Searches for new phenomena at Jefferson Lab

(see http://conferences.jlab.org/boson2010/)

OK Baker (for Andrei Afanasev)

7th Patras Workshop

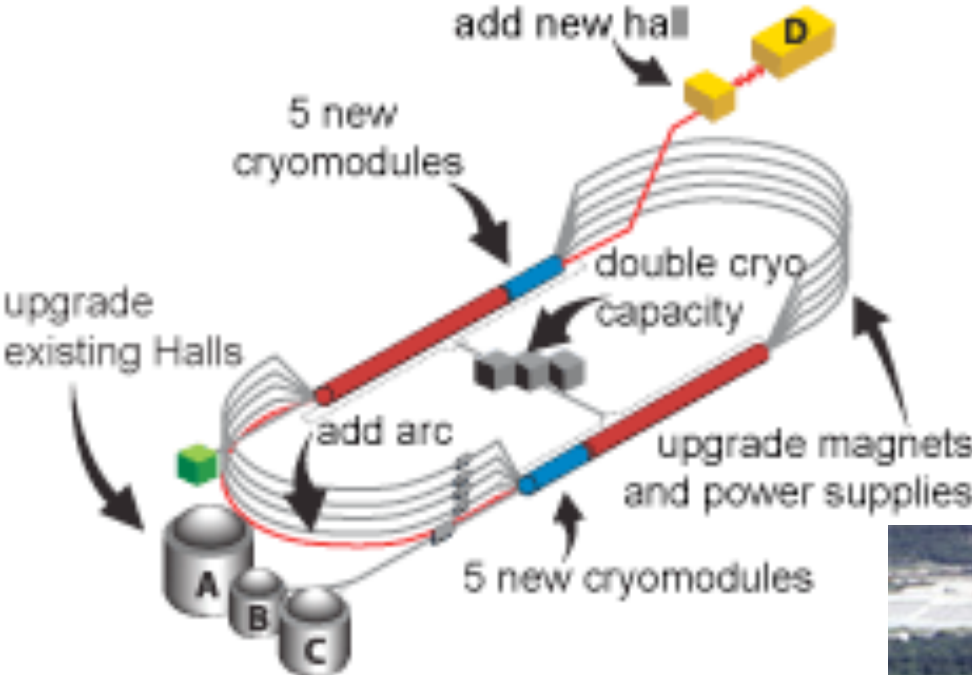
Mykonos, Greece

June 29, 2011

overview

- recent and proposed near-term LIPSS searches
- DARKLIGHT search at FEL
- Heavy Photon Search (HPS) in Hall B
- Hall A experiment (APEX)
- summary

Jefferson Lab



LIPSS at JLab collaboration

A. Afanasev, R. Ramdon
Hampton University
G. Biallas, J. Boyce, M. Shinn
Jefferson Lab
K. Beard
Muons, Inc
M. Minarni
Universitas Riau
O.K. Baker, P. Slocum
Yale University

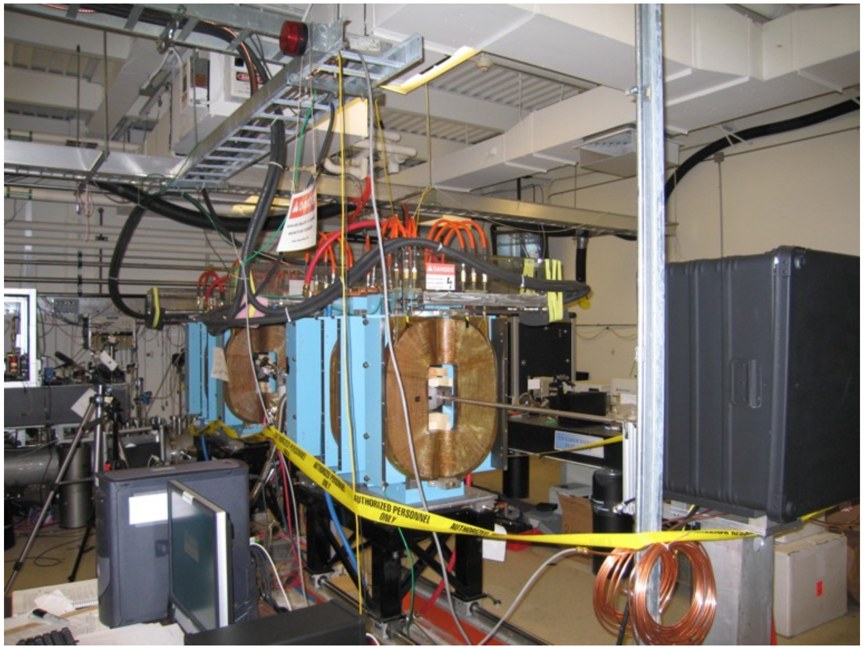
Yale UNIVERSITY

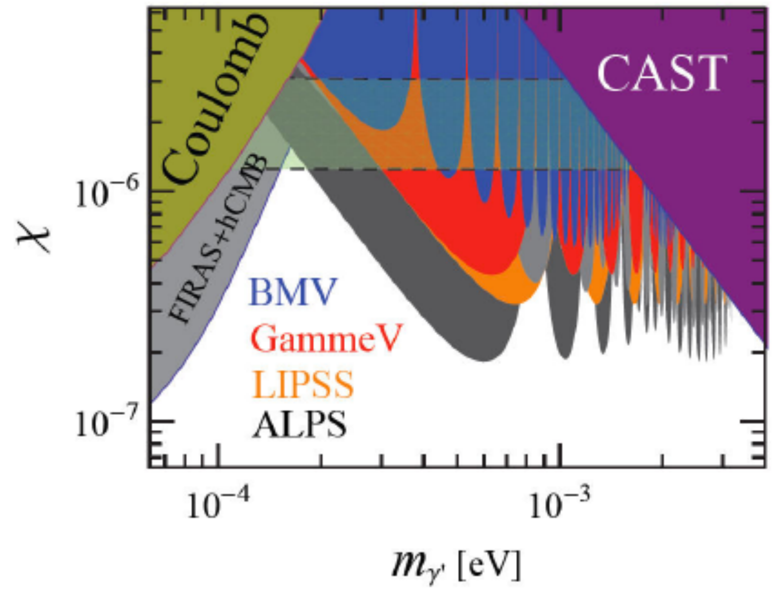
Jefferson Lab

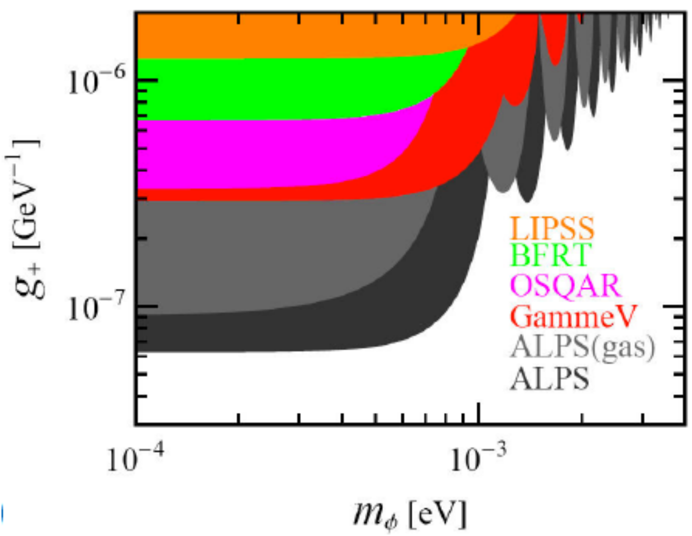
Office of Naval Research

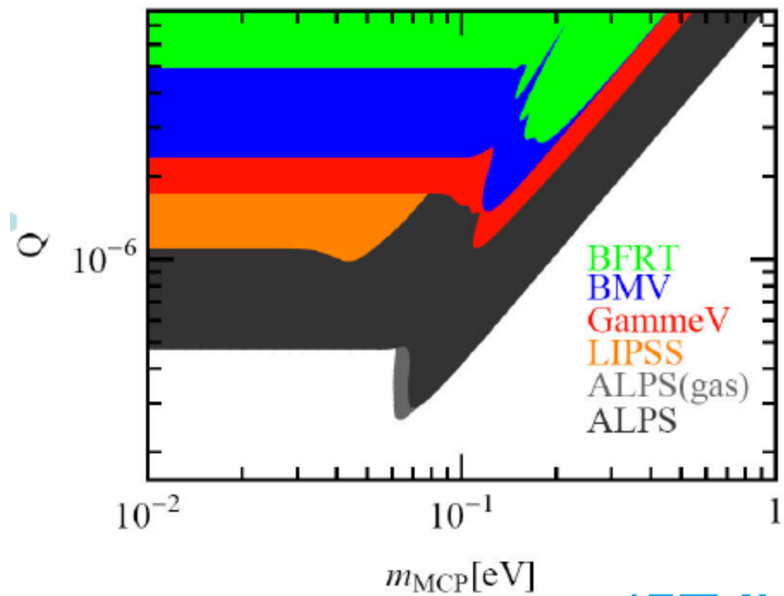
Office of Science U.S. DEPARTMENT OF ENERGY

