The HPS Experiment

Per Hansson Adrian

on behalf of the HPS Collaboration

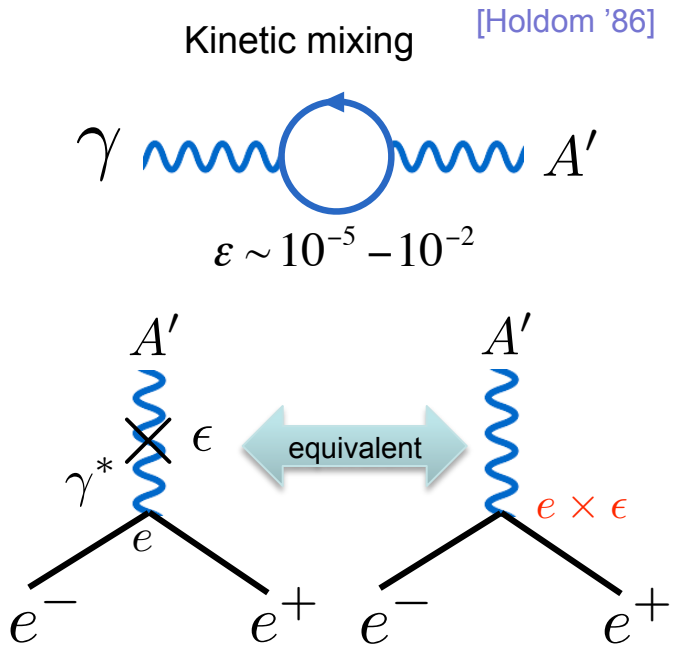
SLAC NATIONAL ACCELERATOR LABORATORY

U.S. DEPARTMENT OF ENERGY | Office of Science

LELAND STANFORD JUNIOR UNIVERSITY 1891

Heavy Photon/A'

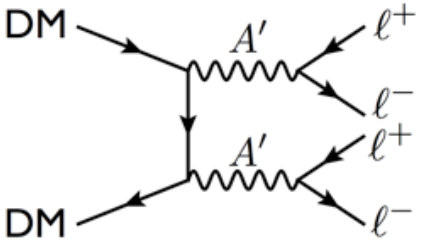
- Conjectured new vector boson (U(1))
  - Extra U(1)'s appear in many BSM models
  - Couples weakly (e×ε) to electric charge
  - GeV-scale mass "inherited" from electro-weak scale $m_{A'}^2 \sim \varepsilon \times m_W^2$
- Electrically charged **ordinary** matter acquire milli-charge under the A'
- What makes it interesting now?



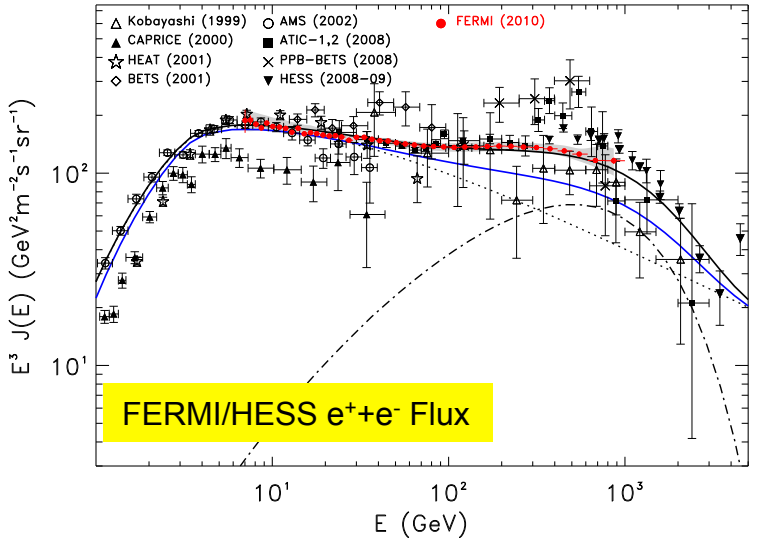
A', Dark Matter & Muon g-2

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

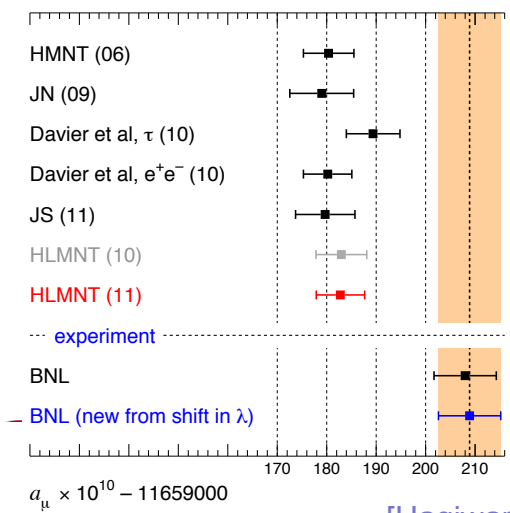
[Arkani-Hamed, Finkbeiner,Slatyer, Weider, Pospelov, Ritz]



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



[Fermi 1008.3999; PAMELA 0810.4995]



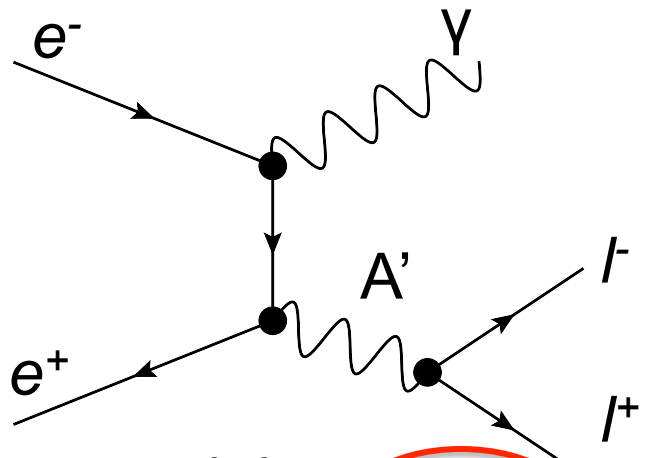
- Muon anomalous magnetic moment (g-2)
  - >3σ deviation from Standard Model
  - GeV-scale heavy photon could play a role

