Using the HERA Polarization Measurements
– Recommendations for the Summer 2007 Conferences –

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Abstract

In this note we briefly describe the state of the understanding of the polarization measurements of the two HERA polarimeters as of summer 2007, and describe the recommended treatment of the polarization values. We recommend to use an additional relative systematic error of the polarization of 3.0% for all results. Results and recommendations presented in this note are preliminary.

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1 Introduction

The polarization in the electron ring of the HERA collider has been measured routinely with two polarimeters, the Transverse Polarimeter (TPOL) and the Longitudinal Polarimeter (LPOL). In addition the Cavity Polarimeter was operated occasionally in spring 2007. For the purpose of this note the data from the Cavity Polarimeter are not used.

Both TPOL and LPOL operated throughout the 2003-2007 data taking period. They delivered polarization measurements with high efficiency. The purpose of this note is to discuss briefly the relative systematic uncertainties connected to the measurements, and to propose a method to derive a central value for the polarization.

2 Transverse Polarimeter

The measurement of the polarization by the TPOL relies on the determination of the position of the Compton photons on the TPOL calorimeter front-face. This position is determined from the energy sharing between the upper and the lower part of the calorimeter.

The polarization is calculated online on a minute by minute basis, based on the measured spatial asymmetry between the two halves of the detector, introduced by the two helicity states of the laser light. The recording of data is regularly interspersed with an automatic calibration procedure, which ensures that the calorimeter is centered on the Compton beam, that the gain of the upper and the lower part of the calorimeter is equal, and that the system operates with sufficient luminosity.

Background primarily comes from Bremsstrahlung photons, from Synchrotron radiation and from blackbody radiation events which scatter into the calorimeter. Background is subtracted online, based on events recorded where the laser is blocked off and only background photons reach the calorimeter.

The online data are corrected for the so-called focus dependence. The focus is a measure for the size of the vertical Compton photons spot at the calorimeter location. It is related to the electron beam emittance and the Twiss parameters at the TPOL interaction point [1]. A correlation exists between the size of the focus and the measured value of the polarization. Based on Monte Carlo studies this correlation has been determined, and the online data are corrected for this [2].

Although the laser light is measured to be 100% circularly polarized at the location of the laser, imperfections in the transport optics result in a small residual linear light polarization. A non vanishing linear light polarization biases the measured value of the polarization. At the moment no correction based on this effect is applied, but a systematic error is assigned instead. During the low energy running in May and June of 2007, values of the linear polarization larger than usual have been observed, due to some damaged optics element.

Several studies have recently been done to estimate the systematic error on the determination of the polarization. Several other studies are still ongoing, which promise to decrease the systematic error further, and which will result in more reliable numbers. A preliminary list of relative systematic errors as quoted by the Transverse Polarimeter group is given in Table 1. A detailed description of these errors can be found in [3].

The dominant contribution to the systematic error comes from the uncertainty on the position of the IP of the laser beam and the lepton beam. This error has only recently been recognized as a sizeable error source. At the moment no method exists to determine this position to better than the geometric acceptance given by beam elements. Half of the

Source	Name	$\Delta P/P(\%)$
Electronic noise		< 0.1
Calorimeter calibration		< 0.1
Background subtraction		< 0.1
Light polarization	$\Delta P_{\text{lin}}/P$	0.1
Focus correction	$\Delta P_{\text{focus}}/P$	1.0
Compton beam centering	$\Delta P_{\text{table}}/P$	0.4
Interaction region	$\Delta P_{\text{IR}}/P$	0.3
Interaction point	$\Delta P_{\text{IP}}/P$	2.1
Absolute scale	$\Delta P_{\text{scale}}/P$	1.7
Total	$\Delta P/P$	2.9

Table 1: Preliminary list of the relative systematic errors of the TPOL. The error on the light polarization is quoted for the majority of the fills, where the linear light polarization on average is around 10%. For the low energy running period in May and June 2007 larger linear light polarization values have been observed. The contribution to the error in this period is still under investigation.

maximal possible variation has therefore been taken as the corresponding systematic error, which clearly defines an upper limit on this error. In the near future, it is expected that improved algorithms will significantly reduce this error.

The second most important contribution comes from the scale uncertainty. The number quoted in Table 1 has been derived from a stand alone measurement of the polarization using the SI detector [3]. This measurement has not yet been finalized, and its interpretation is still being discussed. The error therefore has to be treated as preliminary.

