Hybrid Electron Compton Polarimeter with online self-calibration

August 24, 2007

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single electron  single photon  multi photon
Outline

• Physics behind Compton polarization measurements
  - single photon mode (differential asymmetry)
  - multi photon mode (energy weighted asymmetry)

• Hybrid design using:
  - chicane
  - scattered electron
  - pair spectrometer
  - sampling calorimeter

• Advantages multiple detection scheme

• First Monte Carlo studies

• Conclusions
Physics behind $P_e$ measurement using Compton scattering

Compton scattering:
$$e(E) + \lambda(k) \rightarrow e'(E') + \gamma(k')$$  (~ zero crossing angle)

Cross section:
- Transverse polarization → position asymmetry (HERA TPOL)
- Longitudinal polarization → energy asymmetry (HERA LPOL)

Due to experience: LPOL-like polarimeter described here

$$\frac{d\sigma}{dk'} = \frac{d\sigma_0}{dk'} [1 + P_e P_\lambda A_z (k')]$$  

$P_\lambda$: circular polarization ($\pm 1$) of laser beam (measured after IP)  
$P_e$: longitudinal polarization of electron beam

$e$ (5-25 GeV)  
$\lambda$ (248 - 1064 nm)  
$\alpha$  
backscattered Compton photon  
scattered electron  
k',E'  
Detection
Different cross section for positive and negative photon helicity $S_3$.

Difference largest at higher electron beam energy. (HERA = 27.5 GeV)

Laser energy:
- 1064 nm (1.17 eV)
Physics behind $P_e$ measurement using Compton scattering

Different cross section for positive and negative photon helicity $S_3$.

Difference largest at higher electron beam energy. (HERA = 27.5 GeV)

Laser energy:
- 1064 nm (1.17 eV)
- 532 nm (2.33 eV)
Different cross section for positive and negative photon helicity $S_3$.

Difference largest at higher electron beam energy.

(HERA = 27.5 GeV)

Laser energy:
- 1064 nm (1.17 eV)
- 532 nm (2.33 eV)
- 248 nm (5.0 eV)
Single photon mode: measure energy of every Compton photon.

- Highest photon energy: Compton edge $k'_{\text{max}} \sim k \cdot E^2$
Single photon mode: measure energy of every Compton photon.

• Highest photon energy: Compton edge $k'_{\text{max}} \sim k \cdot E^2$

• Highest asymmetry at Compton edge: $A(k'_{\text{max}}) \sim k \cdot E$
Single photon mode: measure energy of every Compton photon.

- Highest photon energy: Compton edge $k'_{\text{max}} \sim k \cdot E^2$
- Highest asymmetry at Compton edge: $A(k'_{\text{max}}) \sim k \cdot E$
- Cross check at zero asymmetry crossing
- Calibration at sharp Compton edge

Two points with known energy (QED)
Physics behind single photon mode

Single photon mode: measure energy of every Compton photon.

→ Higher laser energy has some advantages (higher asymmetry)

→ Variable laser energy: move zero-crossing and Compton edge around

But...

Everything has its price: differential cross section smaller!
Advantages:
• Uses all information in photons
• Calibration using **Compton edge**

Disadvantages:
• Sensitive to absolute calorimeter calibration
• Background from Bremsstrahlung
Advantages:
• Effectively independent of bremsstrahlung background
• \( \frac{dP}{P} = 1\%/\text{min} \) now already
• Independent from absolute energy calibration (first order)

Disadvantages:
• No monitoring of calorimeter performance and linearity

Energy weighted asymmetry:
\[
A_m = \frac{I_{3/2} - I_{1/2}}{I_{3/2} + I_{1/2}} = P_e P_{\lambda} A_p
\]

Analyzing power
\[
A_p = \frac{\Sigma_{3/2} - \Sigma_{1/2}}{\Sigma_{3/2} + \Sigma_{1/2}}
\]

Physics behind multi photon mode

Precision Electron Beam Polarimetry for the EIC
Combine both photon methods and measure simultaneously.

