The HPS Experiment: Update

Rafayel Paremuzyan

University of New Hampshire

2019 JLAB USERS ORGANIZATION MEETING

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

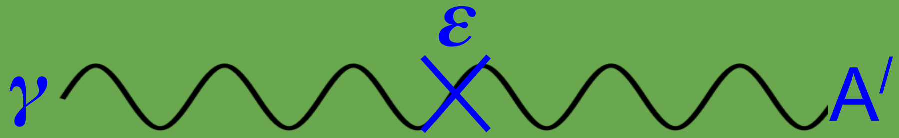
The Dark Photon A′

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)

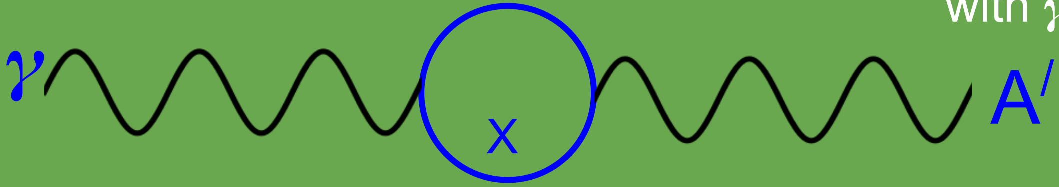
$$\mathcal{L} = \mathcal{L}_{SM} + \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu} + \frac{1}{4} F'^{\mu\nu} F'_{\mu\nu} + m_{A'^2} A'^{\mu} A'_{\mu}$$

Kinetic mixing

Induces week coupling to electric charge



Generated by heavy particles X interacting with γ and A′

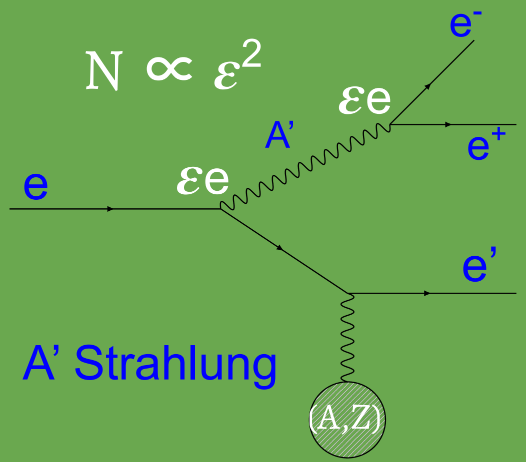


Where can A's be produced

Where there are photons, there can be dark photons!

