H1–06/98–545
ZEUS-Note 98–043
DESY-PRC 98–07
June 18, 1998

Polarization 2000

Polarization 2000 Group

V. Andreev[7], D. Barber[3], E. Barrelet[11], Y. Bashmakov[7], P. Biddulph[13], V. Boudry[10], A. Caldwell[6], J. Dainton[14], A. Deshpande[8], A. DeRoeck[3], S. Dhawan[8], M. Fleischer[3], A. Fomenko[7], V. Gharibyan[12], E. Gianfelice[3], N. Gogitidze[7], L. Gorbov[7], V. Hughes[8], I. Malinovski[7], E. Kinney[2], R. Klanner[5], K. Königsmann[4], M. Korbut[7], R. Kose[3], A. Lebedev[7], S. Levonian[7], B. Löhr[3], M. Lomperski[3], W. Lorenzon[1], L. Losev[7], N. Meyners[3], F. Moreau[10], A. Most[1], S. Rusakov[7], P. Schüler[3], K. Sinram[3], A. Specka[9], J. Vazdik[7], F. Willeke[3], F. Zetsche[5]

[1] *University of Michigan, Ann Arbor MI 48109-1120, USA*
[2] *University of Colorado, Boulder CO 80309-0446, USA*
[3] *DESY, Deutsches Elektronen-Synchrotron, 22603 Hamburg, Germany*
[4] *University of Freiburg, 79104 Freiburg, Germany*
[5] *University of Hamburg, 22761 Hamburg, Germany*
[6] *Columbia University, Irvington on Hudson NY 10027, USA*
[7] *Lebedev Physical Institute, 117924 Moscow, Russia*
[8] *Yale University, New Haven CT 06520-8121, USA*
[9] *LPNHE, University Paris-Sud, 91898 Orsay, France*
[1]0 *LPNHE, Ecole Polytechnique, 91128 Palaiseau, France*
[11] *LPNHE, Universites Paris VI and VII, 75252 Paris, France*
[12] *Yerevan Physics Institute, 375036 Yerevan, Armenia*
[13] *University of Manchester, Manchester M13 9PL, UK*
[14] *University of Liverpool, Liverpool L69 3BX, UK*

Abstract

The aim of the Polarization 2000 project is to set up a system of polarimeters which is able to determine the electron/positron beam polarization P at HERA to an accuracy of $\delta P/P \leq 0.02$ in the year 2000 after the HERA luminosity upgrade. The proposed system consists of the existing transverse polarimeter located in the HERA West area and the longitudinal polarimeter which is located in the HERA East area near the HERMES experiment. These polarimeters exploit different and independent methods to measure the beam polarization and thus complement each other. In order to meet the more stringent future requirements for the polarization measurement major parts of the hardware and the software need to be added, rebuilt or upgraded, mainly for the transverse polarimeter. In addition the analysis methods and tools have to be extended and refined.

1 Introduction and Physics Motivation

In the HERA Shutdown 1999/2000 spin rotators will be installed around the interaction regions of the H1 and ZEUS experiments to enable these experiments to run with longitudinally polarized electrons and positrons[1]. Together with the realization of the HERA luminosity upgrade program electroweak precision measurements will be feasible. The HERA physics program with polarized electrons has mainly been defined in the Workshop *Future Physics at HERA* [1]. This program investigates the potential of deep inelastic lepton nucleon scattering to set limits on right handed charged current reactions, to measure standard model parameters and to test the neutral current couplings of the quarks. These studies assume a delivered total luminosity of 500–1000 pb^{-1} and a degree of polarization P of 70 %. With these conditions the electron polarization has to be known to 2 % relative accuracy in order to fully exploit the potential of HERA for the proposed measurements.

Currently the measurement of the electron polarization at HERA is done with two different devices. The so-called transverse polarimeter (TPOL) [2] which is located in the West area of HERA measures the polarization of the — at that location — transversely polarized beam. The longitudinal polarimeter (LPOL) [3] in contrast measures the longitudinal polarization of the beam near the HERMES interaction point.

Both devices and their current performance will be discussed below, following a section which describes the requirements for future polarization measurements. The next chapter then deals with the proposed upgrades. These mainly affect the transverse polarimeter. The major part of the upgrade concerns the data acquisition system. Various methods for the determination of the polarization and for the improved calibration of the polarization scale are discussed in the following chapter, including requirements on test beam measurements and Monte Carlo studies. Finally a working plan and time schedule is presented together with comments about finances and responsibilities.

2 Requirements for Future Polarization Measurement

After the HERA luminosity upgrade the default mode of running for HERMES, H1 and ZEUS will be with longitudinally polarized electrons at their interaction points. If, however, H1 or ZEUS required nominally transverse polarization (corresponding to the current situation) their rotators could be re-tuned to simulate the effect of their compensating magnets which will be removed in the course of the luminosity upgrade. In the case of default running the polarization measurement will become as important as the luminosity measurement for H1 and ZEUS, since neutral and charged current ep cross sections and hence the corresponding event rates depend sensitively on the beam polarization. Therefore care has to be taken that a continuous, reliable beam polarization measurement is available throughout the HERA collision program with a relative accuracy of 2 % to satisfy the physics requirements quoted above. Ideally, the accuracies of both, luminosity and polarization measurement, should be the same. The luminosity measurement for H1 and ZEUS currently has an uncertainty of about 1–2 % in accordance with the projected polarization uncertainty.

[1] In the following the term "electrons" will be used to denote both, electrons and positrons.

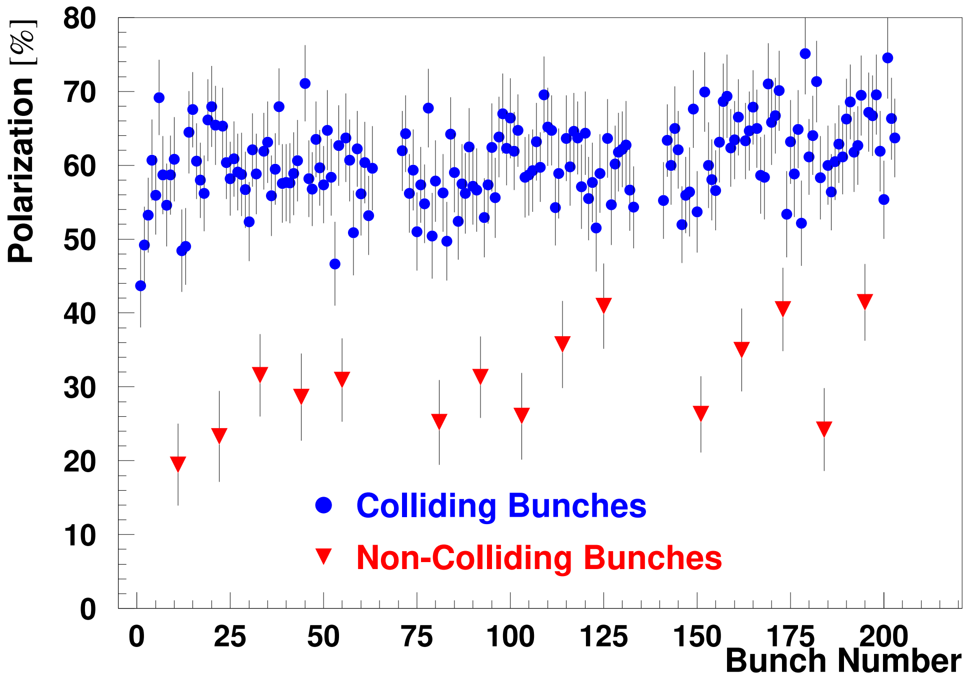

Figure 1: *Polarization measurement of single electron bunches with the longitudinal polarimeter. The non-colliding electron bunches show a systematically lower polarization than the electron bunches which collide with proton bunches at ZEUS and H1.*

