Searching for a *(dark)* needle in a *(hidden)* haystack: The ***HPS*** and ***APEX*** Experiments

Matt Graham
SLAC
SMU HEP Seminar
November 14, 2011

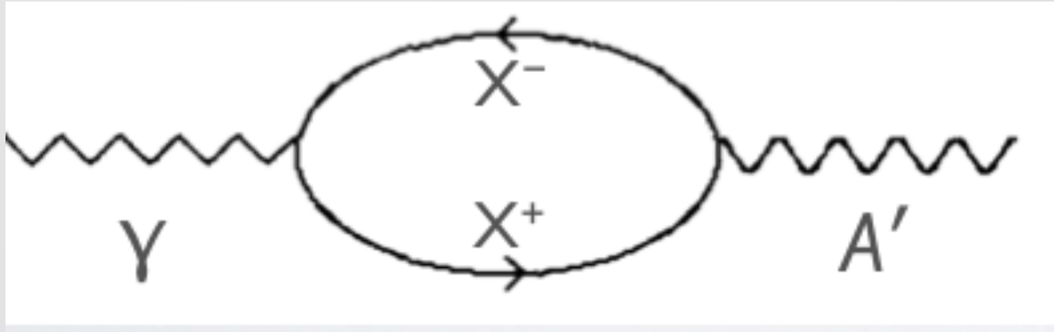
U(1)′ and kinetic mixing

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

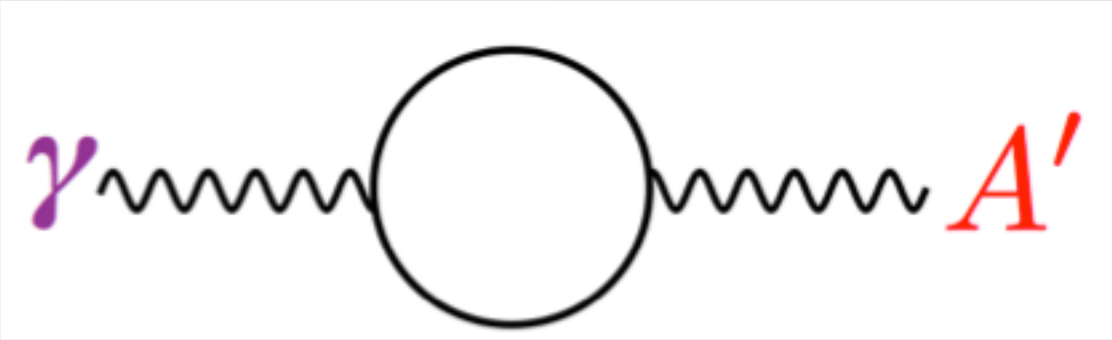
$$\mathcal{L}_{U(1)'} = -\frac{1}{4}V_{\mu\nu}^2 - \boxed{\frac{\epsilon}{2}V_{\mu\nu}F^{\mu\nu}} + |D_\mu\phi|^2 - V(\phi)$$

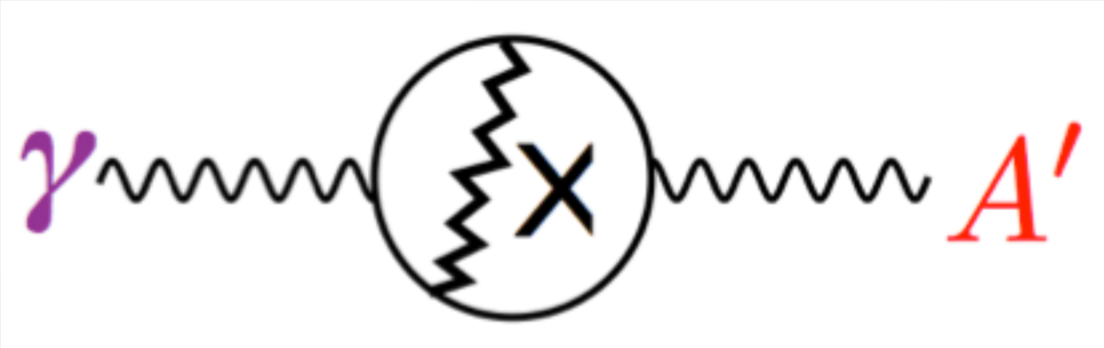
Kinetic Mixing term



- 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" $q=\varepsilon e$

"Natural" coupling and mass





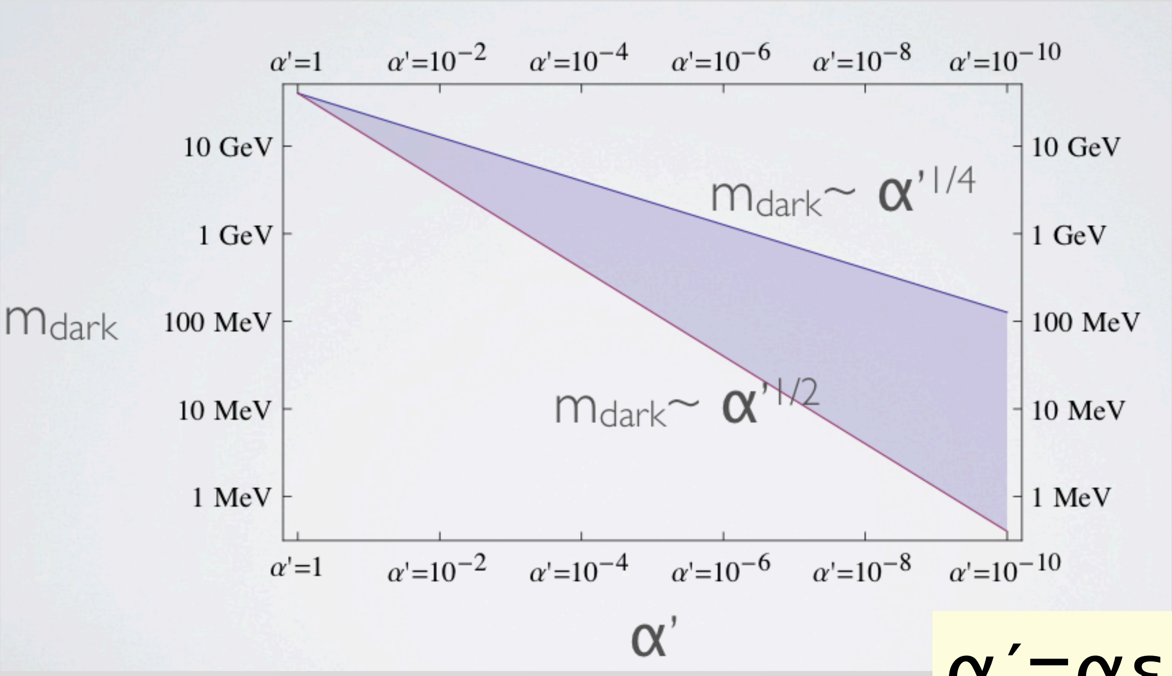
$$\epsilon \sim 10^{-3} - 10^{-2} \xrightarrow[\text{symmetry}]{\text{enhanced}} \epsilon_{GUT} \sim 10^{-5} - 10^{-3}$$

Depending on model, mass scales like:

M(A´)/M(W)~ε^{1}-$\varepsilon^{1/2}$

leading to

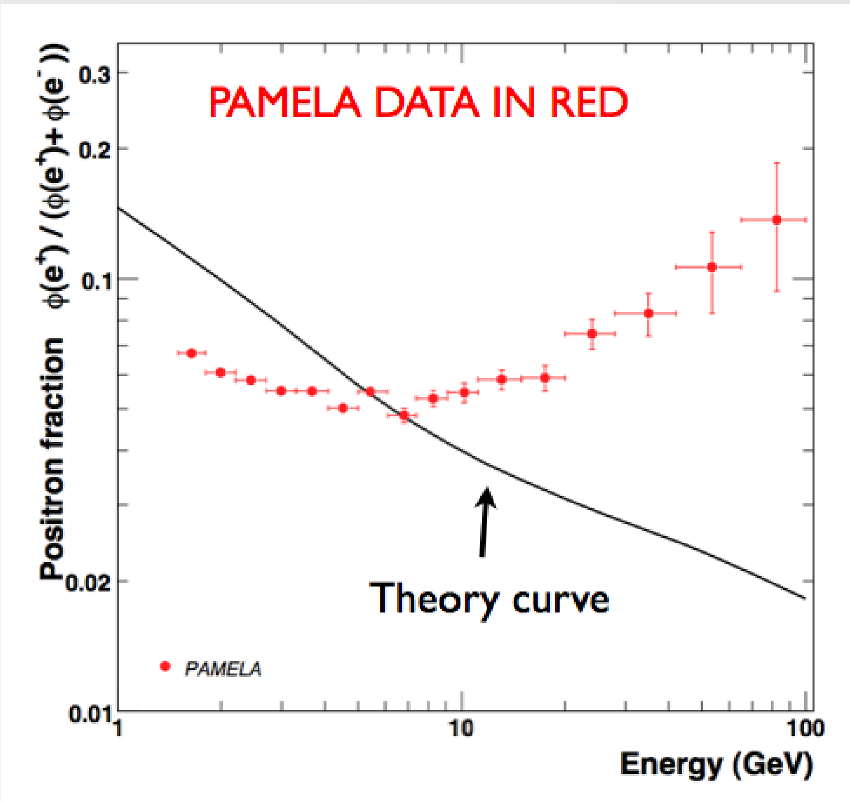
M(A´)~MeV-GeV



N.Weiner, JLAB PAC37 Talk

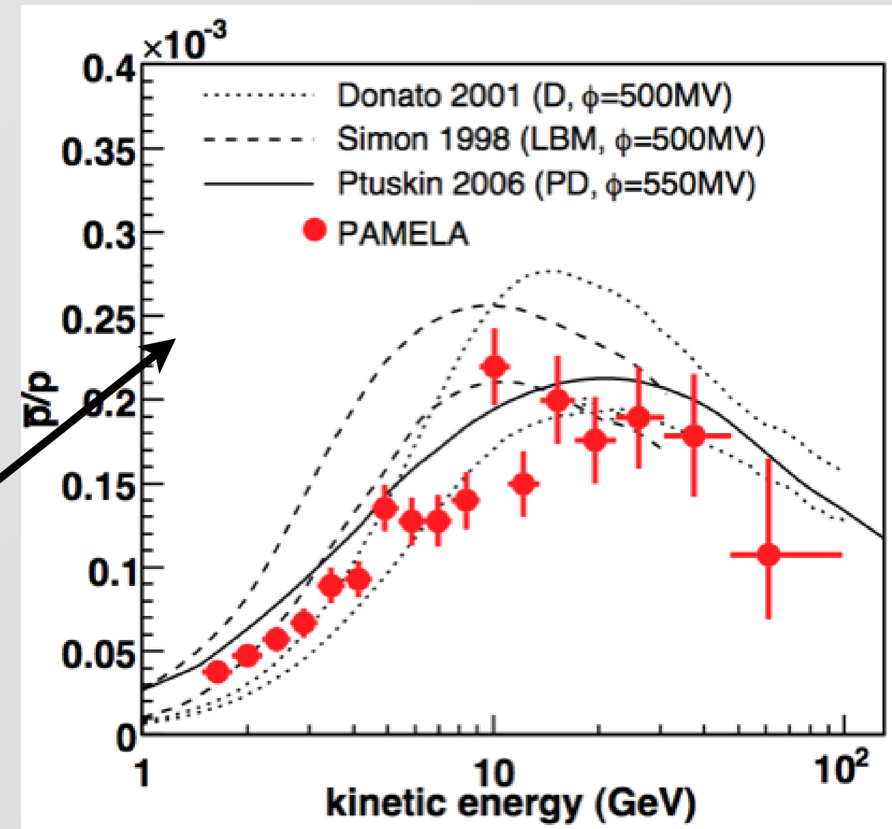
α´=αε

Hint from astrophysics?

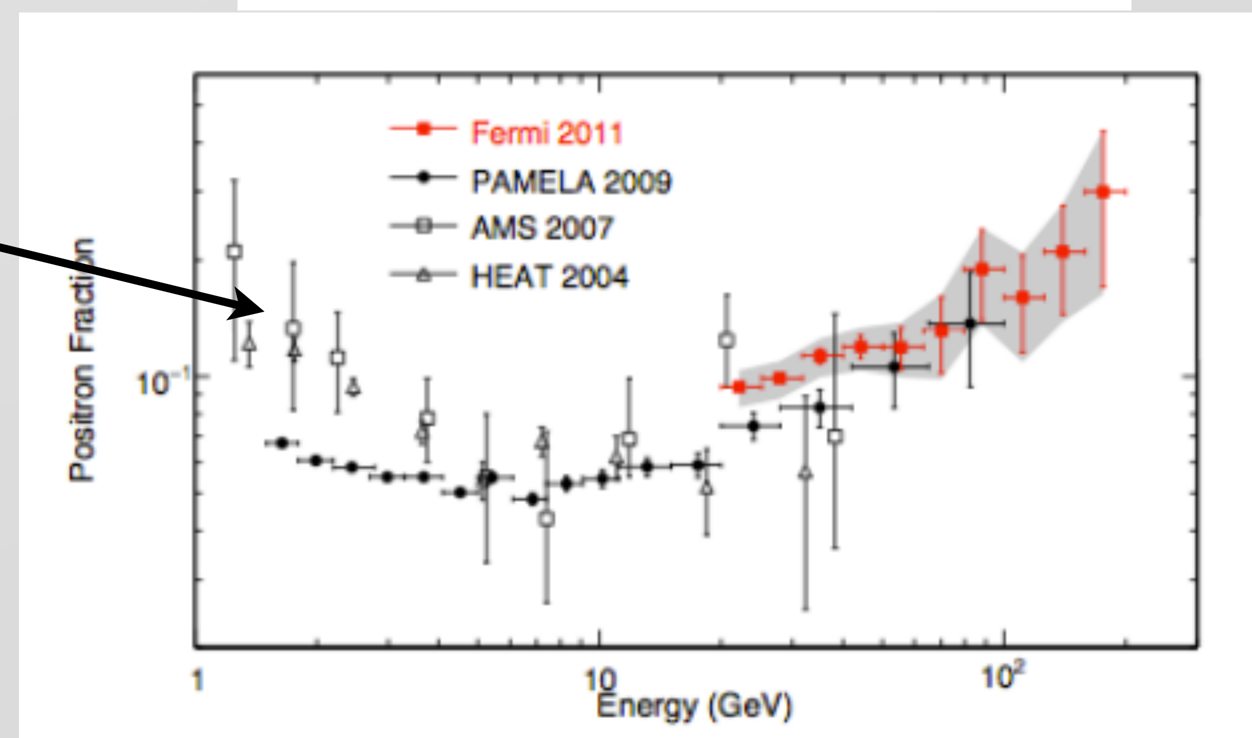


excess in e^+/e^- ratio

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



•FERMI sees it too!

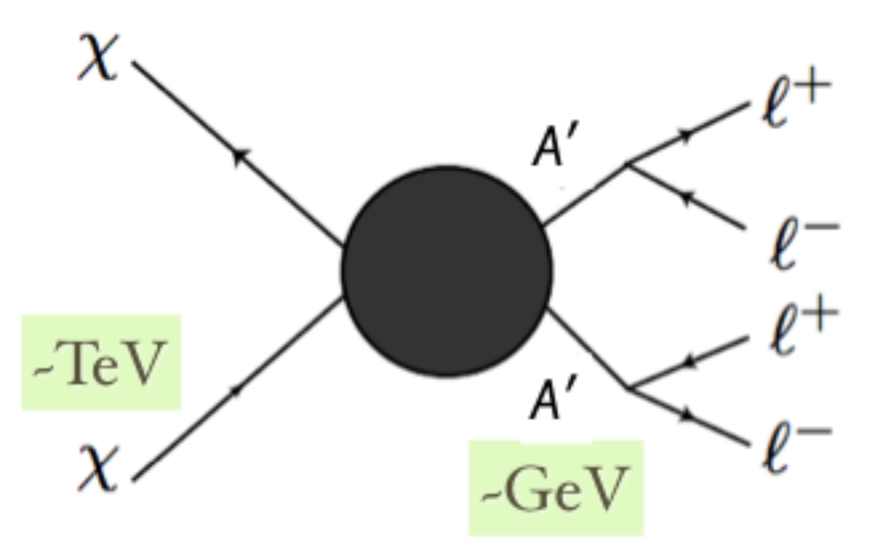


Unknown source of high energy positrons...

Is this astrophysics or particle physics?

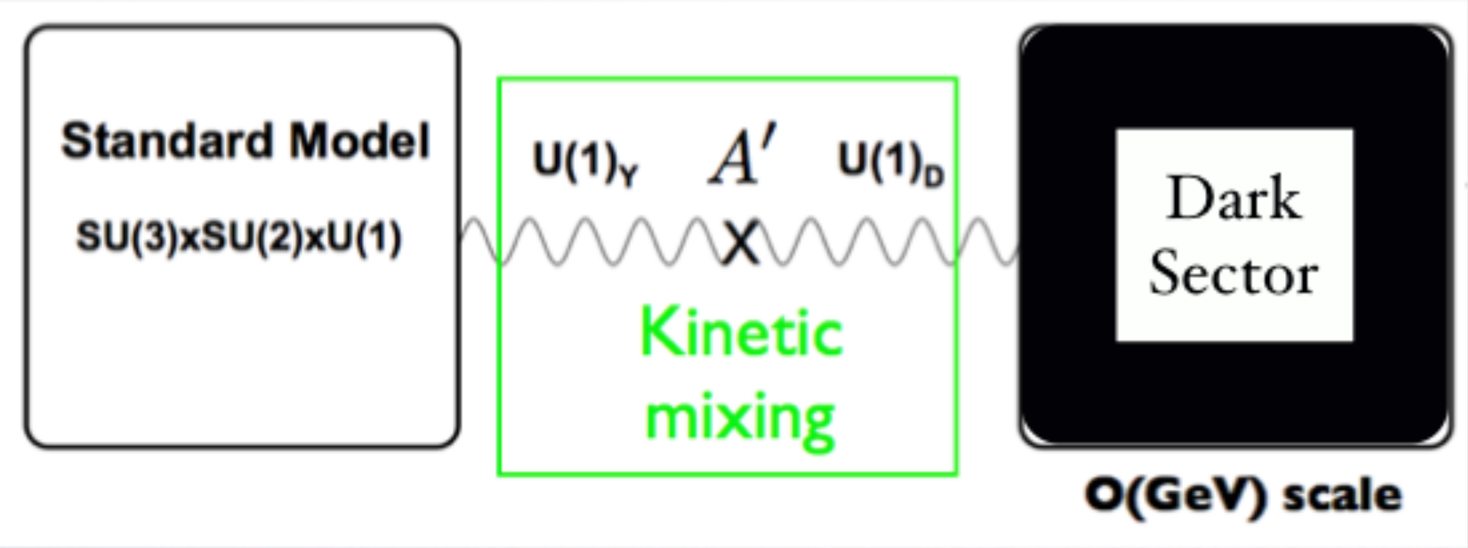
Dark matter annihilation and the dark sector

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−, μ+μ−) but $p\bar{p}$ decays are kinematically forbidden

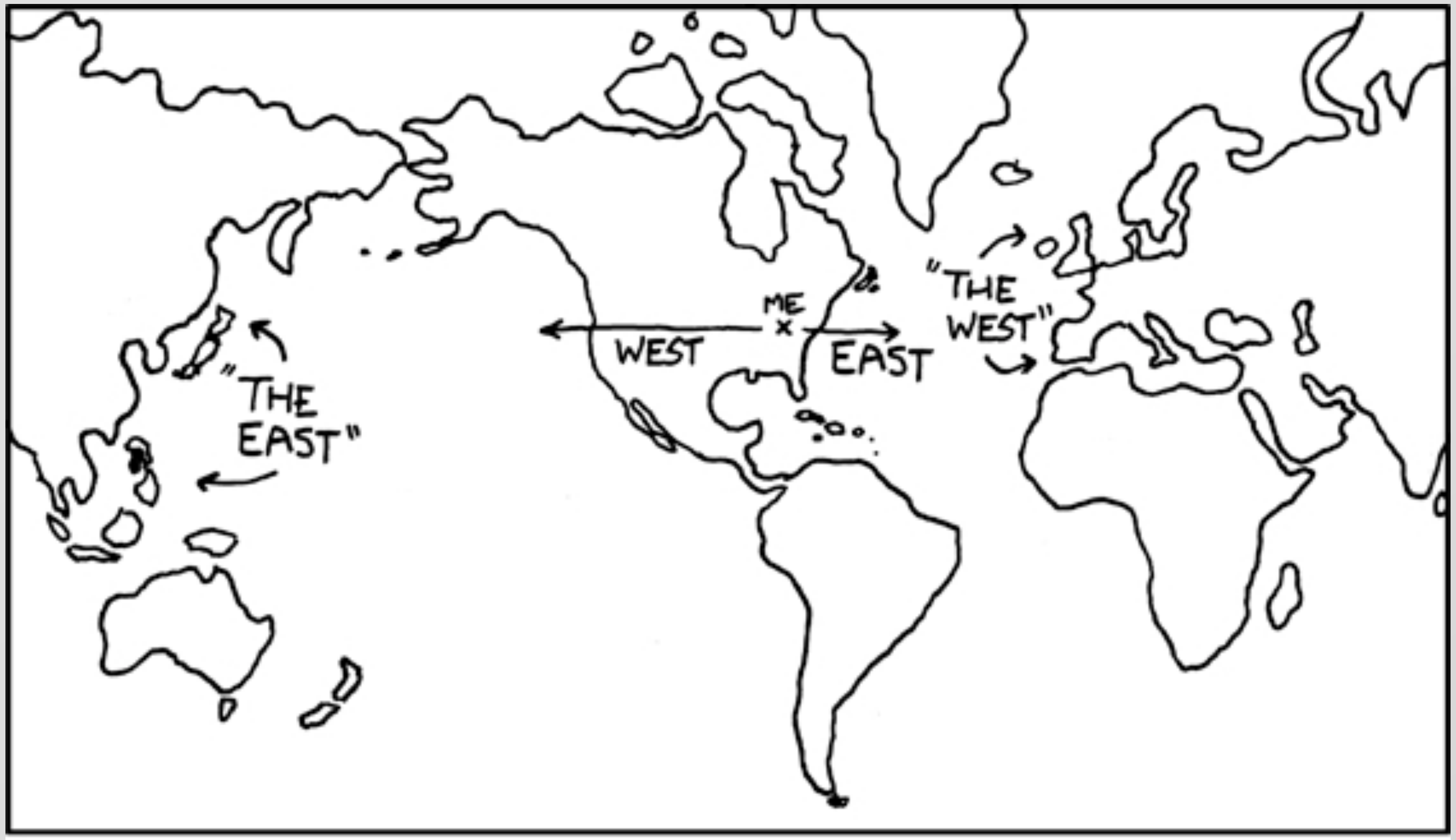


The idea of a dark sector has generated intense interest from both theory and experiment communities

Terminology break

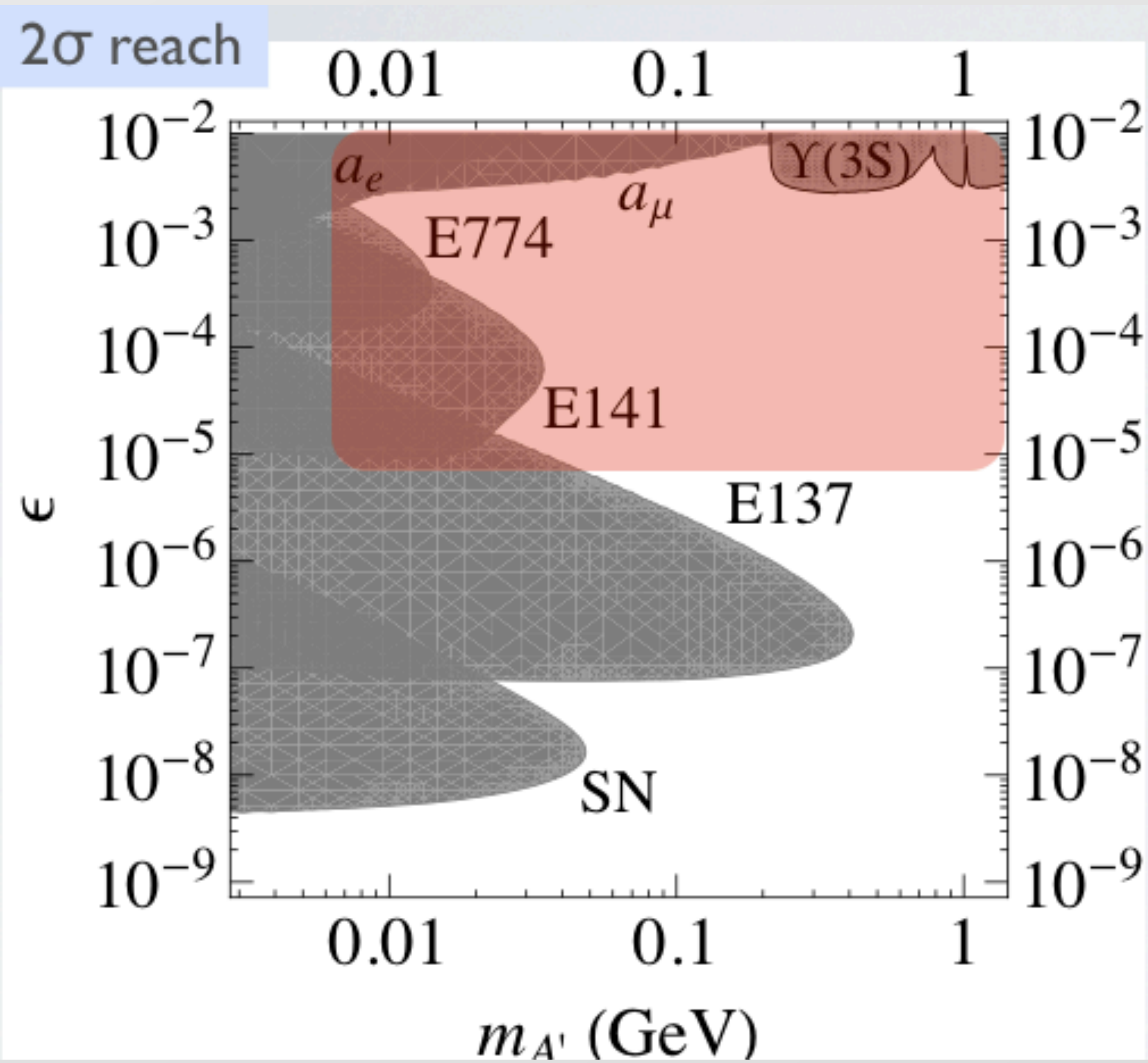
- The literature is infested with different terms for (basically) the same things...
  - dark sector=hidden sector=secluded sector
  - dark photon=hidden photon=heavy photon=A'=U-boson
  - $\varepsilon^2=\kappa^2=\alpha'/\alpha$

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



THIS ALWAYS BUGGED ME.

The coupling-mass sweet spot



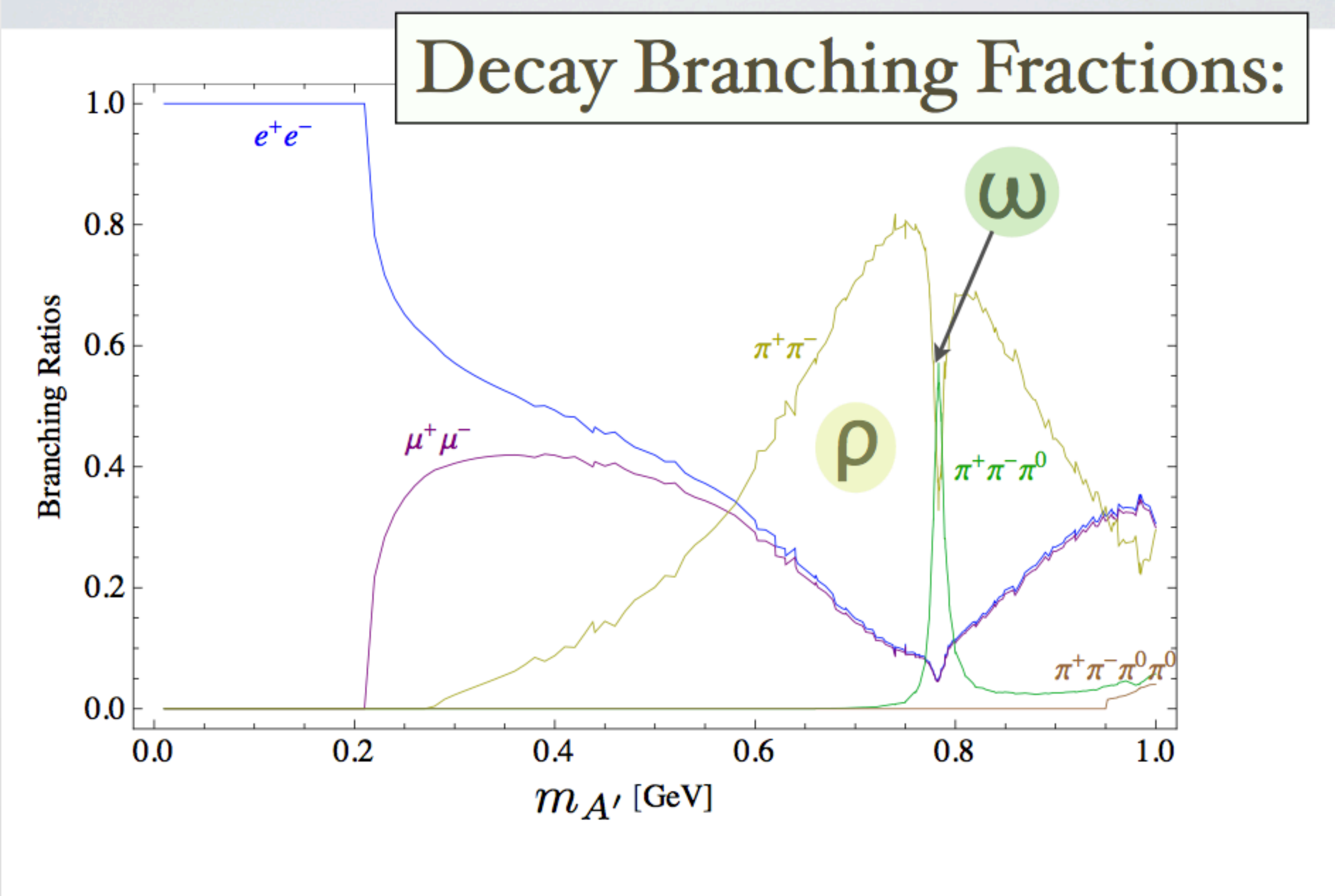
Both “naturalness” arguments and hints from experiments block out the same region in mass-coupling space:

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

m(A´) ~ MeV – GeV

Most of this region is unexplored!

