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Proposal to Upgrade the Longitudinal Polarimeter

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Abstract

We propose to construct a new laser system to significantly increase the power of the existing longitudinal polarimeter. The main ingredient of the new system is a Fabry–Perot cavity surrounding the interaction point of the lepton beam and the laser. This system will allow very large laser power at the interaction point, resulting in a rate of backscattered Compton photon of around one photon per bunch crossing. With this system it will be possible to operate the longitudinal polarimeter in the single photon mode, and at the same time to increase the statistical power of the device.

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1 Introduction

The study of polarised electron-proton scattering at very high energies will be one of the major new physics topics after the upgrade of the HERA storage ring. The colliding-beam experiments H1 and ZEUS will for the first time have access to longitudinally polarised leptons. This will allow detailed studies of the helicity structure of the weak currents.

To fully exploit the potential of the machine and the luminosity to be delivered to the experiments, we propose a significant upgrade of the existing longitudinal polarimeter (LPOL). The focus of this paper will be on a replacement of the laser system, to enable the LPOL to operate in the so-called single photon mode, with the goal of reaching a polarisation uncertainty well below one percent. We propose to install a Fabry–Perot cavity around the interaction point. This will allow to reach an effective power of the laser close to 10 kW, sufficient to obtain one backscattered photon per bunch crossing. With this system the statistical uncertainty of the polarisation can be reduced to 0.1% per minute and group of bunches in HERA, or 1% per minute and per bunch. The obtainable error is shown in fig 1. A schematical view of the system is shown in figure 2.

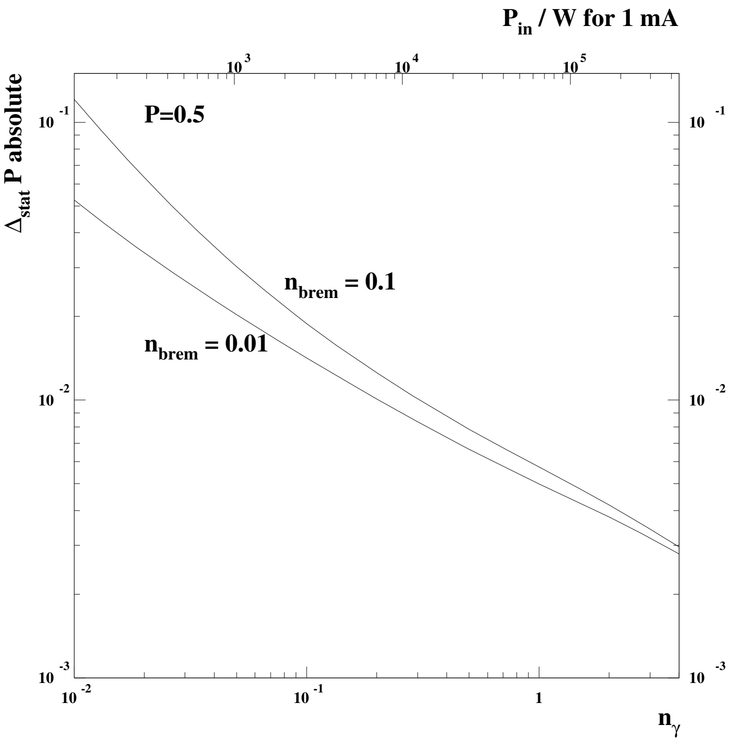

Figure 1: Statistical uncertainty of the polarization per bunch and per minute as a function of the backscattered photon rate n_γ. Two background rates are shown, 1% corresponding to the present rate and 10%. Also shown is the laser power needed to obtain the backscatter rate, assuming a crossing angle of 58 mrad.

In this paper we will argue that such a high precision device should be installed for a number of reasons: it allows to fully exploit the physics potential of HERA, it allows

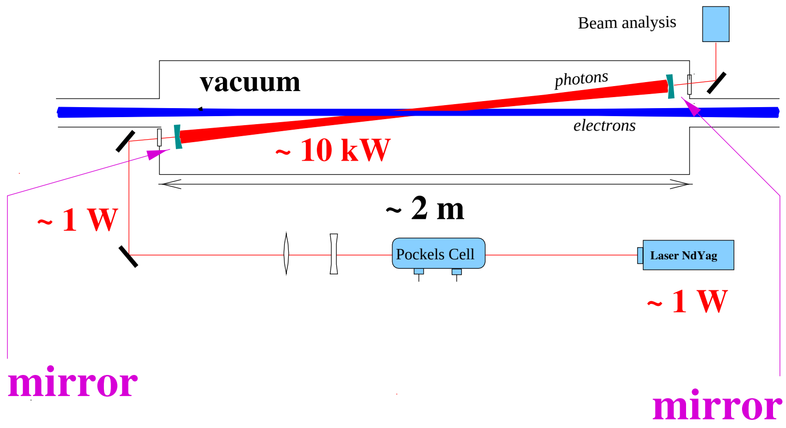

Figure 2: Simplified scheme of a Fabry-Pérot cavity and laser system located around the electron beam. The power indicated in the cavity is the equivalent power a CW laser must deliver to obtain the same Compton scattering rate.

to have a polarisation measurement which can be fully calibrated from the data, and it allows a fast and efficient feedback to the machine to optimise the degree of polarisation in the machine.

The structure of this paper is as follows: We will start with a short discussion of the physics done with polarised beams, and the resulting requirements for the polarimeter. We will then turn to a discussion of the proposed system, and finish with a review of the costs and a proposed distribution of responsibilities of the groups involved. Much of the material covered in this note has already been presented in the letter-of-intend, submitted in June 2000 [4].

2 The physics case

Physics with polarised lepton beams will be a central part of the physics program of HERA after the luminosity upgrade. The basic program has been described in a series of workshops [1, 2, 3]. In this section we will concentrate on the role the polarisation will play in this.

Three topics are of particular relevance: the Charged Current (CC) cross section measurement, the Right Handed Charged Current (RH CC) and the measurement of the light quark electroweak couplings. In the following each of these topics will be discussed in detail.

2.1 Charged Current Cross Section Measurements

A precise determination of charged current cross section at HERA can serve as a sensitive test bed of the Standard Model. One test is the helicity structure of the charged current, which will be discussed in the next section. Another such test is the precise measurement of the total cross section, and its interpretation in the Standard Model.

One particular interesting quantity is the mass of the W boson. Although no large data sample of directly reconstructed W–bosons will be available HERA, a precise indirect determination of the W–mass is possible [7]. As an example, with 1000pb^{-1} CC and NC data and a polarisation of 70%, 1% of total systematic error leads to a determination of M_W with an accuracy of 55 MeV. This determination would be competitive to the LEP and TEVATRON results and, because the W is accessible via the t channel at HERA, would provide a test of the universality of the Standard Model.

More details on the measurement of the CC may be found in the LOI [4], or in the proceedings of the HERA workshop [1, 2, 3]

2.2 Search for Right Handed Charged Currents

In the standard model of the electroweak and strong interactions, Charged Currents (CC) are carried by left-handed W bosons. Right handed CC should not exist. So far no experimental evidence for right handed CC has been found. The present limit, expressed in terms of the mass of a right-handed W boson, is 720GeV at 95 C.L. [6]. In studying collisions between polarised leptons and unpolarized protons, as will be done at HERA, sensitive and direct searches for right-handed charged currents can be done.

To estimate the reach of HERA we shall assume the following parameter: HERA will operate with two helicities of the lepton (electron or positron) beam. The level of polarisation for each helicity state is taken to be 50%. For each helicity an integrated luminosity of 250 pb^{-1} is considered. This corresponds to about one year running per helicity state at the nominal luminosity of the machine after the upgrade.

