The Heavy Photon Search @ JLab

Maurik Holtrop - University of New Hampshire
for the HPS Collaboration.

Art: http://yonnicolas.nl

Nomenclature

The literature has many terms for basically the same things:

Heavy Photon = A′

= Dark Photon = U-boson = Dark Force

= Light Dark Gauge Boson = ...

Dark Sector = Hidden Sector = Secluded Sector

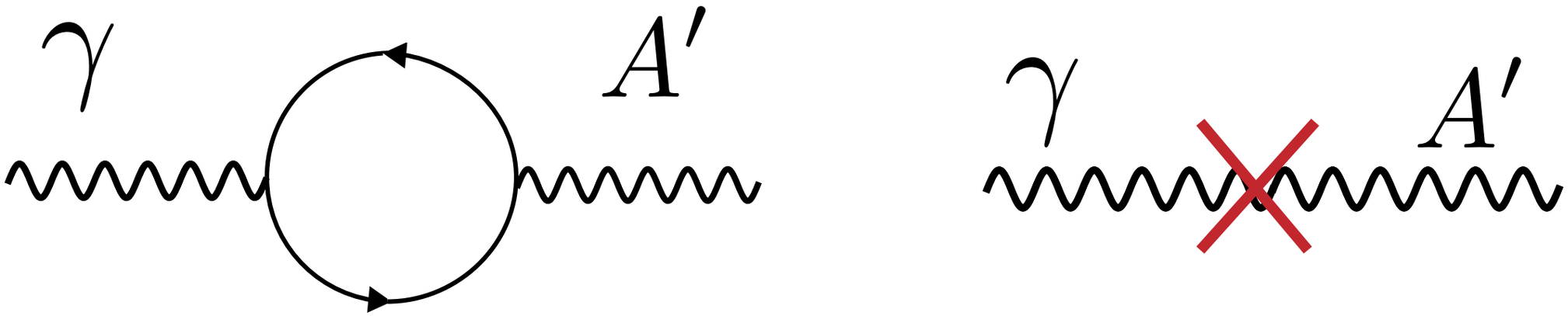
Coupling strength: $\epsilon^2 = k^2 = \chi^2 = \alpha'/\alpha$

Dark Sector Gauge Boson

- Dark matter ⊂ dark sector, few portals to SM physics.
- Lots of theoretical motivation for an additional U(1)′ symmetry ⊂ dark sector ⇒ new vector boson A'
- A' will mix with SM photon through kinetic mixing.

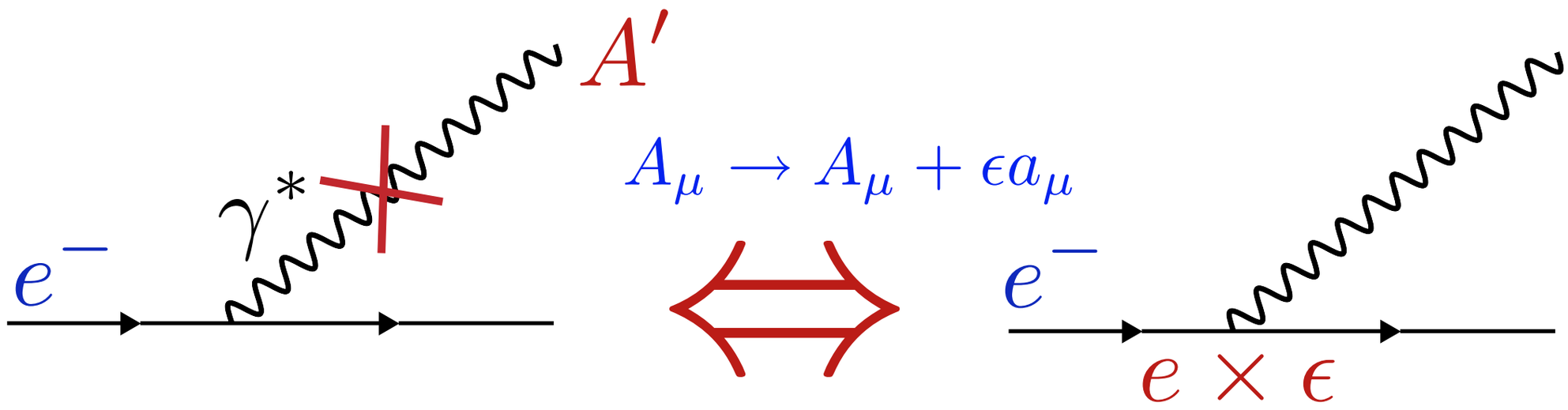
Holdom '86

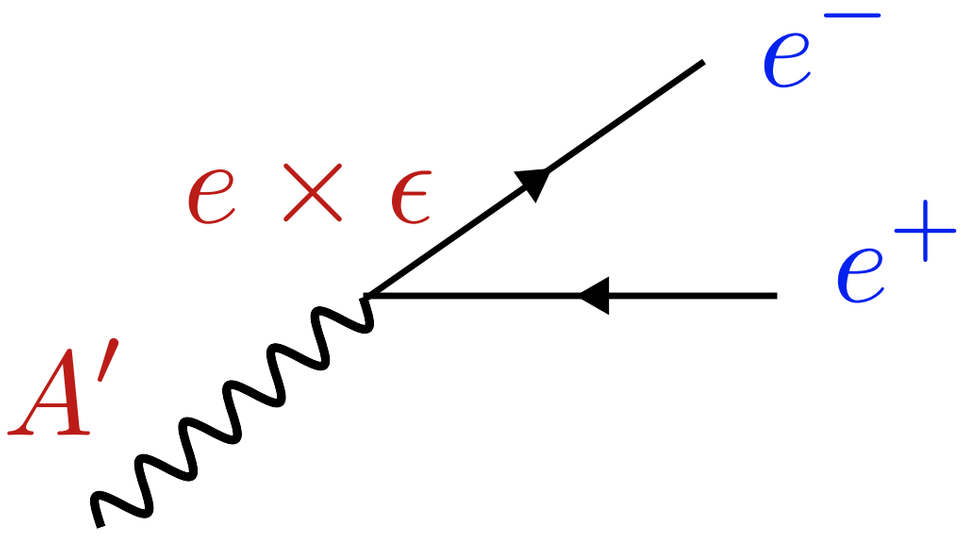
$$\Delta\mathcal{L}_{kin.mix} = \frac{\epsilon}{2} F'_{\mu\nu} F_Y^{\mu\nu}$$



Heavy Photons

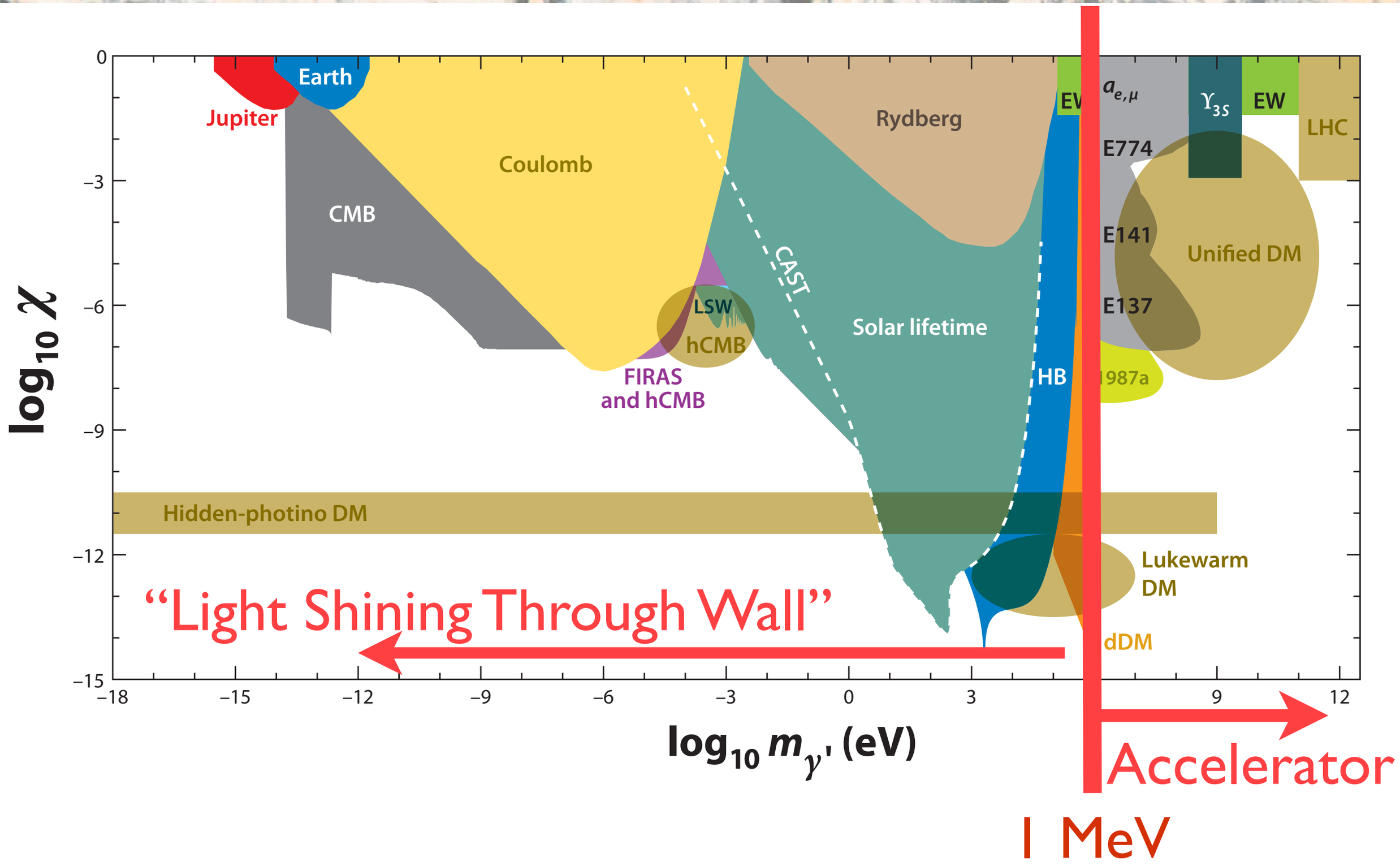
Photon mixing with A′ is equivalent to ordinary charged matter acquiring a milli-charge under the A′





A’ will pair produce
e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^-$, ...

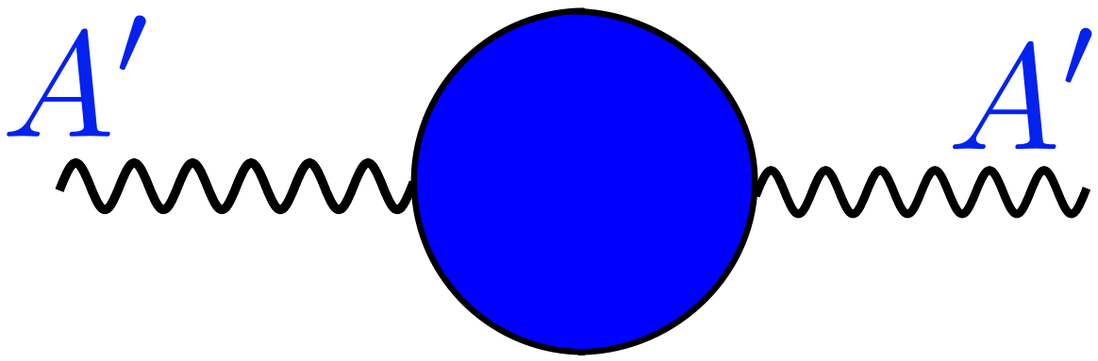
Where could it be?



Jaeckel and Ringwald ('10) *Ann.Rev. of Nuclear and Particle Science*, *60*(1), 405–437

"Natural*" Coupling and Mass

* Depends on the model



Mass inherited from "electro-weak" scale

$$m^2_{A'} \sim \epsilon M^2_W$$

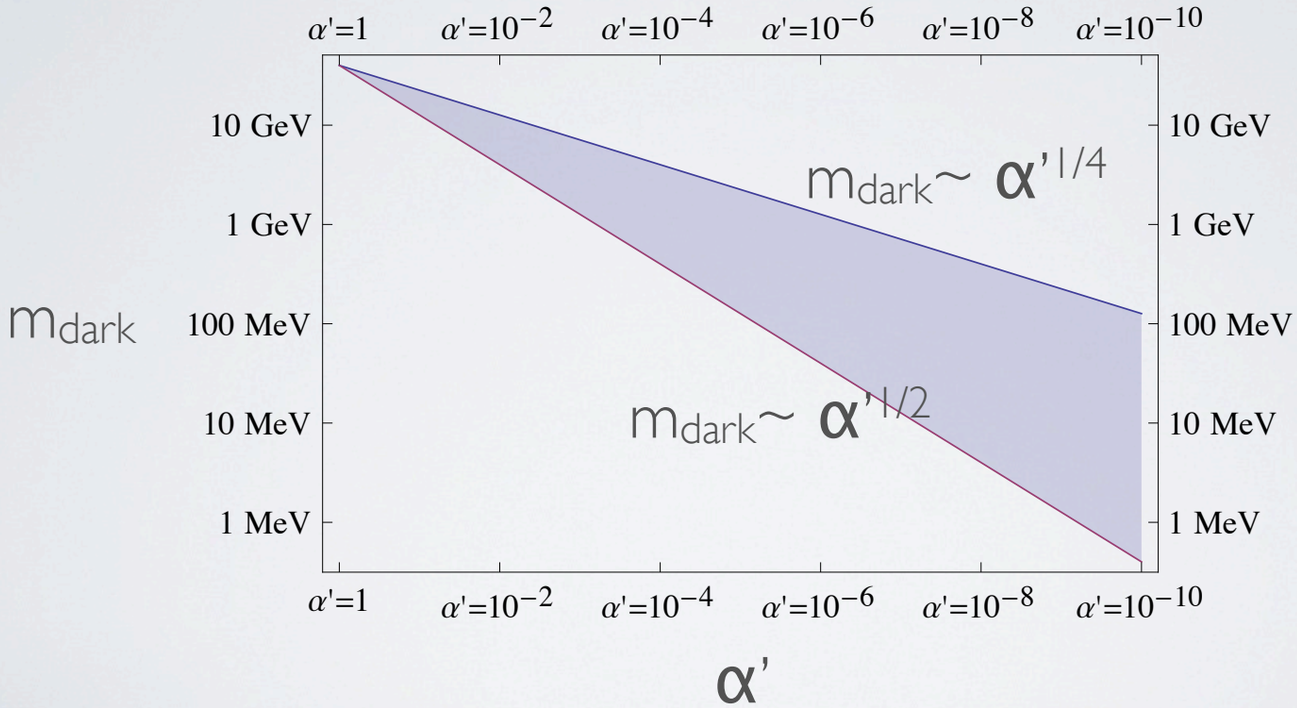
or

$$m^2_{A'} \sim \frac{e g_D}{16\pi^2} M^2_W$$

or

Stückelberg mechanism:

$m_{A'}$ ~ meV



Neil Weiner, Intensity Frontier WS '11

Natural ε could be ~ 1 (tree level)

Or $1 < \varepsilon < 10^{-8}$ (loops)

