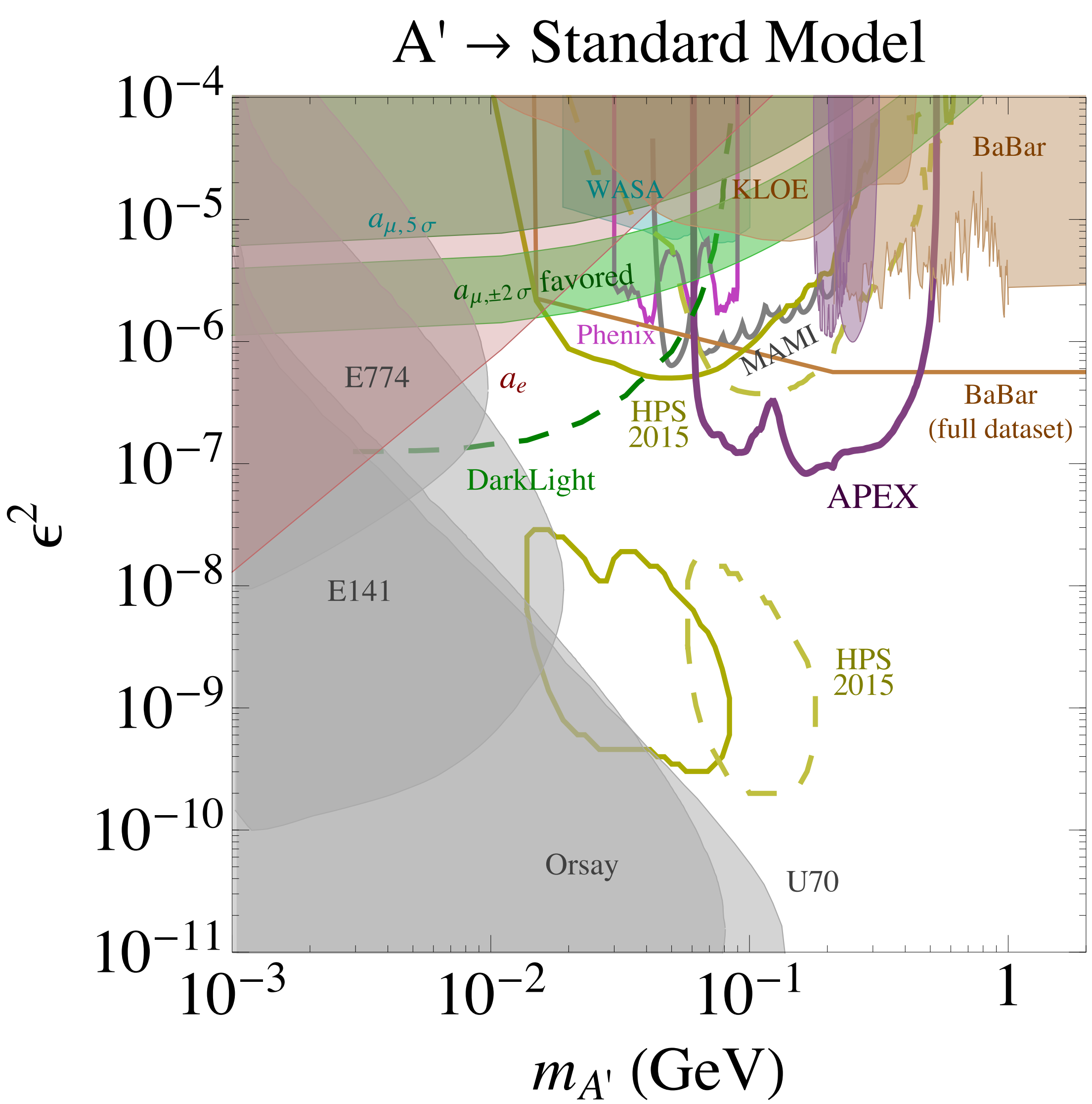
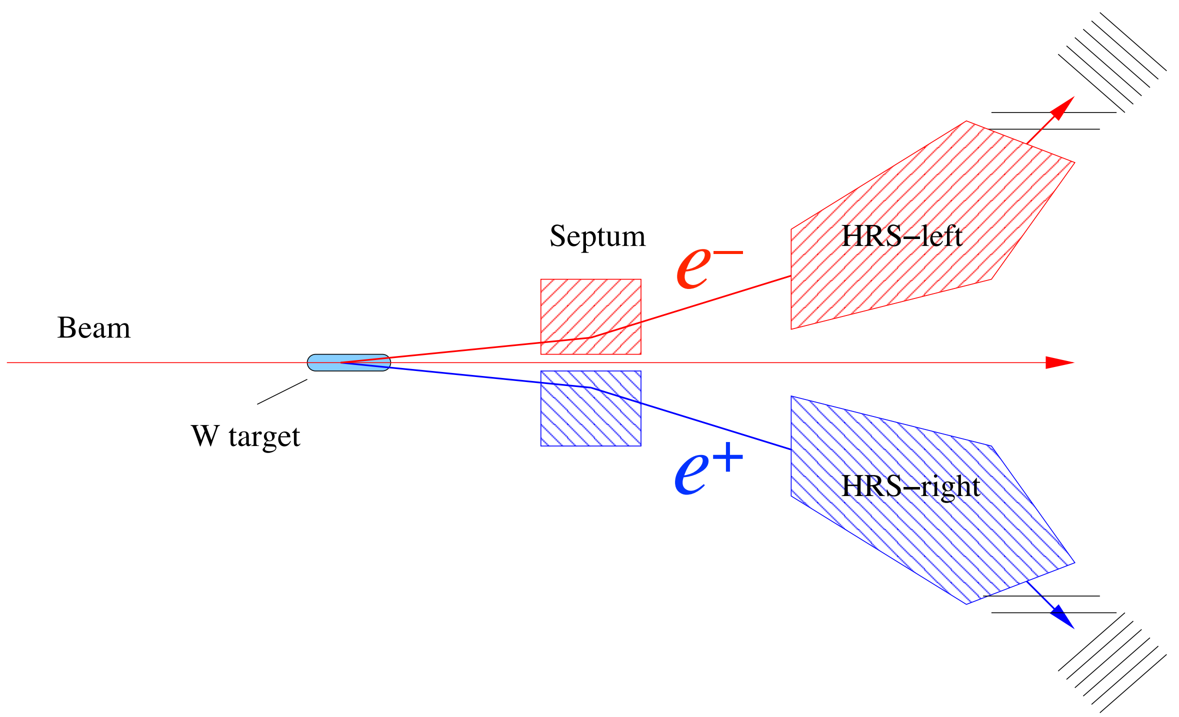
APEX: Goals and Strategy

Natalia Toro (Perimeter Institute)



