The A’ Experiment (APEX)
Searching for New Gauge Bosons in the A’ Experiment at Jefferson Laboratory

February 2014 Status Report

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Bogdan Wojtsekhowski (JLab)
don behalf of APEX
In brief: APEX is a spectrometer-based search, at JLab Hall A, for 50-500 MeV hidden-sector photons decaying promptly to $e^+e^-$. 

1) The APEX experiment: 
   general setup and rationale 
   a few important details 
   JHEP 1102:009,2011, arxiv:1001.2557

2) Test run (July 2010) 
   results 

3) Full APEX 
   extended target 
   SciFi optics calibration for 
   better mass resolution 
   new septum
In brief: APEX is a spectrometer-based search, at JLab Hall A, for 50-500 MeV hidden-sector photons decaying promptly to $e^+e^-$. 

1) The APEX experiment: general setup and rationale a few important details JHEP 1102:009,2011, arxiv:1001.2557

2) Test run (July 2010) results PRL 107:191804,2011, arxiv:1108.2750

3) Full APEX extended target SciFi optics calibration for better mass resolution new septum
APEX Concept and Dark Photon Production

\[ e^- \]

Energy = \( E \)

\[ \sim \left( \frac{m_A}{E} \right)^{3/2} \] (narrow)

\[ \sim \left( \frac{m_A}{E} \right)^{1/2} \] (wide)

\[ E_{A'} \approx E_{beam} - m_{A'} \]

\[ E_{e^-} \approx m_{A'} \]

Electron, \( P = E_0/2 \)

Positron, \( P = E_0/2 \)

Wednesday, 26 February, 14
The High Resolution Spectrometers

<table>
<thead>
<tr>
<th>Range</th>
<th>Acceptance</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.3 &lt; p &lt; 4.0 \text{ GeV/c}$</td>
<td>$-4.5% &lt; \Delta p/p &lt; 4.5%$</td>
<td>$\delta p/p \leq 2 \times 10^{-4}$</td>
</tr>
<tr>
<td>$12.5^\circ &lt; \theta_0 &lt; 150^\circ$</td>
<td>6 msr</td>
<td>$\delta \phi = 0.5 \text{ mrad (H)}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\delta \theta = 1 \text{ mrad (V)}$</td>
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</table>

(4.5 msr at $\theta_0 = 5^\circ$ with septum)
A’ Production and Background Kinematics (m_{A'} \ll E_{\text{beam}})

**A’ Production**

\[ \sigma \sim \alpha' / m^2 = \varepsilon^2 \alpha / m^2 \]

Nucleus

\[ e^- \rightarrow A' \rightarrow e^- + e^+ \]

rates before angular cuts

(E_+ + E_-)/E_{\text{beam}}

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

Distinctive kinematics

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

\[ A' (\alpha'/\alpha = 3 \times 10^{-6}) \]

QED Backgrounds

\[ \gamma^* \]

(\gamma s)

\[ A' \text{ products carry (almost) full beam energy!} \]

Symmetric energy, angles in two arms optimize A' acceptance

Also suppresses e^- singles & other pair backgrounds

After rejecting accidental e^-\pi^+ (demonstrated in test run), event rate dominated by QED backgrounds above
APEX test run

- Test run performed in Hall A, July 2010
  Many thanks to JLab & Hall A staff for tremendous support!
- Verified all key aspects of apparatus performance
  - VDC tracking performance at 4–6 MHz singles rates
  - Gas Cerenkov detector in coincidence trigger to reject π⁺’s
  - spectrometer optics & mass resolution
  - measurement of physics backgrounds
- Resonance search on 700K good trident events
Full APEX run plan and sensitivity

Sensitivity of Proposed Run Plan

1 Month Beam Time
– 6 days at 1, 2, 3 GeV
– 12 days at 4.5 GeV
>100x test-run statistics

 Fully approved by JLab PAC 37 & JLab management
Explores parameter space with unparalleled efficiency
(particularly above ~300 MeV)
APEX run in 2016/17...

