



# The HPS Experiment: Update

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**2019 JLAB USERS ORGANIZATION MEETING**

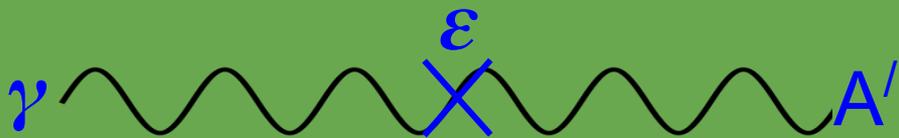
June 24, 2019 to June 26, 2019. Jefferson Lab

# The Dark Photon $A'$

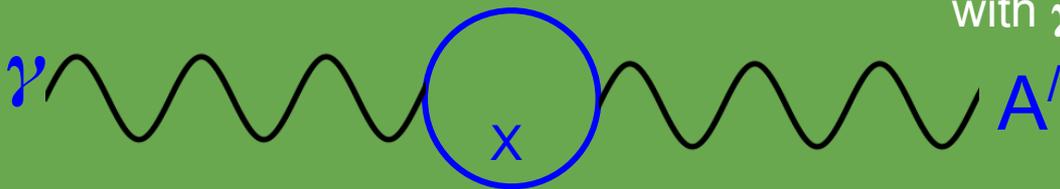
What if Nature contains an additional broken U(1) (Abelian) force mediated by a massive vector boson,  $A'$ ? Bob Holdom, Phys.Lett.,B166, 2, (1986)

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

Kinetic mixing      Induces weak coupling to electric charge



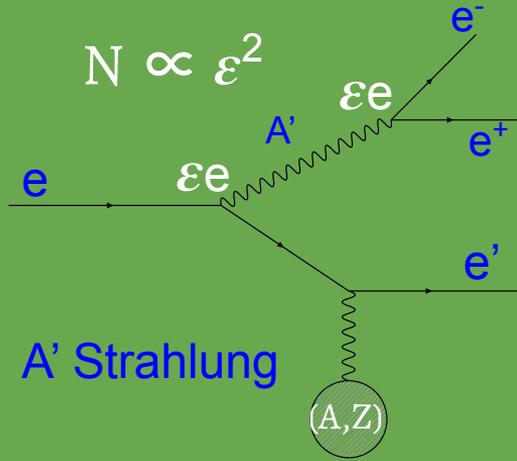
Generated by heavy particles X interacting with  $\gamma$  and  $A'$



# Where can A's be produced

Where there are photons, there can be dark photons!

## Fixed target experiments



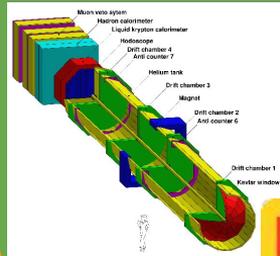
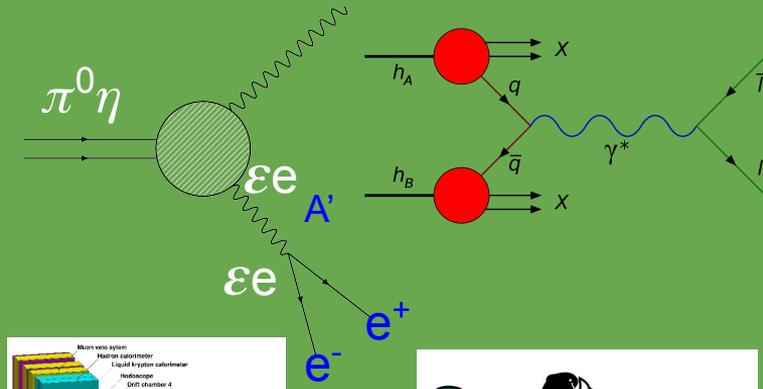
A' Strahlung



**APEX**

**DARKLIGHT**

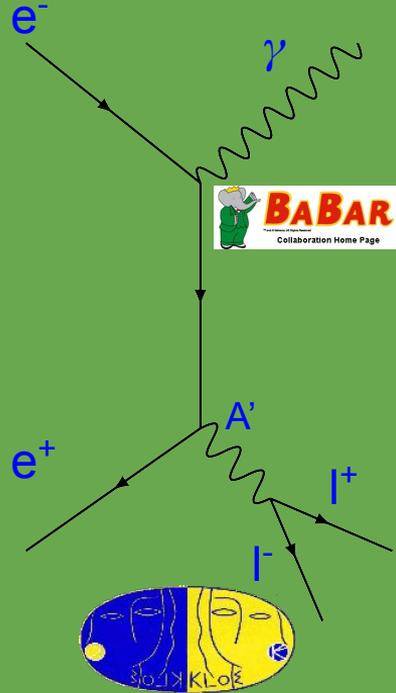
## Protons on fixed target



**NA48**

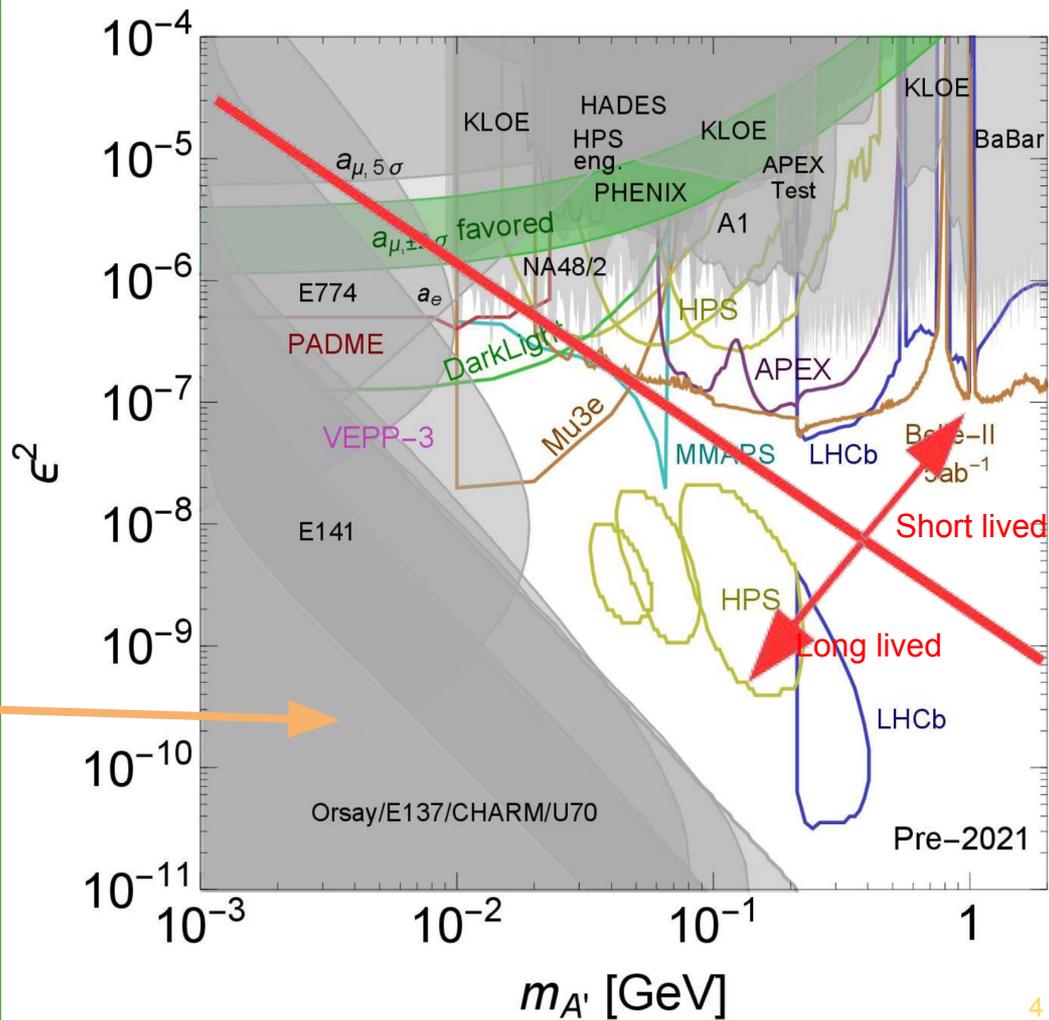
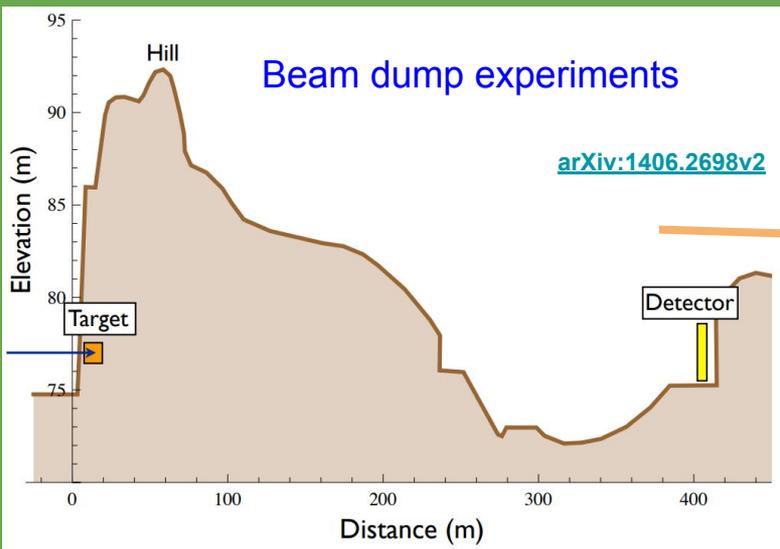
**SeaQuest E906**

