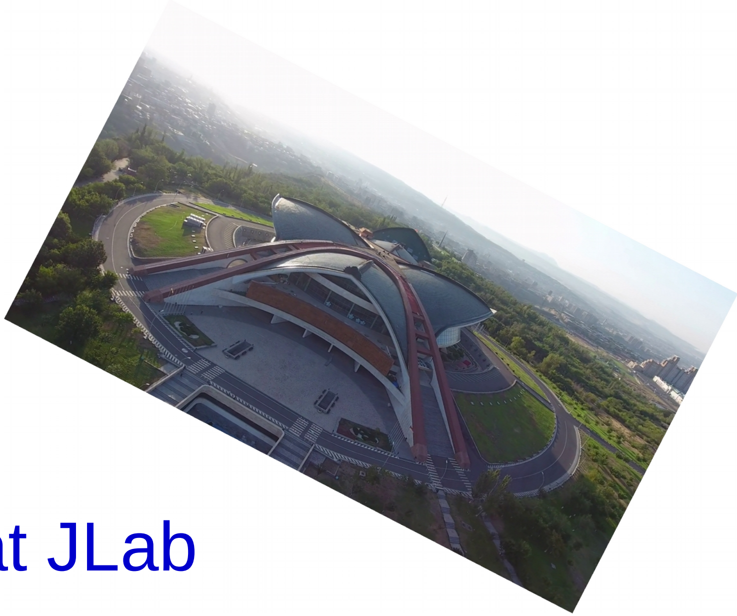


Search for heavy photons at JLab

Rafayel Paremuzyan

University of New Hampshire

Correlations in Hadronic and Partonic interactions

Yerevan, Sept. 24–28

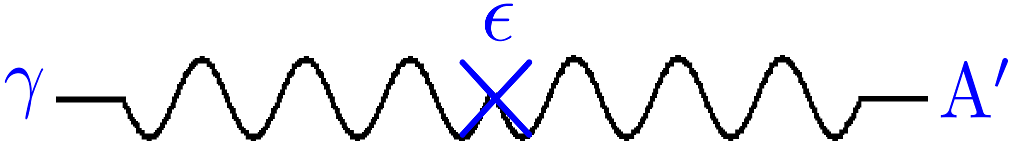
The Continuous Electron Beam Accelerator Facility

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)

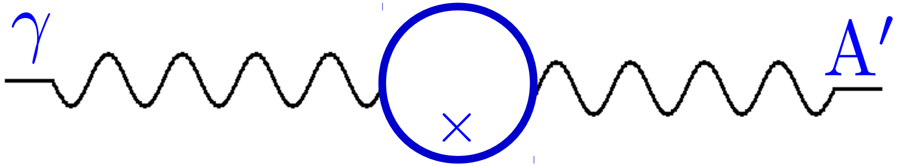
$$\mathcal{L} = \mathcal{L}_{SM} + \boxed{\frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}} + \frac{1}{4} F'^{\mu\nu} F'_{\mu\nu} + m_{A'^2} A'^{\mu} A'_{\mu}$$

Kinetic Mixing Induces week coupling to electric charge



ϵ is the mixing strength

generated by heavy particles
$\times$ interacting with γ and A'

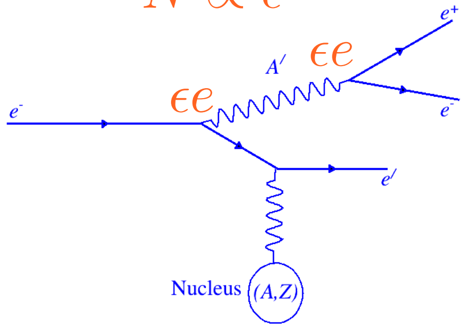


Where can A's be produced

Where there are photons, there can be dark photons!

Electrons on fixed target

$N \propto \epsilon^2$



A'Strahlung

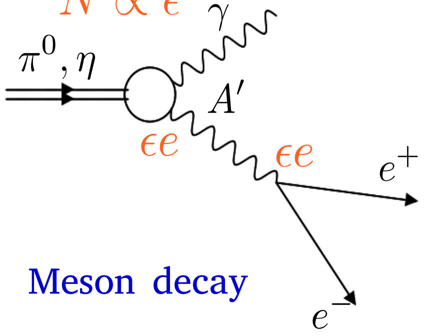
HEAVY PHOTON SEARCH

APEX

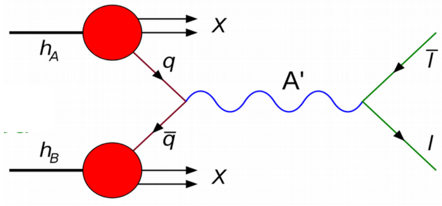
DARKLIGHT

Protons on fixed target

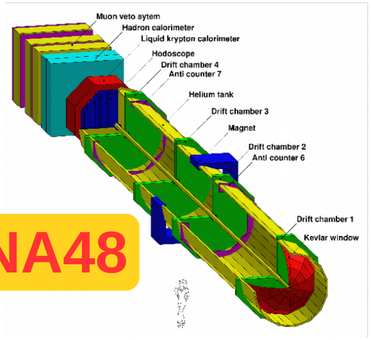
$N \propto \epsilon^2$



Meson decay



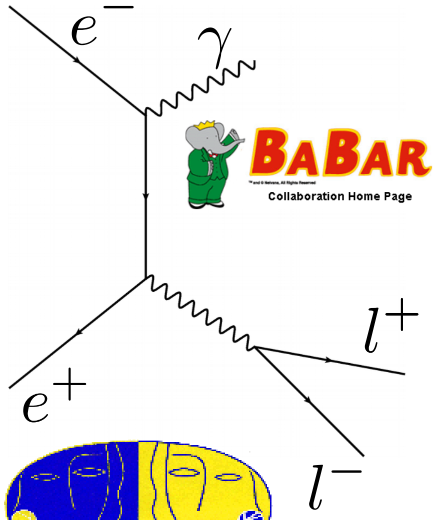
Drell-Yan



NA48

SeaQuest E906

e^-e^+ colliders



BABAR Collaboration Home Page

KLOE

$e^-e^+ \to A'\gamma$

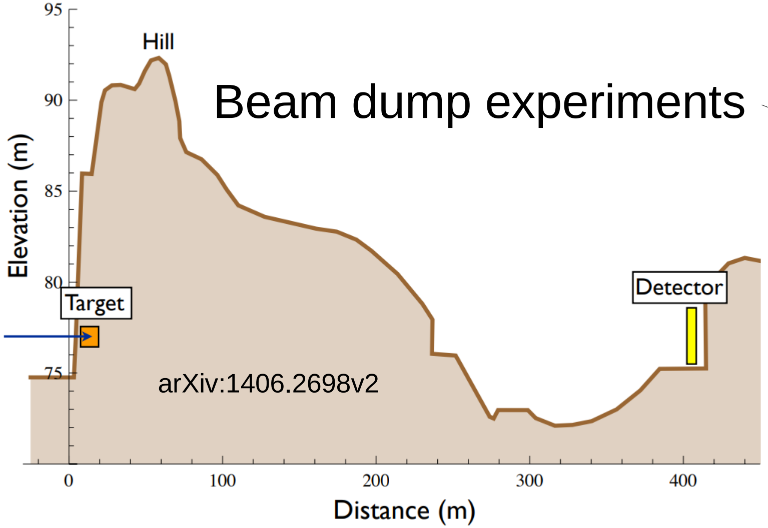
Meson decay

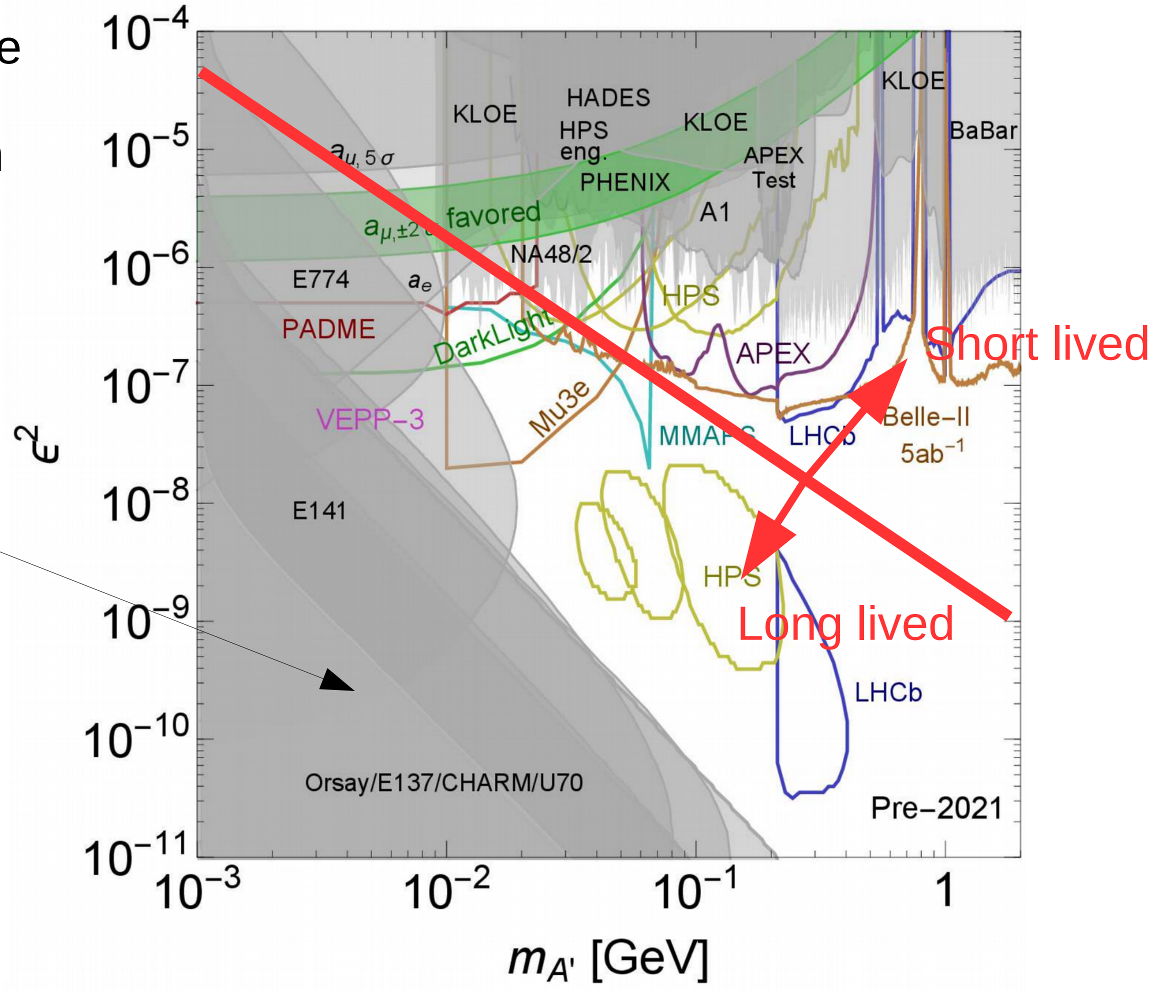
Existing and projected constraints on A’

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

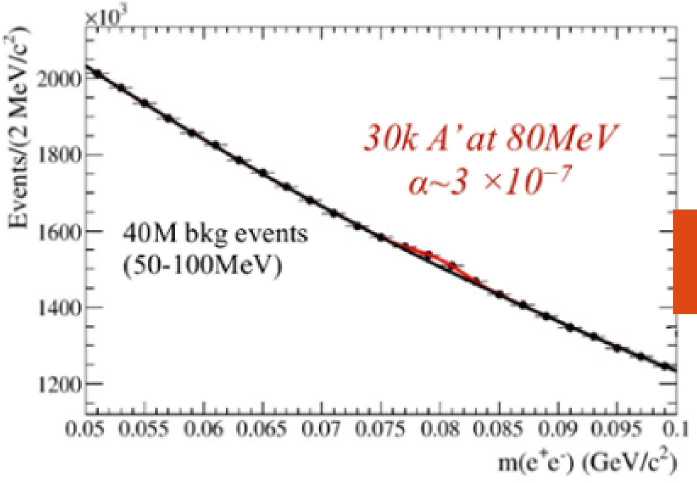
$$l_0 \equiv \gamma c \tau \propto \frac{1}{\epsilon^2 m_{A'^2}}$$

