The APEX experiment at JLab

The A′ Experiment (APEX)

Searching for a new Vector Bosons A' Decaying to e^+e^-

Jefferson Laboratory

G.B. Franklin (Carnegie Mellon University)

for the APEX Collaboration

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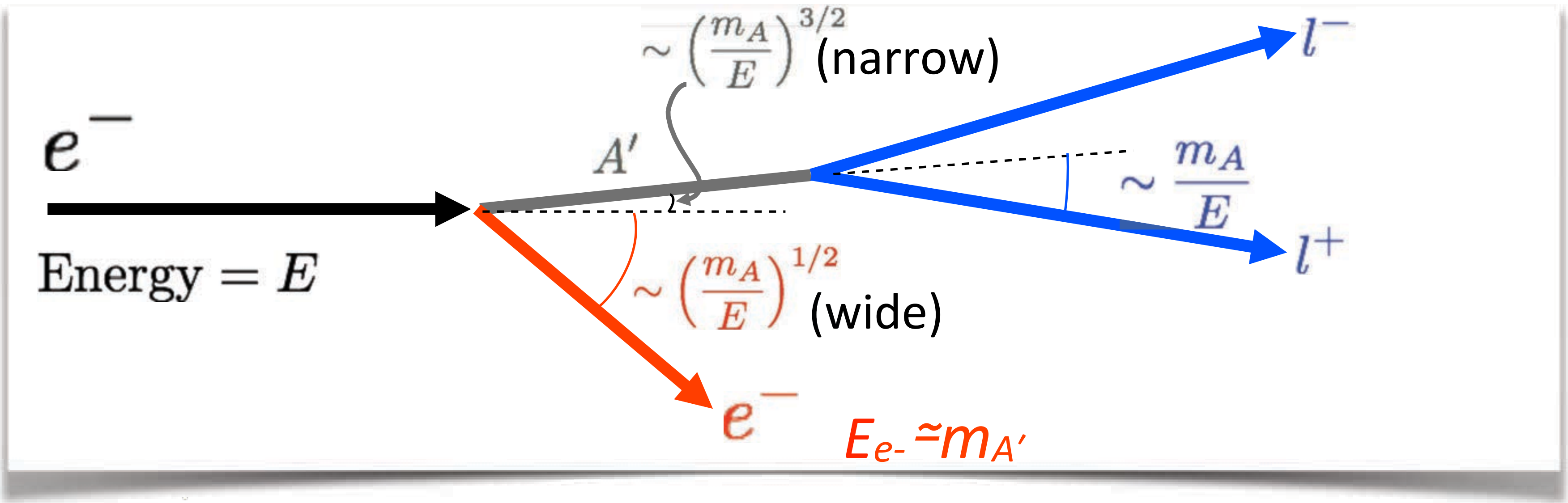
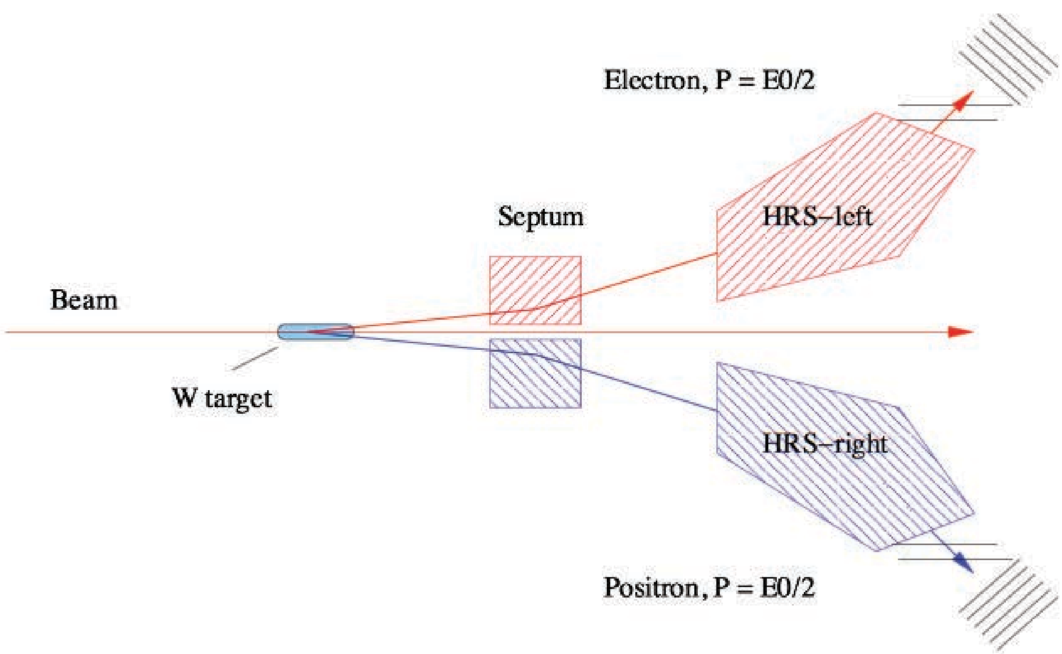
and **The Hall A Collaboration**

Yerevan Physics Institute, Syracuse University, University of Kentucky, Saint Mary's University, Haifax, College of William and Mary, University of Virginia, University of New Hampshire, New York University, Florida International University, Thomas Jefferson National Accelerator Facility, SLAC National Accelerator Laboratory, North Carolina Agricultural and Technical State University, Carnegie Mellon University, Longwood University, Massachusetts Institute of Technology, California State University at Los Angeles, Norfolk State University, Kent State University, University of Massachusetts, University of South Carolina,[1]Tel Aviv University, Perimeter Institute for Theoretical Physics, Waterloo, George Washington University, Stanford University, State University of New York

- Overview of JLab's APEX Experiment
    - Production Mechanism
    - Major Components
- The APEX Reach
    - Signal and Background
    - Resolution Requirements
    - Region of Sensitivity
- Key Components
    - HRS Spectrometers
    - Septum Magnet
    - Novel Foil Target
- Achieving δm=0.5% Invariant Mass Resolution
    - Kinematic Considerations
    - Angle and Momentum Resolution
- Other Details
- APEX Test Run Results
- Summary

➢ Overview: Dark Photon Production and Detection





Jefferson Lab Electron Accelerator

Now in the "12 GeV era"

6 GeV → 11 GeV

- Increase # RF modules
- Upgrade existing RF modules
- Upgrade arc magnets
- 11 GeV to Hall A
- Extra ½ turn for Hall D gives 12 GeV

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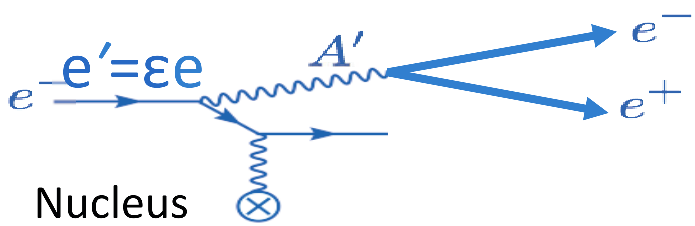
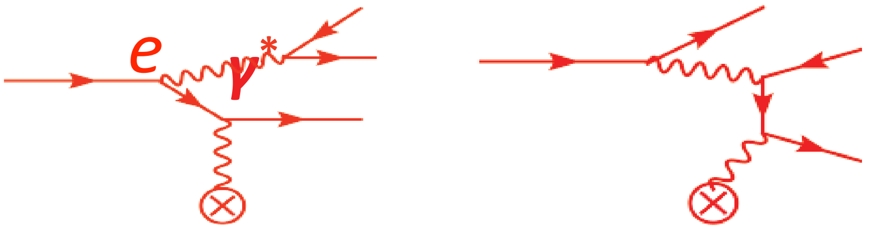
The APEX Reach: A' Signal and Background