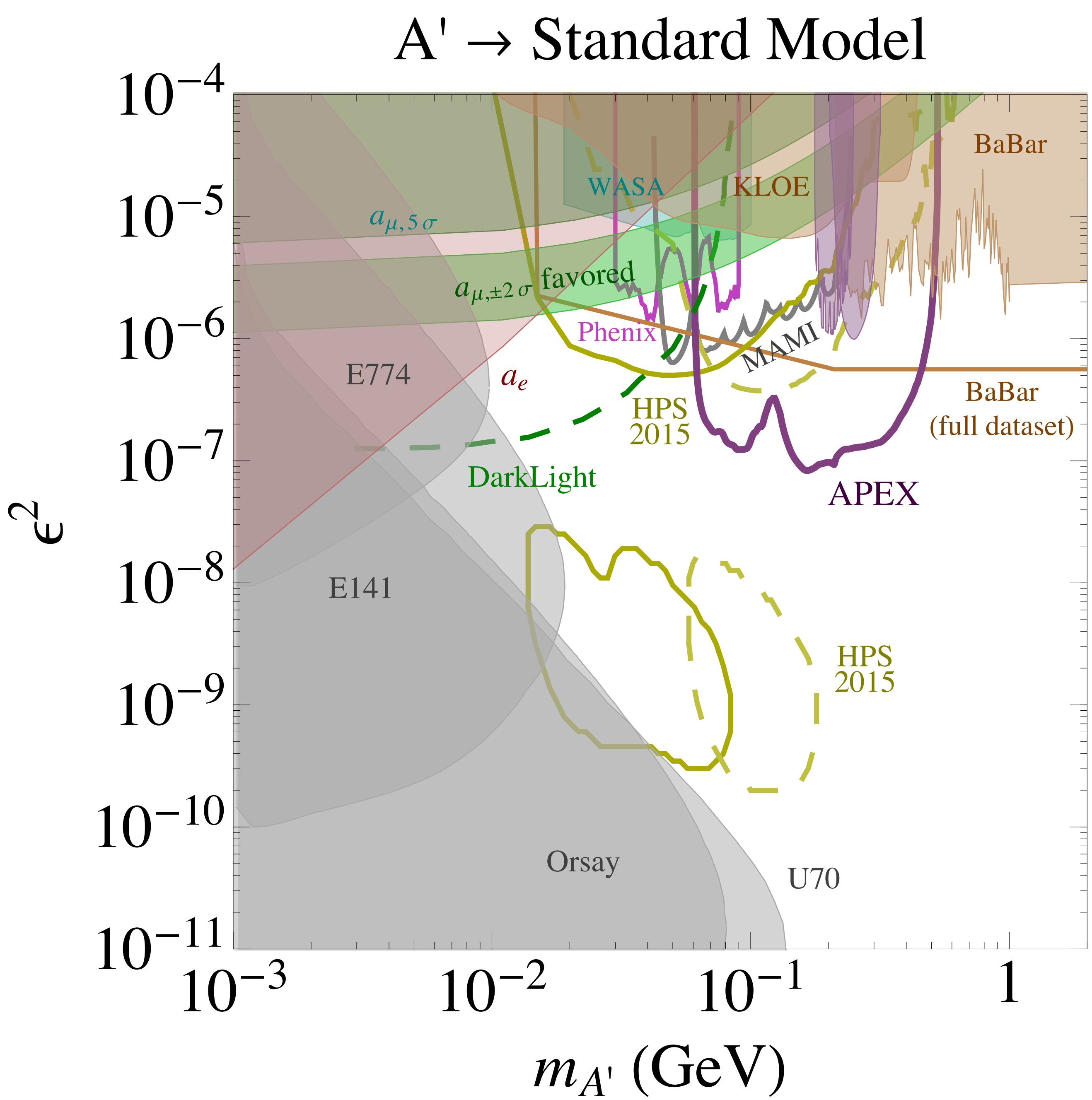


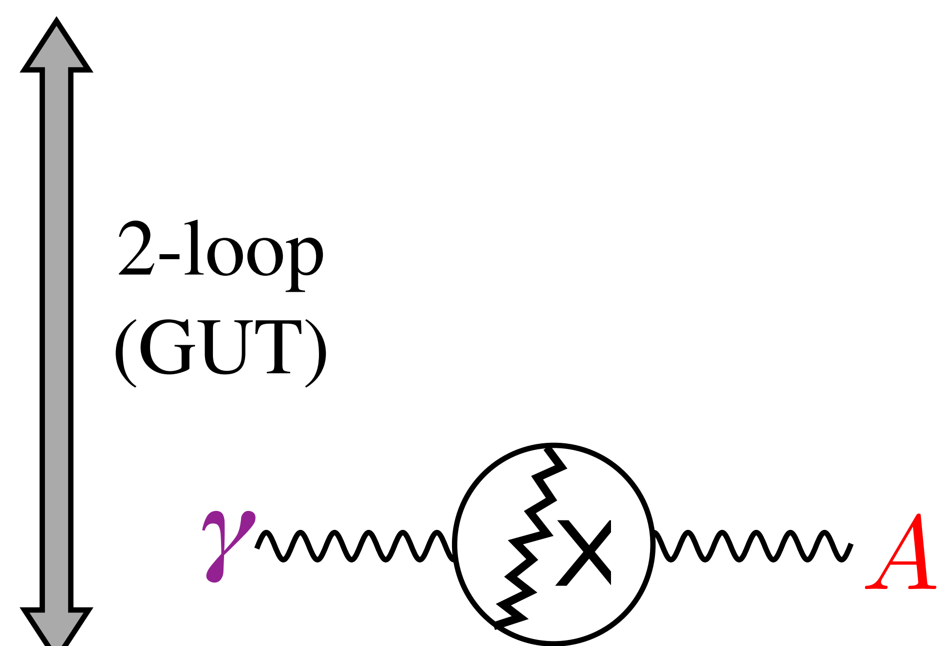
Collaboration Meeting

April 22, 2014

Search for new forces mediated by ~100 MeV vector boson A' (*dark photon*) with weak coupling to electrons

Possible connections to dark matter and muon *g–2*





The A′ Experiment (APEX): Physics Motivation and Goal

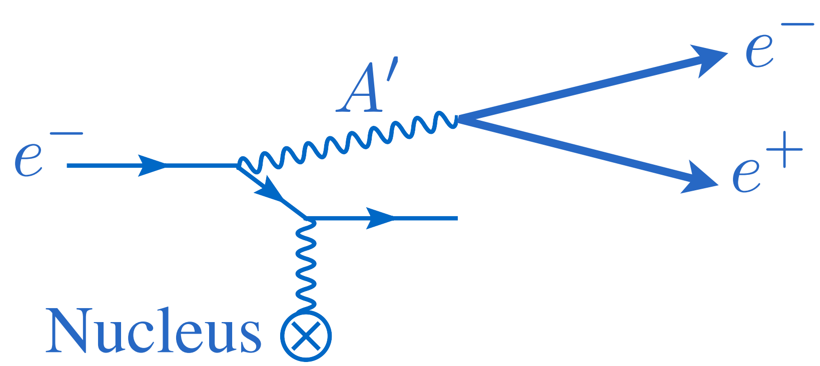
Search for new forces mediated by ~100 MeV vector boson A' (*dark photon*) with weak coupling to electrons

Possible connections to dark matter and muon g–2

The A′ Experiment (APEX): Physics Motivation and Goal

Search for new forces mediated by ~100 MeV vector boson A' (*dark photon*) with weak coupling to electrons

Possible connections to dark matter and muon g–2



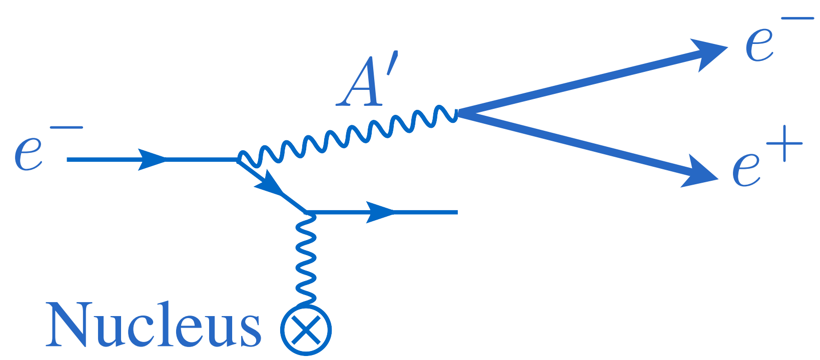
>1 A'/sec for
75 μA beam, 0.1 X_0

A′ signal: small bump in e^+e^- mass distribution over large but **smooth** background

The A′ Experiment (APEX): Physics Motivation and Goal

Search for new forces mediated by ~100 MeV vector boson A' (*dark photon*) with weak coupling to electrons

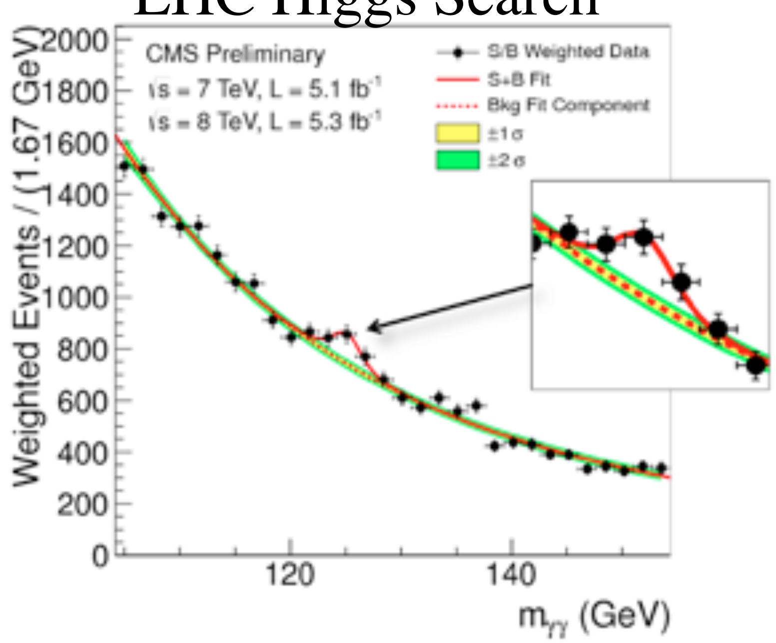
Possible connections to dark matter and muon *g–2*



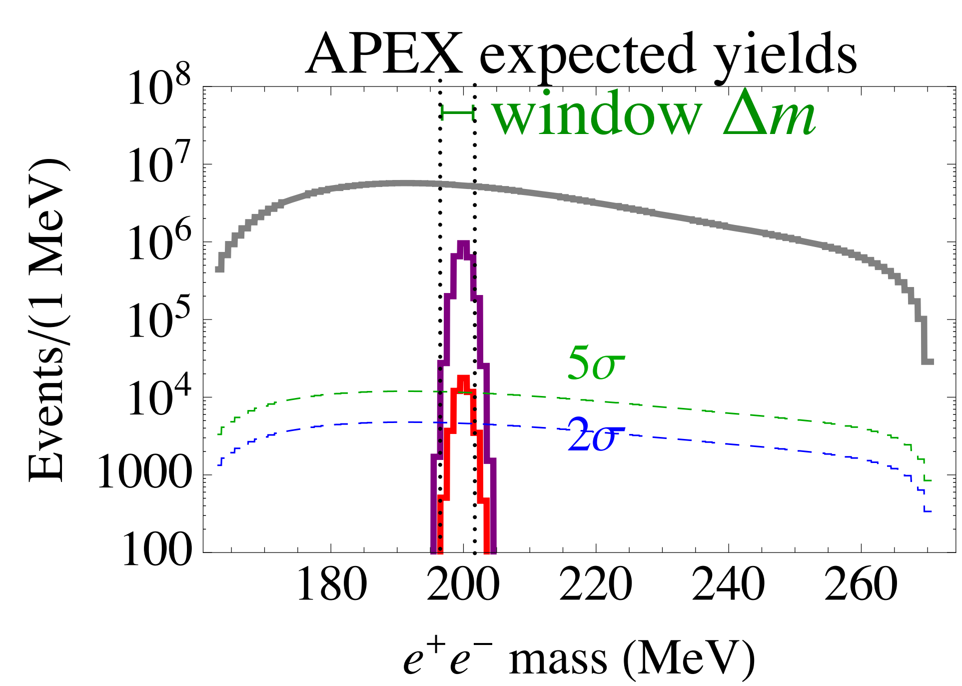
>1 A'/sec for
75 µA beam, 0.1 X_0

A′ signal: small bump in e^+e^- mass distribution over large but **smooth** background