LIPSS at FEL Lab 1

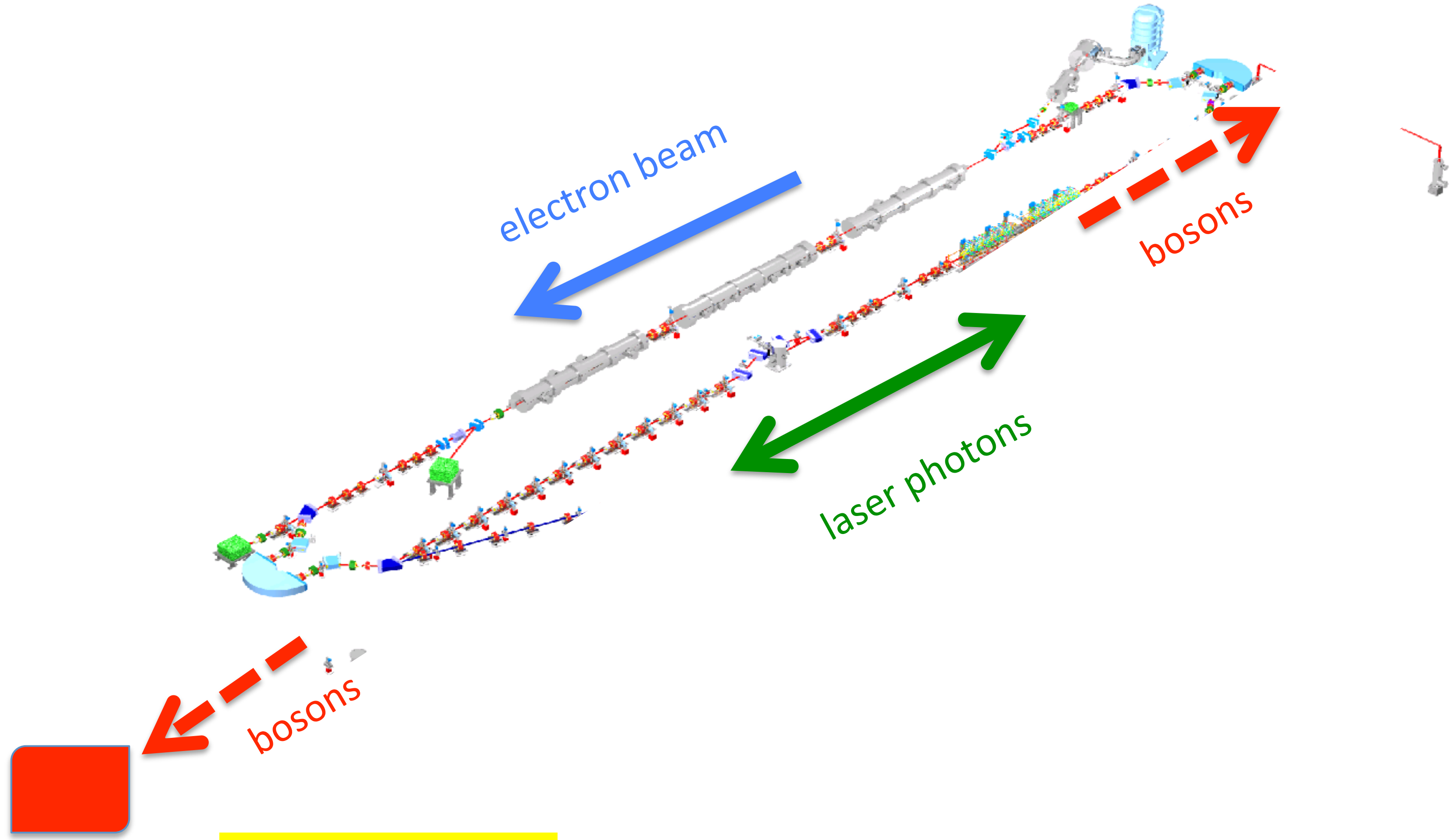






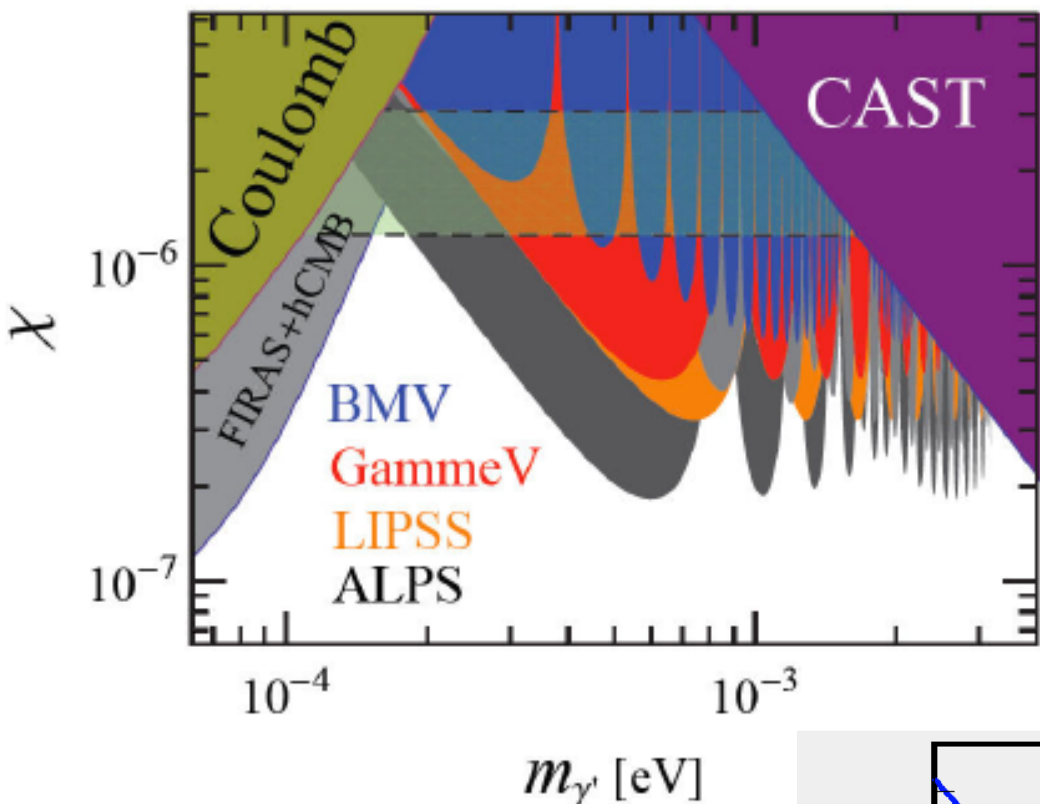


photon-boson kinetic mixing; next steps



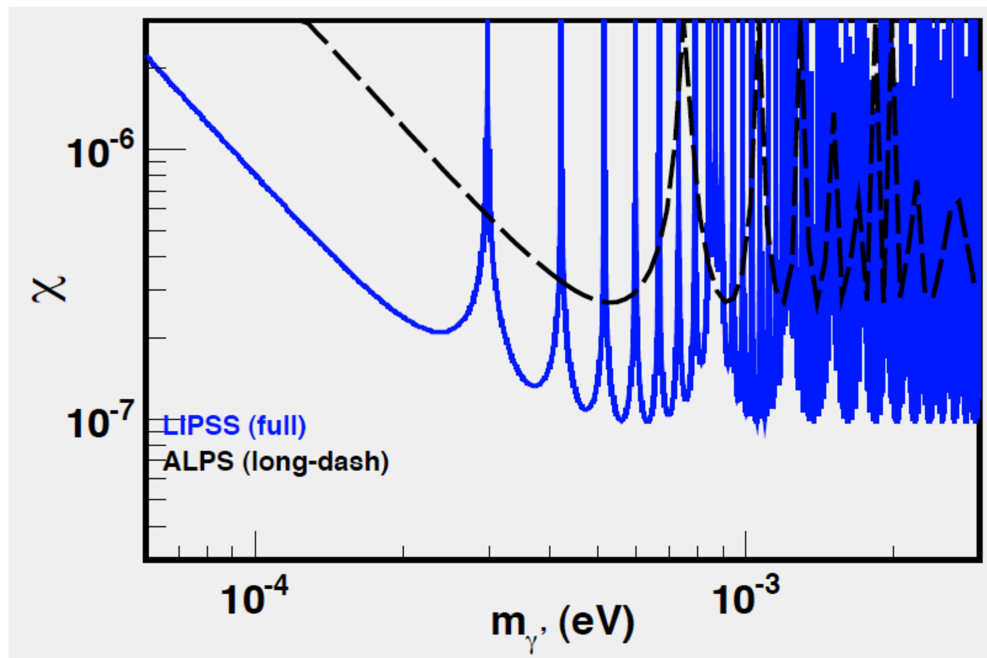
LIPSS 2

detector in line with cavity



K. Ehret et al,
ALPS results
arXiv:1004.1313

predicted LIPSS results



$L_1 = 25\ m$

$L_2 = 2.5\ m$

$\lambda = 1.6\ \mu$

70 KW laser power

$t \sim 10$ days

boson beam dump

- based upon LSW principle of photon regeneration
- Compton scattering at FEL
- long lifetimes

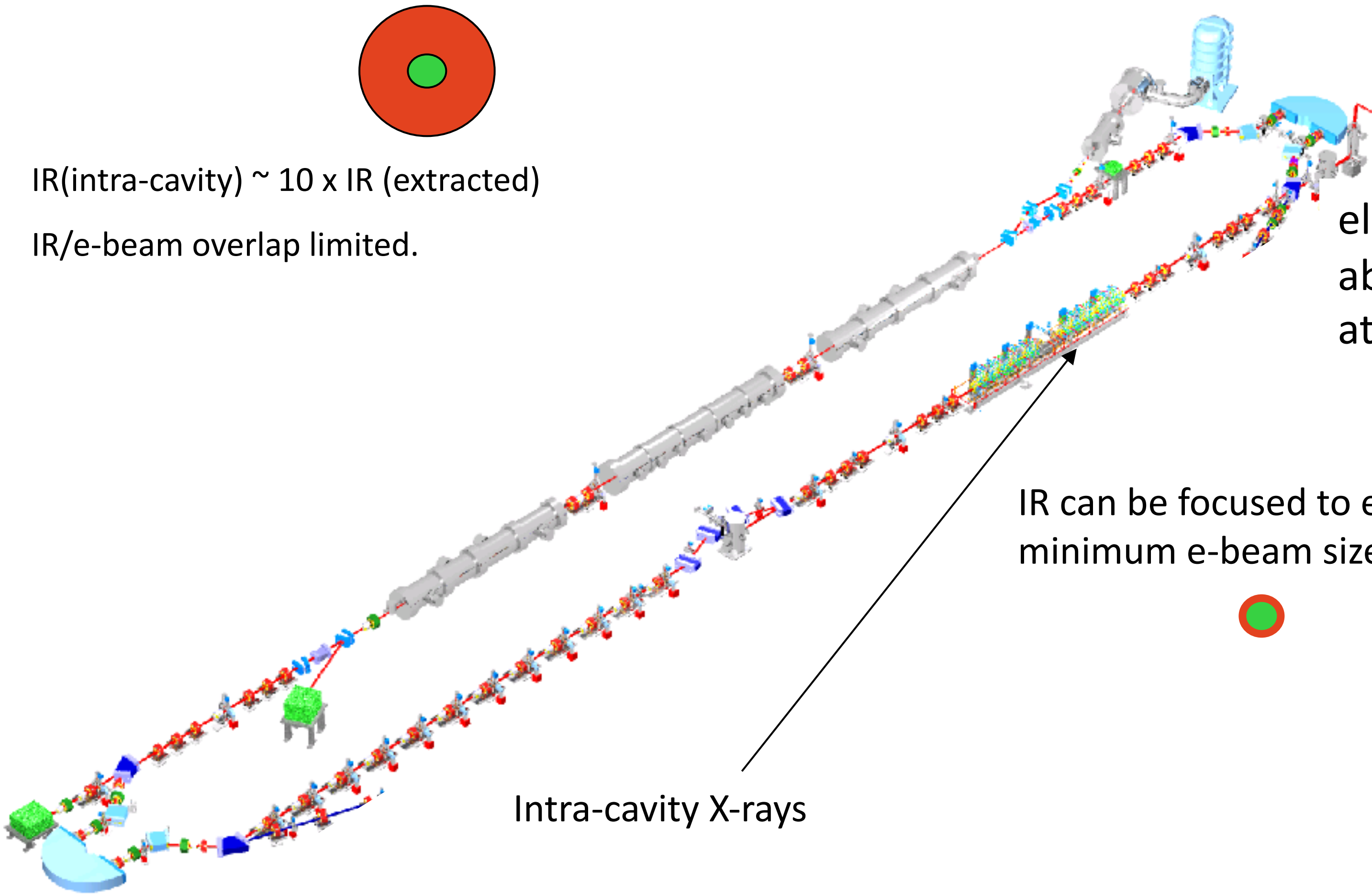
- coupling at vertex enters twice
- limited to ~25 keV mass boson production

Compton scattering and high luminosity

from J. Boyce 2003

IR(intra-cavity) ~ 10 x IR (extracted)

IR/e-beam overlap limited.

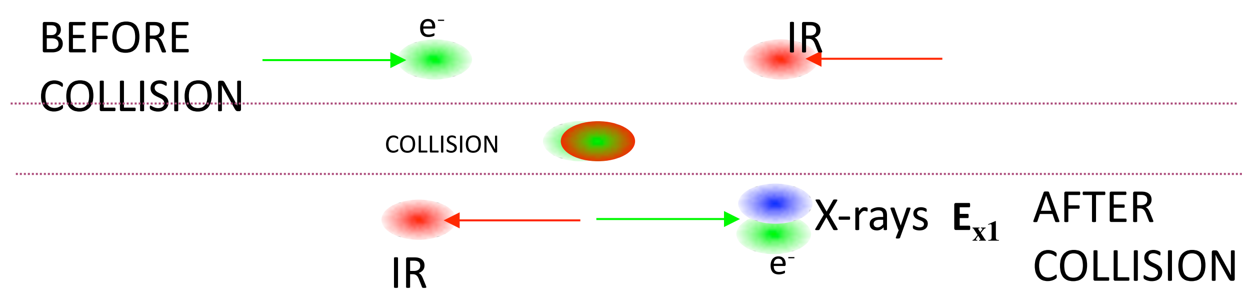


LIPSS 2

elevated ~ 15 cm
above beamline
at end of cavity

IR can be focused to e-beam spot
minimum e-beam size is 200 μm.

Intra-cavity X-rays



"Standard" 180° Thomson Scattering. X-rays produced are traveling with electron bunch after IR scatters off electrons at interaction region.

$$\ell \sim \frac{n_e \cdot n_\gamma}{\sigma_e \cdot \sigma_\gamma} \sim 2 \times 10^{43} \quad \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$$ luminosity

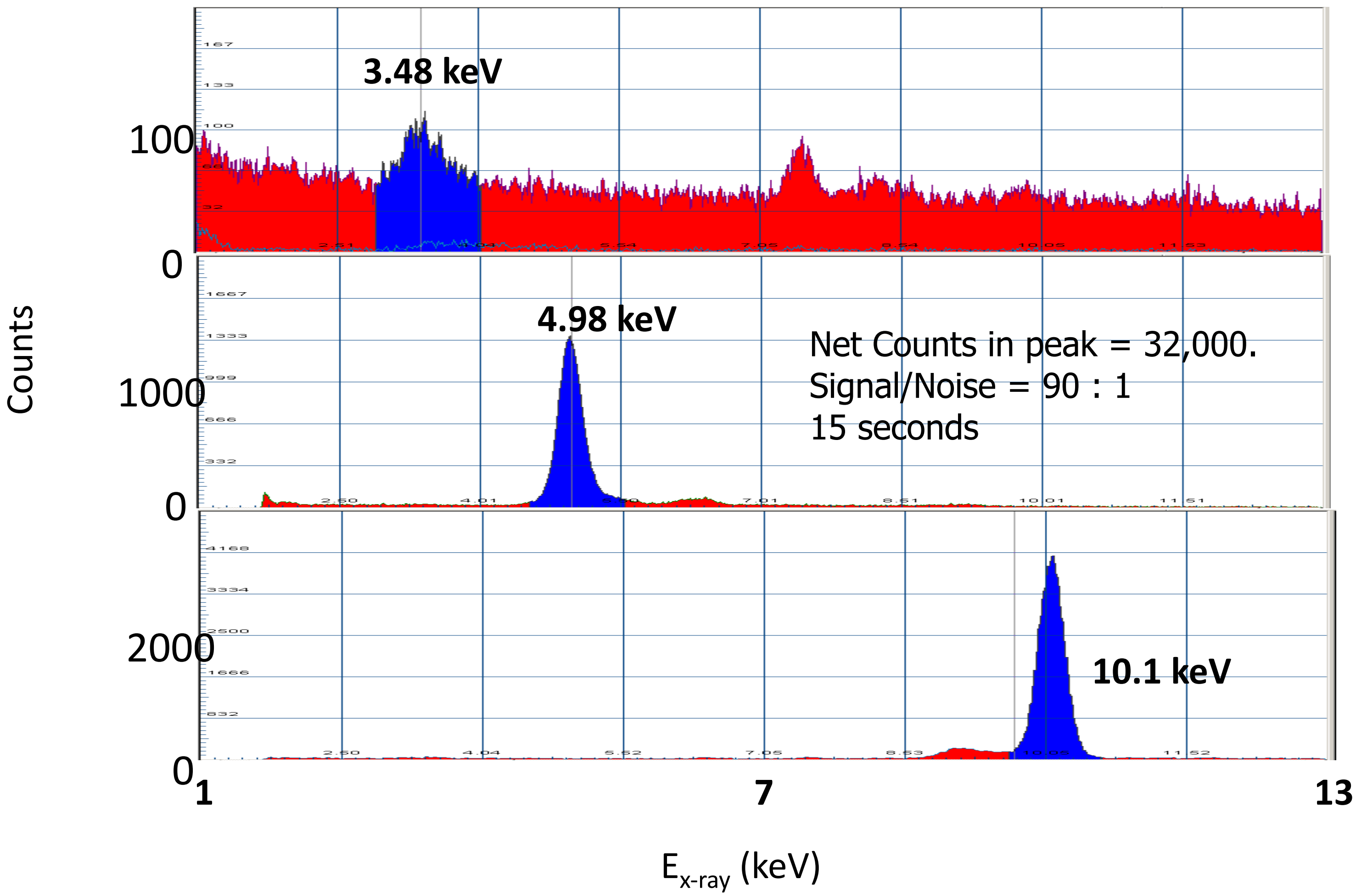
$$n_e \sim 5\ mA = 3 \times 10^{16}\ Hz$$ electron current