Fixed target experiments

$N \propto \varepsilon^2$



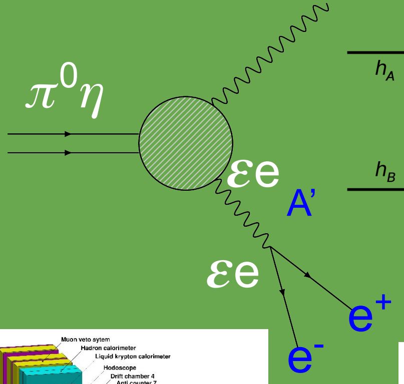
A' Strahlung

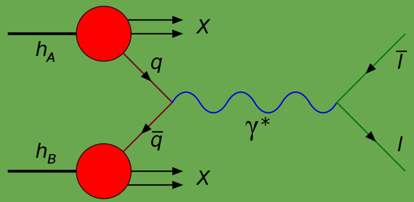
HEAVY PHOTON SEARCH

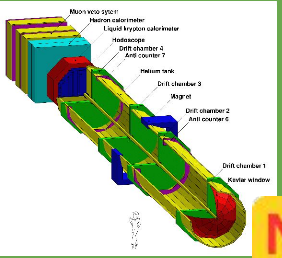
APEX

DARKLIGHT

Protons on fixed target



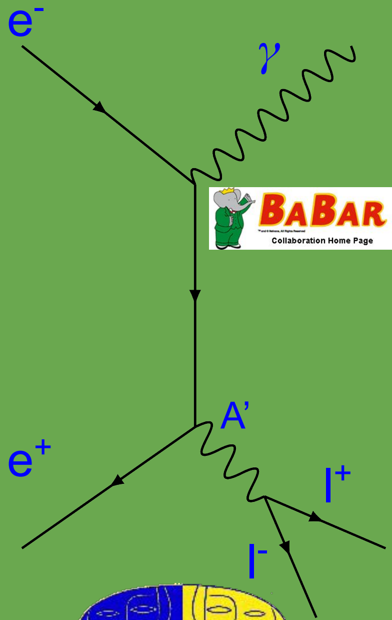




NA48

SeaQuest E906

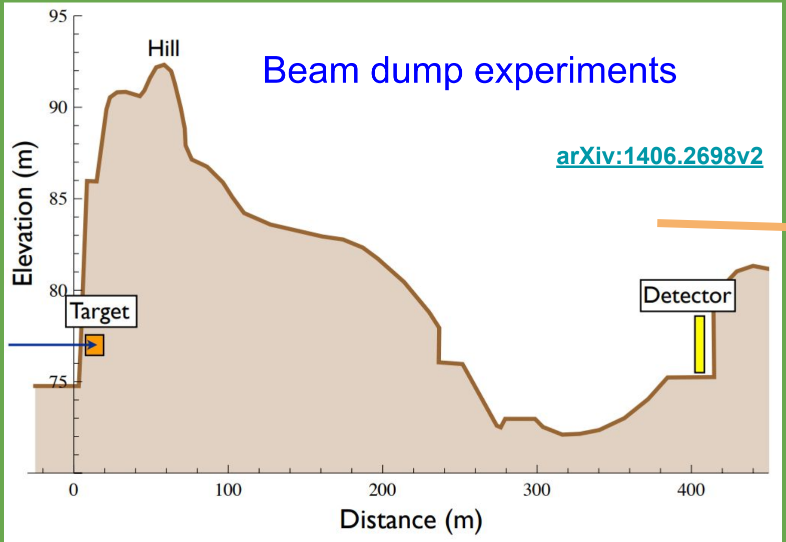
e^-e^+ colliders

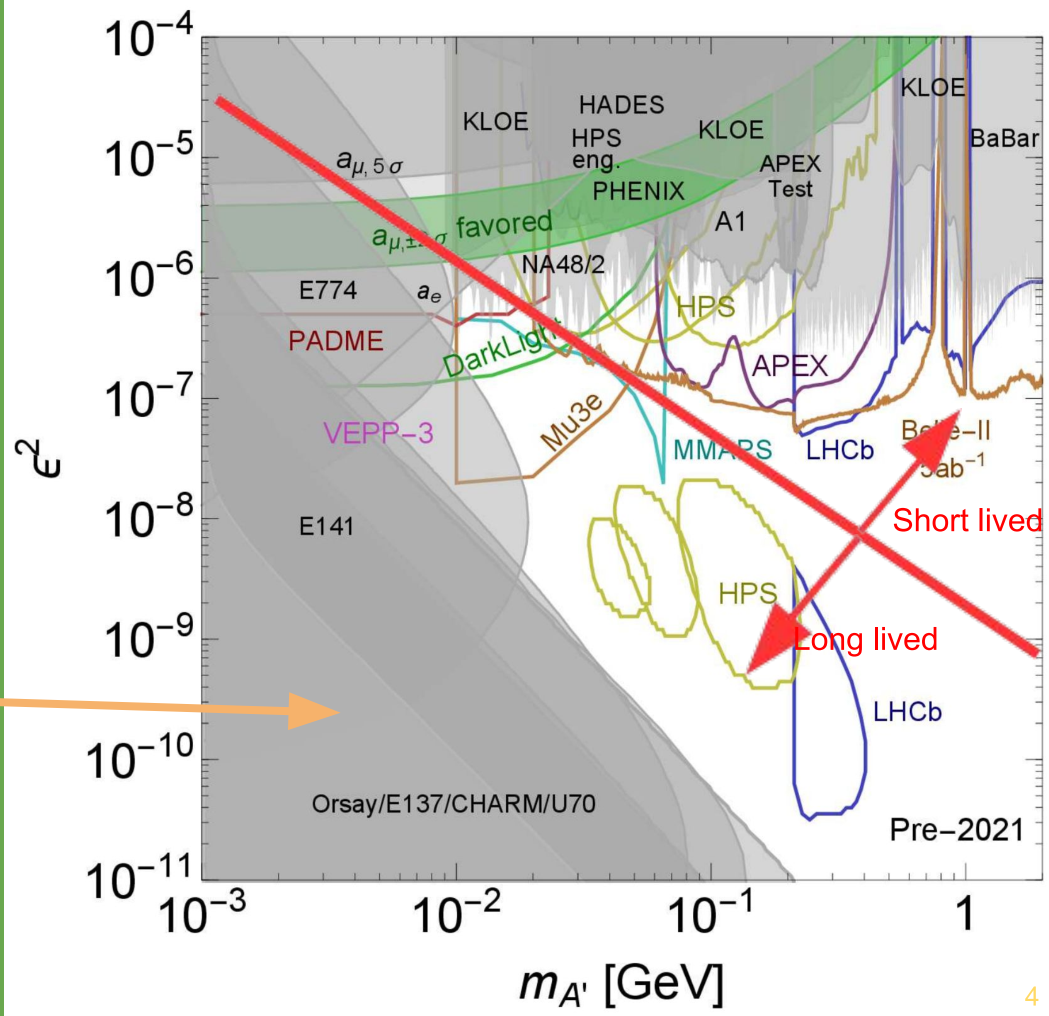


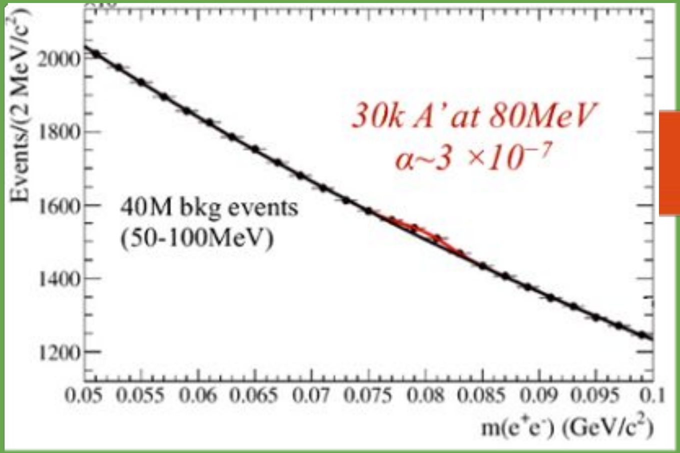
BaBar

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

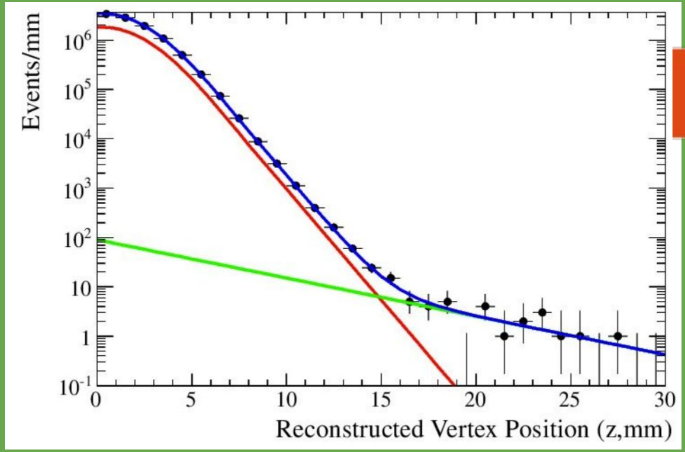
$$l_0 \equiv \gamma c \tau \propto \frac{1}{\epsilon^2 m_{A'^2}}$$



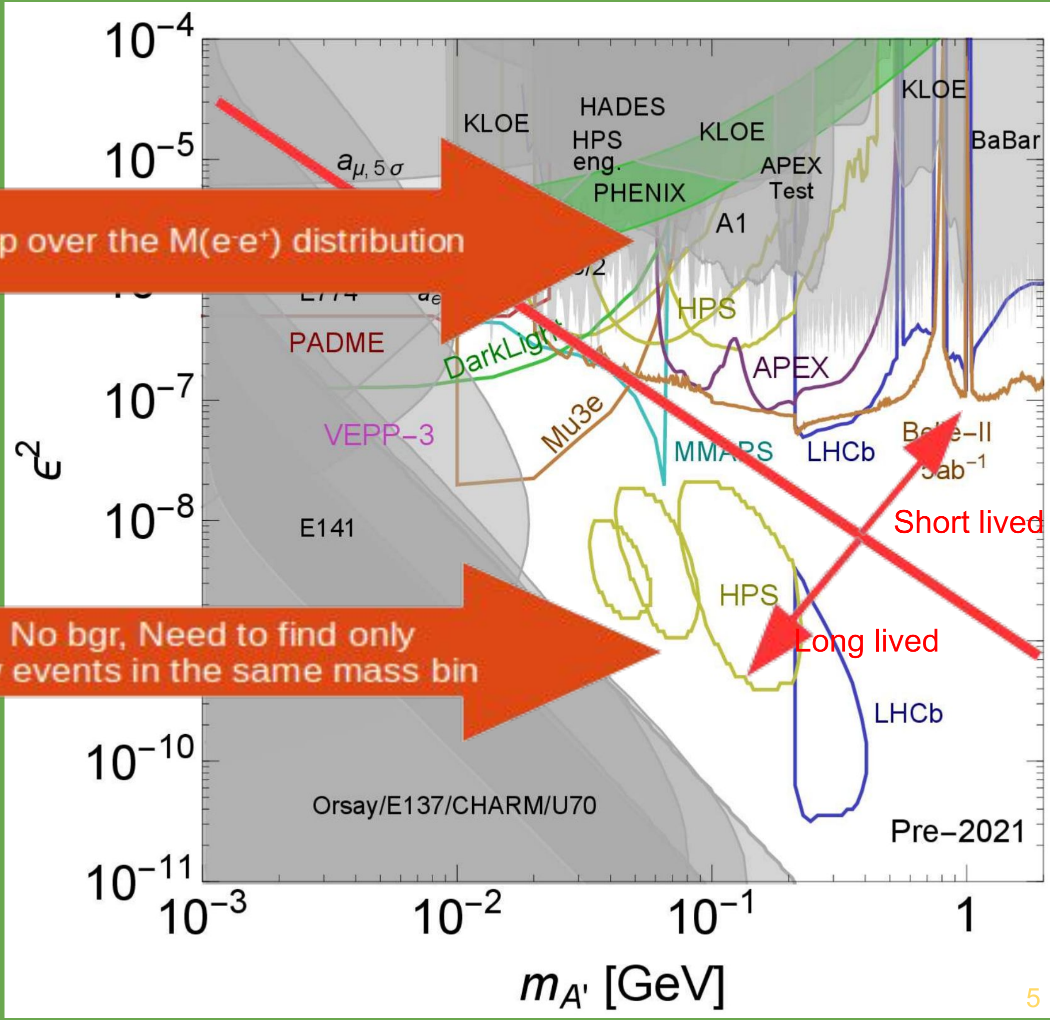




Bump over the M(e⁻e⁺) distribution

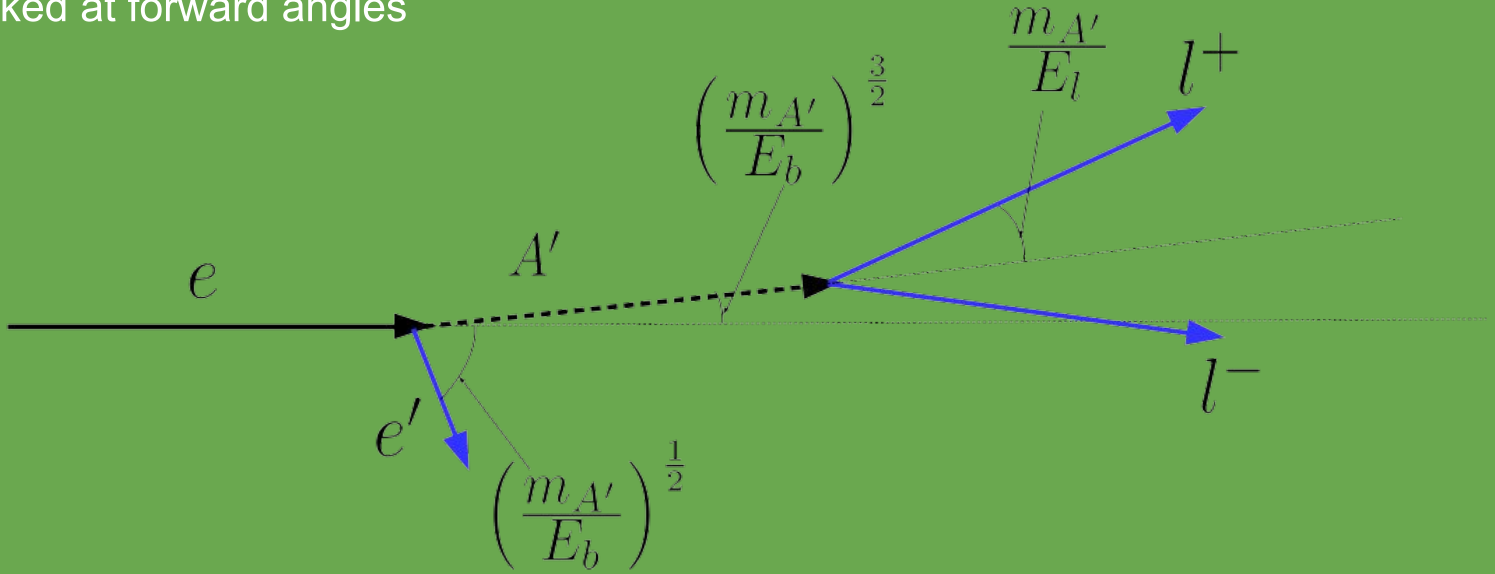


No bgr, Need to find only
few events in the same mass bin



Electro-produced heavy photon kinematics on fixed targets

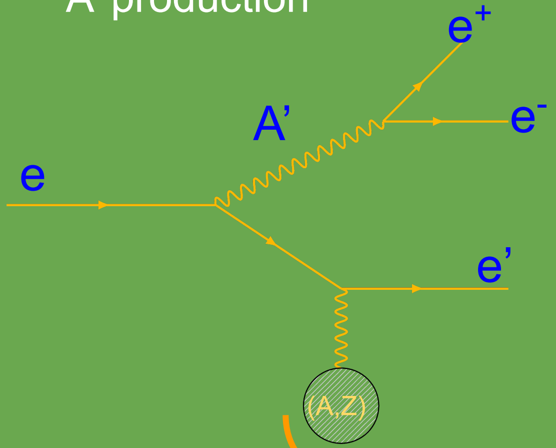
- Unlike Bremsstrahlung, A' takes almost all the beam energy
- Peaked at forward angles



