Searching For Dark Photons at Jefferson Lab

Omar Moreno
on Behalf of the Heavy Photon Search Collaboration

Santa Cruz Institute for Particle Physics
University of California, Santa Cruz
Santa Cruz, CA
omoreno1@ucsc.edu

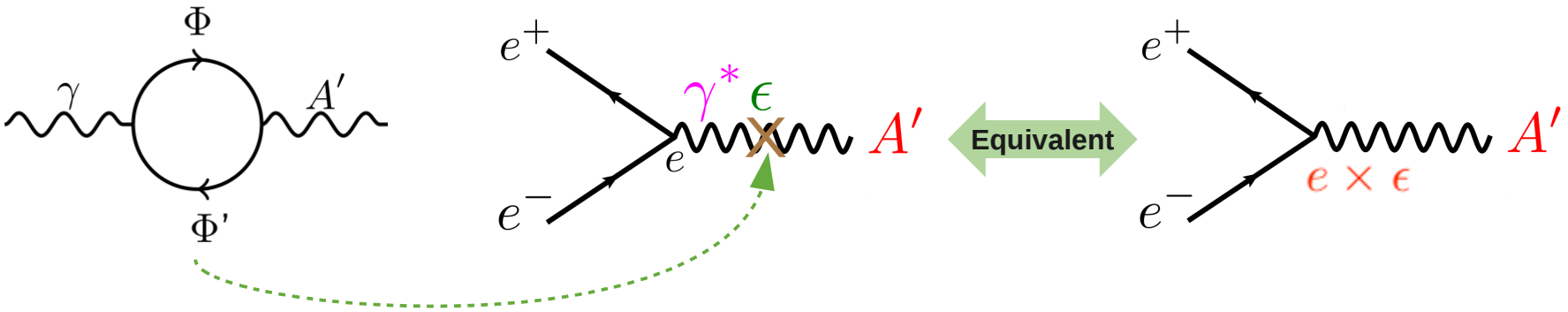
2012 Fall Meeting of the Division of Nuclear Physics
October 25, 2012

What is a "Dark Photon"?

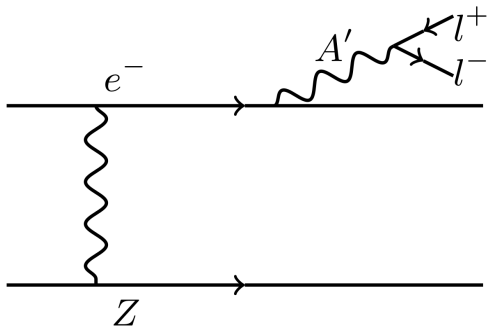
- Consider a theory in which nature contains an additional Abelian gauge symmetry, $U(1)_D$
  [Holdom, Phys. Lett.B166, 1986]

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \frac{\varepsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu} + \frac{1}{4} F'^{\mu\nu} F'_{\mu\nu} + m^2_{A'} A'^{\mu} A'_{\mu}$$

- This gives rise to a kinetic mixing term where the photon mixes with a new gauge boson, "dark photon" or A', through interactions of massive fields $\rightarrow$ induces small coupling to electric charge



- The coupling to electric charge allows for A' production through a process analogous to bremsstrahlung

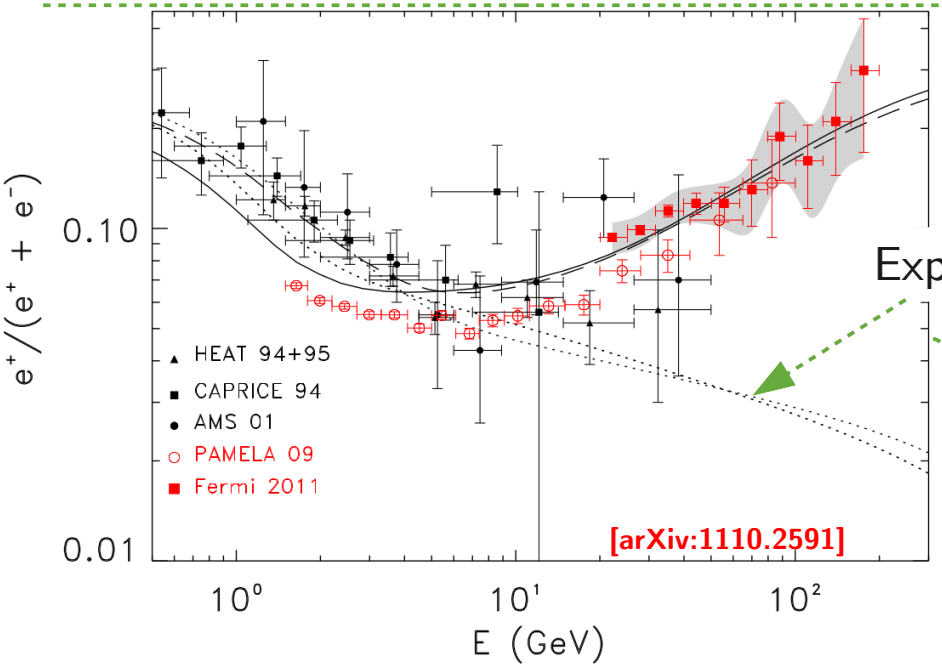


So Why Search for an Dark Photon?

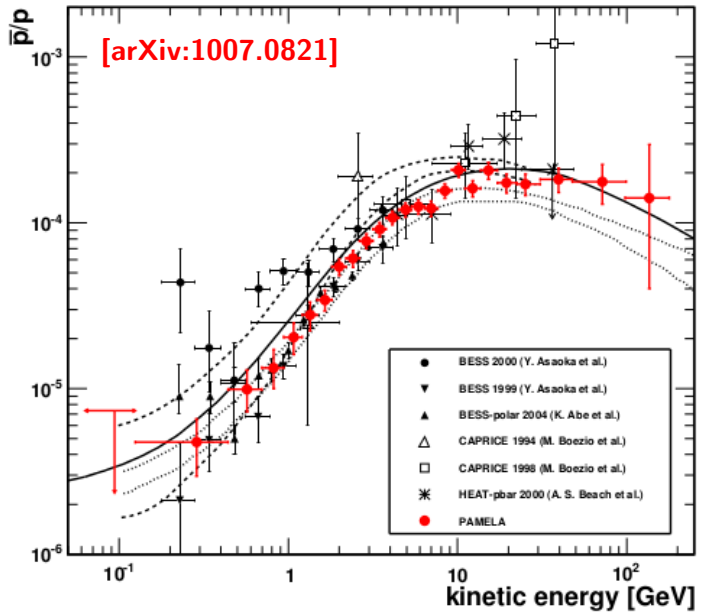
Both PAMELA and Fermi observe an excess in the positron fraction

But ...

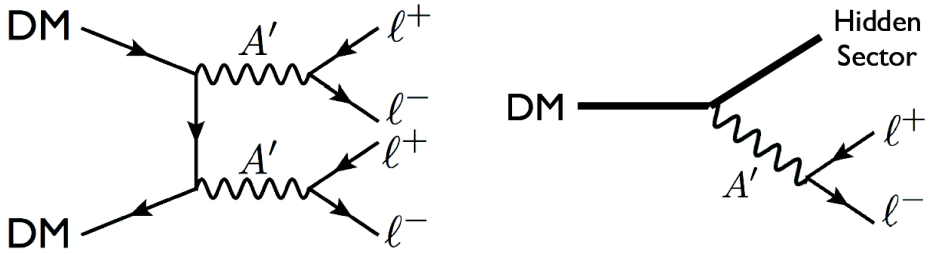
No excess protons are observed



Expected

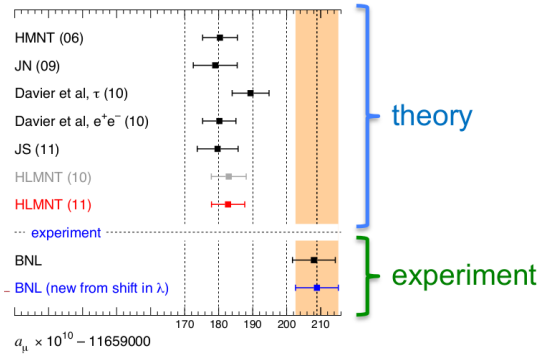


If dark matter annihilates or decays to an A' it may explain these anomalies



[Essig Schuster, Toro]

May also play a role in the anomalous magnetic moment of the muon

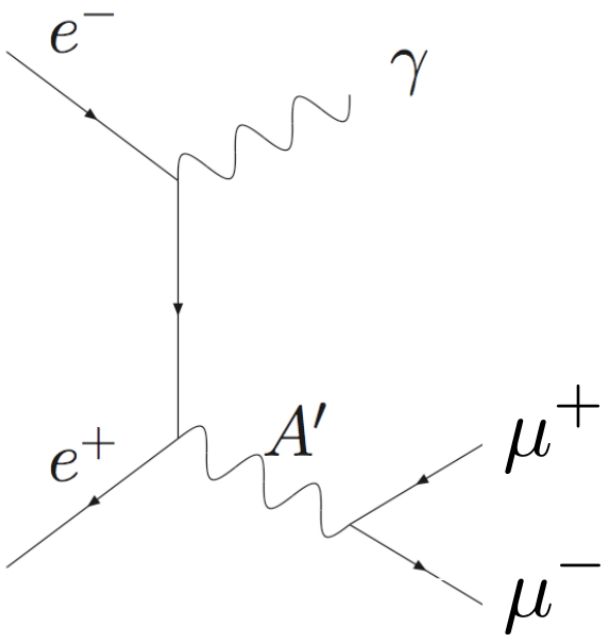


[hep-ex/0602035]

How to Search for a Dark Photon?