The observed CC cross sections as a function of the lepton polarisation P is given by

$$\sigma^{e^-}_{obs,CC}(P) = \frac{1-P}{2}\sigma^{e^-}_L + \frac{1+P}{2}\sigma^{e^-}_R \tag{1}$$

where $\sigma^{e^-}_R$ is the right handed CC cross section, $\sigma^{e^-}_L$ correspondingly the left handed CC cross section, and P is the luminosity weighted polarisation valid for the whole data sample:

$$P = \frac{\sum_i^{N_{run}} \int_{t_{min,i}}^{t_{max,i}} P_i(t)\mathcal{L}_i(t)dt}{\sum_i^{N_{run}} \int_{t_{min,i}}^{t_{max,i}} \mathcal{L}_i(t)dt} \,. \tag{2}$$

In this equation the number of runs taken is denoted with N_{run}, and $(t_{max,i} - t_{min,i})$ is the duration of the i-th run, $\mathcal{L}_i(t)$ and $P_i(t)$ are the instantaneous luminosity and polarisation respectively.

Using eq. 1 a measurement can be performed of the right handed CC cross section, if the two data samples taken with positive and negative helicity are used. Such a measurement with an assumed data sample of 250pb^{-1} is shown in figure 3, for data at large $Q^2 > 1000$ GeV.

To estimate the uncertainty of the right handed CC cross section, it is convenient to define the ratio $r = \sigma^{e^-}_R/\sigma^{e^-}_L$. This ratio should be zero in the standard model. From the observed cross sections for charged currents, $\sigma_{\mathrm{obs},CC}$, at $+|P|$ and at $-|P|$, the ratio of measured quantities $R = \sigma^{e^-}_{obs,CC}(|P|)/\sigma^{e^-}_{obs,CC}(-|P|)$ is defined, which can be expressed as

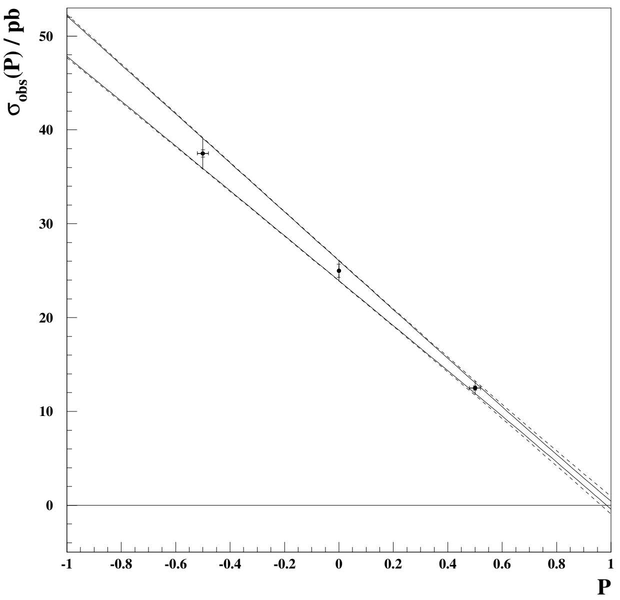

Figure 3: Measured charged current cross sections (including a systematc uncertainty of 4.2 %) at positive, zero (100 pb^{-1}) and negative helicity, for $Q^2 > 1000$ GeV, and extrapolation to the point of $P = +100\%$. The solid lines are the extrapolation using a polarisation uncertainty of 0.2 % and the dashed ones an uncertainty of 2 %.

a function of the theoretical ratio of cross sections, r, as

$$R(|P|) = \frac{\alpha + r}{1 + \alpha r}\ , \text{ with } \quad \alpha = \frac{1 - |P|}{1 + |P|}\ . \tag{3}$$

From this one obtains:

$$r = \frac{R - \alpha}{1 - \alpha R}\ . \tag{4}$$

Fig. 4 shows how $\delta_{stat} r$ changes with the uncertainty on the polarisation measurement $\delta_{stat} P$. The two solid curves shown correspond to different levels of polarisation of the lepton beam, of 50% and 70%. It is clearly visible that a higher polarisation minimizes the uncertainty on r.

In this measurement, one must carefully distinguish systematic uncertainties which are proportional to the CC cross section (scaling systematics: luminosity uncertainty, hadronic energy scale etc.) from those which are independent of the cross section (additive systematics: background mainly). A measurement of the right-handed CC cross section is only sensitive to the second part, the additive systematic uncertainties. The luminosity uncertainty, at least in first order, does not enter the extrapolation to $P = +1$. From the current CC analysis in the H1 experiment for the high Q^2 analysis ($Q^2 > 1000$ GeV), the first type of uncertainly is estimated to be around 4%, while the additive systematic uncertainty is expected to be smaller than 0.1%. Therefore, to a good approximation, the

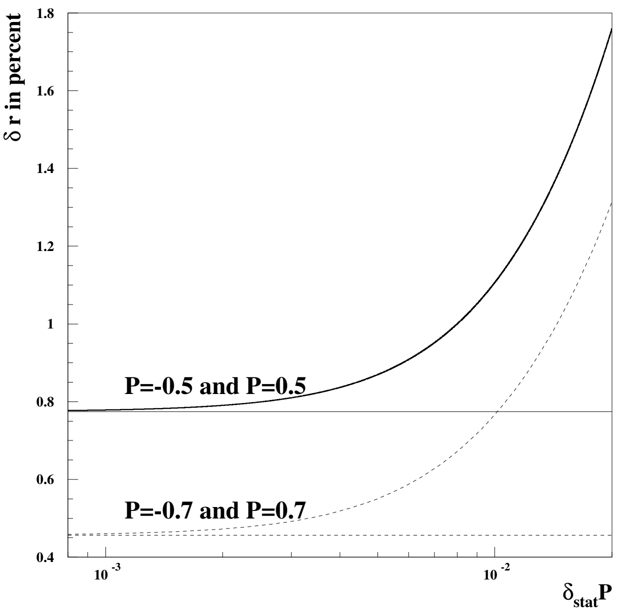

Figure 4: Relative uncertainty of the right handed charged current cross section, as a function of the uncertainty of the polarisation measurement. The solid curve is for 50% polarisation, the dashed one for 70% polarisation. Also indicated is the contribution to the uncertainty which does not depend on the polarisation.

RH cross section uncertainty depends only on the statistical accuracy of the cross section measurements and on the statistical and systematic uncertainties of the polarisation measurement.

From this studies one concludes that in order that the errors from the polarisation do not limit the final accuracy of the measurement, the total error of the polarisation should be kept around $2 \cdot 10^{-3}$.

This simple picture changes slightly if the polarisation measurement introduces correlations between the measured cross sections. If e.g. systematic uncertainties are fully correlated between the cross sections at different beam helicities, it can be easily shown, that

$$\delta(r_{\rm sys}) \approx \frac{\delta_{\rm sys}P}{2}\ , \tag{5}$$

where $\delta_{\rm sys}P$ is the correlated part (scaling or additive) of the systematic uncertainty of the polarisation measurement. Such effects therefore should be controlled at the 0.5% level to not limit the final result. This appears difficult but possible.

The reach of HERA compared to other experiences is best expressed in terms of a mass of a hypothetical right handed W boson [7]. Given the current estimates of systematics, and assuming a high precision determination of the polarisation to 0.2%, the results are summarised in figure 5. From the figure it is clear that for competing with the Tevatron we need a very large data sample. If the uncertainties can be tightly controlled, the reach of HERA becomes comparable to that of the Tevatron with the advantage of a pure and direct measurement.

