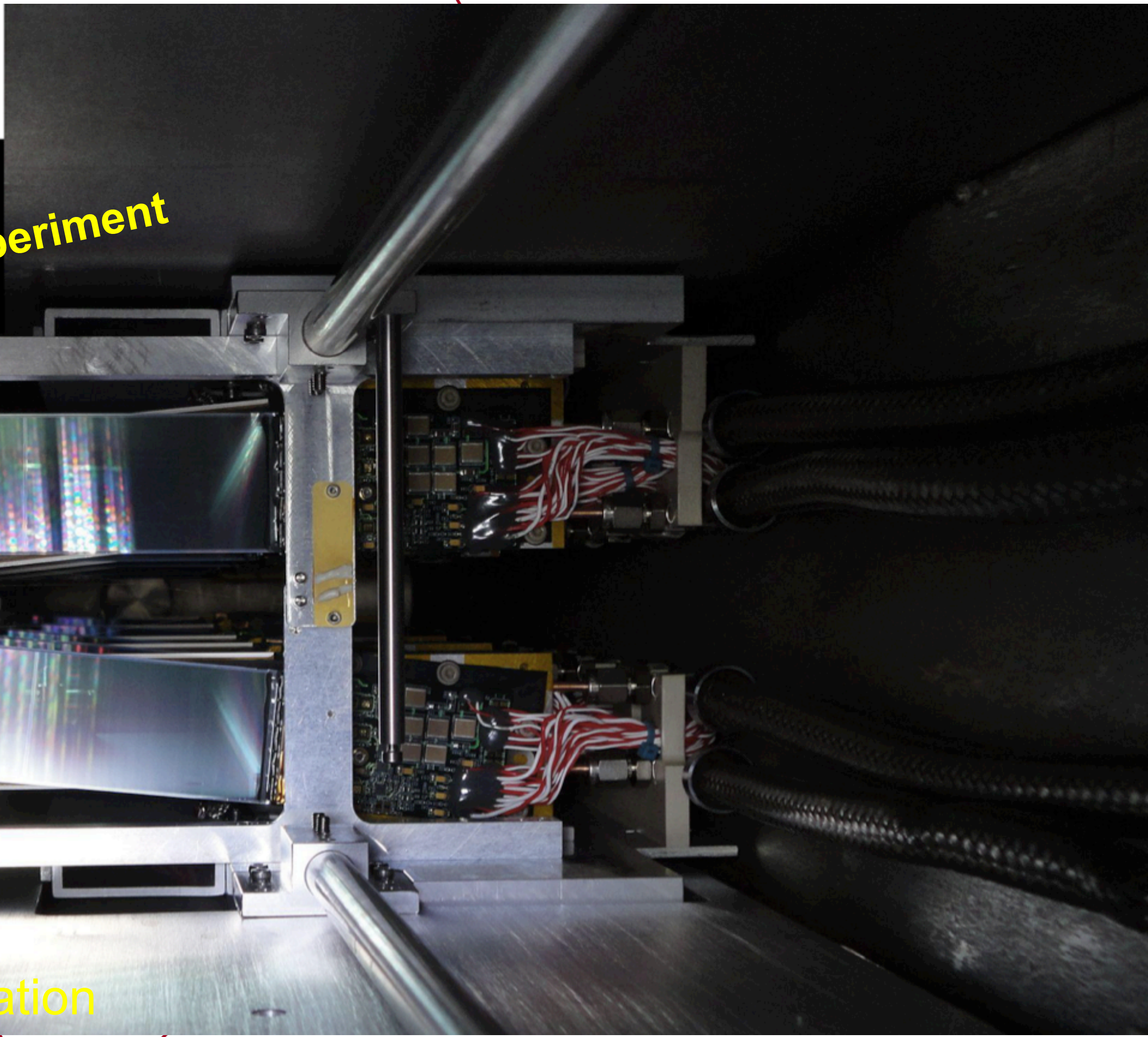


Heavy Photon Search Experiment

Per Hansson Adrian
on behalf of the HPS Collaboration

U.S. Department of Energy Office of Science

UCLA Dark Matter 2014

SLAC National Accelerator Laboratory

Hidden Sectors and Heavy Photons

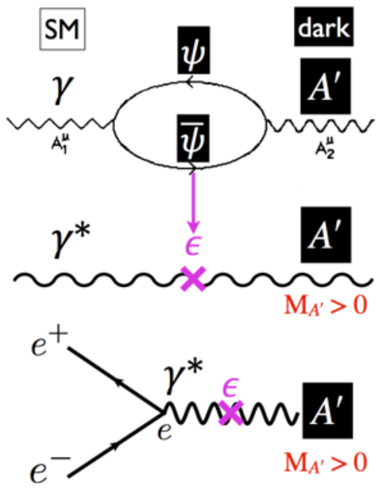
Dark matter can be a part of a hidden sector

The heavy photon/dark photon/A’ is the U(1) equivalent of the SM photons

- Couples to analogue of electric charge – *dark charge*

Hidden sectors would interact with ordinary matter through gravity and one or more “portals”

- E.g. vector portal: kinematic mixing with SM photon



⇒ Electrically charge matter have a small coupling to heavy photons

Coupling suppressed w.r.t. EM coupling by ε

$$\epsilon \sim 10^{-4} - 10^{-2}$$

$$\epsilon \sim 10^{-5} - 10^{-3}$$

Natural mass term?

$$m_{A'} \sim \sqrt{\epsilon}\, m_Z \approx \mathrm{MeV} - \mathrm{GeV}$$

Limits on Heavy Photons

Parameter space of particular interest

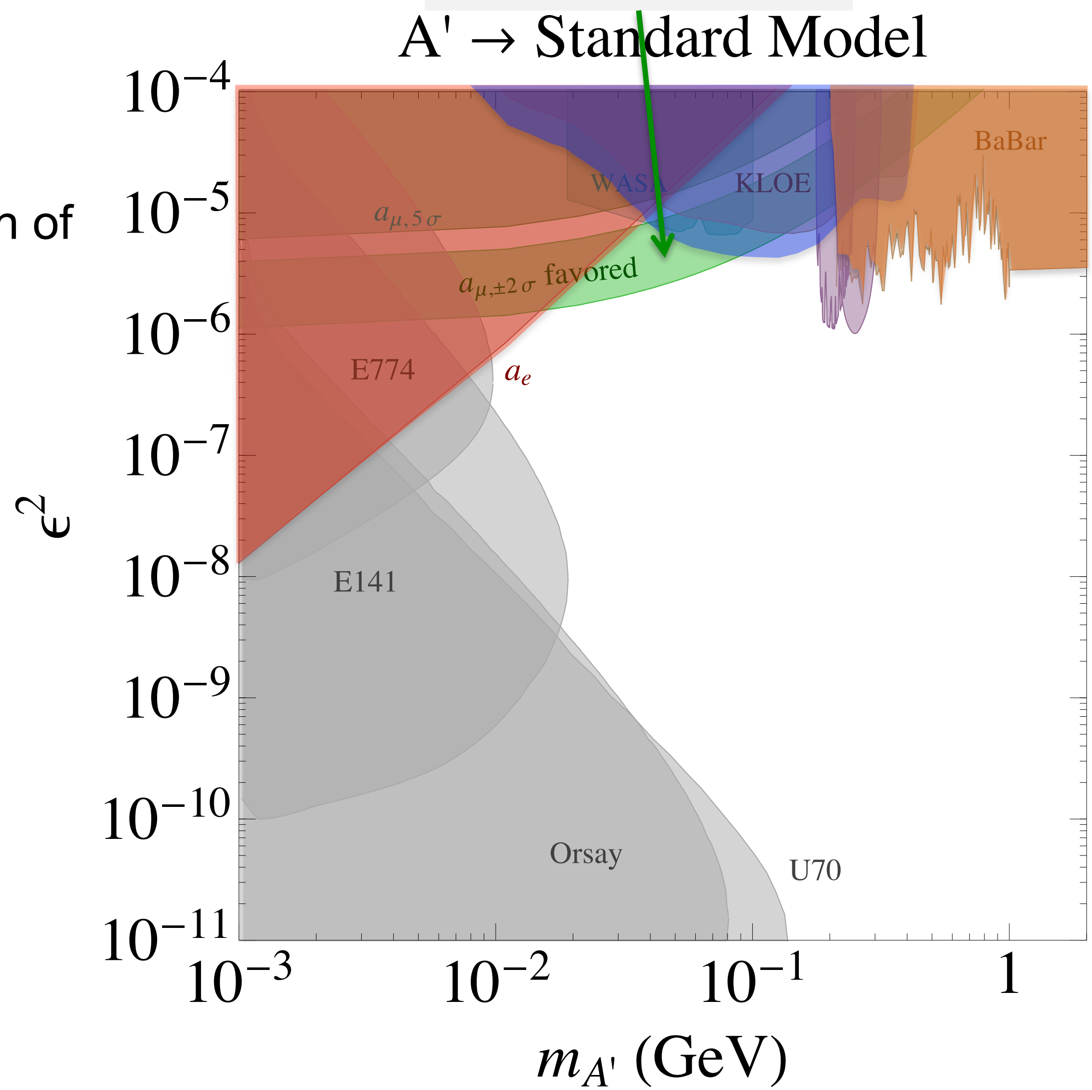
⇒ Hidden sector Dark Matter annihilation valid over much of this space

Constraints from QED precision tests (e^-/μ^- g-2)

Direct production at colliders

(Rare) decays (K,ϕ,π^0,η)

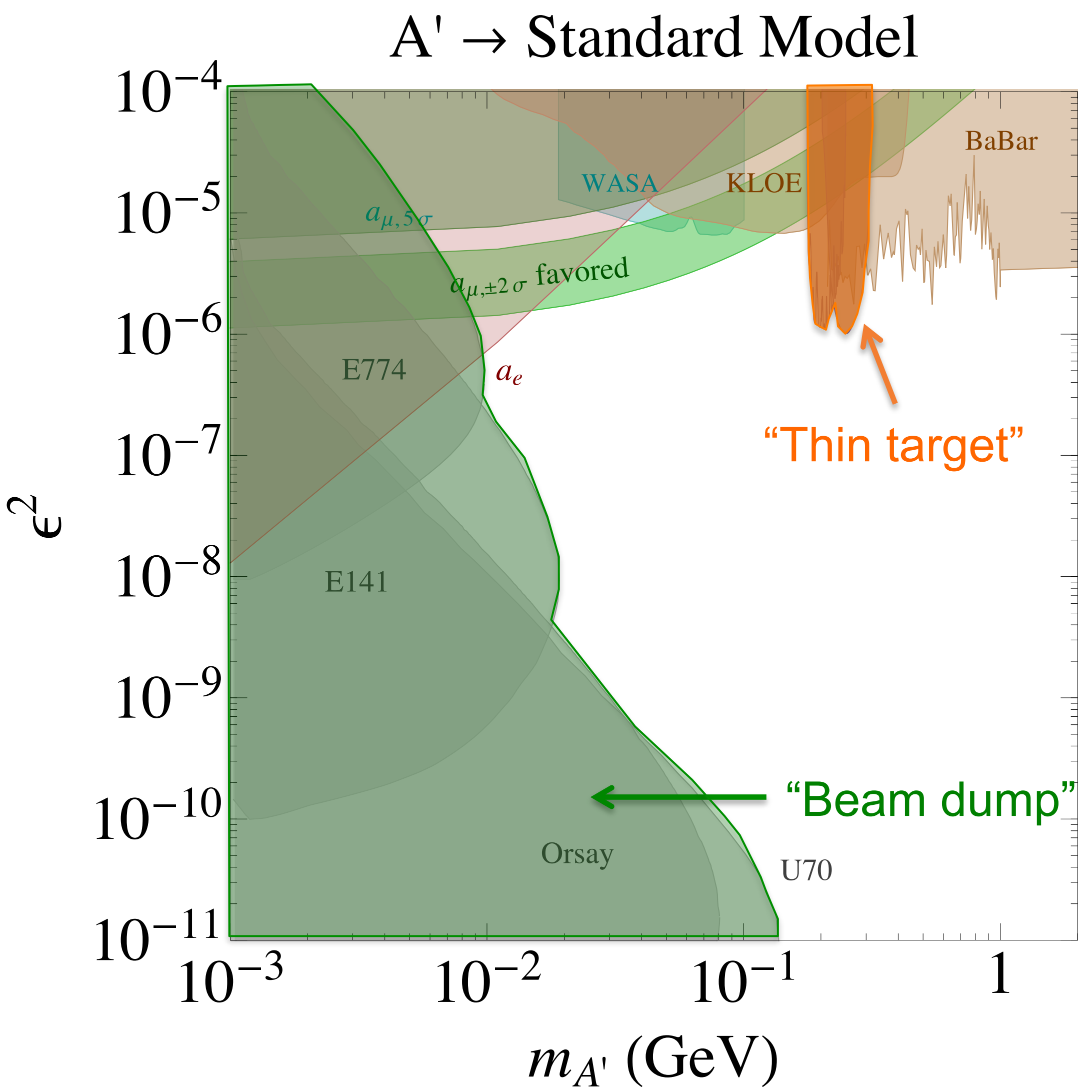
g_μ-2 explained by heavy photon



Heavy Photon Search

Fixed-Target Experiments

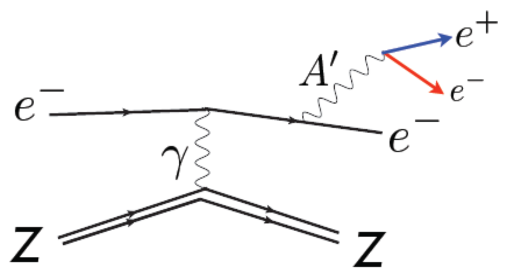
Focus here on fixed target experiments

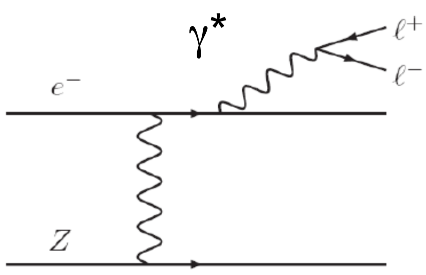


Fixed Target Electro-Production Signatures

Resonance bump

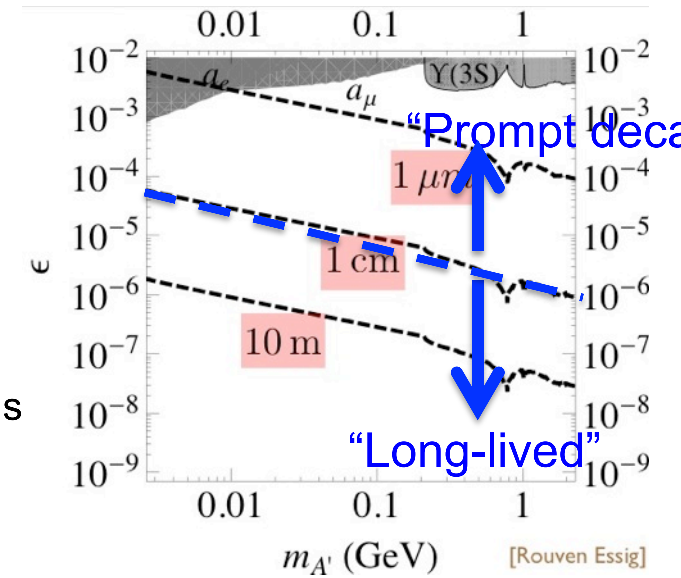
- Heavy photon appears as narrow e^+e^- resonance on a copious QED “trident” background





Long life-time: displaced decay vertex

- Heavy photons with mass MeV-GeV may have decay lengths from um’s to 10’s of m’s for appropriate couplings
- Distinct signature – smaller backgrounds



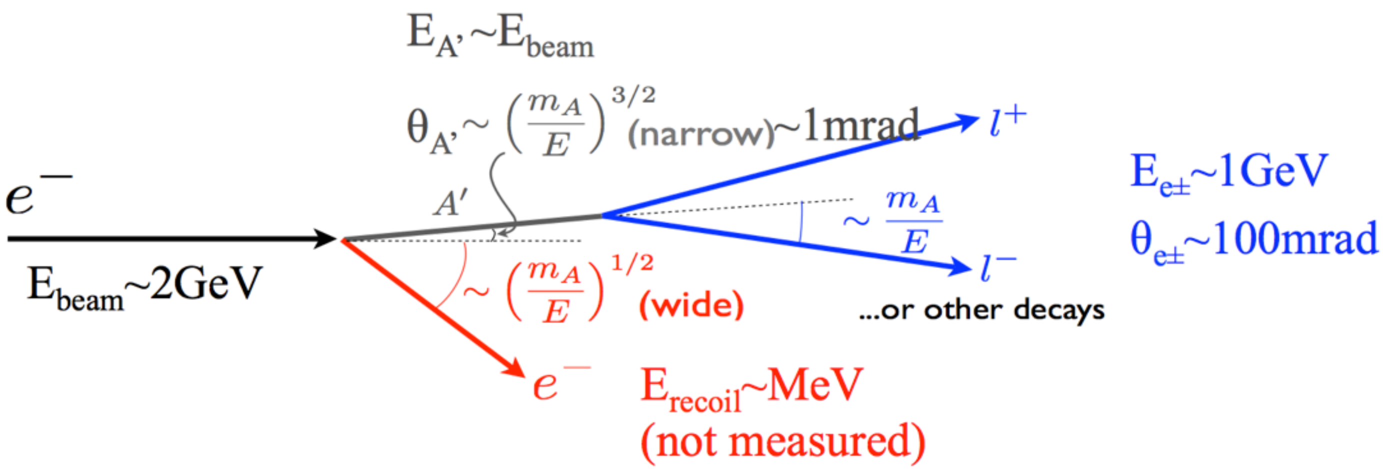
Small signal and large backgrounds

- Intense beams, fast detectors and high rate data acquisition
- Intensity frontier physics!

