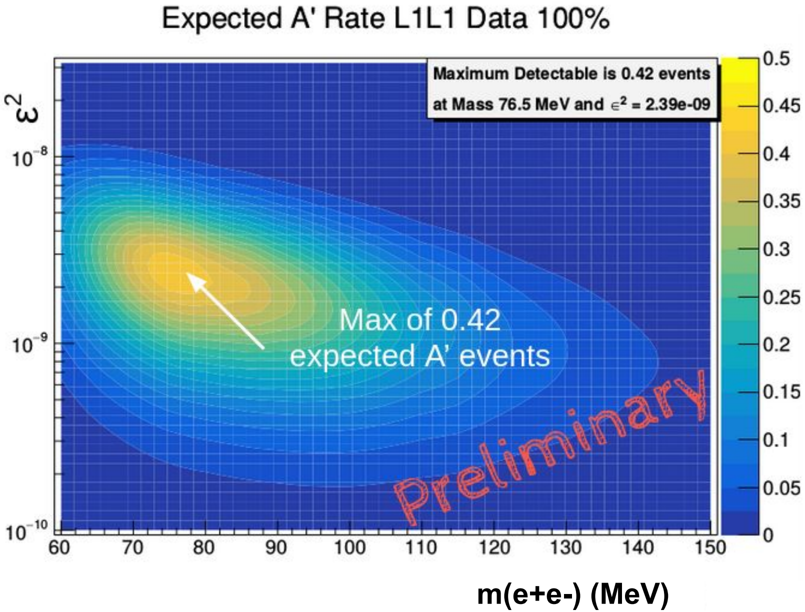
Displaced Vertex Search Final Results

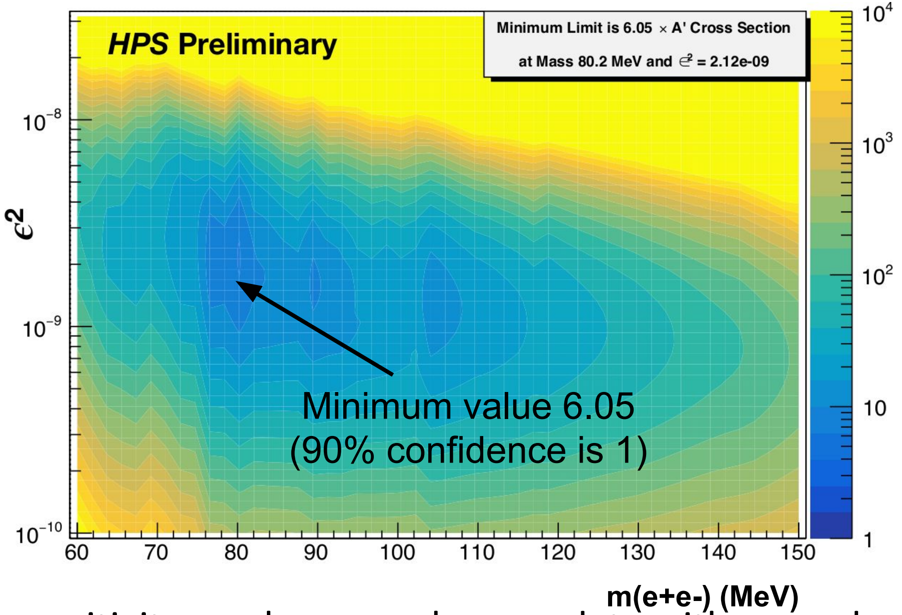
arXiv:physics/0203002v2

Plot the expected number of A′ events integrated past zcut.

$$N_{A'} = \int_{z_{cut}}^{z_{max}} \mathrm{sig}(m, \epsilon, z)\, \mathrm{accept}(m, z)\, \mathrm{eff}_{cut}(m, z)\, dz$$

Optimum Interval Method (OIM) was developed for DM direct detection and is used to set a limit.



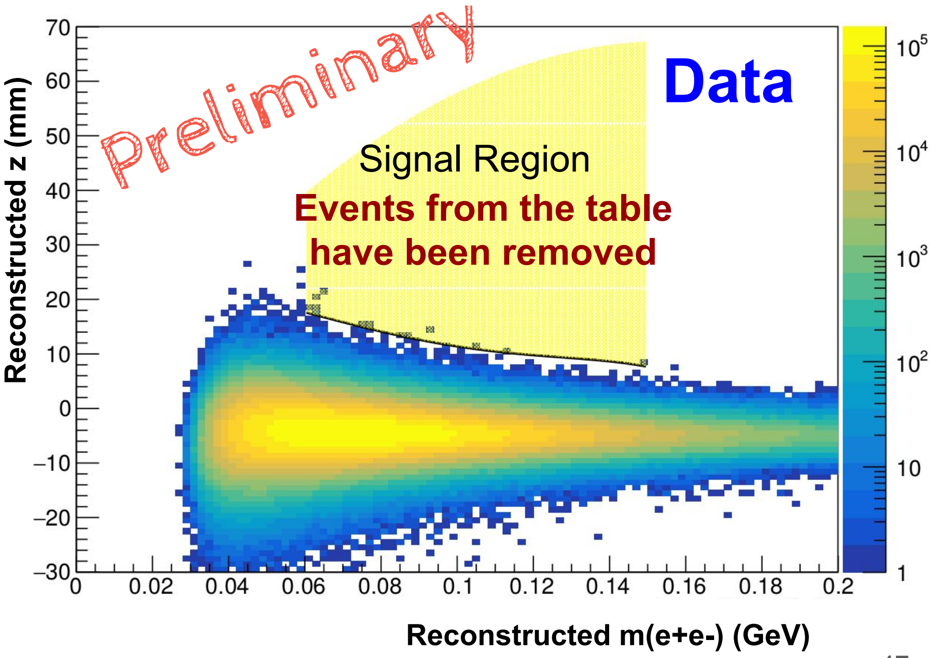


Proof of principle, though not enough luminosity for A′ sensitivity, we have much more data with upgrades!

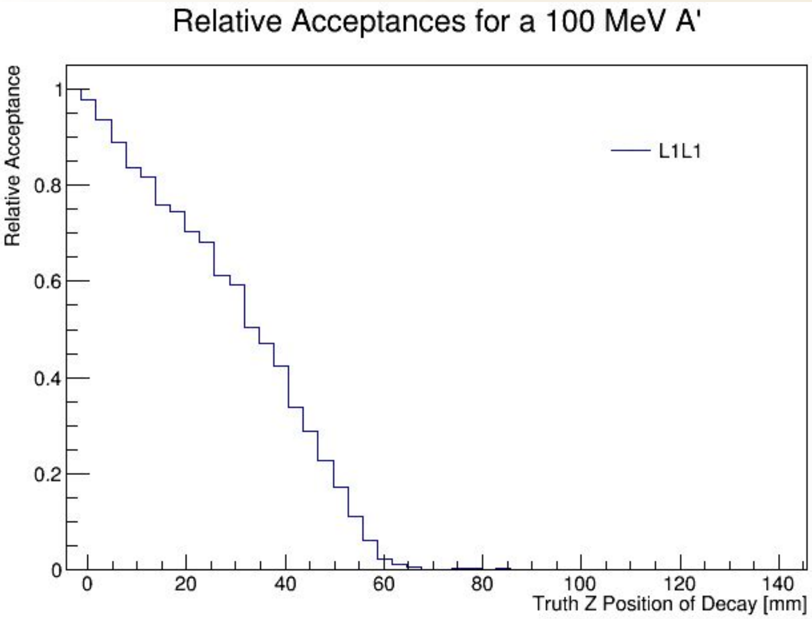
Discussion of Excess Displaced Vertices at Low Mass

- These events are under investigation
- Possible backgrounds - Beam-gas interaction (< 0.1 events) and Mis-tracking + hit inefficiency (likely)
- Possible signal (unlikely, see below)