Beam dump experiments

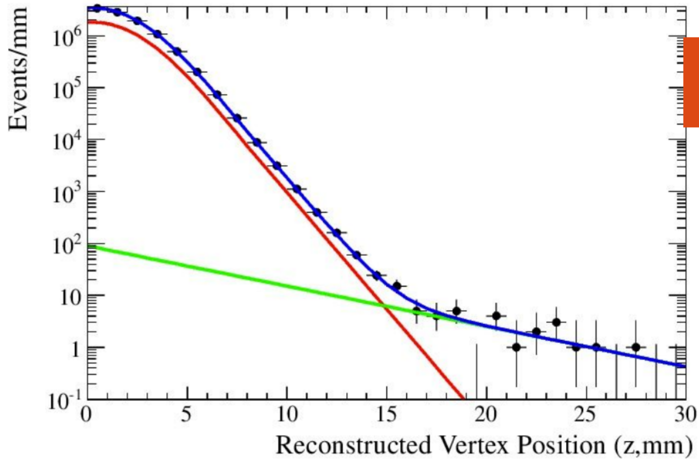




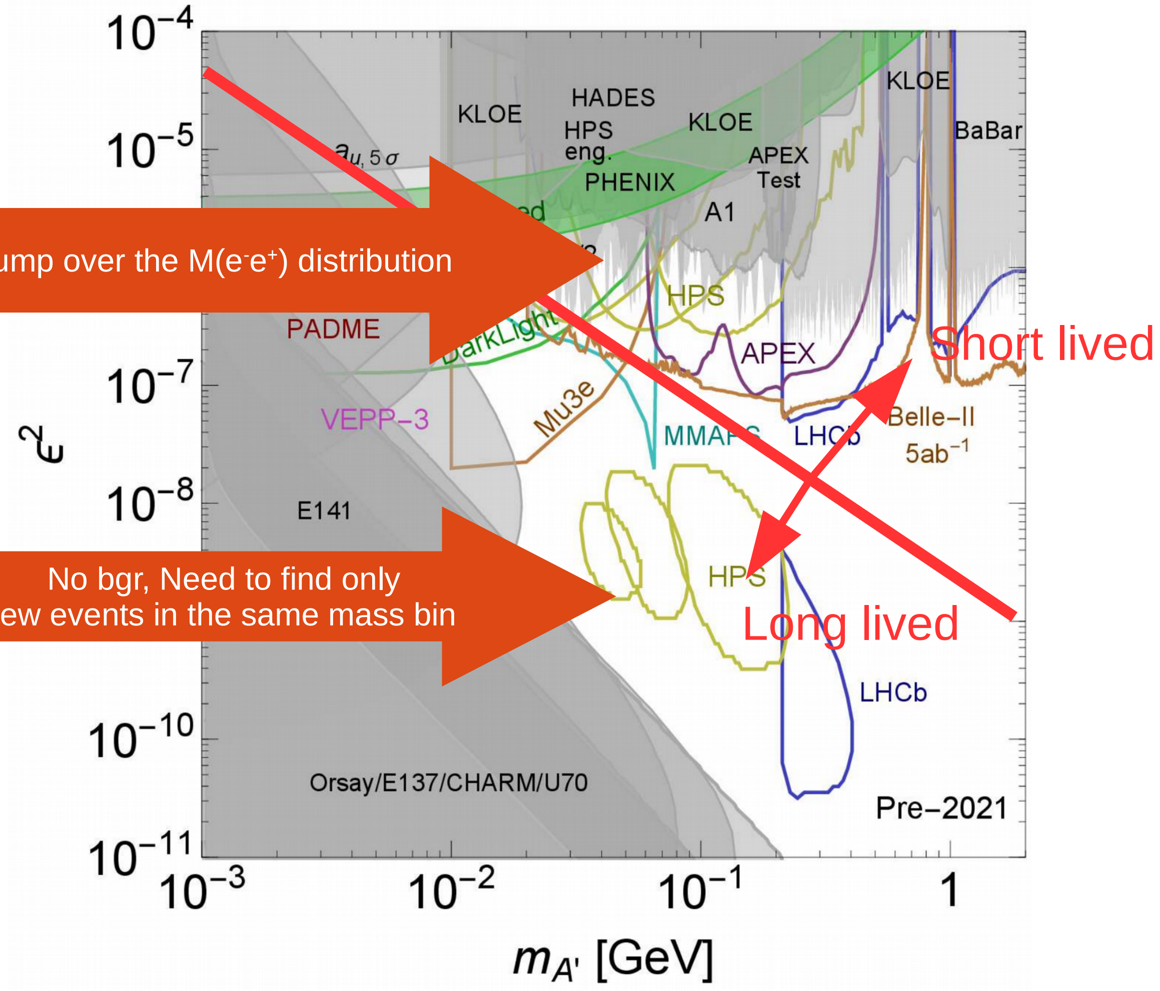
Existing and projected constraints on A’



Bump over the M(e⁻e⁺) distribution

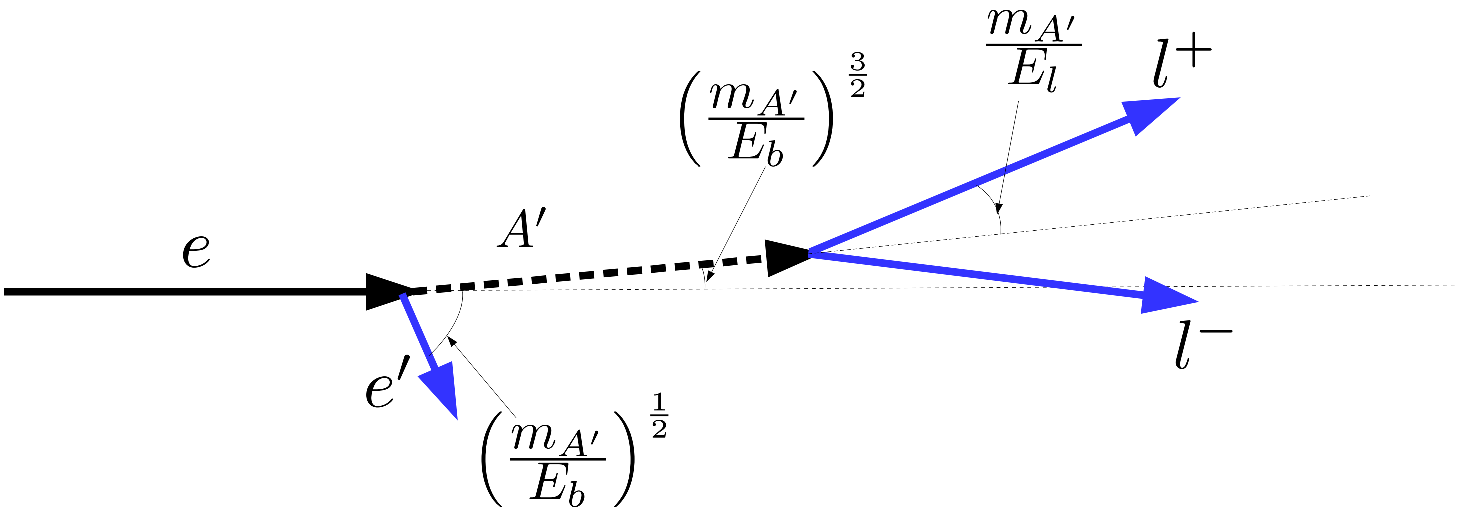


No bgr, Need to find only
few events in the same mass bin



Heavy photon kinematics on fixed target experiments

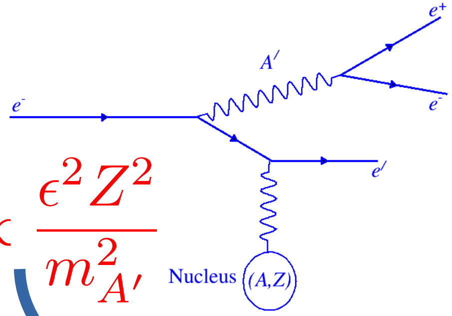
* Unlike Bremsstrahlung A’ takes almost all the beam energy
* Peaked at forward angles



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

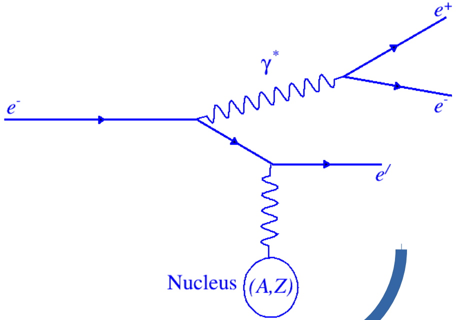
Background process in A’ production w/ e- beam of fix target

A' production

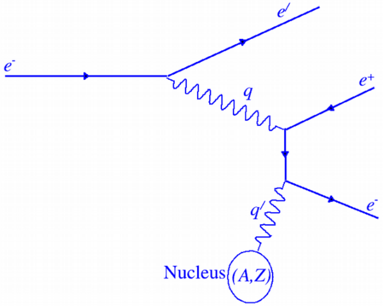


$$\sigma \propto \frac{\epsilon^2 Z^2}{m_{A'}^2}$$

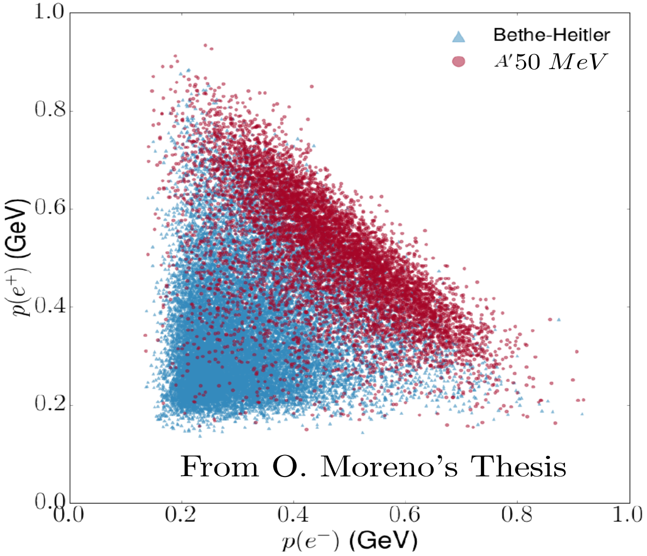
Prodution of Timelike photon (radiative Tridents)



Bethe Heitler



Much larger cross section,
But very different kinematic



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

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

Mass bin

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

It is critical to have a good mass resolution

Experiments at JLab

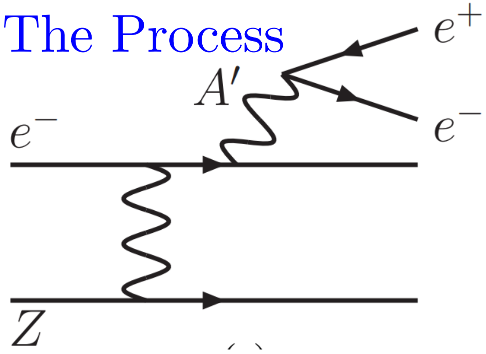
APEX in Hall-A

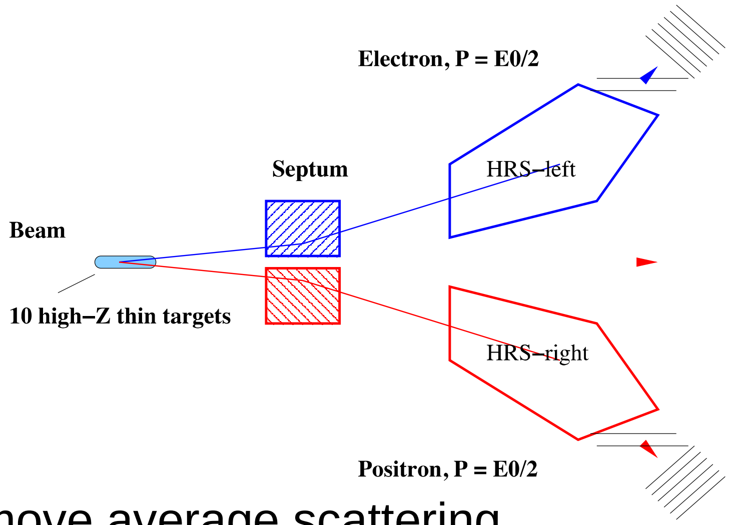
DarkLight in LERF (FEL)

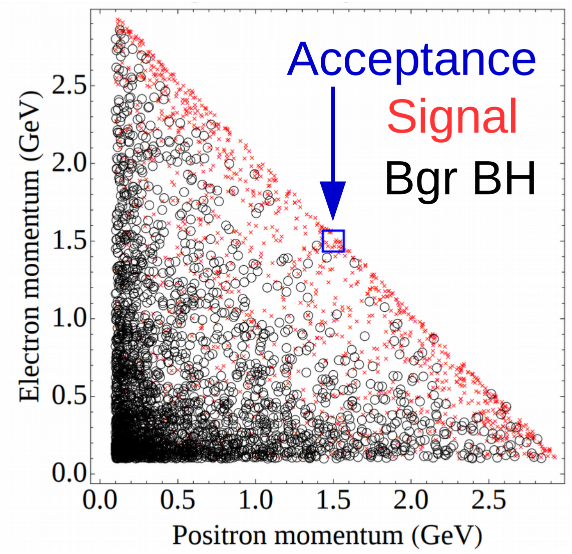
BDX, new underground facility
Behind the Hall-A dump

HPS in Hall-B

A Prime Experiment







*Septum magnet allows to move average scattering angles from 12° to 5°.

*Momentum Acc: P_0 ~ 9%,

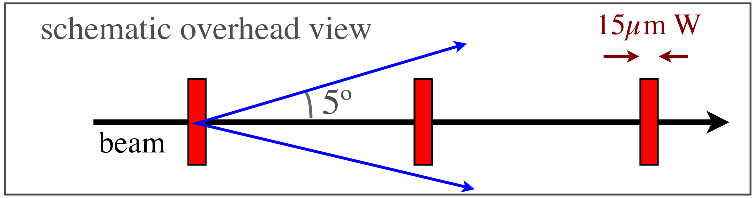
*e- and e+ have symmetric acceptance P ≈ 0.5*Ebeam.

*Momentum resolution is below $1*10^{-3}$.

