Searching for heavy photons at JLAB

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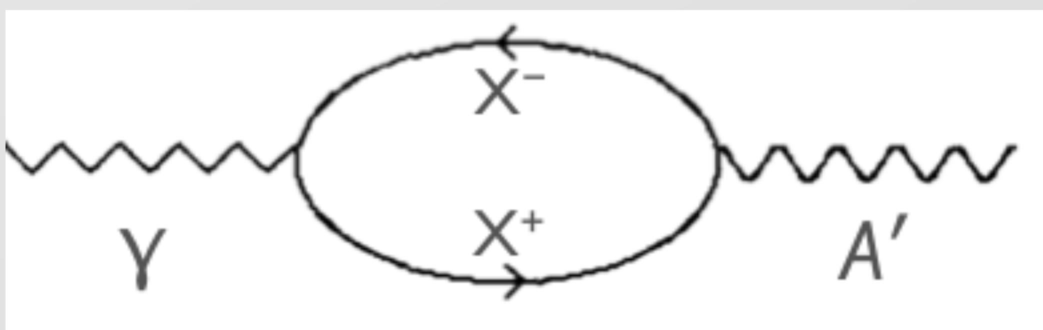
of behalf of APEX, Dark/Light, and HPS
2012 JLAB Users Meeting
June 6, 2012

U(1)′ and kinetic mixing

an old idea: if there is an additional U(1) symmetry in nature, there will be mixing between the photon and the new gauge boson

Holdom, Phys. Lett B166, 1986

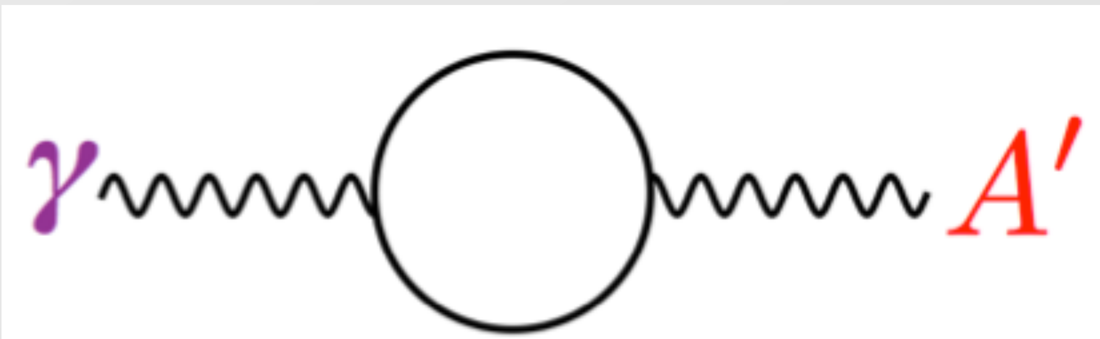
$$\mathcal{L}_{U(1)'} = -\frac{1}{4}V_{\mu\nu}^2 - \boxed{\frac{\epsilon}{2}V_{\mu\nu}F^{\mu\nu}} + |D_\mu\phi|^2 - V(\phi)$$

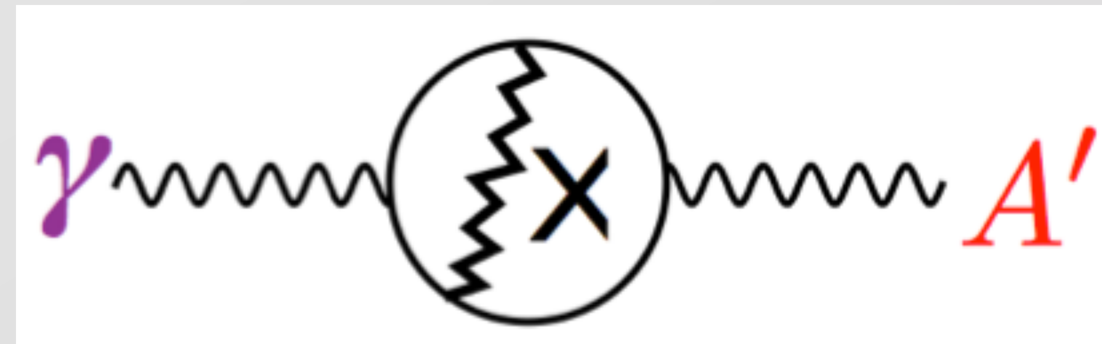


Kinetic Mixing term

- extremely general conclusion...even arises from broken symmetries
- one of the very few portals for a new force to communicate with the standard model
- gives coupling of normal charged matter to the new "heavy photon" q=εe

"Natural" coupling and mass





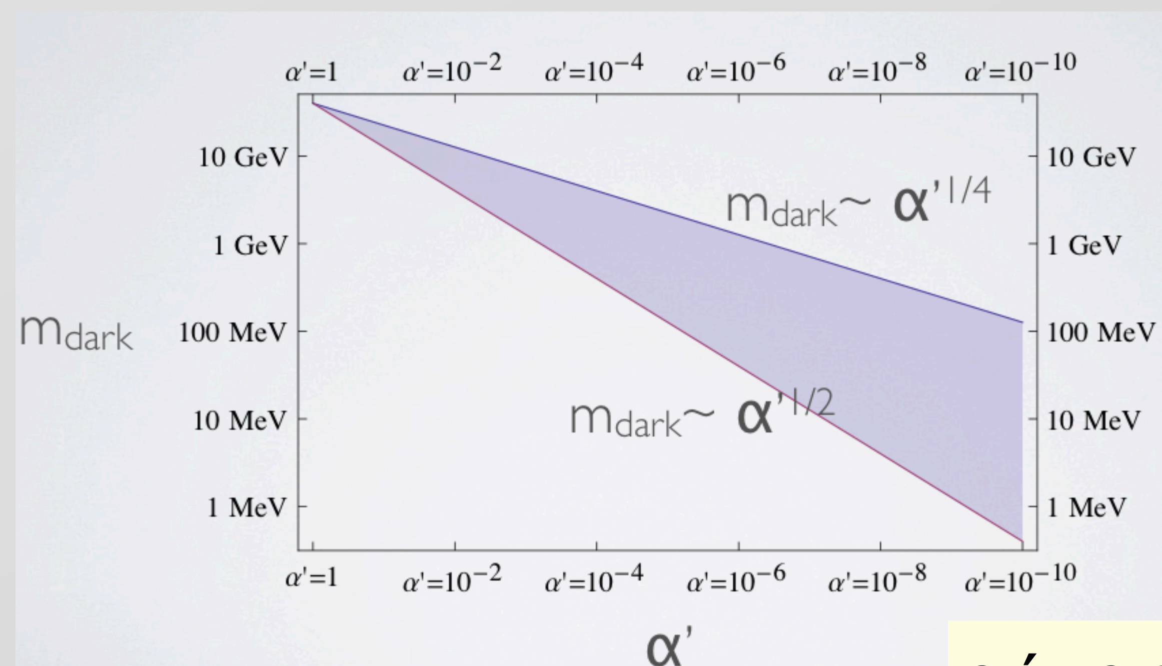
$\epsilon \sim 10^{-3} - 10^{-2}$ —enhanced symmetry→ $\epsilon_{GUT} \sim 10^{-5} - 10^{-3}$

Depending on model, mass scales like:

M(A´)/M(W)~ε^{1}-$\varepsilon^{1/2}$

leading to

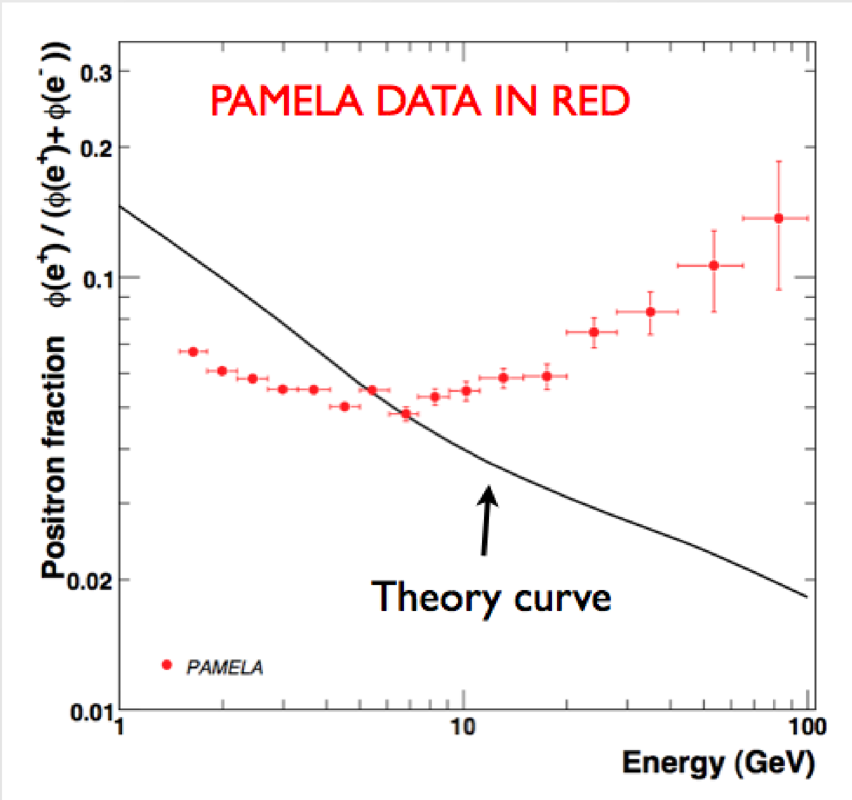
M(A´)~MeV-GeV



N. Weiner, JLAB PAC37 Talk

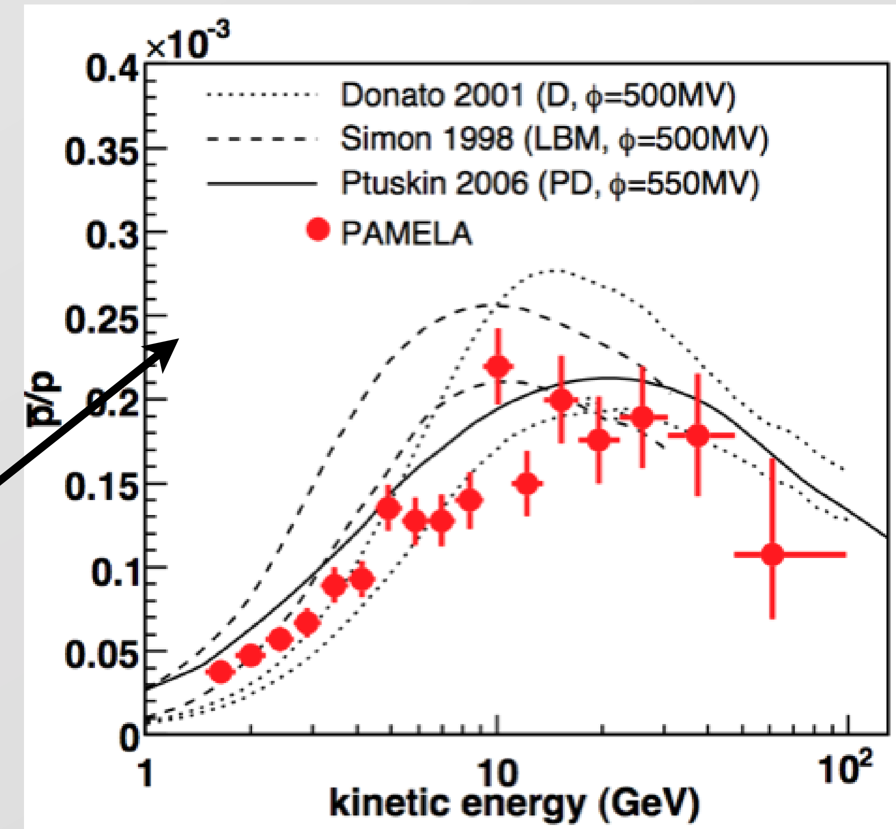
α´=αε

Hint from astrophysics?

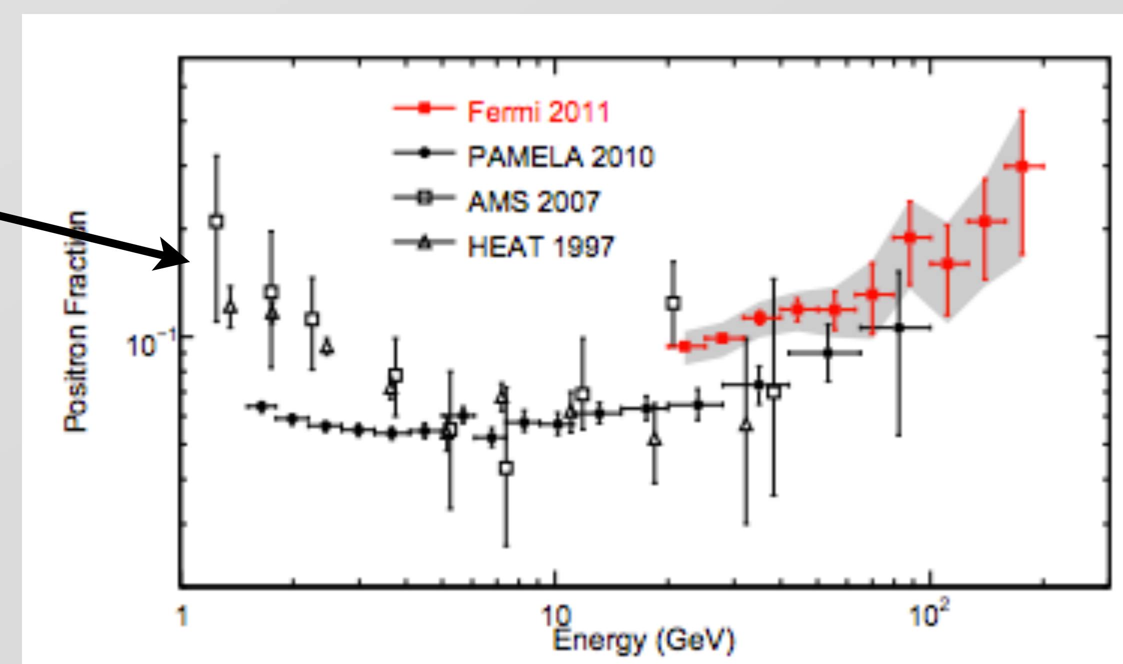


excess in e^+/e^- ratio

...but not in $\bar{p}/p$ ratio



•FERMI sees it too!

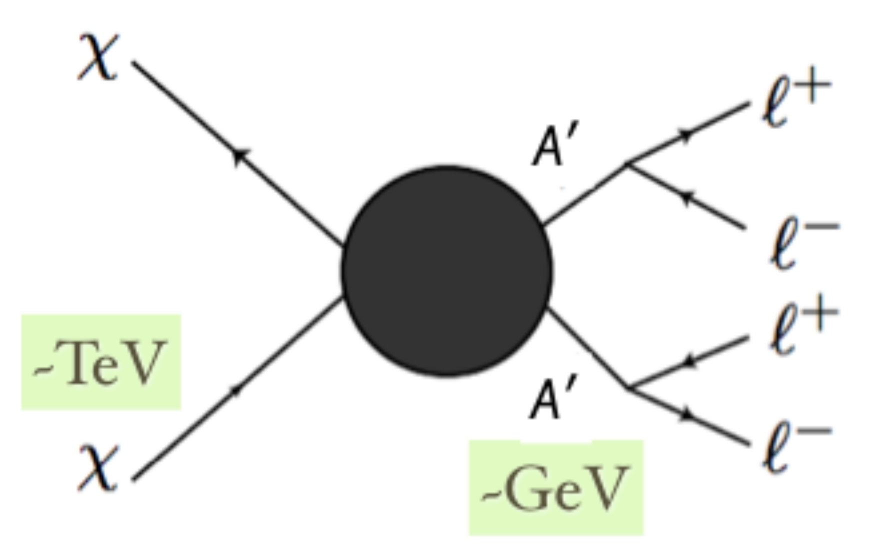


Unknown source of high energy positrons...

Is this astrophysics or particle physics?

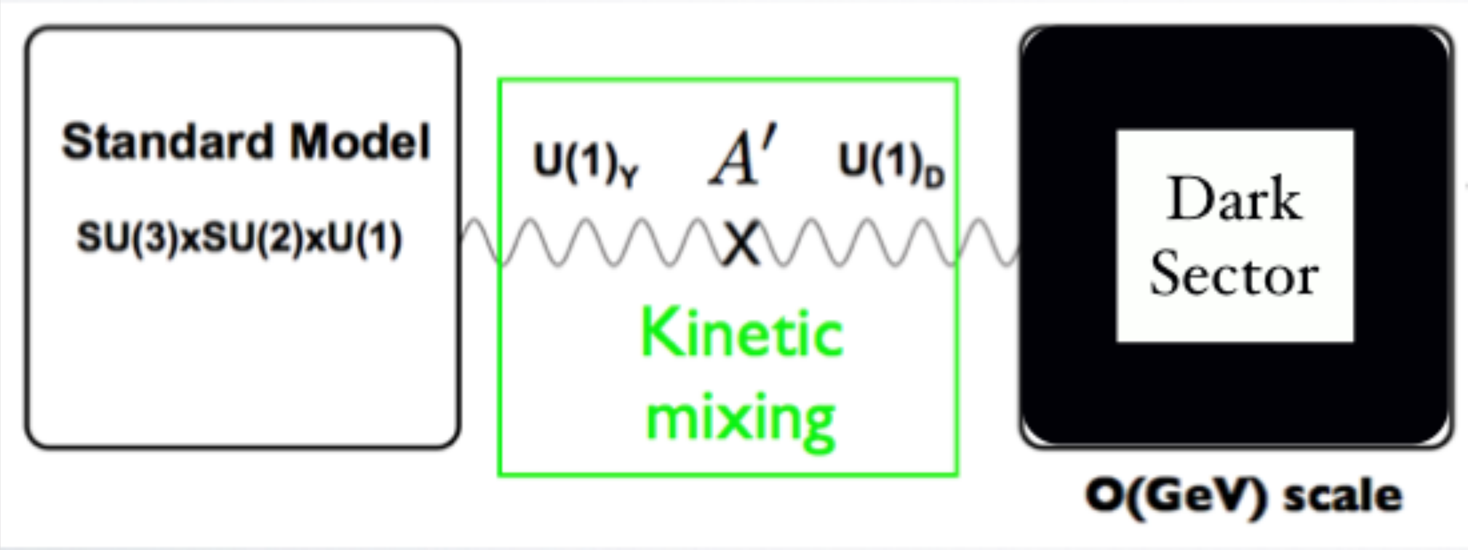
Dark matter annihilation and the dark sector

N. Arkani-Hamed *et al.*, PRD **79**, 015014 (2009).



M. Pospelov and A. Ritz, Phys. Letters B **671**, 391 (2009).

- new "dark force" with gauge boson ~ GeV while the dark matter particle (charged under the new force) ~ TeV
- decays to lepton pairs (e^+e^-, $\mu^+\mu^-$) but $p\bar{p}$ decays are kinematically forbidden

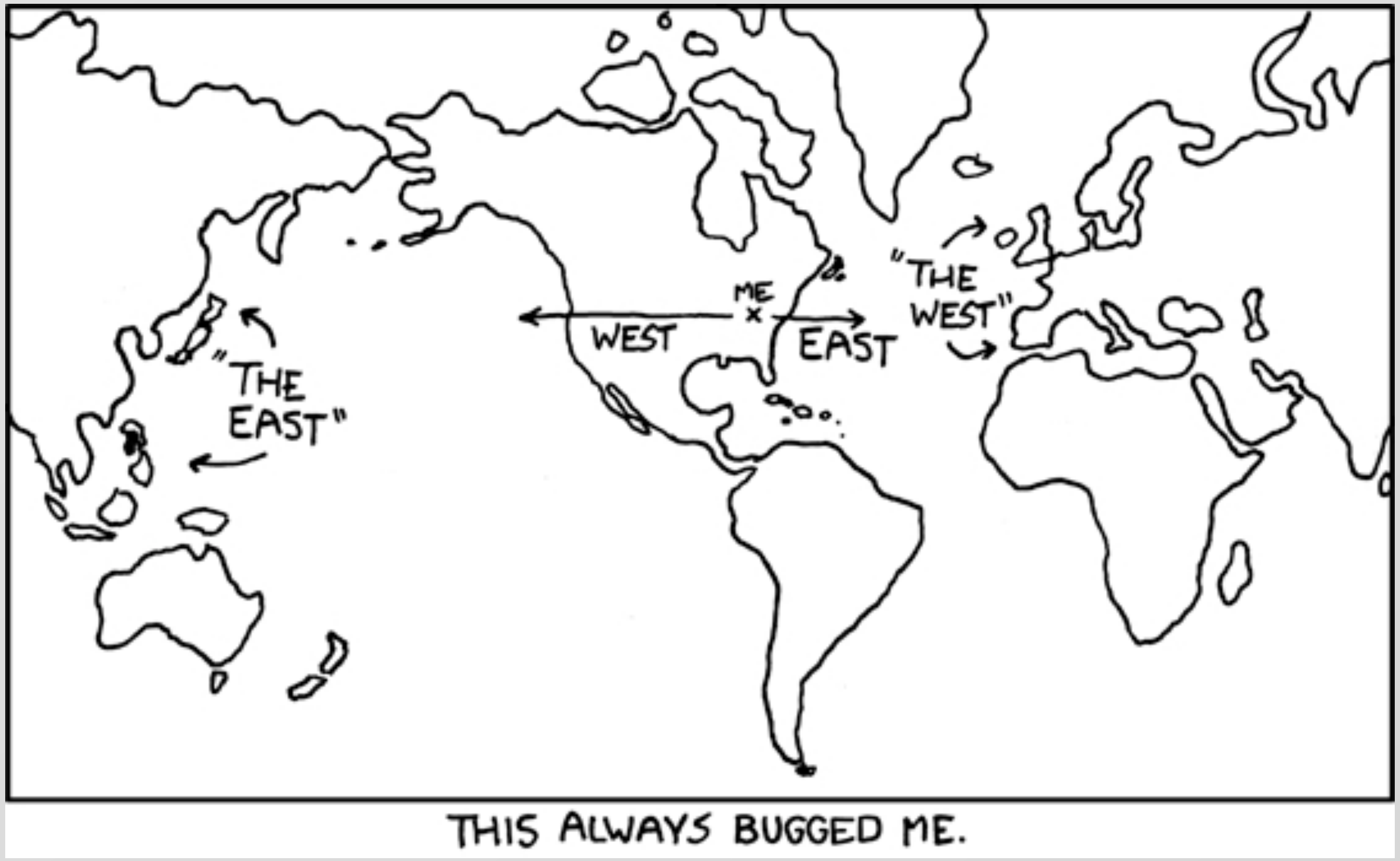


The idea of a dark sector has generated intense interest from both theory and experiment communities