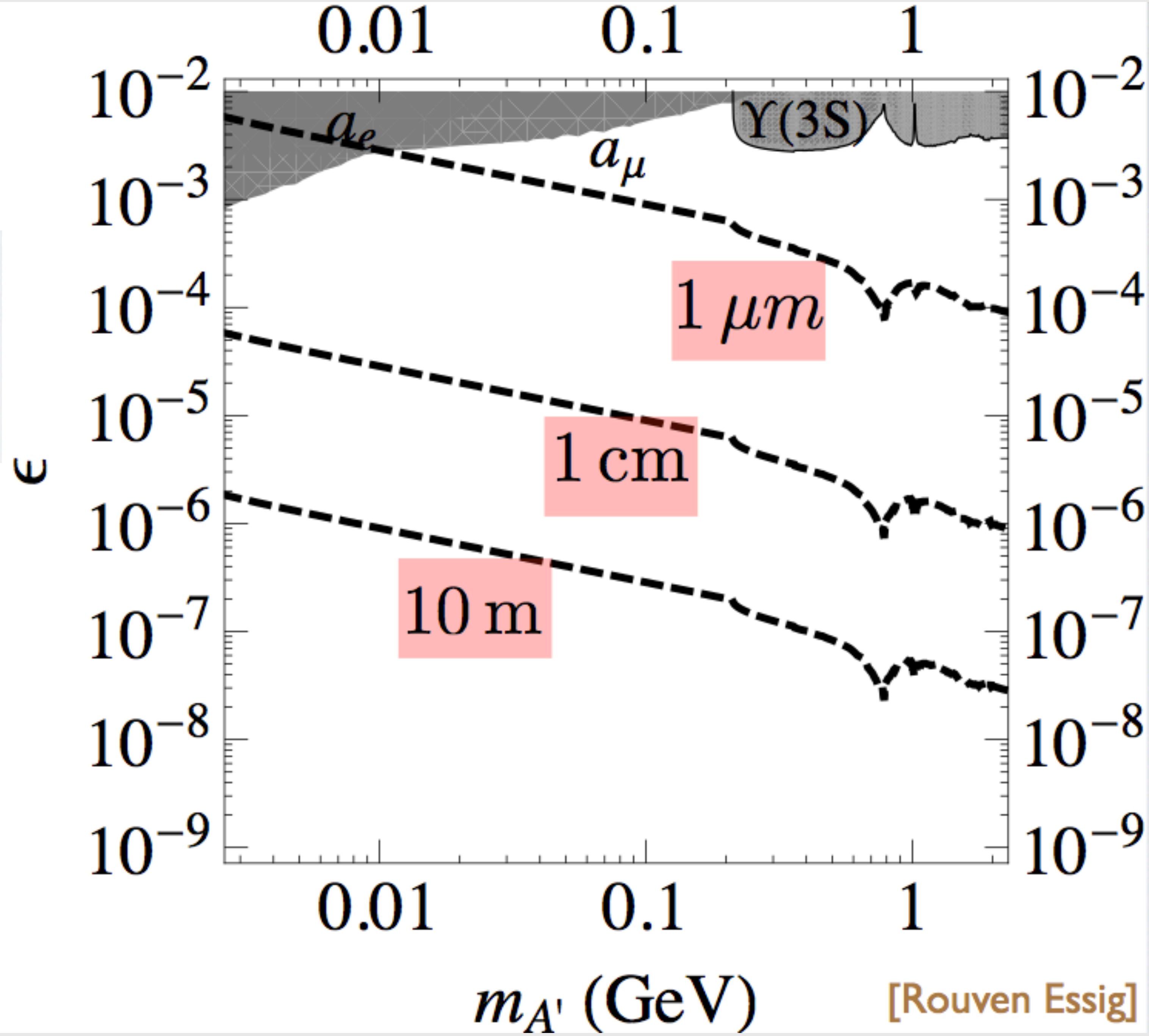
A′ decay products



A′ lifetime

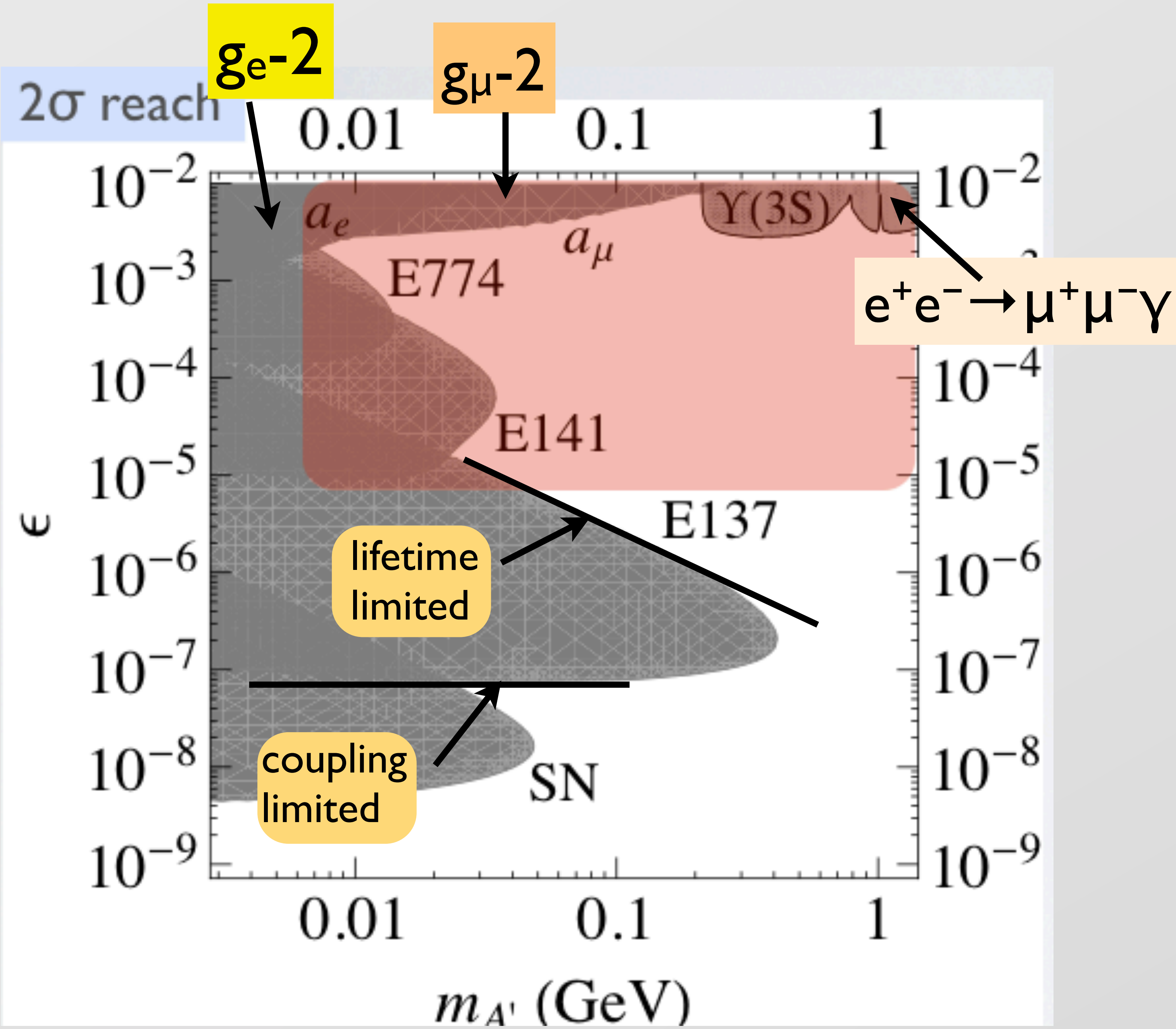
$$\gamma c\tau \propto \left(\frac{10^{-4}}{\epsilon}\right)^2 \left(\frac{100\ \mathrm{MeV}}{m_{A'}}\right)^2$$

lower ε, lower mass
→ longer lifetime



Monday, November 14, 2011

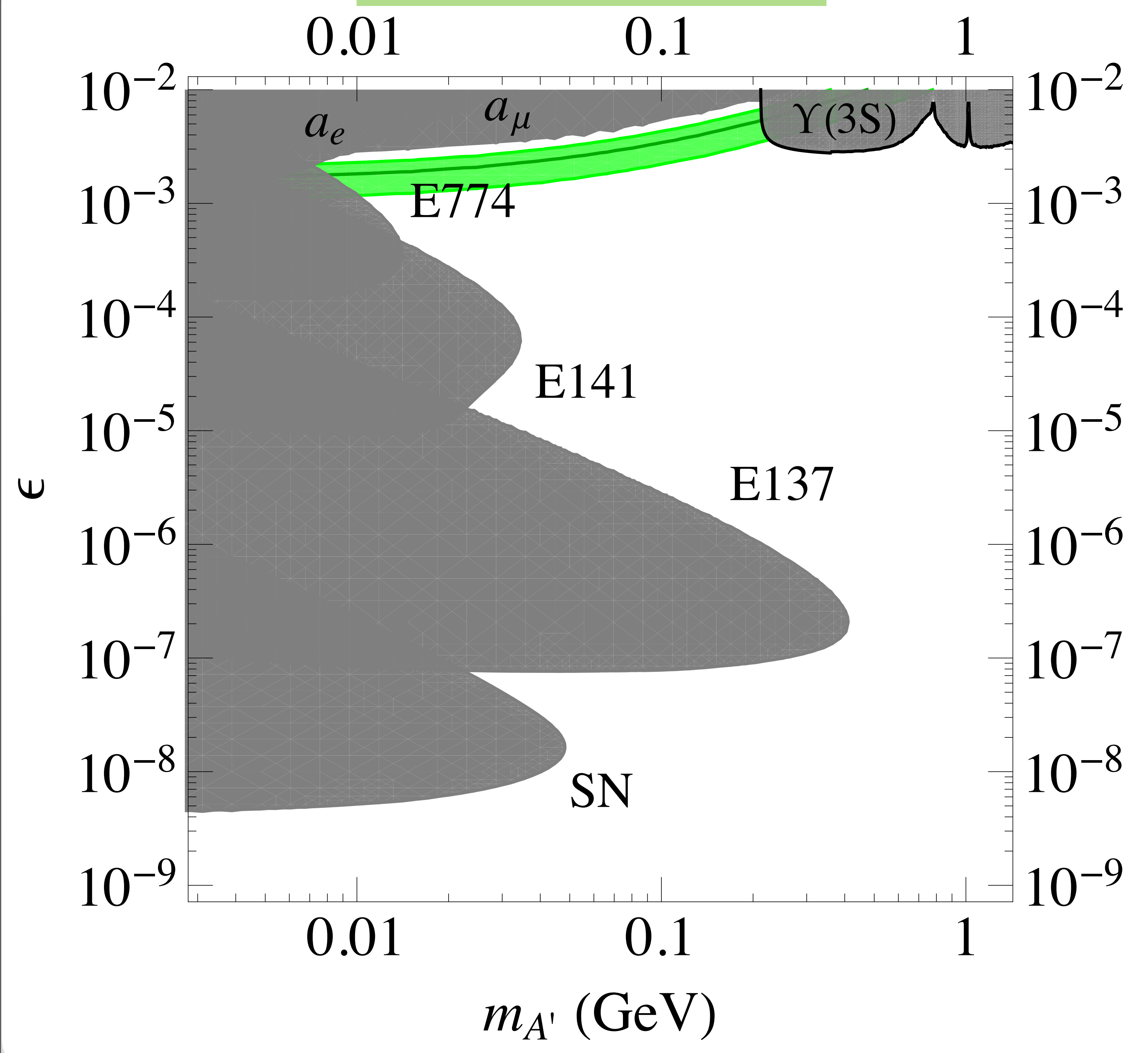
Some existing constraints



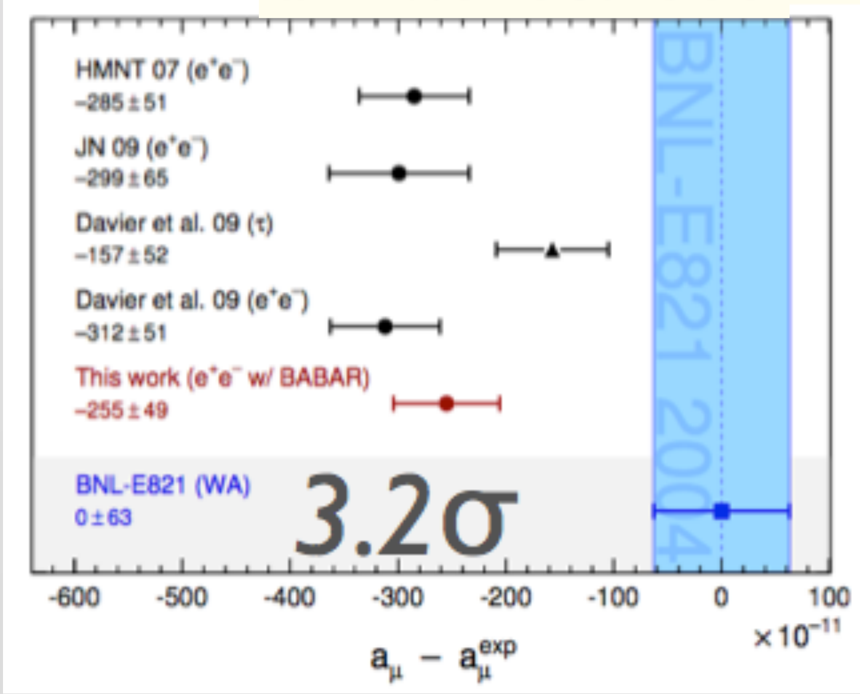
	Shield (m)	E_{beam} (GeV)	Lumi (e^-)
E137	200	20	10^{20}
E141	0.12	9	2×10^{15}
E774	0.3	27.5	5×10^{9}

Dark photons and the g-2 anomaly

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



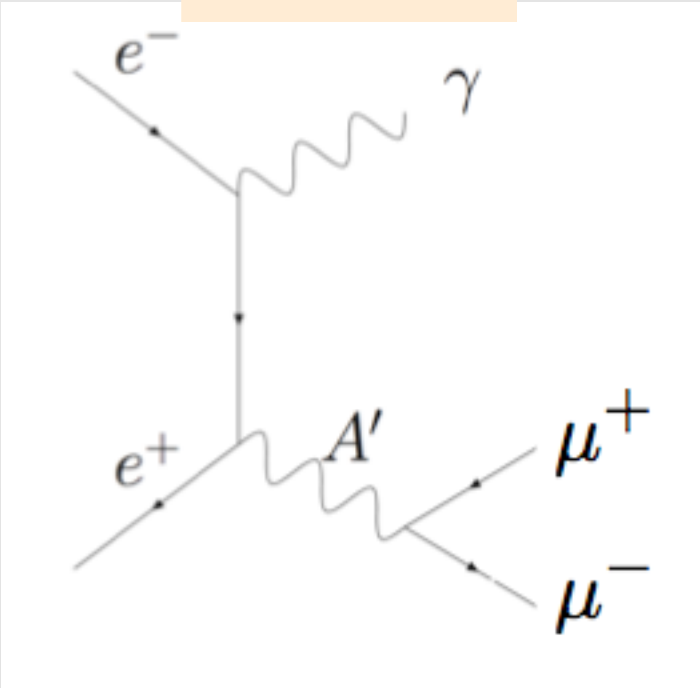
Davier *et al.*, arxiv:0908.4300



Collider vs. Fixed Target

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

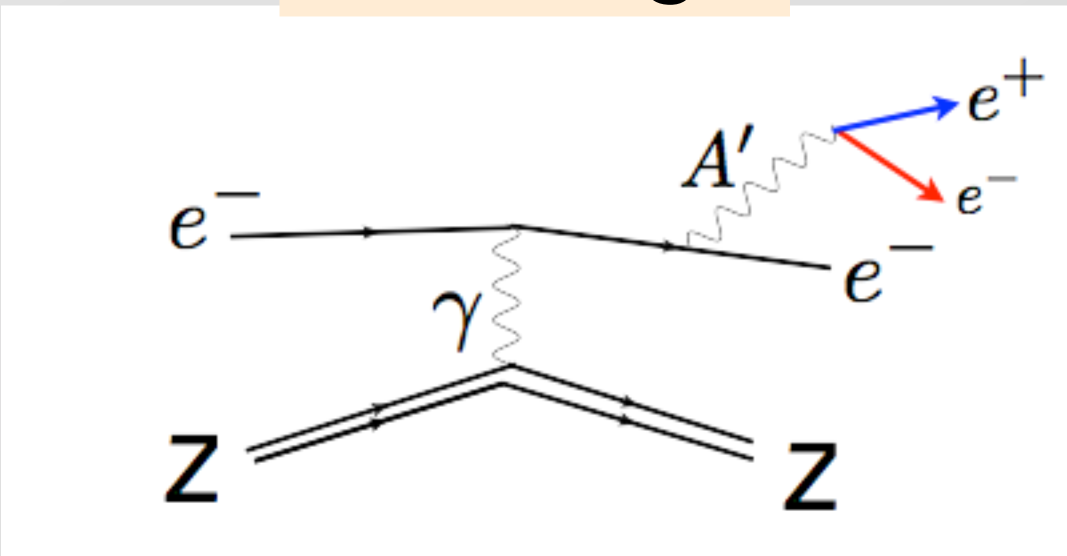
Collider



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

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

Fixed Target

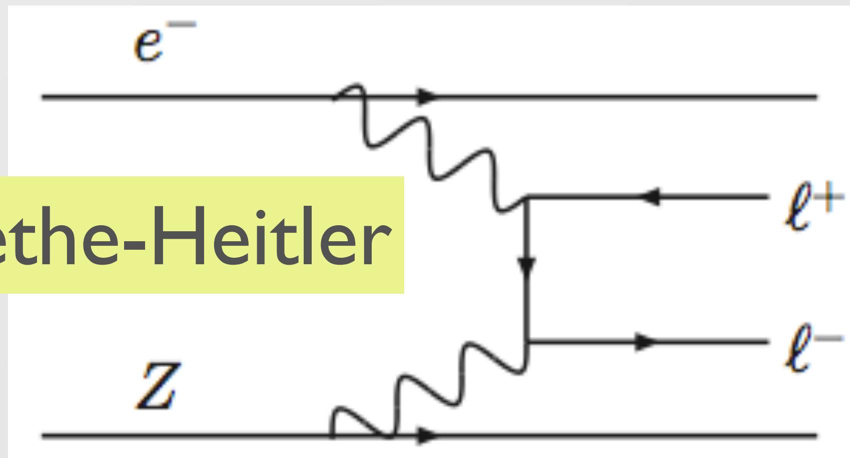


$$\sigma \sim \frac{\alpha^3 Z^2\epsilon^2}{m^2} \sim O(10\ pb)$$

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

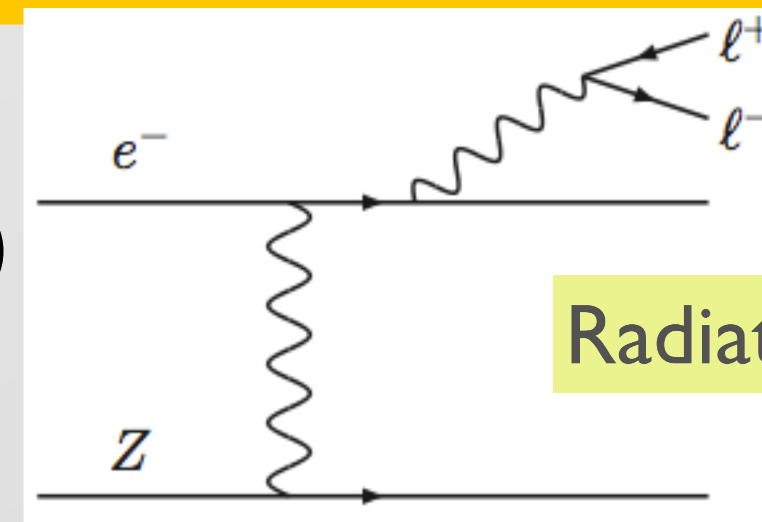
...much higher backgrounds

Backgrounds at fixed target experiments

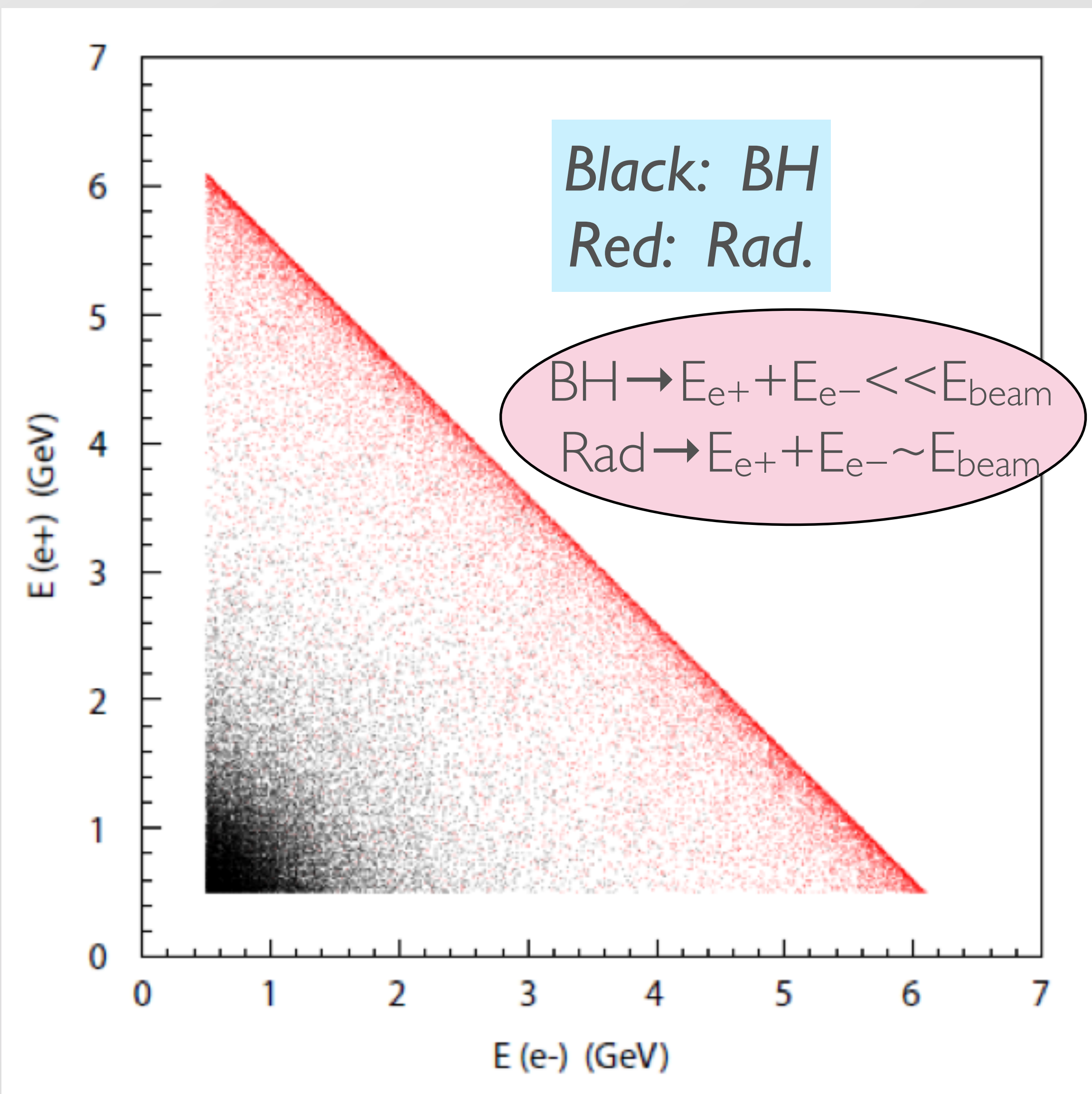


Bethe-Heitler

Two main backgrounds



Radiative



production rates of A' and radiative are related:

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

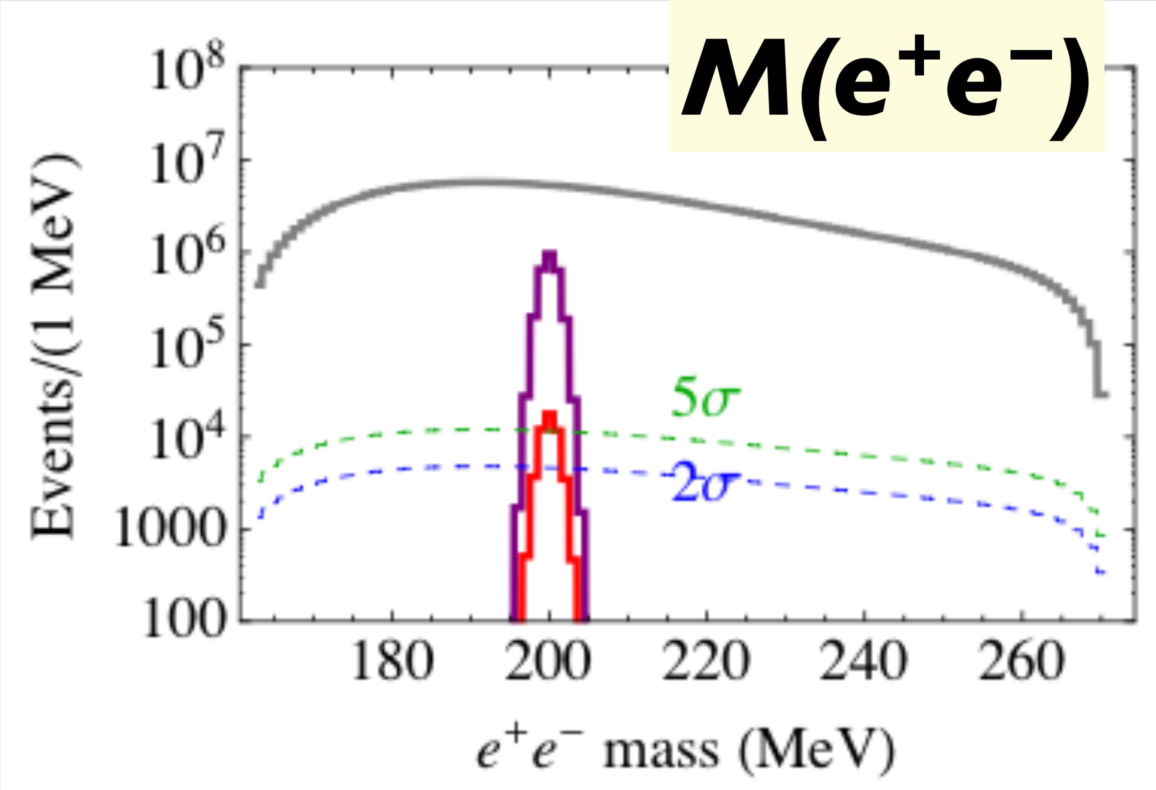
Cross-section for BH>>Radiative, but kinematics much different... Even after energy cut, BH background ~5x radiative

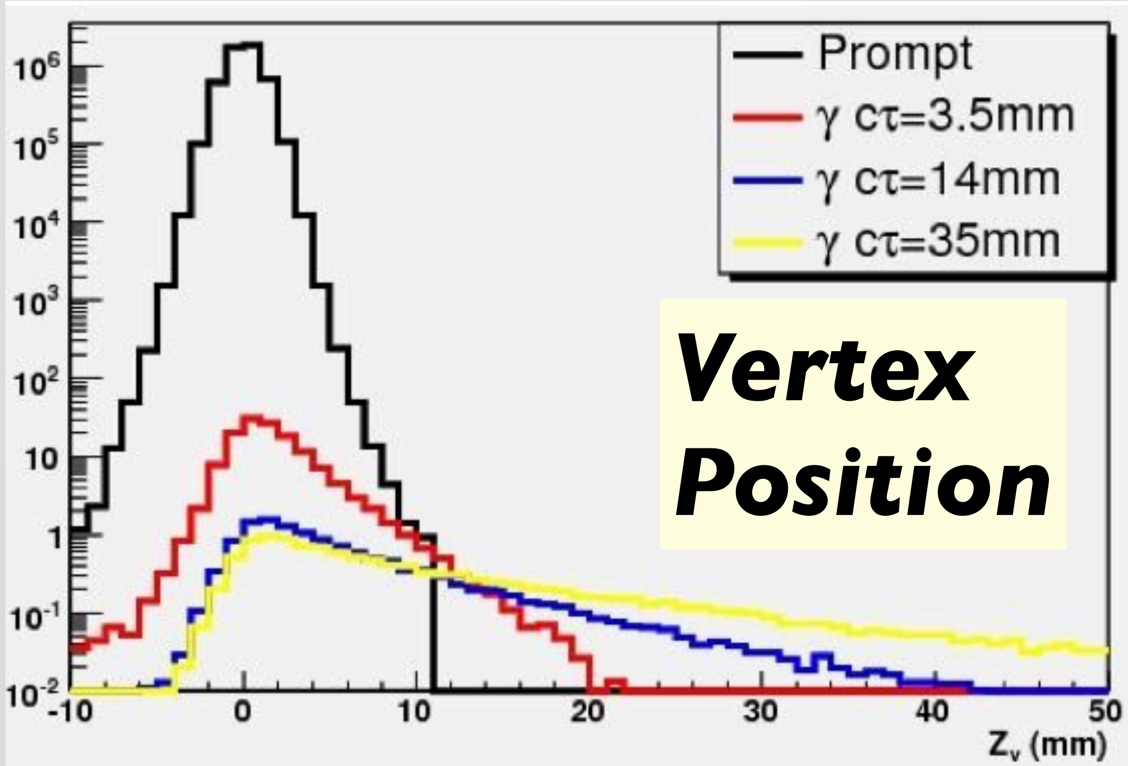
Radiative vs A' Events

Bethe-Heitler background is reducible but radiative is not...

Radiative events look exactly like A' events ***except***:

- Invariant mass of A' events peak at the A' mass
  - ➡ Bump-hunt
- In certain regions of parameter space, A' vertex is displaced
  - ➡ Bump-hunt+Lifetime search

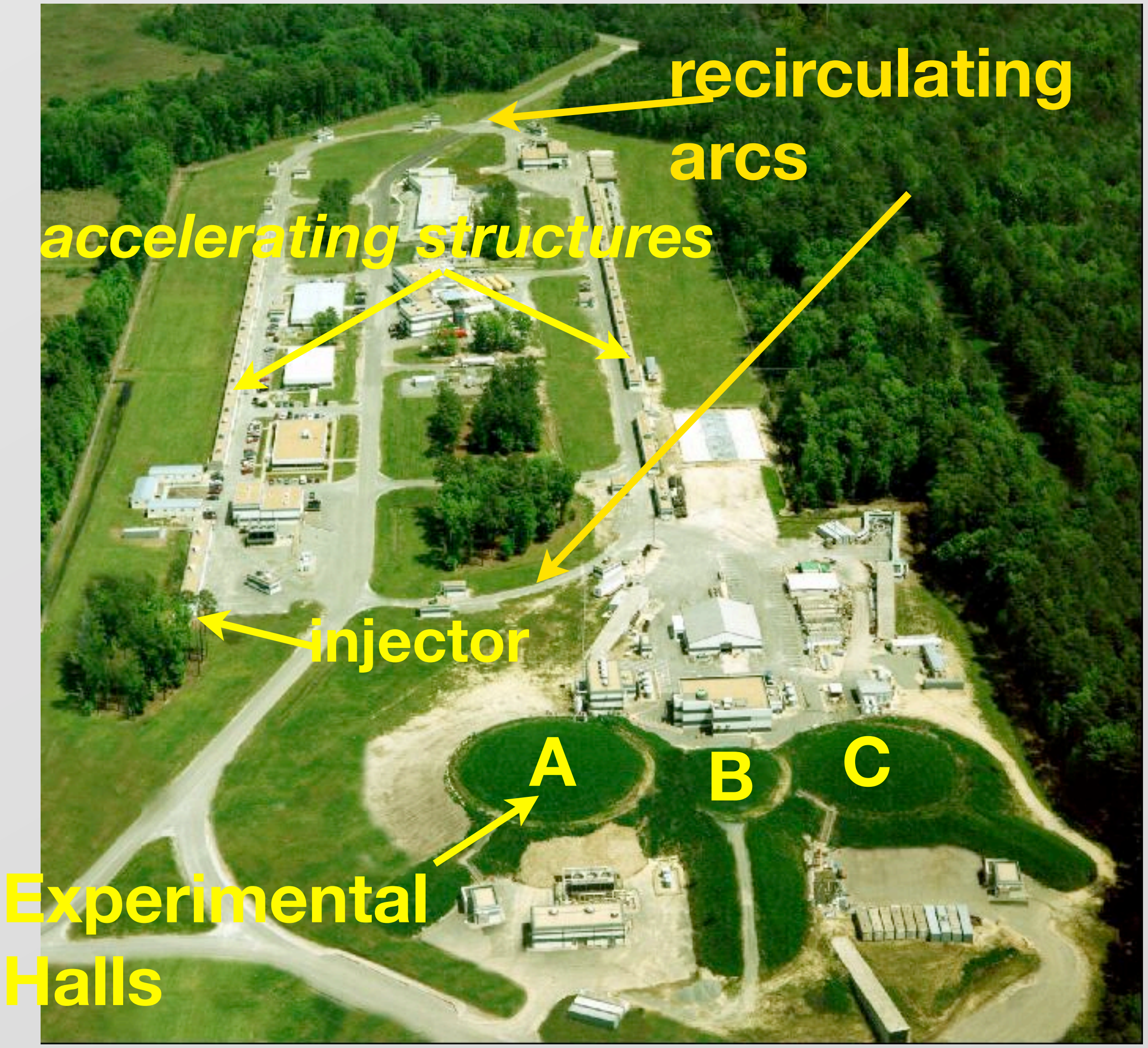




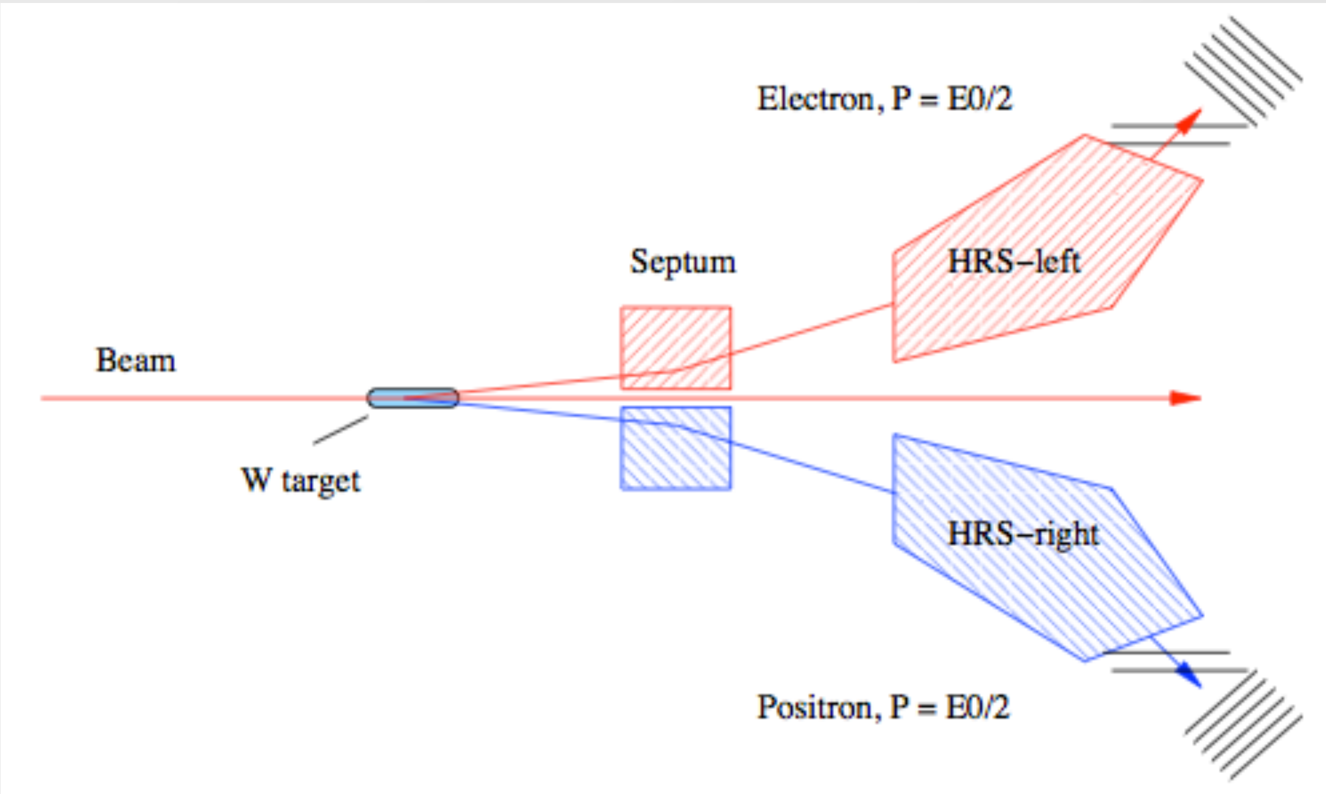
The CEBAF Accelerator

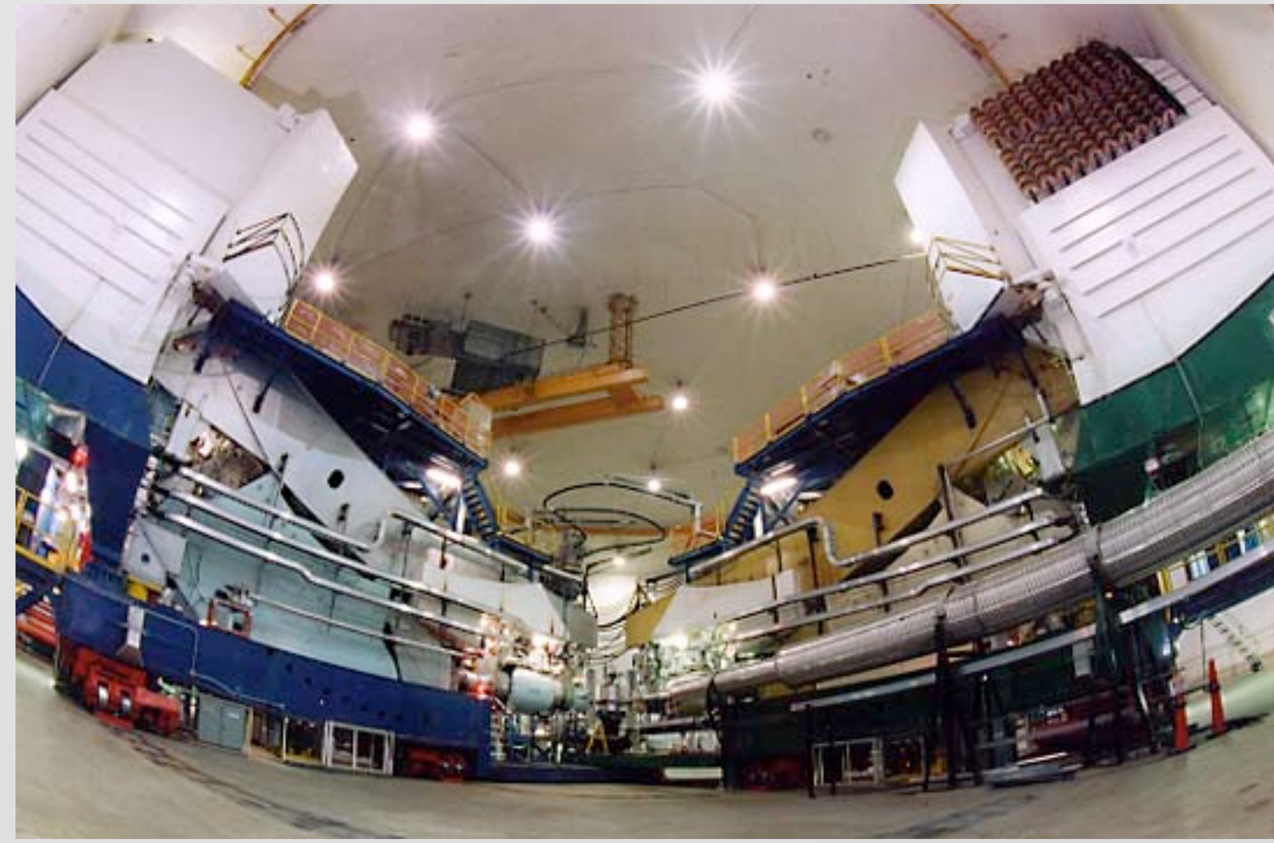
Simultaneous delivery of electron beams at different energies and intensities in three experimental halls.