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

Collider

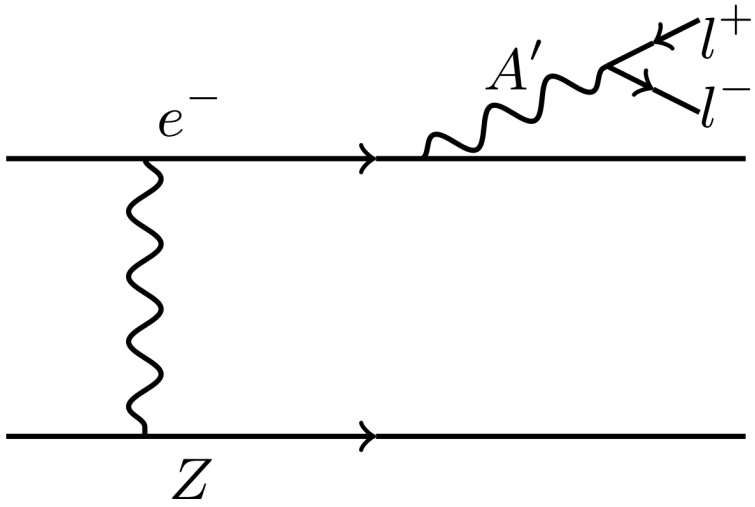


$$\sigma \sim \frac{\alpha^2 \varepsilon^2}{E_{CM}^2} \sim \mathcal{O}(10 \text{ fb})$$

$\mathcal{O}(ab^{-1})$ per decade

vs.

Fixed Target



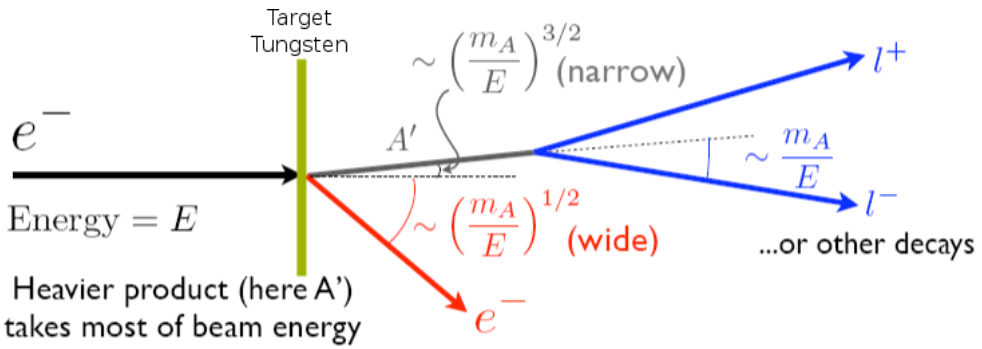
$$\sigma \sim \frac{\alpha^3 Z^2 \varepsilon^2}{m^2} \sim \mathcal{O}(10 \text{ pb})$$

$\mathcal{O}(ab^{-1})$ per day

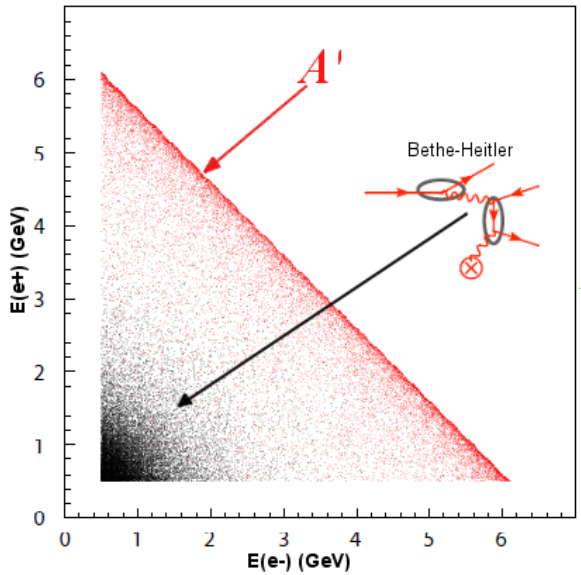
Fixed target experiments are ideal A' hunting grounds!

A' Fixed Target Kinematics & Backgrounds

Signal

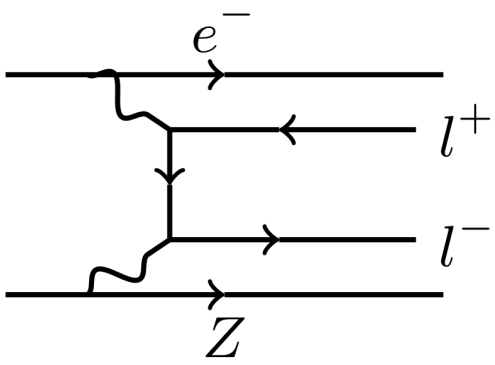


- A' is produced very far forward $\rightarrow$ $E_{A'} = E_{beam}$
- A' decay products opening angle, $m_{A'}/E_{beam}$
- Long lived A' will have a displaced vertex $\rightarrow$ Help in the reduction of background

