A Calibration of the HERA Transverse Polarimeter for the 2003/2004 Data

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Abstract

This document summarizes the results of a discussion in the polarimeter meeting on the 13th of July 2004, following analyzes presented by the authors. The Transverse Polarimeter (TPOL) setup and its data analysis are briefly described. The main difference between HERA I and HERA II running conditions in view of the TPOL are emphasized.

Three methods to calibrate the TPOL are presented. Based on the Monte Carlo method, a calibration of the TPOL, independent of the longitudinal polarimeter (LPOL) is developed. Recommendations how to apply the results of this preliminary analysis to the TPOL measurements taken in 2003 and 2004 are given, including an estimate of the systematic uncertainties.

1 The TPOL Detector

The transverse beam polarization is measured by analyzing the double-differential cross-section $\frac{d^2\sigma}{dE\,d\eta}$. The asymmetry $\eta = \frac{E_U - E_D}{E_U + E_D}$ and energy $E = E_U + E_D$ are measured in a calorimeter which is split into an upper and lower half with independent readout. The asymmetry $\eta = \eta(y)$ is related to the vertical coordinate $y = r \sin\phi$. The radius $r = r(E, d)$ is a well-known function of the energy of the scattered photon and the distance d to the interaction point ($d = 65\,\mathrm{m}$).

During the 2000 HERA shutdown the TPOL was modified. A silicon detector and a converter (one interaction length, X_0 of lead) have been added in front of the calorimeter. The silicon detector may be used to study the calorimeter response function for photons which have converted. The readout system of the calorimeter has been upgraded. The new readout system has better control of pedestal shifts in the energy measurement. Furthermore, the readout is able to correlate the calorimeter signals with HERA bunch numbers. This is used to determine the polarization of individual bunches or selected groups of bunches (colliding, non-colliding bunches).

2 The TPOL Online Analysis

2.1 The Beam Polarization

For the TPOL online polarization measurement an energy interval with high sensitivity $5.2\,\mathrm{GeV} < E < 11.4\,\mathrm{GeV}$ is selected. In this energy interval the average asymmetry $\langle\eta\rangle$ is measured for circular-left and circular-right polarized laser light. The transverse beam polarization is calculated as

$$P_y = \frac{1}{A}\frac{1}{\bar{S}_3} \times (\langle\eta\rangle_L - \langle\eta\rangle_R)\,.$$

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The analyzing power A depends on the calorimeter properties and on the properties of the lepton beam. The circular light polarization $\bar{S}_3$ is being measured between HERA fills. If necessary the Pockel's cell voltage is adjusted. We find that $\bar{S}_3 = 1$ within an accuracy of 0.5%.

2.2 The Focus Size

The most critical parameter which is currently not accounted for in the online analysis is the size of the Compton beam at the calorimeter. The size of the Compton beam is related to the size and the angular divergence of the electron beam at the TPOL interaction point. The critical contribution is due to the angular divergence, as the beam is transported over a distance of 65 meters. The beam size is constantly monitored by analyzing the width of the η distribution at high photon energies $11.2\,\text{GeV} < E < 13.8\,\text{GeV}$. This focus size f was found to be stable at HERA I. At HERA II we observe a much increased size of the focus, varying from fill to fill, especially in the fall of 2003.

2.3 The TPOL Analyzing Power

For the TPOL online analysis a constant analyzing power is used. The TPOL analyzing power has been calibrated in 1994 and 1997 using the rise-time method. The rise-time-method is based on measurements of the polarization built-up time and the maximum polarization. The maximum polarization is connected to the build-up time by an analytic formula, so the analyzing power can be deduced from these data. Note that this analyzing power is valid only for beam conditions similar to those where the rise-time data was taken. Table 1 summarizes the TPOL analyzing power and attempts to assign a new analyzing power for the TPOL online analysis at HERA II conditions.