A′ Production



QED Backgrounds



$\sigma \sim \varepsilon^2\alpha/m^2 = \alpha'/m^2$

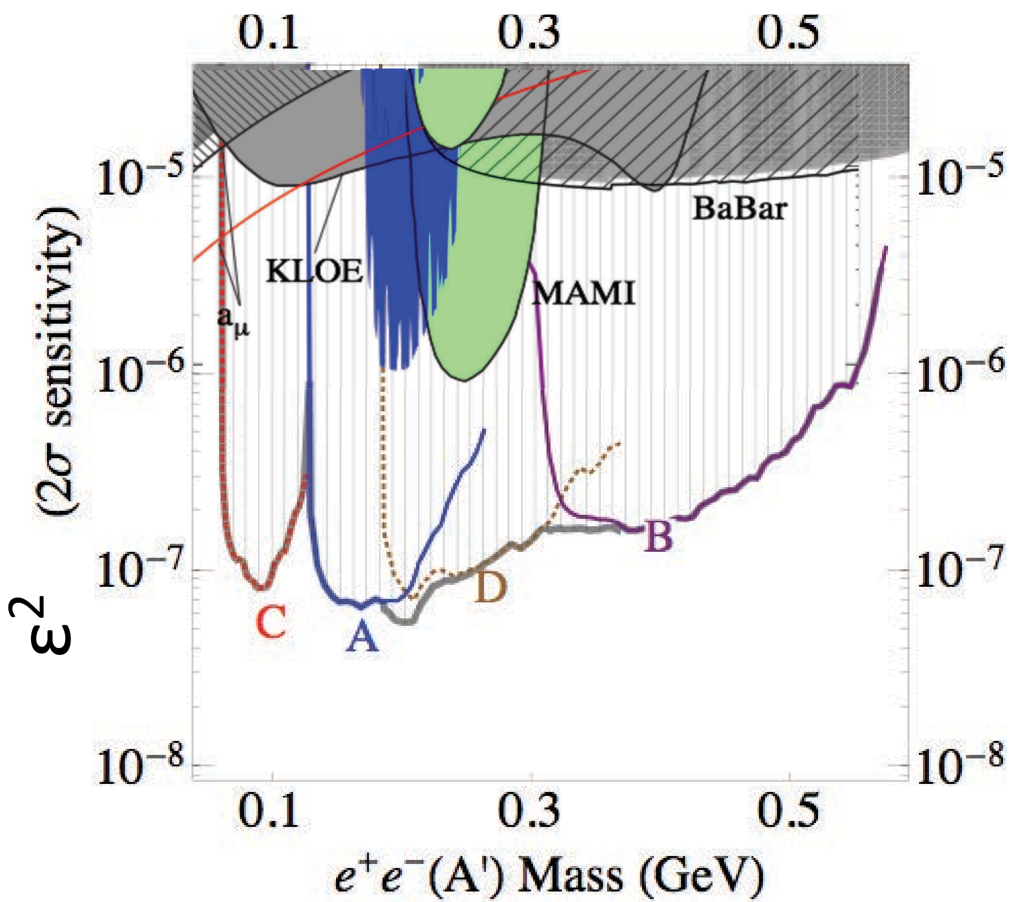
$d\sigma \sim \alpha^2/m^3\, dm$

- Narrow peak on broad background
- Region of sensitivity: $\varepsilon^2 > 9 \times 10^{-8}$
  $65\ \text{MeV} \leq m_{A'} \leq 525\ \text{MeV}$

- Requires invariant-mass resolution: $\delta m = 0.5\%$
- APEX achieves this using:
  1) JLab's twin High Resolution Spectrometers (HRS)
  2) Septum Magnet to reach ± 5° central acceptance
  3) Novel tungsten-foil target

