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

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September 7, 2011

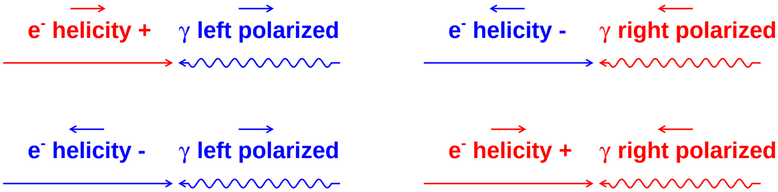
Outline

1. Compton Polarimetry Introduction
2. Hall A Compton Polarimeter Upgrade
3. HAPPEX-III Beam Polarizations
4. Conclusion

Motivation

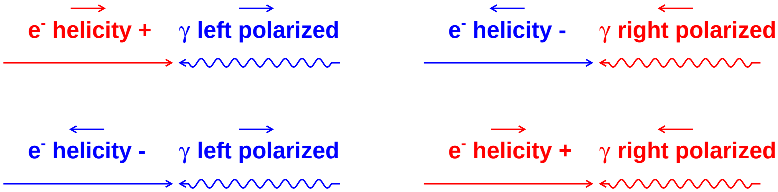
- New parity violation experiments require a better than 1% absolute measurement of the electron beam polarization
    - HAPPEX-III measured a parity violating asymmetry with 1.5% overall systematic error – required 1% polarimetry
- Compton asymmetry is 1% – requires a precision of 1×10^{-4}
- Upgrades 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

Compton Polarimetry



- The measured experimental asymmetry (for one laser polarization) is:

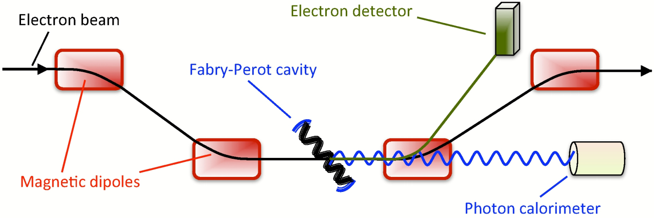
$$A_{exp} = \frac{S^+ - S^-}{S^+ + S^-}$$

- The measured Compton asymmetry gives the electron beam polarization:

$$A_{exp} = A_{th} P_{elect} P_{phot} \qquad \Rightarrow \qquad P_{elect} = \frac{A_{exp}}{P_{phot} A_{th}}$$

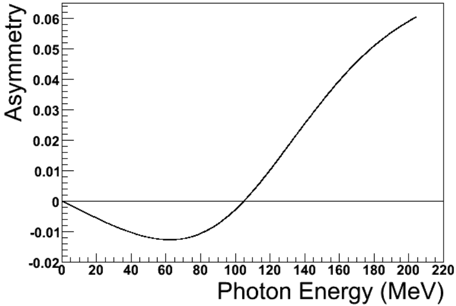
Jefferson Lab Hall A Compton Polarimeter

- 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



Counting vs Integrating Mode

Counting Mode

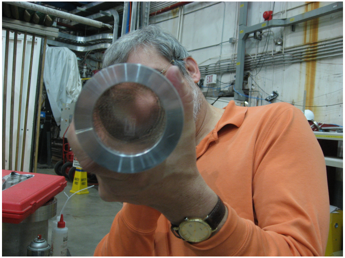
- **Count all pulses which cross some threshold**
- Not energy weighted – measures a smaller asymmetry
- Has threshold
- Sensitive to dead-time and pileup
- Less sensitive to non-linearities/gain shifts
- Works well at low photon rate
- $\sim$3% systematic error

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

Polarimeter Upgrade

- New photon calorimeter: 15cm long, 6cm diameter GSO crystal
  - Ce-doped Gd_2SiO_5
  - $\sim$150 photo-electrons per MeV
  - "Linear" PMT and base
    - LED pulser built to measure linearity

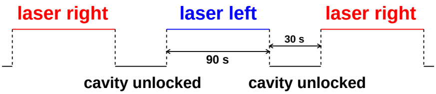


- New integrating photon DAQ
  - Customized SIS3320 FADC
  - Two simultaneous modes: Accumulator (integrating) and Triggered
  - Integrating mode allows for stand-alone photon measurement
- New electron microstrip detector (can be used for calibration)
- Upgraded to green laser (used IR laser for HAPPEX-III measurement)

