Upgraded photon calorimeter with integrating readout for the Hall A Compton Polarimeter at Jefferson Lab

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1. Compton Polarimetry Introduction

2. Hall A Compton Polarimeter Upgrade

3. HAPPEX-III Beam Polarizations

4. Conclusion
New parity violation experiments require a better than 1% absolute measurement of the electron beam polarization

- HAPPEX-III measured a parity violating asymmetry with 1.5% overall systematic error – required 1% polarimetry

- Compton asymmetry is 1% – requires a precision of \(1 \times 10^{-4}\)

- Upgrades to existing Hall A equipment were necessary
**Compton Polarimetry**

- Longitudinally polarized electron beam scatters off circularly polarized IR laser light
  - Different scattering cross section depending on relative polarizations
The measured experimental asymmetry (for one laser polarization) is:

\[ A_{\text{exp}} = \frac{S^+ - S^-}{S^+ + S^-} \]

The measured Compton asymmetry gives the electron beam polarization:

\[ A_{\text{exp}} = A_{th} P_{\text{elect}} P_{\text{phot}} \quad \Rightarrow \quad P_{\text{elect}} = \frac{A_{\text{exp}}}{P_{\text{phot}} A_{th}} \]
Detection of scattered photons in photon detector
Detection of scattered electrons in electron detector
Only 1 electron in $10^9$ scatters – non-invasive
Energy Weighted Compton Measurement

- The Compton analyzing power is small and negative at low energies and large and positive at high energies.
- Thus an energy weighted measurement is useful – integrating mode.
- Upgraded Compton DAQ (FADC DAQ) integrates the detected signal.
- Adding a threshold could increase measured asymmetry, but also increases systematic error.

![Graph showing asymmetry vs. photon energy](image)
Counting vs Integrating Mode

Counting Mode
- Count all pulses which cross some threshold
- Not energy weighted – measures a smaller asymmetry
- Has threshold
- Sensitive to dead-time and pileup
- Less sensitive to non-linearities/gain shifts
- Works well at low photon rate
- $\sim 3\%$ systematic error

Integrating Mode
- Integrate all PMT output within a 33 ms time window
- Energy weighted – measures a larger asymmetry
- No threshold
- Insensitive to dead-time and pileup
- More sensitive to non-linearities/gain shifts
- Noise at low photon rate
- $1\%$ systematic error
Hall A Compton Polarimeter Upgrade

**Polarimeter Upgrade**

- New photon calorimeter: 15cm long, 6cm diameter GSO crystal
  - Ce-doped Gd$_2$SiO$_5$
  - $\sim$150 photo-electrons per MeV
  - “Linear” PMT and base
    - LED pulser built to measure linearity
- New integrating photon DAQ
  - Customized SIS3320 FADC
  - Two simultaneous modes: Accumulator (integrating) and Triggered
    - Integrating mode allows for stand-alone photon measurement
- New electron microstrip detector (can be used for calibration)
- Upgraded to green laser (used IR laser for HAPPEX-III measurement)
**Experimental Asymmetry**

\[ P_{\text{elect}} = \frac{A_{\text{exp}}}{P_{\text{phot}}A_{\text{th}}} \]

\[ A_{\text{exp}} = \frac{S^+ - S^-}{S^+ + S^-} \]

- Laser cycles between right and left circularly polarized
- Asymmetry integrated over helicity windows for entire laser-cycle
- Subtract local background from cavity-unlocked period

- Grouped into \( \sim 50 \)-laser-cycle ‘slugs’ for each laser state
- 1% gain shift between cavity-locked and -unlocked
Photon Polarization

\[ P_{\text{elect}} = \frac{A_{\text{exp}}}{P_{\text{phot}}A_{\text{th}}} \]

- **99.04 ± 0.80%** for laser right, **98.99 ± 0.80%** for laser left
- Laser polarization was found to be stable throughout HAPPEX-III – single value for photon polarization was used
  - Photon polarization monitored continuously at end of optical path (as stability check)
  - On-line QWP scans are done “daily”
- Used transfer function measurement to get mean polarization
  - Off-line absolute polarization measurements are made at the Compton interaction point and end of optical path
- Systematic error of 0.8% comes from uncertainty in transfer function measurement
Theoretical Asymmetry

\[ P_{\text{elect}} = \frac{A_{\text{exp}}}{P_{\text{phot}} A_{\text{th}}} \]

- Simulated using GEANT4
  - Generate Compton photons
  - Let them interact with beamline items/GSO
  - Include PMT non-linearity
  - Include Radiative Correction
  - Fit MC to triggered data
    - Include 2.5% smearing factor
    - Include detailed pileup
- Use simulation to calculate energy weighted asymmetry
Final HAPPEX-III polarization results:
Compton: $[89.41 \pm 0.05(\text{stat}) \pm 0.84(\text{sys}) \pm 0.18(\text{gaps})] \%$
Møller: $89.22 \pm 1.7(\text{sys}) \%$
## Summary of Compton Errors

<table>
<thead>
<tr>
<th>Systematic Errors (Relative)</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Laser Polarization</td>
<td>0.80%</td>
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<tr>
<td>Analyzing Power:</td>
<td></td>
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<tr>
<td>Non-linearity</td>
<td>0.3%</td>
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<tr>
<td>Energy Uncertainty</td>
<td>0.1%</td>
</tr>
<tr>
<td>Collimator Position</td>
<td>0.05%</td>
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<tr>
<td>MC Statistics</td>
<td>0.07%</td>
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<tr>
<td>Total on Analyzing Power</td>
<td>0.33%</td>
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<tr>
<td>Gain Shift:</td>
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<tr>
<td>Background Uncertainty</td>
<td>0.31%</td>
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<tr>
<td>Pedestal Uncertainty</td>
<td>0.20%</td>
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<tr>
<td>Total on Gain Shift</td>
<td>0.37%</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>0.94%</strong></td>
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</table>

<table>
<thead>
<tr>
<th>Other Errors (Relative)</th>
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<tbody>
<tr>
<td>Statistical</td>
<td>0.062%</td>
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<tr>
<td>Gaps</td>
<td>0.20%</td>
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</tbody>
</table>
Conclusion

Conclusion

- Upgrade to the photon arm of the Jefferson Lab Hall A Compton Polarimeter is complete
  - New GSO crystal
  - New integrating DAQ
- Better than 1% Compton polarization measurement for HAPPEX-III
REFERENCES