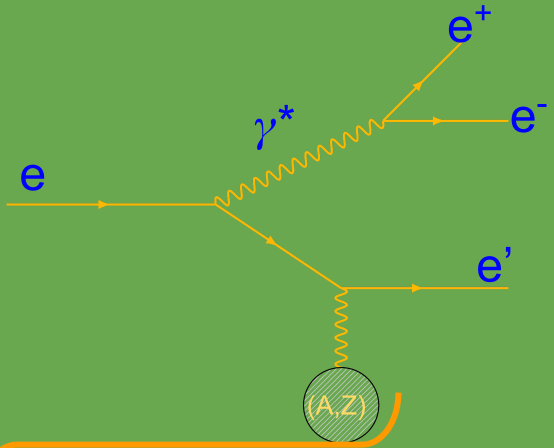
- Fixed target experiments are therefore designed to be sensitive to small angles
- Maximize acceptance for high E_{sum}

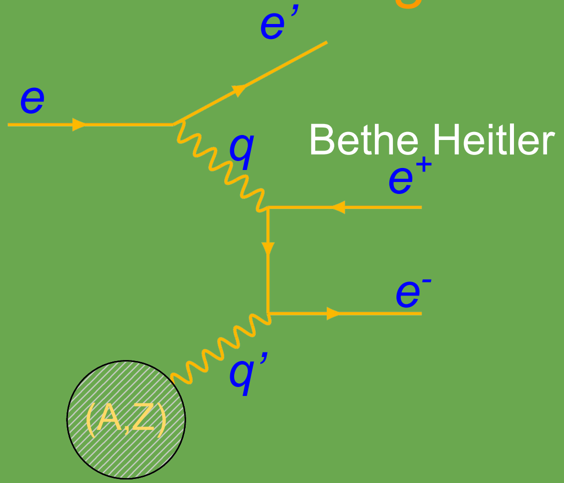
Background processes in A’ production w/ e- beam off fixed target

A’ production



Production of a time like photon (radiative tridents)



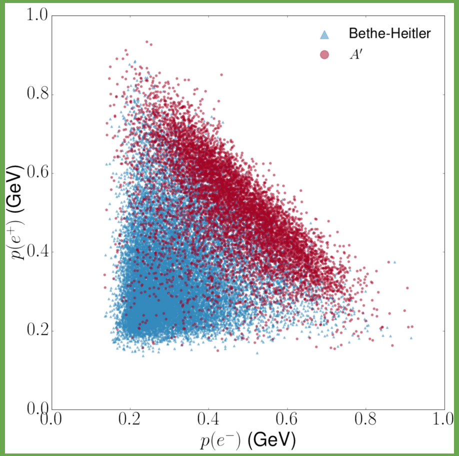


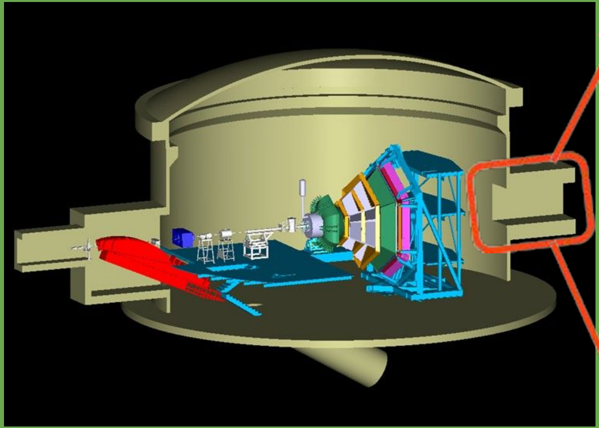
Same kinematics for fixed $M(e^-e^+)$

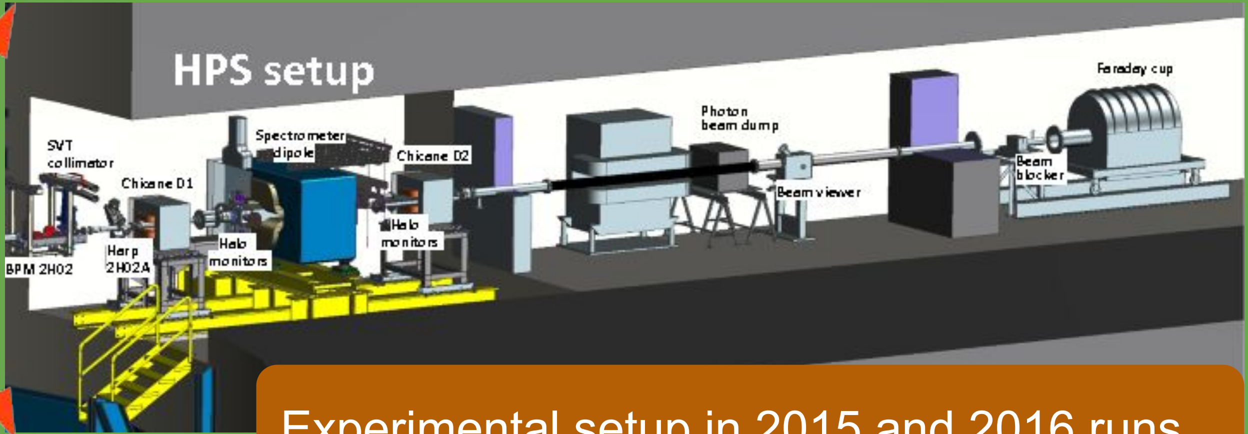
$$\frac{\sigma(eA \to e'A'(\to e^-e^+))}{\sigma(eA \to e'\gamma^*(\to e^-e^+))} = \left(\frac{3\pi\epsilon^2}{2N_f\alpha}\right)\frac{m_{A'}}{\delta m}$$