- $E_{\mathrm{beam}} = n{\times}1.1$ GeV, n≤5 (5.5 GeV Max)
- $I_{\mathrm{beam}} < 200\ \mu\mathrm{A}$ (A&C), <700 nA (B)
- bunch separation: 2.004 ns
- energy upgrade complete 2014:
  $E_{\mathrm{beam}} = n{\times}2.2$ GeV, n≤5 (11 GeV max)



Hall-A overview



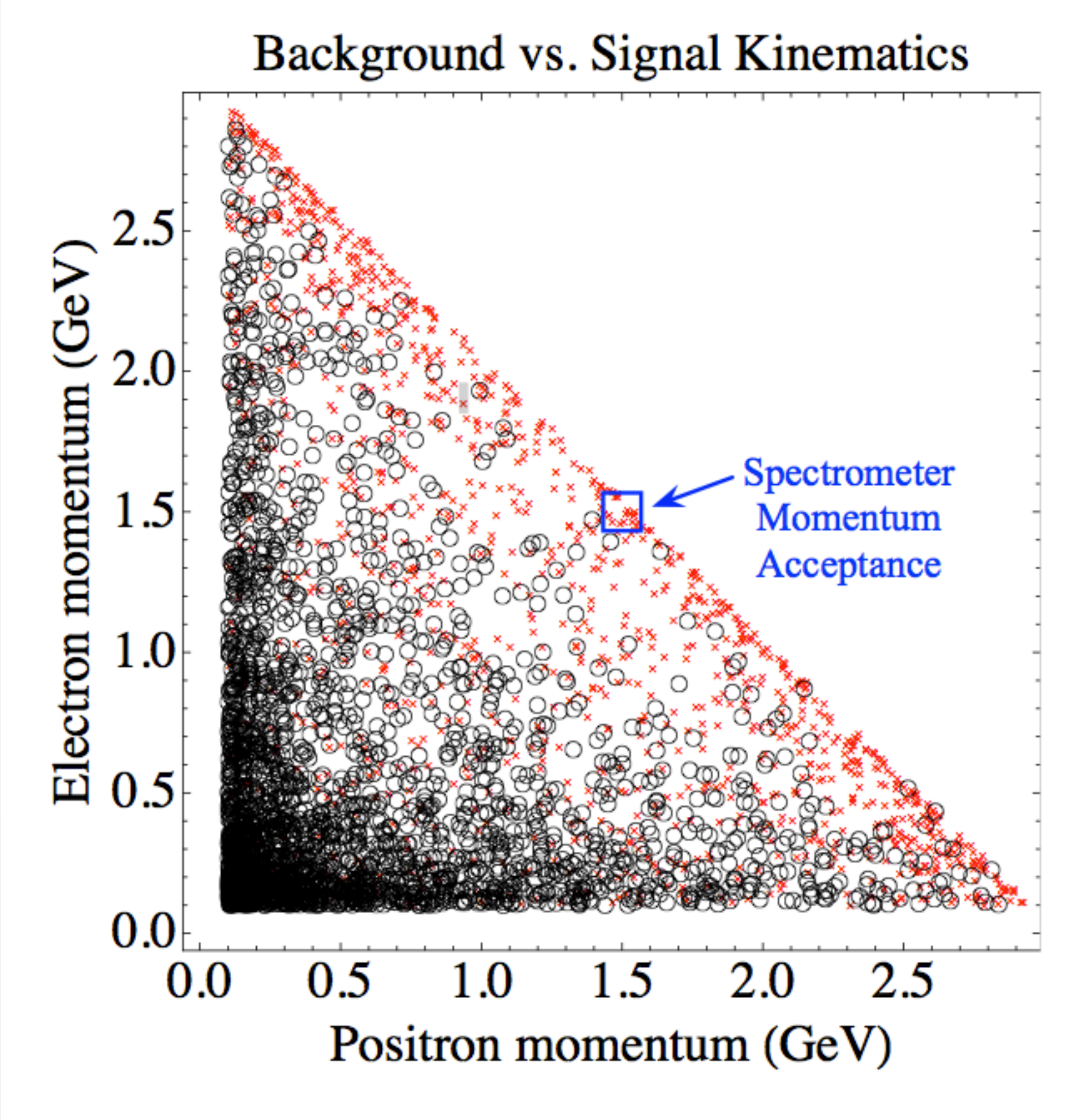


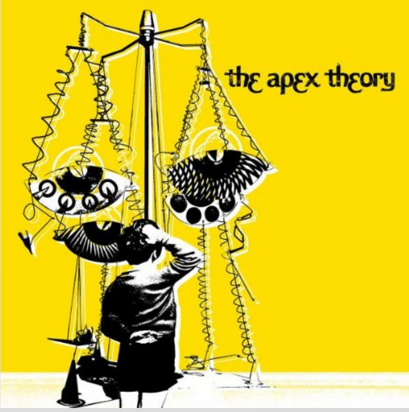
- High current → up to ~200μA
- Existing dual-armed spectrometer (HRS)
- Each arm is on a pivot and is independently adjustable from ~12° - 140°; Septum magnet lets us look at angles down to ~5°
- Excellent momentum/angular resolution → $\Delta p/p = \text{few} \times 10^{-4}$; $\Delta\theta \sim 1$ mrad
- Small acceptance → $-4.5\% < \delta p/p < +4.5\%$; $\delta\theta_x \sim \pm 30$ mrad; $\delta\theta_y \sim \pm 60$ mrad

APEX Overview

- Kinematics of signal and background dictate we use the spectrometer in forward and symmetric configuration
  - Total A′ acceptance ~0.1%

➡We need the high current × target thickness
  - HALL-A provides the current...
  - need target ~ X_0 ~ 5-10% but that doesn't ruin mass resolution





The APEX Collaboration

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

A Proposal to Jefferson Lab PAC37

J.D. Bjorken, **R. Essig (co-spokesperson)**
Theory Group, SLAC National Accelerator Laboratory, Menlo Park, CA 94025

P. Schuster (co-spokesperson), N. Toro (co-spokesperson)
Perimeter Institute, Canada

K. Allada, P. Bosted, J. Boyce, P. Brindza, A. Camsonne, E. Chudakov, M. Dalton, A. Deur, A. Gavalya, J. Gomez, C.W. de Jager, E. Folts, O. Hansen, D. W. Higinbotham, J.J. LeRose, D. Meekins, R. Michaels, S. Nanda, Y. Qiang, Y. Roblin, A. Saha, B. Sawatzky, J. Segal, S. Stepanyan,
B. Wojtsekhowski (co-spokesperson and contact)
J. Zhang
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606

C. Field, M. Graham, J. Jaros, T. Maruyama, J. McDonald, K. Moffeit, A. Odian, M. Oriunno, R. Partridge, D. Waltz
SLAC National Accelerator Laboratory, Menlo Park, CA 94025

J. Beacham, K. Cranmer
New York University, NY

S. Abrahamyan, S. Malyan, A. Shahinyan
Yerevan Physics Institute, Armenya

E. Aliotta, A. Barbieri, R. Lindgren, N. Liyanage, V. Nelyubin, B.E. Norum, S. Riordan, K. Saenboonruang
University of Virginia, Charlottesville, VA 22901

K. Aniol, S. Iqbal, D. J. Magaziotis
California State University, Los Angeles, CA 90032

J. Bono, P. Markowitz, V. Maxwell
Florida International University, Miami, FL 33199

A. Glamazdin
Kharkov Institute of Physics and Technology, Kharkov 310077, Ukraine

S. Gilad, J. Huang, A. Kelleher, V. Sulkovsky
Massachusets Institute of Technology, Cambridge, MA 02139

M. Khandaker, V. Punjabi
Norfolk State University, Norfolk, VA 23504

R. Gilman, G. Kumbartzki, R. Ransome, Y. Zhang
Rutgers, The State University of New Jersey, Piscataway, NJ 08854

S. Beck, O. Hen, I. Korover, E. Piasetzky, I. Pomerantz, R. Shneor
Tel Aviv University, Israel

D. Armstrong, T. Averett, E. Jensen, B. Zhao
College of William and Mary, Williamsburg, VA 23185

M. Mihovilovič, S. Širca
Jožef Stefan Institute and Dept. of Physics, University of Ljubljana, Slovenia

G. Ron
Lawrence Berkeley National Lab, Berkeley, CA 94720

A. Afanasev
Hampton University, VA

Z. Ahmed
Syracuse University, NY

D. Anez
Saint Martin's University, WA

K. Bartlett, J. Donaghy
University of New Hampshire, NH

N. Bubis
Technion, Israel

E. Long, L. Selvy
Kent State University, OH

J. Mammei
University of Massachusetts, MA

A. Gasparian
North Carolina Agricultural and Technical University, NC

N. Goeckner-Wald
Carnegie-Mellon, PA

T. Holmstrom
Longwood University, Farmville, VA 23909

B.E. Norum
University of Virginia, Charlotteville, VA

M. Paolone
South Carolina University, SC

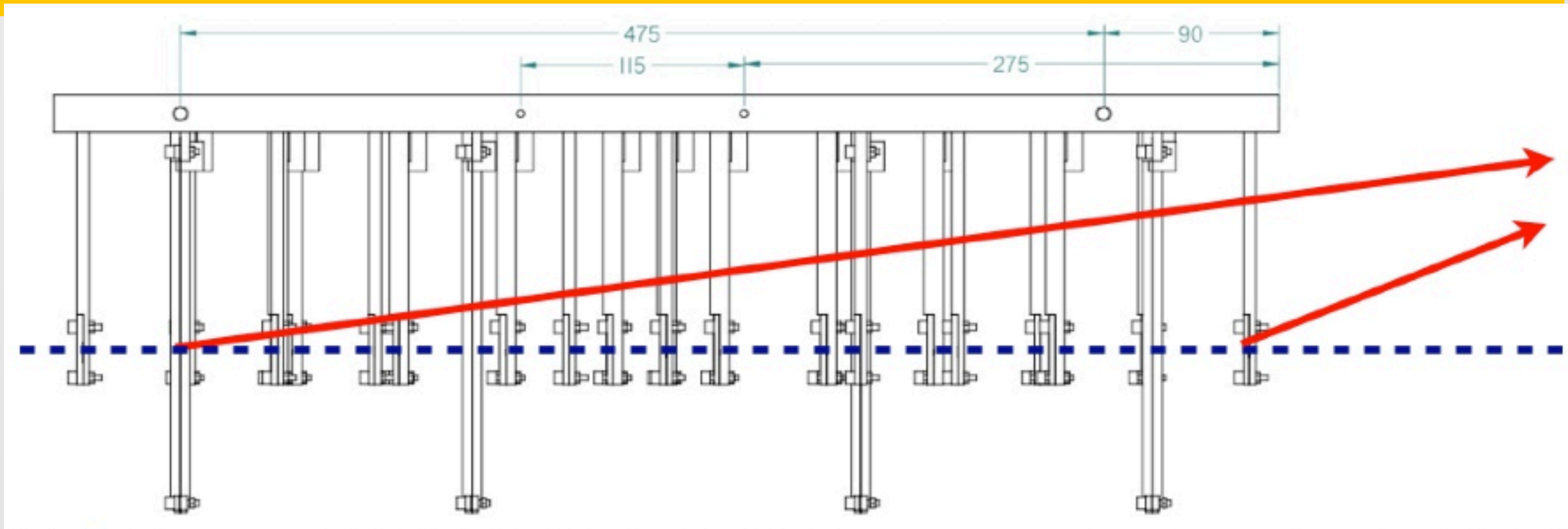
A. Puckett
Los Alamos, NM

R. Subedi
George Washington University, DC

L. Weinstein
Old Dominion University, Norfolk VA

The Hall A Collaboration

APEX Production Target



Production Target:

10 layers of 15μm (X_0=0.43%) W ribbon

→beam sees X_0=4.3%

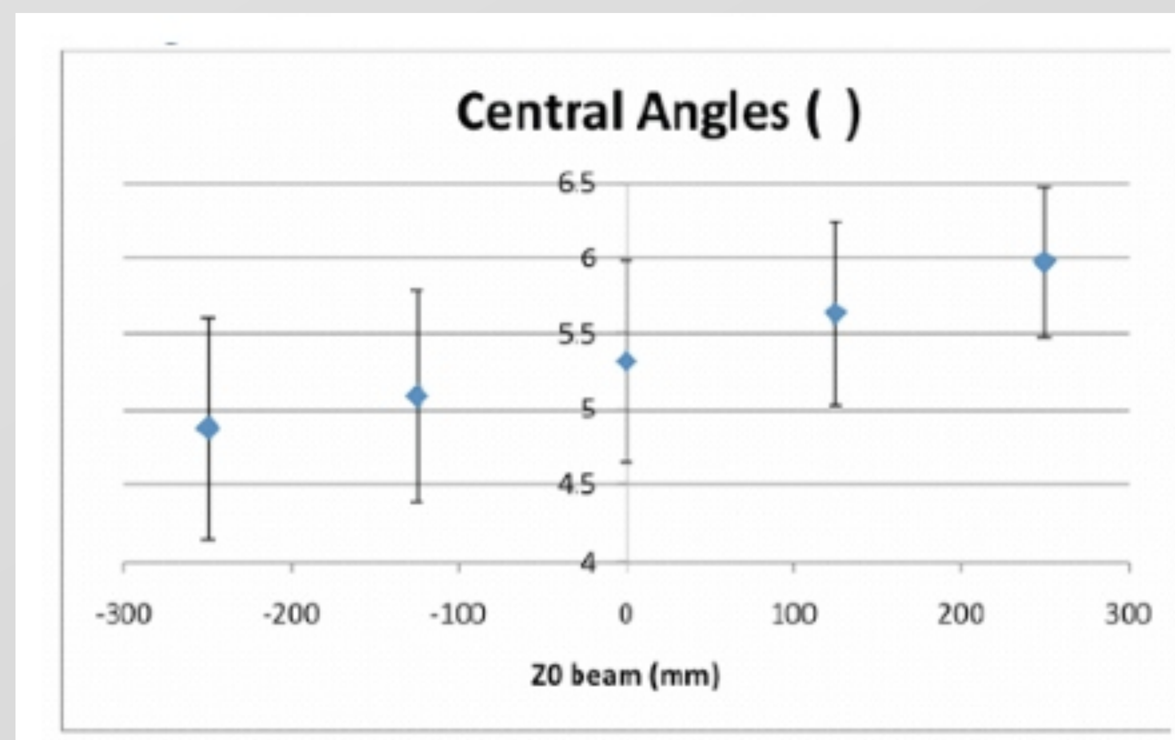
→we can get thicker ones

separated by 5.5cm each

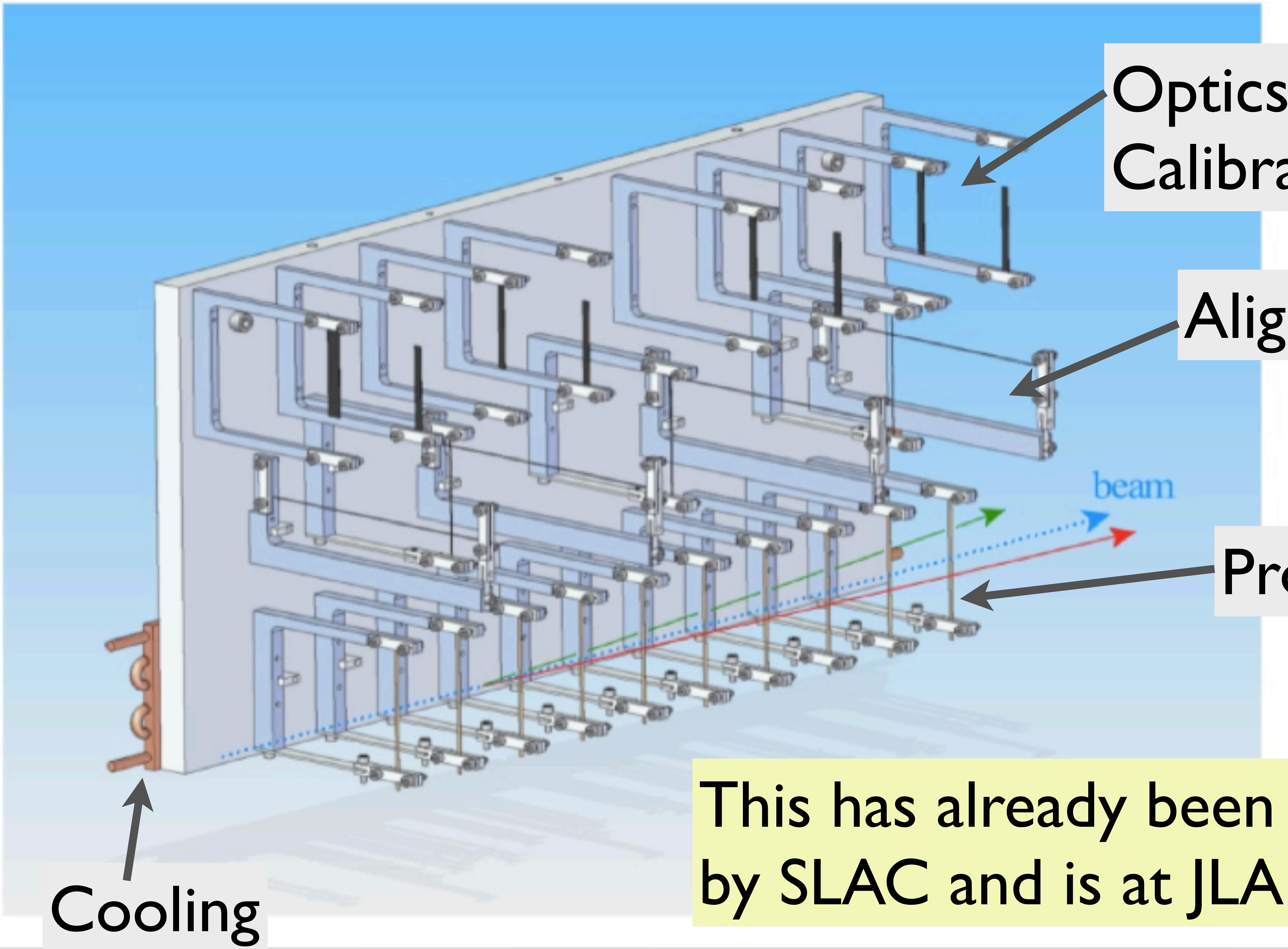
→outgoing e^+ & e^- miss subsequent layers...

→decay products see only 0.43% (max)

extended target also increases the momentum range in acceptance

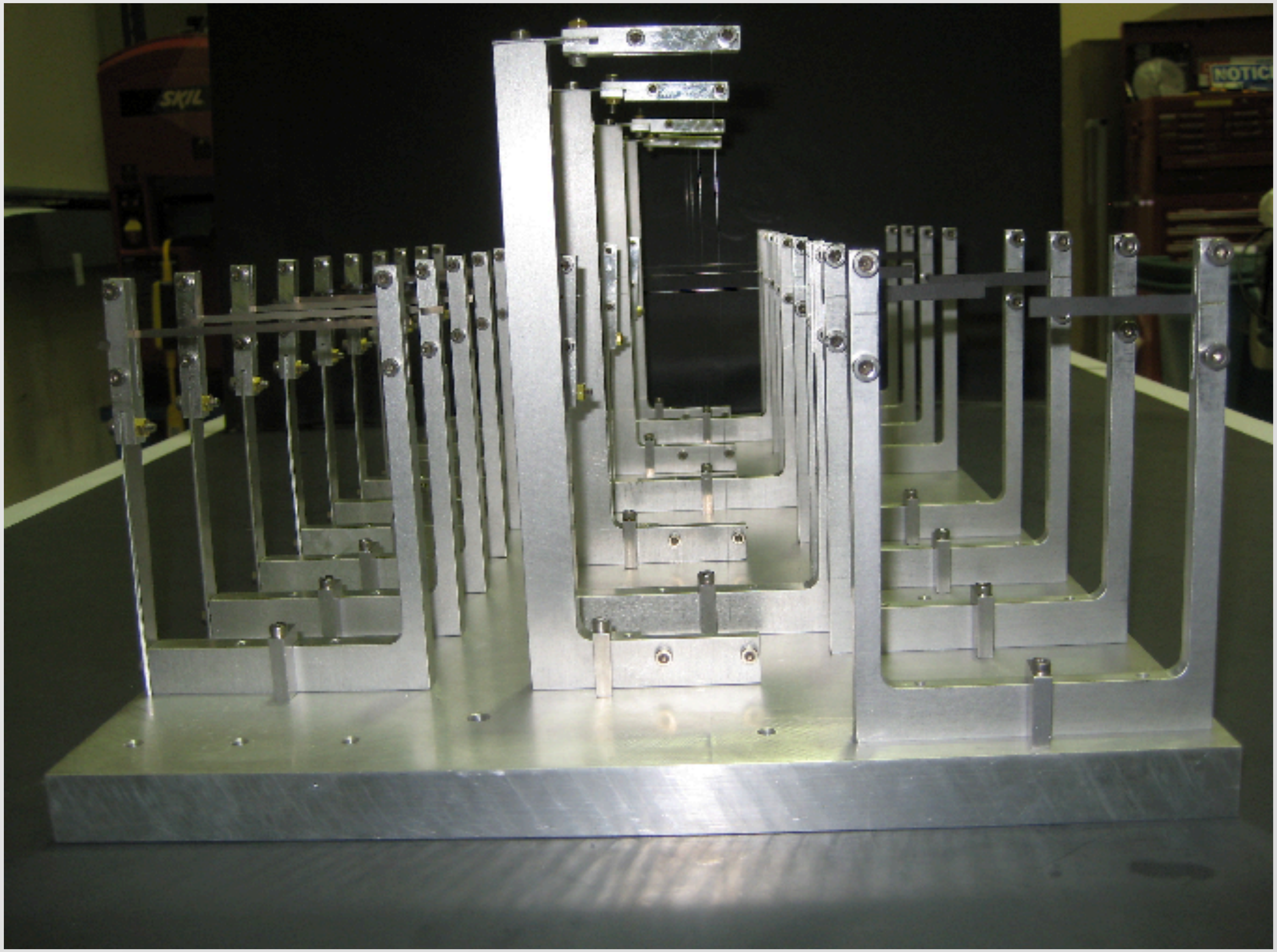


The APEX Target



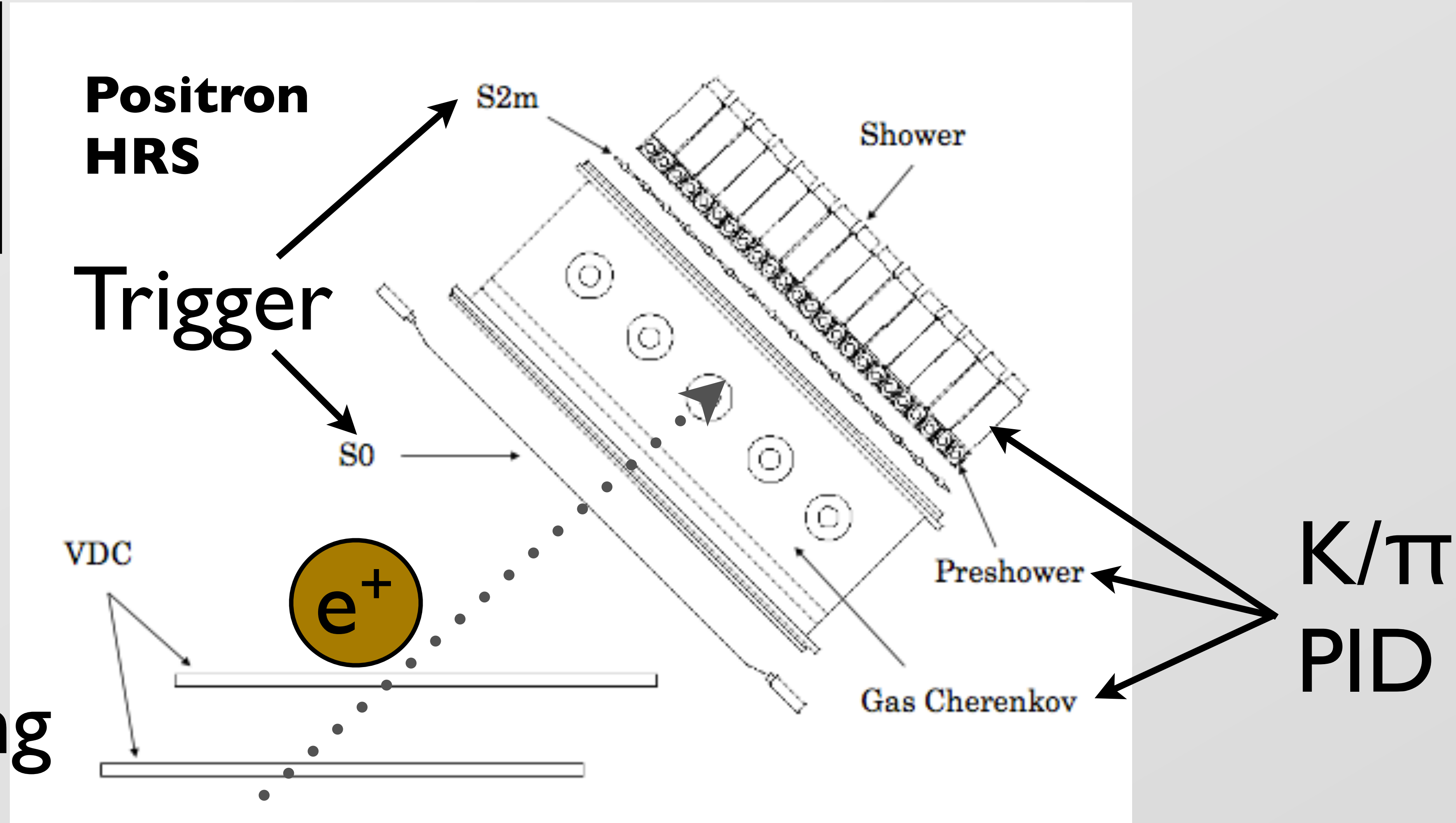
This has already been built by SLAC and is at JLAB

APEX Target in real life



the HRS Detectors

Electron HRS is similar
but without the
shower detector

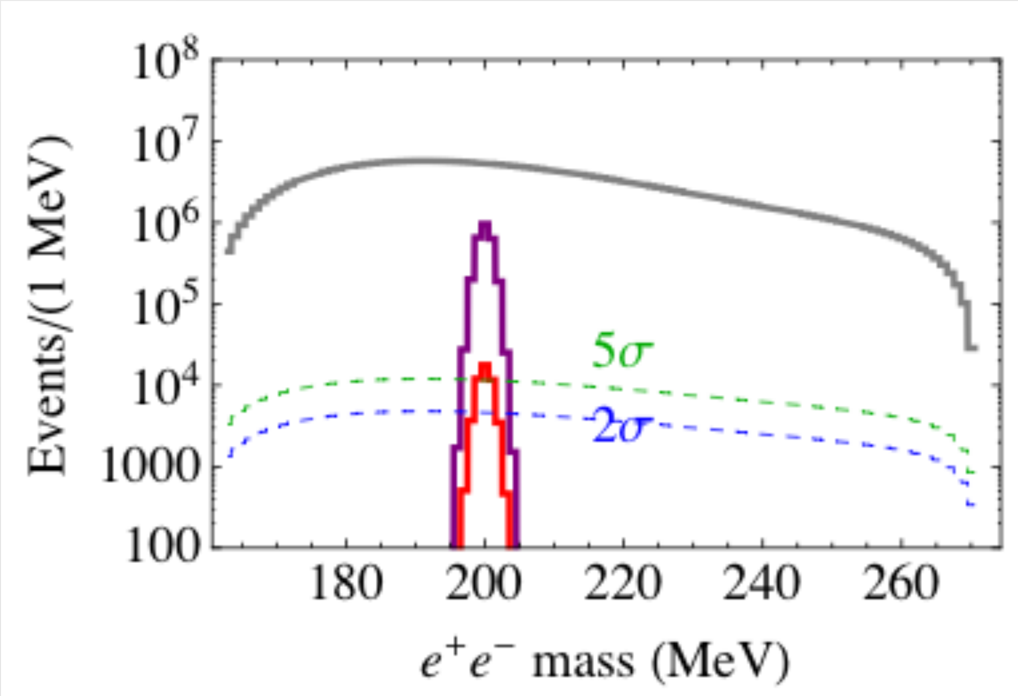


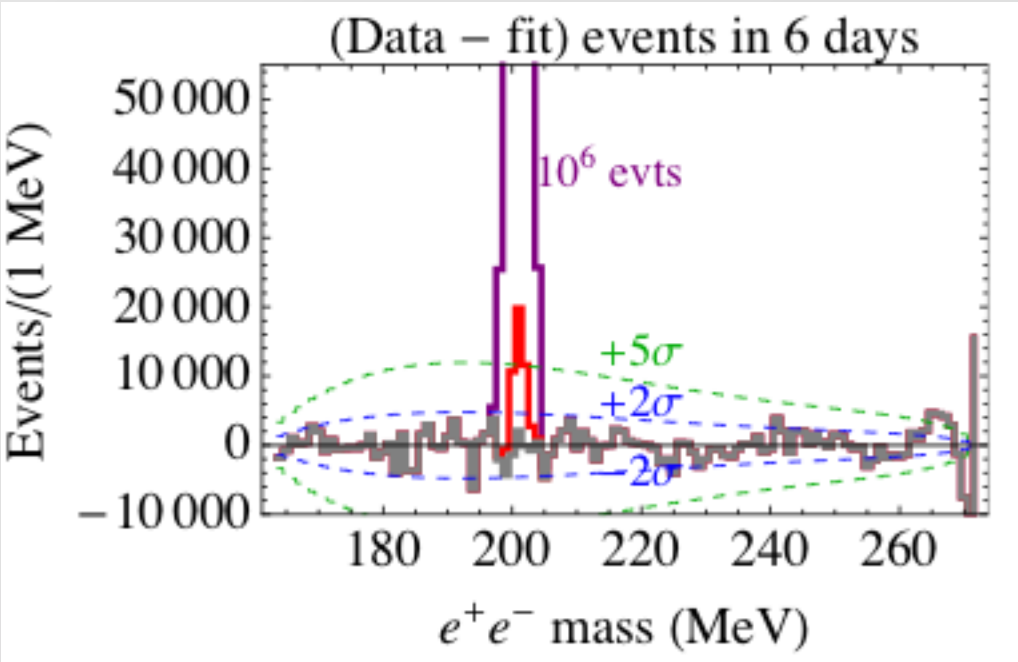
- Rate of tracks through electron arm ~ 5MHz
  - need a trigger timing resolution <20ns
- main trigger: coincidence of
  electron S2m ⊕ positron S2m ⊕ positron GC
- All detector components equipped with multi-hit TDCs

HRS in real life

APEX
Newport News

APEX Bump hunt





~5×10^{-4} ~negligible

$$\left(\frac{\delta_m}{m}\right)^2 = \left(\frac{\delta_p}{p}\right)^2 + 0.5 \times \left(\frac{\delta_\theta}{\theta}\right)^2$$

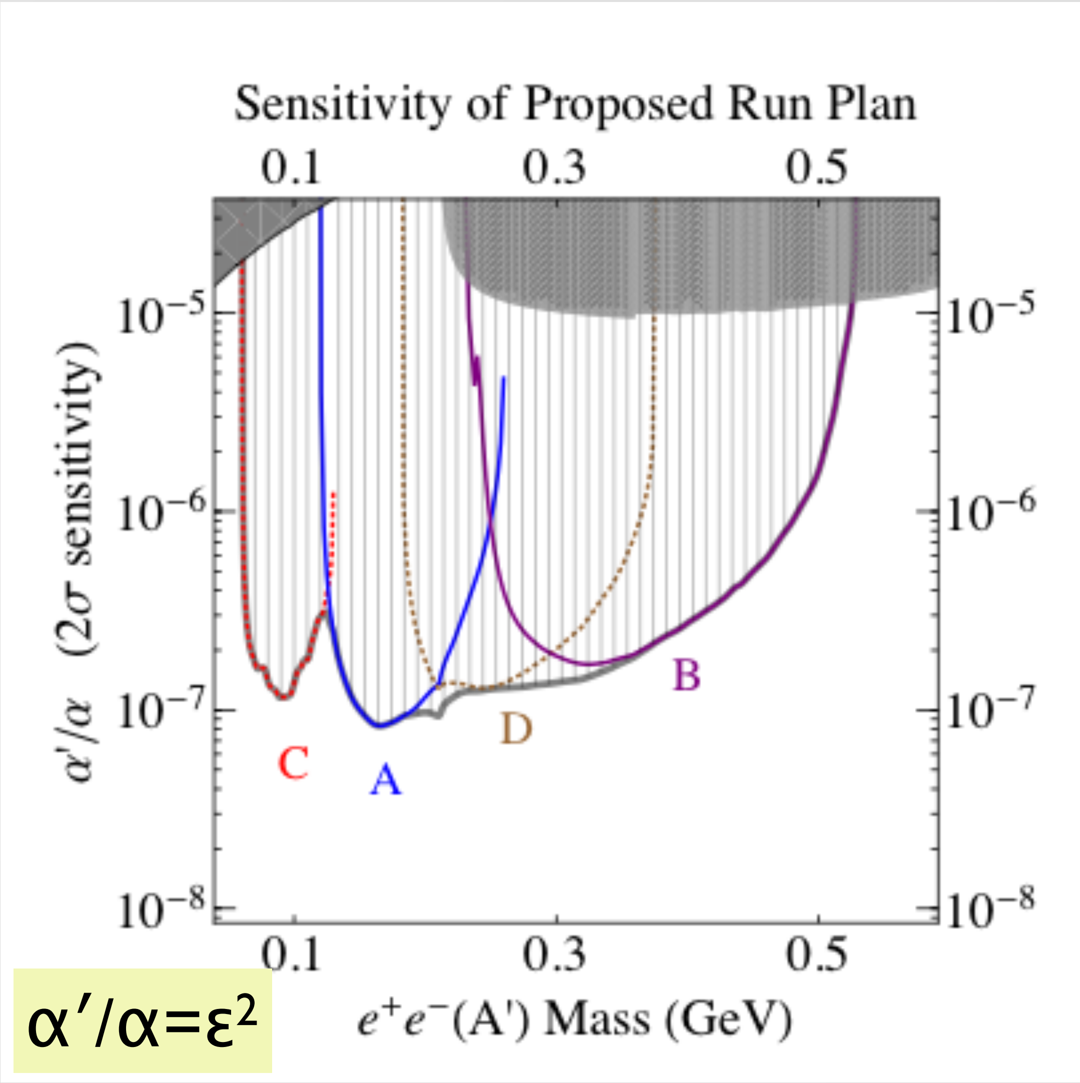
$$(\delta_\theta)^2 = (\delta_{HRS})^2 + (\delta_\theta^{ms})^2$$

~0.5mrad ~0.4mrad

at typical angles/momenta,
δ ~ 1-2 MeV

APEX Run Plan & Reach

Settings	A	B	C	D
Beam energy (GeV)	2.2	4.4	1.1	3.3
Central angle	5.0°	5.0°	5.0°	5.0°
Effective angles	4.5–5.5	4.5–5.5	4.5–5.5	4.5–5.5
Target T/X_0 (ratio[a])	4%	8%	0.69% (1:3)	8%
Beam current (μA)	70	60	65	80
Central momentum (GeV)	1.095	2.189	0.545	1.634
Singles (negative polarity)				
e^- (MHz)	4.1	0.7	5.8	2.2
π^- (MHz)	0.1	1.7	0.03	0.9
Singles (positive polarity)				
$\pi+$ [p] (kHz)	90	1700	30	900
e^+ (kHz)	27	5	23	17
Trigger/DAQ:				
Trigger[b] (kHz)	3.0	3.1	3.15	3.3
Coincidence Backgrounds:				
Trident: $e^-Z \to e^-e^+e^-Z$ (Hz)	500	110	330	370
e^+e^- from real γ conversion (Hz)	30	16	4	45
Accidentals [c] (Hz)	55	30	70	40



Total beam time: ~34 days

Response to APEX Proposal

- APEX proposal submitted to JLAB in Dec. 2009 and was approved in Jan. 2009 conditional on answering a few questions, including:
  - Can we get the trigger timing resolution where we need it?
  - Does the PID system work adequately a these high singles rates? Can we use the GC to trigger (positron arm)?
  - What about the VDC?
  - How well do our background estimates compare to measurements?