Clearly, one important consideration for H1 and ZEUS is the fact that physics measurements are only based on colliding electron and proton bunches. However, the existing TPOL measures the mean polarization of *all* electron bunches in the ring, whereas the LPOL can measure the polarization of single bunches, small bunch groups, or the mean polarization of all electron bunches. It has been observed from measurements with the LPOL that non-colliding electron bunches can have different polarization patterns than colliding bunches (Fig. 1) which also vary in time. This pattern depends sensitively on the tuning of the polarization. Hence H1 and ZEUS need a system which measures the polarization of colliding and non-colliding bunches separately, whereas HERMES needs to know the mean polarization of all electron bunches. Thus a flexible system is needed which provides simultaneously a polarization measurement for any combination of bunches.
Since the absolute value of the degree of polarization of the electron beam is the same everywhere in the ring, in particular $|P_{\rm long}| = |P_{\rm trans}|$, the location of the polarization measurement is not confined to the experiments' interaction regions. Instead the place with the best infrastructure should be used and the best understood methods and experimental techniques should be exploited in order to achieve a precision measurement of the polarization. We think the existing transverse polarimeter facility at the HERA West area with its specially (for polarization measurement) designed beam optics and the existing longitudinal polarimeter at HERMES are the best practical choices. The TPOL has been operated for some years already and valuable knowledge of its performance and its systematic errors has been collected [2, 4, 5]. From this experience it is clear that certain additions and improvements have to be made. However, the general method for the polarization measurement is well established and we think it is possible to make a reliable estimate on the future performance of the device after a suitable up-

grade. The LPOL complements the TPOL measurement with an independent method, but has not yet reached its full potential. It is expected that its performance will come up to the specifications in the near future. Both polarimeters can back-up each other in case of technical problems.
Typically the polarimeters deliver one polarization measurement per minute with a statistical error of about 1–2 %. Given the much larger time constants of the polarization process this rate is sufficient and it seems appropriate to feed the polarization information from the TPOL and the LPOL into the experiments' data streams and to the HERA control room on a minute-by-minute basis.
To summarize, the requirements for the future polarization measurements after the HERA luminosity upgrade in the year 2000 are:

- Polarization measurement of colliding and non-colliding electron bunches separately (but simultaneously) on a minute-by-minute basis.
- Polarization accuracy of $\delta P/P \leq 2\,\%$.
- Redundant system (i.e. TPOL *and* LPOL) for cross checks and as back-up.
- Different methods of polarization determination for the systems.

3 Current Performance of HERA Polarimeters

Both polarimeters exploit the spin dependent Compton scattering of polarized laser light off the polarized electrons. The TPOL measures single photon scattering events with a vertically segmented calorimeter and analyses the spatial asymmetries for left and right circularly polarized light. The LPOL records multi-Compton signals in a crystal calorimeter and determines the beam polarization from energy asymmetries for the different laser light helicities.

3.1 Transverse Polarimeter

The transverse polarimeter [2] measures the transverse polarization of the electron beam in the HERA West area where no spin rotators are (or will be) installed. In routine operation the average polarization of all electron bunches is measured. It has operated continuously with high efficiency since 1995 when the HERMES experiment started to take data.
Currently the standard polarization measurement is based on the $\Delta\eta$ method which relates the mean values $\langle\eta\rangle_{L,R}$ of the vertical distribution of the Compton photons to the electron beam polarization P_Y in the following way

$$\Delta\eta(E_\gamma) = \frac{\langle\eta\rangle_L - \langle\eta\rangle_R}{2} = P_Y\,\Delta S_3 \Pi_\eta(E_\gamma)\,. \tag{1}$$

Here the up-down energy asymmetries $\eta = (E_{up} - E_{down})/(E_{up} + E_{down})$ of the Compton photons are recorded with the calorimeter and ΔS_3 is the difference in helicity of the laser light. $\Pi_\eta(E_\gamma)$ is an effective analysing power which fixes the polarization scale. It depends on the Compton cross section and detector and electron beam parameters. This analysing power has originally been derived in simulations/calculations and data studies ([2, 4]) to a precision of 5.3 %.

Since then additional test beam data have improved the knowledge of those detector parameters which dominate this error [6]. Preliminary Monte Carlo work, based on this more precise input data, indicates that the fractional error of the analysing power and the polarization scale may be reduced to a level of about 2 % [7]. More detailed simulation studies will be required before an accurate number can be quoted.
The polarization scale can be derived independently by measuring the characteristic build-up time and the asymptotic value of the polarization [8]. This method, which is currently the standard procedure to obtain the polarization scale, will be explained further in Section 3.3. The present-day fractional uncertainty of the polarization scale, as obtained from these measurements, is 3.3 % [9]. New measurements are planned for 1998, which could reduce the error to 2 %.
The absolute values of the polarization scales as obtained from the two methods can not be compared directly since they apply to different beam energies (26.7 GeV and 27.5 GeV, respectively). Still, the numbers differ by about 6 % and are in agreement with their uncertainties.
In contrast to the scale errors, the minute-to-minute variations in the polarization measurement due to time varying effects are controlled at the 1 % level. Also the statistical errors, which depend on the electron beam current, typically amount to 1–2 % per minute. Thus the dominant error on the polarization measurement is the systematic uncertainty on the polarization scale.
A breakdown of various error sources from a recent data analysis [5] is given in Table 1.

Source	Rel. uncertainty $\delta P/P$ [%]
Calorimeter centering	0.55
Calorimeter calibration	0.08
Rate dependence	0.10
Light polarization	0.52
Point-to point quadratic sum	0.87
Rise time calibration	3.26
Total average syst. error	3.42

Table 1: *Current systematic errors of the transverse polarization measurement (from [5])*

In addition to the $\Delta\eta$ method, which was described at the beginning of this chapter, there is at least one more method for determining the transverse polarization from the data. This is the $A(\eta)$ asymmetry method [2] which will be discussed in chapter 5.

3.2 Longitudinal Polarimeter

The longitudinal polarimeter [3] measures the longitudinal polarization of the electron beam between the HERMES spin rotators. In routine operation it records the average polarization of the electron beam. The main reason for building the longitudinal polarimeter was to have a second, independent measurement of the beam polarization, and to reduce the overall systematic uncertainty in the absolute polarization value. The longitudinal polarimeter was installed in the 1995/96 shutdown and commissioned

during 1996. Since then it has provided reliable polarization data to HERMES for the entire 1997 running period with an overall efficiency of greater than 90%.
The measurement of the longitudinal polarization (P_Z) is based on large asymmetries $\mathcal{A}_m$ in the energy distributions of the backscattered photons. Because of large bremsstrahlung background at the calorimeter of the longitudinal polarimeter, the "multi-Compton mode" is preferred. (In contrast to the "single Compton mode" utilized in the transverse polarimeter, where the energy of every individual Compton photon is analysed.) In this mode the total energy of about 1000 Compton photons from a single bunch crossing is measured in the detector. The longitudinal polarization is then obtained from measurements of the energy weighted asymmetry

$$\mathcal{A}_m(E_\gamma) = \Delta S_3 P_Z \mathcal{S}_Z, \tag{2}$$

with

$$\mathcal{S}_Z = \frac{\mathcal{S}_R - \mathcal{S}_L}{\mathcal{S}_R + \mathcal{S}_L}, \quad \text{and} \quad \mathcal{S}_i = \int_{E_{min}}^{E_{max}} \left(\frac{d\sigma}{dE}\right)_i \cdot E \cdot r(E)\, dE, \quad \text{where} \quad i = L, R.$$

The analysing power $\mathcal{S}_Z$ is 0.184 for the ideal energy response function r = 1. The polarization is finally determined from the measured shifts of the energy spectra for the two light polarization states.
To achieve a statistical error δP_Z of 0.01, a measurement takes about 40 s. The laser power can be adjusted easily to keep the luminosity constant. The background is measured between laser pulses and is negligible in the "multi-Compton mode".
The polarization scale of the LPOL is currently obtained with the rise time method and by comparison to the TPOL. This revealed that the LPOL measures asymmetries which are 25 % larger than those expected from the calculated $\mathcal{S}_Z$. Many systematic studies have been performed to understand this 25% deviation. These are summarized below (see Table 2), but no clear explanation has been found yet.
The overall systematic error ($\delta P/P$) for the longitudinal polarimeter in 1997 was 4.3%. It is composed of two parts, the uncertainty obtained from the (TPOL) rise time calibration (3.3%), and the uncertainty obtained from the comparison to the transverse polarimeter (2.7%) (cf. Section 3.4).
Table 2 shows an overview of systematic studies performed in 1997 to explicitly look for the source of the 25 % deviation mentioned above. These studies can be used to estimate typical systematic uncertainties of an absolute calibration method provided

	$\delta P/P$ [%]	
Source	1997	1998 expected
Helicity dependence of IP position	<1%	<1%
Slope & horiz. beam pos. at IP	<1%	<1%
Laser polarization	0.5%	0.5%
Detector linearity	0.5%	0.5%
Electronic noise	<1.0%	<1.0%
Calorimeter Calibration	1.5%	1.0%

Table 2: *List of various measured (1997) and expected (1998) systematic errors to the longitudinal polarization, assuming the 25 % deviation is identified.*

the source of the 25 % can be clearly identified. The investigated error sources amount to a fractional systematic error for the longitudinal polarization of about 2.5 % and give an idea of the potential of the LPOL. It is believed that the 25% effect can be solved or largely reduced in the near future after more detailed Monte Carlo studies and more extensive experimental studies are completed (cf. also Section 4.2).