Fixed Target Heavy Photon Kinematics

Cross-section peaks at incident electron energy
(contrast with 1/k for bremsstrahlung)

$m_{A'}$~300MeV



Key experimental features
⇒ A' carries most of the beam energy and appears ~ along beam line
⇒ Recoil electron not measured for signal events (in most experiments)
⇒ A' decay products may appear close to the beam ~$m_{A'}$
⇒ Possibly a displaced vertex

Beam-dump Experiments

Beam dump produces EM shower
(e^+ and e^- radiate A')

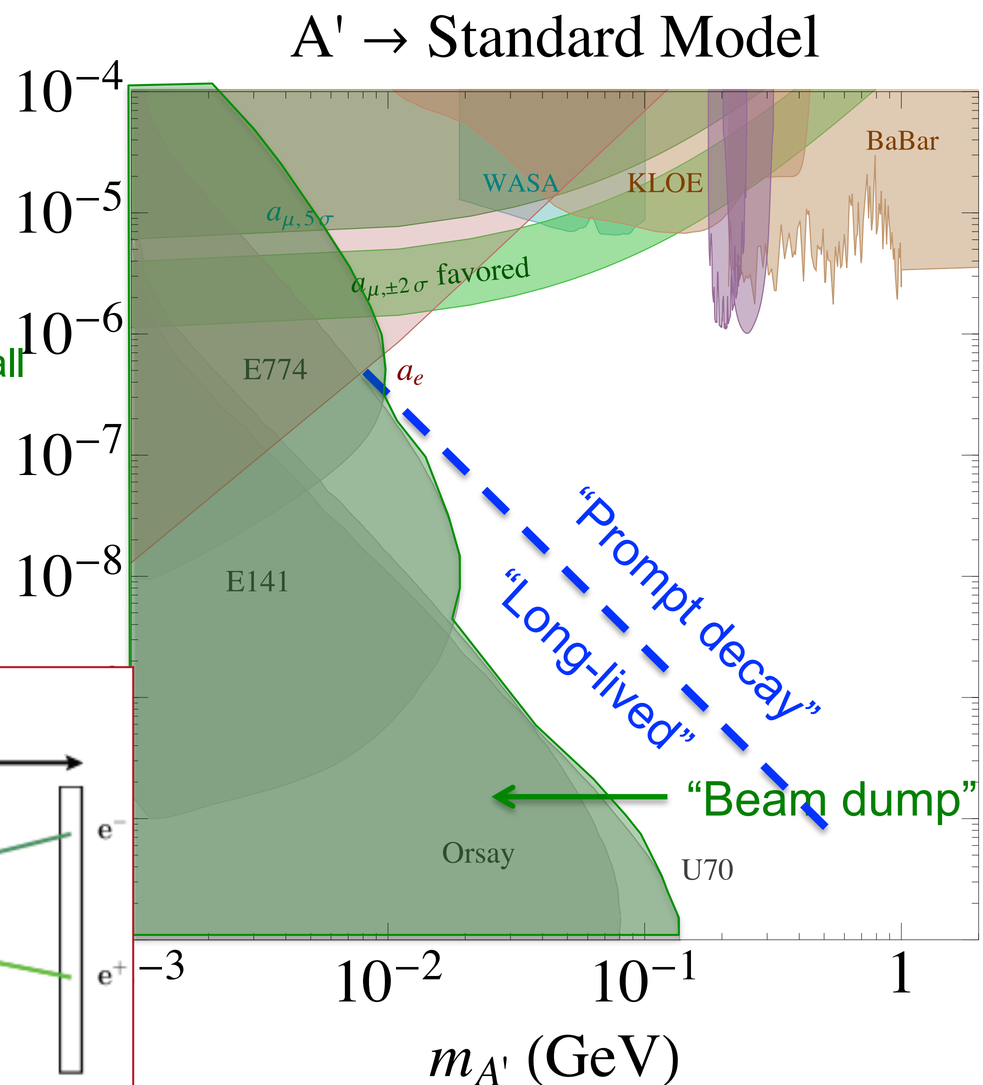
A' with long life-time can escape dump and decay near detector

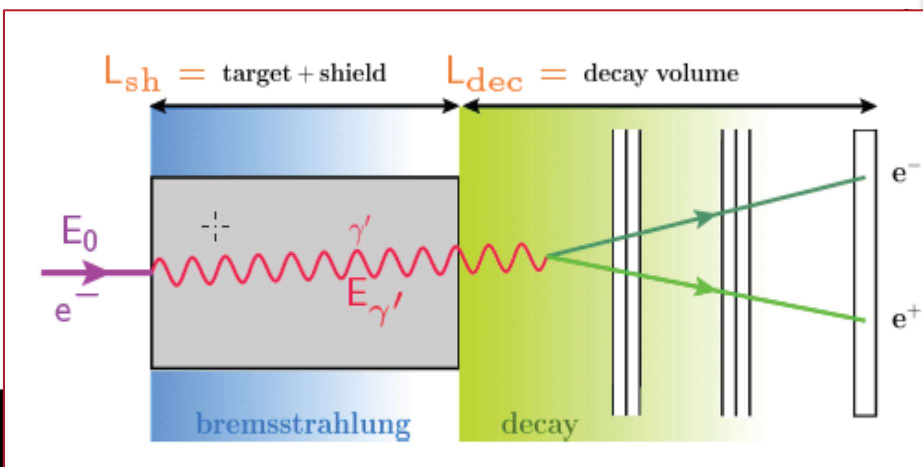
⇒ High luminosity, access to low couplings

⇒ Small acceptance, sensitivity to small $m_{A'}$

Previous beam dump experiments reinterpreted

S. Andreas DARK2012





Thin Fixed Target Experiments

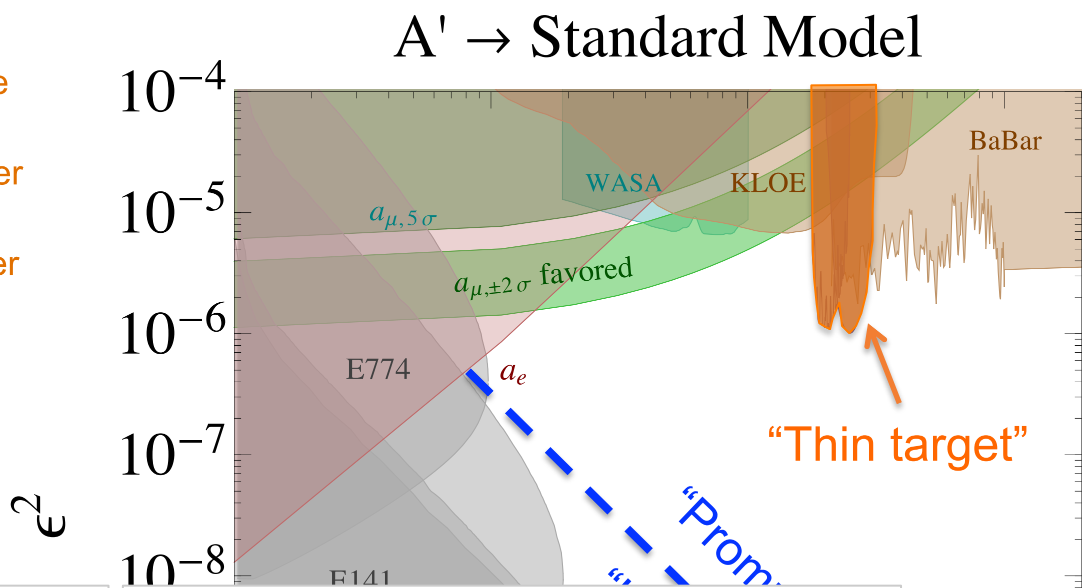
A' radiated of beam electron in thin target

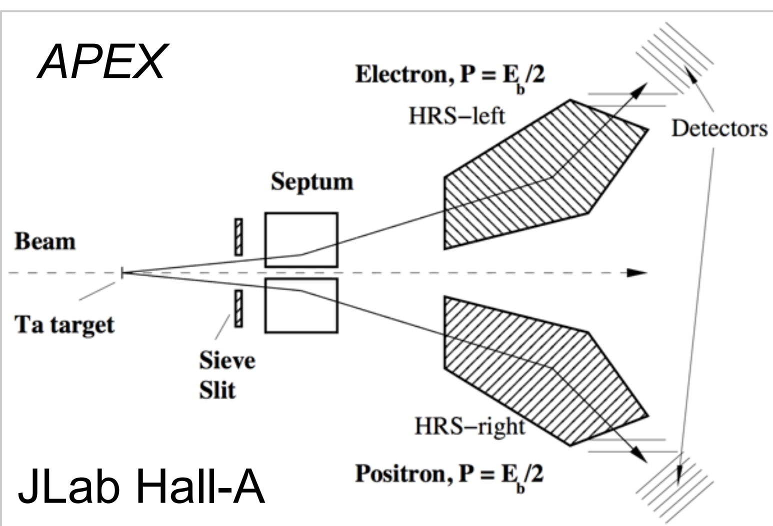
A' appear as narrow resonance on large background

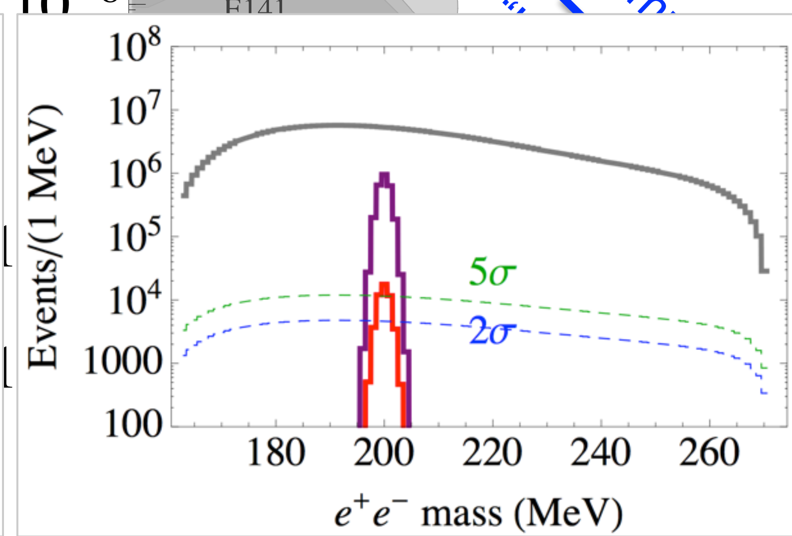
- ⇒ No decay in shield: access to higher couplings
- ⇒ Better acceptance: access to higher mass

Bump-hunt analysis: mass resolution matters

- ⇒ Typically background/rate limited
- ⇒ Small acceptance

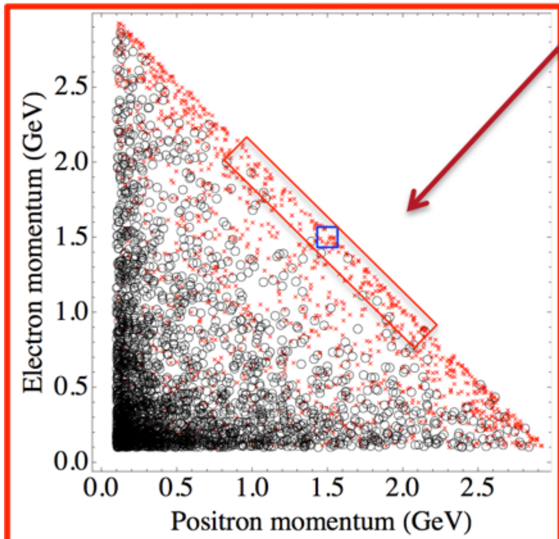




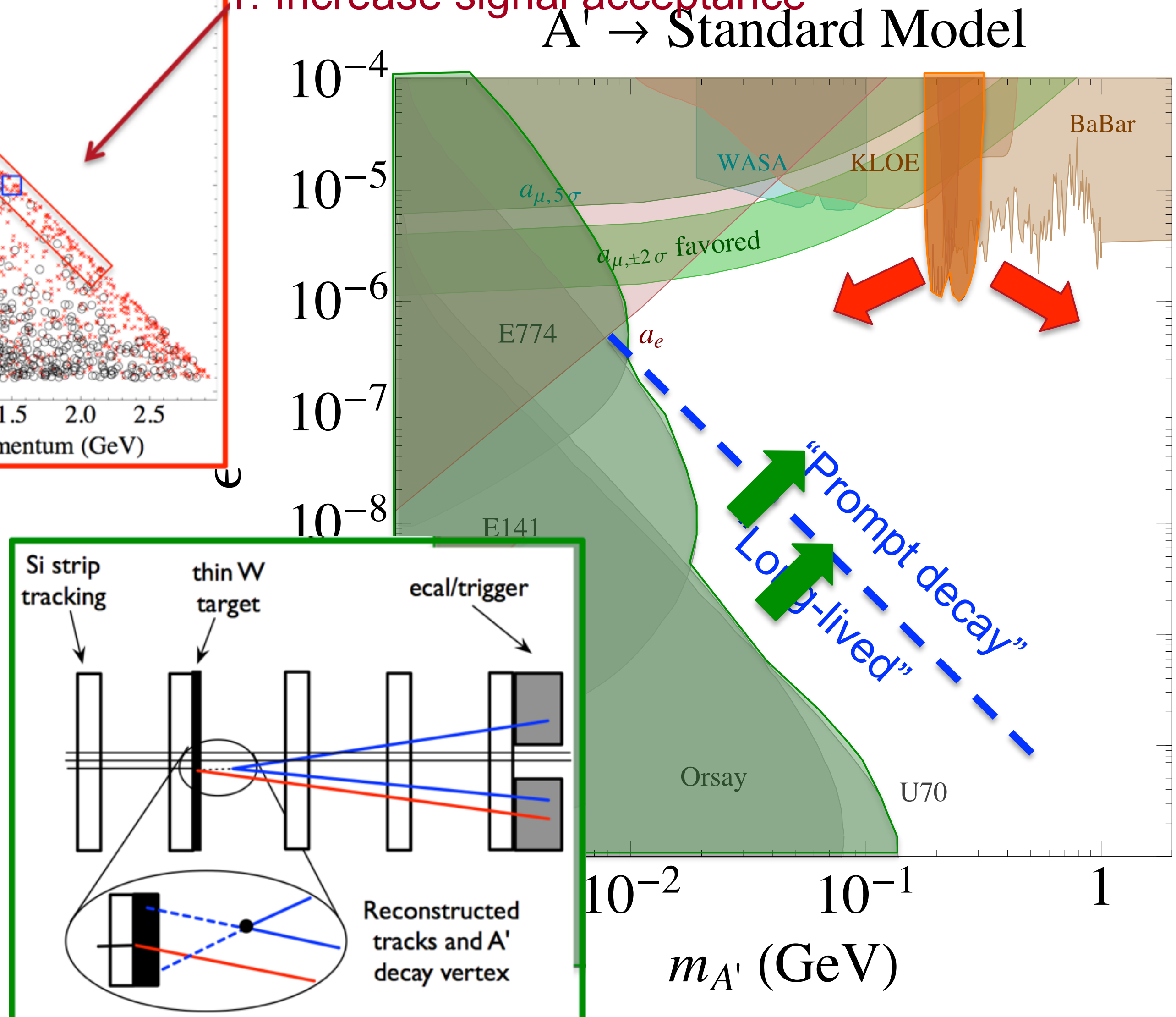


Fixed Target Experiments: how can we improve?