### Hall A Projected Experiment Schedule as of 12/2013

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Fall</th>
<th>Spring</th>
<th>Fall</th>
<th>Spring</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>Hall Checkout</td>
<td>DVCS – I / G_{M}^{p}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td>DVCS – I / G_{M}^{p}</td>
<td>³H/³He</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2016</td>
<td></td>
<td></td>
<td>(A_{1}^{n}) (APEX) (PREX) (CREX)</td>
<td></td>
<td>(A_{1}^{n}) (APEX) (PREX) (CREX)</td>
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<tr>
<td>2017</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(as above, plus DVCS-II and SBS)</td>
</tr>
</tbody>
</table>

Experiments in parentheses are anticipated to be ready and appropriate for the indicated time slot, and so represent potential options - in no particular order.
Status Report & Readiness

- **APEX extended target**
  - target built for test run is at JLab

- **SciFi detector for optics calibration**
  - Both detectors, optical cables, and PMT assemblies are constructed. One detector is tested (without PMT).

- **Septum**
  - Design is finalized. Drawings are produced. Magnet has been ordered. Delivery is expected in June.

- **HRS detector maintenance is proceeding**
  - Detectors are installed, cosmics tests underway, beam tests in March 2014
Assumptions were made:

a) The SBS power supply is installed, operational with the current bus to the SBS location
b) Shielding plan for the HRS power electronics is accepted by RadCon (needs a review)
c) Installation manpower is provided by Hall A
d) Hall A scientific manpower is not counted

### Beam line hardware

<table>
<thead>
<tr>
<th>Item</th>
<th>Design and engineering cost</th>
<th>Construction cost</th>
<th>Status, 3/1/2014 Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Septa</td>
<td>$16k (NCCU), complete</td>
<td>$79k, Canadian NSERC Discovery Accelerator Award, P. Schuster, Waterloo &amp; Perimeter Institute</td>
<td>ordered, $134k, delivery in July 2014</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$25k, Alfred P. Sloan Foundation, R. Essig, Stony Brook</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>$15k, Dep. head’s Fund, G. B. Franklin, Carnegie Mellon</td>
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<tr>
<td></td>
<td></td>
<td>$15k, NSF, CSULA, K. Aniol</td>
<td></td>
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<tr>
<td>Vacuum connections</td>
<td>$3k, (HU+RU)</td>
<td>estimated cost $30k</td>
<td>design is under way</td>
</tr>
<tr>
<td></td>
<td>$5k, Collaboration 1 m-w design, Hall A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrector magnets</td>
<td>$2k, Collaboration 2.5 m-d design, Hall A</td>
<td>estimated cost $5.5</td>
<td>ready for design</td>
</tr>
<tr>
<td>Extended target</td>
<td>SLAC, 2010, complete</td>
<td>SLAC, $5k (2010)</td>
<td>requires 3 m-m postdoc, Collaboration</td>
</tr>
<tr>
<td>Sieve slits (optics)</td>
<td></td>
<td>existing pair</td>
<td></td>
</tr>
<tr>
<td>Beam line corrector</td>
<td></td>
<td>existing magnet</td>
<td></td>
</tr>
<tr>
<td>Septa magnet infrastructure:</td>
<td>Hall A designers:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. support platform</td>
<td>a) 1 m-m design</td>
<td>Hall A, estimated $5k</td>
<td></td>
</tr>
<tr>
<td>b. water distribution</td>
<td>b) catalog items</td>
<td>Hall A, estimated $5k</td>
<td></td>
</tr>
<tr>
<td>c. current bus</td>
<td>c) 1 m-m design</td>
<td>Hall A, estimated $10k</td>
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## Expenses and Funding

### APEX detectors

<table>
<thead>
<tr>
<th></th>
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<th>Part of HRS(s) preparation</th>
<th>ready by March 2014</th>
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</thead>
<tbody>
<tr>
<td>HRS(s) detector</td>
<td>Hall A, 2013-2014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>packages</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SciFi - optics</td>
<td>Hall A, 2012</td>
<td>Hall A OPS, $25k (2012),</td>
<td>requires 3 m-m</td>
</tr>
<tr>
<td>detectors</td>
<td>complete</td>
<td>complete</td>
<td>postdoc, Collaboration</td>
</tr>
</tbody>
</table>

### Hall A preparation

|                  |                  | Hall A, estimated $3.5k    | Reuse of existing (GEn) |
|------------------|-------------------|----------------------------| lead/steel shield      |
| Radiation shield | 1 m-w design      |                            |                      |
| of the HRS power |                   |                            |                      |
| electronics      |                   |                            |                      |
| supply           |                   |                            |                      |
| Beam line        | JLab geod. survey | Hall A, estimated $10k     |                      |
| alignment        | team              |                            |                      |
| Installation     |                   | Hall A technical team      | 3 months              |

