The HPS Experiment

Per Hansson Adrian

on behalf of the HPS Collaboration

SLAC NATIONAL ACCELERATOR LABORATORY

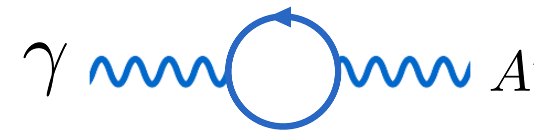
U.S. DEPARTMENT OF ENERGY | Office of Science

Heavy Photon/A'

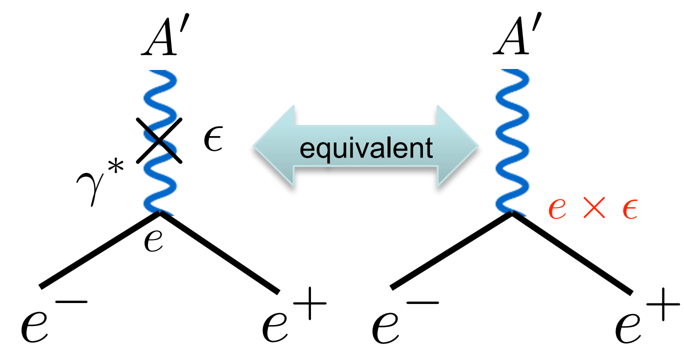
- Conjectured new U(1) vector boson
  - Extra U(1)'s appear in many BSM models
  - Couples weakly (e×ε) to electric charge
  - GeV-scale mass "inherited" from electro-weak scale
- Electrically charged **ordinary** matter acquire milli-charge under the A'
- What makes it interesting now?

[Holdom '86]

Kinetic mixing



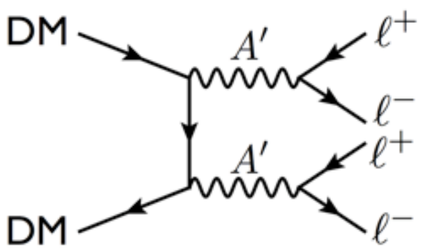
$\varepsilon \sim 10^{-8} - 10^{-2}$



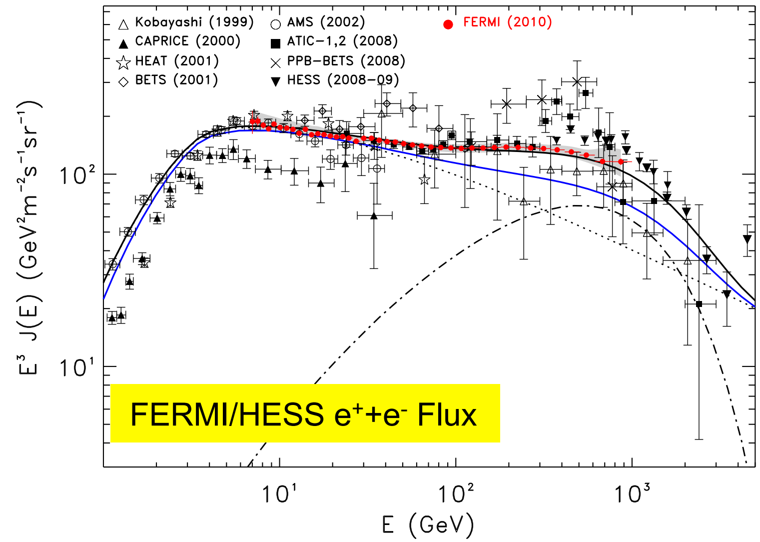
A’, Dark Matter & Muon g-2

- Excess flux of cosmic e^+ and e^- at high energy
  - Dark matter annihilation through GeV-scale A’?

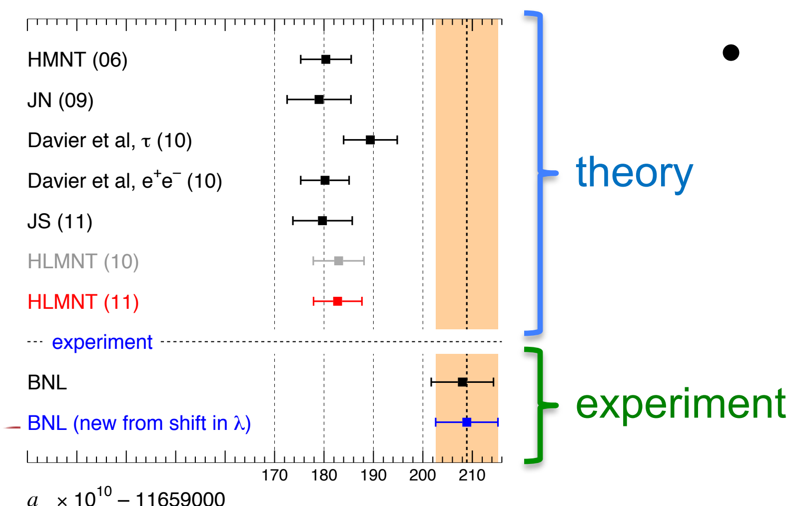
[Arkani-Hamed, Finkbeiner,Slatyer, Weider, Pospelov, Ritz]



$$m_{A'} < 1GeV \Rightarrow A' \rightarrow l^+ + l^-$$



[Fermi 1008.3999; PAMELA 0810.4995]



- Muon anomalous magnetic moment (g-2)
  - >3σ deviation from Standard Model
  - GeV-scale A’ could play a role

[Pospelov 0811.1030]

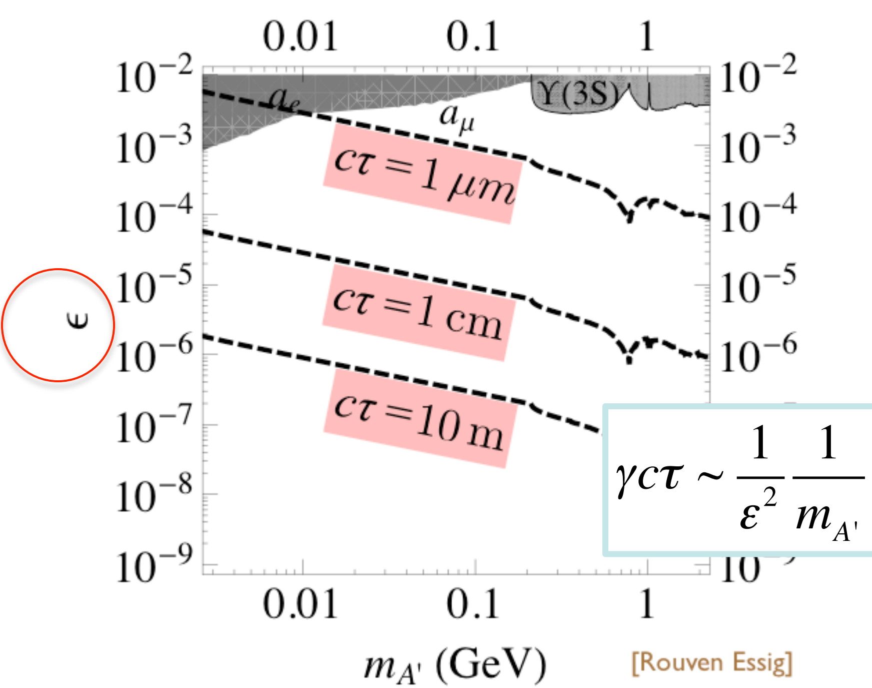
[Hagiwara et al; Bennet hep-ex/0602035]

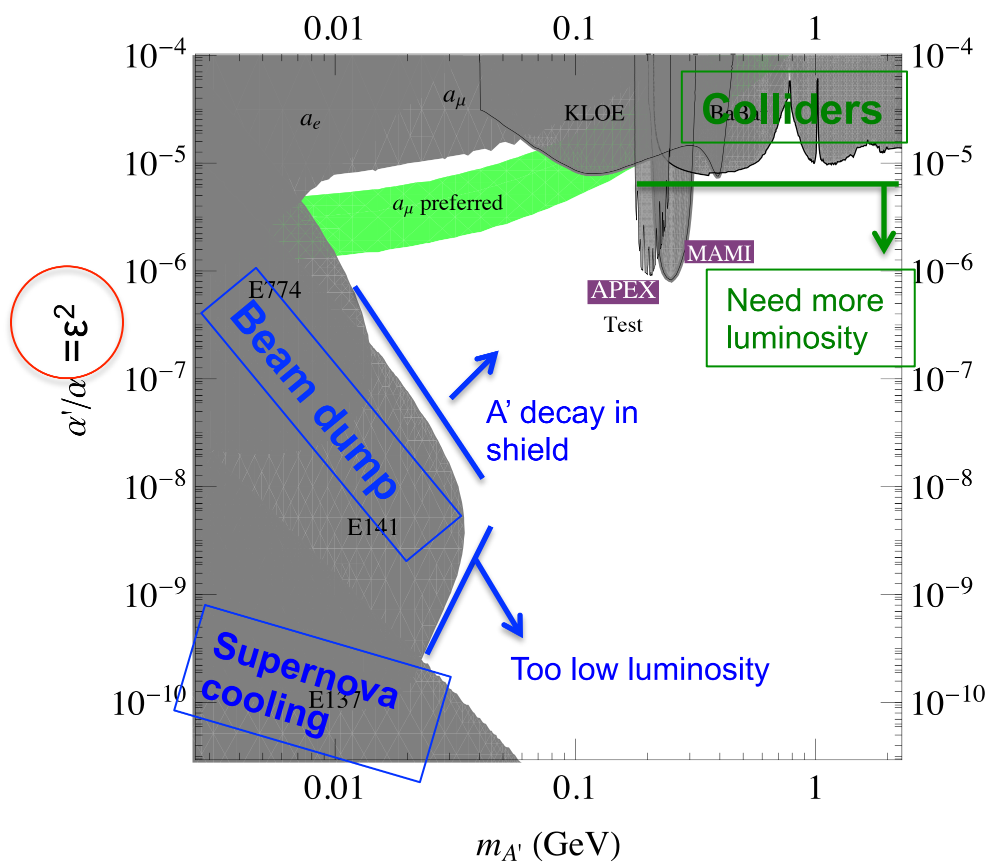
A' Searches and HPS

[Bjorken, Essig, Schuster, Toro 0906.0580]