* $\delta\theta$ =0.5 mrad $\delta\varphi$ = 1mrad

*Multi-foil targets: increase the mass range and reduce the multiple scattering

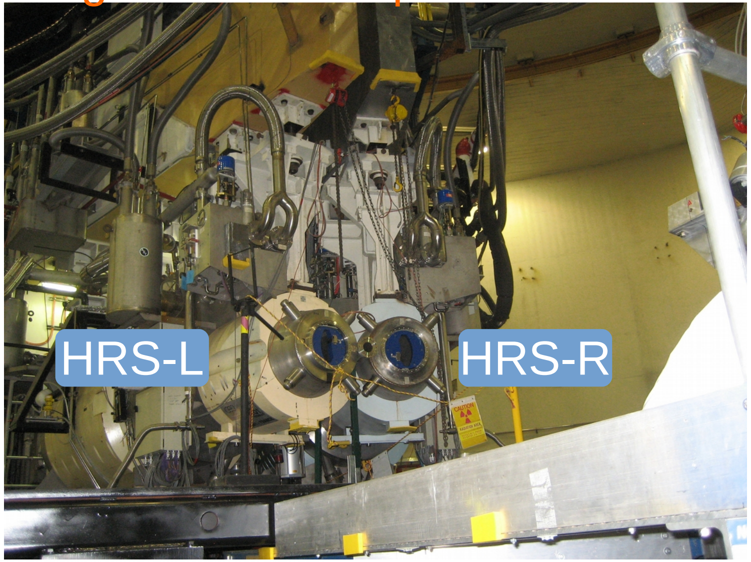
- $\sigma(\theta)_{\text{mult scat}} \leq 0.5$ mrad
  $\Rightarrow$ typical e^+e^- pair must only go through 0.3% X_0 (2-pass)
- Target thickness 0.7–8% X_0 (depending on E_{beam})



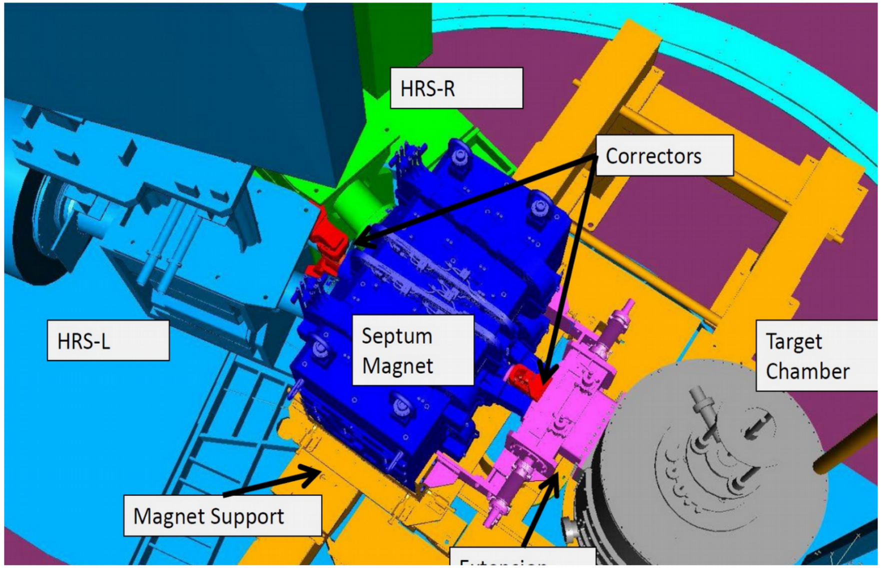
- High-Z target (reduce π yield for given QED rates)
- Stable under currents up to ~100 μA

Detector components

High resolution spectrometers

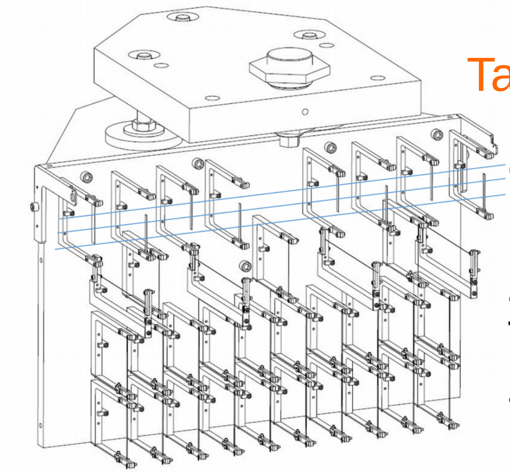


Whole assembly, from top



Electrons will be detected in HRS-L, while positrons in HRS-R

Target



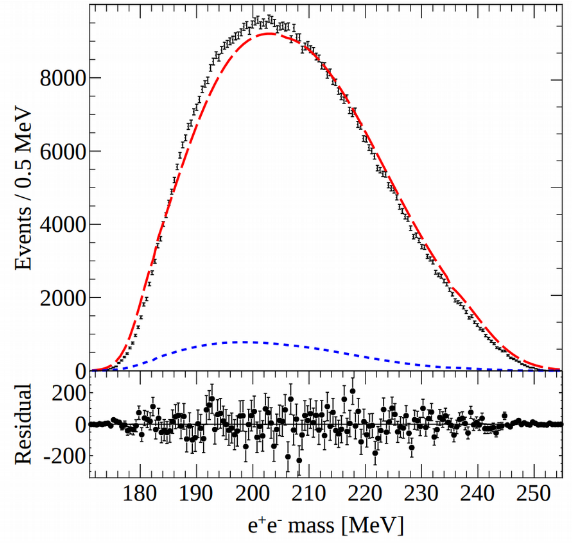
Calibration of magnetic optics

10 Graphite foils, tot 0.07% RL

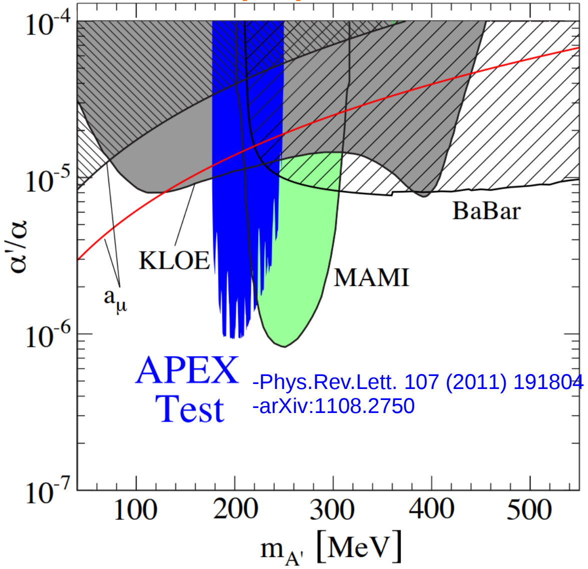
10 Tungsten foils, 2.8% RL

Test run and expected reach

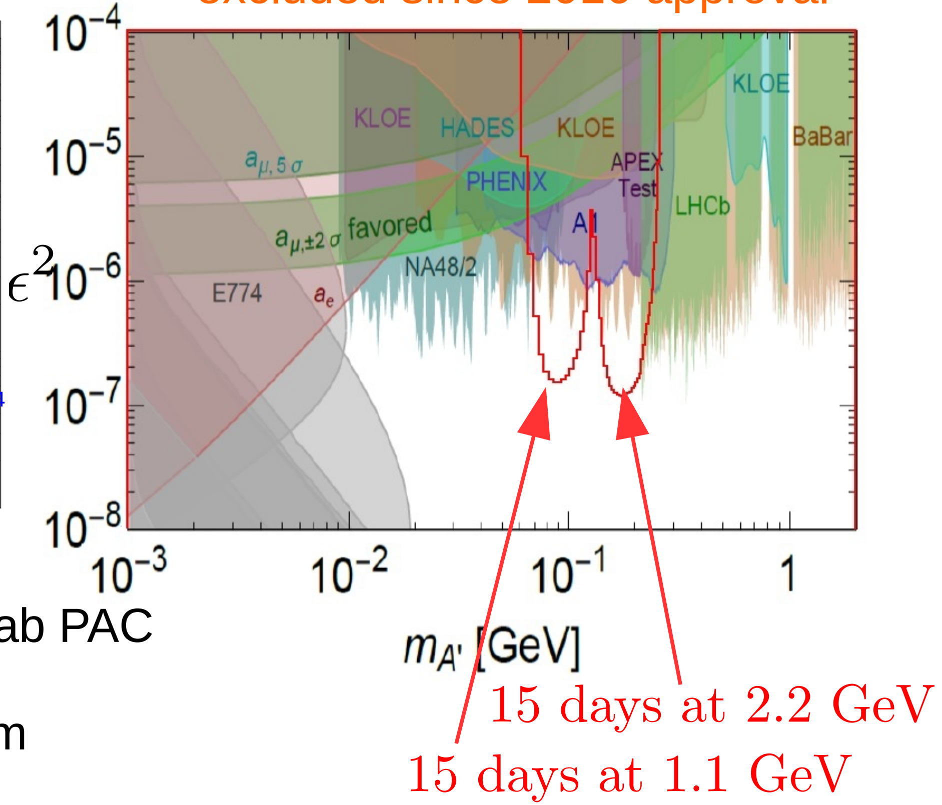
APEX test run



Territory at the time of test run paper



Significant territory is already excluded since 2010 approval



APEX is classified as a high impact experiment by JLab PAC

Next run: Jan 30 - March 10, 2019 with 2.1 GeV beam
Beam current up to 120 uA
Luminosity 10^{39} cm^{-2} s^{-1}.

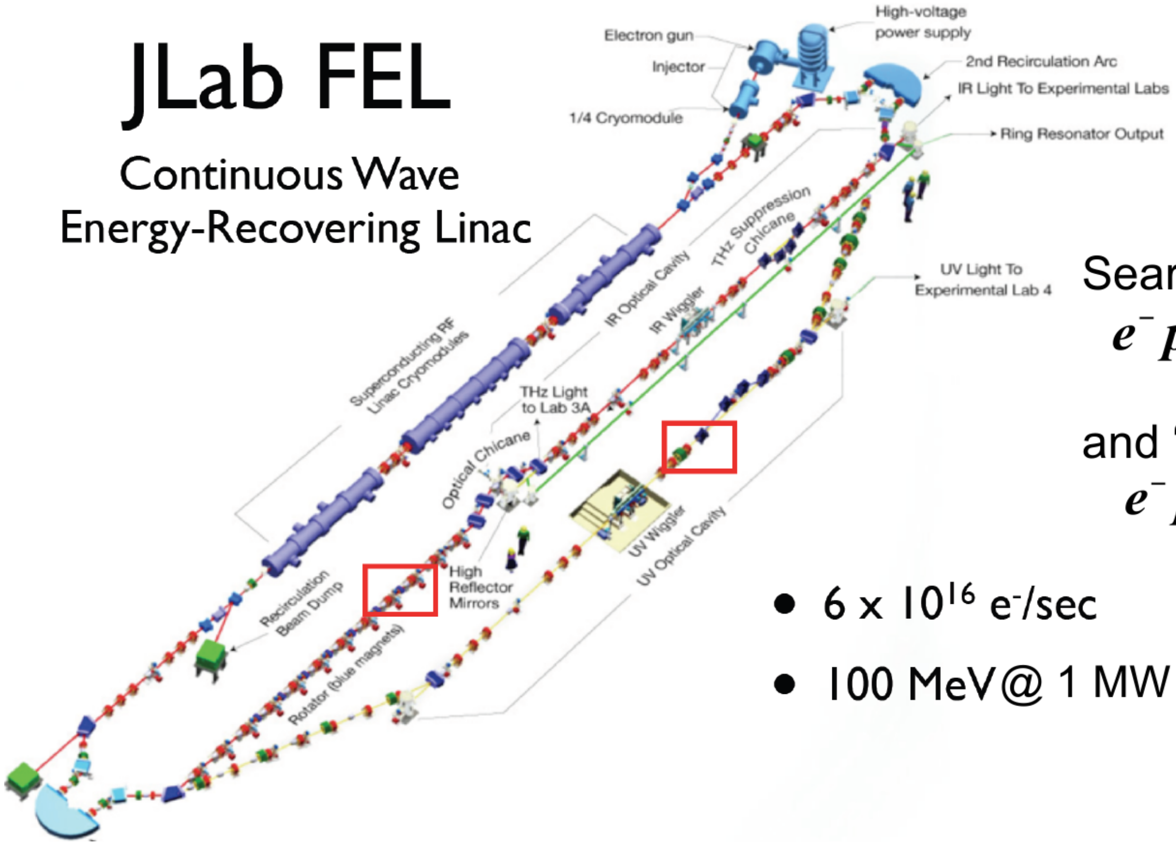
High resolution, high luminosity experiment!