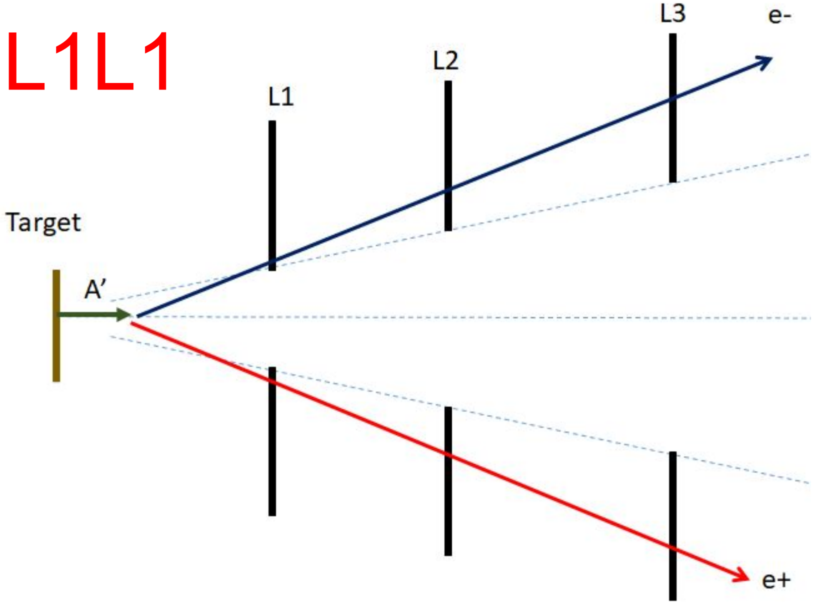
Δz_{cut}	VZ (mm)	Mass (MeV)	χ^2_{unc}	VY (n_σ)
0.44	17.67	63.17	$\boxed{8.55}$	0.18
0.50	17.12	66.21	$\boxed{7.90}$	1.41
3.80	20.03	68.19	$\boxed{4.63}$	0.55
4.51	20.72	68.24	0.13	$\boxed{3.61}$
7.75	23.33	71.48	1.52	$\boxed{2.95}$
11.74	27.27	71.71	0.12	$\boxed{2.49}$
2.22	15.62	84.02	$\boxed{8.65}$	1.04
3.54	15.05	98.57	$\boxed{4.55}$	0.06



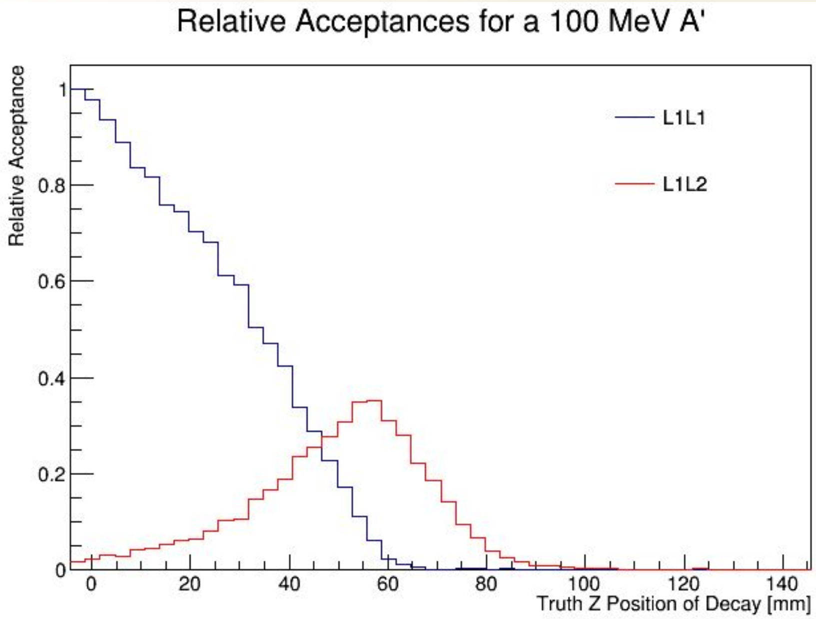
Extending HPS Acceptance for Longer Livetimes

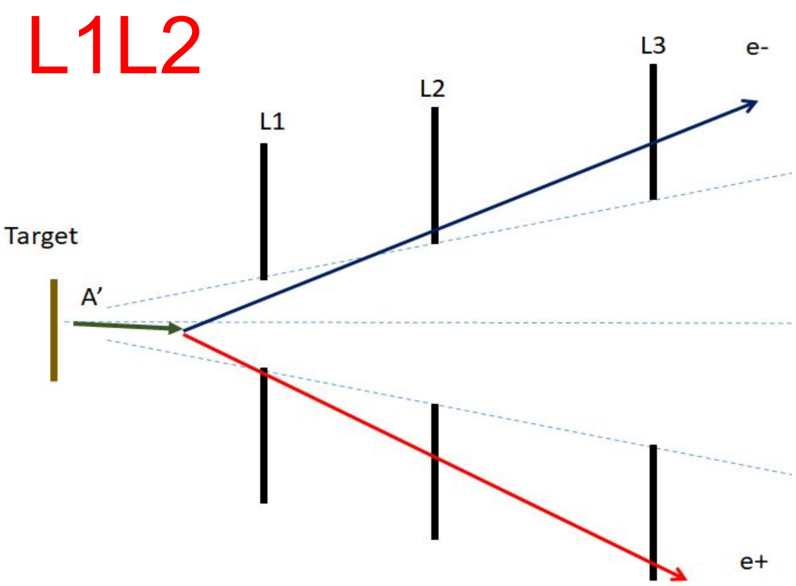


L1L1

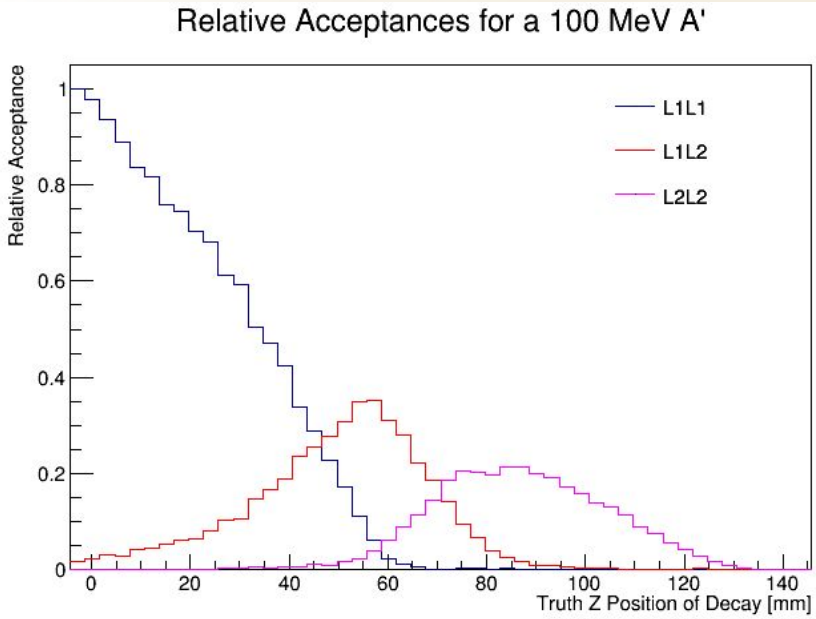


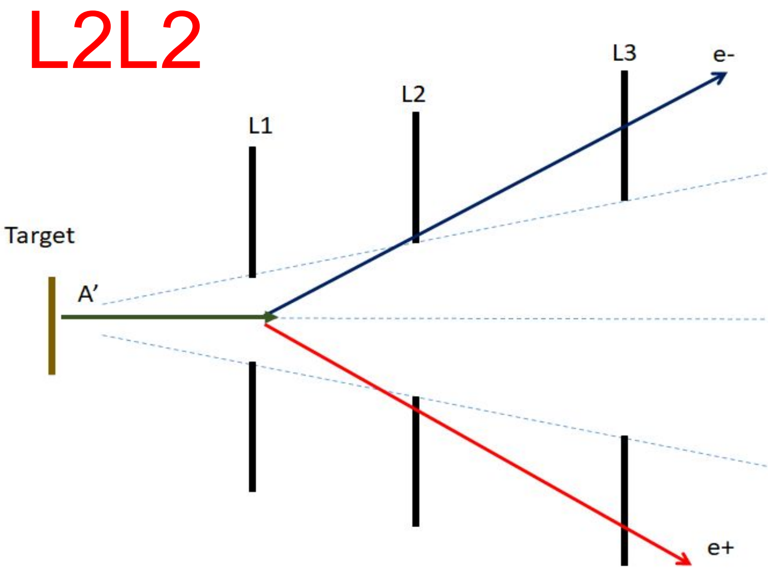
Extending HPS Acceptance for Longer Livetimes