SLAC



1. Increase signal acceptance



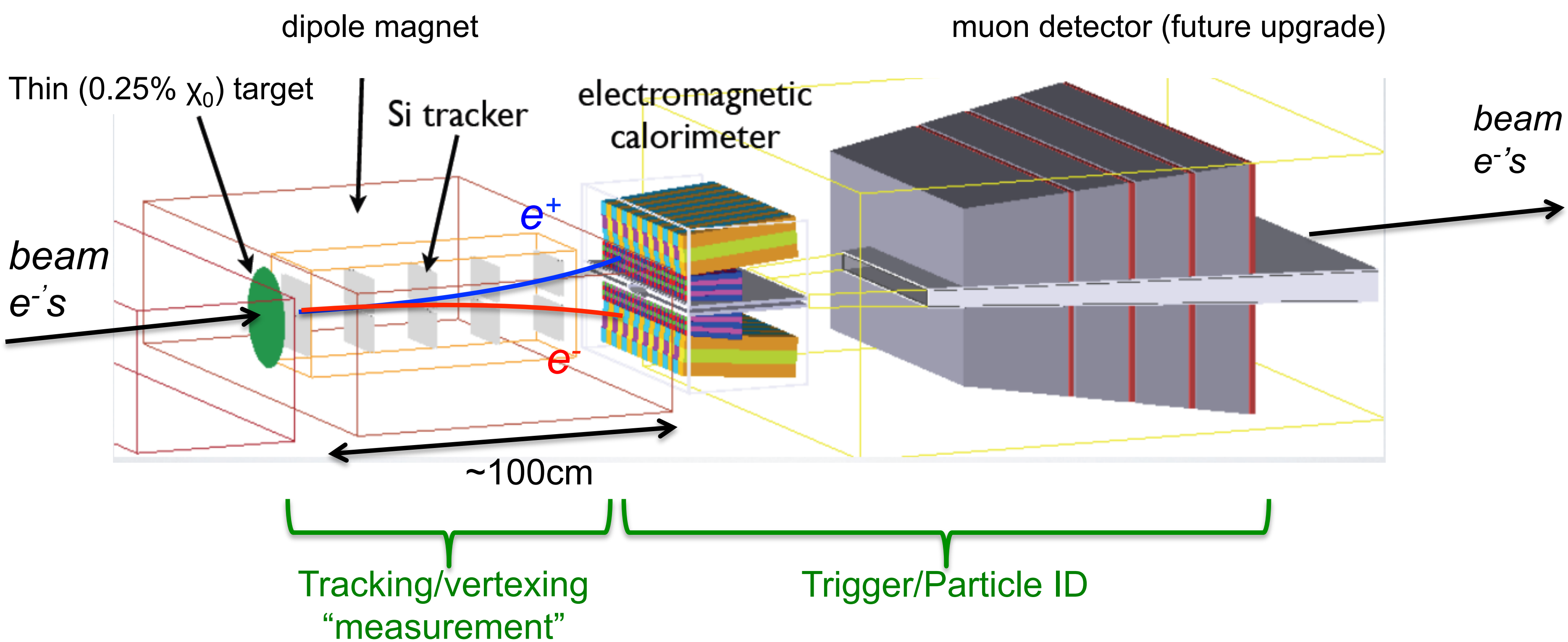
2. Reconstruct A' decay vertex to beat down background

Heavy Photon Search

The Heavy Photon Search Experiment (HPS)

Conceptual design

⇒ Determine invariant mass of heavy photon decay products
⇒ Discriminate between prompt and non-prompt decays



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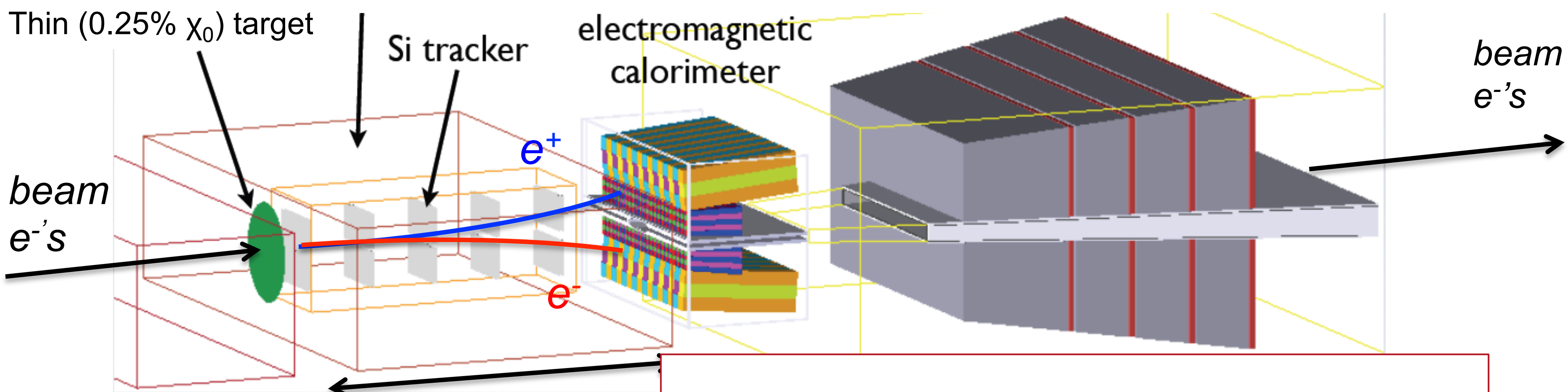
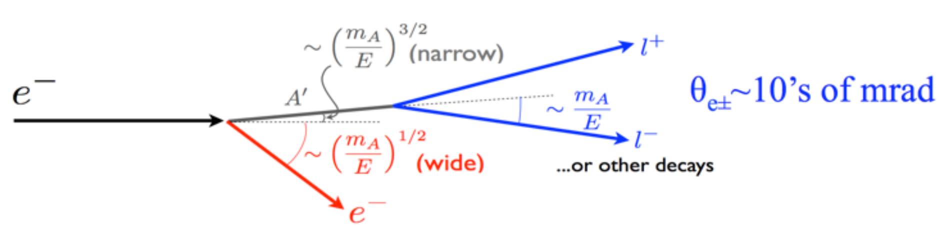


Tracking/vertexing “measurement”



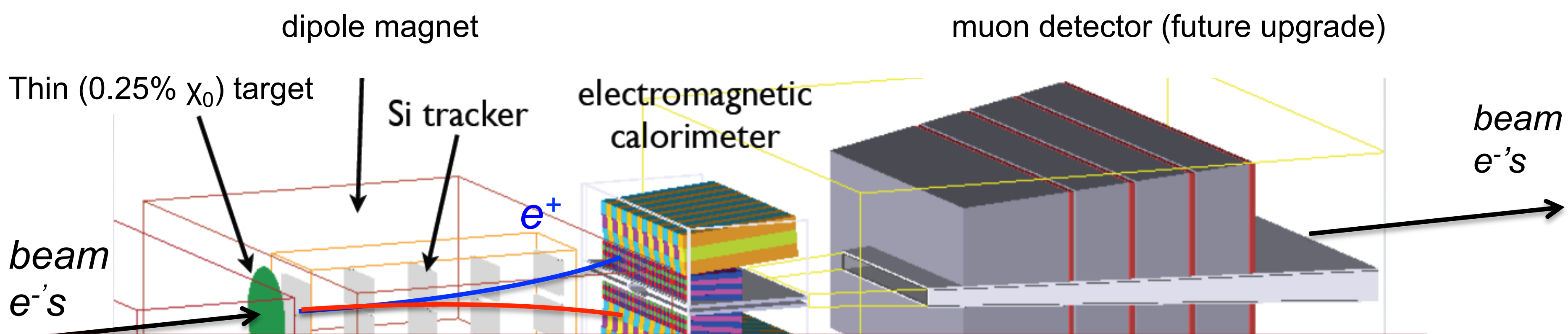
➔Need acceptance close to target and beam…

The Heavy Photon Search Experiment (HPS)

SLAC

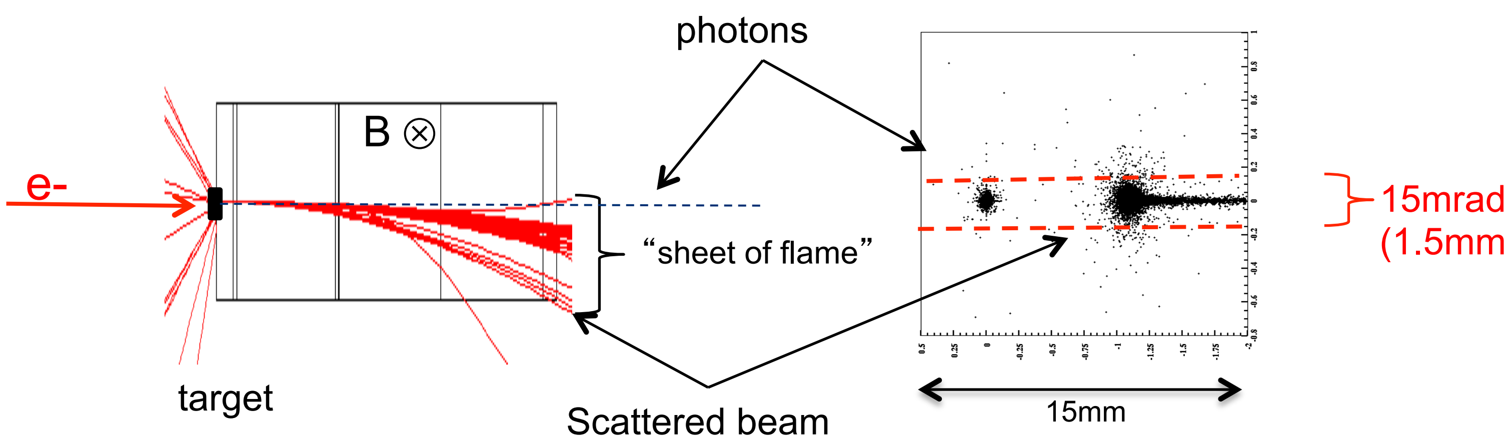
Conceptual design

⇒ Determine invariant mass of heavy photon decay products
⇒ Discriminate between prompt and non-prompt decays



View from top

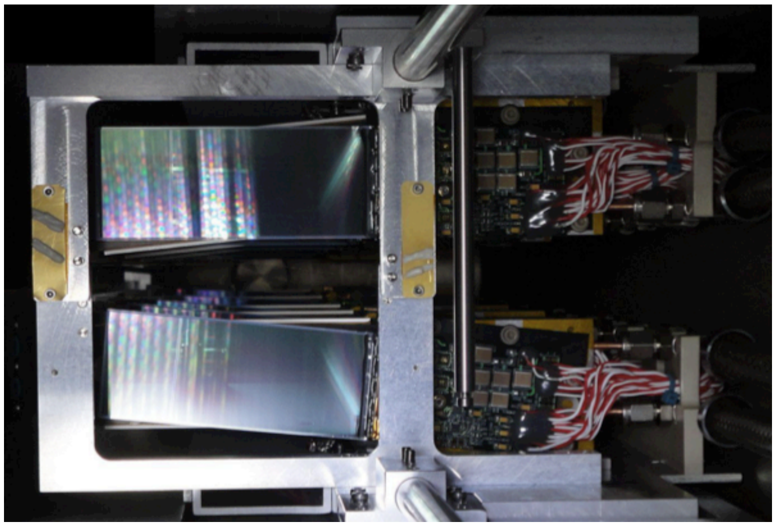
Beam's eye view



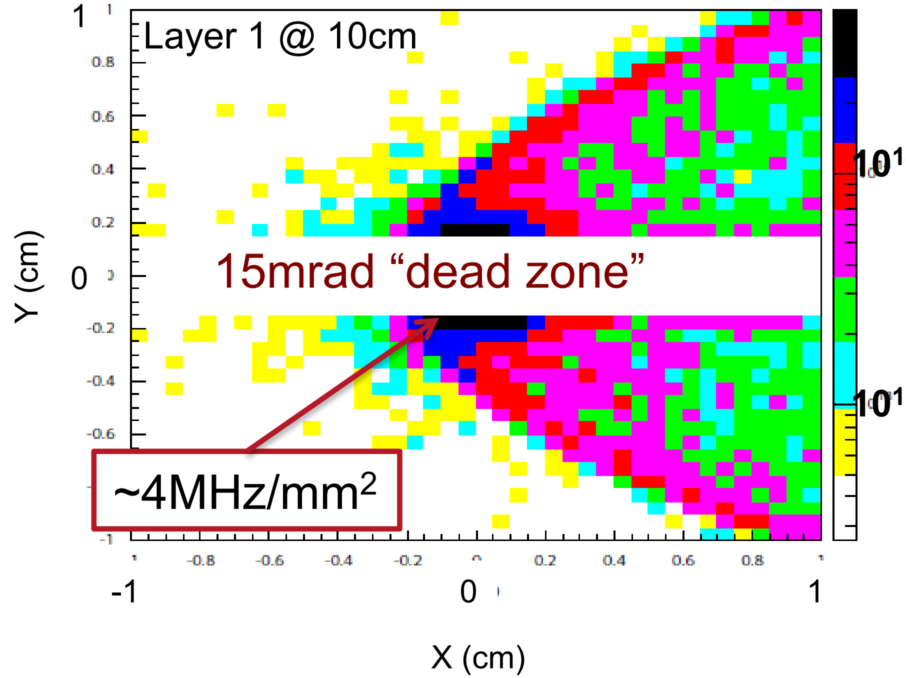
Beam Backgrounds Dominate Occupancy

SLAC

Split detector in two halves



Beam's eye view



Additional handles

- High current, thin target to minimize scattered beam
- Operate in vacuum to eliminate beam-gas interactions
- Spread out background in time -> continuous beam
- Fast detectors able to time stamp hits belonging to signal e^+e^- events

HEAVY PHOTON SEARCH

High-current Electron Beam

CEBAF at Jefferson Lab is ideal for HPS!

