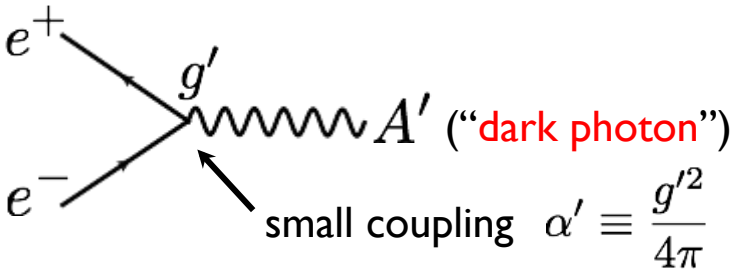
APEX: A Search for Dark Photons in Hall A (E12-10-009)

Spokespersons: R. Essig (SUNY), P. Schuster (Perimeter), N. Toro (Perimeter),
B. Wojtsekhowski (JLab)

Goal: Search for a new ~100 MeV gauge boson (A′) with very weak coupling to electrons

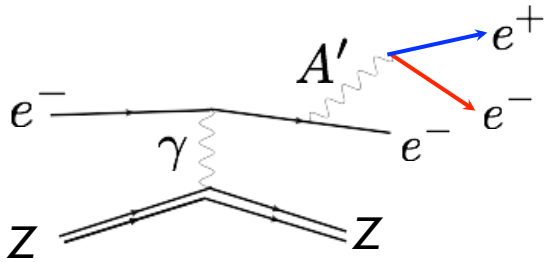


- Large interest in A′ search
- Number of considerations *naturally* give A′ mass ~ 100s MeV

A′ is motivated from theory and anomalies related to dark matter

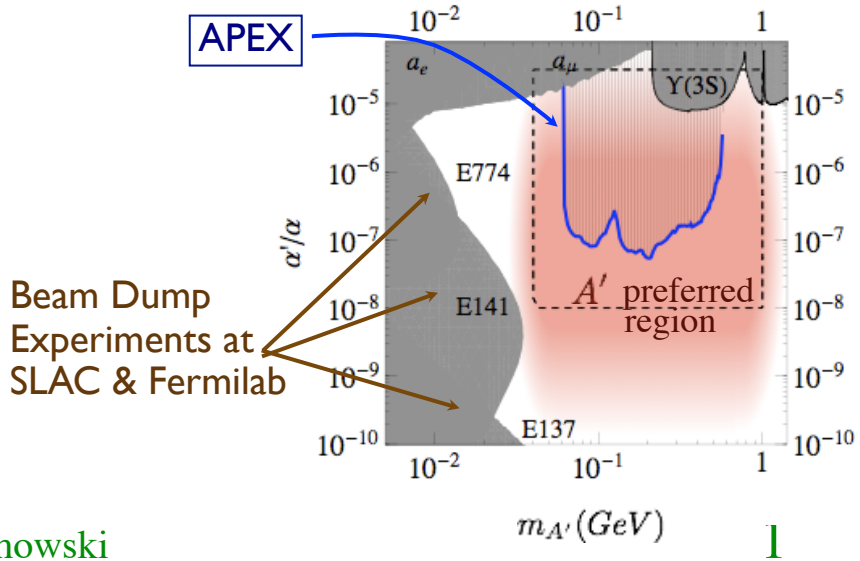
- A' can be a force carrier of new Abelian force (*ubiquitous* in extensions of Standard Model)
- New high-energy physics *generically* mixes A′ with the photon giving $\alpha'/\alpha \sim 10^{-6}-10^{-8}$
- Dark Matter charged under A′ may explain *famous* data "anomalies" (PAMELA, Fermi, DAMA)

Discovery potential in Hall A:



★ APEX will achieve unprecedented statistics
~10^9 e^+e^- trident events ~10,000-fold gain

★ All equipment is ready for measurements



APEX: A Search for Dark Photons in Hall A

Why do a search for new physics at JLab?

- It is the most interesting thing that a physicist can do.

- Our nuclear physics lab has the only 100% d.f. high energy high intensity electron accelerator existing in the US.

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There are two ways to search for new physics:

i) Direct search, as done for VMs, Z, W, top, Higgs

ii) Deviation in some well-known observable, such as Θ_W

The parameter space: the mass and the coupling constant. Direct search often covers a limited range of mass and could be very sensitive to small coupling.

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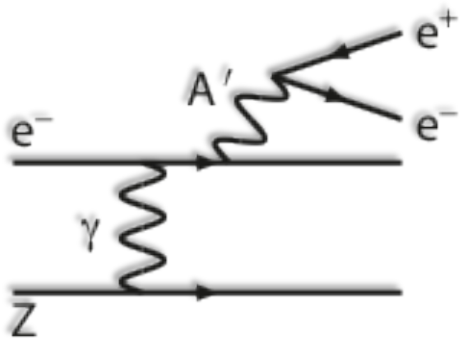
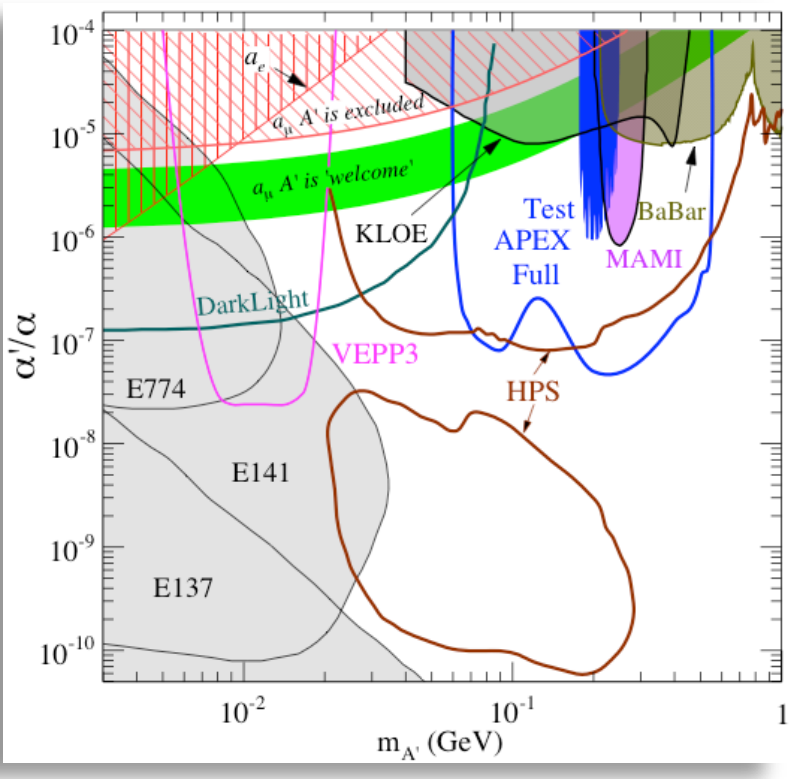
The LHC found Higgs, so far a Great Desert beyond SM
The focus is shifting to Dark Matter: WIMPs, A', Z_d … Dark forces