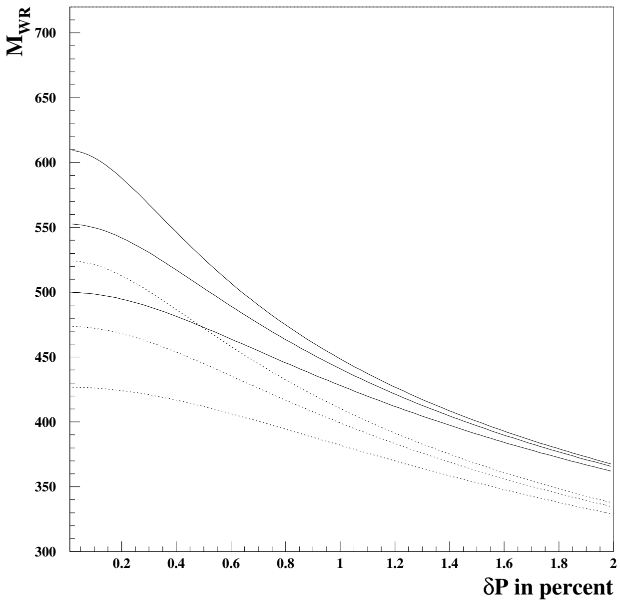

Figure 5: Possible exclusion limit (95% CL) obtainable at HERA, for a right handed W-boson, as a function the precision of the polarisation measurement. Full curves are for $P = 0.7$, dotted ones for $P = 0.5$. For each polarisation value, the top curve corresponds to 1000pb^{-1}, the middle one to 500pb^{-1} and the lower one to 250pb^{-1}.

In conclusion the investigation of the RH CC requires the highest possible precision from all parts of the experiment and the machine: luminosity, polarisation and detector systematic all should be controlled very tightly to maximise the reach of HERA.

2.3 Neutral Current Cross Section Measurements

The cross section for the neutral current events in polarised lepton - proton scattering can be written as :

$$\begin{aligned} \sigma_{NC}^{e^\pm p} &= \frac{2\pi\alpha^2}{xQ^4}\left(H_0^\pm + PH_P^\pm\right) \quad \text{with} \\ H_{0,P}^\pm &= \left(1+(1-y)^2\right)\, F_2^{0,P} \mp \left(1-(1-y)^2\right)\, xF_3^{0,P}\,. \end{aligned} \tag{6}$$

For large Q^2-large x, where the longitudinal function F$_L$ can be neglected, F$_2^{0,P}$ and x$F_3^{0,P}$ are the DIS structure functions and contain linear combination of the quark densities and quadratic functions of the vectorial and axial couplings of the fermions to the Z^0. By measuring the neutral current cross section for different lepton charges and different helicity states the vector and axial-vector coupling constants v$_u$, v$_d$, a$_u$ and a$_d$ can be measured.

The analysis consist of a χ^2 fit to four NC differential cross section measurements: $e^-_{+|P|}$, $e^-_{-|P|}$, $e^+_{+|P|}$ and $e^+_{-|P|}$. Unknown parameters of this fit are the light quark electroweak couplings a_u, v_u, a_d and v_d.

In figure 6 the 1σ contour plot in the a_u - v_u plane are shown. For this plot it was assumed that at each of the four data points an integrated luminosity of 250pb^{-1} is available. The ellipse corresponds to a 50 % lepton beam polarisation. Also shown is a

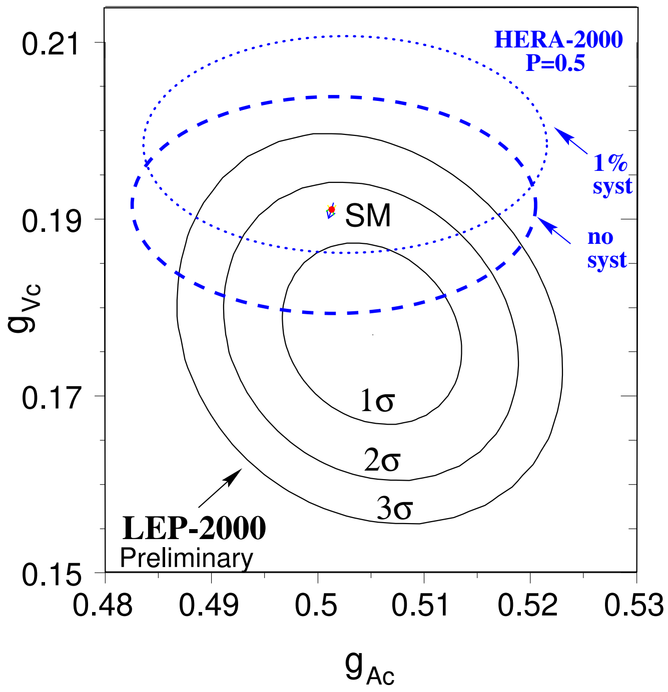

Figure 6: Couplings constants for up-type quarks, as measured at LEP, and expected measurement at HERA.

second shifted ellipse which corresponds to the result of a measurement if a systematic shift of 1% is present in the polarisation measurement. From this curve it is clear that such systematic effects on the polarisation should be controlled to better than one percent.

In conclusion the determination of the netral-current coupling constants for light quarks at HERA will provide a stringent test of the consistency of the Standard Model. To achieve a precision comparable to that of LEP a determination of both luminosity and polarisation to around 1% is needed.

2.4 Conclusion

From the studies presented above a total uncertainty of the polarisation well below the 1% level is necessary. The most stringent requirements come from the determination of the right-handed charged current cross section, where an error of the polarisation below 0.5% is the goal. Other measurements require a determination of the polarisation to around 1%. To fully exploit the physics potential of HERA however it is not only necessary to measure the polarisation precisely, but also to obtain the highest possible polarisation in the machine, and to accumulate a large integrated luminosity.

3 Calibration

One of the main advantages of operating the LPOL in the single photon mode is that the calibration of the detector is much simpler. The energy spectra of the photons scattered into the detector have a very physical meaning, and provide a number of unambiguous calibration points for the energy calibration of the detector. The method which can be used to calibrate the energy response of the calorimeter has already been discussed in the letter of intent. The main idea is to use the Compton edges for 1, 2, and maybe three photons, and the bremsstrahlungs edge in the energy spectra, to define the energy scale of the calorimeter. In the letter of intent it was argued that this procedure should allow a calibration of the device on the few per mill level. In figure 7 the spectrum (left) and the differentiated spectrum (right) for an assumed operation of the device with $n_\gamma = 0.1$ and $n_\gamma = 2$ is shown. Clearly visible are the location of the single and double Compton peaks, and the position of the bremsedge.

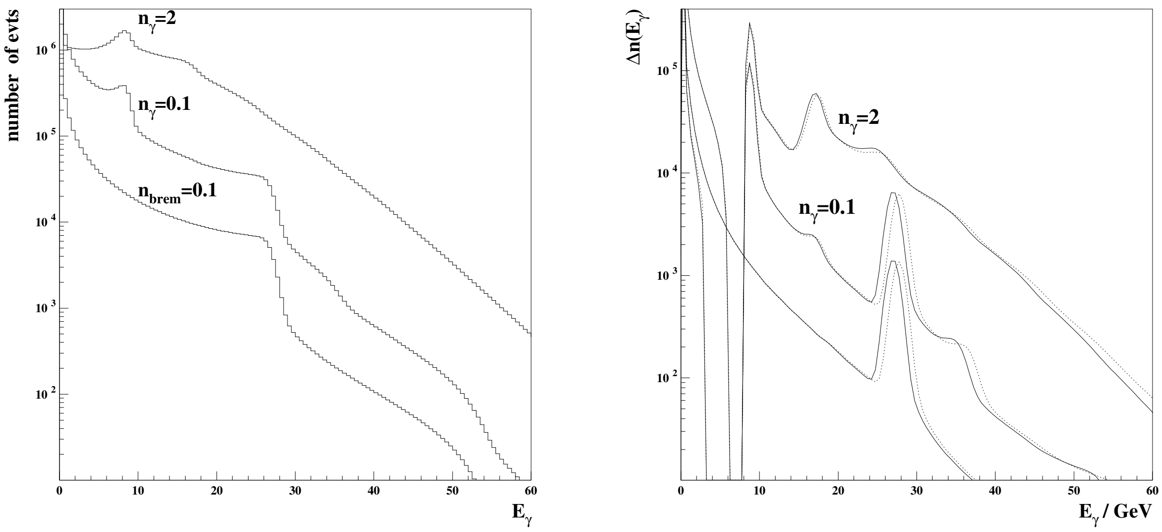

Figure 7: Compton spectra (left) including background, and differentiated spectra (right), for $n_\gamma = 0.1, 2$. The dotted curves on the right are obtained by including a 1% non-linear contribution in the energy calibration of the calorimeter. The lowest curve is an estimate of the background, obtained by taken simulating the observed spectrum if the laser is off.