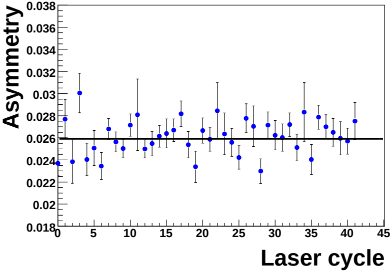
Experimental Asymmetry

$$P_{elect} = \frac{A_{exp}}{P_{phot} A_{th}} \qquad A_{exp} = \frac{S^+ - S^-}{S^+ + S^-}$$

- 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 ~50-laser-cycle 'slugs' for each laser state
- 1% gain shift between cavity-locked and -unlocked

Photon Polarization

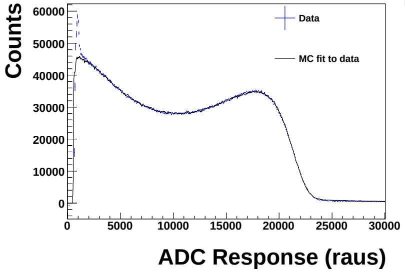
$$P_{elect} = \frac{A_{exp}}{P_{phot} A_{th}}$$

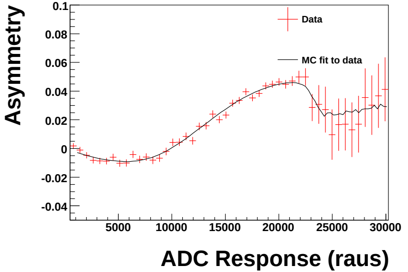
- **99.04 ± 0.80%** for laser right, **98.99 ± 0.80%** for laser left
- Laser polarization was found to be stable throughout HAPPEX-III – single value for photon polarization was used
  - Photon polarization monitored continuously at end of optical path (as stability check)
  - On-line QWP scans are 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

$$P_{elect} = \frac{A_{exp}}{P_{phot} A_{th}}$$

- 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



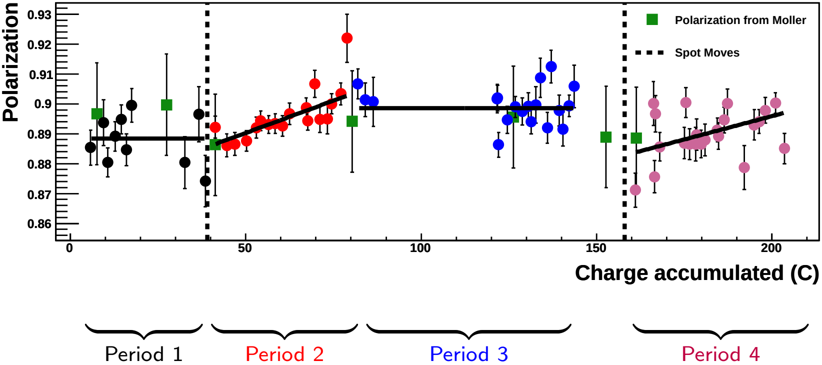


HAPPEX-III Electron Beam Polarizations

Final HAPPEX-III polarization results:

Compton: $[\mathbf{89.41} \pm \mathbf{0.05}(\mathbf{stat}) \pm \mathbf{0.84}(\mathbf{sys}) \pm \mathbf{0.18}(\mathbf{gaps})]\%$

Møller: $89.22 \pm 1.7(\text{sys})\%$



Summary of Compton Errors

Systematic Errors (Relative)	
Laser Polarization	0.80%
Analyzing Power:	
Non-linearity	0.3%
Energy Uncertainty	0.1%
Collimator Position	0.05%
MC Statistics	0.07%
Total on Analyzing Power	0.33%
Gain Shift:	
Background Uncertainty	0.31%
Pedestal Uncertainty	0.20%
Total on Gain Shift	0.37%
Total	**0.94%**

Other Errors (Relative)	
Statistical	0.062%
Gaps	0.20%

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

- M. Friend, D. Parno, F. Benmokhtar, A. Camsonne, G. B. Franklin, R. Michaels, S. Nanda, K. Paschke, B. Quinn, and P. Souder, "Upgraded photon calorimeter with integrating readout for Hall A Compton Polarimeter at Jefferson Lab," *Submitted to Nucl. Instr. and Meth. A* (2011) , `arXiv:1108.3116`.
- M. Friend, G. B. Franklin, and B. Quinn, "An LED pulser for measuring PMT linearity," *Submitted to Nucl. Instr. and Meth. A* (2011) , `arXiv:1108.3096`.