[Pospelov 0811.1030]

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

A' Direct Production

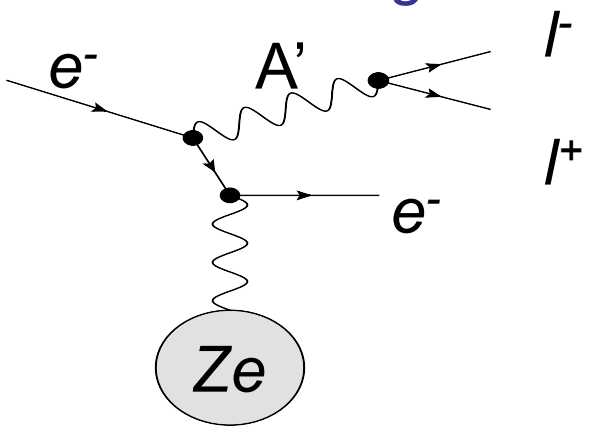
Collider



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

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

Fixed Target



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

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

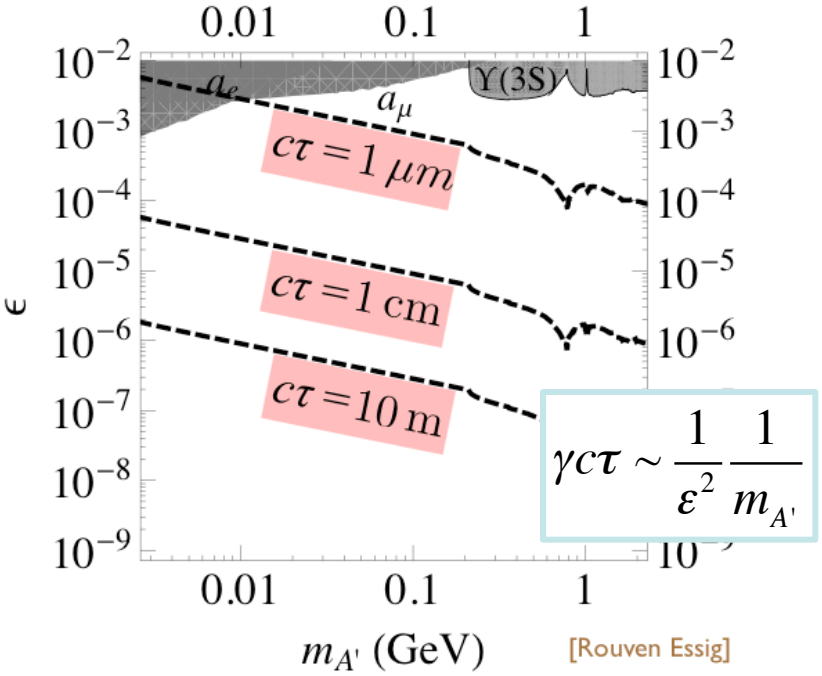
- Fixed target is an ideal hunting ground

A' Searches and HPS

[Bjorken, Essig, Schuster, Toro 0906.0580]

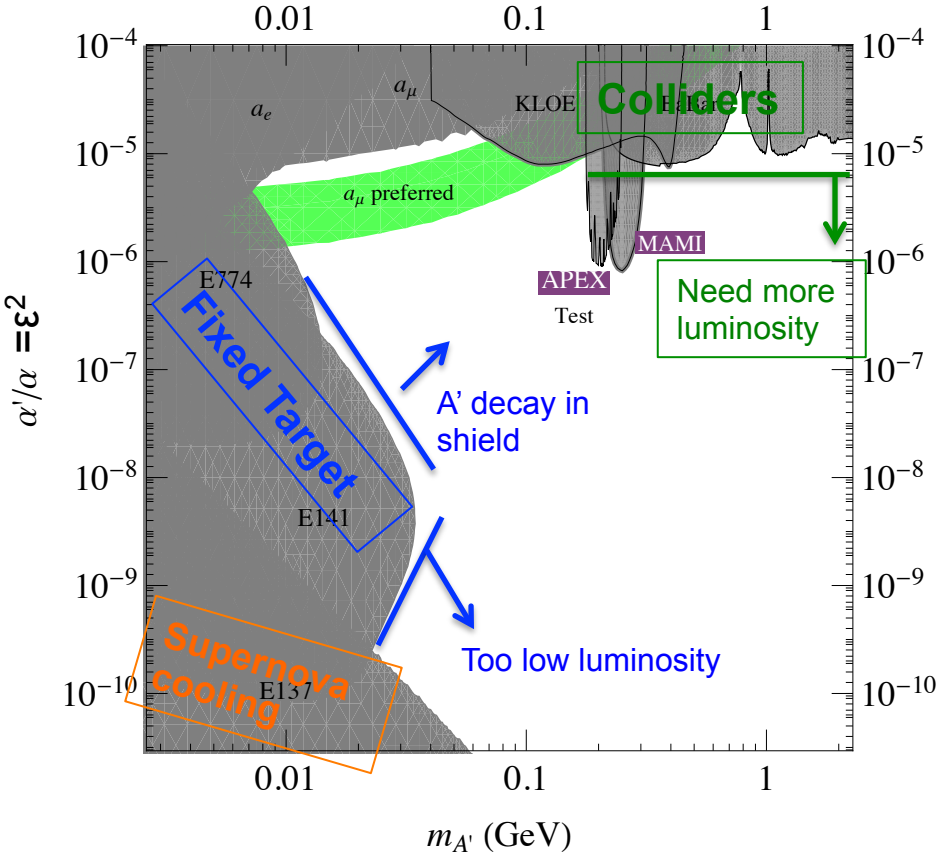
- Key experimental issues
  - Cross section relative to QED backgrounds
  - Lifetime (the A' can be long-lived!)