3.3 Rise Time Calibration

As pointed out in the previous sections the polarization scales of both polarimeters are determined from rise time calibrations. An example of such a measurement is shown in Fig. 2. The polarization build-up due to the Sokolov-Ternov effect obeys an exponential law,

$$P(t) = P_{\infty}(1 - e^{-t/\tau}) \,, \tag{3}$$

where P_{∞} is the asymptotic polarization value for the current machine parameters and τ the corresponding time constant (rise time). In addition the following theoretical relation holds,

$$P_{\infty,\text{theo.}} = \frac{P_{ST} \cdot (1+\delta)}{\tau_{ST}} \cdot \tau \,, \tag{4}$$

where P_{ST} and τ_{ST} are the maximum polarization that can be achieved from the Sokolov-Ternov effect alone (i.e. in the absence of depolarization effects) and the corresponding rise time for the HERA electron ring at $E_{beam} = 27.5\,\text{GeV}$. The quantity δ accounts for the so-called "kinetic polarization effect" [10]. This is a side effect of the more familiar depolarization effects. With the current HERA optics and the HERMES spin rotator switched off ("flat machine") these values are 90.8 % and 36.4 minutes, respectively, and the quantity δ is practically zero. With the spin rotator switched on, however, P_{ST} is reduced by about 1.8 % and the quantity δ takes on a finite value of the order of a few percent but cannot be estimated reliably. In addition, it is also sensitive to the current state of the machine.

By extracting P_{∞} and τ from measured polarization rise curves and calculating $P_{\infty,\text{theo.}}$ from eqn. 4 the polarization scale can be calibrated experimentally. As pointed out in the above discussion only measurements of rise times with a flat machine will give unbiased results (unless the quantity δ could be measured). Thus for the LPOL no direct and exact rise time calibration is possible since for a flat machine there is no longitudinal polarization and hence no measurement from the LPOL.

In 1994 a set of rise time measurements has been taken for the TPOL with a flat machine and the uncertainty in the polarization scale from this method is 3.3 % [9]. It is limited by statistical errors and the stability of the electron beam and the polarimeter which result in deviations from the ideal relation eqn. 3. The rise time calibration measurement will be repeated in 1998 with the aim to reduce the uncertainty to about 2 %.

3.4 Comparison Between the Polarimeters

The polarization scale of both polarimeters is currently obtained from the rise time method. The scale from the TPOL is transferred to the LPOL by means of simultaneous routine polarization measurements and rise time measurements with spin rotators switched on. During these measurements both polarimeters track each other very well, as demonstrated in Fig. 2. By fixing the polarization scale in this way, both polarimeters deliver the same polarization value on average.

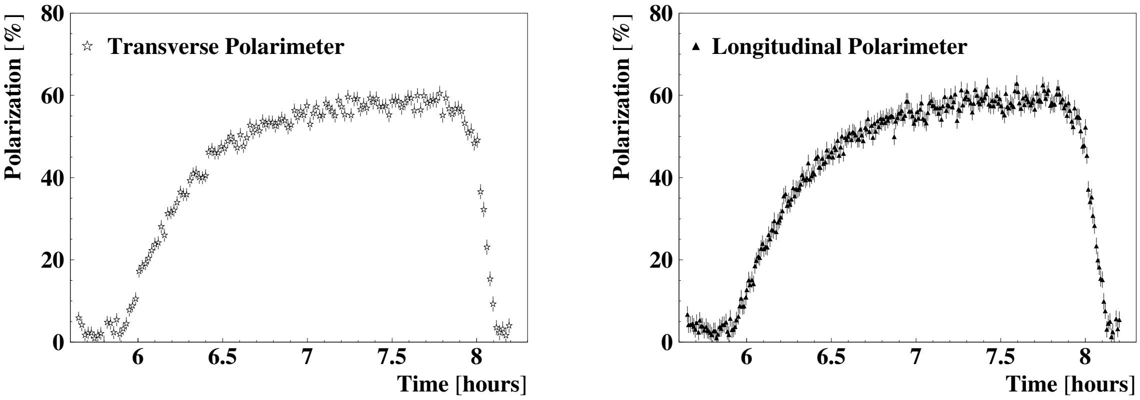

Figure 2: *Rise time curve taken simultaneously with the transverse (left) and longitudinal polarimeter (right). At the beginning and at the end of the measurement, the beam was depolarized on purpose.*

The relative long term stability of both polarimeters was studied by comparing the ratio of the polarization values of the two polarimeters over the entire 1997 running period. The distribution of this ratio is displayed in Fig. 3 and is well fitted by a Gaussian. One can conclude that the transverse and longitudinal polarization measurements agree within 2.7 % (1-standard-deviation) with respect to point-to-point (systematic) variations.

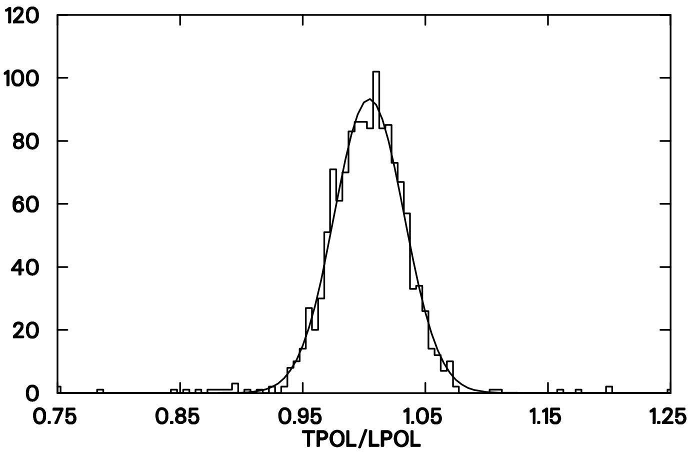

Figure 3: *Distribution of ratios of polarization values from transverse and longitudinal polarimeters for all measurements in 1997. Ratios are taken for 30 minute time intervals to reduce the contribution from statistical errors.*

4 Upgrade Plans

Most of the upgrade plans involve the TPOL, and here the upgrade of the data acquisition system is particularly important. Nevertheless all components of the TPOL have to be examined in order to exploit the potential for decreasing all possible error sources for the polarization determination. For the LPOL the emphasis is on the more accurate determination of the analysing power. A strong contribution to this understanding is expected to come from improvements to the existing calorimeter and the test of a new calorimeter. Otherwise no major upgrade plans exist currently for the LPOL.

4.1 Upgrade Plans for Transverse Polarimeter

The transverse polarimeter has been described in detail in [2]. Fig. 4 shows an overview of the general layout of the TPOL in the HERA West area with the laser and the light transport and analysis system, the HERA tunnel and the electron beam pipe and the calorimeter for Compton photon detection.
In the following all the components of the TPOL will be discussed in terms of necessary upgrades. Table 3 gives an overview of the proposed actions in order to fulfill the requirements outlined in the previous chapters.

Component	Task	Comment
Laser	Reevaluate	Ensure reliability and service
Optical System	Reevaluate	Examine measurement of laser light polarization
	New	Laser-electron beam pipe extension, laser spot size measurement
Calorimeter	Reevaluate	Upgrade (replace) HV and LED systems
	Test beam	Two identical calorimeters are available. Re-investigate their properties with dedicated test beam.
DAQ, Trigger	New	New analog and digital signal chain (ADC, trigger logic, readout, computer)
Miscellaneous Electronics	New	Pulse generator to simulate calorimeter signals, signal generator and dedicated kicker magnet for beam depolarization
Online Software	New	New run control, new readout software, adapted slow control
Offline Software	Upgrade	Extend and refine analysis procedures
Monte Carlo	Upgrade (New)	Produce improved MC simulation of data distributions, understand detector, beam and laser parameters in more detail

Table 3: *Overview of components of the transverse polarimeter at HERA and proposed upgrades.*

The biggest part of the upgrade is concerned with the data acquisition system and the corresponding online and offline software which will allow the separate polarization determination of colliding and non-colliding bunches. This will be discussed in the next section. The proposed improvements for the other TPOL components are necessary to decrease and quantify various error sources to the polarization determination. These are covered afterwards. Monte Carlo simulations and test beam measurements will be discussed in the context of Chapter 5.