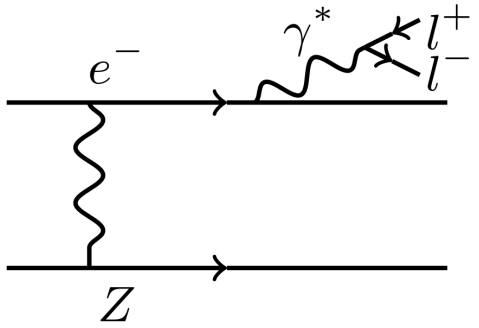


Trident Backgrounds

Bethe-Heitler

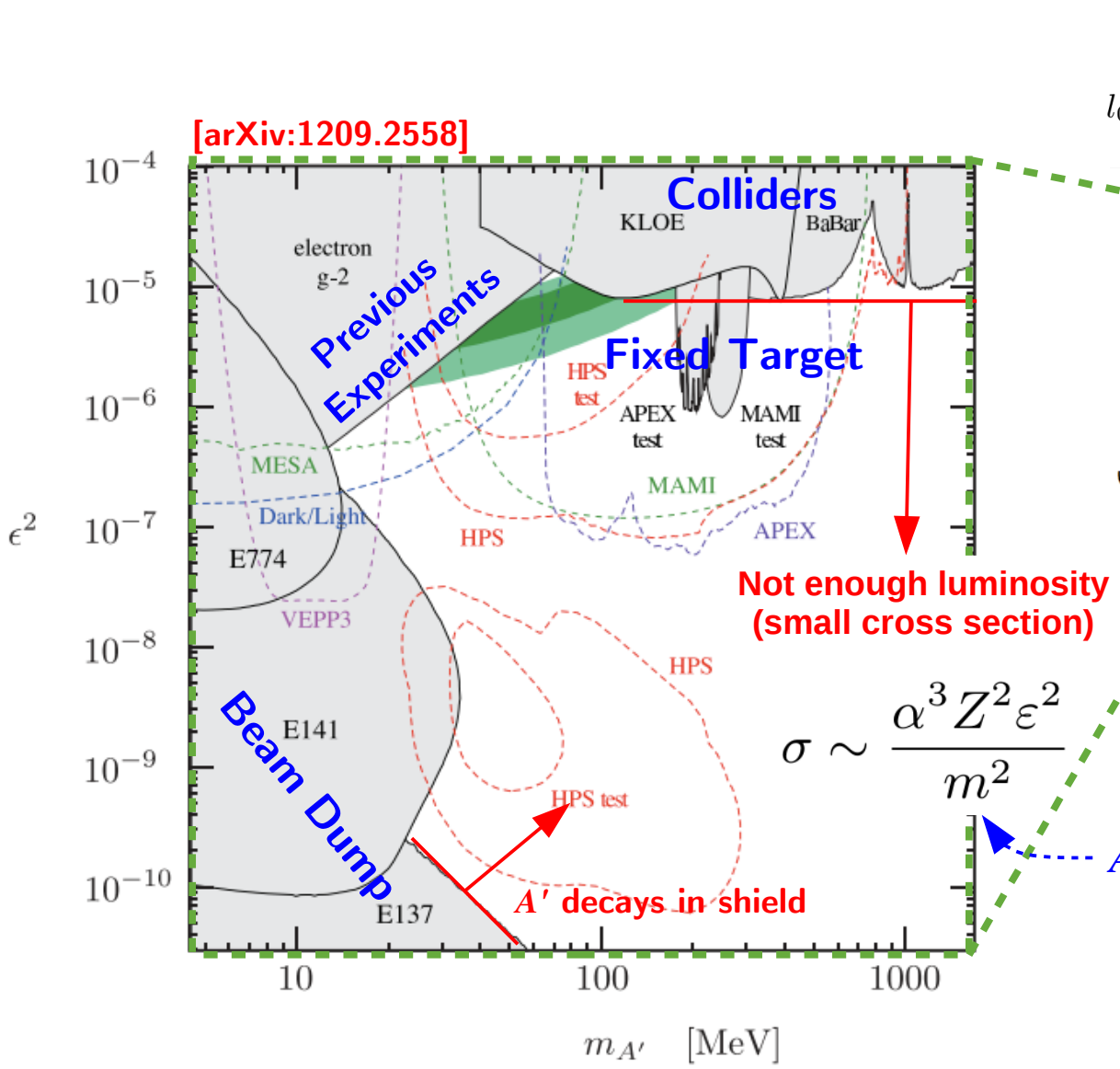


Radiative



- Bethe-Heitler cross section is much larger than radiative but is kinematically distinct
- Radiative and A' signatures are kinematically **identical**

Some Existing A' Constraints



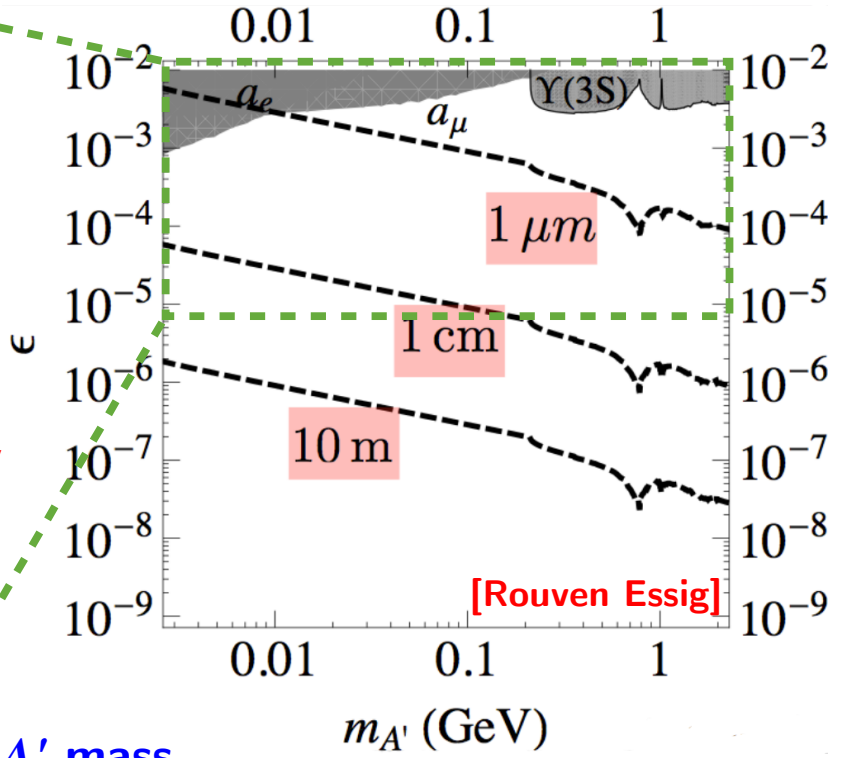
Not enough luminosity
(small cross section)

$$\sigma \sim \frac{\alpha^3 Z^2 \varepsilon^2}{m^2}$$

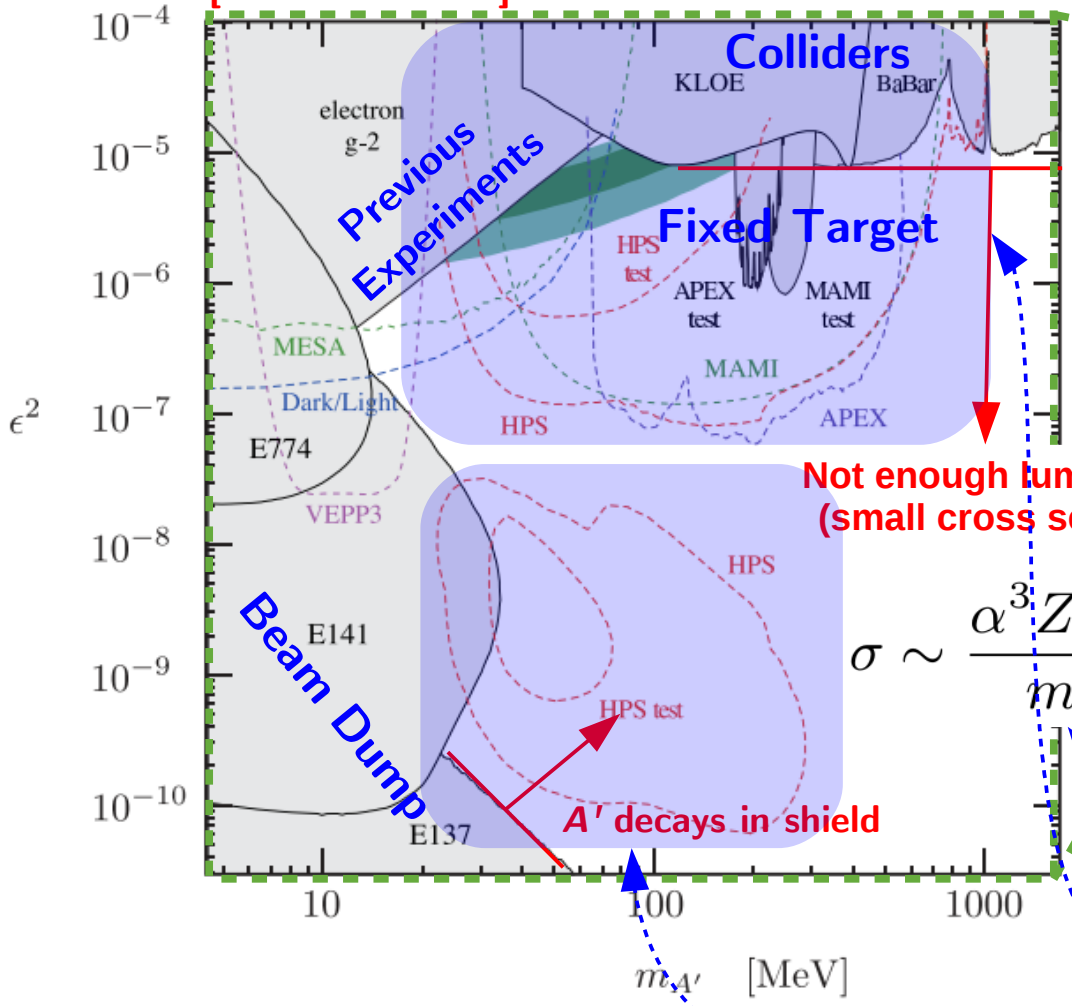
A′ mass

A′ Decay Lengths

$$l_0 \equiv \gamma c\tau \simeq \frac{0.8cm}{N_{\text{eff}}} \left(\frac{E_0}{10\ \text{GeV}}\right) \left(\frac{10^{-4}}{\varepsilon}\right)^2 \left(\frac{100MeV}{m_{A'}}\right)^2$$