Other studies on the determination of the analyzing power are under preparation [4, 5]. No final errors on the absolute scale of the TPOL have been derived from these analyses at this moment.

Without taking the error of the interaction distance into account, the total error adds up to 2.0%. This is compatible with previous analyses of the TPOL. Considering all errors from Table 1 as uncorrelated, the total systematic uncertainty of the TPOL measurements results to be $\pm 2.9\%$.

3 Longitudinal Polarimeter

In contrast to the small spatial Compton photon asymmetry measured with the Transverse Polarimeter, the measurement of the LPOL polarimeter relies on large asymmetries in the energy distributions of the scattered photons.

The systematic uncertainties of the LPOL polarimeter have been published in [6], and they account for a 1.6% relative change of the measured polarization value. Over the last years intense studies have been performed to verify the procedures and error values [7, 8, 9, 10]. No indications have been found that the error estimation is not correct.

The dominant systematic error source is the error of the analyzing power. It has been determined from test-beam data, and cross-checked with data taken with a sampling calorime-

Source	$\Delta P/P$ (%)
Analyzing power	1.2
- response function	(0.9)
- single to multi photon extrapolation	(0.8)
Long term stability	0.5
Gain mismatch	0.3
Laser light polarization	0.2
Pockels cell misalignment	0.4
Electron beam / laser beam interaction region	0.8
Total HERA I error	1.6
Extra uncertainty for new calorimeter	≤ 1.2
Total HERA II error	2.0

Table 2: Systematic (relative) uncertainties of the LPOL measurements. The so-called HERA I contributions are described in [6]. The extra contribution to the error is estimated from the studies in [8], and should be applied to the LPOL values measured from July 2^{nd} 2004 onwards, after the replacement of the cracked calorimeter crystals.

ter. Test-beam data are used to make the transition from single- to multi-photon mode.

In summer 2004 the crystals of the calorimeter cracked, and have been replaced. The linearity of the new detector could not be investigated with test-beam measurements. Instead, the performance of the new calorimeter was monitored alternating the polarization measurement with the sampling calorimeter. Based on the results reported in [8], an upper limit of the systematic uncertainty due to this source is estimated to be 1.2%, which increases the total systematic error to 2%. This increased error should be applied to the data collected from July 2^{nd} 2004 onwards.

The current values of systematic errors as provided by the LPOL group are reported in Table 2.

4 Comparison of LPOL and TPOL Measurements

The ratio LPOL/TPOL for the years 2003-2007 is shown in Figure 1. Normal data taking periods are presented with blue points, while red marks indicate periods where serious problems with at least one of the two polarimeters existed. For these plots only data taken during luminosity operation of the experiments are included, and only after the initial build-up period of the polarization at the beginning of a fill has finished. The ratio is clearly not stable at one. In 2005, between weeks 30 and 37, a drop in the ratio is visible. The reason for this drop is not yet understood. These data therefore need to be treated with care. At the moment we recommend to exclude them from any polarization analyses. In the future a more sophisticated treatment is envisioned. The known periods of poor data quality and the corresponding recommendations are reported in Table 3.

The ratio distributions are plotted in Figure 2, separately for each year. Removed from

