Compton Polarimetry at HERA, more than 10 years of operation

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Outline

• Demand for electron polarization measurements: from HERMES to H1/ZEUS

• Polarimeters at HERA (TPOL ,LPOL, Cavity)

• LPOL under detailed look

• Conclusions & Suggestions for EIC
HERMES: Main Customer until 2000

- SPIN “crisis”

1987: EMC/CERN ($\mu$ p)

\[ \Delta \Sigma = 0.12 \pm 0.09 \pm 0.14 \]

Contribution of quark spins to nucleon spin is very small

Most precise determination of $\Delta \Sigma$

\[ \Delta \Sigma = 0.330 \pm 0.025 \pm 0.011 \pm 0.028 \]

HERMES: P. R. D 75 (2007) 012007
HERMES: Main Customer until 2000

Using hadron asymmetries:

\[ h = \pi^\pm, K^\pm, p \]

Targets: \[ H, D \]

First determination of sea quark polarisation:
consistent with zero.

After 2000: HERMES, H1 and ZEUS

\[ \sigma^{CC}(e^\pm p) = (1 \pm P_e) \cdot \sigma^{CC}_{P_e=0}(e^\pm p) \]

- Linear dependence of \( \sigma^{CC} \) \( P_e \) confirmed
- Extrapolation to \( P_e = \pm 1 \),
- No sign of right-handed charged currents
H1 and ZEUS

- Asymmetry of two helicity states:
  \[ A^{+-} = \frac{2}{P_L - P_R} \frac{\sigma_{P_R}^{+-} - \sigma_{P_L}^{+-}}{\sigma_{P_R}^{+-} + \sigma_{P_L}^{+-}} \]

- A≠0 at highest Q²:
- Evidence for parity violation in neutral currents
- At small distances 10⁻¹⁸ m
- Expect A⁺=−A⁻ in standard model

\[ A = \frac{\sum_q e_q \nu_q (q + \bar{q})}{\sum_q e_q^2 (q + \bar{q})} \]
West Hall (TPOL): Principle of Measurement: Compton-Scattering

- kinematics described by 2 variables:
  - polar angle $\theta \leftrightarrow E_\gamma$ (photon energy)
  - azimuthal angle $\phi \Rightarrow y$ (vert. position)
- $S_1, S_3$: lin. & circ. polarisation of laser
- $P_Y, P_Z$: transv. & long. beam polarisation

$$\frac{d^2 \sigma}{dE \, d\phi} = \Sigma_0(E) + S_1 \Sigma_1(E) \cos 2\phi + S_3 (P_Y \Sigma_2 Y(E) \sin \phi + P_Z \Sigma_2 Z(E))$$

TPOL: measure (energy dependent) angular asymmetry
- up-down asymmetry very small (even at 65m!)
- need very precise position measurement (better than 10$\mu$m)
- distance from IP also has to be measured very precisely (not trivial)
Transverse Polarimeter (I)

**Laser:**
- continuous wave, $E_\lambda = 2.4$ eV, $\lambda = 514$ nm
- crossing angle: 3.1 mrad

**Calorimeter:**
- Tungsten-Scintillator-Sampling calo.
- segmented in upper and lower half
- four channels read out by wavelength shifters and photomultipliers:
  - up, down, left, right
Transverse Polarimeter (II)

- measured quantities:
  \[ E_\gamma = E_{up} + E_{down} \]
  \[ \eta = (E_{up} - E_{down}) / (E_{up} + E_{down}), \]
  \[ y = y(\eta) \leq \text{main uncertainty!} \]
East Hall (Cavity-LPOL, LPOL): Principle of Measurement:

\[
\frac{d\sigma}{dE_\gamma} = \frac{d\sigma_0}{dE_\gamma}[1 + P_e P_\lambda A_z(E_\gamma)]
\]
Cavity Polarimeter: Setup

- laser
- ccd
- bellow
- pillar for mirror mount
- vacuum window
- pump
- cavity leg
- ccd
- p-diode for feedback
- QWP
- glan Thomson
Cavity uses LPOL Calorimeter

Wave length shifters
PMT
Scintillator plates
Tungsten plates

Test beam results

\begin{align*}
\text{ADC output} & \quad \text{CERN} \\
\text{Incident Energy (GeV)} & \\
\text{Deviation from Linearity (\%)} & \quad \text{DESY} \\
\text{Incident Energy (GeV)} & \\
\end{align*}