To estimate the precision with which the polarisation can be measured with this device, a number of systematic effects have been simulated and their impact on the polarisation has been studied:

- The knowledge of the energy scale of the calorimeter translates into an error on the polarisation. Simulations have shown that a 0.5% uncertainty of the energy scale corresponds to an error of the polarisation of 0.1% for a 50% polarisation.

- If a non-linear component exists in the response of the calorimeter this will change the analysing power and therefore the measured polarisation. However, a 1% effect at 10 GeV leads to a very large non linearity in the position of the peaks (see right plot of fig. 7) Therefore, such a non linear effect can be controlled at the few per mill level. Assuming a possible residual non-linearity of 0.2% at 10 GeV we find a contribution to the uncertainty of the polarisation of a few per mill.
- The polarisation of the laser light inside the cavity is the same as the polarisation of the light entering the cavity within 0.1%, as measured with the CEBAF cavity.
- Fluctuations of the laser power inside the cavity will change the form of the spectra, and in turn will influence the way in which calibration constants are derived from the spectra. From CEBAF such fluctuations are known to be controllable to better than 0.5%, which translates into an error of the polarisation of 0.05%.
- The shape of the spectra will be changed by additional material in front of the polarimeter. As an example in figure 8 the effect of an additional 10% of a radiation

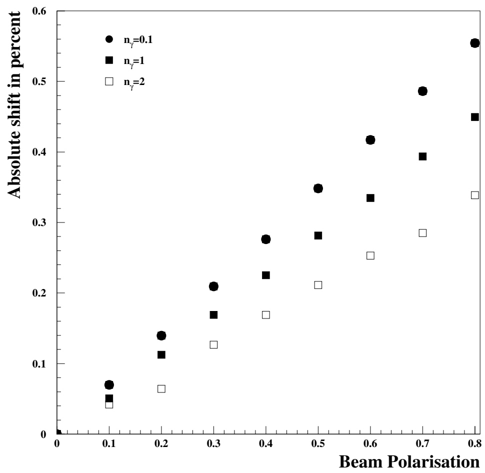

Figure 8: Change in the polarisation, if the photon beam has to traverse an additional 10% of a radiation length of material in front of the calorimeter, for different levels of beam polarisation and for different Compton photon rates.

length of material in front of the polarimeter is shown. At 50% beam polarisation this translates into an error of the polarisation of around 0.3%. Therefore it is important that the amount of the material in front of the polarimeter is carefully controlled at the 1% of a radiation length level.

- The properties of the electron beam directly influence the distribution of photons on the font–face of the calorimeter. With a well calibrated device, with a homogeneous response across the calorimeter, the influence of this can be reduced to the level of a few per mille.

In addition it is planned to install a fibre-detector in front of the calorimeter. This detector will be able to measure the position of the Compton cone. Therefore corrections can be applied as a function of the Compton cone position. This scheme only works if enough data can be accumulated fast enough by the system, on a time scale which is small compared to the typical time scale of variations of the polarisation in the machine. This is clearly the case of a precise determination of the polarisation is done within a few minutes, so should not present a problem to the proposed system.

In conclusion it seems likely that the systematic errors of the polarisation can be controlled very well with the proposed device. An essential condition is that the LPOL can be operated in the single photon mode, and that the polarisation is precisely determined within a few minutes, on a timescale short in comparison to the intrinsiv variations of the polarisation in the machine.

4 Luminosity - Polarisation Correlations

The effective polarisation needed for the different measurements discussed is a luminosity weighted sum, as defined in eq. 2. Based on typical HERA fill durations of around 12h, and a typical turn-on time of the experiments after the declaration of physics, the effective polarisation in the machine is reduced from its asymptotic value by $6-10\%$ (e.g., assuming an asymptotic polarisation of 50%, averaged over the run the luminosity weighted polarisation is e.g. 47%).

In figure 9 the measured polarisation from a typical HERA fill is shown, as a function of the bunch number. Two things are visible: there are clear differences between colliding and non–colliding bunches, and there appears to be a clear structure in the polarization of the colliding bunches. In figure 10 the variation of the polarisation is shown as a function of time throughout a fill. The observed variation are seen by both polarimeters. Typical time-scales for these variation are a few 10 min. Taking both plots together it is important that the polarisation of individual bunches can be tracked with suffucient accuracy ($< 1\%$) on a time-scale of a few minutes per point. This way a correction to the overall polarisation can be done, based on the actual polarisation of the bunches and on their individual behaviour.

Since the luminosity is highest early in the fill, it is important that these data are also used in the analysis. important to take possible correlations between the polarisation and the luminosity into account. There are two possible sources of this correlation:

- bunch-to-bunch correlations
- time evolution

The latter source has already been described above. To control it one must simply measure accurately the polarisation during the early phase of the polarisation build up. This implies a very fast polarimeter.

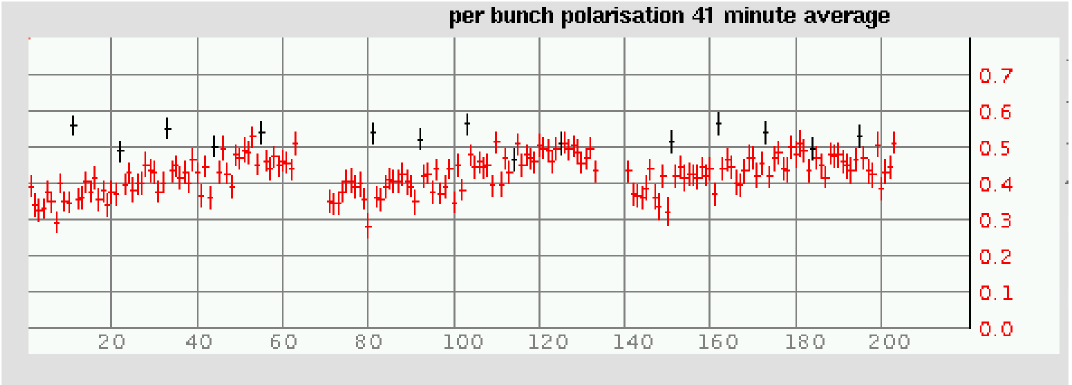

Figure 9: Transverse polarisation, measured during the test of the new TPOL DAQ system [10], as function of the bunch number. Data points with polarisation $P \approx 0.55$ are the non colliding bunches.

The time evolution of the bunch to bunch correlation coefficient between P and a variable X is defined as:

$$C^t(P,X) = \left[\ \Sigma_{i=1}^{N}(P_i - \bar{P})\right] \left[\Sigma_{i=1}^{N}(X_i - \bar{X})\ \right]\ /\ \sqrt{\sigma_P^2 \times \sigma_X^2}$$

$$\text{with} \qquad \bar{P} = \left(\Sigma_{i=1}^{N} P_i\right)/N, \qquad \text{and} \qquad \bar{X} = \left(\Sigma_{i=1}^{N} X_i\right)/N,$$

where the summation is over all the N colliding bunches and X can be e.g. the luminosity $\mathcal{L}$, the lepton beam intensity I_e or the proton beam intensity I_P. In figure 11 (a) the polarisation as a function of time is shown for a typical HERA fill. For this fill the correlations to the luminosity, the electron and the proton current are shown in figures (b), (c) and (d). The luminosity and the current intensity data are taken every 10 s and the polarisation is calculated for 10 min intervals.

However, with the present accuracy it is difficult to determine if a significant level of correlation exists. To do so a precise bunch by bunch polarisation measurement is desirable. In conclusion while with the current state of knowledge there are no really compelling reasons to assume that large correlations between luminosity and polarisation do exist, there are a number of effects which, if confirmed with a more precise polarimeter, might show such a correlation. Therefore it is desirable to have a system which is capable of delivering the data needed to exclude this possible source of systematic errors.