**chicane**

**scattered electron**

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**single photon**

**single/multi photon**

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*PSM — Polar Spectrometer Magnet*
*C — Adjustable Converter*
*H1, H2 — Hodoscopes*
Advantages of chicane setup

- Moves Compton cone away from electron beam
- Reduces bremsstrahlung background (maybe less at EIC)
- (Possibly) compensation of focusing magnets around experiment IR

We have not yet put a great deal of thought into this...
Pair spectrometer magnet with $e^+e^-$ pair production

- **Convertor** material (movable, with variable thickness) produces $e^+e^-$ pairs of fraction of the Compton photons
- **Dipole magnet** separates electrons and positrons
- Detection in Si, SciFi, scintillator detectors

**Legend:**
- PSM -- Pair Spectrometer Magnet
- C -- Adjustable Converter
- H1, H2 -- Hodoscopes

**Diagram:**
- Pair spectrometer magnet with $e^+e^-$ pair production
- Convertor material (movable, with variable thickness)
- Dipole magnet separates electrons and positrons
- Detection in Si, SciFi, scintillator detectors
• **Convertor** material (movable, with variable thickness) produces $e^+e^-$ pairs of fraction of the Compton photons
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**Pair spectrometer magnet with $e^+e^-$ pair production**

- Rate selection

**PSM -- Pair Spectrometer Magnet**

**C -- Adjustable Converter**

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*Precision Electron Beam Polarimetry for the EIC*
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**Rate selection**

**Momentum determination $\rightarrow$ energy $k'$

**Diagram labels:**
- PSM -- Pair Spectrometer Magnet
- C -- Adjustable Converter
- H1, H2 -- Hodoscopes

Precision Electron Beam Polarimetry for the EIC
Use experience gained at HERA LPOL:
sampling calorimeter with W convertor plates and scintillator

Wavelength shifters  One PMT

Plastic scintillator plates  Tungsten plates

Operated in
• single photon mode at high PMT voltage (lower laser power)
• multi photon mode at lower PMT voltage (higher laser power)

Good energy resolution and linearity in test beams (DESY and CERN)
Sampling calorimeter with spatial resolution

Monte Carlo in Geant:
• model detector
• Compton cross section
• shower simulation

Simulated asymmetry agrees with theoretical curve, at $E = 7.5$ GeV
Sampling calorimeter with spatial resolution

Additional energy smearing could complicate things:

No additional smearing
Sampling calorimeter with spatial resolution

Additional energy smearing could complicate things:

Additional smearing: 5%
Sampling calorimeter with spatial resolution

Additional energy smearing could complicate things:

Additional smearing: 10%
Additional energy smearing could complicate things:

Sampling calorimeter with spatial resolution

Additional smearing: 15%
Sampling calorimeter with spatial resolution

Shower development in calorimeter

- Compton centering important, to avoid losing part of the shower (beam sizes from HERA used in this Monte Carlo simulation)
Sampling calorimeter with spatial resolution

Shower development in calorimeter → add spatial resolution

- Optically separate sides of detector with separate PMTs
- Four PMTs enough to determine position of Compton cone
- Eight PMTs in simulation

Precision Electron Beam Polarimetry for the EIC
Position of Compton photons:

Asymmetry $\eta$ in PMT signal correlated to position on calorimeter
Comparison Monte Carlo and theory

In single photon mode

Energy weighted asymmetry
multi photon mode
Precision Electron Beam Polarimetry for the EIC

Sampling calorimeter with spatial resolution

Linearity of the calorimeter:

Use Compton edge to calibrate calorimeter

Change beam energy to access different Compton edge values
Advantage of two polarimeters

Systematics:
- simultaneous or interleaved measurements with two devices
- disentangle effects of machine and polarimeter

Efficiency:
- redundancy leads to high efficiency, in cases of failure
Summary

**chicane**

Dedicated beam component and space for a polarimeter

**scattered electron**

Scattered electron measurement (with Si,...)

**pair spectrometer**

Single photon mode by $e^+e^-$ pair production in variable convertor

**single/multi photon**

Single photon mode:
- calibration at zero-crossing and Compton edge

Multi photon mode
- independent of calorimeter response

Sampling calorimeter with W and plastic scintillator plates