- Key experimental issues
  - Cross section relative to QED backgrounds
  - Lifetime (the A' can be long-lived!)

$$\sigma_{A'} \sim \frac{\varepsilon^2}{m_{A'}^2}$$





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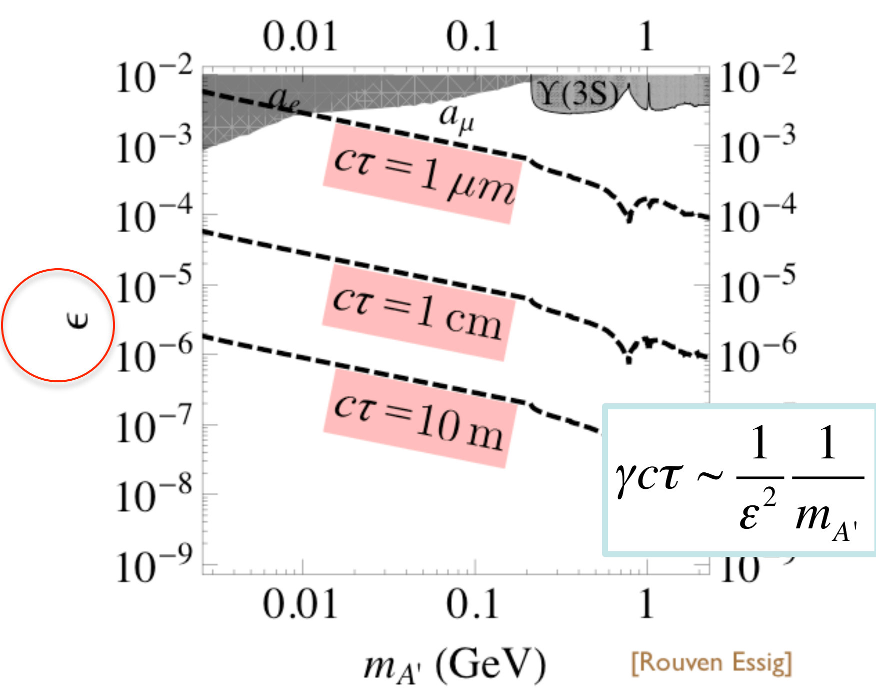
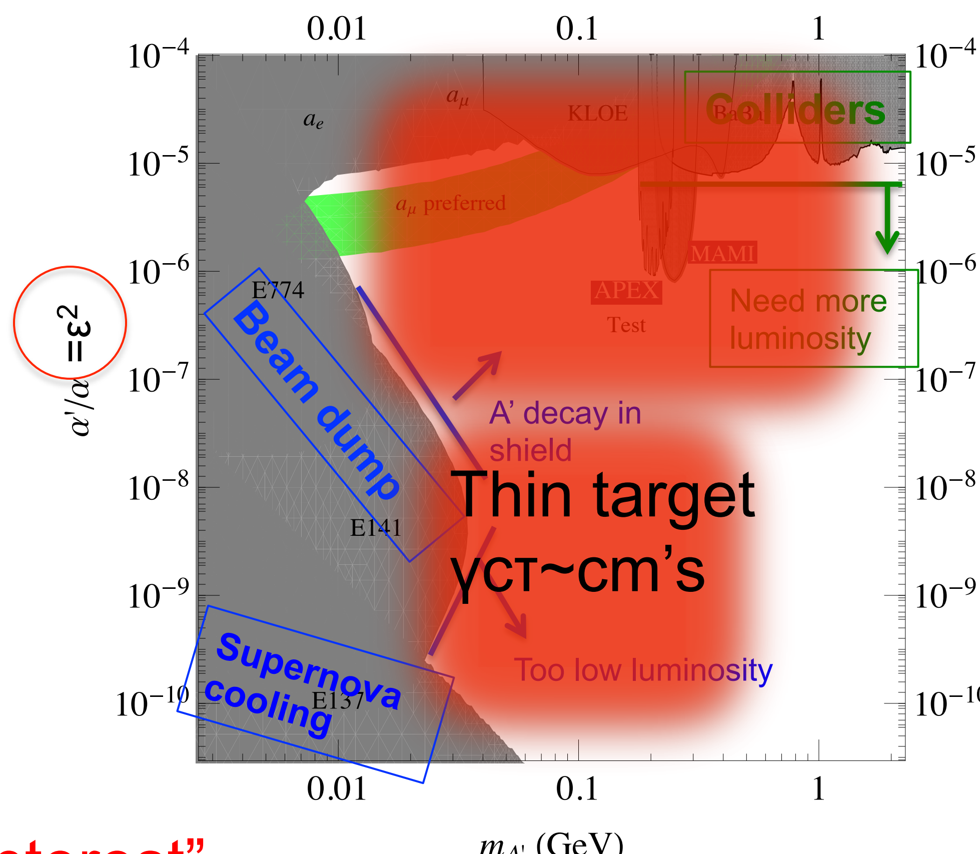


$$\gamma c\tau \sim \frac{1}{\varepsilon^2}\frac{1}{m_{A'}}$$



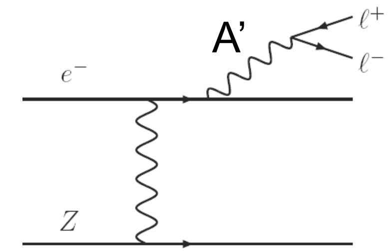
HPS "region of interest"

A' Signal Characteristics

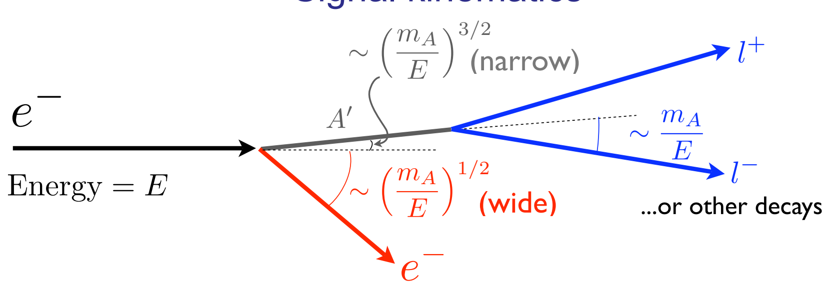
[Bjorken, Essig, Schuster, Toro 0906.0580]

- Qualitative A' features
  - Very forward: $\mathbf{E_{A'} \approx E_{beam}}$
  - Decay prod. opening angle: $\mathbf{\sim m_{A'}/E}$
  - Possibly displaced vertex
- Main backgrounds
  - Bethe-Heitler suppressed by kinematic selections
  - "Radiative" are kinematically **identical** to A'

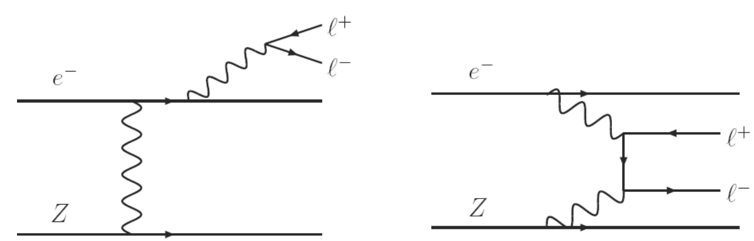
"Bremsstrahlung" A' production



Signal kinematics



Trident backgrounds



"Radiative" "Bethe-Heitler"