5 Optimisation of the Polarisation

From the above discussions it is clear that the most important input to the physics reach of HERA for polarised physics is, asides from the luminosity, the degree of polarisation in the machine. The higher the polarisation, the smaller the errors. The optimisation of the polarisation therefore will play a crucial role in the running of the machine after the upgrade.

One way to reach higher polarisation is to take advantage of the time to time and bunch to bunch fluctuations (see Fig. 9 and 10). To use this possibility, a fast polarimeter,

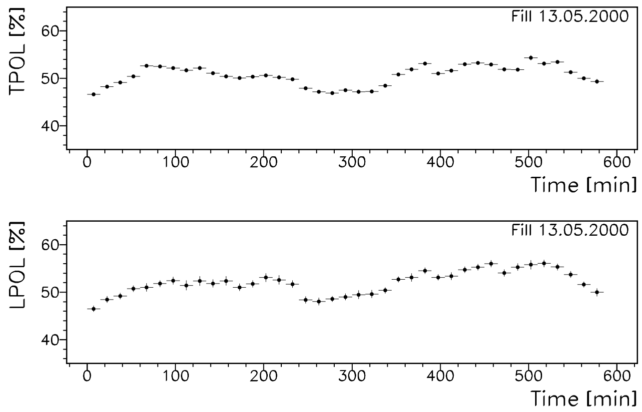

Figure 10: Transverse polarisation and longitudinal polarisation averaged over all bunches, for a given fill, as function of time [9]. Time variations are observed simultaneously by the TPOL and LPOL polarimeters.

allowing a precise bunch by bunch polarisation measurement, is required.

At the moment the polarisation is optimised in an empirical procedure, by using so-called harmonic bumps. These are ensembles of magnets, arranged at different locations symmetrically around the ring. They are used to spin-match the machine, and also to compensate for the effect from magnet misalignments.

An important input in the procedure is the effect on the polarisation. A fast and precise measurement of the polarisation can help to speed up the procedure, to detect changes in the polarisation faster, and to start corrective actions earlier before a significant loss of polarisation occurs. The result of an adjustment of the harmonic bumps is shown in figure 12. The steps seen in the polarisation are the result of an optimisation. As can be seen the time between adjustments is of the order of hours, before the full effect of an optimisation can be judged.

A fast and precise measurement of the polarisation can help in two ways:

- a change of the polarisation after a change in the machine parameters can be quickly detected. A feedback therefore is available to the machine on whether or not a particular operation was successful;

- if the measurements is precise enough a determination of the speed with which the polarisation changes after an operation can be made. This information can be used to determine the theoretically possible maximum polarisation in the machine, if no further changes are done. Thus at least in theory it is possible to perform a number of optimisation steps within a relatively short time, optimising the asymptotic polarisation without having to wait each time for the full effect of the preceding optimisation step.

Note that in order to avoid oscillations the measurement does not only need to be fast, but also precise, to avoid taking decisions based on statistical fluctuations.

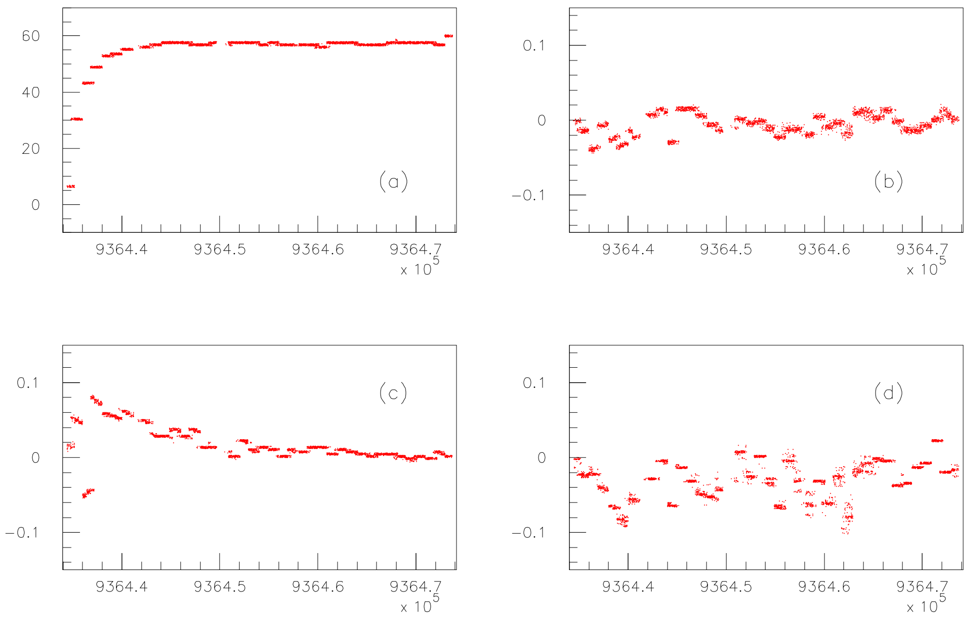

Figure 11: Polarisation (a), $C^t(P,L)$ (b), $C^t(P,I_e)$ (c) and $C^t(P,I_p)$ (d) versus time for one typical fill.

To estimate what one could gain with a fast and precise polarisation measurement, a simple model is considered. The rise-up curve is modelled by

$$P(t) = P_\infty - (P_\infty - P_0)\exp(-(t-t_0)/\tau) \tag{7}$$

where P_0 is the polarisation at $t = t_0$ and $P\infty = P_{ST}/\tau_{ST} \times \tau$ with $P_{ST} = 0.916$, $\tau = 43.2$ s, τ_{ST} is the intrinsic rise-time of the polarisation in the machine, and τ the time of the measurement.

5.1 Feedback loop

If is conceivable to install a simple feedback in the machine, which would help keeping the polarisation at a maximum. This procedure would rely on a fast and precise determination of the polarisation in the following way: over a time interval ΔT the polarisation is measured each a number of times, e.g. every 6 s, and the data points are fitted with a simple model, as, e.g. given in eq. 7. If the fit is based on data point of sufficient precision, a prediction can be made whether the polarisation in the machine is stable, or is changing in a significant fashion. Among a large number of decision criteria, we have investigated the determination of the asymptotic value P_∞: after a period ΔT one decides if a significant polarisation change is observed if the uncertainty ΔP_∞, determined by the fit, is smaller than a given value. However, such a criteria is reliable only for a short period of time because of machine changes and would be, in this sense, more efficient if applied on the non colliding bunches polarisation measurement.

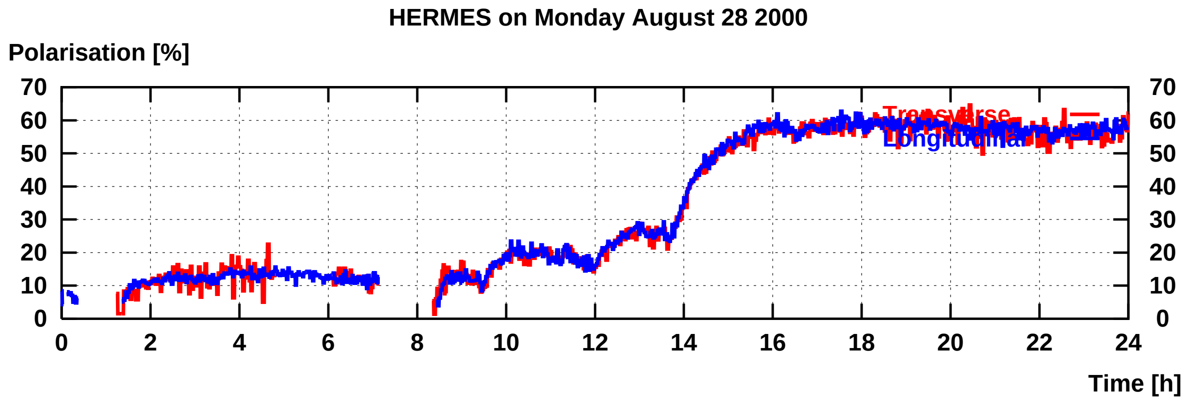

Figure 12: Development of the polarisation throughout a typical HERA fill. Visible are a number of increases of the polarisation, which are the result of harmonic bump optimisations.