$$n_\gamma \sim (50KW\ \ ,\ 1.6\mu m) = 3 \times 10^{23}\, Hz$$ photon flux

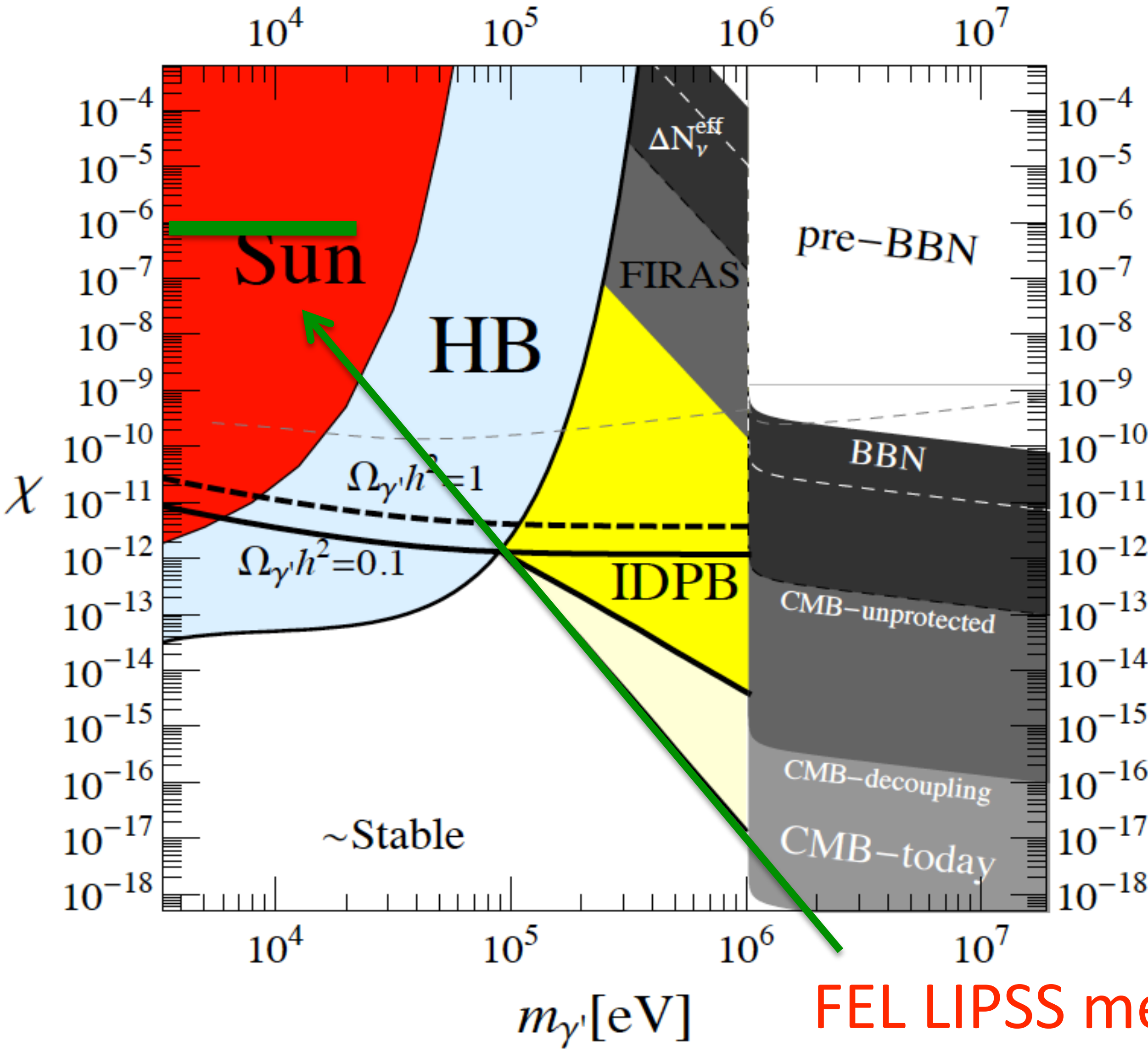
$$\sigma \sim 200\mu m$$ beam diameter

from J. Boyce 2003

actual typical spectra



boson beam dump

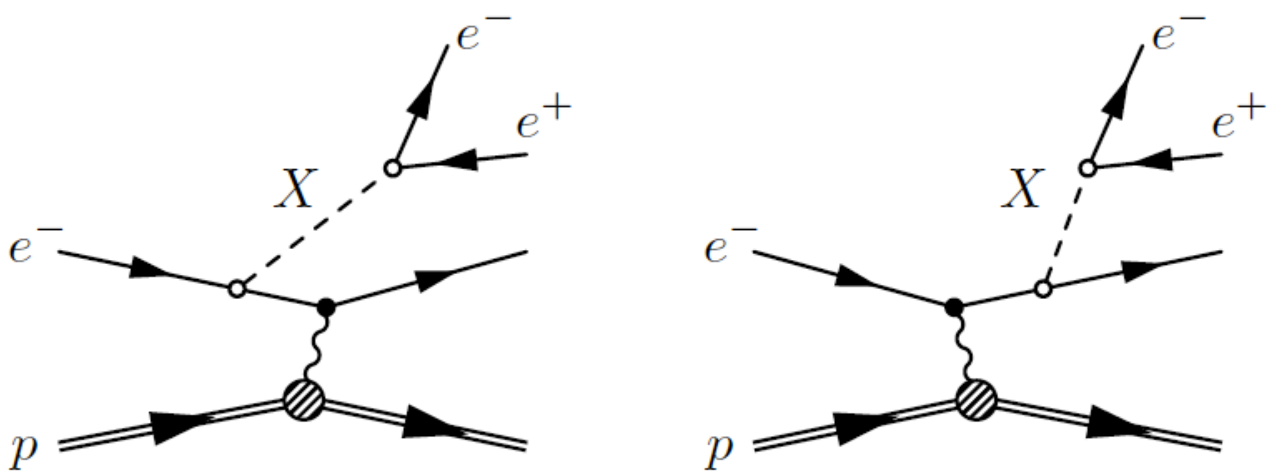


Marieke Postma, Javier Redondo, JCAP 0902:005,2009; arXiv:0811.0326

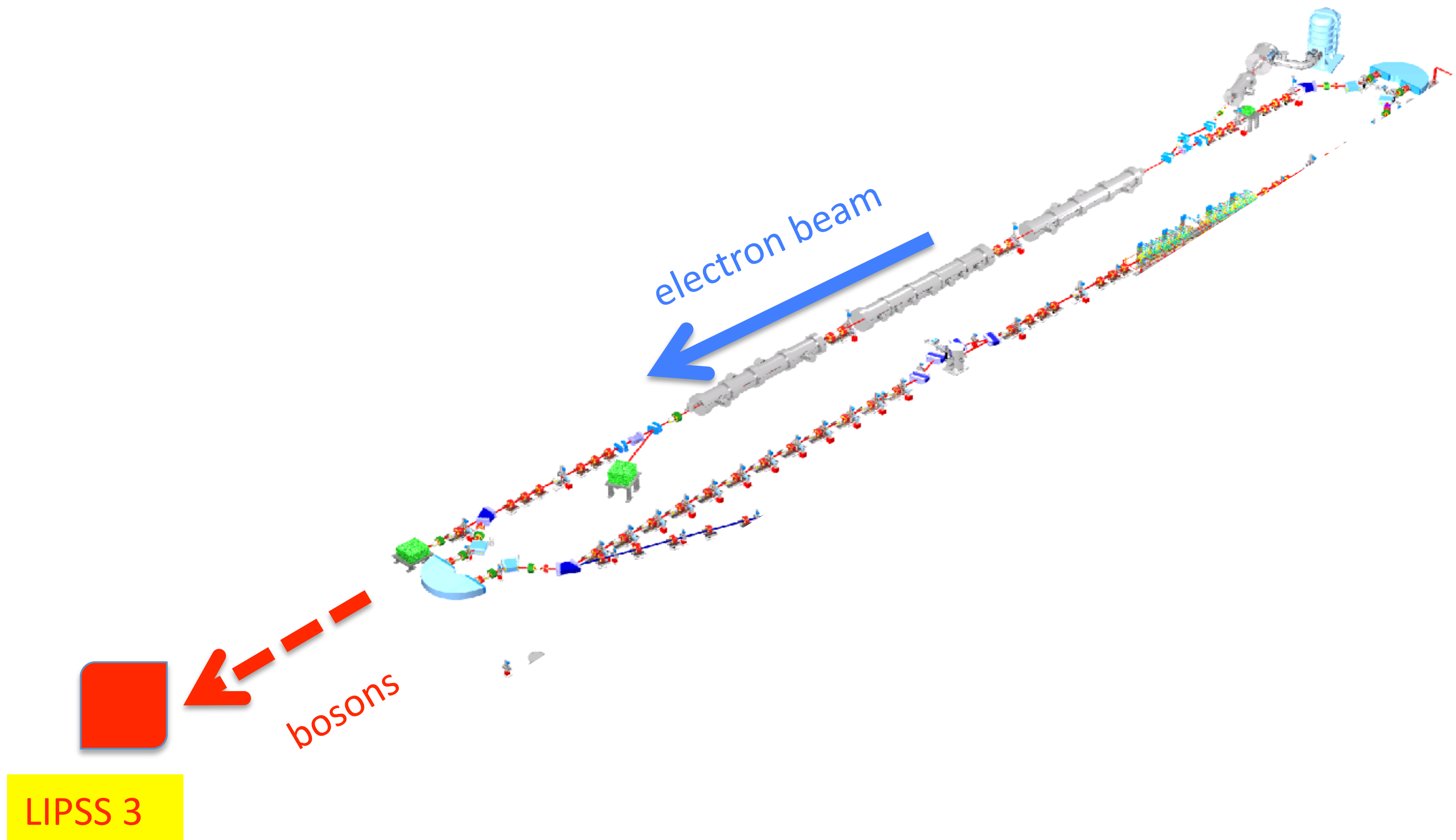
FEL LIPSS measurement:
~ one month

electron beam dump

- also based upon LSW principle photon regeneration
- useful for large range of boson lifetimes
- coupling at vertex enters twice

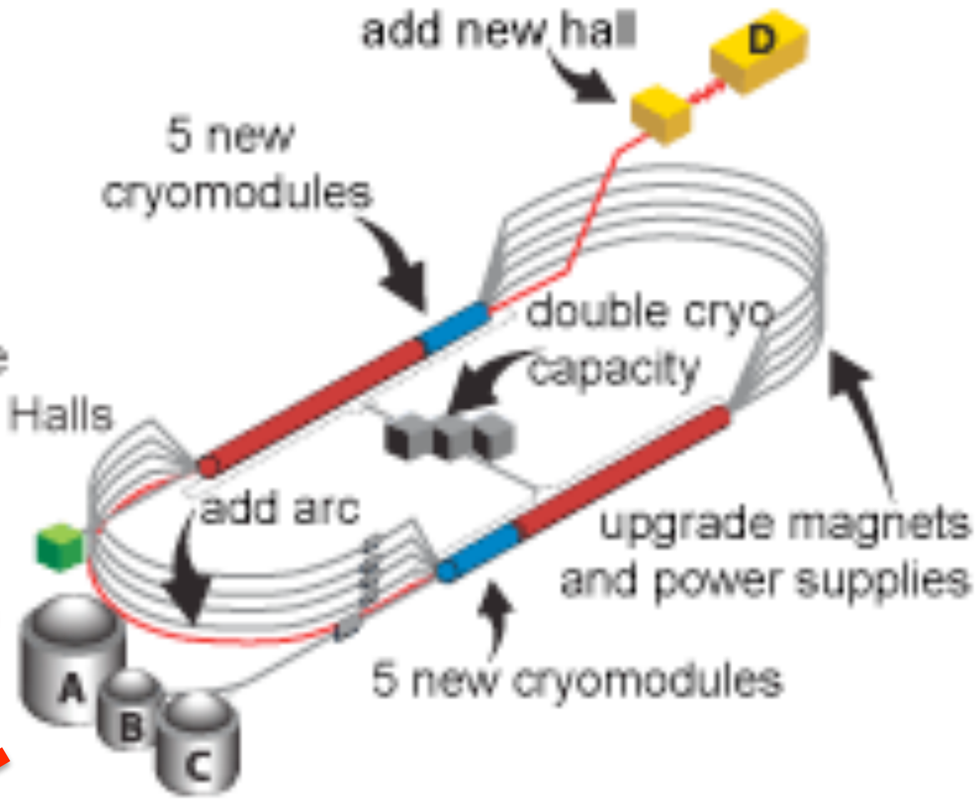


electron beam dump at FEL



~0.13 MW beam dump exists;
excavation behind FEL beam dump(?)

electron beam dump at CEBAF



detector behind
experimental hall

high power beam dumps exists;
excavation behind CEBAF beam dumps(?)

electron beam dump

$$Y_i \sim r_e \cdot n_t \cdot t \cdot \sigma \cdot \varepsilon \;= \mathcal{l} \cdot \sigma \cdot \varepsilon$$ experimental yield, Hz

$$r_e(1\ mA) \sim 6 \times 10^{15}\ \ \text{Hz}$$

$$n_t \sim 2 \times 10^{23}\ \ \text{cm}^{-3}$$

$$t \sim 100\ \text{cm}$$

$$\mathcal{l} \sim 10^{41}\text{cm}^{-2}\text{s}^{-1} \quad \rightarrow \quad \boxed{\sim 1\ \text{ab/min}}$$

FEL beam dump luminosity

$$r_e(100\ \mu A) \sim 6 \times 10^{14}\ \ \text{Hz}$$

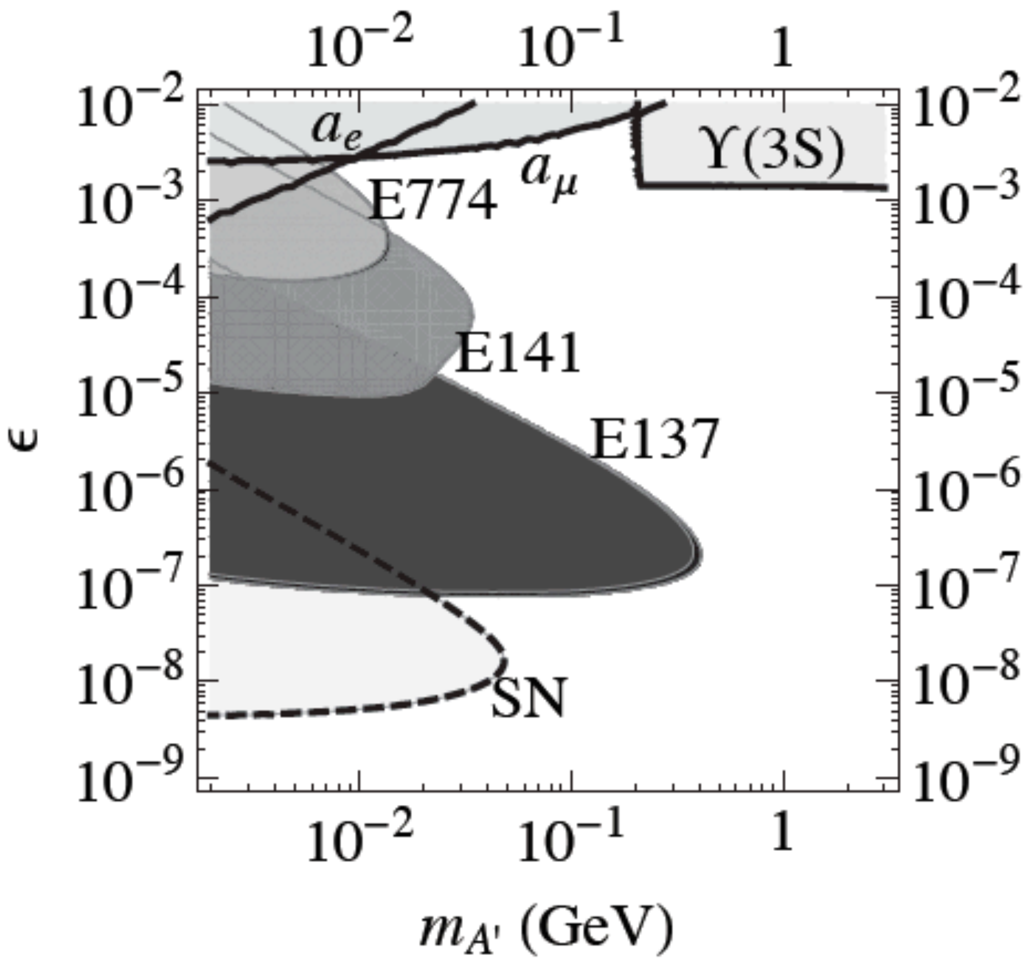
$$n_t \sim 2 \times 10^{23}\ \ \text{cm}^{-3}$$

$$t \sim 100\ \text{cm}$$

$$\mathcal{l} \sim 10^{40}\text{cm}^{-2}\text{s}^{-1} \quad \rightarrow \quad \boxed{\sim 1\ \text{ab/hour}}$$