➔Search for a signal in narrow inv. mass window

Resonance search ("bump hunt")
+ displaced vertex search

HPS key measurements

Invariant mass of decay products

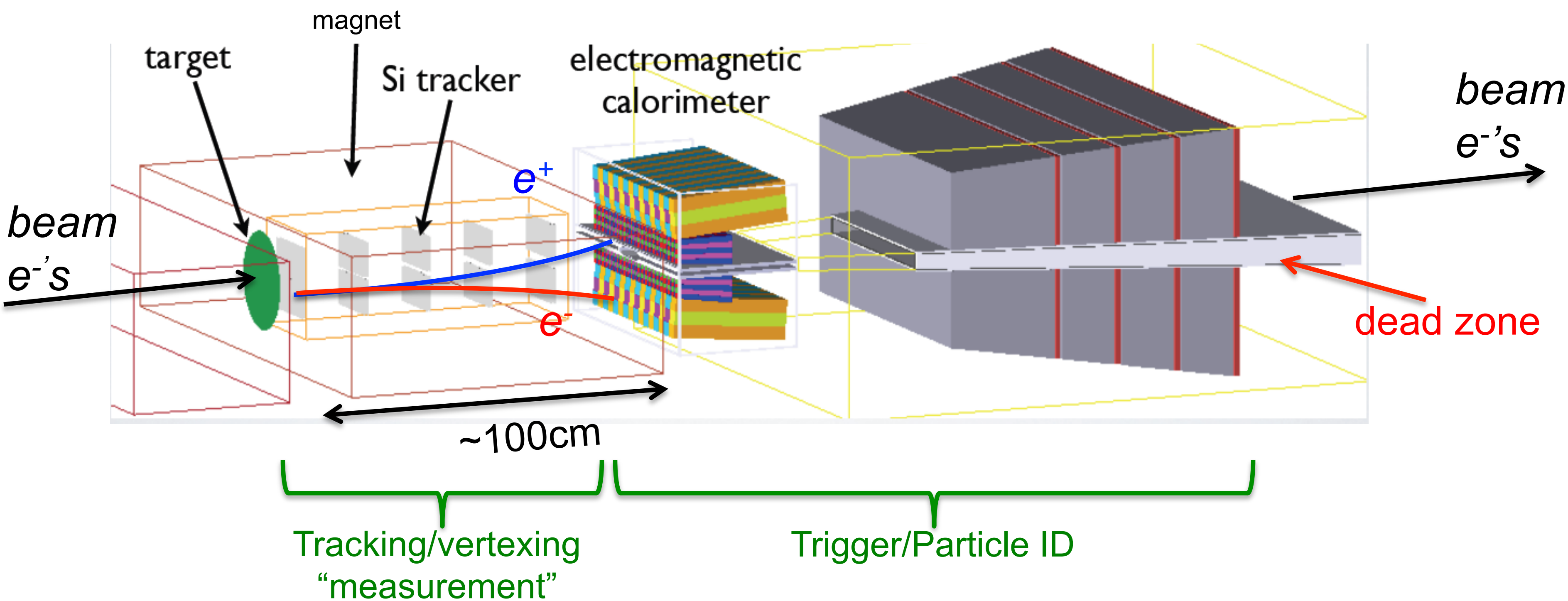
Reconstruction of decay vertex

Experimental Requirements

- Forward acceptance; small A' decay opening angles
- Large luminosity; access to small cross sections
- "Continuous" beam; spread out "angry" backgrounds
- Fast electronics and trigger; "pick out" hits in continuous beam
- Thin target($<<1X_0$); lower multiple scattering
- Good momentum and vertex resolution; low-mass, high-precision, very close to target (reach $\gamma c\tau \sim 1$mm)

HPS Detector Overview

- Compact large forward acceptance spectrometer
- Silicon tracker/vertexer, inside magnet close (10cm!) to target

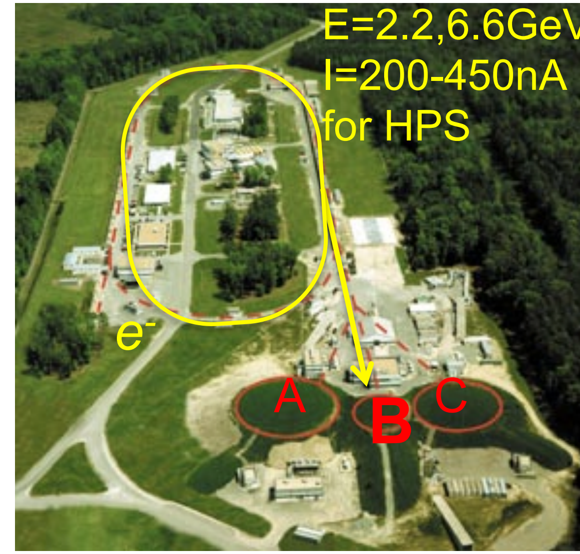


- All detectors split vertically to avoid "sheet of flame"
  - Primary beam, degraded electrons, bremsstrahlung photons, etc.

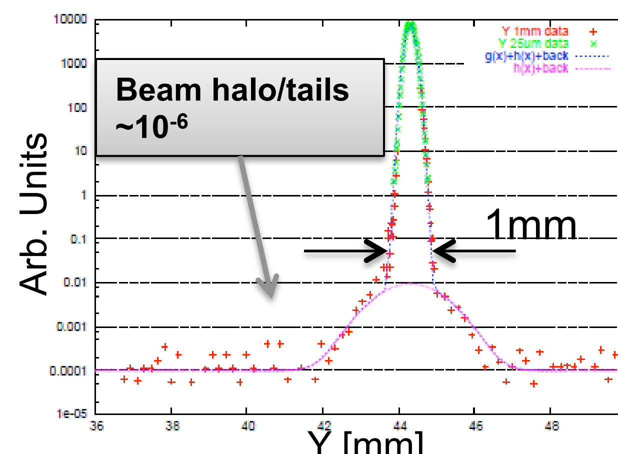
HEAVY PHOTON SEARCH

Jefferson Lab CEBAF

- CEBAF electron beam ideal for HPS
  - Configurable beam; energy and current
  - Near continuous; 2ns bunch spacing
  - High luminosity; 2-8ab^{-1}/day
- Excellent beam quality & stability
- Small beam spot size (<30μm); helps vertexing
- Schedule not ideal for HPS
  - Machine down May12' – 2015' for 12GeV upgrade
  - Aim for first beam after upgrade



Vertical Beam Size



[A. Freyberger]
https://twindico.hep.anl.gov/indico/getFile.py/access?contribId=23&resId=0&materialId=slides&confId=751]

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Tracking Challenges

- Excellent vertex and momentum (➔mass) resolution
  - Track momentum ~few GeV (depending on E_{beam})
    ➔ multiple scattering dominates resolution
  - **Need low mass detector**

- Operation of tracker close to the primary beam: 500µm from beam!
  - Primary beam and scattered “secondary’s” pass “through” tracker
  - Safety of detector in case of beam incident
  - **Need motion system for tracking sensors to minimize “dead zone”**

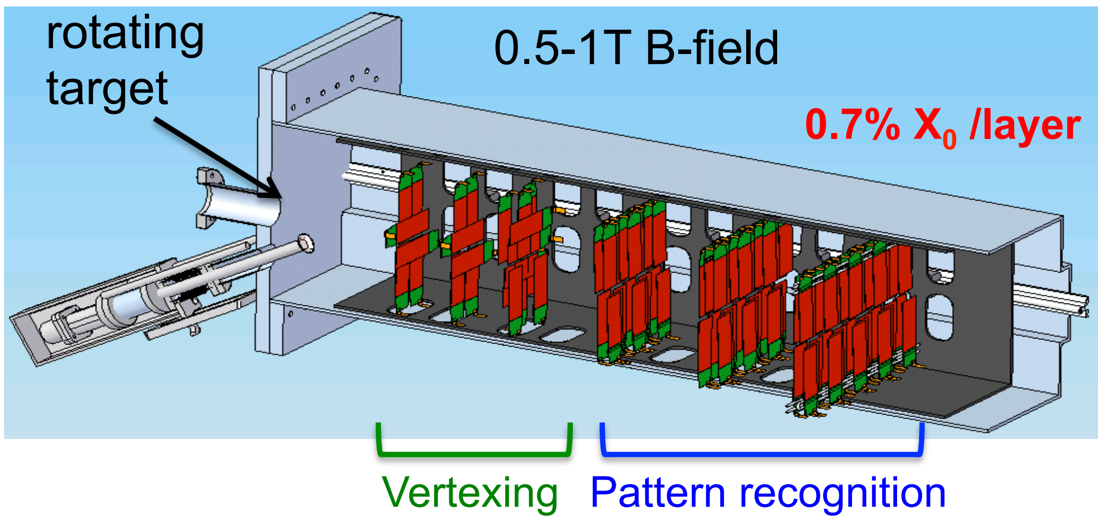
- Operation in beam vacuum
  - Intolerable occupancies from intense beam interacting with gas
  - **Need vacuum compatible materials, cooling and retraction system**

- Cope with extreme occupancies
  - Hit assignment problems in dense environment
  - Innermost strips sees **~10MHz hits/mm^2**
  - **Need robust, fast, radiation hard sensors and readout electronics**

Silicon Vertex Tracker

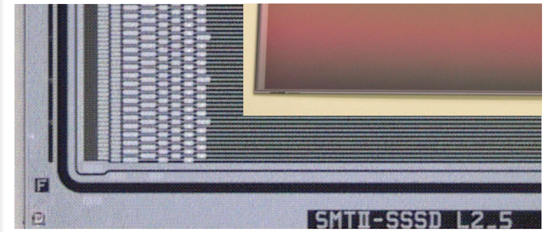
- Pairs of micro-strip sensors
- Layout for optimal performance
  - Multiple scattering error dominate: low mass
  - Bend plane measurement in all layers (for momentum)
  - 90° stereo for vertexing
- Carbon fiber & rohacell support
  - Water/glycol cooling (-5°C, 1.7W/sensor)
  - Piezoelectric motion system
- 106 sensors/67840 channels

Layer->	1	2	3	4	5	6
z position [cm]	10	20	30	50	70	90
Stereo angle [mrad]	**90°**	**90°**	**90°**	**50**	**50**	**50**
Bend plane res. [um]	≈6	≈6	≈6	≈6	≈6	≈6
Stereo res. [μm]	≈6	≈6	≈6	≈130	≈130	≈130
Dead Zone [mm]	±1.5	±3.0	±4.5	±7.5	±10.5	±13.5