Fig. 13 shows ΔT as function of P_0 (see eq. 7) for $P_\infty = 0.5$ and a required $\Delta P_\infty = 1\%$. The three curves correspond to different polarisation measurement accuracies $\delta P = 0.1\%$ (=colliding bunches), 0.3% (=non colliding bunches) and 1%.

From this simple simulations and from comparisons to typical HERA fills, it is found that reliable statements can be made if the Polarisation is measured over periods of a few minutes with an accuracy of a few per mill over a few seconds.

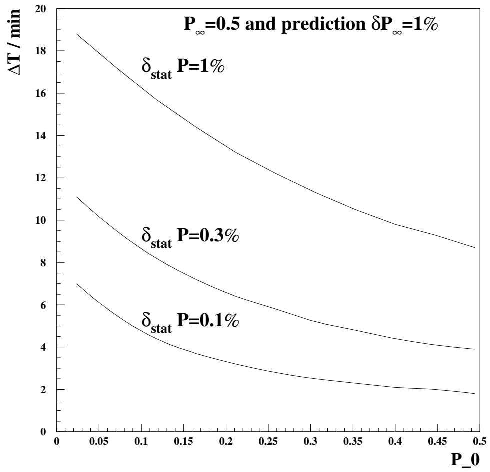

Figure 13: ΔT as function of P_0 (see text) for $P_\infty = 0.5$ and$\Delta P_\infty = 1\%$. The three curves correspond to different polarisation measurement accuracies $\delta P = 0.1\%$, 0.3% and 1%.

6 The Proposed Longitudinal Polarimeter

We propose to add to the existing longitudinal polarimeter a second, new laser system which will allow the operation of the device in the single or few photon mode [1] The new laser should be able to raise the probability of the number of backsacttered photons to at least $n_\gamma = 0.1$, which means that the power of the laser beam at the intersection with the lepton beam has to be around 10kW, if a beam current of 1mA and a crossing angle of 58 mrad are assumed. Such power levels cannot be reached with commercially available lasers. We therefore propose to add a Fabry–Pérot cavity around the interaction point, to boost the equivalent laser power to the required level. A very similar system has been installed and operated at the CEBAF laboratory for a number of years [13].

The conceptual layout is shown in figure 2, and a basic system layout is shown in figure 14. The cavity surrounds the interaction point for a length of 2 m. It is mounted on a solid table. It is driven by a small–power solid state laser mounted on the same table. Additional elements needed are a series of optical components to circularly polarised the laser light, and a system of monitoring devices to measure and control the properties of the laser beam. A fast feedback system controls the frequency of the laser thus keeping the cavity in resonance.

This new laser system is planned to be installed in addition to the existing high power pulsed laser. This will allow the parallel operation of the LPOL in both modes, at least for a period of time until the new system runs stable.

6.1 Mechanical Design of the Cavity

The basic mechanical design of the Fabry-Perot cavity has been described in the letter of intent [4]. The cavity is realised as a monolithic cavity, where the mirrors are connected solidly to the body of the cavity. Tuning of the system is done by changing the frequency of the laser in a feedback loop, and not by varying the mechanical dimensions of the cavity. Such a design has been successfully employed at CEBAF [13].

The feedback system is able to correct for mechanical deformation of the cavity if they stay below $70 \mu m$. Therefore it is essential that the cavity is stable at this level. The biggest problem is that of thermal expansion and contraction of the system, if the ambient temperature changes. A temperature change of 2^o corresponds to the limit of an overall length change of $70 \mu m$, if the cavity is made from stainless steel. This can be

[1] Three different modes of operation can be distinguished for a polarimeter using the backscattered photon beam:

- Single Photon Mode: The probability to scatter a photon is very low (0.001 for the existing TPOL), so that at most one photon is detected in the detector.
- Few Photon Mode: the probability is high enough that on average one photon per bunch crossing is observed. In the detector a distribution ranging from one to a few photons is detected. The shape of the Compton spectra is still visible.
- Multi Photon Mode: Per bunch crossing a large number of photons is scattered into the detector (e.g. around 1000 for the LPOL).

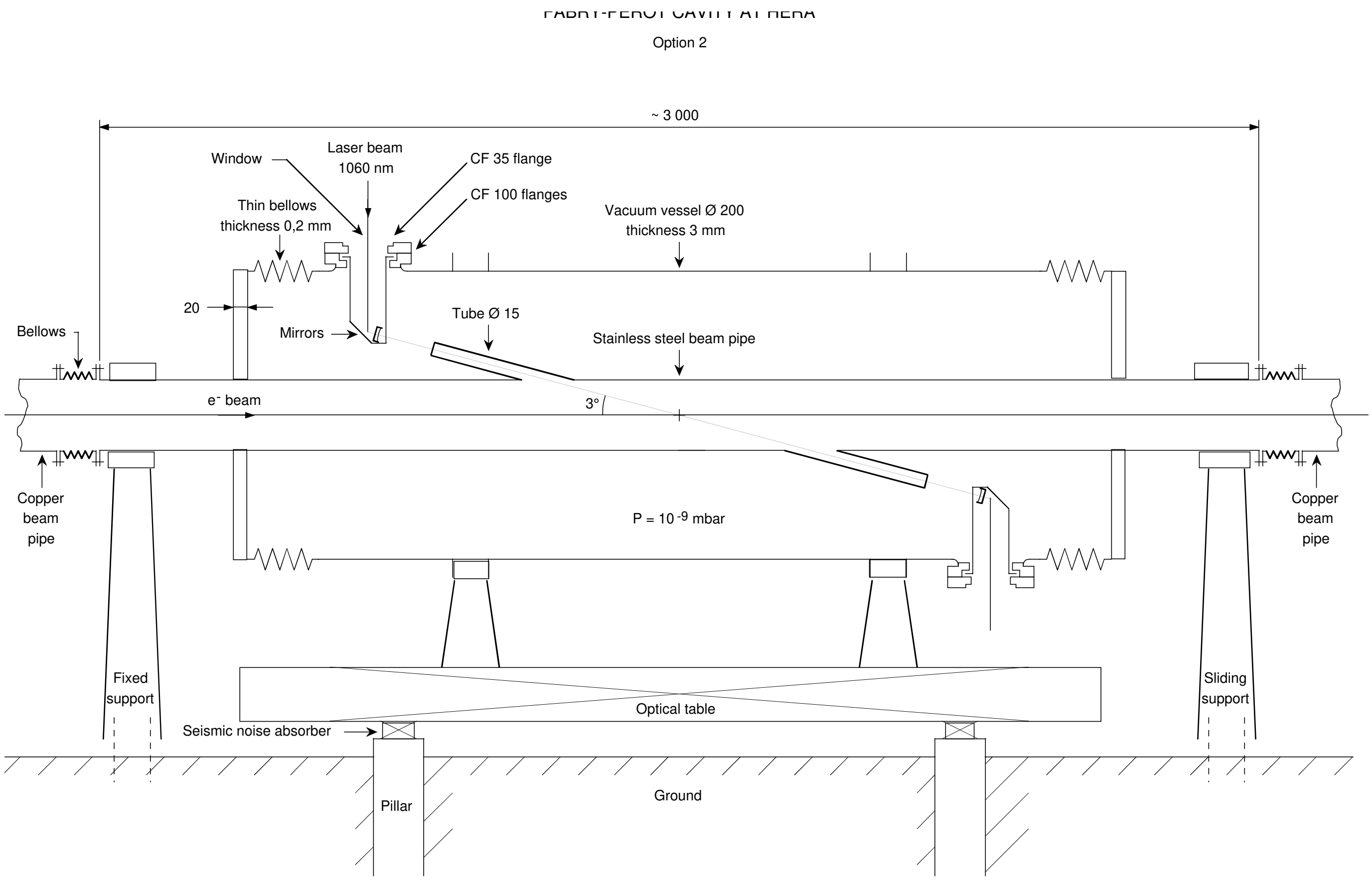

Figure 14: Layout of the cavity

reduced by approximately a factor of 10 if a special alloy with a low thermal expansion coefficient is used.