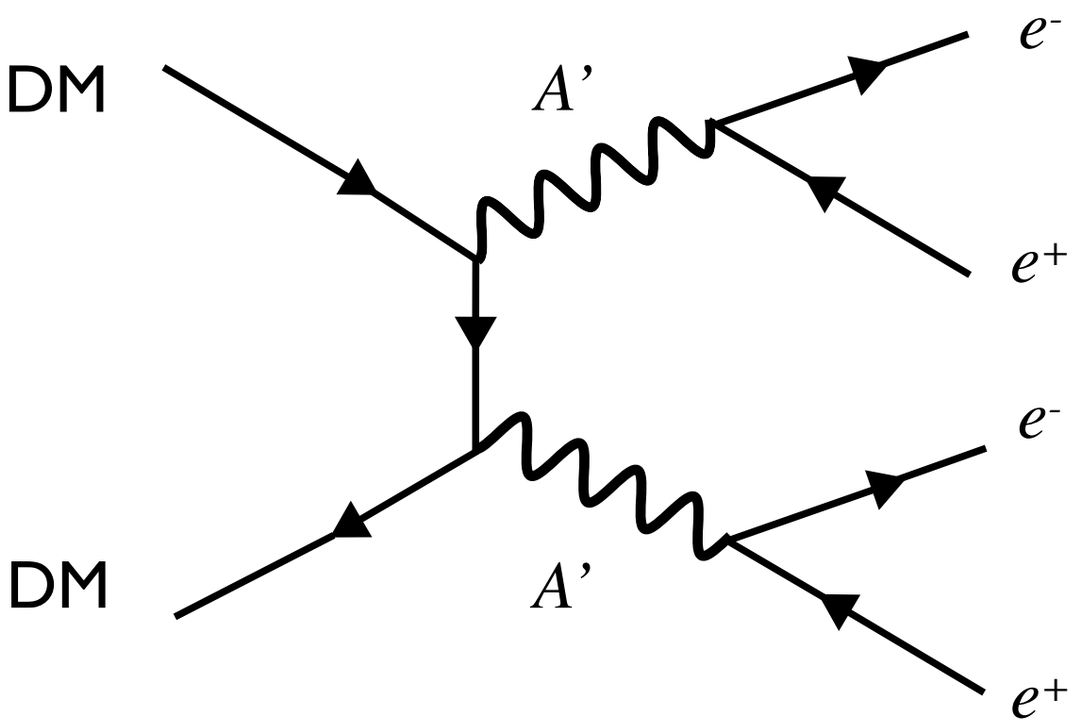
or "anything" ...

Leading to: $M_{A'} \sim \mathrm{MeV} - \mathrm{GeV}$

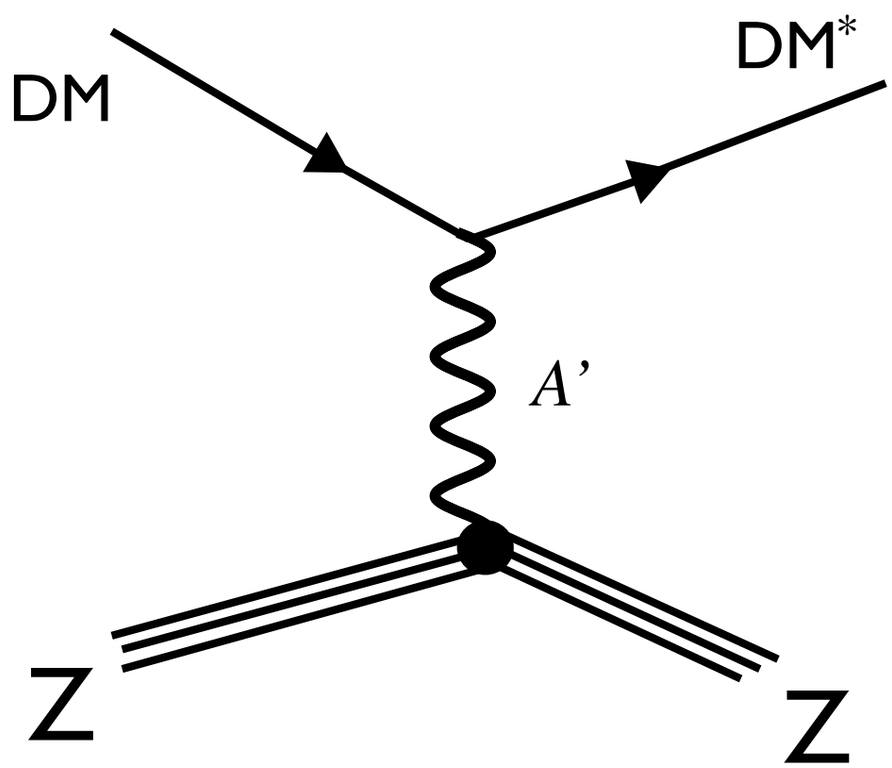
See: R. Essig et al, Intensity Frontier WS '11 summary paper.

Can mediate DM decay & scattering

DM decays through intermediate A'



A' mediates DM scattering

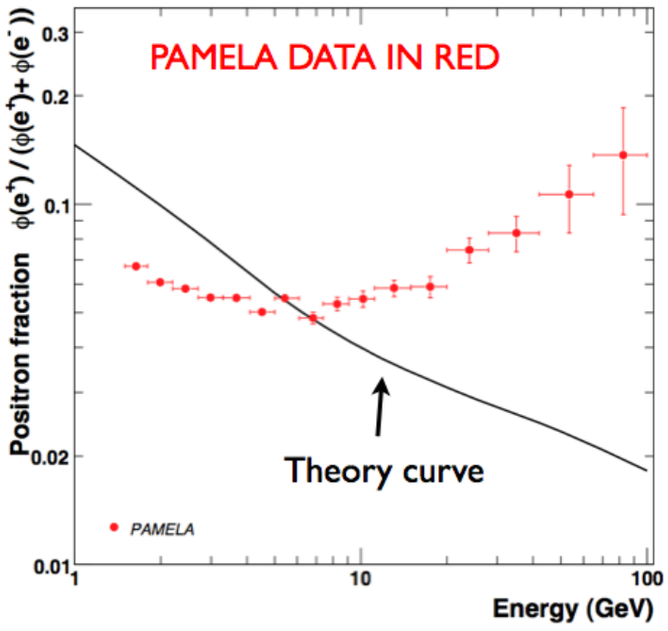


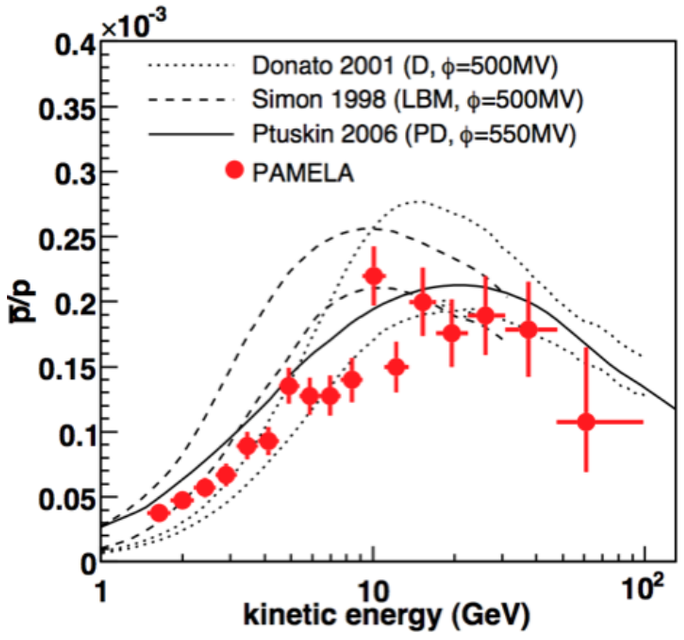
Arkani-Hamed, Finkbeiner, Slatyer, Weiner

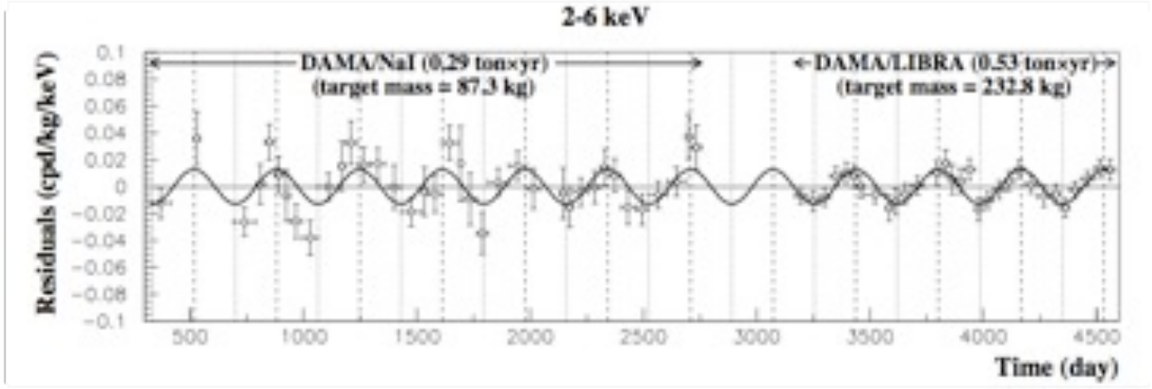
Hints from astrophysics?

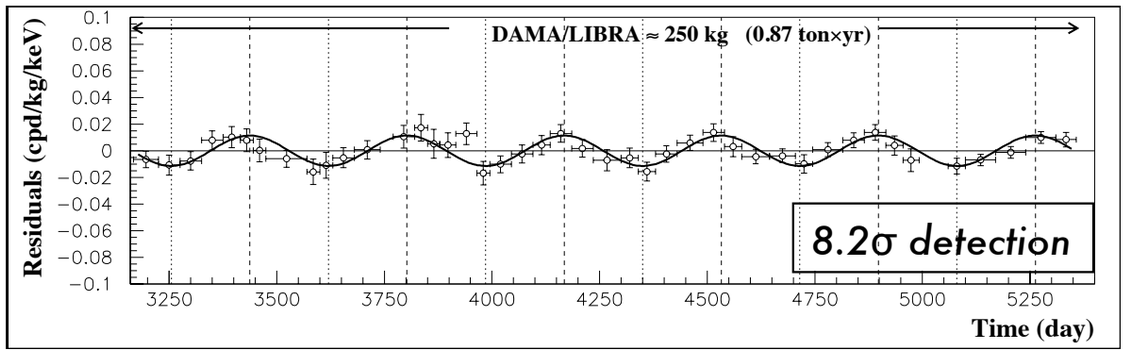
PAMELA, FERMI
Energetic e+/e- cosmic rays from DM annihilation through A'

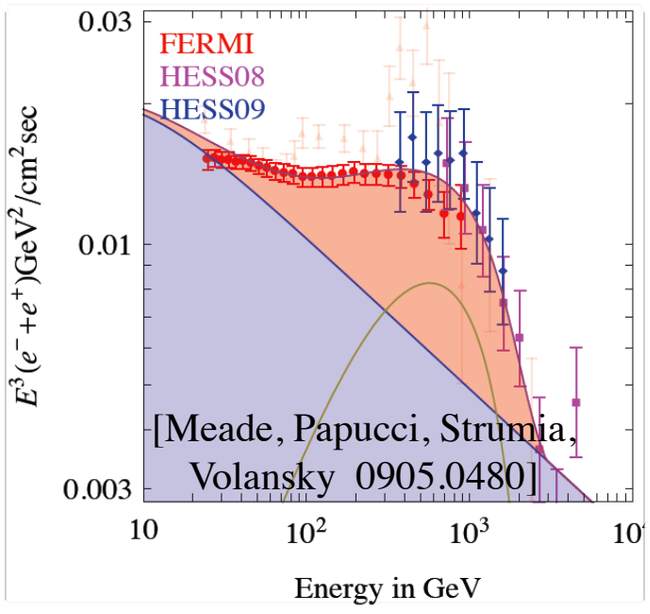
DAMA/LIBRA,...
A' mediated DM transitions