LHC Higgs Search



x10⁴ in statistics



APEX Strategy: Considerations

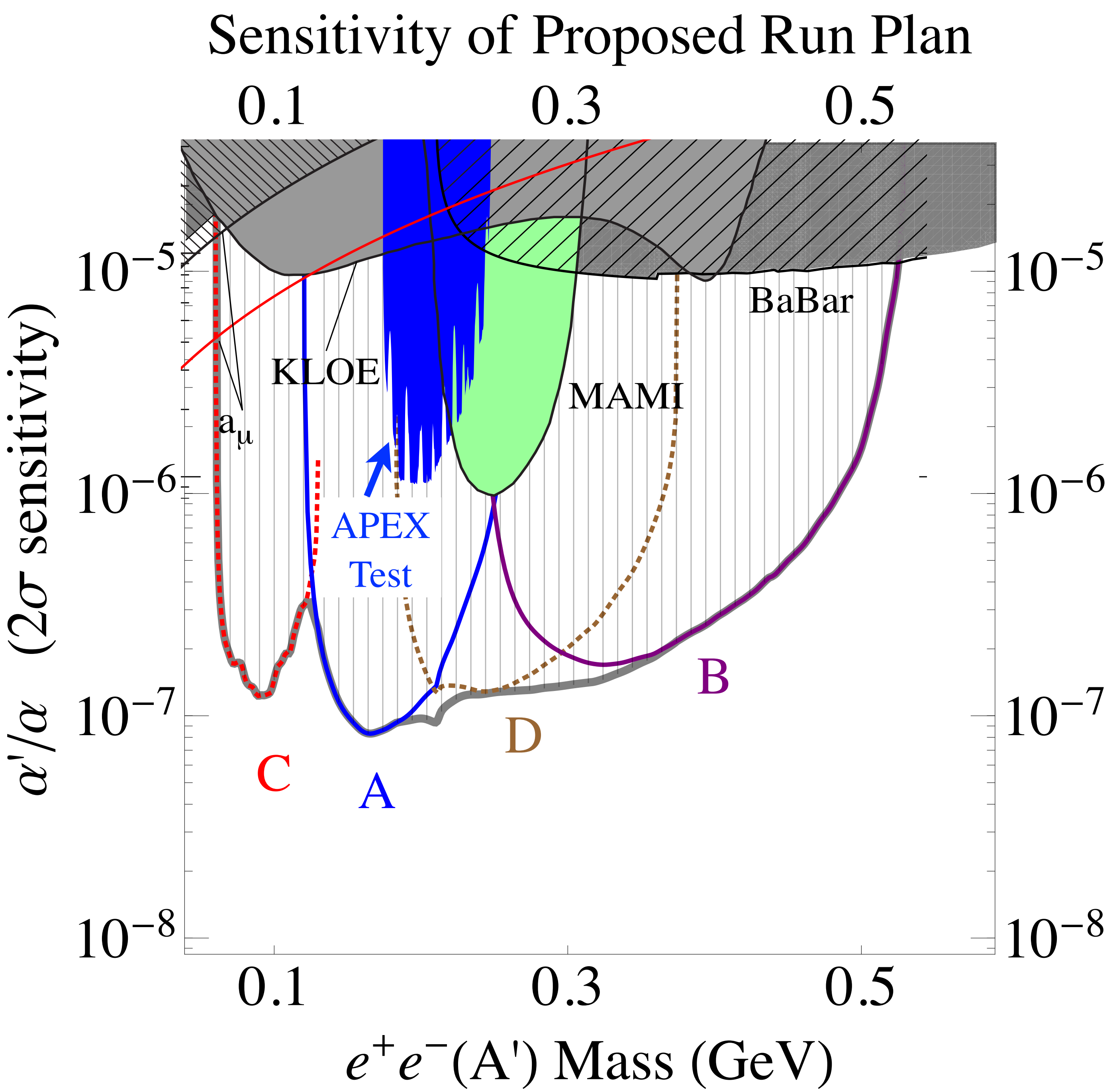
Sensitivity controlled by $S/\sqrt{B}$ in mass window Δm,

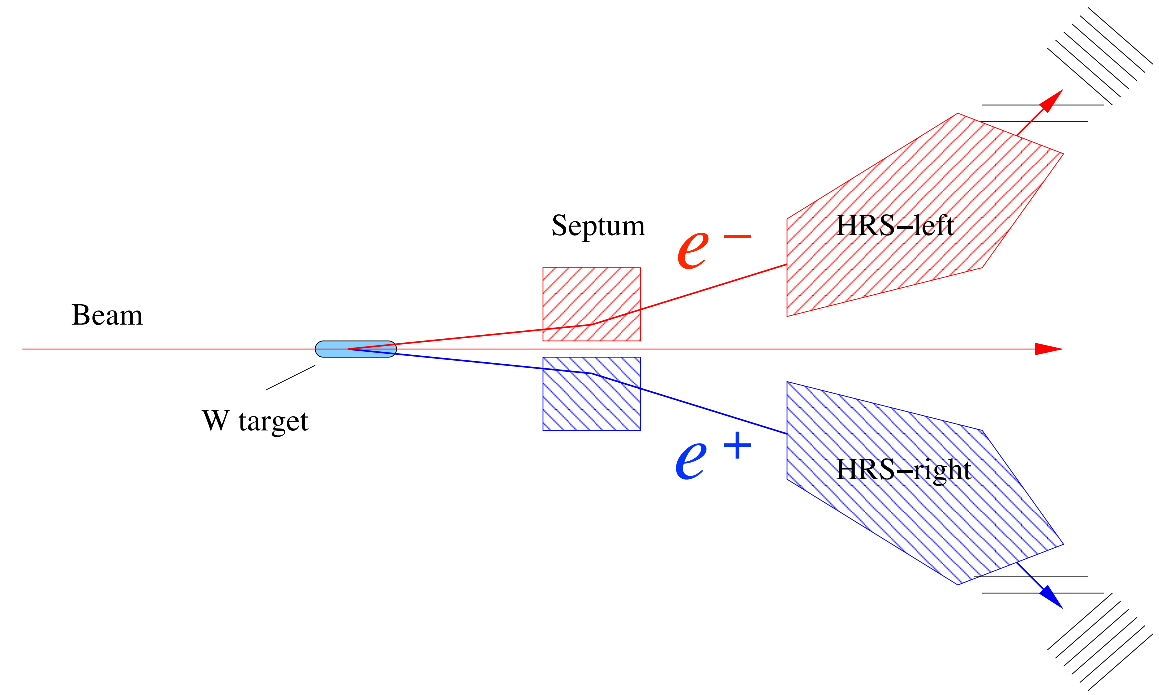
$$\frac{S}{\sqrt{B}} \sim \frac{\alpha'}{\alpha^2}\sqrt{N_{QED}\left(\frac{m_{A'}}{\Delta m}\right)}$$

Maximize e^+e^- statistics and minimize mass resolution:

- Spectrometer central momentum $p \approx E_{\mathrm{beam}}/2$ maximizes signal acceptance (and reduces many backgrounds)
- Septum magnet for forward-angle coverage increases signal acceptance
- DAQ strategy to cope with high e^- and π^+ singles rates:
  - higher-sensitivity VDC electronics
  - two-arm coincidence trigger using GC in e^+ arm
  - tight coincidence timing (10 ns)
- Optimize optics calibration for both polarities
- Multi-foil target minimizes multiple scattering in target and increases mass coverage per beam energy

APEX Run Plan





1 Month Beam Time
- 6 days at 1,2,3 GeV
- 12 days at 4.5 GeV)

>100x test-run statistics

Approved by JLab PAC 37 with recommendation to run as soon as possible

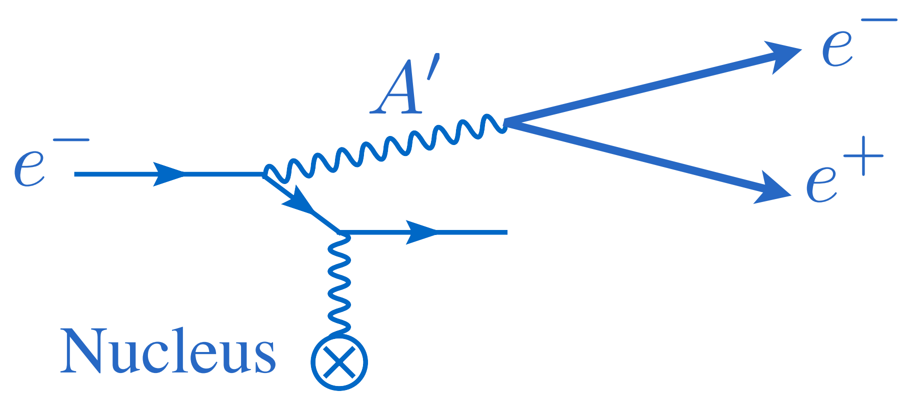
Explores parameter space with **unparalleled efficiency** (particularly above ~300 MeV)