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



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

[Rouven Essig]



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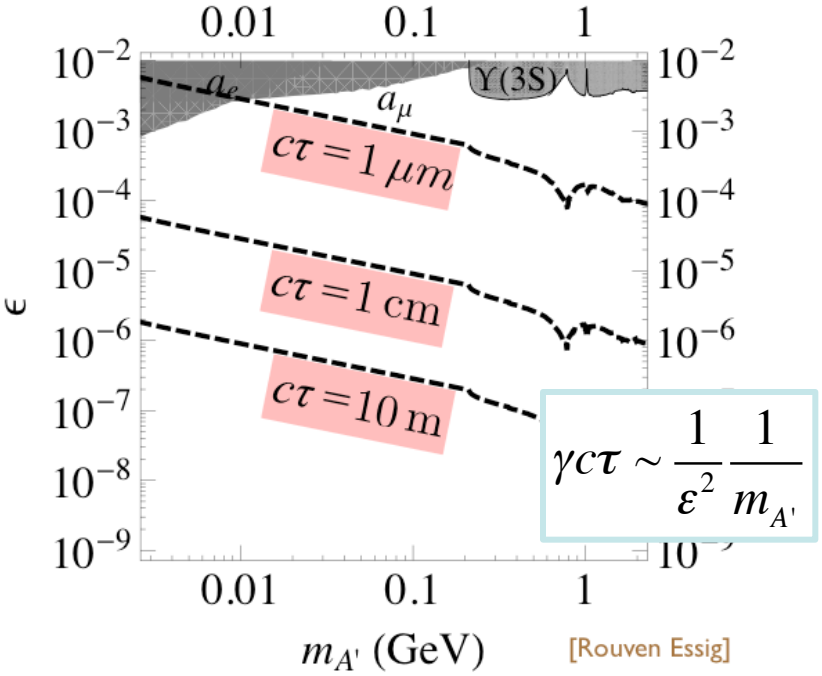

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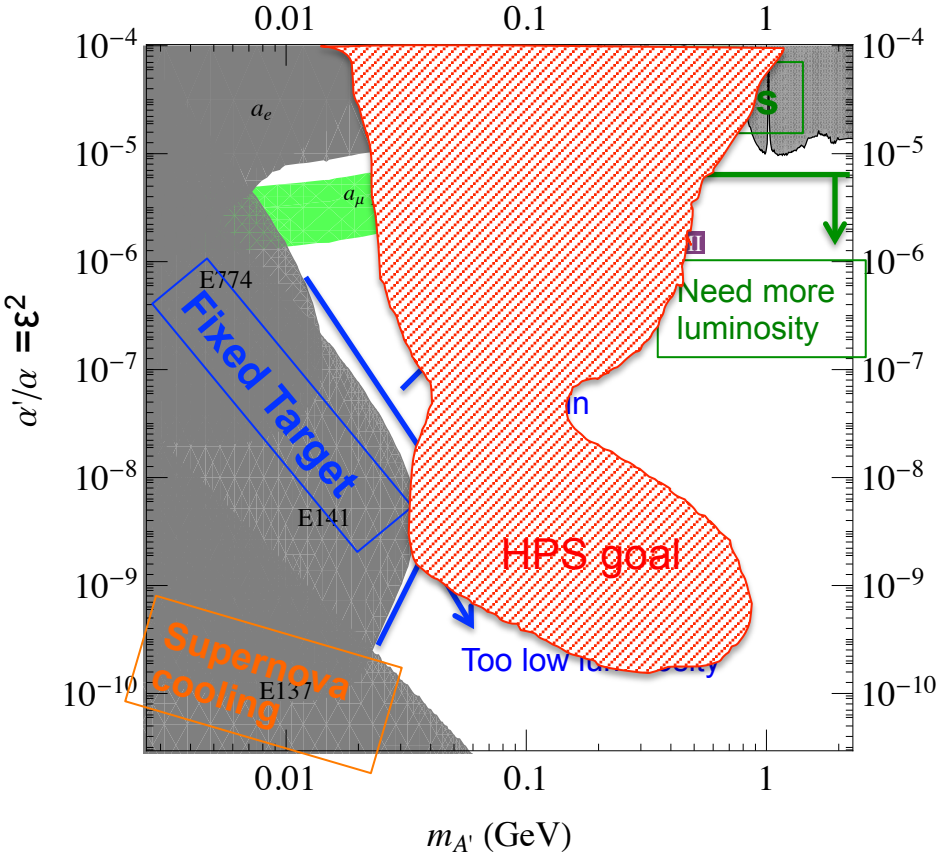
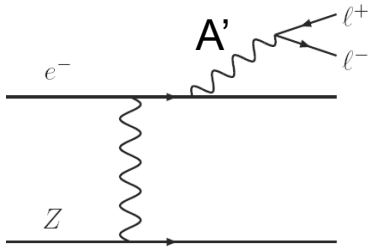


A' Signal Characteristics

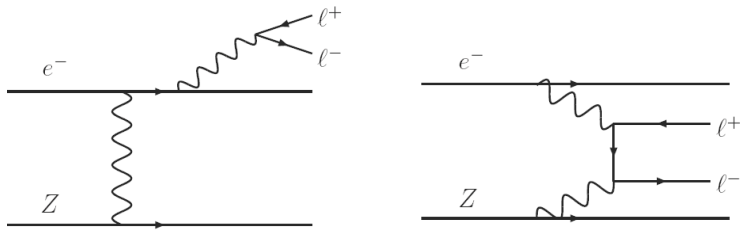
[Bjorken, Essig, Schuster, Toro 0906.0580]