DARKLIGHT

Electron scattering of hydrogen gas target

JLab FEL

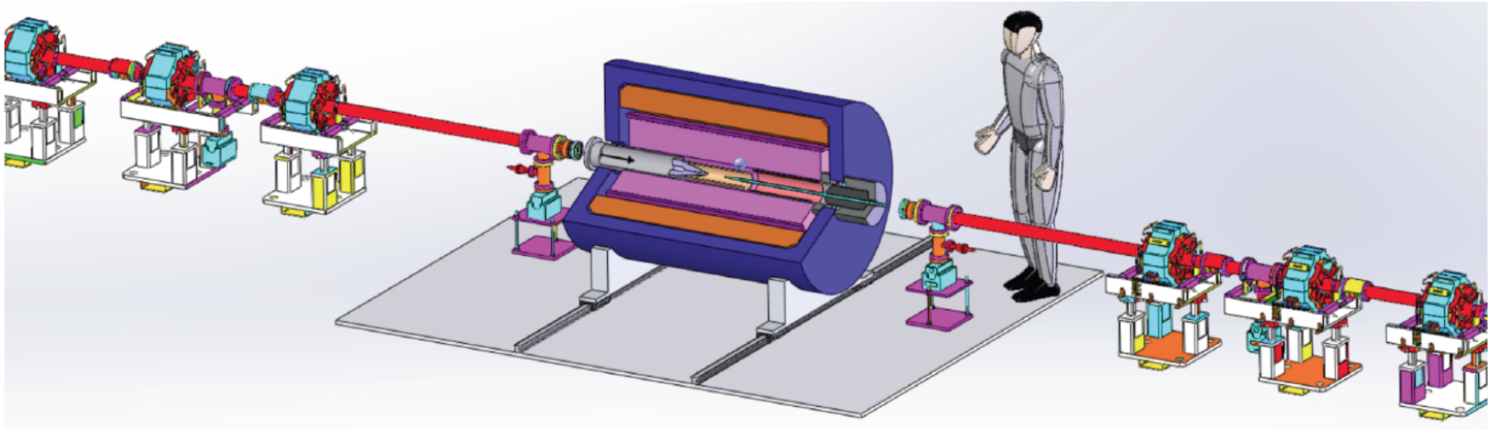
Continuous Wave
Energy-Recovering Linac



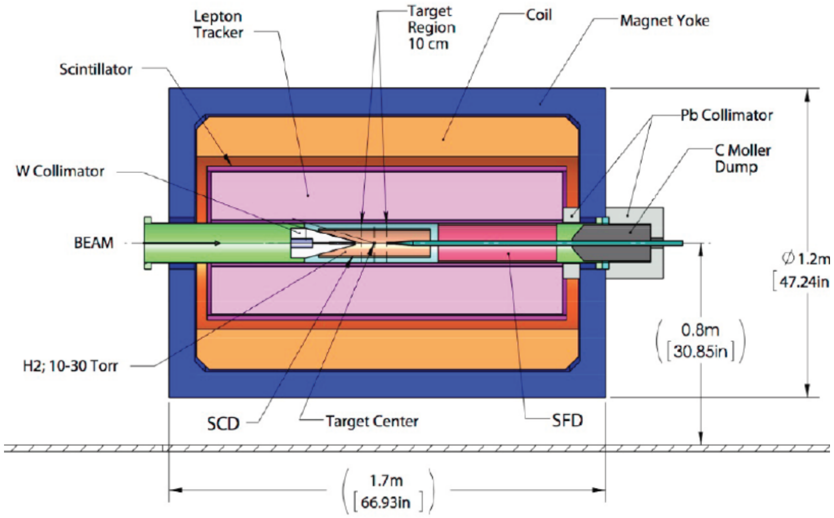
Search for A‘ in “visible“
$$e^- p \to e^- p A',\ A' \to e^+ e^-$$

and “invisible“ decay modes
$$e^- p \to e^- p A',\ A' \to inv.$$

- 6×10^{16} e^-/sec
- 100 MeV@ 1 MW

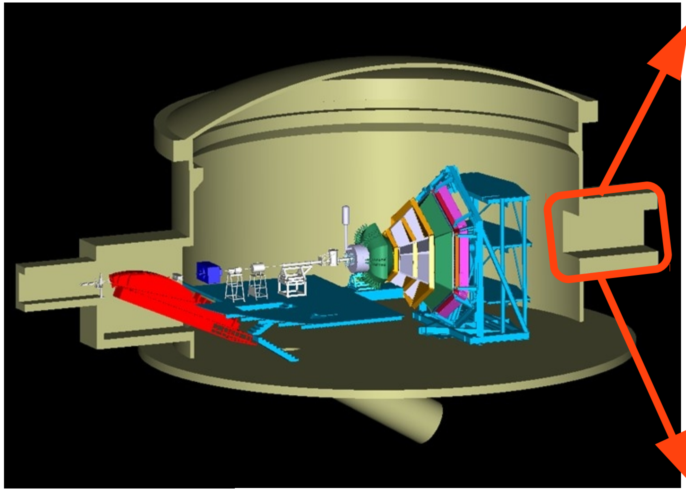


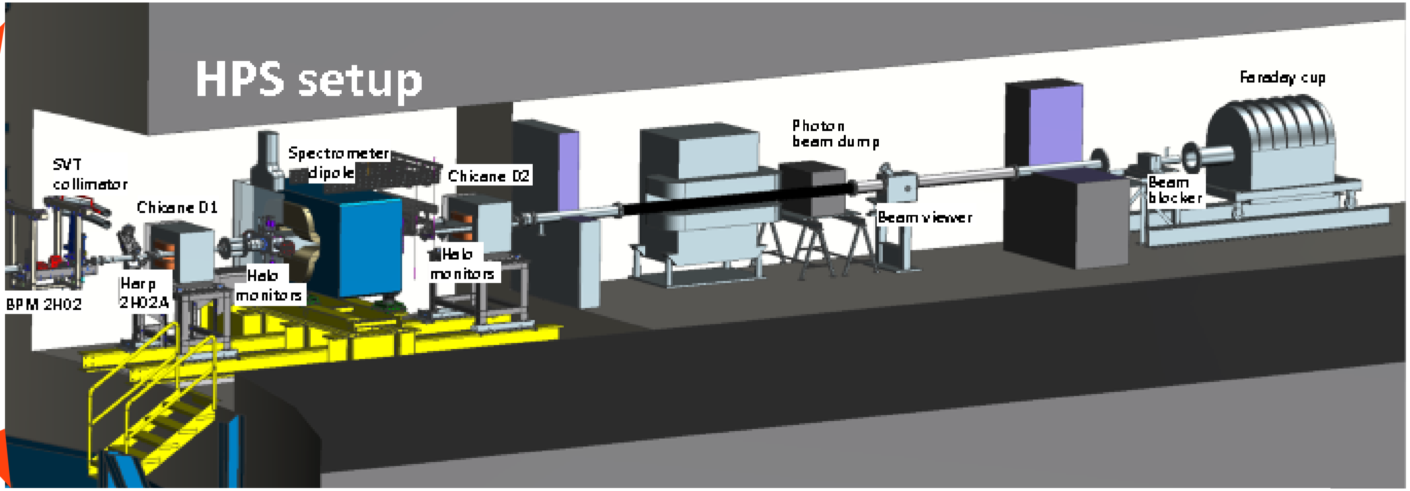
- Windowless target, aggressively pumped
- Gas thickness ~10^{19}cm^{-2} with 10mA beam yields~0.5 ab^{-1}/month
- Thin beryllium beam pipe
- Si detector for proton recoil
- TPC + 0.5 T magnet
  - High track density
  - ~250 μm hit res.
  - Magnet confines low-p_T backgrounds (e-p and Moller)
- Scintillators serves as veto for invisibles search



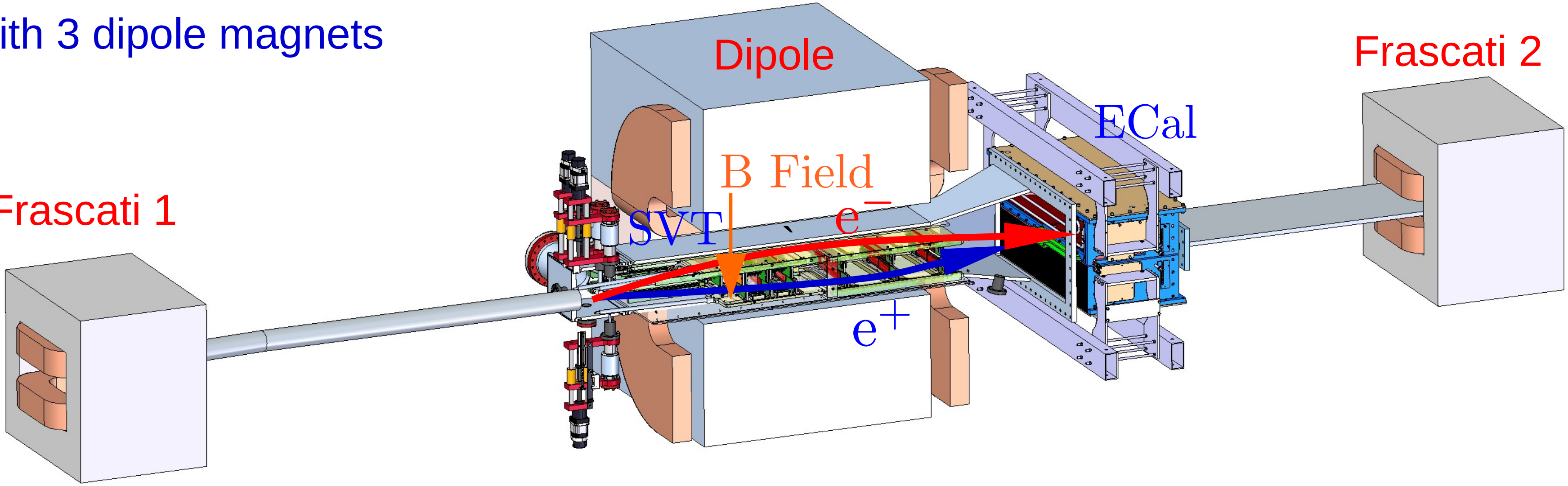
Hall-B

Hall-B Alcove





Chicane with 3 dipole magnets

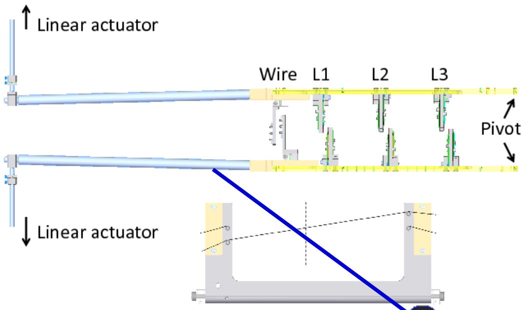


Silicon Vertex Tracker

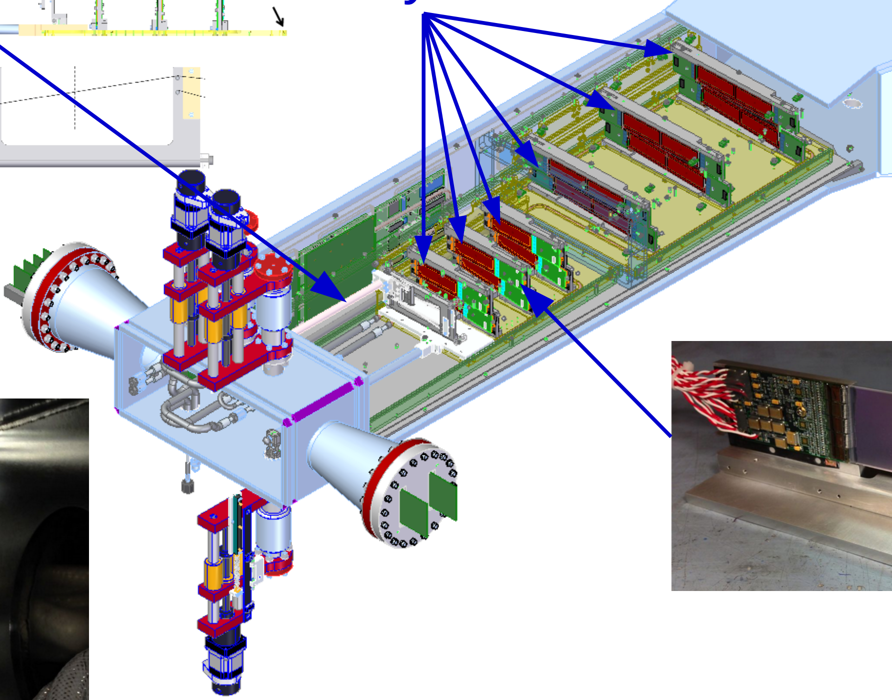
1st three layers are retractable

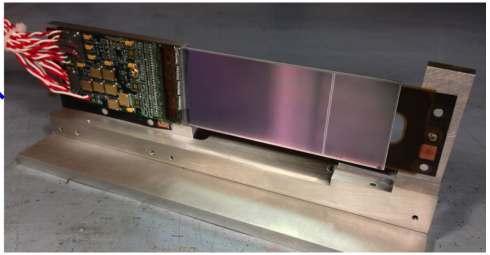
Each layer consists of two sensors stereo and axial

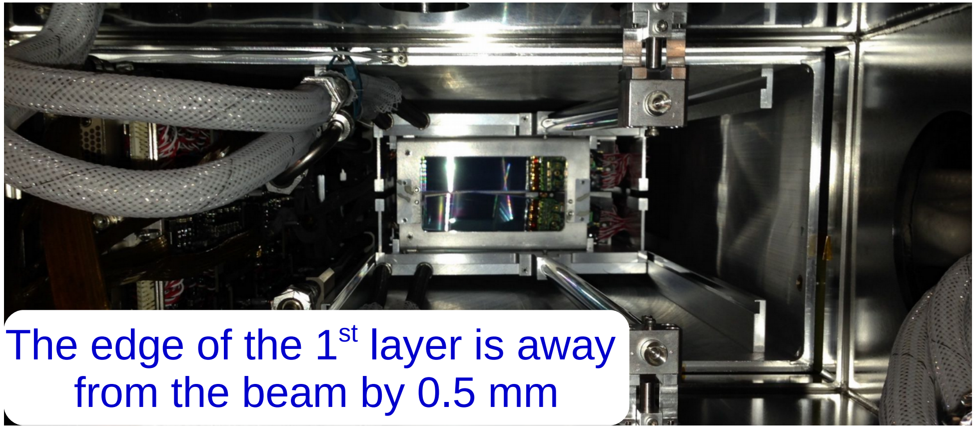
Layers 1-3 single sensor
Layers 4-6 double sensors