Delivering DC beam to multiple halls

- 500MHz, 100% duty factor
- Currents up to 500nA (Hall B) or 100uA (Hall A&C)

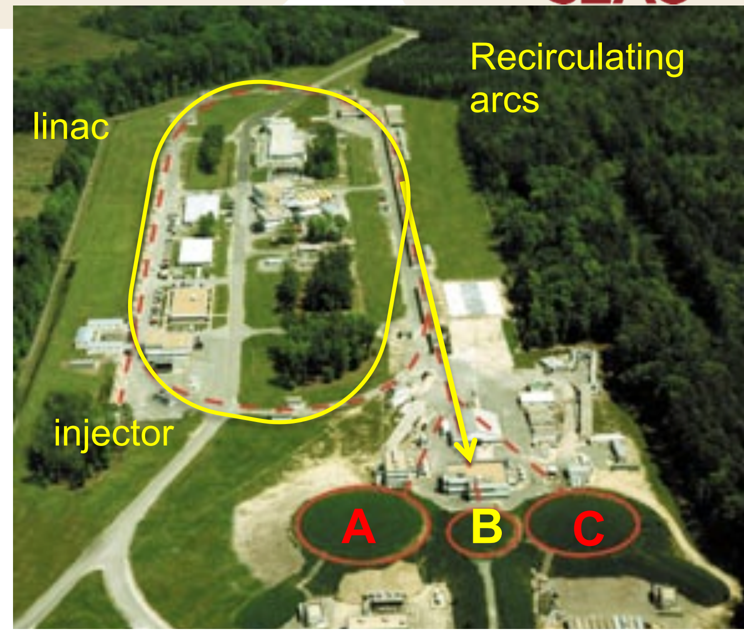
Excellent beam quality & stability

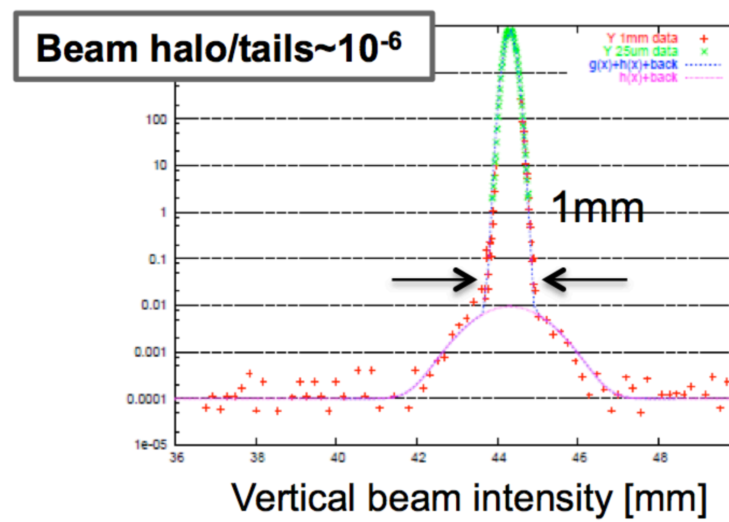
- Small beam spot size, <30μm, for HPS
  (helps vertexing and resonance search)

Configurable beam energy

- HPS: 2.2, 6.6GeV (11GeV max)
- Lower (1.1GeV) with special dedicated runs

12GeV upgrade project finish this year– HPS will be one of the first experiments to run

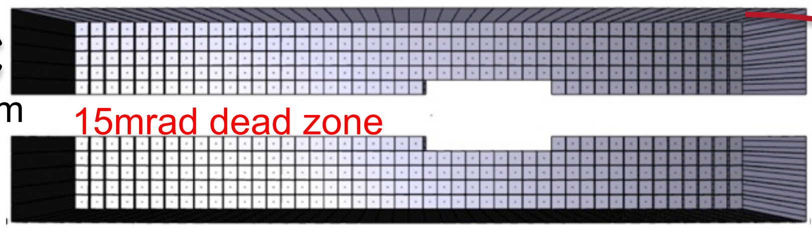


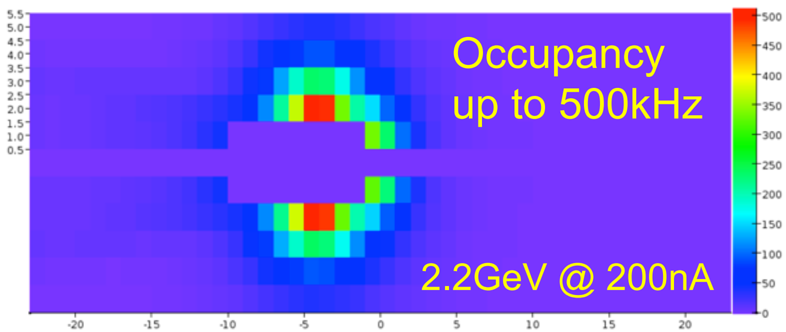


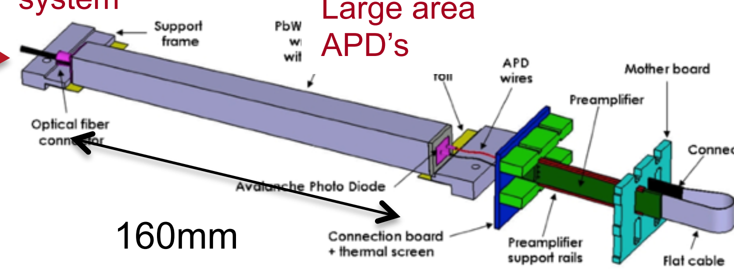
Fast Calorimeter Trigger

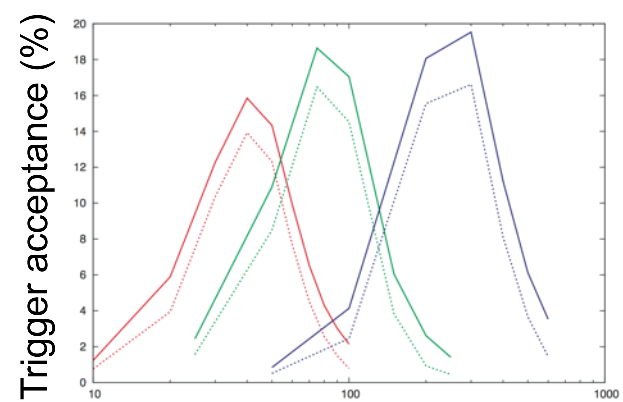
PbWO4 crystals with APD readout good match for HPS

⇒ Fast, readily available (JLab CLAS IC), radiation tolerant









- Split in two halves
- Fast readout: virtually no dead time
- Trigger time resolution: 8ns
- Acceptance matched to tracker

Silicon Vertex Tracker Layout

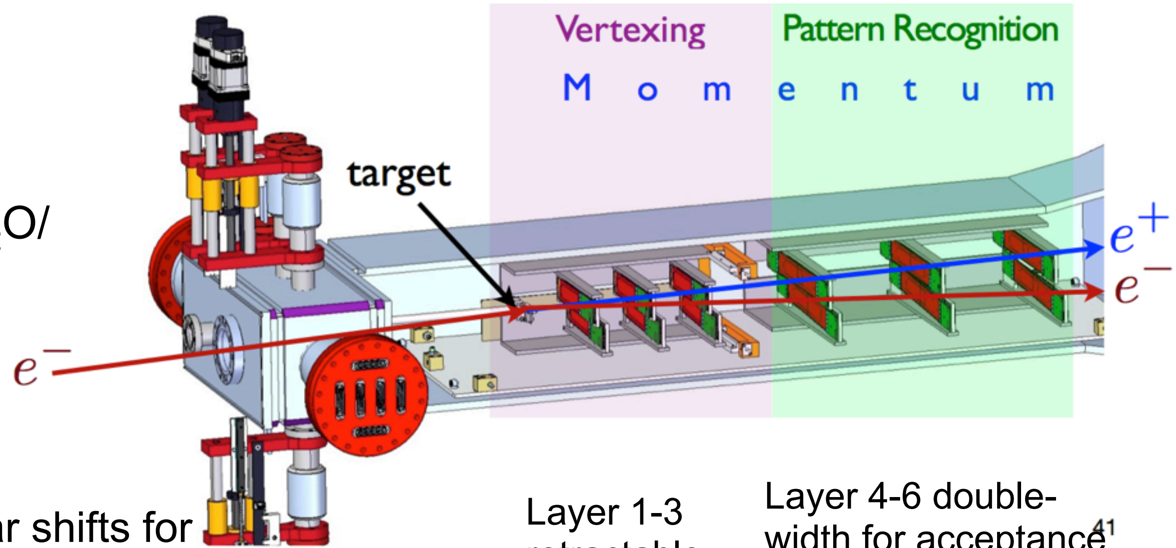
Measures momentum and vertex position

- Small angle stereo-pairs (Si micro-strip sensors)
- Fit inside existing dipole magnet
- Optimized for low mass; multiple scattering dominates measurement

Layers	1-3	4-6
z position [cm]	10,20,30	50,70,90
Stereo angle [mrad]	100	50
Non-bend res. [um]	≈6	≈6
Stereo res. [μm]	≈60	≈120
Dead Zone [mm]	1.5-4.5	7.5-13.5

Split in two halves

- Motion system
- Cooled support structure (H_2O/ glycol ~ -20C)
- Operates in vacuum!



Linear shifts for motion control

Layer 1-3 retractable

Layer 4-6 double-width for acceptance

Silicon Vertex Tracker Modules

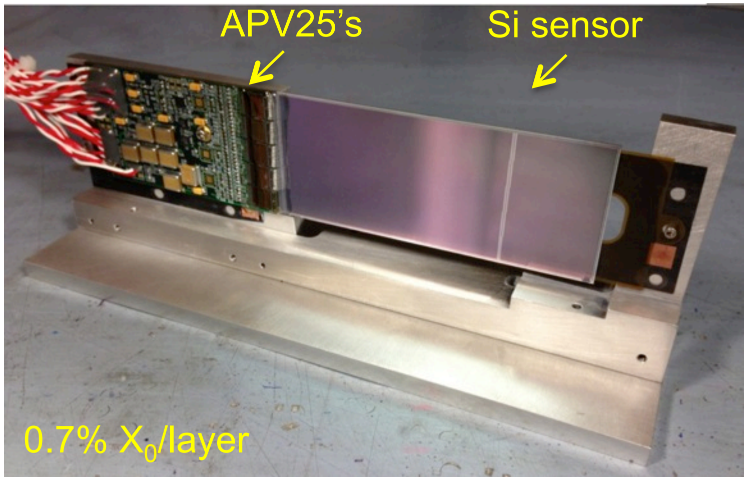
Radiation hard D0 RunIIb sensors

- High readout granularity (60μm readout pitch)
- Low mass support: tension CF between cooled uprights

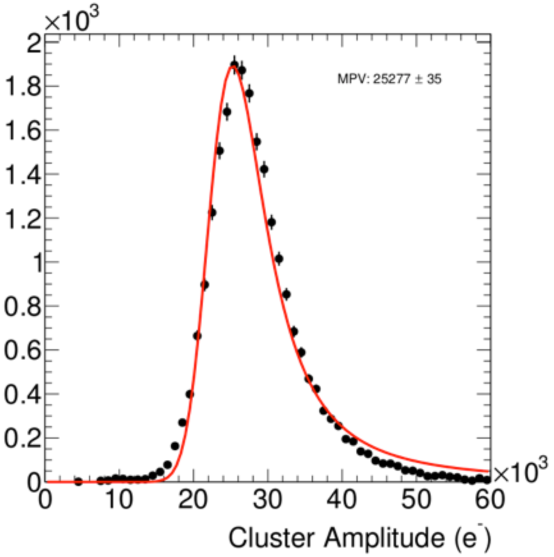
Readout using APV25 ASIC (CMS@LHC)

- Fast: 40MHz sampling, short (35ns) shaping time
- Six sample readout allows time reconstruction

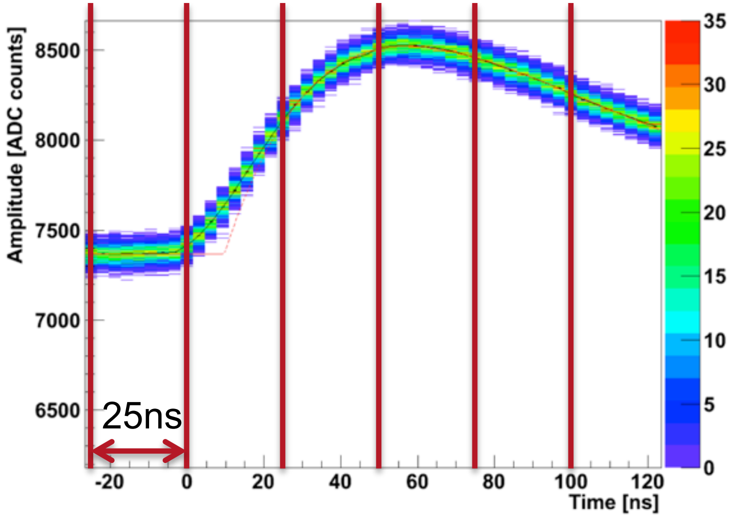
Key performance parameters proven in Test run



S/N>25

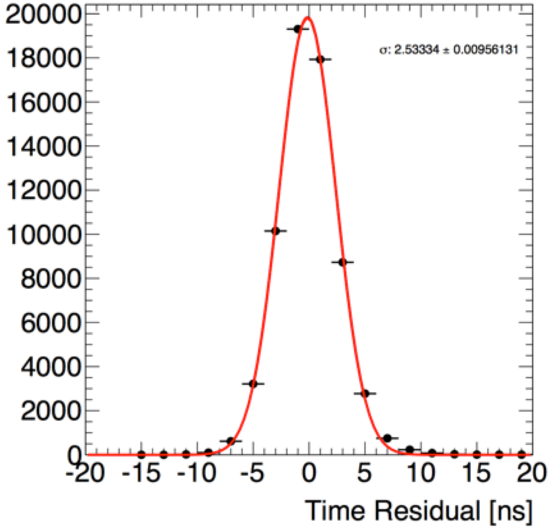


40MHz, 6-sample readout



Fit CR-RC pulse shape to determine t_0

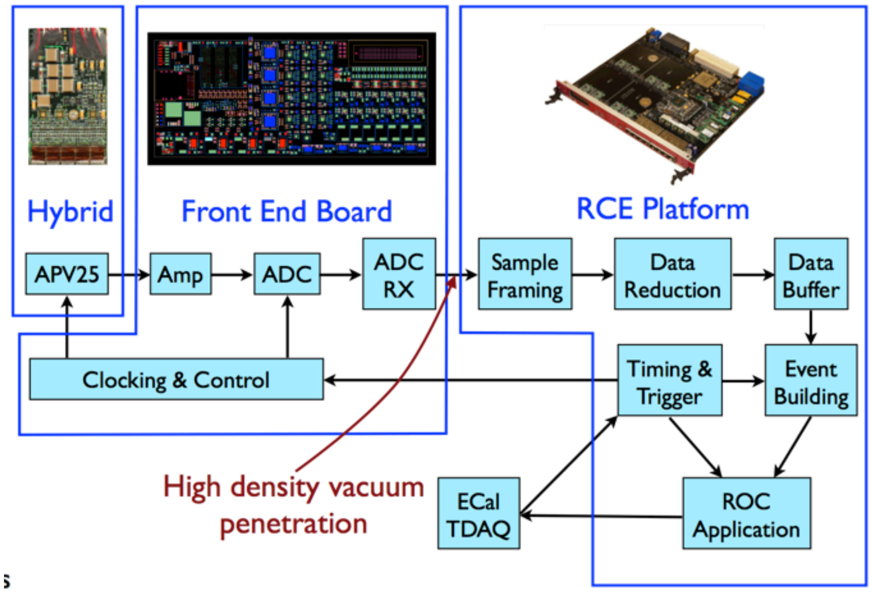
<2.5ns time resolution



High Rate Data Acquisition

Tracker DAQ

- SLAC-developed generic RCE platform (ATCA)
- In-vacuum ADC, voltage regulation and power distribution
- Optical conversion
- 50kHz trigger rate and 100MB/s



ECal Trigger and DAQ

- Crystals readout by 250MHz FADC
- 8ns e^+e^- coincidence time resolution
- Tested to above 50kHz at HPS occupancies

