Gordon Research Conference
Photonuclear Reactions

Heavy Photon Search experiment at JLAB

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Introduction


\[
\mathcal{L} = \mathcal{L}_{SM} + \frac{\epsilon}{2} F_{Y,\mu\nu} F'_{\mu\nu} + \frac{1}{4} F'_{\mu\nu} F'_{\mu\nu} + m_{A'}^2 A'_{\mu} A'_{\mu}
\]

Kinetic Mixing

\[\gamma \times \hspace{1cm} A'\]

$\epsilon$ is the mixing strength

\[\gamma \times \hspace{1cm} A'\]

generated by heavy particles interacting with $\gamma$ and $A'$

Many Dark Matter searches are based on this hypothesis
Producing $A'$ in fixed target experiments

Since $A'$ “can” couple to electric charge, then it is possible to expect it to be produced in a Bremsstrahlung process.

$A'$ production

\[ \sigma \propto \frac{e^2 Z^2}{m_{A'}^2} \]

Prodution of Timelike photon (radiative Tridents)

Similiar kinematics for fixed $M(e^- e^+)$

Angle: Forward

Energy: takes almost all the beam energy

\[ \theta_{A'} \approx \max \left( \frac{\sqrt{m_{A'} m_e}}{E_0}, \frac{m_{A'}^{3/2}}{E_0^{3/2}} \right) \]

\[ \frac{E_{A'}}{E_{beam}} \approx 1 - \max \left( \frac{m_e}{m_{A'}}, \frac{m_{A'}}{E_0} \right) \]

\[ \frac{\sigma(eA \rightarrow e'A' \rightarrow e^- e^+)}{\sigma(eA \rightarrow e'\gamma^* \rightarrow e^- e^+)} = \left( \frac{3\pi e^2}{2N_f \alpha} \right) \frac{m_{A'}}{\delta m} \]

From O. Moreno’s Thesis

Bethe Heitler

Much larger cross section, But very different kinematic
The CEBAF, Hall B and HPS

CEBAF Energy: 2.2 GeV/pass
Simultaneous delivery to 4 Halls

5 pass

Hall A
Hall C

Hall B

Alcove

HPS
HPS experimental setup

Chicane system with 3 dipole magnets

4 μm tungsten target

Electromagnetic Calorimeter

442 PbW0₄ Crystals

Initiates the trigger (Main, and 3 diagnostic)

Measures particle’s energy

Resolution $\frac{4\%}{\sqrt{E}}$ at 1 GeV

Silicon Vertex Tracker

6 layers of silicon

1ˢᵗ layer of silicon is at 0.5 mm from the beam

Measures charged particle’s momentum

Vertical hit resolution ≈ 6 μm

Horizontal hit resolution ≈ 60 μm (1st 3) and ≈ 120 μm (3 other layers)
**HPS reach**

**180 approved days**

Opportunistic runs:
Run only after work hours (2015)
And only on weekends (2016)

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**2015 Spring:**
- Beam current: 50 nA
- Beam energy: 1.05 GeV
- 30% of proposed amount of production data

**2016 Spring:**
- Beam current: 200 nA
- Beam energy: 2.3 GeV
- 77% of proposed amount of production data

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**Prompt decay, but large coupling**

Find a peak over a large background

**Small coupling, but longer decay time**

No background, few events are enough
2015 run

1.05 GeV

Goal: 30 mC

Achieved: 10 mC with SVT at 1.5 mm, 10 mC with SVT at 0.5 mm
2016 run

Goal: 120 mC

2.3 GeV     Only weekends

Achieved: 92.5 mC $6.3 \times 10^9$ triggers (77% of proposed running)
**Beam properties**

Before moving SVT to 0.5 \( mm \) beam properties were extensively studied

**Good Beam position stability**

Narrow vertical beam size at the target: \( \approx 50 \, \mu m \)

**Horizontal profile**

**Vertical beam position distribution**

**Vertical profile**

Width: \( 45 \, \mu m \)
Beam motion studies

Small vertical beam motions ($\sim 0.5\ mm$) can damage silicon.

Signals from four halo counters summed up and as an input sent to Fast ShutDown card.

Integration time: $1\ ms$

Placing harp wire close to the beam, with fast Struck scaler, we have measured fast beam motions.

We have estimated the fast motion amplitude: less than $20\ \mu m$.
2016 Ecal performance

Cosmic gains for initial calibration

18 MeV per crystal

Time difference between two clusters

Time offsets were calibrated wrt “precise” RF time

σ = 330 ps

Beam bunch structure
2016 SVT performance

Hit Efficiency for Layers 1-6

Cluster Energy Over Track Momentum

Momentum resolution is $\sim 7\%$ at 1 GeV
Final selection sample

Bump hunt: search for a peak over $M(e^-e^+)$ background

Preliminary
1.05 GeV beam

2.3 GeV beam
2015 Analysis

We need this for bump hunt

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Proposal value</th>
<th>Measured value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam current</td>
<td>50 nA</td>
<td>50 nA</td>
</tr>
<tr>
<td>SVT occupancy</td>
<td>&lt;1%</td>
<td>1%</td>
</tr>
<tr>
<td>DAQ/trigg. rate</td>
<td>18 kHz</td>
<td>19 kHz</td>
</tr>
<tr>
<td>Pair mass res. @ 34 MeV/c²</td>
<td>1.5 MeV</td>
<td>1.5 MeV</td>
</tr>
<tr>
<td>Pair vertex res. @ 40 MeV/c²</td>
<td>4.4 mm</td>
<td>4.6 mm</td>
</tr>
</tbody>
</table>
Blind analysis

Blind analysis: 10% of the data, 74 $nb^{-1}$

Most significant Poll

$m_{A'} = 27.525$ MeV

Bump hunt in the mass range 20-60 MeV

90% confidence level

Background: 7-th order polynomial
Signal width is fixed according to mass resolution
Summary

- HPS experiment allows heavy photon search through bump hunt and displaced vertex search
- HPS has completed successfully data taking in 2015 and 2016
- 165 days still remain: We expect next physics runs in 2018 and later
- Data analysis demonstrated good ECal and SVT performance during these runs, and instrumentation papers are in preparations for beamline, SVT and Ecal.
- Analysis codes are now close to be finalized, and we expect 1st publications before the end of 2016