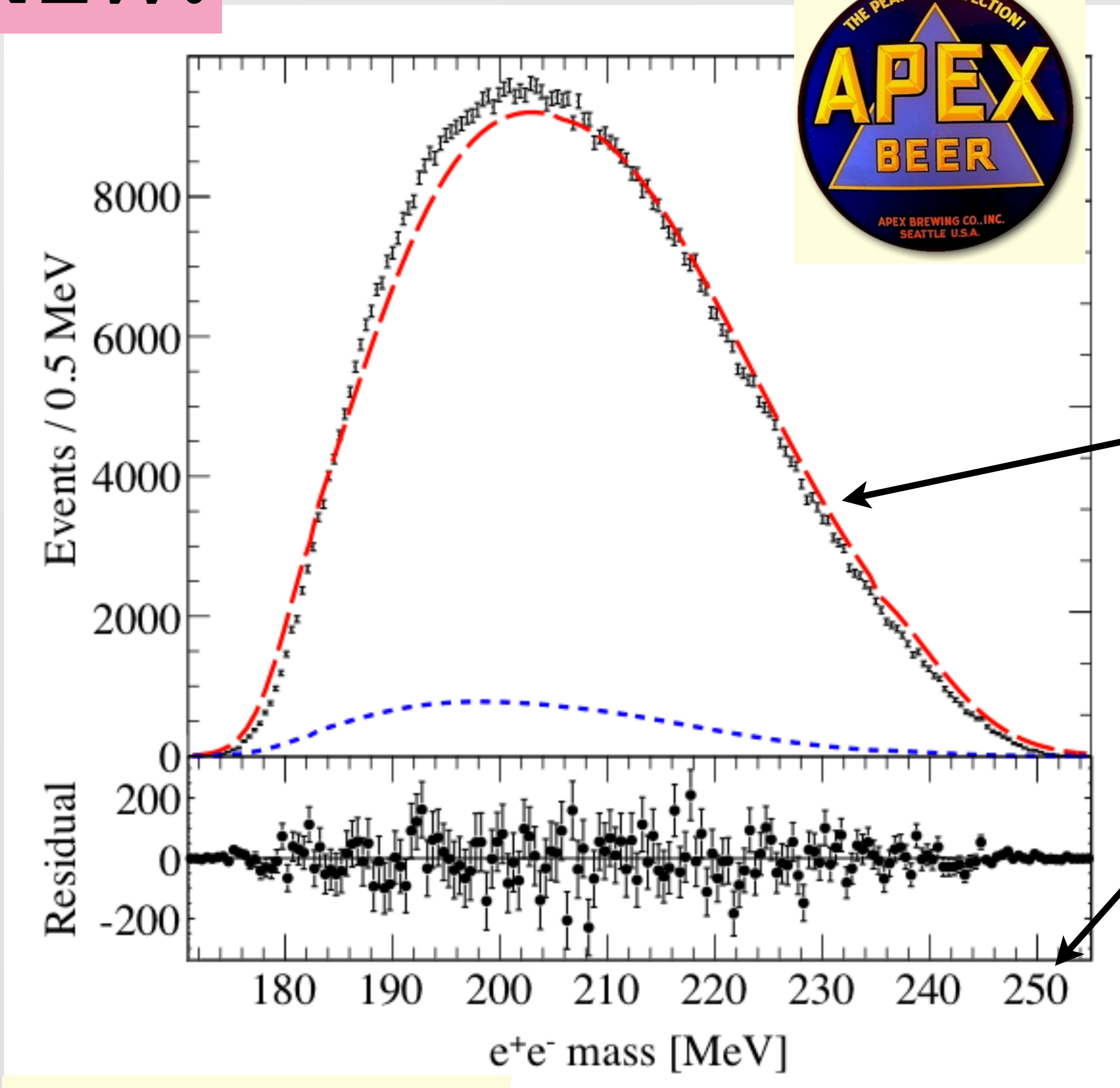
APEX was given a 2 week test run in June 2010...

The APEX Test Run

- APEX had the HALL A floor from June 20 to July 12 (after getting an extension)
- We had to put detector package together (previous experiment used minimum)
  - The checkout took ~1 week
- Had hoped to get the target in but target from previous too hot to handle

Test run results!

NEW!

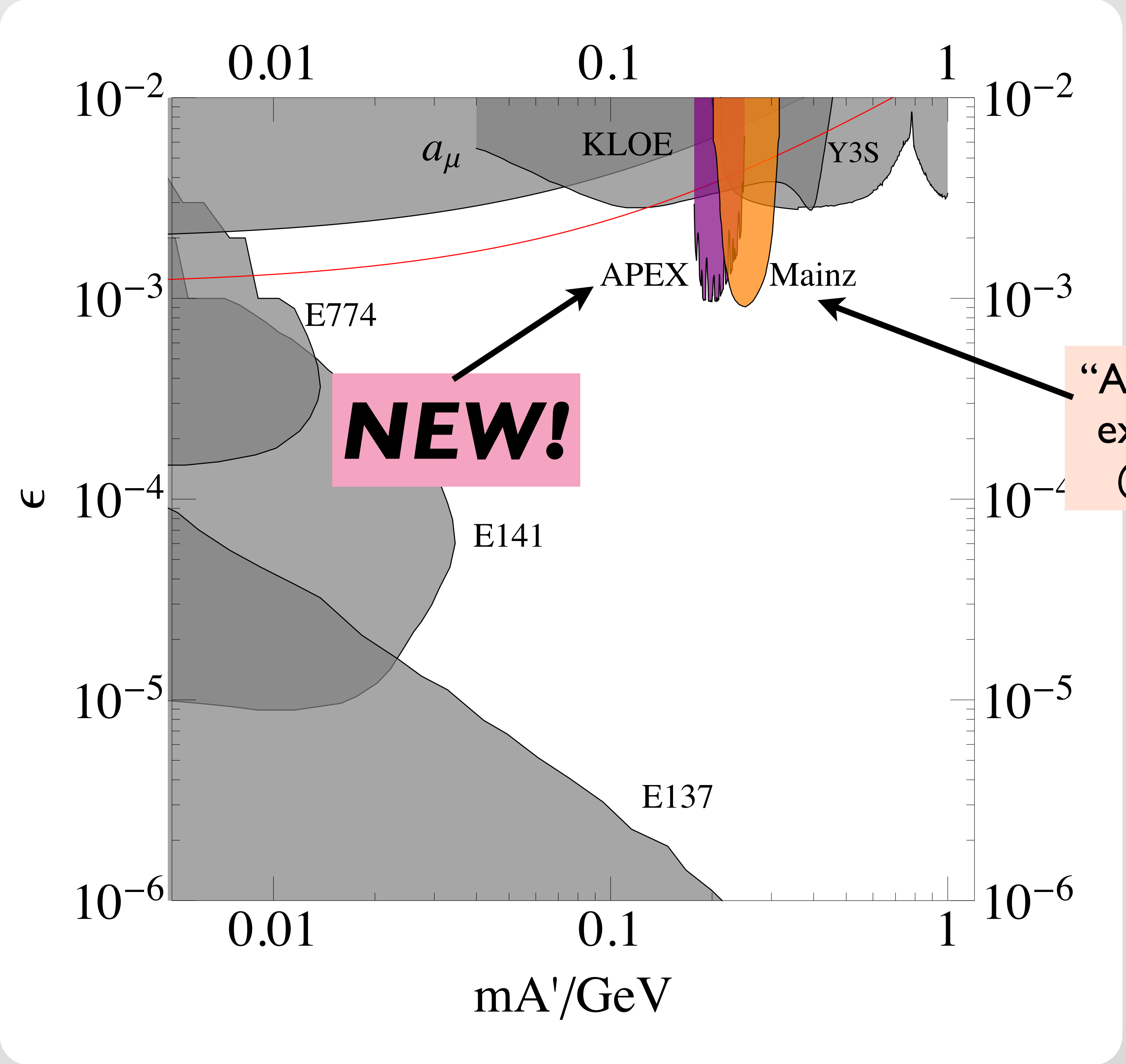


Phys.Rev.Lett.107:191804,2011.

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

small mass range...
reflects small acceptance.

APEX test run constraint



"APEX-style" experiment @ MAMI

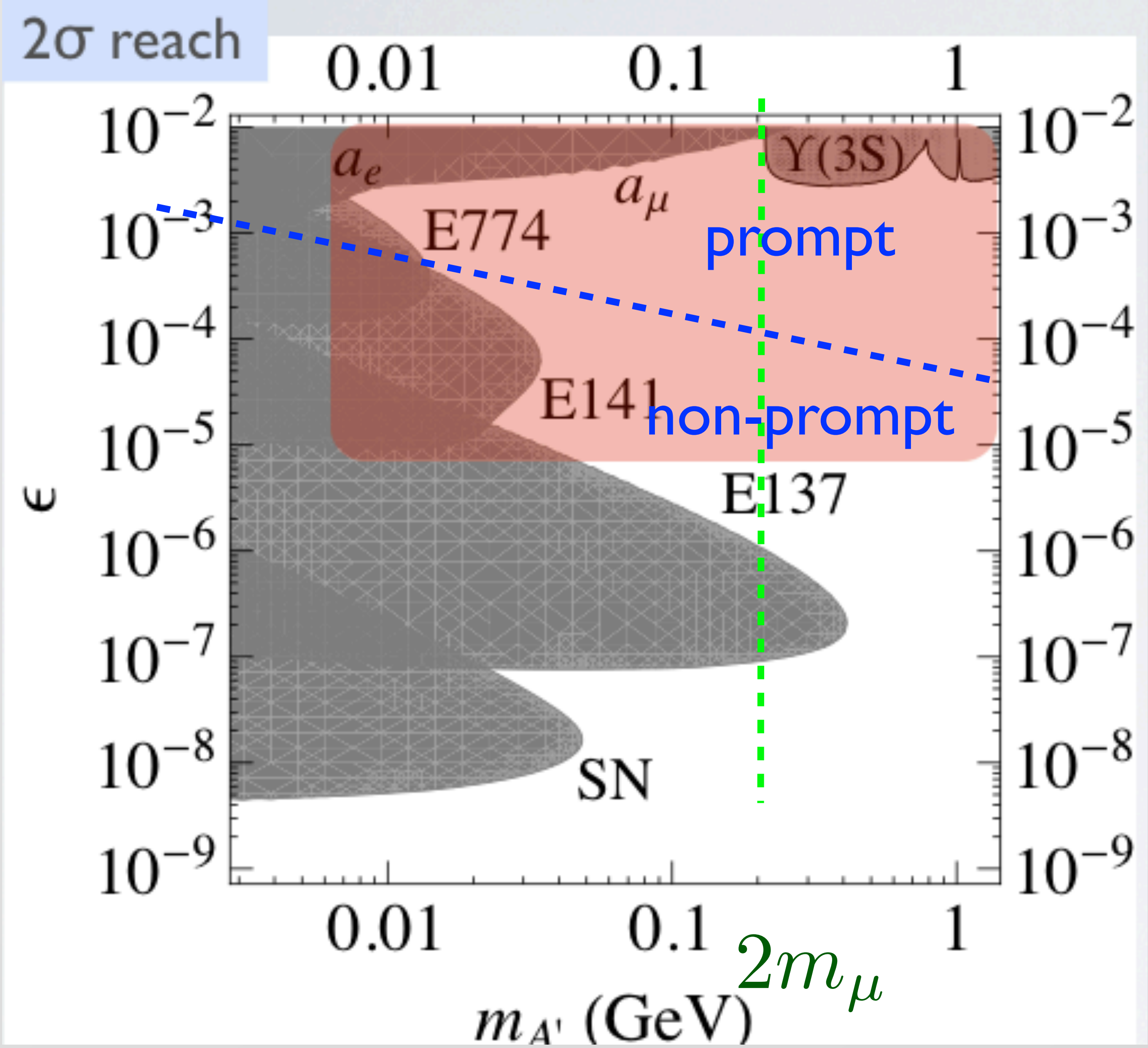
APEX: Where we are at

- We've answered all of the PAC's comments and resubmitted the proposal.
- Fully approved by the PAC in January
- Technically, this proposal was geared for the 12GeV era but we can be ready at very short notice...if there is a break in the current 6 GeV schedule we will jump at it.
- We hope, hope, hope that we can get on the floor again this winter (sounds like there is a chance)

HPS: A Dual Approach

HPS is designed to access the ε region ~$10^{-4} \rightarrow 10^{-5}$*** in the mass range 10MeV ~ 300 MeV...in this region of parameter space, vertices are displaced ~few mm→few cm...

To do this we need:
→Good mass resolution
→Good vertex resolution



***We get reach for ε>$10^{-3.5}$ in this mass region for free!

The 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, E. Ebrahim
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, 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

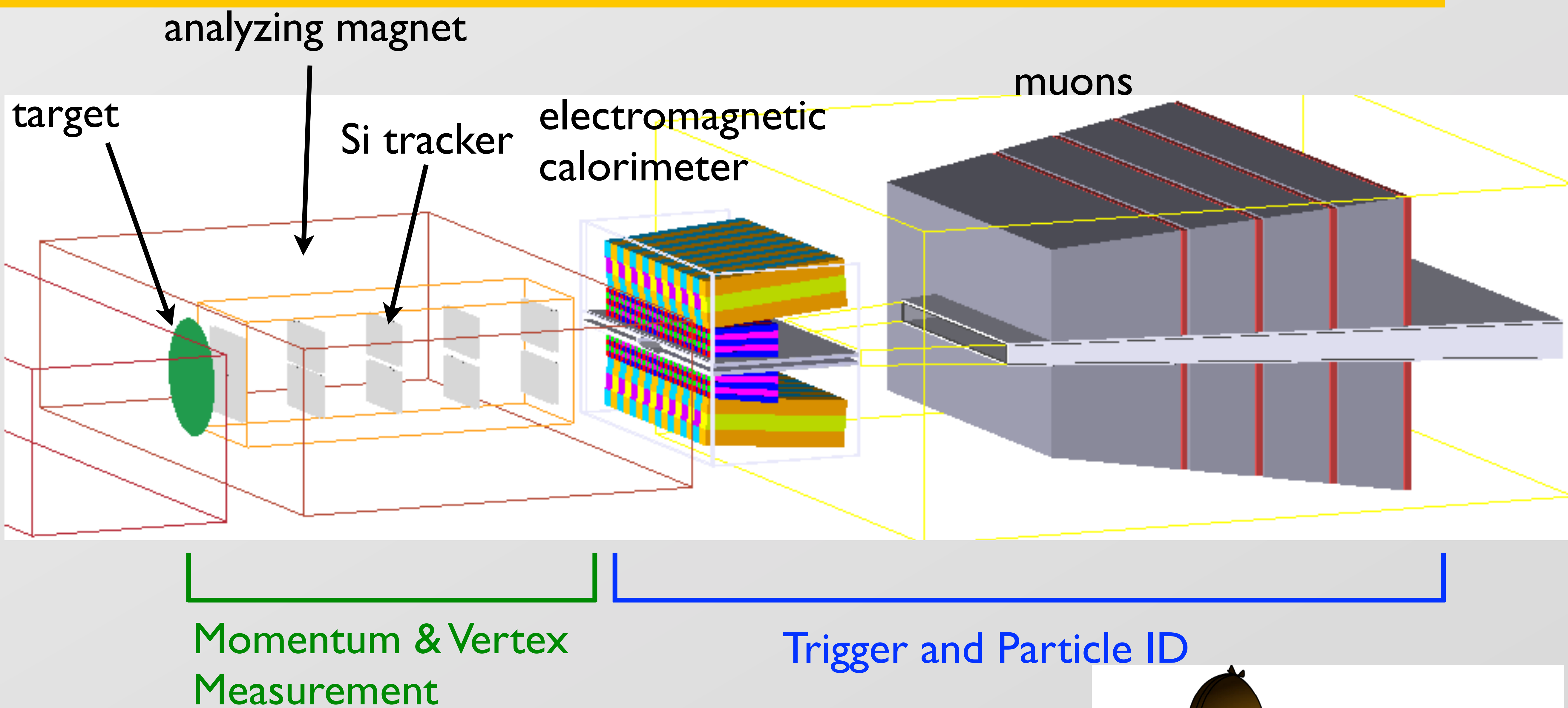
N. Dashyan, N. Gevorgyan, R. Paremuzyan, H. Voskanyan
Yerevan Physics Institute, 375036 Yerevan, Armenia

Proposal submitted Dec 1, 2010

HPS
HEAVY PHOTON
SEARCH

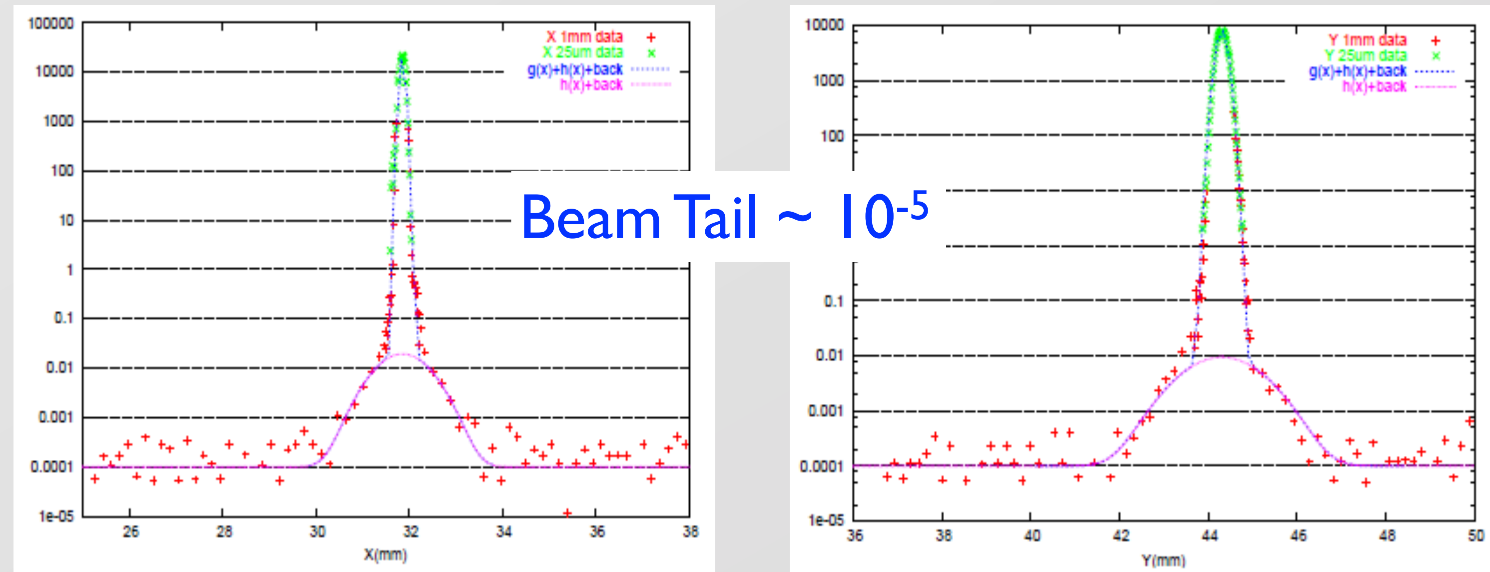
A Proposal to Search for Massive Photons at Jefferson Laboratory

HPS: A Dual Approach

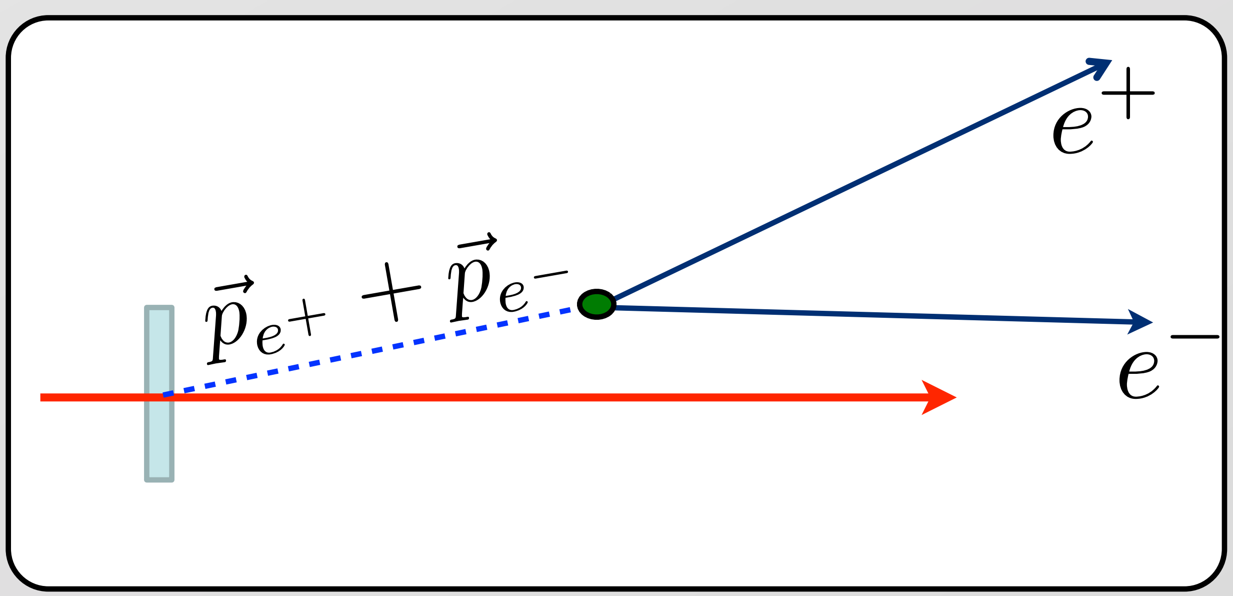


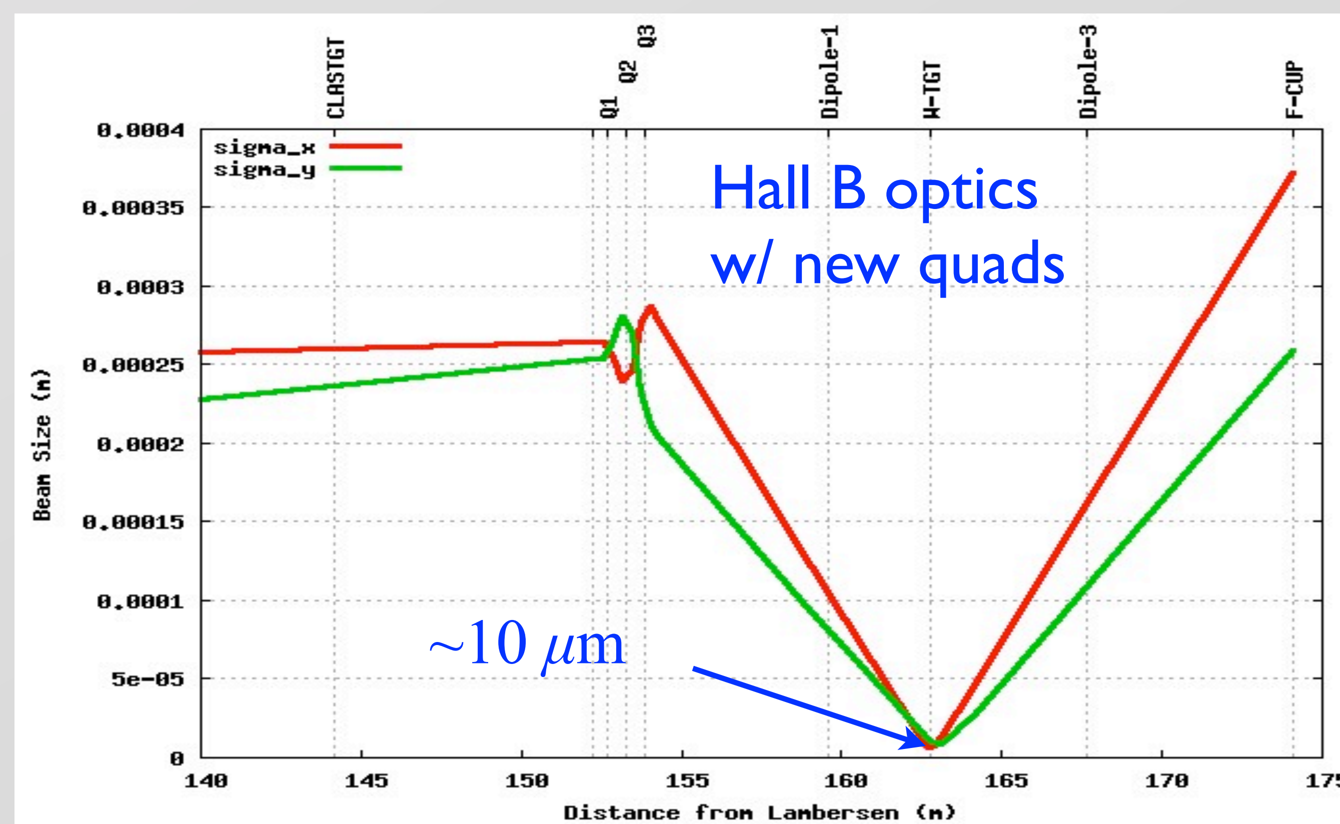
- Hall B at JLAB has the perfect beam for this and has room→behind the CLAS detector

The beam @ Hall B



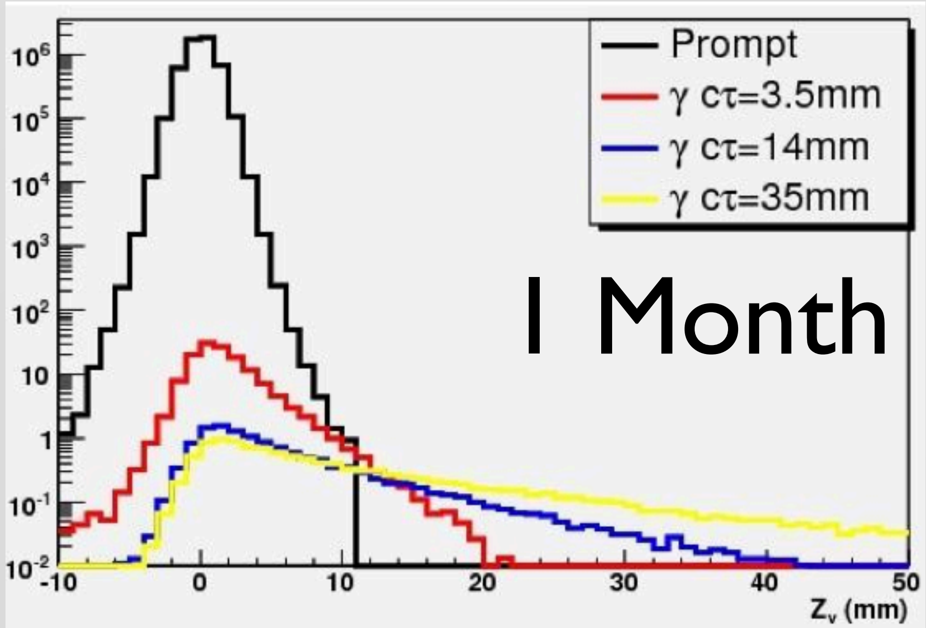
- Excellent beam quality, stability
- Capable of currents up to ~700nA
- 10 μm spot possible with additional quads: constrains A′ trajectory, reducing background





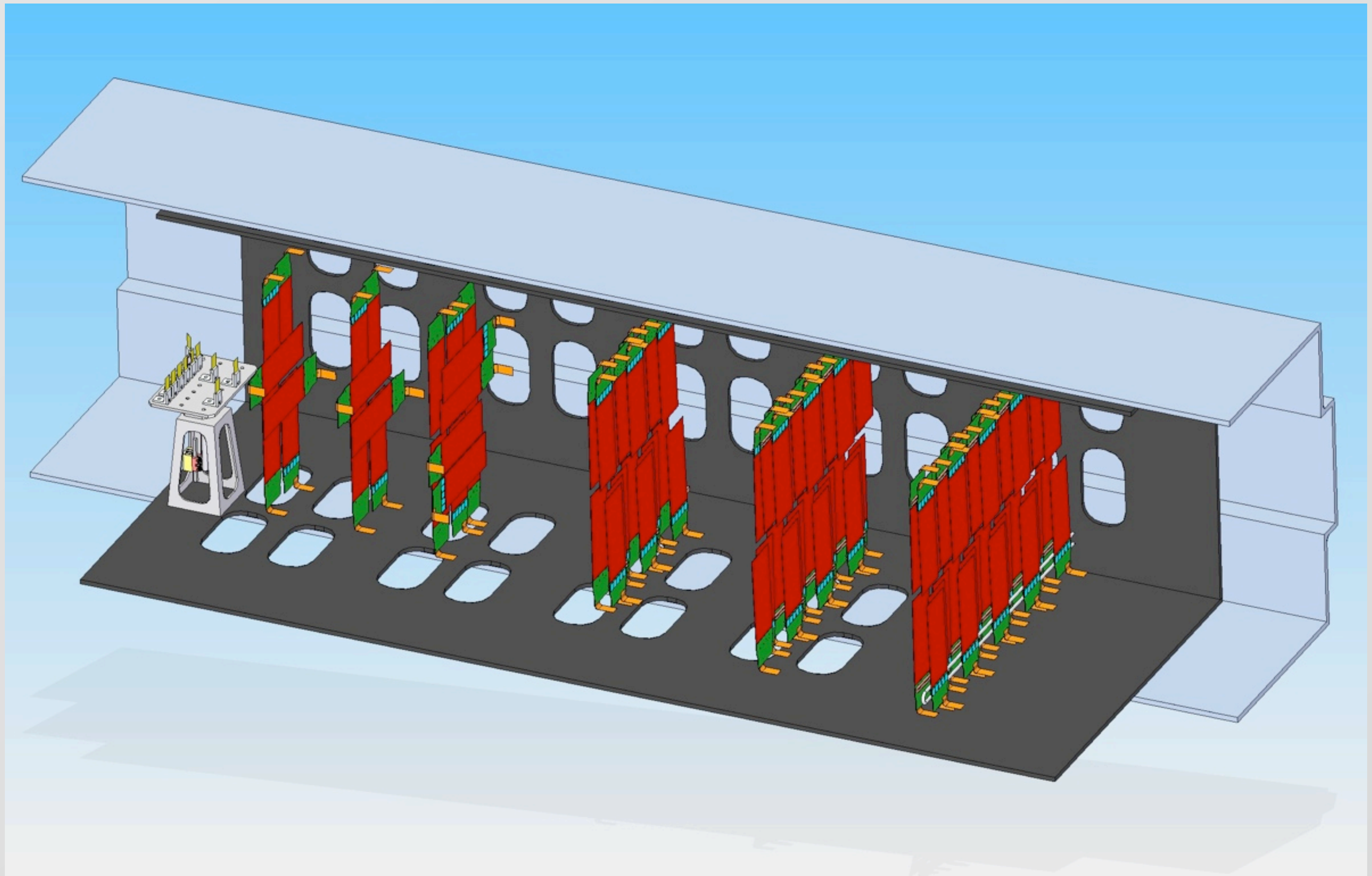
Tracking Challenges

- At relevant beam energies and interesting A′ masses, decay products tend to be electrons with momenta order a few GeV. Multiple scattering...
  - dominates both mass and vertexing measurement errors
  - leads to pattern recognition mistakes in dense environments
- Proximity to target means primary beam must pass through apparatus.
  - scattered beam sweeps out a "dead zone" of extreme occupancy and radiation, compounded by beam-gas interactions
  - puts low-mass acceptance in opposition to longevity and tracking purity
- Long-lived A′ signal very small: vertexing must be exceedingly pure to eliminate fakes.