Hall A, C beam dump luminosity

electron beam dump

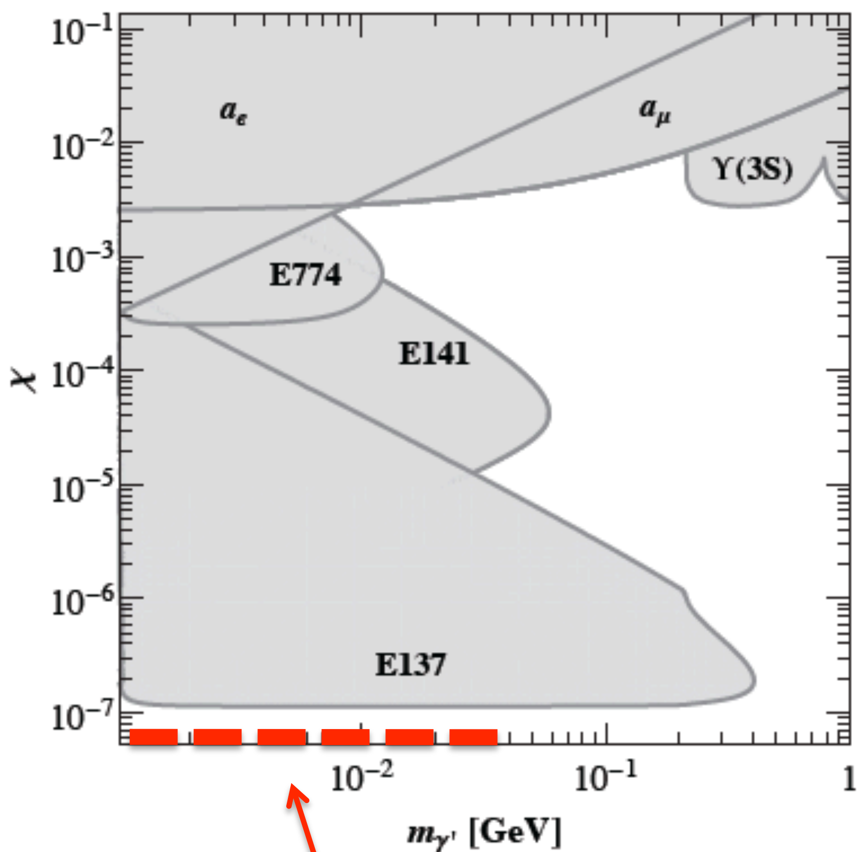


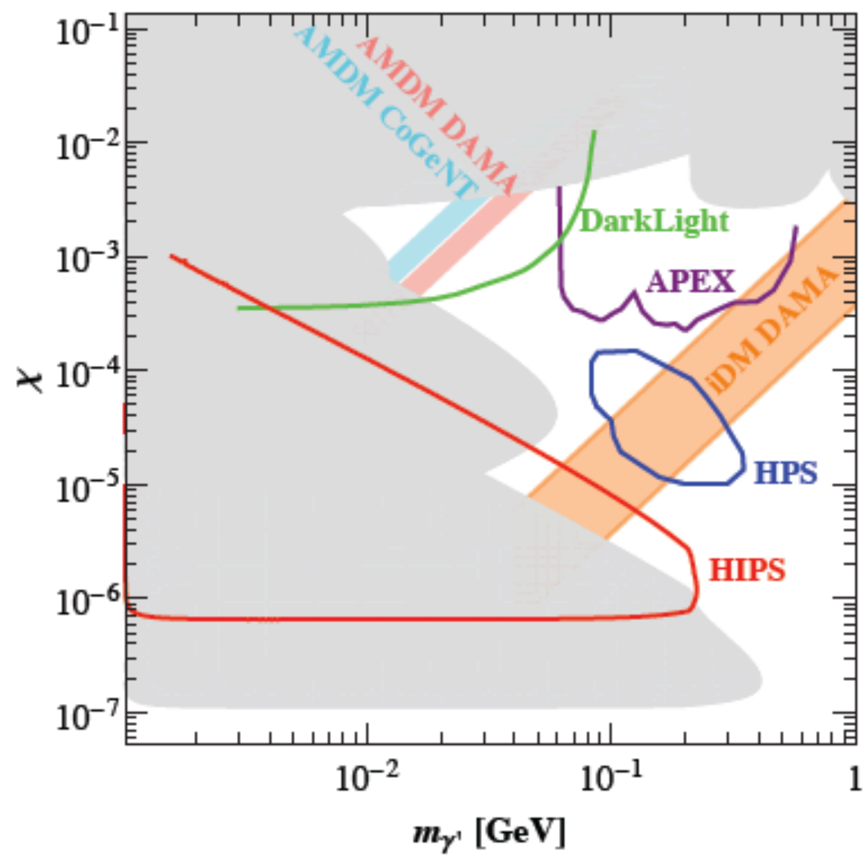
- SLAC E137
  - 2 x 10^{20} elec
  - 20 GeV
  - d ~ 400 m
- SLAC E141
  - 2 x 10^{15} elec
  - 9 GeV
  - d ~ 35 m
- FNAL E774
  - 5 x 10^{10} elec
  - 275 GeV
  - t ~ 1 m

JD Bjorken et al, PhysRevD.80.075018 (2009)

electron beam dump

S. Andreas, A. Ringwald contribution to 6th Patras Workshop on Axions, WIMPs and WISPs, Zurich University, Switzerland, 5-9 July 2010 arXiv:1008.4519



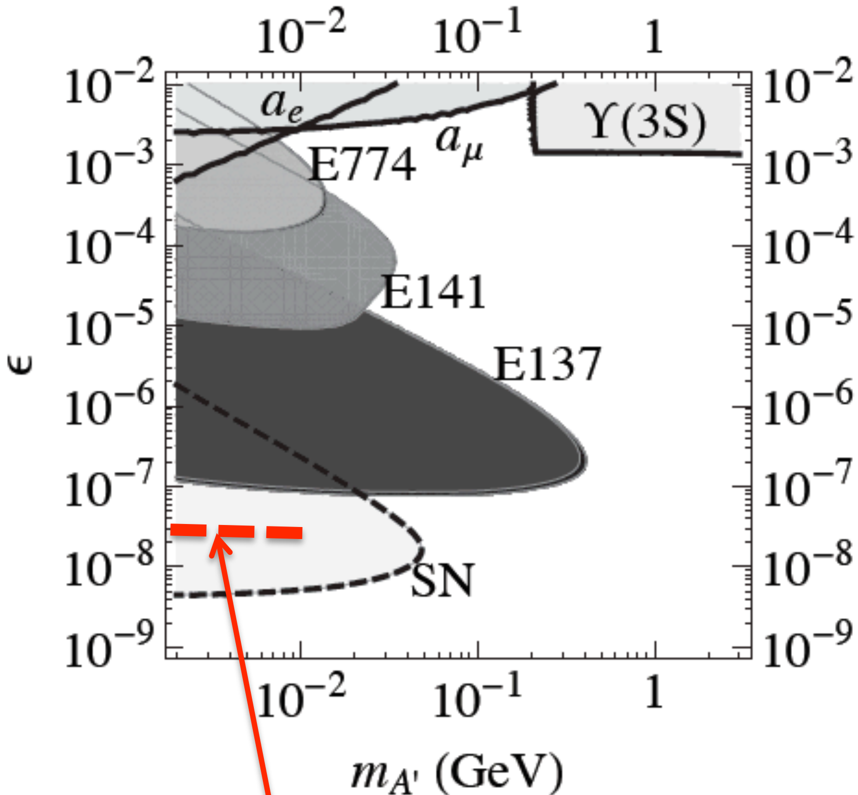


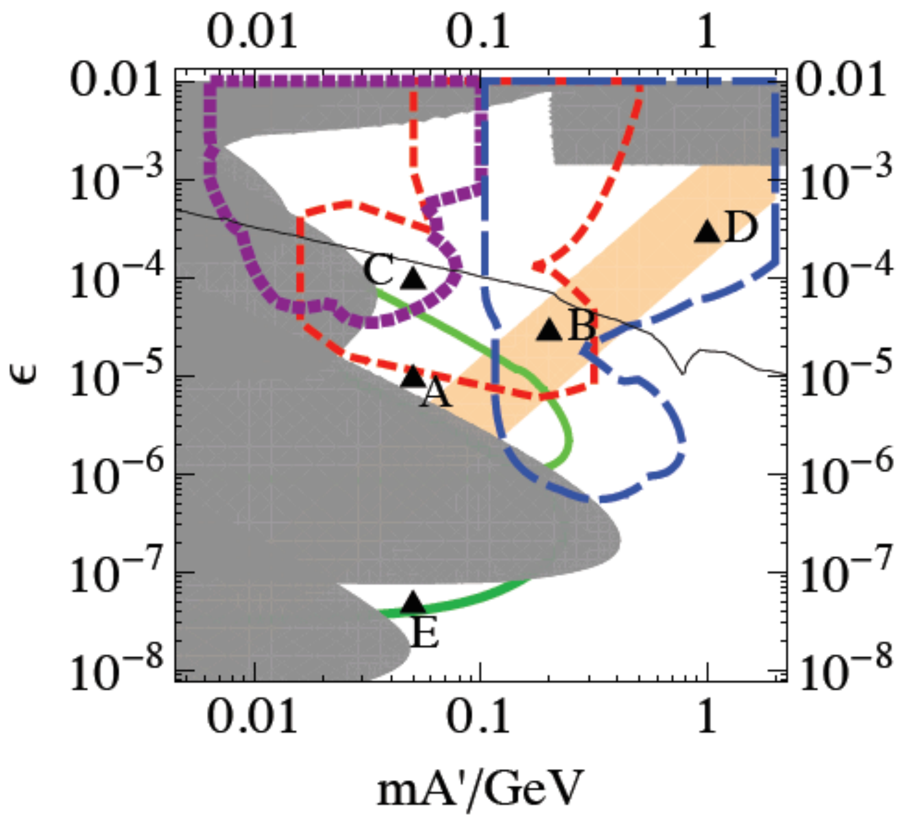
CEBAF LIPSS in ~ one month

χ : CEBAF LIPSS ~2 *x* E137

electron beam dump

JD Bjorken et al, PhysRev D80, 075018 (2009);
Freytsis, Ovanesyan, Thaler ; arXiv:0909.2862





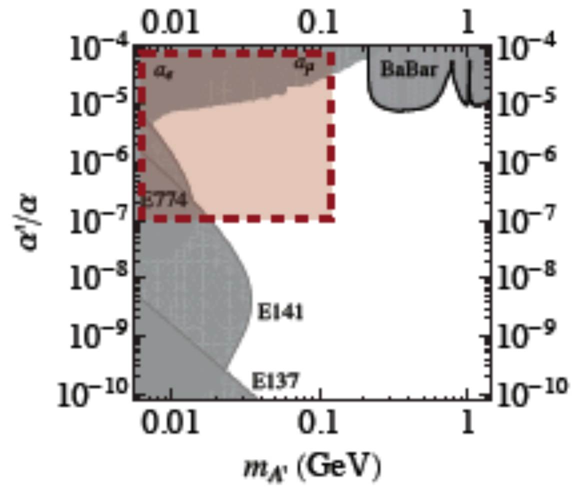
FEL LIPSS in ~ one month

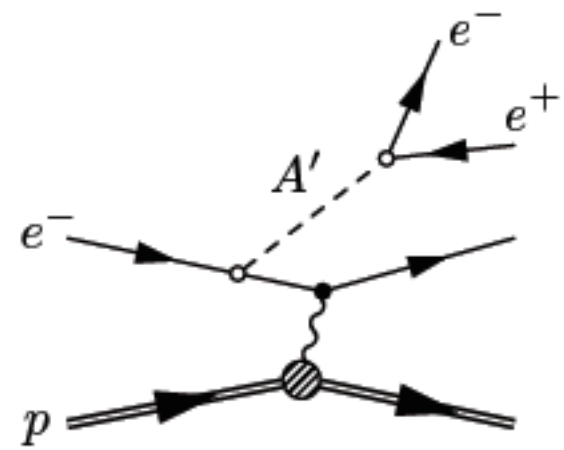
ε : FEL LIPSS 3 *x* E137

DARKLIGHT at the Free Electron Laser Facility

DarkLight Proposal

Detecting **A** **R**esonance **K**inematically with
e**L**ectrons **I**ncident on a **G**aseous **H**ydrogen **T**arget





High Intensity, Low Energy Electron Beam (JLab FEL)
on Diffuse Hydrogen Gas Target ⇒ Luminosity: 1 ab^{-1} / month

Large Tracking Volume + Pixels ⇒ Full Event Reconstruction

Low Q^2 ep scattering ⇒ Unique Opportunity for Basic Science

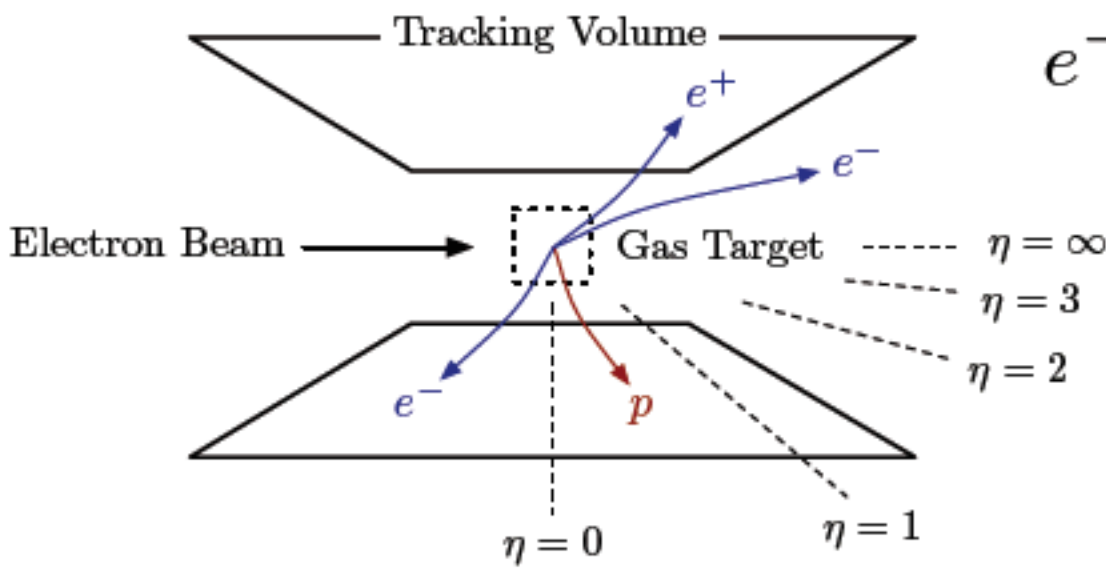
DARKLIGHT

A Search for New Light Bosons Using the JLab FEL

Arizona State	Ricardo Alarcon
Berkeley	Marat Freytsis
JLab	Steve Benson, Jim Boyce, David Douglas, Rolf Ent, Kevin Jordan, George Neil, Michelle Shinn
LANL	Grigory Ovanesyan
Maryland	Ralph Fiorito, Patrick O'Shea
MIT	Purnima Balakrishnan, Bill Bertozzi, Ray Cowan, Shalev Gilad, Peter Fisher, James Hays-Wehle, Yoni Kahn, Aiden Kelleher, Richard Milner, Becky Russell, Jesse Thaler, Sinh Thong, Christoph Tschalär
Yale	Keith Baker

"Dark Force Detection in Low Energy e-p Collisions"
[Freytsis, Ovanesyan, JDT: arXiv:0909.2862 (JHEP 1001:111)]

Electron-Proton Collisions

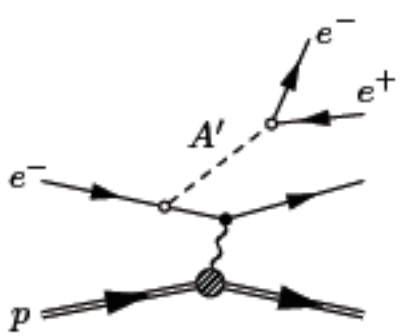


$$e^- p \to e^- p + A'$$
$$\hookrightarrow e^+ e^-$$

$$E_{\text{beam}} \lesssim 140 \text{ MeV}$$

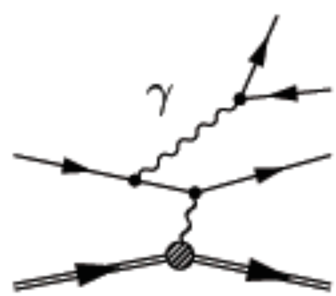
$$\text{ab}^{-1}/\text{month}$$

Narrow Resonance on Huge QED Background

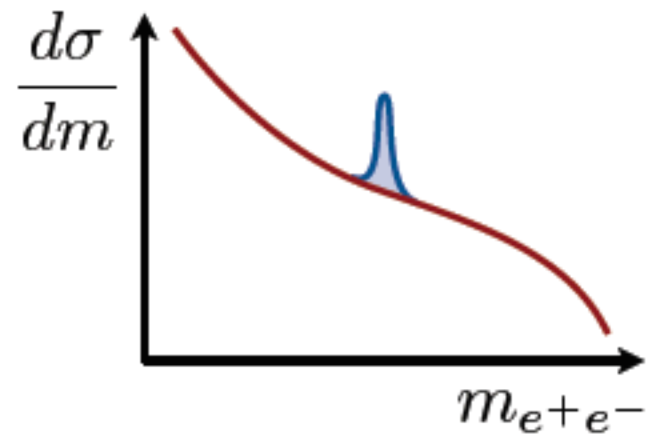


S

vs.