APEX Strategy: Overview

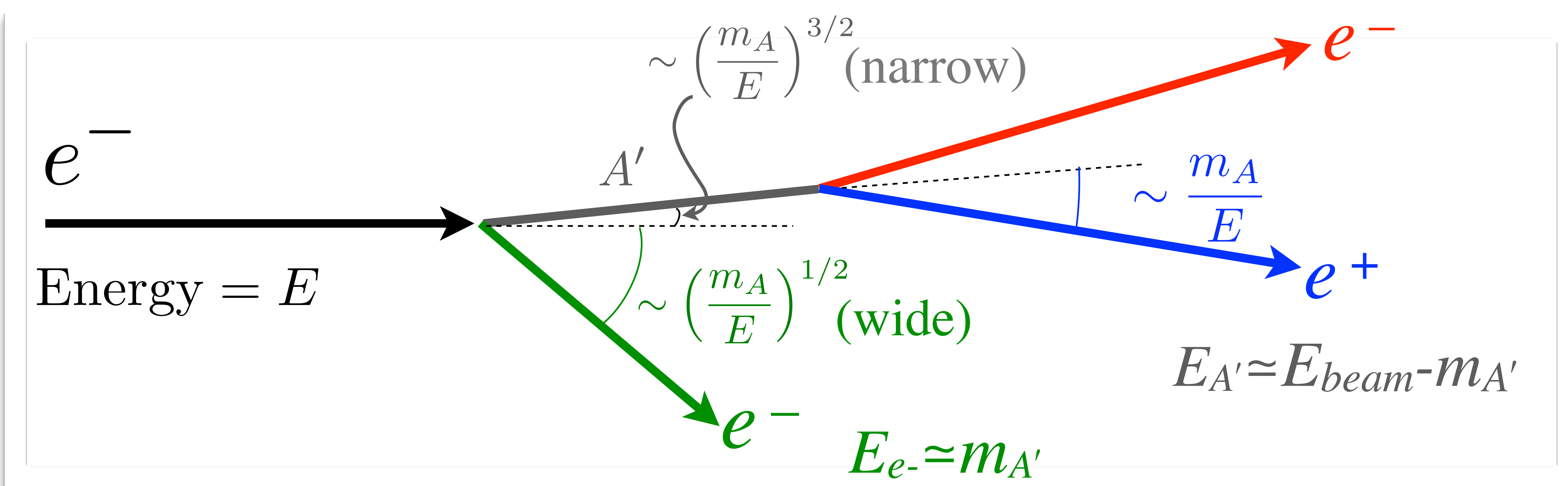
- **Central momentum $p \approx E_{beam}/2$ maximizes signal acceptance (and reduces many backgrounds)**
- Septum magnet for forward-angle coverage increases signal acceptance
- DAQ strategy to cope with high e^- and π^+ singles rates:
  - higher-sensitivity VDC electronics
  - two-arm coincidence trigger using GC in e^+ arm
  - tight coincidence timing (10 ns)
- Optimize optics calibration for both polarities
- Multi-foil target minimizes multiple scattering in target and increases mass coverage per beam energy

Optimizing for A′ Production Kinematics

A′ production has distinctive kinematics:

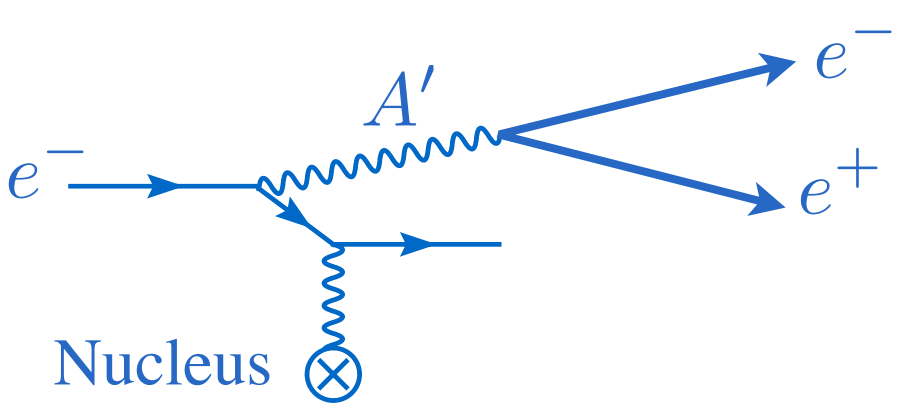


A′ is produced forward
and carries majority of beam energy

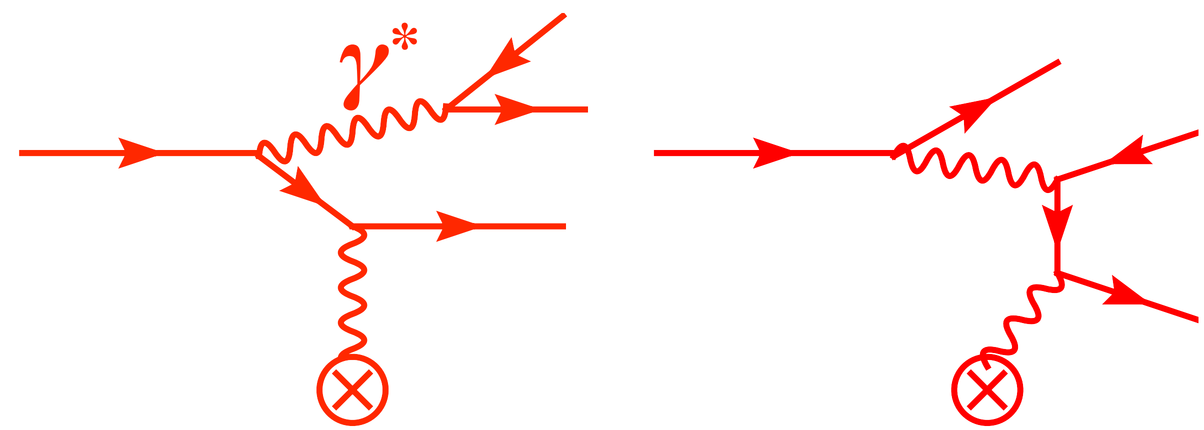


Optimizing for A′ Production Kinematics

A′ Production

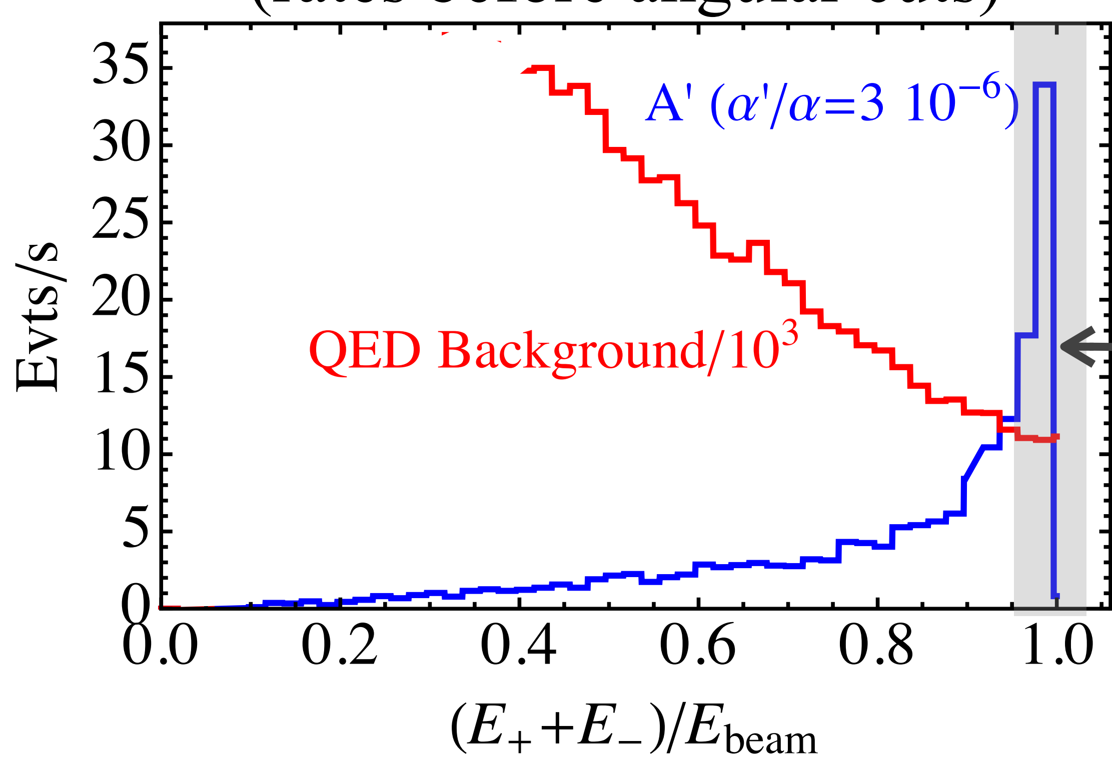


QED Backgrounds



(dominant pair background after PID)

(rates before angular cuts)



Symmetric energy & angles in two arms optimize A′ acceptance

$\boldsymbol{E}^+ \approx \boldsymbol{E}^- \approx E_{beam}/2$

also suppresses e^- singles & other pair backgrounds

APEX Strategy: Overview

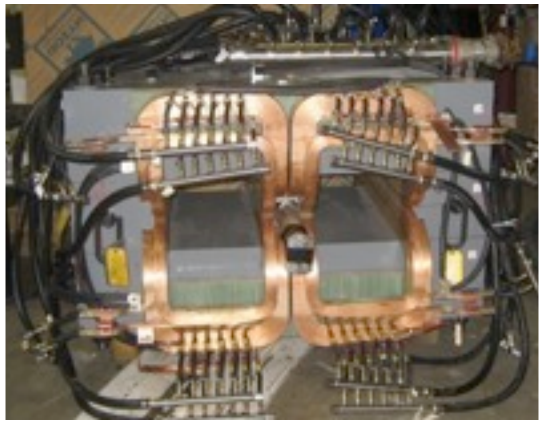
- Central momentum $p \approx E_{\text{beam}}/2$ maximizes signal acceptance (and reduces many backgrounds)
- **Septum magnet for forward-angle coverage increases signal acceptance**
- DAQ strategy to cope with high e^- and π^+ singles rates:
  - higher-sensitivity VDC electronics
  - two-arm coincidence trigger using GC in e^+ arm
  - tight coincidence timing (10 ns)
- Optimize optics calibration for both polarities
- Multi-foil target minimizes multiple scattering in target and increases mass coverage per beam energy