Some Existing A' Constraints

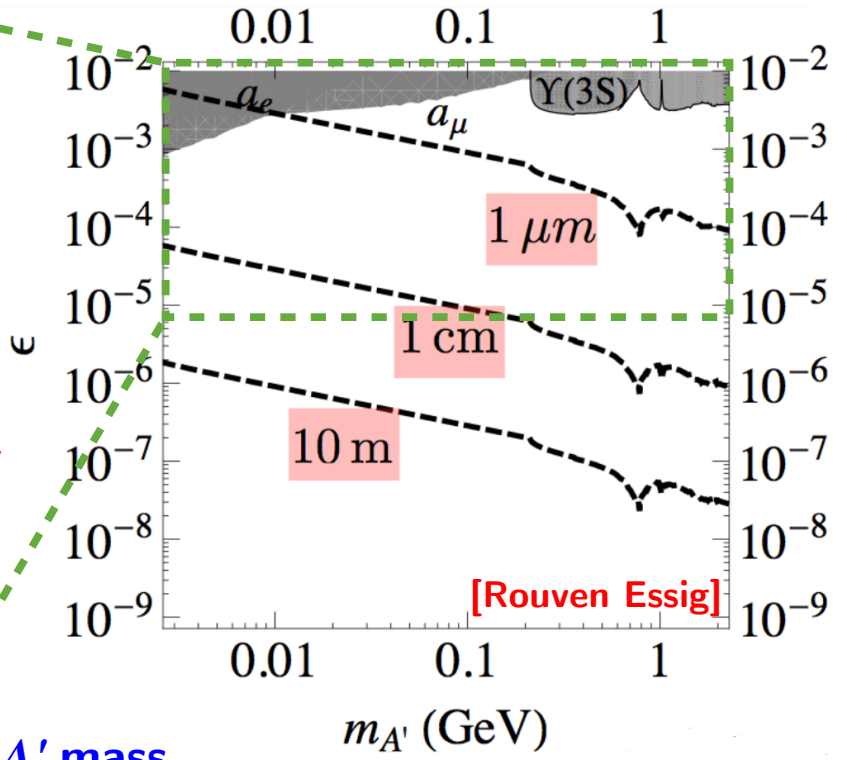


Not enough luminosity (small cross section)

$$\sigma \sim \frac{\alpha^3 Z^2 \varepsilon^2}{m^2}$$

A′ Decay Lengths

$$l_0 \equiv \gamma c\tau \simeq \frac{0.8cm}{N_{\text{eff}}} \left(\frac{E_0}{10\ \text{GeV}}\right) \left(\frac{10^{-4}}{\varepsilon}\right)^2 \left(\frac{100MeV}{m_{A'}}\right)^2$$



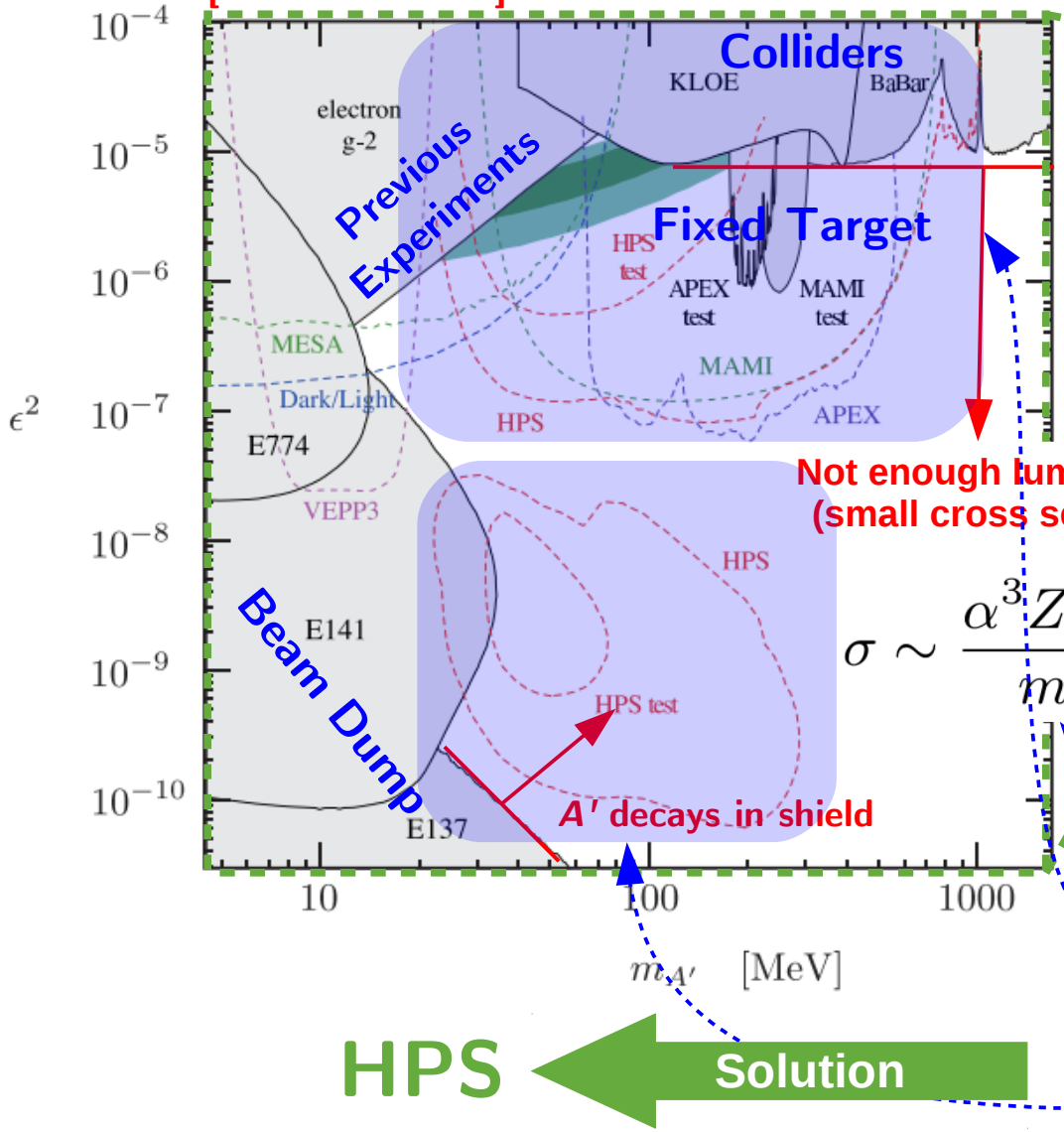
A′ mass Sensitivity to these regions will rely on

Determination of the invariant mass of the A′ decay products → Good mass (momentum) resolution

Distinguishing A′ decay vertices as Non-prompt → Good vertex resolution

Some Existing A' Constraints

[arXiv:1209.2558]

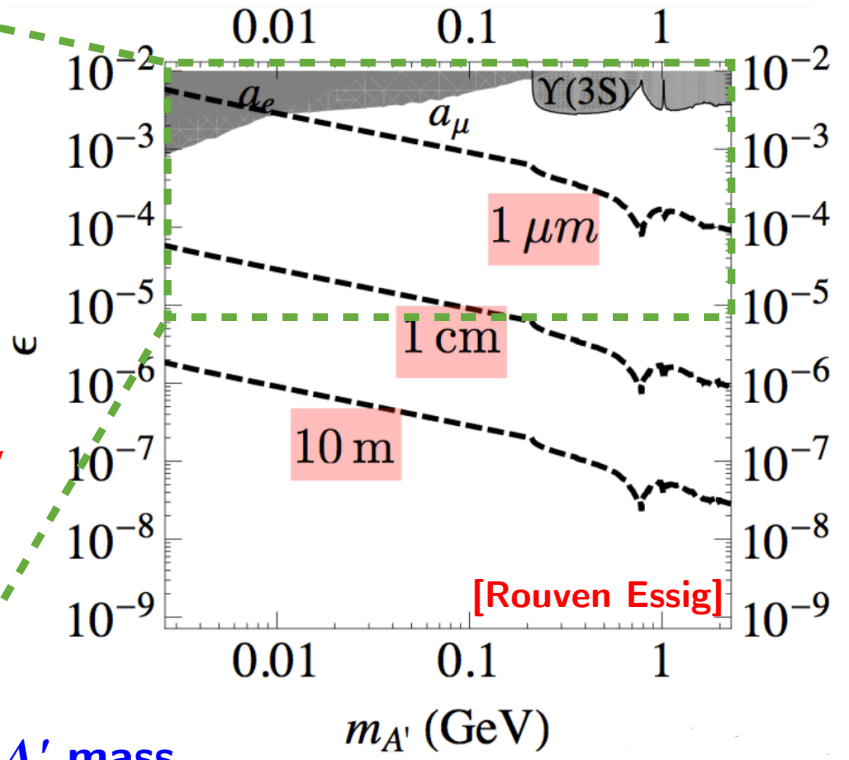


Not enough luminosity (small cross section)

$$\sigma \sim \frac{\alpha^3 Z^2 \varepsilon^2}{m^2}$$

A' Decay Lengths

$$l_0 \equiv \gamma c\tau \simeq \frac{0.8cm}{N_{\text{eff}}} \left(\frac{E_0}{10\ \text{GeV}}\right) \left(\frac{10^{-4}}{\varepsilon}\right)^2 \left(\frac{100MeV}{m_{A'}}\right)^2$$