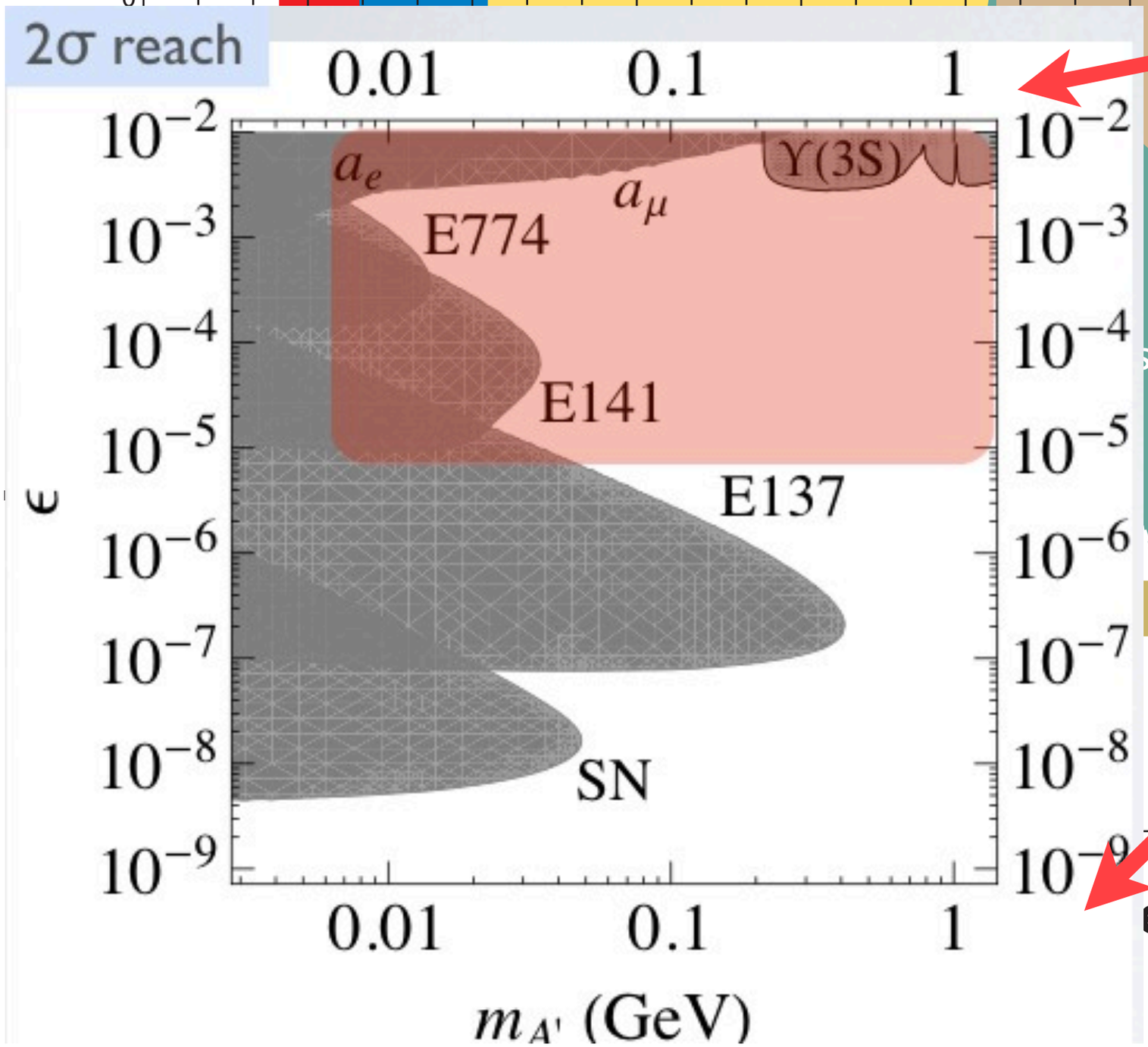


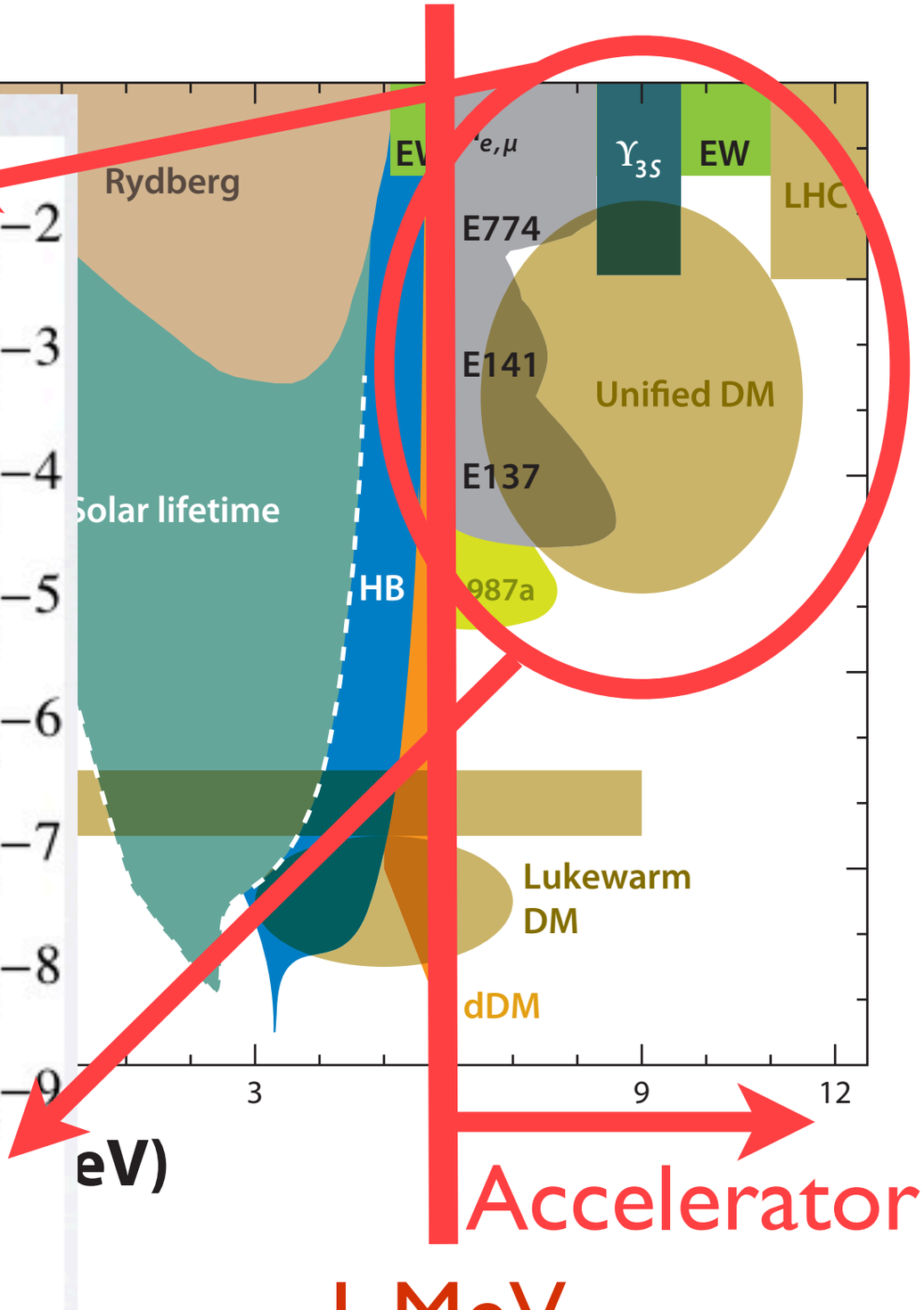




Arkani-Hamed, Finkbeiner, Slatyer, Weiner. '09 PRD 79, 015014
Pospelov and Ritz '09 PLB, 671, 391–397
Cholis, Finkbeiner, Goodenough, Weiner '09 JCAP 0912 (2009) 007

Where could it be?





Lots of interest = many papers

J. Jaeckel and A. Ringwald, "The Low-Energy Frontier of Particle Physics," Ann. Rev. Nucl. Part. Sci. 60, 405 (2010) [arXiv:1002.0329 [hep-ph]].
B. Holdom, "Two U(1)'s and Epsilon Charge Shifts," Phys. Lett. B 166 (1986) 196.
P. Galison and A. Manohar, "Two Z's Or Not Two Z's?," Phys. Lett. B 136 (1984) 279.
R. Essig, P. Schuster and N. Toro, "Probing Dark Forces and Light Hidden Sectors at Low-Energy E+E- Colliders," Phys. Rev. D 80 (2009) 015003 [arXiv:0903.3941 [hep-ph]].
M. Goodsell, J. Jaeckel, J. Redondo and A. Ringwald, "Naturally Light Hidden Photons in LARGE Volume String Compactifications," JHEP 0911, 027 (2009) [arXiv:0909.0515 [hep-ph]].
M. Cicoli, M. Goodsell, J. Jaeckel and A. Ringwald, "Testing String Vacua in the Lab: From a Hidden CMB to Dark Forces in Flux Compactifications," JHEP 1107, 114 (2011) [arXiv: 1103.3705 [hep-th]].
M. Goodsell, S. Ramos-Sanchez, A. Ringwald, "Kinetic Mixing of U(1)s in Heterotic Orbifolds," [arXiv:1110.6901 [hep-th]].
M. Goodsell and A. Ringwald, "Light hidden-sector U(1)s in string compactifications," Fortsch. Phys. 58, 716 (2010) [arXiv:1002.1840 [hep-th]].
P. Candelas, G. T. Horowitz, A. Strominger and E. Witten, "Vacuum Configurations for Superstrings," Nucl. Phys. B 258, 46 (1985).
E. Witten, "New Issues in Manifolds of SU(3) Holonomy," Nucl. Phys. B 268, 79 (1986).
P. Fayet, "U-Boson Production in E+ E- Annihilations, Psi and Upsilon Decays, and Light Dark Matter," Phys. Rev. D 75 (2007) 115017 [arXiv:hep-ph/0702176].
C. Cheung, J. T. Ruderman, L. T. Wang and I. Yavin, "Kinetic Mixing as the Origin of Light Dark Scales," Phys. Rev. D 80 (2009) 035008 [arXiv:0902.3246 [hep-ph]].
N. Arkani-Hamed and N. Weiner, JHEP 0812, 104 (2008) [arXiv:0810.0714 [hep-ph]].
D. E. Morrissey, D. Poland and K. M. Zurek, "Abelian Hidden Sectors at a Gev," JHEP 0907 (2009) 050 [arXiv:0904.2567 [hep-ph]].
J. D. Bjorken, R. Essig, P. Schuster and N. Toro, Phys. Rev. D 80, 075018 (2009) [arXiv:0906.0580 [hep-ph]].
M. Freytsis, G. Ovanesyan and J. Thaler, "Dark Force Detection in Low Energy E-P Collisions," JHEP 1001 (2010) 111 [arXiv:0909.2862 [hep-ph]].
R. Essig, P. Schuster, N. Toro and B. Wojtsekhowski, JHEP 1102, 009 (2011) [arXiv:1001.2557 [hep- ph]].
S. Abrahamyan et al. [APEX Collaboration], Phys. Rev. Lett. 107, 191804 (2011) [arXiv:1108.2750 [hep-ex]].
The Heavy Photon Search Collaboration (HPS), https://confluence.slac.stanford.edu/display/hpsg/
H. Merkel et al. [A1 Collaboration], Phys. Rev. Lett. 106, 251802 (2011) [arXiv:1101.4091 [nucl-ex]].
B. Batell, M. Pospelov and A. Ritz, Phys. Rev. D 80, 095024 (2009) [arXiv:0906.5614 [hep-ph]].
R. Essig, R. Harnik, J. Kaplan and N. Toro, Phys. Rev. D 82, 113008 (2010) [arXiv:1008.0636 [hep-ph]].
M. J. Strassler and K. M. Zurek, "Echoes of a Hidden Valley at Hadron Colliders," Phys. Lett. B 651 (2007) 374 [arXiv:he
M. Reece and L. T. Wang, "Searching for the Light Dark Gauge Boson in Gev-Scale Experiments," JHEP 0907 (2009) 051
G. Amelino-Camelia et al., "Physics with the Kloe-2 Experiment at the Upgraded DaΦNe," Eur. Phys. J. C 68 (2010) 619
B. Aubert et al. [BABAR Collaboration], "Search for Dimuon Decays of a Light Scalar in Radiative Transitions Y(3S) - Ga
B. Batell, M. Pospelov and A. Ritz, "Probing a Secluded U(1) at B-Factories," Phys. Rev. D 79 (2009) 115008 [arXiv:0903
B. Aubert et al. [BABAR Collaboration], "Search for a Narrow Resonance in E+E- to Four Lepton Final States," arXiv:09(
B. Wojtsekhowski, "Searching for a U-Boson with a Positron Beam," AIP Conf. Proc. 1160 (2009) 149 [arXiv:0906.5265 |
V. M. Abazov et al. [D0 Collaboration], Phys. Rev. Lett. 103, 081802 (2009) [arXiv:0905.1478 [hep-ex]], Phys. Rev. Lett.
F. Archilli et al., arXiv:1107.2531 [hep-ex].
M. Baumgart, C. Cheung, J. T. Ruderman, L. T. Wang and I. Yavin, JHEP 0904, 014 (2009) [arXiv:0901.0283 [hep-ph]].
N. Arkani-Hamed, D. P. Finkbeiner, T. R. Slatyer and N. Weiner, "A Theory of Dark Matter," Phys. Rev. D 79 (2009) 0150
M. Pospelov and A. Ritz, "Astrophysical Signatures of Secluded Dark Matter," Phys. Lett. B 671 (2009) 391 [arXiv:0810.
M. Pospelov, "Secluded U(1) Below the Weak Scale," Phys. Rev. D 80 (2009) 095002 [arXiv:0811.1030 [hep-ph]].

A lot of papers,
A lot of interest,
Covering wide range of physics and parameter space.

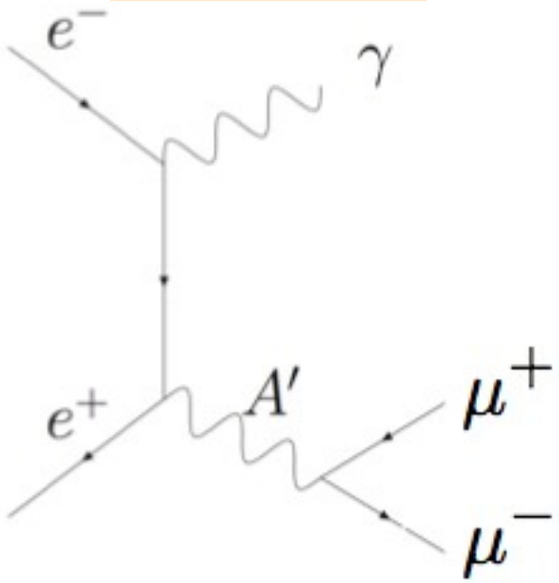
Sorry if I missed your favorite paper.

refs from R. Essig et al, Intensity Frontier WS '11 summary paper.

How to search? $M_{A'}$>1MeV

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

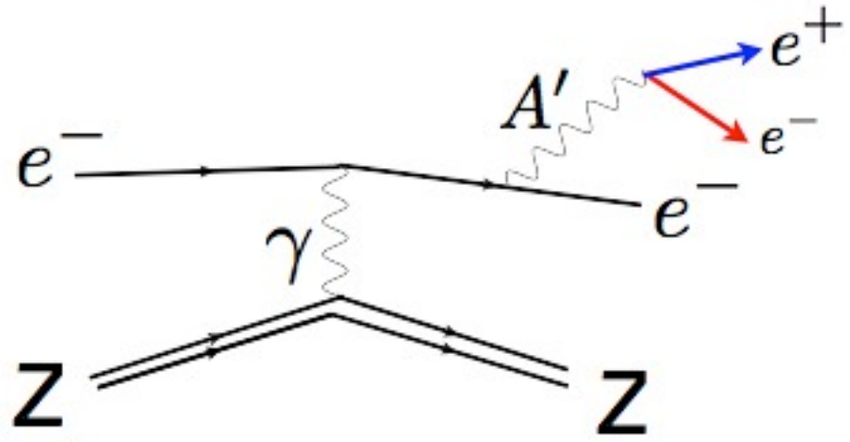
Collider



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

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

Fixed Target



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

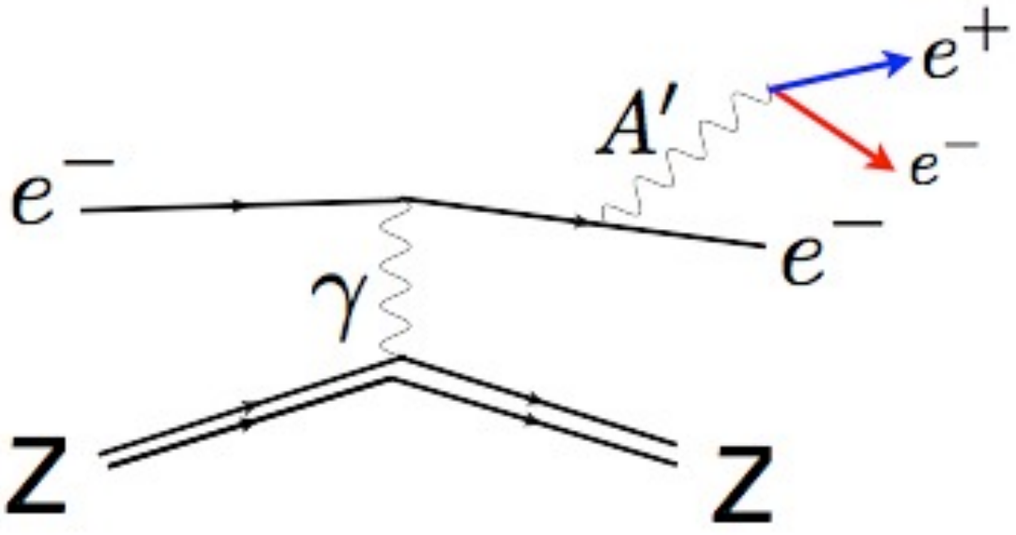
$$O\ ab^{-1}\ \text{per day}$$

...but much higher backgrounds

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

Fixed Target Searches

Look for radiated A′ decay to e^+e^-, ($\mu^+\mu^-$)



Bump Hunt:

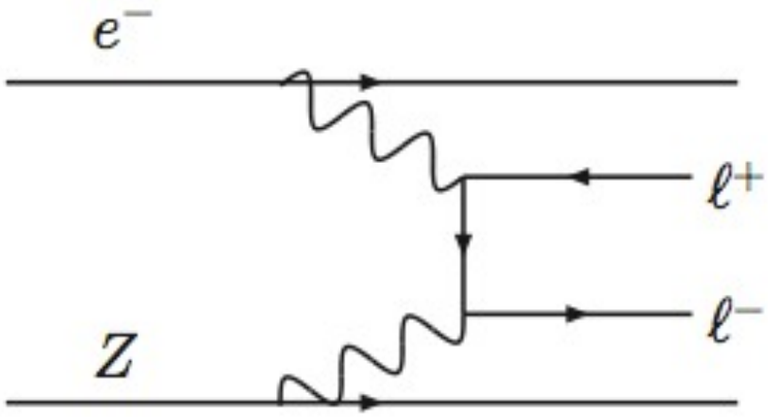
Look for signal over background.

