Project Polarimeter 2000

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Abstract

The aim of Project Polarimeter 2000 is to set up a polarimeter system which is operational in the year 2000 and which is able to determine the electron/positron beam polarization P to an accuracy of $\delta P/P \leq 0.02$ with two independent methods. The proposed polarimeter system will measure the transverse polarization of the electron/positron beam in the HERA West area and will be based on the principles and on the experience with the existing transverse polarimeter. However, major parts of the hardware and the software need to be rebuilt in order to take advantage of newly available technology and to integrate additional features and functionality. This document should also serve as a guide and invitation for interested ZEUS groups to participate in the upgrade.

1 Introduction

In the HERA Shutdown 1999/2000 spin rotators will be installed around the interaction regions of the H1 and ZEUS experiments which 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] and has been reviewed in a recent ZEUS-Note [2]. 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 % 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) [3] which is located in the WEST area of HERA measures the polarization of the — at that location — transversely polarized beam. The HERMES longitudinal polarimeter (LPOL) [4] in contrast measures the longitudinal polarization of the beam at the HERMES interaction point. The systematic uncertainty of the polarization measurement is estimated to be 4 % at the moment [5]. It is dominated by the uncertainty in the polarization scale which currently is solely obtained from rise time curves.

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

In the following some general requirements for the polarization measurement after the HERA luminosity upgrade will be discussed. Then the principle of transverse polarization measurement with two different methods will be introduced. The next chapter deals with the proposed upgrade for the transverse polarimeter followed by a discussion of a possible working plan and time schedule. At the end the most important items are summarized.

2 General Considerations

In storage rings electrons become *transversely* polarized through the emission of synchrotron radiation which is known as the Sokolov-Ternov effect [6]. *Longitudinal* polarization of the electrons at an electron-proton interaction point in a straight section of HERA can then be achieved by the introduction of a pair of spin rotators [7]. This means that the polarization of the electron beam is transverse around the ring except at the interaction points equipped with spin rotators. The spin direction must be transverse (and parallel to the dipole fields) in the arcs of HERA in order not to destroy the polarization.
Currently the compensator magnets in ZEUS and H1 compensate for the spin tilt of the transversely polarized electron beam which is caused by the main solenoid. After the luminosity upgrade the compensator magnets will be removed to make room for beam focusing and separating elements, i.e. the polarization of the electron beam could not be maintained if it were transversely polarized at the ZEUS and H1 interaction regions. This means that longitudinal polarization at the ZEUS and H1 interaction regions is required for the electron beam to be polarized since in this case the solenoid does not influence the (longitudinal) spin. Therefore all experiments have to run with longitudinally polarized electrons (spin rotators switched on) if polarization is required by at least one experiment, which probably will be the default scenario.
In this case the polarization measurement is as important as the luminosity measurement, since neutral and charged current ep cross sections and hence the corresponding event rates sensitively depend on the beam polarization. Ideally the accuracies of both, luminosity and polarization measurement, should be the same. The luminosity measurement in ZEUS currently has an uncertainty of about 1–2 %.
Since the absolute value of the degree of polarization of the electron beam is the same everywhere in the ring, especially $|P_{\mathrm{long}}| = |P_{\mathrm{trans}}|$, 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 HERA West area with its specially (for polarization measurement) designed beam optics and the existing transverse polarimeter facility (TPOL) are the best choices, although there also have been discussions about a local polarization measurement in ZEUS [8]. The TPOL has been operated for some years already and valuable knowledge on its performance and its systematic errors has been collected [3, 5]. Some of the limitations which have shown up are not tolerable for our purposes. However the general method for the polarization measurement is well established. Therefore we think that a reliable estimate on the future performance of the device after a suitable upgrade is possible.
One important consideration for ZEUS and H1 is the fact that physics measurements clearly are only based on colliding electron and proton bunches. However the existing