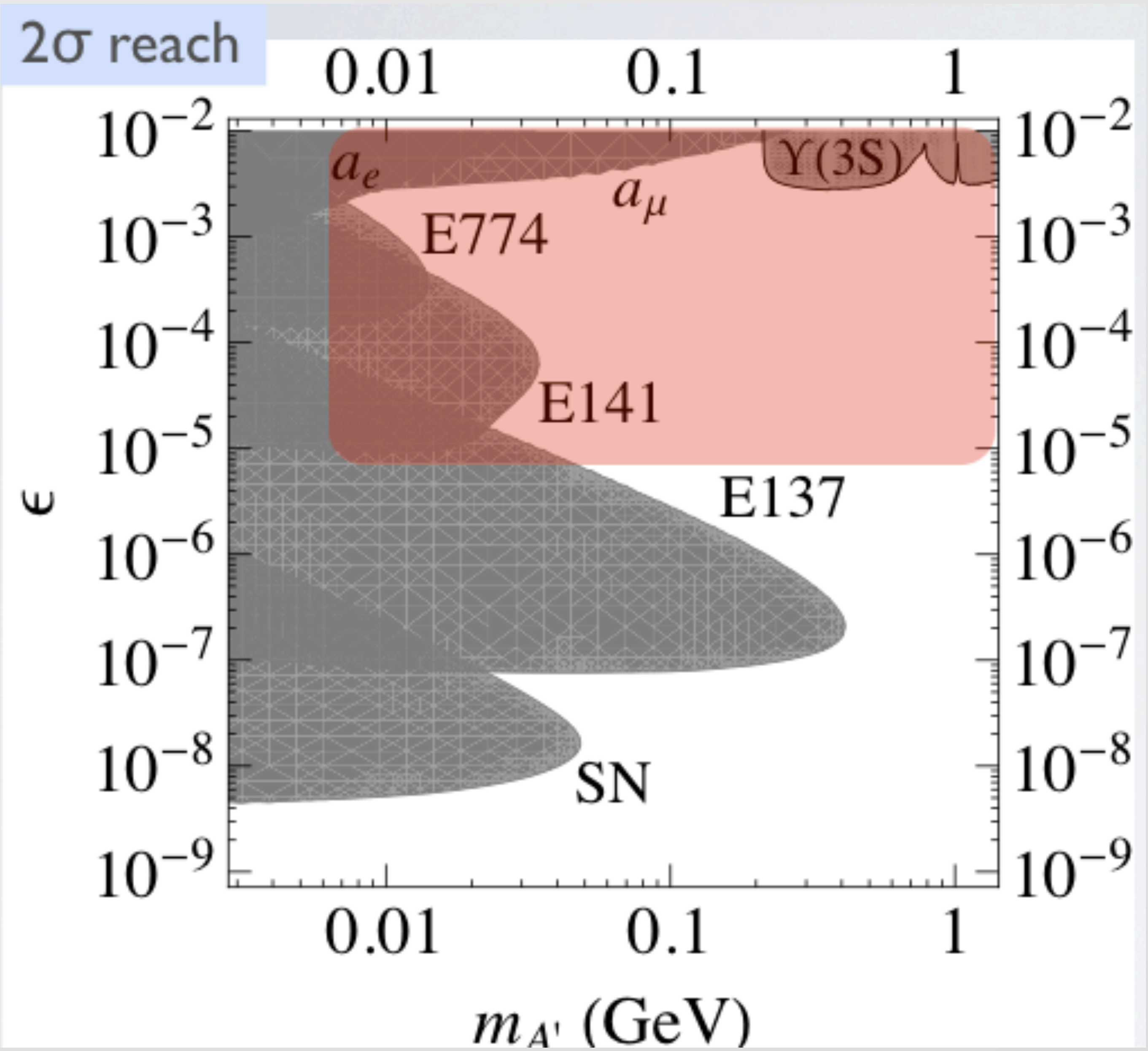
Terminology break

- The literature is infested with different terms for (basically) the same things...
  - dark sector=hidden sector=secluded sector
  - dark photon=hidden photon=heavy photon=A′=U-boson
  - $\varepsilon^2=\kappa^2=\alpha'/\alpha$

I will try to stick to dark sector, A′, and ε!



The coupling-mass sweet spot



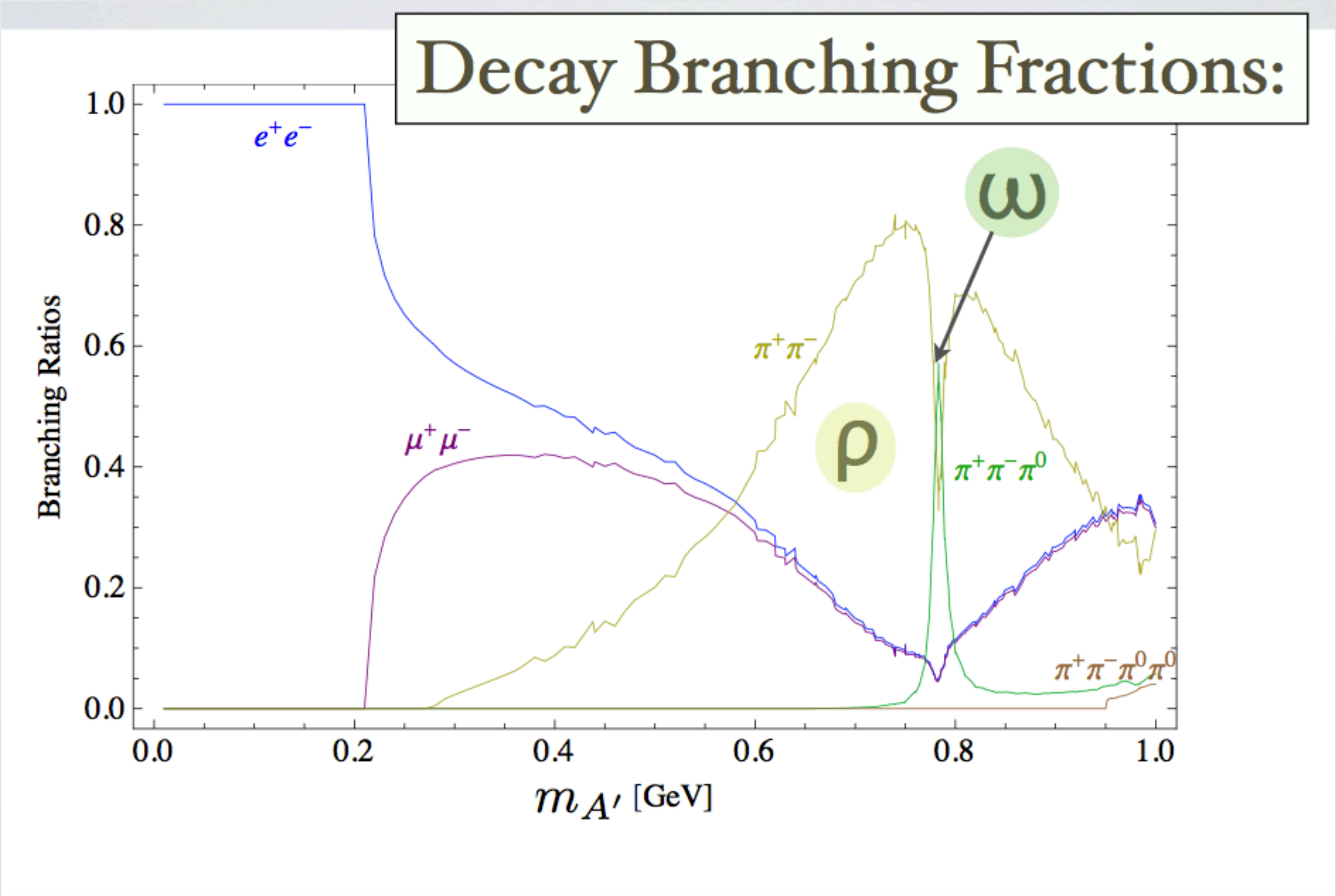
Both "naturalness" arguments and hints from experiments block out the same region in mass-coupling space:

$\varepsilon \sim 10^{-2} - 10^{-5}$

m(A´) ~ MeV – GeV

Most of this region is unexplored!

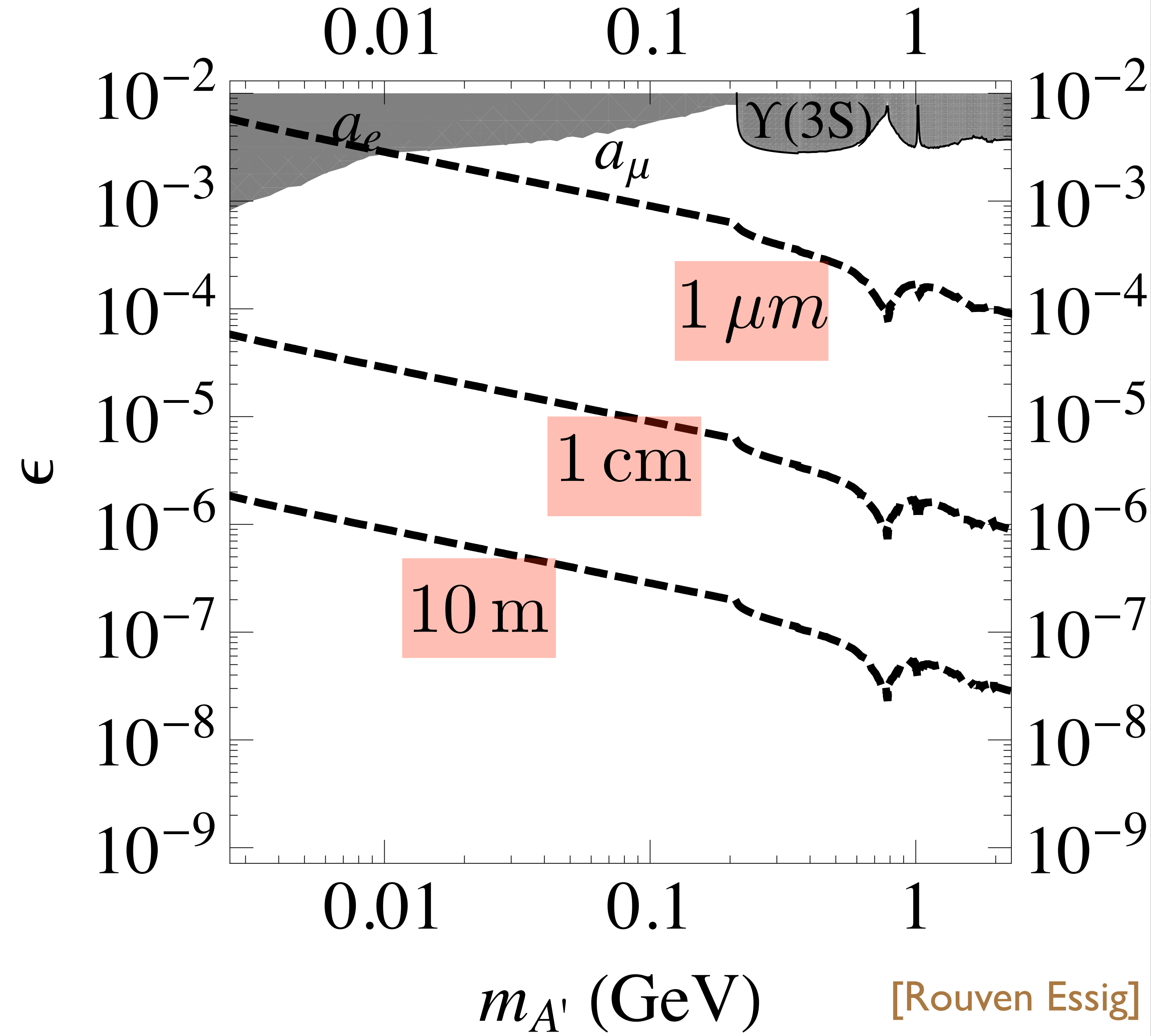
A´ decay products



A′ Lifetime

$$\gamma c\tau \propto \left(\frac{10^{-4}}{\epsilon}\right)^2 \left(\frac{100\ \text{MeV}}{m_{A'}}\right)^2$$

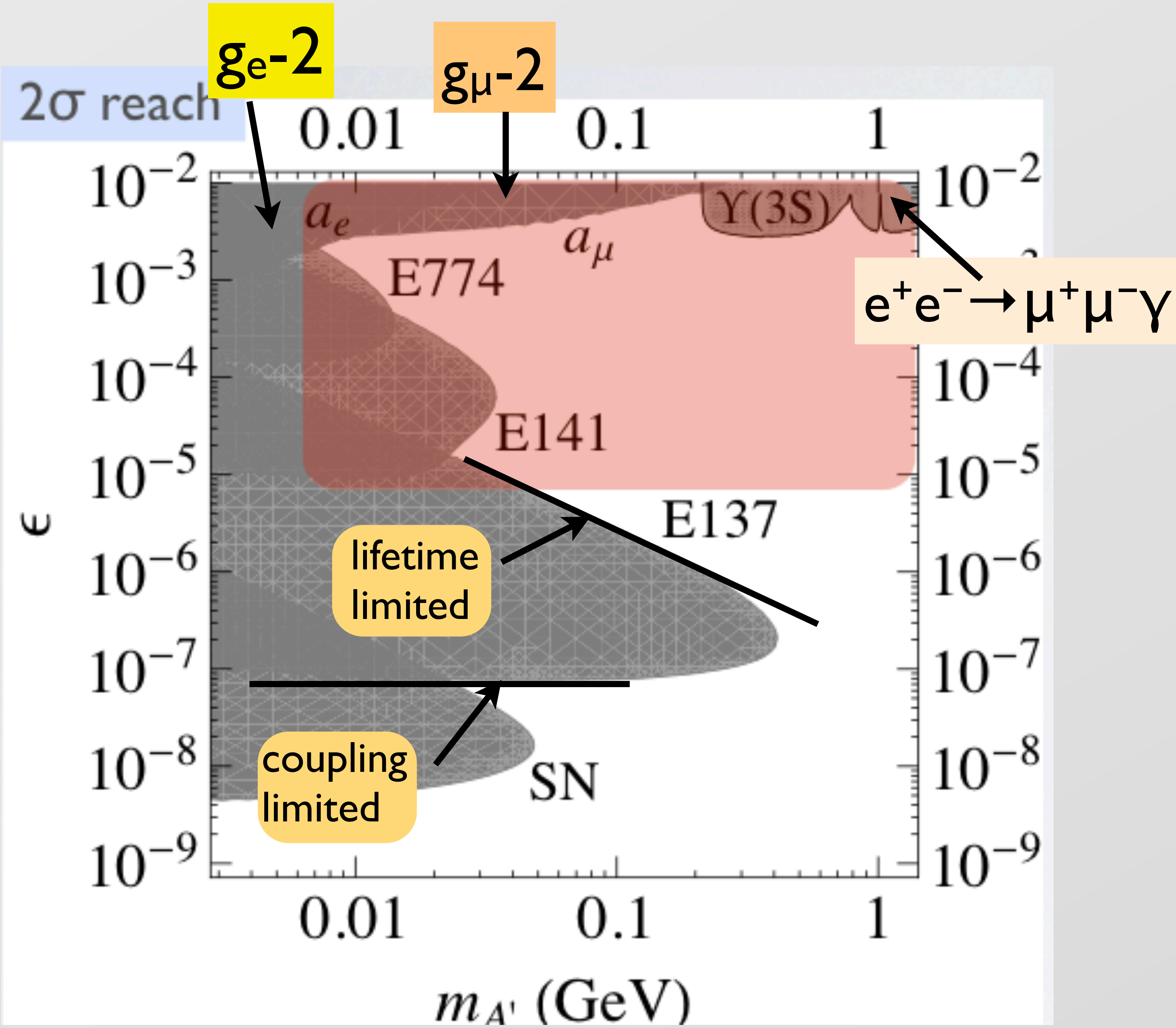
lower ε, lower mass
→ longer lifetime



[Rouven Essig]

Much of parameter space will have displaced vertex

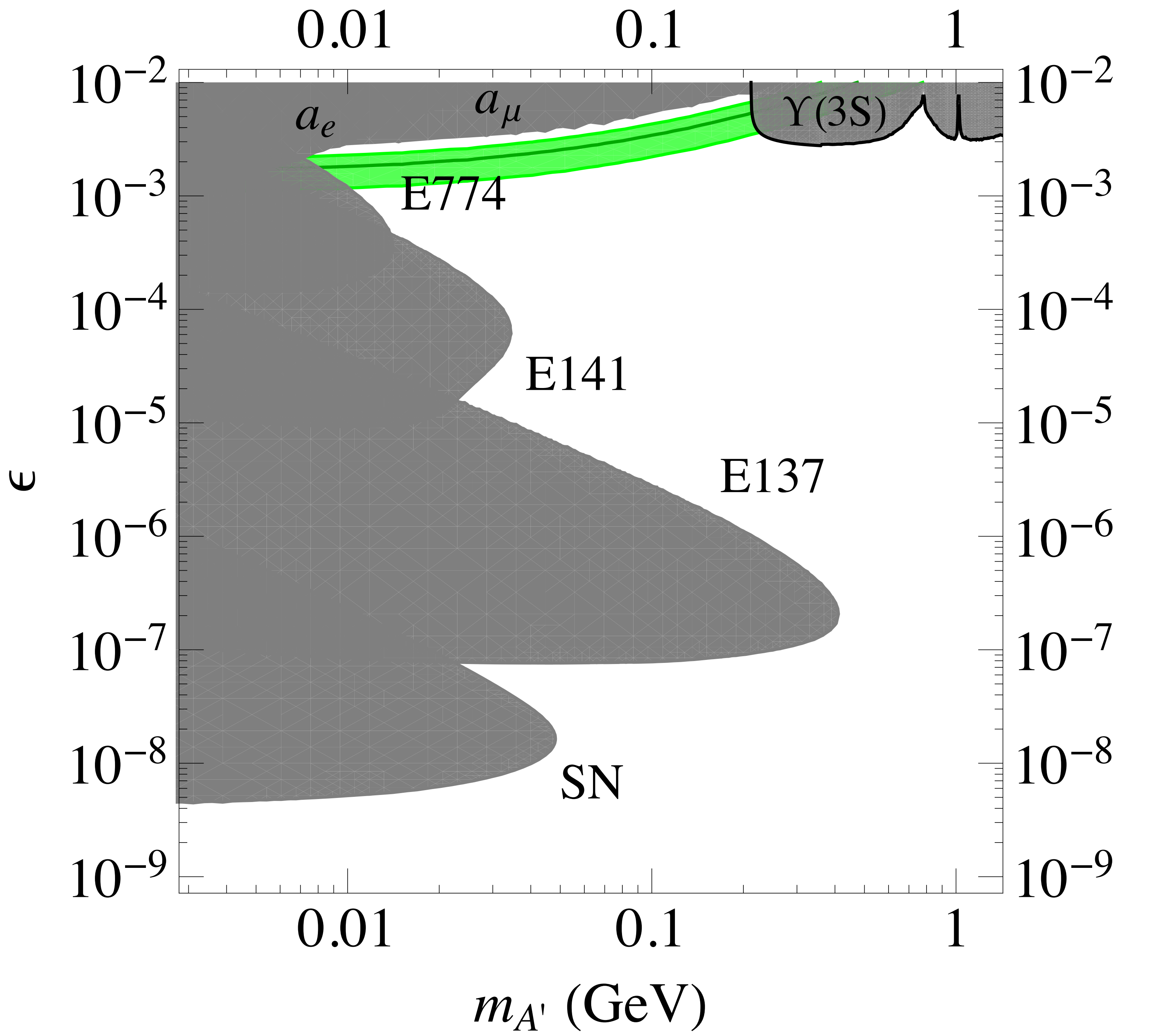
Some existing constraints



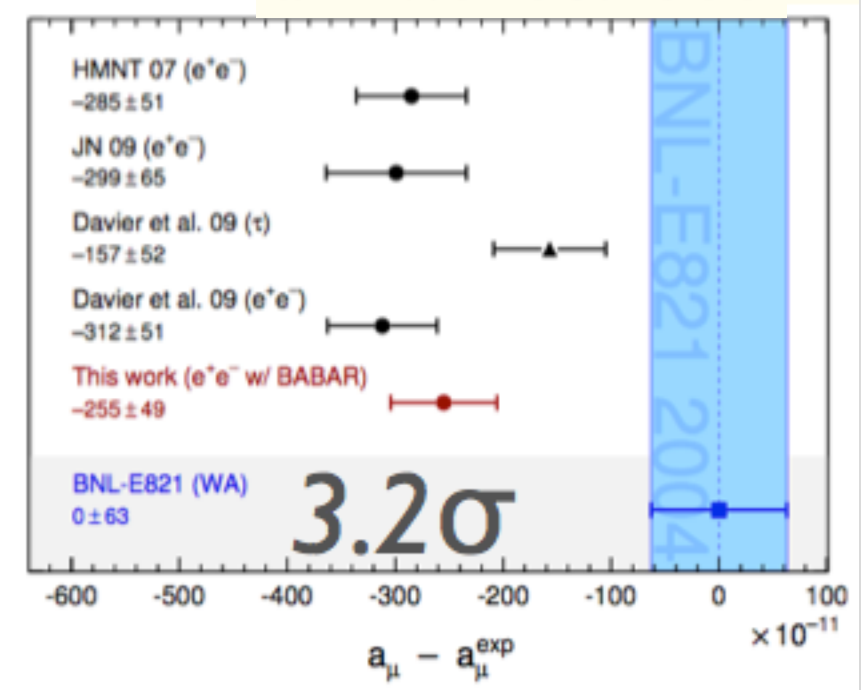
	Shield (m)	E_{beam} (GeV)	Lumi (e^-)
E137	200	20	10^{20}
E141	0.12	9	2×10^{15}
E774	0.3	27.5	5×10^{9}