Method	TPOL Online Analyzing Power
(1) Rise-time calibration 1994 and 1997	$A_0 = 0.09608 \pm 0.00106$
(2) Correction based on test-beam data and MC 2002	$A_0 = 0.09608 \times \frac{1}{1.0779}$
(3) Cross-calibrate online to offline analysis 2003	$A_0 = 0.09608 \times \frac{1}{1.0372}$

Table 1: TPOL online analyzing power. Method 1 was used for the HERA I data. Method 2 was used in 2002 and Spring 2003. Method 3 is the analyzing power used for the HERA II data collected from September 2003 up to August 2004

3 Calibrating the TPOL for Non-constant Focus

Three alternative approaches have been studied to calibrate the dependence of the TPOL analyzing power as a function of the focus.

3.1 Cross-calibration to the Offline Analysis

The offline analysis is based on an analytic description of the Compton cross section, the beam parameters and the calorimeter response. The beam polarization, beam size and other parameters are extracted in a multi-parameter fit. The analyzing power of the online measurement as a function of the focus can be determined by comparing the online and offline results. As there are no free parameters in the offline analysis, this method is completely independent of the rise-time calibration and Monte Carlo studies.

However, it turns out that this analytic approach is not yet able to give a completely satisfactory description of the TPOL data. In particular, we observe relatively large χ^2 values. Furthermore, the fit results are not consistent for different methods to determine the $\eta - y$ transformation of the calorimeter. At present this method yields systematic uncertainties of order 10%. However, the analyzing power clearly shows a strong correlation to the focus. Within the known systematic limitations the offline correction method is compatible to the other methods presented below.

3.2 Cross-calibration to the LPOL

The ratio of the polarization measured by the LPOL and the TPOL has been studied as a function of the focus. We observe a strong linear dependence of increasing $\frac{1}{A}$ as the focus is increased. This method may be used to correct the TPOL measurements such that they agree with the LPOL. In particular, periods where the LPOL was not operational could equally be bridged using the corrected TPOL data. However, after applying the LPOL cross-calibration, the TPOL no longer has independent systematic uncertainties. Therefore we favor the Monte Carlo method described below. Note that the results of the LPOL cross-calibration are consistent to the method given below.

3.3 Monte Carlo Based Focus Correction

A Monte Carlo simulation can be used to study the response of the TPOL detector to varying beam conditions. It may be set up such that it describes the TPOL detector and online analysis as they were present for either the HERA I or the HERA II data taking period. In order to investigate the focus dependence of the analyzing power, the beam divergence was varied. The resulting relative change to the analyzing power $\frac{A_0}{A}$ and focus size f is depicted in figure 1 for the HERA II data taking period. A_0 is the analyzing power used during data taking, while A is the analyzing power predicted

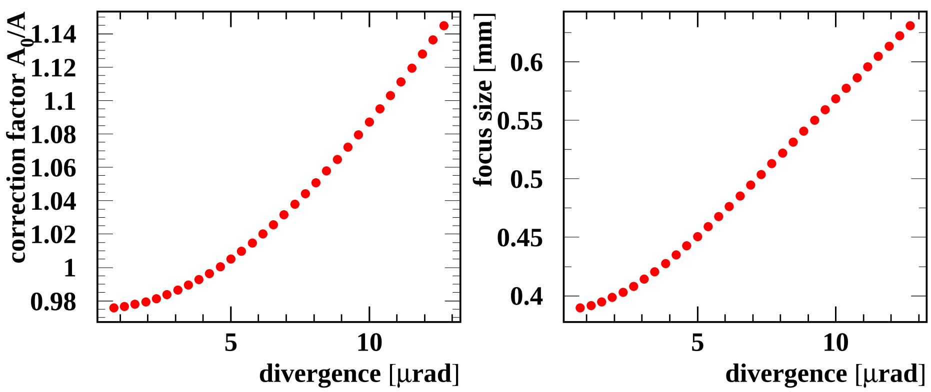

Figure 1: *Polarization correction factor and focus as a function of the angular divergence of the Compton beam for the HERA II detector setup. The Monte Carlo is tuned such that it is able to describe the risetime data if the HERA I detector configuration is selected.*