Extending HPS Acceptance for Longer Livetimes



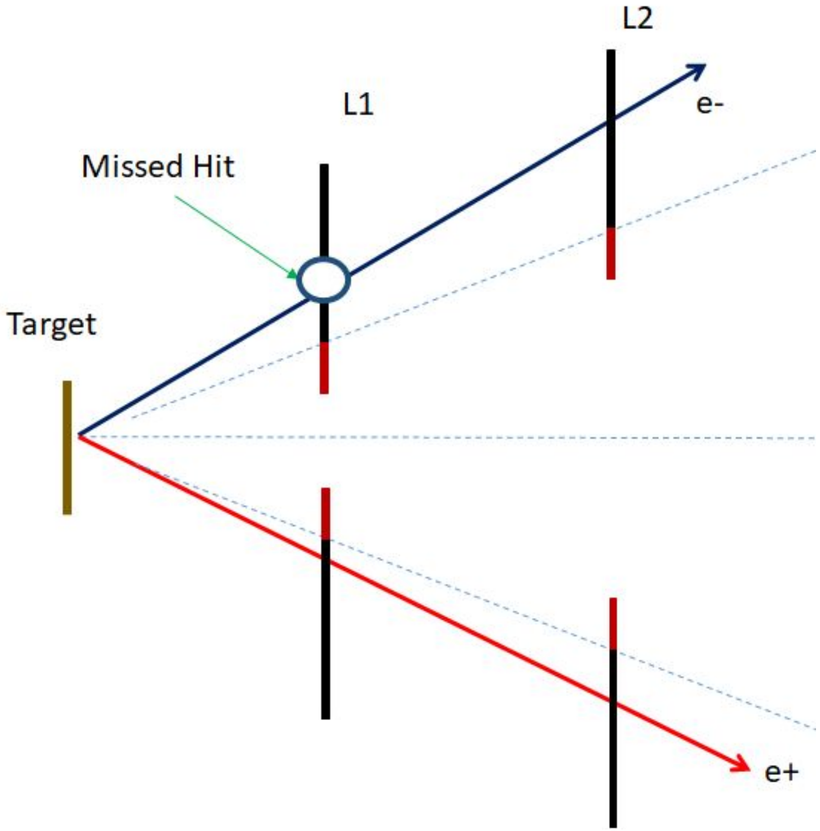


Backgrounds in L1L2 and L2L2 are much trickier!

Longer-lived A's will miss L1 of the SVT. Divide the analysis in 3 mutually exclusive categories L1L1, L1L2, L2L2

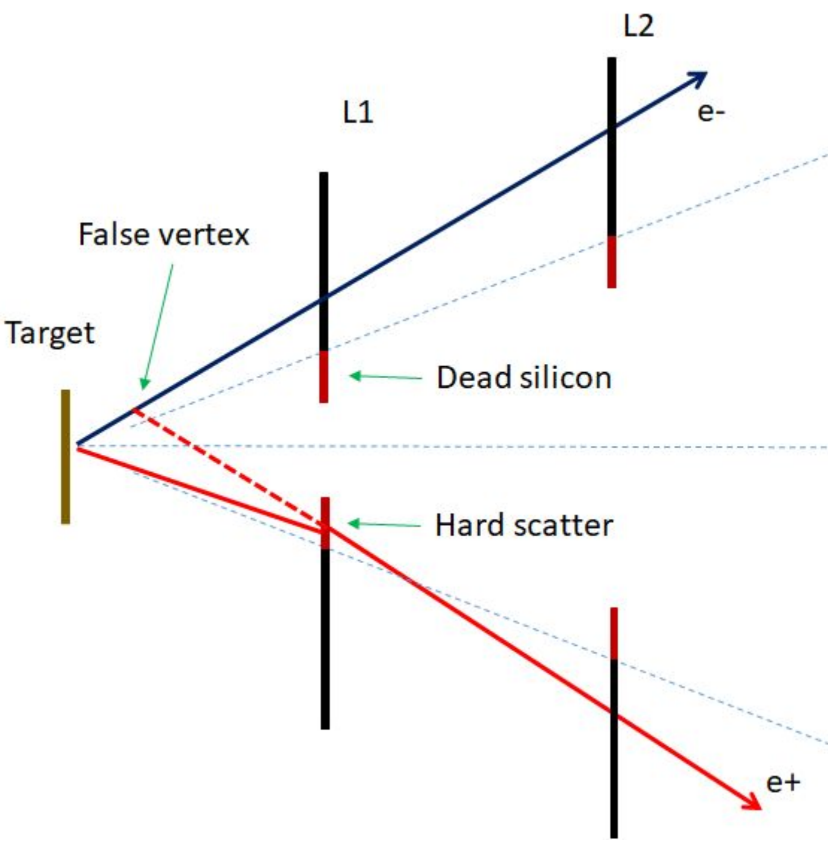
Backgrounds for Longer Livetimes

- Hit inefficiencies
  - Still points back to the primary (but with degraded resolution)
  - Not present in MC yet



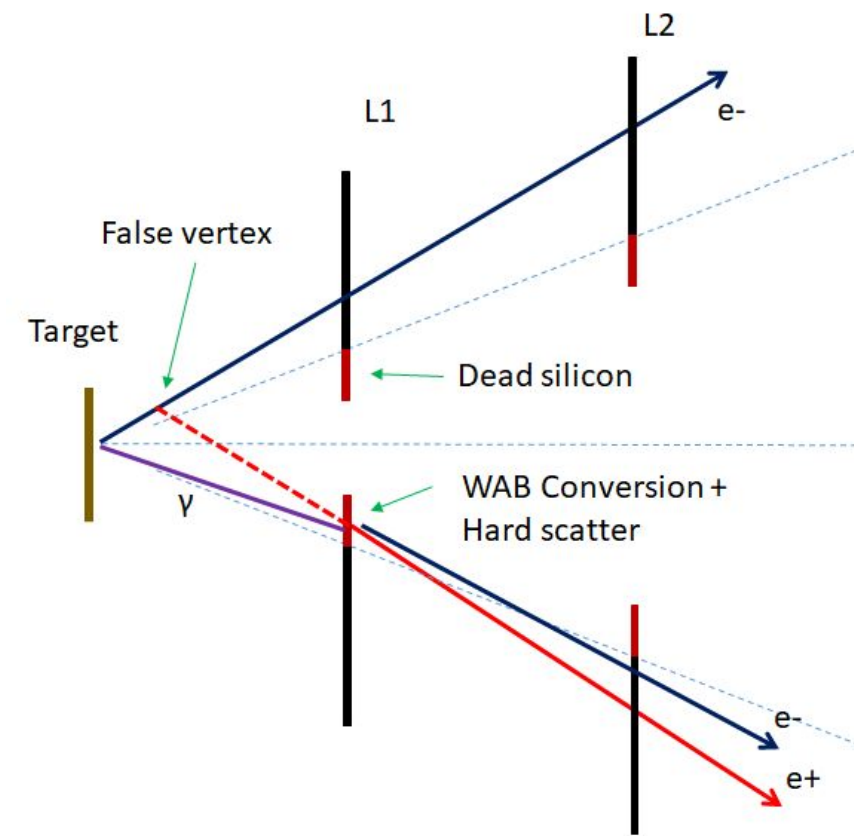
Backgrounds for Longer Livetimes

- Hit inefficiencies
  - Still points back to the primary (but with degraded resolution)
  - Not present in MC yet
- Large scatters in the dead silicon into the active region



Backgrounds for Longer Livetimes

- Hit inefficiencies
  - Still points back to the primary (but with degraded resolution)
  - Not present in MC yet
- Large scatters in the dead silicon into the active region
- Wab conversion in dead silicon and large scatter into the active region