Coverage Achieved With 4 Kinematic Settings

65 MeV ≤ $m_{A'}$ ≤ 525 MeV



1 Month Beam Time

A) 6 days @ 2.3 GeV
B) 12 days @ 4.5 GeV
C) 6 days @ 1.1 GeV
D) 6 days @ 3.3 GeV

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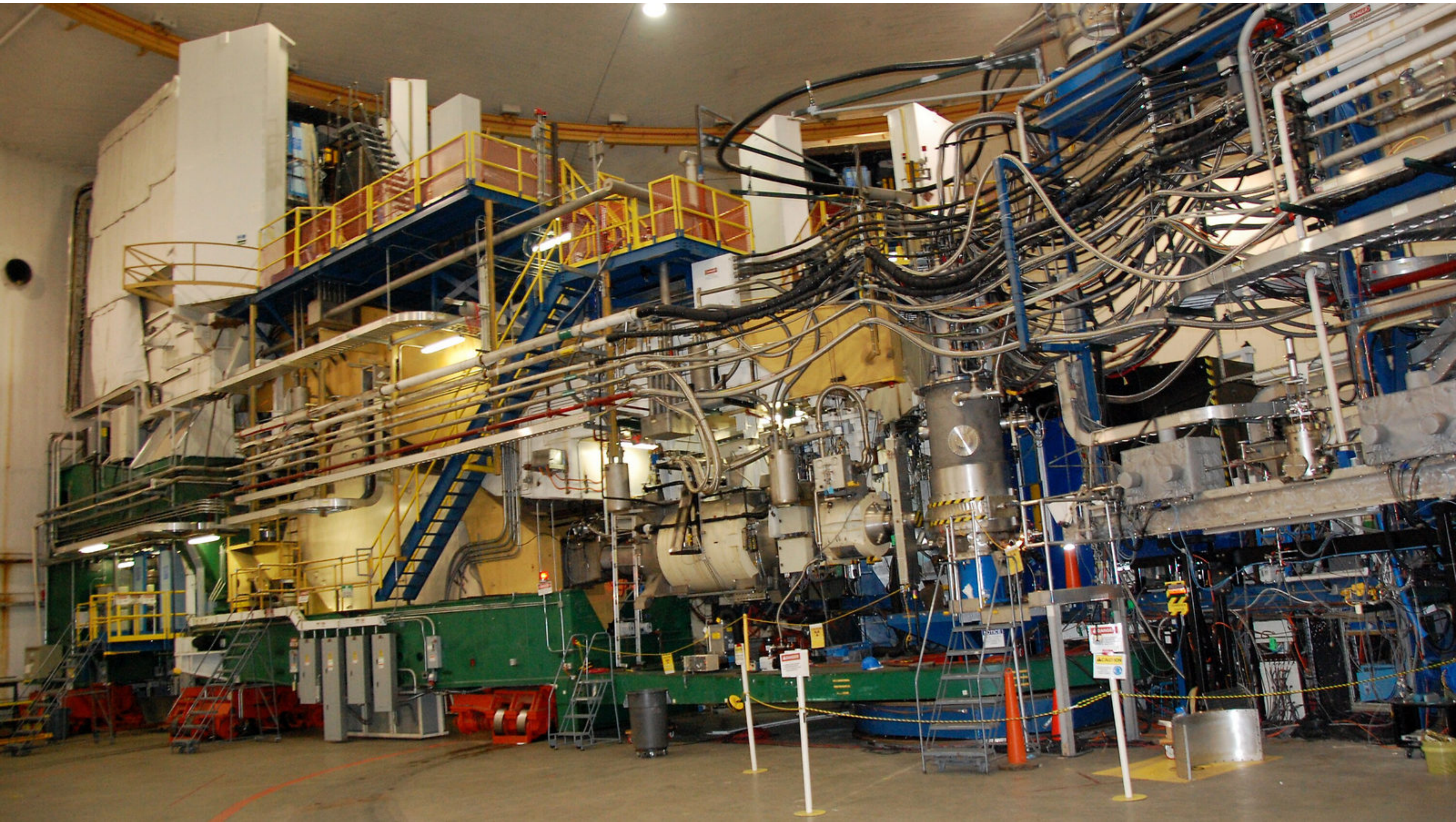
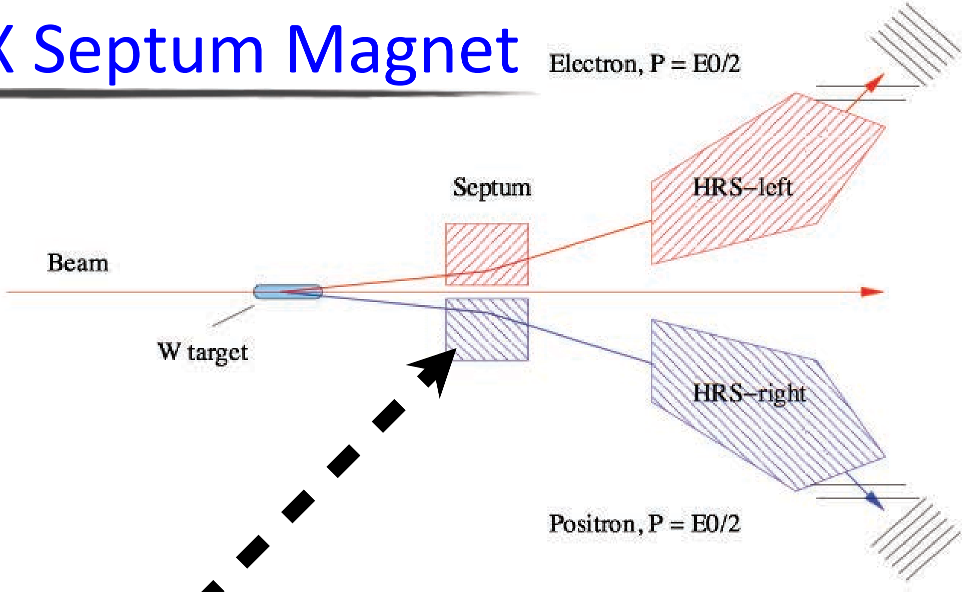
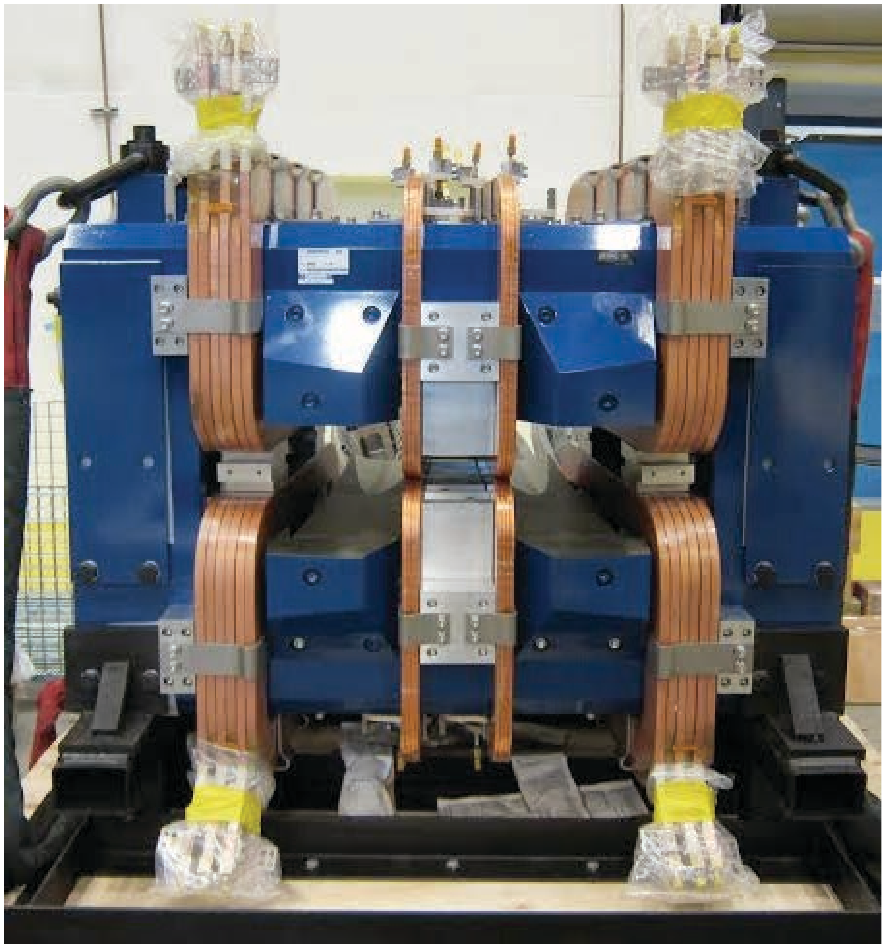
Key Component 1: Twin High Resolution Spectrometers

Left HRS



Key Component 2: The APEX Septum Magnet

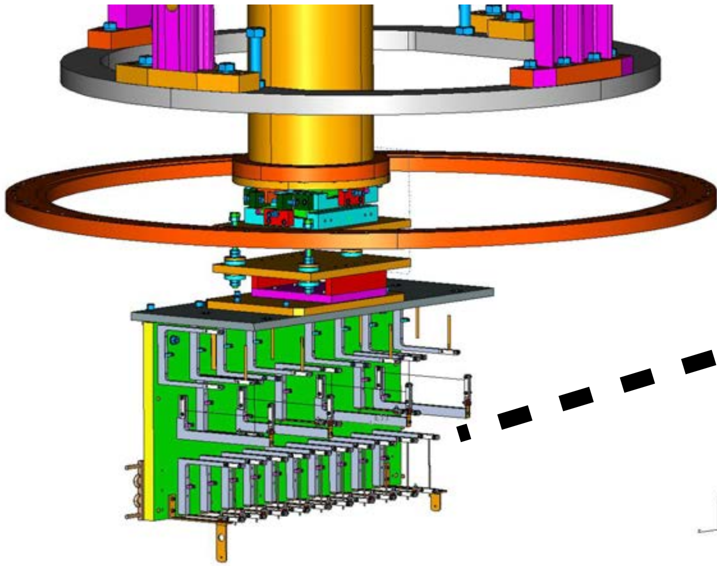


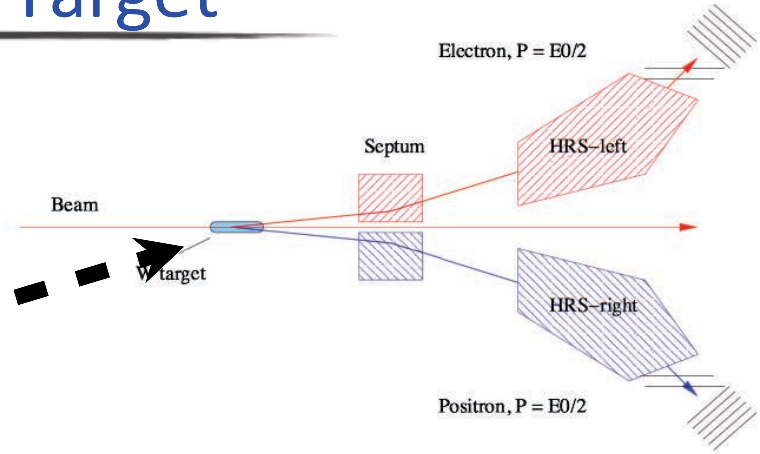


- e^+e^- pairs at ~±5°
- Septum magnet required
- Completed Aug. 2014

Funding was provided by five universities: NCCU, CMU, CSULA, SBU, UW(Ca)