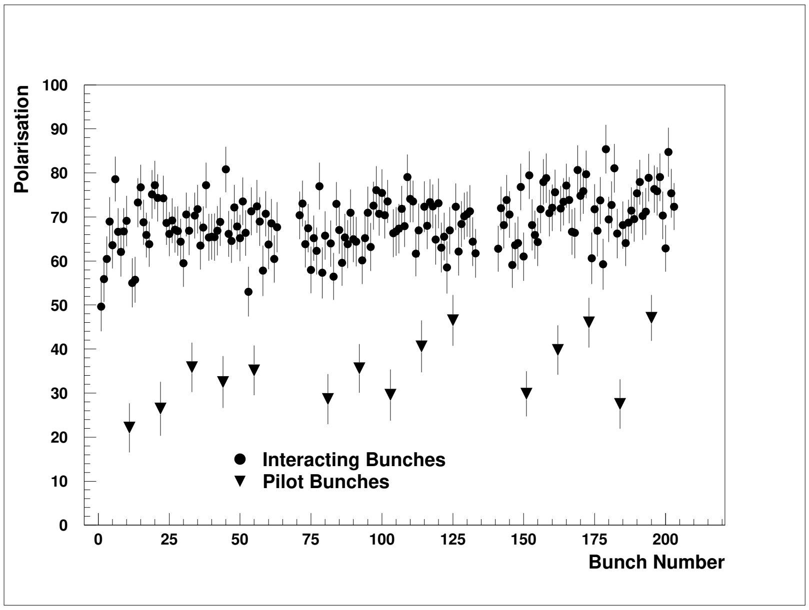

Figure 1: *Polarization measurement of single electron bunches with the HERMES longitudinal polarimeter. The electron pilot bunches show a systematically lower polarization than the electron bunches which collide with proton bunches at ZEUS and H1.*

TPOL measures the mean polarization of *all* electron bunches in the ring. With the HERMES longitudinal polarimeter (LPOL) which is able to measures the polarization of single bunches, it was shown that non-colliding electron bunches (pilot bunches) can have different polarization patterns than colliding bunches (Fig. 1) which also vary in time. This pattern sensitively depends on the tuning of the polarization. Hence ZEUS and H1 need a system which measures the polarization of colliding and non colliding bunches separately. Ideally, the polarization measurement of any combination of bunches should be possible.
Typically the TPOL delivers 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. For ZEUS it seems to be appropriate to feed the polarization information from TPOL into the environmental records of the ZEUS data stream.

3 Measurement of Transverse Polarization

The transverse polarimeter [3] employs the spin dependent Compton scattering of polarized laser light off the electrons. In the following two independent methods will be discussed in order to establish the scale of the polarization measurement.

3.1 Spatial Asymmetries

It is the difference in the differential Compton cross sections for left and right circularly polarized laser light which is exploited for the electron polarization measurement. It results in an azimuthal asymmetry of the backscattered photons which also depends on their energy. These quantities are measured with a tungsten-scintillator sandwich calorimeter which is split in an upper and a lower half. It delivers total energy and up-down energy asymmetry (which is related to the transverse position y) of single Compton photons.

The theoretical relation between the spatial asymmetry in y of backscattered Compton photons from left (L) and right (R) circularly polarized laser light and the transverse polarization P_Y is given by

$$\Delta y(E_\gamma) = \frac{\langle y \rangle_L - \langle y \rangle_R}{2} = P_Y \Delta S_3 \Pi_y(E_\gamma)\,, \qquad (1)$$

where $\langle y \rangle$ is the mean y position on the calorimeter of a large sample of Compton photons, $\Delta S_3 \approx 1.0$ is related to the circularity of the laser light (and is well measured), and $\Pi_y(E_\gamma)$ is the analyzing power which can be calculated from the Compton cross section and which depends on the energy of the Compton photons.
In practice the polarization P_Y is derived from the measured up-down energy asymmetries $\eta = (E_{up} - E_{down})/(E_{up} + E_{down})$ of the Compton photons,

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

Here $\Pi_\eta(E_\gamma)$ is an effective analyzing power which also has to take into account the (nonlinear) relation between y and η, the projected transverse size of the electron beam, energy resolution effects etc.. The quantity $\Pi_\eta(E_\gamma)$ fixes the polarization scale and its precise determination is therefore decisive for the quality of the measurement. The single photon method allows the experimental determination of the relevant parameters. Therefore one needs test beam measurements of the calorimeter, real data taking with different laser polarisations and Monte Carlo simulations to calculate $\Pi_\eta(E_\gamma)$ and its uncertainty. The following table gives an overview of the relative uncertainty in $\Pi_\eta(E_\gamma)$ from different analyses and measurements.