$\sqrt{B}$

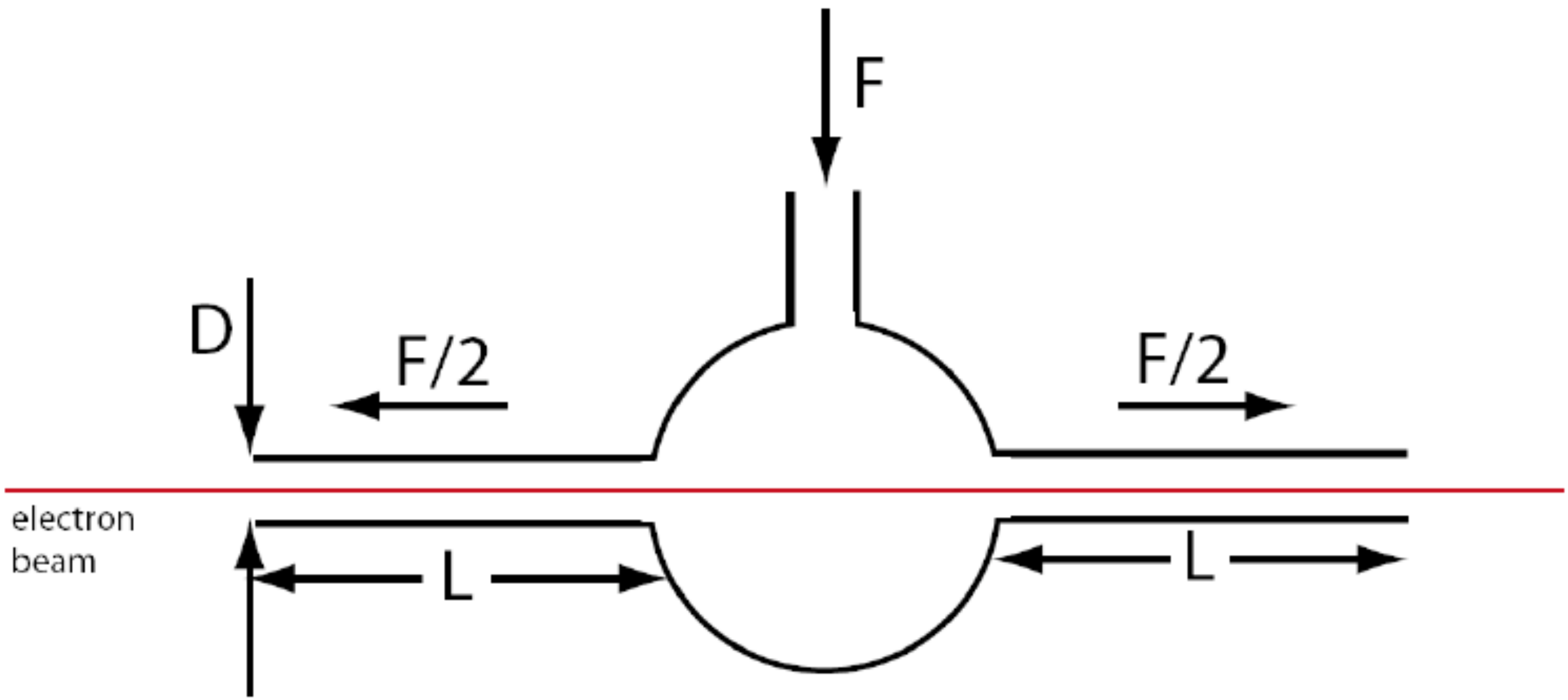


DarkLight Target design considerations

Rebecca Russell, Richard Milner, Chris Tschalär
MIT-LNS

- Must accept 1 MWatt beam => gas target
- Searching for rare events => maximize thickness
- Must allow MeV proton to exit => thin container walls
- Beam core has σ_x~ 50 μm and σ_θ~ 3 mrad
- What about tails?

DarkLight Gas Target Concept



T=15 K, F = 1.5 x 10^{18} s^{-1} (100 mTorr-liter per sec), L= 10 cm, D = 2 mm
Target thickness = 10^{19} cm^{-2}

Detector layout

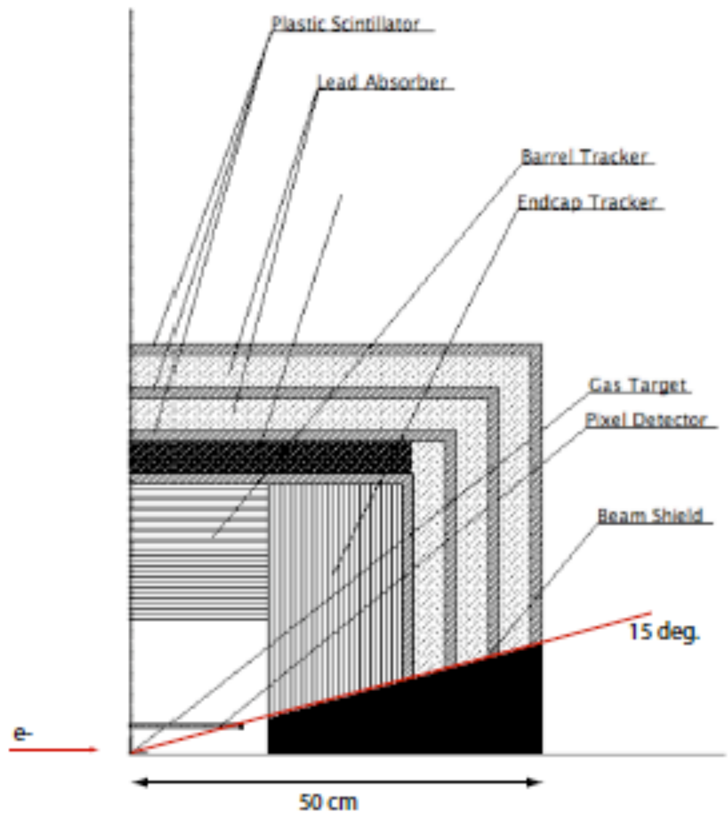


Figure: Detector quadrant.

- Gas target with $10^{19}\mathrm{cm}^2$ thickness
- Be beampipe
- Pixel detector at 5 cm radius
- 25 layer open cell drift chamber with 100 μm resolution
- Scintillator/lead sandwich trigger
- Toroidal magnet

Toroidal Magnet

- $\int \vec{B}_{\perp} \cdot d\vec{l} = 0.5$ T-m
- Normal copper conductor requires $\sim$ 500 cm^2 of conductor
- Use of LN_2 cooled copper (80 K) reduces requirement to 50 cm ^{2}
- 13% loss of acceptance for single track, geometric acceptance of 66% for three track events

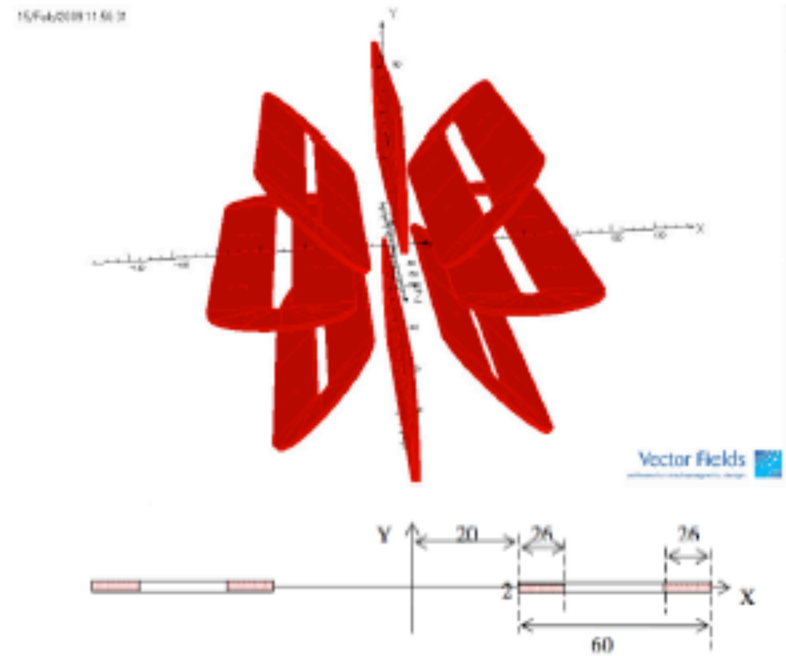
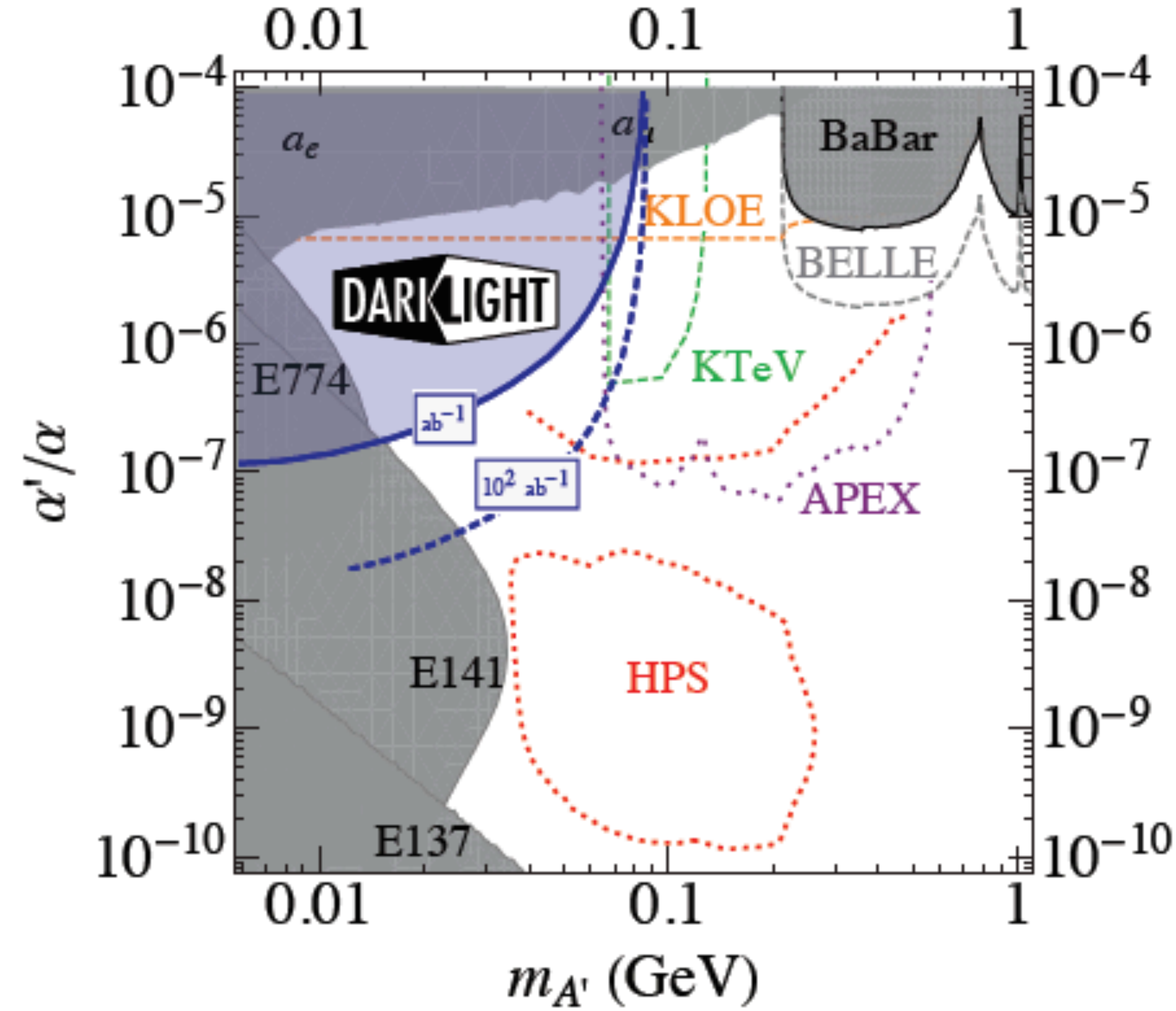


Figure: Eight coil toroidal magnet. Upper panel shows perspective drawing, lower shows cross section.



(DarkLight projected 5σ vs. other projected 2σ)

Heavy Photon Search in Hall B

Authors

W. Cooper, M. Demarteau
Fermi National Accelerator Laboratory, Batavia, IL 60510-5011

S. Bueltmann, L. Weinstein
Old Dominion University, Norfolk, VA 23529

A. Grillo
University of California, Santa Cruz, CA 95064

M. Holtrop, K. Slifer, S. Phillips, E. Ebrahim
University of New Hampshire, Durham, NH 03824

P. Schuster, N. Toro
Perimeter Institute, Ontario, Canada N2L 2Y5

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, D. Walz
SLAC National Accelerator Laboratory, Menlo Park, CA 94025

S. Boyarinov, V. Burkert, A. Deur, H. Egiyan, A. Freyberger, F.-X. Girod,
V. Kubarovsky, S. Stepanyan (Co-Spokesperson)
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606

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

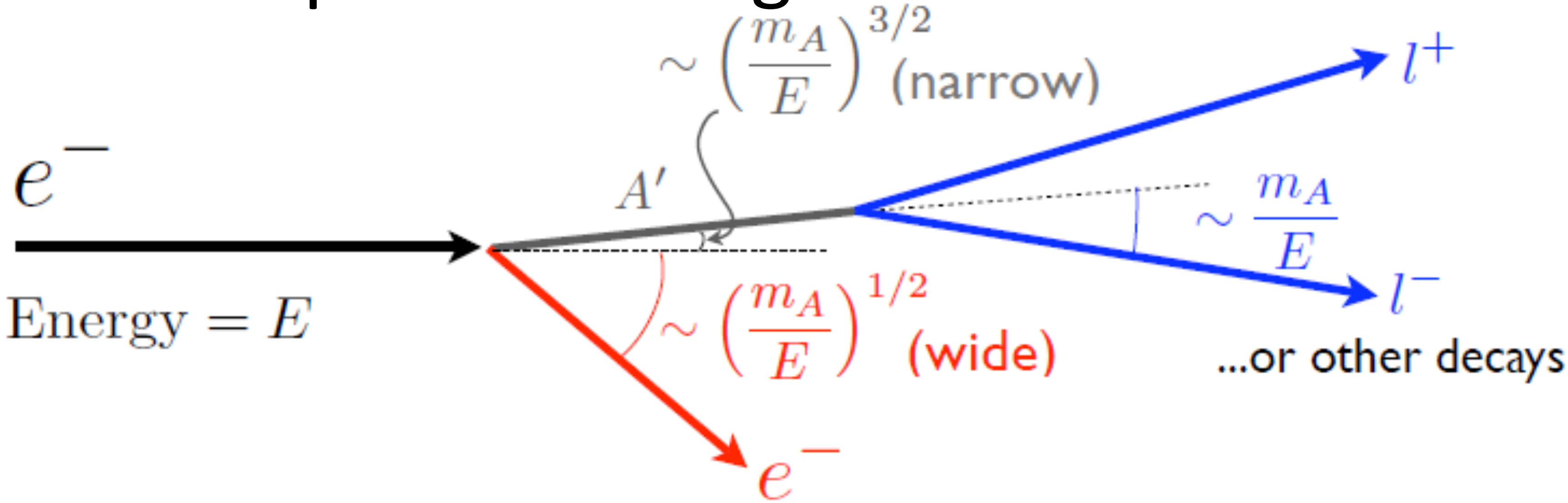
M. Khandaker, C. Salgado
Norfolk State University, Norfolk, VA 23504