Known QED process => ε can be calculated by above ratio

It is critical to have a good mass resolution

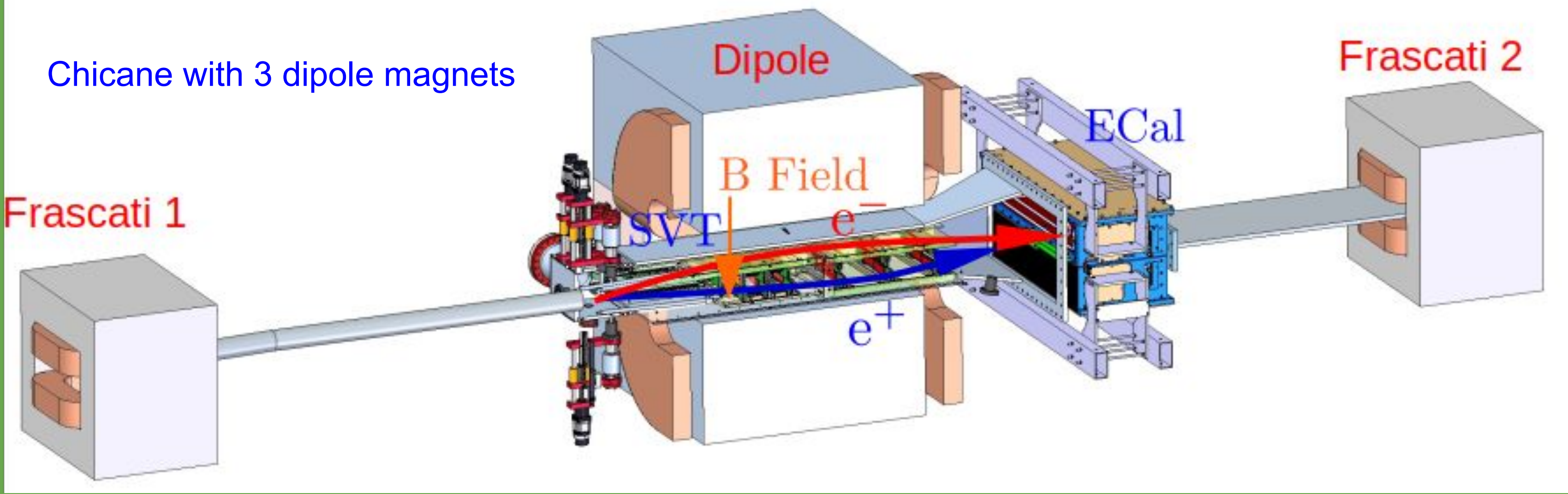




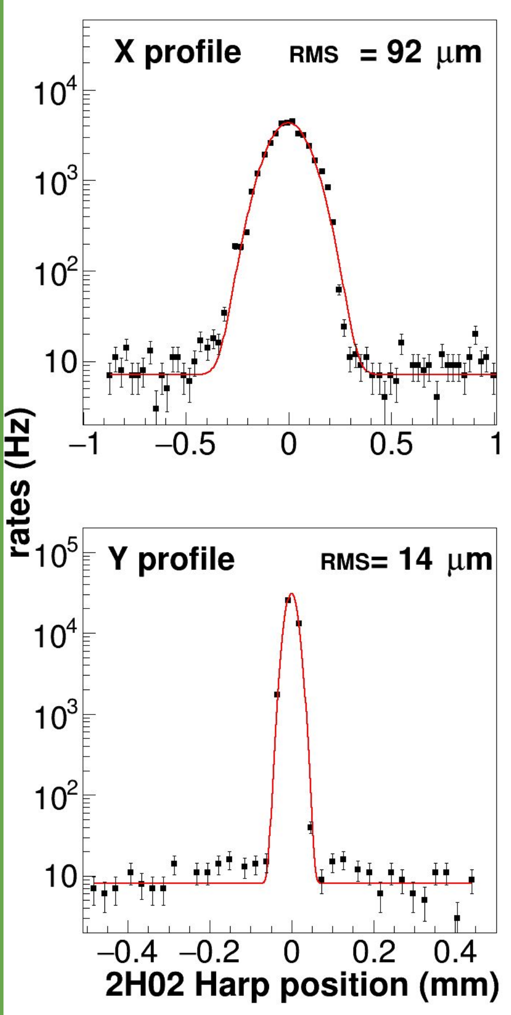


Experimental setup in 2015 and 2016 runs

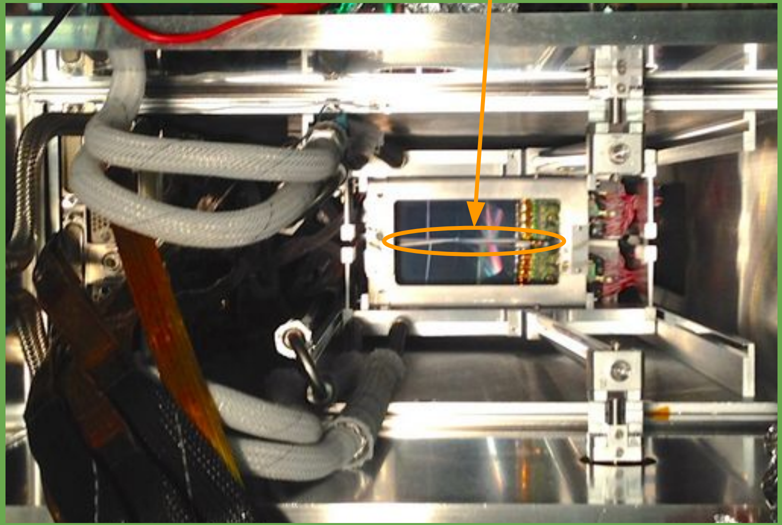
Chicane with 3 dipole magnets



Main beam requirements



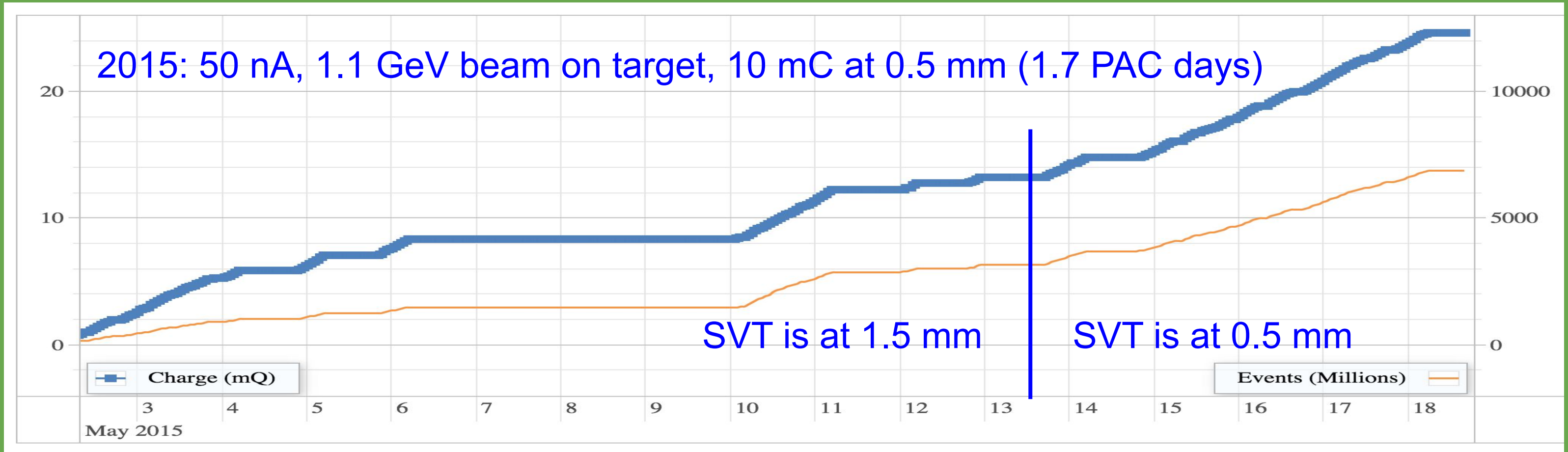
1st layer of SVT is only 0.5 mm away from the beam

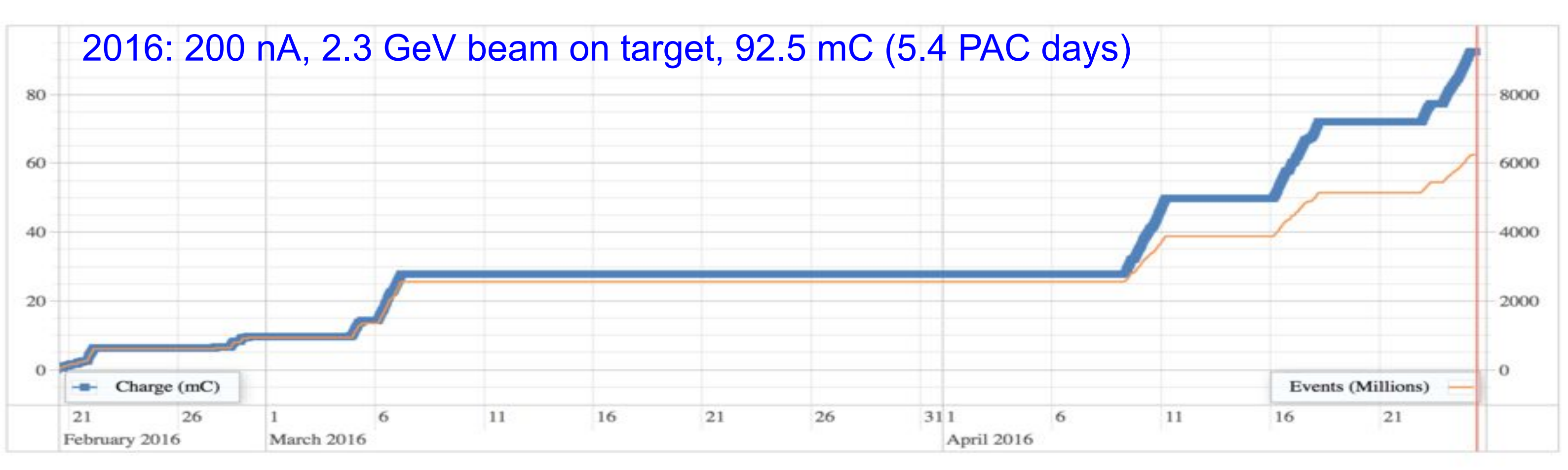


During 2015 and 2016 runs beam vertical profile was kept below 50 micron.

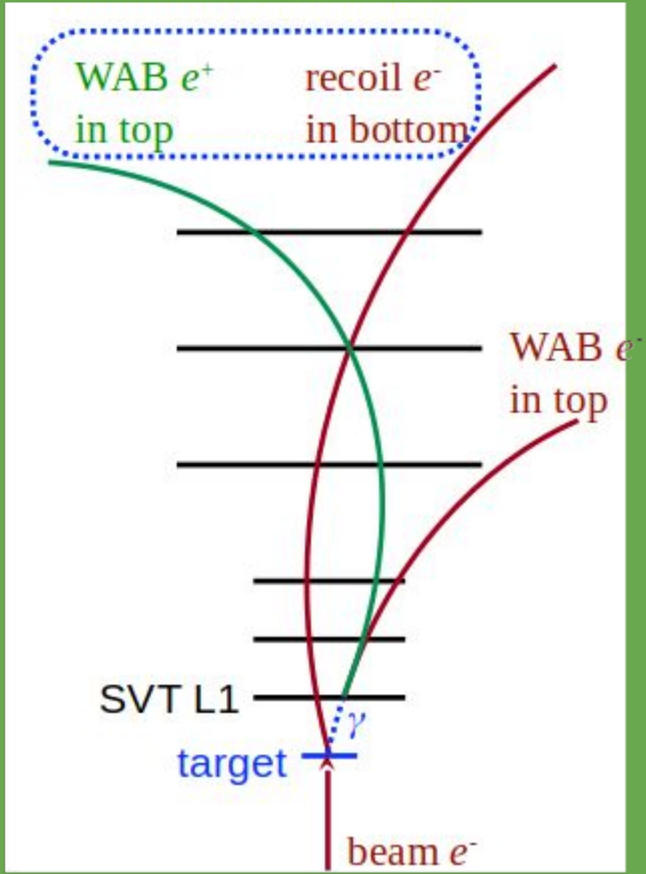
In case of beam excursions FSD shuts the beam down within 10 ms