Bump Hunt + Vertexing:

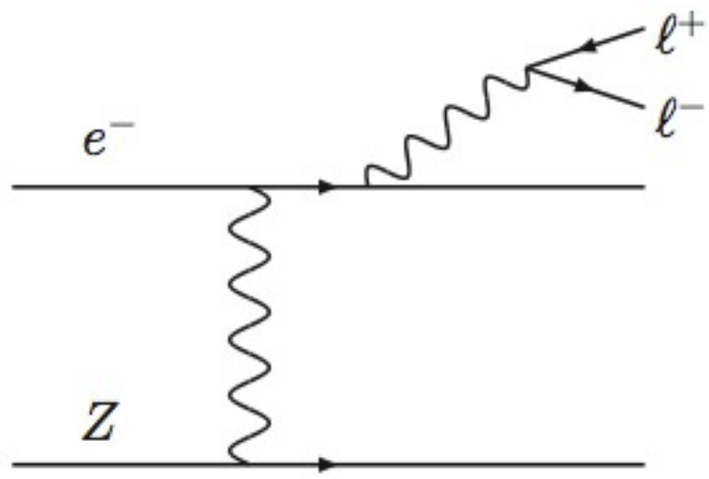
Look for signal over background, reduce background with vertexing.

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

Background

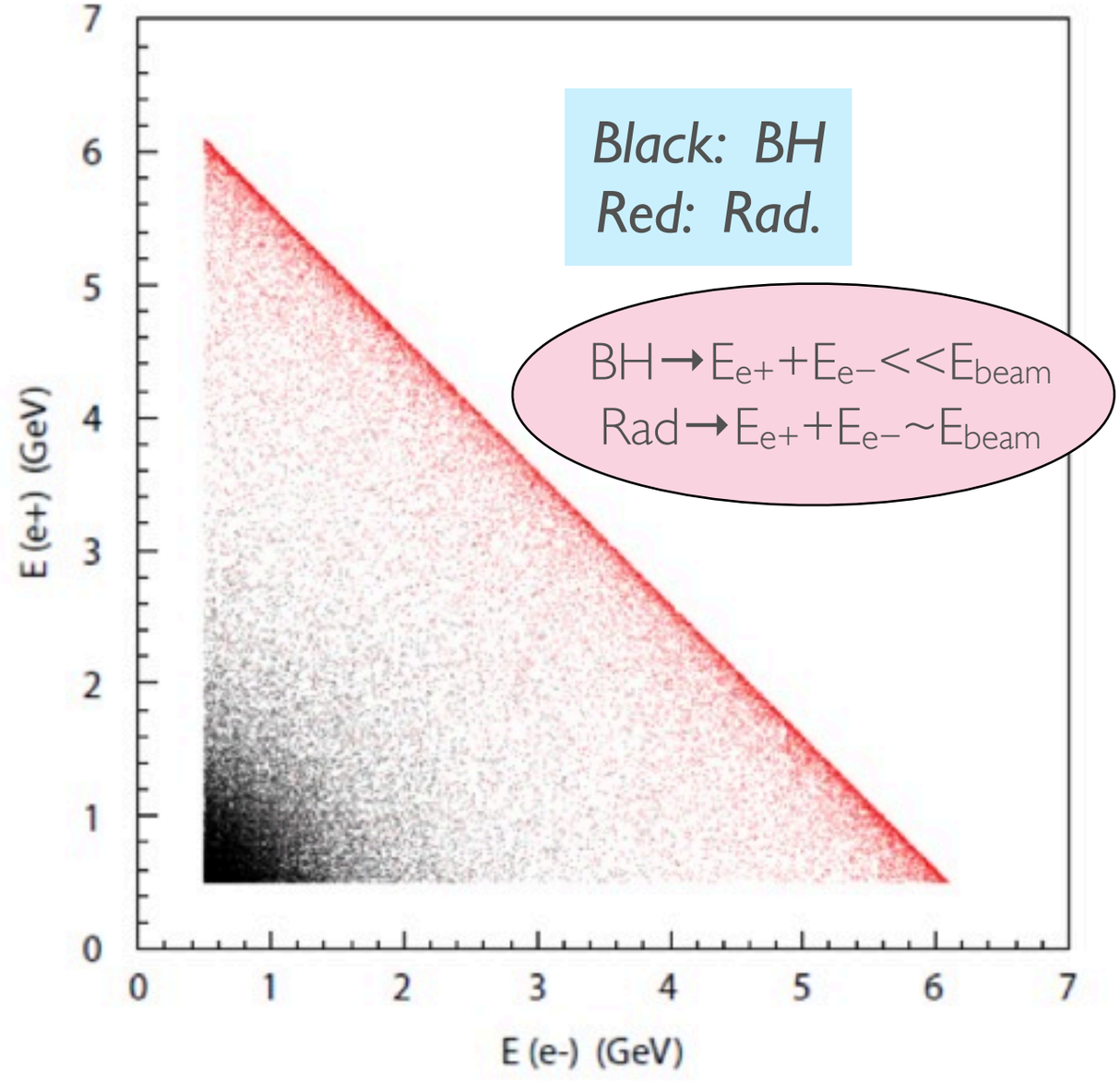


Bethe-Heitler



Radiative

$\sigma_{B\text{-}H}$ very large » σ_{Rad}.
But kinematically distinct →
Use clever trigger to separate.

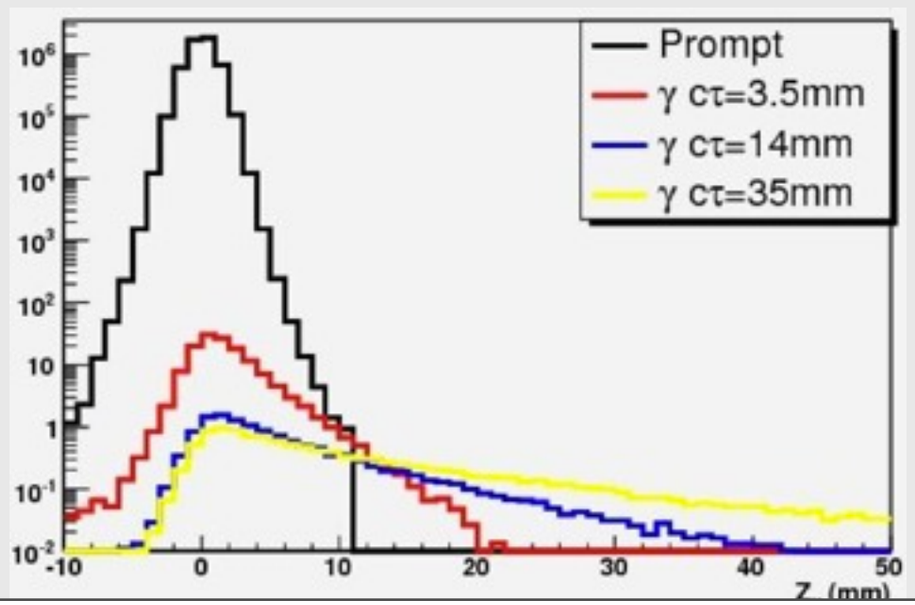


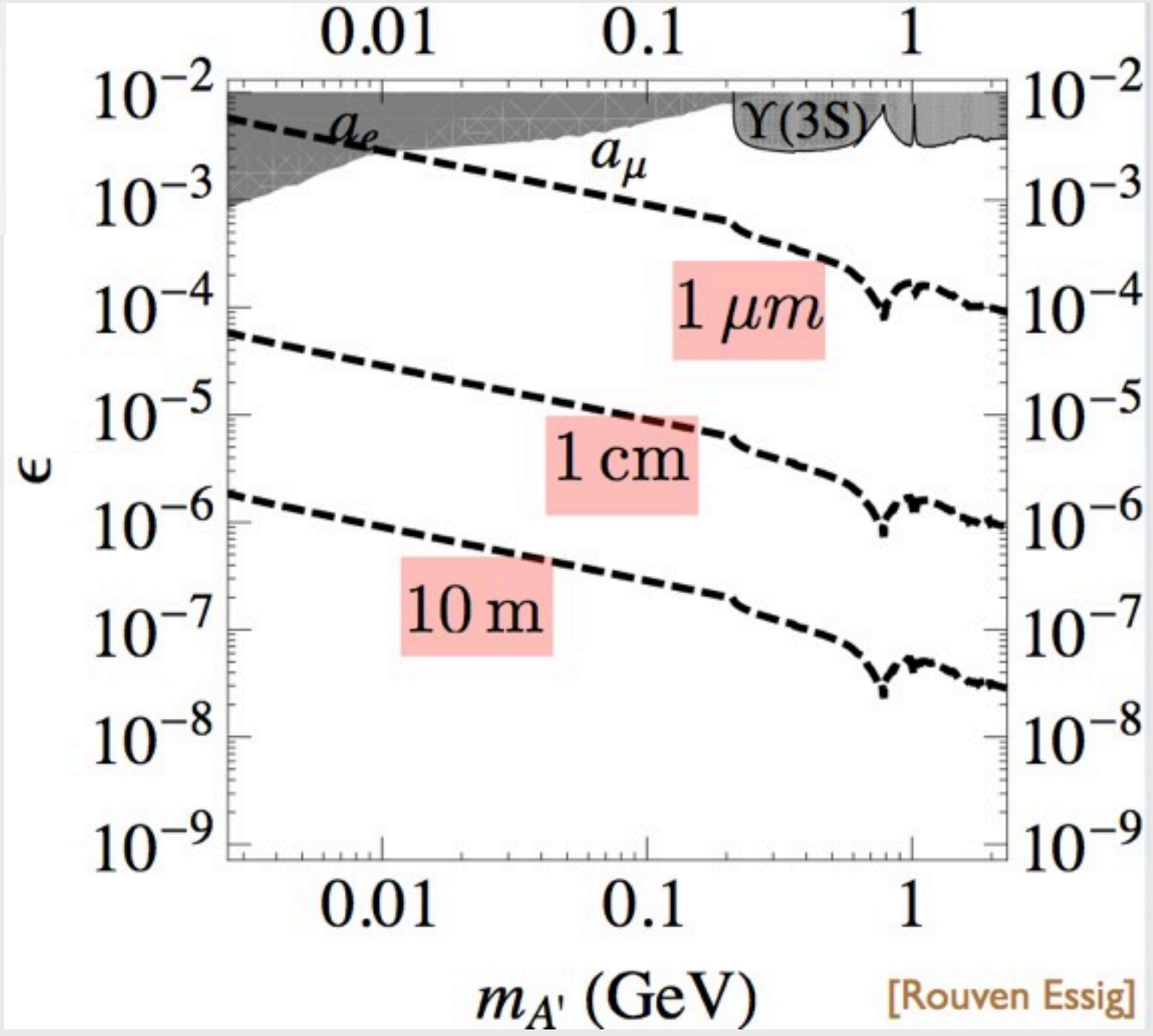
A´ lifetime

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

Lower ε, lower mass
→longer lifetime

Background is all prompt
➜ Lower coupling can be reached using vertexing.



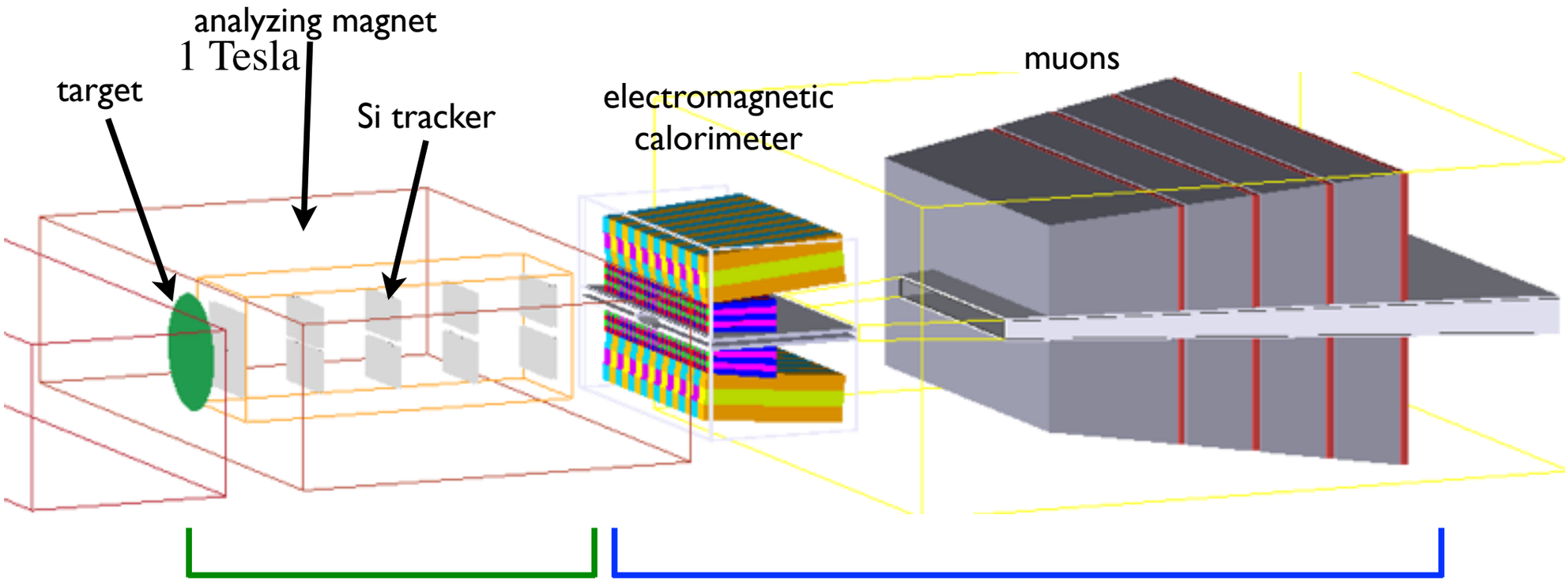


HPS Collaboration

A. Grillo, V. Fadeyev
University of California, Santa Cruz, CA 95064
M. Ungaro
University of Connecticut, Department of Physics, Storrs, CT 06269
W. Cooper
Fermi National Accelerator Laboratory, Batavia, IL 60510-5011
A. Micherdzinska
The George Washington University, Department of Physics,Washington, DC 20052
G. Ron
Hebrew University of Jerusalem, Jerusalem, Israel
M. Battaglieri, R. De Vita
INFN, Sezione di Genova, 16146 Genova, Italy
M. Holtrop (Co-Spokesperson), K. Slifer, S. K. Phillips
University of New Hampshire, Department of Physics, Durham, NH 03824
M. Khandaker, C. Salgado
Norfolk State University, Department of Physics, Norfolk, VA 23504
S. Bueltmann, L. Weinstein
Old Dominion University, Department of Physics, Norfolk, VA 23529
A. Fradi, B. Guegan, M. Guidal, S. Niccolai, S. Pisano, E. Rauly, P. Rosier and D. Sokhan
Institut de Physique Nucleaire d'Orsay, 91405 Orsay, France
P. Schuster, N. Toro
Perimeter Institute, Ontario, Canada N2L 2Y5
P. Stoler, A. Kubarovsky
Rensselaer Polytechnic Institute, Department of Physics, Troy, NY 12181
R. Essig, C. Field, M. Graham, G. Haller, R. Herbst, J. Jaros (Co-Spokesperson), C. Kenney, T. Maruyama, K. Moffeit, T. Nelson, H. Neal, A. Odian, M. Oriunno, R. Partridge, S. Uemura, D. Walz
SLAC National Accelerator Laboratory, Menlo Park, CA 94025
S. Boyarinov, V. Burkert, A. Deur, H. Egiyan, L. Elouadrhiri, A. Freyberger, F.-X. Girod, V. Kubarovsky, Y. Sharabian, S. Stepanyan (Co-Spokesperson), B. Wojtsekhowski
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606
K. Griffioen
The College of William and Mary, Department of Physics, Williamsburg, VA 23185
N. Dashyan, N. Gevorgyan, R. Paremuzyan, H. Voskanyan
Yerevan Physics Institute, 375036 Yerevan, Armenia

About 50 members from 16 institutions.