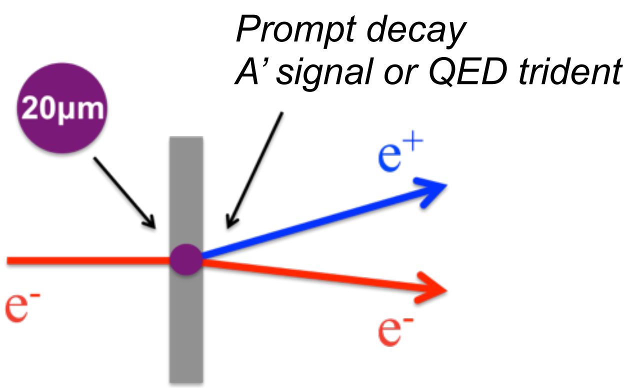
JLab 250MHz Flash ADC

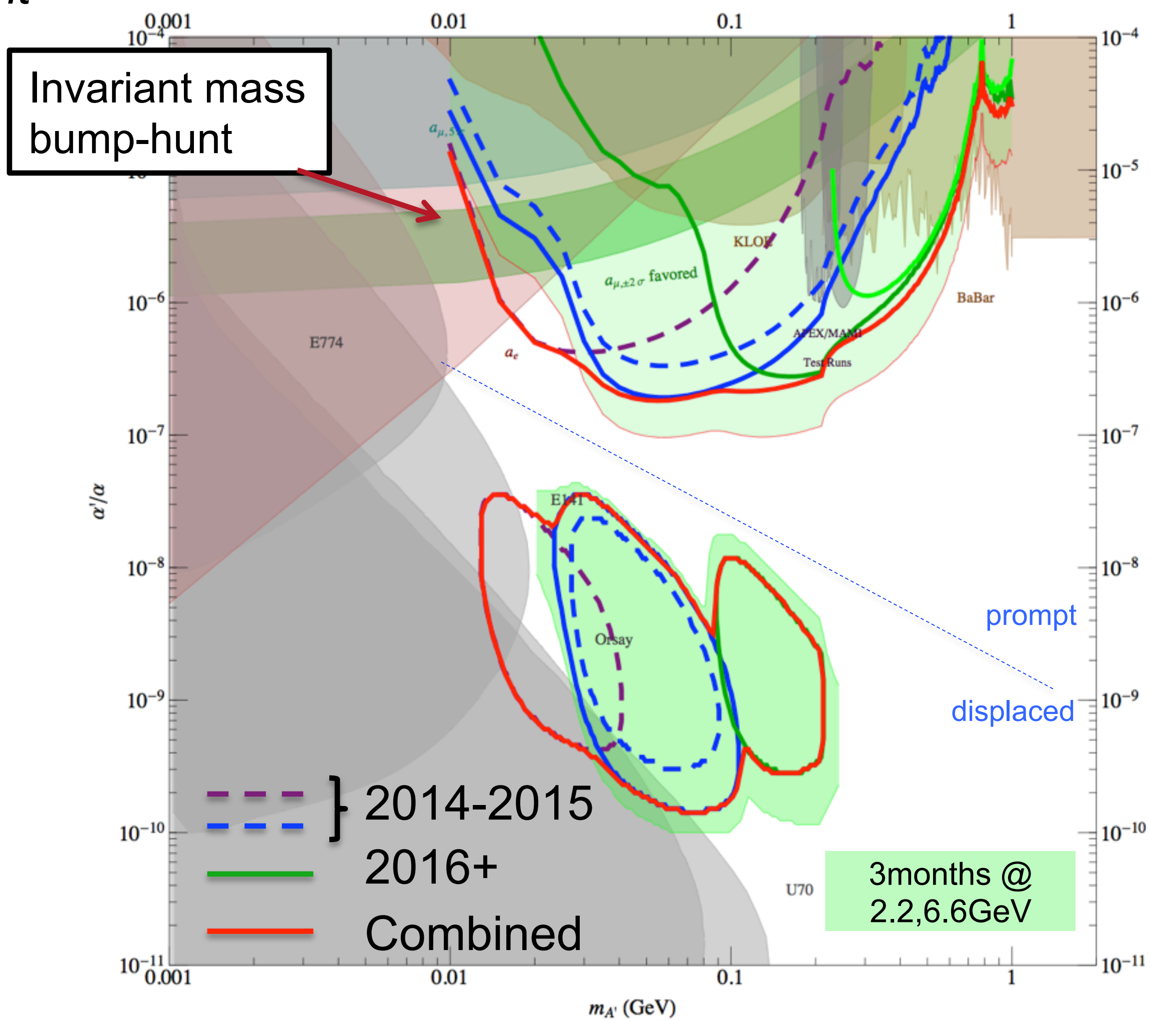
Expected rates

Run	Rate (kHz)
1.1 GeV	18.3
2.2 GeV	15.8
6.6 GeV	13.5

Reach 2014-2015 and Beyond

Two searches in one experiment





Reach 2014-2015 and Beyond

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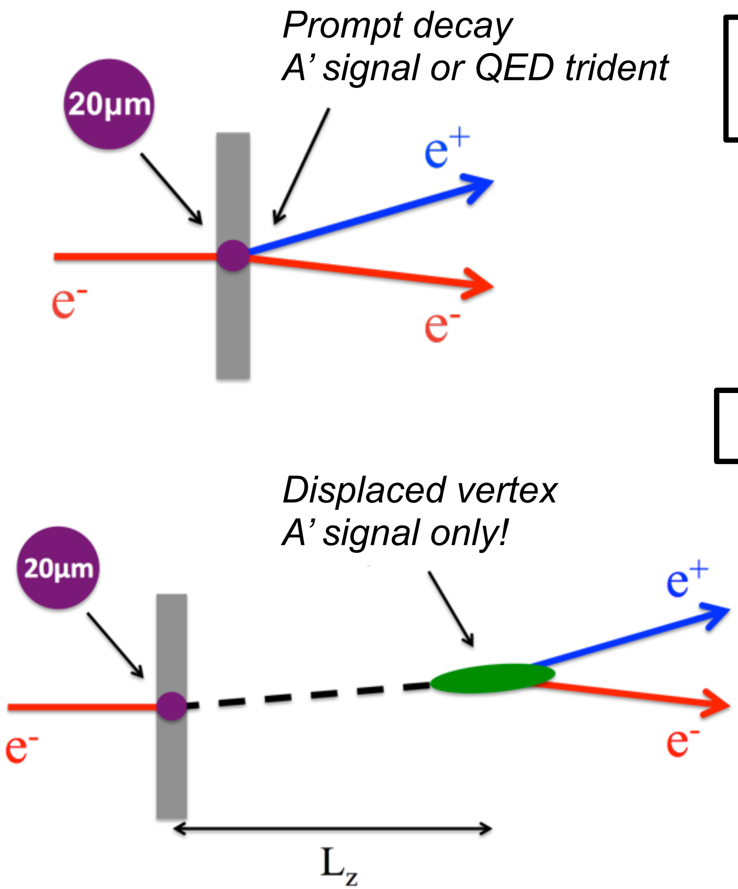
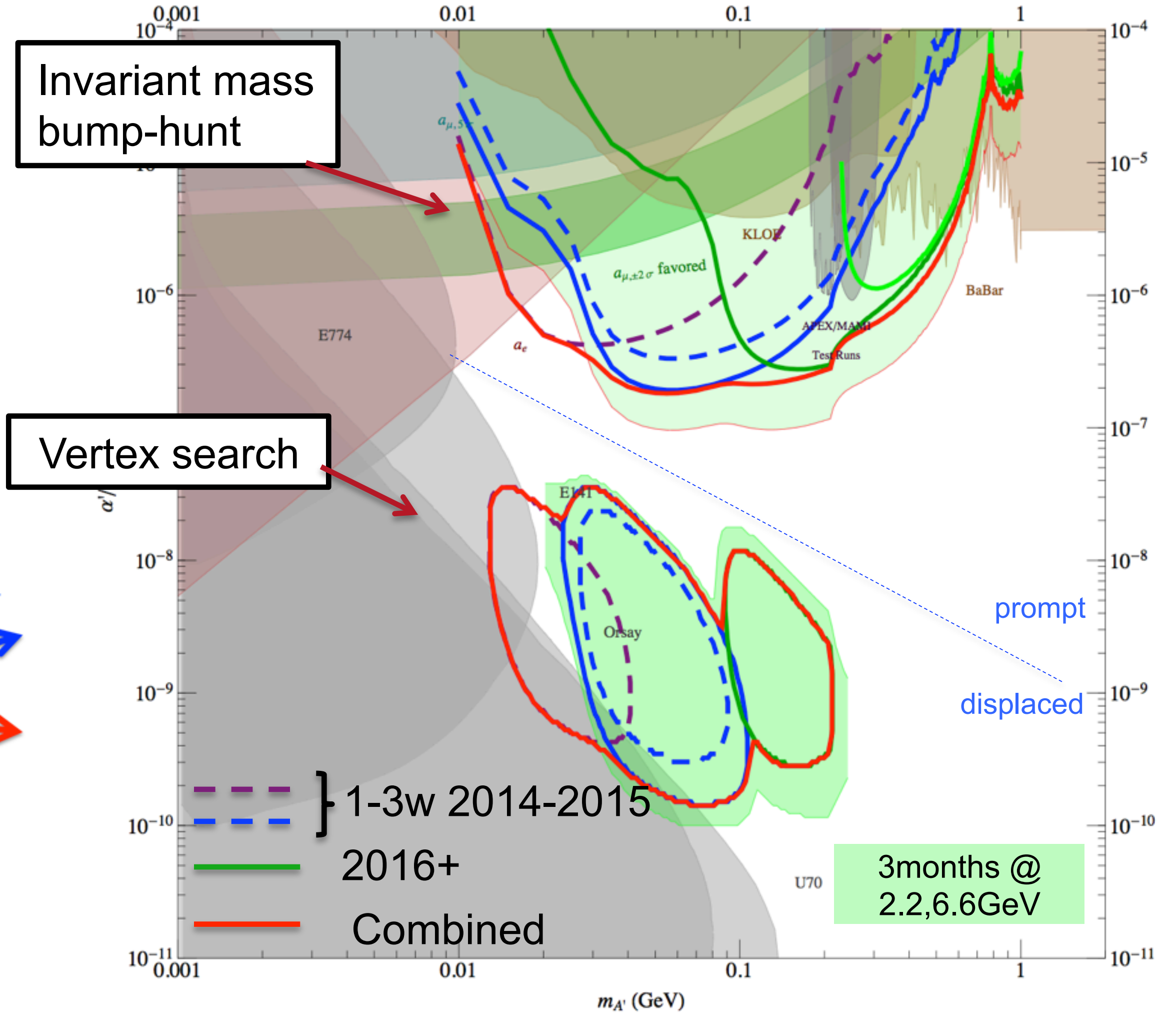




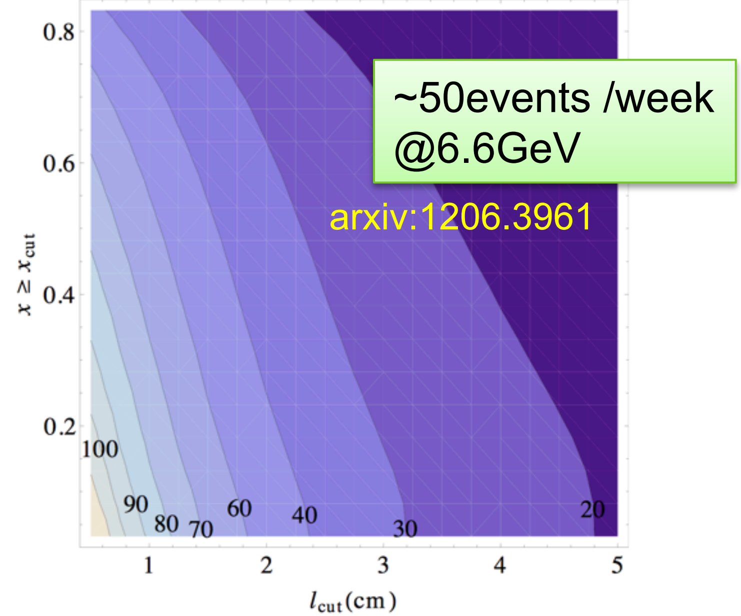
More Opportunities with HPS

Discovery of True Muonium!

- Hydrogen-like long-lived bound state of $\mu^+\mu^-$
- Multiple states: all decays to e^+e^- pairs
- Same experimental signature as A' but: <u>known mass and decay lengths (~cm's)</u>

⇒ Great demonstration of vertexing!

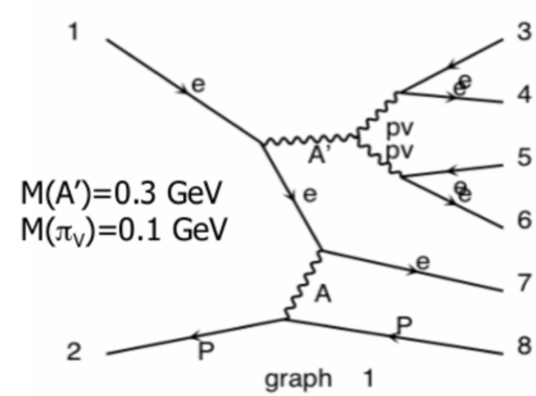
Events produced /10^{18} e- on target



Complex final states

- A' decays to lighter dark sector particles
- Search for e.g. 4 $e^\pm$ final states
- Tiny background, but small acceptance

Ex. Hidden Valley cascades



Summary

Searches for heavy photons are well motivated

- Heavy photons are prevalent in many models beyond SM
- Dark Matter may be part of a hidden sector

$\Rightarrow$ Heavy photons candidate explanation for observed discrepancies

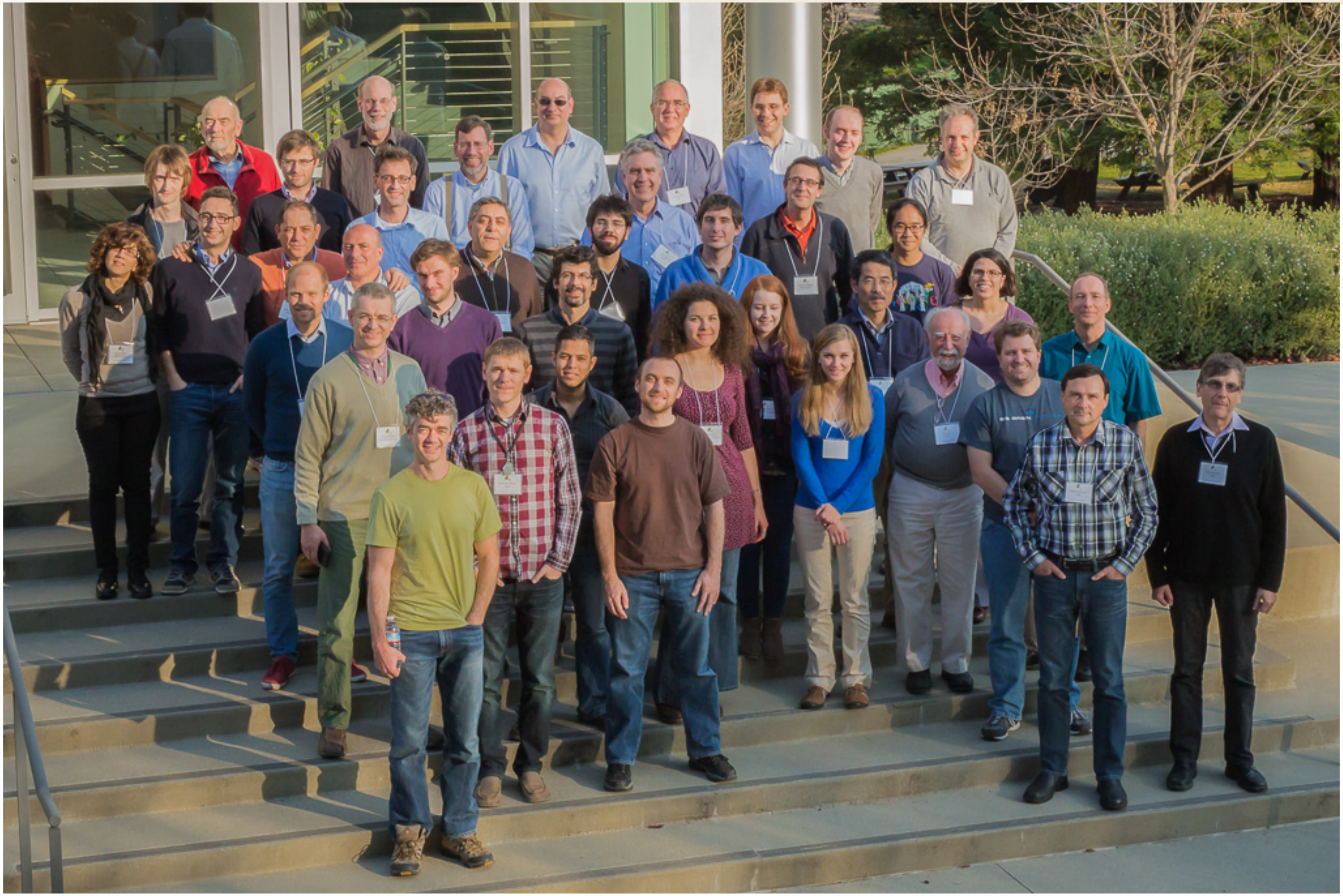
The Heavy Photon Search (HPS) experiment explores new territory

- Particle physics view: both access remaining g-2 preferred region and unexplored intermediate coupling region
- Experimental view: precise tracking and vertexing 0.5mm from intense electron beam

HPS is funded and approved

- Construction ongoing now
- Install later this year
- Run during 2014-2015 and beyond

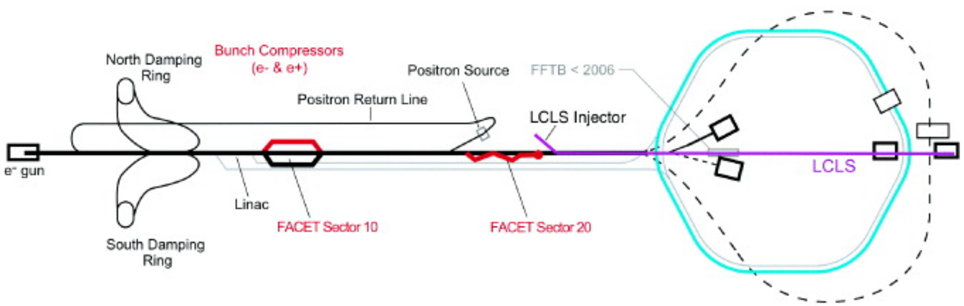
HPS Collaboration

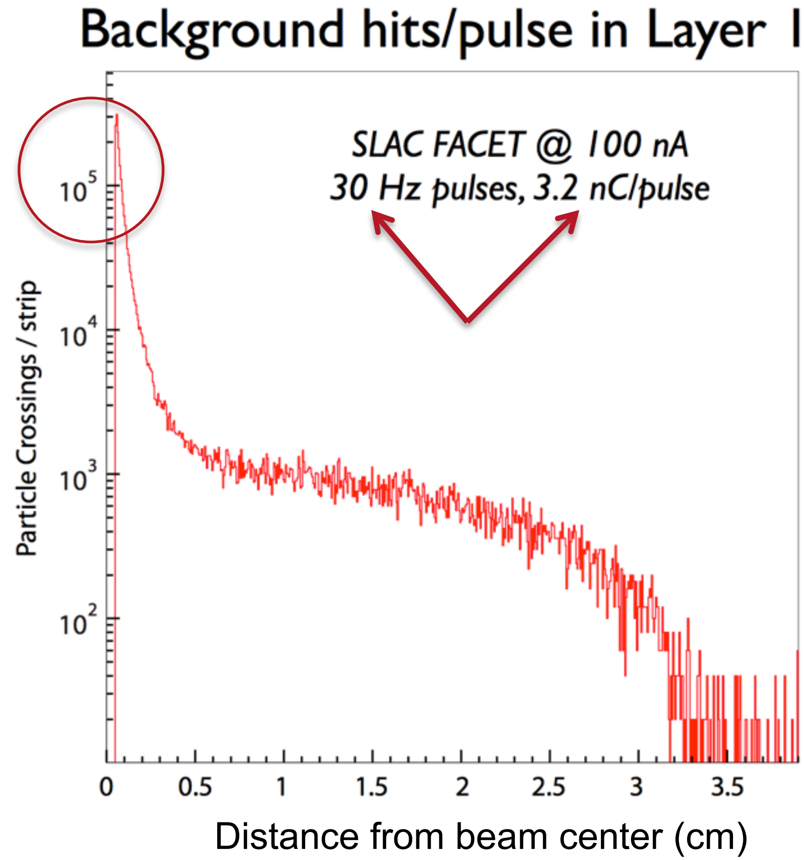


Backup

High-current Electron Beam

HPS at SLAC's high current FACET beam?