Key Component 3: Tungsten-Foil Target



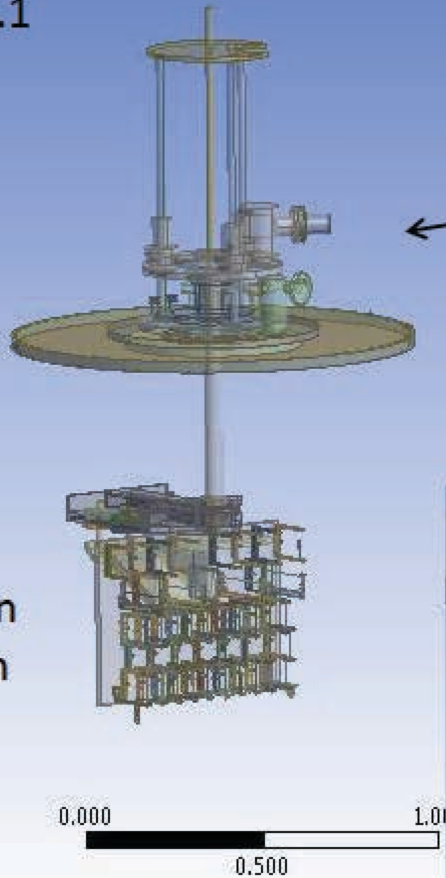


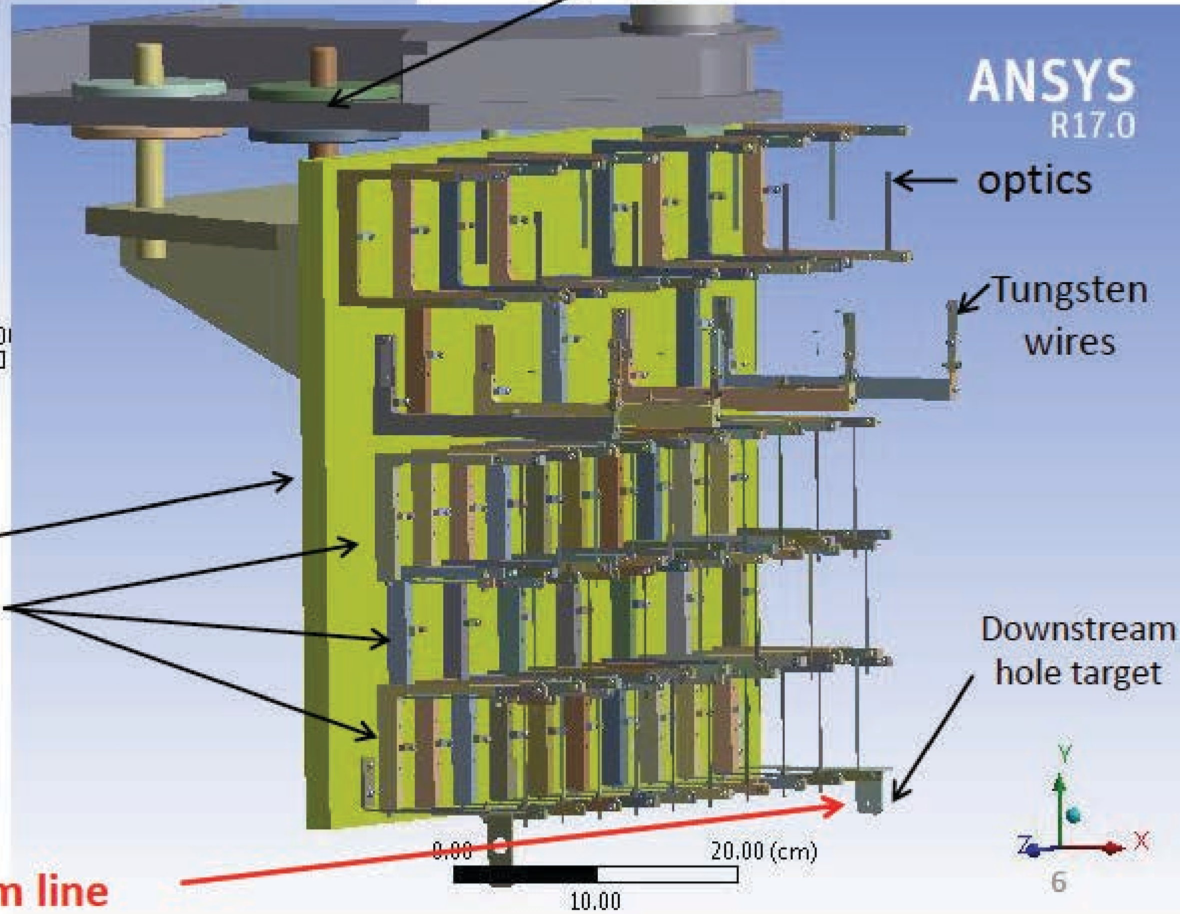
- Multi-foil, tungsten target
- 0.7% to 5% radiation lengths
- Minimizes multiple scattering

  e^+e^- pairs miss downstream foils
- Distributed along beam

  increases HRS angular acceptance
- SLAC-designed target
- Hall A Radiation-Load analysis critical
- Thermal heating/cooling a (solved) issue

Charge bullet 5.1





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Achieving δm=0.5%

Invariant Mass:

$$\begin{aligned} M^2 &= (p_1^\mu + p_2^\mu)^2 \\ &= 2E_1E_2 - 2\vec{p}_1 \cdot \vec{p}_2 \\ &= 4p_1p_2 sin^2\frac{\theta}{2} \\ &= p_1p_2\theta^2 \end{aligned}$$

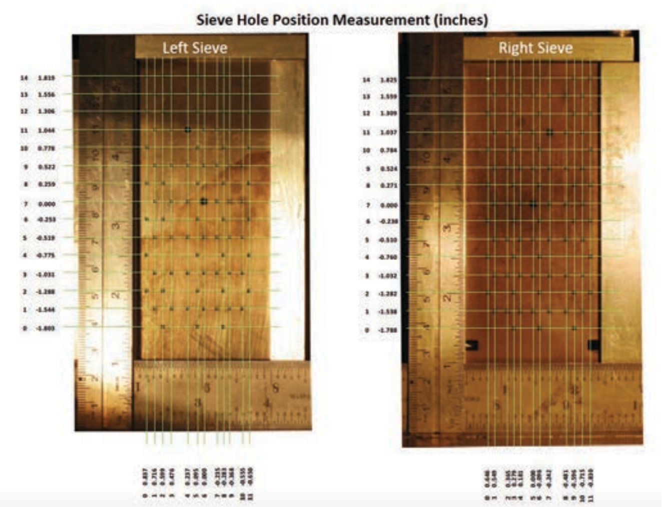
Mass Determination:

$$\frac{\delta M}{M} = \frac{\delta p_1}{2p_1} + \frac{\delta p_2}{2p_2} + \frac{\delta\theta}{\theta}$$

Spectrometer Positioning:

Angle between the 2 central holes determined to 0.3 mrad.