'r(E) = 1'
Cavity: Method of Measurement

An example for one single bunch
(taken in $4 + 4$ seconds)
Cavity: fitting procedure

- **Step 1:** Fit laser-off (brem.) spectrum to fix calorimeter related parameters

- **Step 2:** Fit laser-on spectra in two laser polarization states to get the beam polarization $P_e$ & other beam/background related parameters

**Caveat:**
Brem. spectrum taken at slightly different beam conditions than the laser-on spectra

→ To be improved in further data taking, NOW OFFLINE analyses
TPOL and Cavity: Rise-Time Measurements

- Rise-Time measurements by Cavity-LPOL and TPOL during last week of HERA operations
TPOL and Cavity: Rise-Time Measurement

Note: 5 times increase of frequency of measurement by Cavity-LPONL
Compton Scattering:
e^+\gamma \rightarrow e'^+\gamma

Cross Section:
\[ \frac{d\sigma}{dE_\gamma} = \frac{d\sigma_0}{dE_\gamma}[1 + P_e P_\lambda A_z(E_\gamma)] \]

- \( P_e \): longitudinal polarization of e beam
- \( P_\lambda \): circular polarization \((\pm 1)\) of laser beam

\( d\sigma_0, A_z \): known (QED)
Multi-Photon Mode

\[ A_m = \frac{I_{3/2} - I_{1/2}}{I_{3/2} + I_{1/2}} = P_e P_A m A_p \]

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

Advantages:
- eff. independent of brems. bkg
- \( dP/P = 0.01 \) in 1 min
- in first approximation, independent from absolute energy calibration

Disadvantage:
- no easy monitoring of calorimeter performance
LPOL, LIVE

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S. Borissov
A. Simon
M. Beckman
B. Zihlmann
R. Fabbri
W. Lorenzon
W. Deconinck
J. Seibert
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Workshop August 24 2007
Longitudinal Polarimeter
(M. Beckmann et al. NIM A479 (2002) 334-348)

- Laser frequency doubled Nd:YAG
- $E_\lambda = 2.33 \text{ eV}$, with pulse length 3 ns
- Operated at 100 Hz, 200 mJ/pulse
LPOL: Details I

- Use HERA Clock and bunch structure to generate an appropriate trigger
- Depending on the type of trigger (Laser ON, OFF, BEAM ON, OFF) fire (don’t fire) the laser
- Produce right (left) circularly polarized laser pulse using a Pockels Cell (depending on trigger)
- Send to IP and get Compton photons (background signal) to calorimeter
- Open the GATE and read all information you need to calculate bunch polarization
- Analyze laser pulse after IP to monitor S3
LPOL: Details II

- Use HERA Clock and bunch structure to generate an appropriate trigger
- HERA electron bunches are separated by 96 ns. Depending on the fill there might be up to 180/220 bunches filled
LPOL: Details III

Trigger logic

- Depending on the type of trigger (Laser ON, OFF, BEAM ON, OFF), laser is fired (or not)

LPOL startup, Triggers
LPOL: Details IV

- Produce right (left) circularly polarized laser pulse using a Pockels Cell

- Laser travels ~80 m to IP
LPOL: Details V

- Send laser pulse to IP and get Compton photons (background signal) to calorimeter
LPOL: Details V

- Send laser pulse to IP and get Compton photons (background signal) to calorimeter
LPOL: Main Calorimeter

Calorimeter position

NaBi(WO₄)₂ crystal calorimeter

segmentation → position detection of Compton photons

NaBi(WO₄)₂ crystals: 22 x 22 x 200 mm³

- ρ : 7.57 g cm⁻²
- X₀ : 1.03 cm
- R_M : 2.38 cm
- σ⁺ : 12 ns
- rad. hard. : < 7 x 10⁷ rad
- n : 2.15

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LPOL: Details VI

- Open the GATE and read every information you need to calculate bunch Polarization

An elegant way to estimate Pedestal

\[ f(x) = a + b \cdot x \]