	Uncertainty in Π_η (%)		
Source	Bar(92) [3] TB+MC	Wes(93) [9] MC	Ruh(97) [10] TB (*)
η–y Transformation	7.9	4.4	1.5
Electron spot	4.0	2.6	
Pedestal	1.1		
Total	8.9	5.2	3.2

Table 1: *Relative uncertainties in* Π_η *in % from different test beam (TB) and Monte Carlo (MC) studies. The study labeled (*) was only done with the spare calorimeter of TPOL. The total uncertainty is the quadratically added sum of the individual terms. Where no measured number is given the number in the column to the left is assumed for the calculation of the total uncertainty.*

The method of polarization measurement outlined above which is based on equation 2 is the standard measurement technique which delivers one polarization measurement per minute.

3.2 Rise Time Curves

The polarization scale as calculated from Π_η can be derived independently by measuring the characteristic build-up time and the asymptotic value of the polarization [11]. Most stable and reproducible conditions for polarization rise time measurements can be obtained after resonant depolarization of the beam. An example of such a measurement

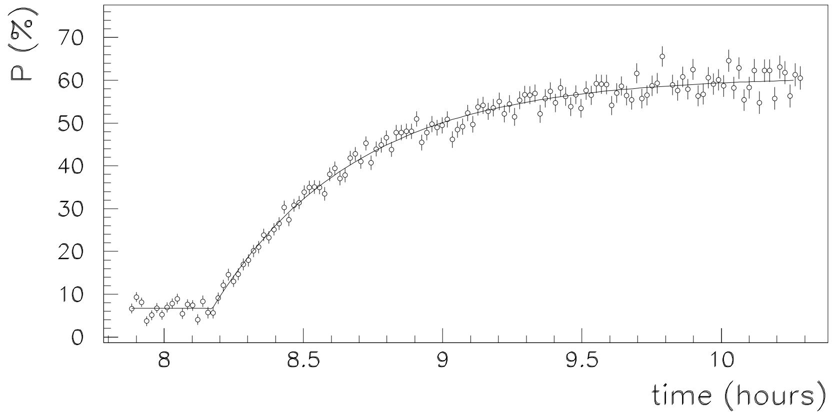

Figure 2: *Measurement of the build-up of the polarization vs. time after depolarizing the beam. The line is a superimposed fit according to equation 3.*

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,

$$P_{\infty,\mathrm{theo.}} = \frac{P_{ST}}{\tau_{ST}} \cdot \tau\,, \tag{4}$$

where P_{ST} and τ_{ST} are the maximum theoretically achievable polarization (91.6 %) and the corresponding rise time (37 min.) for the HERA electron ring at $E_{beam} = 27.5$ GeV with all spin rotators switched off ("flat machine"). For spin rotators switched on these values change slightly and they are less well determined theoretically. By extracting P_{∞} and τ from measured polarization rise curves and calculating $P_{\infty,\mathrm{theo.}}$ from eq. 4 the polarization scale can be calibrated experimentally.

A series of 16 rise time measurements done in 1996/97 with the HERMES spin rotator switched on gives an indication of the reproducibility and stability of the method. Preliminary results compare the quantities $P_{\infty,\mathrm{theo.}}$ and P_{∞}, equivalent to the ratio of the analyzing powers of the spatial asymmetry method and the rise time method. The mean value of the ratio is 1.023 with a spread (R.M.S) of 0.036. As outlined above the interpretation of these numbers in terms of absolute polarization scale is difficult, since the influence of the HERMES spin rotator is not taken into account and systematic error studies have to be done.