- Qualitative A' features
  - Very forward ($E_{A'} \approx E_{beam}$)
  - Decay prod. opening angle ~m_A
  - Possibly displaced vertex
- Main backgrounds
  - Bethe-Heitler suppressed by kinematic selections
  - "Radiative" are kinematically **identical** to A'

"Bremsstrahlung" A' production

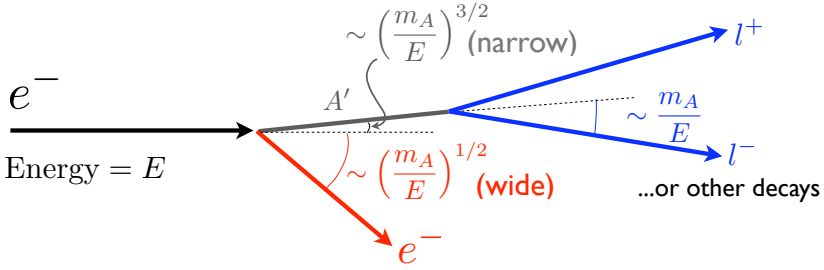


Trident backgrounds



"Radiative" "Bethe-Heitler"

Signal kinematics



➔Search for a signal in narrow invariant mass window

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

HPS key measurements

Invariant mass of decay products

Reconstruction of decay vertex

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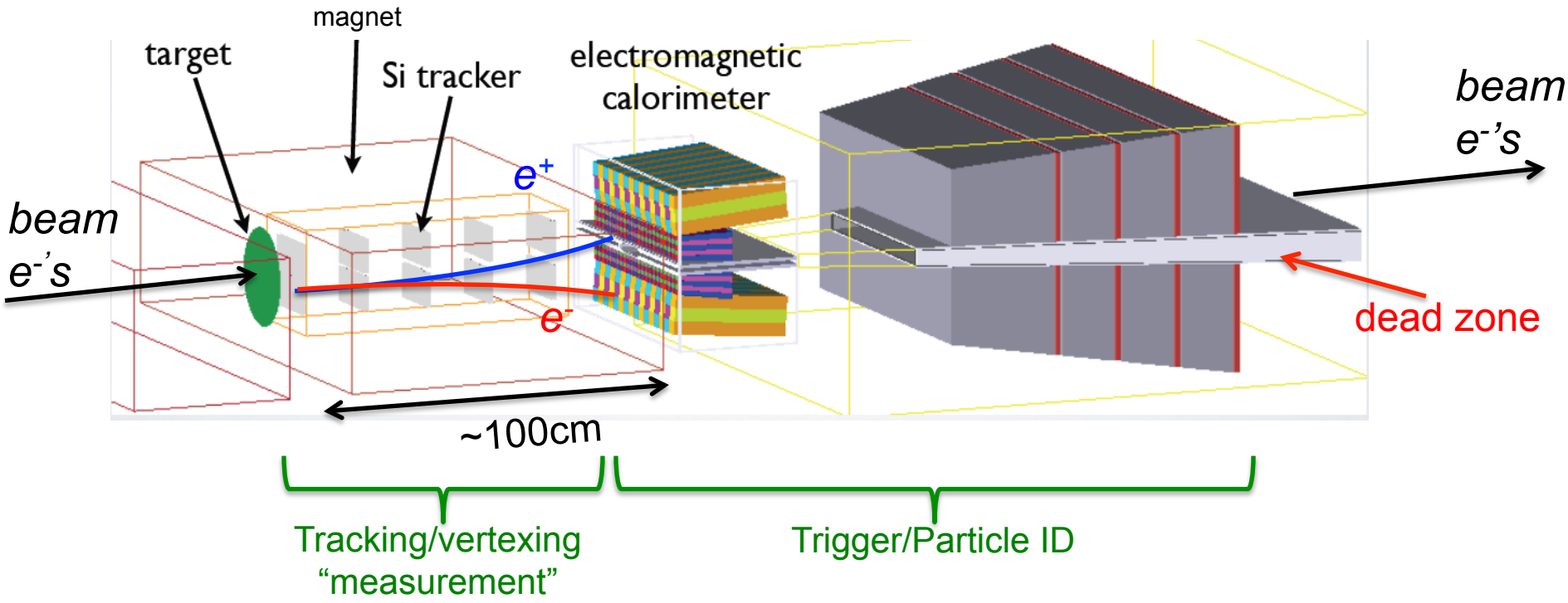
Experimental Requirements

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

HPS Detector Overview

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

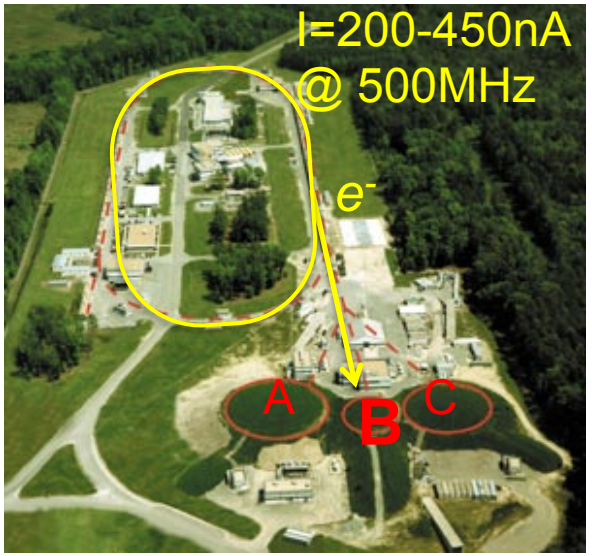


- All detectors split vertically to avoid "sheet of flame"
  - Primary beam, degraded electrons, bremsstrahlung photons, etc.