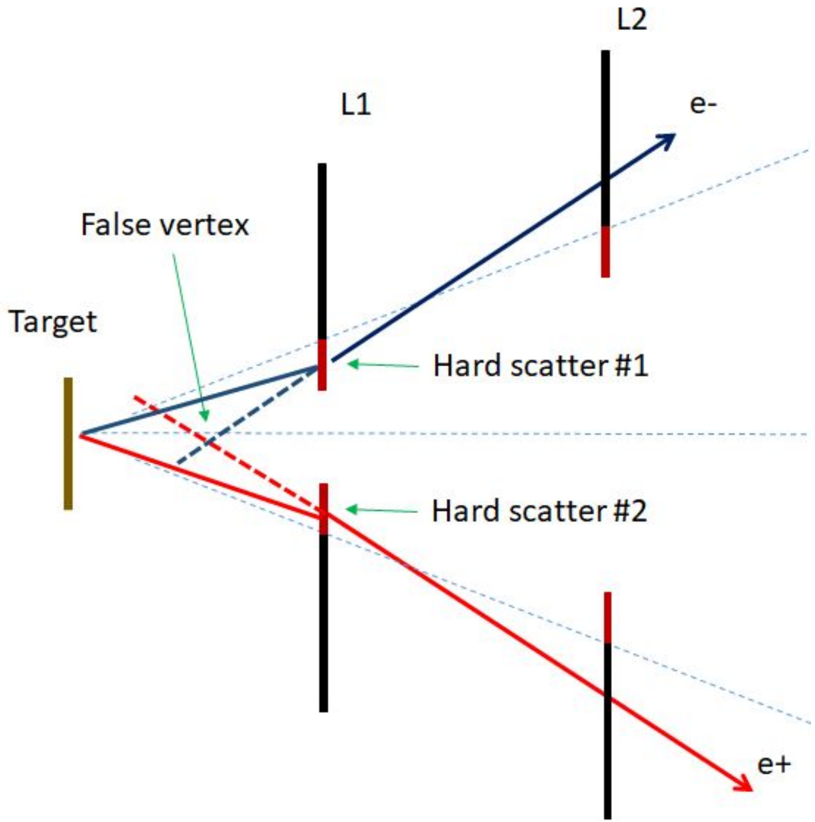


Backgrounds for Longer Livetimes

- Hit inefficiencies
  - Still points back to the primary (but with degraded resolution)
  - Not present in MC yet
- Large scatters in the dead silicon into the active region
- Wab conversion in dead silicon and large scatter into the active region
- Or some combination of these.

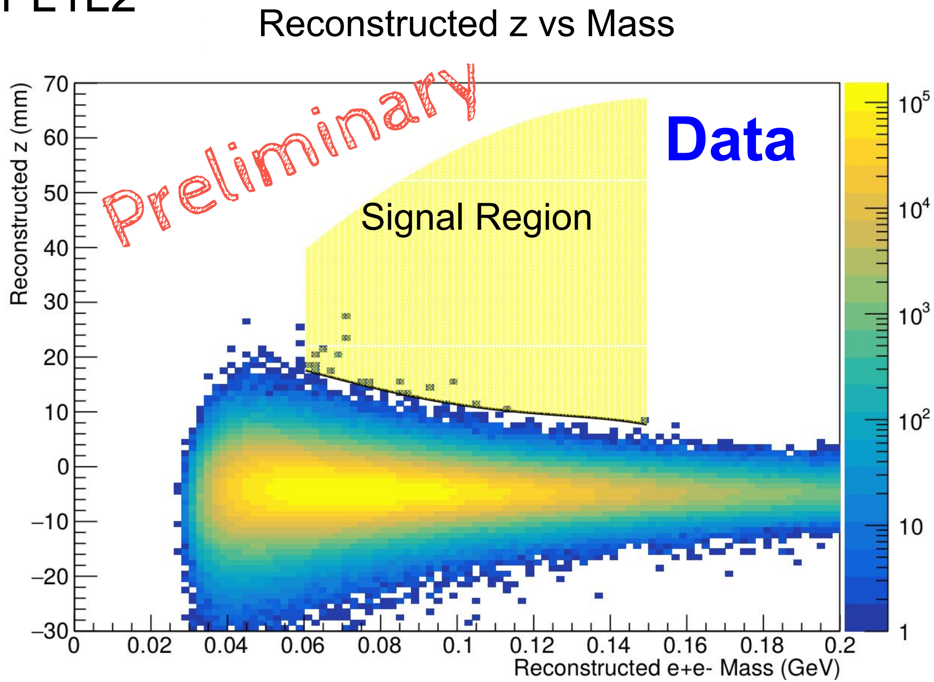
Similar idea for L2L2

A quantitative understanding of these backgrounds is a work in progress



Show L1L2 results and maybe L2L2

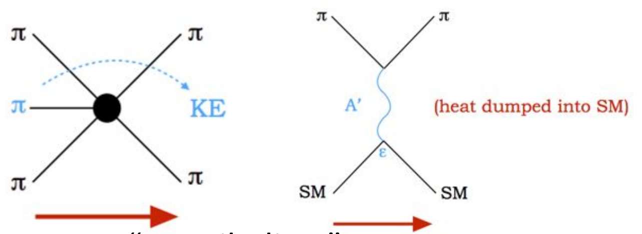
Show the same plot to the right except for L1L2



Other Possible Signatures at HPS

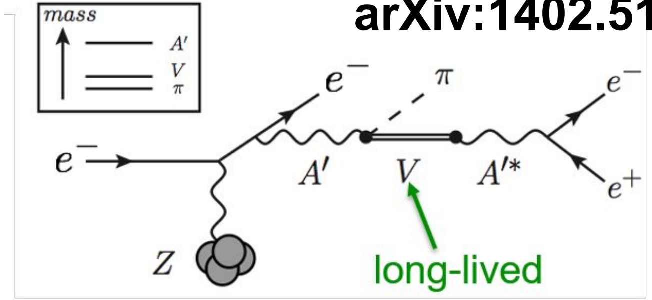
Can we probe other models? Strongly Interacting Massive Particles (SIMPs) are one such example, motivated by SIMP miracle

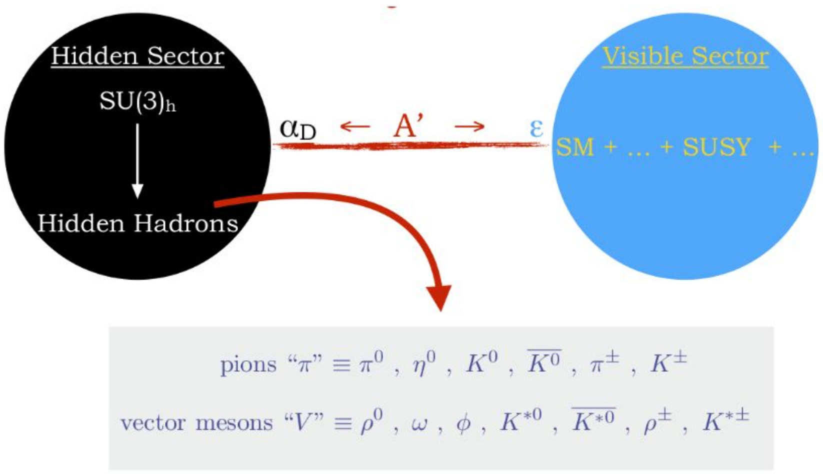
The SIMP Miracle



“Cannibalism”