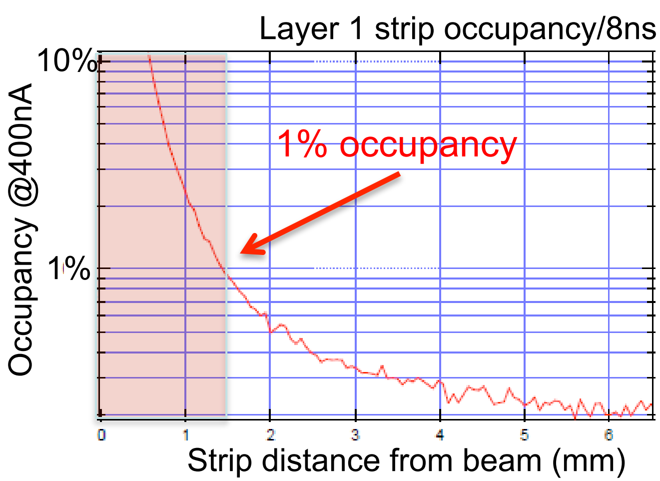


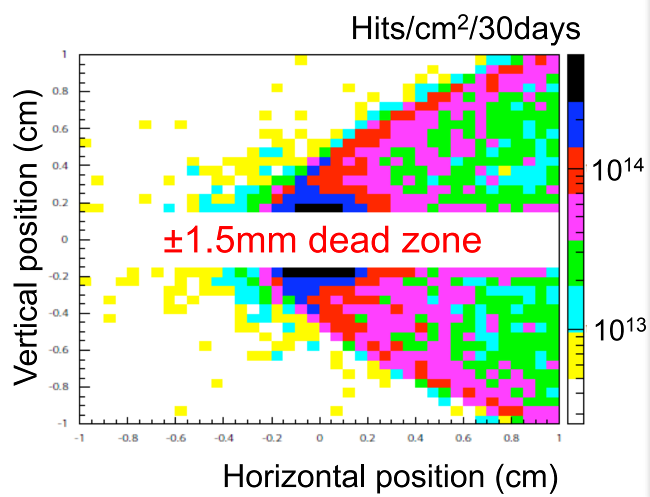
Silicon Vertex Tracker

- D0 RunIIb (cancelled) upgrade sensors
  - Radiation hard (3x expected run)
  - High readout granularity
  - Low mass solution (readout outside tracking volume)
- Readout: APV25 (CMS development)
  - Fast, available, proven
  - 40MHz readout, analog deep pipeline
  - t_0 resolution ≅2ns



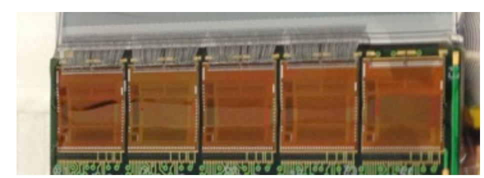
# channels	639
Active area (mm^2)	98.33x38.34
Readout (sense) pitch	60(30)µm
Thickness	320µm
Rad. Hardness ["e-"]	~3×10^{15}





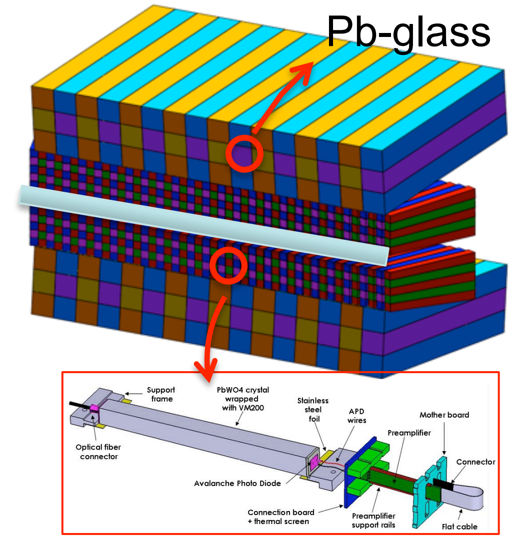
APV25

# channels	128
Input pitch [µm]	44
Signal/noise	>25
Shaping time [ns]	35 (50)



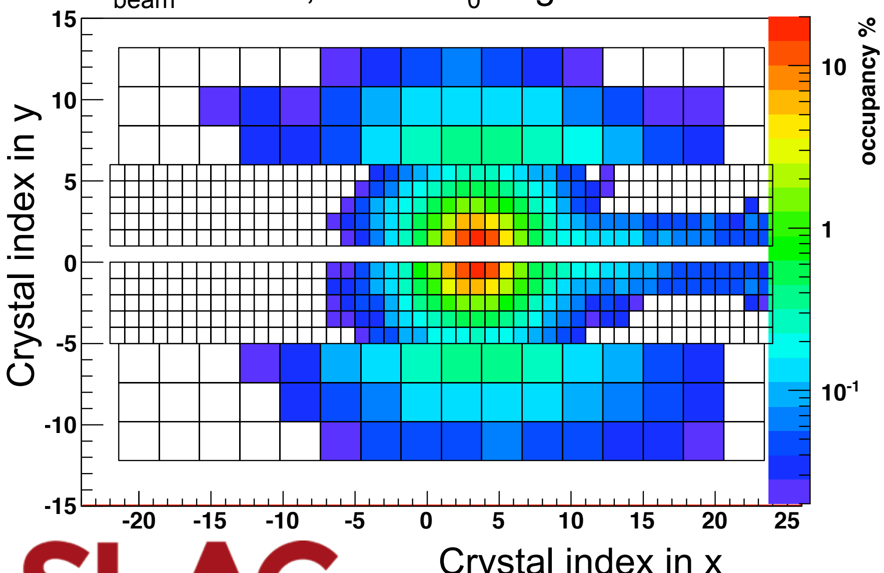
EM Calorimeter & Trigger

- Good acceptance, fast, readily available
- Existing $PbWO_4$ and Pb-glass modules
  - CLAS inner calorimeter
  - Readout: APD and photo multipliers
- Large occupancy close to primary beam
  - 10% occupancy; optimized layout and signal handling



APD & preamp.

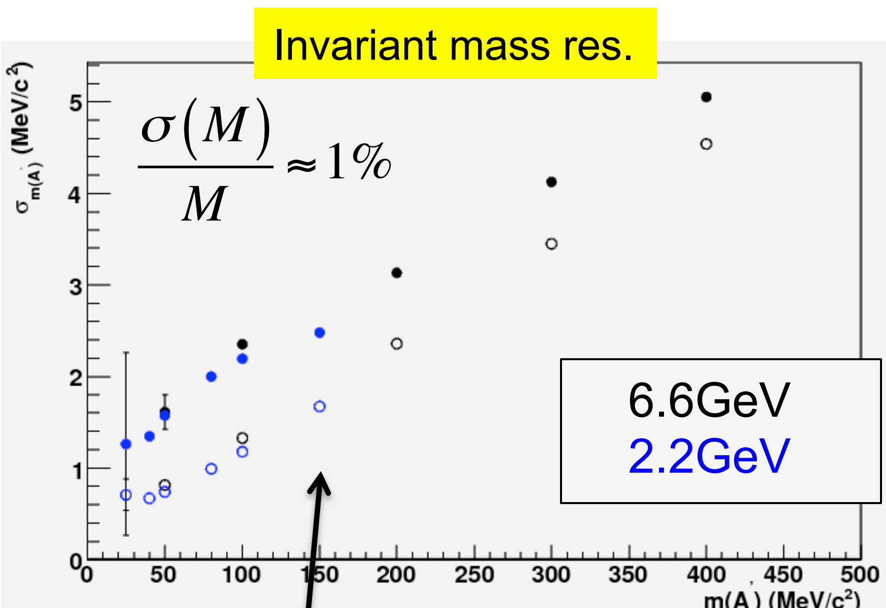
I_{beam}=400nA, 0.25% X_0 target

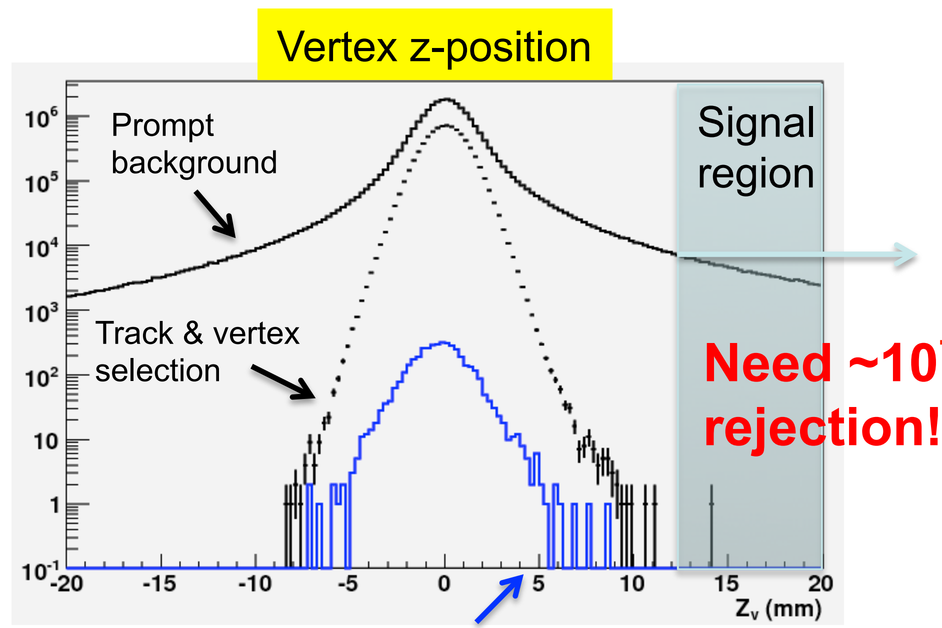


- Readout by JLab 250MHz FADC
- Trigger provides 8ns trigger time window, 3μs latency
- Trigger and DAQ capable of 50kHz rate

HPS Performance

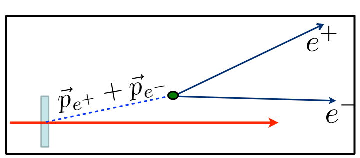
- Key variables: invariant mass and vertex resolution
- Multiple scattering limits performance
- Success for vertexing relies on rejecting tails





Tracks w/ bad hits

<20μm beam spot constraint is good!