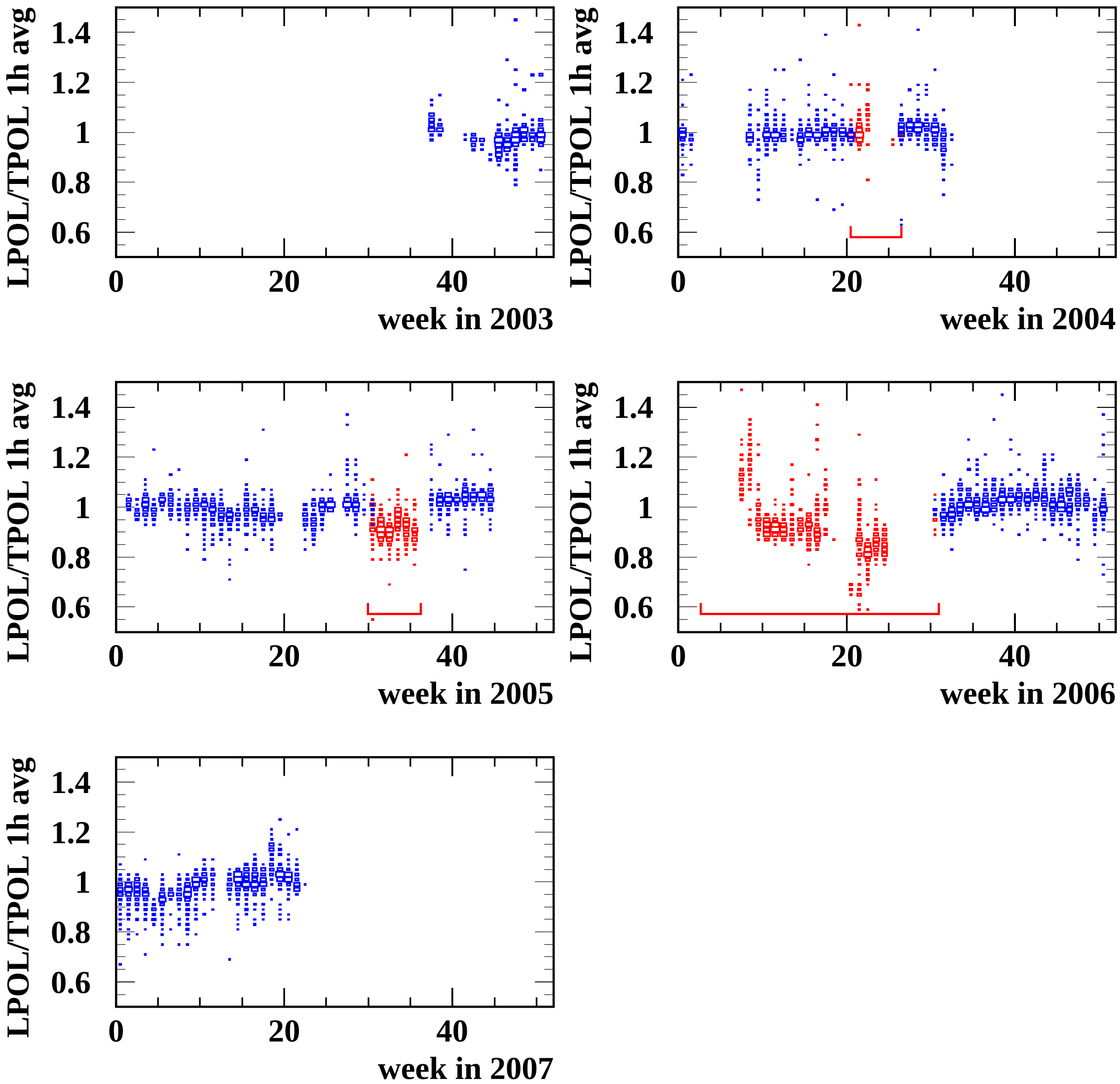

Figure 1: Ratio LPOL/TPOL for the years 2003-2007. Good periods are presented in blue colour, while periods with severe problems are indicated by red marks and the brackets at the bottom of the plots.

this plot are the periods marked in red in Figure 1, which are summarized in Table 3.