A' mass Sensitivity to these regions will rely on

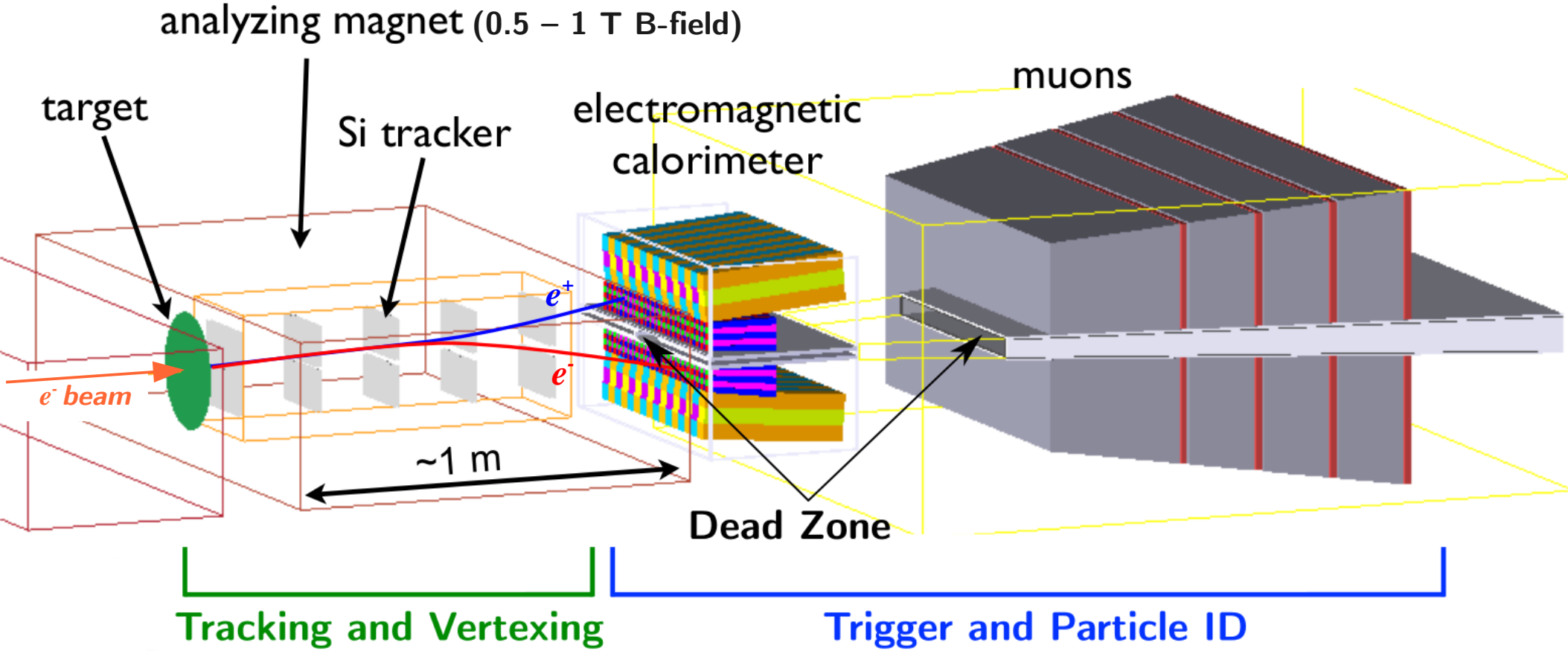
Determination of the invariant mass of the A' decay products → Good mass (momentum) resolution

Distinguishing A' decay vertices as Non-prompt → Good vertex resolution

HPS ← **Solution**

The HPS Experiment

- The HPS Experiment will make use of a compact large acceptance, **vertex** detector capable of handling high rates

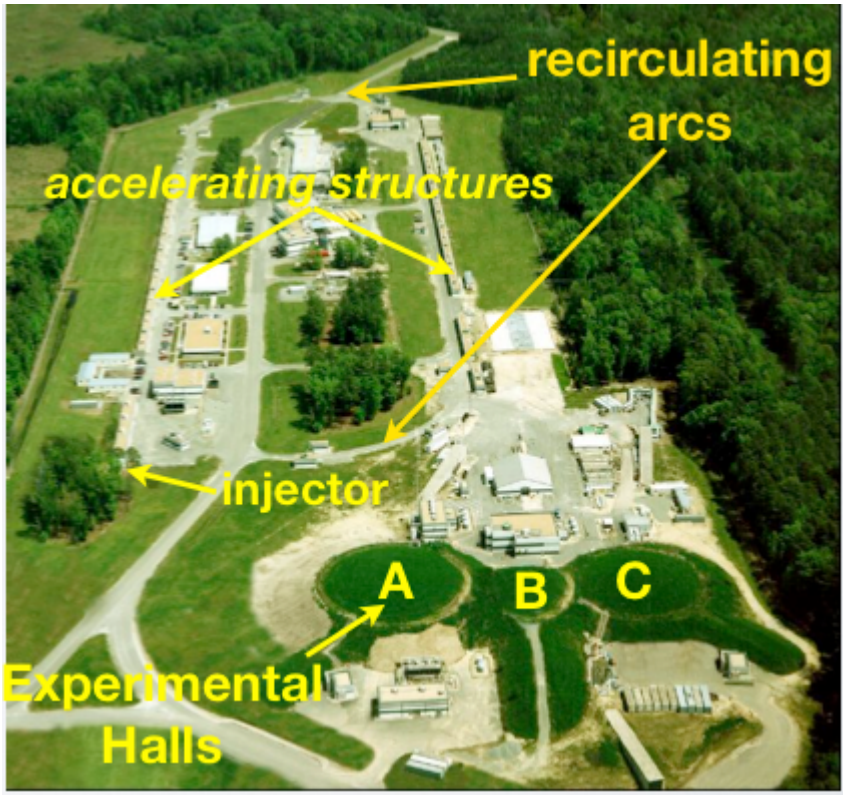


- The HPS detector will be split in half in order to avoid the "Wall of Flame" i.e. beam electrons, bremsstrahlung photons, etc.

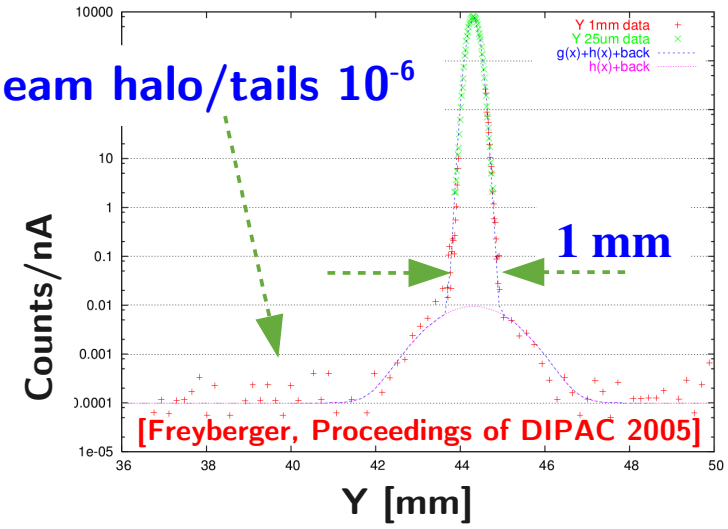
CEBAF @ Jefferson Lab

Simultaneous delivery of electron beams at different energies and intensities to three experimental halls

- E_{beam} = n x 1.1 GeV, n < 6 up to a maximum of 5.5 GeV (until May 2012)
- **Hall A, C:** $I_{beam} < 100\ \mu$A, **Hall B:** $I_{beam} < 800$ nA
- Beam delivery is nearly continous: 2 ns bunch structure
- Able to provide small beam spot (<30 μm) which will help improve vertexing
- Energy upgrade expected to be complete in 2014 E_{beam} = n x 2.2 GeV, n < 6 up to a maximum of 11 GeV (12 GeV for Hall D)



Vertical Beam Size

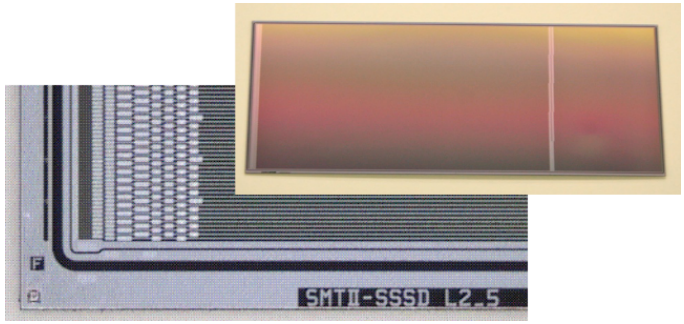


CEBAF is ideal for this experiment, however, schedule is not

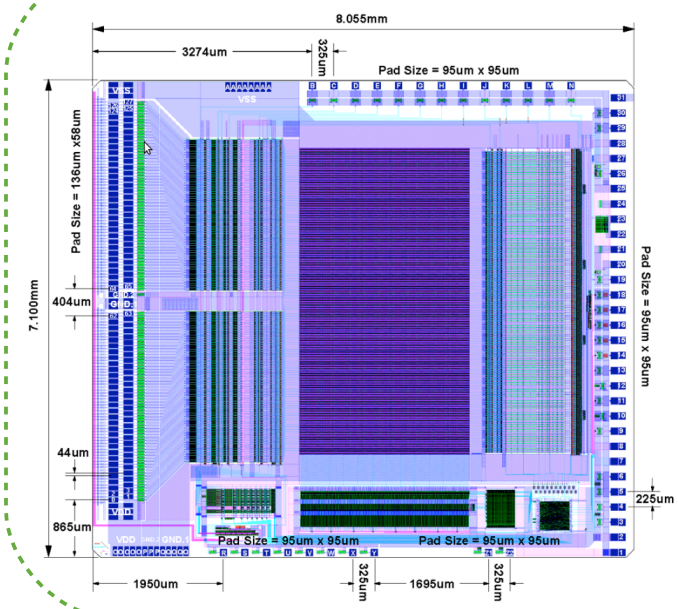
- Beam is down until 2015 for 12 GeV upgrade
- Aim is to run using first beam with possible commissioning run in late 2014 (**Will make use of existing Test Run detector**)