Engineering runs in 2015 and 2016





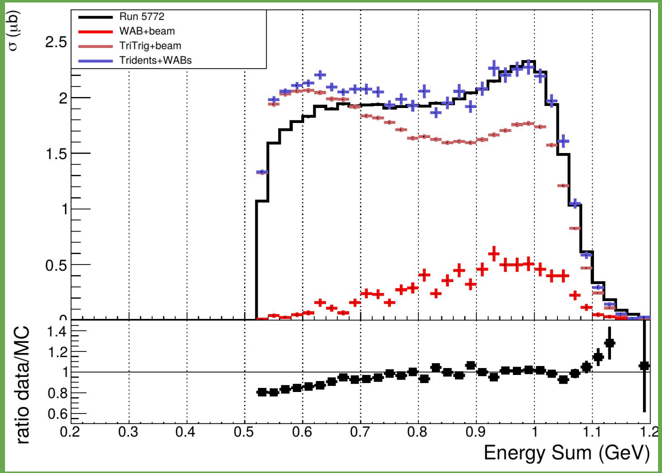
Wide Angle Bremsstrahlung and pair conversion



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

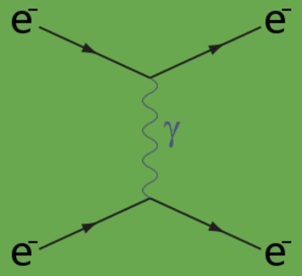
WABs aren't in any of the standard generators or MC systems (GEANT4, EGS).

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



Mass resolution

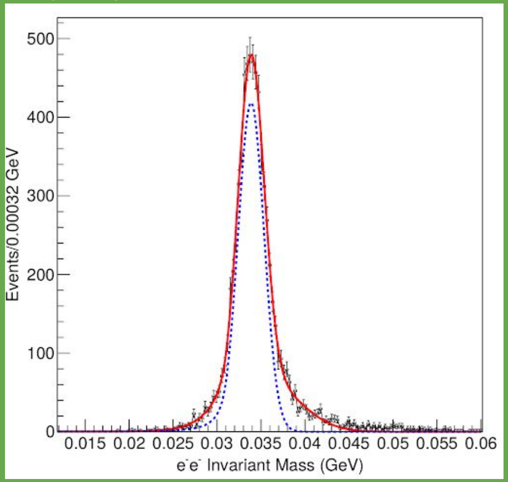
Good understanding of the mass resolution is a critical component in the "Bump Hunt" analysis

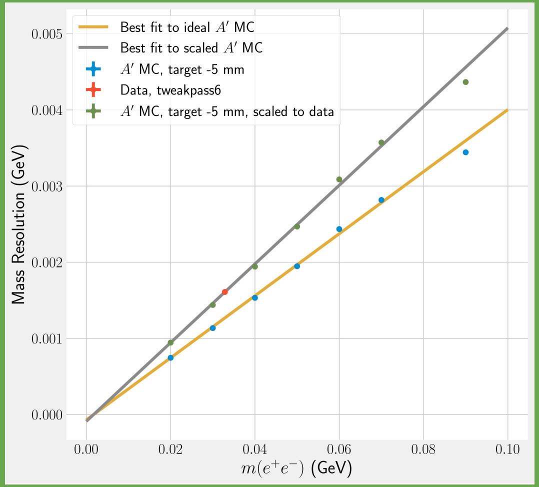


We know the mass resolution of the data at a single point, Moeller mass.

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

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



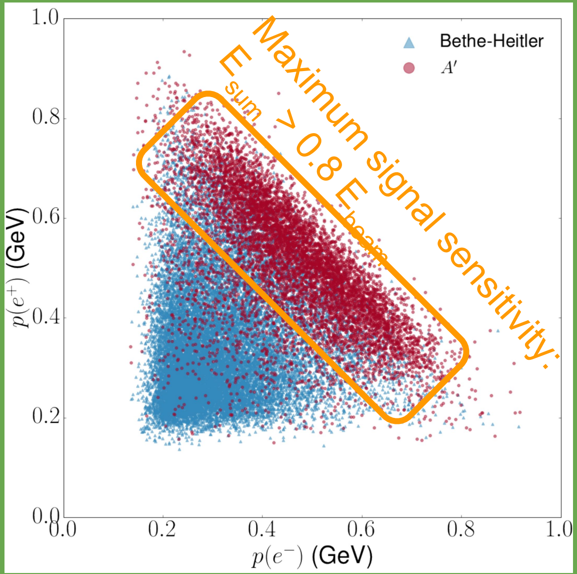


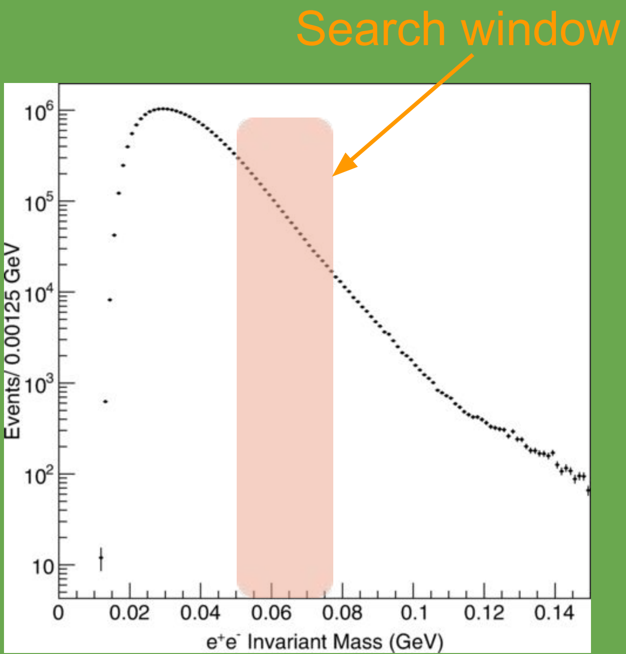
- The mass resolution difference between the Data and MC is due to momentum resolution difference between the data and MC.

- 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

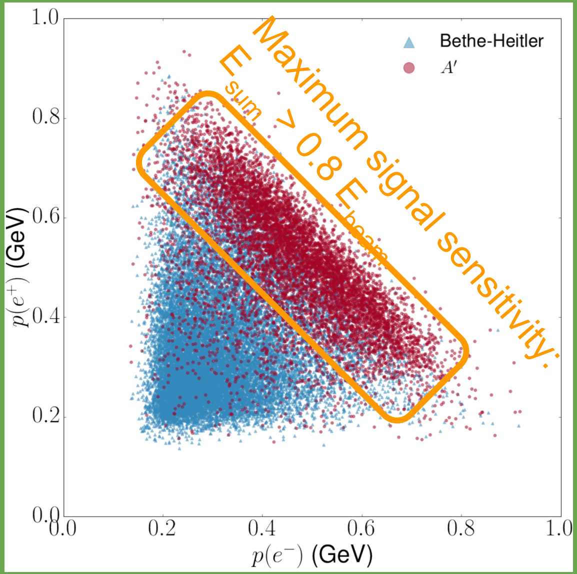
-Search for the peak in the given mass range

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

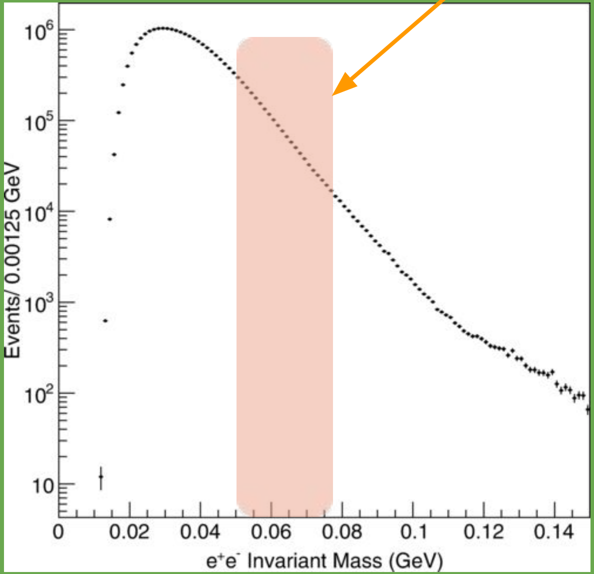
- Use log likelihood ratio to quantify any excess/bump