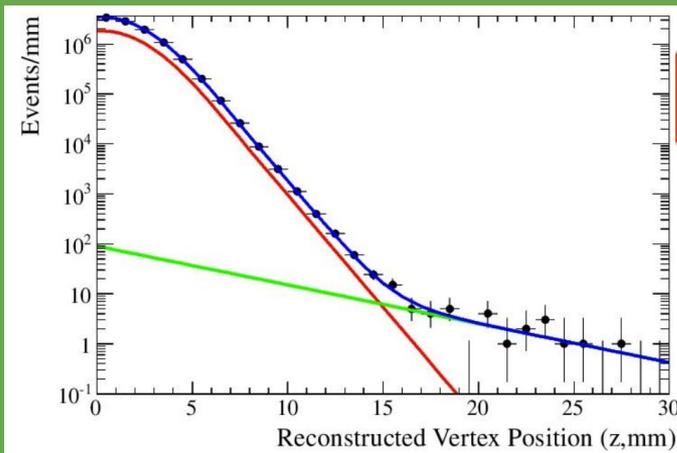
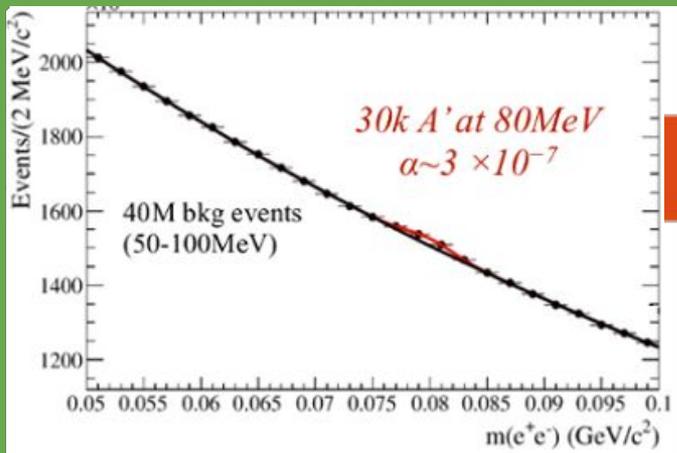
## $e^- e^+$ colliders



Most constraints come from “bump hunt” searches, looking for a resonance in the e-e+ mass spectrum.

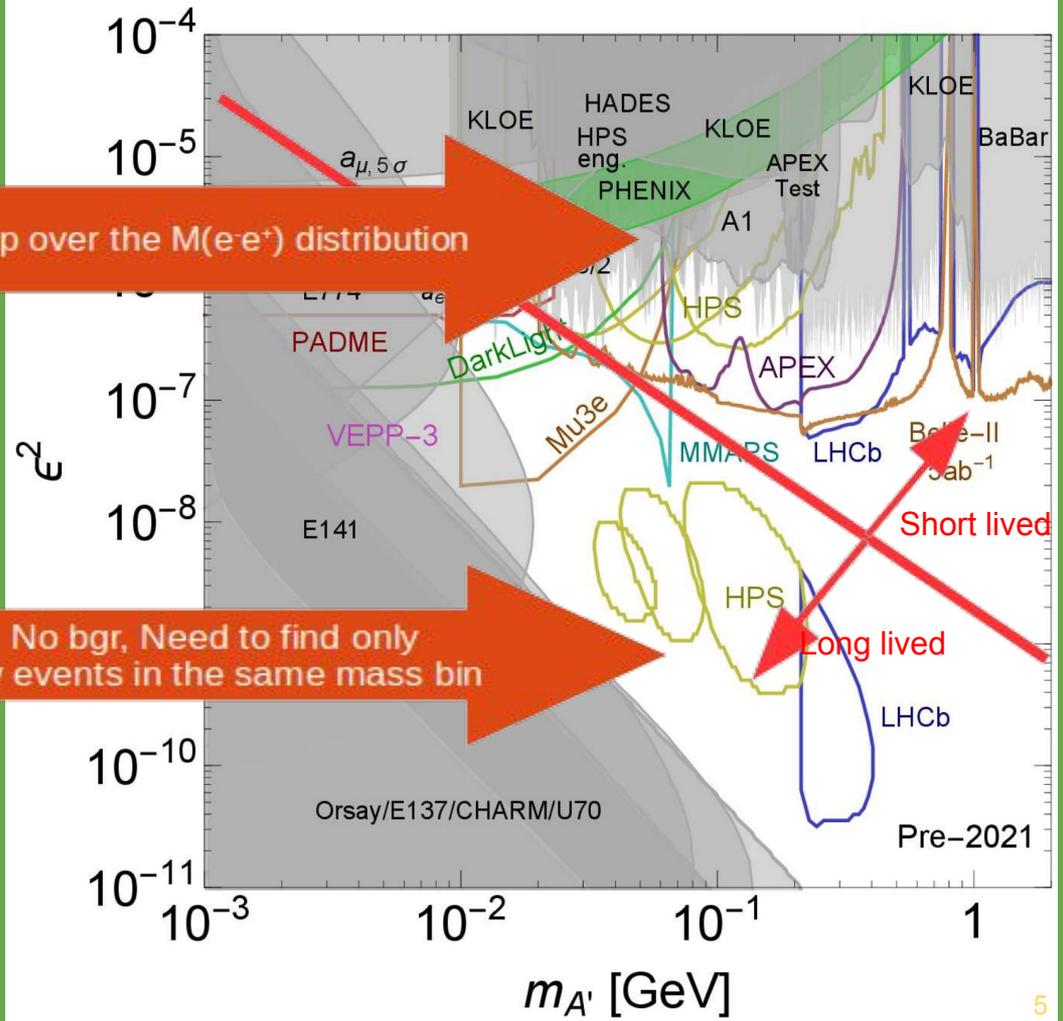
$$l_0 \equiv \gamma_{CT} \propto \frac{1}{\epsilon^2 m_{A'}^2}$$





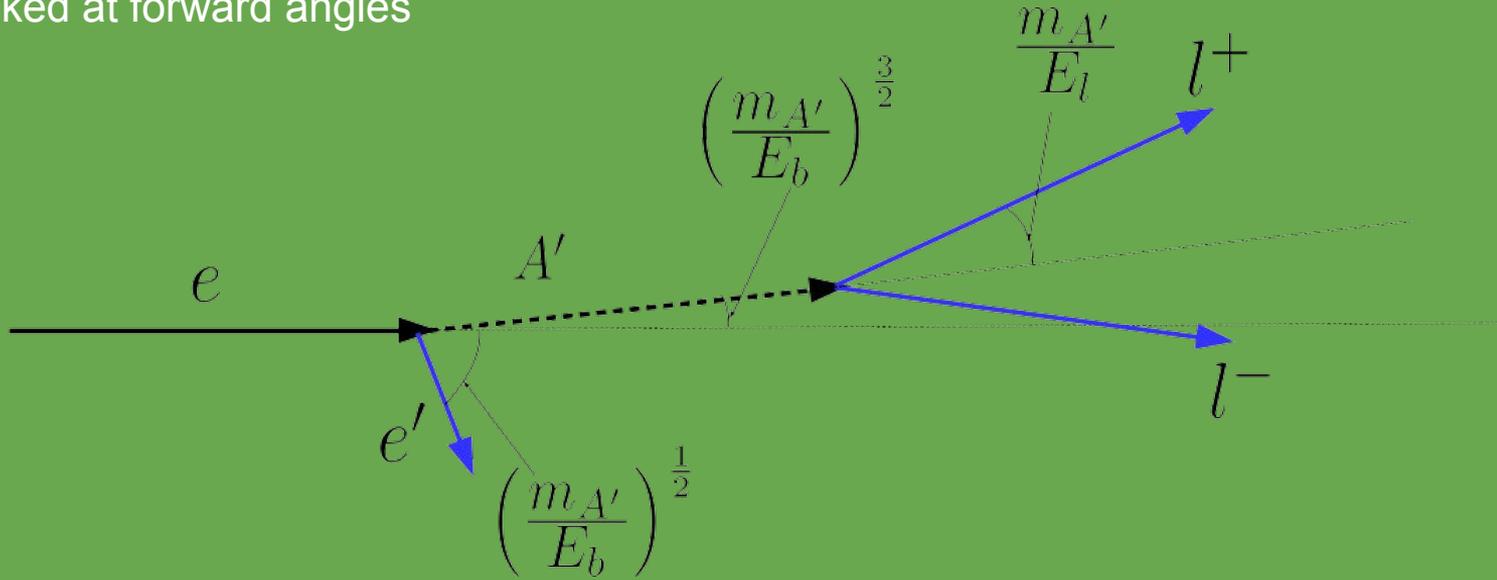
Bump over the  $M(e^+e^-)$  distribution