Silicon Vertex Tracker

D0 RunIIb sensors



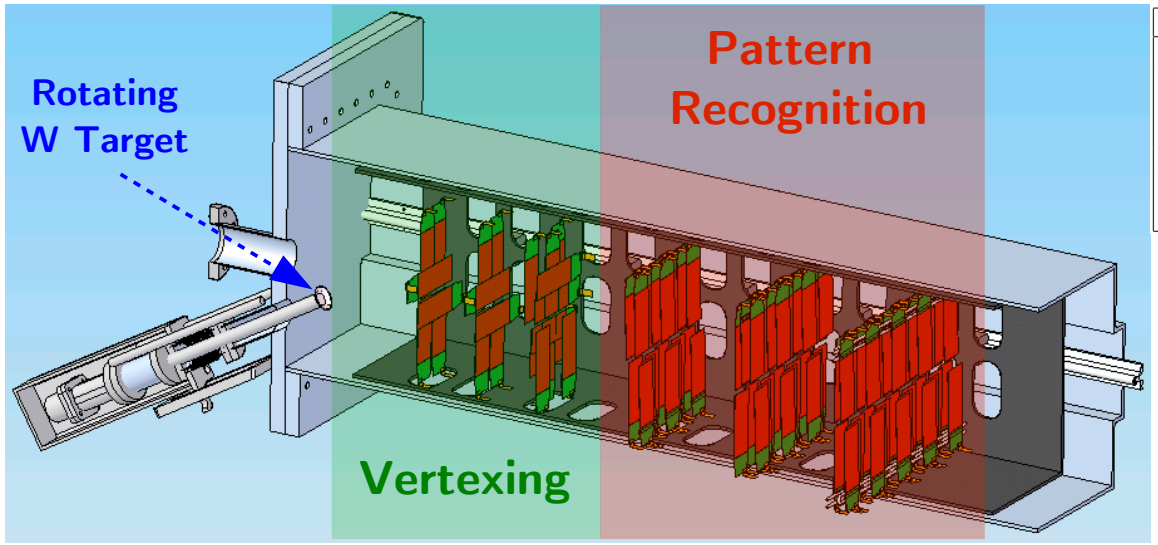
Cut Dimensions (L × W)	100 mm × 40.34 mm
Active Area (L × W)	98.33 mm × 38.34 mm
Readout (Sense) Pitch	60 μm (30 μm)
# Readout (Sense) Strips	639 (1277)
Breakdown Voltage	$>$ 350 V
Defective Channels	$<$ 1%



APV25 Readout Chip

# Readout Channels	128
Input Pitch	44μ
Shaping Time	50 ns nom. (adjustable)
Output Format	multiplexed analog
Noise Performance	270 + 36 × C(pF) e^-
Power Consumption	345 mW

- 40 MHz readout
- Low noise: S/N $>$ 25
- High radiation tolerance
- "Multi-peak" readout
- t_0 resolution approx. 2 ns



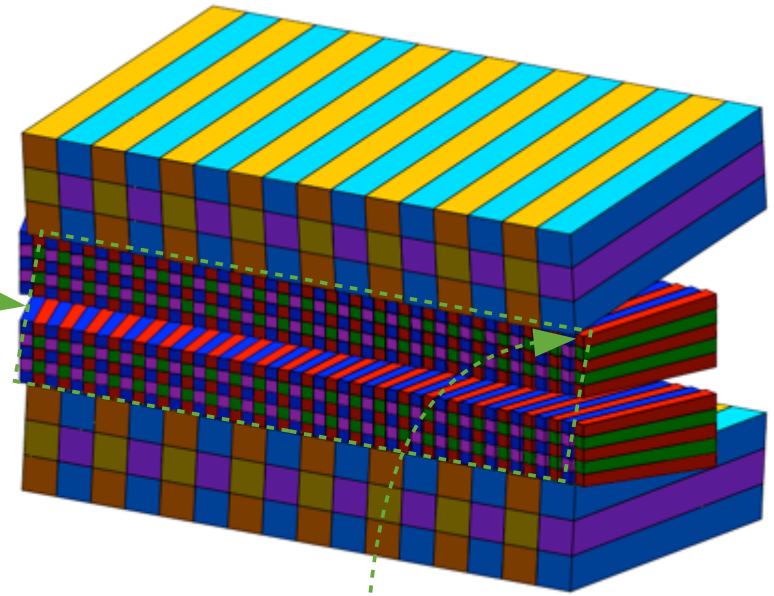
Layer	1	2	3	4	5	6
z position, from target [cm]	10	20	30	50	70	90
Stereo angle	90^o	90^o	90^o	50 mrad	50 mrad	50 mrad
Bend Plane Resolution (μm)	$\approx$ 6	$\approx$ 6	$\approx$ 6	$\approx$ 6	$\approx$ 6	$\approx$ 6
Stereo Resolution (μm)	$\approx$ 6	$\approx$ 6	$\approx$ 6	$\approx$ 120	$\approx$ 120	$\approx$ 120
# Bend Plane Sensors	4	4	6	10	14	18
# Sterep Sensors	2	2	4	10	14	18
Dead Zone [mm]	$\pm$ 1.5	$\pm$ 3.0	$\pm$4.5	$\pm$7.5	$\pm$10.5	$\pm$13.5

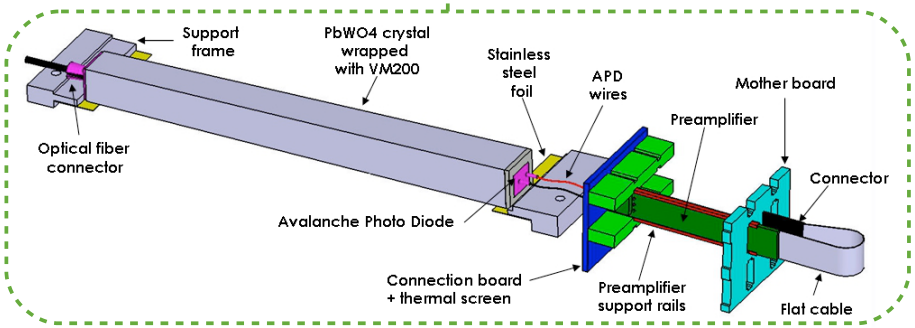
- Thin layers in order to reduce multiple scattering ($0.7\%X_0$/layer)
- Bend plane measurements in all layers (for momentum)
- 90 degree stereo will be used for vertexing

The SVT will be comprise of 106 sensors & hybrids and 530 APV25 ASICs for a total of 67840 Channels

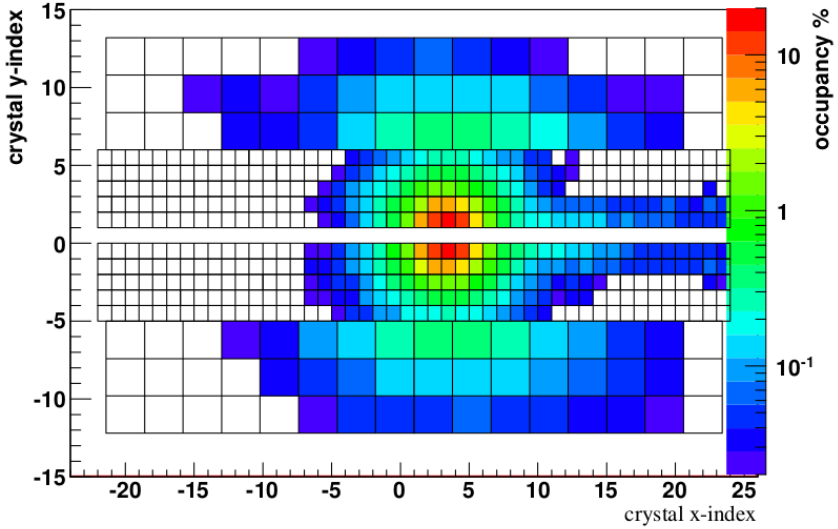
Trigger – Hybrid Calorimeter

- Hybrid design comprised of 460 existing PbWO4 crystals and 96 lead-glass crystals
- FADC readout at 250 MHz $\rightarrow$ allows for a narrow trigger window
- FPGA based trigger selection (Two clusters along with some constraints on their energy and geometry) reduces background trigger rate from 3 MHz to 27 kHz
- Trigger and DAQ capable of a rate of > 50 KHz