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



Search window

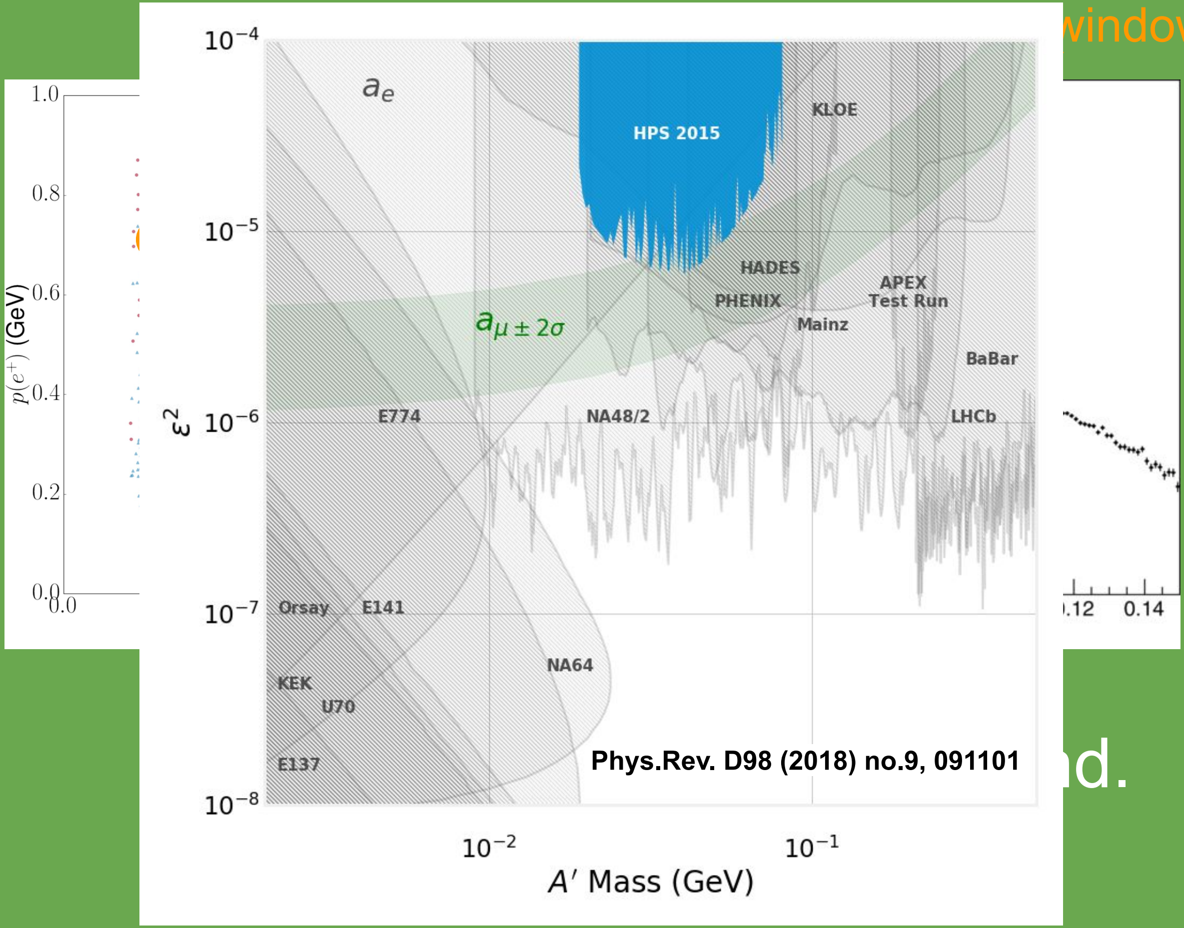


- -Range 19 MeV – 81 MeV
- -Scan w/ 0.5 MeV step
- -Search for the peak in the given mass range
- - Maximize Poisson Likelihood with Bgr only, and Bgr+signal hypothesis
- - Use log likelihood ratio to quantify any excess/bump

No significant peak is found.
2σ limit is placed

Invariant mass distribution

window



Phys.Rev. D98 (2018) no.9, 091101

-Range 19 MeV – 81 MeV

-Scan w/ 0.5 MeV step

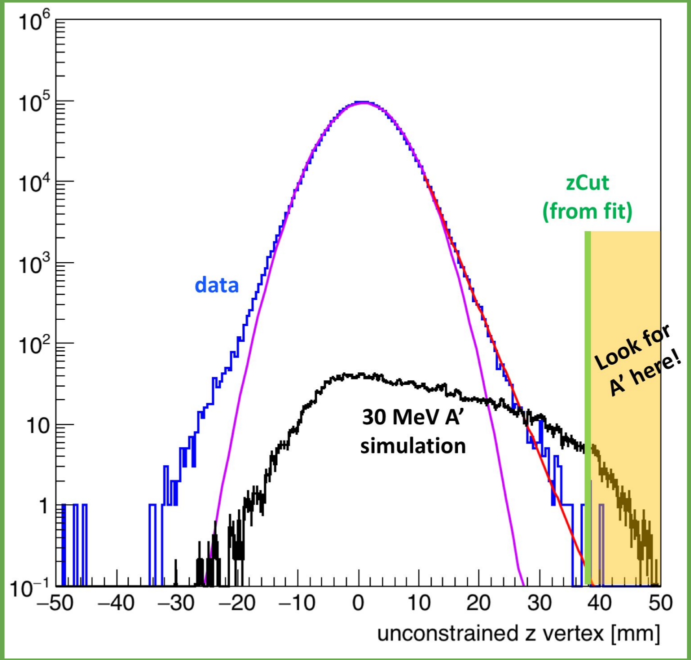
-Search for the peak in the given mass range

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

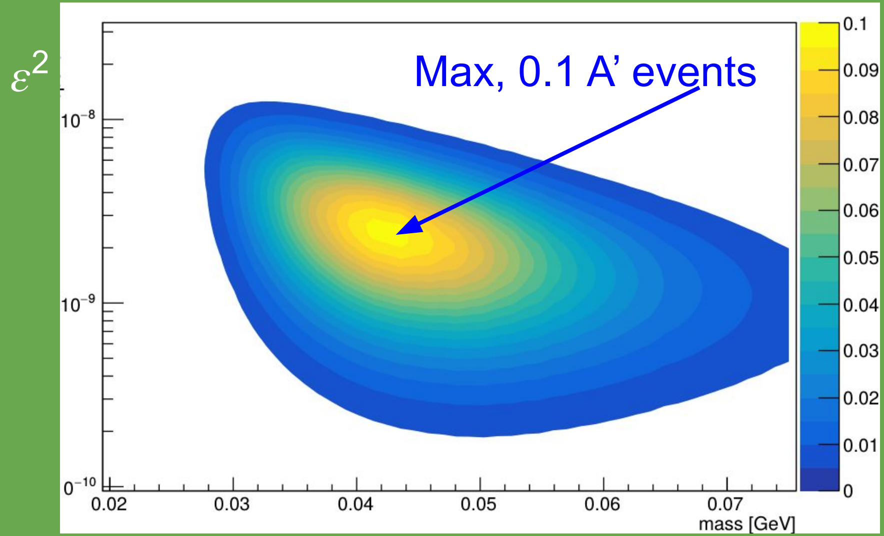
- Use log likelihood ratio to quantify any excess/bump

nd.

Vertexing analysis

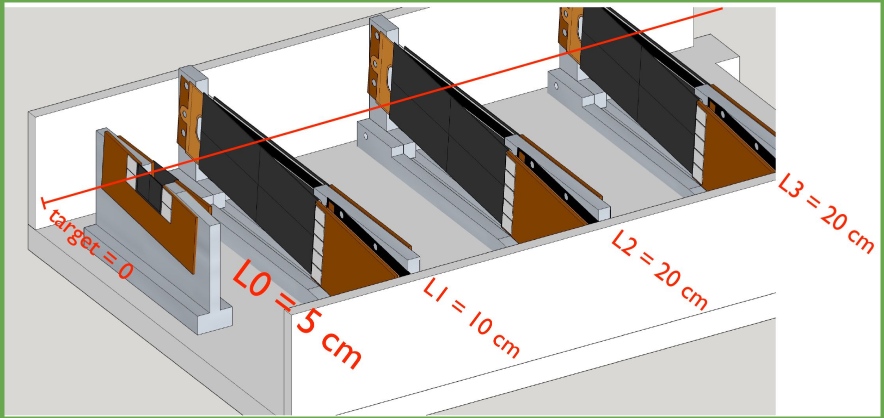


2015 data: 1.5 PAC dats



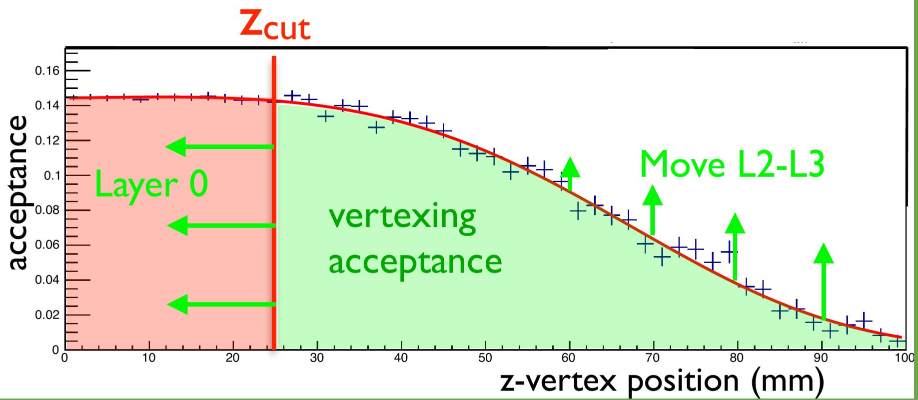
Analysis is in a quite advanced state, however with 1.5 days of data, we will not have any reach (2.5 expected A' events)

SVT upgrade



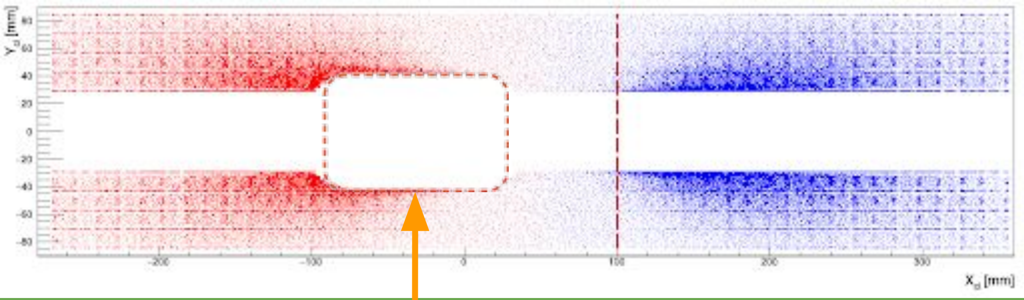
- Adding a new thin SVT layer at 5 cm downstream of the target, will significantly improve the vertexing resolution.