by the Monte Carlo simulation. Note that $\frac{A_0}{A}$ is a correction factor which should be multiplied with the online polarization measurement to correct for varying beam divergence. The figure shows that the focus f is well suited to extract the beam divergence, which in turn may be used to evaluate $\frac{A_0}{A}$. The correlation between $\frac{A_0}{A}$ and f can be written in good approximation as the linear function:

$$\frac{A_0}{A} = 1 + B(f - f_0),\ B = 0.6649\,\mathrm{mm}^{-1},\ f_0 = 0.44358\,\mathrm{mm}.$$

where B is a slope parameter. The focus offset f_0 is the value of the focus for which the corrected analyzing power A agrees with the analyzing power A_0 used for the online analysis.

The constants B and f_0 are determined as follows: The focus size and the analyzing power measured during the HERA I rise-time calibration are used to determine the absolute calibration of‘ the Monte Carlo, using the HERA I detector configuration with an adequate size of the beam divergence. The parameters B and f_0 are then taken from the HERA II detector configuration, by varying the beam divergence as shown in Figure 1.

3.3.1 Systematic Uncertainties

The dominant systematic uncertainty on the extrapolation procedure is the stability of the focus during the rise-time calibration, which translates as an uncertainty of 1% on $\frac{A_0}{A}$. On top of that the systematic uncertainties of the rise-time calibration itself have to be applied. For HERMES papers based on HERA I data an uncertainty of $\frac{\Delta P}{P} = 3.4\%$ was employed. More recent investigations [1] show that this uncertainty may be reduced to well below 2%. However, for the time being we propose to assign the HERMES error of 3.4% in addition to an uncertainty of 1% due to the extrapolation procedure. The resulting uncertainty on the TPOL absolute scale after correction is:

$$\left(\frac{\Delta P_{\rm TPOL}^{\rm corr}}{P_{\rm TPOL}^{\rm corr}}\right)_{\rm syst} = 3.5\%.$$

3.3.2 Comparison to LPOL Measurements

In order to verify the results of the correction procedure, the corrected TPOL measurements are compared to the measurements from the LPOL. The following data quality cuts have been applied:

$$P_{\rm LPOL} > 20\%,\ \Delta P_{\rm LPOL} < 8\%,$$

where $P_{\rm LPOL}$ and $\Delta P_{\rm LPOL}$ are the per minute online measurements from the LPOL and their statistical uncertainty. Figure 2 shows the results of this investigation. All data collected since October 2003 are included. The ratio $R = \frac{P_{\rm LPOL}}{P_{\rm TPOL}}$ is studied for averaging periods of 1 minute, 10 minutes, and 100 minutes. As the size of the averaging period is increased, statistical uncertainties of the polarization measurements are reduced and the width of the distributions is dominated by systematic effects.

The uncorrected TPOL measurements are found to differ from the LPOL, causing a shift of the mean R by more than 7%. For an averaging period of 100 minutes the uncorrected data exhibits clear evidence of systematic effects, visible as multiple peaks in the distribution. In contrast, the corrected TPOL data are in good agreement with the LPOL. The position of the mean is consistent with $R = 1$. The width of the distribution for the 100 minute average is as small as 1.9%. This is an indication that the systematic uncertainty of 3.5% quoted in this paper is a conservative estimate and may be improved in the future.

4 Summary

A calibration of the TPOL per minute online measurements $P_{\rm TPOL}^{\rm online}$ based on the TPOL measurement of the vertical spread of the Compton beam f has been developed. The corrected TPOL polarization $P_{\rm TPOL}^{\rm corr}$ of each per minute measurement may be calculated using the formula:

$$P_{\rm TPOL}^{\rm corr} = P_{\rm TPOL}^{\rm online} \times \left(1 + 0.6649\,{\rm mm}^{-1} \times (f - 0.44358\,{\rm mm})\right).$$

The corrected statistical uncertainty $\delta P_{\rm TPOL}^{\rm corr}$ may be calculated by applying the same correction factor to the statistical uncertainty of the online polarisation $\delta P_{\rm TPOL}^{\rm online}$. The uncertainties on f are small and hence may be safely neglected. The systematic uncertainty on the absolute scale of these corrected TPOL measurements is 3.5%.