$6.6\ \mathrm{GeV},\ I_{beam} = 400\ \mathrm{nA},\ 0.25\%\ \mathrm{X}_0$ target

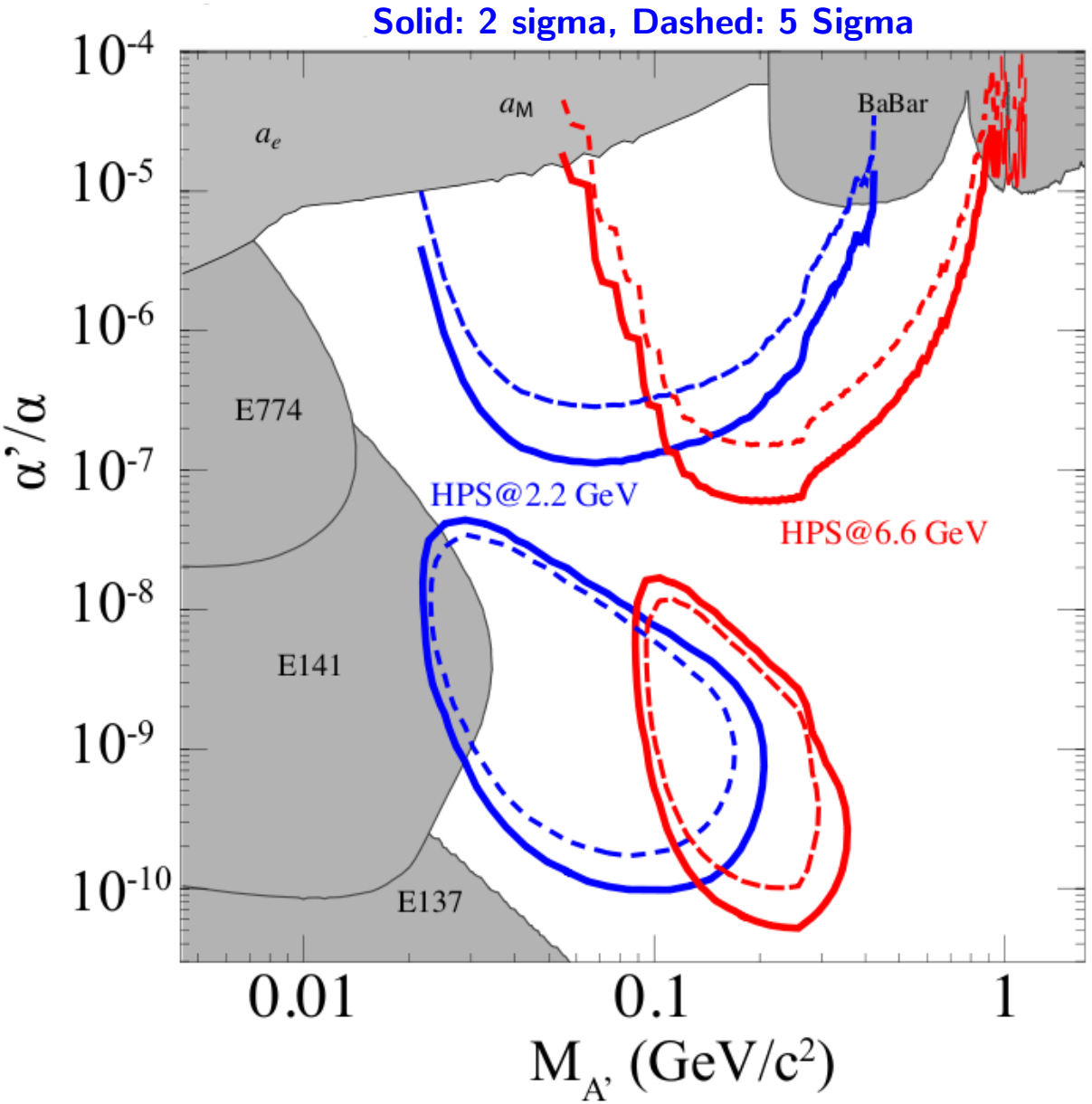


HPS Reach

Beam = 2.2 GeV @ 200 nA
Target = 0.125%X_0

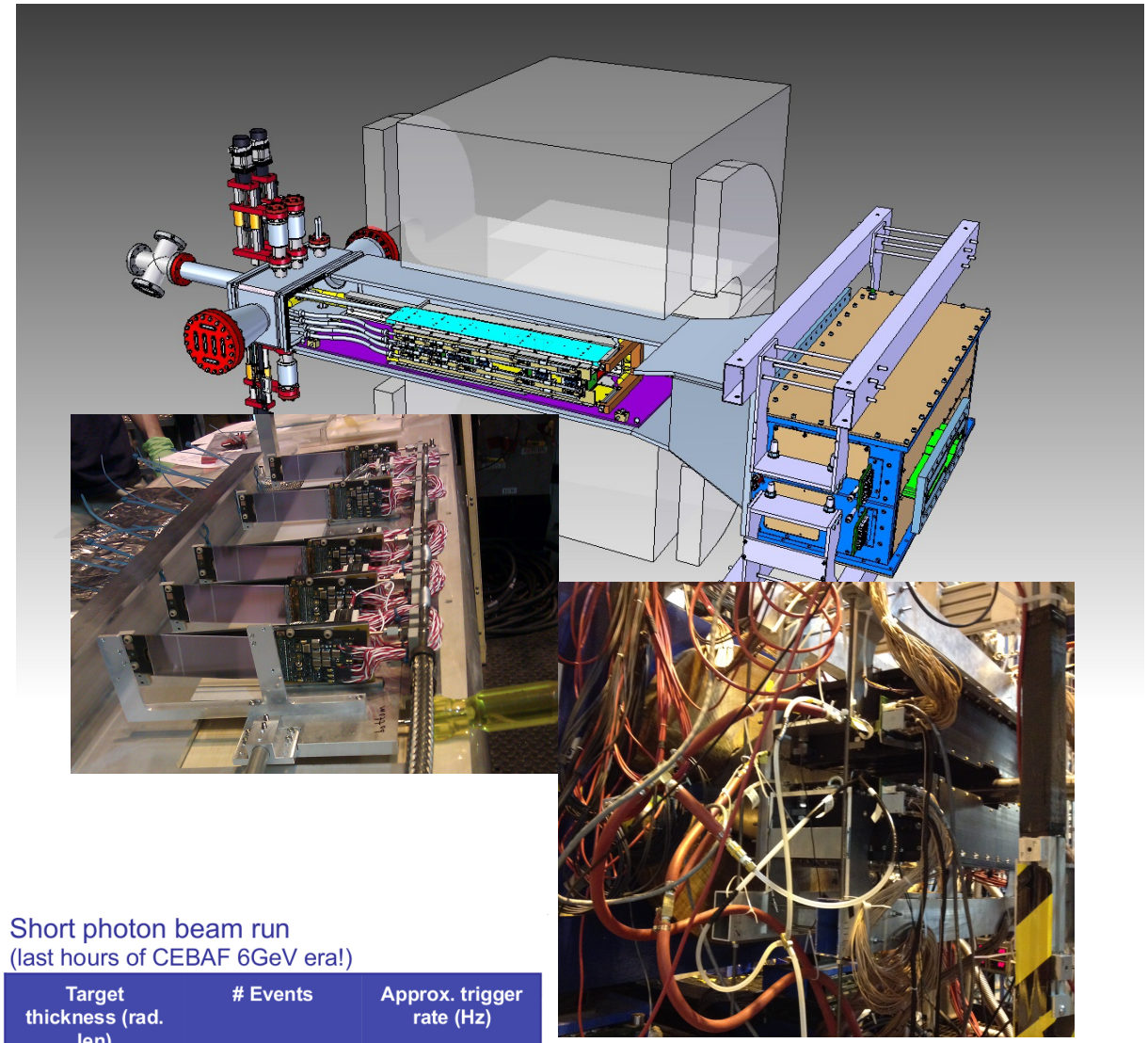
Beam = 6.6 GeV @ 450 nA
Target = 0.25%X_0