Heavy Photon Search



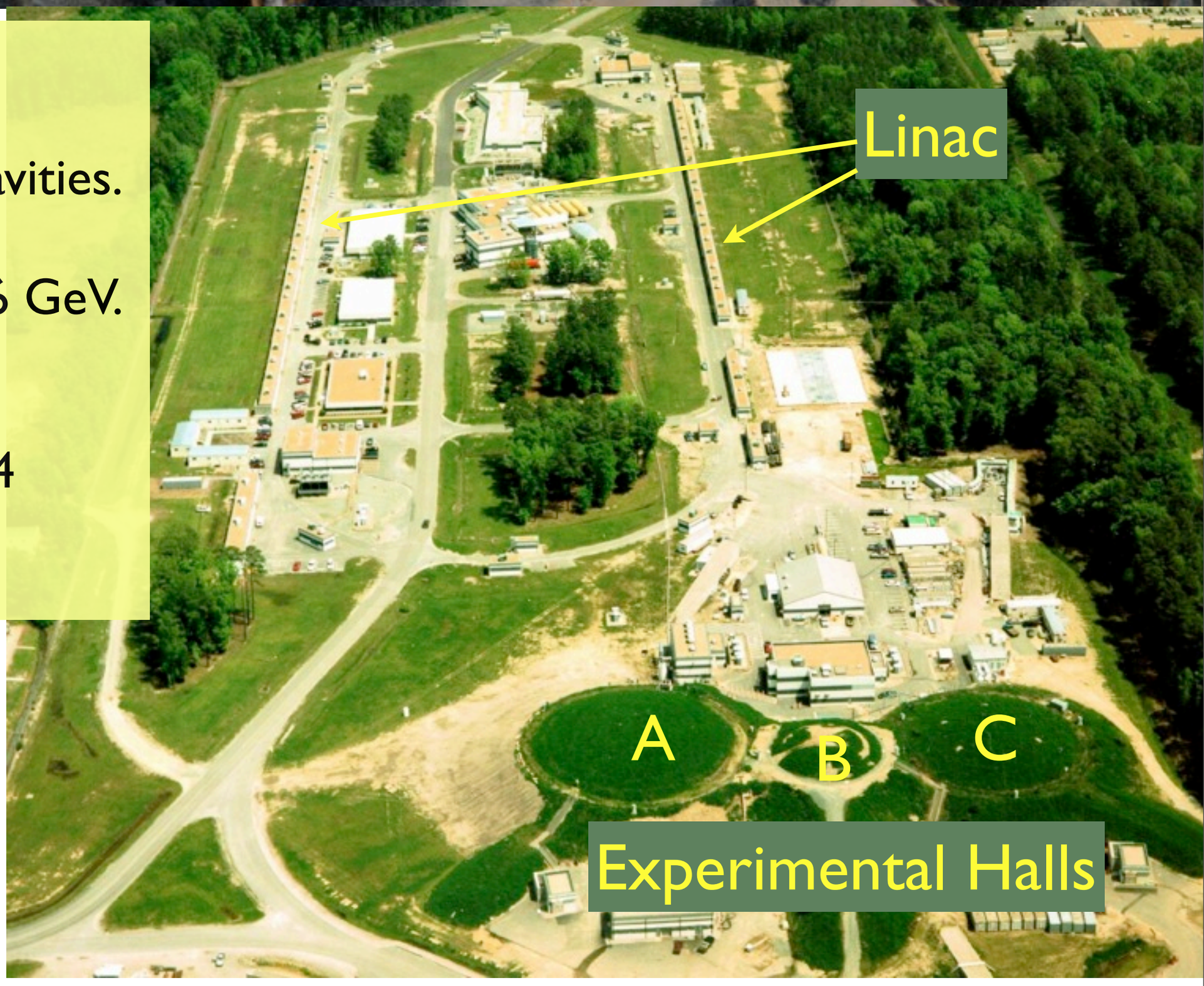
High rate, high acceptance, high mass & vertex resolution detector.
"Table top" size.
Use Jefferson Lab e^- beam in Hall B.
JLAB PAC37 January 2011 - conditional approval.
Received DOE funding to build test run apparatus.
Test run this Spring!

Jefferson Lab

High intensity
e- accelerator
Superconducting cavities.

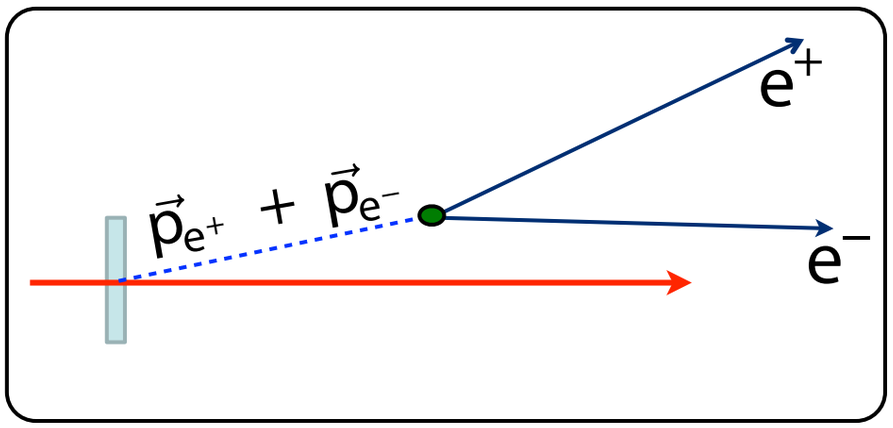
Currently Up to ~6 GeV.
(n x 1.1 GeV)

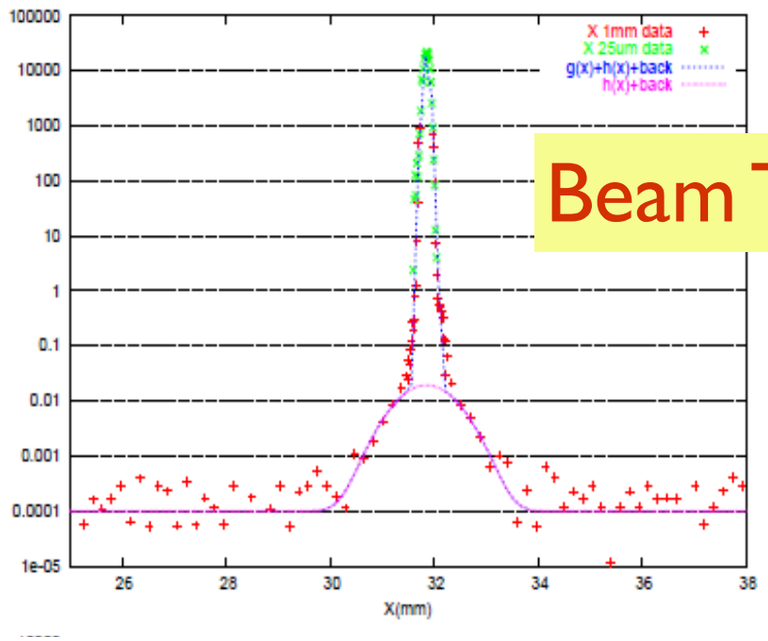
Upgrade 2012-2014
to ~11 GeV
(n x 2.2 GeV)