Septum Magnet

- ➢ Essential to design
  - – Brings mass range of interest into acceptance

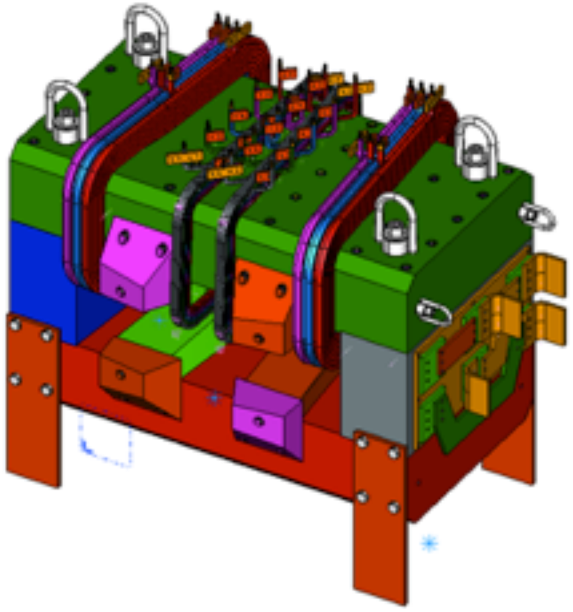
    $$m_{A'} \approx E_{\mathrm{beam}}\,\theta$$

  - – Higher A′ signal acceptance at 5° than 12.5°



- ➢ Used PREX septum for test run

- ➢ APEX septum
  - – Designed to minimize fringe field on beamline, access small A′ decay angles
  - – Delivery (Buckley Systems) expected July 2014
  - – Funded by NCCU, CMU, CSULA, SBU, UW grants
  - – Need to commission & develop expertise in acceptance calculations (John LeRose did this before)



APEX Strategy: Overview

- Septum magnet for forward-angle coverage increases signal acceptance

- Central momentum $p \approx E_{\text{beam}}/2$ maximizes signal acceptance (and reduces many backgrounds)

- **DAQ strategy to cope with high e^- and π^+ singles rates:**
  - higher-sensitivity VDC electronics
  - two-arm coincidence trigger using GC in e^+ arm
  - tight coincidence timing (10 ns)

- Optimize optics calibration for both polarities

- Multi-foil target minimizes multiple scattering in target and increases mass coverage per beam energy

APEX running conditions require high singles rates:

- e^- (radiative elastic & inelastic) – about 10^4 x coincidence rate
- $\pi^\pm$ rate up to 50 x **larger** than e^{+*}

  *… but $\pi^\pm$ rate in test run, SaGDH much lower than expectations from higher-energy fits.

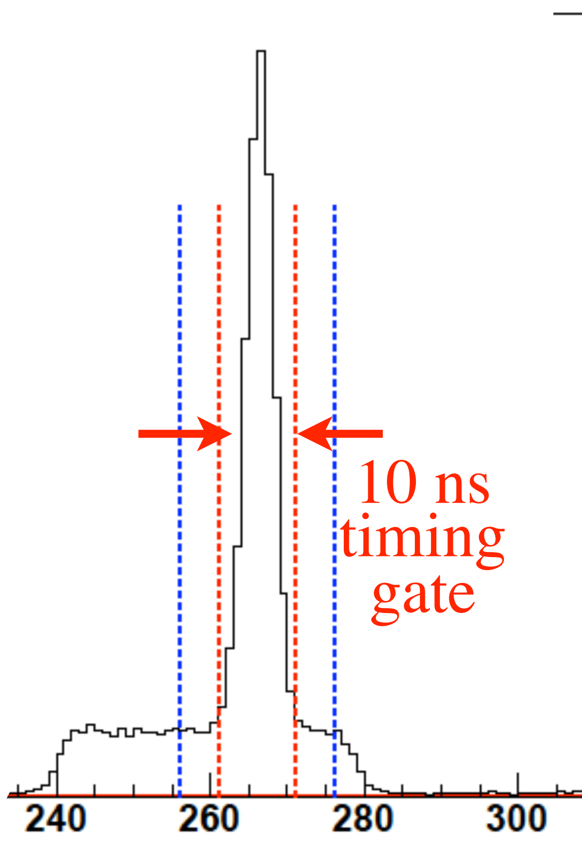
- $e^-\pi^+$ accidentals dominate DAQ bandwidth

Challenging but validated in test run

- Tested tracking up to ~5 MHz e^- rate (highest rate expected for full run), obtained **60%** track reconstruction efficiency – may be improvable to 75%
- "Golden" trigger for e^+e^- pairs rejects $e^-\pi^+$ accidentals

  Left S2m + Right S2m + Right Gas Cherenkov (e^+)

- 10 ns online timing achieved in test-run ⇒ manageable DAQ rates (≲2.5 kHz)



APEX Strategy: Overview

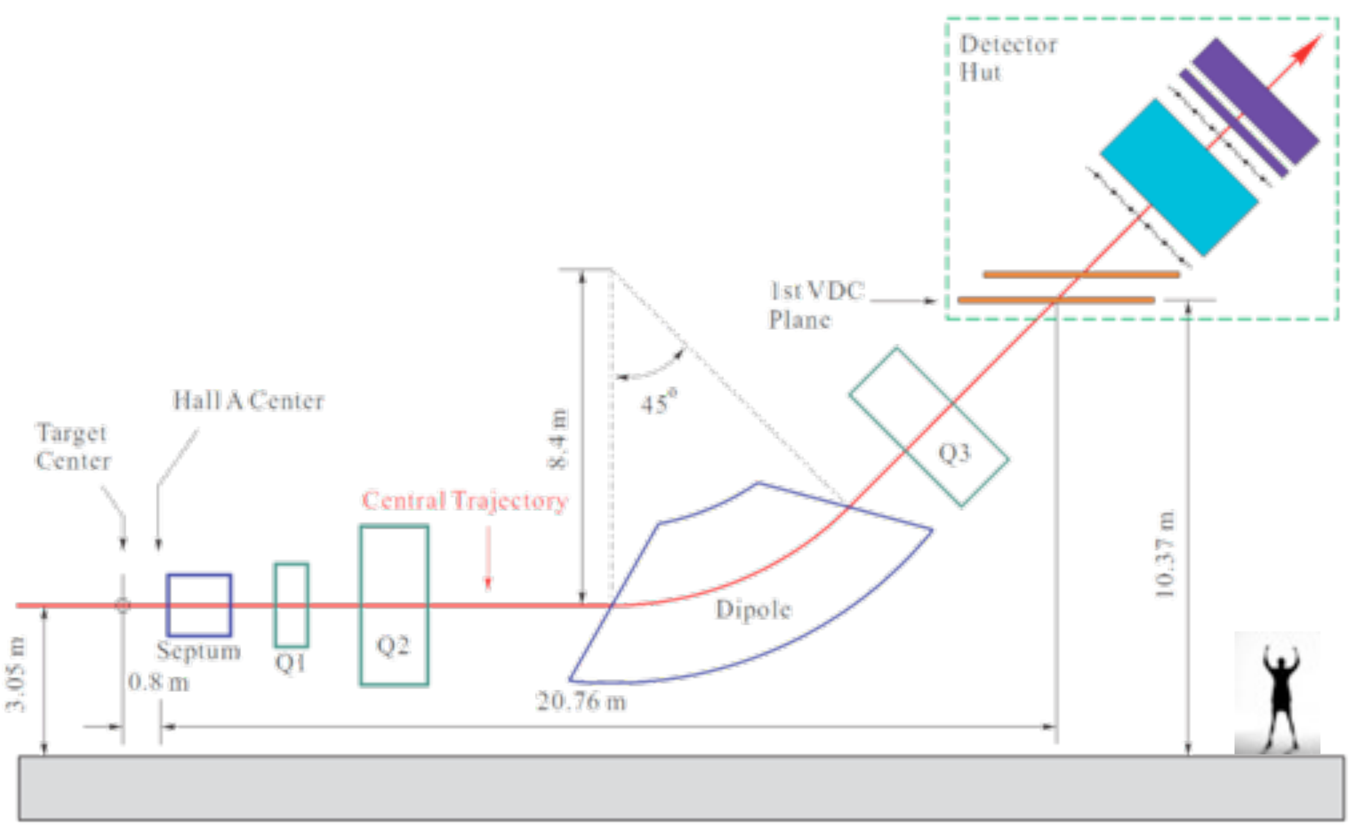
- Septum magnet for forward-angle coverage increases signal acceptance
- Central momentum $p \approx E_{\mathrm{beam}}/2$ maximizes signal acceptance (and reduces many backgrounds)
- DAQ strategy to cope with high e^- and π^+ singles rates:
  - higher-sensitivity VDC electronics
  - two-arm coincidence trigger using GC in e^+ arm
  - tight coincidence timing (10 ns)
- **Optimize optics calibration for both polarities**
- Multi-foil target minimizes multiple scattering in target and increases mass coverage per beam energy