No bgr, Need to find only few events in the same mass bin



# Electro-produced heavy photon kinematics on fixed targets

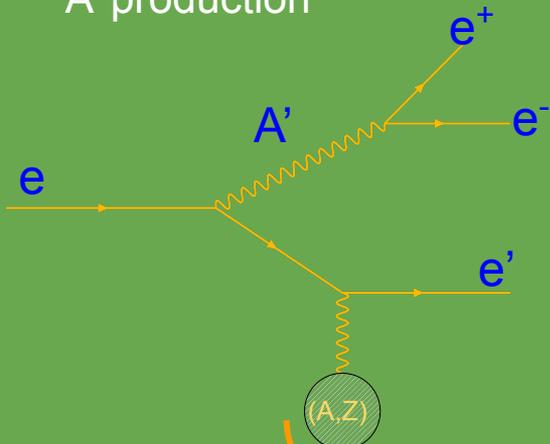
- Unlike Bremsstrahlung,  $A'$  takes almost all the beam energy
- Peaked at forward angles



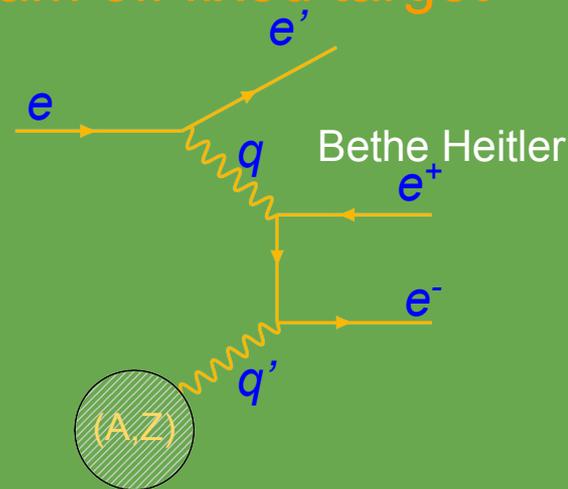
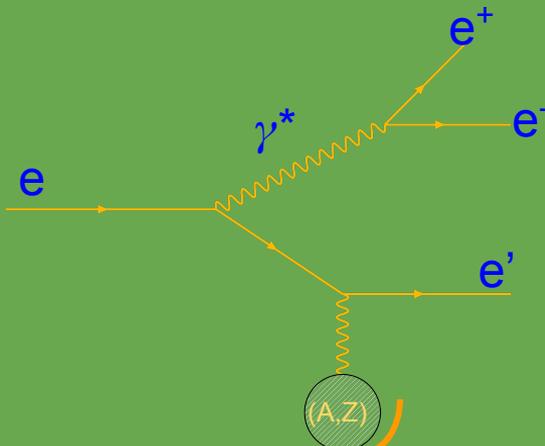
- Fixed target experiments are therefore designed to be sensitive to small angles
- Maximize acceptance for high  $E_{\text{sum}}$

# Background processes in $A'$ production w/ $e^-$ beam off fixed target

$A'$  production



Production of a time like photon (radiative tridents)

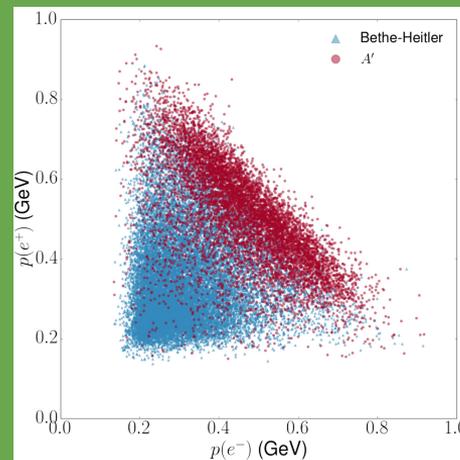


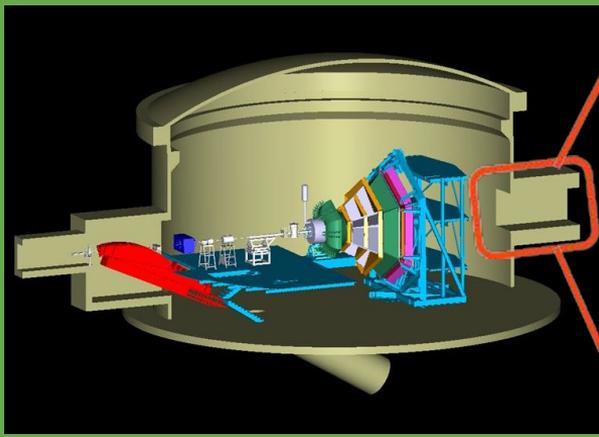
Same kinematics for fixed  $M(e^-e^+)$

$$\frac{\sigma(eA \rightarrow e' A' (\rightarrow e^- e^+))}{\sigma(eA \rightarrow e' \gamma^* (\rightarrow e^- e^+))} = \left( \frac{3\pi\epsilon^2}{2N_f\alpha} \right) \frac{m_{A'}}{\delta m}$$

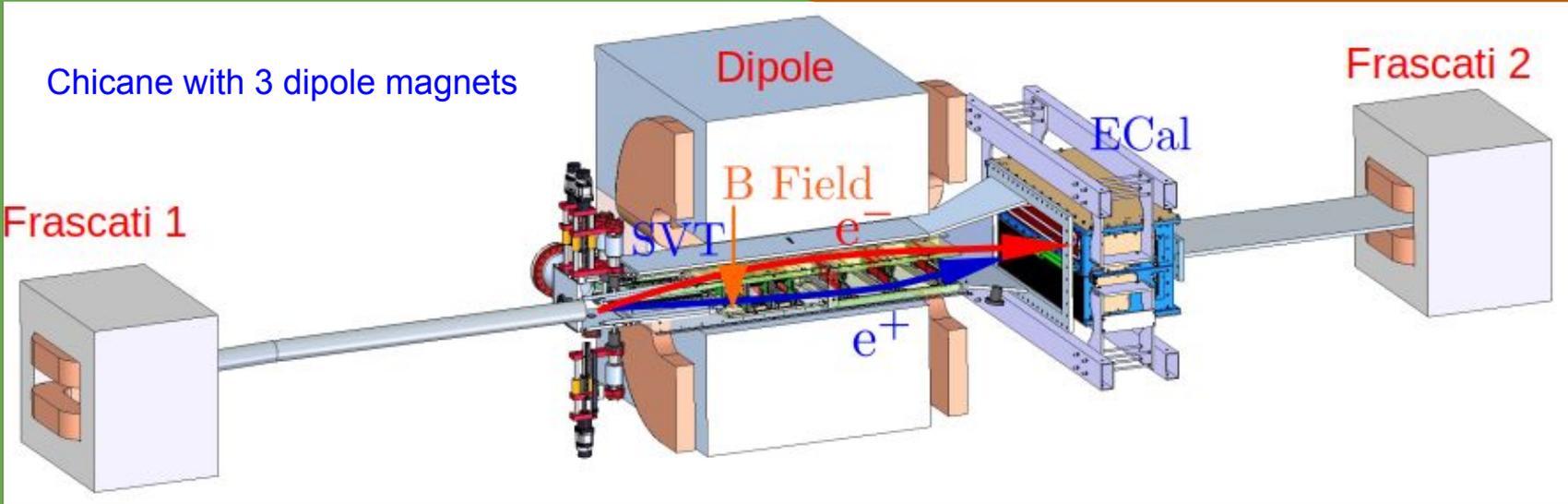
Known QED process  $\Rightarrow \epsilon$  can be calculated by above ratio

It is critical to have a good mass resolution



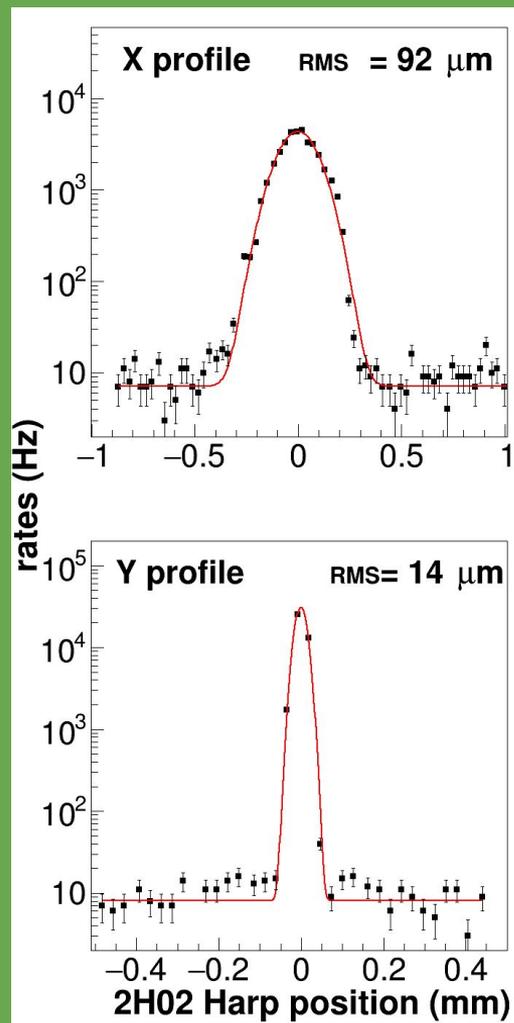
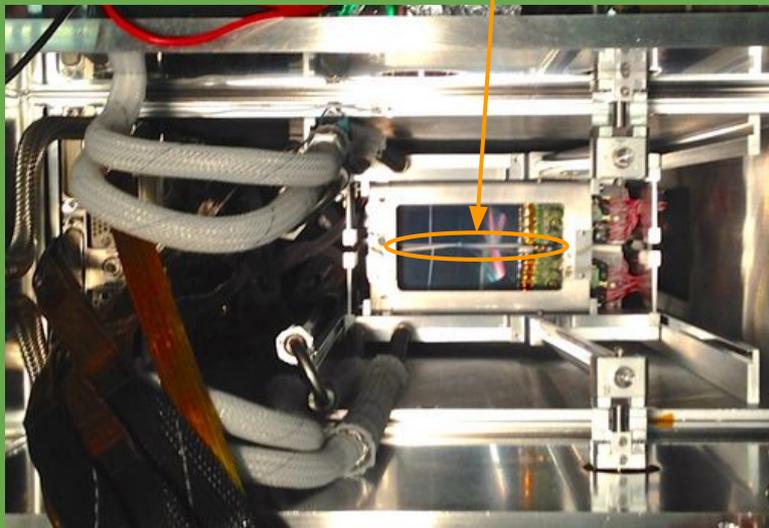