Searches for a gauge boson A' – APEX Test Run Result

Electroproduction of A'



decay



Published results :
- Beam dump searches: SLAC:E137, 141; FNAL: E774
- electron and muon (g-2), limits
- BaBar, Υ(3s)-> γ and μ+μ- (inferred limit)
- KLOE, mass of e+e- pair (bump search)
- **APEX test run, mass of e+e- pair – in publication**
- MAMI – APEX type scheme

Mont's slide

Future searches for a new force carrier:
- APEX – electron-nucleus fixed-target, a e+e- pair in two focusing spectrometers
- HPS – same, the e+e-, μ+μ- pairs in a custom Si-tracker magnetic spectrometer
- DarkLight – an internal target with an electron beam in Jefferson Lab ERL, detect a e+e- pair and e'p
- VEPP3 – a positron beam incident on an internal H_2 target, missing mass in (e+e-, γ X)
- MAMI – APEX type scheme with lower beam energy

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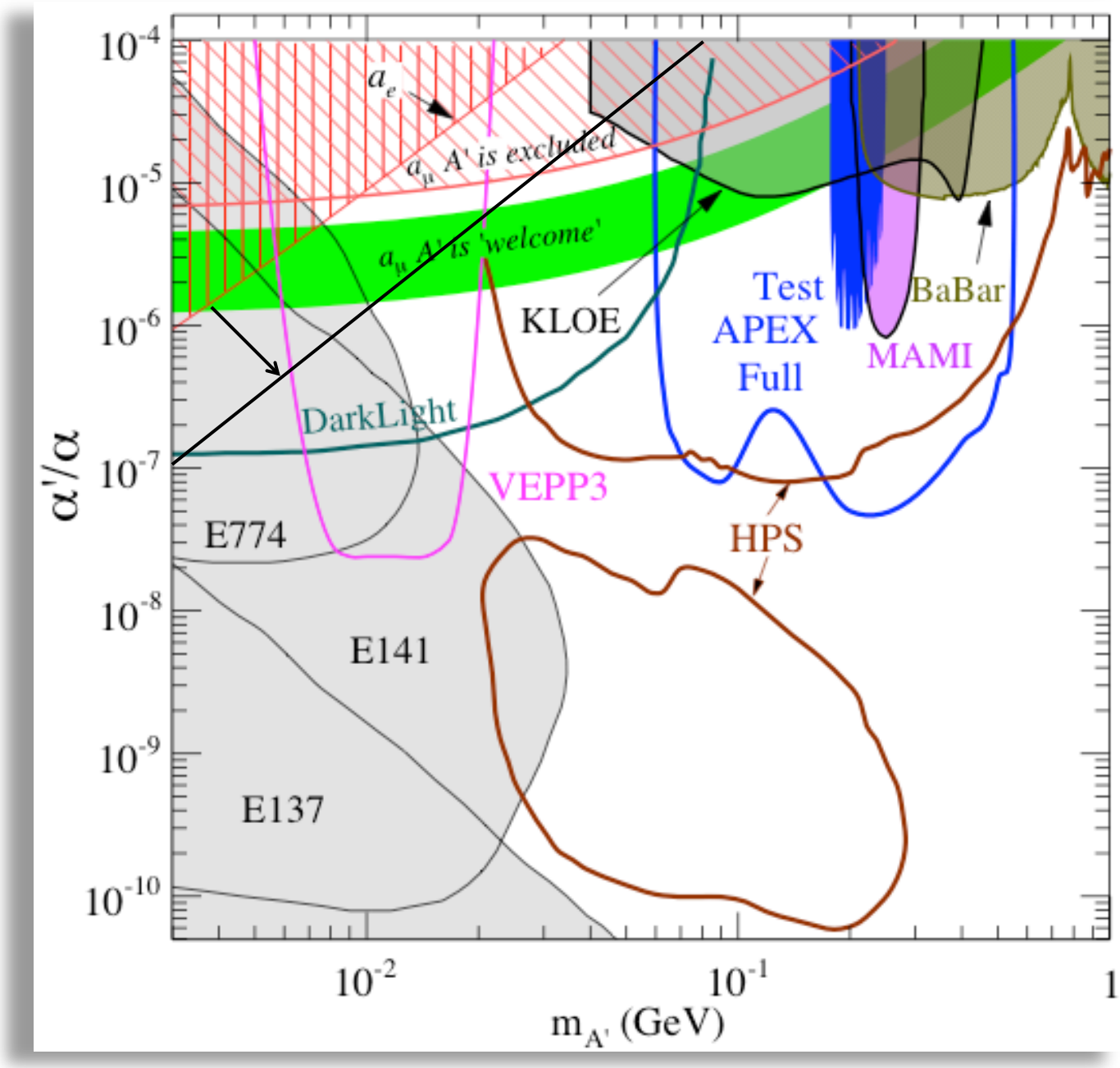
• Our nuclear physics lab has the only 100% d.f. high energy high intensity electron accelerator existing in the US.