For a good rise time measurement absolute stability of electron beam and 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. 3). Stable asymptotic polarization of the polarized bunches then assures 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 done.

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. These sets of measurements then should be repeated during the course of the data taking in regular time intervals (e.g. every month or every other month).

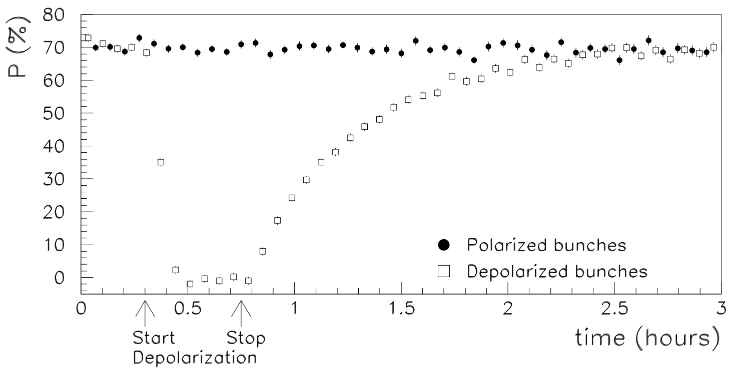

Figure 3: *Monte Carlo simulation of a rise time curve with polarized and depolarized electron bunches. After the polarimeter upgrade the polarization of both groups of bunches can be measured simultaneously.*

4 Upgrade Plans for Transverse Polarimeter

The transverse polarimeter has been described in detail in [3]. Fig. 4 shows an overview of the general layout of TPOL in the HERA West area. A scheme of the current data acquisition system is given in fig. 5. It is a very heterogeneous system with many different hardware components which could be considerably simplified.
In the following all the components of TPOL will be discussed in terms of necessary upgrades. Table 2 gives an overview of the proposed actions in order to fulfill the requirements outlined in the previous chapters.

Component	Action	Comment
Laser	Revisit and Check	Ensure reliability and service
Optical System	Revisit and Check	Evaluate measurement of laser light polarization
Calorimeter	Revisit HV, LED	Two identical calorimeters are available. Investigate calorimeters with dedicated test beam. Upgrade (replace) HV and LED systems
DAQ, Trigger	New	New equipment computer, ADC/TDC, readout, trigger modules etc.
Miscellaneous Electronics	New	Pulse generator to simulate calorimeter signals, signal generator and dedicated kicker magnet for beam depolarization
Online Software	New	More functional user interface, new readout software, adapted slow control
Offline Software	Upgrade	More sophisticated analysis procedures
Monte Carlo	New (Upgrade?)	Produce reliable MC simulation, understand detector, beam and laser parameters
Theory	Update	Refine calculation of beam polarization in presence of 3 spin rotator pairs

Table 2: *Overview of components of the transverse polarimeter at HERA and proposed upgrades.*

There is a group of components which don't need much work, especially the optical