arXiv:1402.5143

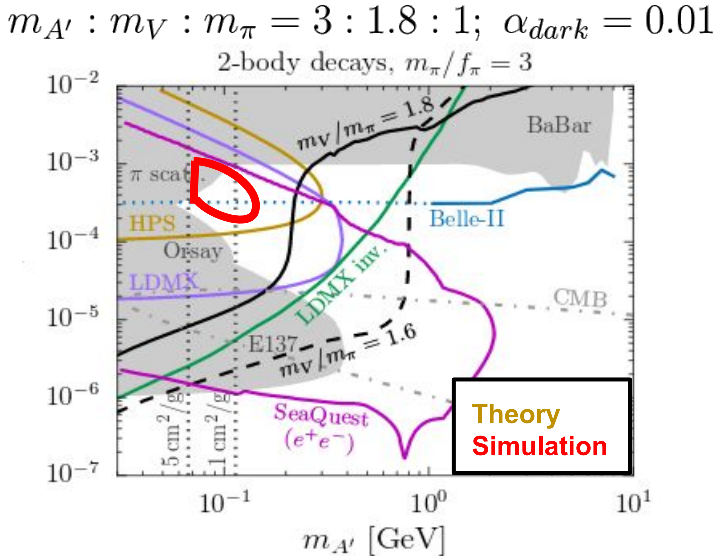


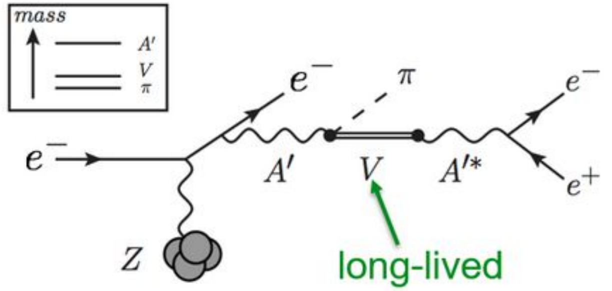


Proposes an additional SU(3) symmetry in a hidden sector. Allows for self-interacting DM and more complex structure

Preliminary SIMP Reach 2016 Engineering Run (2.3 GeV)

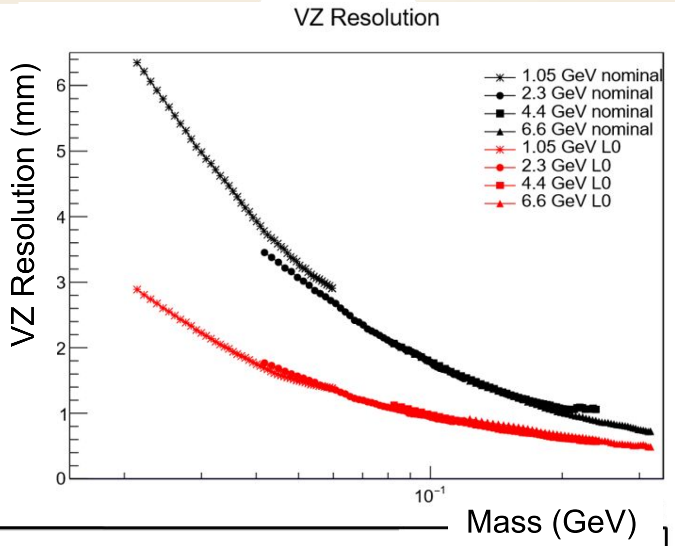
- **Possibly sensitive to Strongly Interacting Massive Particles** (SIMPs) in 2016 data
- Motivated by the “SIMP Miracle” (DM in ~1-10 GeV range)
- Missing energy due to dark pion, thus the search isnin a lower energy sum region
- HPS can probe long-lived dark vectors (V) in a similar method to searching for A’s
- SIMP model decouples A’ cross-section and V livetimes. High rate of long-lived particles!
- Much of this analysis can be done in parallel with the minimal A’ search

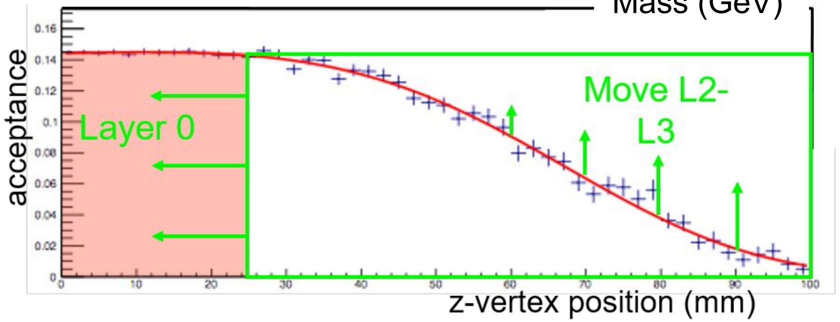




HPS Upgrades

- Analysis from 2015/2016 motivated simple upgrades
- **Add a tracking layer** (Layer 0) between target and current first layer
  - Dramatically improves vertex resolution, hence the vertex reach
- **Move L2-L3** slightly towards beam
  - Improves acceptance for longer-lived A′s
  - Also replaced L1 with new thin sensor and moved closer to the beam





HPS Upgrades

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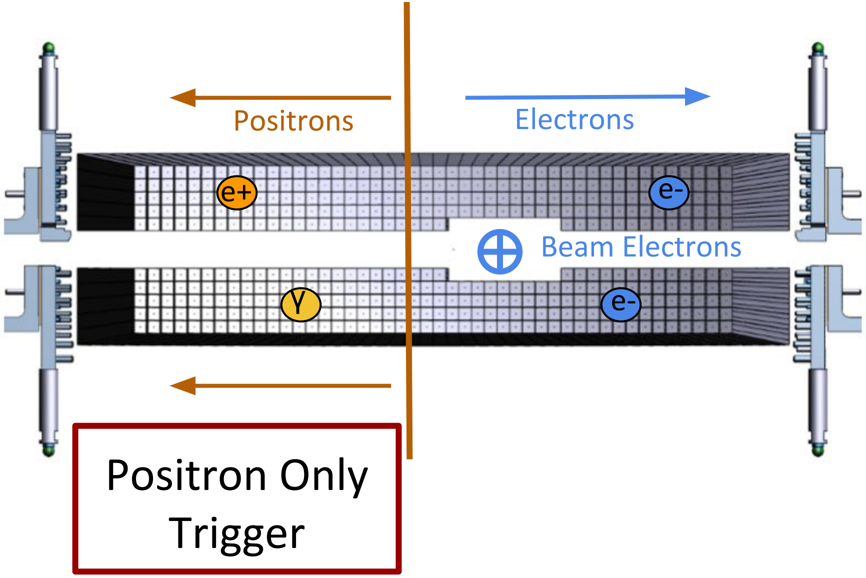
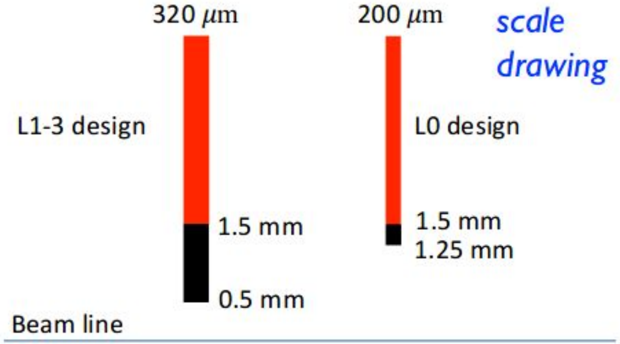
- **Add a tracking layer** (Layer 0) between target and current first layer
  - Dramatically improves vertex resolution, hence the vertex reach
- **Move L2-L3** slightly towards beam
  - Improves acceptance for longer-lived A′s
  - Also replaced L1 with new thin sensor and moved closer to the beam
- **Add hodoscope** inside vacuum chamber
  - Positron only trigger reduces acceptance losses in the “Ecal hole”