Assumes 3 months of running at each energy



The HPS Test Run

- The aim was to **determine if the occupancies and trigger rates have been well modeled and are manageable, as well as to show if detector performance estimates were reasonable**
- Used a scaled down version of the HPS detector
  - 5 Si tracker layers with two sensors per layer (1 axial, 1 stereo)
  - Only use the inner crystals of the Ecal
  - The muon chamber was absent
  - Use existing beamline elements
- HPS Test Run was installed on April 19th and **successfully** ran until the CEBAF shutdown
  - SVT design was conceived, built and installed in less than 14 months!
  - Scheduling conflict prevented running using electrons $\rightarrow$ **Ran parasitically using a photon beam instead**

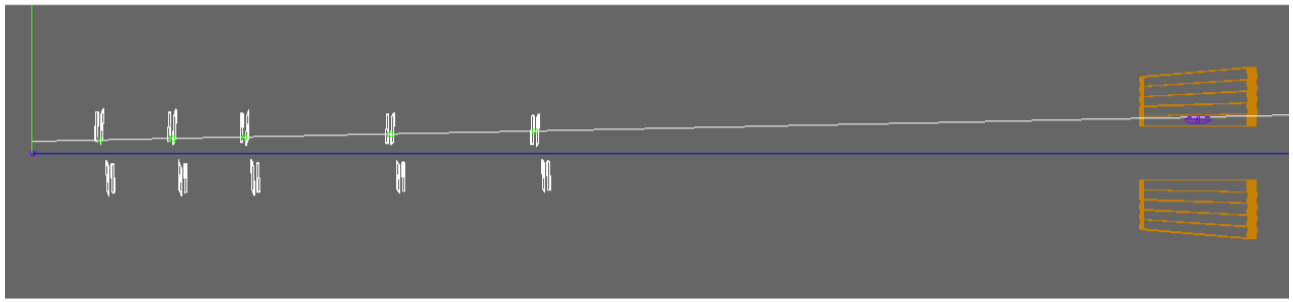


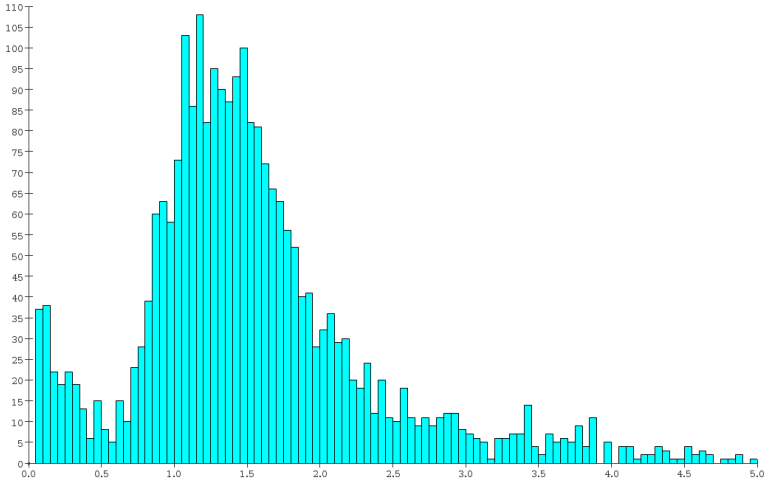
Short photon beam run
(last hours of CEBAF 6GeV era!)

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

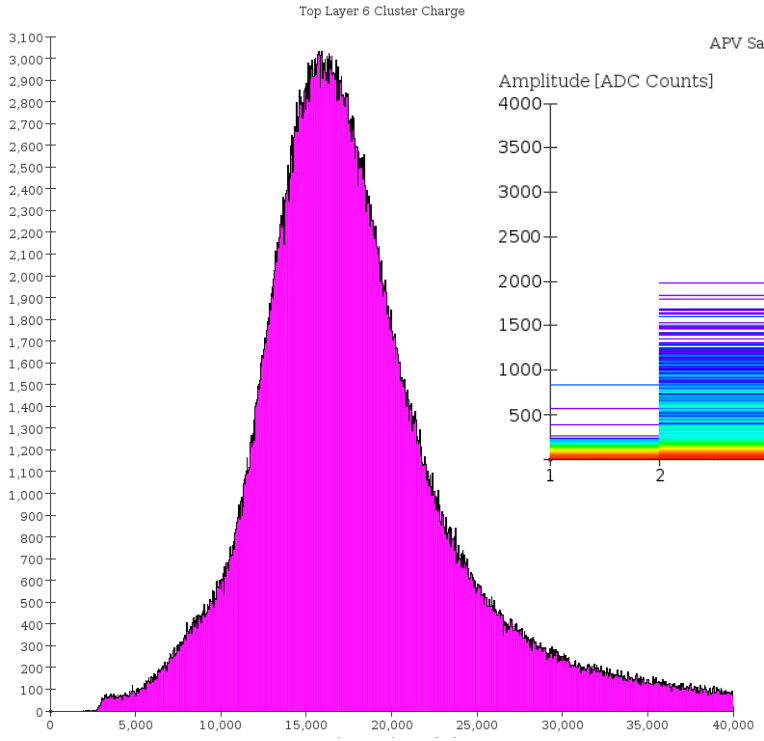
Test Run Performance

Y-Z view of a track

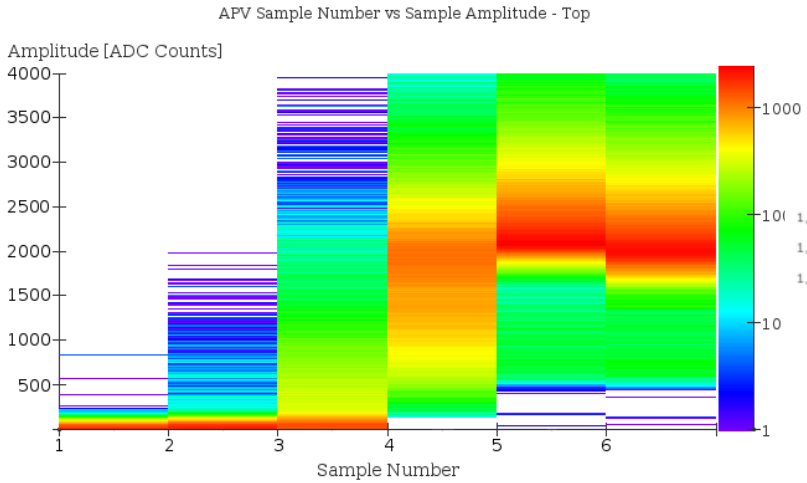


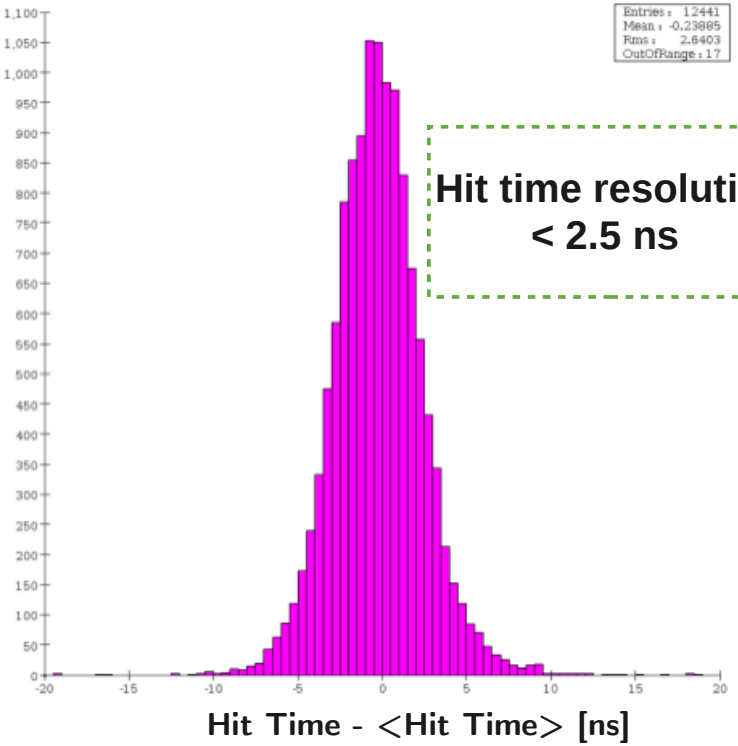


Momentum [GeV]



Cluster Charge [e-]





Hit time resolution < 2.5 ns

Hit Time - <Hit Time> [ns]

Analysis of Test Run data is still ongoing
→ Comparison to full simulation is beginning

HPS Collaboration

P. Hansson Adrian, C. Field, N. Graf, M. Graham, G. Haller,
R. Herbst, J. Jaros 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,
Girod, V. Kubarovsky, Y. Sharabian, S. Stepanyan M. Ungaro, B. Wojtsekh
Thomas Jefferson National Accelerator Facility, Newport News, Virginia 2360

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

M. Holtrop , 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)

Backup