Dark photons and the g-2 anomaly

If the g-2 anomaly is due to a heavy photon



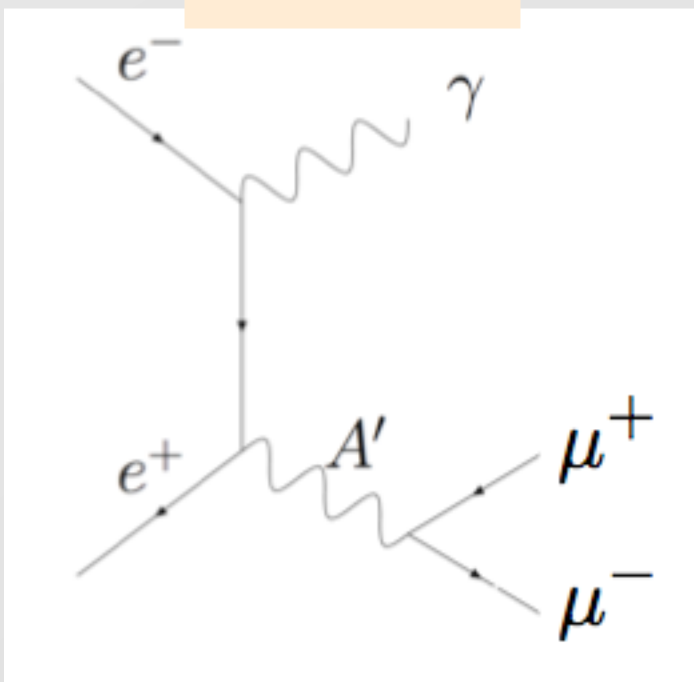
Davier *et al.*, arxiv:0908.4300



Collider vs. Fixed Target

Wherever there is a photon there is a dark photon...

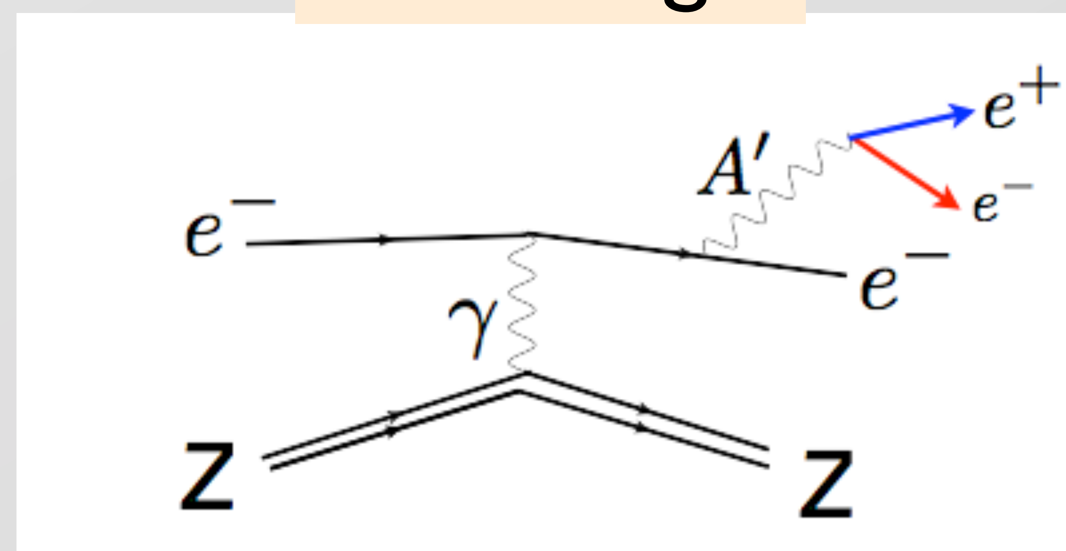
Collider



$$\sigma \sim \frac{\alpha^2 \epsilon^2}{E^2} \sim O(10\ fb)$$

$O\ ab^{-1}$ per ~~decade~~ month

Fixed Target

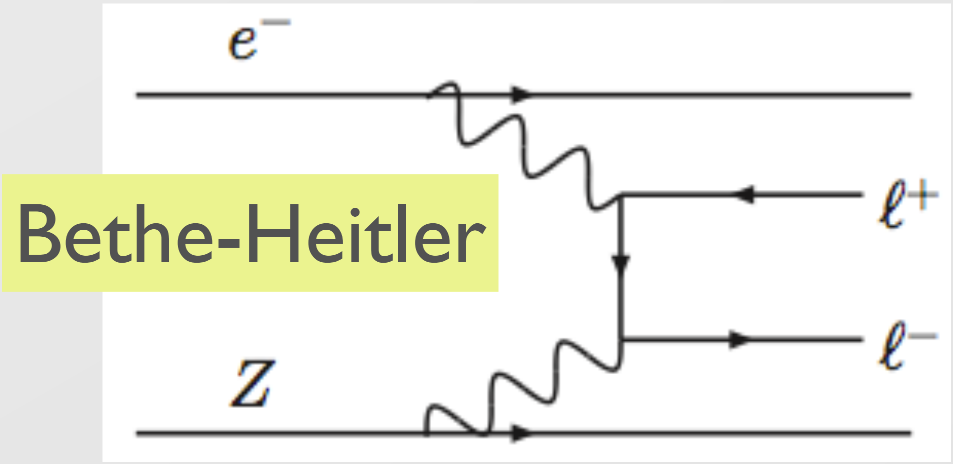


$$\sigma \sim \frac{\alpha^3 Z^2 \epsilon^2}{m^2} \sim O(10\ pb)$$

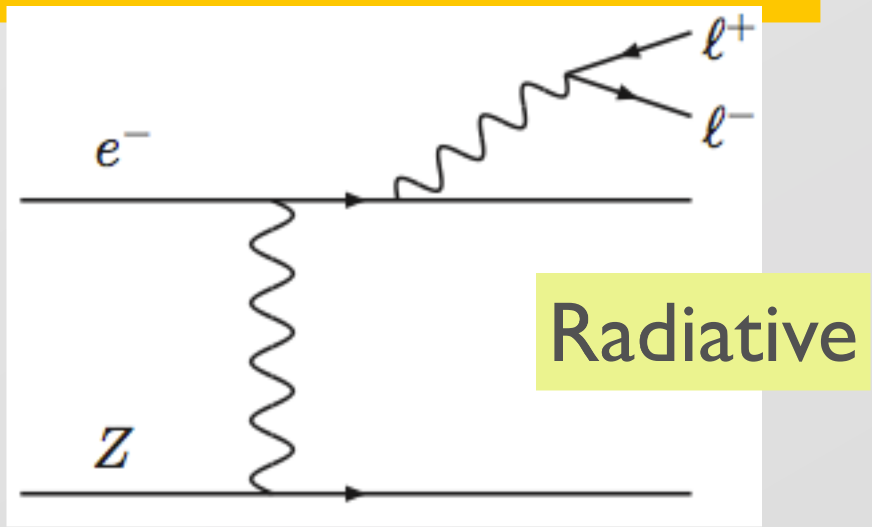
$O\ ab^{-1}$ per day

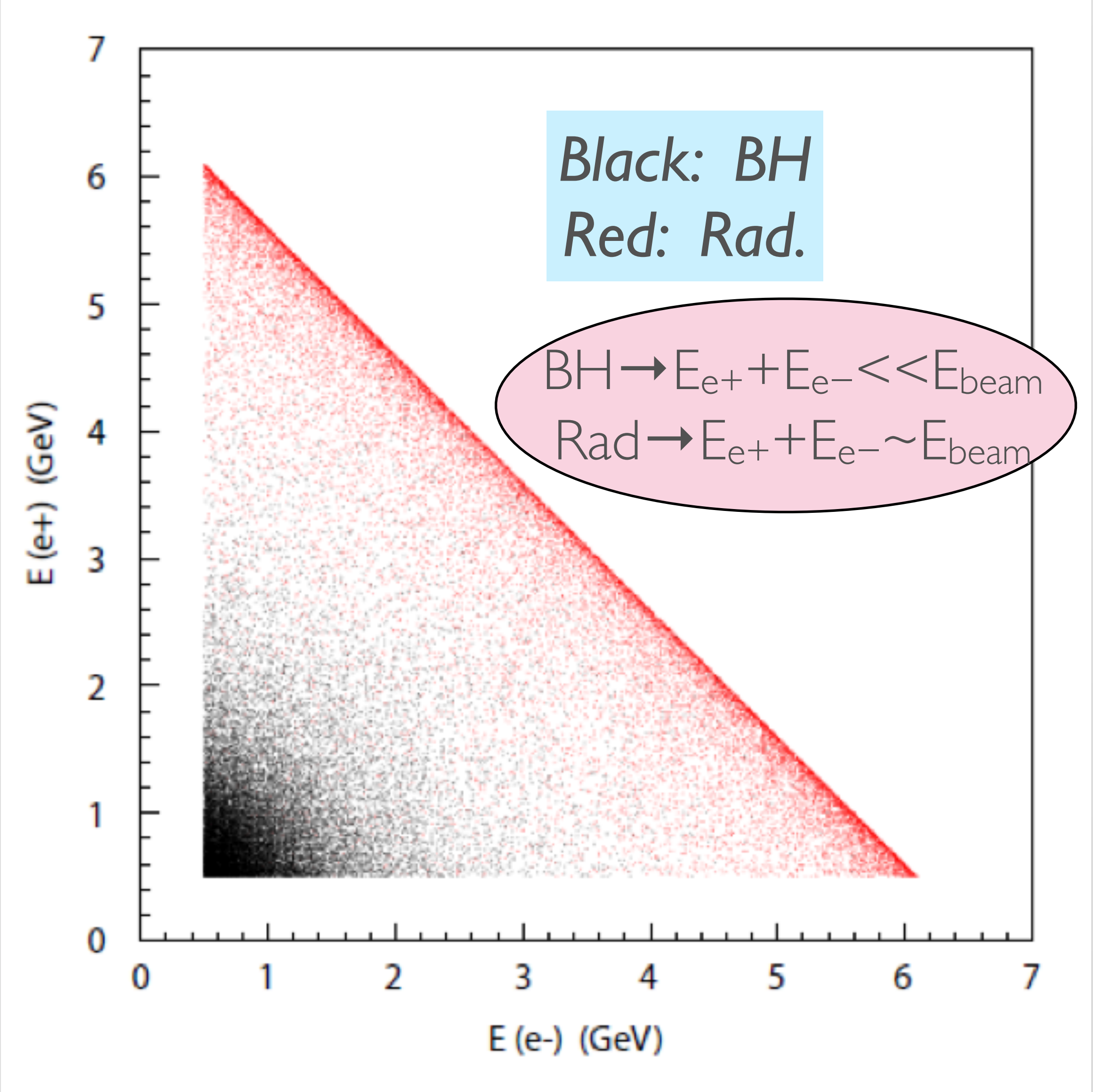
...much higher backgrounds

Kinematics at Fixed Target



Two main backgrounds





production rates of A' and radiative are related:

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

Cross-section for BH>>Radiative, but kinematics much different... Even after energy cut, BH background ~5x radiative

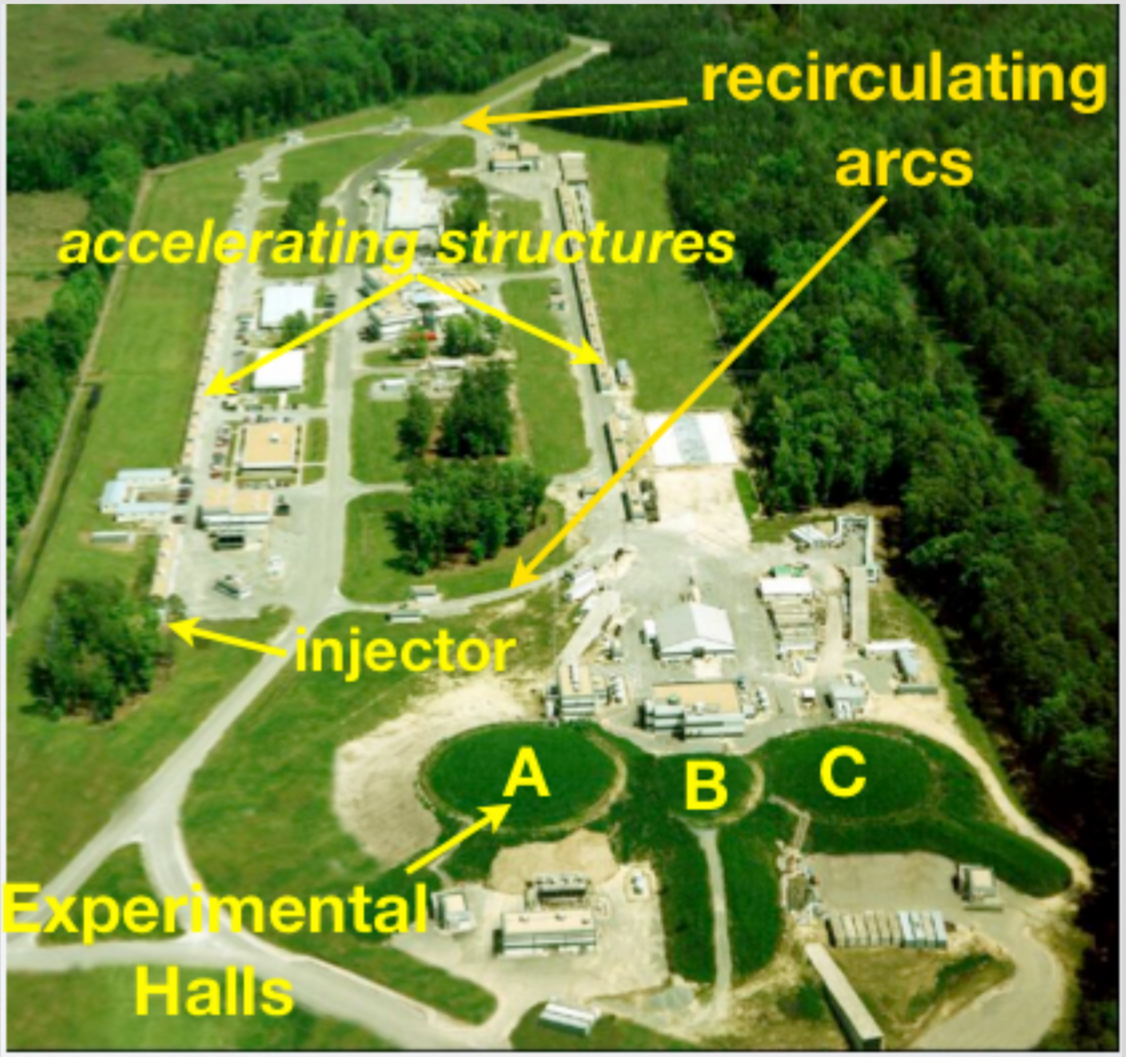
A ***P**rime* ***EX**periment @ Hall A*

BEST laid out a few methods to look for a dark photon in various ε/m(A′) regions...

Bjorken, Essig, Schuster, Toro, Phys.Rev. D80 (2009) 075018

First...slam a huge number of electrons on a target and look for a bump!

	Hall A	ignore this
Experiment	*APEX*	
E_{beam}	$n \times 1.1$ GeV	
I_{beam}	$<200\ \mu A$	
bunch separation	*~ Continuous*	



Who is APEX?

Search for a New Vector Boson A' Decaying to e^+e^-

A Proposal to Jefferson Lab PAC37

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The Hall A Collaboration

APEX 2010

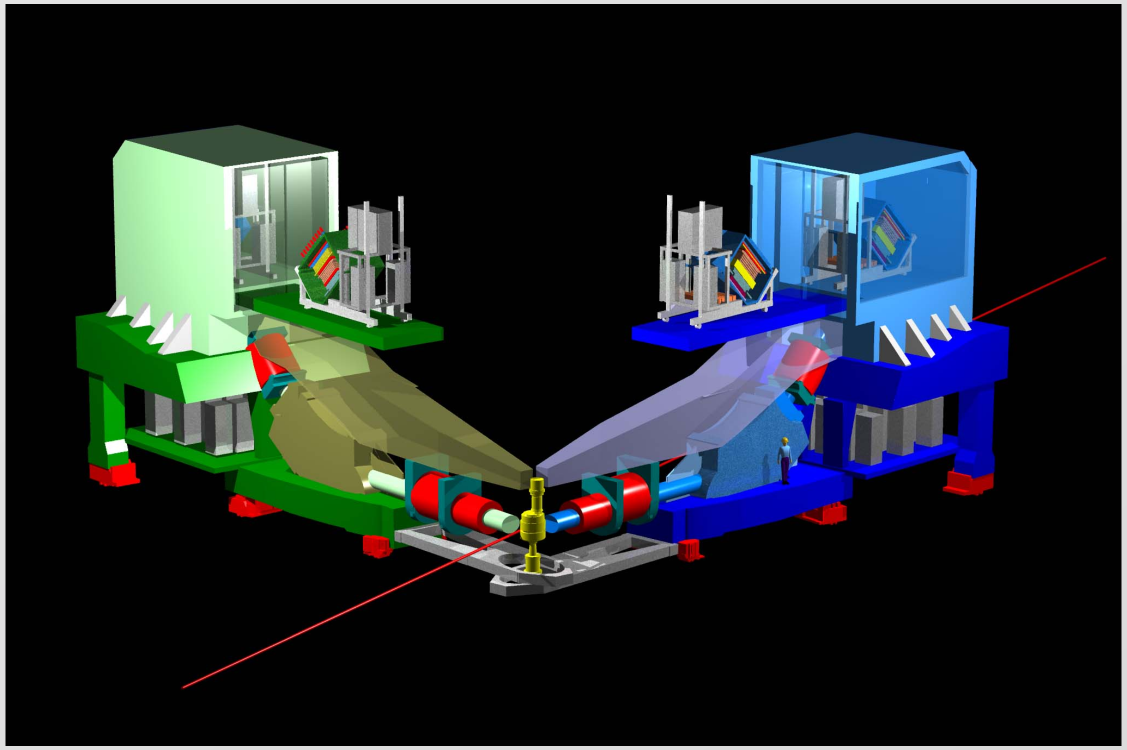
APEX @ Hall A

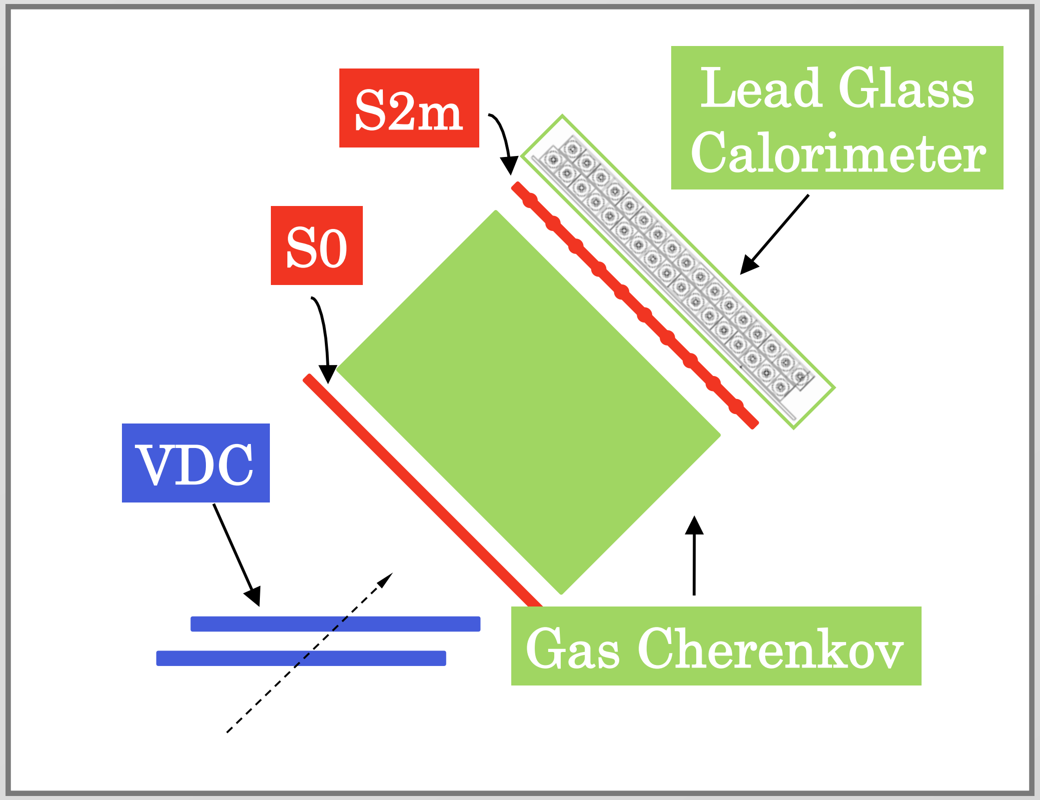
APEX uses the HALL A dual armed spectrometers to reconstruct the e^+e^- pair.