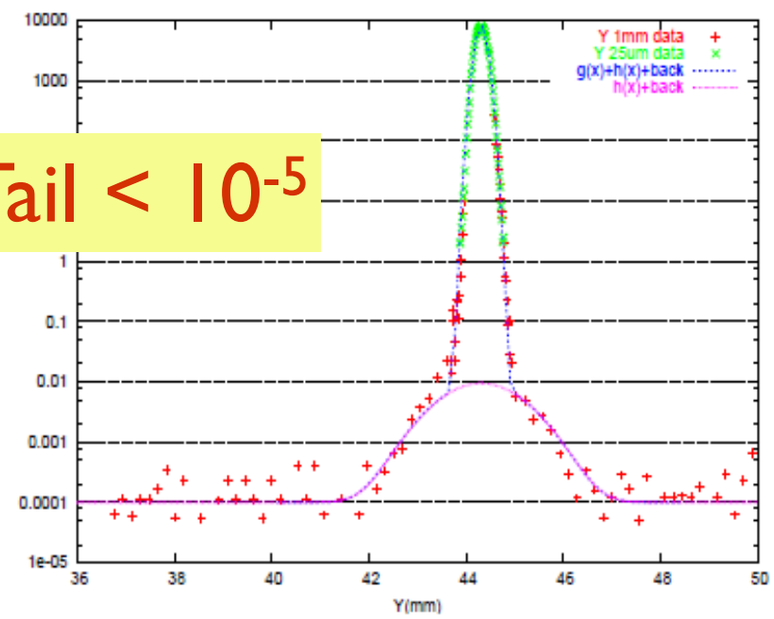


http://www.jlab.org

Beam Quality in Hall-B





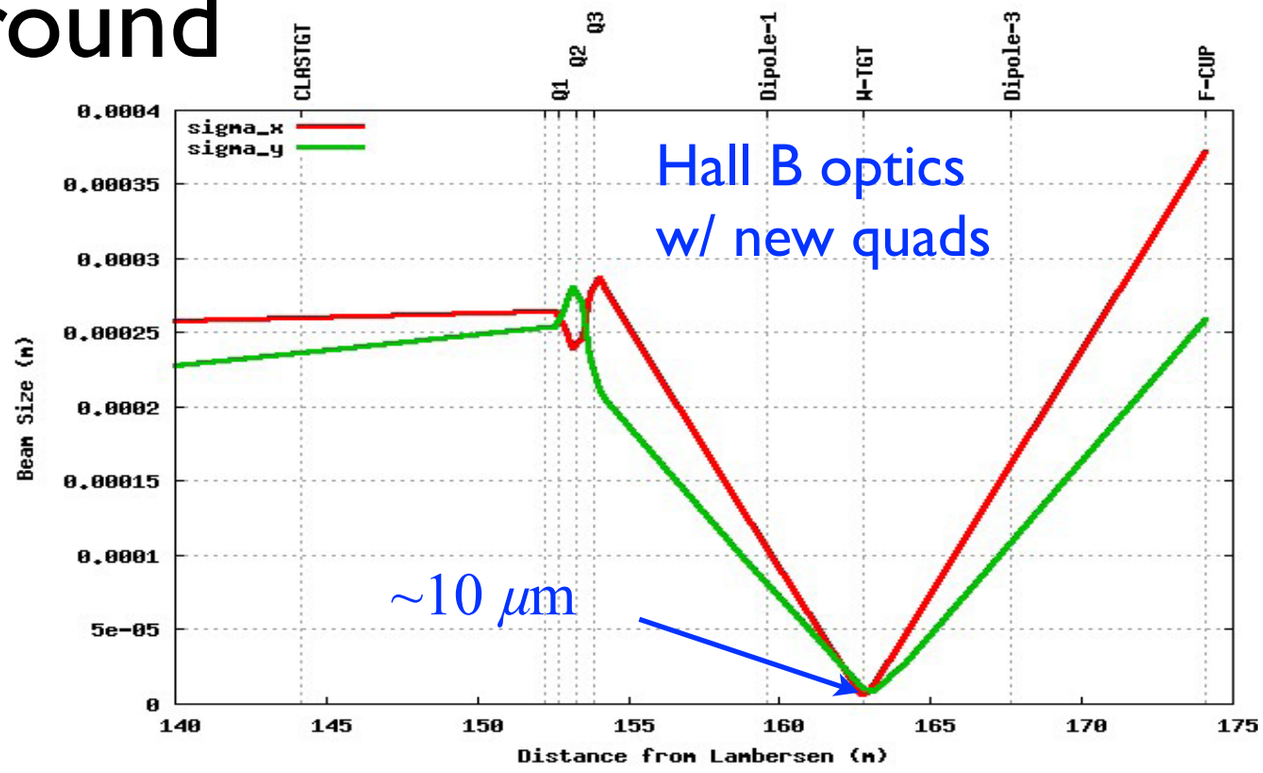


Beam Tail < 10^{-5}

Very low halo = low background

Tight beam spot helps tracking & vertex

I_{beam} = 1 to 500 nA



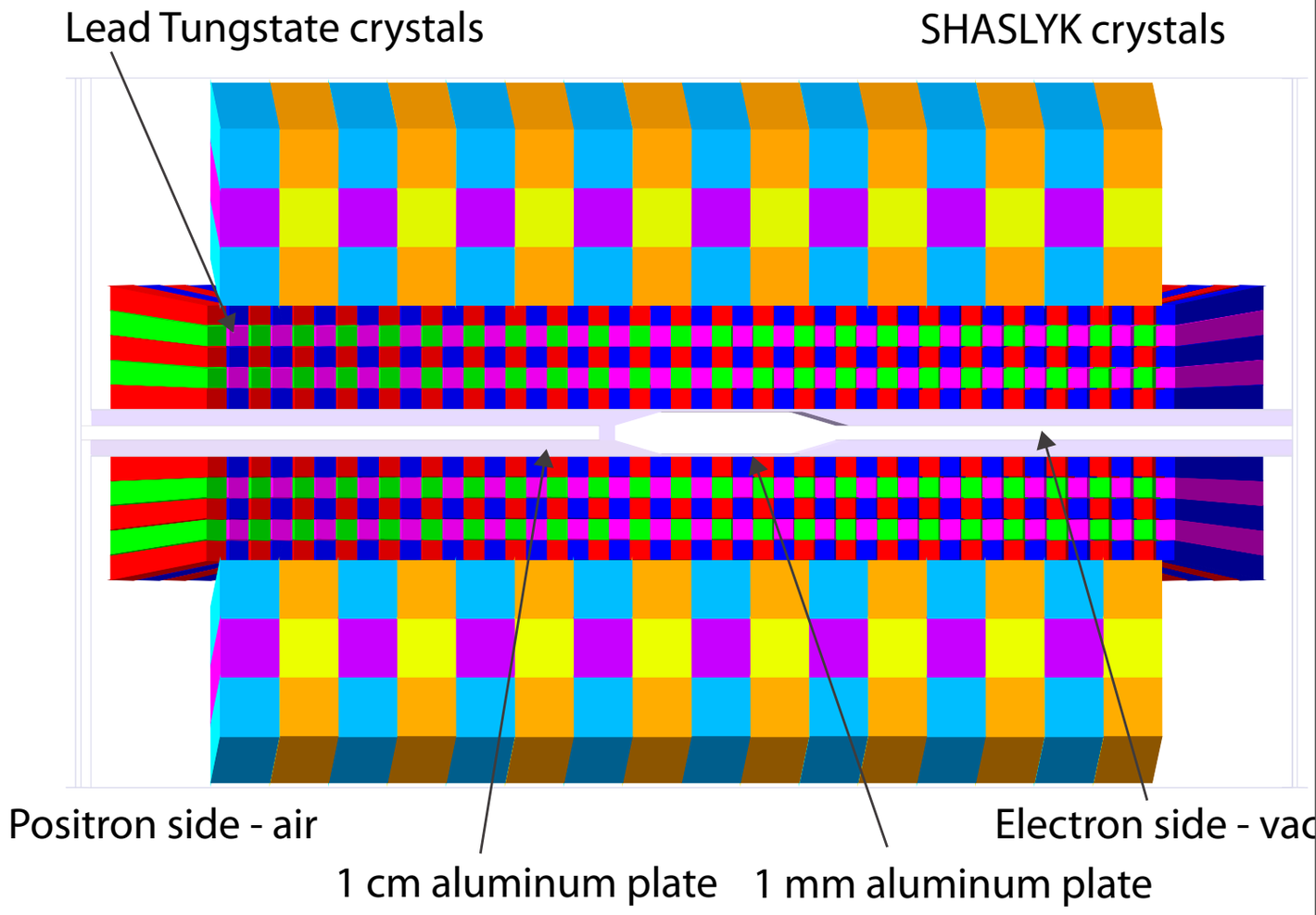
Calorimeter & Trigger

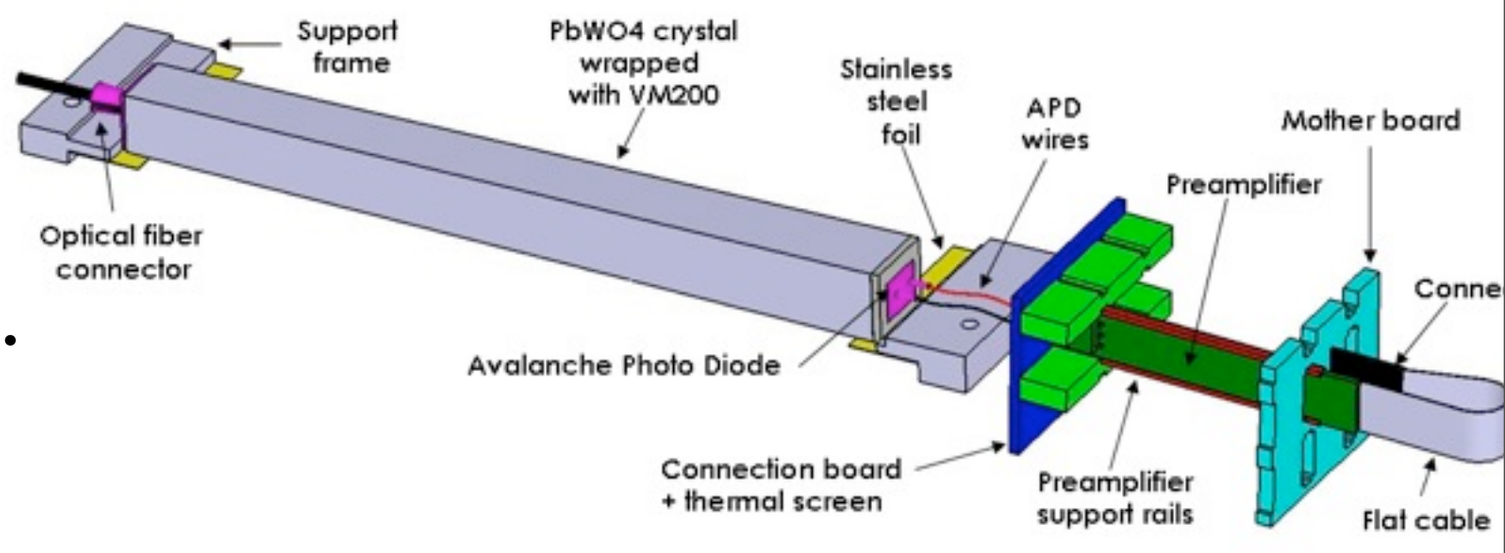
Hybrid design =
recycles 460 existing
PbWO4 crystals,
96 LeadGlass crystals.

Flash-ADC readout
@ 250 MHz continuous.

FPGA based trigger logic:
Reduces two cluster
background trigger rate
from ~4 MHz to ~20 kHz,
by using unique A' signature.

Keep high A' acceptance.

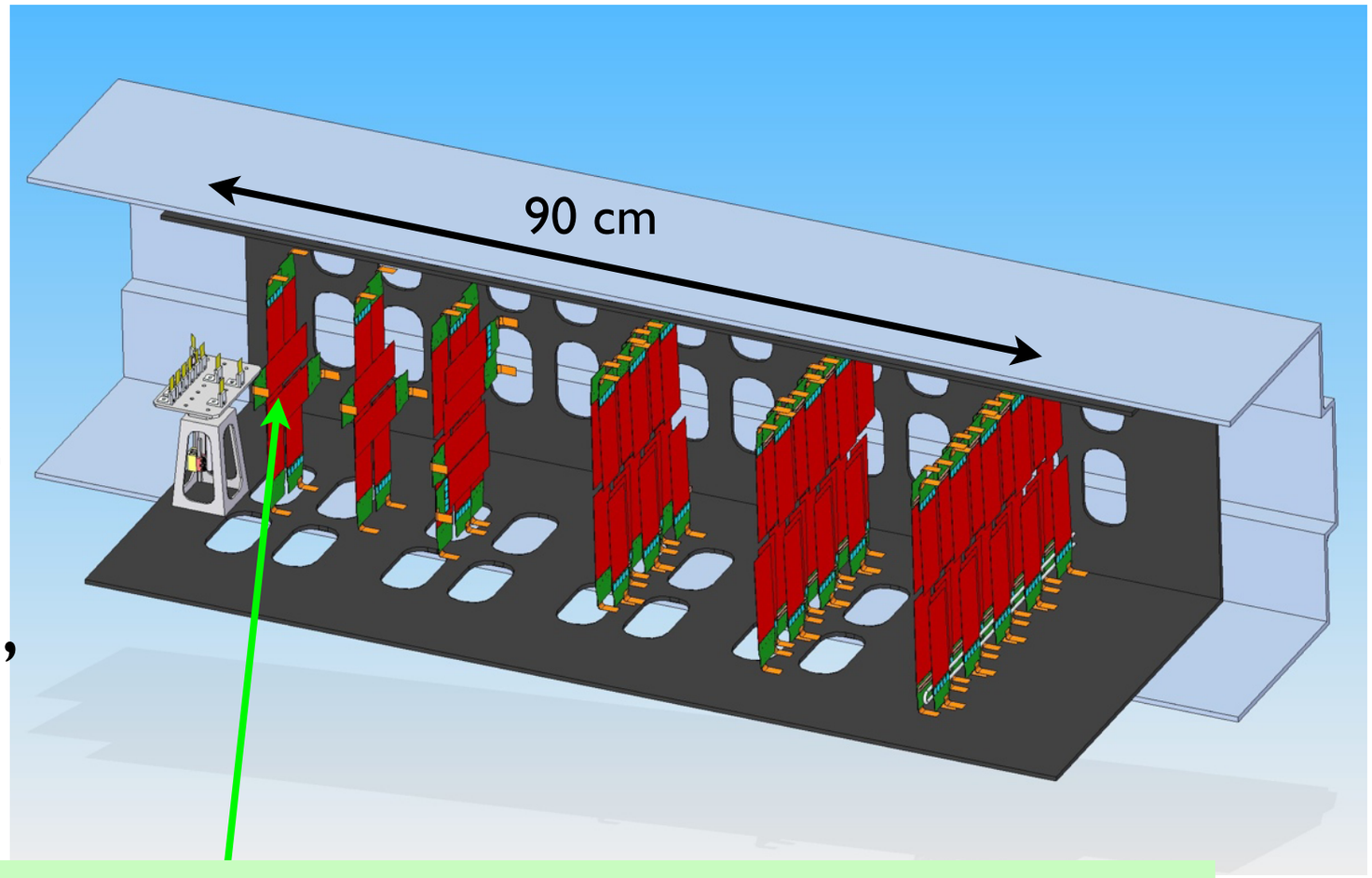




Tracker

Requirements:

- ✳Forward angular coverage gives large acceptance (1000x two spectrometers)
- ✳High Rate capable = 25 MHz
- ✳Thin (reduce M.S.)
- ✳Robust, movable, replaceable, operate in vacuum
- ✳Excellent hit resolution
- ✳Cost is acceptable.



±1.5 mm Gap for beam = ±15 mRad
Small "dead zone" in acceptance.

Using:

Si Microstrip detectors (106, thin, leftover from Tevatron run IIb)

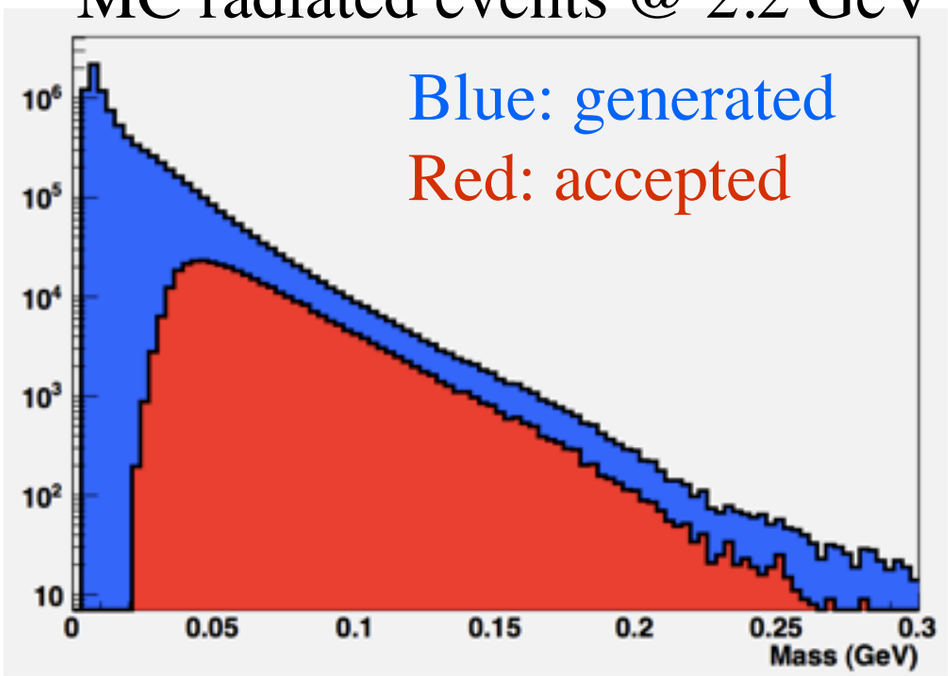
AVP25 readout chip (67840 channels, from CMS, S/N~25, timing ~ 2ns)

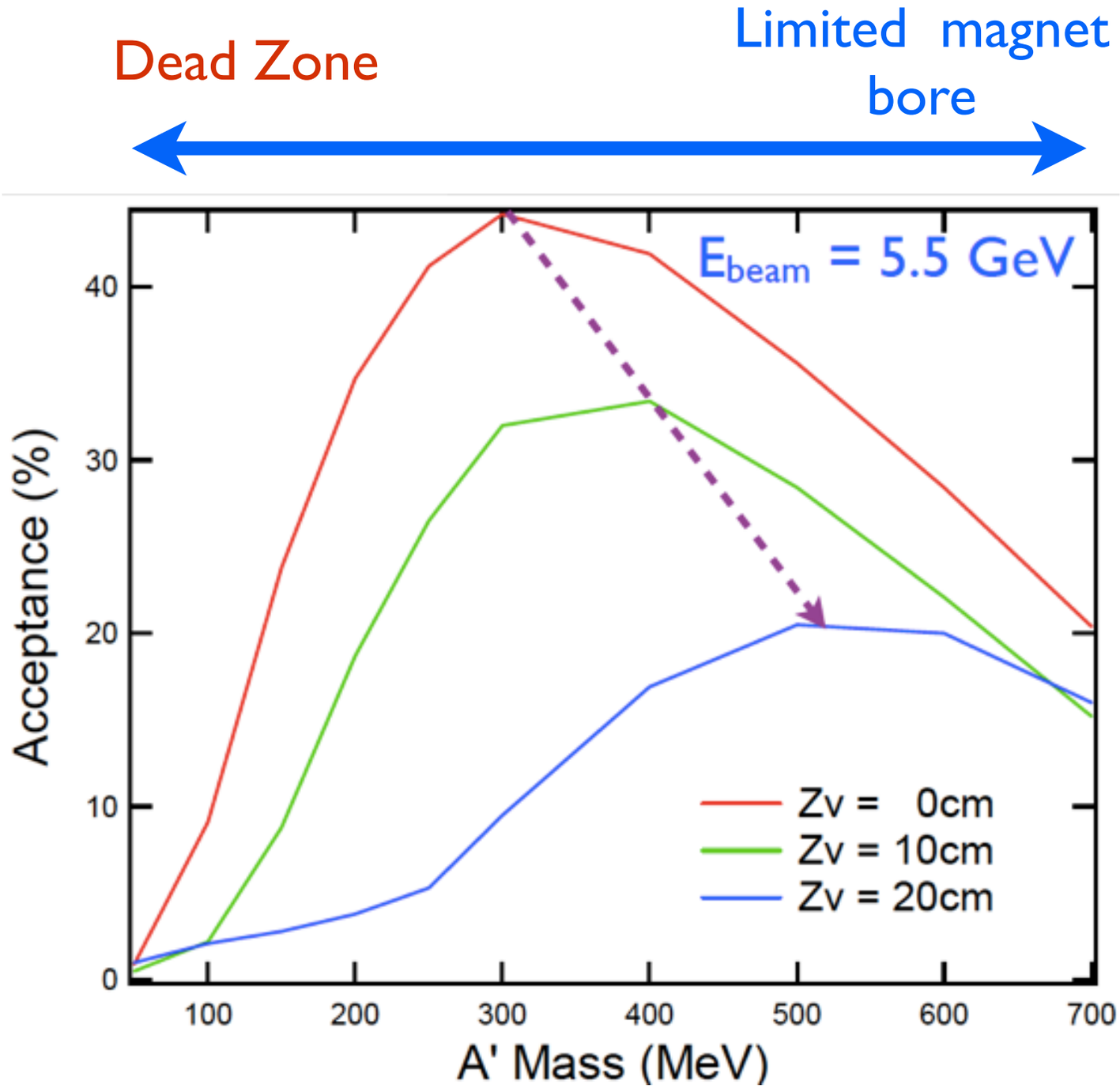
Cooling outside tracking volume. (~0.5% X_0 per layer)