Experimental setup in 2015 and 2016 runs



# Main beam requirements

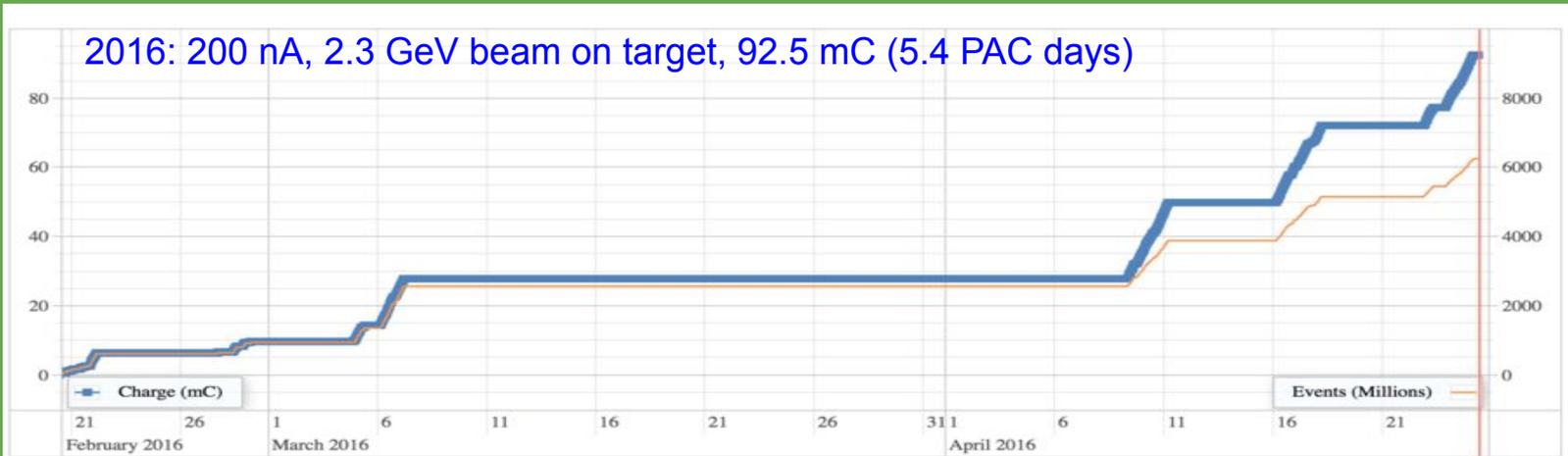
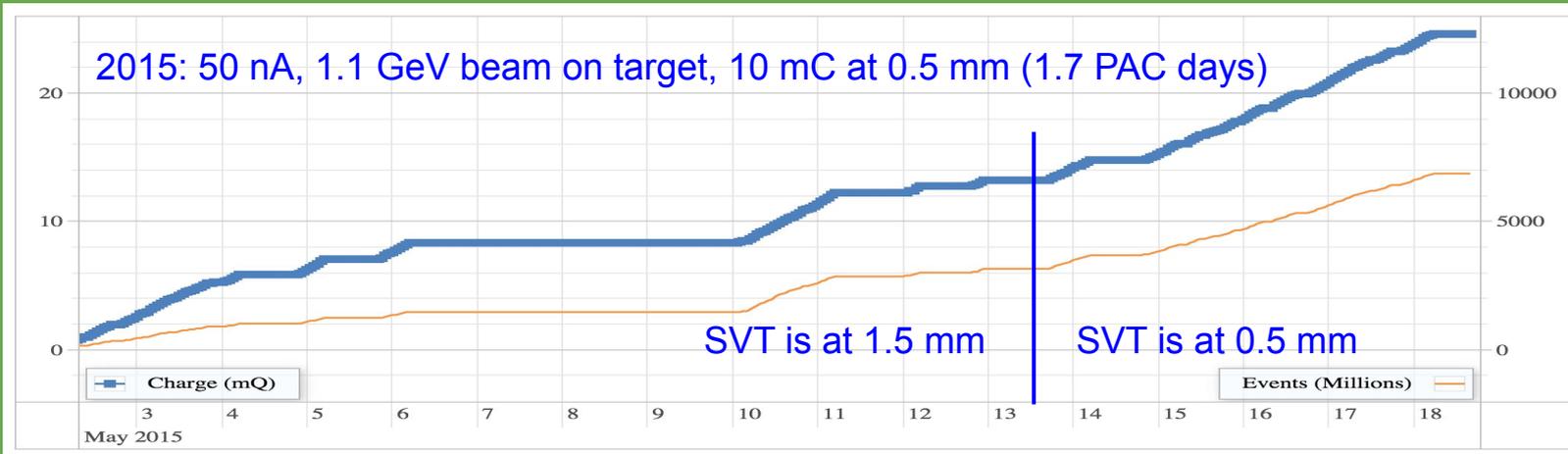
1st layer of SVT is only 0.5 mm away from the beam



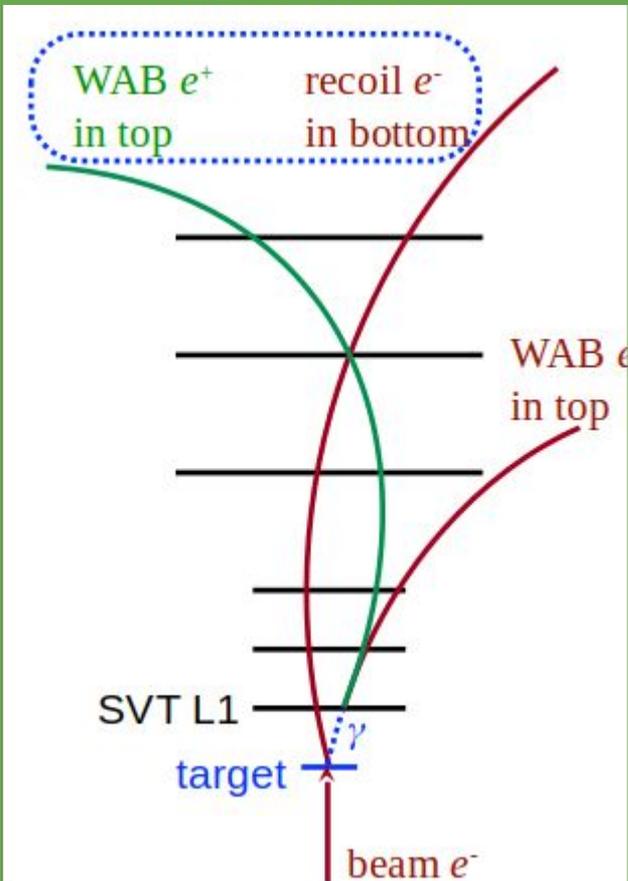
During 2015 and 2016 runs beam vertical profile was kept below 50 micron.

In case of beam excursions FSD shuts the beam down within 10 ms

# Engineering runs in 2015 and 2016



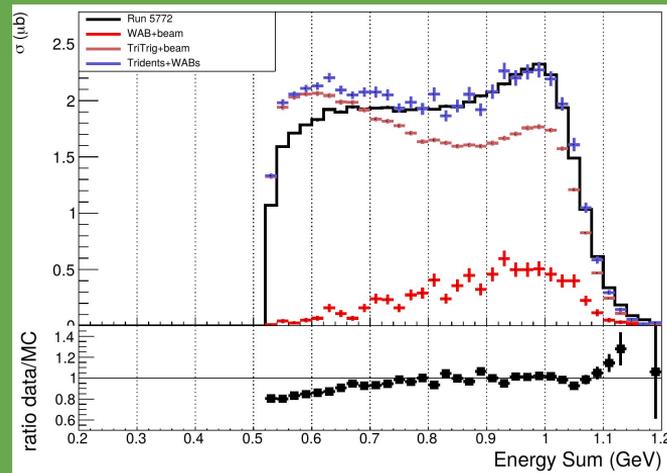
# Wide Angle Bremsstrahlung and pair conversion



During the analysis we realized that in the final state there is a significant contribution from the two step process: WAB  $\rightarrow$  conversion in SVT layers

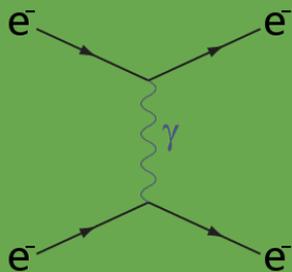
WABs aren't in any of the standard generators or MC systems (GEANT4, EGS).