For 0.3 mrad error,
reconstructed mass shifts 0.17%



Achieving δm=0.5%

Mass Resolution: $$\left(\frac{\sigma_M}{M}\right)^2 = \frac{1}{2}\left(\frac{\sigma_p}{p}\right)^2 + \left(\frac{\sigma_\theta}{\theta}\right)^2$$

Mass Resolution Goal: $$\frac{\sigma_M}{M} \leq 0.5\%$$

HRS Resolution: $$\frac{\sigma_P}{P} < 10^{-3}$$ (Not a problem)

Thus goal requires: $$\frac{\sigma_\theta}{\theta} \leq 0.5\%$$

For $\theta = 10^0$, requires: $\sigma_\theta < 0.9$ mrad

Target multiple scattering: $\sigma_{\theta-targ} \approx 0.5$ mrad (p_{beam}=2.2 GeV)

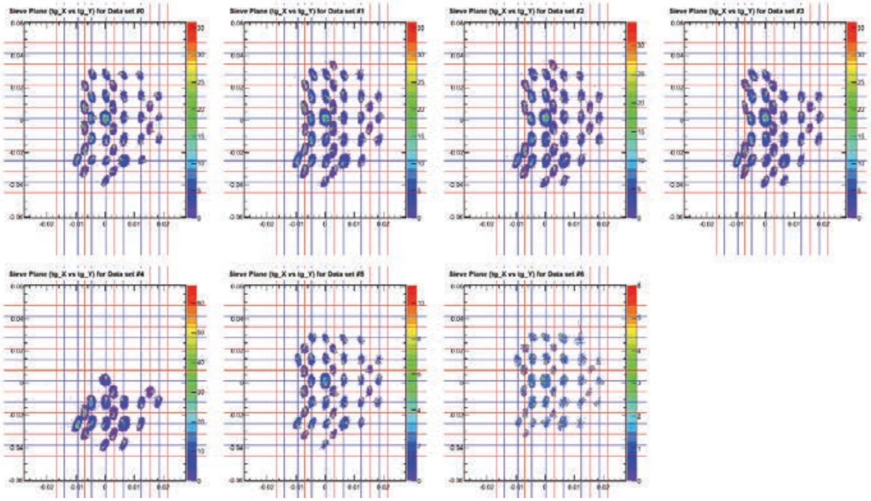
Combined HRS resolution budget: $\sigma_{\theta-HRS} < 0.7$ mrad

Achieving δm=0.5%

Required Angular Resolution $$\frac{\sigma_\theta}{\theta} \le 0.5\% \rightarrow \sigma_\theta \le 0.7\text{mrad}$$

APEX Test Run W-Sieve Data Analysis shows we can get this

- Used to tune optics transport parameters
- Track measurement and magnetic optics uncertainties
  - 0.54 mrad (horizontal)



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Other Details: Active SciFi Sieve

- Sieve Calibration gives track measurement and magnetic optics uncertainties: 0.54 mrad (horizontal)
- But this was for electrons (not positrons)
- Aberrations observed when reversing field in one HRS/Septum
- Test Run ran with larger resolution uncertainty
  - Estimated at $\sigma_\theta \leq 0.7\,\mathrm{mrad}$

- Need to minimize and measure with new septum installed
- Need to calibrate optics with positrons

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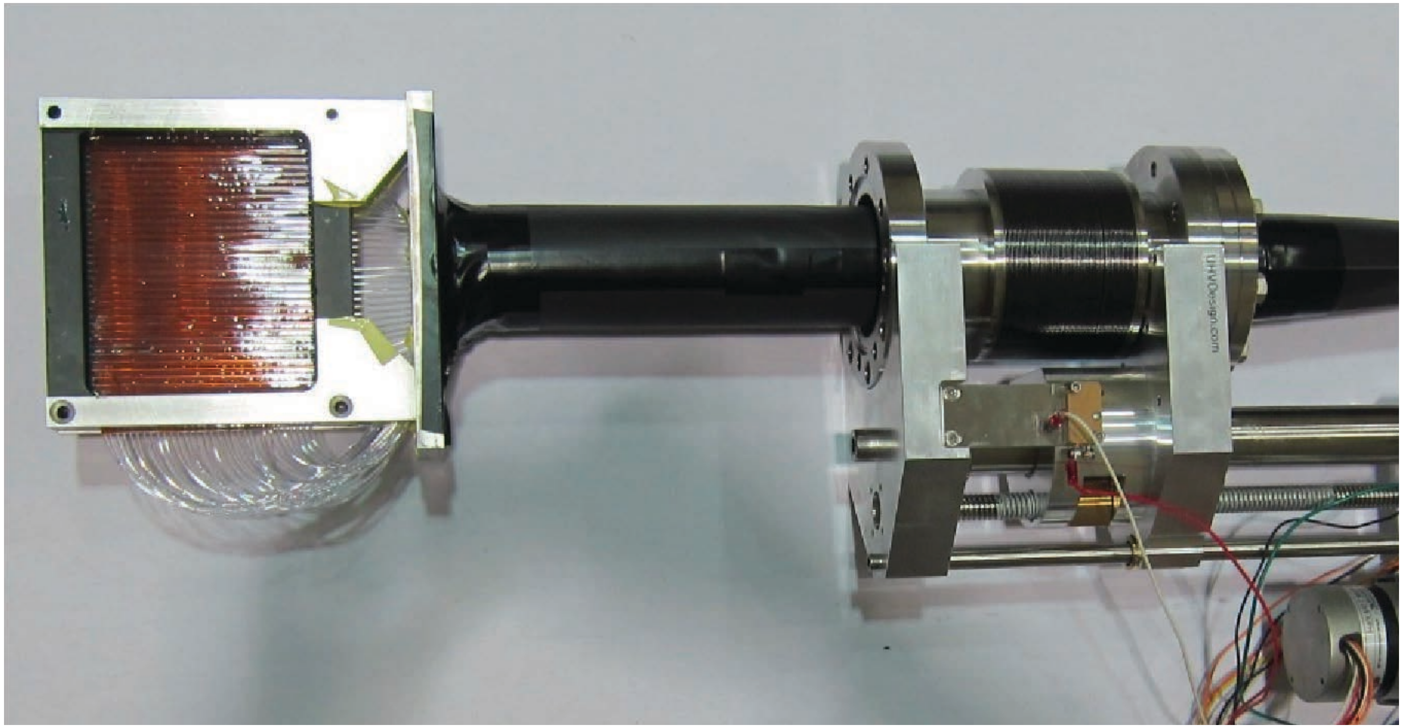
Problem: W Sieve didn't work for positrons

- Test Run: No signal above background
- Monte Carlo: Not remedied by thicker sieves

Other Details: Active SciFi Sieve

Solution: Use a scintillating fiber hodoscope at sieve position



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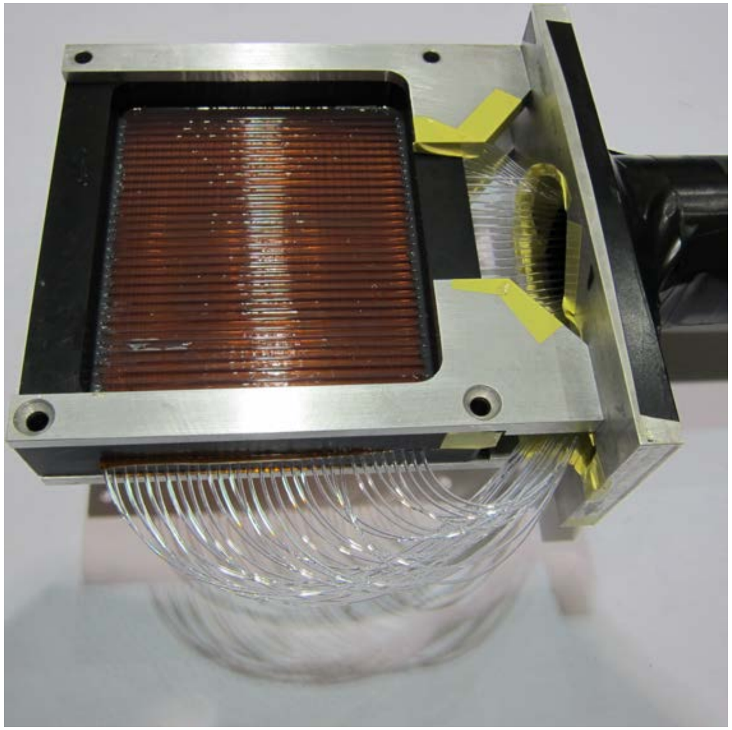