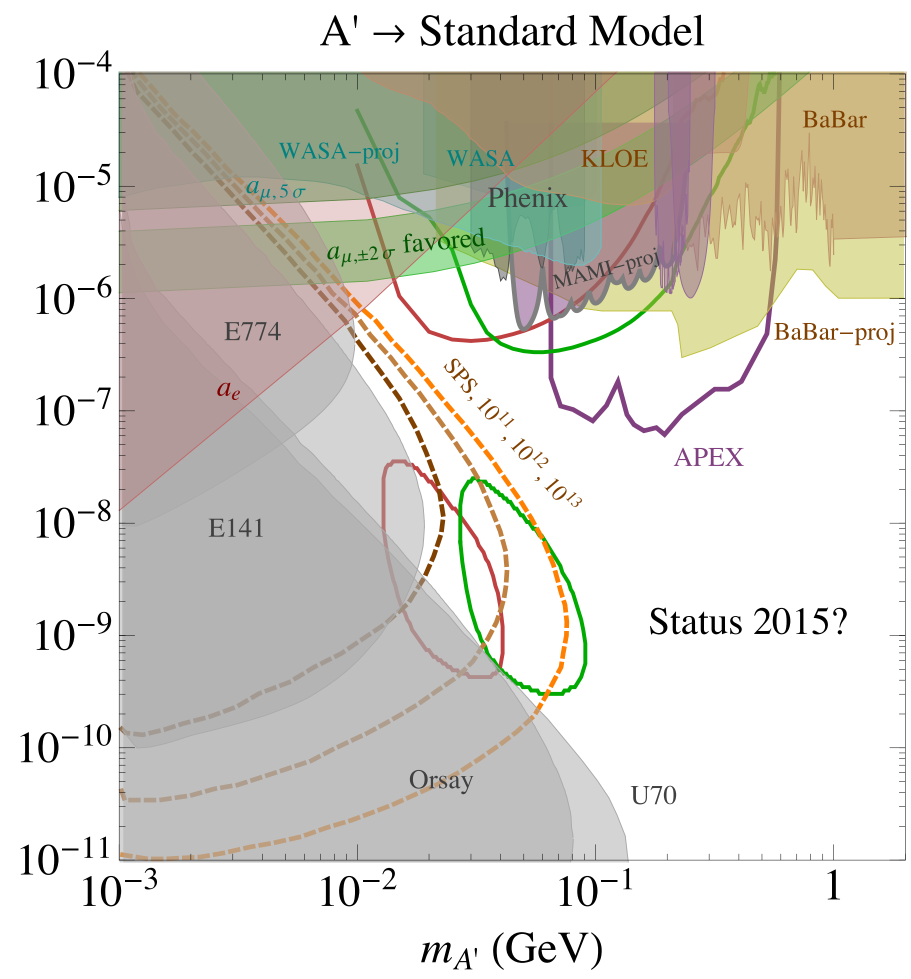


10^5 hits/strip => This will not work!

⇒ Need to spread out beam background in time

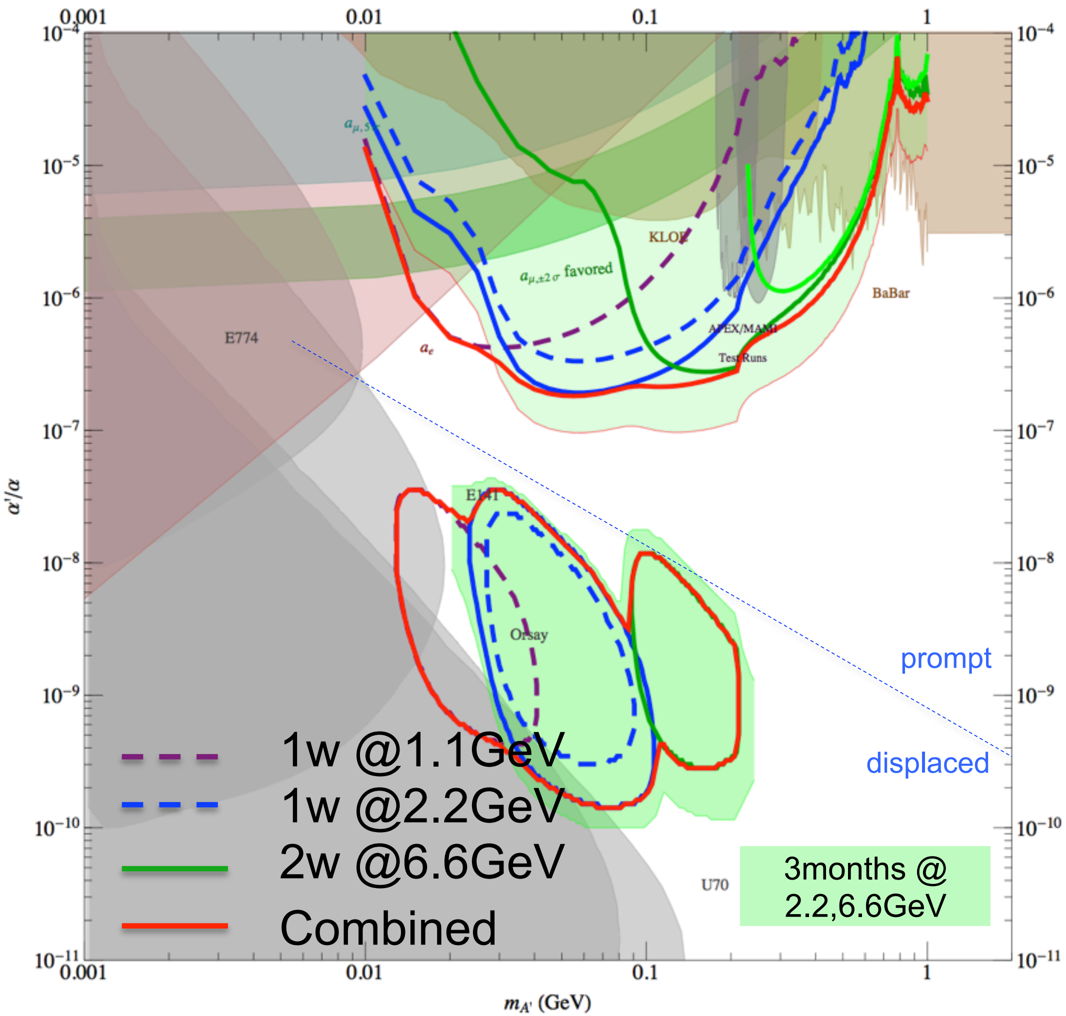
It’s getting crowded

HPS 1.1GeV and 2.2GeV only



Reach

SLAC

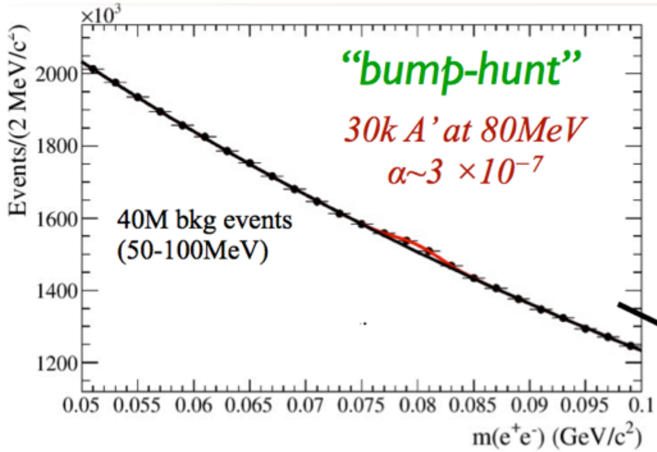


0.001
0.01
0.1
1
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
α'/α
$m_{A'}$ (GeV)
$a_{\mu,5\sigma}$
KLOE
$a_{\mu,\pm2\sigma}$ favored
BaBar
APEX/MAMI
Test Runs
E774
a_e
E141
Orsay
U70
prompt
displaced
1w @1.1GeV
1w @2.2GeV
2w @6.6GeV
Combined
3months @
2.2,6.6GeV

HEAVY PHOTON
SEARCH

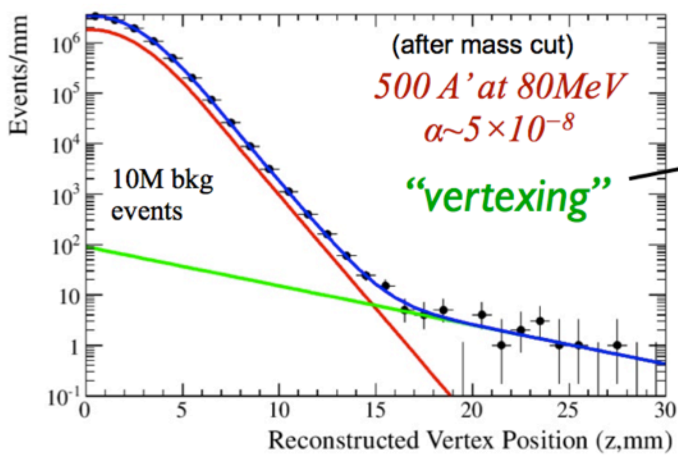
Physics Reach

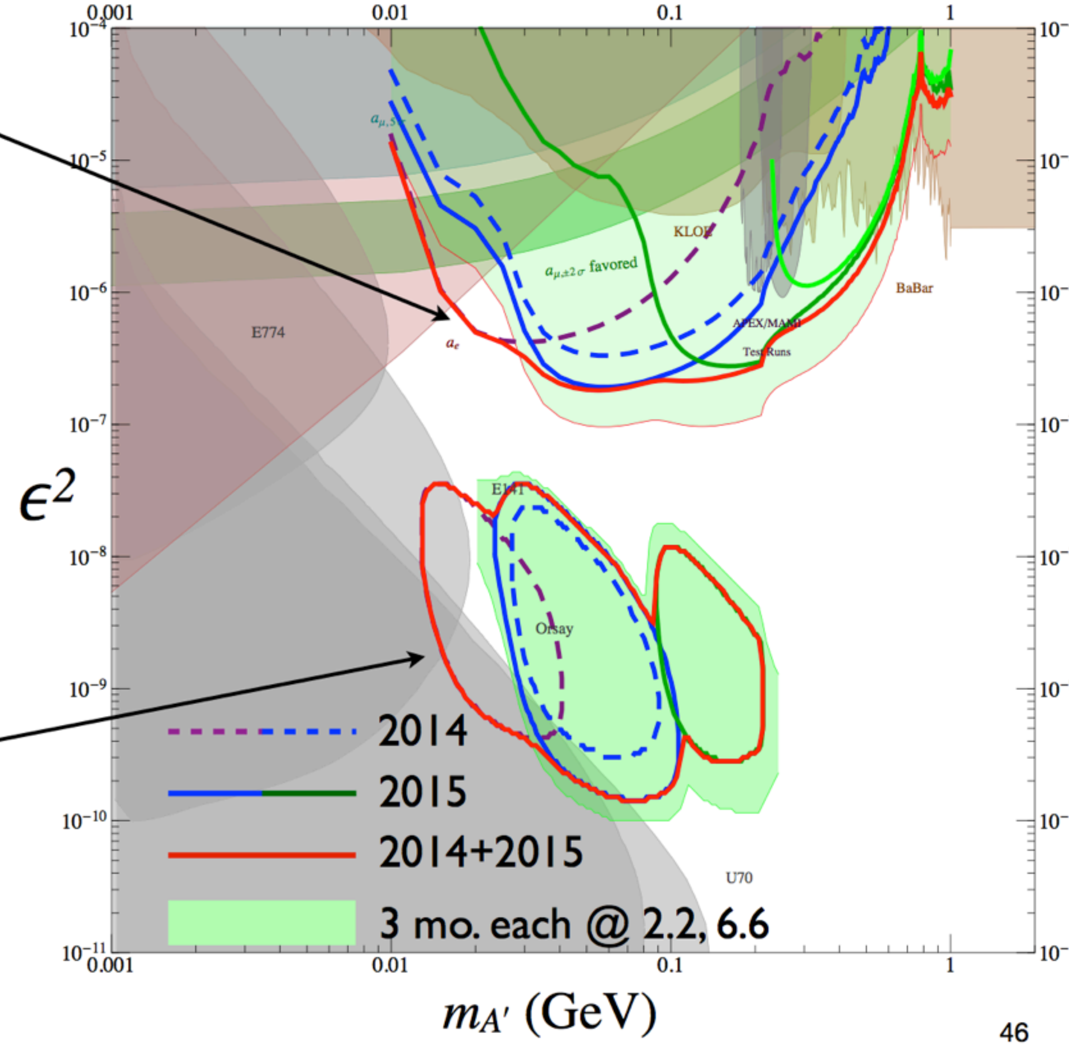
Large signal, *HUGE* background



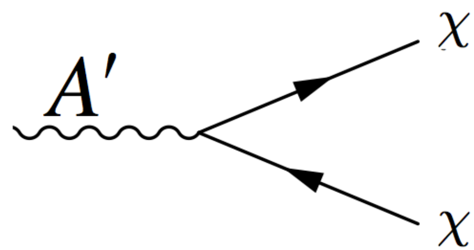
vertexing

Small signal, *NO* background





What if $M_\chi < M_{A'}$?