N. Dashyan, N. Gevorgyan, R. Paremuzyan, H. Voskanyan
Yerevan Physics Institute, 375036 Yerevan, Armenia

M. Battaglieri, R. DeVitta
INFN, Sezione di Genova, 16146 Genova, Italy

Philip Schuster

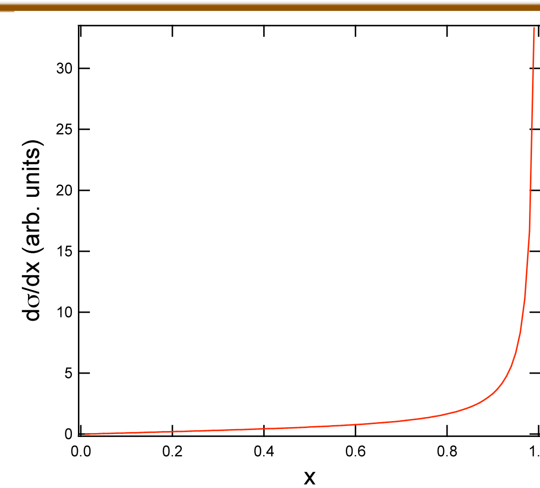
Unique Fixed-Target Kinematics



Heavier product (here A')
takes most of beam energy

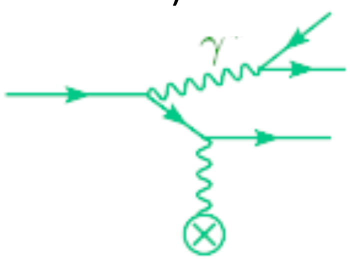
$$E_A \sim E - m_A$$
$$E_e \sim m_A$$

$$\frac{d\sigma}{dx} \approx x\left(1 + \frac{x^2}{3(1-x)}\right)$$

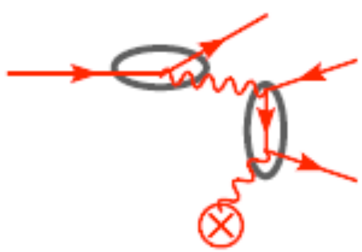


Backgrounds

- Multiple Coulomb scattering in the target
- Secondary particle production in the target
  - Bremstrahlung
  - Delta-rays
- Pair conversion of bremstrahlung photon
  - Two step process; the rate ~(target thickness)^2

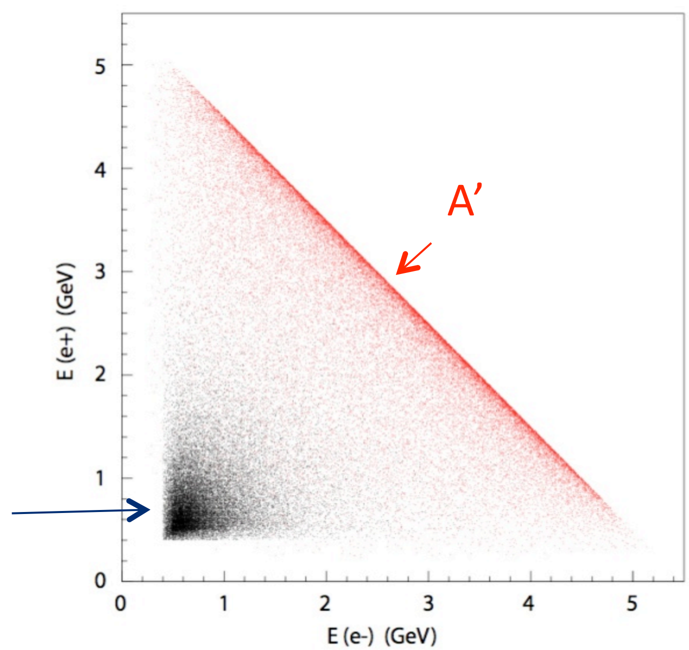


- Virtual photon conversion and Bethe-Heitler processes



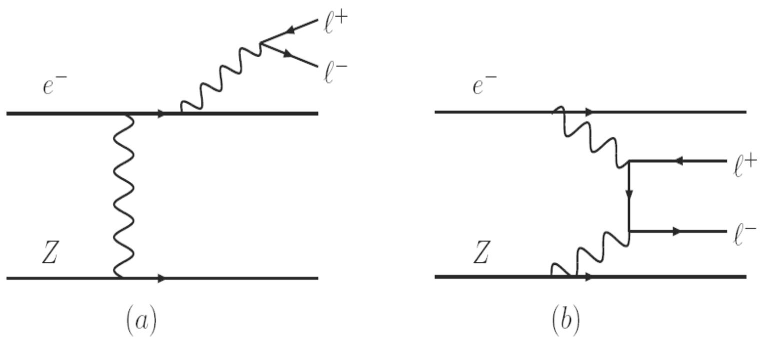
- Thin target to reduce the rate
- Magnetic field to remove low energy e-
- Define dead zone

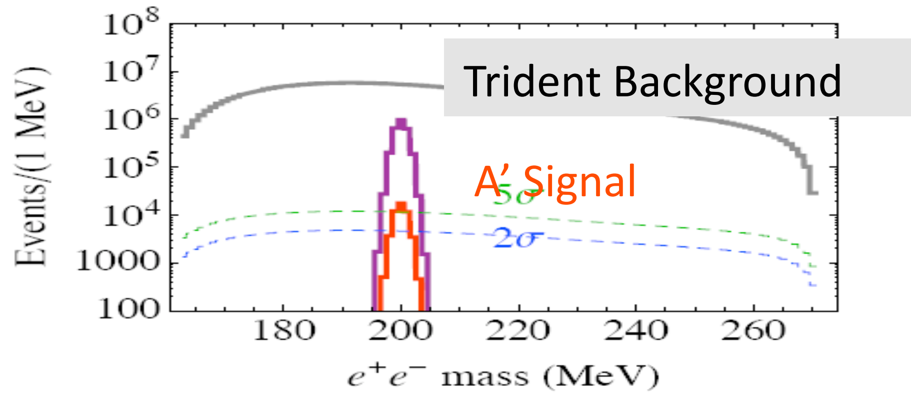
- Target thickness is 0.25% X_0
  - $\sigma(\gamma \rightarrow ee) \ll \sigma(\gamma^* \rightarrow ee)$



Heavy Photon Signatures

- A heavy photon appears as an e^+e^- resonance on a large background of QED tridents.





- S/B depends on ε and resolution.

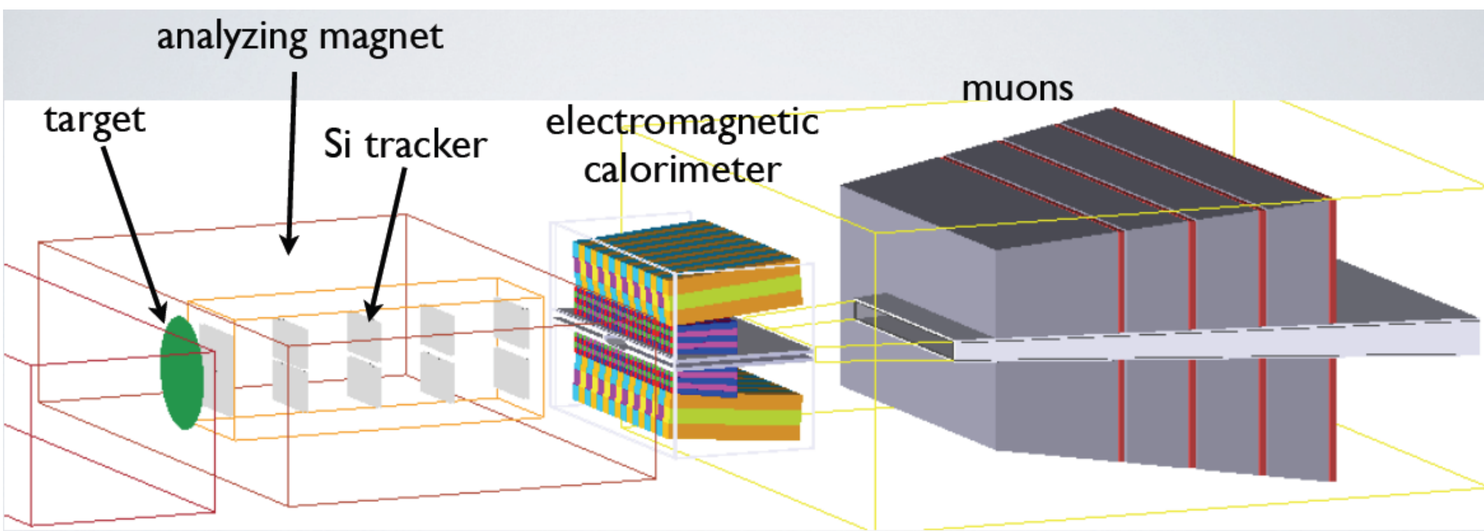
$$\frac{d\sigma(e^-Z \to e^-Z(A' \to e^+e^-))}{d\sigma(e^-Z \to e^-Z(\gamma^* \to e^+e^-))} = \left(\frac{3\pi\epsilon^2}{2N_{eff}\,\alpha}\right)\left(\frac{m_{A'}}{\delta m_{A'}}\right) \quad \propto \varepsilon^2/\delta m$$

- The heavy photon lifetime depends on mass and ε. For suitable values, a secondary decay vertex can be identified, distinguishing the A' from the trident background.

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

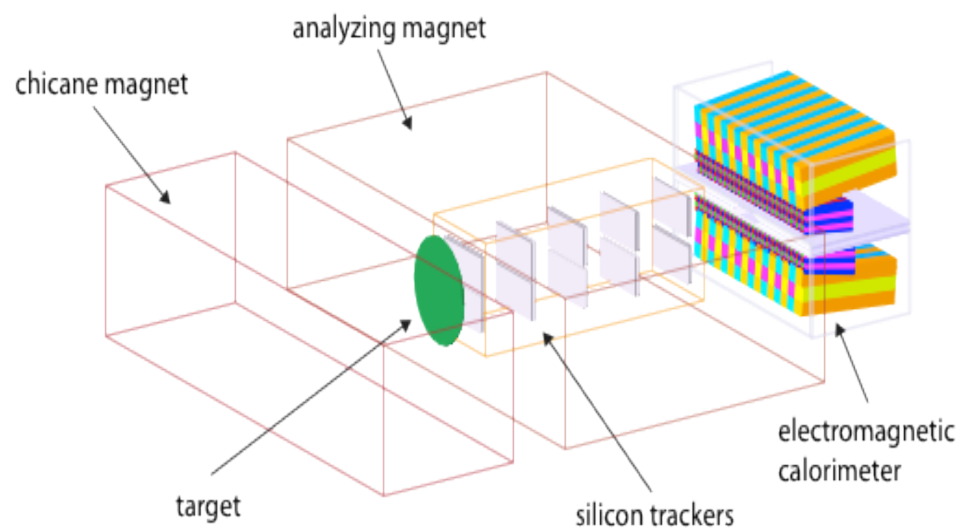
Full HPS

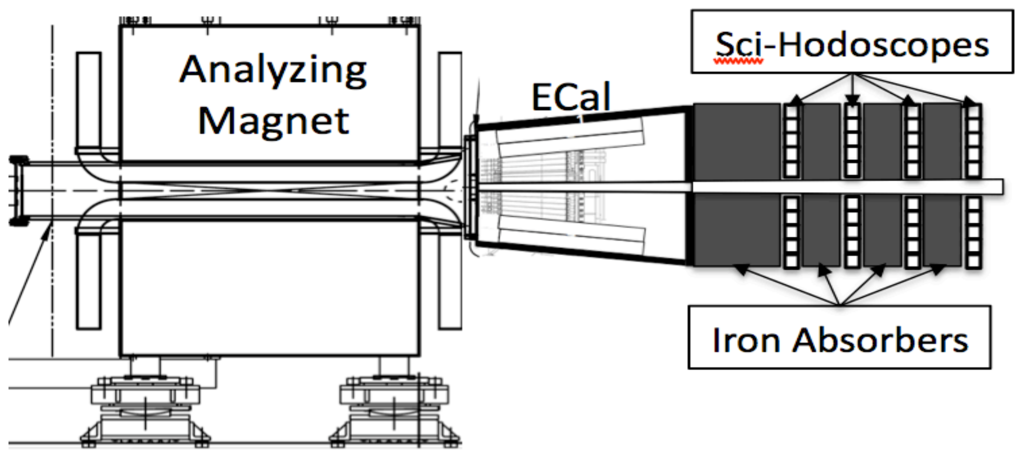
- Forward, compact spectrometer/vertex detector measures mass and decay length
- EM Calorimeter provides fast trigger and electron ID.
- 100% CEBAF duty cycle and high rate DAQ provide the sensitivity to search for rare processes
- All detectors crowd the hot electron beam and avoid the “wall of flame”.