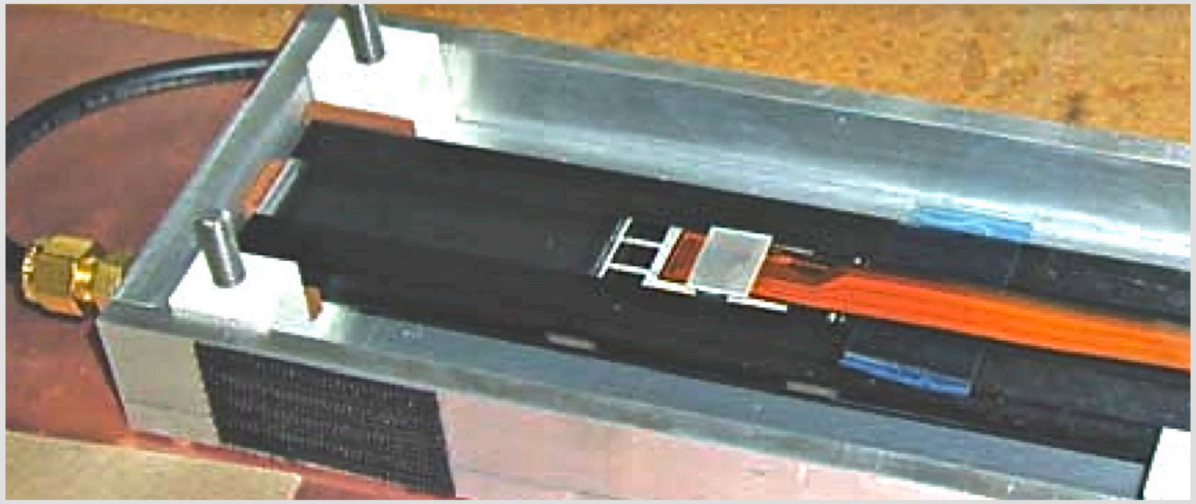
Tracking Detector requirements

- Mass and vertex resolution
  - low-mass construction
- Occupancies and radiation
  - fast, robust sensors / readout
  - movability / replaceability
  - operation in vacuum
- Acceptance/Purity
  - optimized sensor layout



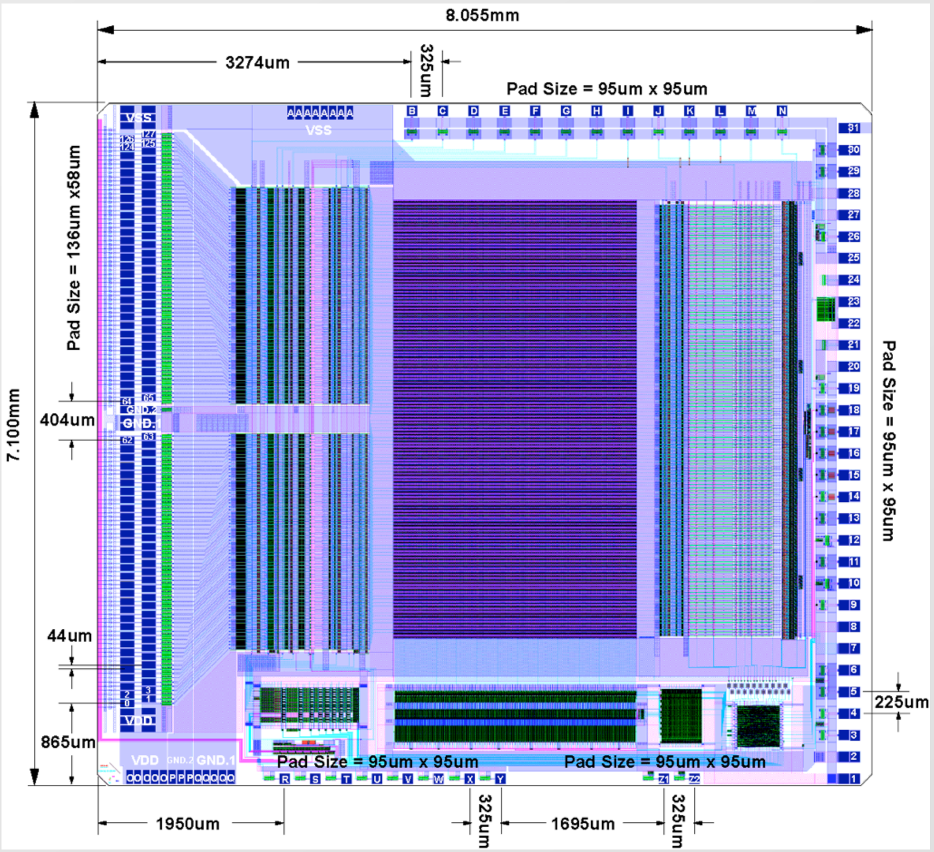
Si Strip Detectors

- pixels too massive, costly, complex: microstrips are the simple, lightweight solution
- Production Tevatron RunIIb sensors
  - many capable of 1000V bias: fully depleted to $> 4{\times}10^{15}$ e^{-}/cm^{2}
  - Fine readout granularity
  - Available in sufficient quantity
  - free! (at least, already paid for)



Cut Dimensions (L×W)	100 mm × 40.34mm
Active Area (L×W)	98.33 mm × 38.34mm
Readout (Sense) Pitch	60µm (30µm)
# Readout (Sense) Strips	639 (1277)
Breakdown Voltage	>350V
Total Interstrip Capacitance	<1.2 pF/cm
Defective Channels	<1%

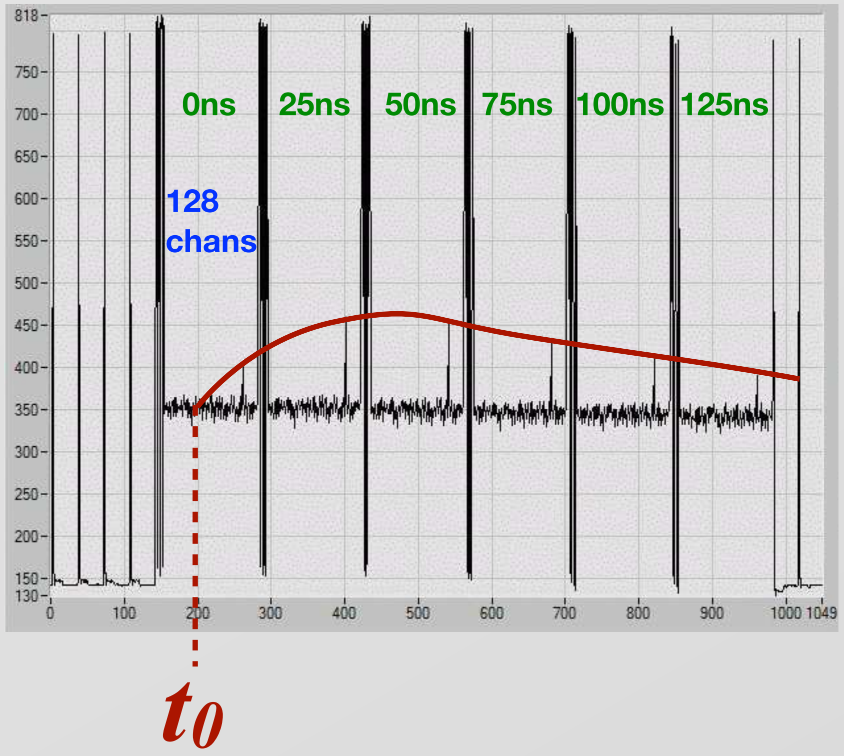
Fast Si Readout: APV25

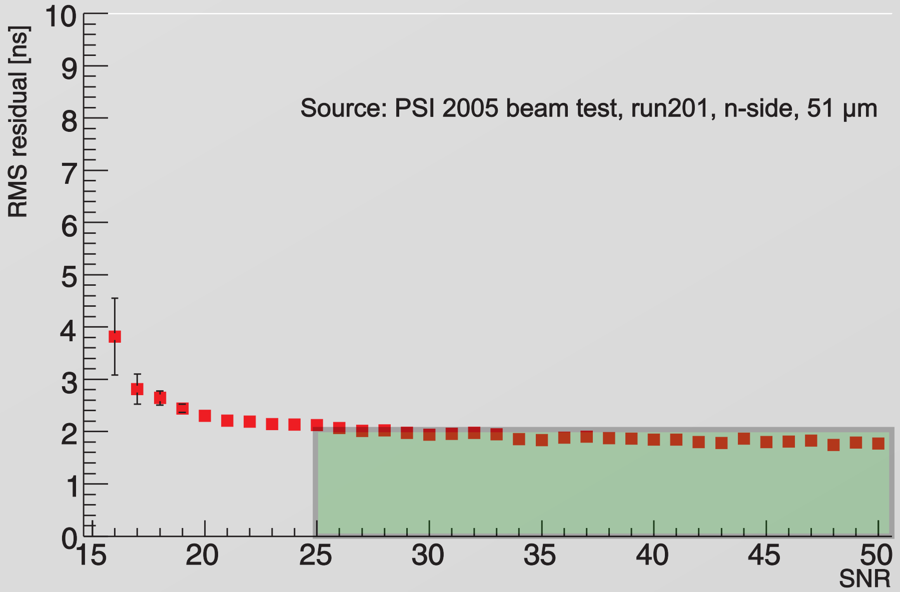


# Readout Channels	128
Input Pitch	44 μm
Shaping Time	50ns nom. (35ns min.)
Noise Performance	270+36×C(pF) e⁻ ENC
Power Consumption	345 mW

Developed for CMS

- readily available
- radiation tolerant
- low noise: S/N = 34
- 2 ns t_0 resolution

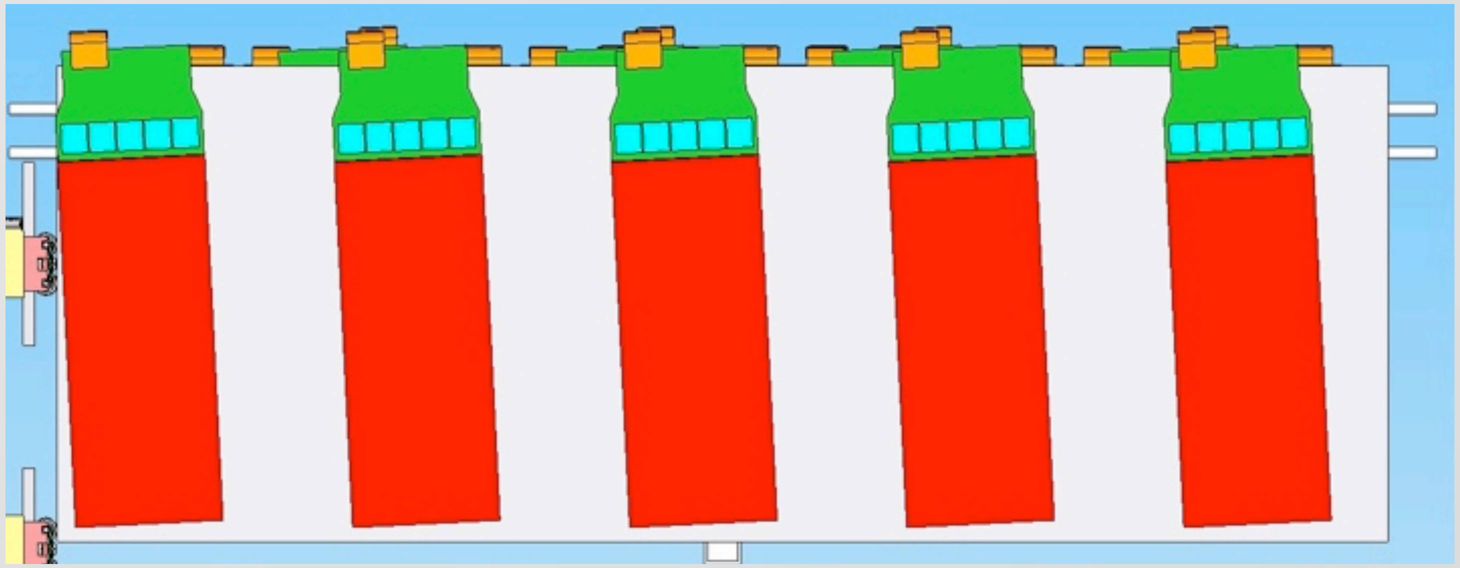




Monday, November 14, 2011

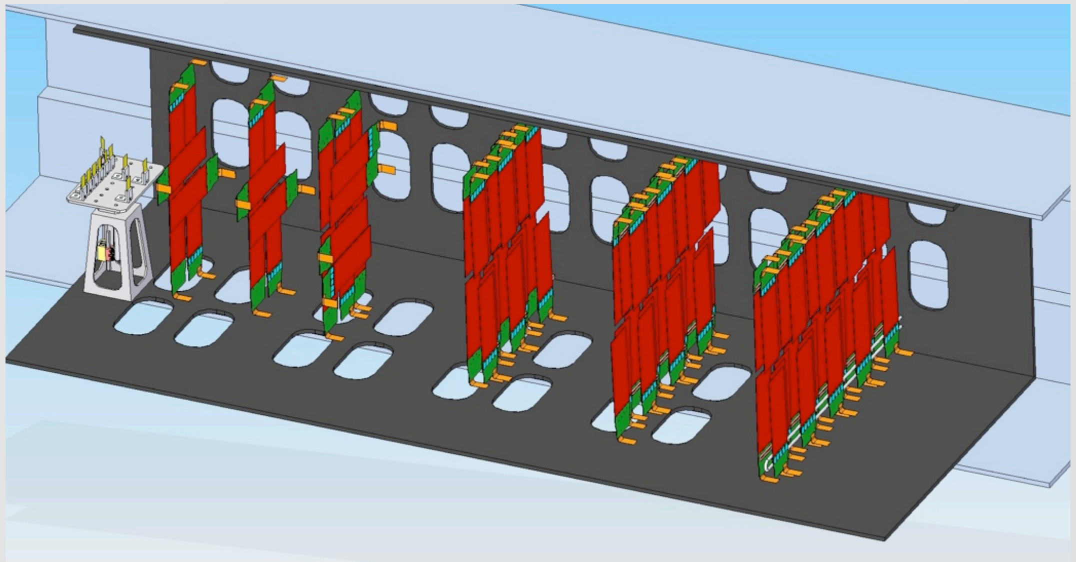
Material Budget

- CF-composite/rohacell-foam
  - 1.0% X_0/layer
  - dominated by Si
- H_2O/glycol at -10°C
  - outside tracking volume
  - vacuum minimizes heat load on sensors



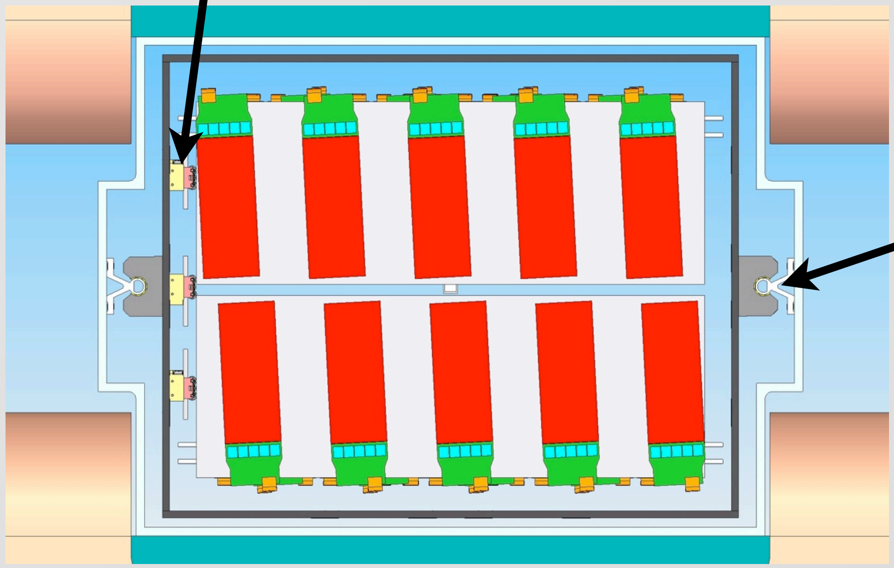
	Radiation Length (mm)	Thickness (mm)	Coverage/Unit Acceptance	Scattering Material (% X_0)
Silicon	**93.6**	**0.320**	**1.2**	**0.410**
Rohacell Foam	13800	3.0	0.5	0.011
Carbon Fiber	242	0.150	0.5	0.031
PGS Passivation	256	0.101	1.25	0.049
Epoxy	290	0.050	0.5	0.009
Total	-	-	-	**0.510**

Movable & Replaceable

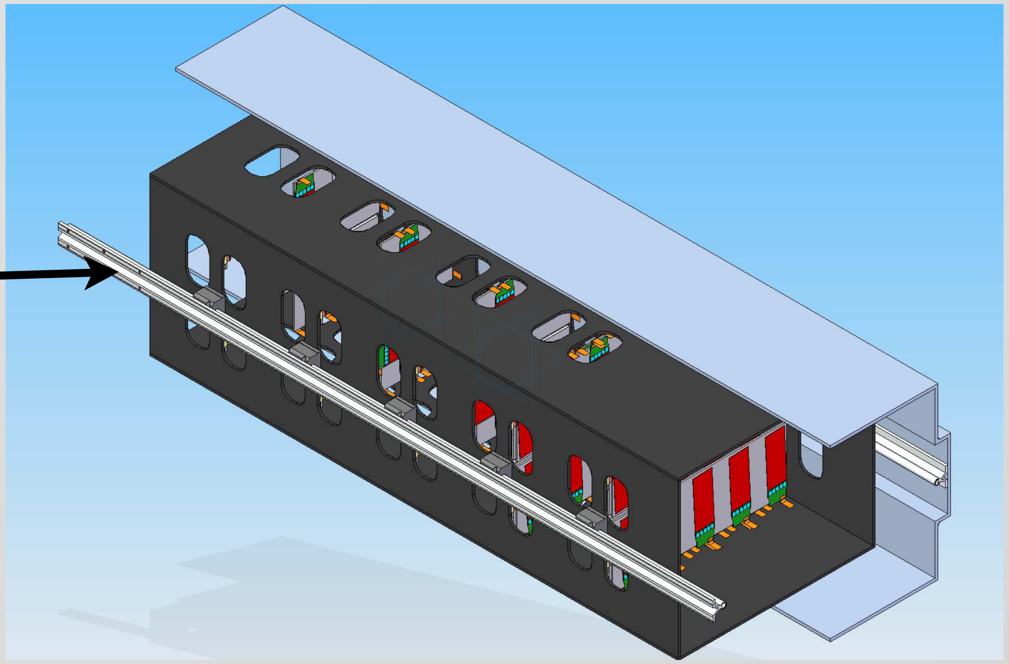


carbon fiber
support box
inside
vacuum chamber

piezo motors
allow retraction
of planes



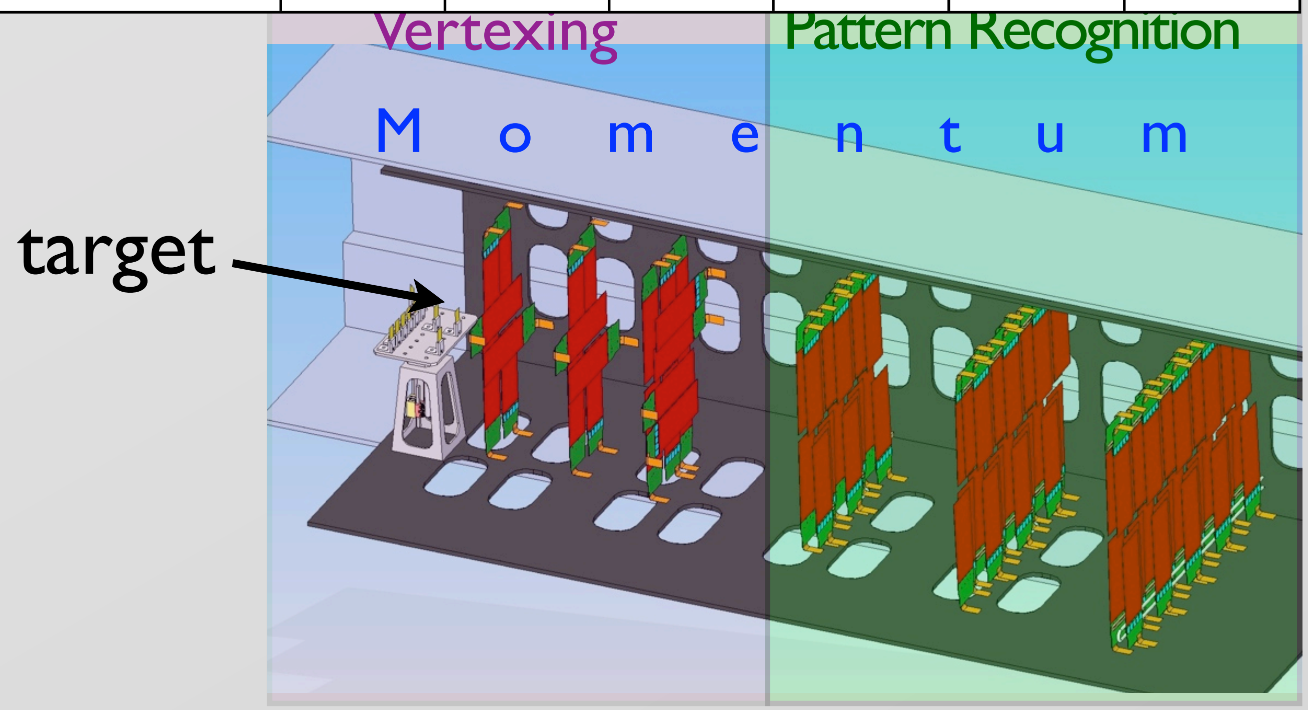
rail system for
easy removal of
tracker



Tracker Layout

- Layers 1-3: vertexing
- Layers 4-6: pattern recognition with adequate pointing into Layer 2.
- Bend plane measurement in all layers: momentum
- 106 sensors/hybrids
- 530 APV25 chips
- 67840 channels

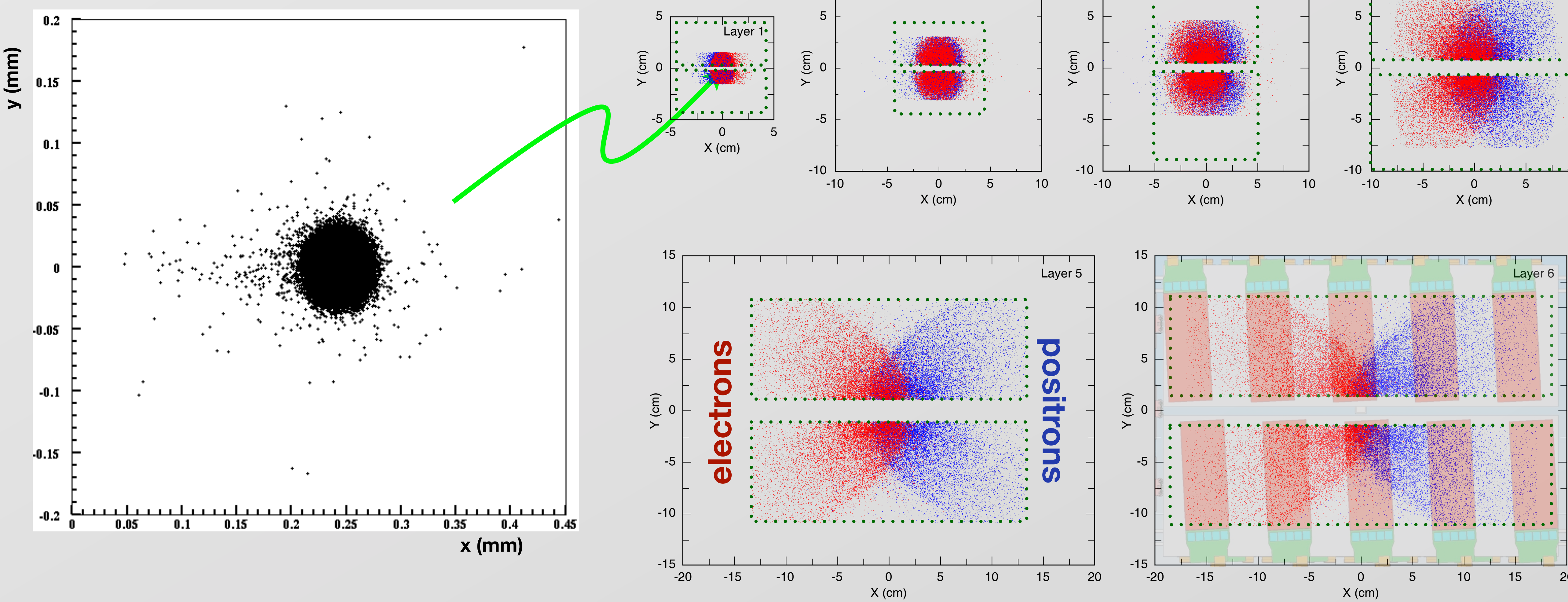
	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
z position, from target (cm)	10	20	30	50	70	90
Stereo Angle	90 deg.	90 deg.	90 deg.	50 mrad	50 mrad	50 mrad
Bend Plane Resolution (µm)	≈ 6	≈ 6	≈ 6	≈ 6	≈ 6	≈ 6
Stereo Resolution (µm)	≈ 6	≈ 6	≈ 6	≈ 120	≈ 120	≈ 120
# Bend Plane Sensors	4	4	6	10	14	18
# Stereo Sensors	2	2	4	10	14	18
Dead Zone (mm)	±1.5	±3.0	±4.5	±7.5	±10.5	±13.5
Power Consumption (W)	10.5	10.5	17.5	35	49	63



Deadzone & Acceptance

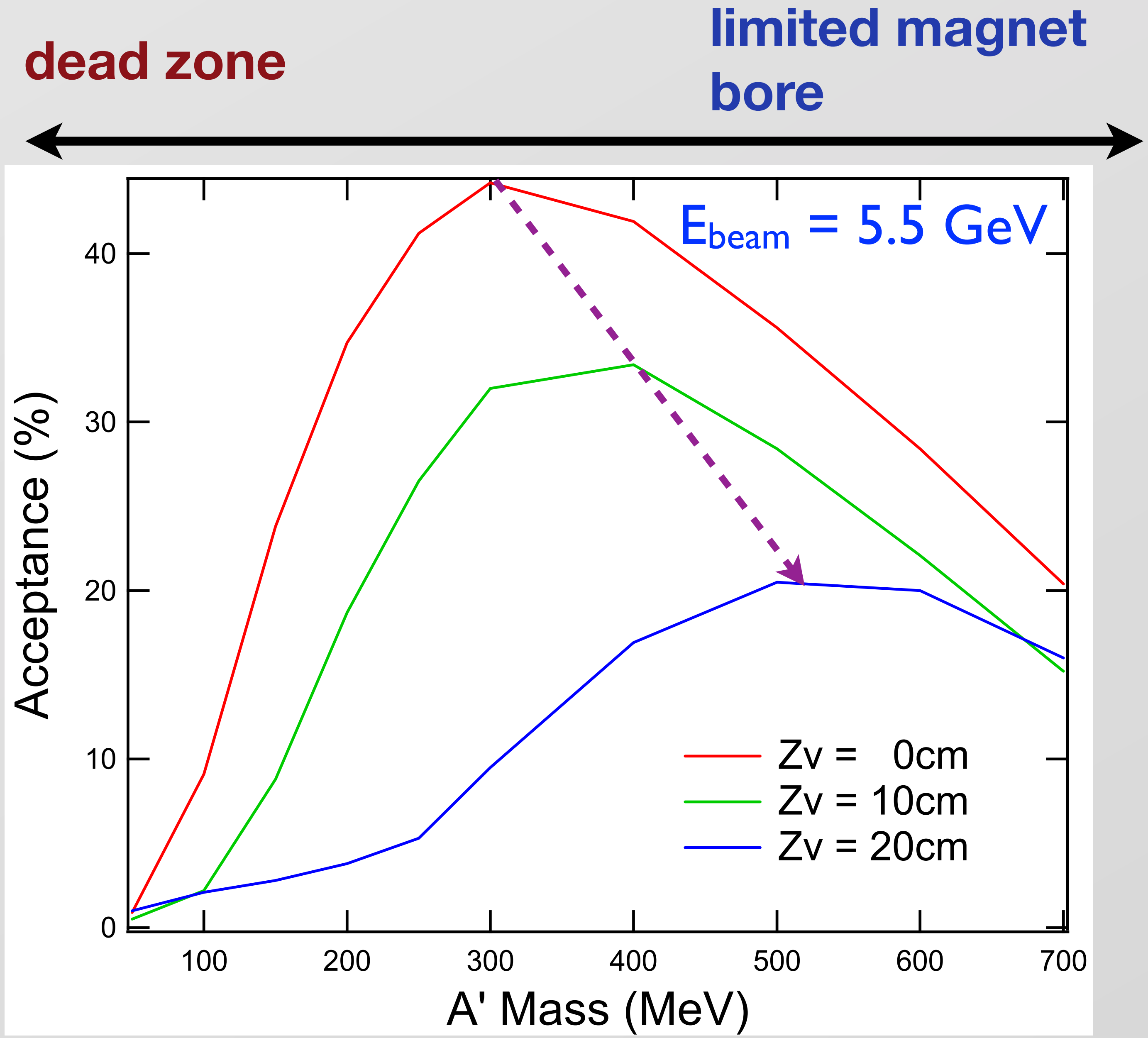
Hits from A′ daughters within acceptance;
E_{beam}=5.5 GeV, $m_{A'}$ = 300 MeV/c^2

75 ns of beam at Layer 1

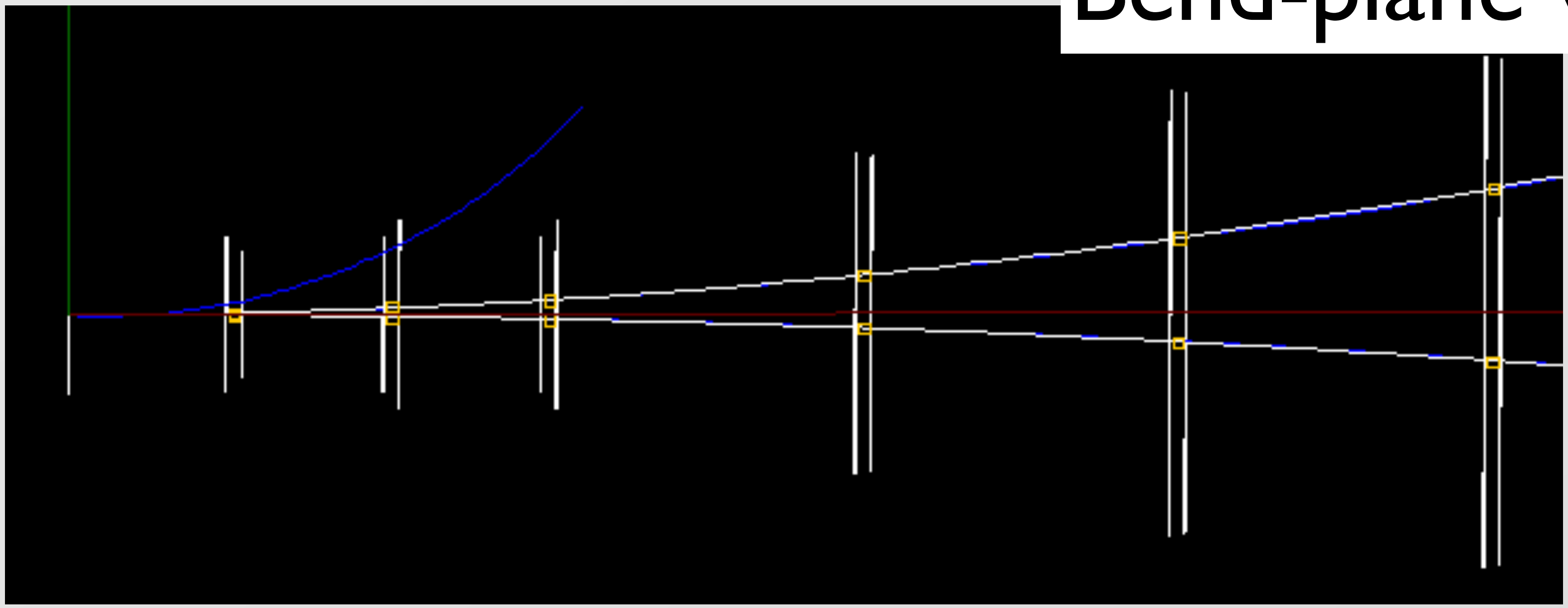


Tracker acceptance

- At smaller masses, dead-zone limits acceptance
- At larger masses, losses due to limited coverage in layers 5 and 6 become important.
- Solid angle of dead zone increases with increasing z-vertex position



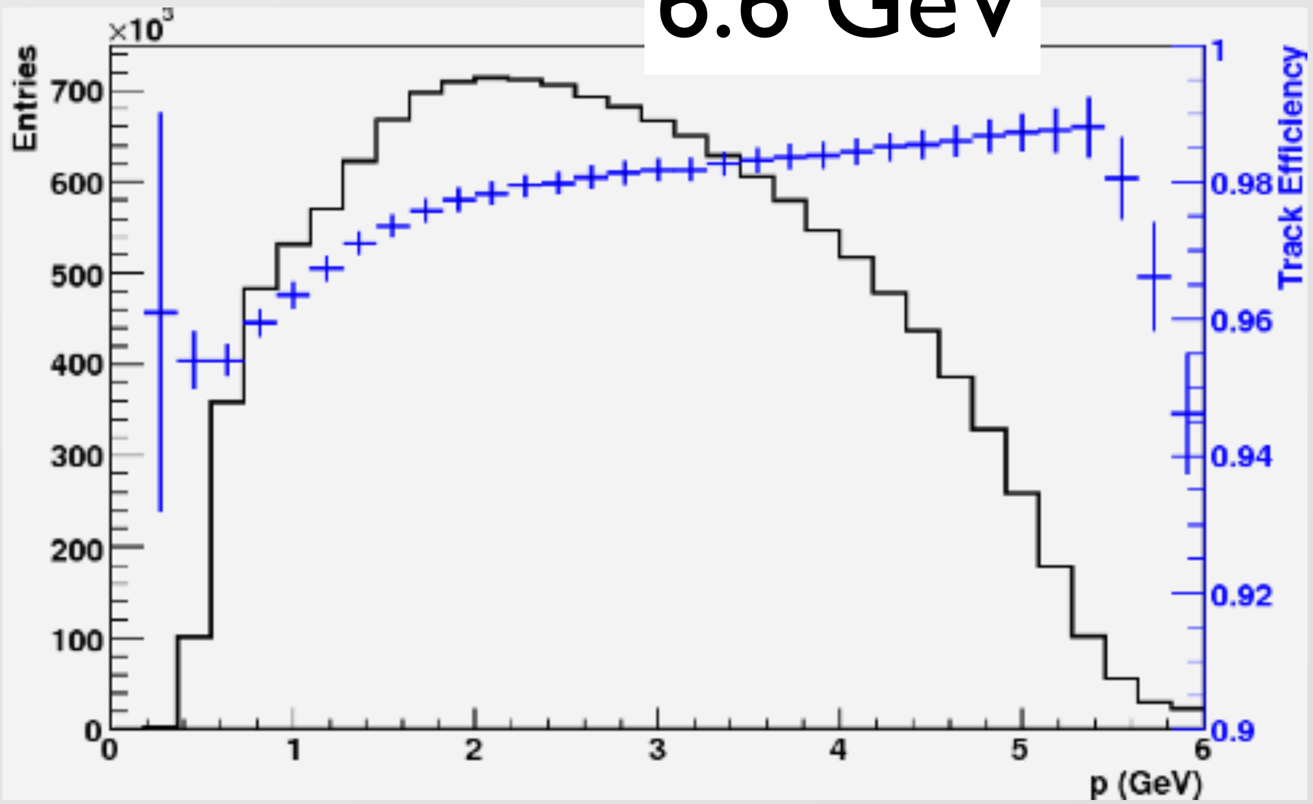
Tracking Performance


Bend-plane view

- We use the SLAC developed packages SLIC, for simulation, and org.lcim, for tracking reconstruction and analysis
- Overlay events (signal, radiative bkg, etc) with simulated beam "pileup" for which we use #electrons = 7.5ns x beam current
  - we use the 7.5ns to approximate the timing resolution of the APV25; eventually we will use the timing in the track fitting itself
- Results of the simulation used in the reach calculation