• The heavy photon is a window which our electromagnetic community has a chance of opening. It is like the searches for new physics with the Qweak and future Moller exp-ts.

Searches for a gauge boson A'

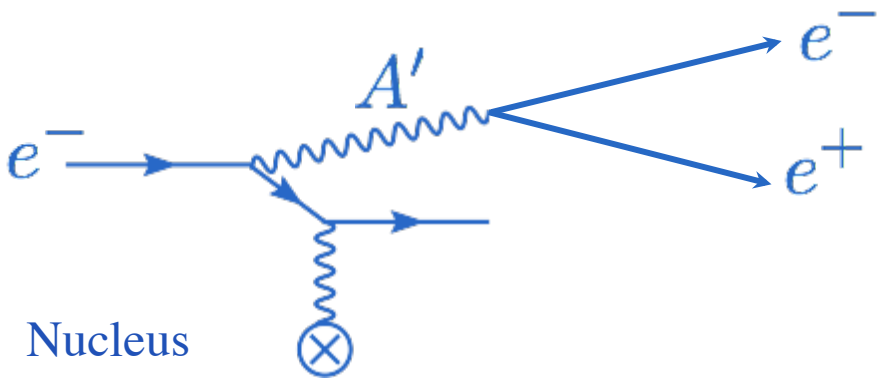


APEX: A Search for Dark Photons in Hall A

Why do a search for new physics at JLab?

What are the A' particle status and perspectives?

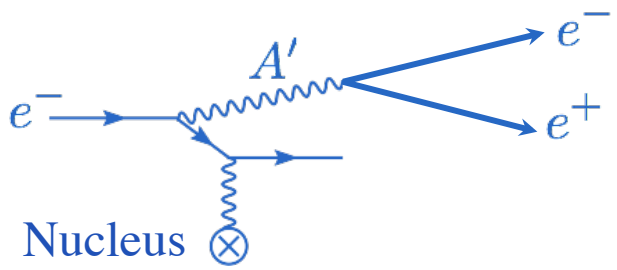
What is the APEX search method?



Strategy: measure e^+e^- mass spectrum with high resolution, in kinematic region optimized for A′ acceptance and QED background suppression.

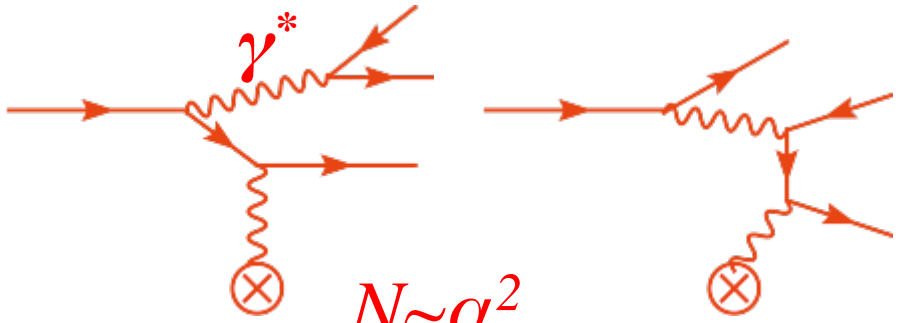
Approach: A′ Production and Background Kinematics

Production diagrams analogous to photon bremsstrahlung



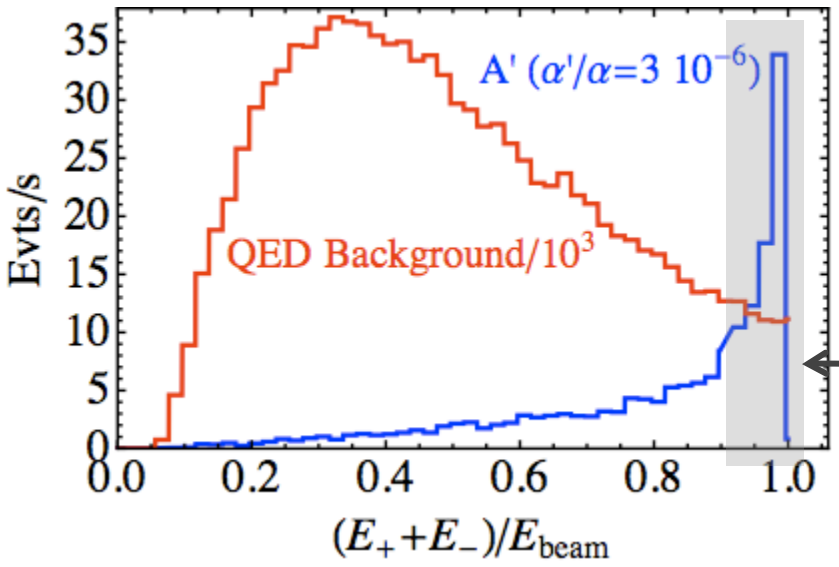
$N \sim \alpha'$ x Branching → O(1)

QED Backgrounds



$N \sim \alpha^2$

(rates before angular cuts)