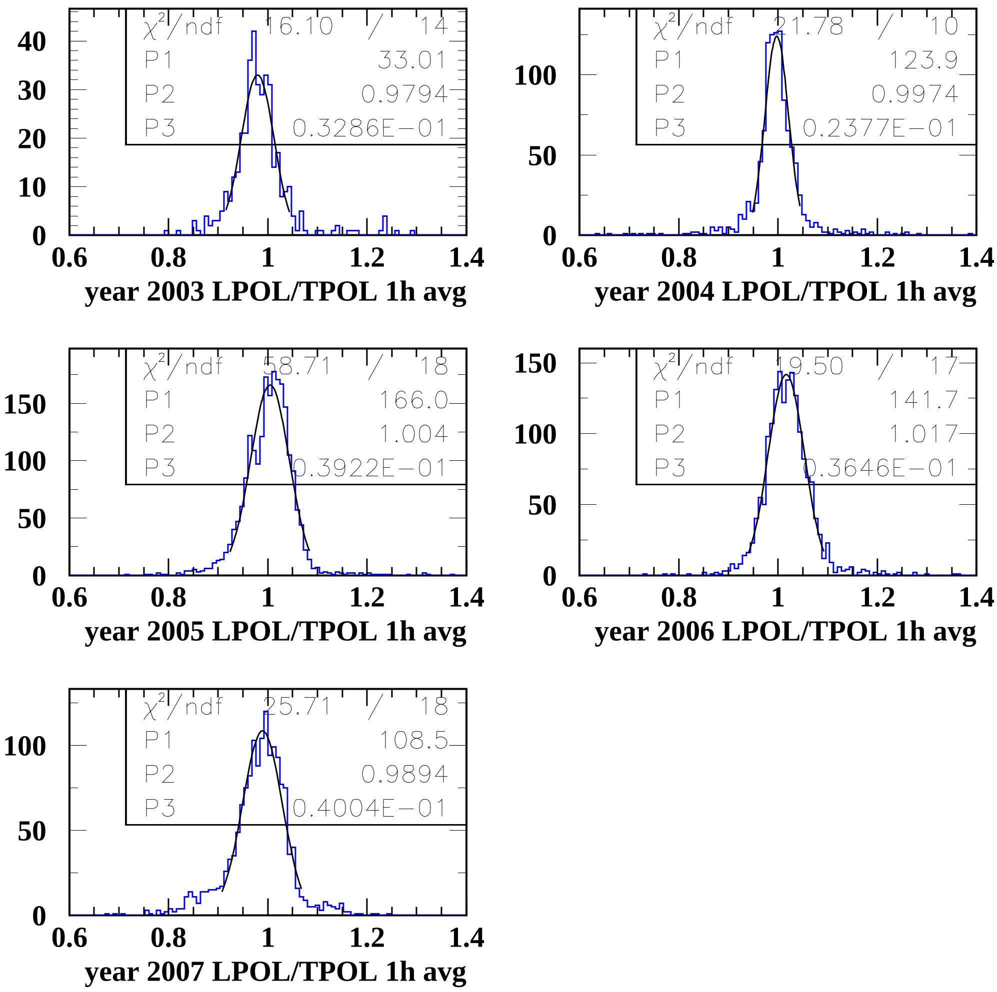

Figure 2: Ratio LPOL/TPOL for the years 2003-2007. Superimposed is a fit to a single gaussian curve, with the fit range restricted to be within $\pm 2\sigma$.

No large systematic shifts are visible throughout the years. There still are indications of

Year	Start	End	POL2000 Recommendation
2004	1085373000 (May 24)	1088786591 (July 2)	Discard LPOL
2005	1122850800 (Aug. 1)	1126306800 (Sep. 10)	Discard LPOL and TPOL
2006	1136070000 (Jan. 1)	1154386800 (July 31)	Discard LPOL

Table 3: Long periods with polarimeter problems. The start/stop time is given as a UNIX time-stamp (seconds since 1/1/1970).

Year	Mean	Width
2003	0.979	0.033
2004	0.997	0.024
2005	1.004	0.039
2006	1.017	0.036
2007	0.989	0.040

Table 4: Mean and width values from the gaussian fit to the LPOL/TPOL distributions.

variations of the ratio in a systematic manner, but on shorter time scales, which are not yet understood. The recently recognized dependence of the TPOL measurement on the IP position might account for some part of these shifts, but no final result exists yet.

Also shown in the plots is a single-gaussian fit superimposed to the ratio distributions. The range of the fit is restricted to be within $\pm 2\sigma$, and the results of the fits are reported in Table 4. The distributions are reasonably gaussian like, though in 2005 a large value of the χ^2 does indicate some problems. Each displayed data point is the average value of 1 hour of sequential accumulation of measurements. Statistical uncertainties of the measurements therefore do not contribute to the width of the observed distribution.