4.1.1 DAQ and Trigger System

A schematic diagram of the current data acquisition system is given in Fig. 5. It is a very heterogeneous system with many different hardware components which has to be

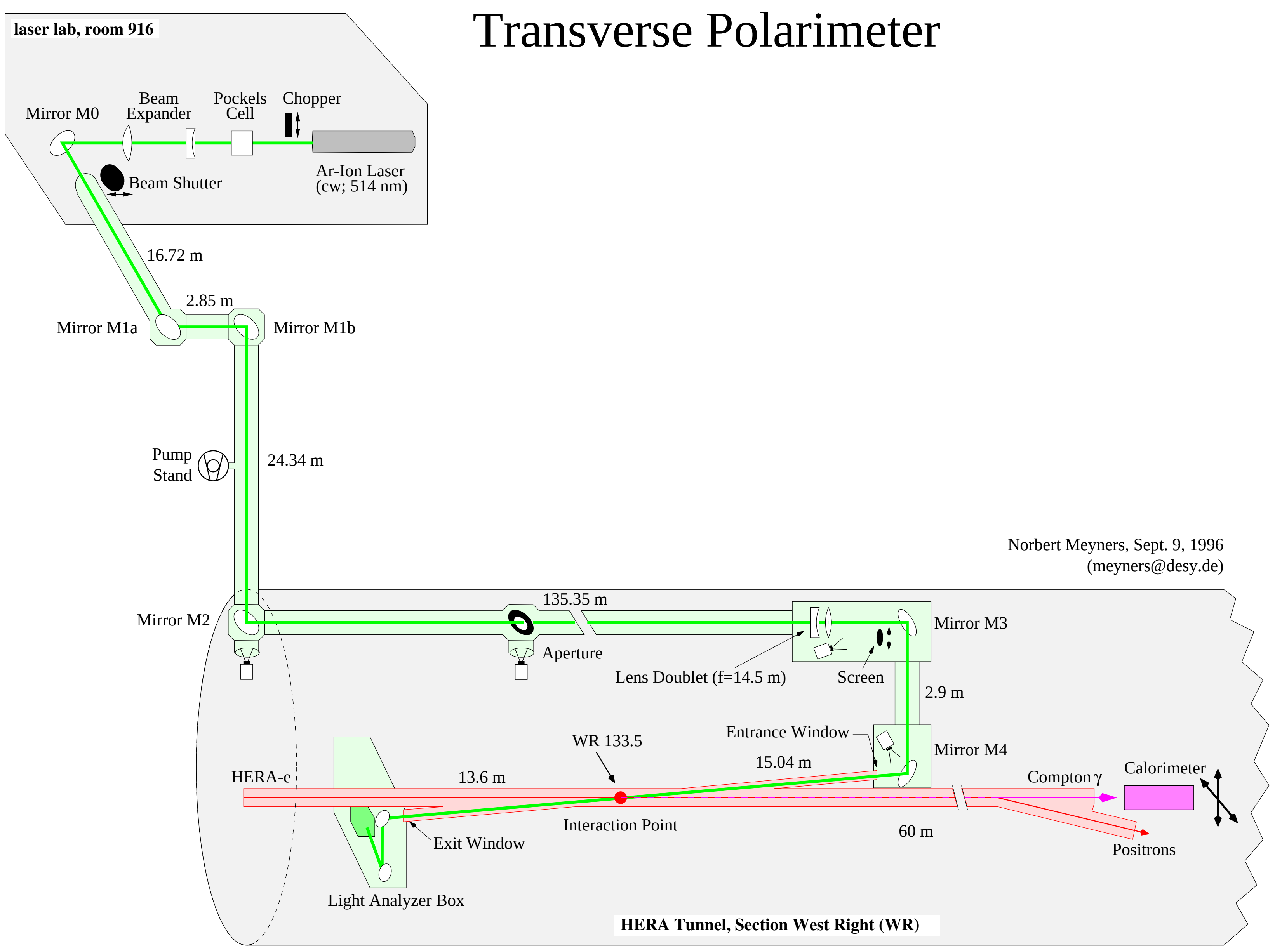

Figure 4: *Schematic overview of the transverse polarimeter at HERA. Shown are the laser beam line, the electron beam line and the calorimeter which measures the backscattered Compton photons.*

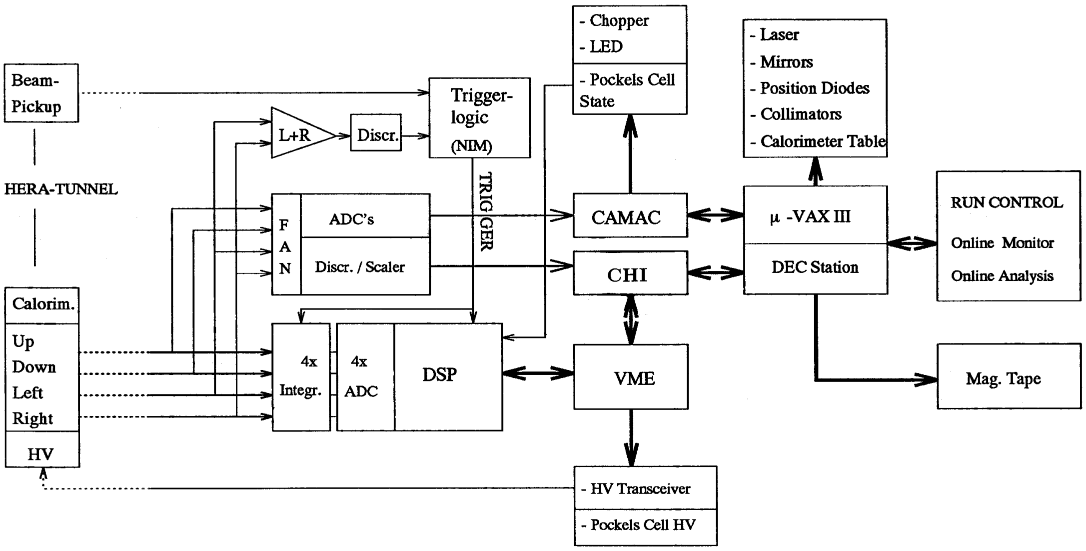

Figure 5: *Schematic overview of the current data acquisition system of the transverse polarimeter at HERA.*

extended in functionality and which should be considerably simplified. Specifically, the upgraded DAQ system has to allow for flexible and fast data sampling in the sense that a polarization measurement of any combination of electron bunches becomes possible. With the current system, which is based on NIM electronics for the trigger and a DSP for polarization calculation, this is not possible. The required gross features for the new DAQ system are:

- Read-out of single Compton events at a rate of 100 kHz with little dead time.
- Event information consists of
  - 4 Energy data: 12 bit each (more data may be useful for baseline monitoring)
  - 1–3 Time data: 10 bit each (new, optional)
  - Bunch number: 8 bit (new)
  - Trigger type: at least 3 bit (new)
  - Status laser light: 3 bit
- Provide average bandwidth of $\approx 1 - 2$ MByte/s.
- Filter events according to bunch number, trigger type etc. and produce distributions and calculations for polarization values in real time (new).

In the new DAQ design special care has to be taken concerning the performance of the analog signal chain.The requirements in terms of linearity, noise, pile up effects etc. are listed in Table 4. The electronics specifications are defined in terms of the maximum signal in GeV which is 30 GeV (and which corresponds to an integrated charge Q_{max}) to allow the measurement of the bremsstrahlung edge (27.5 GeV) and of multiple events. These specifications limit the influence of electronic effects on the polarization measurement to less than 1 % fractional uncertainty.

Two different systems have been proposed which will be able to fulfill the requirements. Both will be discussed in the following. System A is custom designed for the TPOL

Item	Limit
Noise	$<$ 100 MeV (but should be much better)
Baseline stability	
rate 0–1 MHz	$<$ 30 MeV (0.1 % Q_{max})
short term	$<$ 30 MeV (0.1 % Q_{max})
long term	depends on frequency of calibration
Rejection signal at -96 ns	$<$ 2 % (correction possible?)
Rejection signal at -192 ns	$<$ 0.1 %
Gain stability	
rate 0–1 MHz	$<$ 1.3 %
short term	$<$ 1.3 %
long term	depends on frequency of calibration
Nonlinearity (max. deviation from line 0-Q_{max})	$<$ 1.3 %

Table 4: *Specifications for analog electronics requirements*

upgrade, system B is a variation of a system which is being developed for the luminosity monitor upgrade of H1 (see DESY-PRC 98-05). Either system still needs a lot of R & D work. After both systems have been studied and developed in more detail the group will decide which system finally will be implemented.