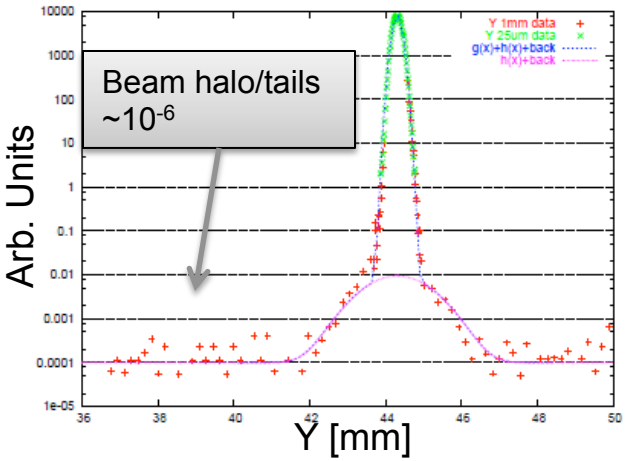
Jefferson Lab CEBAF

- CEBAF electron beam ideal for HPS
  - Configurable beam energy and current; 2.2, 6.6 GeV @ 200,450nA
  - 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

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



Vertical Beam Size



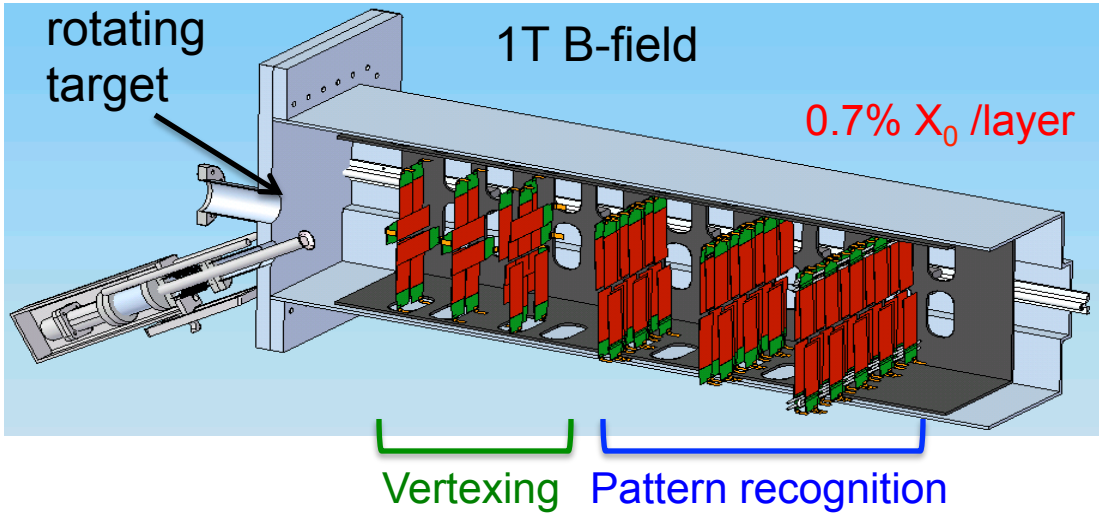
Tracking Challenges

- Excellent vertex and momentum (mass) resolution
  - Track momentum ~1 (few) GeV for E_{beam}=2.2 (6.6)GeV ➔ multiple scattering dominates resolution
  - Hit assignment problems in dense environment
  - **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
  - Innermost strips sees **~10MHz hits/mm^2**
  - Need robust, fast, radiation hard sensors and readout electronics

Silicon Vertex Tracker

- 6 layers of micro-strip sensors supported as two halves
- Layout for optimal performance
  - Multiple scattering error dominate
  - 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

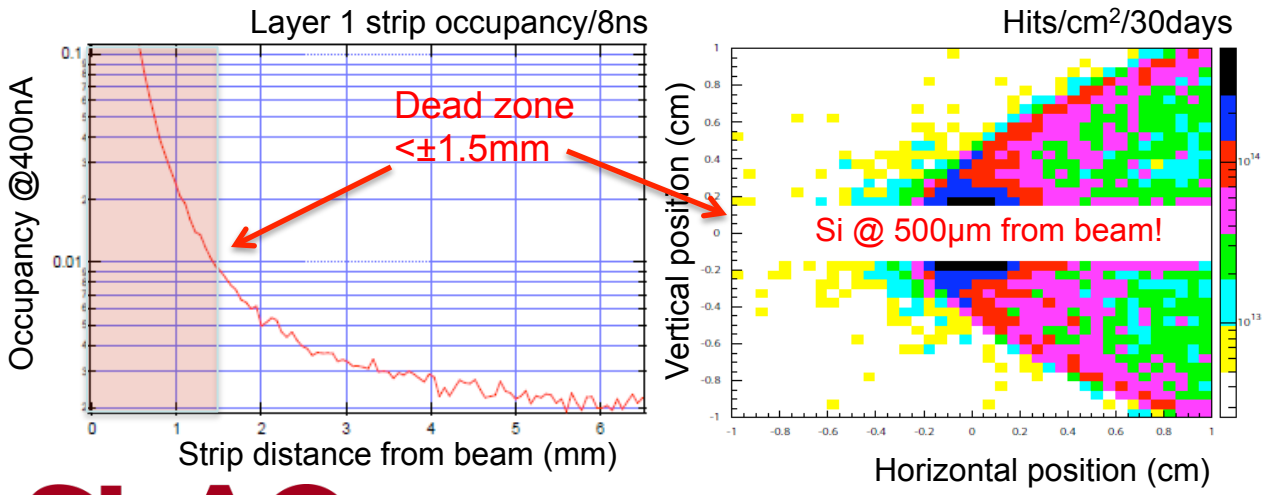
Layer->	1	2	3	4	5	6
z position [cm]	10	20	30	50	70	90
Stereo angle [mrad]	90°	90°	90°	50	50	50
Bend plane res. [um]	≈6	≈6	≈6	≈6	≈6	≈6
Stereo res. [μm]	≈6	≈6	≈6	≈130	≈130	≈130
Dead Zone [mm]	±1.5	±3.0	±4.5	±7.5	±10.5	±13.5