HPS Concept

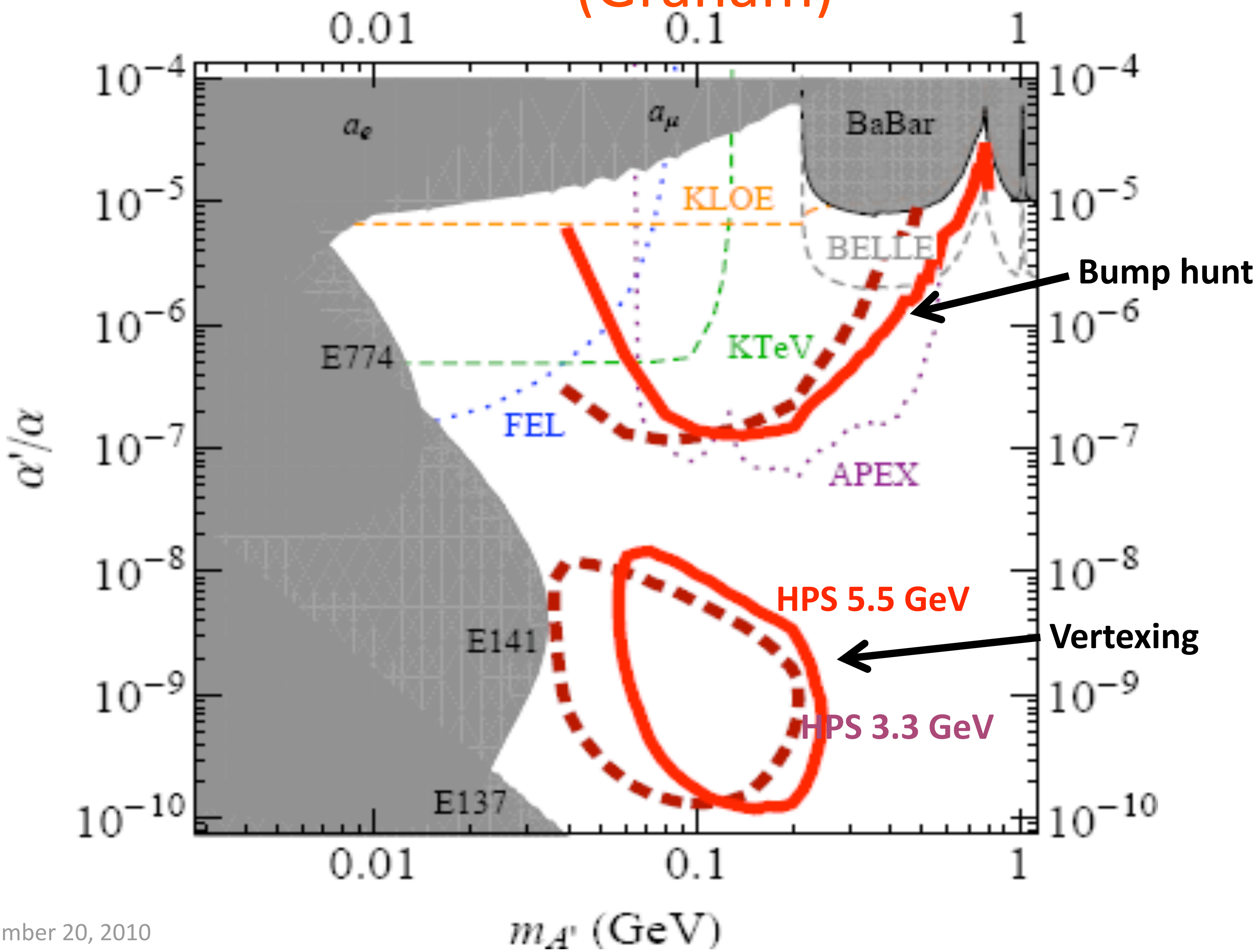
- Thin Target Close to Tracker for vertexing
- Compact Si Tracker/Vertexer in 1T dipole
- Fast, segmented Ecal for triggering, e ID
- Muon detector for alternate trigger, muon ID
- Split detectors vertically to avoid "Dead Zone" occupied by primary beam, brem photons, etc.





HPS Reach: Bump Hunt and Vertex Search (Graham)

1 month run @400nA

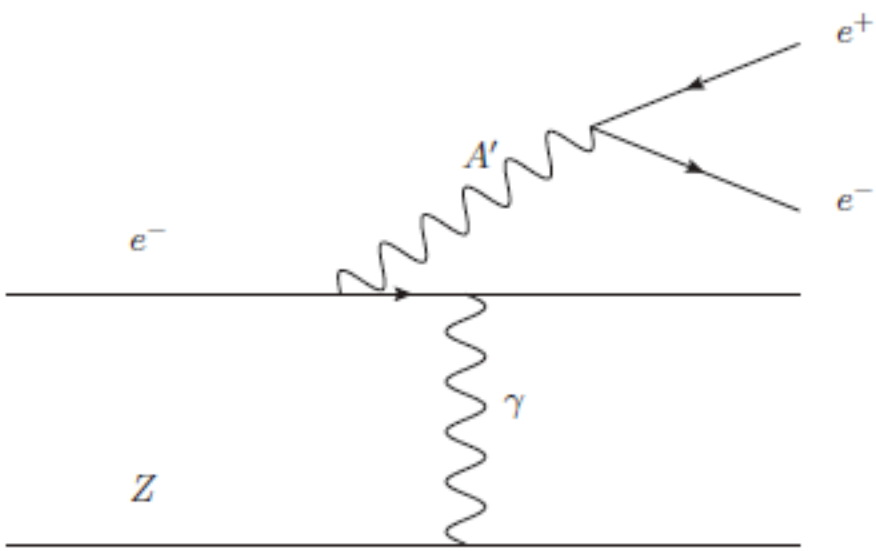


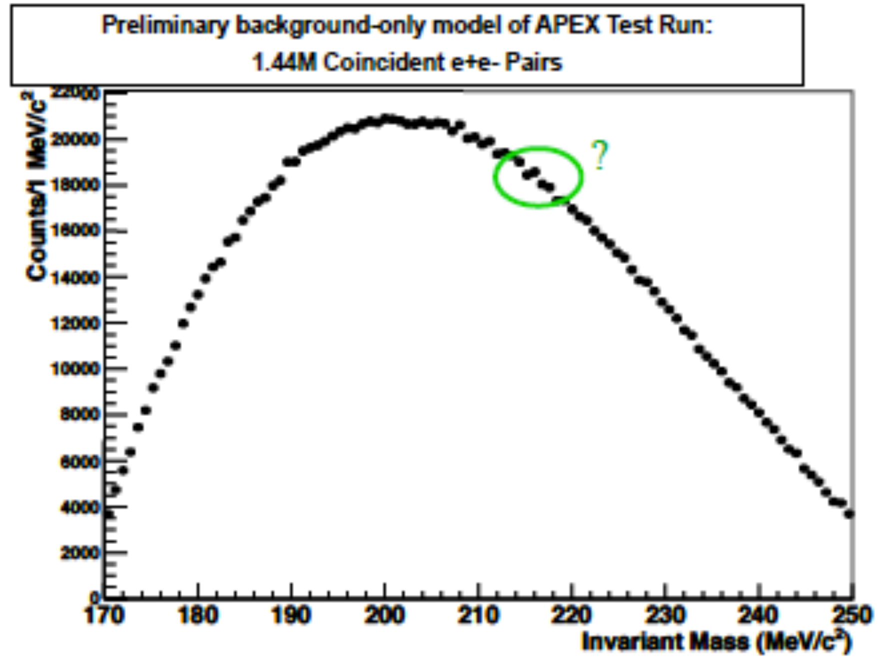
Heavy Photon Search in Hall A

APEX Peak Search

Center for Cosmology and Particle Physics

Looking for a small, narrow resonance in a high-statistics, finely-binned invariant mass spectrum

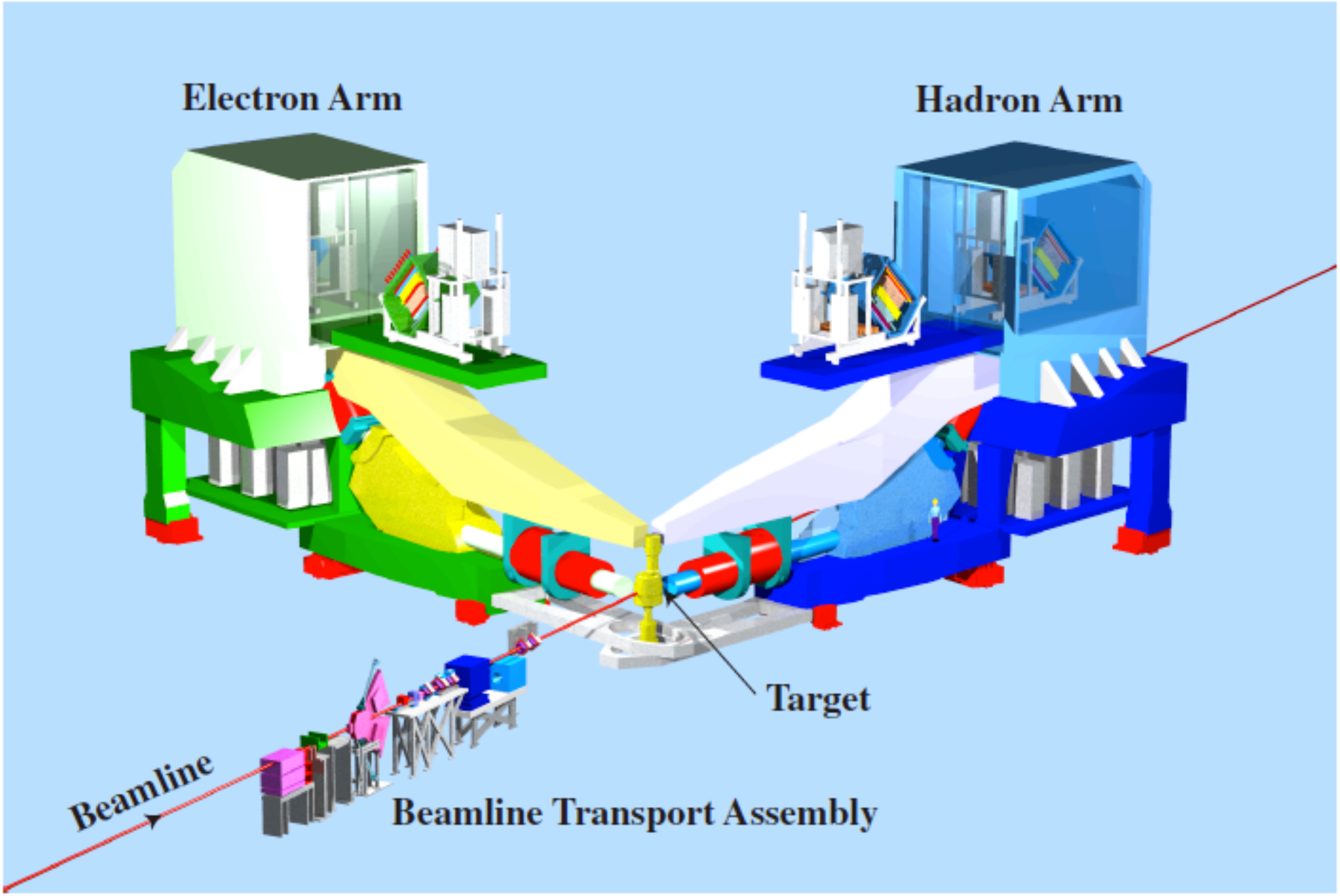




James Beacham
New York University

on behalf of
the ***APEX Collaboration***
and the ***Hall A Collaboration***
at Jefferson Lab

Hall A



m-drive/martz//graphics/3dart/halla/newfolder/arms2.ai jm 7/26/00

Jefferson Lab

The APEX Experiment and Test Run

Natalia Toro (Perimeter Institute)

for the APEX Collaboration

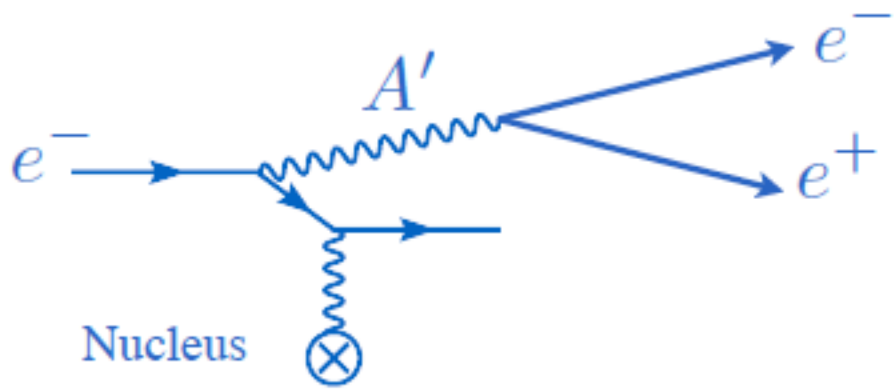
S. Abrahamyan, A. Afanasev, Z. Ahmed, E. Aliotta, K. Allada, D. Anez, D. Armstrong, T. Averett, A. Barbieri, K. Bartlett, J. Beacham, S. Beck, J. D. Bjorken, J. Bono, P. Bosted, J. Boyce, P. Brindza, N. Bubis, A. Camsonne, O. Chen, K. Cranmer, C. Curtis, E. Chudakov, M. Dalton, C. W. de Jager, A. Deur, J. Donaghy, R. Essig (co-spokesperson), C. Field, E. Folts, A. Gasparian, A. Gavalya, S. Gilad, R. Gilman, A. Glamazdin, N. Goeckner-Wald, J. Gomez, M. Graham, O. Hansen, D. W. Higinbotham, T. Holmstrom, J. Huang, S. Iqbal, J. Jaros, E. Jensen, A. Kelleher, M. Khandaker, I. Korover, G. Kumbartzki, J. J. LeRose, R. Lindgren, N. Liyanage, E. Long, J. Mammei, P. Markowitz, T. Maruyama, V. Maxwell, J. McDonald, D. Meekins, R. Michaels, M. Mihovilovič, K. Moffeit, S. Nanda, V. Nelyubin, B. E. Norum, A. Odian, M. Oriunno, R. Partridge, M. Paolone, E. Piasetzky, I. Pomerantz, A. Puckett, V. Punjabi, Y. Qiang, R. Ransome, S. Riordan, Y. Roblin, G. Ron, K. Saenboonruang, A. Saha, B. Sawatzky, P. Schuster (co-spokesperson), J. Segal, L. Selvy, A. Shahinyan, R. Shneor, S. Širca, R. Subedi, V. Sulkosky, S. Stepanyan, N. Toro (co-spokesperson), D. Waltz, L. Weinstein, B. Wojtsekhowski (co-spokesperson), J. Zhang, Y. Zhang, B. Zhao, and **The Hall A Collaboration**

Searching for a New Gauge Boson at JLab

September 20-21, 2010

A′ Properties in APEX Search Region ($\alpha'/\alpha > 10^{-7}$)

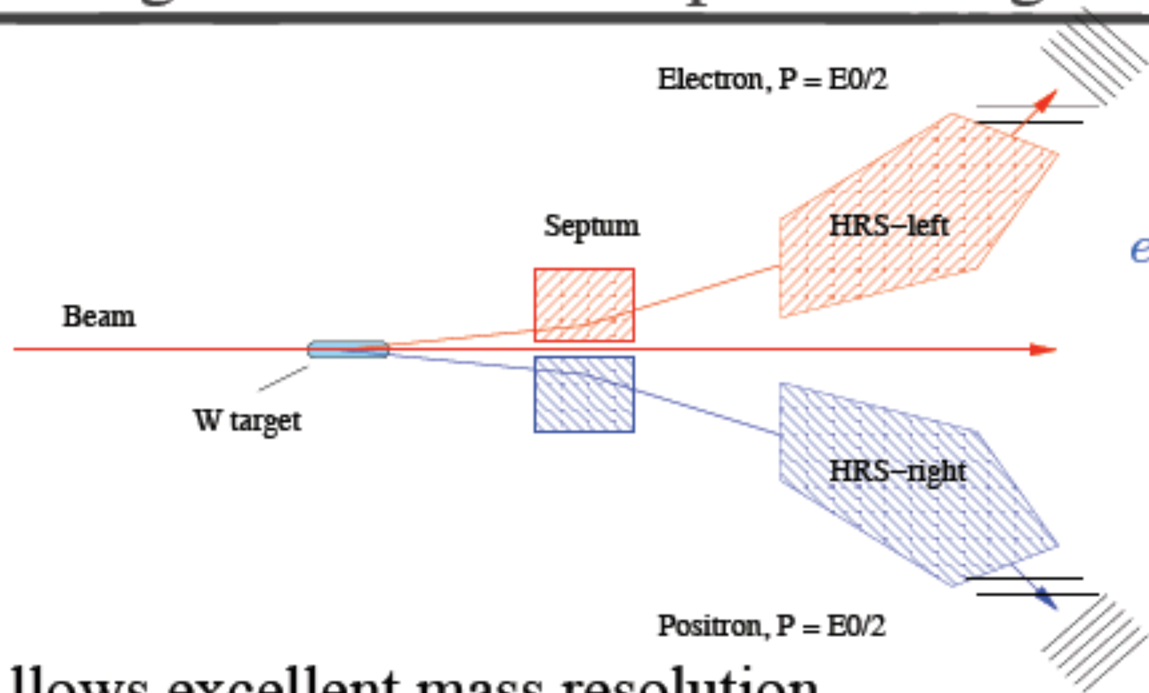
- Produced abundantly through bremsstrahlung
  (e.g. >1/second for 75 μA beam, 0.1 X_0)