System A

This Electronics/DAQ system is custom designed for the TPOL requirements. Special attention is paid to design the system for the best possible analog performance. In this system, the ADC data is pipelined with the pipeline designed to handle each and every bunch crossing. The objective is to reduce the system complexity and make it simple to operate and use. Only 2 custom PC boards are to be developed. Fig. 6 shows the schematic outline of system A.

Analog processing and digitization:

We use a differential linear line driver from the photomultipliers to drive the $>$ 200 meters of coaxial cable. Ground noise is then isolated from the signal lines. A differential analog receiver receives the photomultiplier signals in the counting house. Then a pulse shaper de-convolutes the coaxial cable response function and pulse shaping and integration of the PMT signals is done.
The receiving and shaping electronics will be integrated on an ADC board with 4 ADC channels (Resolution = 14 bits, Sampling Rate = 10.4 MHz (HERA clock), ADC chip = Analog Devices AD9040 is being evaluated). The digitized data will be pushed through a pipeline which is placed, together with a digital discriminator, on the same board.

Digital event processor:

This board takes as inputs ADC data from the pipeline, HERA bunch clock, Laser and Pockels cell information from slow control.
There are 3 output streams: Trigger NIM/TTL signals, PCI bus connection, Ethernet-Web host connection.
The board receives data from all the 4 ADC boards, from slow control status bits,

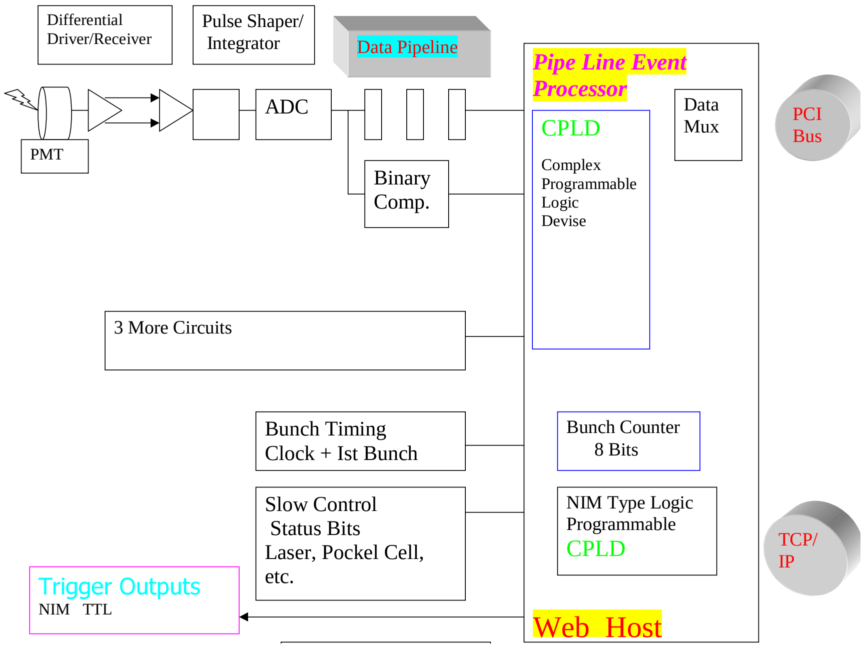

Figure 6: *Electronics scheme for the TPOL (System A)*

from the HERA clock, etc. Binary comparators are used for the digital threshold on each channel and to digitally form coincidences. The event data are sent to the PCI bus. The pattern unit part of the board forms the coincidences, pre-scaling events etc., and will duplicate the currently performed functions like monitoring and scaling signals. Most of the logic will be buried into a few CPLDs (Complex Programmable Logic Device).
The bunch number counter is implemented in a CPLDs logic and the output added to the data word. Similarly, scalers are added for the rate measurements.
A http:// web host will control this functionality and allows access to all the settings and control functions via a Web browser like Netscape or Internet explorer.

Computing:
We propose to use a Dual CPU 450 MHz (Xeon Slot2) with 256 MB DRAM.
The PC will perform the polarization calculations and make $>$ 8 million channel histograms to cover all distributions for all individual electron bunches at the input side. Then we have other tasks running which use the large histogram database to produce smaller histograms (e.g. distributions for various bunch groups) over shorter time intervals. A dual Xeon Pentium II with 100 MHz local bus and a large shared memory will be sufficient for the anticipated requirements. Future CPU upgrade will involve only a simple plug in replacement.
Our tests have shown that the polarization calculations (i.e. calculation of energy asymmetry η and total energy E_γ) and the filling of an 8 million channel histogram takes less than 400 nsec per event in a 300 MHz Pentium II PC. This is to be compared with the mean event rate of 100 kHz corresponding to 10 μs time intervals.
Slow control devices may be driven from a separate PC via a system like LABVIEW. All the communications to the various experimenter computers shall be via Fast Ethernet using TCP/IP protocol.

R & D:
Substantial R & D work needs to be done on this system.

System B

The general electronics layout is shown in Fig. 7. This scheme is designed as an improved solution for the TPOL readout electronics and is derived from the development of an upgraded luminosity monitor DAQ which has to handle almost the same tasks. Basically, the calorimetric chain consists in a fast analog shaping, a 12 bit ADC providing 2 energy samples per bunch and a dedicated fast readout by a commercial processor (Power PC) which performs on-line histograming at a high rate ($\sim 1\,$MHz). The analysis of the produced histograms provides the polarization measurements bunch by bunch.

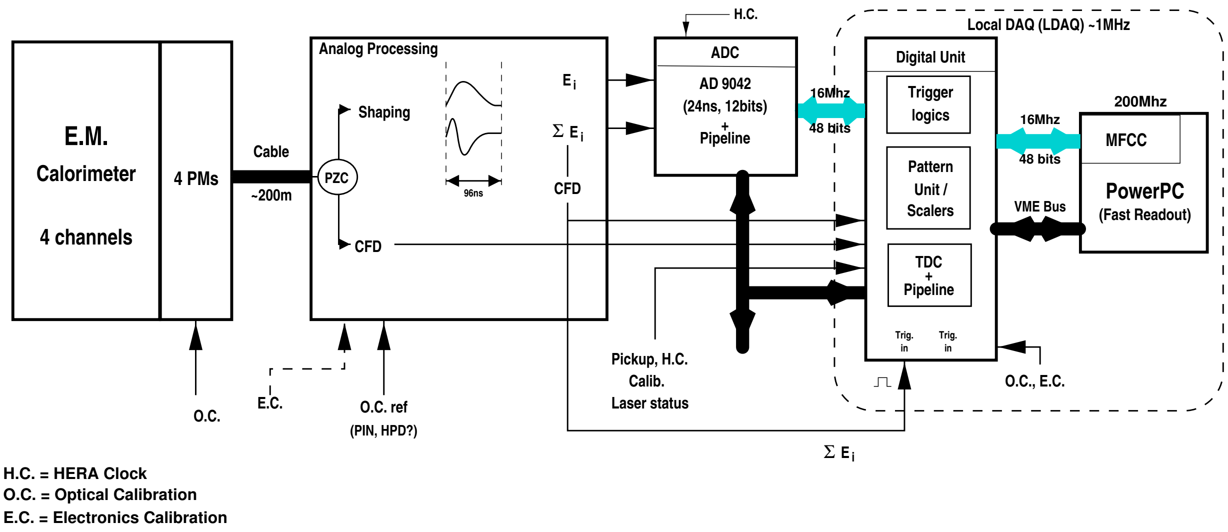

Figure 7: *Electronics scheme for the TPOL (System B)*

Analog processing and digitization:

Shaping: First the skewing effect of the cable at the receiving end is removed by suited filtering. A fast shaping then is performed, (pole-zero compensation PZC + unipolar or bipolar shaping) with a return to the baseline at the level of 1 % within one HERA clock period (96 ns) such that bunch to bunch pile-up effects are removed.
Thresholds: The board includes also few constant fraction discriminators (CFD), their outputs being on one hand used for event counting and, on the other hand, digitized in a TDC (see below) and/or used as input for triggering. The E_{tot} pulse or all 4 channels could be discriminated. The discrimination is also interesting with respect to calibration procedures and also for non-calorimetric channels (background vetoes, optical calibration for instance) which would be processed in the same way.
The analog requirements as outlined above will be achieved and exceeded.
Digitization: The amplitude measurement is performed inside a dedicated board based on a fast ADC. For instance, the AD9042 (Analog Device) chip performs 12 bits conversion at a maximum rate of 41 MHz. For our application, running the device

at half the rate (2 times the HERA clock frequency) would fit our application. The digitized information is stored in parallel inside a pipeline for the fast online DAQ (LDAQ).