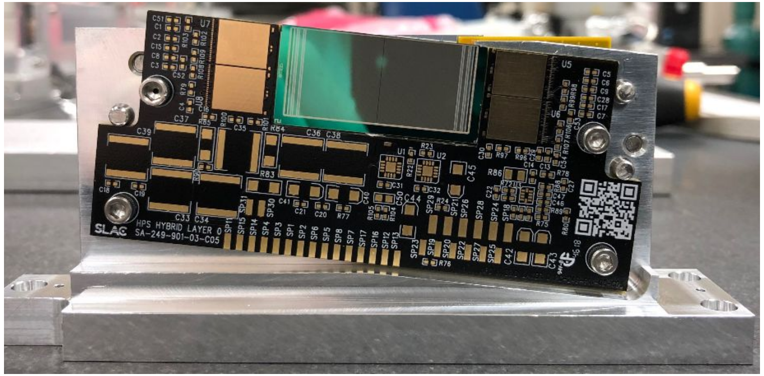


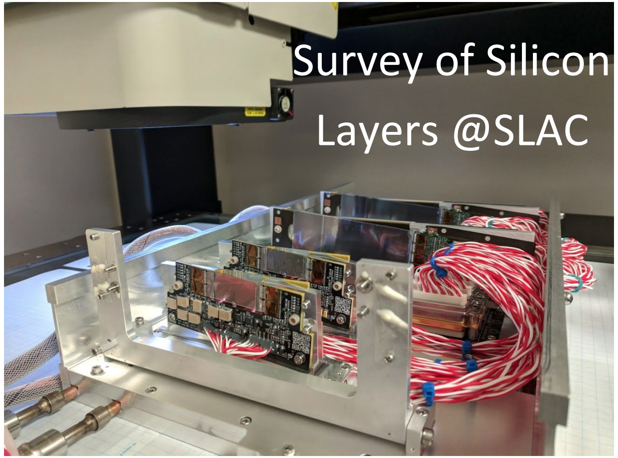
Installing HPS Upgrades

SLAC

HPS upgrades successfully installed in May-June 2019 in time for June start







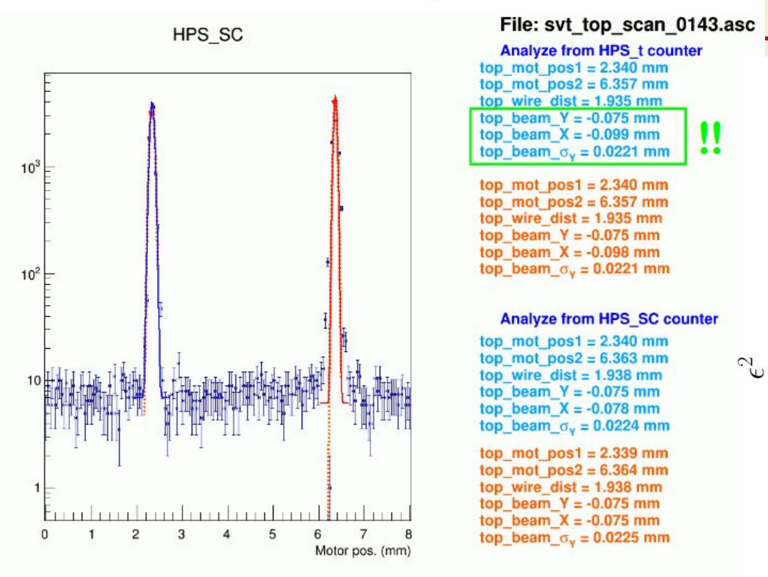
Survey of Silicon Layers @SLAC

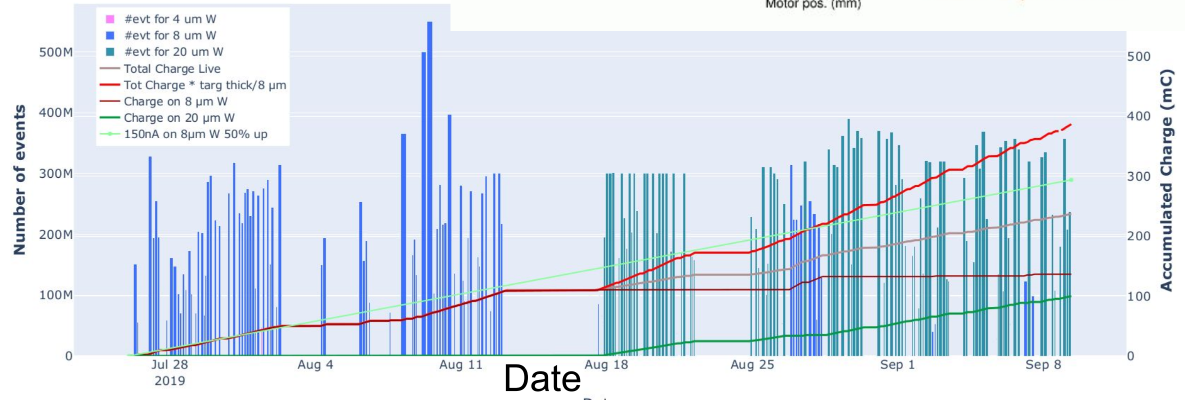
Installing new L0-L3

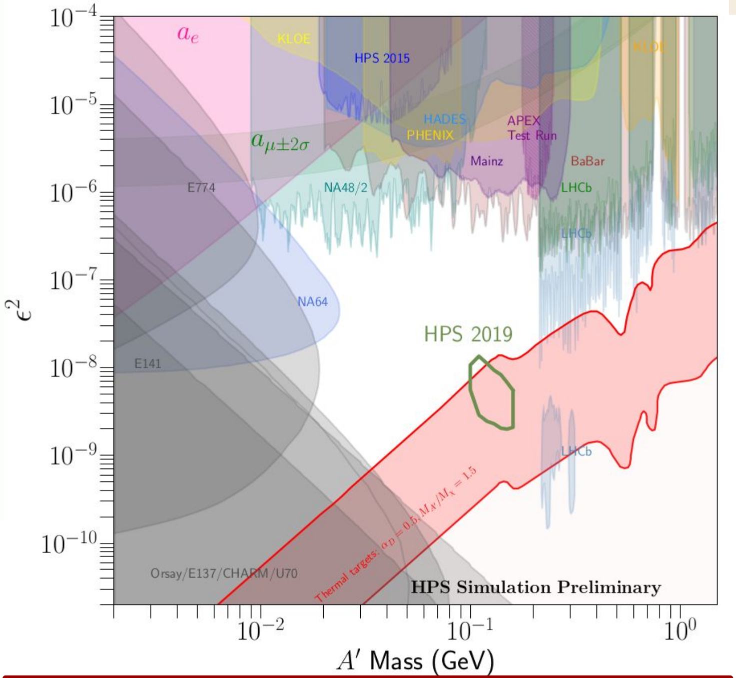
All sealed up and ready to go!

HPS Projected Reach With Upgrades

4.55 GeV beam: Achieved excellent beam at the target.







Reach projection contour scaled to the 2019 Physics Run luminosity

Conclusion

SLAC

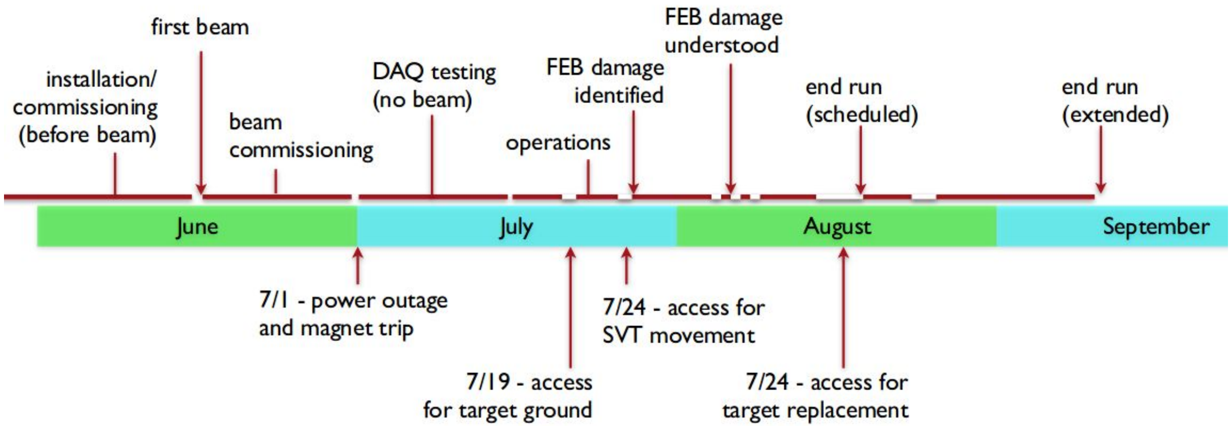
- Heavy photons are well-motivated as the particle that mediates light dark matter interactions with SM matter
- **HPS has successfully completed** two engineering runs at two different beam energies (1.06 GeV in 2015 and 2.3 GeV in 2016)
- **Resonance search** - results from 2015 are published and result from 2016 are now public. Both exclusions are consistent with several other experiments.
- **Displaced vertex search** - demonstrated proof of principle for the displaced vertex search. Analysis for A′s with longer livetimes and SIMPs are ongoing.
- **HPS successfully completed its first physics run** for 2 weeks at 4.55 GeV with tracker and trigger upgrades. This data has **real physics potential.**
- Possibility for more running in 2021 and beyond