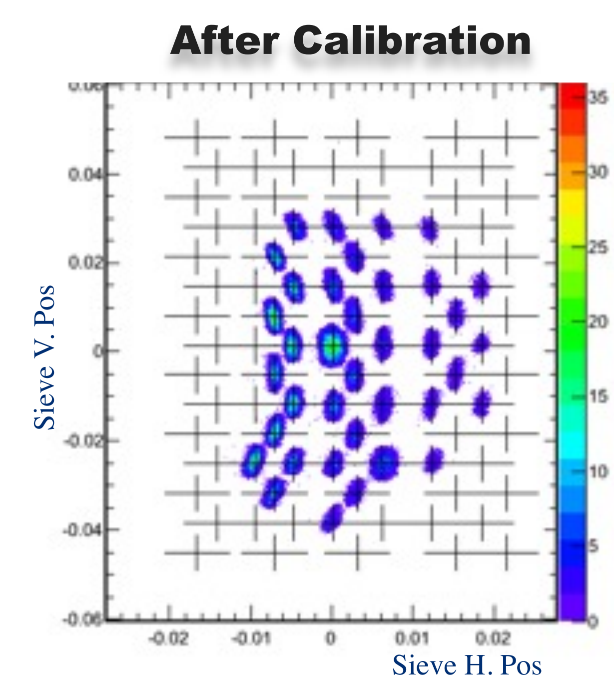
Magnetic Spectrometer Optics

Hall A standard:
- Removable sieve plate upstream of septum.
- Map between surveyed locations of sieve holes and reconstructions to calibrate optics

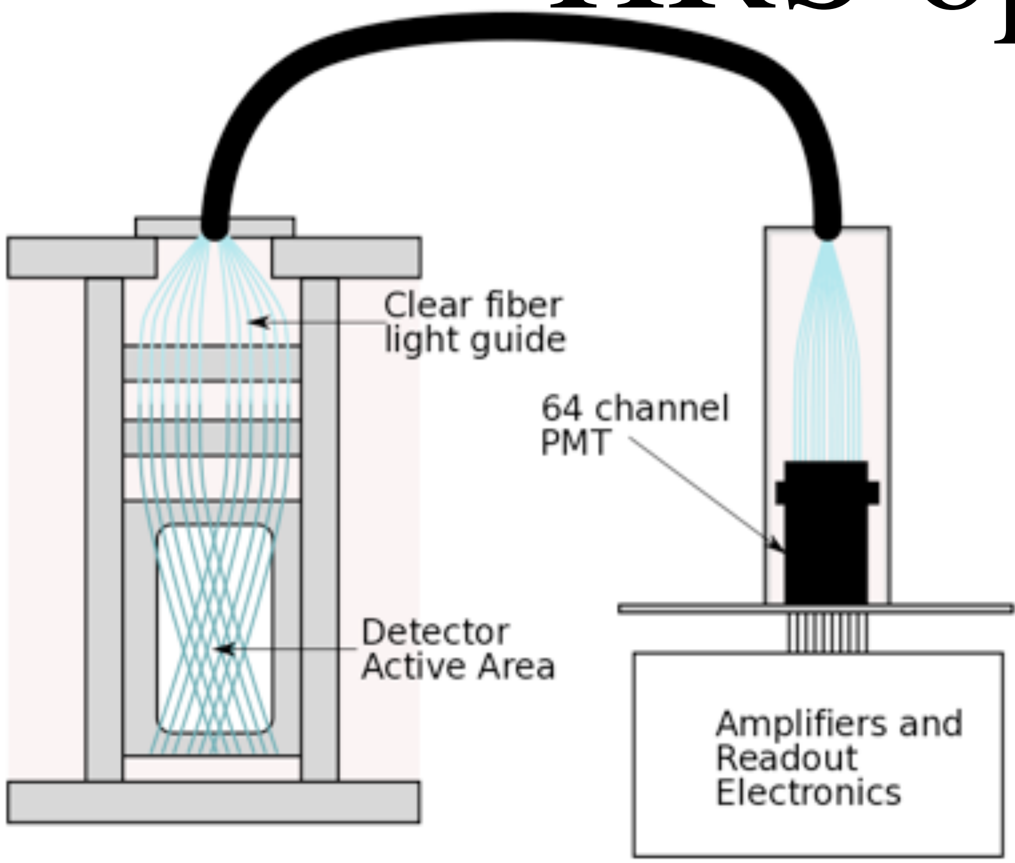
Test run: used reconstructed hole sizes to measure resolution

but this method only works for e^- near elastic peak – for APEX, requires running at different beam energy.





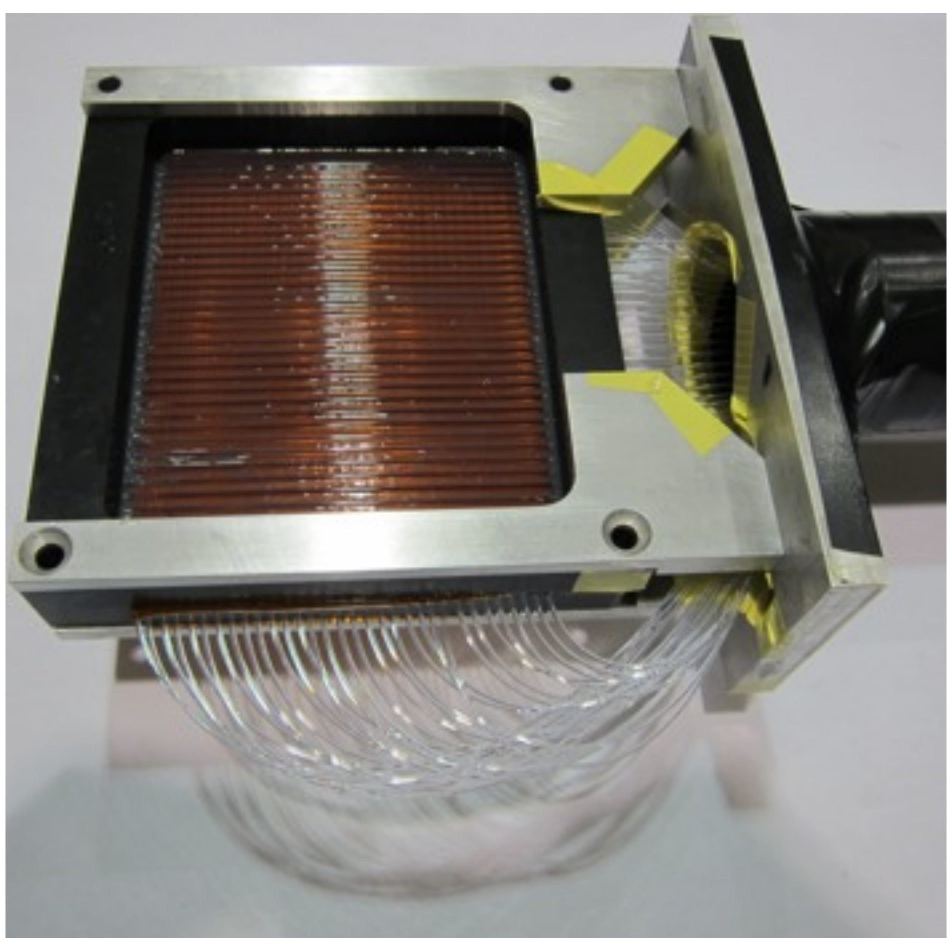
HRS optics for APEX

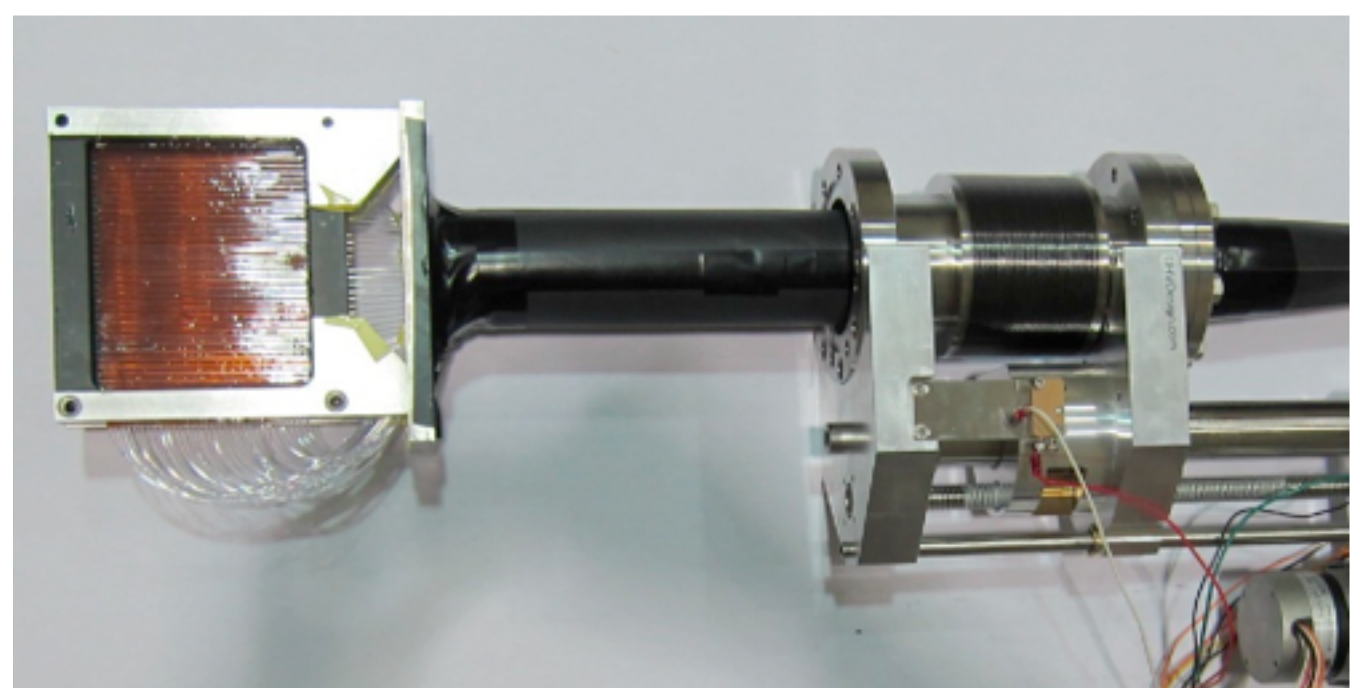


"Active sieve slit": tagging by a Sci Fiber detector

- 1 mm fibers with 1/16" pitch (equivalent to 1024 sieve holes)
- Now built, still needs commissioning and readout software