Silicon Vertex Tracker

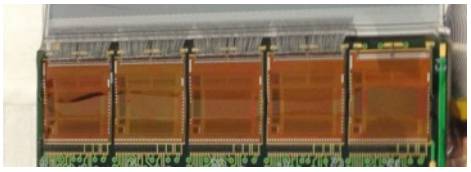
- Sensors: from D0 RunIIb production
  - Radiation hard (<1000V bias)
  - High readout granularity
  - Low mass solution (readout outside tracking volume)
- Readout: APV25 (CMS development)
  - Fast, available, proven
  - 40MHz readout, analog deep pipeline
  - t_0 resolution ≅2ns

# channels	639
Active area (mm^2)	98.33x38.34
Readout (sense) pitch	60(30)μm
Thickness	320μm
Rad. hardness [n.eq.]	~4×10^{15}



APV25

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



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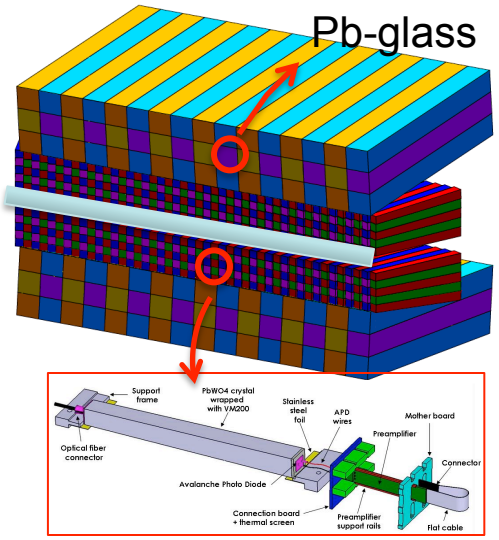
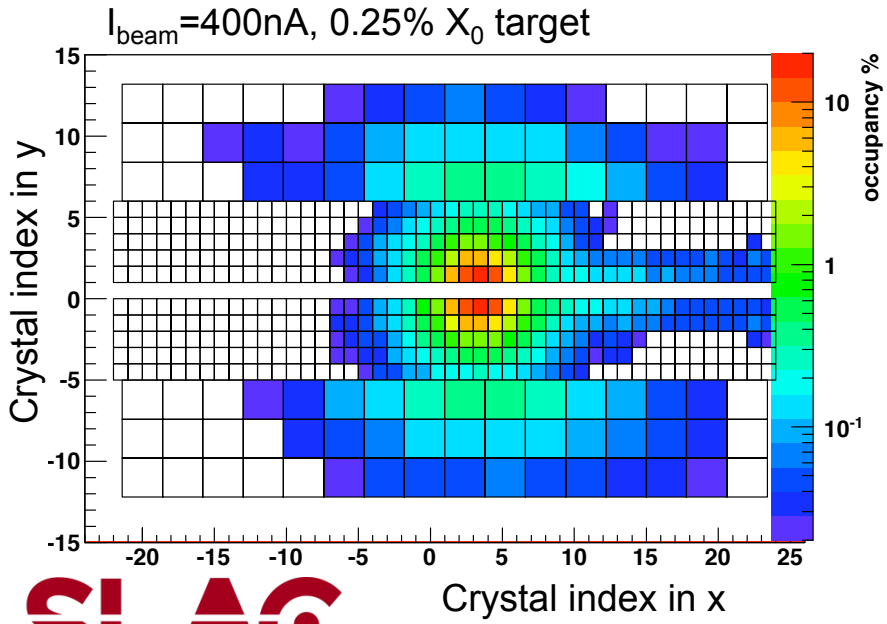
EM Calorimeter & Trigger

- Design requirements: acceptance, low background, fast readout, readily available
- Tapered hybrid $PbWO_4$ and Pb-glass modules
  - Existing modules from CLAS and Yerevan collab.
  - Avalanche photo diodes (APD) and photo multipliers
- Large occupancy close to primary beam
  - <10% occupancy; optimized layout and signal handling



APD & preamp.



- Readout by JLab 250MHz FADC
  - Trigger latency up to 3.2μs
  - Reduce bgks: 8ns trigger time window
- Trigger and DAQ capable of 50kHz rate

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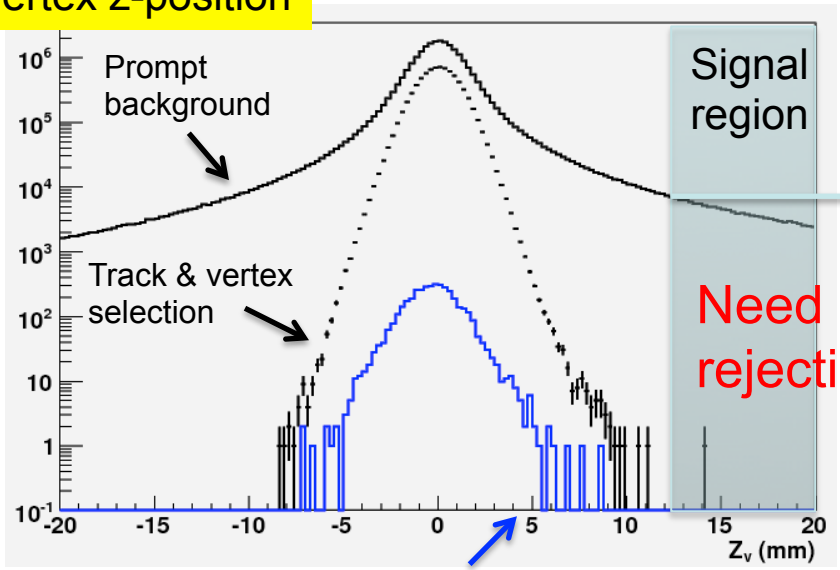
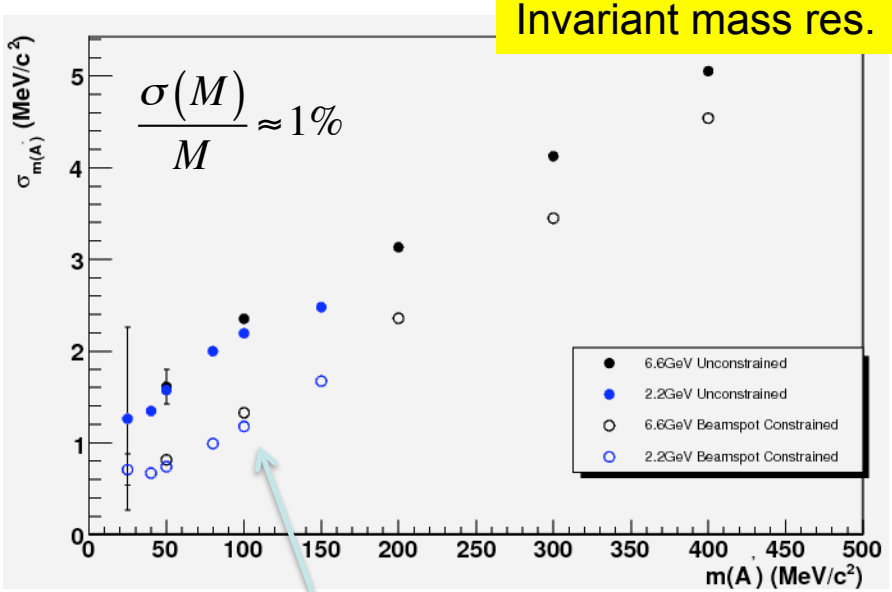
HPS Performance