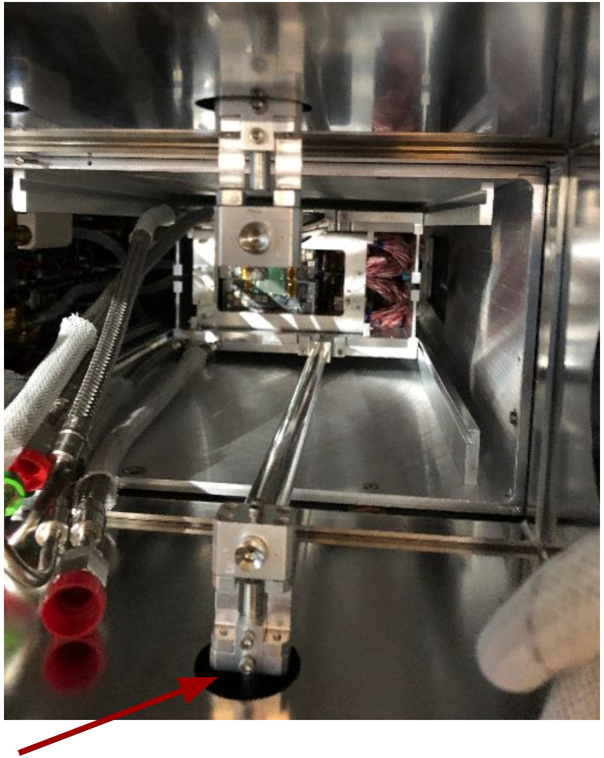
A Long List of Thank You’s

Thanks! Questions?

2019 Operations at 4.55 GeV

- CEBAF - first time simultaneously operating 3 experimental halls in the 12 GeV era
- Major problems delivering clean beam limited uptime and created operational issues as well as damage to several detector components

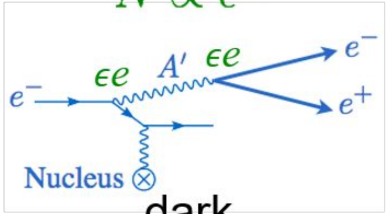




Experiments Searching for Heavy Photons

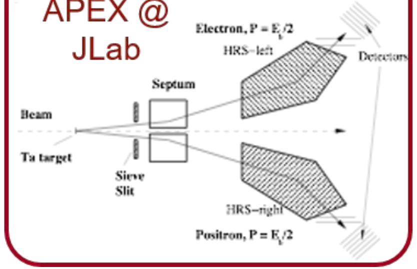
e^- fixed target

$N \propto \epsilon^2$



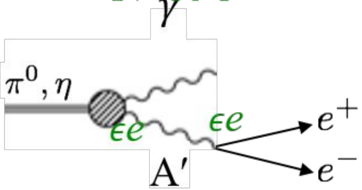
dark bremsstrahlung

APEX @ JLab

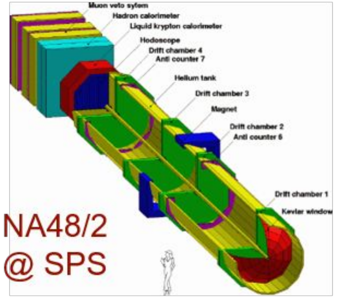


p fixed target

$N \propto \epsilon^2$

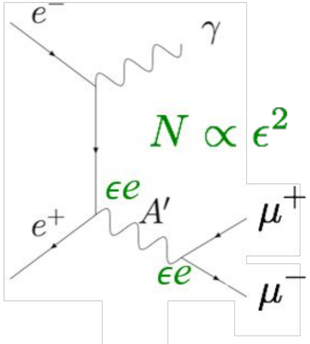


meson decays



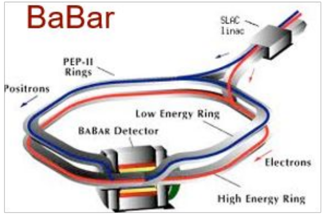
NA48/2 @ SPS

e^+e^- colliders

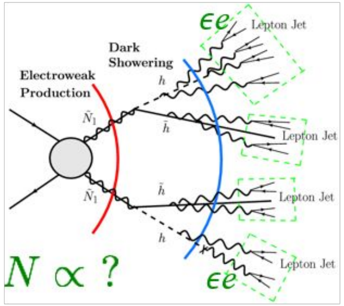


+ meson decays

BaBar



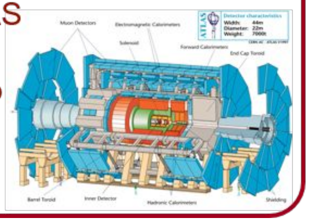
pp collider



"lepton jets"

+ meson decays

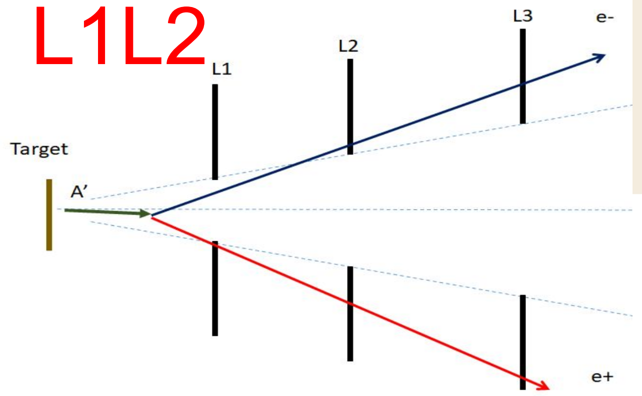
ATLAS
CMS
LHCb

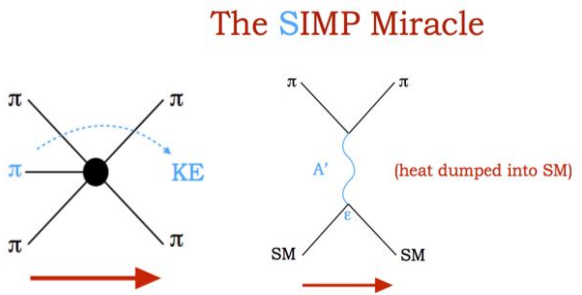


*Focus on dark bremsstrahlung in this talk and the scenario where $2m_e < m_{A'} < 2m_{DM}$

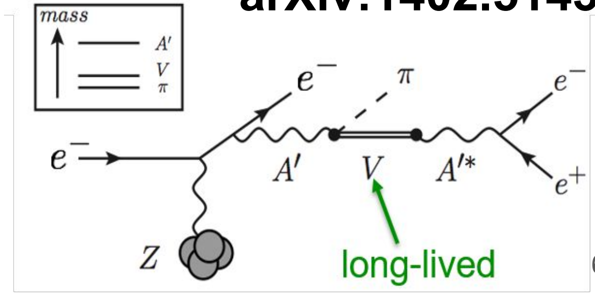
Future of the 2016 Vertexing Analysis

- So far we required layer 1 hits, but A′s can live long enough such that the e+ and/or e- daughter can miss layer 1
    - This introduces **more complicated backgrounds** - hit inefficiencies, scattering in the inactive sensor, conversions, etc. A quantitative study of these backgrounds is ongoing.
- **Possibly sensitive to Strongly Interacting Massive Particles** (SIMPs) in 2016 data
    - HPS can probe long-lived dark vectors (V) in a similar method to searching for A′s
    - Mechanism contains missing energy due to dark pions - search in lower e+e- momentum sum region than A′s