Cuts: requiring a hit in L1 and DOCA cut removes 80% of these events, without significant loss of tridents



# Mass resolution

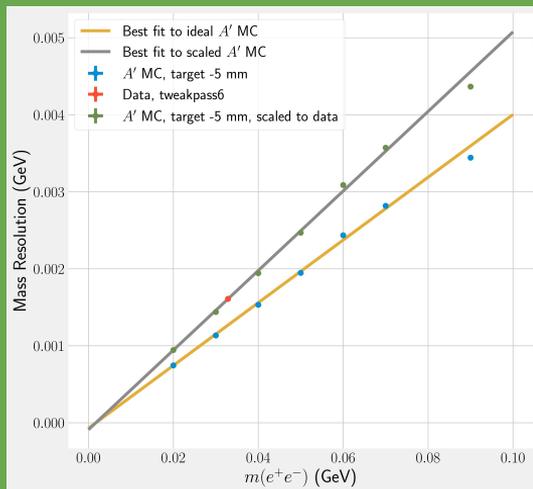
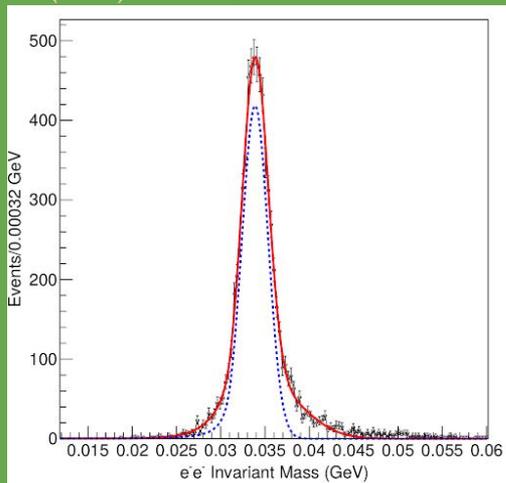
Good understanding of the mass resolution is a critical component in the “Bump Hunt” analysis



We know the mass resolution of the data at a single point, Moeller mass.

We have to rely on the Monte Carlo mass resolution for all other mass

$$M(ee) \equiv \sqrt{2 \cdot E_b \cdot m_e} = 32.7 \text{ MeV}$$

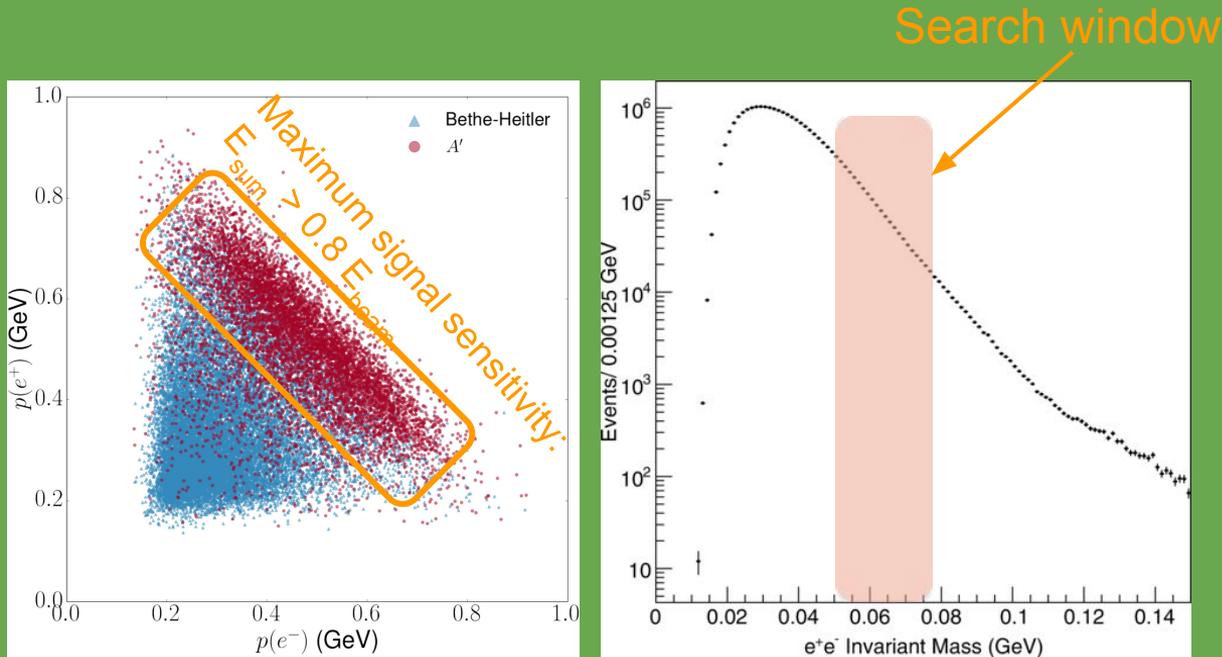


- The mass resolution difference between the Data and MC is due to momentum resolution difference between the data and MC.

- Linear fit of MC A' masses

- Scale MC to match the data Moeller resolution

# Invariant mass distribution



-Range 19 MeV – 81 MeV

-Scan w/ 0.5 MeV step

-Search for the peak in the given mass range

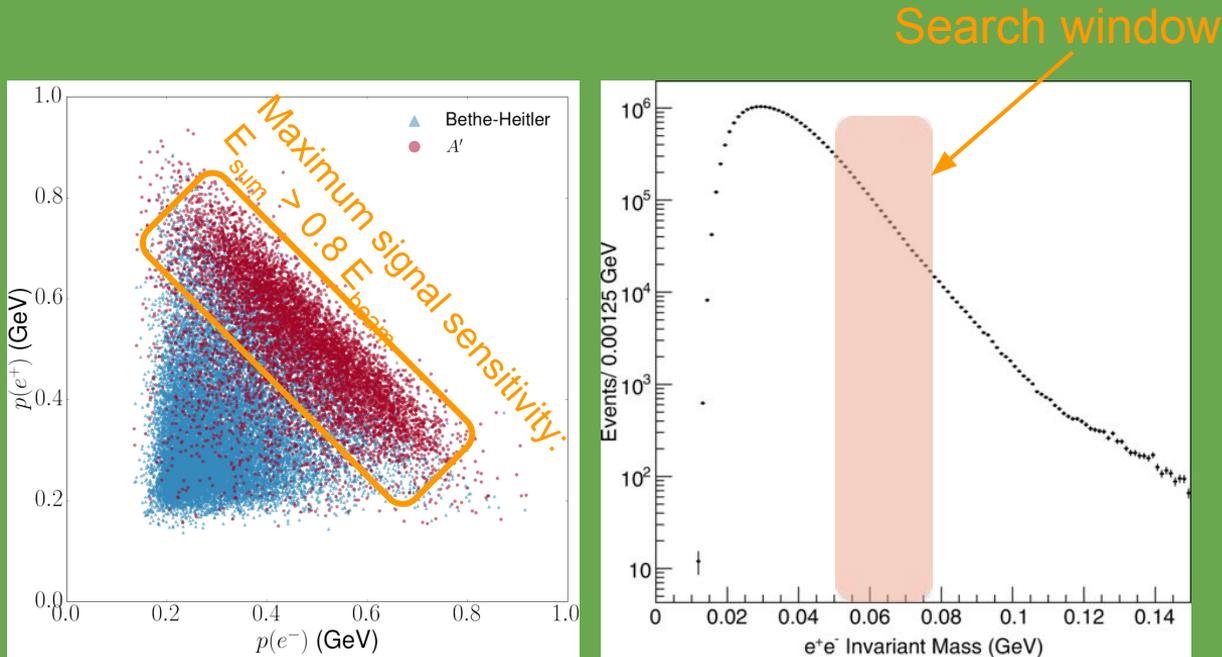
- Maximize Poisson Likelihood with Bgr only, and Bgr+signal hypothesis

- Use log likelihood ratio to quantify any excess/bump

Use MC to correct significance for “look elsewhere” effect.