Configuration

8.8 cm x 10.3 cm

Two planes of 1 mm scintillating fibers

32 fibers per plane

Readout for two active sieves

Two 64 -fiber bundles,

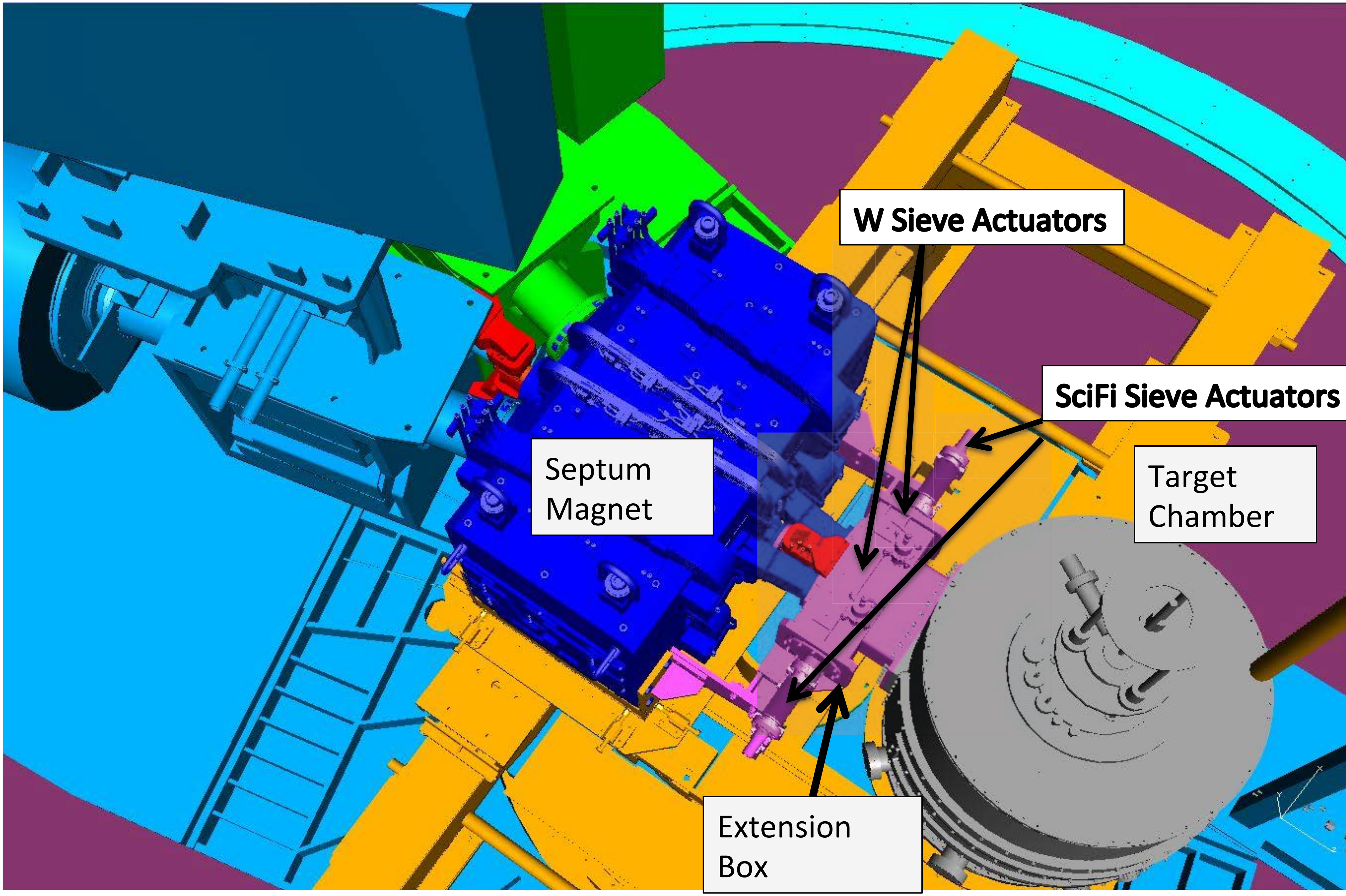
1.5 mm diam. fibers

Two multi-anode PMTs

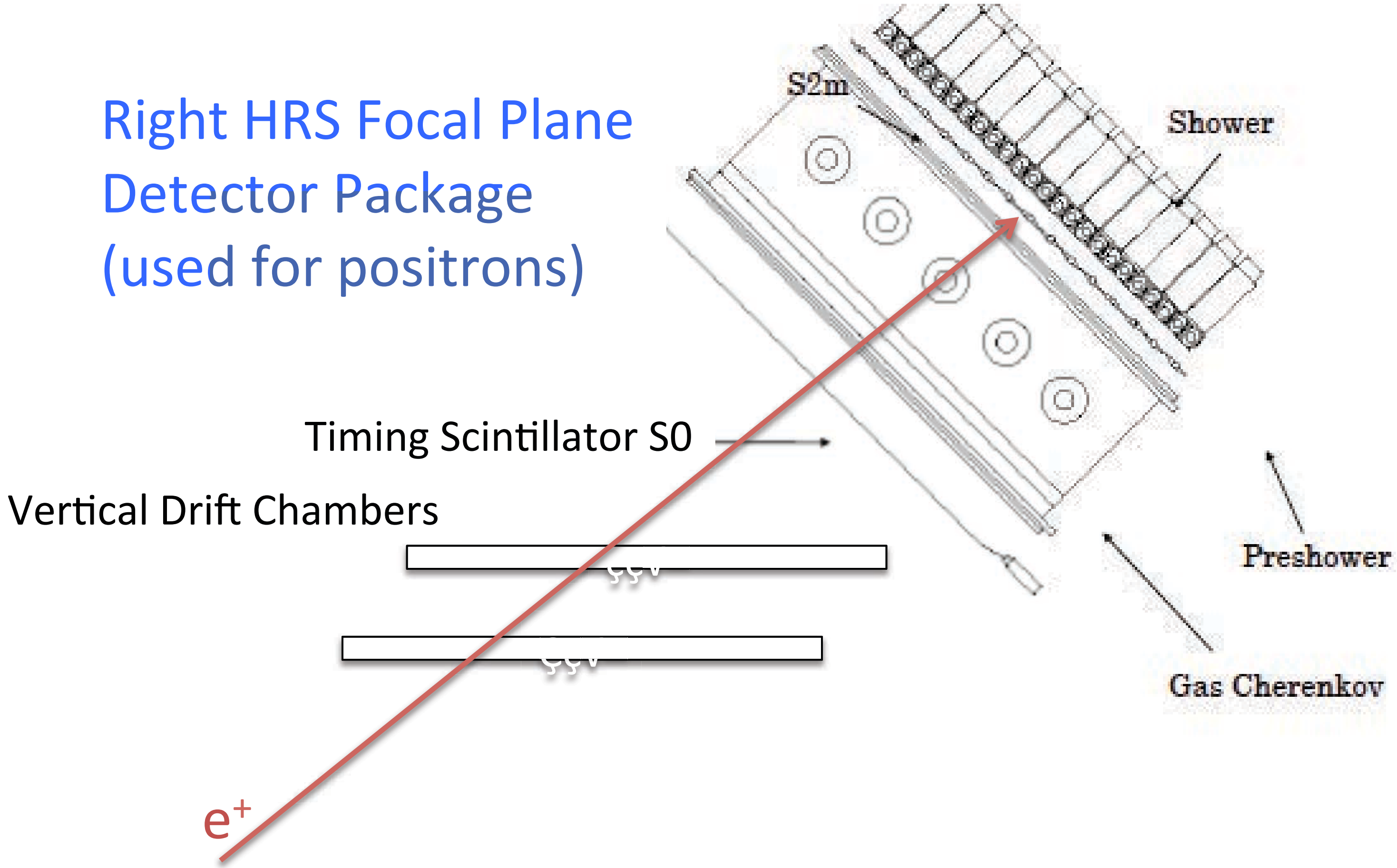
x10 signal amplifiers

Eight 16-channel FADCs (JLab F250)