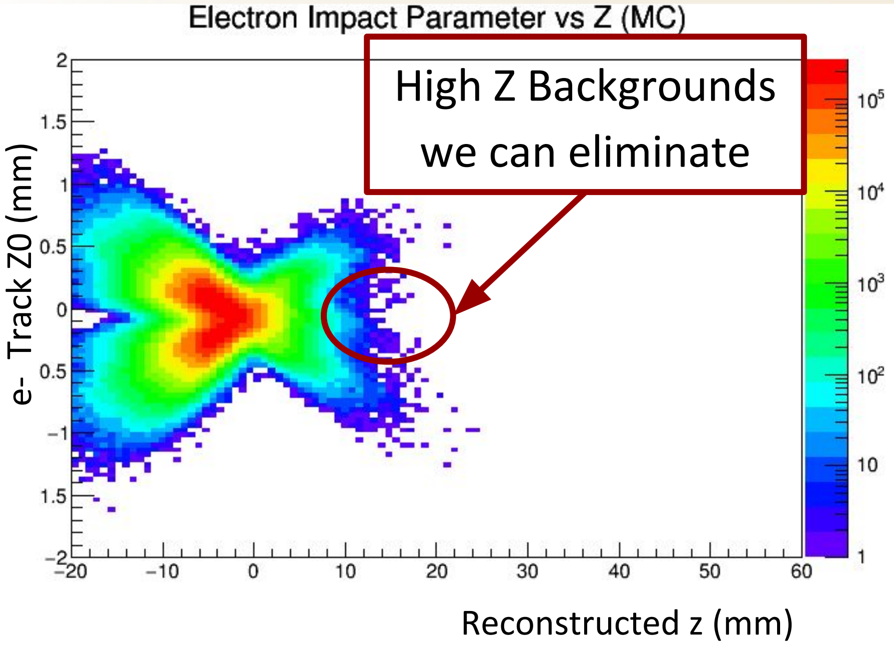


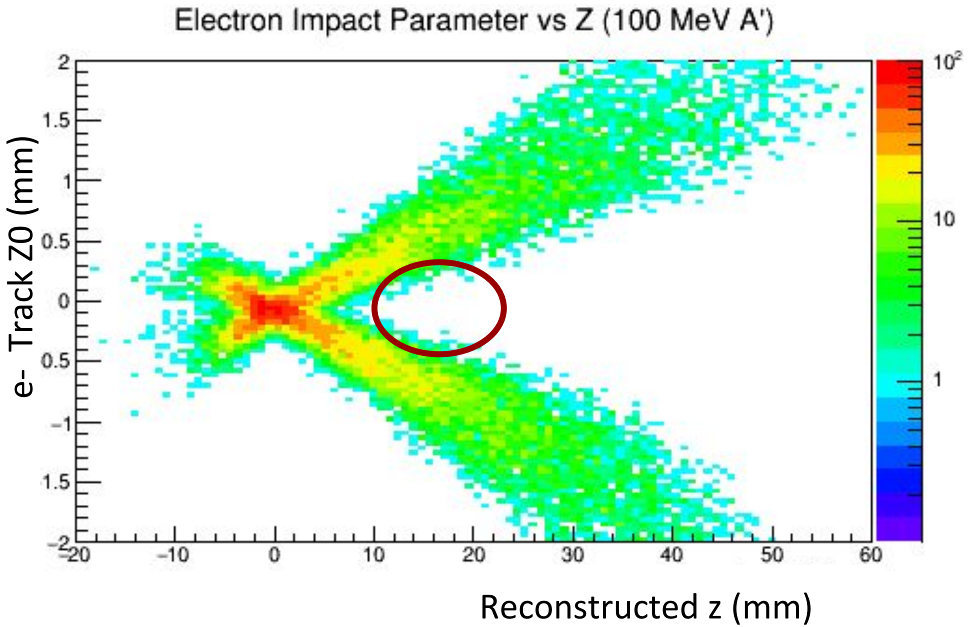


arXiv:1402.5143



Track Impact Parameters

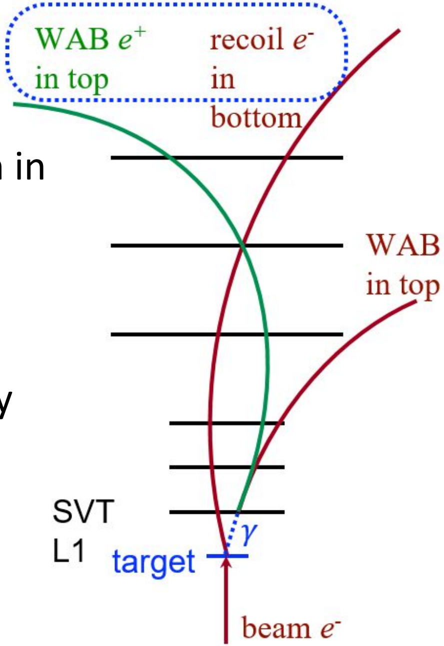


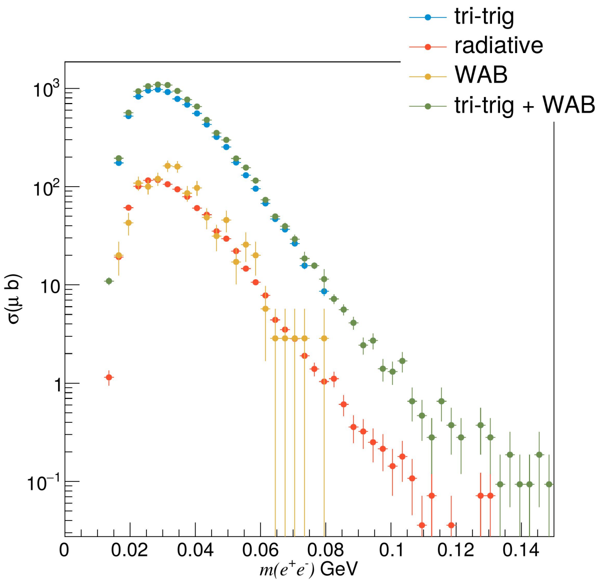


- Other track/vertexing variables (e.g. vertex positions & errors, track angles, etc.) can discriminate between signal and background
- Can we combine all this info to more effectively separate signal and background?

Converted Wide Angle Bremsstrahlung (WABs)

- Converted photons in tracker/target are common, but pairs in the same hemisphere
  - Recoils are generally soft, but can trigger with a conversion positron in opposite hemisphere: **rate comparable to tridents**
  - Daughter particles and recoil electron point back to the primary
- Simple cuts **eliminate about 80% with minimal signal loss**
  - Require a layer 1 positron hit

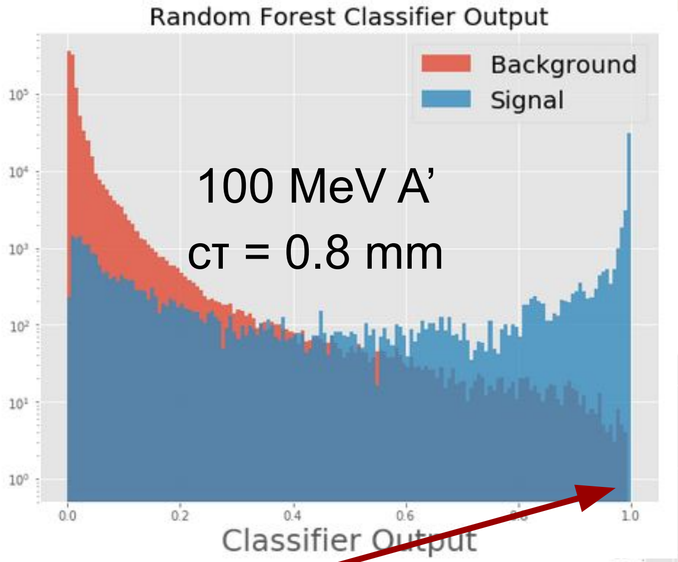




$$rad\ frac = \frac{rad\ e^+e^-pairs}{total\ e^+e^-pairs}$$

Machine Learning at HPS

SLAC



Can an ML technique improve by utilizing all relevant tracking & vertexing variables?

Preliminary results are promising!

We can cut at the classifier output (0.995) to achieve "zero" background