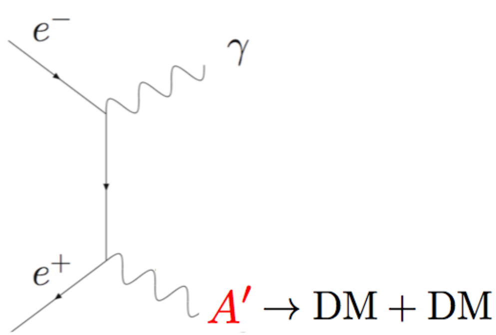


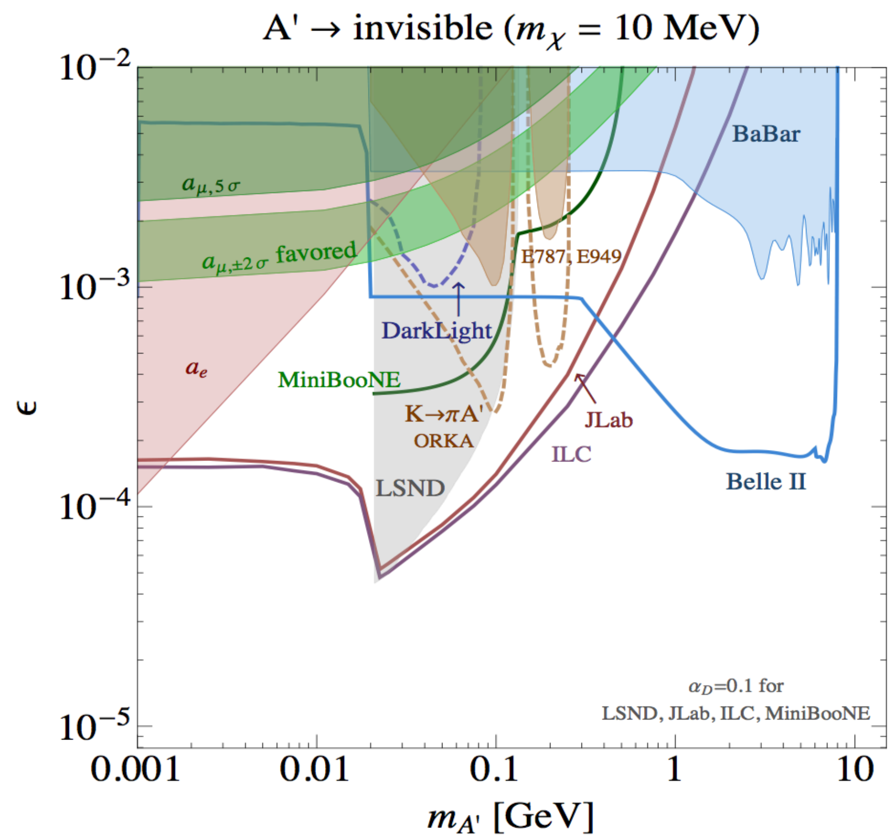
Constraints from:

$(g-2)_e$ $(g-2)_\mu$

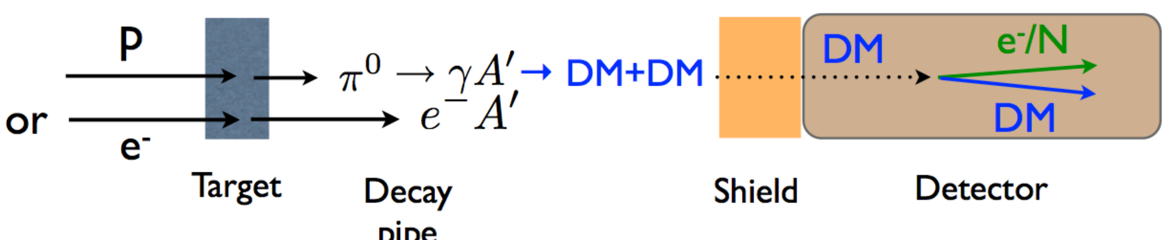
$K \to \pi\nu\bar{\nu}$ (e.g. E787, E949)

BaBar

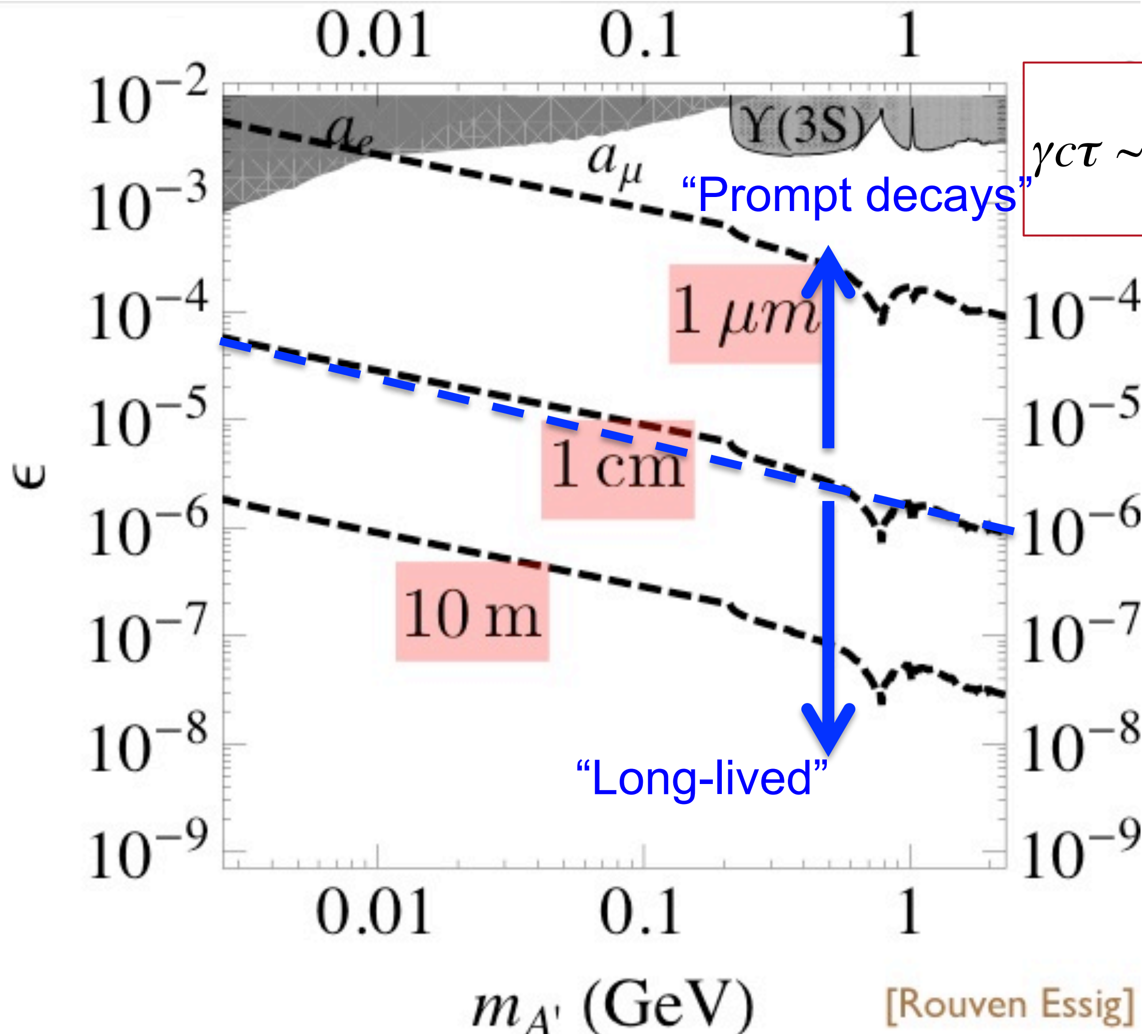




Make a dark matter beam!!



A' Lifetime

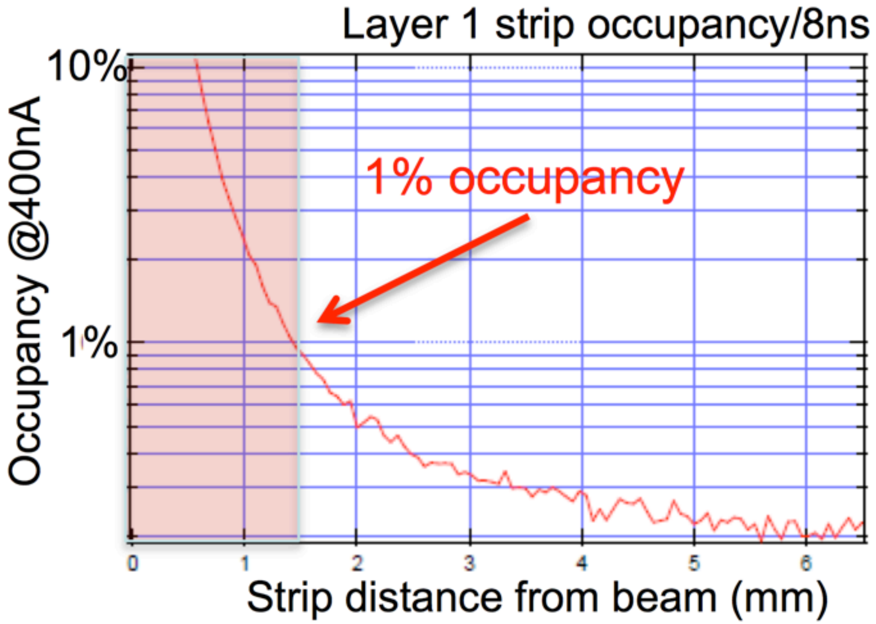


$$\gamma c\tau \sim 0.8cm\left(\frac{E}{10GeV}\right)\left(\frac{10^{-4}}{\varepsilon}\right)^2\left(\frac{100MeV}{m_{A'}}\right)^2$$