4000 pseudo data is generated, to provide mapping between the local p-value and the global p-value

# Invariant mass distribution



-Range 19 MeV – 81 MeV

-Scan w/ 0.5 MeV step

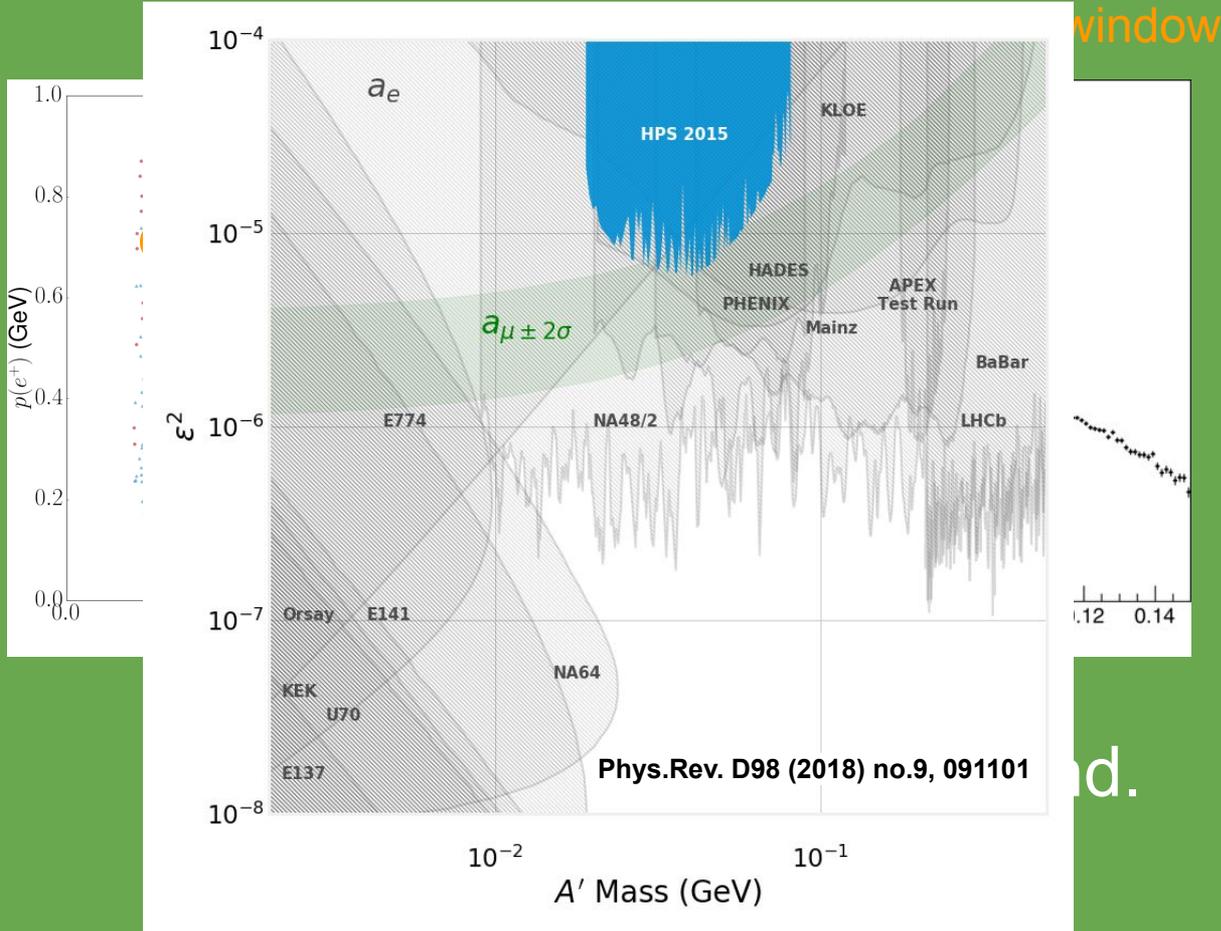
-Search for the peak in the given mass range

- Maximize Poisson Likelihood with Bgr only, and Bgr+signal hypothesis

- Use log likelihood ratio to quantify any excess/bump

No significant peak is found.  
 $2\sigma$  limit is placed

# Invariant mass distribution



Window

- Range 19 MeV – 81 MeV

- Scan w/ 0.5 MeV step

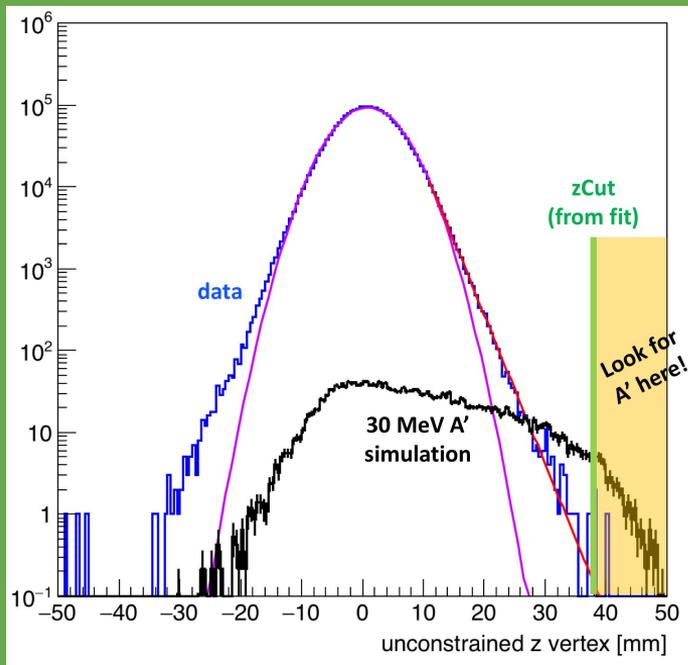
- Search for the peak in the given mass range

- Maximize Poisson Likelihood with Bgr only, and Bgr+signal hypothesis

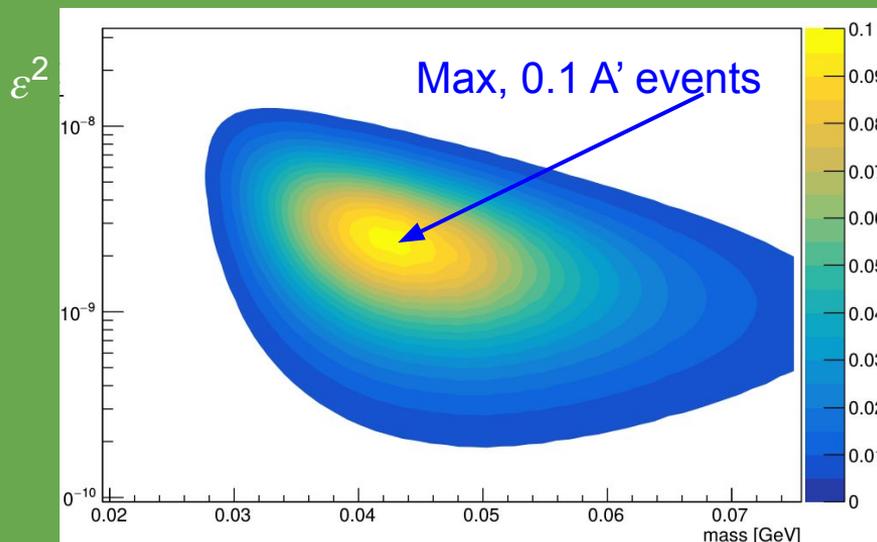
- Use log likelihood ratio to quantify any excess/bump

d.

# Vertexing analysis

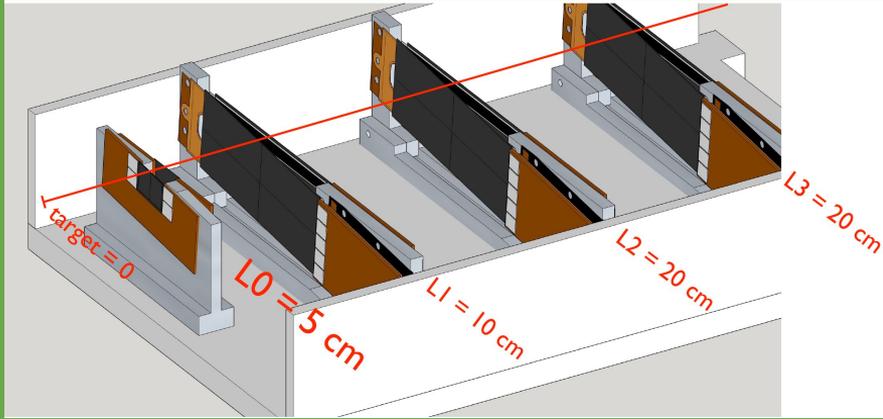


2015 data: 1.5 PAC dats



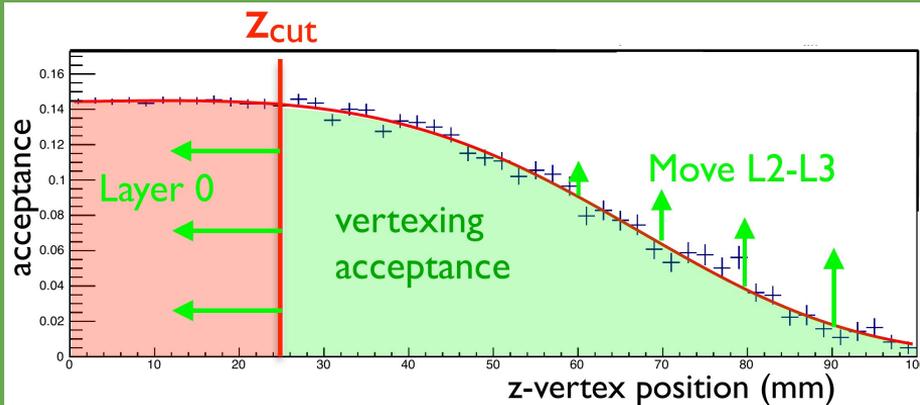
Analysis is in a quite advanced state, however with 1.5 days of data, we will not have any reach (2.5 expected  $A'$  events)