6 layers

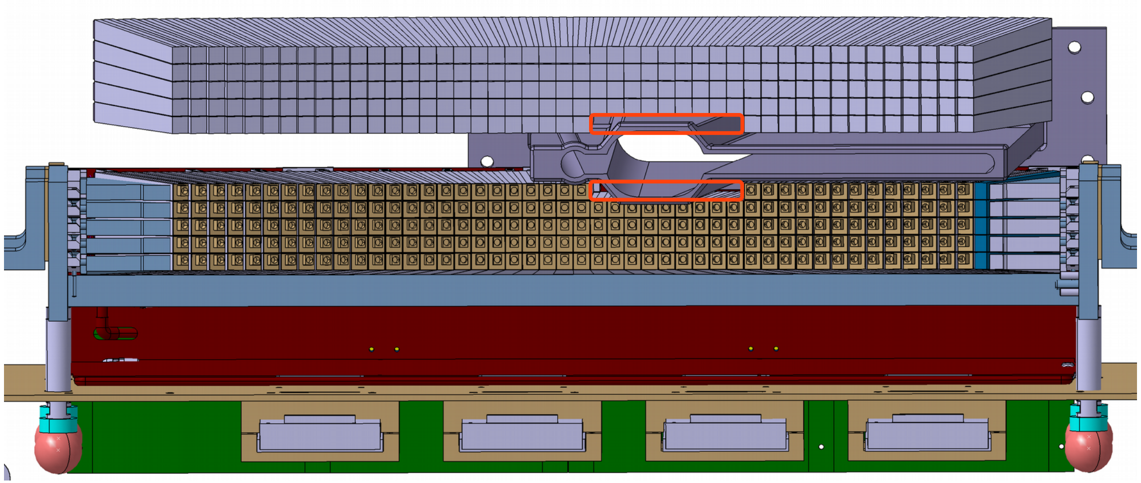






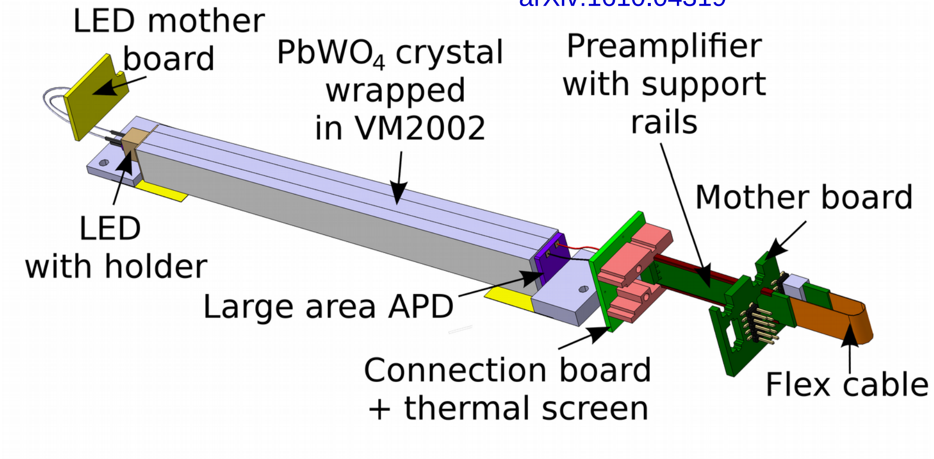
The edge of the 1st layer is away from the beam by 0.5 mm

Electromagnetic Calorimeter



Nucl.Instrum.Meth. A854 (2017) 89-99

arXiv:1610.04319



A homogeneous calorimeter made of 442 (221 per sector) lead tungstate (PbWO4) crystals readout with 10x10mm^2 APDs.

Crystal: 13.3x13.3 mm^2 front face

160 mm long (18 rad length)

In both sectors, 9 “Very HOT” crystals are removed from the 1st row

Signals are readout through 250 MHz fADC boards

FADC demonstrated pretty good time resolution, and after the 1st engineering run TDCs were removed

The trigger

The trigger logic works based on ADC value and time of EC signals.

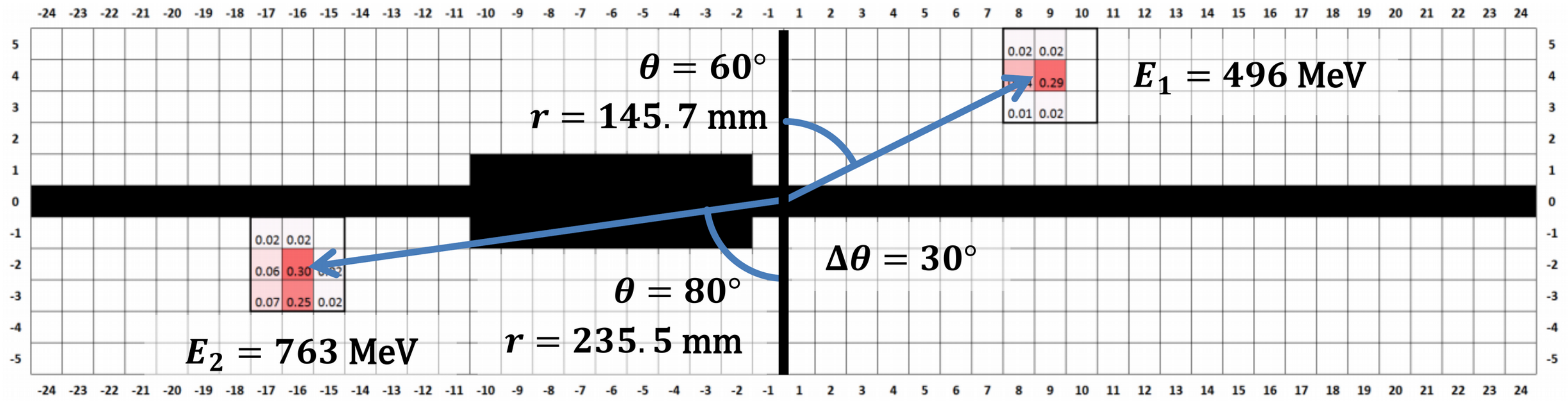
CTP performs cluster finding (collection of 3x3 hits within 12 ns time interval) then clusters are sent to SSP which searches for time coincidence of of pairs of clusters from top and bot halves and applies topological cuts.

Two types of triggers
singles and pairs.

N_hits > threshold
E_min < Eclust < E_max

N_hits > threshold
E_min < Eclust < E_max
Esum_min < Esum < Esum_max
| Coplanarity | < coplan_max
E > E_min + slope*d

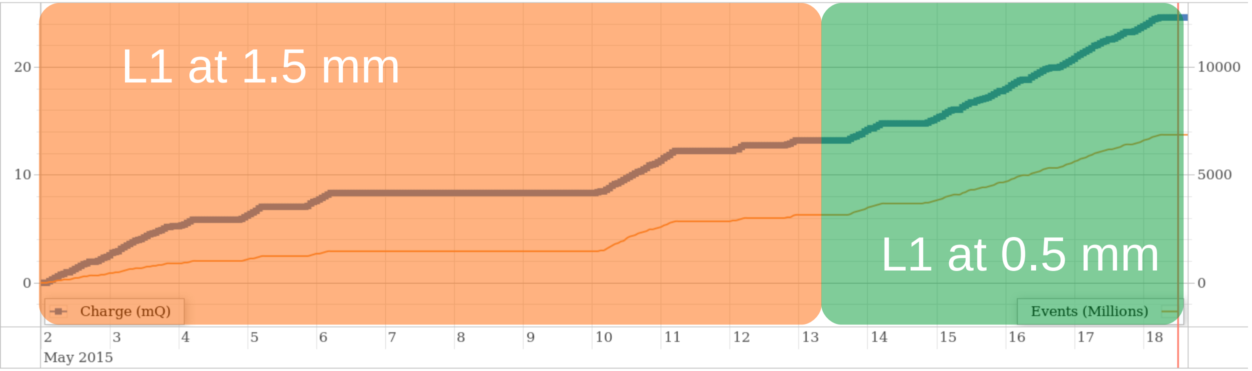
The production trigger: pair1 trigger, cut parameters are optimized for high energy $e^- e^+$ pairs in opposite detector halves



2015 and 2016 Engineering runs

Opportunistic runs: to understand the performance of the detector and take physics data

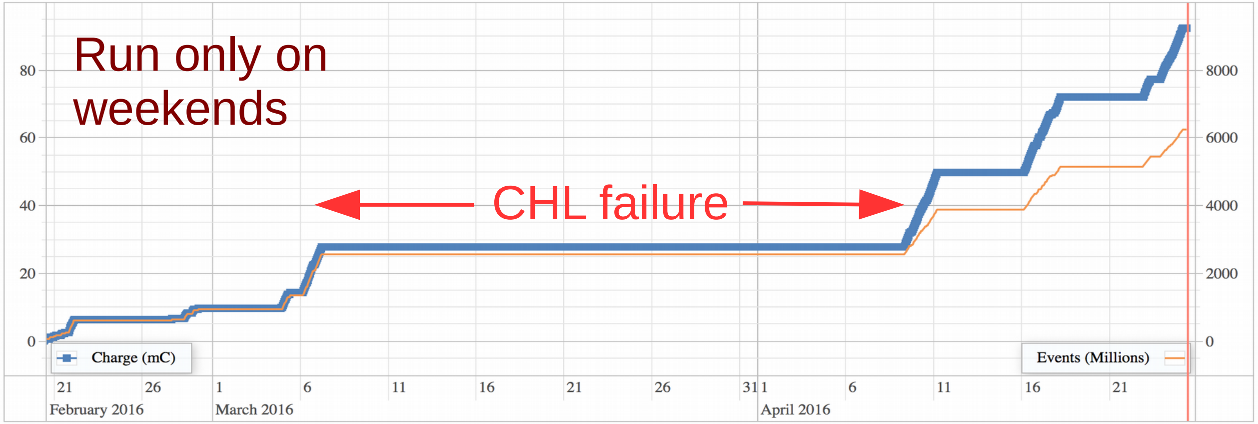
Because of the CLAS12 construction work, HPS run on non-Business hours.



Spring 2015: 1.05 GeV @ 50 nA

10 mC with L1 at 1.5 mm
10 mC with L1 at 0.5 mm (design)

1.5 PAC days with L1 at 0.5mm



Spring 2016: 2.3 GeV @ 200 nA

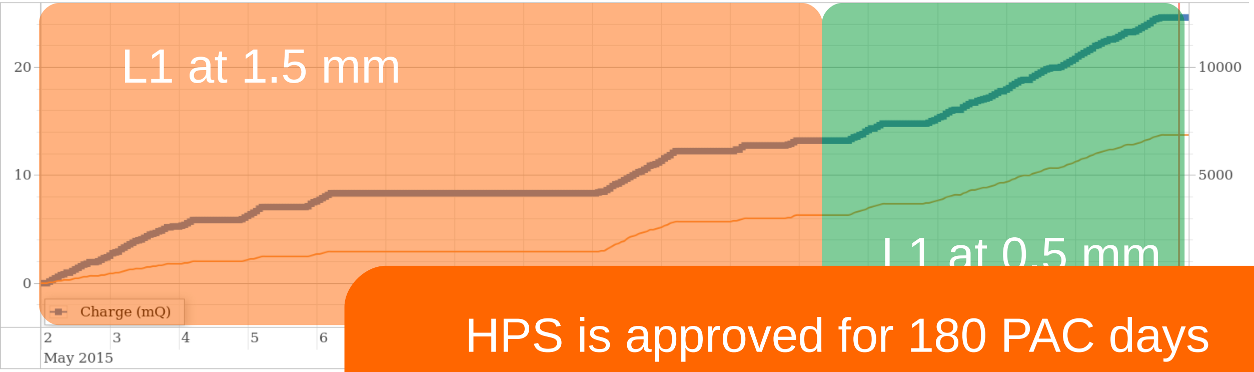
92.5 mC 5.4 PAC days

L1 at 0.5 mm during the data taking

2015 and 2016 Engineering runs

Opportunistic runs: to understand the performance of the detector and take physics data

Because of the CLAS12 construction work, HPS run on non-Business hours.



