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

Philip Schuster (Perimeter Institute)
for the APEX Collaboration

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 and improvements to mass resolution
Continuous Electron Beam Accelerator Facility

- Delivers beam up to 6 GeV to 3 experimental halls
  
  Halls A, C up to 100 µA
  Hall B: 1 µA

- 1.5 GHz RF ⇒ each hall gets bunch every 2 ns

- 12 GeV upgrade by 2014
The High Resolution Spectrometers

Lead Glass Calorimeter

S2m

S0

VDC

Gas Cherenkov
The High Resolution Spectrometers

<table>
<thead>
<tr>
<th>Range</th>
<th>Acceptance</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.3 &lt; p &lt; 4.0$ 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>$\delta \phi = 0.5$ mrad (H)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\delta \theta = 1$ mrad (V)</td>
</tr>
</tbody>
</table>

(4.5 msr at $\theta_0 = 6^\circ$ with septum)
A' Production Kinematics

Energy = E

Note $m_{A'}/E \leftrightarrow \theta : 0.5$ (DarkLight), 0.3 (MAMI), 0.1 (APEX), 0.03 (HPS)
A’ Production and Background Kinematics ($m_{A’} \ll E_{\text{beam}}$)

**A’ Production**

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

Nucleus

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

QED Backgrounds

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

- Distinctive kinematics:
  
  A’ products carry (almost) full beam energy!

Symmetric energy, angles in two arms optimize $A'$ acceptance

\[ E^+ \approx E^- \approx E_{\text{beam}}/2 \]
Advantages of narrow momentum acceptance

Small acceptance allows excellent mass resolution; also greatly suppresses singles and non-QED coincidence backgrounds

Events outside this window never reach spectrometer

Singles:
- Elastic scattered $e^-$ (above acceptance)
- Moller $e^-$

Coincidence:
- $\pi^0 \rightarrow \gamma e^+ e^-$
- Radiated $\gamma \rightarrow e^+ e^-$

Dominant coincidence background (accidental $e^-\pi^+$) can be rejected by using Gas Cherenkov detector in coincidence trigger.
APEX test run

• Test run performed in Hall A, July 2010
  Many thanks to JLab & Hall A staff for tremendous support!

• Demonstrated many key elements for full experiment
  – accurate & efficient VDC reconstruction at high $e^-$ track rate
  – coincidence trigger on S2 scintillators and Gas Cherenkov ($e^+$ arm)
  – tested understanding of background processes
  – spectrometer optics & mass resolution
  – resonance search on 700K good trident events

---

Trigger level timing of $e^+e^-$ with 56 $\mu$A on Tantalum target

Energy of $e^+e^-$ pair

![Graph showing trigger level timing and energy of $e^+e^-$ pair](image)
Test-Run Science Data and Resonance Search

Data

QED (no efficiency correction)

Accidental

example of fit used in peak-search (in toy MC)

mass [MeV]

$e^+e^-$ mass [MeV]

Residual

Events / 0.5 MeV

Fit: Smoothed plus BernCorr, 1

example of fit used in peak-search (in toy MC)

Nucleus

$e^-$

$A'$

$e^-$

$e^+$

$e^-$

$e^-$
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 $\approx 1$ MeV
$\sim 0.5\%$
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 $\approx 1$ MeV
~0.5%
Full APEX run plan and sensitivity

Approved by JLab PAC 37;
Planning underway for full run – will greatly extend sensitivity to dark forces.
Target designed and built by SLAC APEX group for the test run (but not installed), currently at JLab.
Target designed and built by SLAC APEX group for the test run (but not installed), currently at JLab.
Target Design: Minimizing Multiple Scattering

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

Goals:
- $\sigma(\theta)_{\text{mult scat}} \leq 0.5 \text{ mrad}$
  $\Rightarrow$ 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 $\sim 100 \, \mu A$

long target $\Rightarrow$ wider single-run mass coverage
HRS optics

- Active “sieve slit”: tagging by a Sci Fiber detector
- 1 mm fibers with 1/16” pitch connected to a maPMT
- Readout via 1877s TDC
- 1-3 MHz rate per fiber
- Off-line time window of < 5 ns
- Nearing completion
New HRS Septum Magnet

- Designed for parallel field configuration
- Optimized for full angular acceptance
- High density coils used to enable high energy use
- Use of NSERC DAS for partial funding
- Projected delivery time as early as December 2013
APEX has demonstrated feasibility and power of spectrometer searches for hidden-sector photons.
Summary

APEX has demonstrated feasibility and power of spectrometer searches for hidden-sector photons