➡drift chamber (tracking), gas Cherenkov (PID), hodoscopes(trigger)
➡great mass resolution (~MeV), small acceptance (~0.1%)
➡mass resolution dominated by angular resolution (optics+tracker), MS in target

In July, 2010, APEX completed successful test run

- primary goal was to confirm calculated background rates; make sure we wouldn't burn down the detector hall for full run
- we were also able to take some interesting physics data

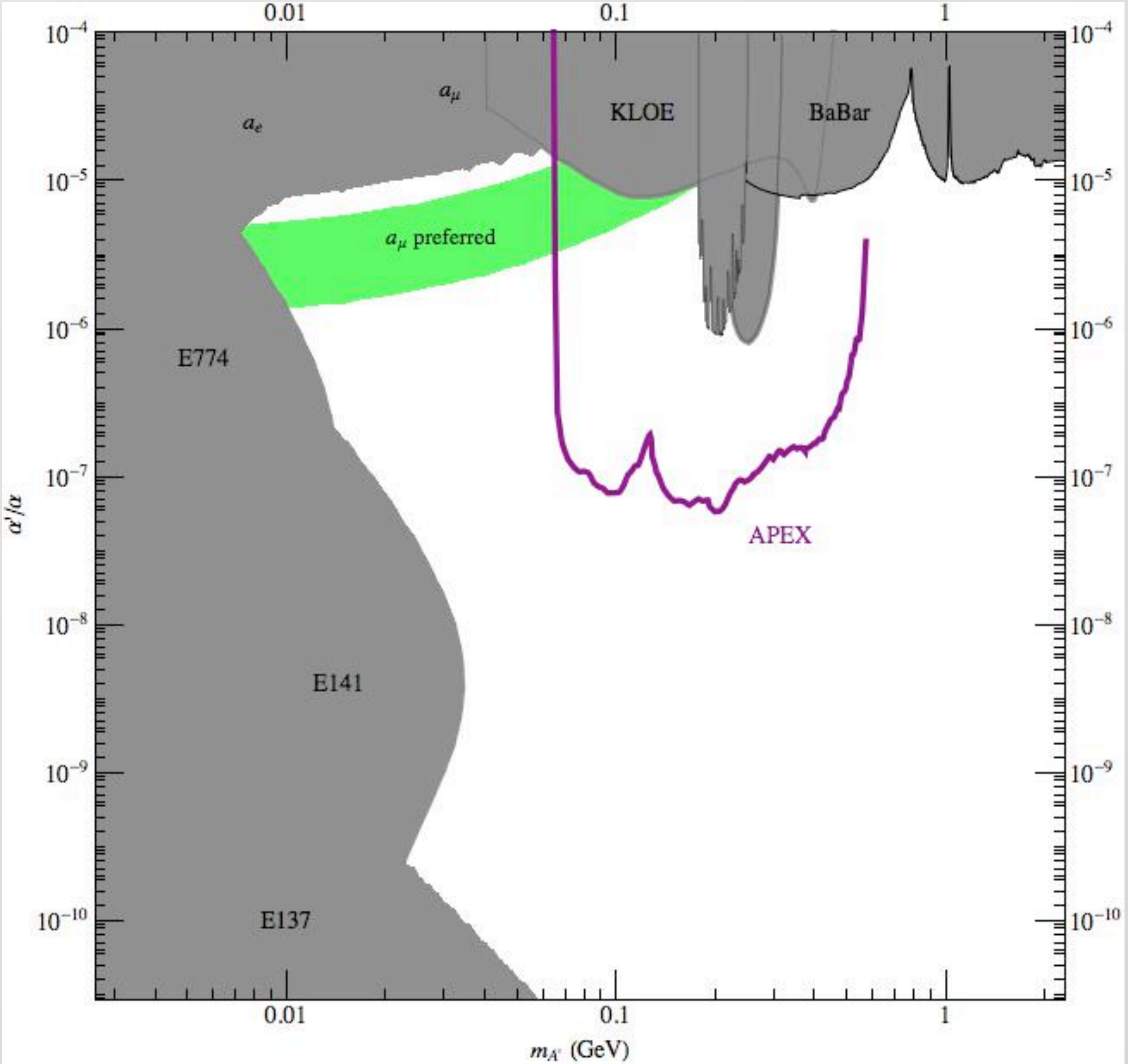




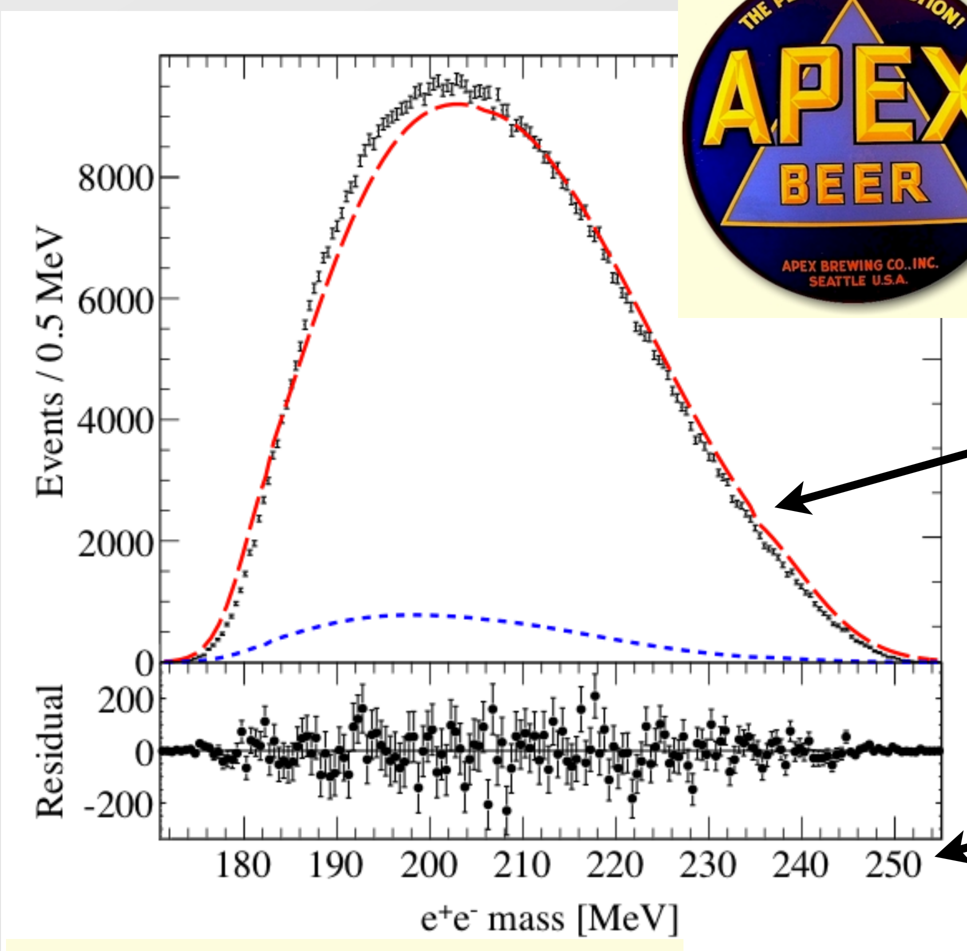
APEX Expected Reach

Effectively scan the parameter space by running at various beam energies and spectrometer settings

Total beam time: ~34 days



APEX Test Run Results!



Phys. Rev. Lett. 107 (2011) 191804.

APEX (and A1) have taken successful test runs and published physics results!

- black points→data
- red→MC (madgraph)
- blue→e+e− accidentals

small mass range...
reflects small acceptance.

- We were able to take quality data at ~high rate (4kHz; DAQ limited), and the trident backgrounds were as expected. Physics data taken at 2.2GeV on X_0~0.3% Ta target
- Excellent mass resolution(→angular resolution) is the key for physics...for test run:

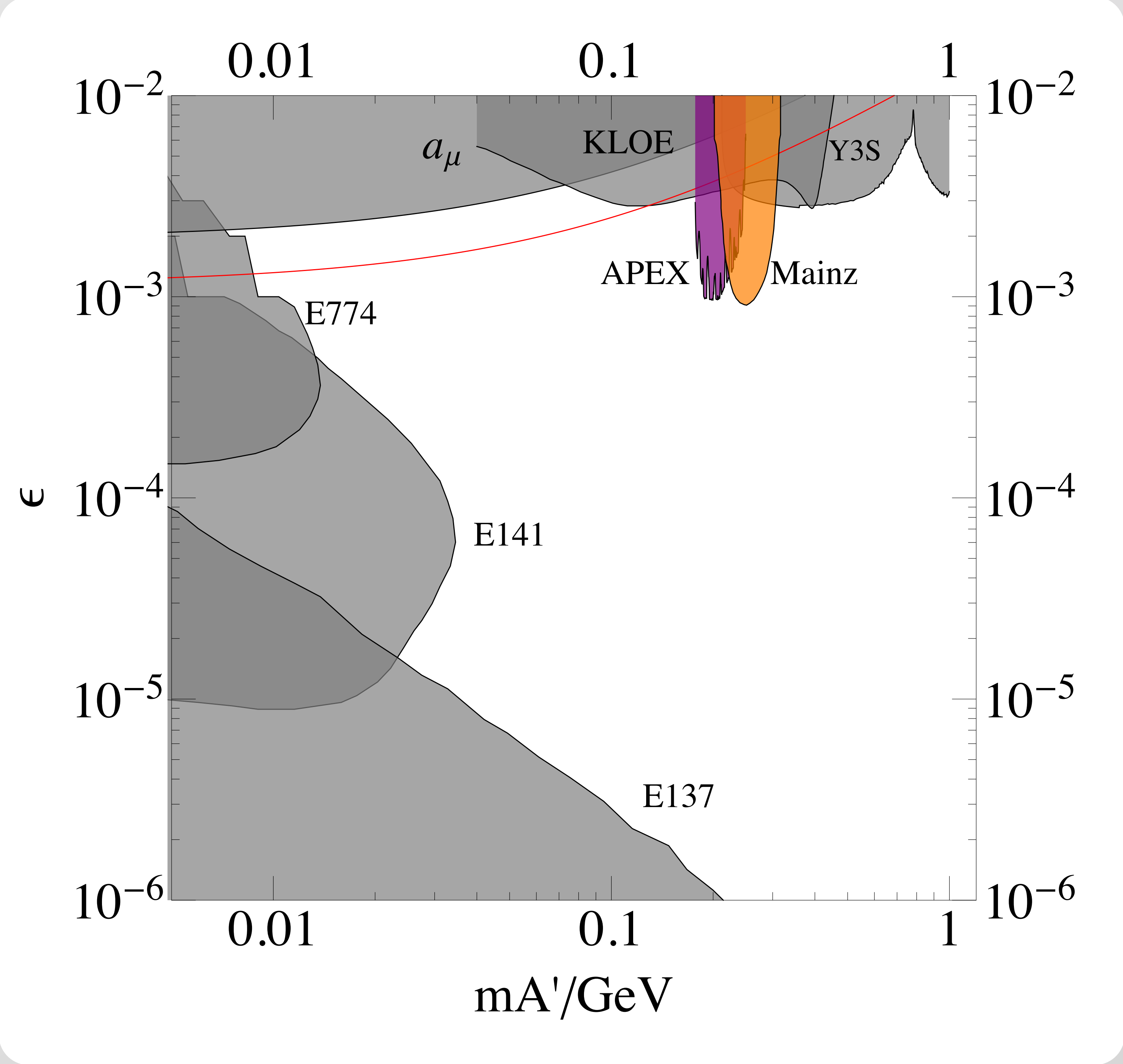
in mrad	optics	tracking	MS in target
σ(horiz)	0.11	~0.4	0.37
σ(vert)	0.22	~1.8	0.37

→ ***σ(M)~1MeV***

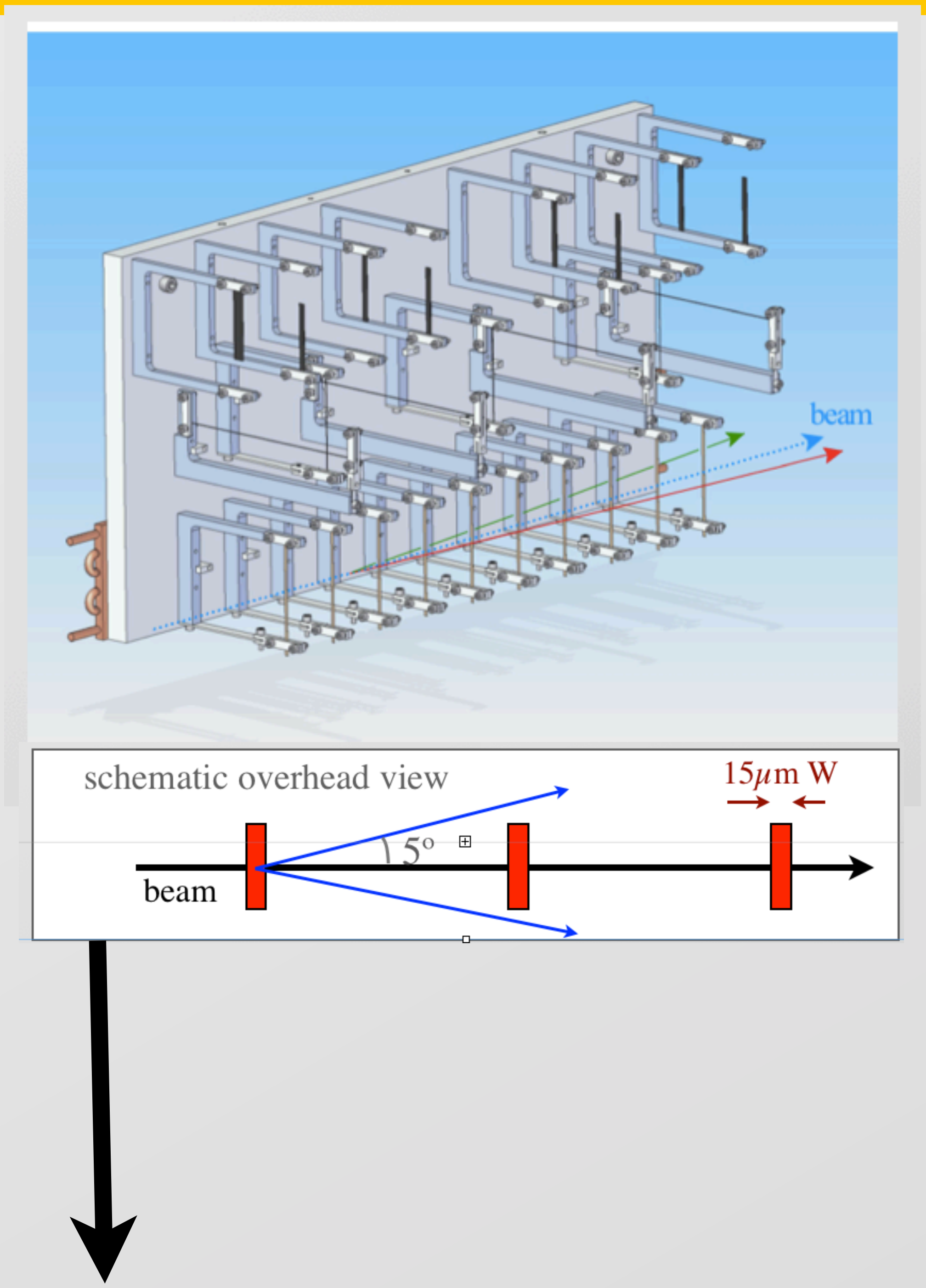
Brute force constraints: APEX & A1

	Hall A	MAMI
Experiment	*APEX*	*A1*
E_{beam}	$n \times 1.1$ GeV	0.855 GeV
I_{beam}	$<200\ \mu A$	$90\ \mu A$
bunch separation	*~ Continuous*	

Competition!!!