Lower ε
Lower $m_{A'}$
} Longer lifetime

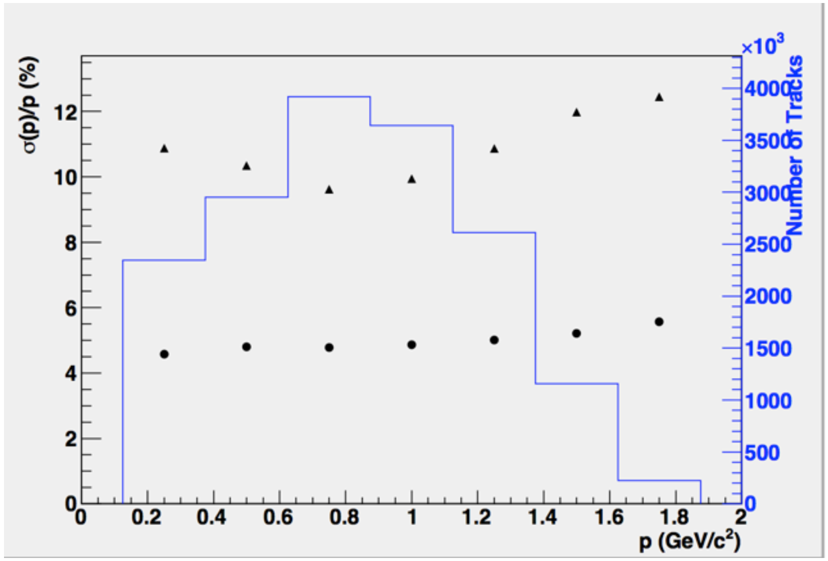
Layer 1 occupancy

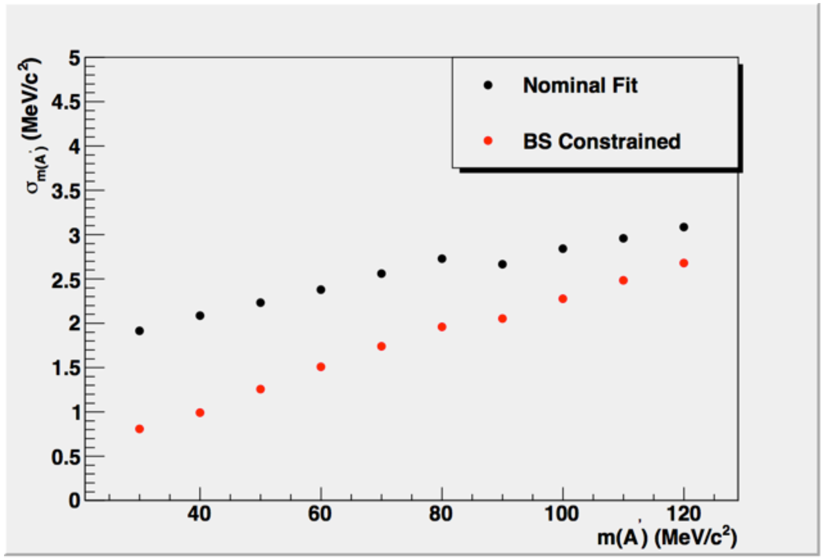
d



Tracking Performance

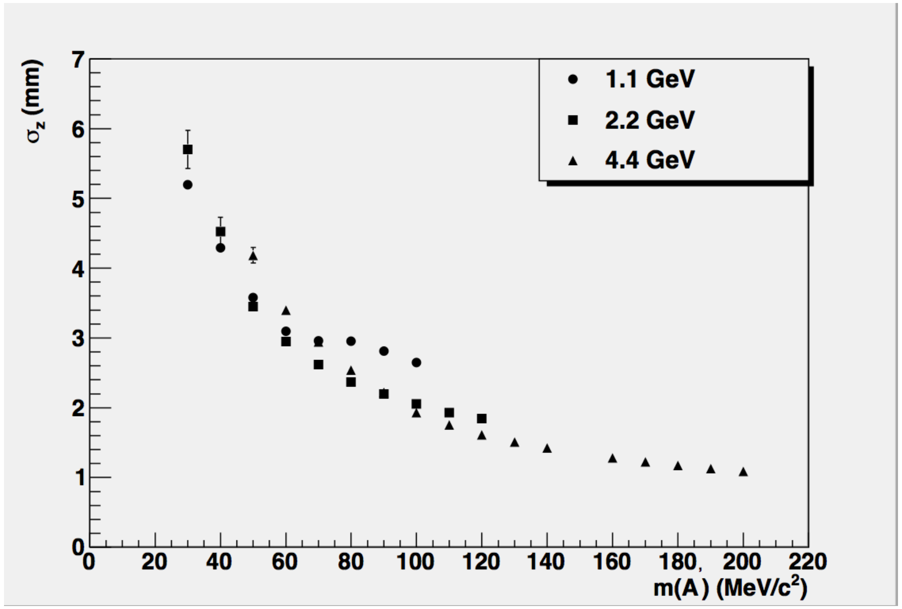
d

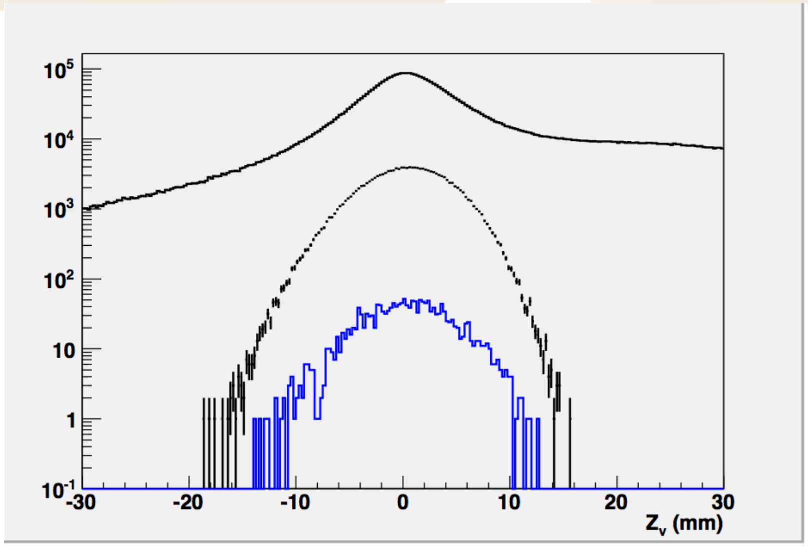


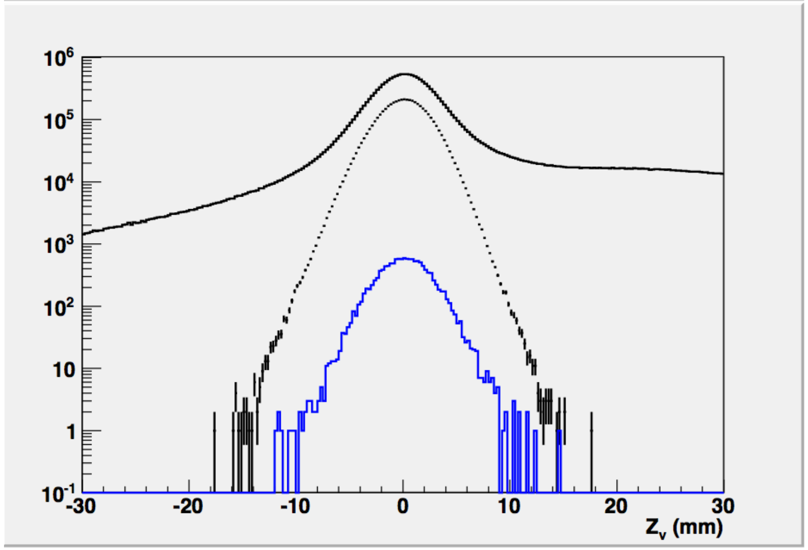


Vertexing Performance

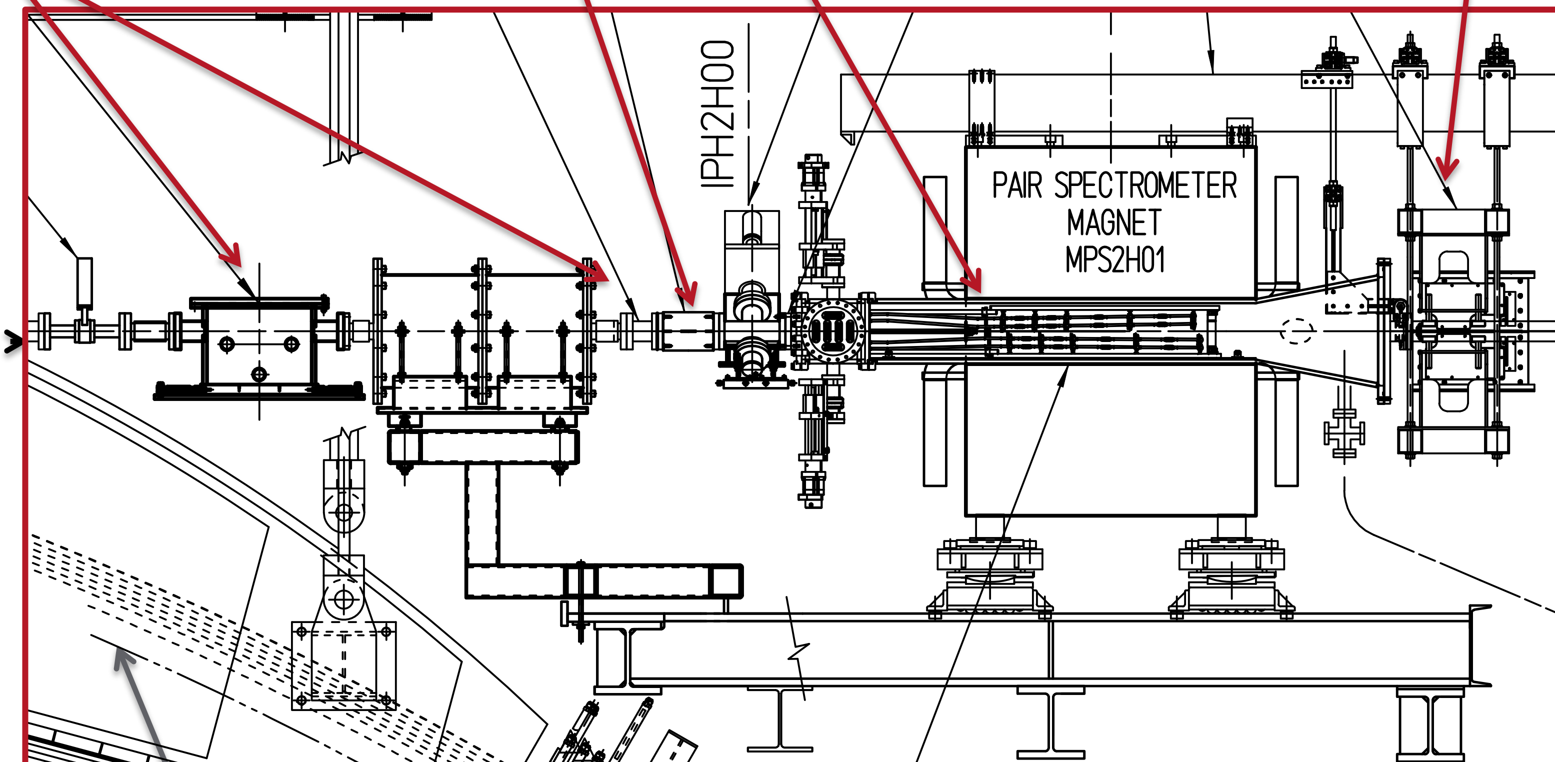
d







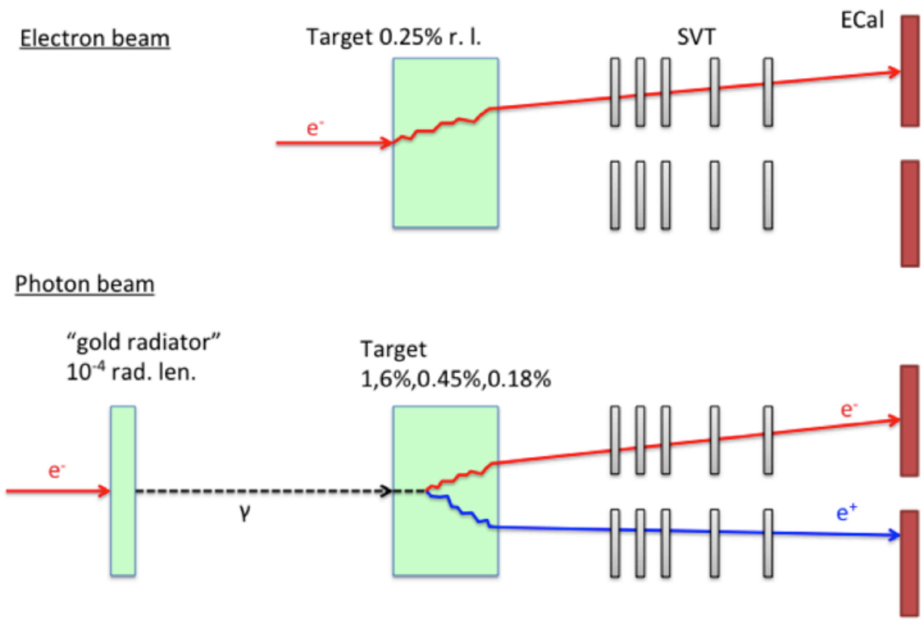
Dedicated Run – Photon beam

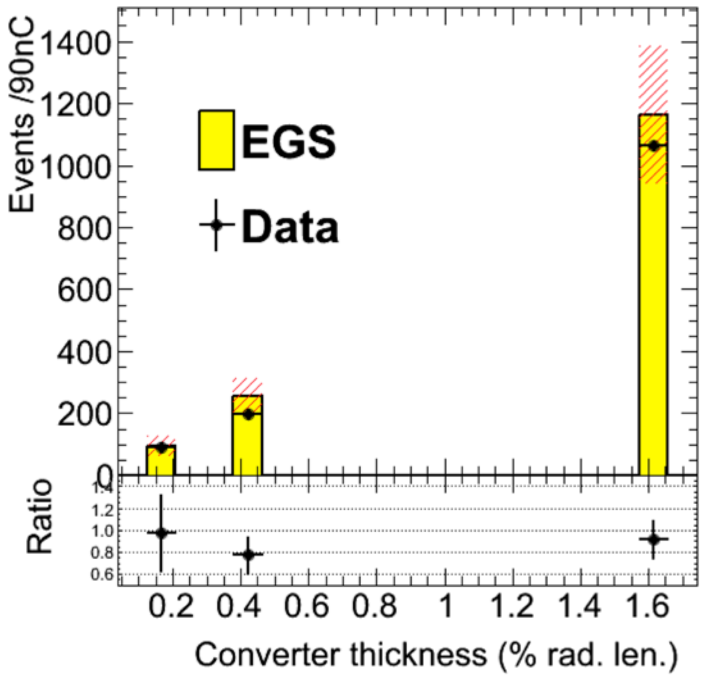


View from side

Beam background verification

Test run detector only exposed to photon beam





HPS Test Run

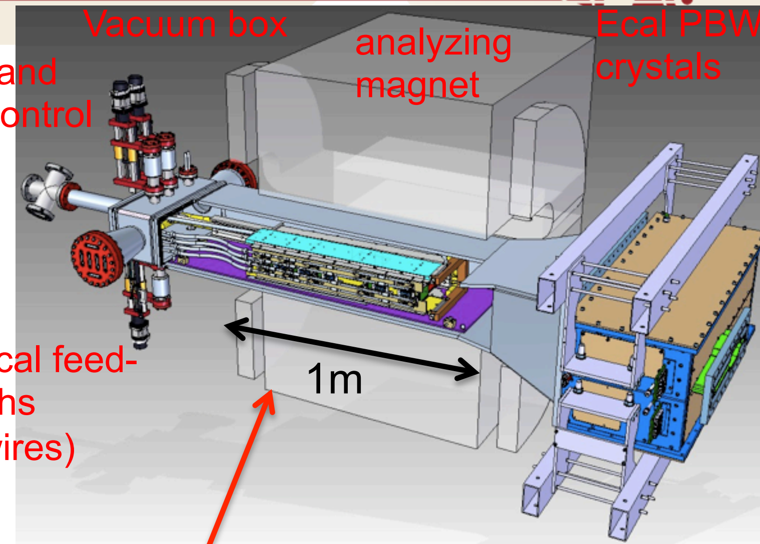
Very busy year!

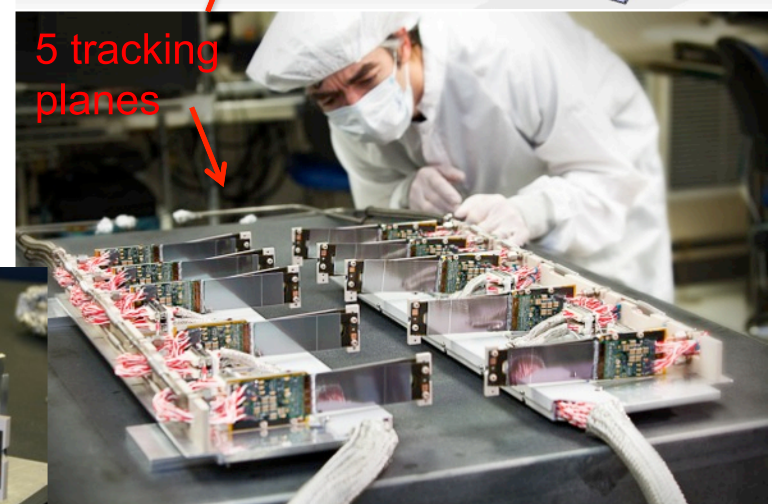
In 2011: “Full” HPS contingent on test run

- Build a tracker and calorimeter that successfully meets key challenges
- Confirm models of backgrounds
- Demonstrate technical approach
- Bonus: physics reach

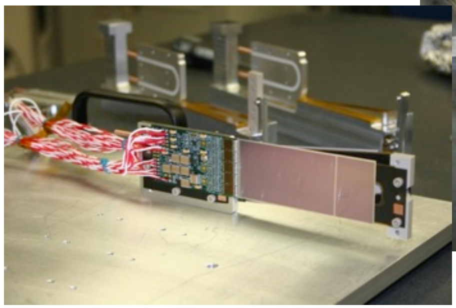
Design choices: sacrifice acceptance

- 20 tracking sensors
- Inner calorimeter: $PbWO_4$ modules
- Complete, integrated full DAQ for SVT and calorimeter





Very tight schedule:
Run before the 12GeV upgrade



Fixed Target Heavy Photon Backgrounds

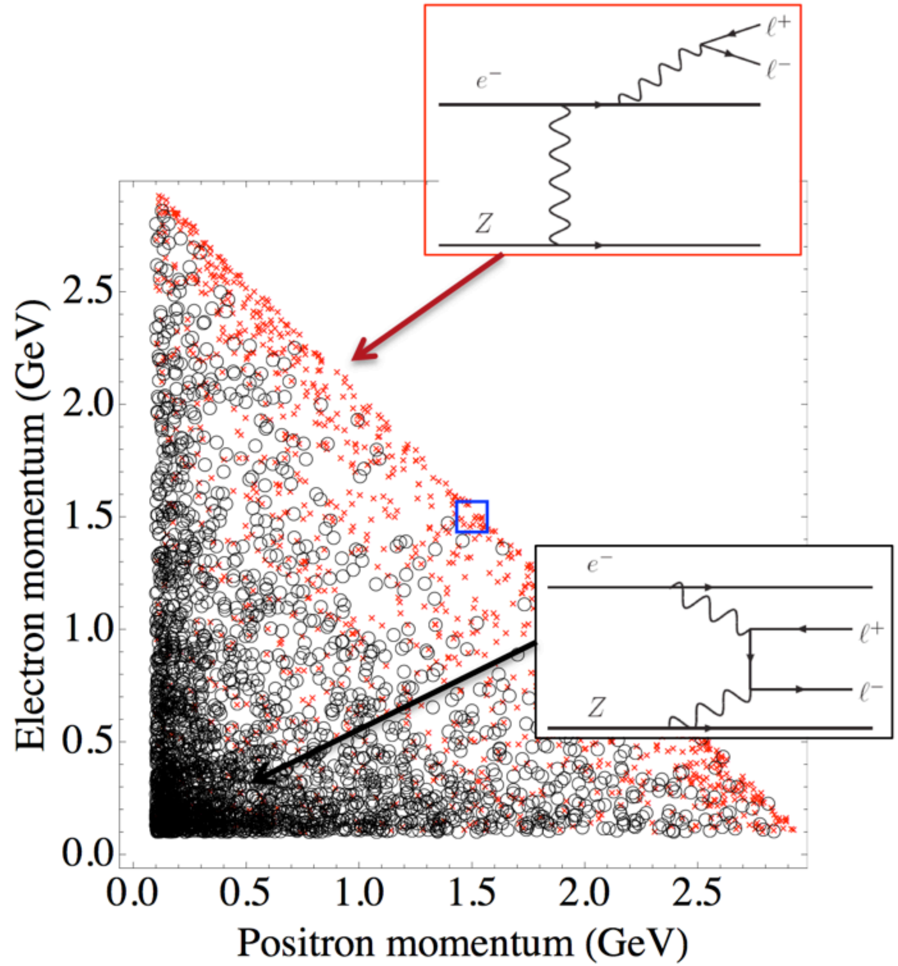
Tridents

- Radiative (irreducible)
- Bethe-Heitler (BH)

σ(BH)>>σ(radiative) Reject through kinematic selection ~5x after basic selections

Beam backgrounds

- Coulomb scattering in target
- Secondary prod. (bremsstrahlung, X-rays)
- Pair conversion (two-step process)



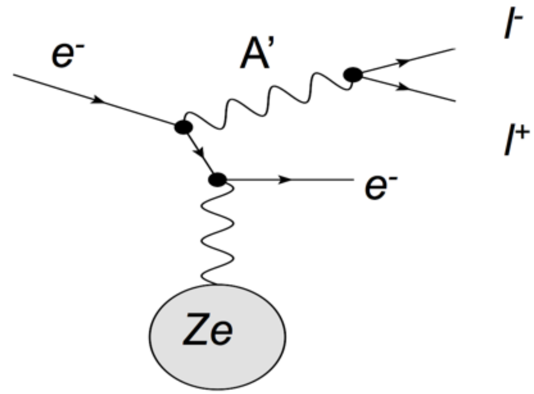
Signal scaled for the plot

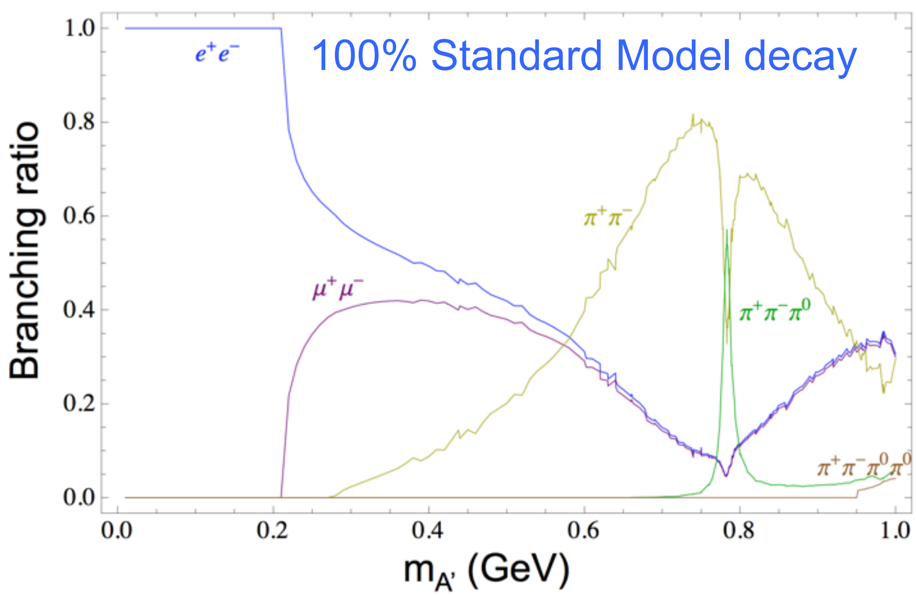
Heavy Photon Fixed Target Production

Much higher luminosity than colliders for masses <1GeV

Radiative production dominate

- Suppressed relative to Bremstrahlung by $\sim\varepsilon^2 m_e^2/m_{A'}^2$





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

Rudimentary wish-list

- High Z target
- High luminosity
- Detect e^+e^- and $\mu^+\mu^-$

⇒ O(**1000**) events/day

⇒ Large backgrounds