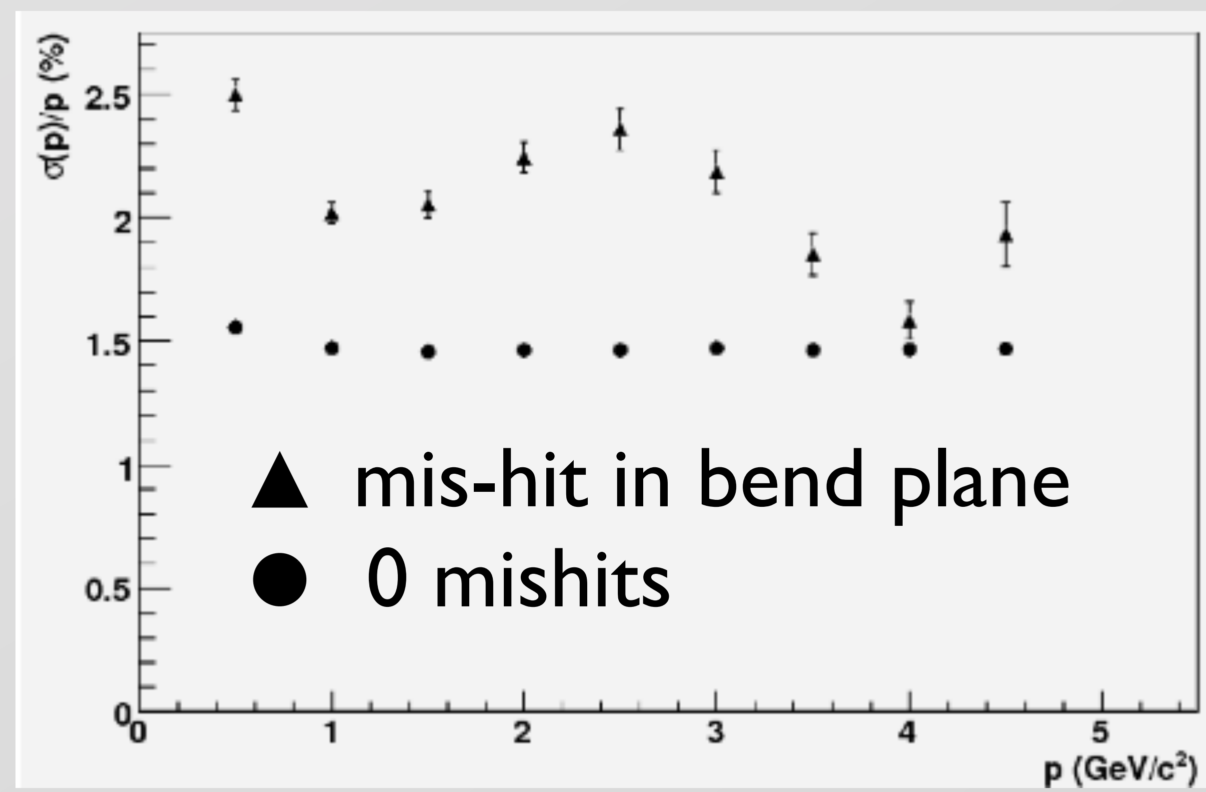
Efficiency & Momentum Resolution

6.6 GeV

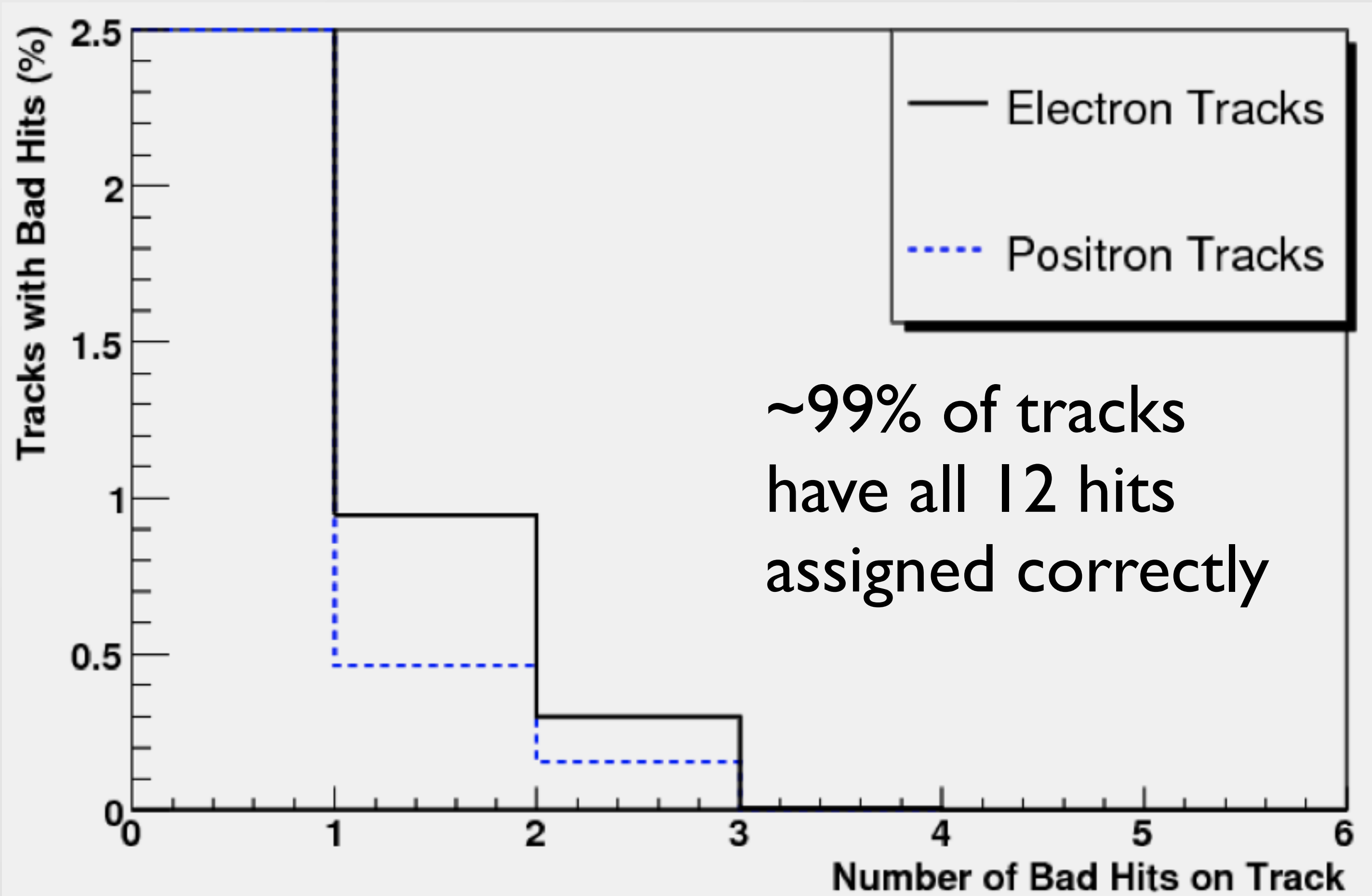


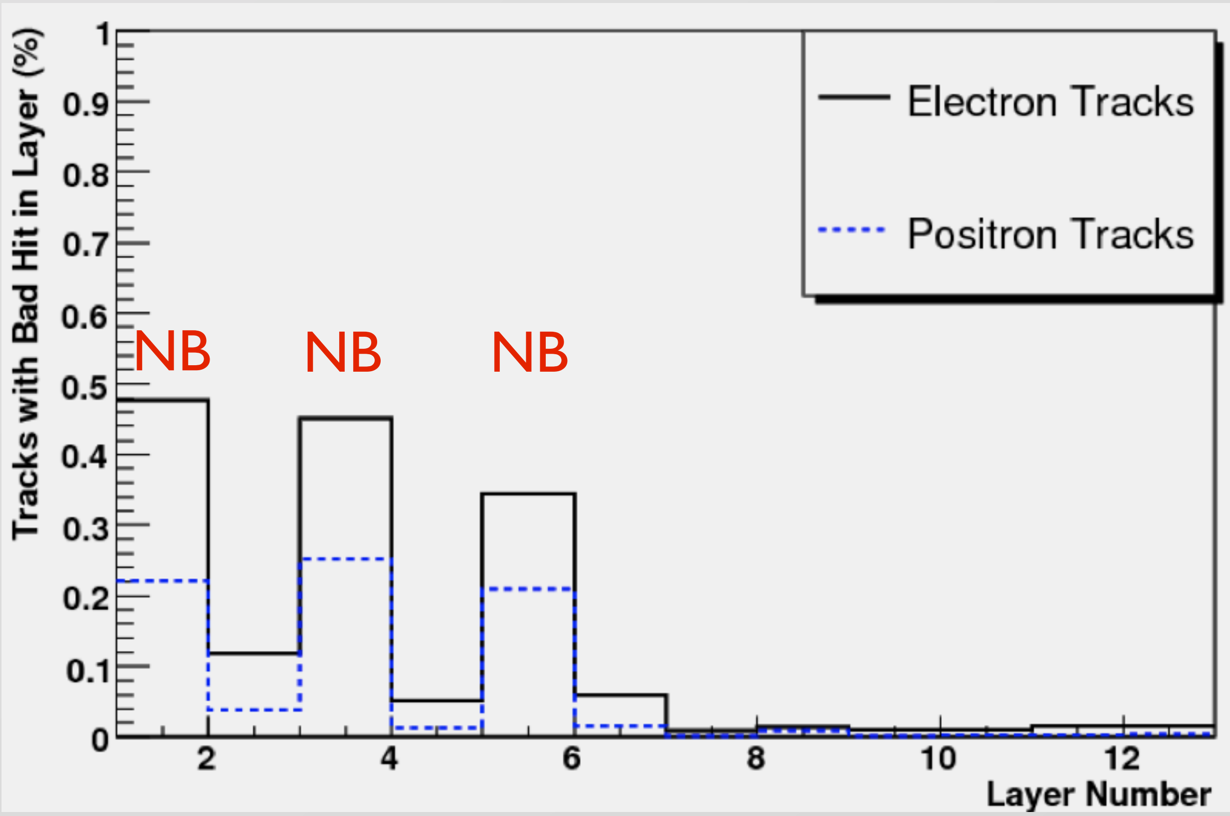
Efficiency>95% for tracks in acceptance over full momentum range

$\sigma(p)/p \sim 1.5\%$



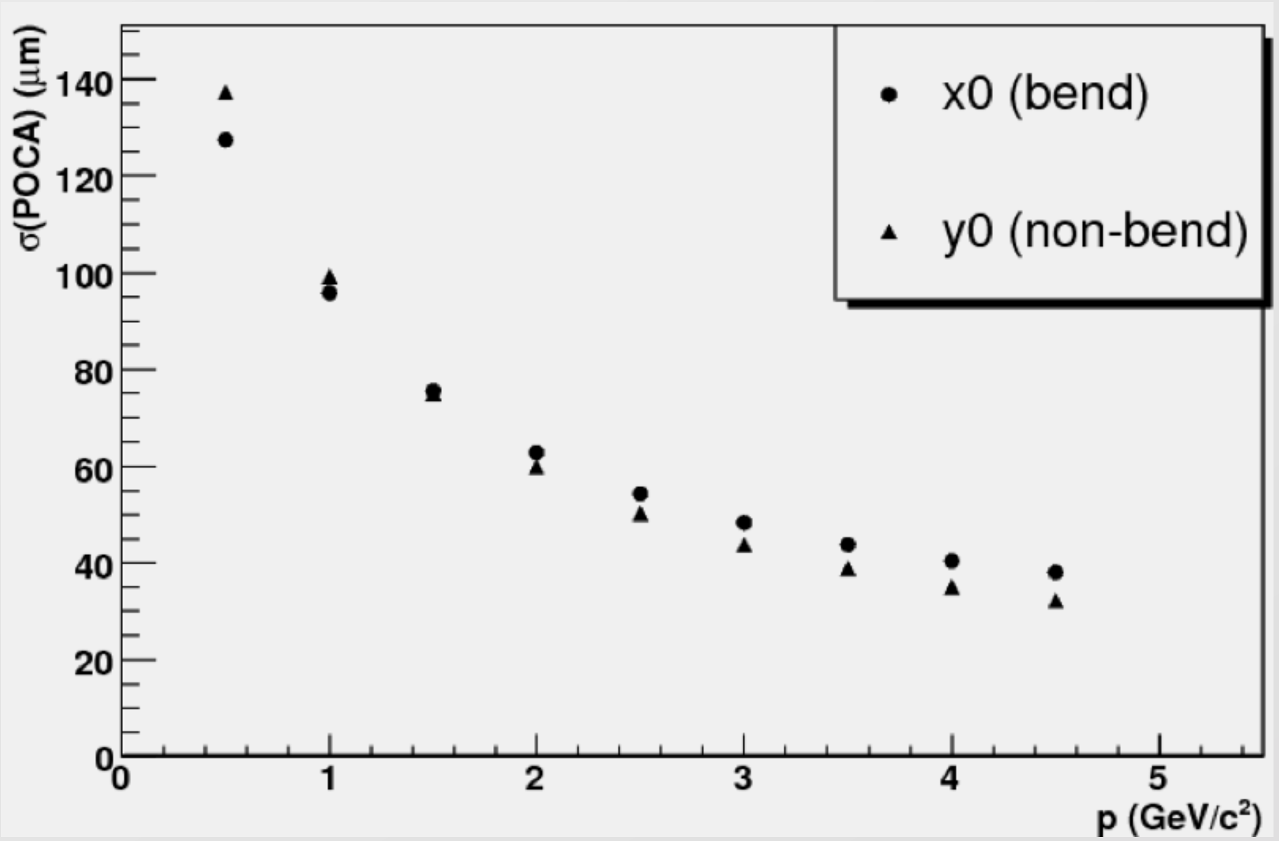
Mis-assigned hits on tracks





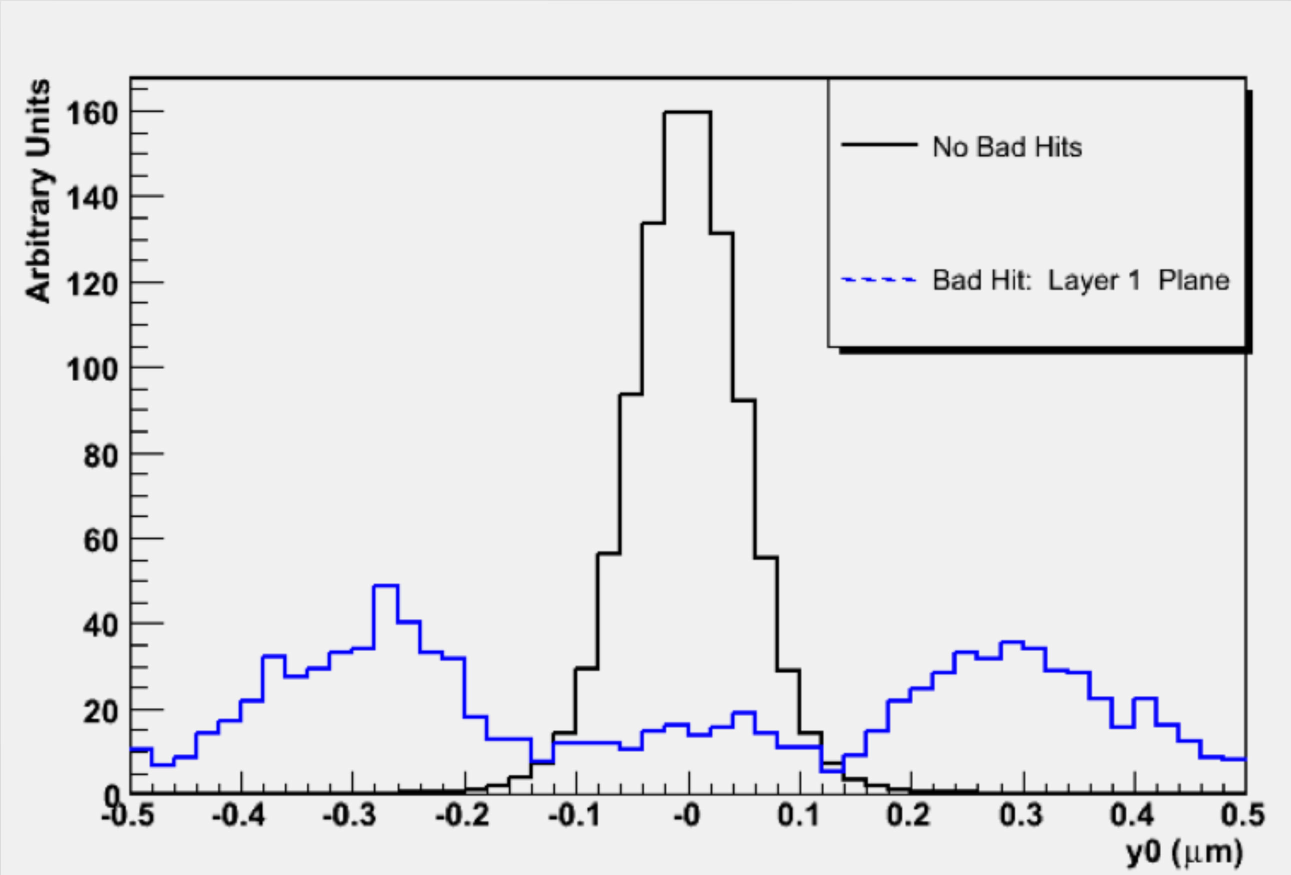
Majority of mis-hits are in non-bend Si layers (1,3,5) →pathological vertex positioning

Track position resolution

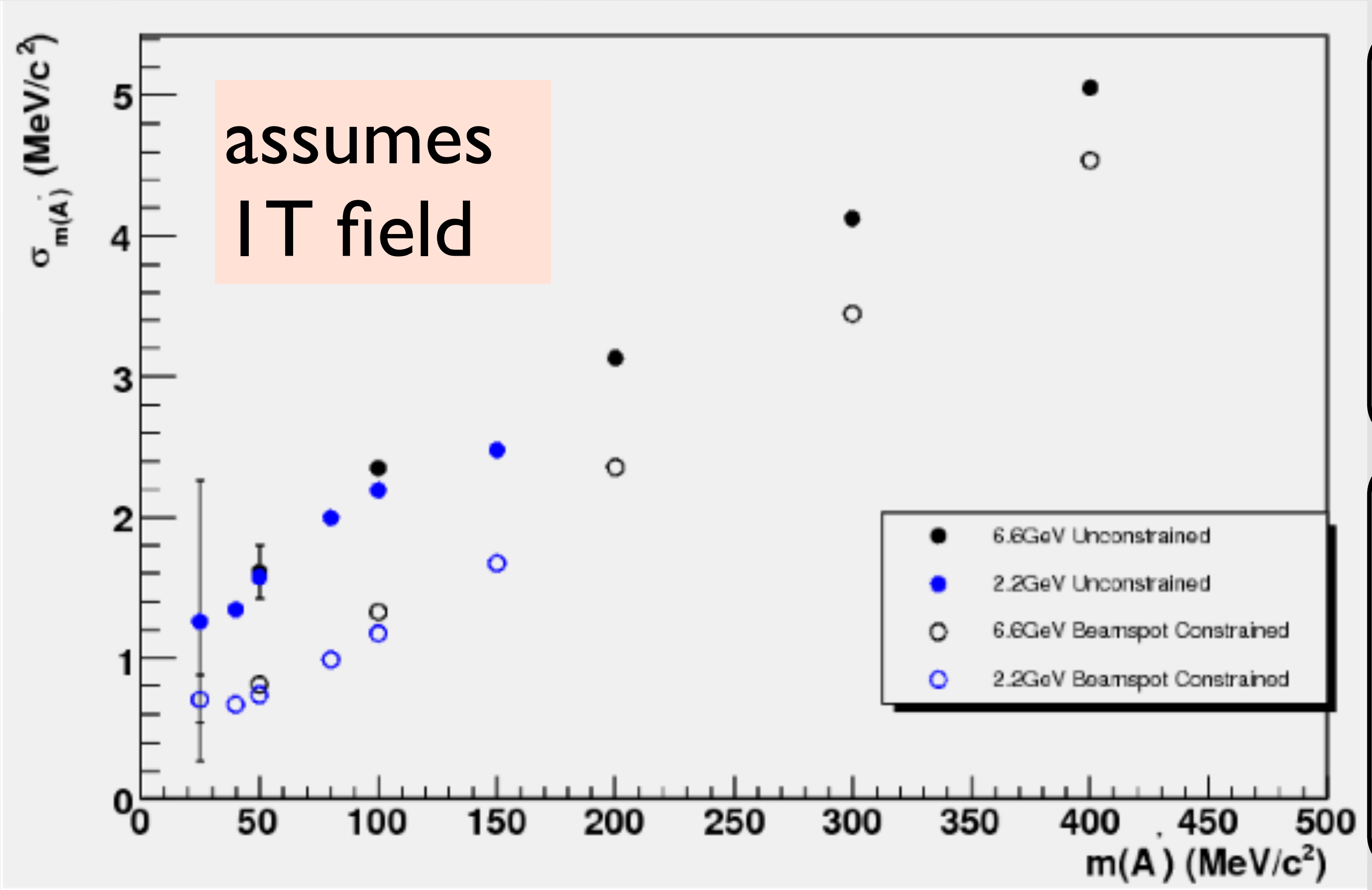


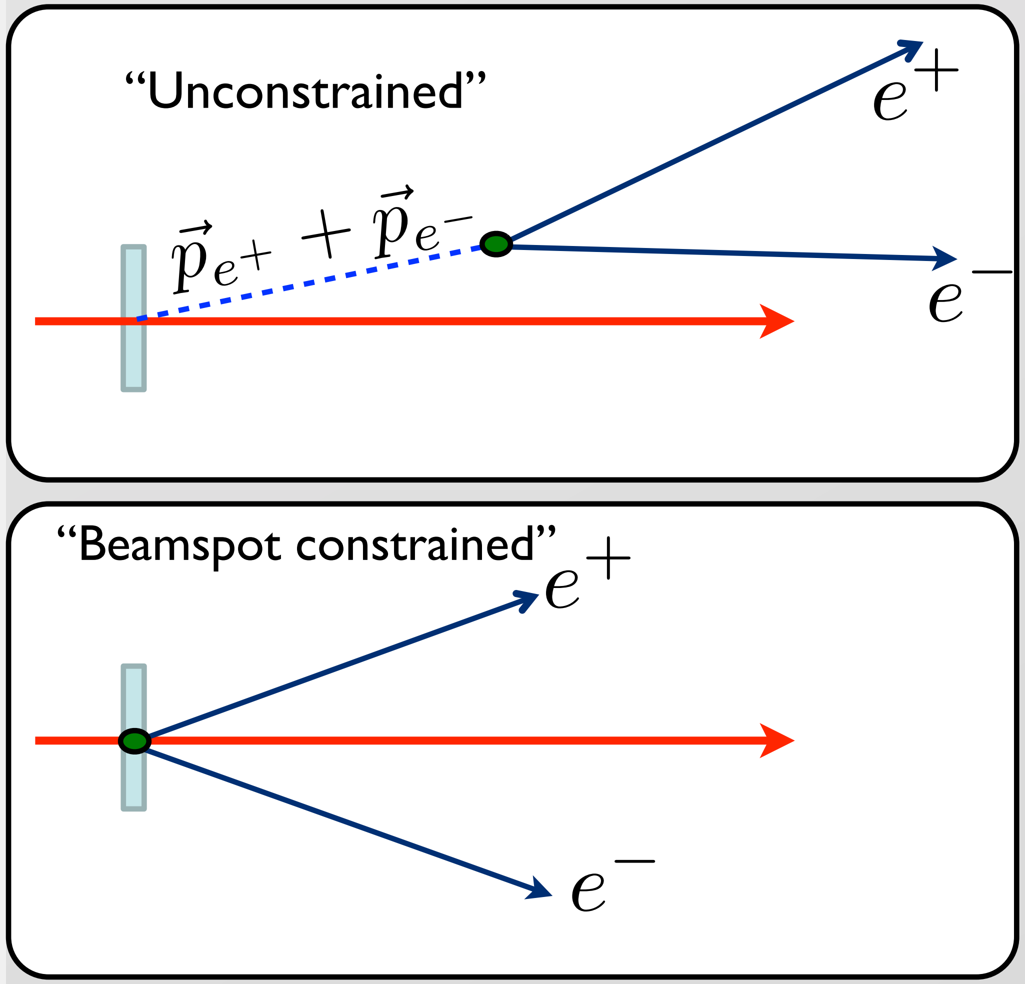
POCA = point of closest approach to beam axis

Here's the pathology...
mishits in first non-bend layer



Mass Resolution



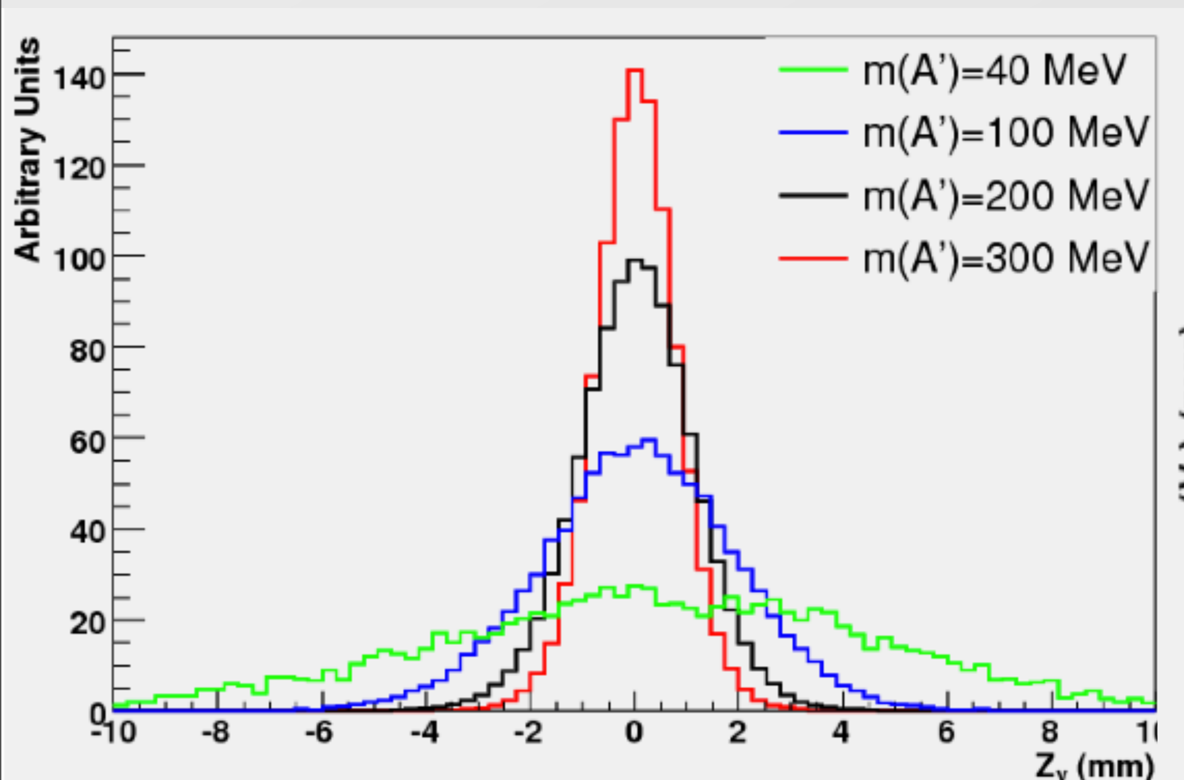


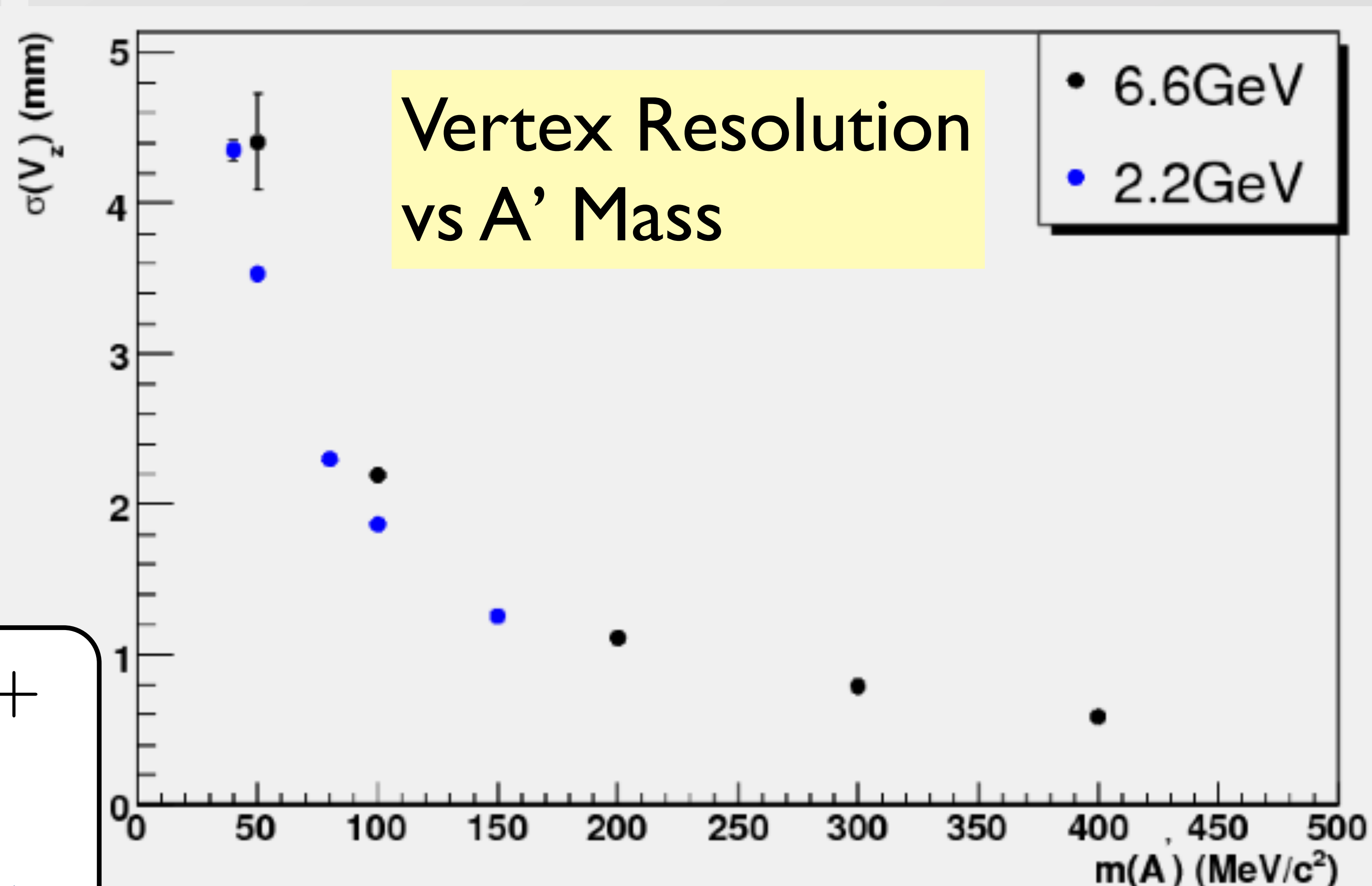
Two vertex fits:

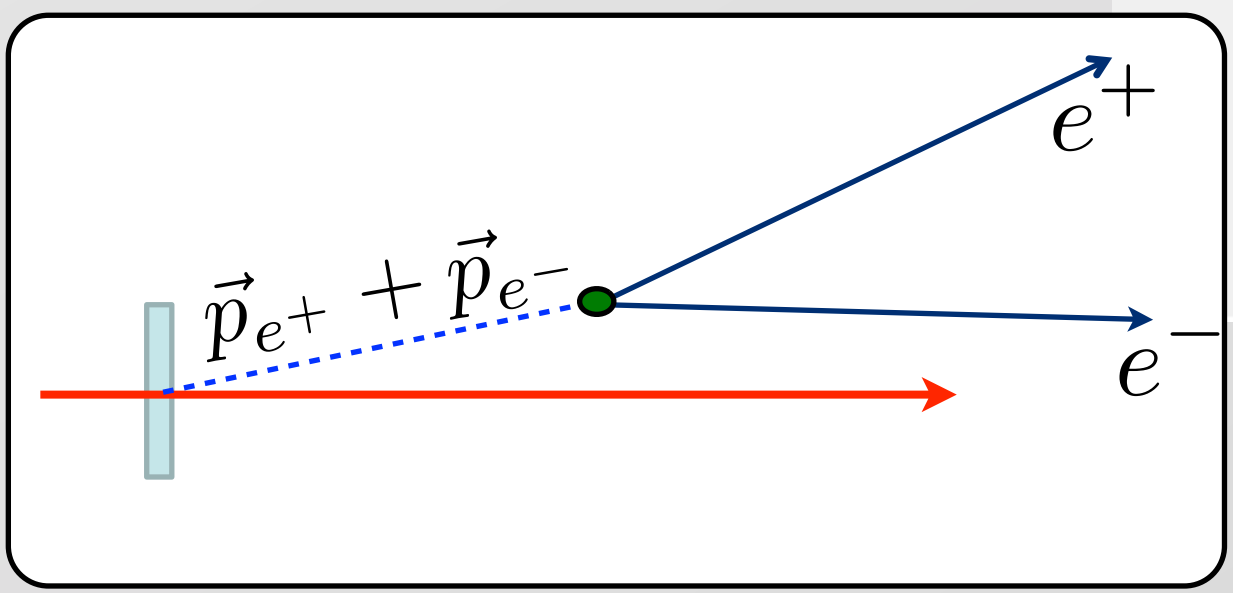
- A' candidate constrained to *come from* the beamspot
- A' candidate constrained to *decay at* the beamspot