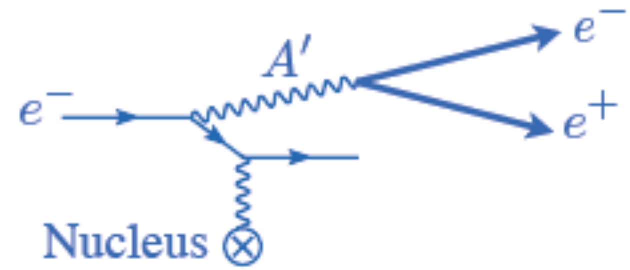


- A′ decays promptly to e^+e^-, $\mu^+\mu^-$, or $\pi^+\pi^-$
  ⇒ large QED background

Strategy: measure e^+e^- mass spectrum **precisely**, search for **small** peak ⇒ maximize rate & resolution

Advantages of small-acceptance magnetic spectrometer





– Allows excellent mass resolution

– Dramatic suppression of large backgrounds

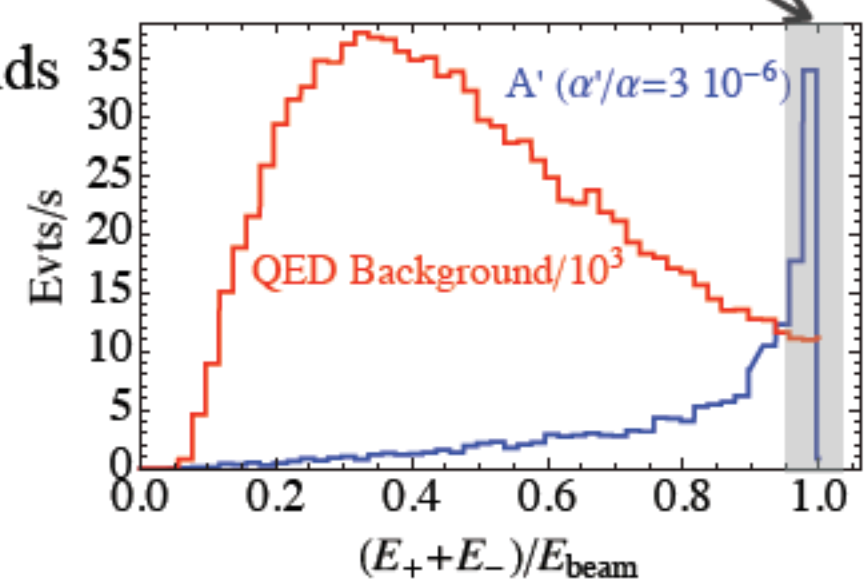
Singles:

- Elastic scattered e^-
- Moller e^-

Coincidence:

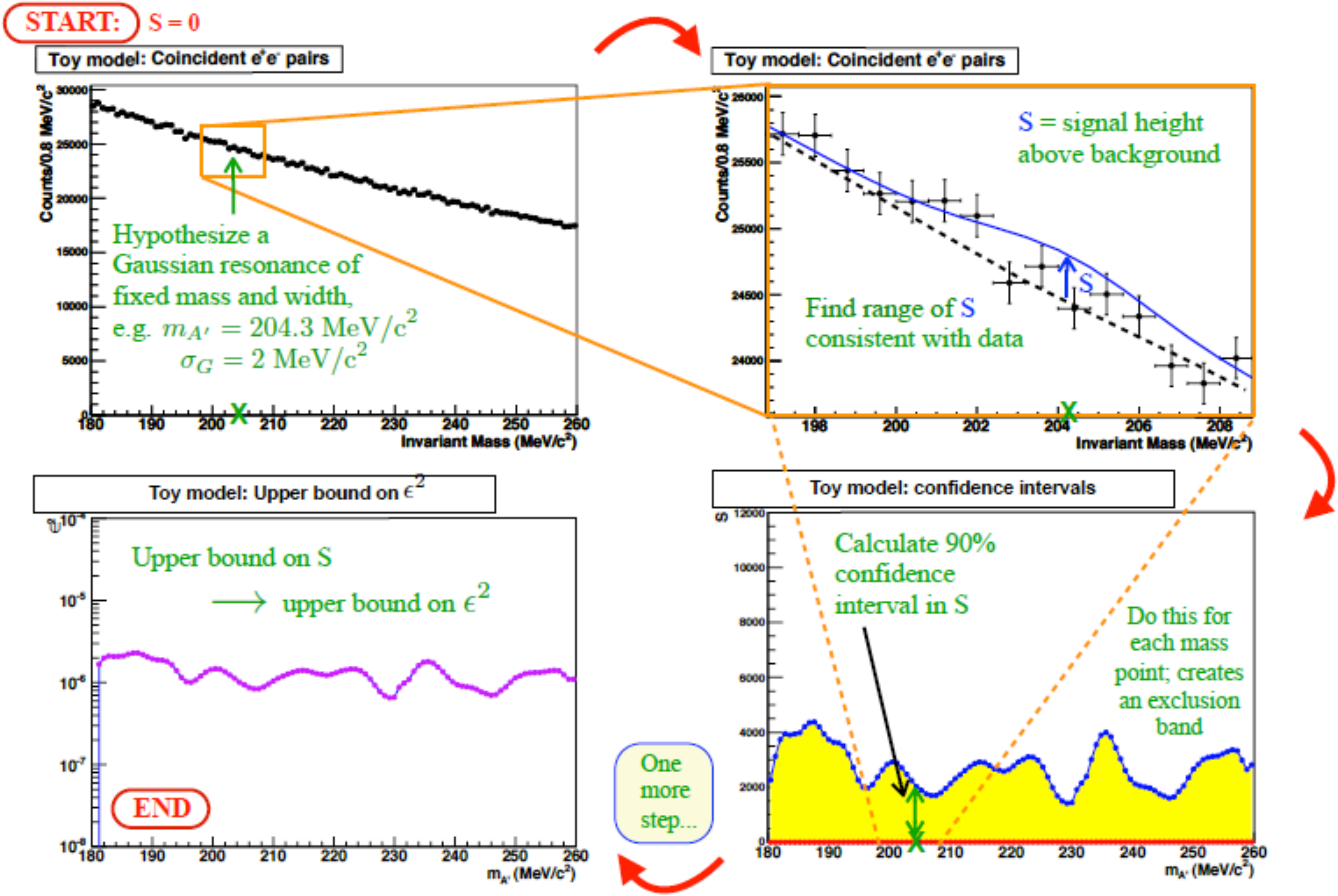
- $\pi^0 \rightarrow \gamma\, e^+e^-$
- Radiated $\gamma \rightarrow e^+e^-$

Events outside this window never reach spectrometer

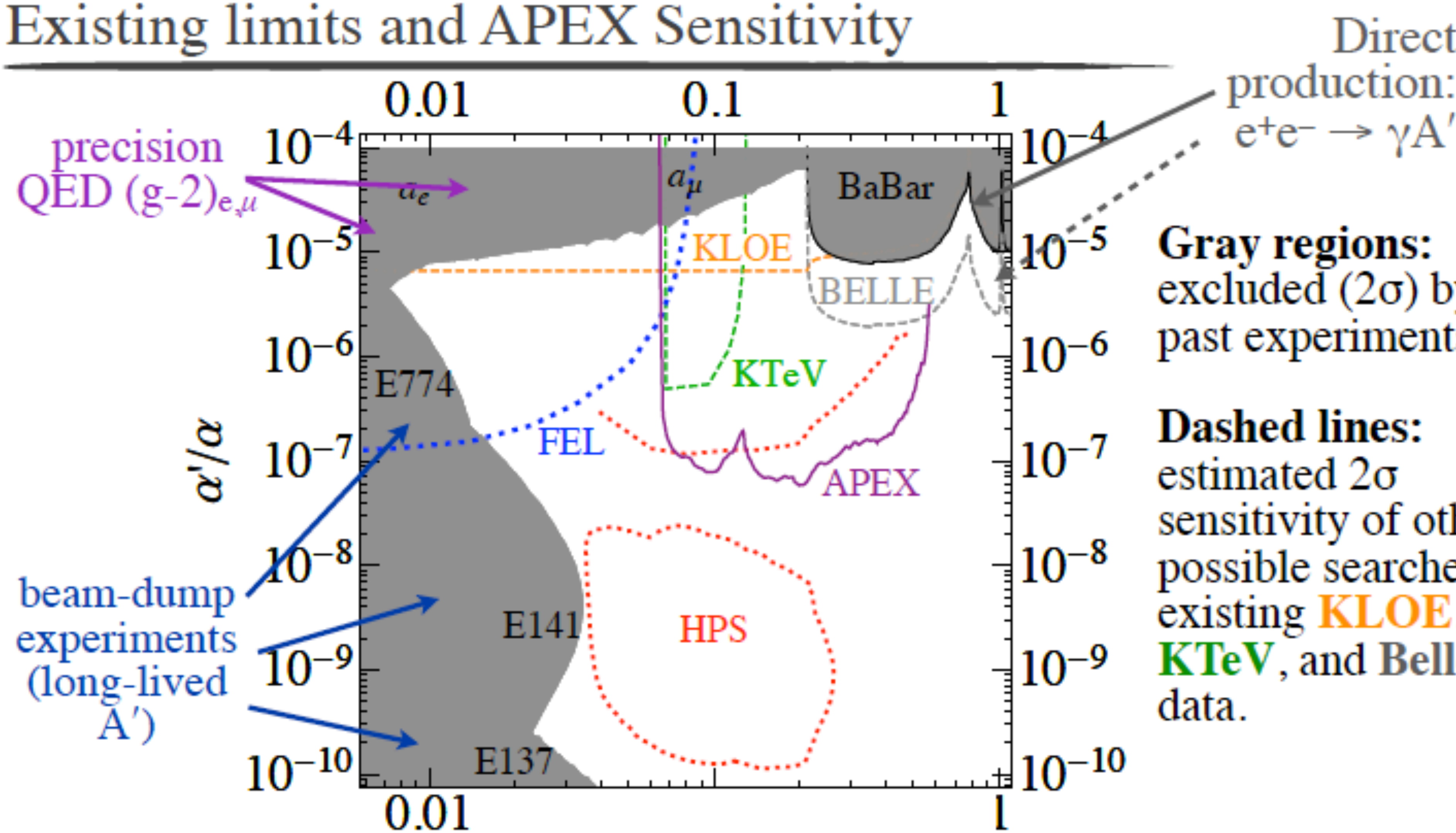


To maximize **angular acceptance**, operate at narrow angles

Setting Limits: General Procedure



Existing limits and APEX Sensitivity



Gray regions: excluded (2σ) by past experiments

Dashed lines: estimated 2σ sensitivity of other possible searches in existing **KLOE**, **KTeV**, and **Belle** data.

✦$(g\text{-}2)_\mu$ ✦dark matter motivation ✦GUT region of α'/α

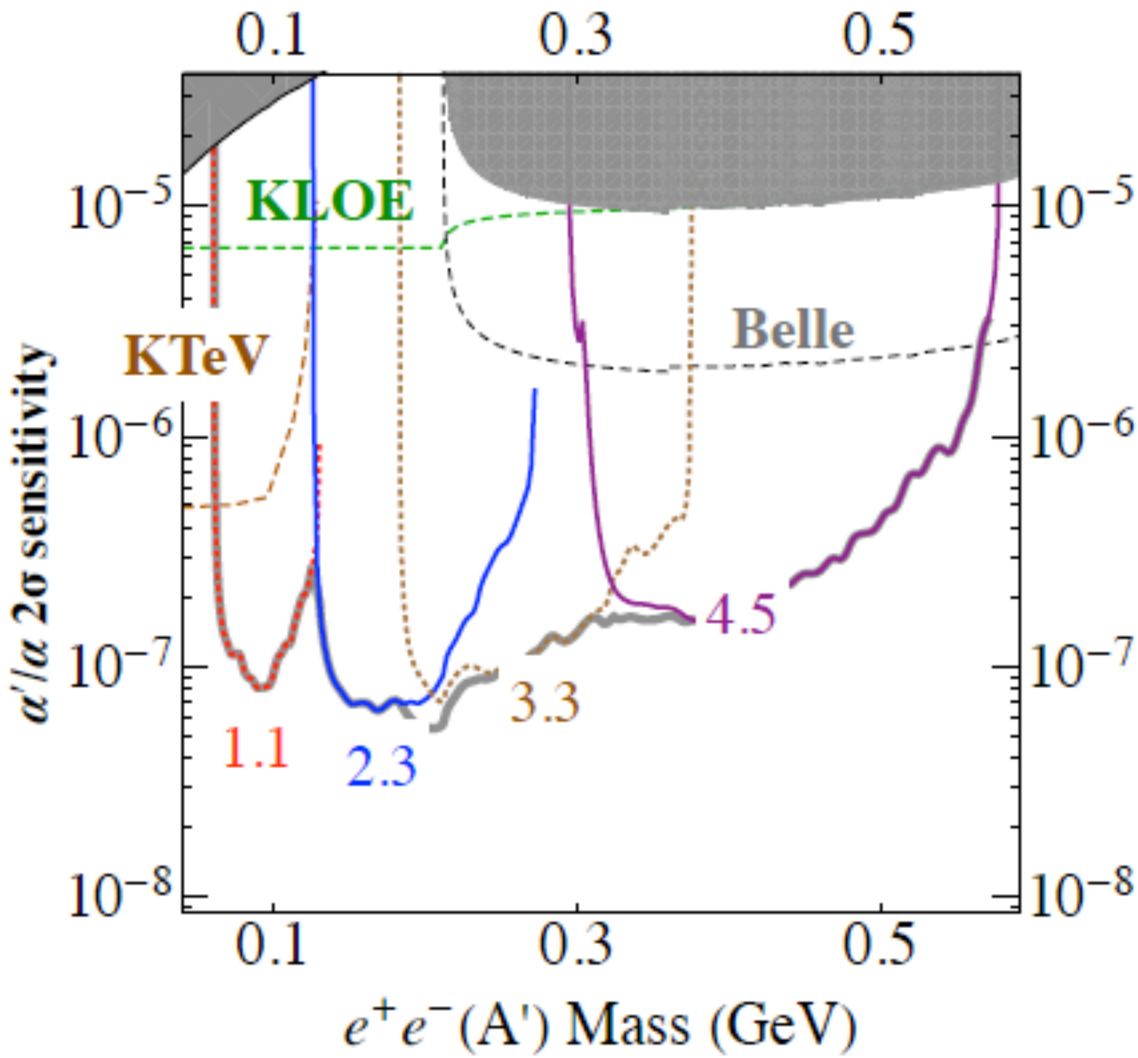
Wide open range of couplings to explore

Timely measurement, ready equipment

Could be ready with 1-month notice

APEX sensitivity

Narrow acceptance ⇒ cover mass range from 60 to 600 MeV with separate 6–12 day runs at 4 beam energies



summary

- LIPSS published results, new plans with high power laser
- DARKLIGHT conditionally approved for running in ~2013
- HPS in Hall B approved for beam time; staged approach
- APEX in Hall A initial running completed