Allows optics calibration at production beam energy & for both polarities



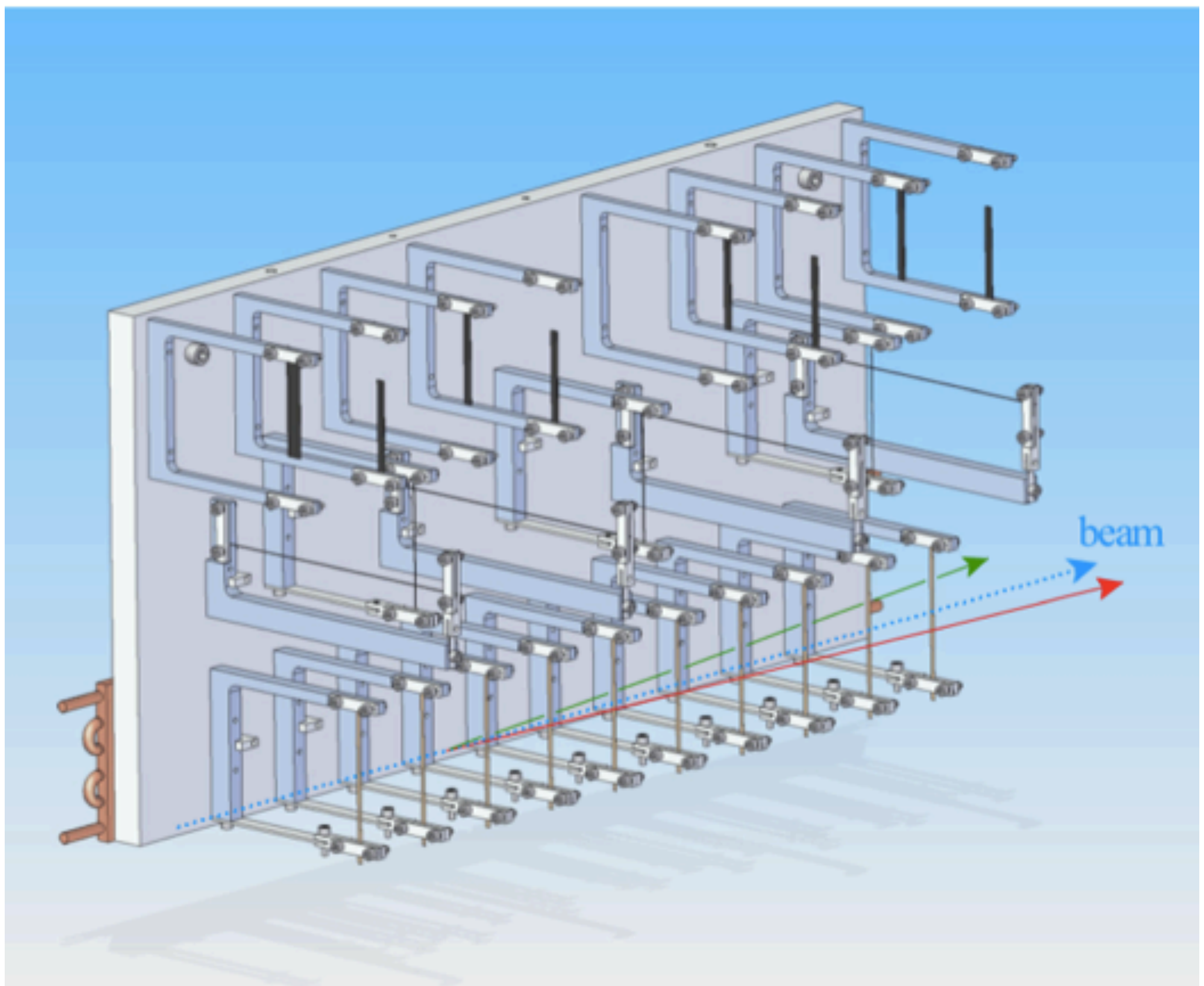


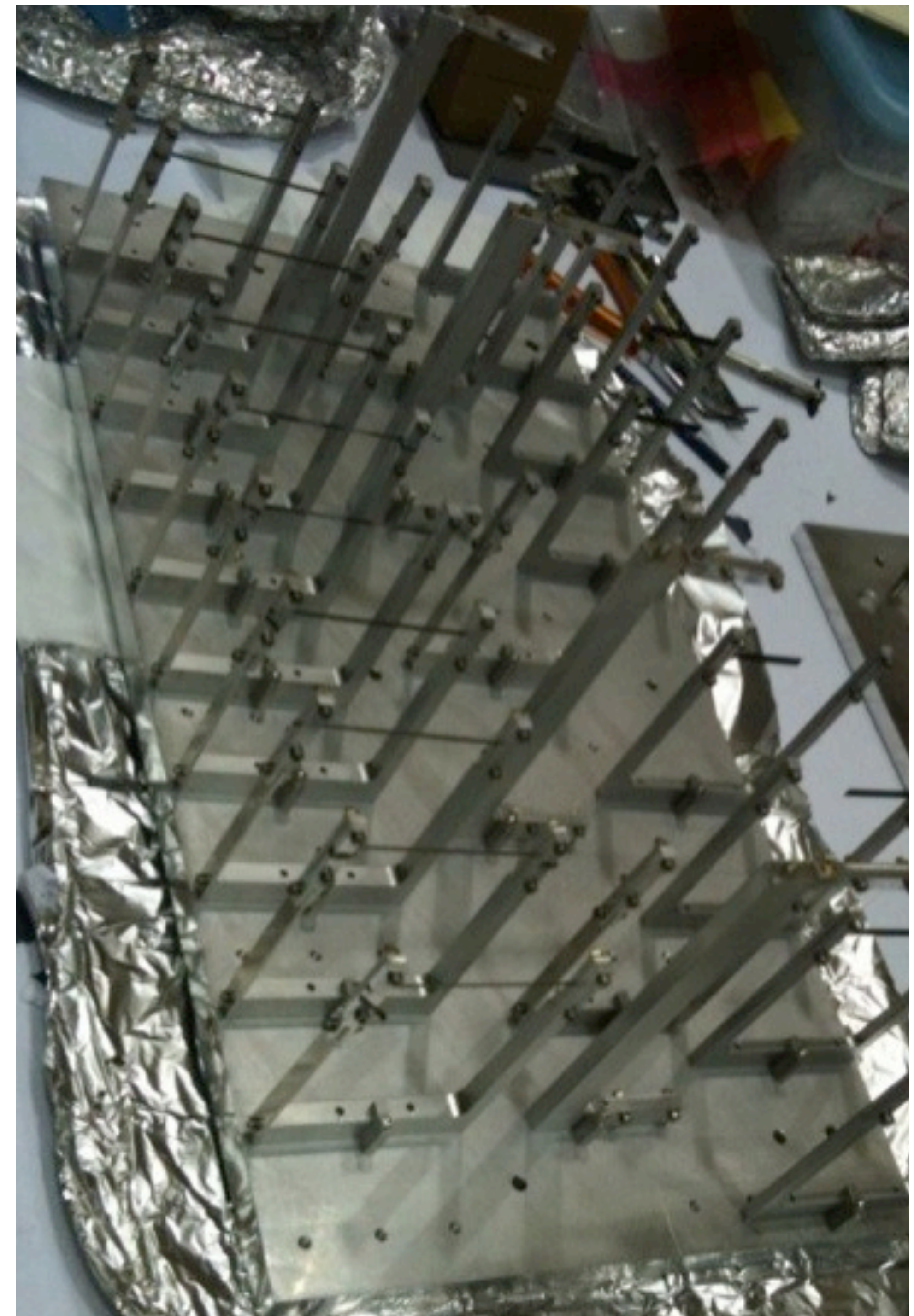
APEX Strategy: Overview

- Septum magnet for forward-angle coverage increases signal acceptance
- Central momentum $p \approx E_{\mathrm{beam}}/2$ maximizes signal acceptance (and rejects many backgrounds)
- DAQ strategy to cope with high e^- and π^+ singles rates:
  - new VDC electronics
  - coincidence trigger with Gas Cerenkov detector
- Optimize optics calibration in parallel-field configuration
- **Multi-foil target minimizes multiple scattering in target**

Target Design: Minimizing Multiple Scattering

Target designed and built by SLAC & JLab APEX groups for the test run, currently at JLab