--- current plan is to use 0.5 T for 2.2 GeV beam

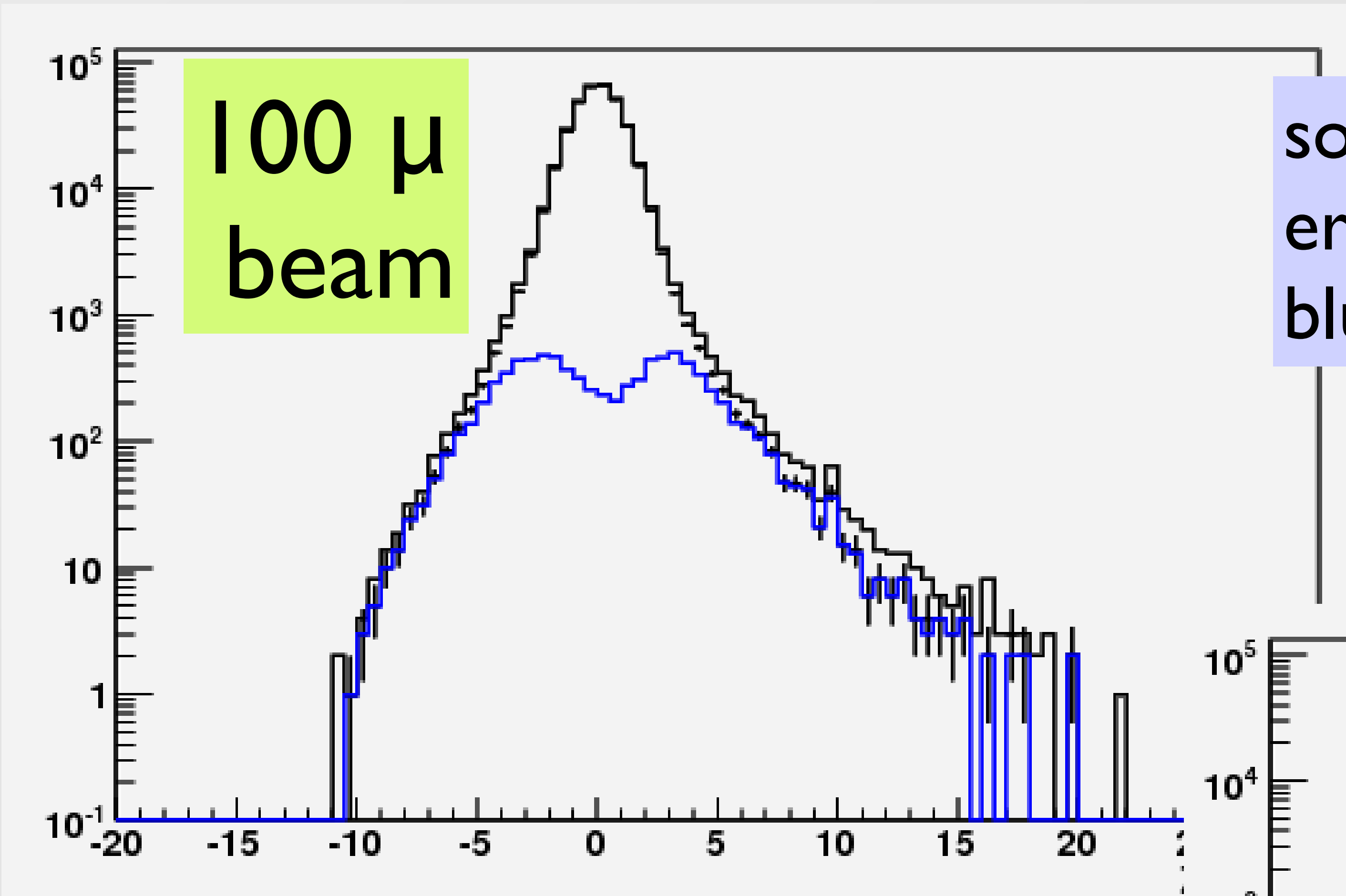
Vertex position Resolution



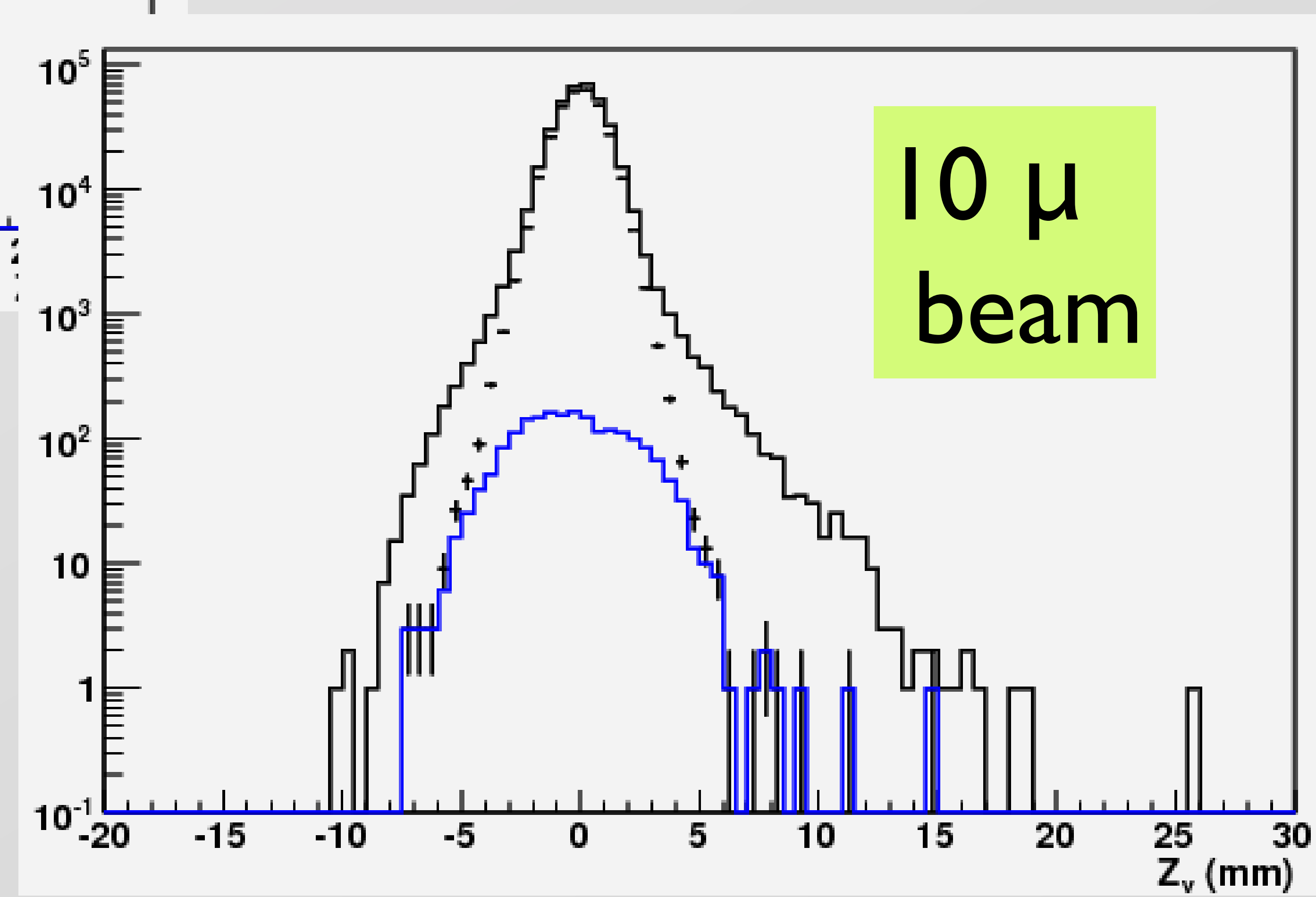




Vertexing + Beamspot Size

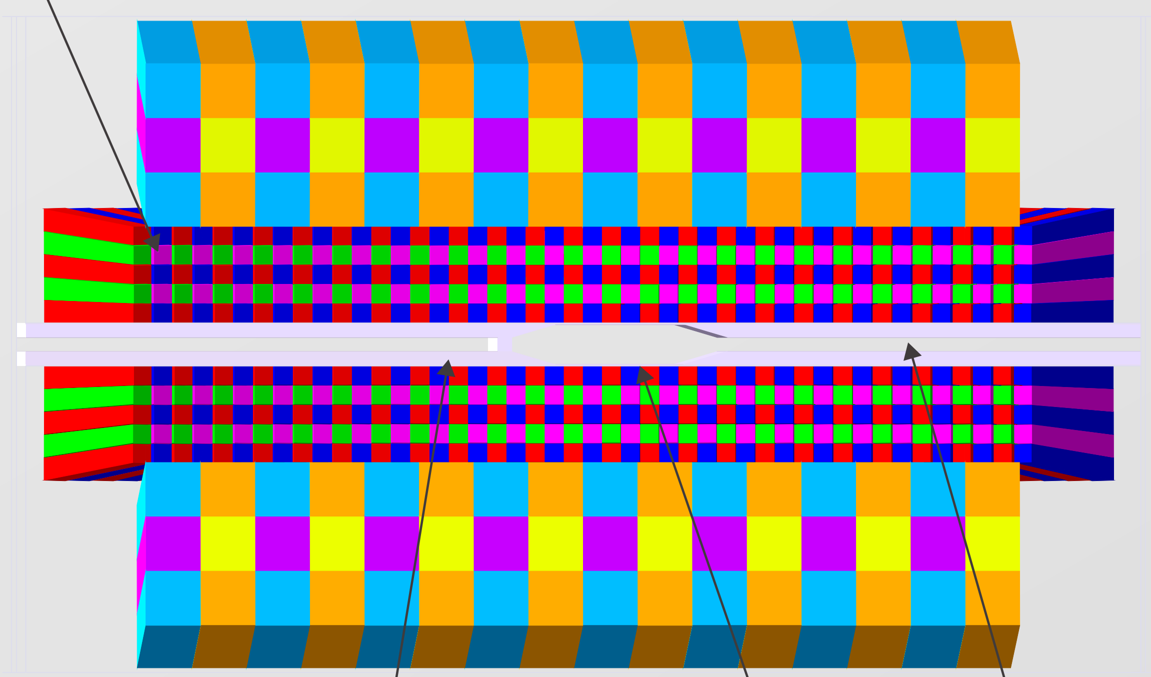


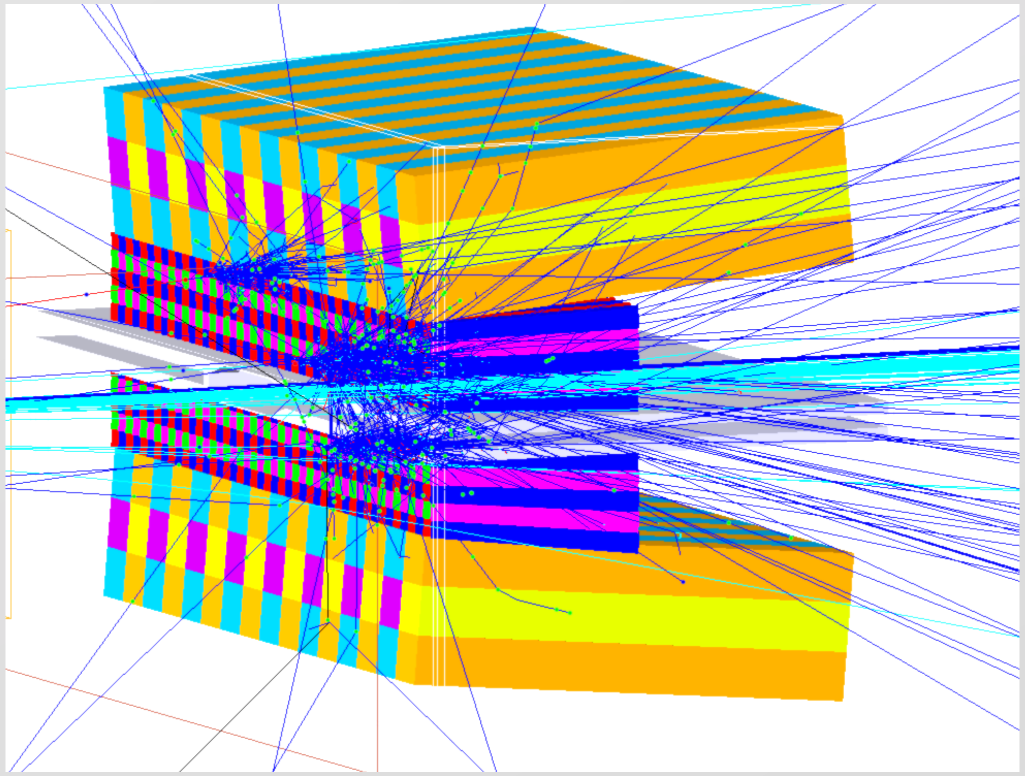
solid: base cuts (unconst)
error: constrained χ^2 cut
blue: mishit L1



- constraining A' from the beamspot does not help much if BS is too big
  - makes sense since unconstrained vertex resolution in x,y ~100µ
- smaller the better...

Hybrid Calorimeter



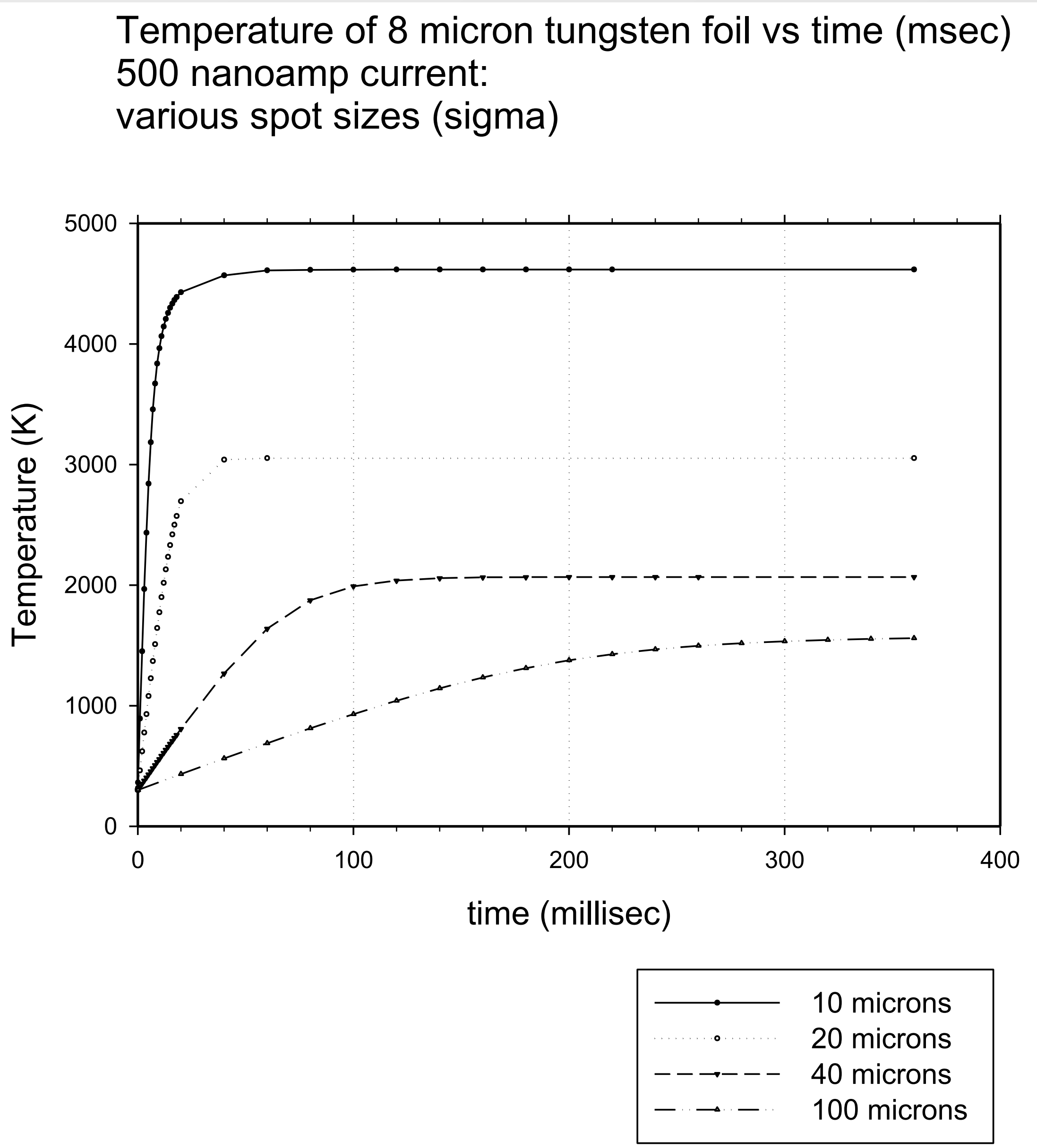


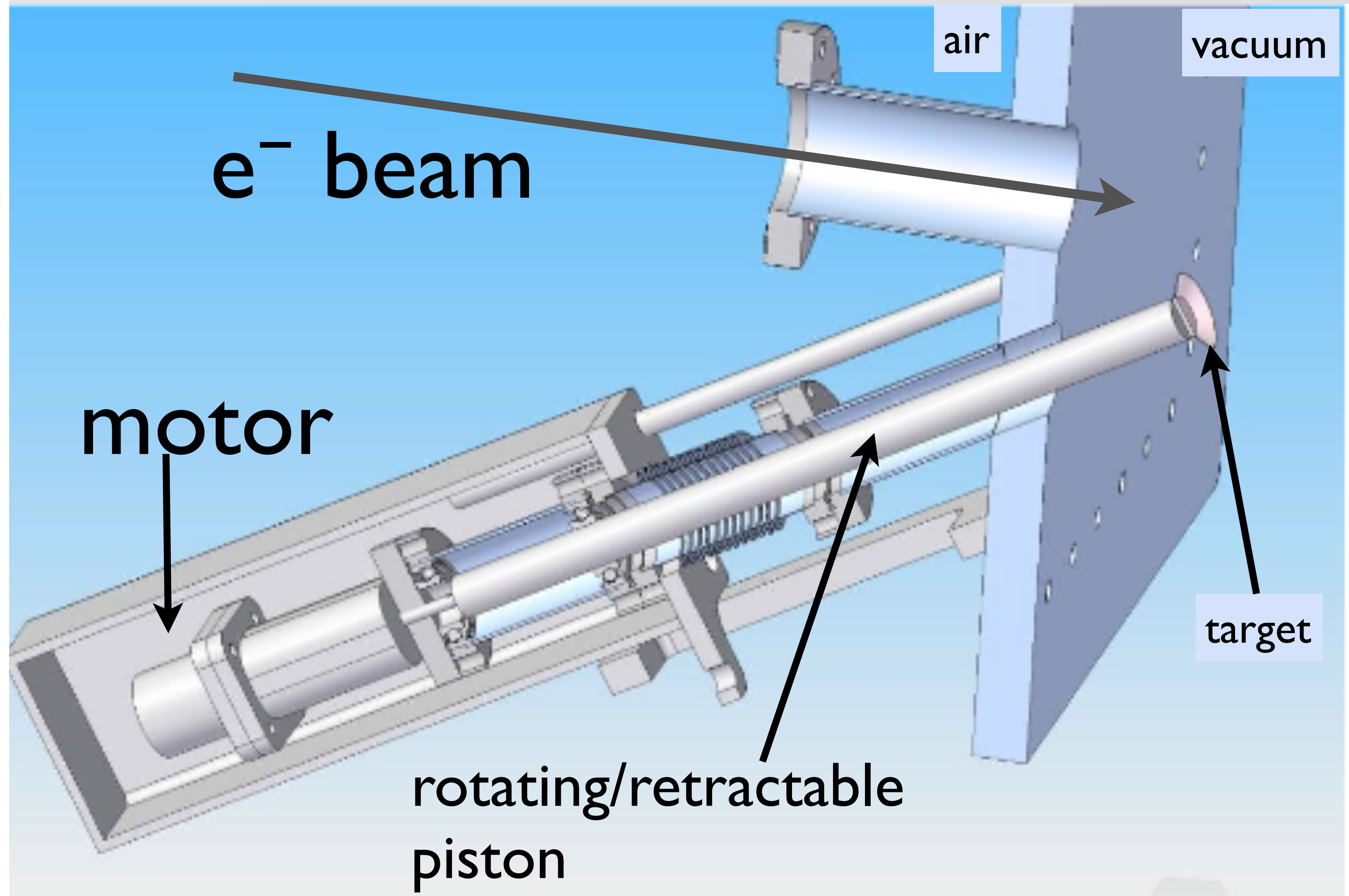
Design criteria: highest acceptance with readily available crystals, low background.

Vacuum box: 1 cm aluminum plate with cutout area for beam.
5 rows of 46 lead-tungstate crystals, total: 460
3 rows of 16 lead-glass or Shashlyk crystals, total: 96

In hand from other experiments

The Tungsten Target



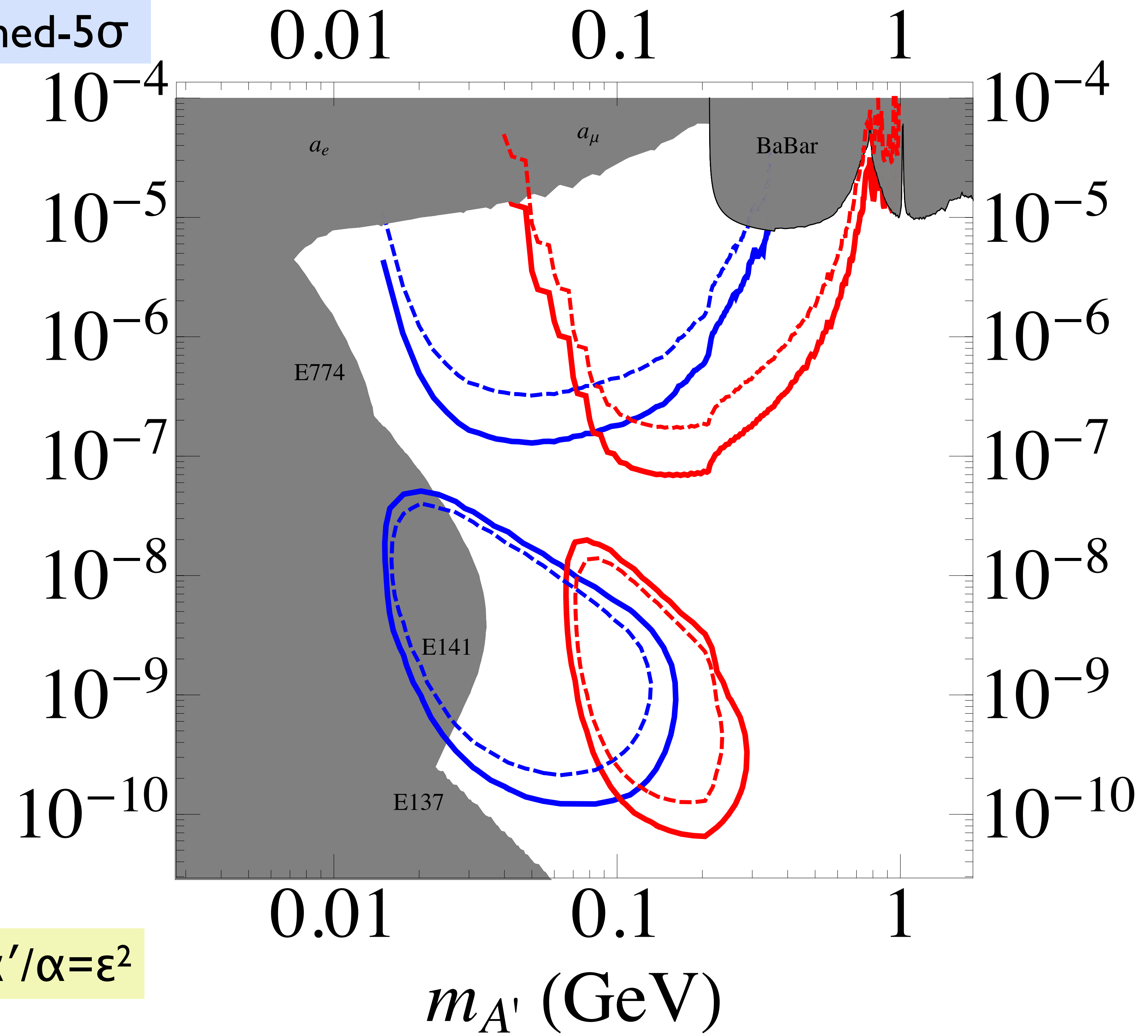


•For small beamspots, target heats up rapidly...need to either move beam (tricky tracking/vertexing) or move target (tricky engineering)

•Current plan is to move the target...a few options; the one above is the most developed which allows target to be rotated at ~1.2 cm/sec and retracted out of the beamline

HPS Expected Reach

solid-2σ
dashed-5σ



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

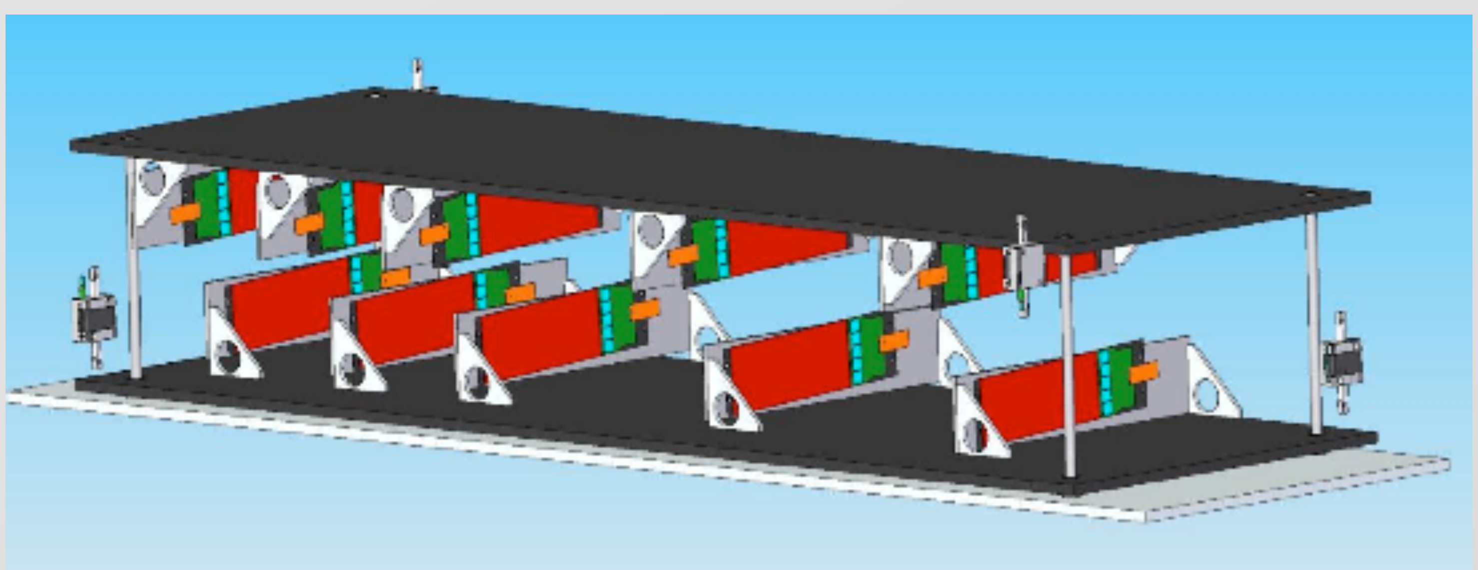
Blue:
200nA @ 2.2GeV
target: 0.125%

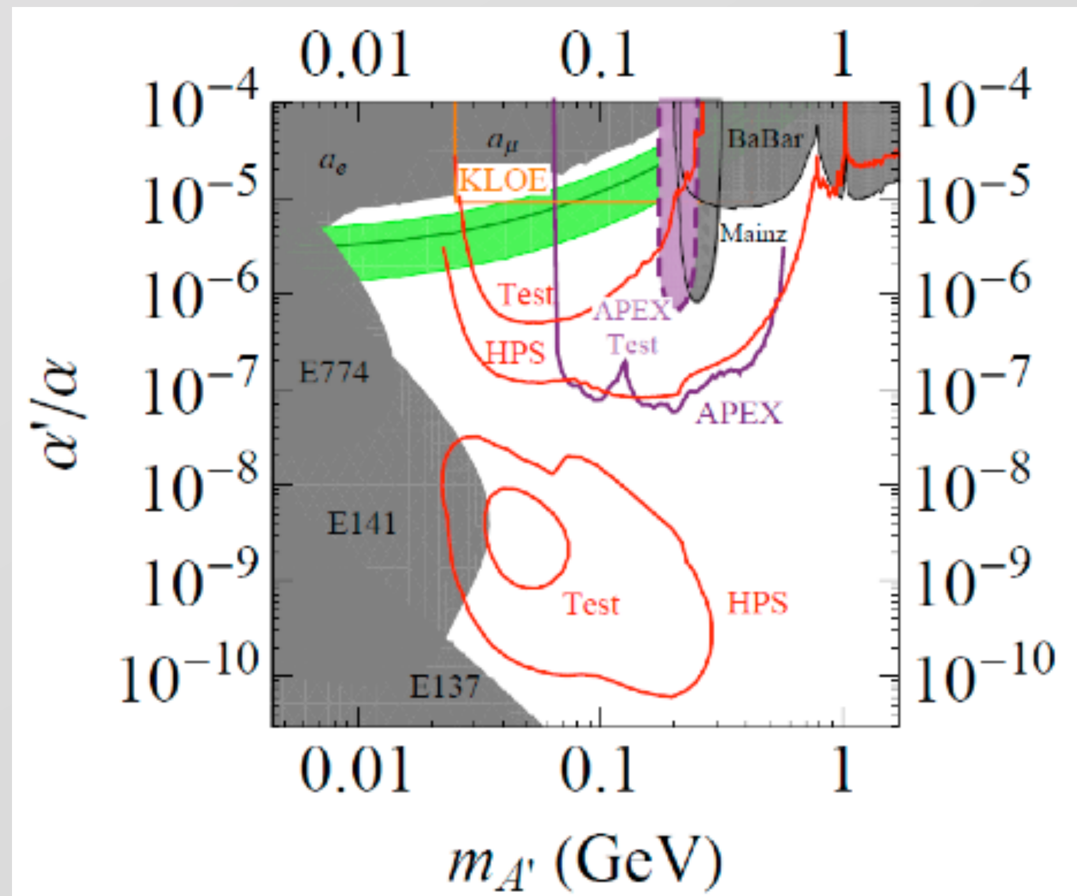
Red:
450nA @ 6.6GeV
target: 0.25%

3 months of beam at each energy

Proposal for a Test Run

- We've requested a test run in order to verify our background estimates→detector performance and trigger rates
- Existing chicane in front of CLAS, including 0.5T analyzing magnet
- Will test occupancies in SVT/calorimeter, viability of trigger algorithms, performance of entire DAQ
- If everything goes well, get some useful reach in parameter space



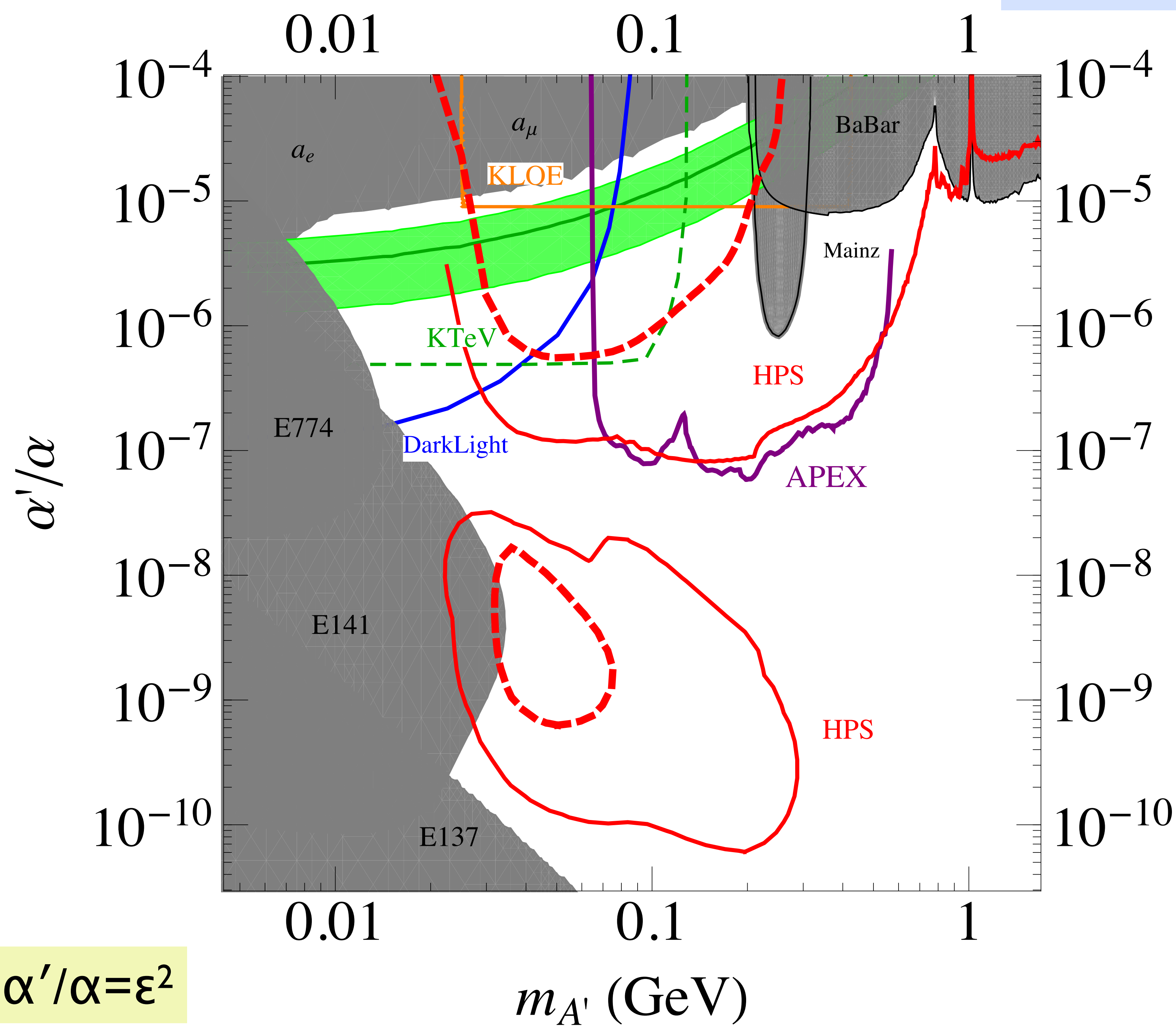


HPS Proposal Status & Outlook

- Approved by JLAB PAC conditional on successful test run
  - Request for a test run in 6 GeV era (ends spring 2012) and a 6-month run in the 12 GeV era (starts ~2014)
- Separate cost between test-run ~ $500k and main physics run ~ $1.9M
  - full costing layout in proposal
  - would be much more expensive if not for donations of equipment/ expertise from JLAB/Fermilab/SLAC
- Met with DOE in Feb. 2011 for review of test-run proposal...received funding to build detector!
- Plan is to construct test detector in stages (ECAL→SVT) AND run parasitically with current Hall-B experiment...then, hope for dedicated beam ~ spring 2012.

The big picture

2σ reach



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

What I've skipped....

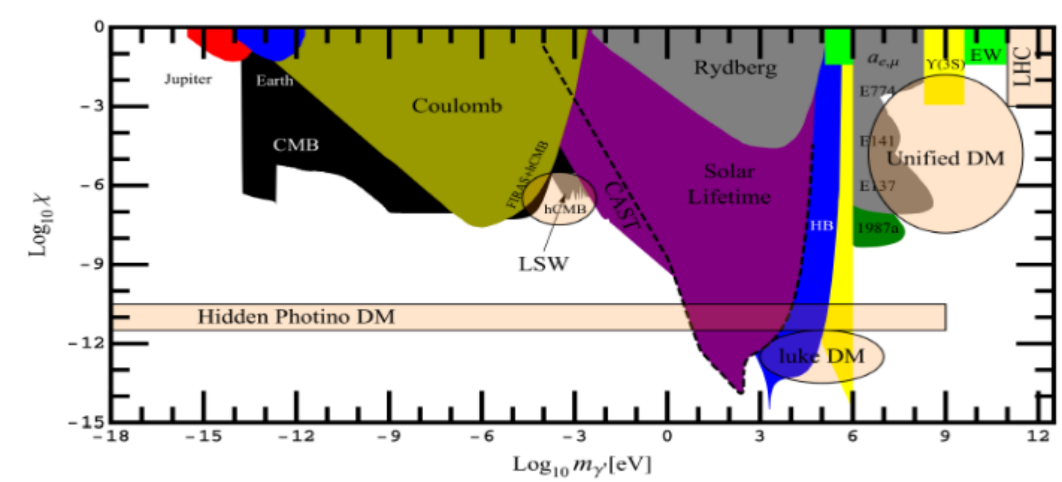
- Motivation, limits from astrophysical experiments
  - INTEGRAL anomaly, WMAP/FERMI "haze", upcoming measurements from PLANK
- Very interesting/confusing results from direct DM searches...maybe DM isn't as simple as the single-state SUSY WIMP we usually think about?
- Rich history of searches for heavy photons/Z′
  - much overlap with axion searches
- Very active searches ongoing in current and (recently) past experiments
  - direct production in e^+e^- (BaBar, Belle, KLOE, BES)
    - including non-abelian/dark higgs/dark scalar searches
  - "lepton-jets" at hadron colliders (D0/CDF, CMS/ATLAS)

Intensity Frontier Workshop

"The Office of High Energy Physics wishes to identify the most exciting opportunities to carry out experiments on the intensity frontier for our future planning."

Working Groups

- Heavy Quarks
- Charged Leptons
- Neutrinos
- *Hidden Sector, Axions, and WISPS*
- Proton Decay
- Nucleons/Nuclei/Atoms



[Jaekel and Ringwald 1002.0329v1]

Nov. 30 → Dec, 2, 2011
Rockville, MD

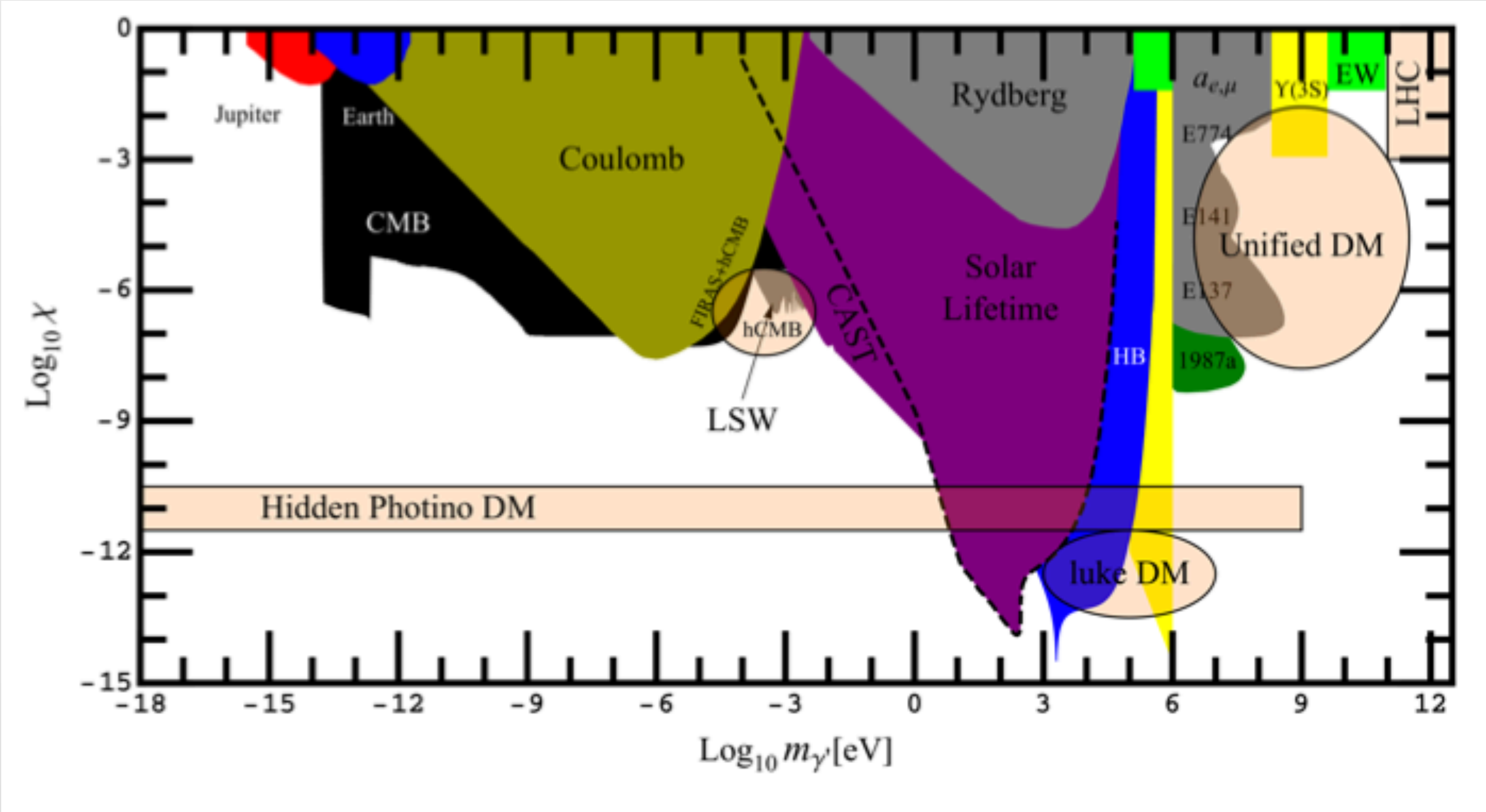
http://www.intensityfrontier.org/

Summary

- We've submitted proposals to JLAB for two dark photon searches
  - APEX -- very quick, easy, cheap while covering $\varepsilon > 10^{-3.5}$ for $85 < m_{A'} < 500$ MeV
    - Already approved
    - Test run was a success...already have published result!
    - HOPEFULLY we can get beam early next year...if not, 12 GeV era
  - HPS -- not as quick, easy, cheap but greater coverage
    - Proposal accepted by JLAB PAC
    - DOE funding for test run on schedule for winter/spring 2012 to answer some outstanding questions
    - Much work is left to do but we have great group of very eager people

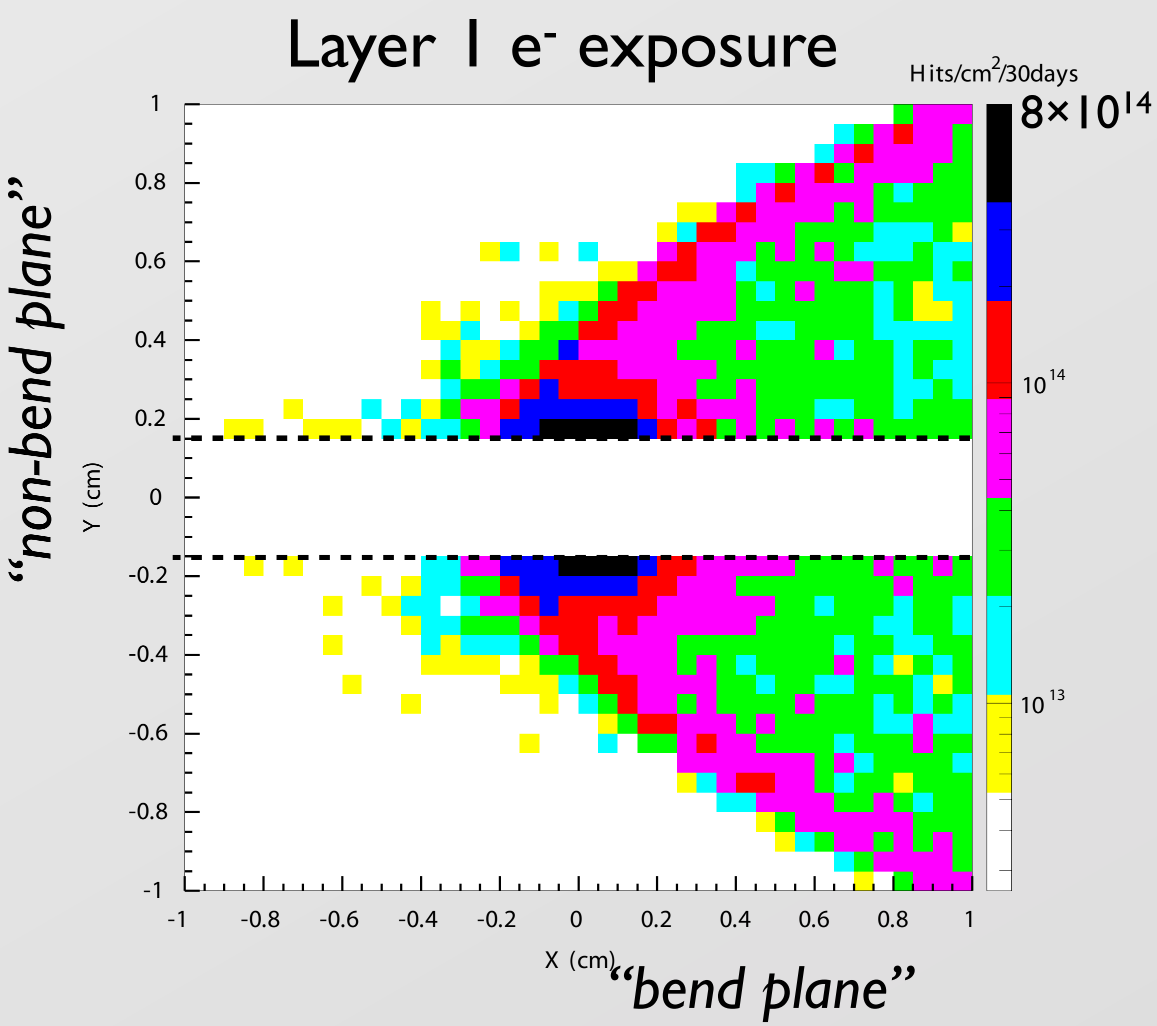
In both cases, we will be able to provide unique and interesting ***limits*** on the existence of the dark sector. Either that, or....