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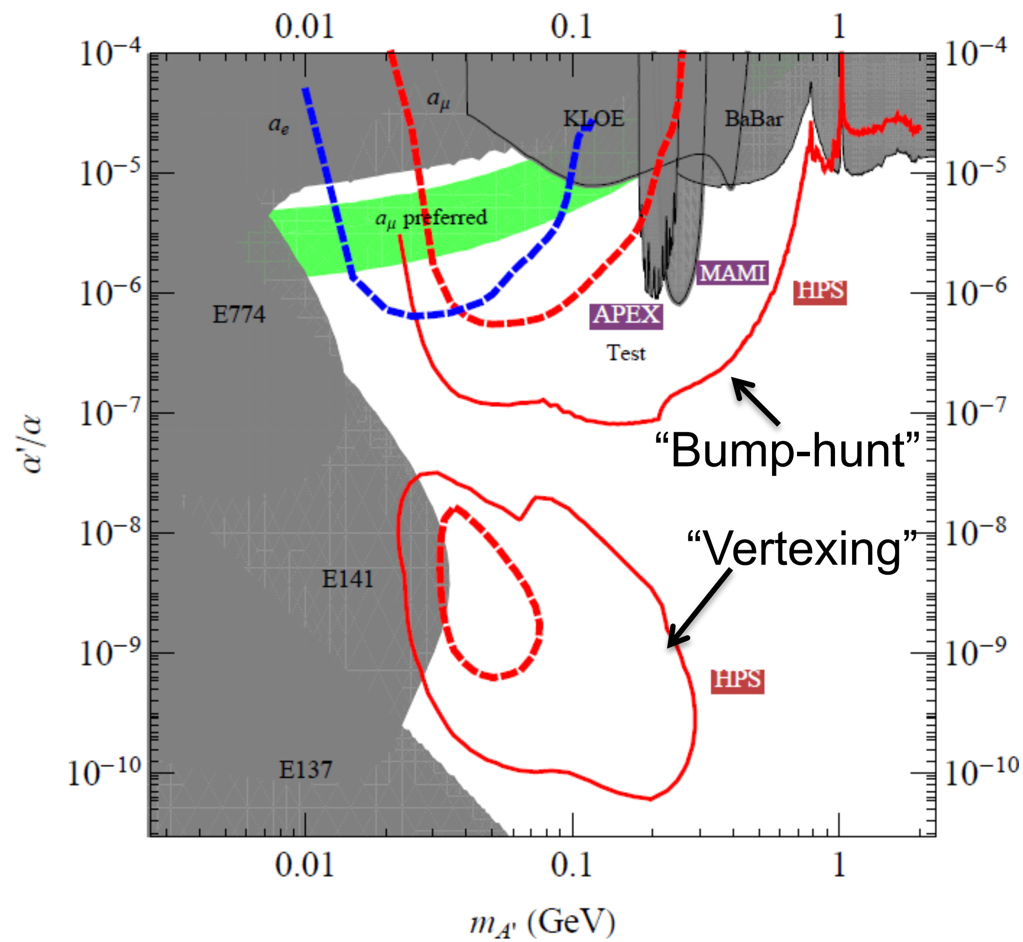
HPS Sensitivity

- Optimized beam energy, current and target thickness (0.25%, 0.14% X_0)
- Explore new regions of parameter space

HPS
3 months 2.2GeV
3 months 6.6GeV

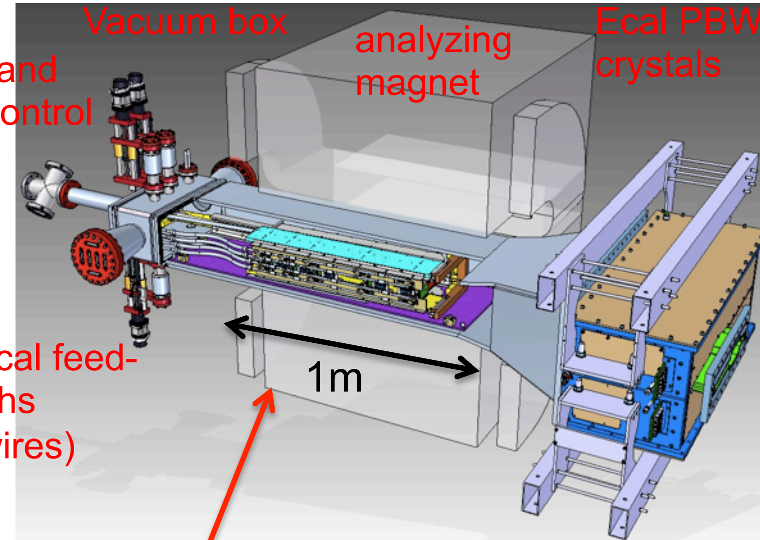
HPS Test Run
1 week 2.2GeV
1 week 1.1GeV

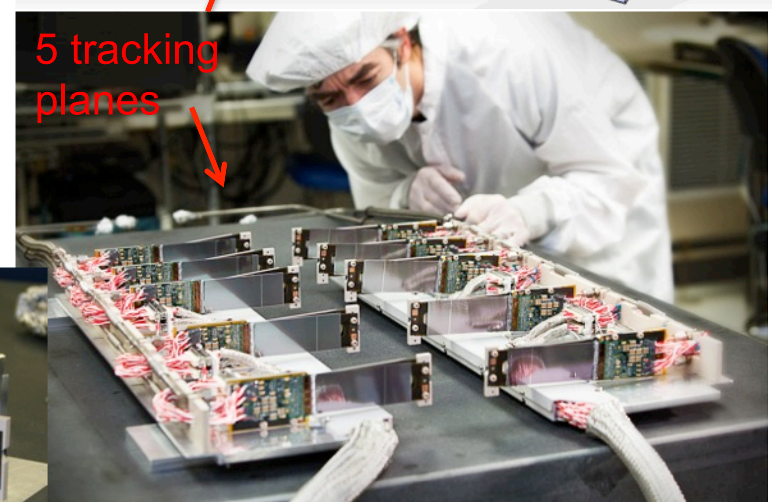


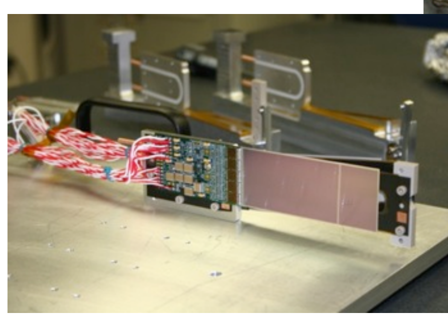
HPS Test Run

- Very busy year!
- In 2011: "Full" HPS contingent on test run
  - Build a tracker and calorimeter that successfully meets key challenges
  - Confirm models of backgrounds
  - Demonstrate technical approach
  - Bonus: physics reach
- Design choices: sacrifice acceptance
  - 20 (/106) tracking sensors
  - Inner calorimeter: $PbWO_4$ modules
  - Complete, integrated full DAQ for SVT and calorimeter

Very tight schedule:
Run before the 12GeV upgrade

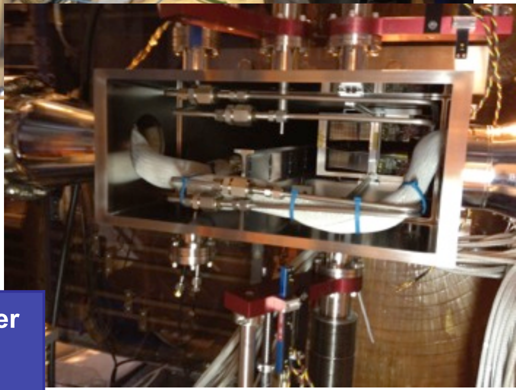


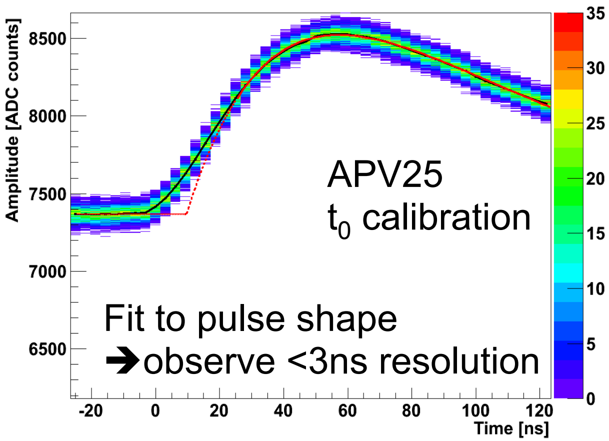




HPS Test Run

- HPS Test ran successfully in April/May 2012 with photon beam
  - Conceived, built and installed novel tracking/vertex detector in ~14 months!
  - Demonstrated FADC, trigger and DAQ rates
  - Tracker timing, S/N, etc., as expected
- Analysis of background models ongoing





Short photon beam run
(last hours of CEBAF 6GeV era!)