### Summary

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<thead>
<tr>
<th></th>
<th></th>
<th>$69k, primarily Hall A OPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary</td>
<td>2.6 m-m Hall A</td>
<td></td>
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<tr>
<td>designer</td>
<td>$7k, Collaboration</td>
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</tbody>
</table>
Expenses and Funding

New grant applications submitted (mainly to fund scientific manpower)

<table>
<thead>
<tr>
<th>Agency</th>
<th>Title &amp; Submitter</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE (HEP) &amp; NSF</td>
<td>“The A' Experiment (APEX): Search for a New Vector Boson A' Decaying to e+e-”,</td>
<td>$422,847, request included 1 postdoc for 3 years, 1 month summer salary, travel, equipment (</td>
</tr>
<tr>
<td>(submitted 9/13 &amp; 10/13)</td>
<td>R. Essig, Stony Brook</td>
<td>$10k corrector magnet, $15k vacuum chamber, $35k septum magnet)</td>
</tr>
</tbody>
</table>

Approved grants (mainly to fund scientific manpower)

<table>
<thead>
<tr>
<th>Agency</th>
<th>Title &amp; Submitter</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE (NP)</td>
<td>“Experimental Medium Energy Physics” G. B. Franklin, Carnegie Mellon</td>
<td>$2,936,000, Includes 3 years of support for Carnegie Mellon’s activities in Hall A and Hall D.</td>
</tr>
<tr>
<td></td>
<td>F: Expect to contribute, 1 graduate student, 50% of a post-doc, 0.25 FTE faculty to the APEX experiment over the 3-year grant period.</td>
<td></td>
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</tbody>
</table>

Good time for this support to begin is Summer 2014
Target Design: Minimizing Multiple Scattering

Target designed and built by SLAC APEX group for the test run (but not installed), 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 $E_{\text{beam}}$)
- High-Z target (reduce $\pi$ yield for given QED rates)
- Stable under currents up to $\sim 100 \, \mu A$

schematic overhead view

beam

15$\mu$m W

$\Rightarrow$ wider single-run mass coverage
Target Design: Minimizing Multiple Scattering

Target designed and built by SLAC APEX group for the test run (but not installed), currently at JLab.
Target To-Do List:

- Develop plan of target operation
- Additional target holders required.
- Analysis of heat load and cooling for 1, 3, & 4 pass settings needed, and repeat 2 pass analysis
Magnetic Spectrometer Optics

Measuring Contributions to the Mass Resolution
(dominant: *angular resolution* + mult. scatter)
Removable sieve plate is inserted upstream of septum.

Use surveyed locations of sieve holes to calibrate magnetic optics.

Use reconstructed hole sizes to measure resolution.

...this method only works for negative polarity, and requires running at different beam energy.

Mass resolution ≈ 1 MeV ~ 0.5%
HRS optics

“Active sieve slit”: tagging by a Sci Fiber detector

- 1 mm fibers with 1/16” pitch (equivalent to 1024 sieve holes)
- Projected rate: 1-3 MHz per fiber
- Off-line time window < 5 ns

Help needed to complete project

Allows optics calibration at production beam energy & for both polarities
SciFi & Optics To-Do List:

- SciFi Commissioning: DAQ and Readout
- Need to develop expertise in SciFi use to prepare for optics calibration
- Help would be immediately useful!
New HRS Septum Magnet

- Designed for parallel field capability (minimize fringe field near beamline)

- Optimized for full angular acceptance

- High density coils used to enable full energy range required (up to 2.2 GeV momentum electron and positron)
New HRS Septum Magnet

- Buckley Systems constructing the magnet system
- New extension box and vacuum connections for beamline and to the spectrometers needed
- Requires 2kA for high-energy settings (same as SBS magnet)
HRS Septum & Beamline To-Do

- New extension box and vacuum connections for beamline and to the spectrometers needed (additional 7K design costs need to be covered by collaboration, 3K already promised)

- Complete magnet preparation (Hall A engineering staff), 2.5 man months

- Need to develop expertise in acceptance calculations with the new septum magnet (John LeRose did this before).
Critical Projects

- SciFi Commissioning
- Target System Preparations
- HRS Septum Magnet, and associated beamline
- Preparation of Software -- VDC & PID (more on this at collaboration meeting)
APEX has demonstrated feasibility and power of spectrometer searches for hidden-sector photons

Strong physics impact already from test run (highly cited Hall A result)

APEX can explore important range of mass and coupling most efficiently and before other experiments

Opportunity for immediate science impact – even with commissioning-quality beam.