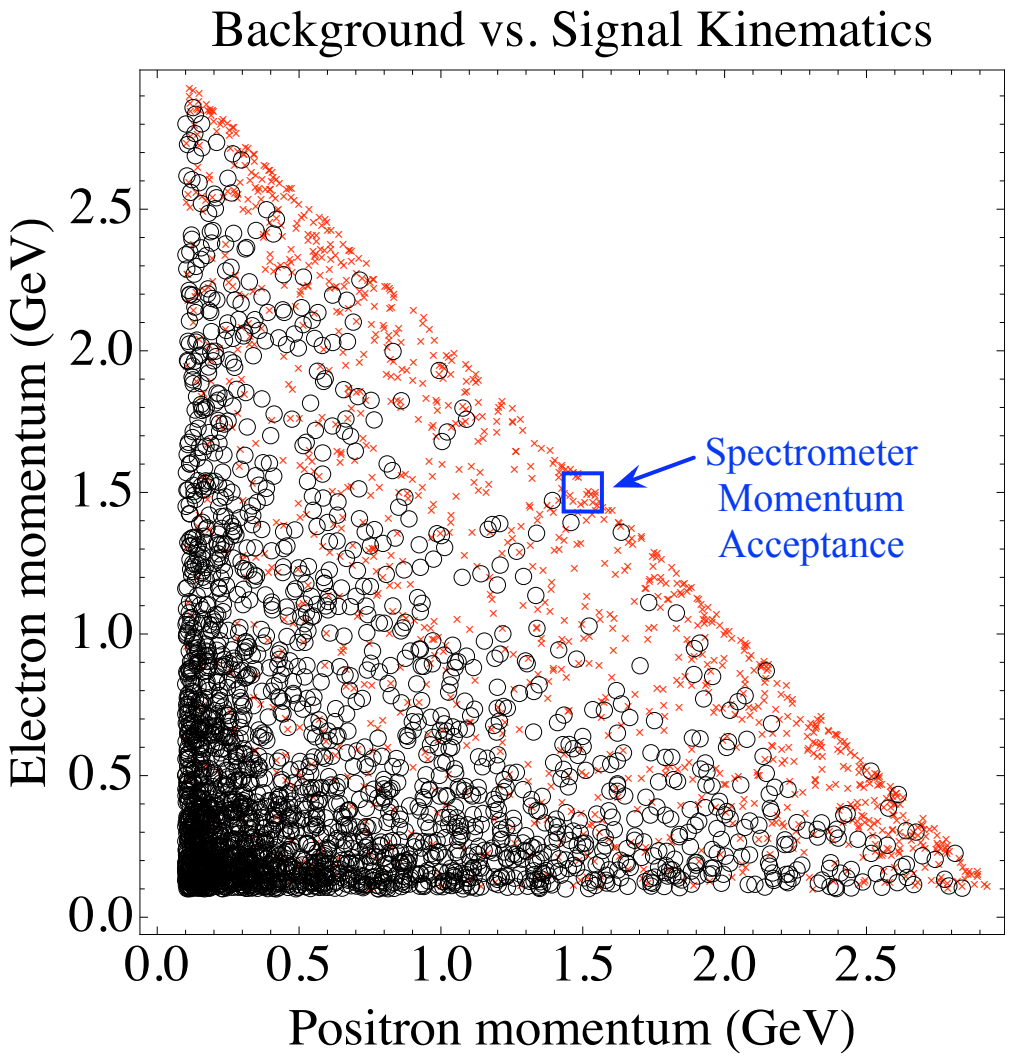


A′ products carry full beam energy!

– Distinctive kinematics
– Δp/p assists in background suppression

Best kinematics to select events for A′ search

Spectrometer Acceptance and S/N Ratio

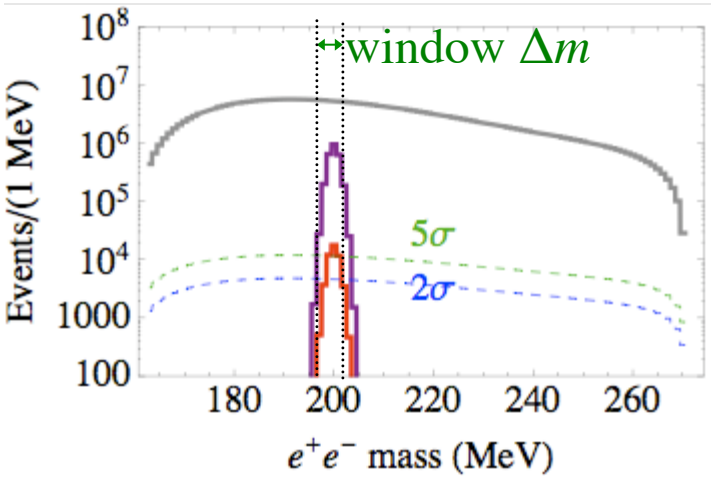


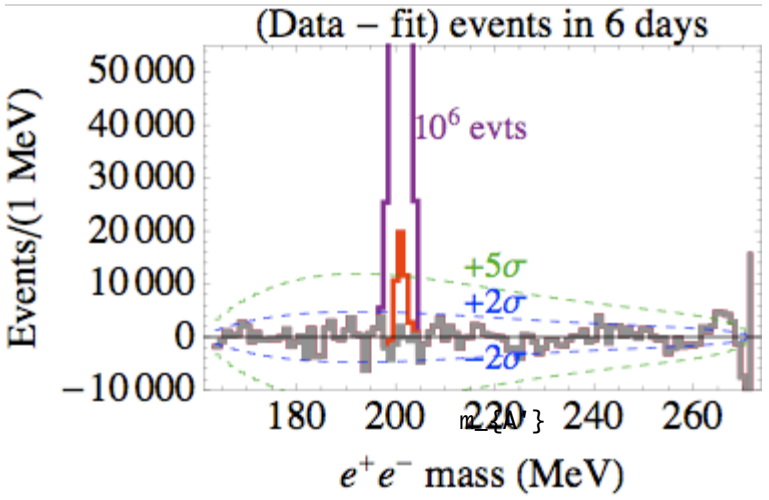
When the productivity reaches the limit of the detector/DAQ capabilities, a modest momentum range is better!