➢ Other Details: The Target Region



Other Details: HRS Focal Plane Instrumentation



Standard HRS instrumentation

+ Improvements in HV supply & Tracking Algorithms for higher rates

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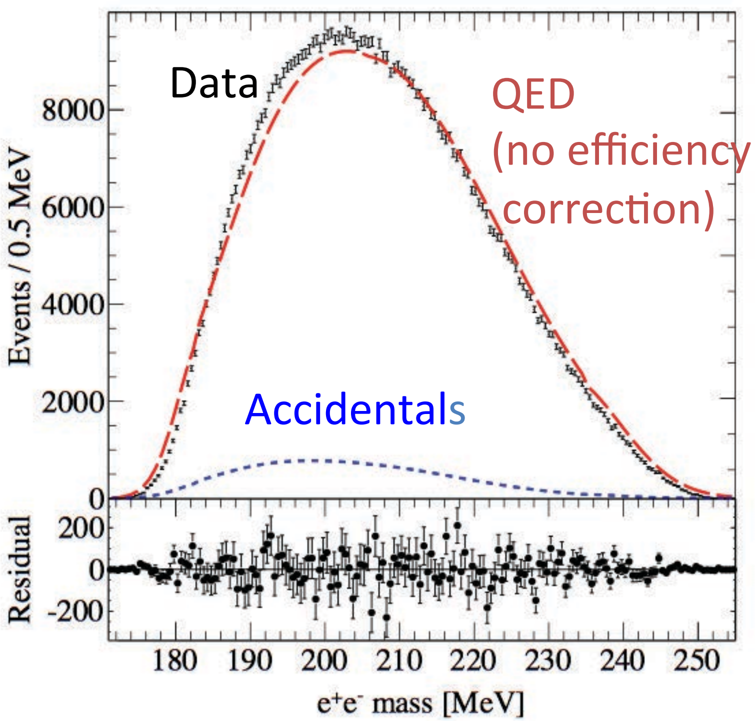
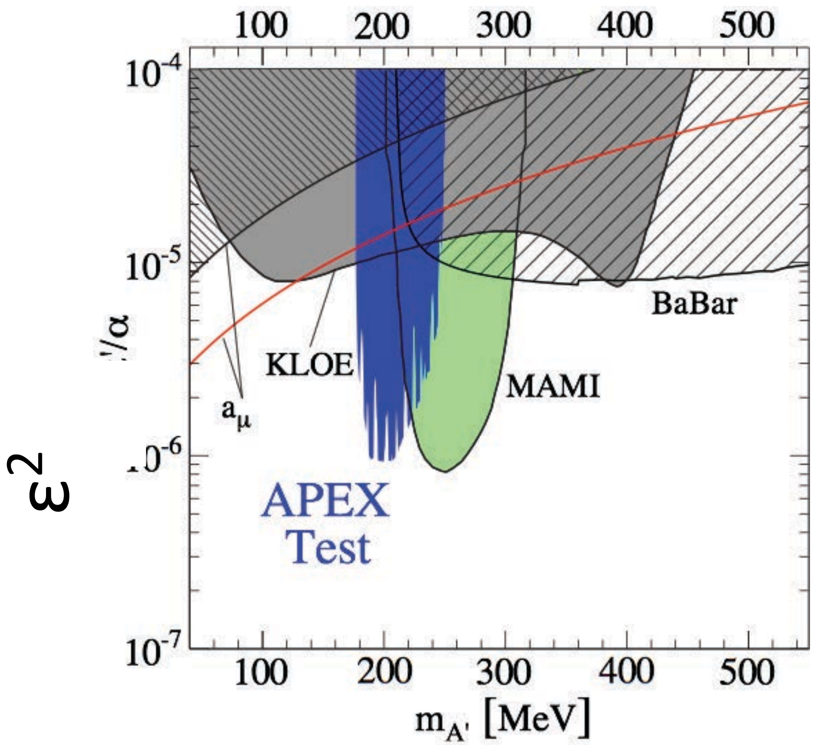
The APEX Test Run

- Test run performed in Hall A, July 2010
- Used existing (non-optimal) septum magnet
- 22 mg/cm^2 tantalum foil
- 2.26 GeV electron beam
- HRSs set at 1.131 GeV ± 4.5%
- Verified all key aspects of apparatus performance
- 770,000 coincidence events
  - 0.9% meson contamination
  - 7.4% accidentals
  - 700,000 good trident events