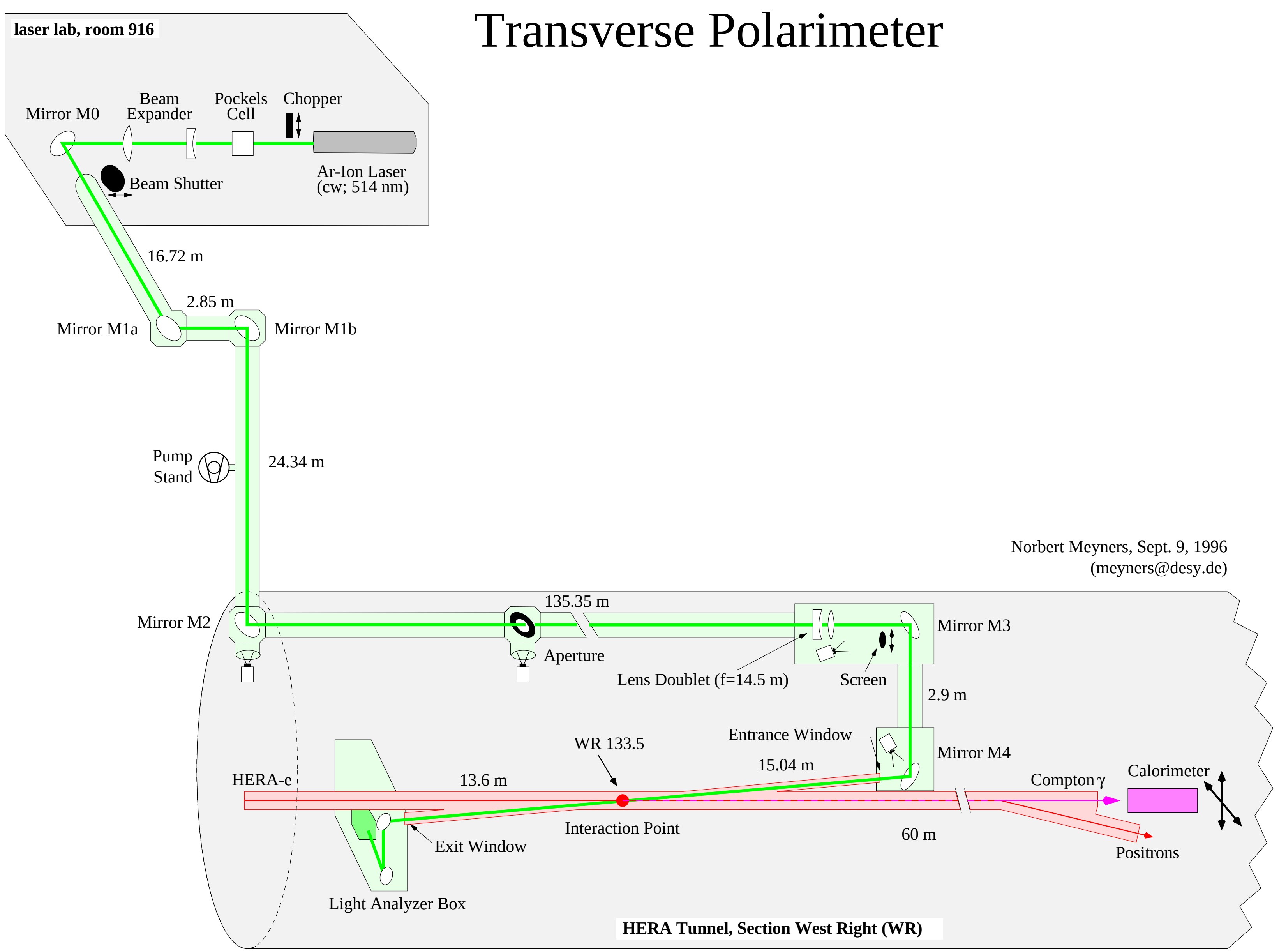

Figure 4: *Schematic overview of the transverse polarimeter at HERA. Shown are the laser beam line, the electron beam line and the calorimeter which measures the backscattered Compton photons.*