Target thickness (rad. len)	# Events	Approx. trigger rate (Hz)
no target	0.6M	0.3k
0.18%	2M	0.4k
0.45%	1M	0.6k
1.6%	1.5M	1.9k

Summary

- HPS designed for discovery of A' for $m_{A'}$=0.1-1GeV
- Keys for success
  - Invariant mass of decay products
  - Reconstruction of long-lived A' decay vertex for small couplings
- Key challenges
  - Excellent tracking and vertexing performance close to fixed-target
  - Occupancies in tracker and electromagnetic calorimeter
  - High-rate trigger and DAQ
- Status and tentative timeline
  - HPS Test Run in April/May 2012 (success, but only photon beam)
  - Approved by PAC
  - Hope to Run HPS Test in 2014 with electron beam
  - Working out details with JLab

The HPS Collaboration

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(Dated: May 7, 2012)

[a]Co-spokesperson
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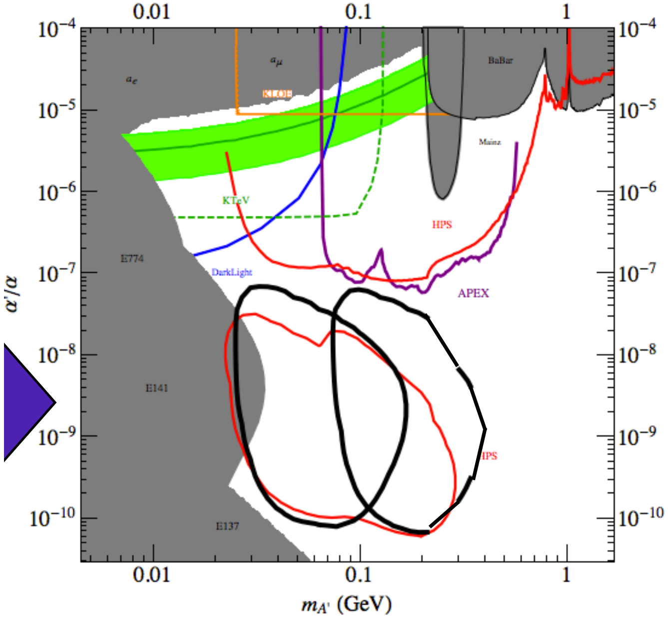
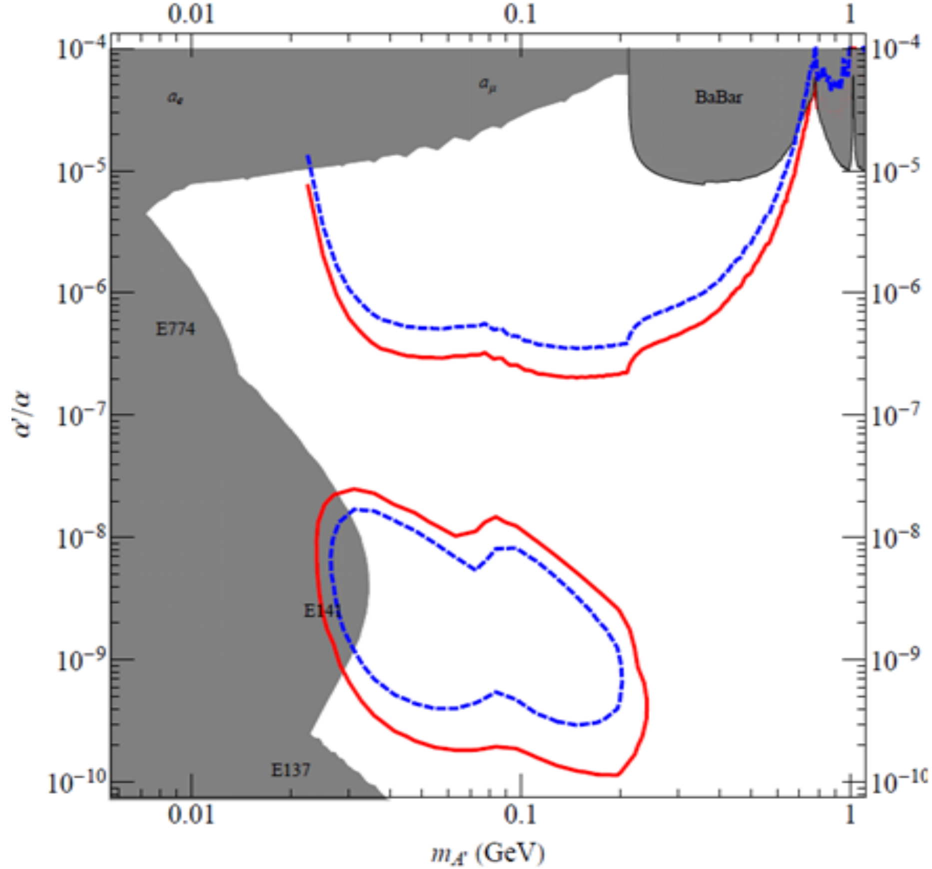
Backup