References

[1] V.Gharibyan and K. P. Schüler, HERA Transverse Polarimeter Absolute Scale and Error by Rise-time Calibration, presented at Xth NATO Advanced Spin Physics Workshop, Nor Amberd Conference Centre of YerPhI, Jun 30 - Jul 3, 2002; HERMES paper number 02-070.

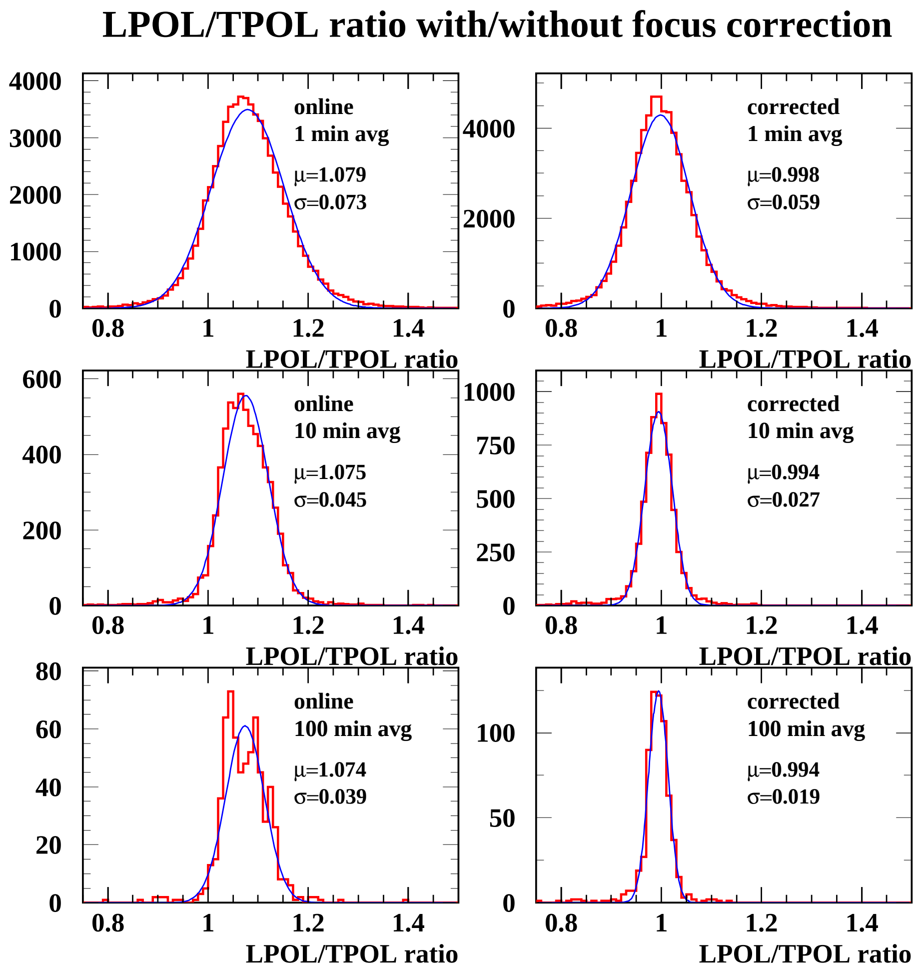

Figure 2: *The ratio* $\frac{P_{\mathrm{LPOL}}}{P_{\mathrm{TPOL}}}$ *for different averaging periods, shown on the left (right) without (with) the TPOL online measurement correction applied. Top: The average of 1 measurement (which takes 1 minute). Middle: The average of 10 consecutive measurements. Bottom: The average of 100 consecutive measurements.*