Temperature changes are coming from changes of the temperature in the tunnel, and from local heating effects of the beam pipe inside the cavity. The first problem can be solved by placing the whole system in a temperature controlled hut, maintaining a stable temperature within 1^o in the hut. The temperature of the beam pipe at the present Lpol location has been measured [14] for different intensities of the e-beam (between 0 and 48 mA), and during different times within a fill. The maximum temperature variation found is about $\sim 2.5^o$C. In addition some heat will be produced by higher order modes induced by the beam due to the holes in the beam pipe needed for the laser tube. The power lost has been estimated to be 18 W during injection, and less than one W during normal running [11]. This should not present a problem, since in the current design, without considering heat conduction, purely by radiative cooling the beam pipe will heat by less than one degree for 25 W of heating power.

Another important source of concern are vibrations. They mostly originate from ground motion. A careful study of these has been made in the HERA tunnel [12]. Other sources of vibrations might come from the machine itself, through cooling water circulation, magnet power supplies, etc. These depend critically on the exact location in the ring, and are not precisely known for the position foreseen for the cavity.

To circumvent these problems a more elaborate design of the cavity has been worked out and is shown in figure 14. The main change compared to the previous design is that the optical elements of the cavity are mechanically decoupled from the beam pipe, and are supported from a stable optical platform.

In the new design the actual cavity together with all other optical elements rests on a single, heavy table, which is isolated from the HERA tunnel through pneumatic isolators. The main part of the cavity is a tube made from stainless steel, with a wall thickness of around 0.3 cm. This tube is fixed rigidly to the table. The cavity mirrors are held by the tube, and are mounted on specially constructed mirror holders, which allow the initial alignment of the mirrors. The central part of the cavity is connected to two end pieces by means of two bellows. Only the end pieces are in contact with the beam pipe. The central part of the cavity therefore is effectively thermally isolated from the rest of HERA. Heat produced in the beam pipe surrounding the cavity can only be transmitted by radiation, not by thermal heat conduction. In addition the bellows act as a vibration filter, blocking vibrations in the machine from reaching the mirrors. Preliminary calculations suggest that this system will be insensitive to the level of temperature changes and vibrations expected in the tunnel.

6.2 Description of the Optical System

The role of the external optical elements is twofold: the laser beam has to be transported into the cavity, and the properties of the laser beam have to be measured and monitored. The laser beam has to be highly circularly polarised (better than 99.5%), and should be focused in the centre of the cavity with a waist of ≈ 0.6 mm.

The chosen cavity design is a close copy of the CEBAF cavity. It consists of two confocal mirrors Mc1 and Mc2, each with a radius of curvature of 2 m. The expected gain of the device is $7.3 \cdot 10^3$, and the bandwidth, if pumped with an IR laser of $\lambda = 1034$nm, is 7 kHz.

A layout of the optical system is shown is figure 15.

The laser chosen to pump the cavity is a Nd:YAG laser from the lightwave company (series 126). Its main parameters (spatial mode TEM00, linewidth < 5 kHz, coarse (fine) frequency tuning range 30 GHz (30 MHz)) are well adapted to the system for both pumping the cavity and locking the system into resonance.

The laser is protected from light reflected from the entrance mirror through a Faraday insulator. A filter is used to linearly polarise the laser light. A system of $\lambda/2$ plate and beam splitter splits off a part of the beam and reflects it into an integrating sphere and photodetector. These will be used to derive a signal for the mode-locking system.

A remote controlled $\lambda/4$ plate transforms the linearly polarised laser light into circularly polarised light. Switching between left and right polarised light is done by rotating the plate.

An optical telescope then focuses the laser beam into the cavity, and matches the focal point of the laser with that of the cavity. One of these lenses (L3 in the drawing) is remote-controllable, so that the focus can be fine-tuned during operation.

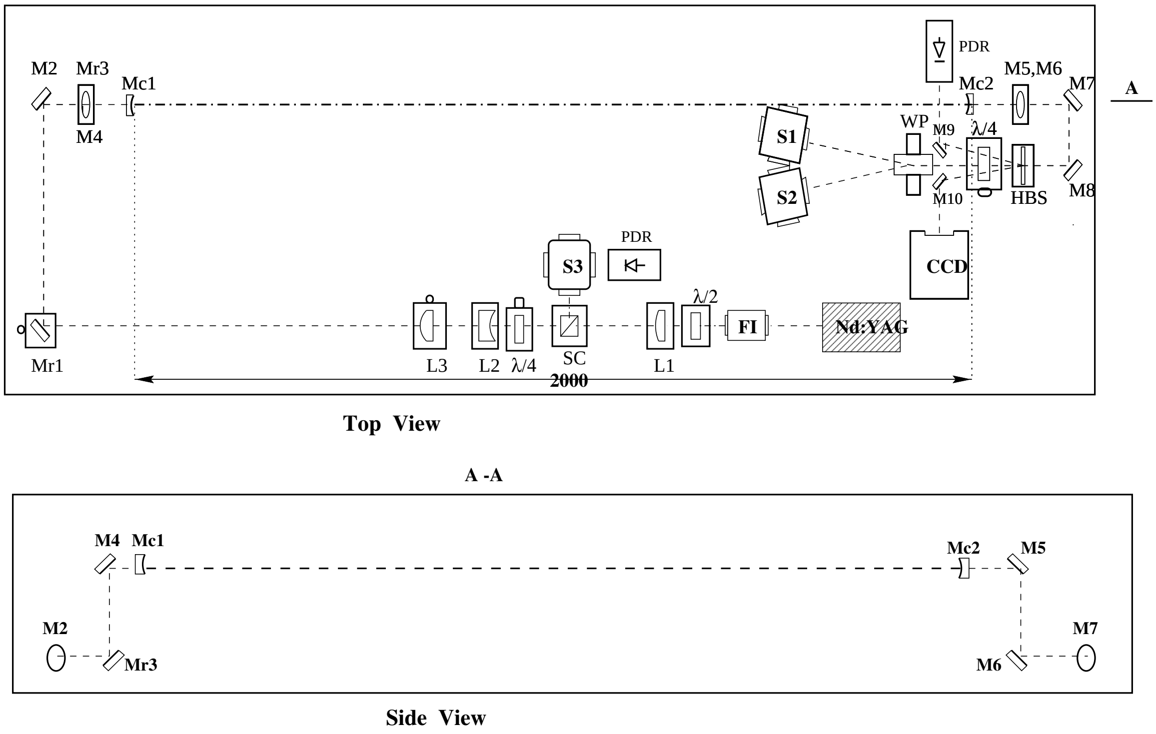

Figure 15: Layout of the optical components needed to operate the cavity.

Care has to be taken that the mirrors used to reflect the light into the cavity do not disturb the circular polarisation. Therefore mirrors Mr1-Mr3 and M2-M4 are matched to have the same properties, thus minimising the distortions. In order to give the system enough degrees of freedom so that the laser beam can be matched to the cavity, the mirrors Mr1 and Mr3 are remote-controllable.

A small fraction of the laser power will exit the cavity and will be reflected into an system of optical measurement devices. They are designed to determine the exact polarisation of the laser light, and the power of the laser beam will be measured.

6.3 Radiation effects on the cavity mirrors

A particular concern is the level of radiation exposure of the optical elements of the cavity, throughout its lifetime. During the months of July and August tests were done in HERA to investigate the effects of radiation on the proposed mirrors. The Laboratoire des materiaux avances (IPN LYON) lent us two mirrors from the same batch used for the CEBAF cavity. These two mirrors were installed next to the HERA beam pipe, at the same place where they would be in the final cavity. One mirror was exposed directly to the radiation levels, the other one was shielded by 2mm of lead. The dose absorbed by the mirrors was in both cases monitored with dosimeters, and was found to be ≈ 0.1 Gy/month inside the lead shielding, and around 10 times more without any shielding.