- Angular resolution dominates key measurements
  - Multiple scattering limits invariant mass and vertexing performance
- Constraining to small beam spot (<20μm) helps!
- Success for vertexing relies on rejecting tails

Vertex z-position



Invariant mass res.

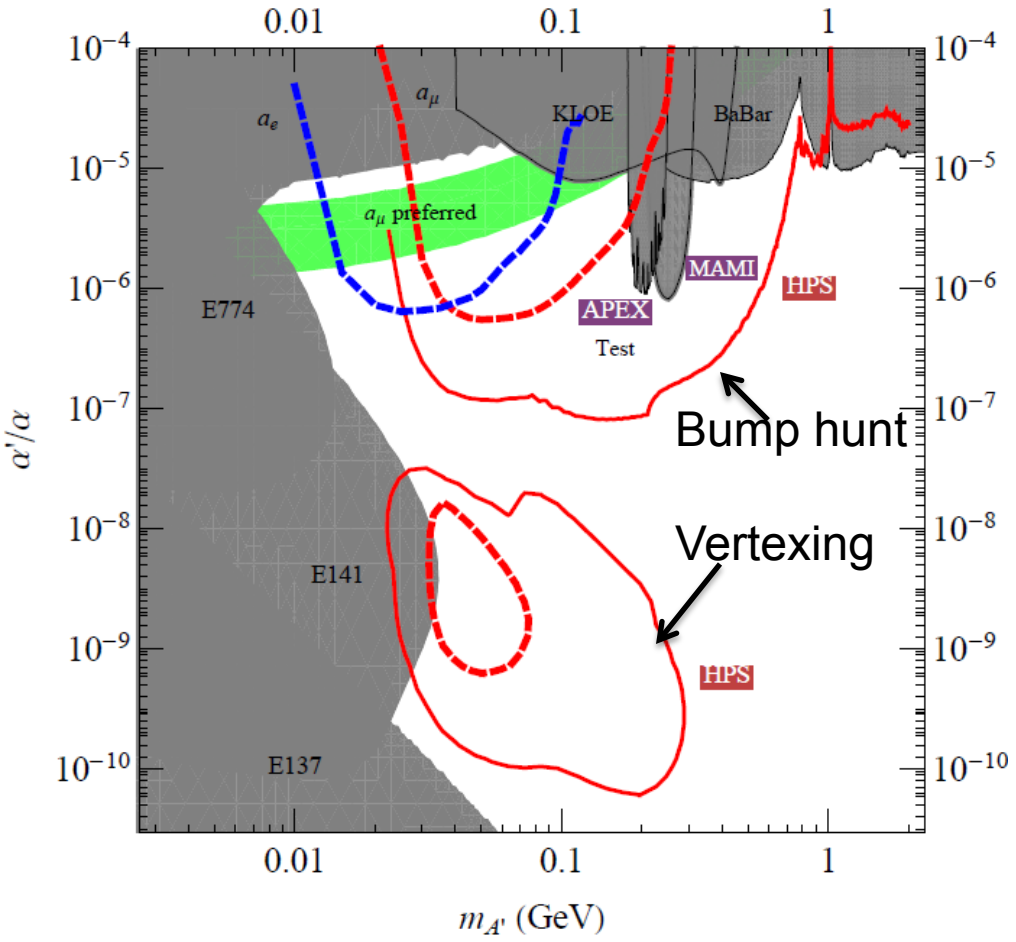


HPS Sensitivity

- HPS will explore new region of parameter space
  - Bump-hunt
  - Vertexing
- Nominal tungsten target thickness of 0.25% X_0
  - Optimized beam energy and thickness