# SVT upgrade



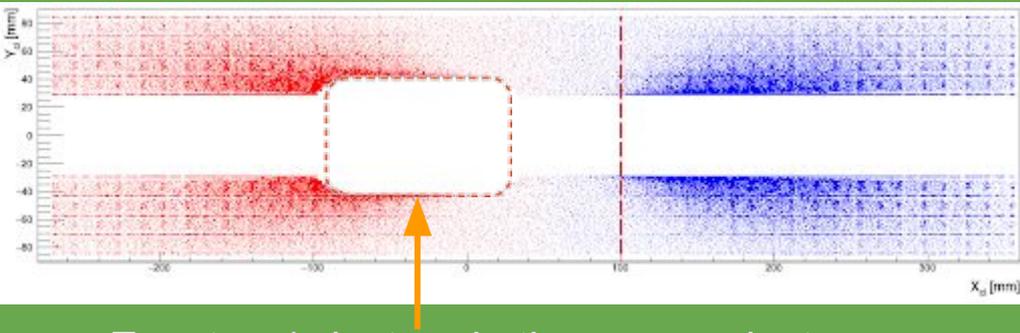
- Adding a new thin SVT layer at 5 cm downstream of the target, will significantly improve the vertexing resolution.

- Thin layer, will not add much background

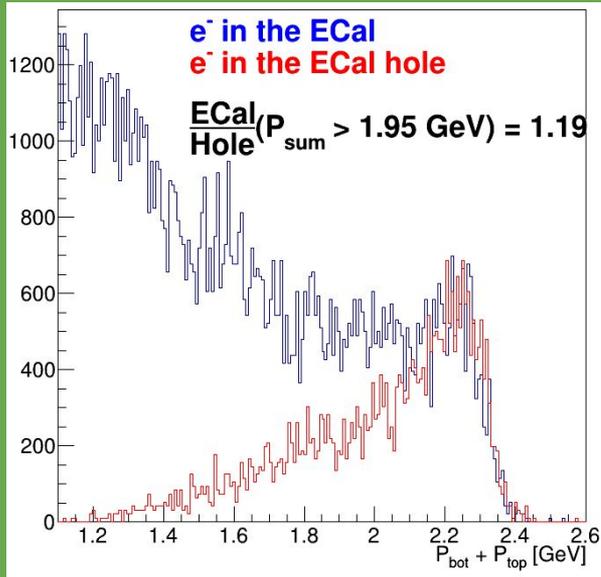


- Moving SVT Layers 2-3 closer to the beam will increase the acceptance

# Hodoscope upgrade

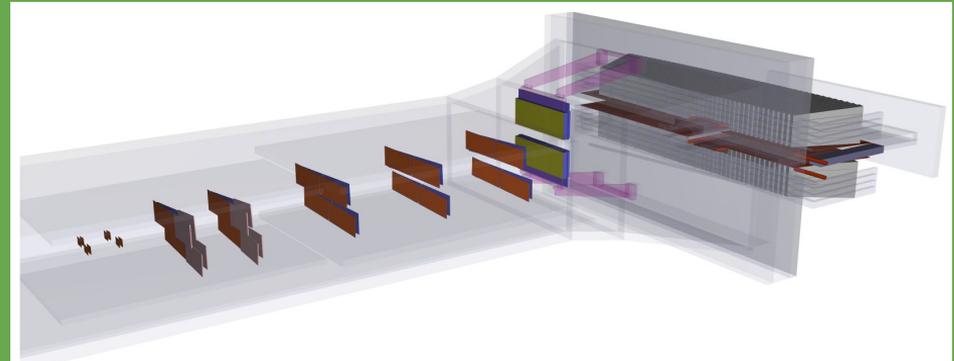


Events w/ electron in the gap are lost



The trigger efficiency to  $e^- e^+$  events was reduced due to  $e^-$  events in the ECal hole.

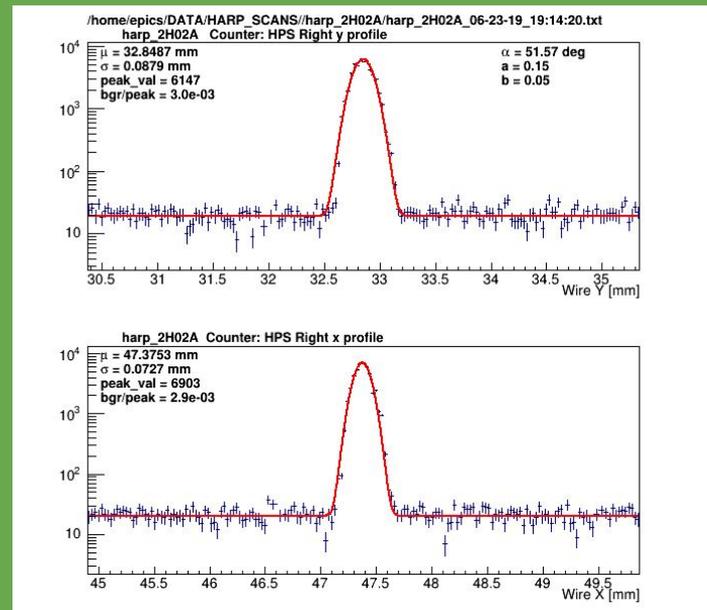
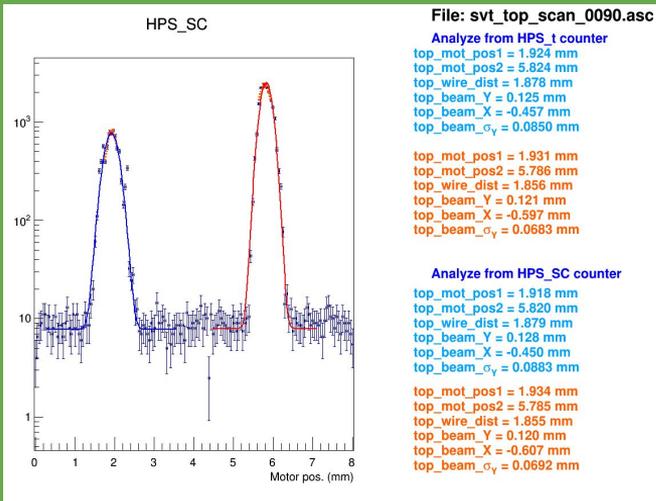
The hodoscope will recover events where the electron passed through the ECal hole



# Summer 2019 Run

*We have just started!*

Beam position and vertical profile at the target



Ebeam = 4.55 GeV

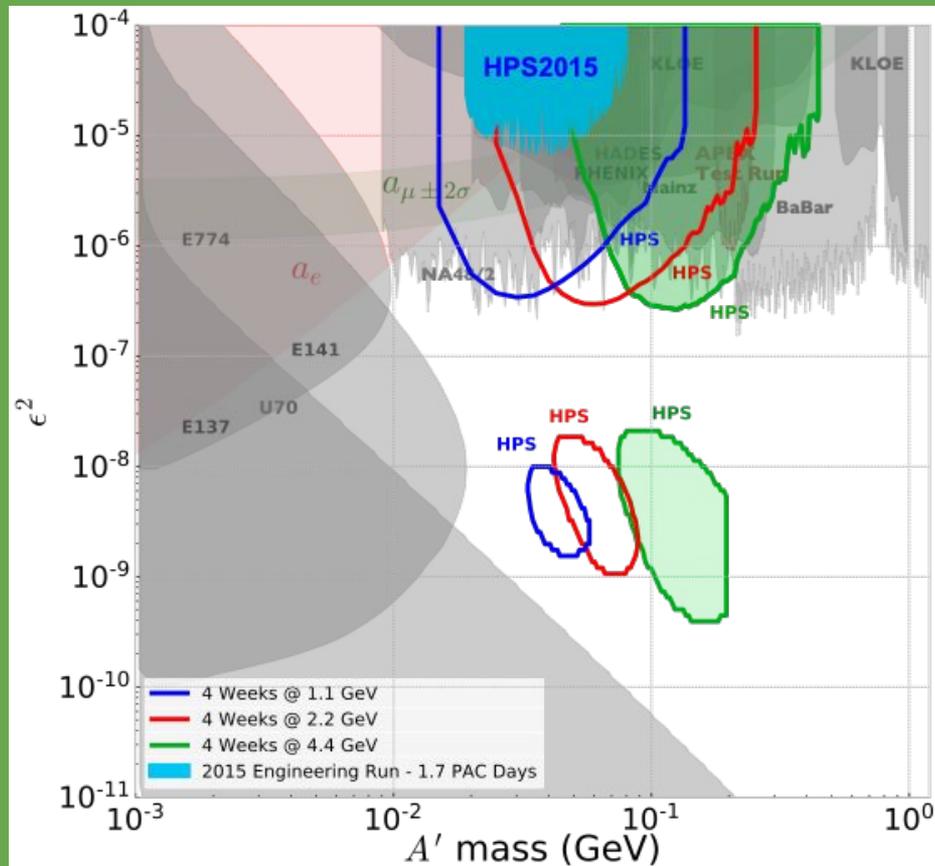
First beam to the tagger dump on Jun 16

Beam profile is quite close the specifications

- Beamline commissioning is complete
- Trigger commissioning is almost finished
- Soon SVT and hodoscope commissioning should be finished.