Tracker Acceptance

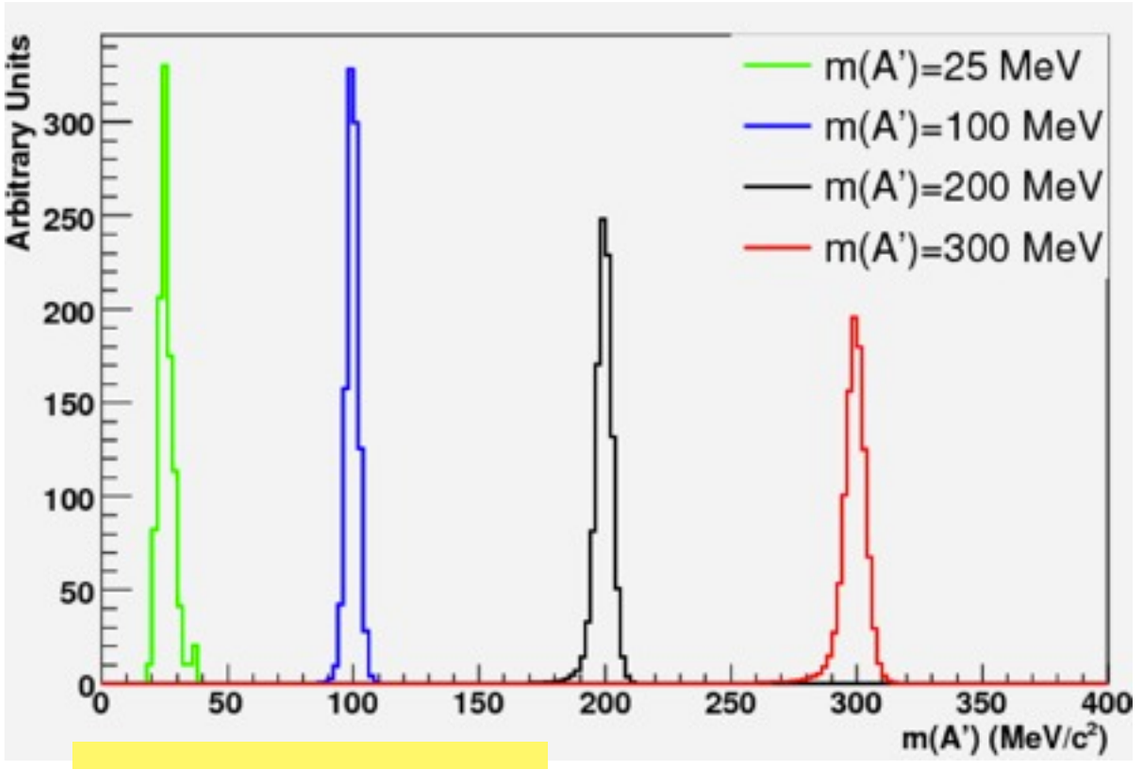
- At small A' mass, dead zone limits acceptance
- At large A' mass, limited by size of layers 5,6
- Increased z-vertex displacement increases dead zone

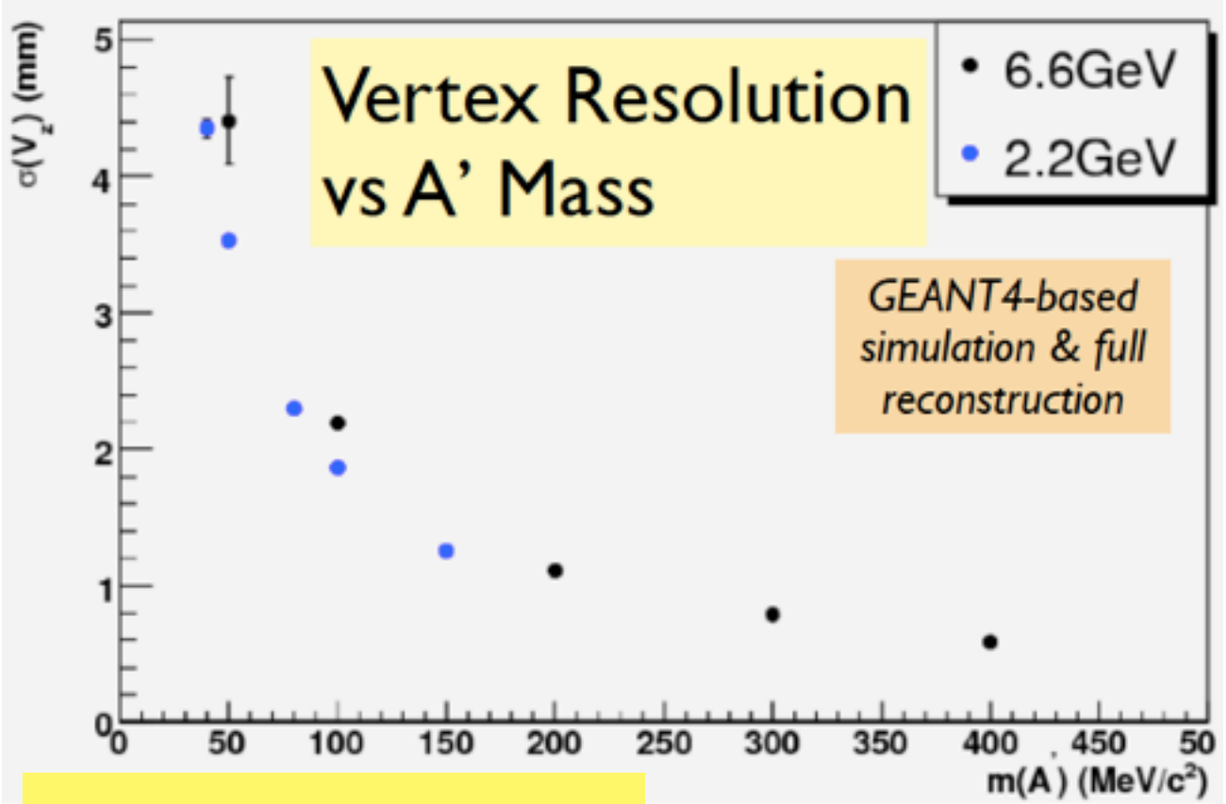
MC radiated events @ 2.2 GeV





Tracker Resolution (MC)





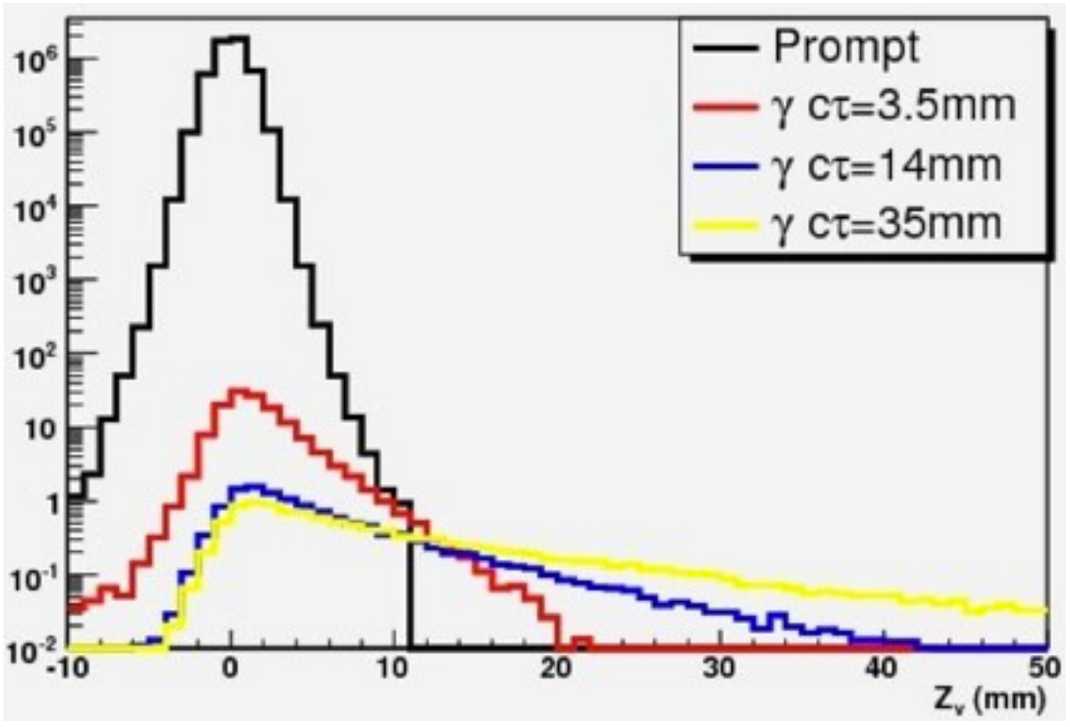
Δm/m~1%

Δz ~1 - 4 mm

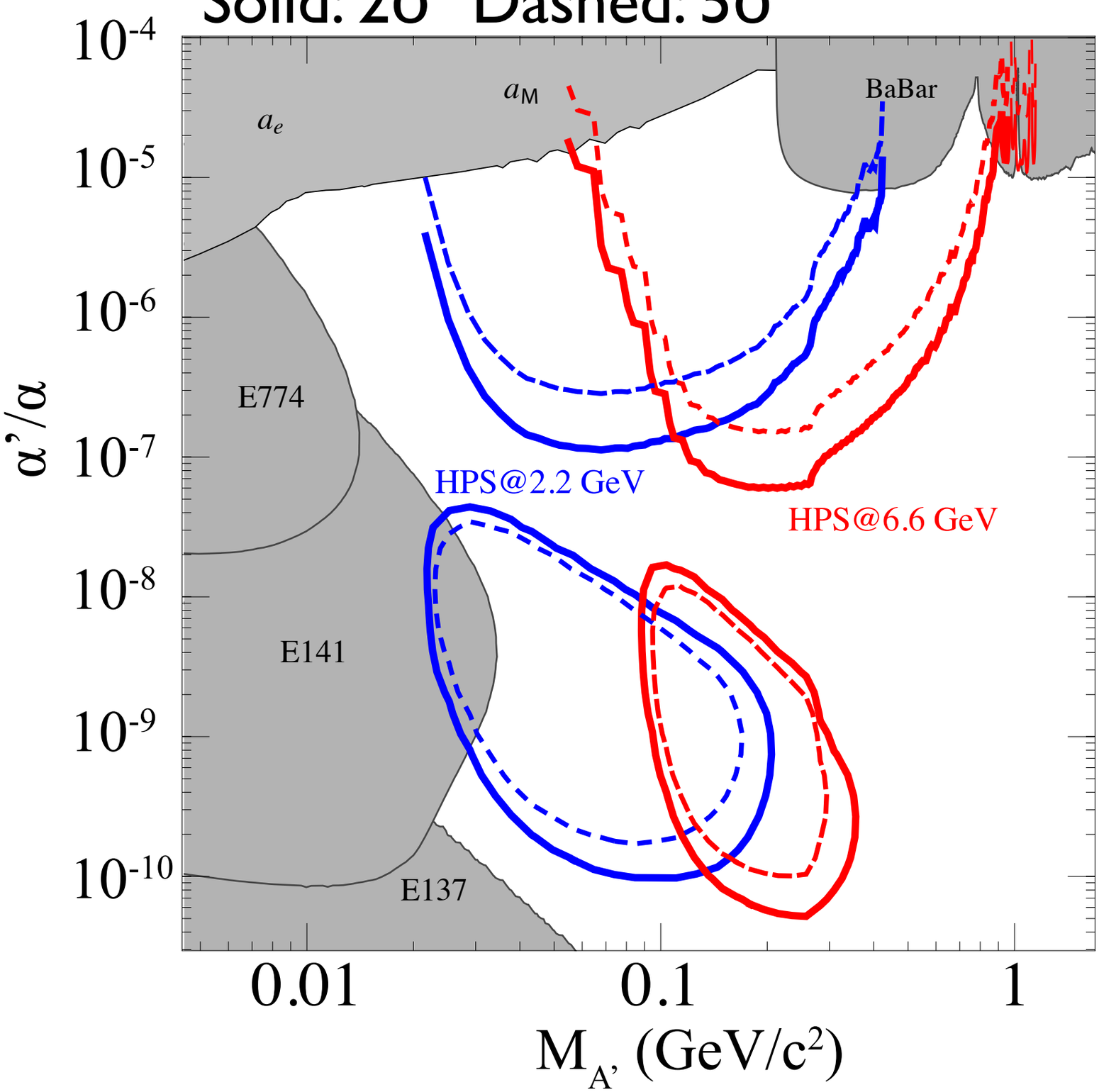
Mass resolution dominated by M.S.

Beat down prompt tails to ~ 0

Tails dominated by fake tracks.