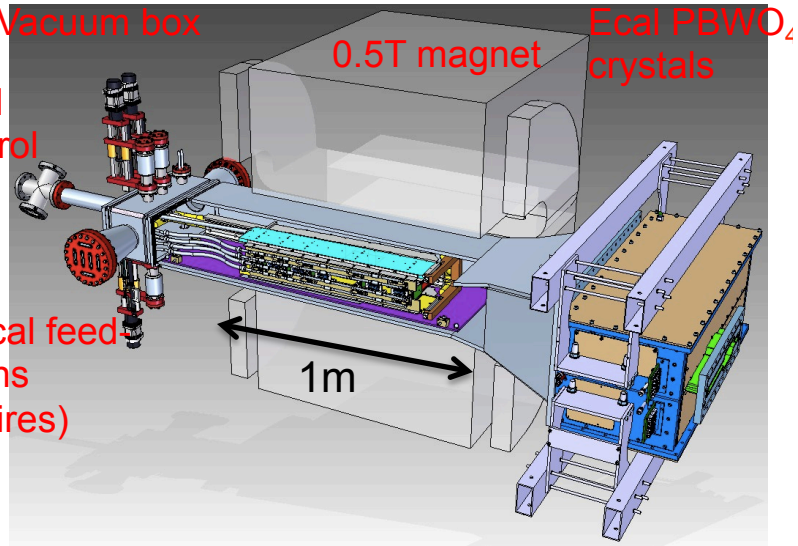
HPS
3 months 2.2GeV
3 months 6.6GeV

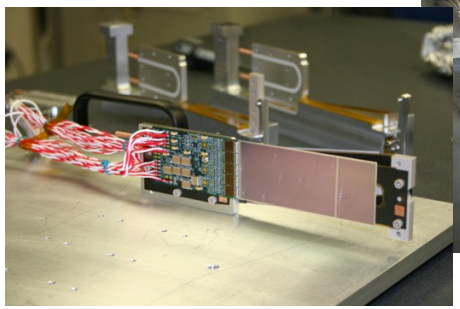
HPS Test Run
1 week 2.2GeV
1 week 1.1GeV



HPS Test Run

- Test Run before JLab 12GeV upgrade
  - Build a tracker and calorimeter that successfully meets challenges
  - Confirm models of backgrounds used in HPS reach estimates
  - Use potential physics reach of HPS Test to determine goals and motive solutions
- Design choices: sacrifice acceptance
  - 20 (/106) tracking sensors
  - Inner calorimeter: $PbWO_4$ modules
  - Complete, integrated full DAQ for SVT and calorimeter

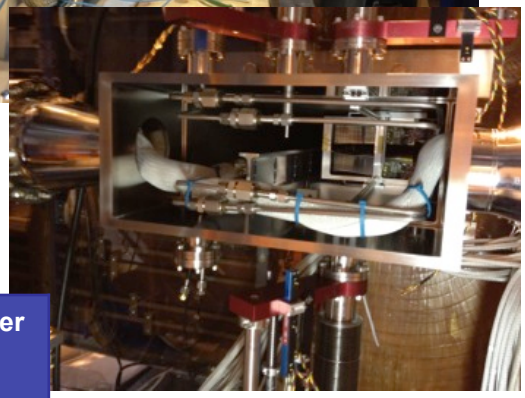




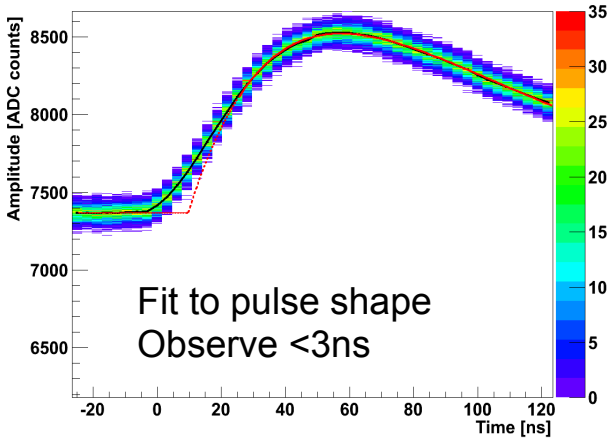
Started spring 2011…

HPS Test Run

- Installed, commissioned and ran in April/May 2012
- HPS Test detector performed remarkably well
  - Conceived, built and installed novel tracking/ vertexing detector in <14 months
  - Encouraging results already
- Results and experience extremely useful
- Success of effort demonstrates the technical feasibility of HPS



APV25 t0 calibration



Short photon beam running
(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

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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
- Goal is to run as soon as machine is ready after upgrade
  - HPS Test Run in April/May 2012 (success, but only photon beam)
  - Conditionally approved by PAC
  - Hope to Run HPS Test in 2014 with electron beam
  - Working out details with JLab

The HPS Collaboration

P. Hansson Adrian, C. Field, N. Graf, M. Graham, G. Haller,
R. Herbst, J. Jaros[a], T. Maruyama, J. McCormick, K. Moffeit,
T. Nelson, H. Neal, A. Odian, M. Oriunno, S. Uemura, D. Walz
SLAC National Accelerator Laboratory, Menlo Park, CA 94025

A. Grillo, V. Fadeyev, O. Moreno
University of California, Santa Cruz, CA 95064

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

S. Boyarinov, V. Burkert, A. Deur, H. Egiyan, L. Elouadrhiri, A. Freyberger, F.-X.
Girod, V. Kubarovsky, Y. Sharabian, S. Stepanyan[a,b], M. Ungaro, B. Wojtsekhowski
Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606

R. Essig
Stony Brook University, Stony Brook, NY 11794-3800

M. Holtrop[a], K. Slifer, S. K. Phillips
University of New Hampshire, Department of Physics, Durham, NH 03824

A. Fradi, B. Guegan, M. Guidal, S. Niccolai, S. Pisano, E. Rauly, P. Rosier and D. Sokhan
Institut de Physique Nucleaire d'Orsay, IN2P3, BP 1, 91406 Orsay, France

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

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

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

M. Battaglieri, R. De Vita
Istituto Nazionale di Fisica Nucleare, Sezione di Genova e
Dipartimento di Fisica dellÚniversita, 16146 Genova, Italy

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

G. Ron
Hebrew University of Jerusalem, Jerusalem, Israel

P. Stoler, A. Kubarovsky
Rensselaer Polytechnic Institute, Department of Physics, Troy, NY 12181

K. Griffioen
The College of William and Mary, Department of Physics, Williamsburg, VA 23185

(Dated: May 7, 2012)

[a]Co-spokesperson
[b]Contact person