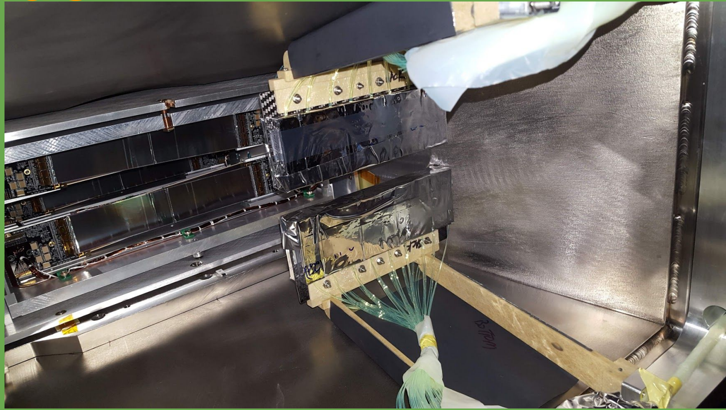
- Thin layer, will not add much background



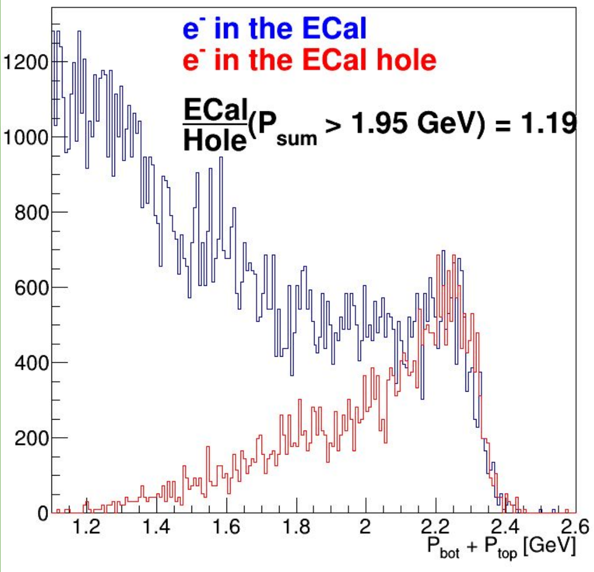
- Moving SVT Layers 2-3 closer to the beam will increase the acceptance

Hodoscope upgrade



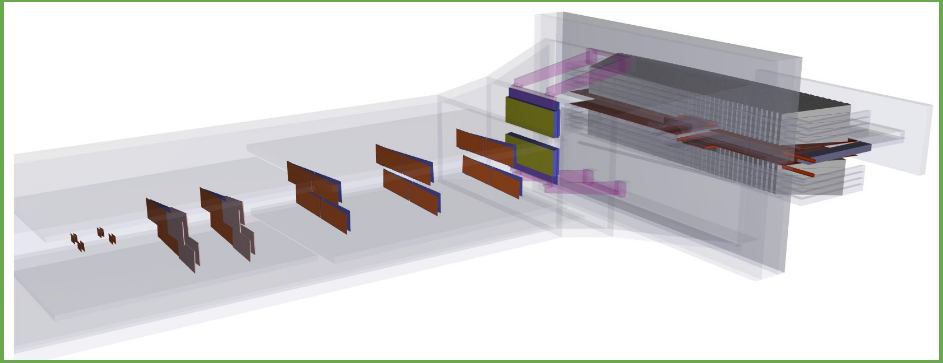


Events w/ electron in the gap are lost



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

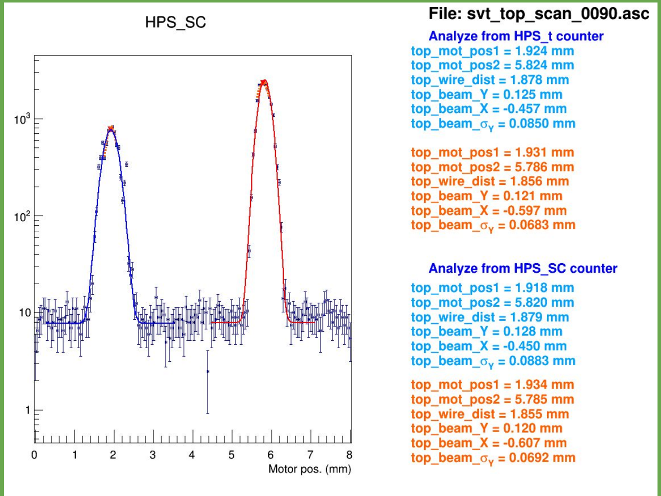
The hodoscope will recover events where the electron passed trrought the ECal hole

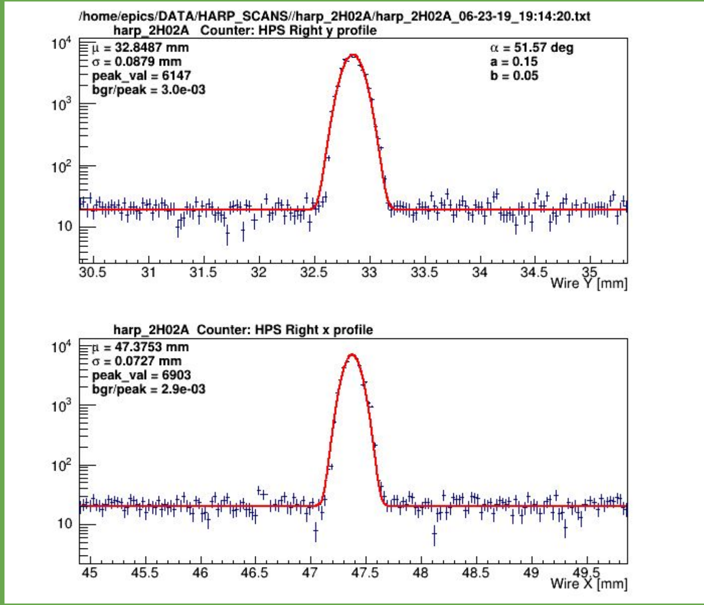


Summer 2019 Run

We have just started!

Beam position and vertical profile at the target





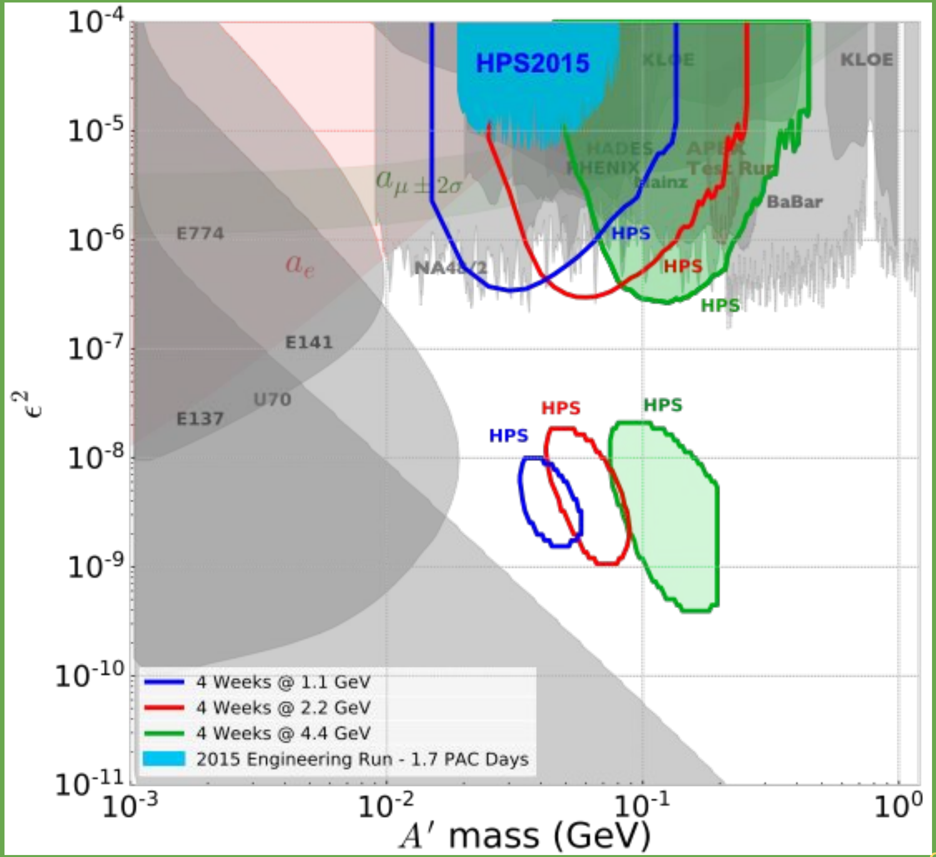
Ebeam = 4.55 GeV
First beam to the tagger dump on Jun 16