Improvements planned for full run

Important range of mass and coupling will be explored
Summary

APEX search region complements and extends region being explored by Mainz

arXiv:1303.2540
Thanks!
BACKUP SLIDES
Coincidence trigger and particle ID performance

**Trigger level timing of e⁺ e⁻ with 56 μA on Tantalum target**

- 10 ns timing gate containing coincident events

**Gas Cherenkov**

- Positron detection eff. 0.964
- Pion rejection eff. 0.979

**Calorimeter**

- f_{scin} = 765 kHz
- Electron detection eff. 0.967
- Pion rejection eff. 0.969
- Pion leakage 0.044
- Electron detection eff 0.956
- Pion rejection eff 0.981
- Pion leakage 0.027

coincidence peak for two-arm X-e⁺ trigger (requires coincident GC signal in positive-polarity arm)
Sieve Slit Method

Left HRS calibration used 35 holes, Right HRS calibration used 38 holes
HRS optics for APEX

**Figure:**
- **Top Left:** x (2,8) graph with peak: 15.128 and sigma: 0.409.
- **Top Center Left:** y (2,8) graph with peak: -5.384 and sigma: 1.624.
- **Top Center Right:** x (5,8) graph with peak: 2.451 and sigma: 0.375.
- **Top Right:** y (5,8) graph with peak: -5.395 and sigma: 1.213.

**Bottom:**
- **Graph:** Angle Deviation (milliradians) with data points for Series 1.
# Angular Resolutions

## Averages weighted according to statistics

<table>
<thead>
<tr>
<th></th>
<th>LHRS (mrad)</th>
<th>RHRS (mrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Optics calibration</strong> precision</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta_\varphi )</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>( \Delta_\theta )</td>
<td>0.24</td>
<td>0.20</td>
</tr>
<tr>
<td>( \sigma_{\varphi\text{-width}} )</td>
<td>0.26</td>
<td>0.43</td>
</tr>
<tr>
<td>( \sigma_{\theta\text{-width}} )</td>
<td>1.81</td>
<td>1.75</td>
</tr>
<tr>
<td><strong>Tracking precision</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \sigma_\varphi )</td>
<td>0.29</td>
<td>0.44</td>
</tr>
<tr>
<td>( \sigma_\theta )</td>
<td>1.86</td>
<td>1.77</td>
</tr>
</tbody>
</table>

\( \varphi/\theta \) – hor / vert angles

---

Monday, 29 April, 13
## Mass Resolution

### Angular resolution averages (mrad) determined for different masses

<table>
<thead>
<tr>
<th>Mass (MeV)</th>
<th>180</th>
<th>195</th>
<th>210</th>
<th>225</th>
<th>240</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left theta (mrad)</td>
<td>1.95</td>
<td>1.87</td>
<td>1.89</td>
<td>1.93</td>
<td>1.88</td>
<td>1.86</td>
</tr>
<tr>
<td>Left phi (mrad)</td>
<td>0.26</td>
<td>0.3</td>
<td>0.32</td>
<td>0.33</td>
<td>0.33</td>
<td>0.29</td>
</tr>
<tr>
<td>Right theta (mrad)</td>
<td>1.69</td>
<td>1.74</td>
<td>1.81</td>
<td>1.85</td>
<td>1.85</td>
<td>1.77</td>
</tr>
<tr>
<td>Right phi (mrad)</td>
<td>0.38</td>
<td>0.43</td>
<td>0.46</td>
<td>0.5</td>
<td>0.53</td>
<td>0.44</td>
</tr>
</tbody>
</table>

### Mass resolutions (MeV) determined for different masses using 3 different methods

<table>
<thead>
<tr>
<th>Mass (MeV)</th>
<th>180</th>
<th>195</th>
<th>210</th>
<th>225</th>
<th>240</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using different angular resolutions for each event</td>
<td>0.833</td>
<td>0.965</td>
<td>1.026</td>
<td>1.061</td>
<td>1.037</td>
<td>1.005</td>
</tr>
<tr>
<td>Using angular resolutions listed in above table for all events</td>
<td>0.822</td>
<td>0.962</td>
<td>1.023</td>
<td>1.054</td>
<td>1.043</td>
<td>-</td>
</tr>
<tr>
<td>Using angular resolutions from &quot;Total&quot; column in above table for all events</td>
<td>0.869</td>
<td>0.965</td>
<td>0.995</td>
<td>0.994</td>
<td>0.966</td>
<td>0.977</td>
</tr>
</tbody>
</table>