In the absence of problems the width of the ratio distribution ($\approx \delta_{ratio} = 4\%$) should be consistent with the systematic errors listed in Table 1 and 2. The errors quoted there can be roughly put into two categories: those which change the value of the polarization in a quasi-statistical way, and those which do not. The latter ones typically are the scale errors, which would shift the measurements of one polarimeter, but not increase the scatter. For the LPOL the scale error is $\delta_{LPOL}^{scale} = 1.7\%$, which includes the contribution from the unknown calorimeter scale after 2002, for the TPOL this error is $\delta_{TPOL}^{scale} = 1.7\%$. Together these errors account for $\delta^{scale} = 2.4\%$. The observed width of the ratio distribution therefore can be explained by the errors not related to the scale ($\delta_{TPOL}^{notscale} = 2.4\%$ for the TPOL, $\delta_{LPOL}^{notscale} = 1.1\%$ for the LPOL, 2.6% in total), and an unknown component not explained by the listed errors:

$$\delta_{POL}^{addsys} = \sqrt{\delta_{ratio}^2 - (\delta_{TPOL}^{notscale})^2 - (\delta_{LPOL}^{notscale})^2} = 3.0\%,$$

where all errors used are relative errors. This error is clearly not covered by the existing systematic errors, and should be applied in addition to the other errors to the combined measurement of the polarization.

5 Recommendations for Polarization Values Treatment

For the summer conferences 2007 the POL2000 Group suggests the collaborations the following preliminary treatment of the polarization values and corresponding errors provided by the two polarimeters.

1. The average TPOL and LPOL polarizations are calculated for a period (at least a few minutes) to make the statistical error negligible. Each experiment will have its own selection criteria, so that no central selection will be performed. Nevertheless,

Polarimeter Availability	Cited Syst. Error	Extra Syst. Error	Total Syst. Error
TPOL only	2.9%	3.0%	4.2%
LPOL only	2.0%	3.0%	3.6%
TPOL and LPOL	1.6%	3.0%	3.4%

Table 5: Relative systematical uncertainties proposed for the measurements by the two polarimeters. For each polarimeter availability condition, the total error is calculated adding in quadrature an extra contribution of 3.0% to the uncertainty.

we recommend to use as input the smoothed values which are regularly provided by the POL2000 Group to the collaborations. These data are stored in the DESY Oracle database. By using the smoothing algorithm, the presented values have already a negligible statistical uncertainty.

2. In case both polarimeters were functioning properly, and no indication exists that the mean values of both disagree, the values of TPOL and LPOL should be combined by a weighted mean method, with the measurement weight given by the corresponding known absolute systematic uncertainty (note that contrary to the tables etc given elsewhere in the note, the weights have to be calculated from the absolute systematic errors, $\sigma = \delta \times P$ of the polarization):

$$\langle P \rangle = \frac{\frac{P_{TPOL}}{\sigma^2_{syst.\ TPOL}} + \frac{P_{LPOL}}{\sigma^2_{syst.\ LPOL}}}{\frac{1}{\sigma^2_{syst.\ TPOL}} + \frac{1}{\sigma^2_{syst.\ LPOL}}} . \tag{1}$$

The absolute error of the combination is given by

$$\sigma_P = \sqrt{\frac{1}{\frac{1}{\sigma^2_{syst.\ TPOL}} + \frac{1}{\sigma^2_{syst.\ LPOL}}} + \sigma^2_{add\ syst}} . \tag{2}$$

We assume that on average the ratio between LPOL and TPOL is one, and that we can replace in the above formula the absolute errors by $\delta_{LPOL,TPOL} \times \langle P \rangle$ and use for P the average polarization. The formula then simplifies and can be expressed purely in terms of relative errors:

$$\delta_P = \frac{\sigma_P}{\langle P \rangle} = \sqrt{\frac{1}{\frac{1}{\delta^2_{syst.\ TPOL}} + \frac{1}{\delta^2_{syst.\ LPOL}}} + \delta^2_{add\ syst}} , \tag{3}$$

where δ_P now is the relative error of the polarization.

3. In case only one polarimeter was operating properly, the error from the corresponding device should be used, to which the overall uncertainty of 3.0% should be added in quadrature.

Using this proposed procedure, systematic uncertainties are summarized in Table 5.

6 Summary and Outlook

In this note we have presented a method to treat preliminarily the polarization values measured by the two polarimeters at HERA. The measurements showed short-term deviations which cannot be understood in terms of the officially released systematic uncertainties. The proposed treatment aims to provide a consistent and more reliable presentation of the polarization values, adding an additional uncertainty on top of the individual errors of both TPOL and LPOL, of 3.0%. The estimation of this error is driven by the data collected by both polarimeters. Following this proposal, more correct values can be used by the HERA collaborations for the upcoming conferences in summer 2007.

The procedure and the values presented in this note are preliminary. It is hoped that based on the ongoing work a reduced systematic error can be presented in the near future.

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