After the exposure both mirrors were tested and the quality of the mirror coating was determined. Within the measurement accuracy no change in the properties of the mirrors were detected.

6.4 Data Acquisition for the Cavity

The general layout of the data acquisition has been described in detail in the letter of intent. Compared to the system currently under construction for the TPOL significant higher rates need to be handled. In this basic option the new LPOL DAQ consists of two almost independent subsystems: It consists of two nearly independent subsystems:

- a laser and cavity control system and its auxiliary electronics for laser alignment, feedback control, switching and monitoring of the cavity power and polarisation. This system is a close copy of the system developed for the CEBAF polarimeter;
- a VME based fast DAQ system for the few photon mode LPOL, which is a close copy of the TPOL fast DAQ.

In addition the slow control functions for the calorimeter will have to be added. For a transition period they can be handled through the DAQ of the existing LPOL system, until they are moved over to the new system.

6.4.1 Fast LPOL DAQ

The fast part of the DAQ for the new LPOL is a close copy of the system which is currently being built for the TPOL. In essence it consists of custom-made fast ADC's and TDC's, which are read out by a dedicated Power-PC based controller (MFCC), while a second Power-PC takes care of the analysis and control of the data. The bandwidth of the ADC allows for the transfer of two data words per HERA bunch, which is enough for the new system (calorimeter total energy and pedestal). The readout and storage of the data however will have to be handled differently to allow for the larger rates. Two solution are being studied:

- The code in the front end Altera chip on the MFCC board can be modified to store the information directly into a 2-dimensional histogram of energy versus bunch number. The bunch number can be automatically incremented by the system.
- A dedicated board could be built which replaces the Altera to store the data in the relevant histogram bins. This solution has the advantage that it is potentially faster, but the disadvantage that it does not allow the changing of histogram parameters once built.

In either case the planned ADC and TDC are fast enough to server as front end analogue-to-digital converters. They have enough flexibility to provide additional channels should at some point an upgrade of the calorimeter be planned.

6.4.2 Laser and Cavity Control

The system needed to control the laser and the cavity has been described already in the letter of intent. It is a close copy of the system developed for the CEBAF cavity. Its main goals are to ensure that the cavity is kept in the resonance condition, adn that adequate monitoring and diagnostics information is available. This system exists and does not require any special development.

6.5 Infrastructure needed for the Cavity

The cavity will be installed close to the existing LPOL interaction point, in a straight section of HERA where currently no beam elements are installed. The main requirements for the installation are:

- The base unit of the cavity is an optical table mounted on feet which are isolated from the HERA tunnel through pneumatic absorbers. The size of the table is approximately 2.5×1 m. Such tables are commercially available, e.g. from the NEWPORT company.
- To ensure that the laser system operates in the tunnel without problems adequate shielding of the system has to be provided. A lead house similar to the one build for the TPOL is envisioned. A mechanism is needed to access the components inside the lead house.
- The temperature inside the lead house should be kept reasonably stable, to $\pm 0.5^o$ under normal operating conditions. This requires that some basic air-conditioning will have to be included in the lead house.
- To ensure a good vacuum inside the cavity additional vacuum pumps should be installed. At the moment two additional pumps with a pumping power of $60l$/min are considered, one each at each endplate of the cavity.
- To maintain the electron and laser beam in collision it is desirable that a system of "bumps" both vertical and horizontal be operated around the interaction point. Within the optics of the machine this appears to be possible without too many problems. Such a system would allow to move the beam by ± 5 mm without further interventions.
- As described a new DAQ will be needed to operate the LPOL and the laser system.

7 Manpower and Costs

The cavity project is primarily the responsibility of the groups which have signed this proposal. The design, procurement of parts and construction of the cavity and the supporting optical elements will be done by the group from Orsay. DESY will be asked to contribute to the necessary modifications of the beam line needed to install the cavity, and to provide the infrastructure discussed above.

item		quantity	price (in kEuro)
laser (0.7W tunable)		1	40
optical table	main table	1	5
	legs	4	4
	subtables	3	4
optical components	lenses	5	2
	$\lambda/2$ plate	1	0.5
	Pockels-cell	1	2
	motorised mirrors	3	24
	photo meter	2	8
	intensity meter	2	7
	Faraday insulator	1	3
	holographic beam sampling	1	2
	Wollaston prism	1	1
Cavity	mirrors	2	25
	entry/exit windows	2	10
	mechanics	-	75
Electronics	cavity feedback	1	12
	DAQ	1	20
	Sum total		≈ 250

Table 1: Breakdown of the costs for the cavity project. Not included are contingency and manpower costs. Prices are in 1000-Euro.

In table 1 a breakdown of the costs for the different components of the cavity is given. Most components are commercially available and can be bought off-the shelf. Not included are costs for the machining of the cavity, which are to be done in-house, and for the infrastructure at the interaction point. Significant funds for the construction of the cavity are already pledged from several French funding agencies. An amount of 95 kEuro has already been obtained from the French Ministery of Research.

The installation and commissioning of the cavity will be the responsibility of the groups which have signed the proposal. After the initial commissioning phase it is expected that the manpower needed to operate and maintain the cavity LPOL is the same if not smaller than what is now needed for the multi-photon LPOL. From the experience gained at CEBAF it is expected that 1/2 full-time-equivalent person with permanent presence at DESY during running of the device is enough to keep it operational.

Given the available resources, it is planned to install the cavity during the 2002 shutdown, one year after operation of HERA at high luminosity has started. This will allow a careful preparation of the device, so that for the second year of HERA running, when high luminosity and high polarisation are expected, a precise polarisation measurement is available.

8 Conclusion

We propose to install a Fabry Perot optical cavity close to the existing LPOL interaction point. The increased power of the laser possible with such a device will enable us to operate the LPOL in the single- to few-photon mode, and still reaching a high statistical accuracy of 0.2%. This has a number of significant advantages:

- The polarimeter can be calibrated using the data alone;
- Systematic errors can be tracked and controlled based on information obtained from the data;
- Fast and reliable feedback can be given to the machine, helping to optimise the polarisation.

The precision which this device should be able to reach will be around $0.2 - 0.4\%$ on the polarisation. This will make sure that the physics potential of HERA will not be limited by the polarimetry, and that high precision measurements in the study of neutral and charged currents are possible.

We think that the proposed HERA polarimeter system consisting of the already upgraded TPOL and the newly improved LPOL will be well suited to meet the demands placed on the measurement of the polarisation by the experiments. We believe that the proposed system will meet the goals both in terms of performance and in terms of reliability.

References

[1] *Proceedings of the 1987 HERA Physics Workshop*, ed. R.D. Peccei (DESY, Hamburg, 1988).

[2] *Proceedings of the 1991 HERA Physics Workshop*, ed. W. Buchmuller and G. Ingelman (DESY, Hamburg, 1992).

[3] *Proceedings of the 1995/1996 Future Physics at HERA* Workshop, ed. G. Ingelman, A. De Roeck and R. Klanner (DESY, Hamburg, 1992).

[4] E. Barrelet etal., *Letter of Intent to Upgrade the Longitudinal Polarimeter*, DESY-PRC-00-02

[5] F. Zomer, POL2000-02/00 and H1-/00.

[6] D0 Collaboration, Phys. Rev. Lett. 76 (1996) 3271.

[7] Cornet and Ruckl, P. 771 Vol. 2, in *Proceedings of the 1987 HERA Physics Workshop*, DESY 1988.

[8] R. J. Cashmore et al. p. 163-207 in ref. 3.

[9] V. Gharibyan, private communication and presentation at the POL2000 meeting of the 21th of September, 2000.

[10] S. Schmitt, private communication and presentation at the POL2000 meeting of the 21th of September, 2000.

[11] S. Wipf, DESY, private communication.

[12] DESY report.

[13] See `http://www.cebaf.gov/compton` for a complete documentation.

[14] P. Schuler, private communication.