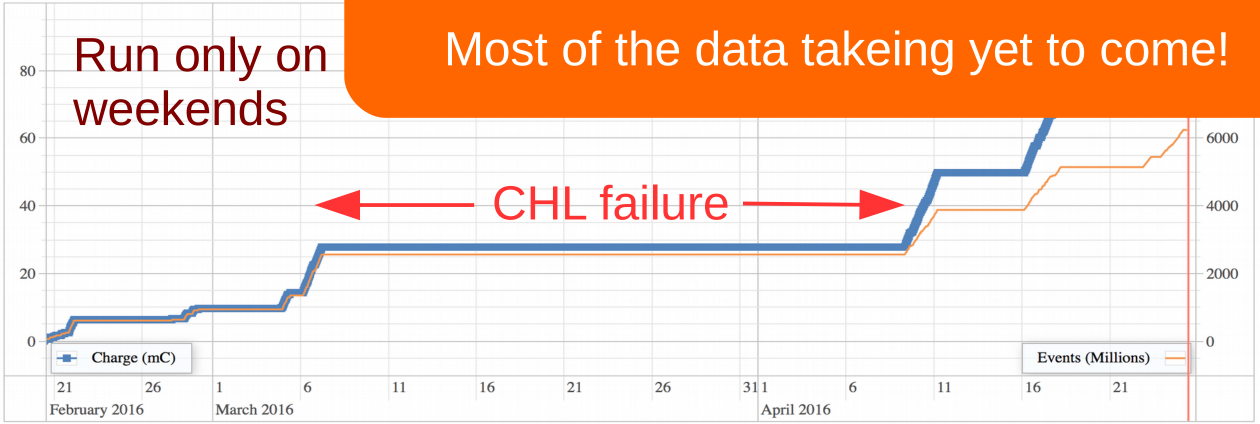
Spring 2015: 1.05 GeV @ 50 nA

10 mC with L1 at 1.5 mm
10 mC with L1 at 0.5 mm (design)

.5 PAC days with L1 at 0.5mm

HPS is approved for 180 PAC days

Most of the data takeing yet to come!

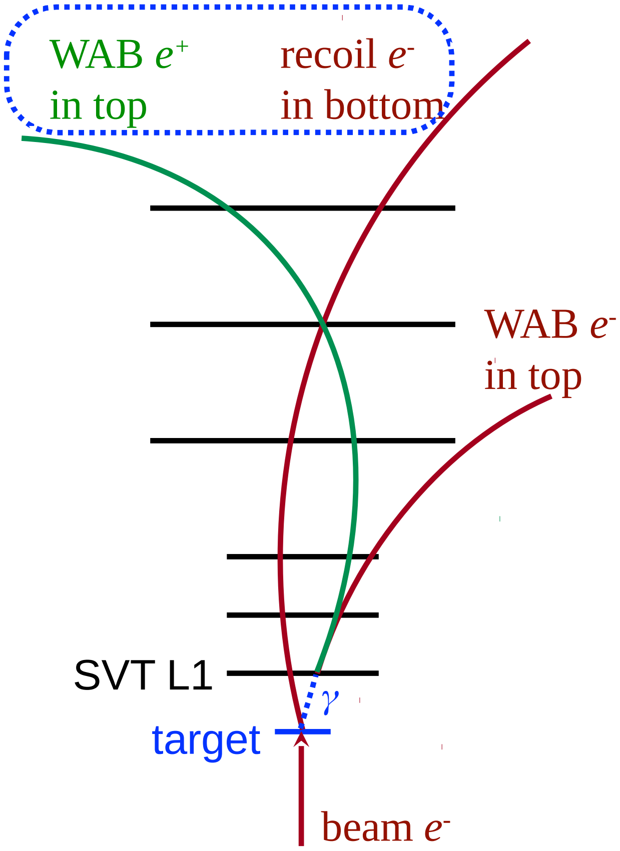


Spring 2016: 2.3 GeV @ 200 nA

92.5 mC 5.4 PAC days

L1 at 0.5 mm during the data taking

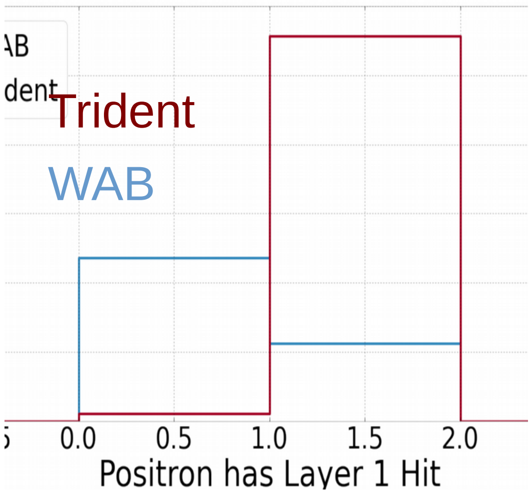
Wide Angle Bremsstrahlung and pair conversion

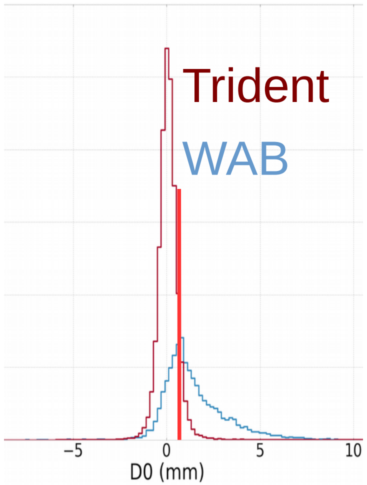


During the analysis we realized that in the final state there is a significant contribution from the two step process: WAB → conversion in SVT layers

Cuts: requirement hit in L1 and d0 removes 80% of these events, without significant loose of tridents

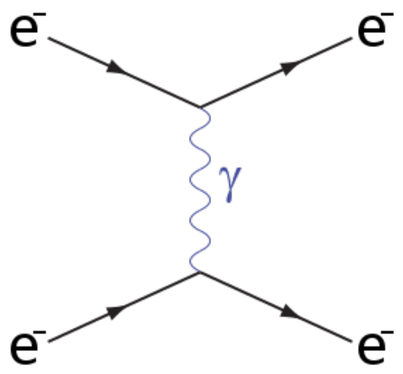
EGS5 doesn't properly simulate electron scattering angle in WABs, and therefore these events didn't show up in the studies of the proposal





Mass resolution

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

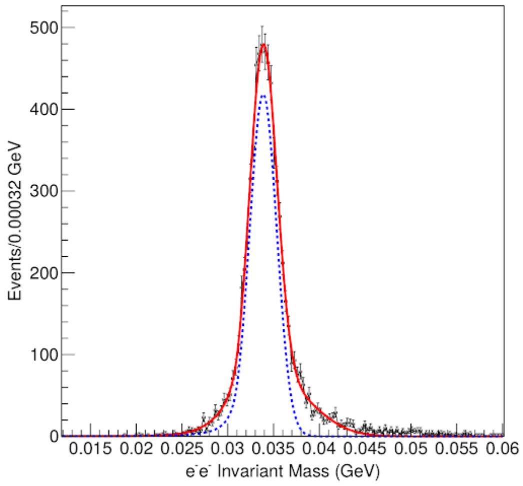


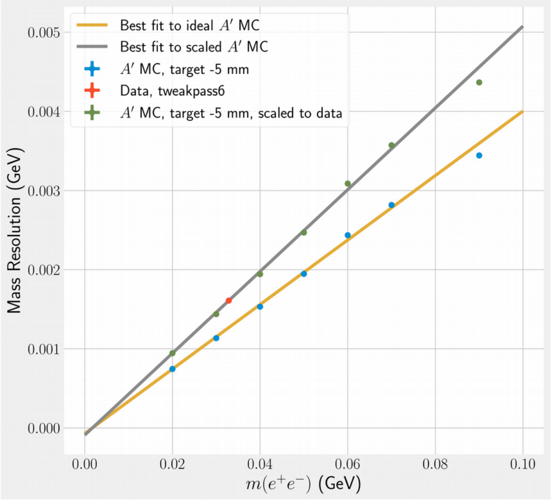
$$M(ee) \equiv \sqrt{2 \cdot E_b \cdot m_e} = 32.7\ MeV$$

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

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

Moeller process allows to check/calibrate the mass resolution

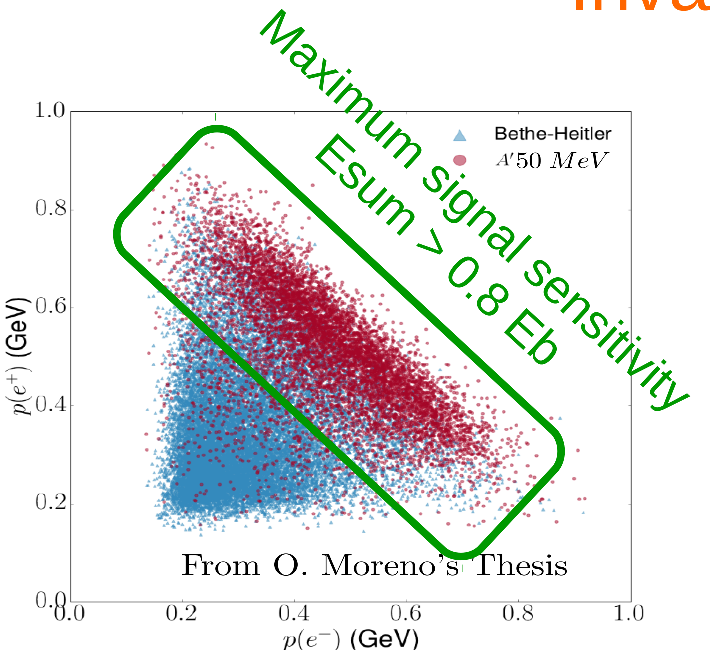


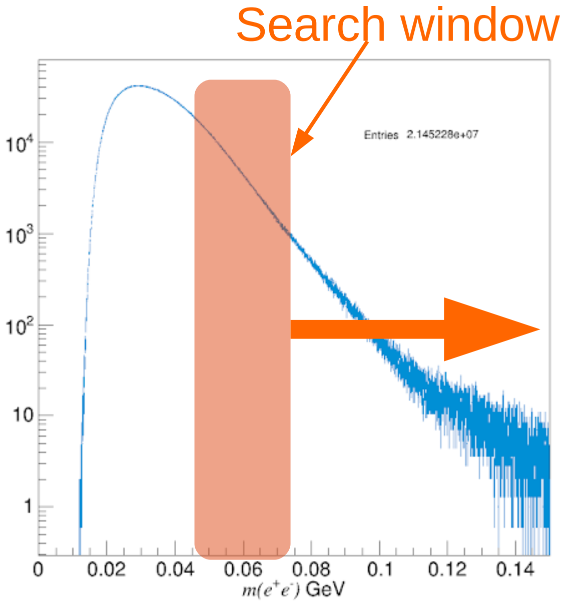


- Linear fit of MC A’ masses

- Scale MC to match the data Moller resolution

Invariant mass distribution





-Range 19 MeV – 81 MeV

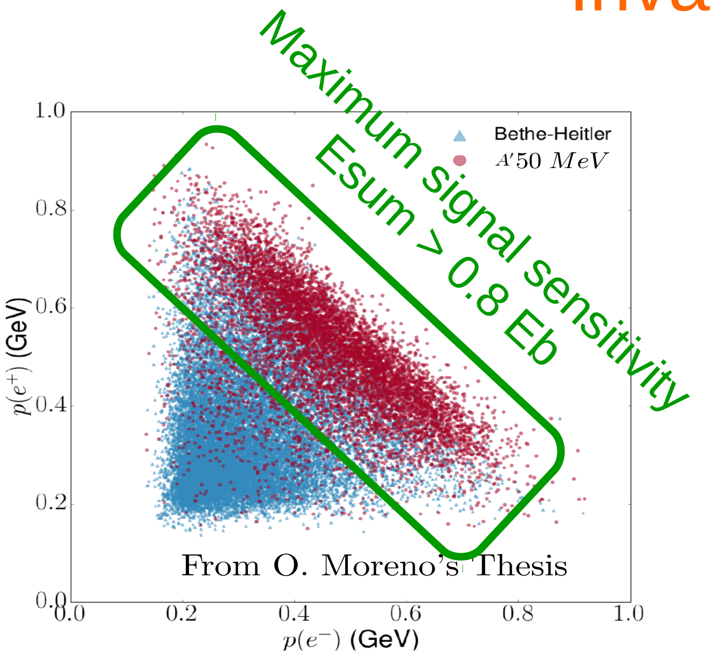
-Scan w/ 0.5 MeV step

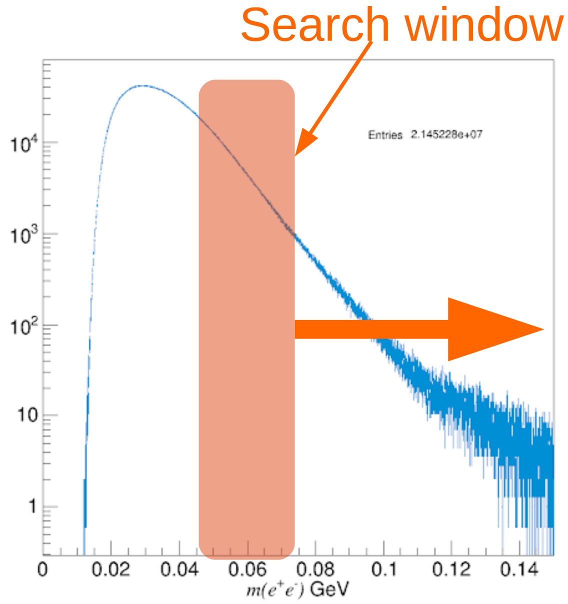
-Search for the peak in the given mass range