Closing the gap

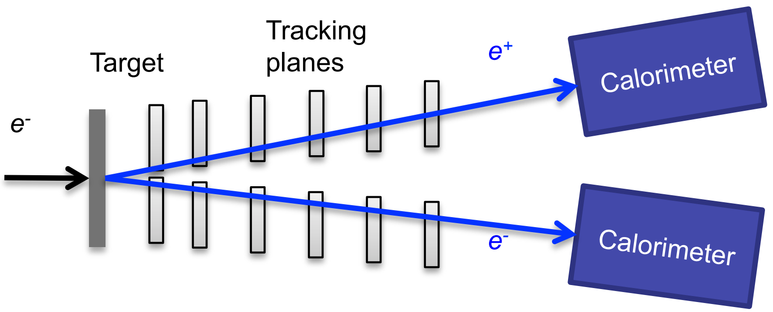
- Additional layer 5cm from target

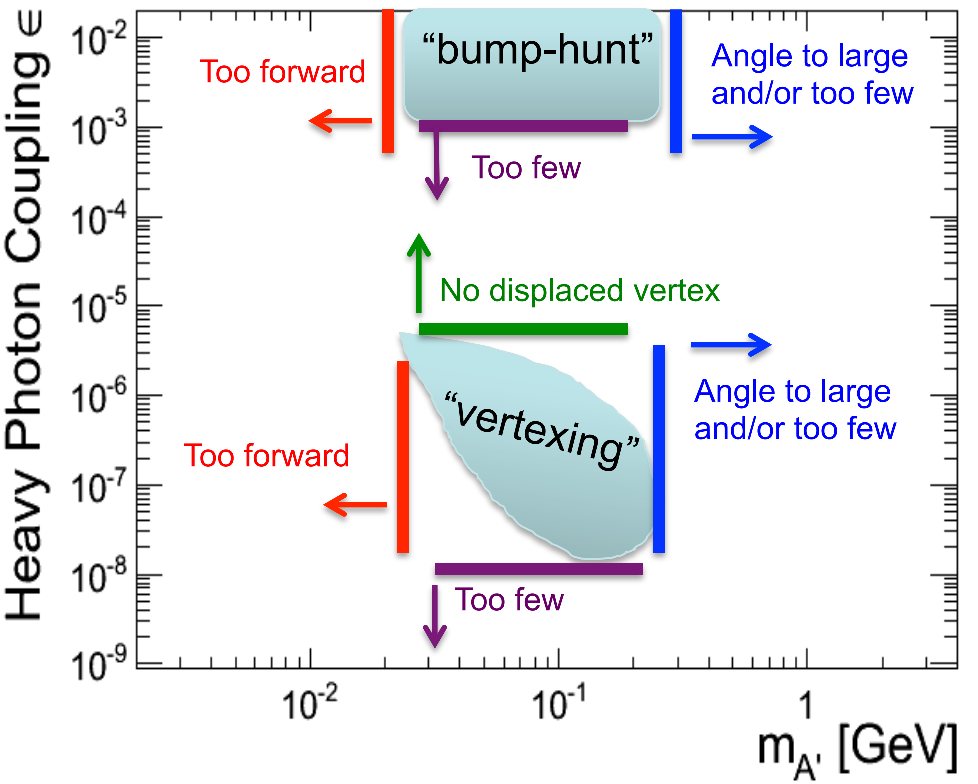


5σ Reach Full luminosity 1/3 Luminosity



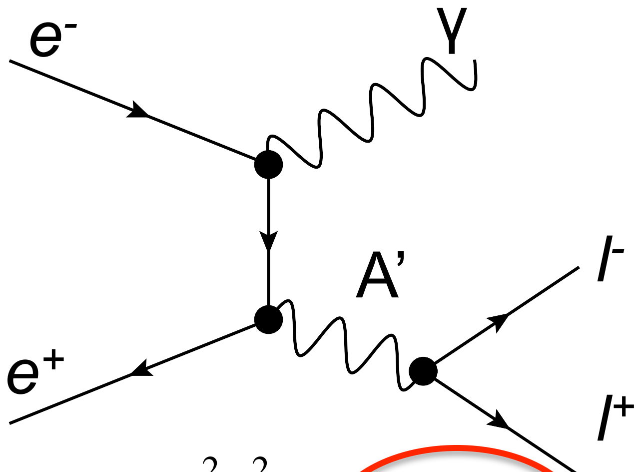
HPS Sensitivity





A' Direct Production

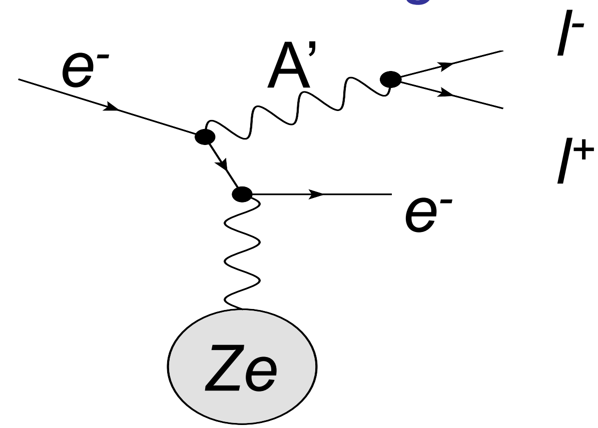
Collider



$$\sigma \sim \frac{\alpha^2 \varepsilon^2}{E_{e^-}^2} \sim O(10\,fb)$$

O(tens) *ab*$^{-1}$ per decade

Fixed Target

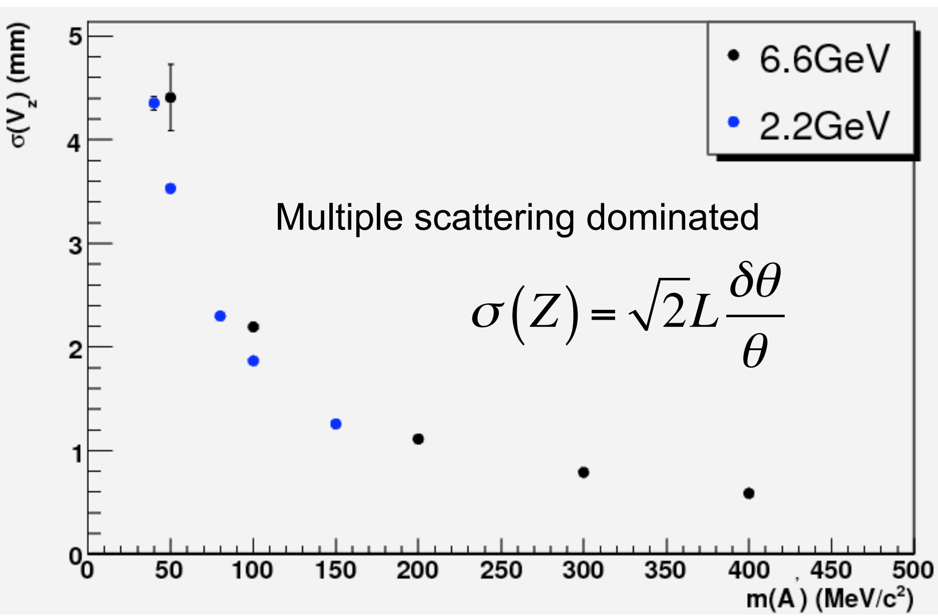


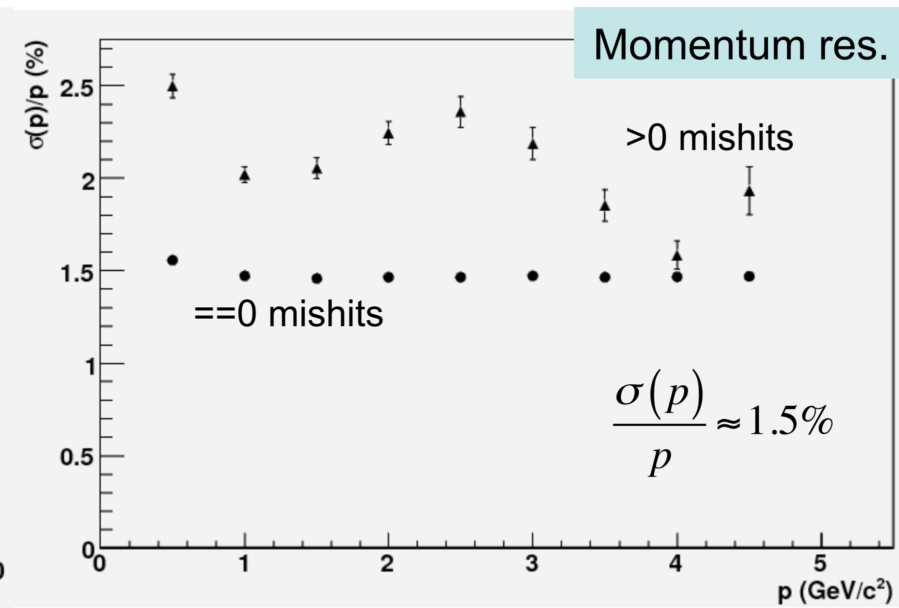
$$\sigma \sim \frac{\alpha^3 Z^2 \varepsilon^2}{m_{A'}^2} \sim O(10\,pb)$$

O(few) *ab*$^{-1}$ per **day**

- Fixed target is an ideal hunting ground

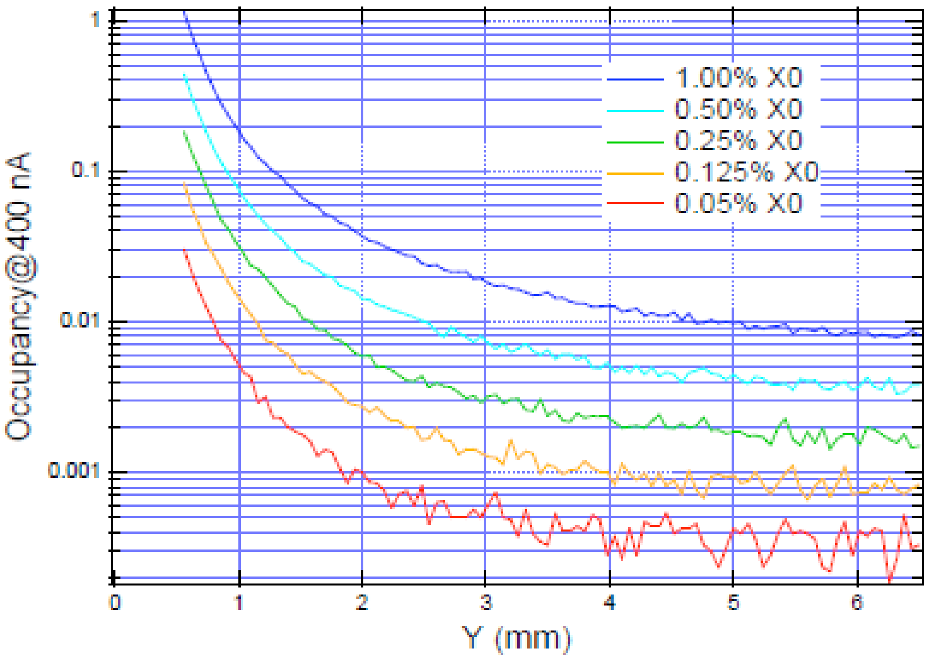
HPS Performance





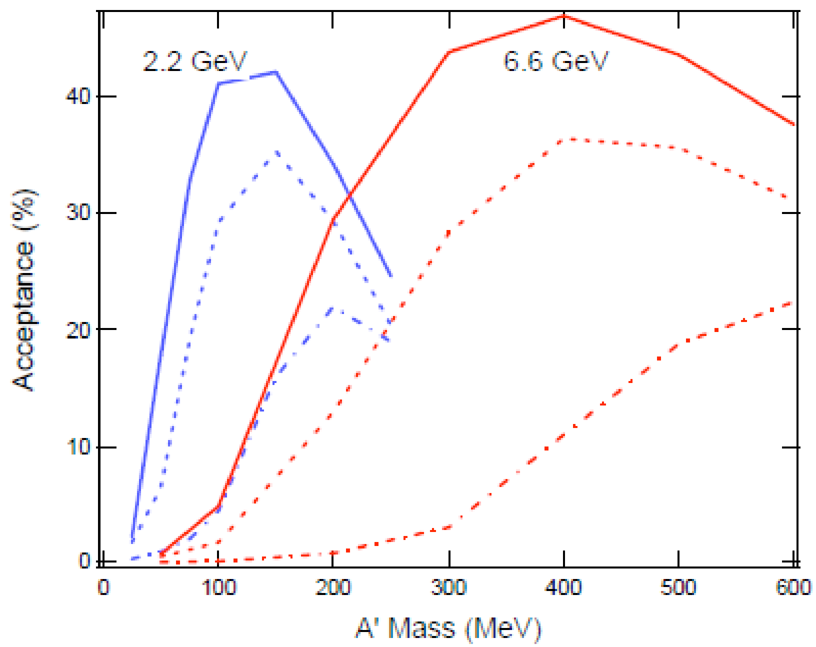
PATRAS2012/HPS Experiment
Chicago, 07/20/2012

HPS Performance



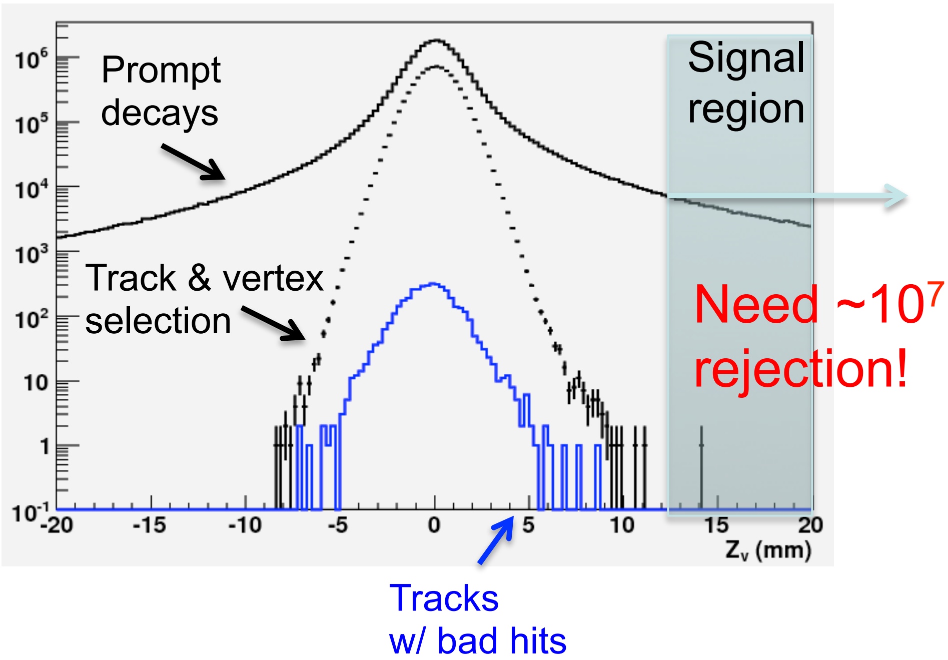
A' production scales like I_{beam}/thickness
Thinner target->less multiple scattering