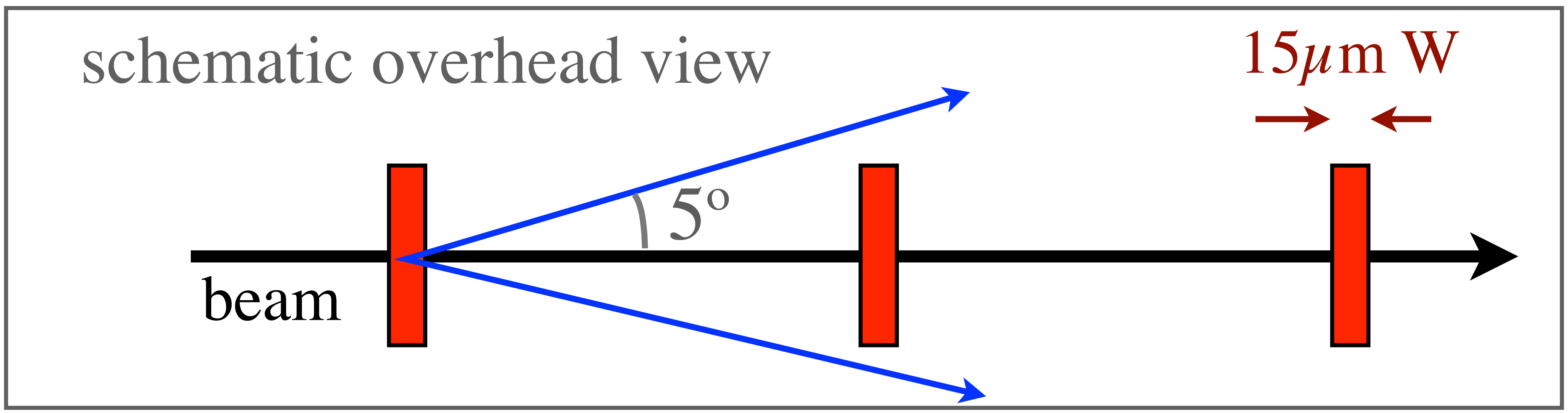


Target Design: Minimizing Multiple Scattering

Target designed and built by SLAC & JLab APEX groups for the test run, currently at JLab

Goals:

- $\sigma(\theta)_{\text{mult scat}} \leq 0.5$ mrad
  $\Rightarrow$ typical e^+e^- pair must only go through 0.3% X_0 (2-pass)



- Target thickness 0.7–8% X_0 (depending on E_{beam})
- Long target extends mass range per setting
- Easy to swap in/out ribbon holders – minimize radiation @ lower energies by using thinner targets

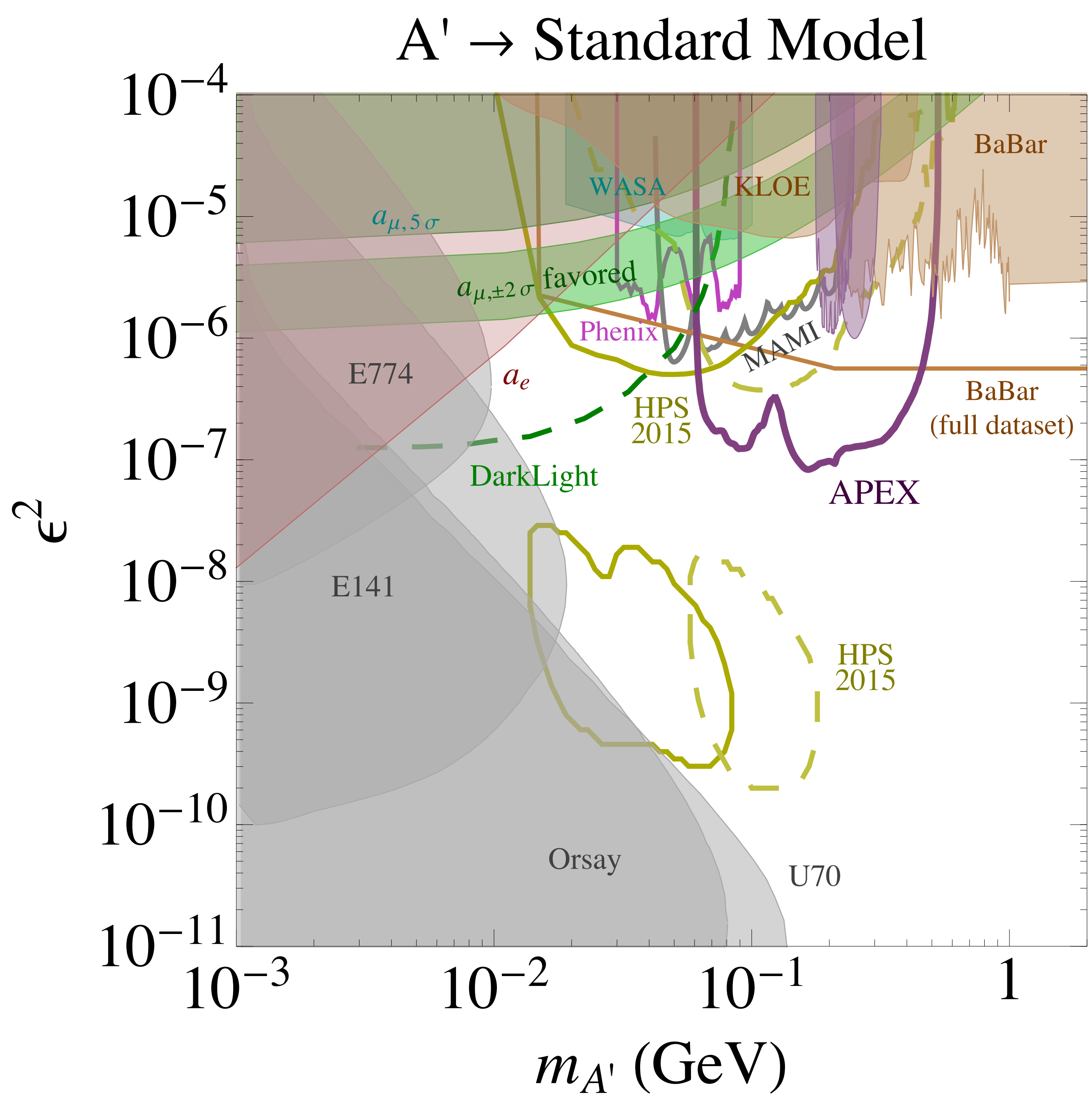
Summary

Test run demonstrated feasibility and power of APEX strategy to search for hidden-sector photons

Full APEX efficiently (34 days) explores new & important mass and coupling range

In many ways, ideal experiment for opportunistic running conditions of early 12 GeV era

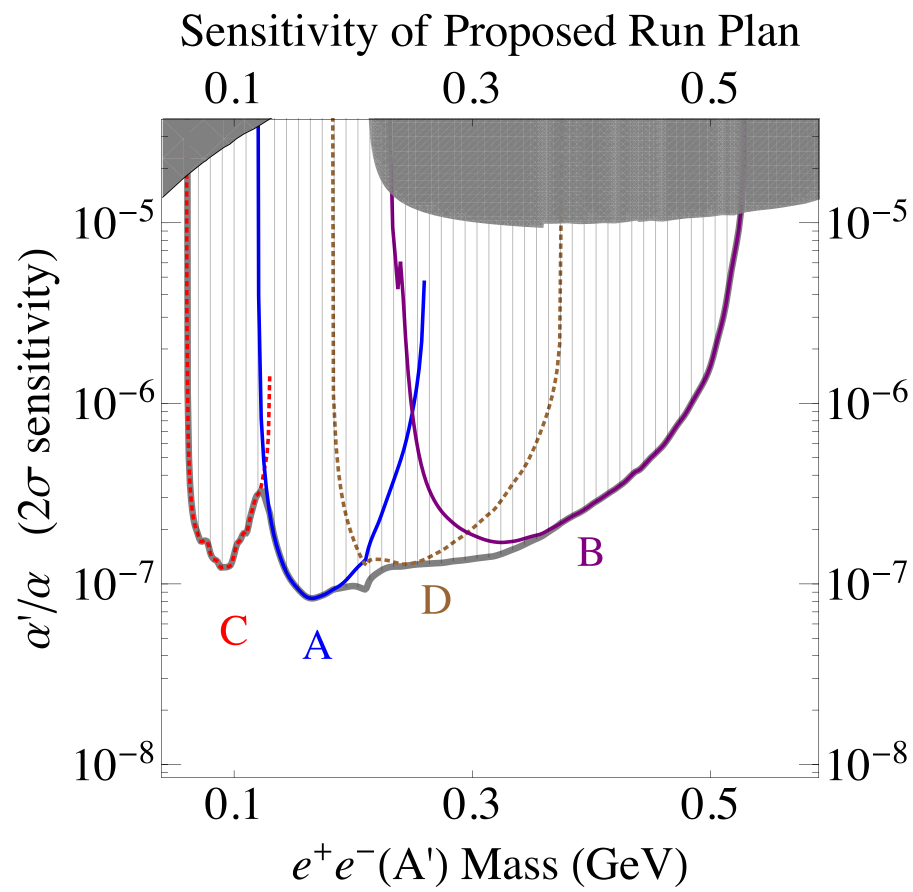
We should be ready!



Backup Slides

Run Plan

Settings	A	B	C	D
Beam energy (GeV)	2.2	4.4	1.1	3.3
Beam current (μA)	70	60	50	80
Nominal central angle	5.0°	5.0°	5.0°	5.0°
Time Requested (hrs)				
Energy change	–	4	4	4
Magnet setup	4	4	4	4
Optics calibration	16	16	16	16
10% $\mathcal{L}$	2	2	2	2
Normal $\mathcal{L}$	144	288	144	144
Total	166	314	170	170



6-12 days at 4 energy settings,

anticipate 8 days to swap target cartridges, check alignment, and calibrate optics

41 days total (33 days beam)