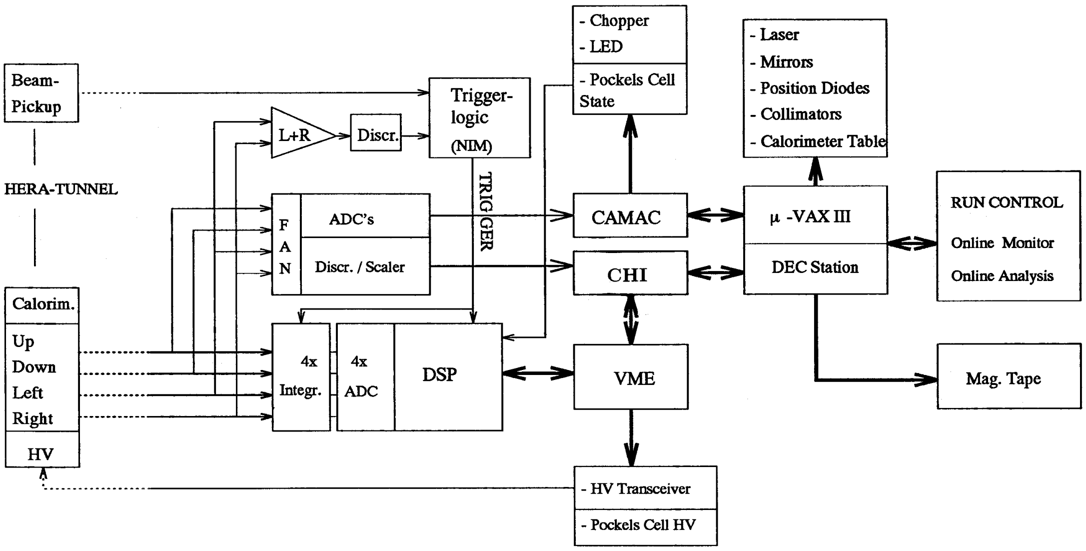

Figure 5: *Schematic overview of the current data acquisition system of the transverse polarimeter at HERA.*

components which have been upgraded 2 years ago. The biggest part of the upgrade is concerned with the data acquisition system and the corresponding online and offline software. Also the Monte Carlo simulation needs to be upgraded.

Laser: The CW Argon ion laser is usually running at a 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.

Calorimeter: The high voltage system has to be improved in reliability. The LED system should be better tuned to equal light output to all 4 channels. Possible radiation damage has to be checked carefully. There are two "identical" calorimeters. The properties of both have to be tested in a dedicated test beam with high position resolution for the beam particles in the appropriate energy range (the currently installed calorimeter was only tested in the low energy DESY test beam). This will result in an optimized $\eta - y$ transformation.

Monte Carlo: A user friendly Monte Carlo program for the Compton process and the calorimeter has to be set up. The simulation must fully agree with test beam and real data describing all dependencies on detector parameters, beam parameters and laser polarization. With the help of dedicated measurements (circular/linear laser polarization, polarized/unpolarized electrons) the corresponding Monte Carlo parameters can be tuned. This will lead to better control and understanding of the detector performance and hence decrease the systematic uncertainty on the analyzing power of the device.

DAQ: The DAQ system should 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 requirements for the new system are outlined below:

- Read out single Compton events at a rate of 100 kHz with little dead time.
- Each event consists of the following information:
  - 4 Energy data: 12 bit each
  - 1–3 Time data: 10 bit each (new)
  - Bunch number: 8 bit (new)
  - Trigger type: 3 bit (new)
  - Status laser light: 3 bit
- Provide average bandwidth of ≈ 1 MByte/s.
- Filter events according to bunch number, trigger type etc. and produce distributions and calculations for polarization values in real time (new).

A possible realization could be a VME based system (VME CPU, 10 MHz ADC, TDC, Scaler) or equivalent. A programmable trigger module which also has to handle the bunch number and the laser status bits has to be developed. After completed conversion for ADC and TDC these data have to be synchronized with the trigger information. For readout of the data a fast network (FDDI/Fast Ethernet) is required. We propose to use a ≥ 300 MHz PC as online event filter and histogram sampler which will do all the necessary polarization computations.
In addition special care has to be taken concerning the performance of the signal chain in terms of linearity and pile up effects. A detailed technical solution has to be worked out.

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.

Online Software: With the new DAQ hardware also a completely new run control program has to be developed. It needs to communicate with the e.g. VME environment, some 15 slow control devices which are mostly RS232 based, and with the histogram sampler.

The software on the histogram sampler has to provide for event filtering according to bunch number, trigger bits and laser status bits and generation of polarization histograms, control histograms and calibration histograms in real time.
Furthermore after one measurement cycle (typically 1 minute) the data (or a subset of it) have to be sent to the experiments. Also status display information has to be distributed on the DESY network.

Offline Software: The offline software should work mainly automatic, 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 accommodated. Short- and longterm statistics and monitoring has to be supplied (WWW based).