Digital event processor:
This unit consists of few boards which will enable various digital information to be recorded and triggering in test mode to be performed.
Scalers: There will be scaler channels on the board to be read out via VME bus every second. Also TDC can be used as scaler (see below).
Timing: This is very useful for the tuning and monitoring of the sampling position of the ADC with respect to the peak value of the analog pulse. The main signals which could be measured permanently by the TDC are: the total energy E_{tot} and the individual channels discriminated in the analog card, the HERA clock, the beam pickups. The TDC function is performed by a chip developed at Paris for the BaBar experiment. It provides a time resolution of 0.5 ns and a history over 20 μs.
Pattern Unit: Digital information such as the bunch number, trigger status (E_{tot} , optical calibration ...) is stored and decoded by the local DAQ for selective histograming.

Computing:
The local high rate DAQ (LDAQ) consists of a VME powerPC mother board equipped with a MFCC (Multi-Function Computer Core) developed by the CES company. The high rate LDAQ readout is performed in two steps: first, the raw data (ADC, TDC, bits) are transferred via the 16 MHz, 48 bit bus (named Altera bus) into the DRAM memory of the MFCC board. The event transfer of 2 energy samples per channel would take 2 cycles of the Altera bus (120 ns). With the depth of the pipeline being 22 μs there will be practically no dead-time due to the data transfer. The PowerPC of this board fills the histograms and/or stores some raw events. Secondly, once per second the histograms/raw data and counters are transferred to the mother board card, on which energy/time scale checks and polarization calculations are done. Also the readout of the scalers is performed each second.

R & D:
Substantial R & D work needs to be done on this system.

4.1.2 Miscellaneous Improvements

This section deals with mainly small but nevertheless important proposed improvements for various components of the TPOL.

Laser: The CW Argon ion laser usually runs at constant power at the maximum of 10 W. Its operation needs some tuning from time to time and yearly service and maintenance must be assured. A possible new feature of laser operation is the increase of the laser power from a certain value up to the maximum power during a beam fill such that the Compton rate would be constant in time. In this way the decreasing electron beam current would be compensated and possible rate dependencies of the measurement as well as statistical fluctuations would be minimized. However the stability of the laser beam spot and polarization for such an operation has to be investigated. Most likely this scheme would only be applicable when the full design electron current of 60 mA can be injected in order to run close to the maximum possible count rate.

Optical System: The performance of the optical system has to be reevaluated in order to produce laser light with circularity as high as possible and to pin down tight systematic errors on the measurement of circularly and linearly polarized light. The operation and control of the optical system can be facilitated with an improved and automated (digitized) position measurement of the laser beam and with a laser spot size measurement at a virtual interaction point. Currently it is not possible to measure the light polarization and the beam polarization simultaneously which would be important for better control of systematic errors. This can only be done if the entrance and exit pipes for the laser light to and from the electron beam pipe are enlarged in diameter.

Calorimeter: The reliability of the high voltage system has to be improved. The LED system should be better tuned to equal light output for all 4 channels. Its stability must be monitored and recorded. Possible radiation damage has to be checked carefully. These improvements help in controlling the stability of the calorimeter calibration and performance.

Miscellaneous Electronics: A pulse generator (charge injection system) is needed to simulate detector signals for testing (in the set up phase) and for checking (in the running phase) of the signal processing chain. Ideally it also would be able to deliver signals drawn from Monte Carlo distributions simulating real polarization measurements at a rate compatible to real signal rates.
For the control of the kicker magnet which is used as a depolarization device a signal generator is needed. This signal generator has to generate the full and partial depolarization modes in a flexible way. This functionality is needed to control the stability of beam and polarimeter during rise time measurements.

Offline Software: The offline software should work automatically, i.e. automatic data quality procedures and systematic checks have to run on the incoming data continuously. Application of corrections (if necessary) has to be included. Short and long term statistics and monitoring has to be supplied (WWW based).

Miscellaneous: The vacuum conditions in the electron beam pipe at the straight section West have to be improved. The background rate in the calorimeter from bremsstrahlung on residual gas atoms should be only about 10 % of the signal rate from Compton events in the energy range above 5 GeV (Currently this rate amounts to 20–30 %).

Additional detectors: There has been a lot of discussion on possible new or additional detectors for the TPOL. Especially detectors with high position resolution have been considered in front of the existing calorimeter as well as different types of calorimeters. However, at the moment these devices are considered only as long term future alternatives and have to be investigated further.

4.2 Upgrade Plans for Longitudinal Polarimeter

There are currently no major hardware upgrades planned for the longitudinal polarimeter. The electronics and the laser plus laser transport systems are optimized for the "multi-Compton mode". The fast electronics is presently included in the HERMES data acquisition system, and the slow control is based on the same client/server system as the one used in HERMES. These systems have proved to be very reliable during the 1997 running period. However, polarimeter information has to be provided to the other experiments.
Currently some improvements to the calorimeter are considered. These will be tested in the 1998 running period. In addition, a second calorimeter has been constructed

which will be installed in the tunnel together with the existing calorimeter. The aim of these studies is to get a better understanding of the 25 % difference between rise time calibration and calculated analysing power for the total absorption Cerenkov calorimeter in the "multi-Compton mode". It is planned to exploit the "single photon method" which has the advantage that the Compton spectra can be verified more easily. For operation in single photon mode the power of the pulsed YAG laser has to be decreased significantly.
The calorimeter used in 1997 consists of four radiation hard Cerenkov crystals and is optimized for the multi-Compton mode. Its resolution for single Compton events is rather poor, and in this mode the polarization measurement of a single bunch to 1 % statistical accuracy takes about 10 minutes.
Therefore a simplified version of the sampling calorimeter of the transverse polarimeter has been constructed, but without vertical segmentation. This device can be used in single and multi-Compton mode. It has been tested for resolution and linearity in the DESY test beam in May 1998. The calorimeter is read out with a photomultiplier in single Compton mode and with PIN diodes in multi-Compton mode. The goal is first to compare the polarization in a single bunch using the single and multi-Compton mode with the sampling calorimeter, and then compare the two calorimeters in multi-Compton mode. In parallel, detailed Monte Carlo studies involving both calorimeters will be performed and compared to the test beam and Compton event data. It is expected that these studies then will lead to the origin of the "25 % effect" for the total absorption Cerenkov calorimeter.
It has been discussed whether to implement the same electronics upgrade to the longitudinal polarimeter as the one proposed to the transverse polarimeter. As mentioned above, there is no need to upgrade the electronics of the longitudinal polarimeter as long as it is operated in the multi-Compton mode. As discussed in [3] the multi-Compton mode was chosen due to high gas bremsstrahlung backgrounds. The two main contributions come from the residual gas in a 50 m long straight section, and from the HERMES gas target. The measured bremsstrahlung rate of 800 kHz (or 0.08 per bunch crossing) is no problem in the multi-Compton mode (1000 Compton photons per bunch crossing).
If one however considers to run the longitudinal polarimeter in single Compton mode using a cw laser, then one has to improve the vacuum in that section by about a factor of 10–20 to reduce the background to a manageable level. Note, that for the transverse polarimeter, background levels are about 10 – 20 kHz. This implies that many more new pumps have to be installed in a section which is filled with cavities, and it would require major work on the HERA machine. The benefit of running in single Compton mode would be to have a) asymmetries of up to 60% and b) Compton spectra which can be easily verified and therefore to have a better handle on systematic uncertainties. In a world with no constraints from the machine, this would be the method of choice (this was in fact the first proposal to the machine in September 1994, but was considered as too costly, since two cavities would have had to be removed in the tunnel section East Right).

5 Polarization Scale Calibration and Analysis

The main improvement for the analysis of the polarization data has to be made on the determination of the polarization scale. Different methods of polarization calculation

require the knowledge of different functions which represent the polarization scale. For the TPOL the $\Delta\eta$ method requires the knowledge of the analysing power Π_η and the $A(\eta)$ asymmetry method requires the calculation of the asymmetry functions $\Sigma_{2Y/0}$ and $\Sigma'_{1/0}$ (cf. [2]). For the LPOL exact knowledge of the energy asymmetry function $\mathcal{S}_Z$ is mandatory. All these functions depend on the Compton cross section, on the calorimeter properties and on electron beam parameters and can be determined with the help of Monte Carlo techniques, test beam measurements and real data distributions. It is important to constrain the input parameters to these simulations as tightly as possible.
An independent method for the polarization scale determination relies on the rise time measurement. This method can serve as a cross check for the methods mentioned above.
In the following both methods for the TPOL, their current limits and possible improvements for polarization scale calibration will be described in more detail. For the LPOL refer to Section 4.2.