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 (≈ 4 PAC weeks)



Summary

HPS has successfully completed two engineering runs in 2015 and 2016

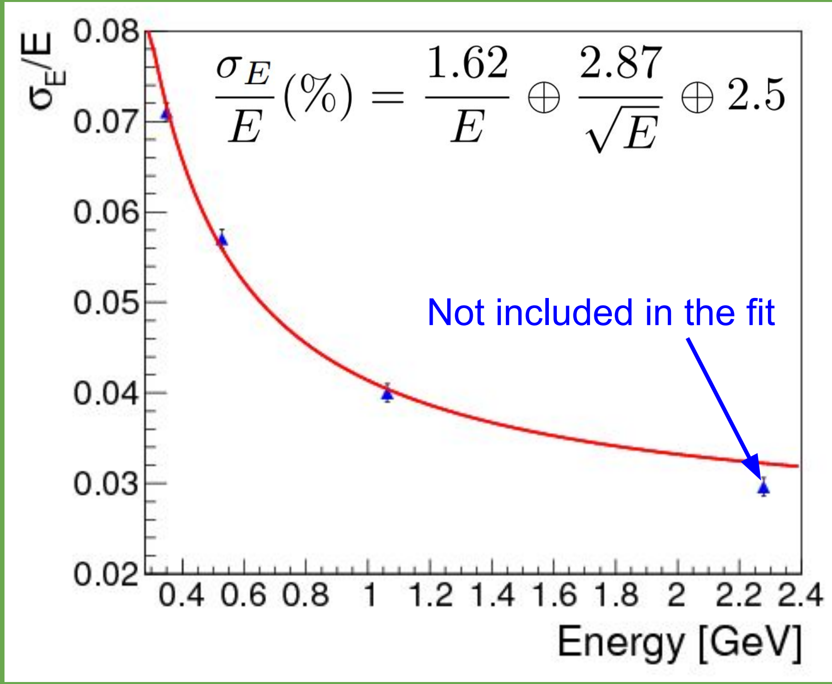
- Showed the concept works!
- Importance of WAB events
- Initiated two major upgrades
- One Physics publications and two NIM papers

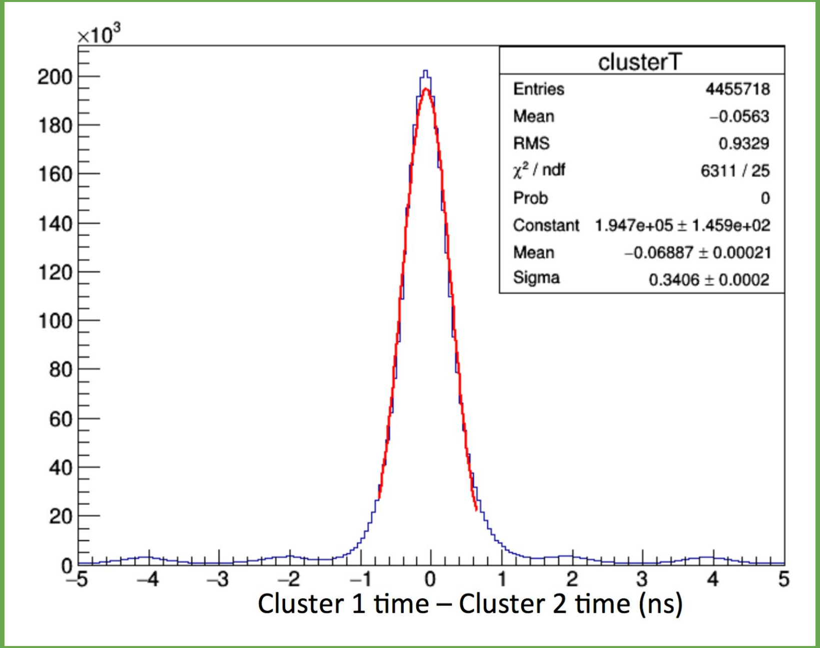
Just started the new run: 8 weeks (≈ 4 PAC weeks) with 4.55 GeV beam

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

Backup slides

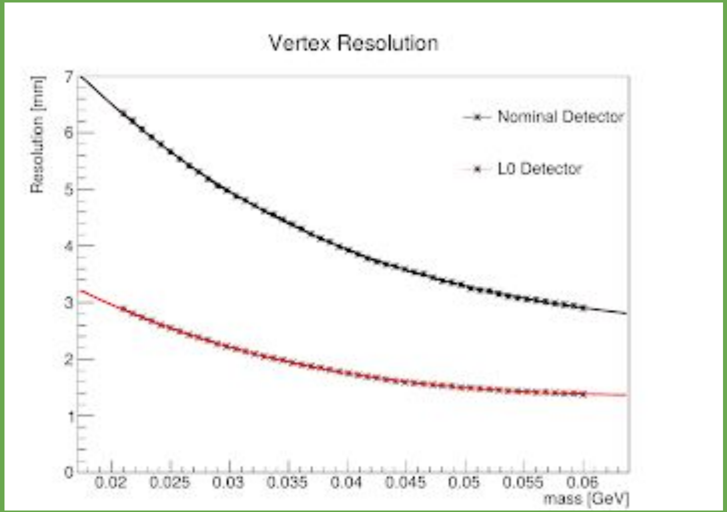
Performance of the ECal



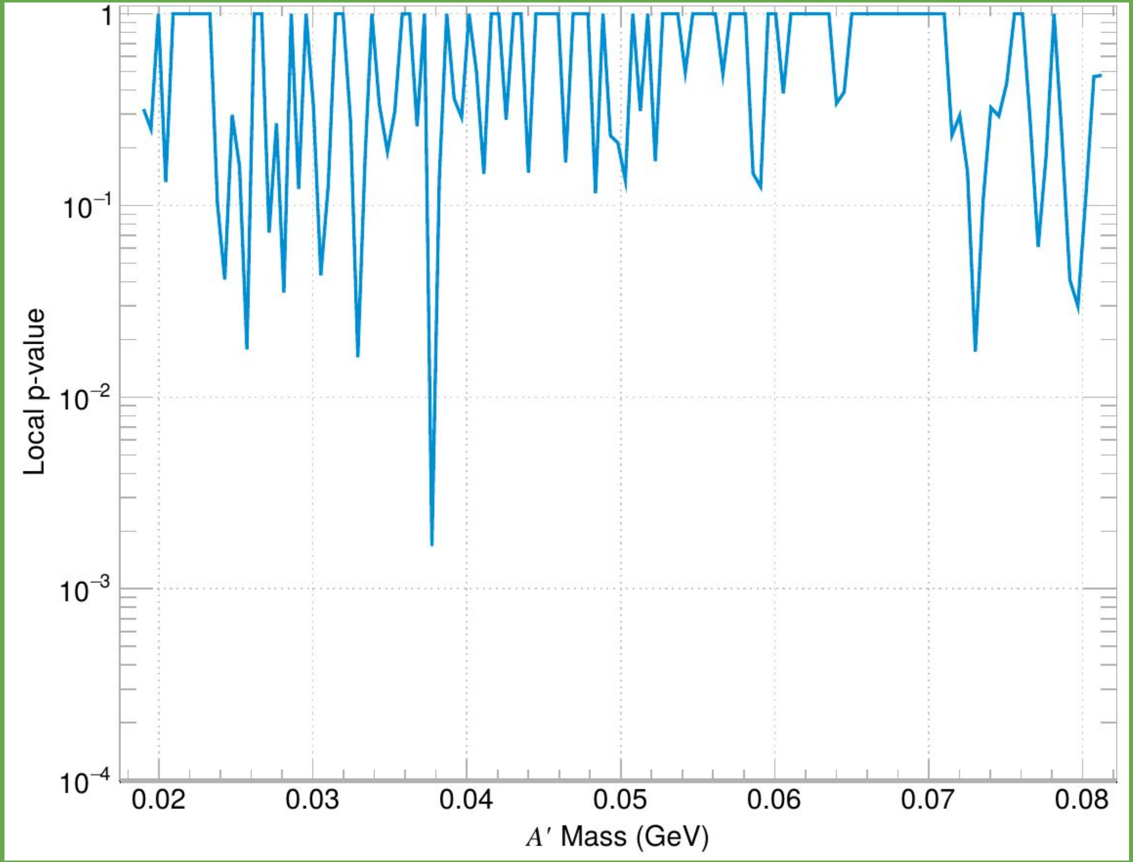


- Good time and energy resolutions!
- Allows to cut accidentals from neighboring beam buckets

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).