Tracker acceptance
A' decay vertex at Z_v=0,10,20cm



HPS Performance

- Event selection
  - Track $\chi^2<20$
  - p(A')<Ebeam
  - $|V_x|<400\mu m$ and $|V_y|<400\mu m$
  - Cluster isolation in Layer 1 >500μm
  - Vertex $\chi^2<15$
- More elaborate selections possible



Trigger Rates

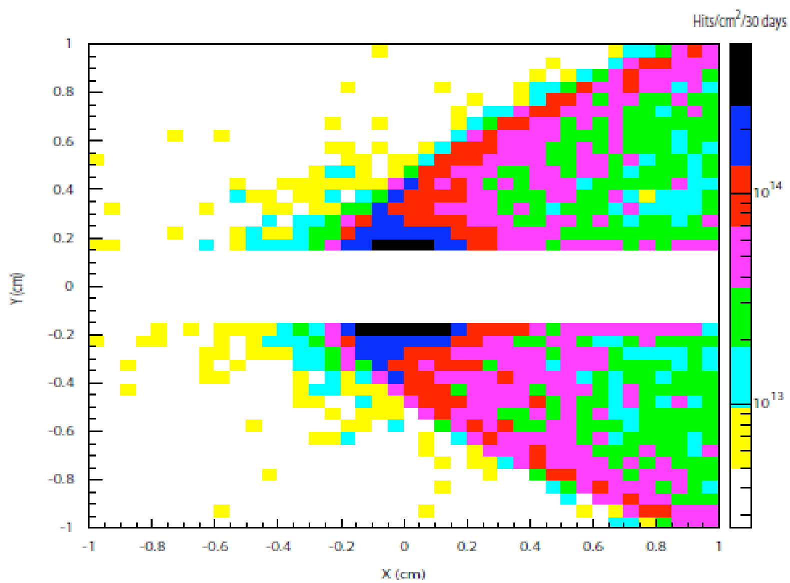
Trigger Cut.	200 MeV/c² A′ Acceptance	Background Acceptance	Background rate
Events with least two opposite clusters	42.35%	2.30%	2.9 MHz
Cluster energy > 500MeV and < 5 GeV	44.25%	0.123%	154 kHz
Energy sum <= E_{beam}*sampling fraction	44.25%	0.066%	82.5 kHz
Energy difference < 4 GeV	44.20%	0.062%	77.5 kHz
Lower energy - distance slope cut	43.46%	0.047%	58.8 kHz
Clusters coplanar to 40°	42.33%	0.0258%	32.3kHz
Not counting double triggers	38.58%	0.0210%	26.3 kHz

Table 5.1.3.1.Trigger selection cuts and their effect on the A' acceptance and background rate, as a percentage of the total number of simulated events. An A' mass of 200 MeV/c^2 was used for this illustration.

Trident	Estimated trigger rate
Coherent trident	
Bethe-Heitler	7.8 kHz
Radiative	130 Hz
Incoherent trident	180 Hz

Radiation Hardness

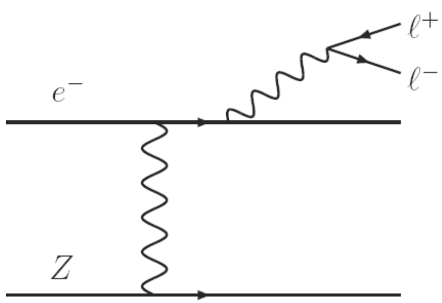
- Radiation hardness set absolute constraints on dead zone
- Sensors fully depleted to about 1×10^{14} 1MeV n.eq. at 1kV
  - With bulk damage by low E (<10GeV) electrons -> 3×10^{15} electrons
  - Sufficient for >3 months running
- Design will allow for replacement of layers



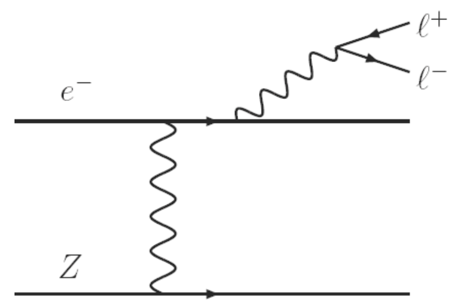
Radiative Background

- Radiative background kinematics identical to A' signal

Brehmsstrahl. A' production



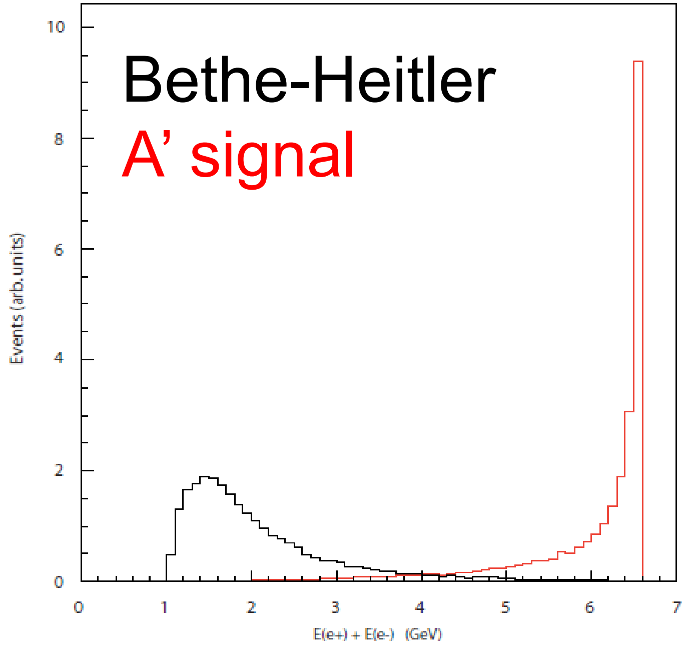
"radiative" trident background

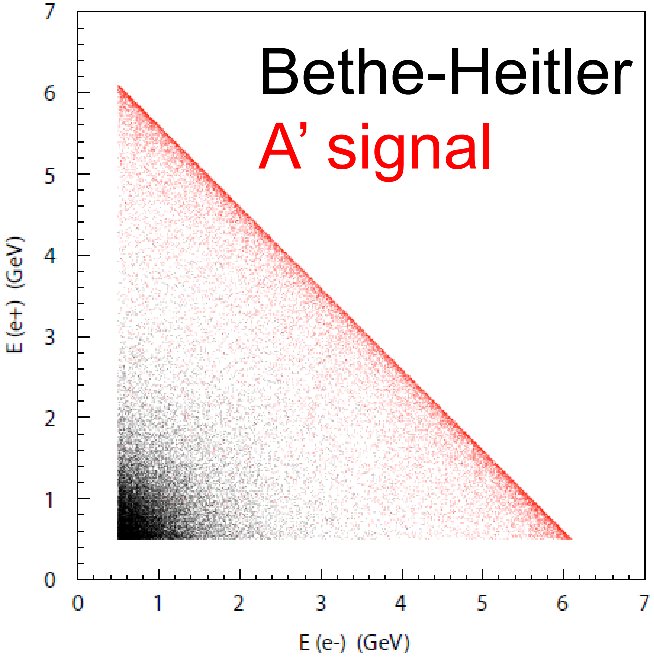


Relation between A' and radiative cross sections

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

QED Trident Background

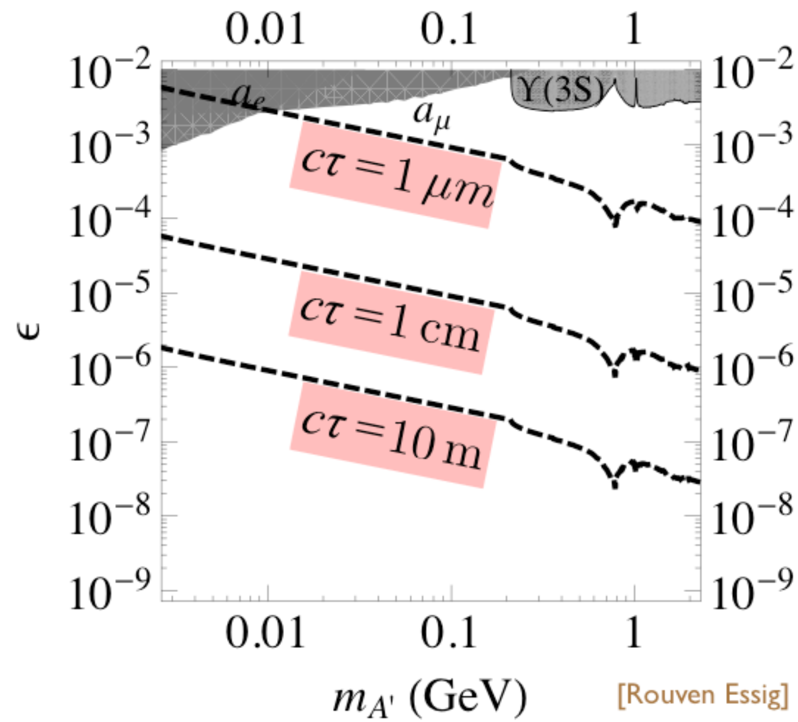




Lifetime & cross section

$$\sigma_{A'} \sim 100\,pb \left(\frac{\varepsilon}{10^{-4}}\right)^2 \left(\frac{100\,MeV}{m_{A'}}\right)^2$$

$$\gamma c\tau \sim 1mm \left(\frac{\gamma}{10}\right) \left(\frac{10^{-4}}{\varepsilon}\right)^2 \left(\frac{100\,MeV}{m_{A'}}\right)$$



Muon Detector

- Conceptual design
  - ~2m from target
  - Iron absorbers: 30cm+3x15cm
  - Four segmented hodoscopes,1.5cm thick