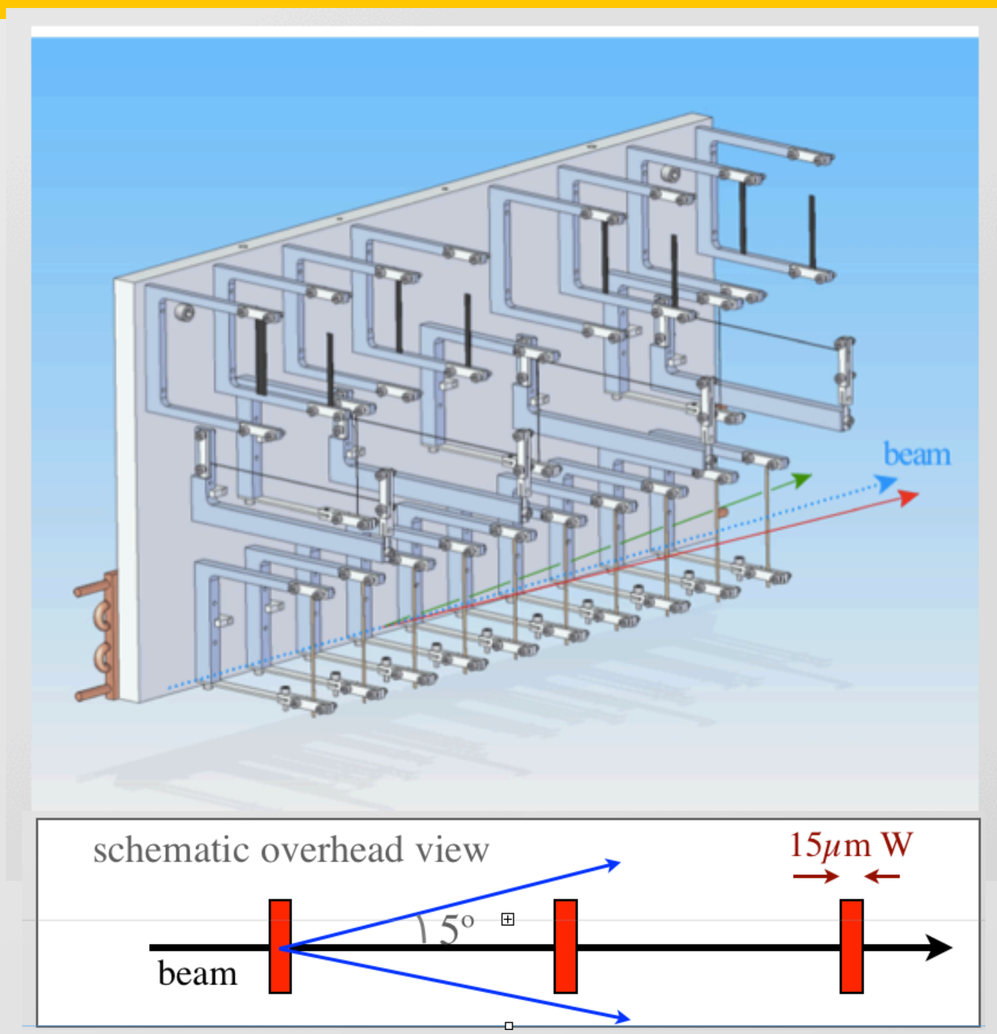


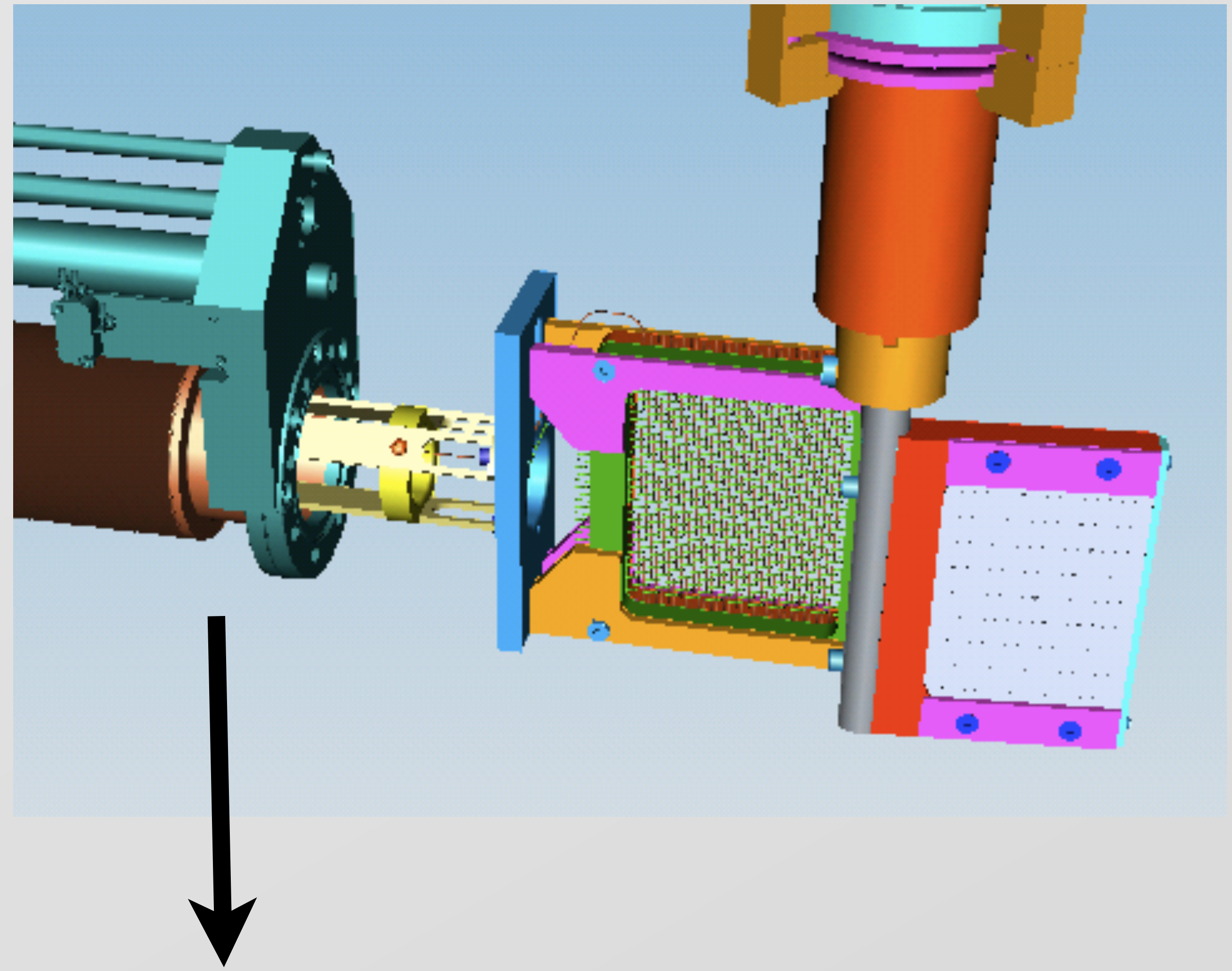
Future plans for APEX



(SLAC designed) smart target...beam sees as much as X_0=8% but daughter electrons only see X_0~0.3%

Future plans for APEX





(JLAB designed) active sieve slit for optics calibration: 2-layer (xy) scintillating fiber detector. Improve the efficiency & reliability of optics calibration.

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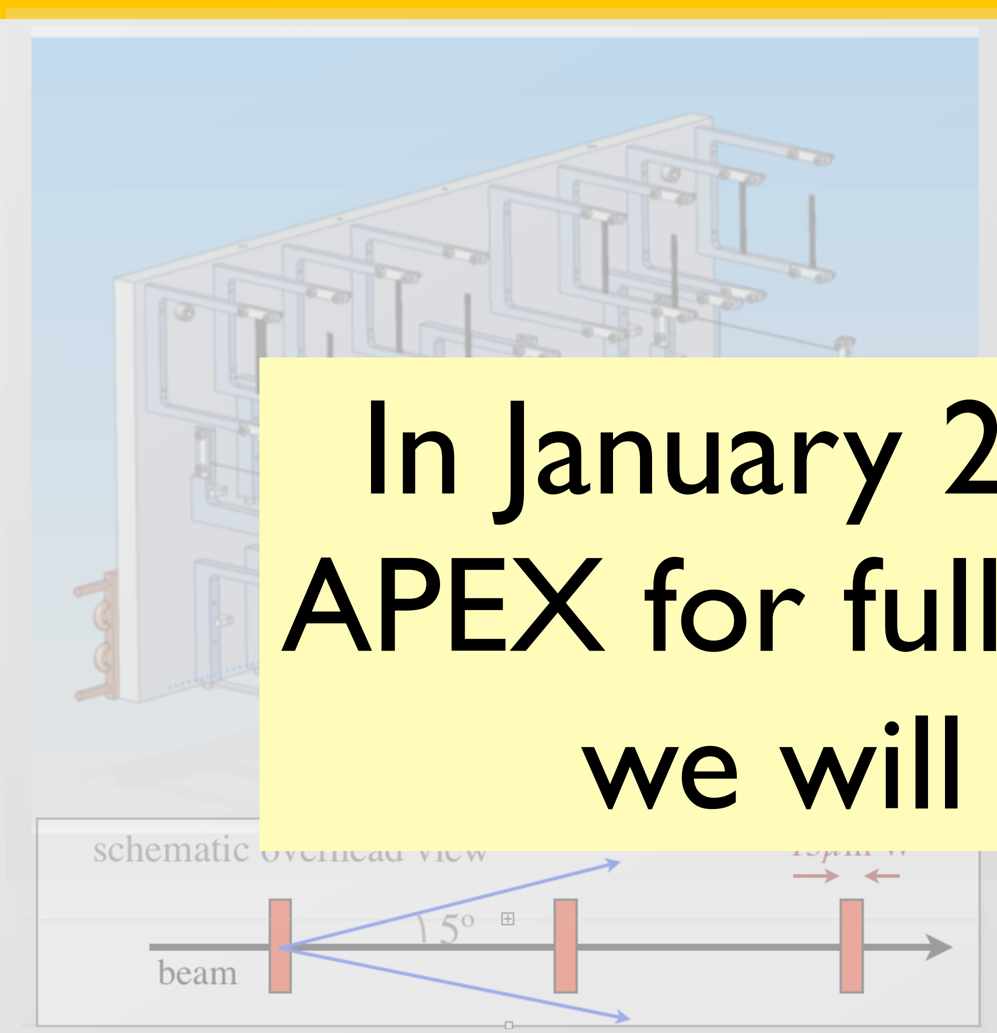
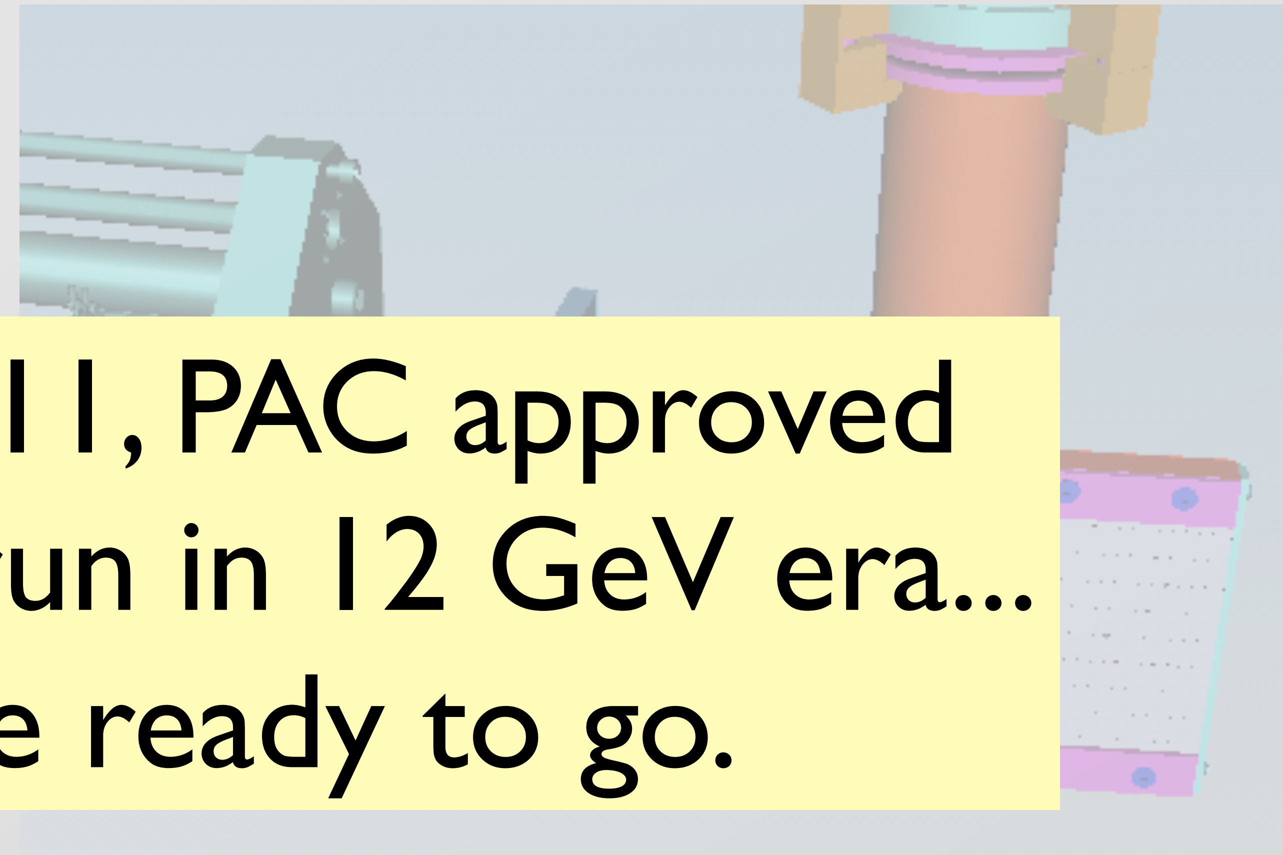




In January 2011, PAC approved APEX for full run in 12 GeV era... we will be ready to go.

(JLAB designed) active sieve slit for optics calibration: 2-layer (xy) scintillating fiber detector. Improve the efficiency & reliability of optics calibration.

(SLAC designed) smart target...beam sees as much as X_0=8% but daughter electrons only see X_0~0.3%

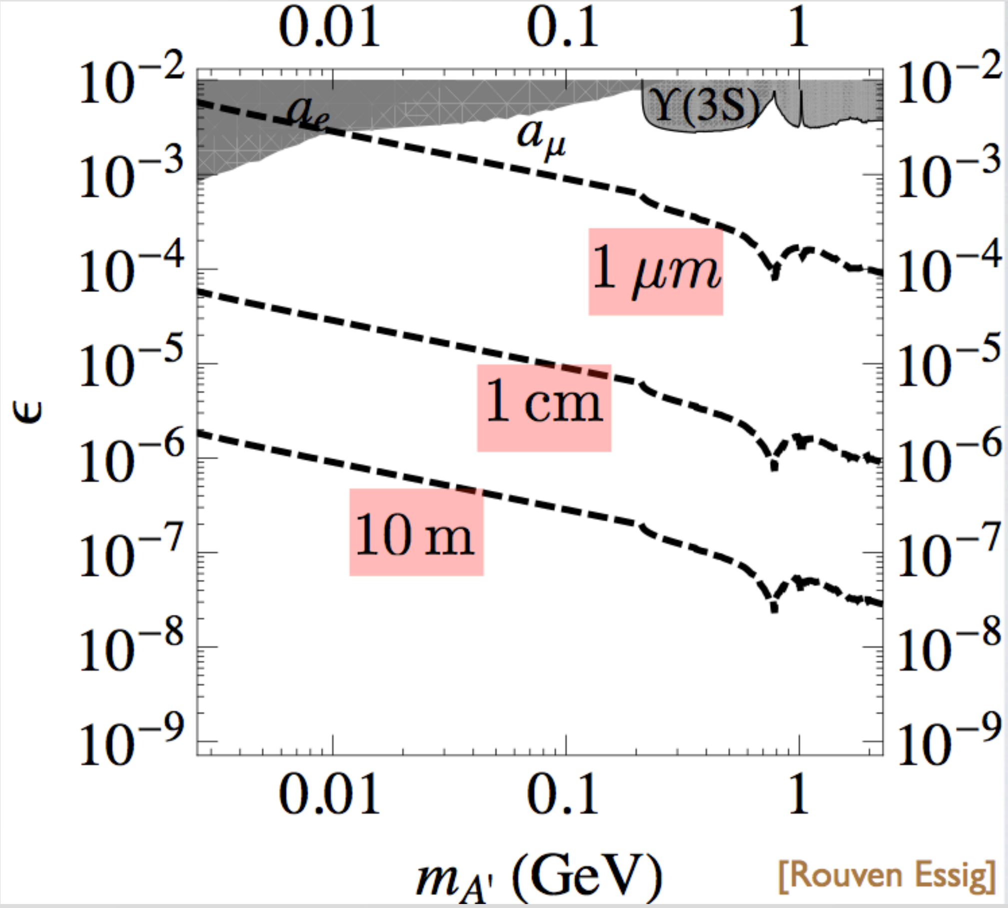
...a little more subtle...

Problem: cover the low coupling (<10^{-4}), intermediate mass (20-200 MeV) region

•low rate ➪ intense beam

•high background ➪ high resolution

•***still*** high background ➪ measure displaced vertex



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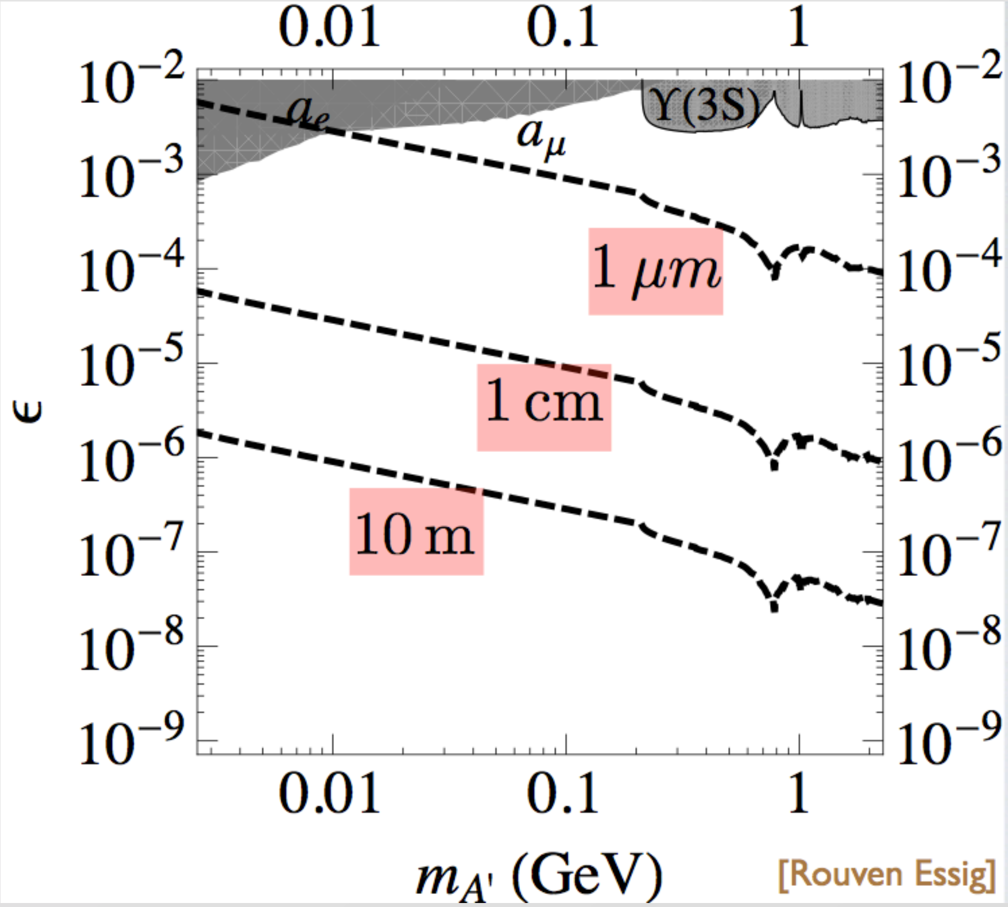
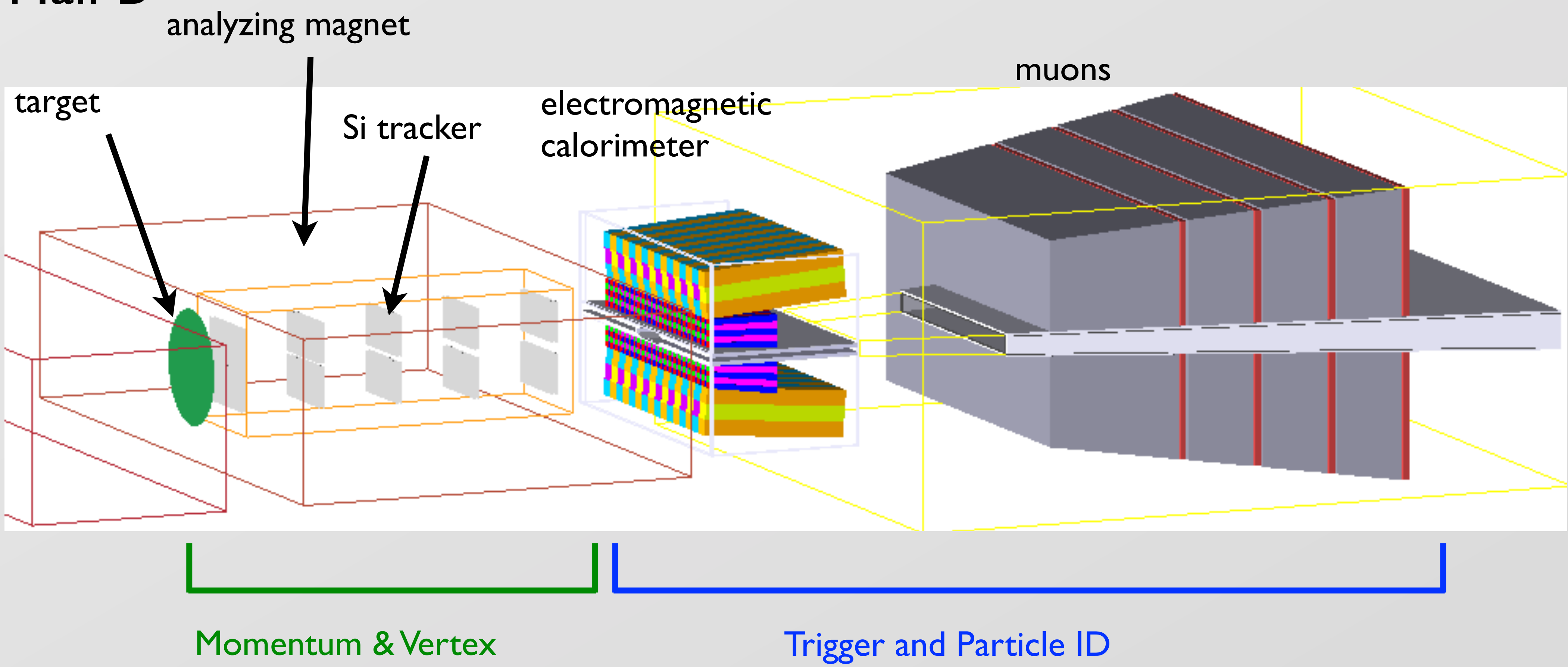


Solution: ***HPS***

Heavy Photon Search @ Hall B

•high rate, high acceptance, high mass & vertex resolution detector intended to run in Hall B



•Silicon strip tracker inside an evacuated dipole for excellent vtx & mom resolution. Use Si sensors donated from Fermilab & APV25 readout chips
•Borrow & reconfigure the CLAS inner calorimeter for high rate triggering

Who is HPS?