Narrow Resonance Search

To identify A′ signal, must study invariant mass distribution

$$m_{A'} \approx \sqrt{E_+ E_-}(\theta_+ + \theta_-)$$





In mass window Δm:

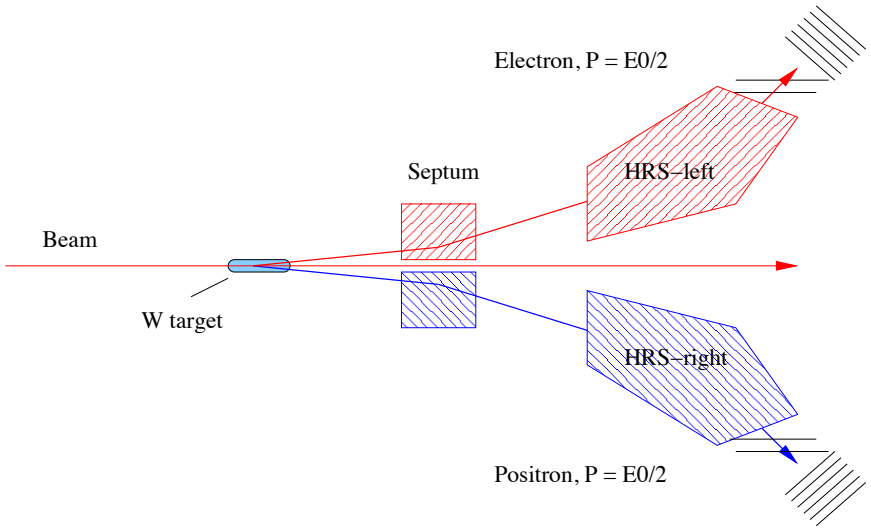
$$\frac{S}{\sqrt{B}} \sim \frac{\alpha'}{\alpha^2}\sqrt{N_{QED}\left(\frac{m_{A'}}{\Delta m}\right)}$$

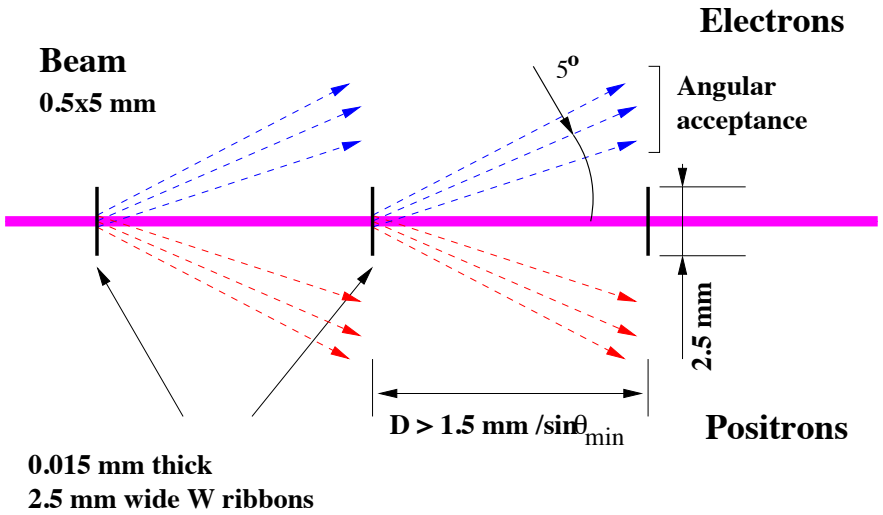
To search at small α', need:

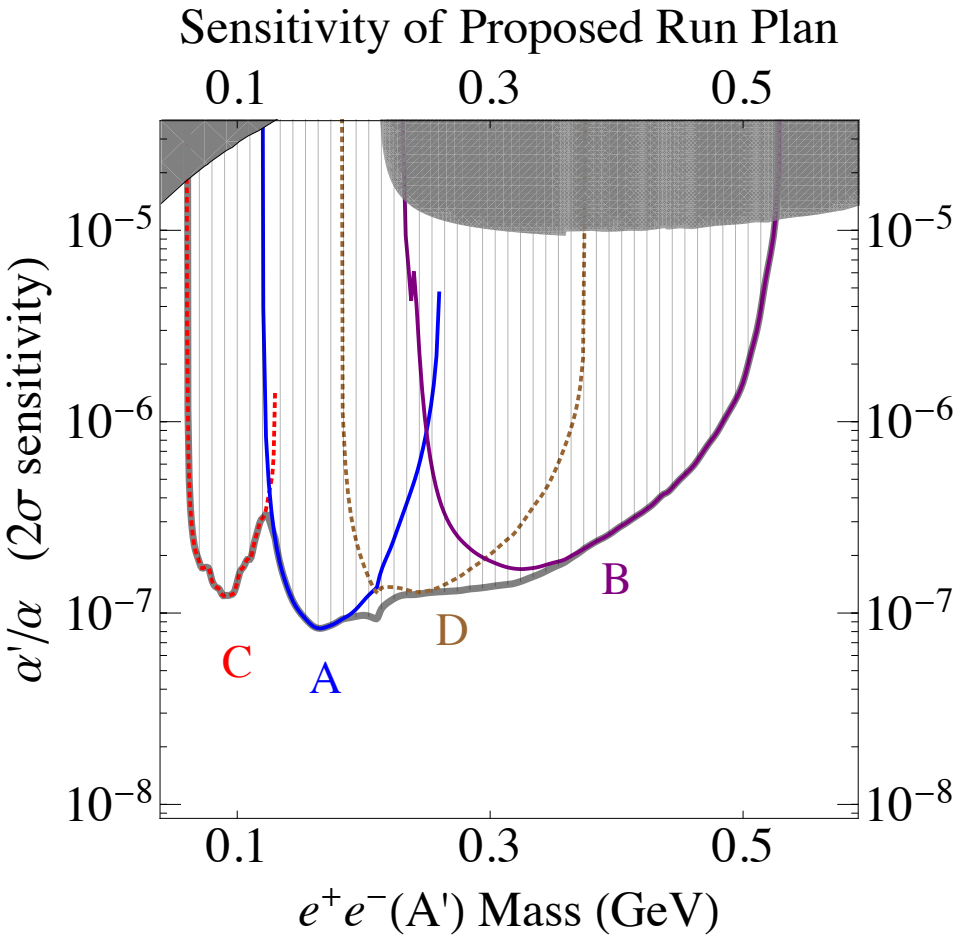
★High e^+e^- statistics

★Excellent mass resolution

Angular Range and Smooth Mass Acceptance







APEX: A Search for Dark Photons in Hall A

What is the APEX search method?

Why will Hall A do a very good experiment?

What are the results of the 2010 test run?

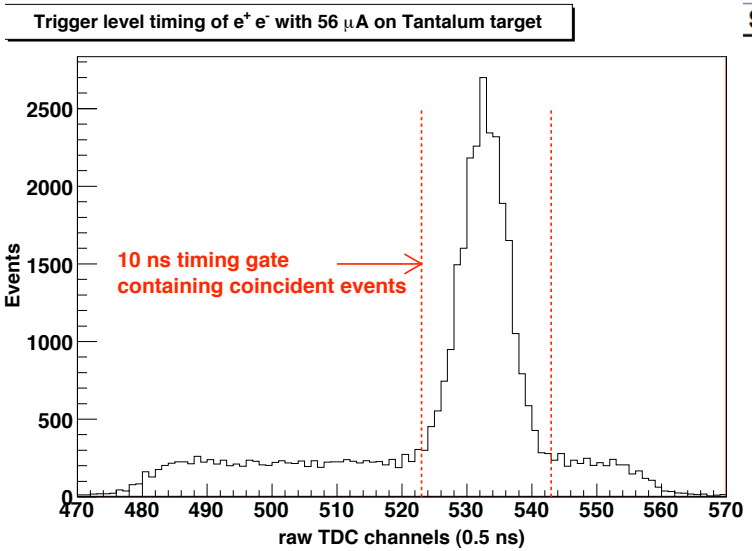
- Validation of every item of the experiment concept
- Full approval by PAC with recommendation to run ASAP
- 3 days of data: PRL, best citation rate in Hall A in the last 5 years

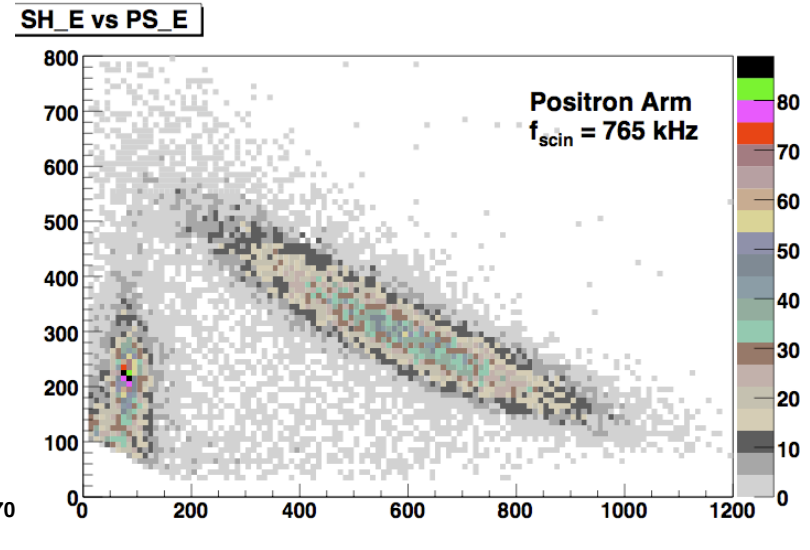
Test Run, June 2010: Collected data to address issues per PAC 35 report

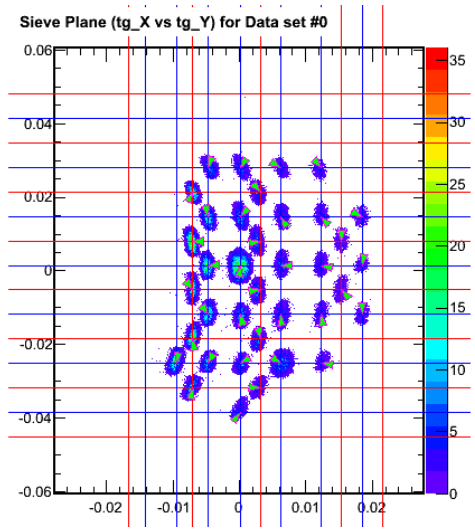
- ✓ Use of the Gas Cherenkov in trigger, timing – proposed 20 ns, demonstrated 10 ns
- ✓ Operation of the VDC at 5 MHz track rate – demonstrated up to 8 MHz
- ✓ Operation of the positron arm PID – demonstrated up to 0.8 MHz (more than needed)
- ✓ Operation of trigger/DAQ – demonstrated total dead time of 8% at full luminosity

Extended multi-foil target designed and built; not installed due to time, manpower constraints and high radiation left after PREX.

- Also checked: optics calibration, singles rates in the HRS spectrometers, signal to background in trigger and offline analysis, a thin Ta foil with 150 μA beam.
- Accumulated about 2 million true e+e- coincidence events & optics data for new physics result for mass range around 200 MeV.







APEX: A Search for Dark Photons in Hall A

Why do a search for new physics at JLab?