Reach



Blue:

Beam = 2.2 GeV@200 nA

Target = 0.125%

Red:

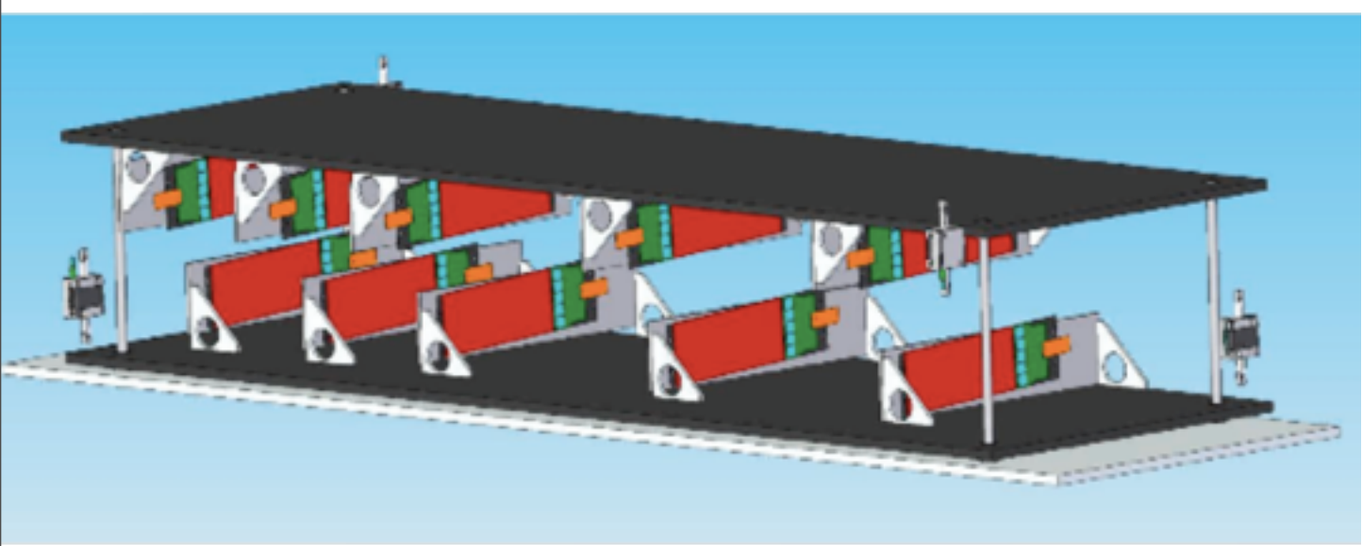
Beam = 6.6 GeV@450 nA

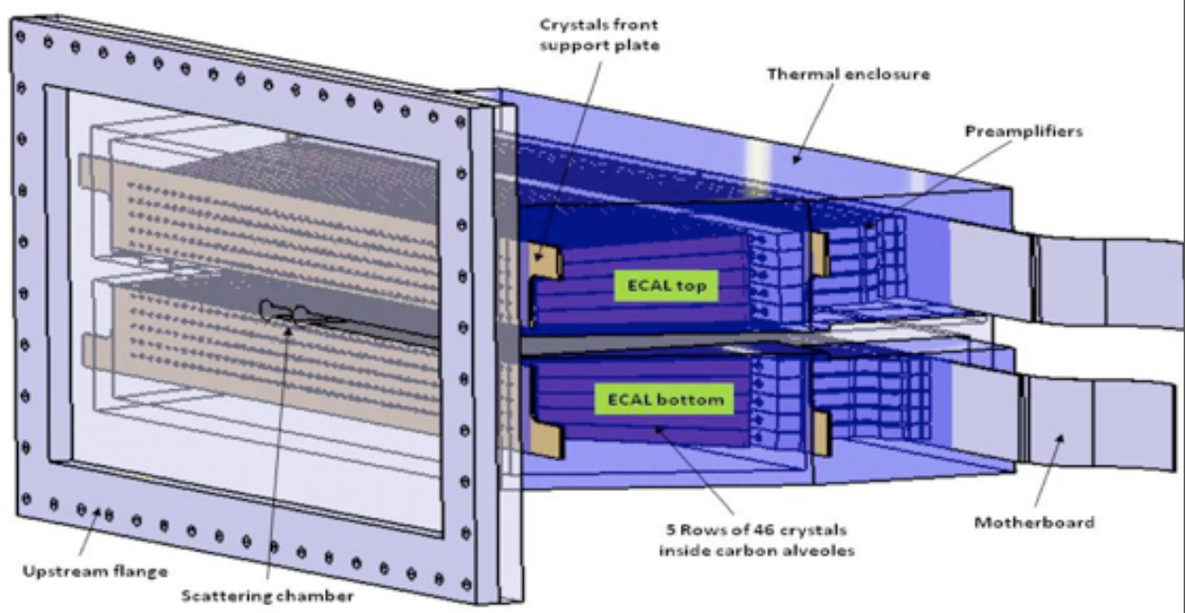
Target = 0.25%

3 months of running each energy = 180 days

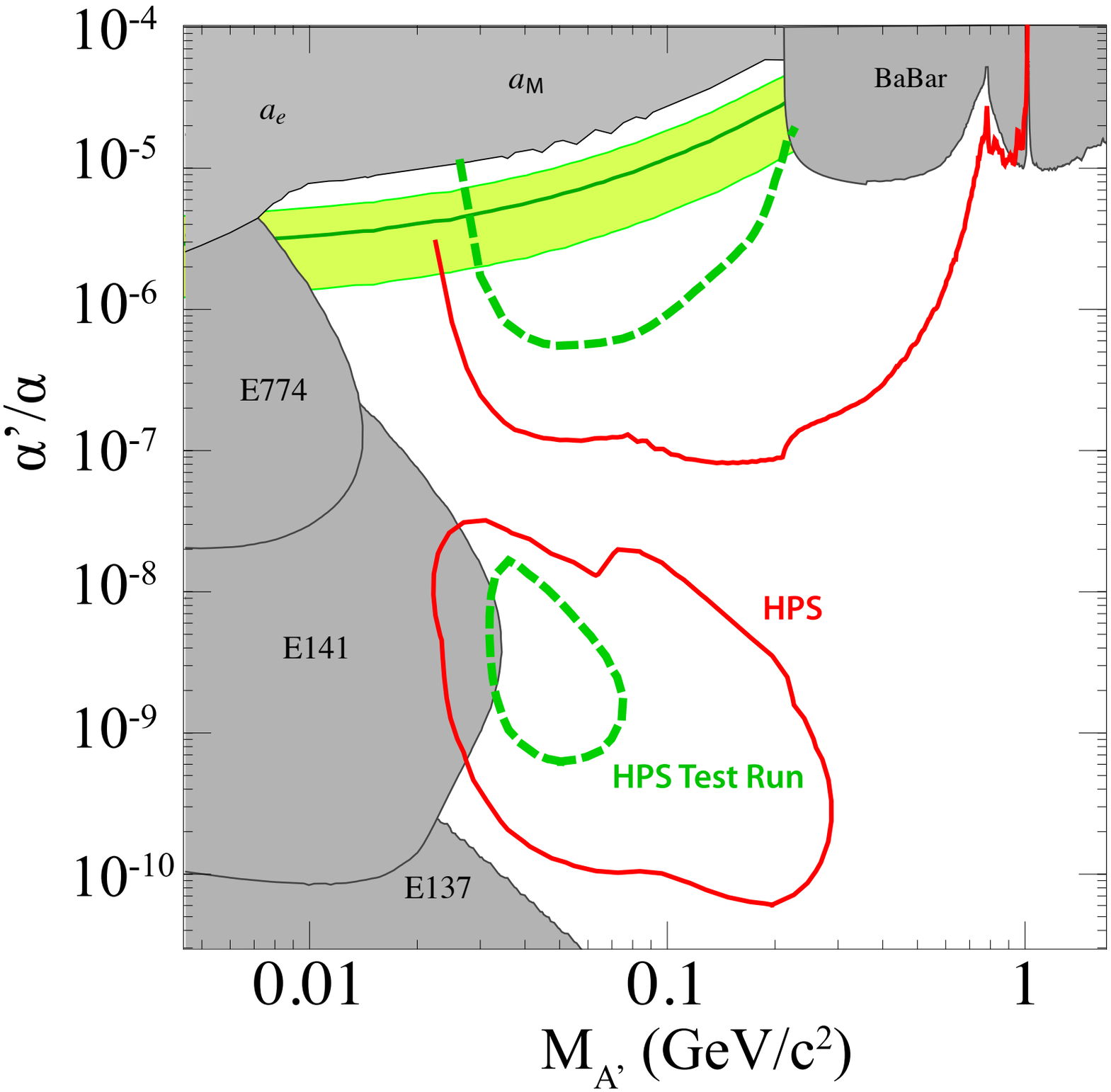
Test Run

- Test the equipment & methods before building full system
- Cheaper & Faster to build.
- Reduced size tracker and calorimeter (no muons)
- Verify background estimates, SVT & Ecal occupancies, trigger algorithm, DAQ performance.
- Run before Jlab 12 GeV upgrade this summer.





Test Run Reach

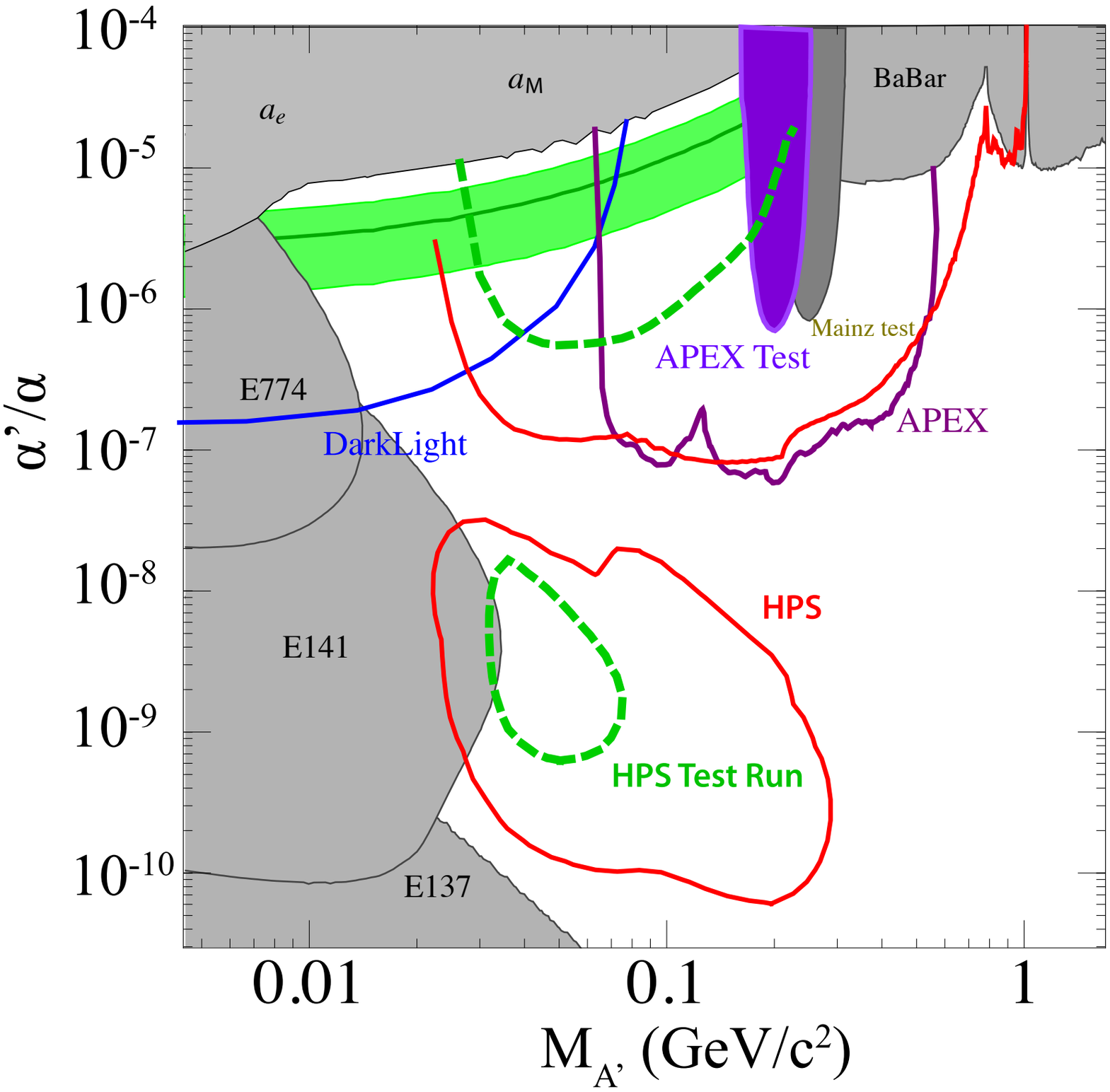


Green dashed:
2.2 GeV, 200 nA
0.125% X_0 target
~1 week of data.

Yellow green band is the region favored by a A′ explanation of the g_μ-2 anomaly.

Pospelov ′08

Other Experiments...



APEX - Jlab Hall-A & **Mainz A1** ~ same region as APEX.
Using spectrometers.

DarkLight - Jlab FEL
Using internal "active" target recoil detector.

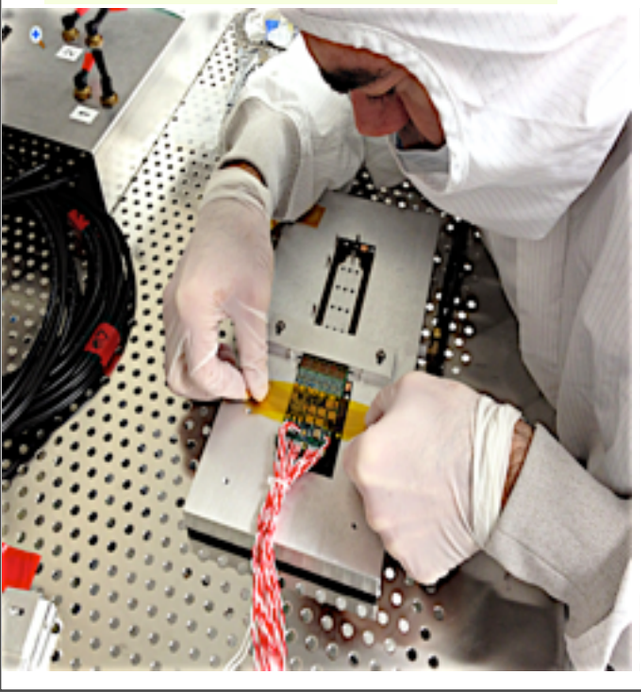
Not shown:
VEPP-3, BABAR, BELLE, KLOE, BES, SuperB, D0, Atlas, CMS,...

Conclusions

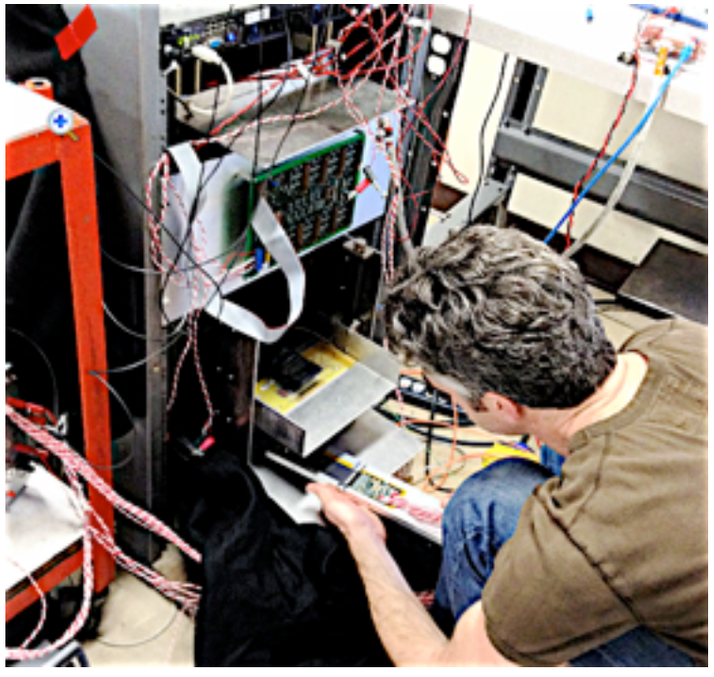
- The Heavy Photon Search at Jlab is an ambitious experiment looking for the A′, a heavy U(1) vector boson.
- Challenging experiment.
- Excellent reach.
- Test run being mounted, stay tuned!

Tracker module

SVT Module assembly



SVT cosmic tests



Vacuum system