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

- Use log likelihood ratio to quantify any excess/bump

Invariant mass distribution





-Range 19 MeV – 81 MeV

-Scan w/ 0.5 MeV step

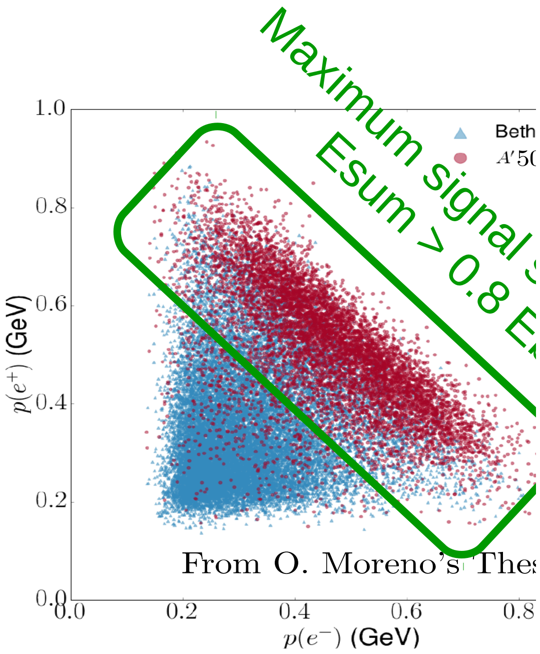
-Search for the peak in the given mass range

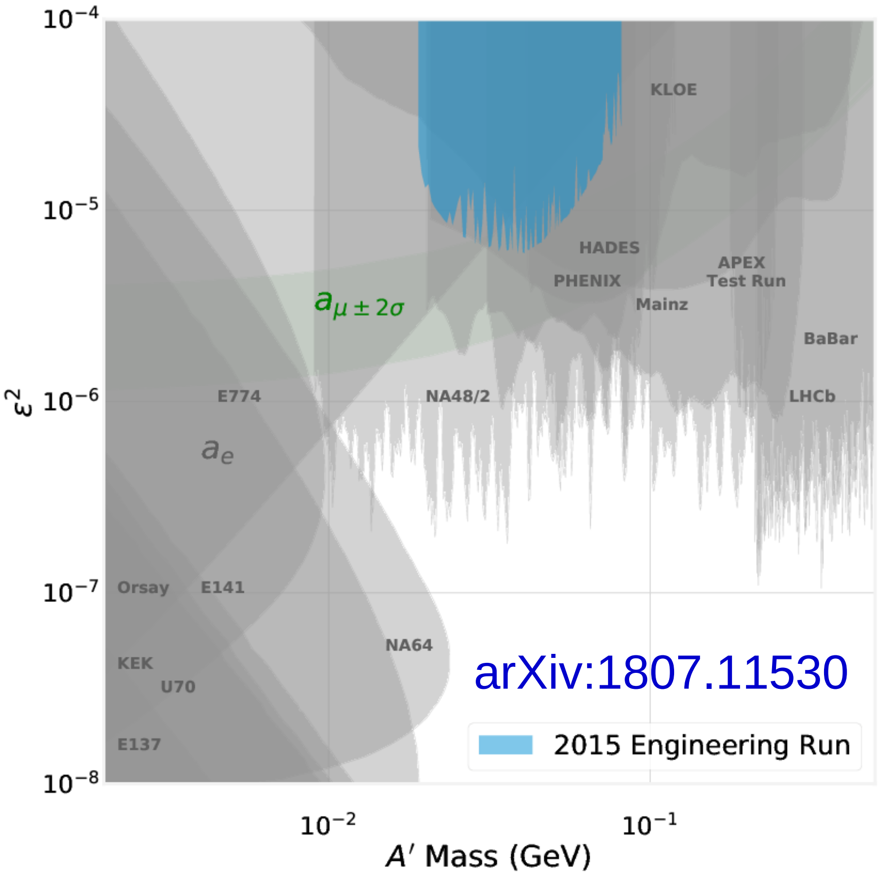
- Maximize Poisson Likelihood with Bgr only, and Bgr+signal hypothesis

- Use log likelihood to quantify any bump

NO significant bump is found!
2σ upper limit is placed

Invariant mass distribution





ge 19 MeV – 81 MeV

n w/ 0.5 MeV step

rch for the peak in the given range

ximize Poisson Likelihood with nly, and Bgr+signal hypothesis

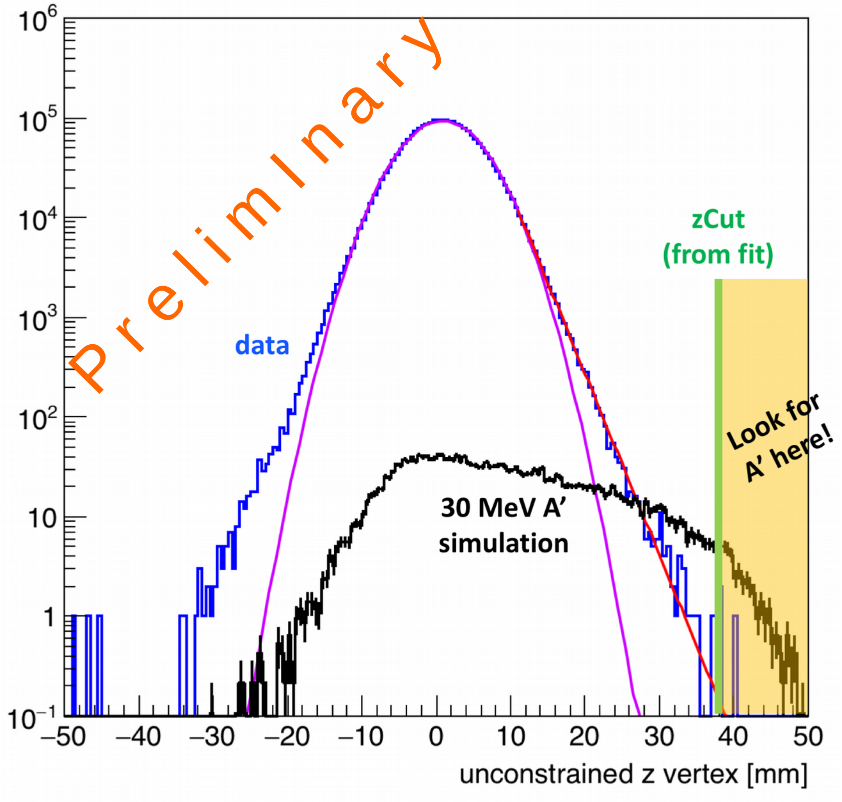
log likelihood to quantify any

NO s

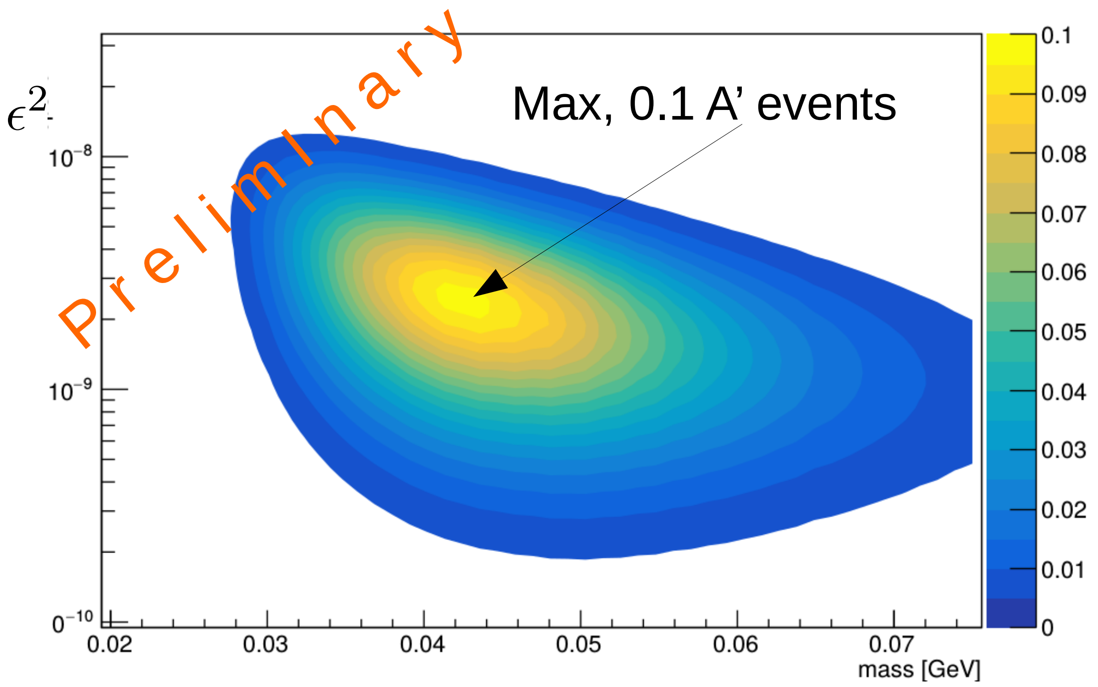
2σ u

Submitted to PhysRrevD RC

Vertexing analysis



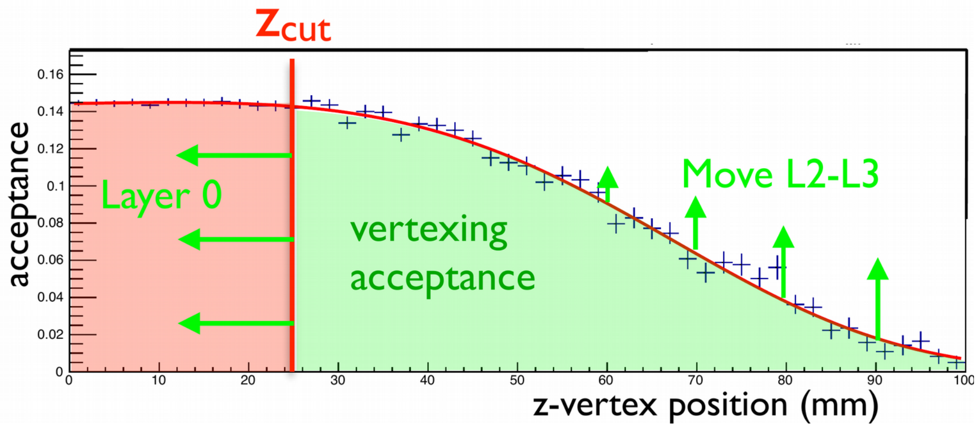
1.5 PAC days



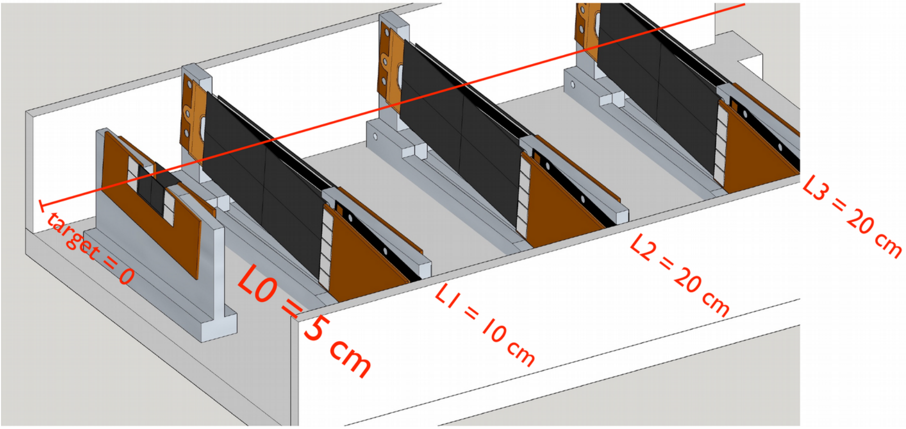
Analysis is in a quite advanced state, however with 1.5 days of data, we will not have any reach (2.5 expected A' events)