# Projected reach for the 2019 summer run

8 calendar weeks ( $\approx 4$  PAC weeks)



# Summary

HPS has successfully completed two engineering runs in 2015 and 2016

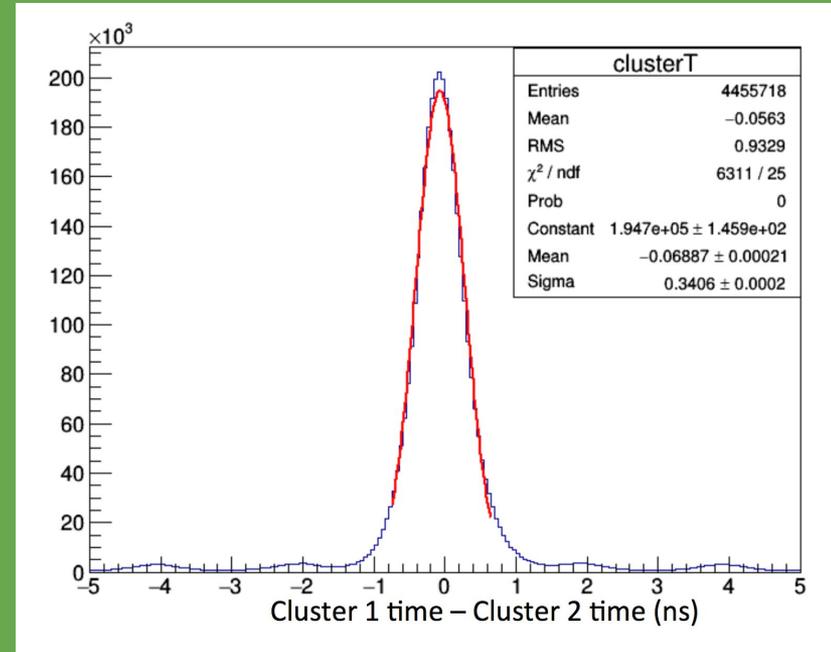
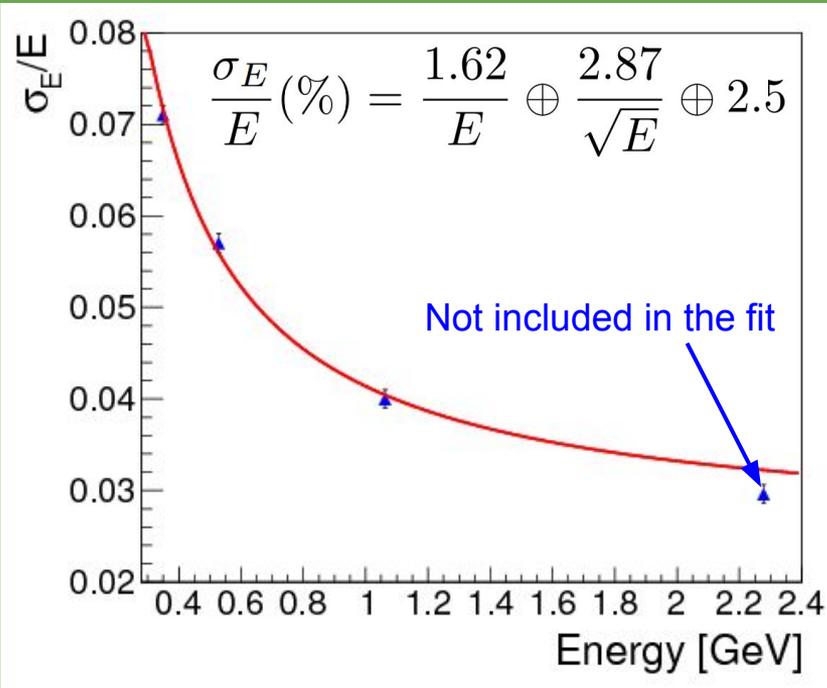
- Showed the concept works!
- Importance of WAB events
- Initiated two major upgrades
- One Physics publications and two NIM papers

Just started the new run: 8 weeks ( $\approx$  4 PAC weeks) with 4.55 GeV beam

- We expect to cover a new territory with a displaced vertex search

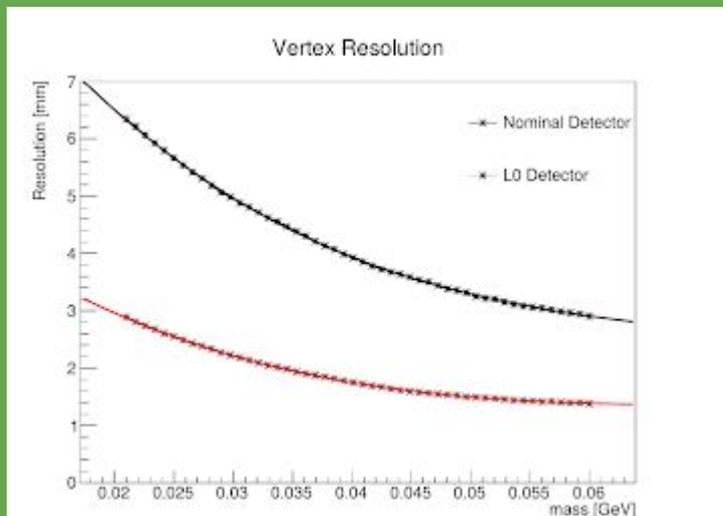
# Backup slides

# Performance of the ECal

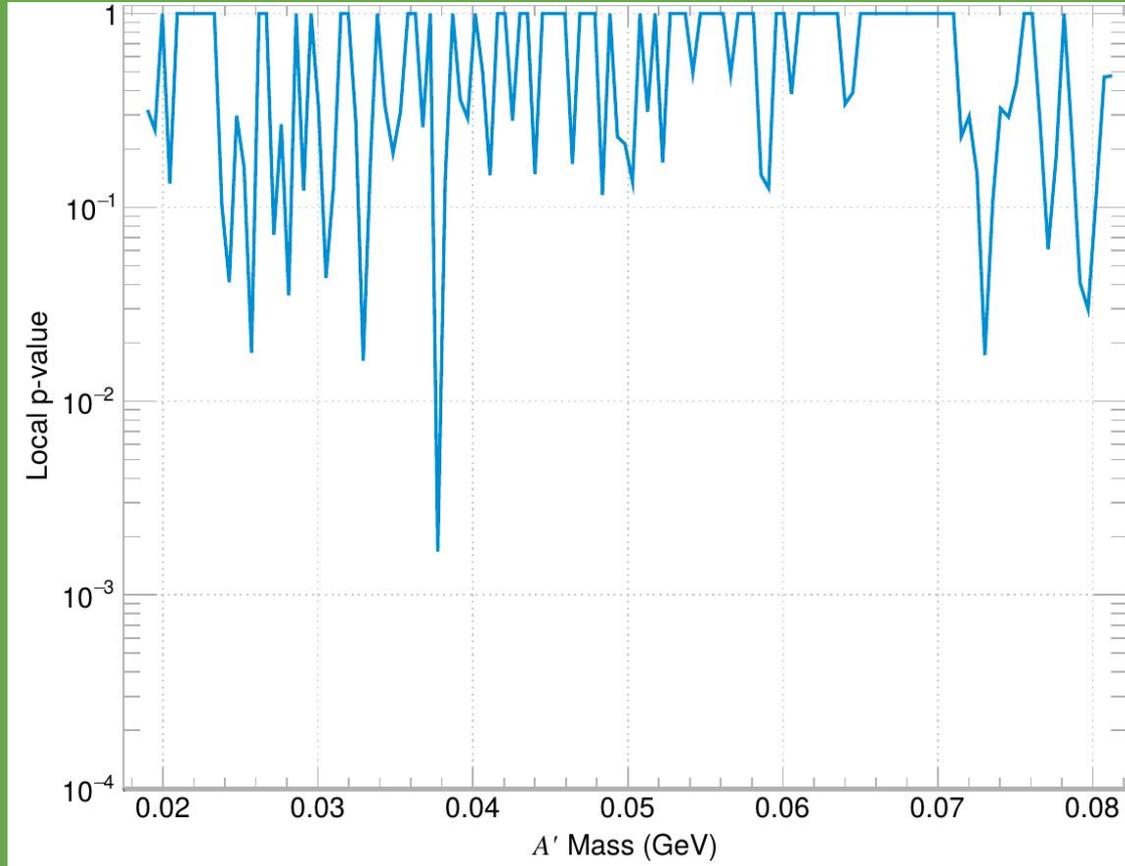


- Good time and energy resolutions!
- Allows to cut accidentals from neighboring beam buckets

# Adding L0 in SVT



# Local p-values from the 2015 analysis



Map between the local p-value and the global p-value is obtained by performing a mass scans over a large number of pseudo data. In each scan calculate the lowest p-value (local).