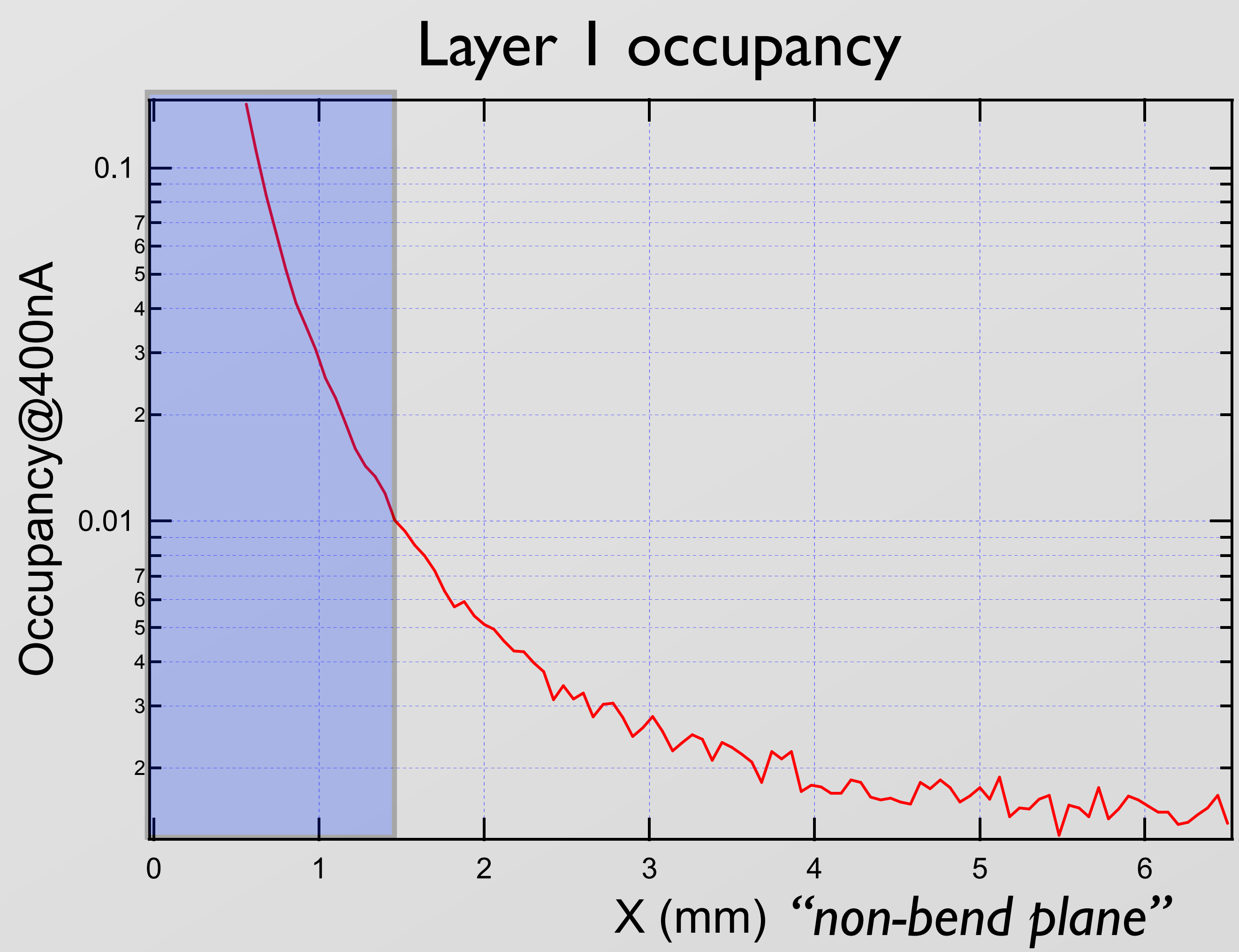
30 Decades of heavy photons



Jaeckel and Ringwald, hep-ph/1002.0329

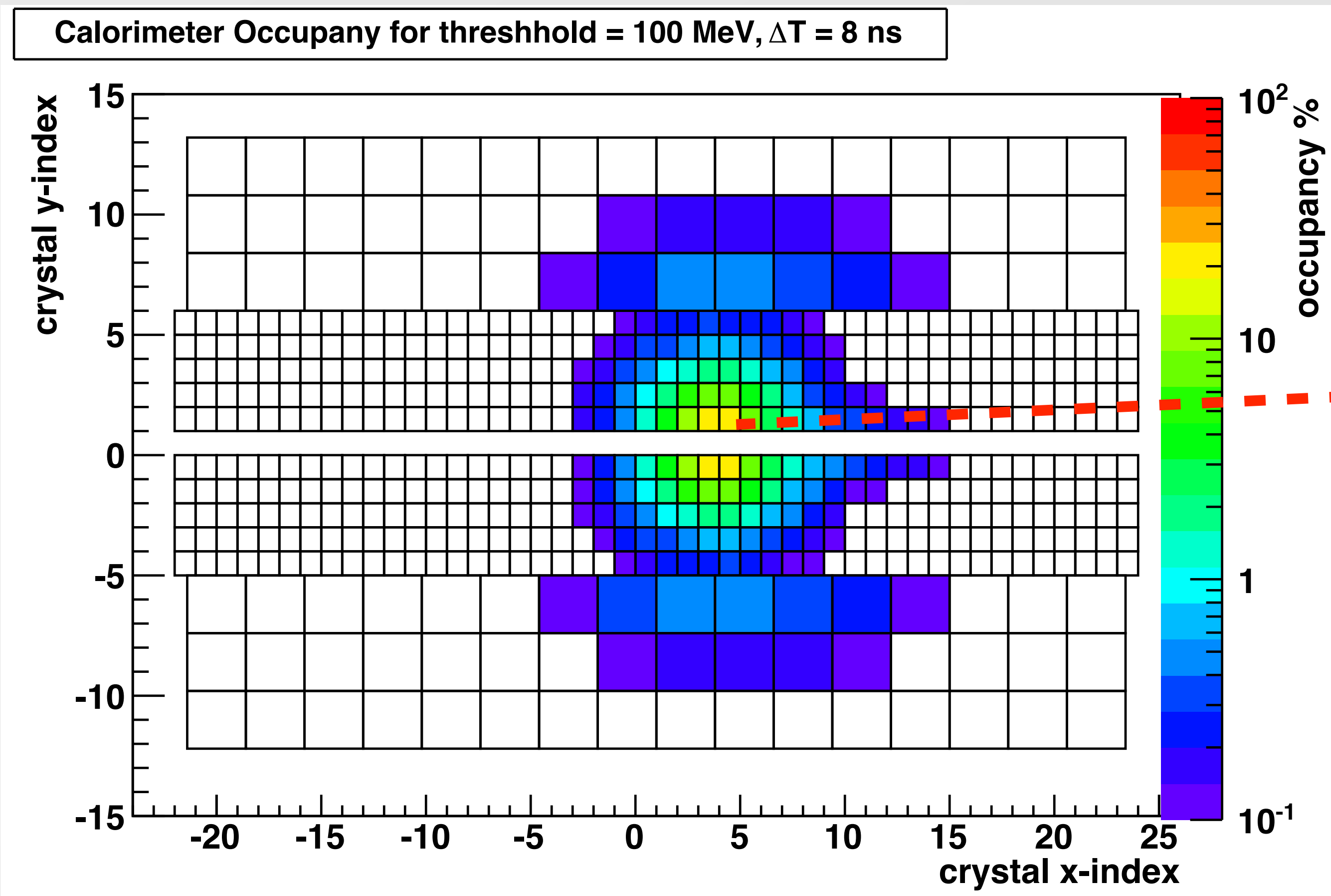
Deadzone Limits

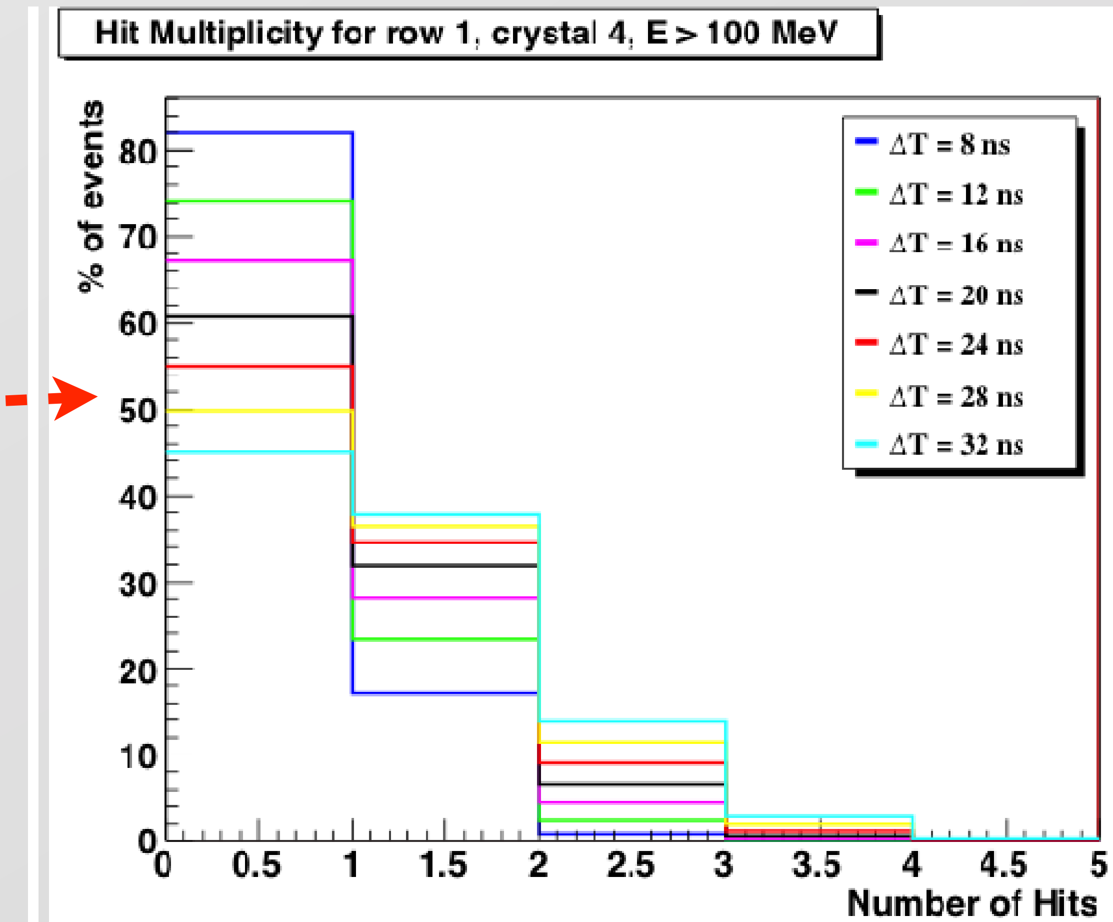




Layer 1 dead zone <±1.5 mm (15 mrad) allows for ~8 months running at acceptable occupancies.

Calorimeter occupancy





Acceptable occupancy and multiplicity can be achieved in all crystals with100 MeV threshold and 8 ns time window.

Trigger requirements

- Total trigger budget estimated at 50 kHz
- Simple 3×3 clustering with 50 MeV seed threshold

Trigger Requirement	A' (200 MeV) Acceptance	Background Acceptance	Background Rate
Events with least two opposite clusters	42.4%	2.30%	2.9 MHz
Cluster energy > 0.5 GeV and < 5 GeV	44.3%	0.123%	154 kHz
Energy sum < 5.1 GeV	44.3%	0.0066%	83 kHz
Energy difference < 4 GeV	44.2%	0.062%	78 kHz
Lower energy - distance slope cut	43.5%	0.047%	59 kHz
Clusters coplanar to 40°	42.3%	0.026%	32 kHz
Not counting double triggers	38.6%	0.021%	26 kHz

A' Mass (MeV)	50	100	200	250	300	400	500	600
Trigger Acceptance	2.9%	15.2%	38.6%	45.2%	45.2%	43.3%	39.3%	34.8%

6.6GeV

A' Mass (MeV)	25	50	75	100	150	200	250
Trigger Acceptance	4.9%	23.8%	32.1%	34.8%	34.6%	26.2%	18.3%

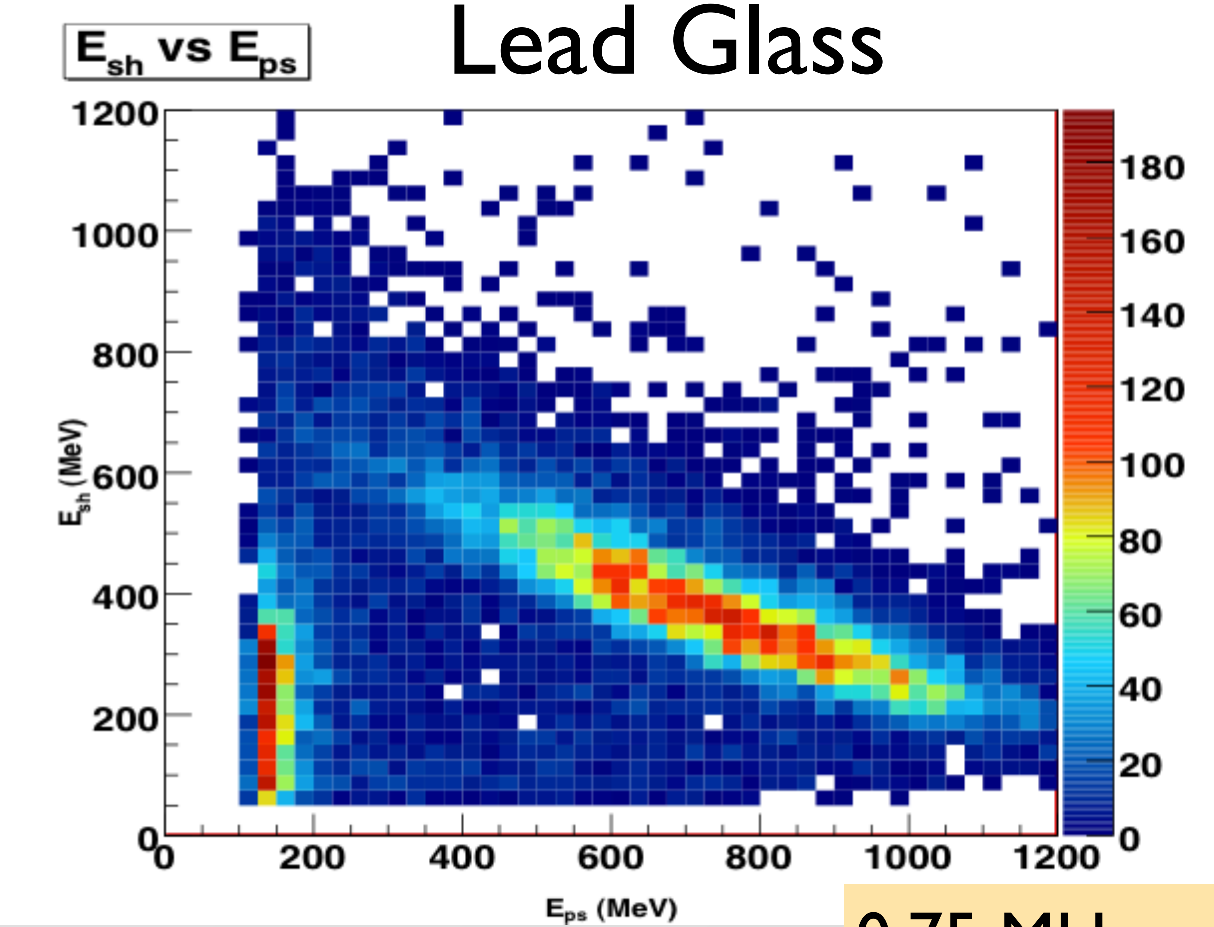
2.2GeV

APEX Test Run: PID

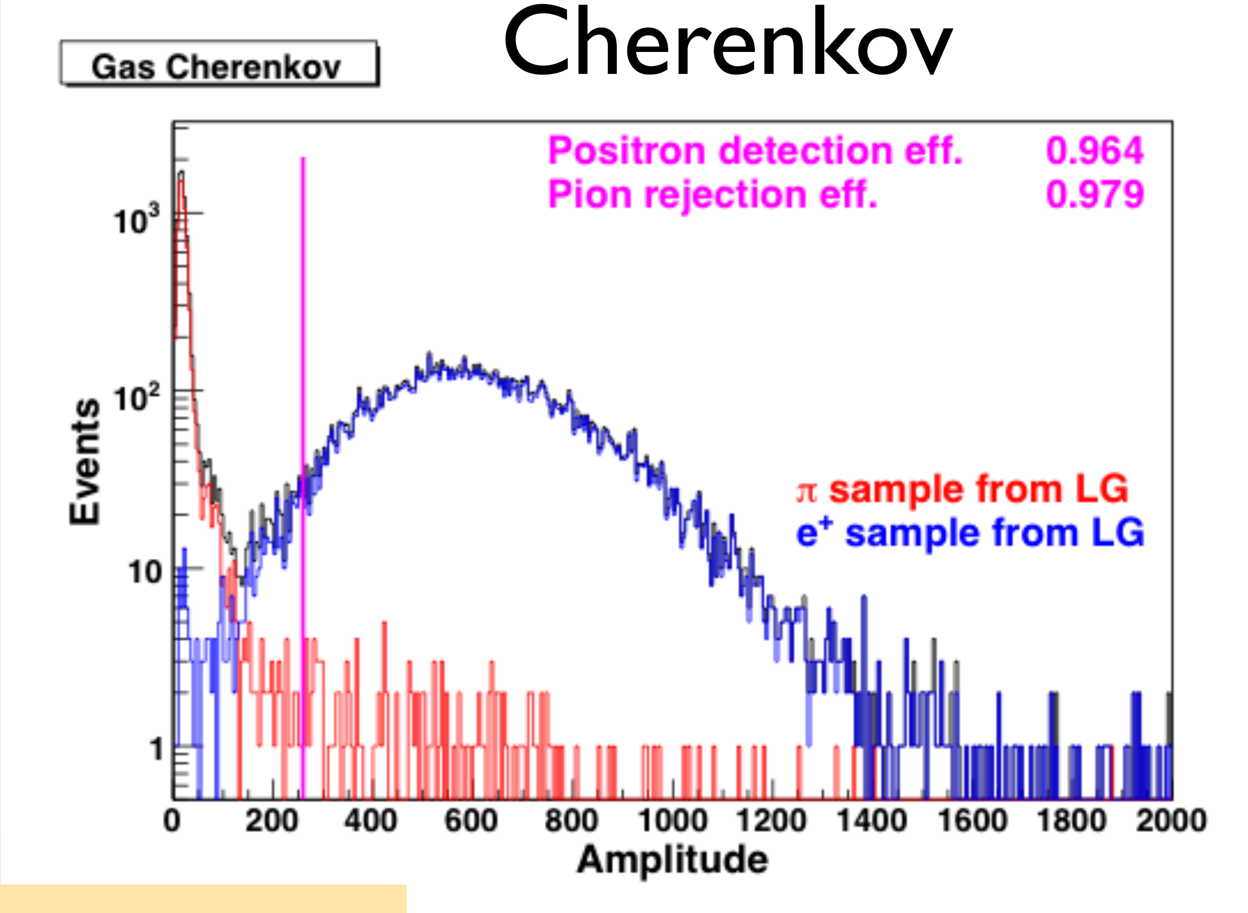
- With HRS-R GC in trigger, saw reduction in pion rate by >×30
- At highest rate taken during test run: ×48 pion additional rejection (offline)

→ We showed that we could get a) trigger rate down to DAQ limit and b) total offline rejection more than good enough to make measurement

Lead Glass

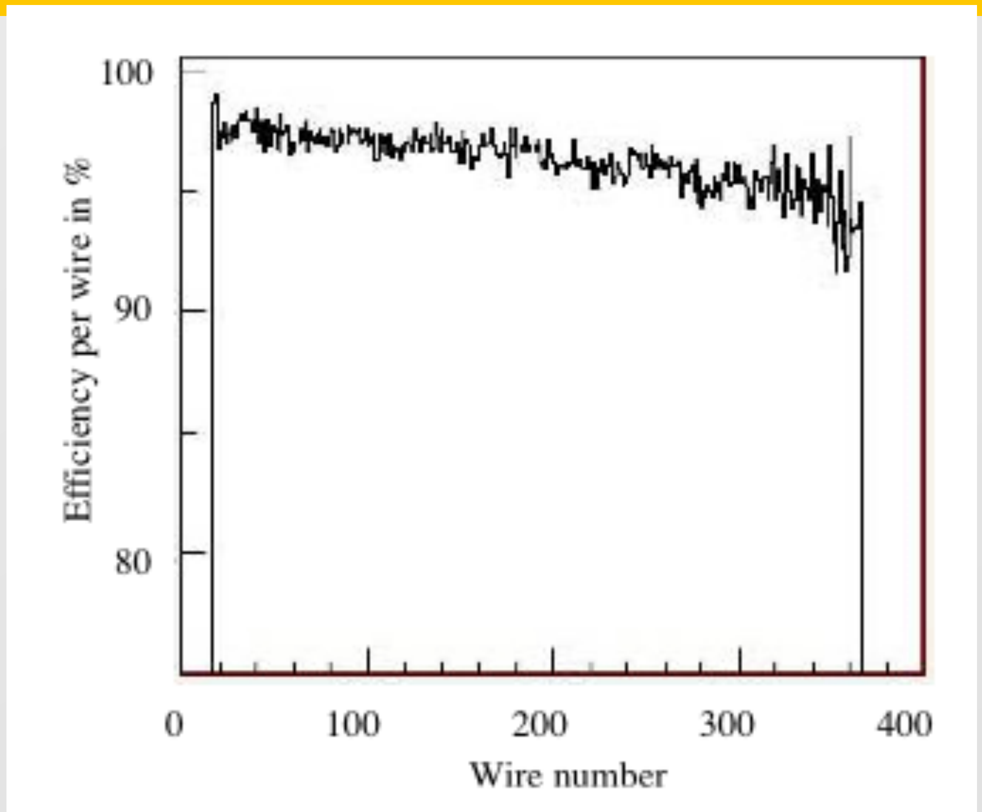


Cherenkov



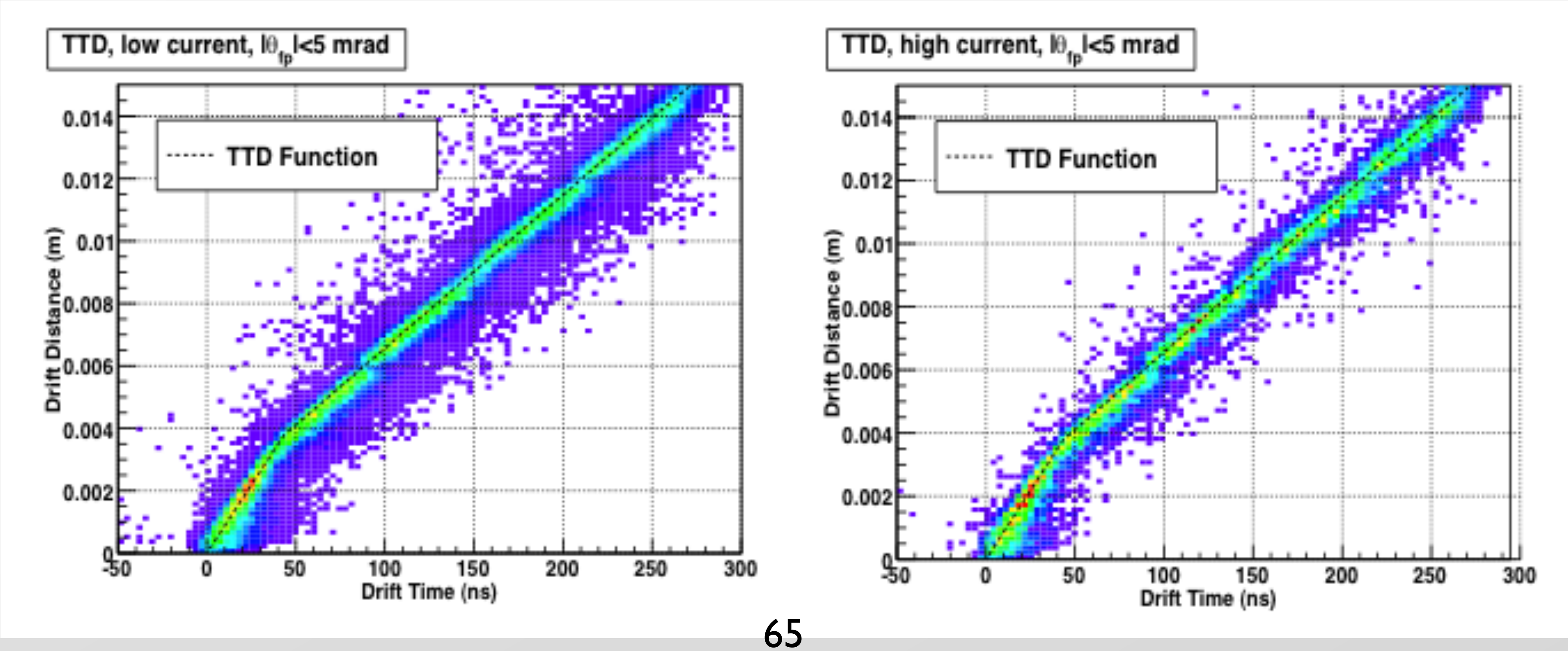
0.75 MHz rate in positron arm

APEX Test Run: VDC

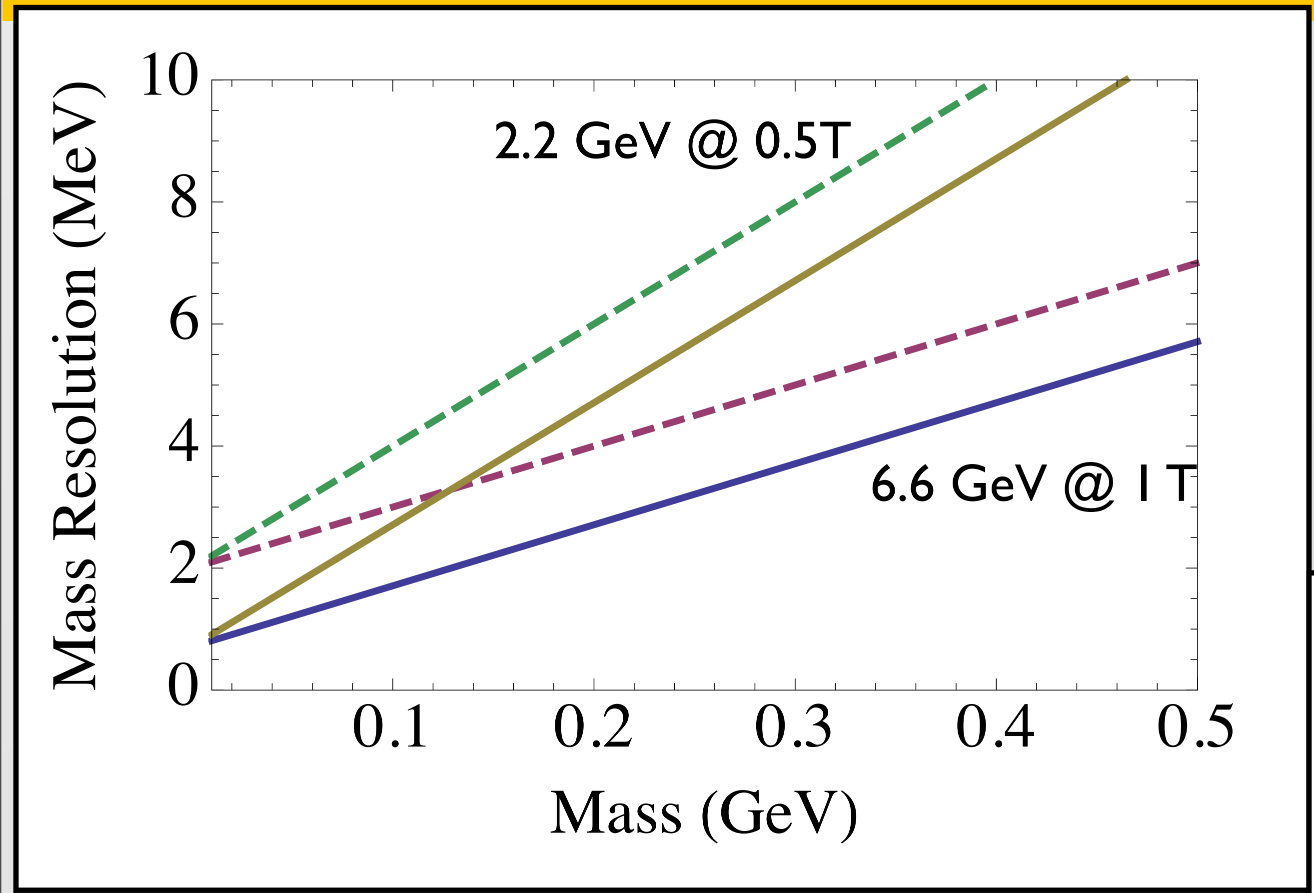


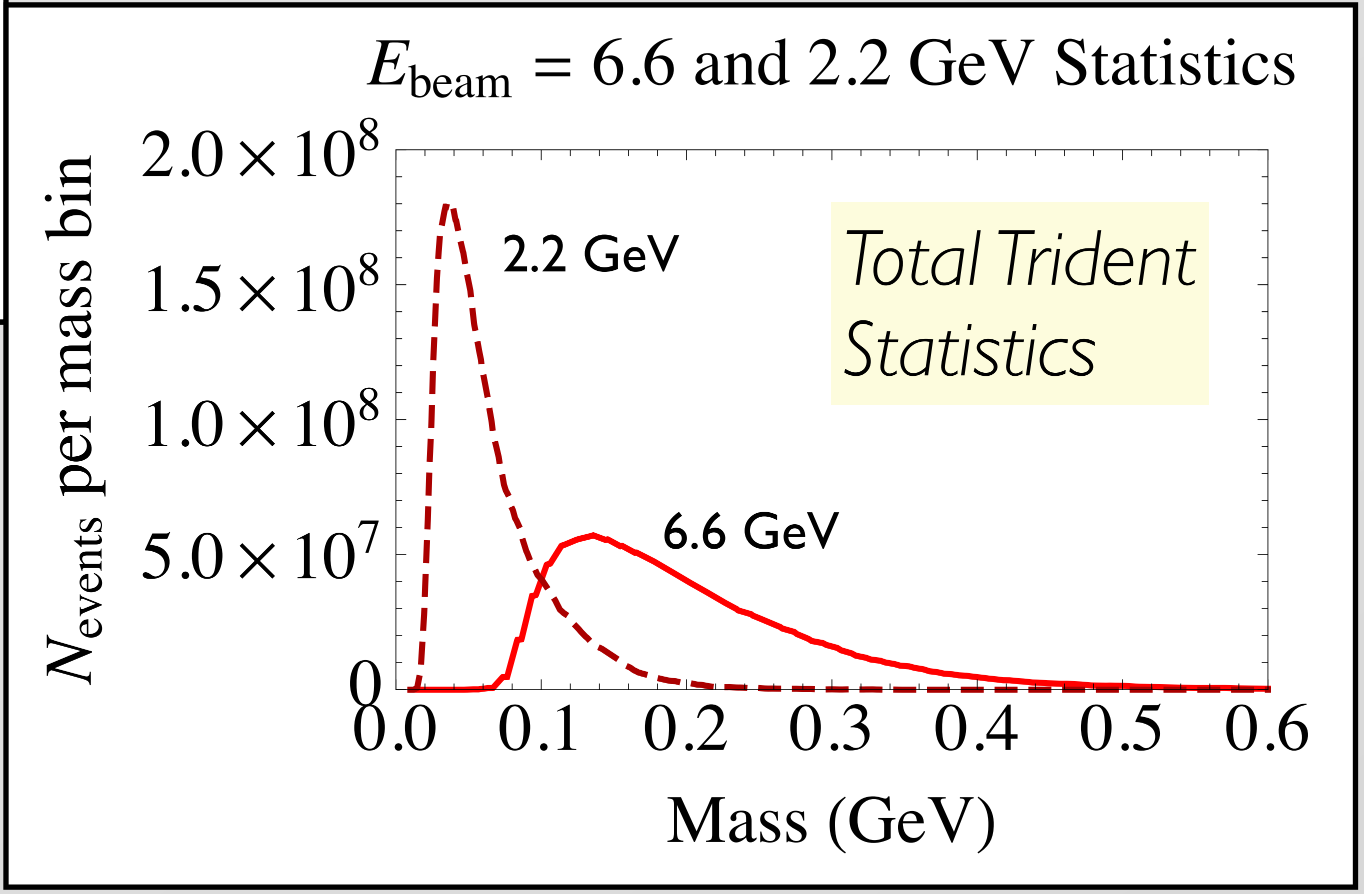
electron arm 5MHz

- VDC performance somewhat effected by high rate (75kHz/wire)
- drift timing is normal
- wire efficiency drops down as much as 5%
- track reconstruction efficiency ~60%...still acceptable
  - expect to recover some efficiency in software (maybe up to 75%)



HPS Reach Calculation





Z-Cut for Vertexing Analysis