The APEX Test Run

JHEP 1102:009,2011, arxiv:1001.2557
PRL 107:191804,2011, arxiv:1108.2750





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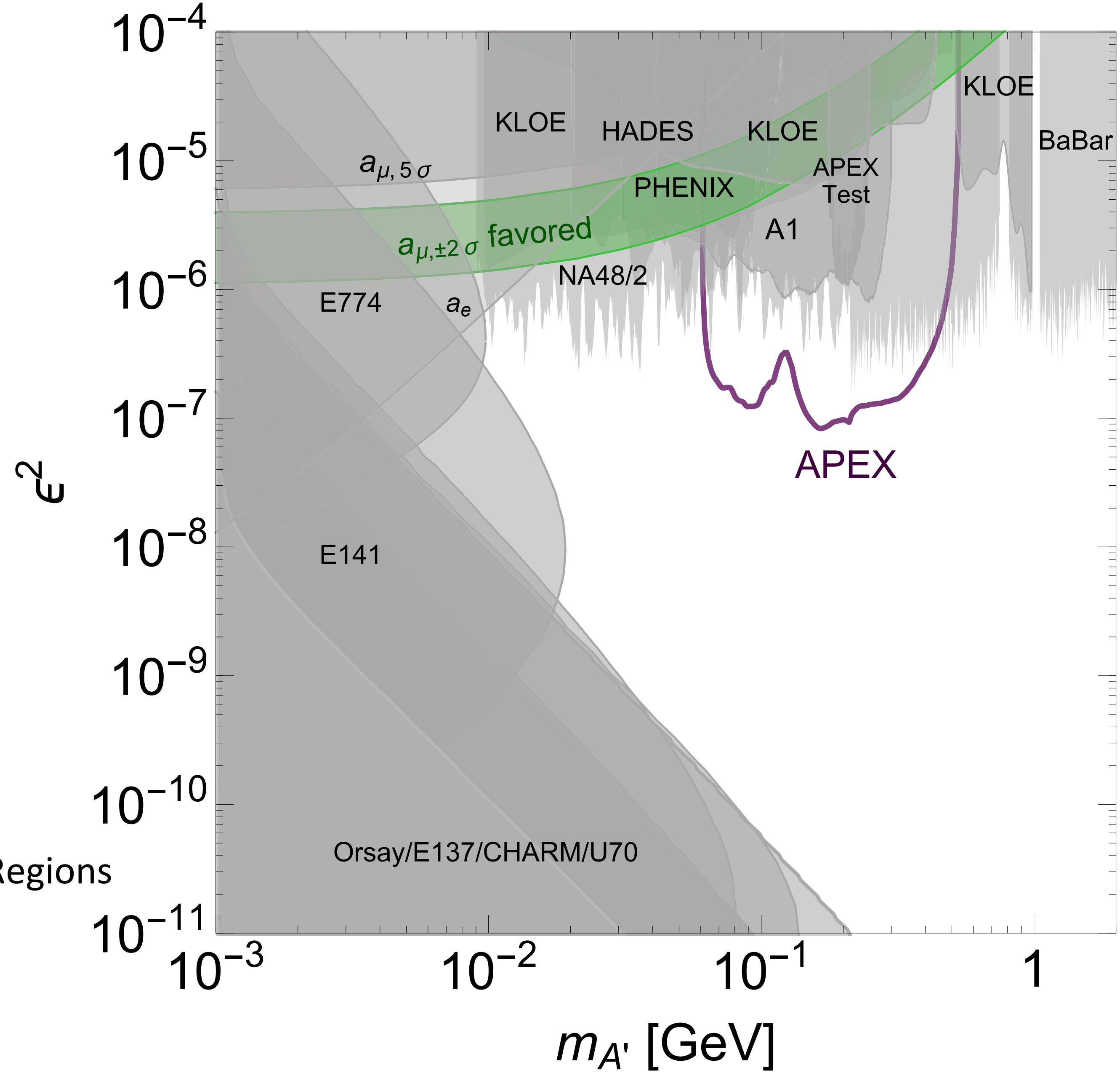
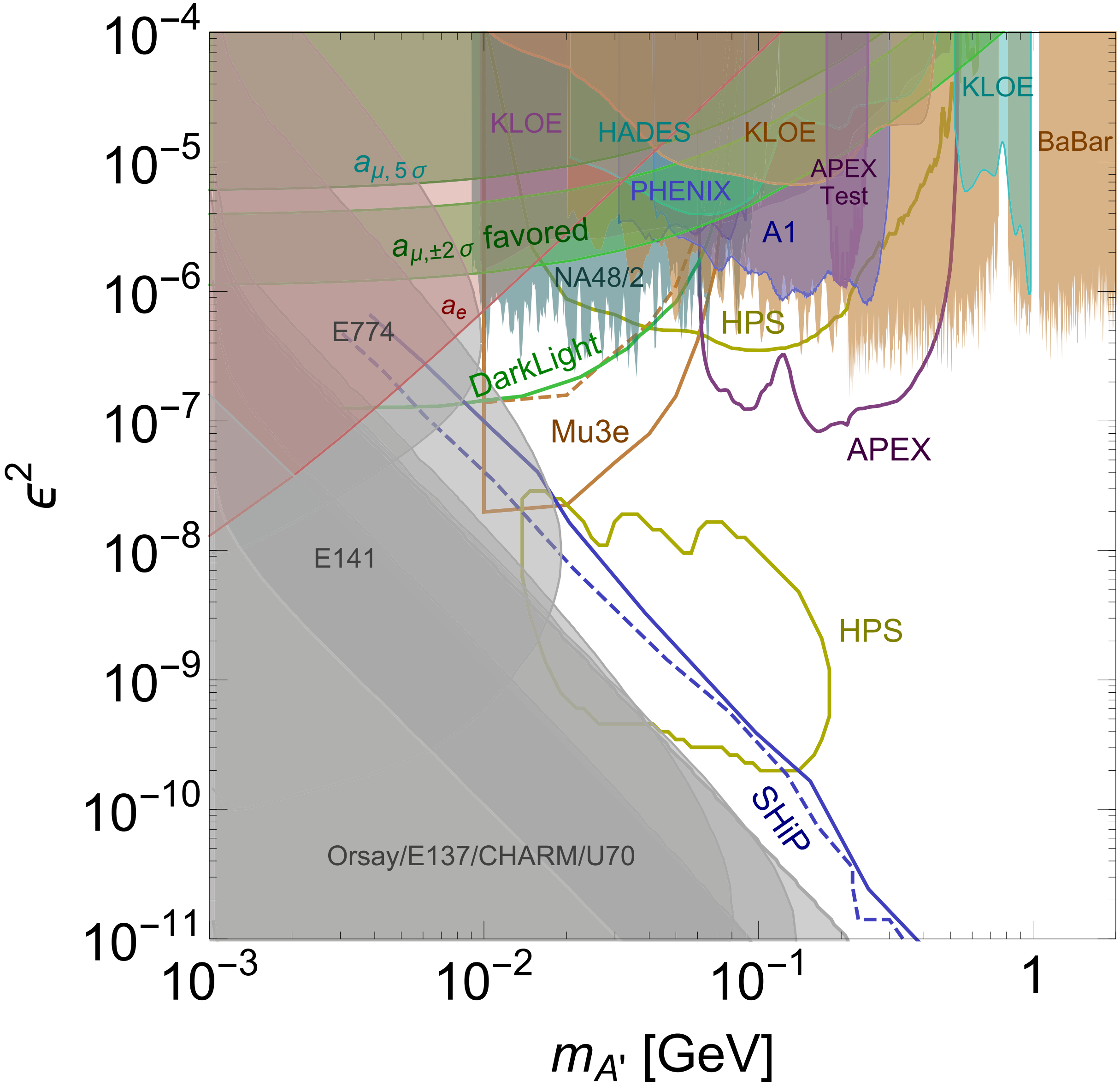
Summary: A' Exclusion Regions



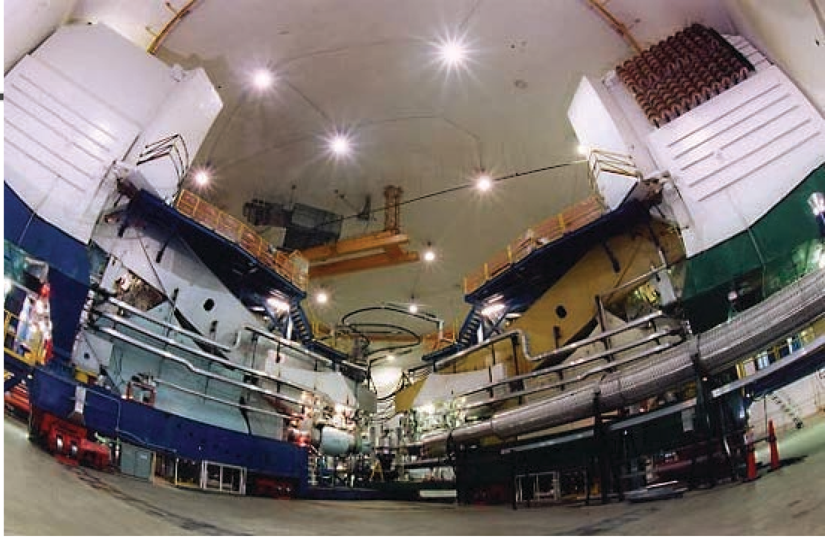
Current Exclusion Regions
Rouven Essig

Summary: A’ Exclusion Regions



Future (2021)
Exclusion Regions
Rouven Essig

Concluding Remarks



JLab High Resolution Spectrometers

- APEX Reach: $\varepsilon^2 > 9 \times 10^{-8}$
  $65\ \text{MeV} \leq m_{A'} \leq 525\ \text{MeV}$

- APEX identified as "High Impact Experiment" (JLab PAC41)

- Was read to run Spring 2016

- Run Schedule: Spring 2018 ?

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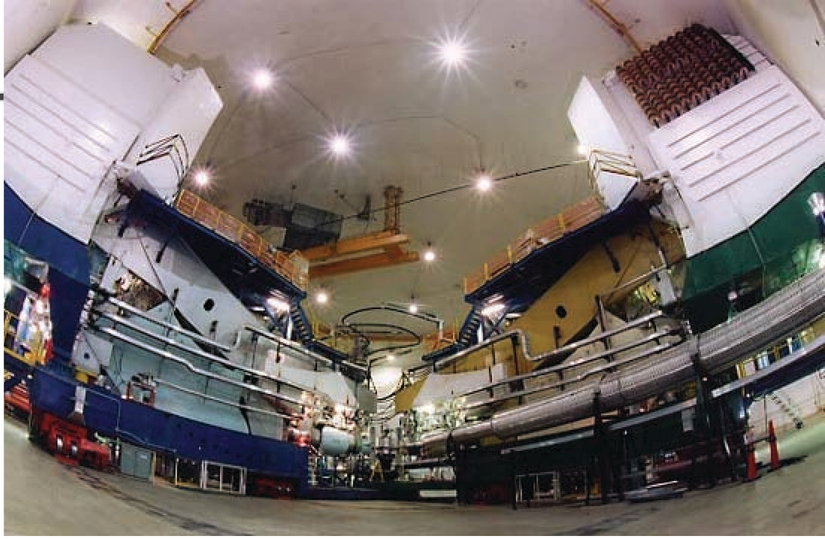

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THANK YOU