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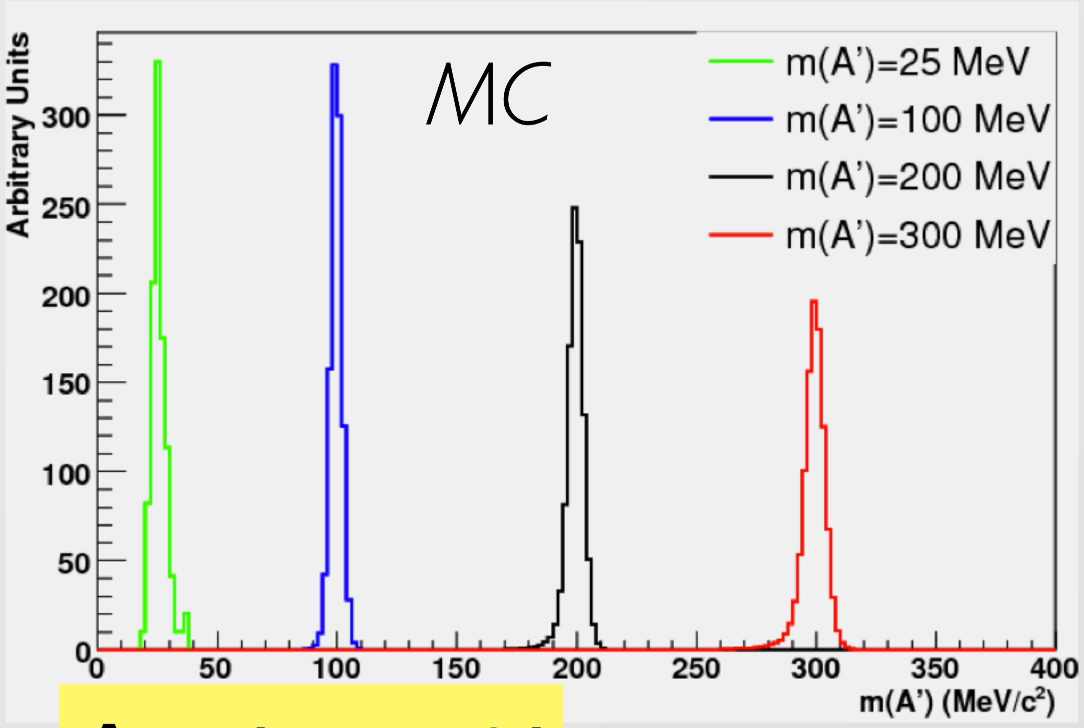
(Dated: May 7, 2012)

Proposal submitted
Dec 1, 2010

HPS
HEAVY PHOTON SEARCH

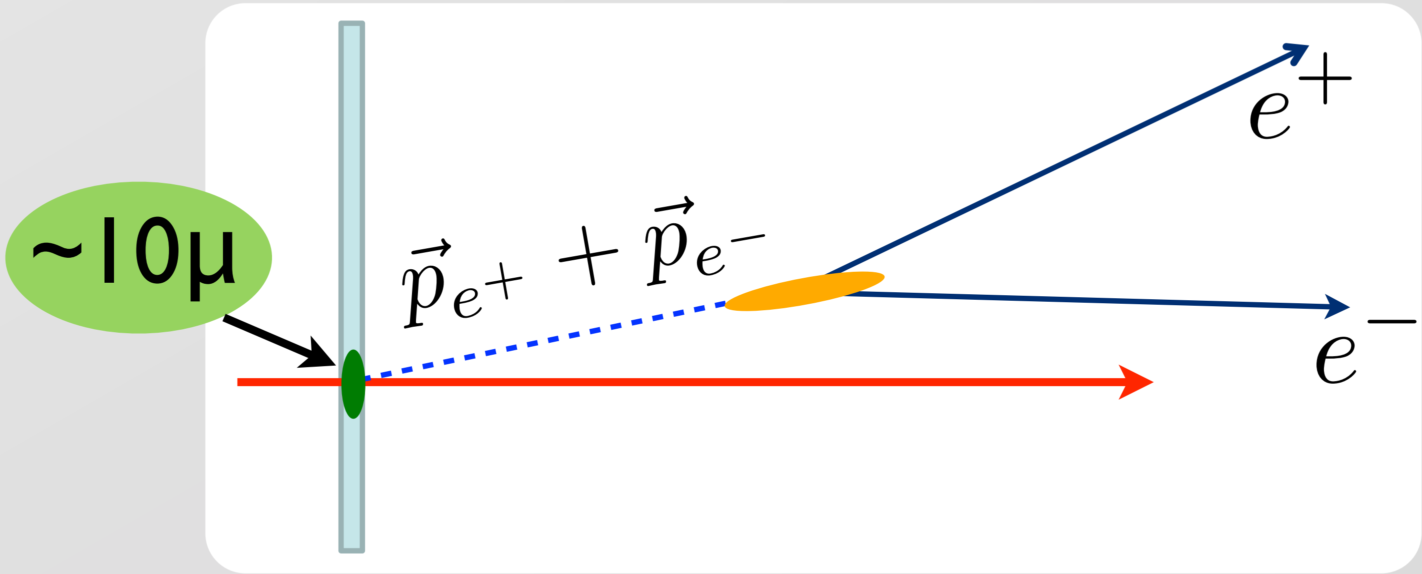
A Proposal to Search for Massive Photons at Jefferson Laboratory

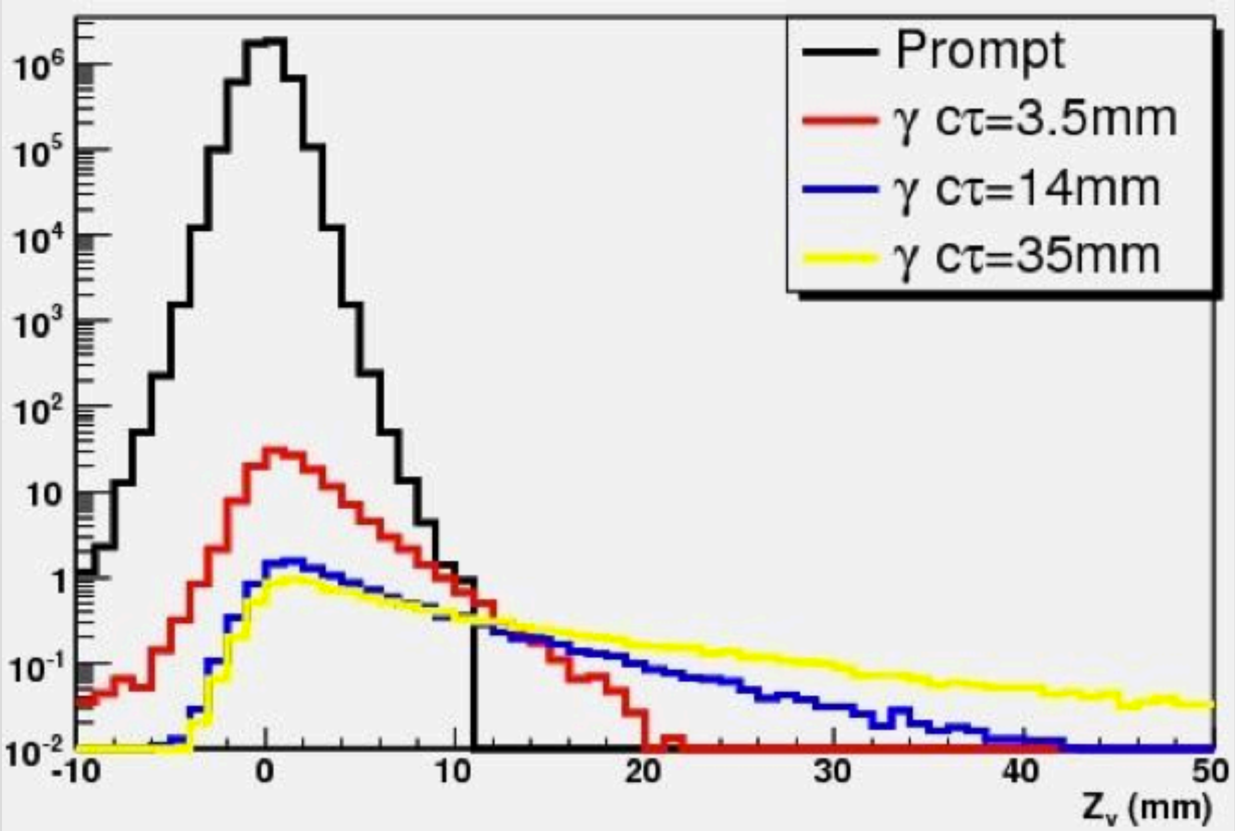
The HPS approach



Δm/m~1%

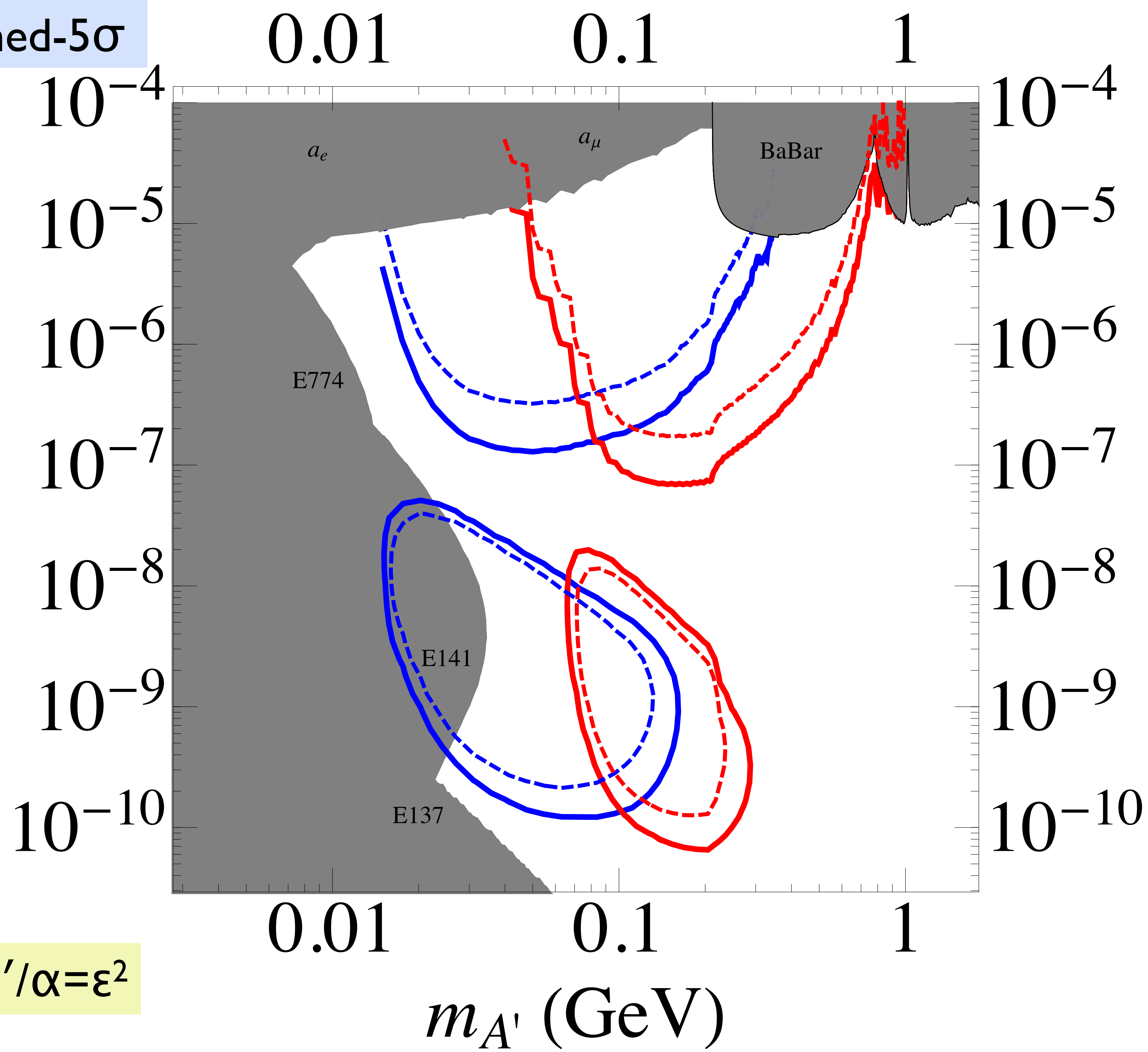
- good mass resolution, dominated by MS in the detector
- use small beam-spot (~10μm) to constrain A´ to point back to IP
  - beat down vertex tails of prompt decays to ~ 0 expected background
  - tails dominated by fake tracks...rate dependent
- Estimate coverage $10^{-4} > \varepsilon > 10^{-5}$ for 200>mA´>20MeV
  - running 3 months each at E_{beam}=2.2 and 6.6 GeV





HPS Expected Reach

solid-2σ
dashed-5σ



$\alpha'/\alpha=\varepsilon^2$

Blue:
200nA @ 2.2GeV
target: 0.125%

Red:
450nA @ 6.6GeV
target: 0.25%

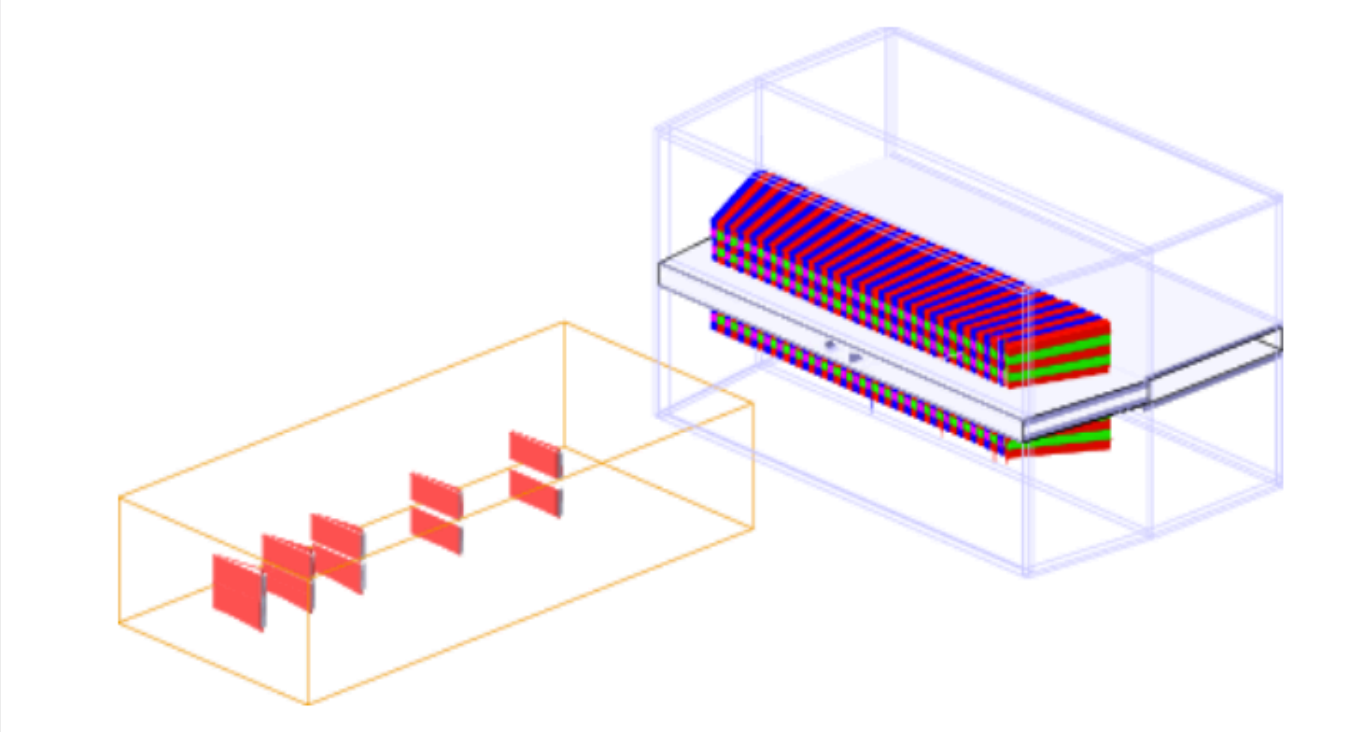
3 months of beam at each energy

HPS Proposal → Test Run

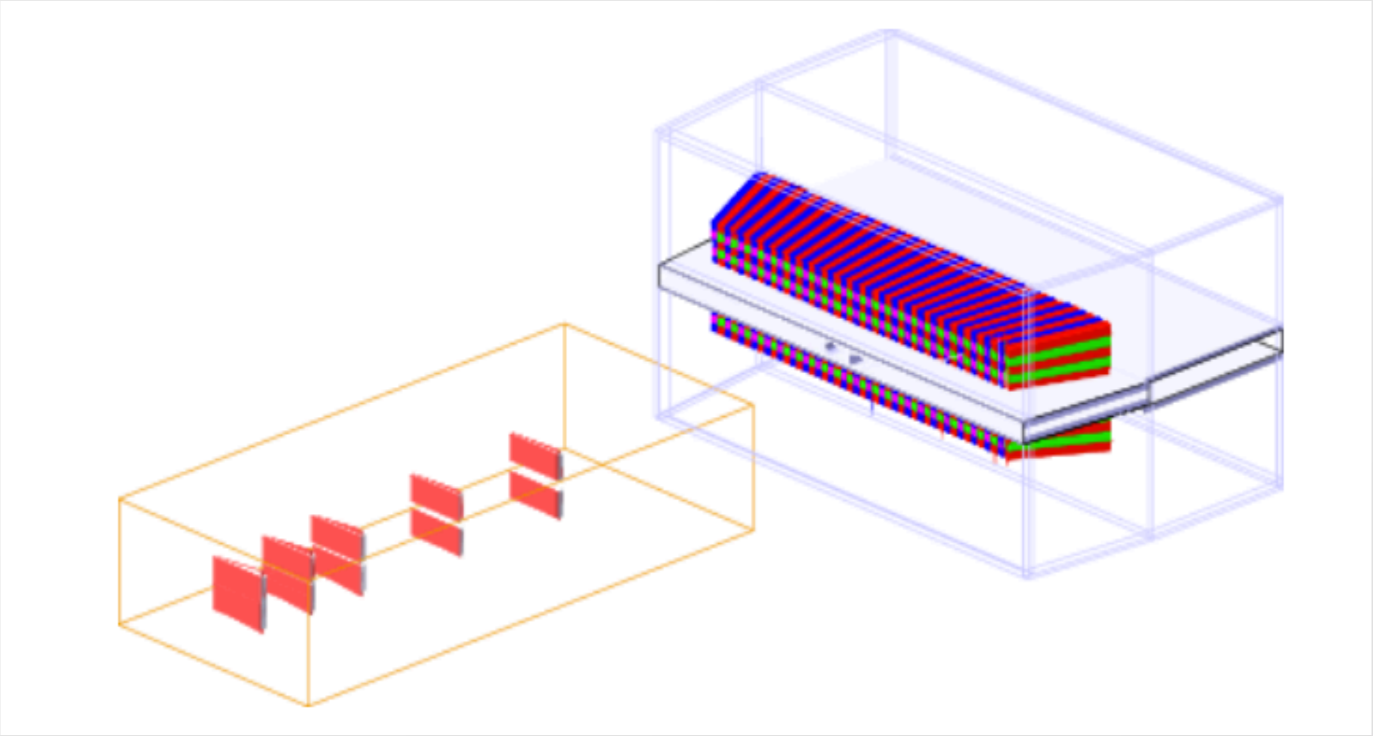
Proposal conditionally approved by PAC, contingent on successful test run, aimed at showing our background estimates, trigger rates and detector performance estimates were reasonable...