SVT Upgrade

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

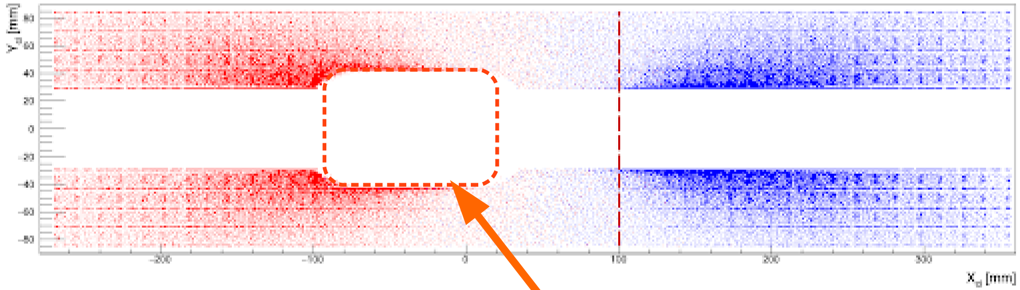


-Moving SVT Layers 2-3 closer to the beam will increase the acceptance

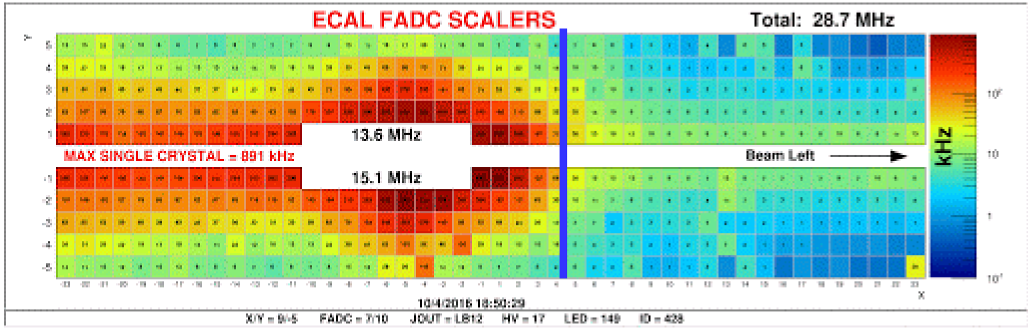


HPS upgrades

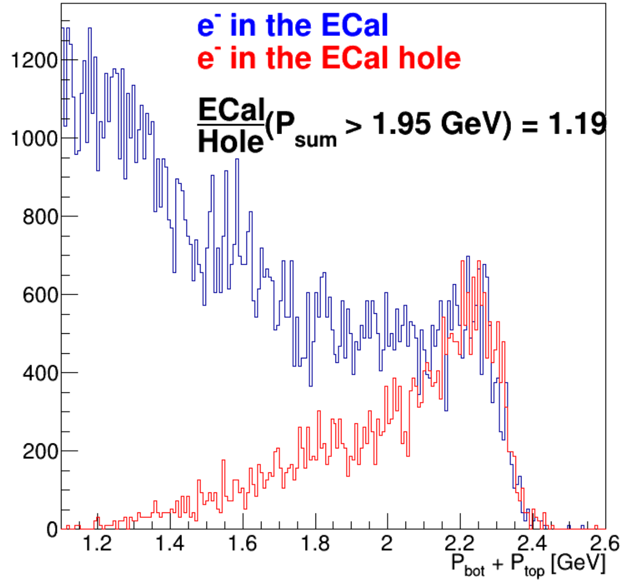
Electrons   Positrons



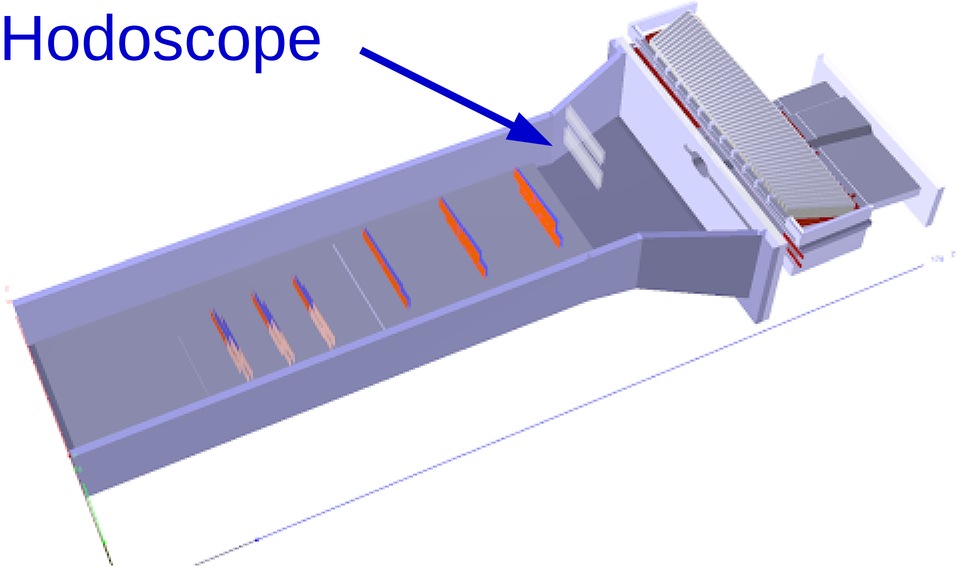
Low rate in positron side



Events w/ electron in the gap are lost



Hodoscope



HPS future

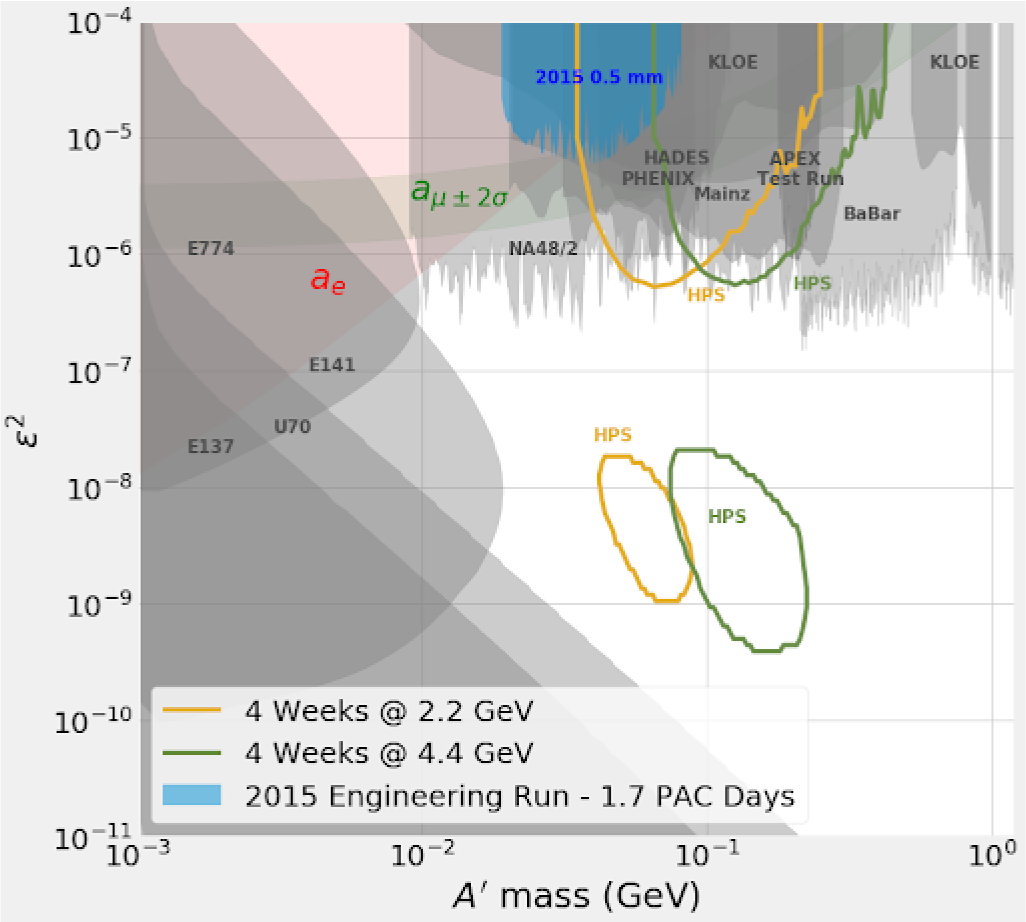
HPS is preparing to run starting Jun 2019 for 8 calendar weeks

Will be upgraded with two detector components, L0 and Hodoscope

Hodo upgrade is expected to increase the reach by about x2

SVT upgrades will significantly improve the vertexing resoulution and acceptance and hence the HPS vertexing reach

It is expected to have a vertex reach, and covered territory!



Summary

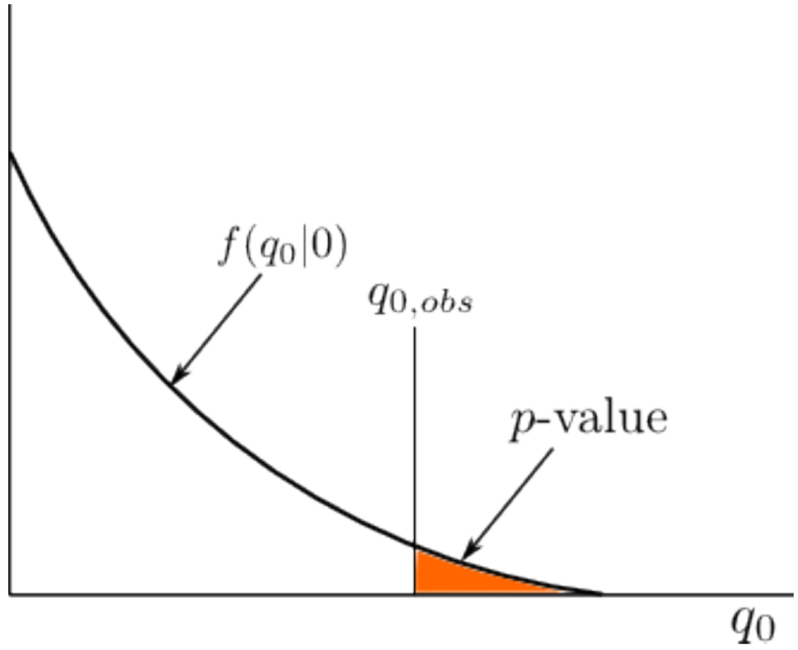
JLab has a broad program in dark sector physics

JLab experiments have capability to cover new uncovered territories

It is exciting time for Dark matter experiments, two of them (APEX and HPS) will take significant amount of data in 2019

1 published paper (APEX test run), 1 submitted (HPS 2015), and more should come (HPS 2016 data, and upcoming experiments)

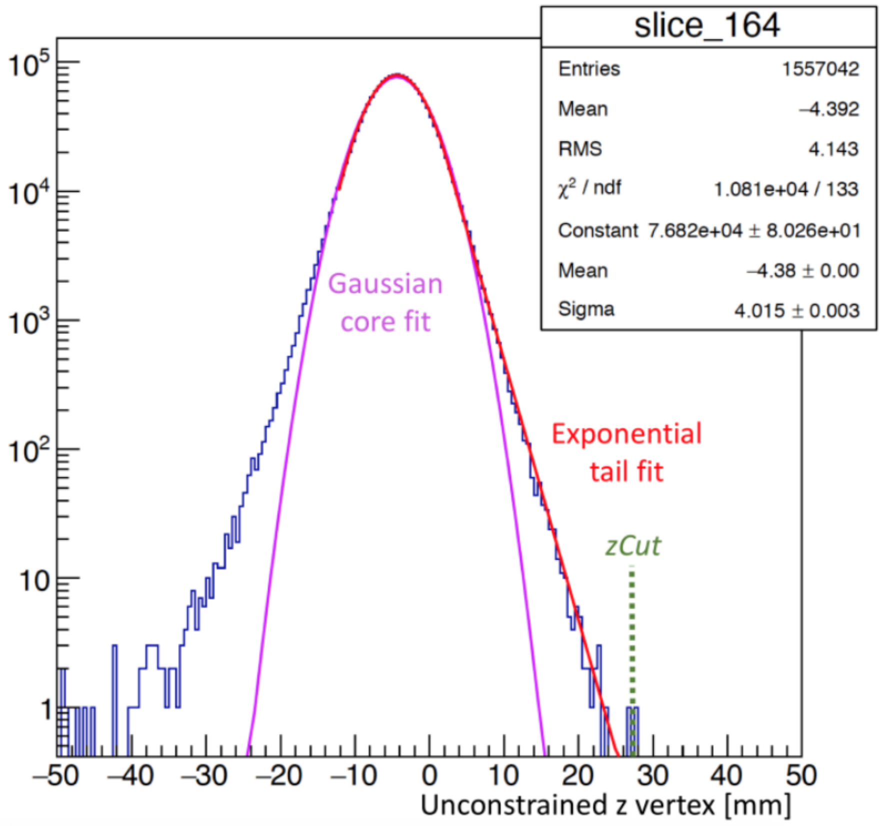
Supporting slides

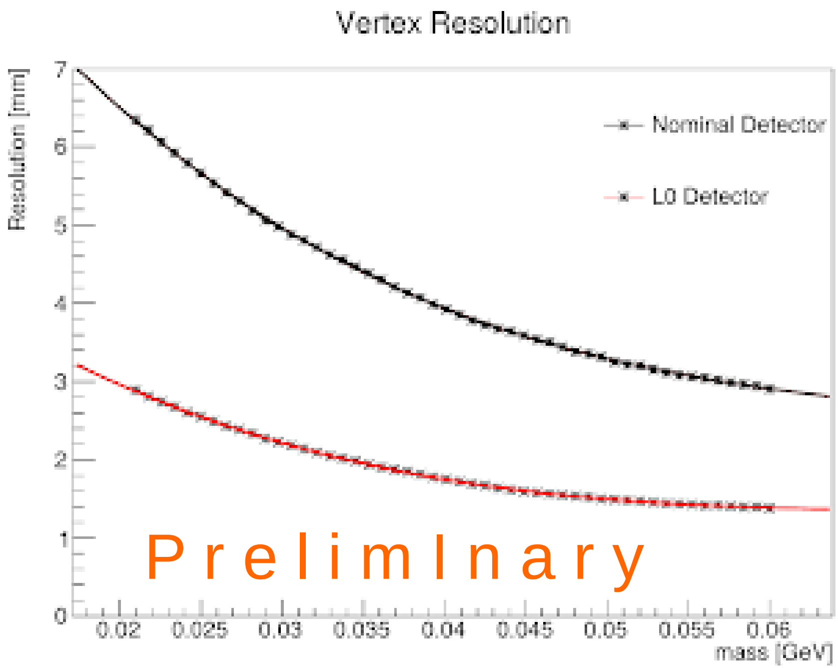


$$q_0 = \begin{cases} -2\ln \frac{\mathcal{L}(0,\hat{\hat{\theta}})}{\mathcal{L}(\hat{\mu},\hat{\theta})} & \hat{\mu} > 0 \\ 0 & \hat{\mu} < 0. \end{cases}$$

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

$$F(z > b) = Ae^{-\frac{b^2}{2\sigma^2} - \frac{z - z_{mean} - b}{l}}$$




Vertex Resolution
Resolution [mm]
7
6
5
4
3
2
1
0
0.02
0.025
0.03
0.035
0.04
0.045
0.05
0.055
0.06
mass [GeV]
Nominal Detector
L0 Detector
Preliminary