5.1 Monte Carlo Studies and Test Beam Measurements

Here the functions which fix the polarization scale for the TPOL are discussed. For the $\Delta\eta$ method the polarization is determined according to

$$\Delta\eta(E_\gamma) = \frac{\langle\eta\rangle_L - \langle\eta\rangle_R}{2} = P_Y \Delta S_3 \Pi_\eta(E_\gamma) \tag{5}$$

and for the $A(\eta)$ method the polarization is calculated from

$$A(\eta) = \Delta S_1 \Sigma'_{1/0} + \Delta S_3 P_Y \Sigma_{2Y/0}\,. \tag{6}$$

Since the linear laser light component ΔS_1 is small the calculation of the beam polarization P_Y depends mainly on the asymmetry function $\Sigma_{2Y/0}$. The documented knowledge on the uncertainty of these functions is given in Table 5. Meanwhile work is in progress to improve these numbers.

Source	Uncertainties in (%) for $\Sigma'_{1/0}$	$\Sigma_{2Y/0}$	Π_η
η–y Transformation	3.0	2.5	4.4
Position resolution	8.9	1.1	0.0
Electron spot size	14.0	5.9	2.6
Calibration	0.6	1.6	0.1
Calorimeter centering	0.7	2.6	0.3
Pedestal	2.8	1.5	1.1
Total	17.1	7.4	5.3

Table 5: *Relative uncertainties in % for analysing power Π_η and asymmetry functions $\Sigma'_{1/0}$ and $\Sigma_{2Y/0}$ for different sources (from [4]).*

It is evident that both methods are differently sensitive to various calorimeter and beam parameters. The $A(\eta)$ method has been successfully applied in special runs and is documented in [8]. In general the $A(\eta)$ method delivers a smaller statistical error for

the beam polarization. It also has the advantage that the linear light component ΔS_1 is obtained from the fit to the asymmetry distributions which can be compared to the direct light polarization measurement and provides an important cross check for the systematic error from the laser polarization.
In order to arrive at uncertainties of less than 2 % for the electron polarization measurement the various error sources have to be reduced and/or better corrected for:
η–y Transformation: Use precise test beam data to better constrain the relation between space coordinate y and energy asymmetry η. Test beam measurements with a spare calorimeter indicate that the error for Π_η due to this source can be reduced to at least 1.5 % [6].
Position resolution: Also here use precise test beam data to improve the description of the position resolution of the calorimeter. The current uncertainty of this parameter is about 15 % and should be reduced by a factor 2–3.
Electron spot size: The projected electron spot size on the calorimeter can only be determined from real Compton data although a first estimate exists from beam optics calculations. It can be obtained and constrained from fits to various data distribution (e.g. $dN/d\eta$). Since the above parameters also enter the fit, they must be well constrained from e.g. test beam data in order to disentangle the effect of the electron spot size with high precision. Investigations of circular and linear laser light distributions with different energy ranges of the Compton photons will provide a redundant set of results on the spot size parameter. It is the aim to improve the knowledge on this parameter of currently about 25 % by a factor of 3.
Calibration: The energy calibration can be controlled very well in the data and can be corrected offline if necessary (cf. Sect. 3.1). This will reduce the error listed in Table 5, especially for $\Sigma_{2Y/0}$.
Calorimeter centering: Also the calorimeter centering can be controlled very well and corrected for if necessary. This is important for decreasing the uncertainty in $\Sigma_{2Y/0}$.
Pedestal: Care will be taken by the analog signal handling (new DAQ) to reduce variations in the pedestal and baseline as much as possible which will result in reduced errors due to this source.

We propose to do dedicated test beam measurements with the two calorimeters from the TPOL, especially with high position resolution for the incoming beam particles. At DESY such a high resolution beam particle position measurement with Si-strip detectors became available recently. Here the beam energies range up to only 6 GeV. Test beams at CERN would have the advantage of covering the full energy range of Compton scattering up to 13 GeV. These measurements then will have to constrain the η–y transformation and the position resolution of the calorimeter at the 5–10 % level.
In order to determine the analysing power and asymmetry functions a Monte Carlo program is needed which simulates the Compton process and includes all detector and beam effects. Work is in progress to upgrade the existing programs. An alternative possibility exploits numerical integration and folding/unfolding techniques of parameterizations as being pursued originally [2, 4]. The most important task is the tuning of the simulated distributions and its input parameterizations to fit experimental distributions from the regular polarization measurements. Special runs with linear laser light polarization which are not sensitive to the electron beam polarization will provide additional constraints. These runs should be taken in regular time intervals. With the best set of asymmetry functions and analysing power determined in this way we will

vary the parameterizations of the detector effects in a reasonable range in order to estimate reliable errors on these functions.
There are two principal possibilities to do the Monte Carlo studies. Either one parameterizes the detector effects and thus circumvents the detector simulation of individual events or one uses a full detector simulation (EGS or GEANT) for the study of detector effects. The latter option – if at all feasible – can only be a long term project since millions of events have to be generated and simulated in order to be sensitive to the small asymmetries measured with the TPOL.

5.2 Rise Time Measurements

The polarization scale as calculated from Monte Carlo simulations with input from test beam and real data distributions can be checked by measuring the characteristic build-up time and the asymptotic value of the polarization [8]. Stable and reproducible conditions for polarization rise time measurements can be obtained after resonant depolarization of the beam. An example of such a measurement is shown in Fig. 8. The polarization build-up due to the Sokolov-Ternov effect obeys an exponential law and the polarization scale can be determined following the procedure outlined in Sect. 3.3. As mentioned there, an unbiased scale calibration can only be obtained with a "flat machine", i.e. with spin rotators turned off.
For a good rise time measurement absolute stability of the electron beam and the polarimeter is essential. The stability of both can be checked when only a fraction of the beam bunches is depolarized for the rise time measurement. Then one is able to monitor the asymptotic polarization value (from the still polarized bunches) and measure a rise time (from the depolarized bunches) simultaneously (Fig. 9). Stable asymptotic polarization of the polarized bunches then indicates stable operation of the beam and the polarimeter during the rise time measurement of the depolarized bunches. First attempts with this scheme of "partial depolarization" of the beam have been successfully carried out. Still, the hardware and control software for the depolarizer must be upgraded (cf. Section 4.1.2). Simulations have to be done in order to quantify how well machine and polarimeter disturbances can be identified with the above mentioned technique.
The application of the rise time method requires the collection of several rise time measurements within a short time interval with all spin rotators switched off. Only with

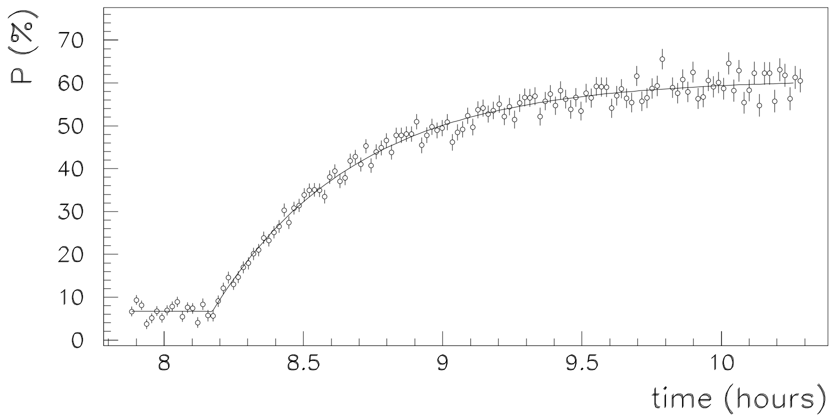

Figure 8: *Measurement of the build-up of the polarization vs. time after depolarizing the beam. The line is a superimposed fit according to equation 3.*

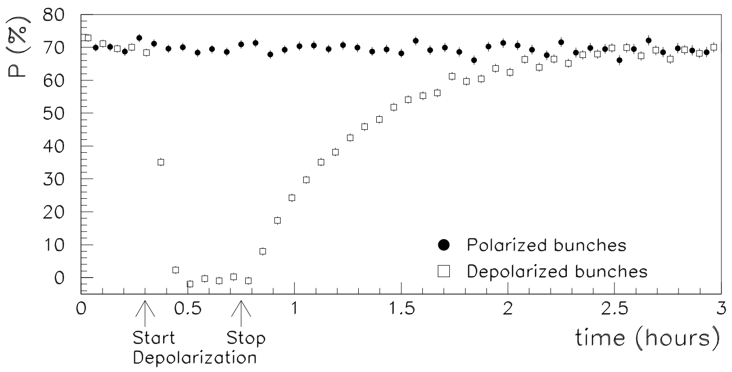

Figure 9: *Monte Carlo simulation of a rise time curve with polarized and depolarized electron bunches. After the polarimeter upgrade the polarization of both groups of bunches can be measured simultaneously.*

about 5–10 measurements will the statistical error be small enough for the envisaged precision determination of the polarization scale. These sets of measurements should then be repeated during the course of the data taking at regular time intervals. In addition, the rise time measurements should be done with only electrons in the machine to avoid the effects of electron-proton beam interactions. In a recent investigation [11] it was pointed out that all electron bunches must have nearly the same polarization value in order to get reliable results from the rise time method. In the case of a polarization distribution as in Fig. 1 deviations of about 3 % from the correct calibration scale will be obtained.
Currently it is not clear, in terms of technical feasibility and loss of beam time for the experiments, how often this procedure can be done. Therefore the rise time method should not be the first choice for the calibration of the polarization scale.