Theory: The presence of spin rotators in the HERA ring decreases the theoretically achievable degree of polarization. Since also its numerical knowledge is deteriorated it complicates the application of the rise time method under these conditions. Refined calculations could overcome this problem.

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.

5 Working Plan

5.1 General considerations

Setup, maintenance and running of the polarimeter system will be a task which involves the HERA machine and the 3 experiments which will make use of the polarization measurement. It is certainly not a ZEUS-only job. However, in a first step we will present our upgrade ideas to ZEUS, thereby giving ZEUS institutes the possibility to identify sub-projects of the polarimeter upgrade which could be pursued by ZEUS members.
The next step involves the presentation of the upgrade proposal and ZEUS interests to HERA/DESY, H1 and HERMES. Thereafter a polarimeter working group has to be set up which has to develop further and agree upon the upgrade concept and which then will distribute and do the work. Currently basically only HERMES members and physicist from the HERA machine group are working for the polarimeter. With H1 and ZEUS involvement the group will be strengthened and be the basis for a successful polarization physics program after the year 2000.
Clearly the polarimeter upgrade has to be done in parallel to the existing and running TPOL, i.e. the undisturbed running of TPOL for HERMES during beam time must be guaranteed. It follows that all hardware of the upgrade project must be set up independently from the existing device and the testing of the new system has to be done with signal generators and the spare calorimeter.
However, after the upgrade is basically completed we propose to connect the real calorimeter signals to the new system for about 2 month during beam time in 1999 to test it under real conditions. This is necessary in order to optimize the system such it will be fully operational in the year 2000, when the upgraded polarimeter will become the default polarization measurement device.

5.2 Milestones and Schedule

As shown in table 3 the aim is to have the basic system set up in 1 year from now and then complete and improve it in the next year. After the first year of real operation the device should have reached the full precision as required.

Date	Job
Mar 1998	Constitute working group and group structure
May 1998	Agree on concept and distribute responsibilities
Oct 1998	Setup of basic DAQ system
End 1998	Take and analyze test beam data vs. Monte Carlo
Beg 1999	Test setup with spare calorimeter/pulse generator and full readout/ analysis chain
Mid 1999	Concluding results on the test setup, connect real signals to new polarimeter system for last 1–2 months of luminosity run
End 1999	Results from test run with real data
Beg 2000	Install improvements
Mid 2000	Take regular luminosity data, understand influence of HERA luminosity upgrade
End 2000	Understand polarimeter in detail, reach desired precision

Table 3: *Time schedule for the development and set up of the upgraded transverse polarimeter.*

Certainly cross-checks with the longitudinal polarimeter will also be important for the understanding of the polarization measurement.

5.3 Men Power and Costs

It is estimated that an equivalent of 4–6 full time persons are needed for the next 2 years in order to implement and test the full upgrade scenario. The hardware costs are estimated to be about 100–150 kDM, where half of it will be spent for the new DAQ system (table 4).

Item	Cost (kDM)
VME Crate/CPU	20
ADC	10
TDC	10
Dual (Quad) PC	20
Fast Ethernet	5
Disk/Tape	12
Trigger	20
Pulse Generators	20
Miscellaneous	30
Total	≈ 150

Table 4: *Rough decomposition of hardware costs for polarimeter upgrade*

6 Conclusions

From the year 2000 on the experiments ZEUS and H1 will be equipped with spin rotators to take data with longitudinally polarized electrons. The measurement of the electron polarization then becomes as important as the luminosity determination. The Project Polarimeter 2000 proposes the upgrade of the existing transverse polarimeter at HERA in order to assure a reliable polarization measurement of the electron beam with a precision of 2 %. This accuracy should be achieved with two independent 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), the trigger system and the Monte Carlo description of the polarimeter. Further work is needed for calorimeter test beam measurements and analysis. New functionality for offline software and data distribution has to be developed.
The polarimeter working group which has to be formed will be a heterogeneous group with members from HERA machine, H1, HERMES and ZEUS. It will be advantageous for ZEUS to have a strong presence in this group. Therefore it is desirable for interested institutes in ZEUS to identify upgrade projects which they are interested in to participate.

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