Proposal: PR12-10-009

Scientific Rating: A
Recommendation: Approval

The PAC approves the proposal contingent on a successful solution of the radiation issue. The PAC feels that the experiment should be carried out as early as possible (ideally before the 6 GeV shut down in 2012).

Title: "Search for new Vector Boson *A'* Decaying to e^+e^-"

Spokespersons: R. Essig, P. Schuster, N. Toro, B. Wojtsekhowski

Motivation: The proposal is to search for a vector boson *A'* with weak coupling of about 10^{-3} e or smaller to electrons in the mass region 65-525 MeV. The proposed search is motivated by recent developments of models trying to explain inconsistencies observed in astrophysical data and dark matter search experiments. Such a vector boson would couple to charged leptons as it will mix with photon. If *A'* is produced by radiation off an electron beam, it would decay producing very narrow resonance in the invariant mass e^+e^- spectrum.

The proposal is very interesting and has the potential to make an important discovery. There are not many places where such measurement can be done, as it requires very high integrated luminosity and good control of the electromagnetic background. Part of the plane of coupling constant *versus* mass of the boson has already been excluded, but the region available for the proposed experiment coincides with the domain of greatest theoretical interest, for example explaining the deviation from SM expectations observed in the latest *g-2* experiment.

APEX: A Search for Dark Photons in Hall A

As you know, your experiment has been conditionally approved in the category C1. This means that it must meet the designated technical requirements to obtain approval from laboratory management.

Jefferson Lab is revisiting the experimental readiness review process in preparation of the 12-GeV startup. The resulting document, expected to be released soon, will give the guidance for running experiments in the 12 GeV era. The document guidelines ask, among others, a) to calculate and document Experiment Operating Envelope (EOE) for all combinations of beam conditions and target planned; b) write a formal Radiation Safety Assessment Document (RSAD) for the experiment that explicitly includes the calculations of the EOE and addresses the EHS&Q issues it raises. Specifically, assessing the amount of radiation being generated in the hall by the experiment and implementing measures to reduce it as well as assessing its impact on the experiment equipment and running efficiency are now a requirement for every experiment and they are part of the Experiment Readiness Review leading to scheduling and running an experiment. In essence, this requirement is identical to the condition imposed by the PAC for running APEX except that now this requirement applies to every experiment. So, APEX no longer has a special condition attached to it. Now, like all other experiments, it needs to demonstrate that if fulfills the above requirements and it is subject to the same procedures than the other experiments.

Therefore there is no need to appoint a separate review committee now for your approval process.

Sincerely,

Patricia Rossi

APEX: A Search for Dark Photons in Hall A

Why will Hall A do a very good experiment?

What are the results of the 2010 test run?

What is the status of the experimental equipment?

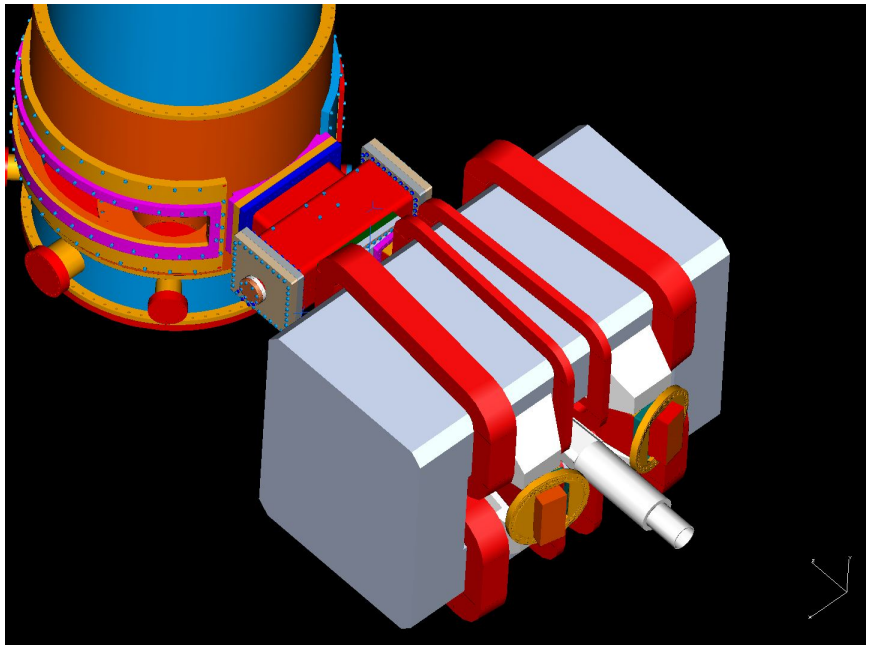
- Spectrometers: maintenance is in progress
- Septa magnet designed, could be delivered by Dec. 2013
- Vacuum chamber design could be completed in August
- Power supply for 2kA is needed for 4.4 GeV running

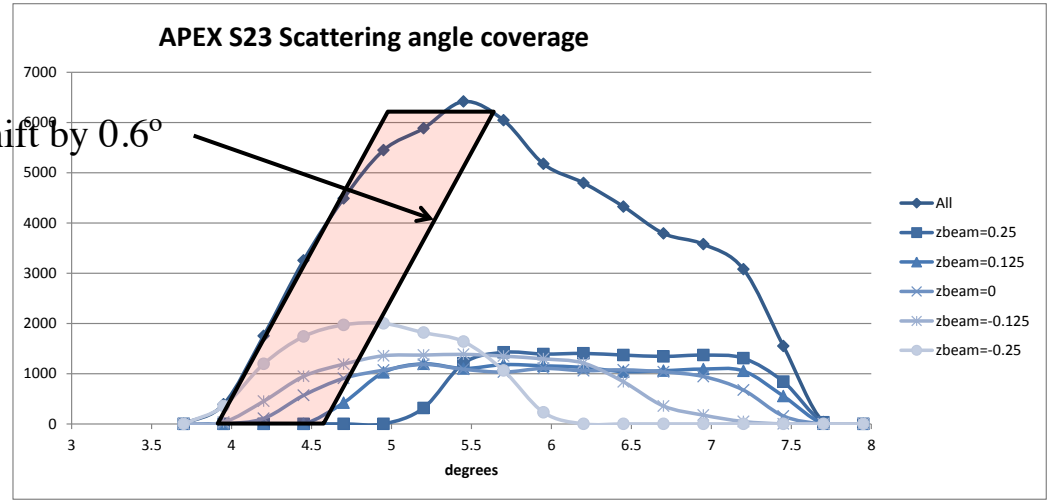
APEX: A Search for Dark Photons in Hall A

What is the status of the experimental equipment?