6 Schedule, Responsibilities, Finances

6.1 General

Members of the 3 HERA experiments HERMES, H1 and ZEUS and from the HERA machine groups have formed the Polarization 2000 Group with the common aim to produce and measure precisely high electron beam polarizations. This inter-collaborational effort stresses the importance of polarized physics at HERA and will cover all aspects of electron beam polarization in a coherent way.
The proposed upgrades to the polarimeters have to be done in parallel with the current running of the polarimeters in order to guarantee the undisturbed polarization measurement during beam time for HERMES. It follows that all hardware of the upgrade project must be set up independently from the existing devices and the primary testing of the new systems has to be done with signal generators and the spare calorimeters. However, especially for the TPOL data acquisition upgrade, a test under real conditions is necessary and we propose to connect the real calorimeter signals to the new DAQ system for about 2 months during beam time in 1999. This operation will help in optimizing the system to have it fully functional in the year 2000, when the upgraded polarimeter systems will become the default polarization measurement devices. During this time interval the LPOL will be the only device available to measure the beam

polarization reliably.

6.2 Milestones and Schedule

The time critical item for the upgrade program is the data acquisition system for the TPOL. The aim is to have a prototype system running in 1 year from now and then complete and improve it in the next year. In parallel, test beam and Monte Carlo studies have to be done for the TPOL and the LPOL from which already the current polarization analysis will benefit. HERA related upgrade items (e.g. upgrades of the optical system in the HERA tunnel) can only be done during the HERA shutdown in 1999 or in 2000. After the first year of real operation of the upgraded polarimeter systems the projected precision of the polarization measurement should be reached. Table 6 shows an overview of the time schedule.

Date	Task
Jun 1998	Agree on concept, work out details, distribute responsibilities
Jul 1998	Start development of DAQ system for the TPOL
End 1998	Take and analyse test beam data vs. Monte Carlo for calorimeters
Mid 1999	Prototype DAQ setup with spare calorimeter/pulse generator
Mid 1999	Improve optical system (laser pipe, laser spot size measurement)
Mid 1999	Optimize depolarizer operation
End 1999	Concluding results on the test setup, connect real signals to new DAQ system for 1–2 months
Beg 2000	Results from test run with real data
Beg 2000	Install corresponding improvements
Mid 2000	Take regular luminosity data, understand influence of HERA luminosity upgrade (commissioning)
End 2000	Understand polarimeter in detail, reach desired precision

Table 6: *Time schedule for the development and set up of the upgraded polarimeter systems.*

6.3 Responsibilities and Costs

Groups from HERMES (DESY, Michigan, Freiburg), H1 (LPI Moscow, Paris/Ecole Polytechnique/Orsay) and ZEUS (Hamburg, Yale) together with members of the HERA machine groups MPY and MEA have joined to form the Polarization 2000 Group. The responsibilities for the TPOL upgrade work have been distributed for the time being as shown in Table 7.

The total costs of the upgrade program are of the order of 350–400 kDM. 100–150 kDM will be spent for the new DAQ system of the TPOL, 50 kDM for improvements in the optical system, about 100 kDM for the modification of the laser-electron beam pipe, 50 kDM for signal generators etc., and 50 kDM for contingency. The distribution of the costs has not yet been finalized.

7 Conclusions

Starting in the year 2000 the experiments H1 and ZEUS will also be equipped with spin rotators and will take data — as HERMES has been doing since 1995 — with

Optical system (Hardware upgrade)	MEA
Laser + Optical System (Reevaluation)	LPI, MEA
Front-end electronics + Trigger	Yale, Paris
Data acquisition (Hardware)	Yale, Paris
Data acquisition (Software)	Yale, Paris, LPI
Slow control, information distribution	LPI
Calorimeter, HV, LED, Test measurements	DESY, Hamburg
Monte Carlo	Yale, LPI
Offline Analysis	HERMES, H1, ZEUS
Depolarization	MPY, ??
Machine aspects	MPY

Table 7: *Distribution of responsibilities for the TPOL upgrades*

longitudinally polarized electrons. For H1 and ZEUS the measurement of the electron polarization then becomes as important as the luminosity determination. The project Polarization 2000 proposes the upgrade of the existing polarimeters at HERA in order to assure a reliable polarization measurement of the electron beam with a relative precision of 2 %. This accuracy should be achieved with several independent analysis methods and methods to calibrate the polarization scale. The upgrade program is necessary for exploiting the full potential of HERA physics after the luminosity upgrade in the year 2000.
Major upgrade needs have been identified for the data acquisition system (hardware and software) and the trigger system of the transverse polarimeter and the Monte Carlo description of the polarimeters. Further work is needed for calorimeter test beam measurements and analysis. New functionality for offline software and data distribution has to be developed.
The HERA Polarization 2000 Group has formed as an inter-collaborational working group in order to concentrate the efforts for an effective and precise measurement of the electron beam polarization.

References

[1] R. J. Cashmore et al., *Electroweak Physics at HERA: Introduction and Summary*, Proceedings of the Workshop *Future Physics at HERA* Vol. 1, edited by G. Ingelman, A. De Roeck and R. Klanner, Hamburg (1996), p. 129.
F. Zetsche, *Lepton Beam Polarization at HERA*, ibid., p. 222.
R. Beyer et al., *Electroweak Precision Tests With Deep Inelastic Scattering at HERA*, ibid., p. 140.
O. Deppe et al., *Measurement of Weak Neutral Current Couplings of Quarks at HERA*, ibid., p. 163.

[2] D. P. Barber et al., *The HERA Polarimeter and the First Observation of Electron Spin Polarization at HERA*, Nucl. Inst. and Meth. **A 329** (1993) 79.

[3] HERMES Collaboration; W. Lorenzon et al., *A Proposal to DESY for a Longitudinal Electron Polarimeter at HERA–EAST Section*, (1995).

[4] D. Westphal, *Polarisationsmessungen am HERA Elektronenstrahl*, Diploma Thesis (in German), University of Hamburg, DESY F35D-93-04 (1993).

[5] B.Tipton, *Analysis of Positron Beam Polarization Measurements in 1996*, Internal Polarimeter Report 97-07 (1997).

[6] M. Ruh et al., *Construction and Beam Test of a Spare Calorimeter for the HERA Transverse Polarimeter*, Internal Polarimeter Report 97-05 (1997).

[7] P. Schüler, private communication (1998).

[8] D. P. Barber et al., *High Spin Polarization at the HERA Electron Storage Ring*, Nucl. Inst. and Meth. **A 338** (1994) 166.
M. Düren, *Electron Spin Polarization Measurements at HERA*, Proc. of High Energy Spin Conference '92, Nagoya, ed. T. Hasegawa et al., Univ. Acad. Press, Tokyo (1993).
F. Zetsche, *Experience with the Fast Polarimeter at HERA*, Proc. of High Energy Spin Conference '94, Bloomington, Indiana, AIP Conference Proceedings 343, ed. K. J. Heller, S. L. Smith (1995).

[9] S. Barrow et al., *Interim Report on the Measurement of the Positron Beam Polarization*, HERMES Internal Note 96-002 (1996).

[10] B. Montague, Physics Reports, **113**, (1984).

[11] A. Most, *Study of Accuracy of Rise Time Calibration Method using Bunches with different Polarization*, Internal Polarimeter Report (in preparation).