- \( a = 2.0016 \)
- \( b = 0.9905 \)
LPOL: Details VII

- Histogram for every event type and trigger

Correct for Pedestal, laser jitter, and gain matching. Then group in 220•2 histograms and calculate polarization for each bunch
LPOL: Details VIII

Analyze laser pulse after IP to monitor S3

Perform regular PC HV scans to ensure maximum and symmetric S3 at working voltage

<table>
<thead>
<tr>
<th>Source</th>
<th>( \Delta P_e / P_e ) (%) (2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyzing Power ( A_p )</td>
<td>± 1.2 (±0.9)</td>
</tr>
<tr>
<td>- response function</td>
<td></td>
</tr>
<tr>
<td>- single to multi photon transition</td>
<td></td>
</tr>
<tr>
<td>( A_p ) long-term instability</td>
<td>± 0.5 (±0.4)</td>
</tr>
<tr>
<td>- PMT linearity (GMS system checked)</td>
<td></td>
</tr>
<tr>
<td>Gain mismatching</td>
<td>± 0.3</td>
</tr>
<tr>
<td>Laser light polarization</td>
<td>± 0.2</td>
</tr>
<tr>
<td>Pockels cell misalignment</td>
<td>± 0.4 (±0.3)</td>
</tr>
<tr>
<td>- ( \lambda/2 ) plate (helicity dep. beam</td>
<td></td>
</tr>
<tr>
<td>shifts)</td>
<td></td>
</tr>
<tr>
<td>- laser-electron beam overlap</td>
<td></td>
</tr>
<tr>
<td>Electron beam instability</td>
<td>± 0.8 (±0.6)</td>
</tr>
<tr>
<td>- electron beam position changes</td>
<td></td>
</tr>
<tr>
<td>- electron beam slope changes</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>± 1.6</strong></td>
</tr>
</tbody>
</table>

- comparison between LPOL and TPOL (1999)
LPOL error budget (2002-2007)

- Regularly check for possible false asymmetries with both sampling and crystal calorimeters
- Constantly monitor with GMS gain of both calorimeters (relative)
- Perform coordinate scans to check gain mismatching
- After every Pockels Cell change (they are subject of laser radiation damage) perform Pockels Cell HV scan to verify alignment
- Perform table offset scans to center Compton photons on calorimeter
- Vary laser power and check calorimeter response and measurement stability
- Alternate regularly between sampling and crystal calorimeters
LPOL error budget (2002-2007)

Have to supply OFFline LPOL measurements to Physics Analysers, but for preliminary results and numbers LPOL Group recommendation is used 2% as an upper limit for the LPOL systematic uncertainty.
LPOL: Accidents

- **Sep 2003**, 1 rad length Pb was not enough!

- To withstand synchrotron radiation from HERMES Transverse Magnet: replaced Pb with 1 rad length W, and monitored temperature

- **June 2004**, beam lost in LPOL area resulted in broken crystals!
LPOL: Our own Mistakes

- In Jan 2005 when rad damaged mirror was replaced, new mirror was mounted incorrectly (coating on wrong side): 3 spots instead of one!
Achievements: TPOL

GREEN light to SPIN physics at HERA (1991)

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Achievements: **LPOL**

- 20 min measurement
  \[ \frac{dP}{P} = 0.03 \text{ in each bunch} \]
  
  *First measurement of BUNCH polarization:*
  New tool for tuning for high polarization!
Achievements: **Cavity LPOL**

Data of Sept. 14, 2005

- The observation with cavity of the anti-correlation between the $P_e$ values and the p-beam current

This effect has to be taken into account in the physics analyses

- Maybe will help for HERA Machine Monte Carlo simulations to pin down polarization risetime scale
Thanks to the People from whom I borrowed slides & graphs

- K.Rith HERA END of DATA Taking Symposium
- S.Schmitt H1&ZEUS talk at Moriond 2007
- W.Lorenzon various talks
- Beautiful, MultyTalent LPOL Group, who designed, built, and maintained LPOL at high level for more than 10 Years
Conclusions

• Compton MultiPhoton mode proved to be very robust in measuring electron/positron beam polarization in a high energy collider
• Polarisation (Polarimetry) is a tool to significantly enhance Physics Programs at many Research centers, therefore:
• It has to be included into design of the new machines and gain appropriate attention (see W. Deconinck’s presentation)