- Septa:

1) A new design of the magnet: shielded beam; simple coils, acceptance from 3.7 degree scattering angle, larger momentum
External funding for design (15k) and construction (120k)
2) Delivery in December 2013 (pending MOU approval).





This septa has the min angle of 3.7° in APEX mode and 3.4° in PREX mode for 2.2 GeV momentum

APEX: A Search for Dark Photons in Hall A

Why will Hall A do a very good experiment?

What are the results of the 2010 test run?

What is the status of the experimental equipment?

What are the cost of preparation and the sources of funding?

- The total cost of APEX equipment was estimated to be $200-250k.

- There is $120k in Schuster's grant for the magnet. PIs will look for additional funding for the vacuum chamber inside the magnet.

APEX: A Search for Dark Photons in Hall A

Why do a search for new physics at JLab?
What are the A' particle status and perspectives?
What is the APEX search method?
Why is APEX an easy experiment to run?
What are the instrumentation requirements?

- HRS momentum resolution < 3 10^{-3} (rel.)
- HRS central angle accuracy < 0.5 degree
- Targets are solid Ta foils, air cooled
- Beam charge accuracy is < 10%
- Beam energy stability < 1% (day by day)
- Radiation dose is OK
- Tracking operation up to 5 MHz - tested
- Positron selection online of 50/1 - tested
- Online timing gate is 20 ns - tested

APEX: A Search for Dark Photons in Hall A

What are the specifics of the APEX optics?

$$m^2_{A'} = |p_{positron} + p_{electron}|^2 = |p_+ + p_-|^2$$

$$m^2_{A'} = 2m^2_e + 2|\vec{p_+}| \cdot |\vec{p_-}| \cdot (1 - \cos\theta_\pm)$$

$$\delta m/m,\ \theta_\pm \sim 0.15; 1 - \cos\theta \approx 1 - \theta^2/2 + \theta^4/24$$

$$m^2_{A'} \approx |\vec{p_+}| \cdot |\vec{p_-}| \cdot (\theta_\pm)^2$$

$$m_{A'} \approx p_{+(-)} \cdot \theta_\pm$$

$$\frac{\delta m}{m} = \frac{\delta p}{p} \bigotimes \frac{\delta\theta}{\theta}$$

APEX: A Search for Dark Photons in Hall A

What are the contributions to mass resolution?

δp - momentum resolution

$\delta\theta_{central}$ - spectrometer central angle uncertainty, CA

$\delta\theta_{optics}$ - matrix reconstruction quality, OP

$\delta\theta_{track}$ - focal plane tracking, incl. window, TR

$\delta\theta_{scatt}$ - scattering in the target, MS

$$\frac{\delta m}{m} = \frac{\delta p}{p} \otimes \frac{\delta\theta_{CA}\times[\Delta p/\sqrt{12}p]}{\theta_{\pm}} \otimes \frac{\delta\theta_{OP}}{\theta_{\pm}} \otimes \frac{\delta\theta_{TR}}{\theta_{\pm}} \otimes \frac{\delta\theta_{MS}}{\theta_{\pm}} \sim 1/200$$

$< 1/1000$ $\quad$ $0.5(^{o})/300$ $\quad$ each $\sim< 0.4/150$

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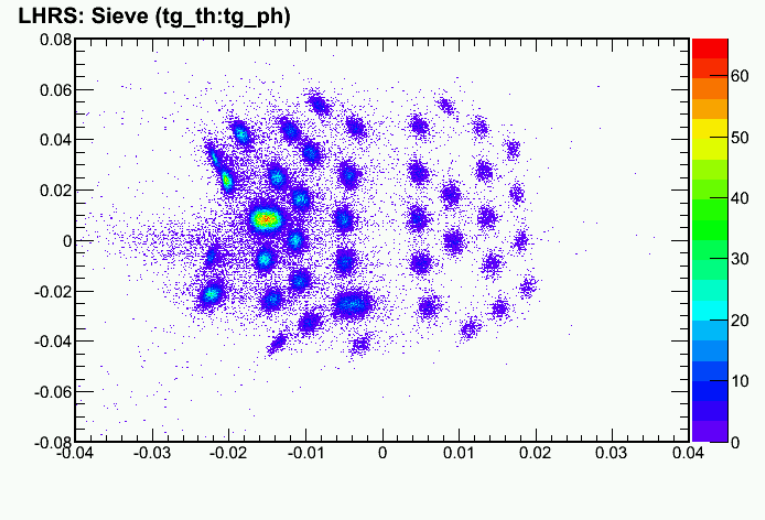
HRS optics

Traditional sieve pattern



Active "sieve slit": a Sci Fiber detector with 1 mm fibers with 1/4" pitch connected via a bundle of 1.5 mm clear fibers to a 64-channel PMT. **Effectively a 1024-hole sieve slit.**
Readout via 1877S TDC; 1-3 MHz rate per fiber; off-line time window of < 5 ns
All components are constructed.
One arm was assembled in February.

Positively charged particle optics needs the SciFi