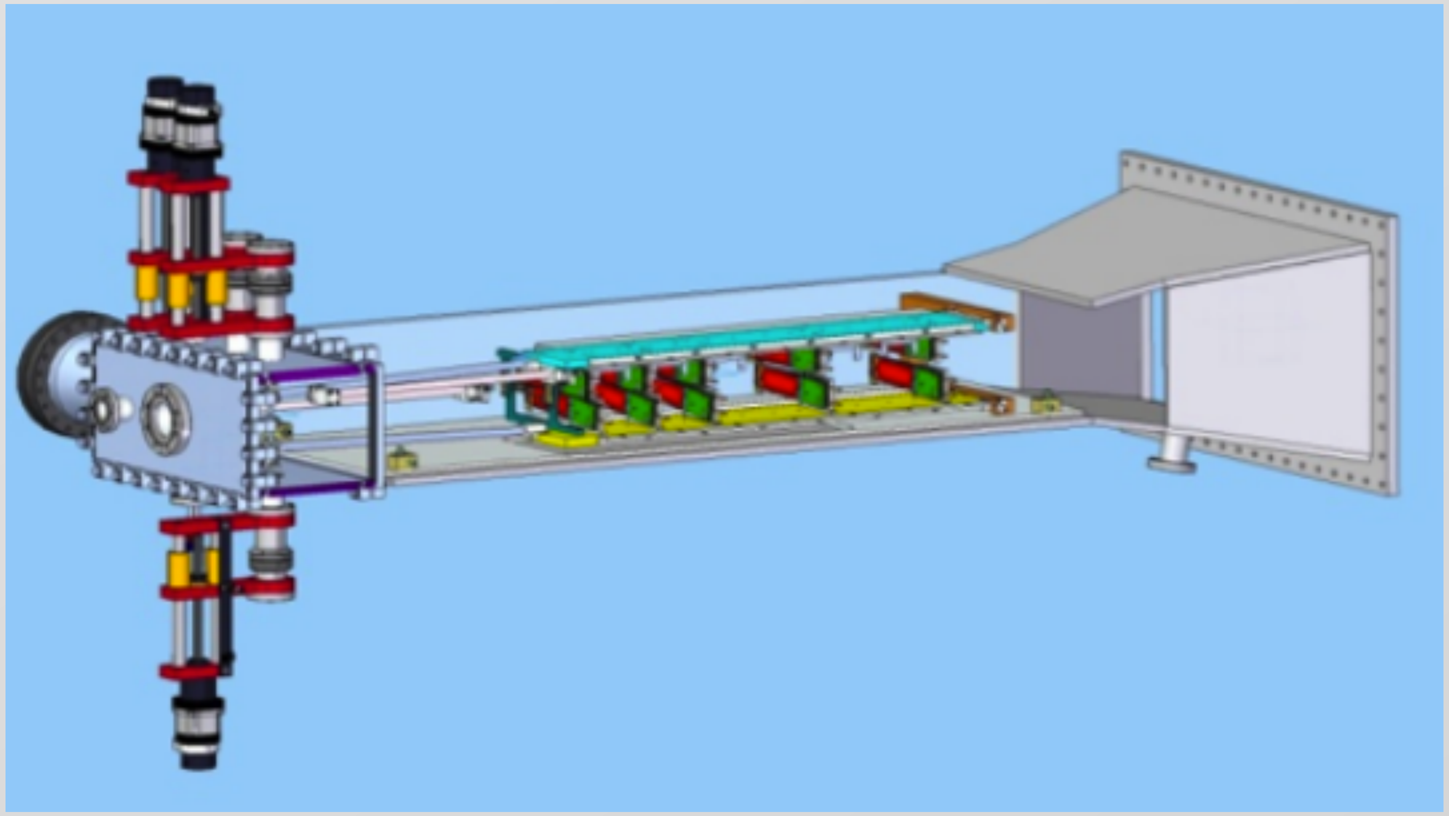
- build scaled down version of HPS
  - 5 double layers of Si tracker; one sensor each top/bottom; smaller ECAL; no muons
  - use the existing pair spectrometer magnet (+ chicane)
- proposal to build this detector submitted to DOE in Feb. 2011 & approved in May 2011

...so we built it.

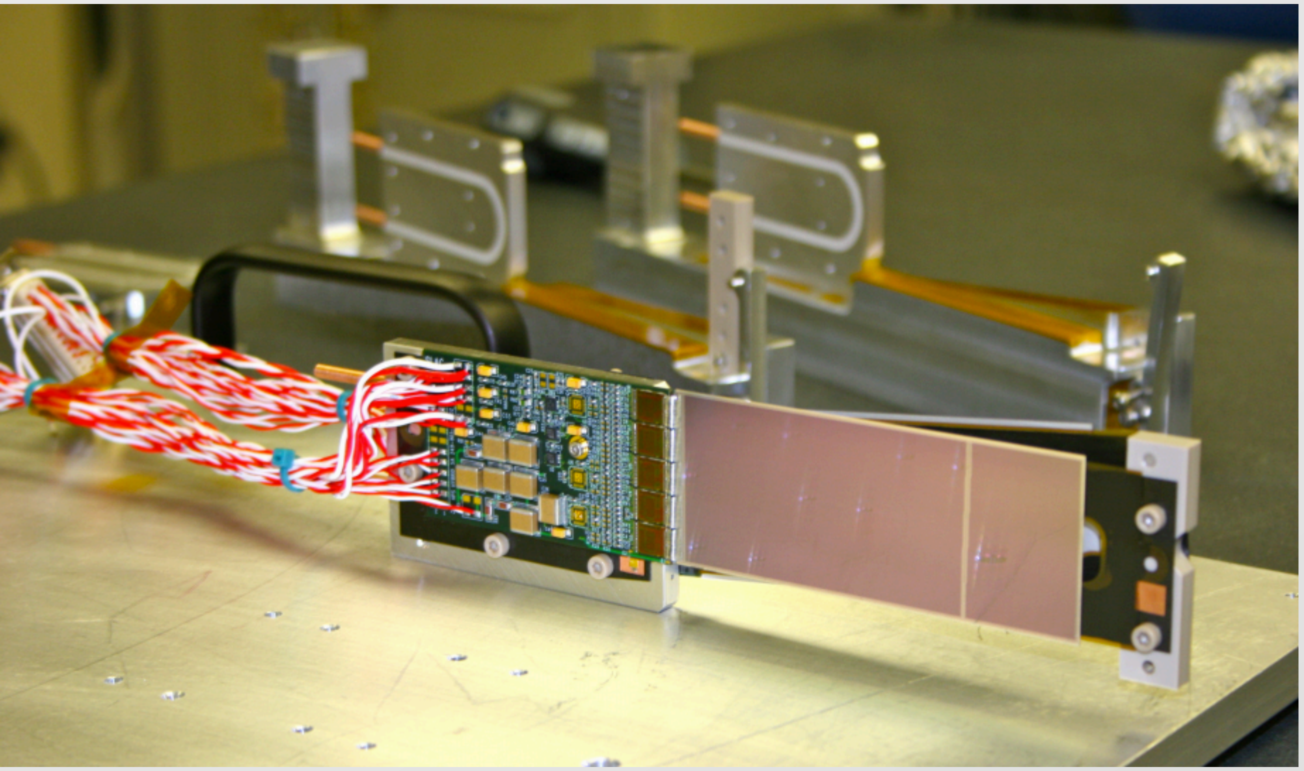


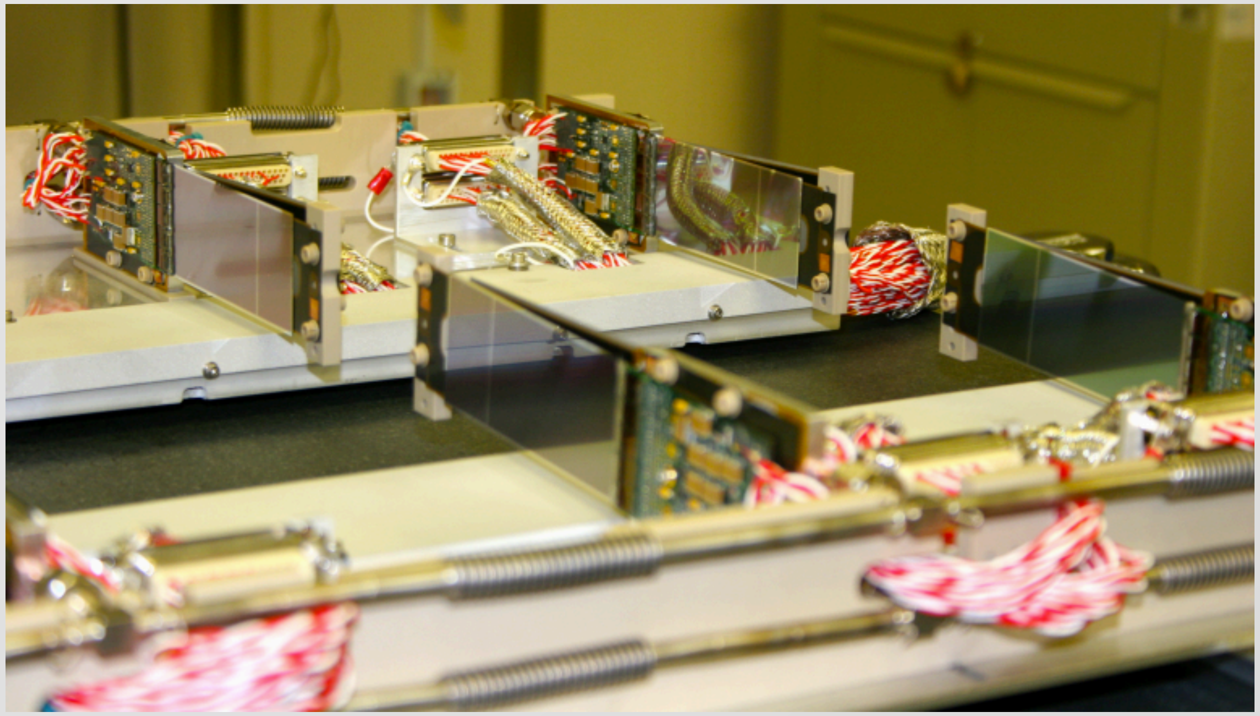
The HPS Test Detector

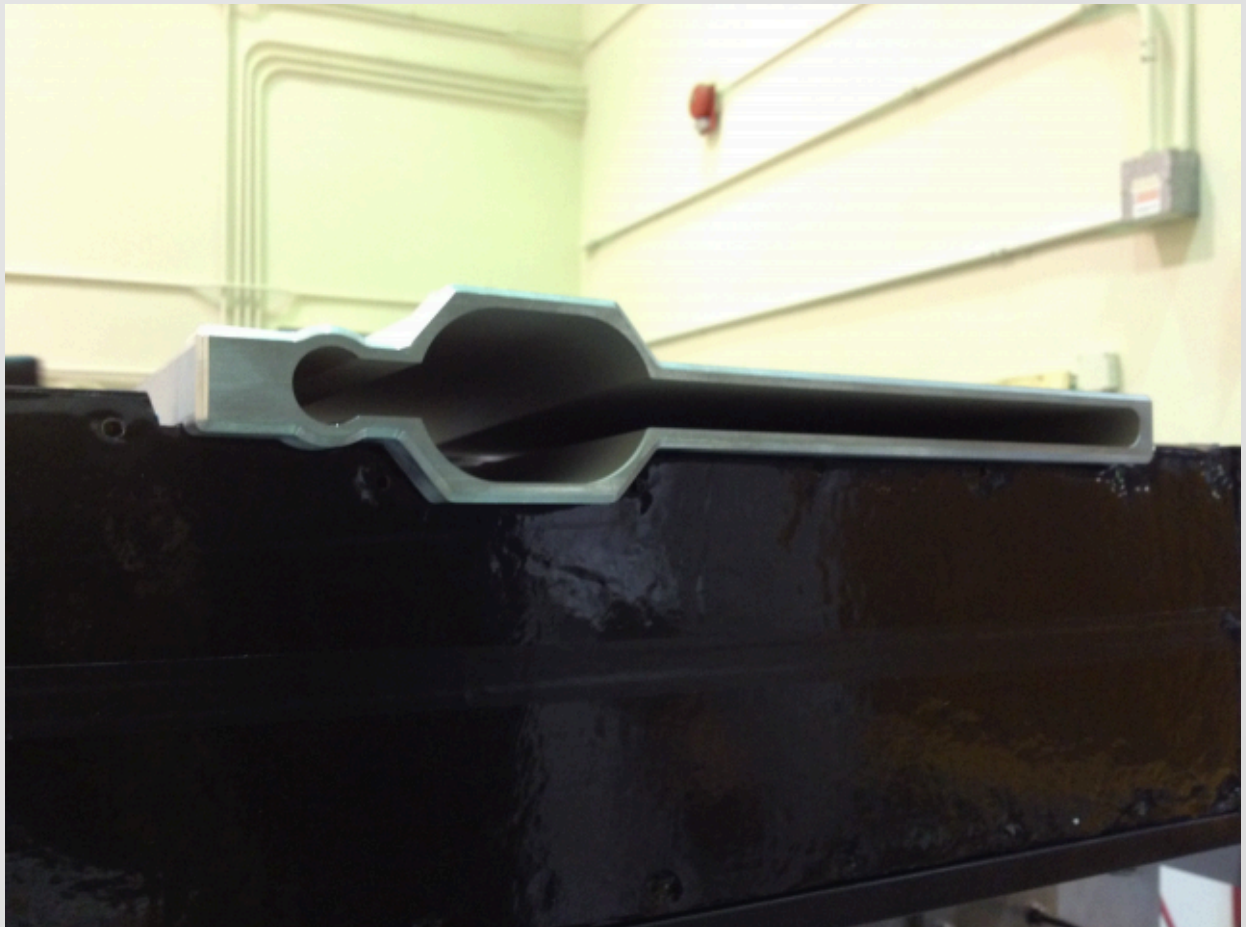




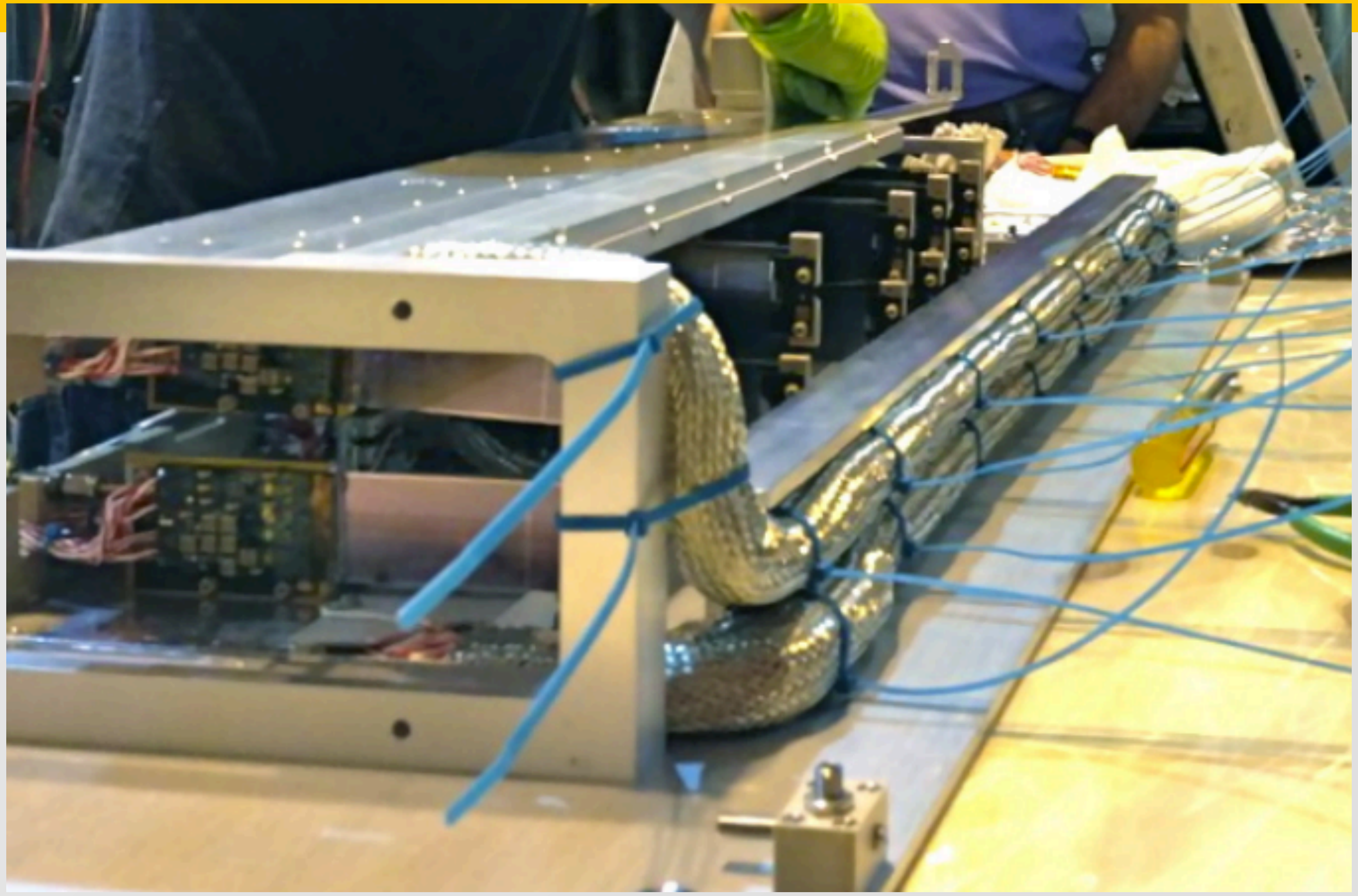
The HPS Test Detector

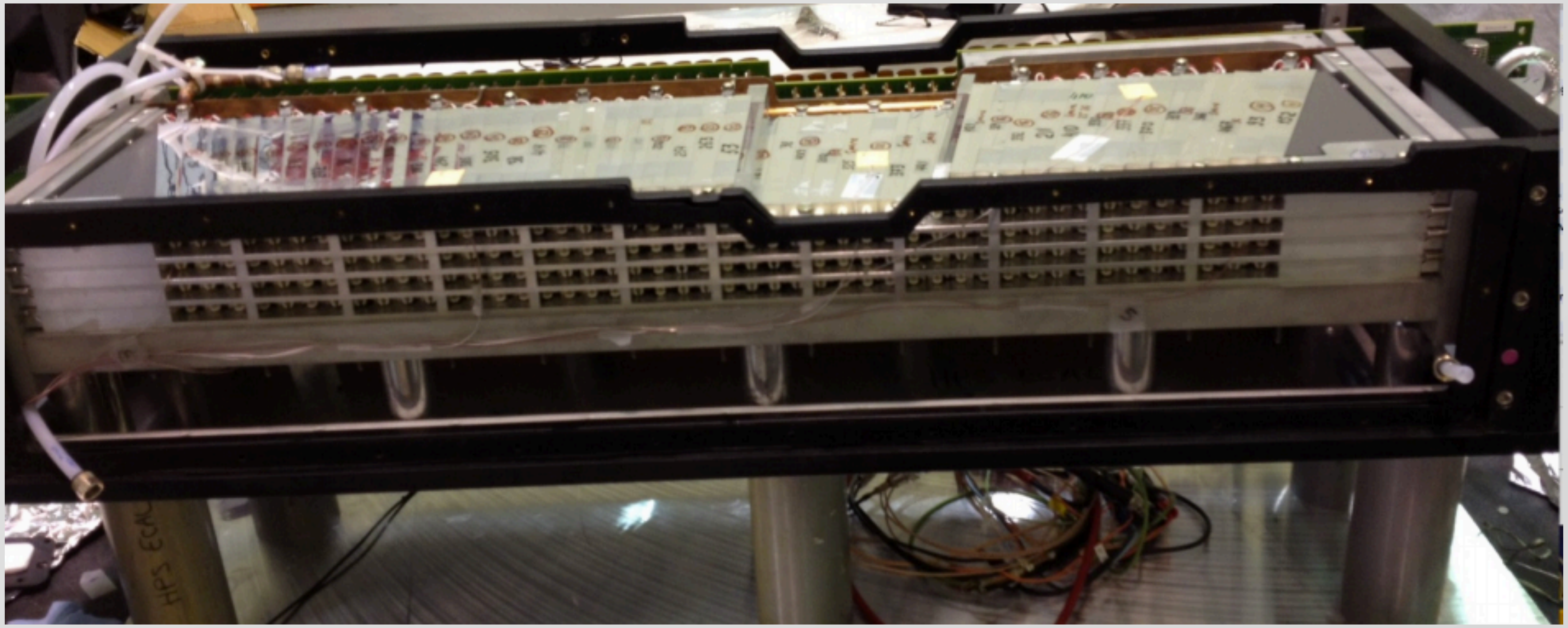




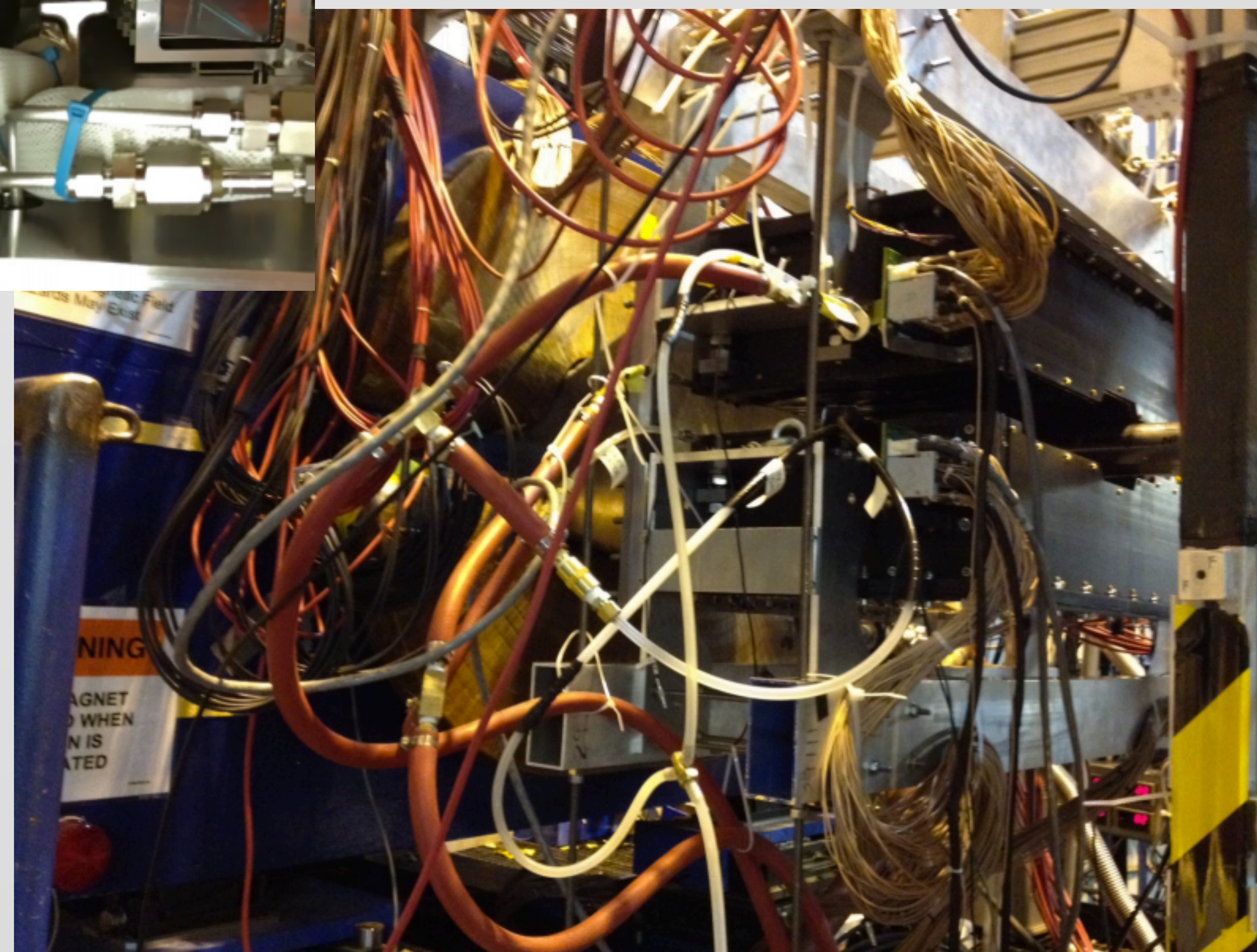


The HPS Test Detector





The HPS Test Detector

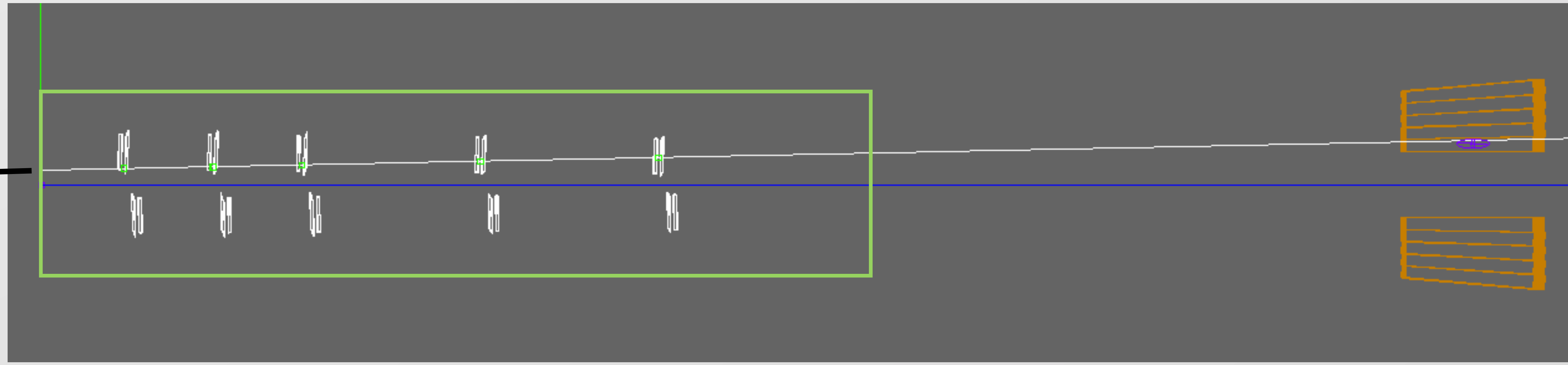


HPS Test Run Highlights

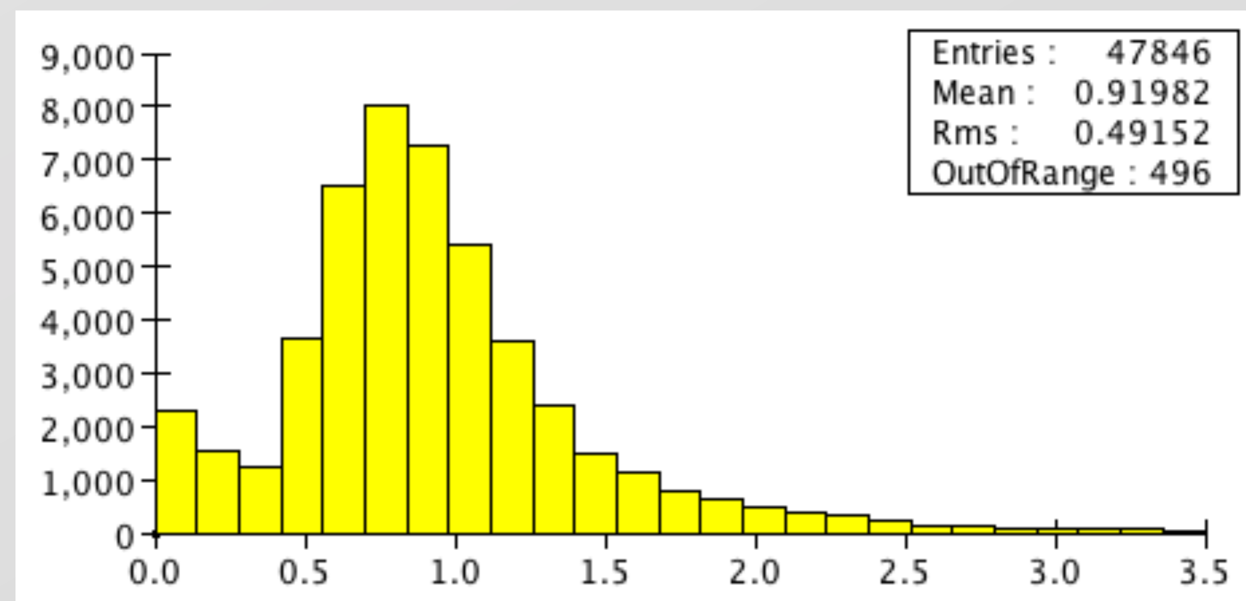
- We installed the tracker in Hall B on April 19th
- No chance for electron beam running; ran parasitically with HDice⇨photon beam
  - tracker all of the way open (gap @ layer 1 ~ ±16mm vs ±1.5mm nominal)
  - literally just before shutdown, we were granted ~8 hours of "dedicated" parasitic running; ran with various converter thicknesses and beam currents
- The HPS test run was on the cutting edge in a lot of ways...which was great...and awful!
  - SVT DAQ built on SLAC developed RCE/COB/ATCA technology
    - making this work nicely with JLAB system was exciting
  - ECAL/trigger first use of fADCs destined for 12 GeV program
  - First experiment to use of EVIO4 data format

Early Results from HPS Test Run

Converter
@ −60cm

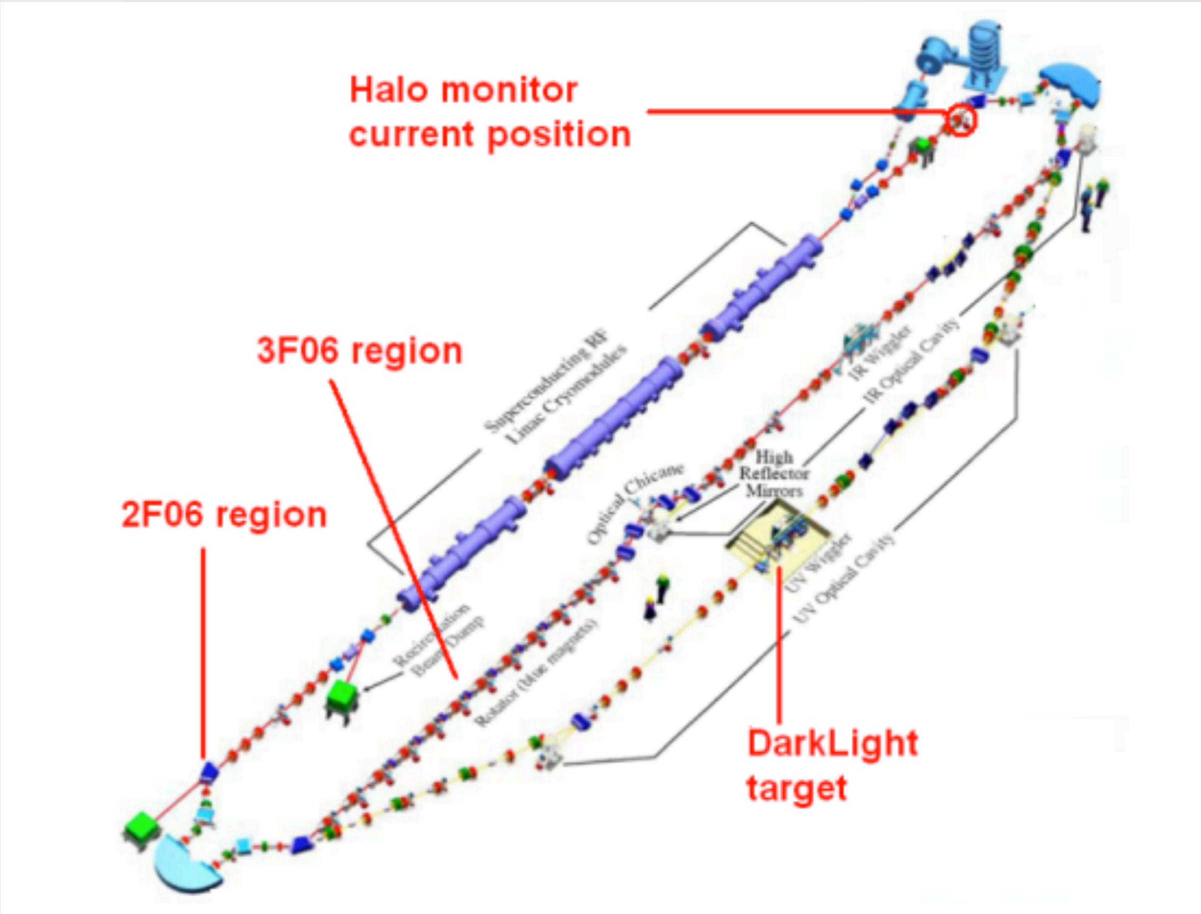


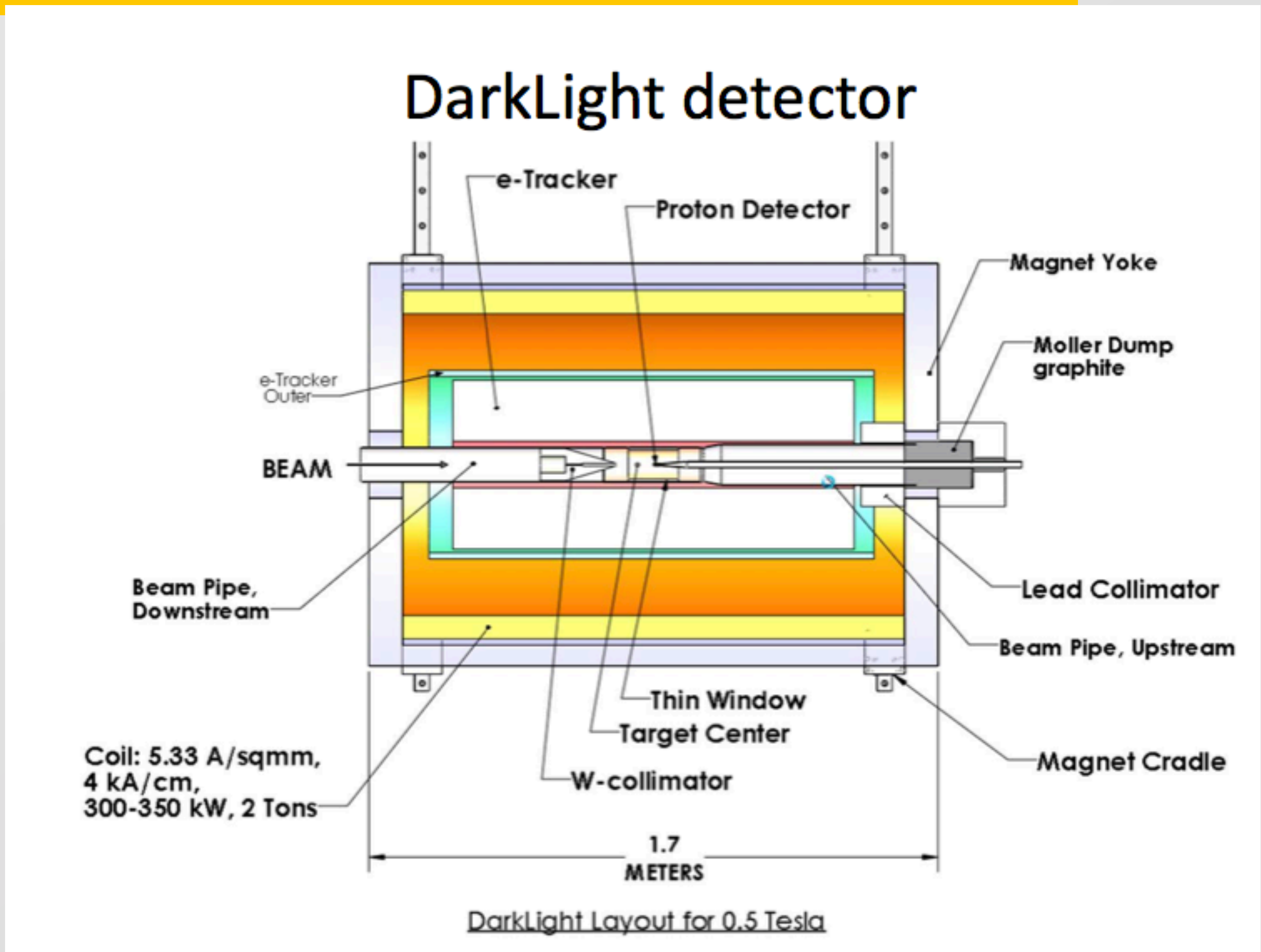
- FADC-based trigger worked well; at end we were triggering on clusters on the
  top || bottom || top&&bottom
- We were able to run up to ~2kHz with reasonable deadtime
  - synchronization problems between ECAL & SVT crates..."ROC-LOC"
- Still in the process of fine-tuning the alignment, but the tracker data looks ~ as expected
- Updated proposal sent to PAC39...looking for approval of full HPS



Track Momentum (GeV)

DarkLight @ the FEL





•use the FEL beam (~1mA, 100 MeV) incident on a H_2 gas jet target ... collect 1/ab in ~ 60 days of beam time

•high acceptance detector inside a 6-coil toroid: gas TPC for recoil proton detection, GEMs for vertexing and low momentum lepton recon., outer drift chambers for lepton momentum, scintillator hodoscopes for triggering.

Dark/Light Status & Plans

- original proposal submitted December 2010 (PAC37) and update submitted in May to PAC39
- beam tests in FEL planned for July 2012
  - run FEL beam through 2mm diameter, 10 cm long tube (simulates the target geometry)
    - investigate the backgrounds, beam halo, etc
- Detailed GEANT4-based detector simulation studies are ongoing

A Proposal for the DarkLight Experiment at the Jefferson Laboratory Free Electron Laser

P. Balakrishnan, J. Bernauer, W. Bertozzi, R. Cowan, K. Dow, C. Epstein, P. Fisher *, S. Gilad, A. Kelleher, Y. Kahn, R. Milner, R. Russell, J. Thaler, C. Tschalaer, A. Winnebeck

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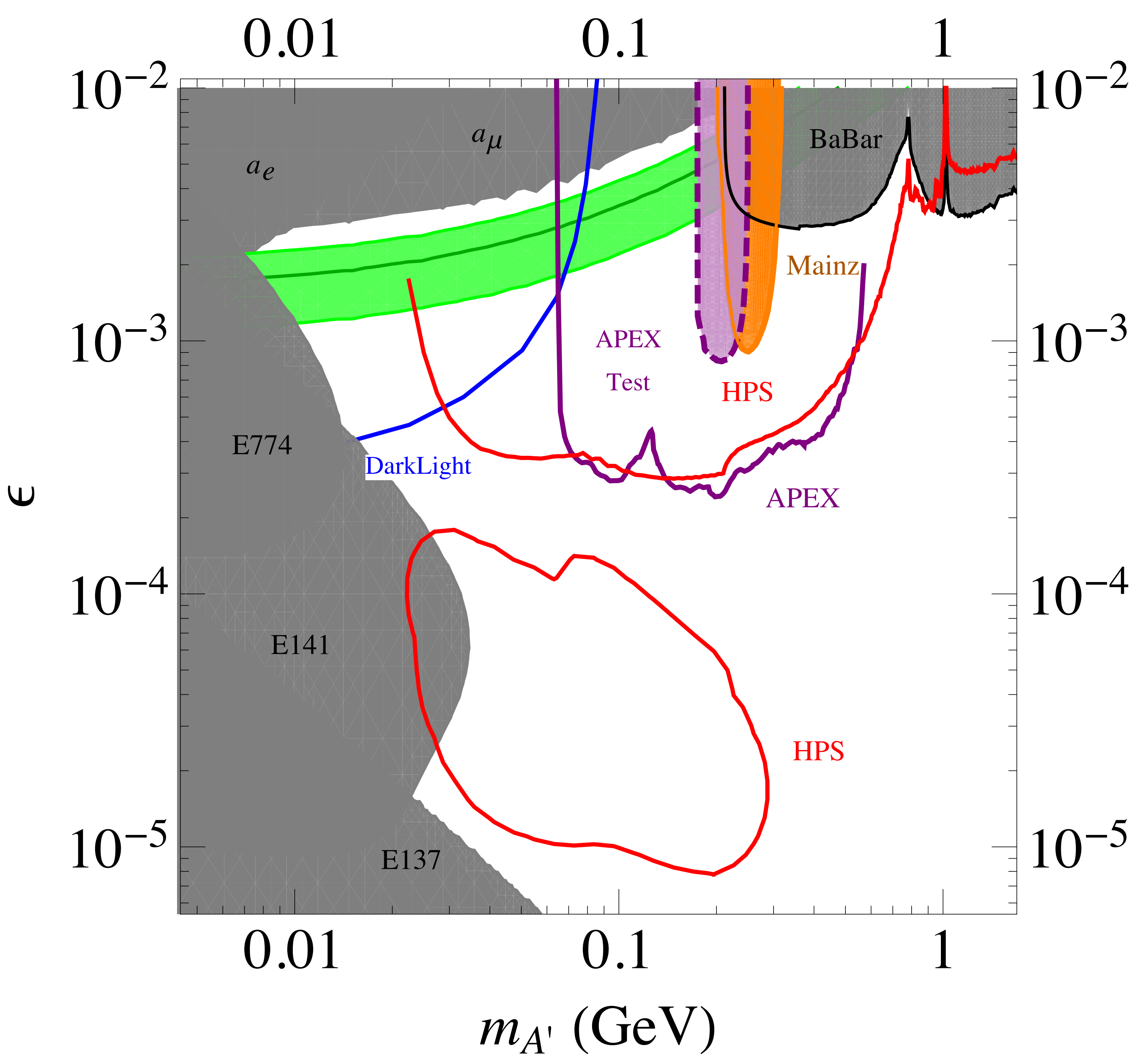
It's getting crowded...



Many experiments in the works to look for heavy photons:

Mainz and APEX (Hall A) ~ forward spectrometers
HPS (Hall B) ~ compact Si-based vertex-tracker
DarkLight (JLab FEL) ~ high acceptance, H_2 gas target