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Electron polarization measurement using a Fabry-Pérot cavity at HERA

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Abstract

A new Compton longitudinal polarimeter currently under construction for HERA is presented. The key component of the polarimeter is a Fabry-Pérot cavity located around the electron beam pipe. With such an optical cavity, a continuous laser power equivalent to 5 kW, much higher than those commercially available, can be achieved, leading to one backscattered photon per bunch crossing. This "few-photon mode" will allow a very precise determination of the calorimeter response with little systematic uncertainty. The electron polarization measurement at the per mill level is expected.

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1 Introduction

The study of deep inelastic scattering of polarized electrons with protons 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 longitudinal polarized electrons[2]. The longitudinal polarization of the electron beam in a storage ring like HERA is achieved with the spin rotators from the naturally polarized transverse polarization through the emission of synchrotron radiation which is known as the Sokolov-Ternov effect [1].

Currently the transverse and longitudinal electron polarizations at HERA are measured with, respectively, a transverse polarimeter (TPOL) and a longitudinal polarimeter (LPOL). The new LPOL will use a Fabry-Pérot cavity to stock photons from a laser in resonance such that an amplified laser beam can be obtained. Such a technique has been successfully employed at CEBAF [2].

The paper is organized as follows. In section 2, the necessities for having a fast and precise polarization measurement are briefly discussed. The new LPOL is presented in section 3.

2 The necessities for having a fast and precise polarization measurement

The basic HERA physics program including using polarized electron beams has been described in a series of workshops [3]. Here we shall only briefly discuss why it is important to have a fast and precise electron polarization (P_e) measurement.

As far as the colliding experiments H1 and ZEUS are concerned, the dominant Standard Model processes, neutral current (NC) and charged current (CC) interactions, are very sensitive to the electron beam polarization at high Q^2 as it is shown for the NC case in figure 1. The NC cross-sections can be expressed in terms of structure

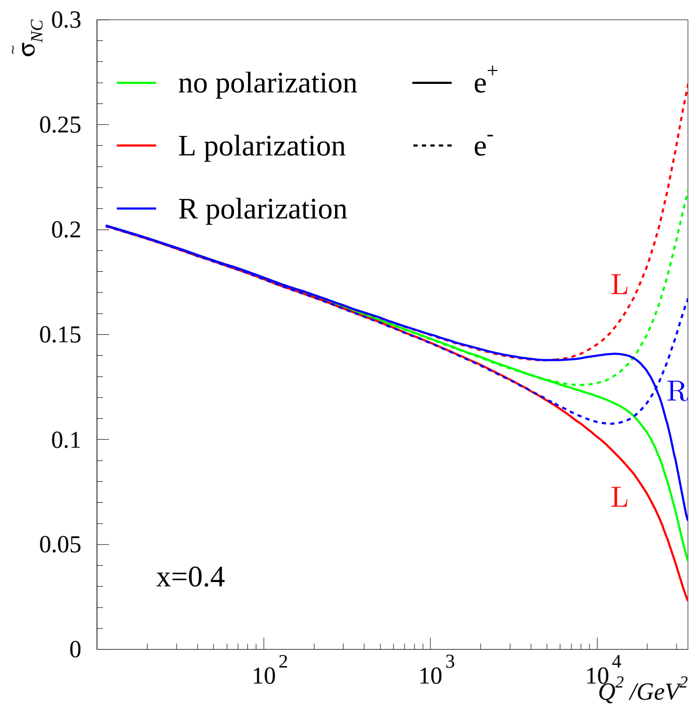

Figure 1: The reduced $e^{\pm}p$ neutral current (NC) cross-section as a function of Q^2 for different electron polarizations. The cross-section is largest (smallest) for left(L) polarization in the e^-p (e^+p) collisions.

[2]In this paper, "electron" is generically used to refer to both electron and positron.

functions $\tilde{F}_2$ and $x\tilde{F}_3$, which contain linear combinations of the quark densities and quadratic functions of the vectorial (v_q) and axial (a_q) couplings of the quarks (q) to the Z boson. A precise knowledge of P_e is thus necessary in order to measure accurately the NC cross-sections, which in turn provide a unique constraint on the parton densities at large x [4]. The same cross-section data can also be used to measure the coupling constants $v_{u,d}$ and $a_{u,d}$ with a precision comparable to those obtained by LEP for the couplings of the heavy quarks. The polarized beam is necessary for determining the vector couplings $v_{u,d}$ and desirable for enhancing the sensitivity for $a_{u,d}$.

Similarly, the reduced CC cross-sections $\tilde{\sigma}_{\rm CC}(e^+p) = (1+P_e)x\left[(\overline{u}+\overline{c})+(1-y)^2(d+s)\right]$ and $\tilde{\sigma}_{\rm CC}(e^-p) = (1-P_e)x\left[(u+c)+(1-y)^2(\overline{d}+\overline{s})\right]$ can be larger or smaller than the unpolarized cross-sections. A larger cross-section will effectively improve the statistical precision in probing the helicity structure of the CC interaction and in determining the propagator mass of the exchanged W boson. The CC cross-sections data also provide a means to search directly for right-handed CC interactions. The search sensitivity depends, however, crucially on the precision of the electron polarization measurement.

Although the current polarimeters do not allow a precise and fast polarization measurement on a bunch-by-bunch base, there is indication that there are significant polarization variations both within a luminosity fill as a function of time and among different bunches (e.g. between colliding and non-colliding bunches). A fast measurement will thus provide the HERA machine a quick feedback to optimize the polarization and maintain the maximum polarization.

3 The new longitudinal polarimeter

The principle of the polarization measurement relies on the non-destructive method of detecting backscattered photons produced in Compton scattering of an intense circularly polarized laser (photon) beam off the electron beam. The transverse polarization is measured from the vertical asymmetries between the left and right circularly polarized photons, whereas the longitudinal polarization is determined from the energy symmetries of the different photon helicities. The current statistical precision of the LPOL is around 1% for 2 minutes of data taking averaged over all bunches in the ring (up to 190). The systematic uncertainty is about 2% which is dominated by the energy scale uncertainty of the calorimeter measuring the backscattered photons in multi-photon mode[3]. To reach a same statistical precision for a single bunch, more than 30 minutes are required due to the low pulsed laser frequency (up to 100 Hz to be compared with the electron bunch repetition rate of 10 MHz). The statistical precision of the TPOL is 1% per minute again averaged over all bunches (the current TPOL data acquisition (DAQ) system does not allow the differentiation of bunch to be made). The systematic uncertainty is about twice that of the LPOL due mainly to the limited statistics of the dedicated rise-time runs taken with a flat machine and needed to define the absolute polarization scale.

The new LPOL will be installed next to the existing LPOL during the shutdown early next year. The new LPOL is expected to provide the most precise measurement of the polarization with a statistical error of 0.1% (0.3%) for the colliding (non-colliding) bunches and 1% per minute for every single bunch, and a systematic uncertainty at per mill level.

The conceptual layout of the new LPOL is shown schematically in figure 2. The cavity surrounds the interaction point for a length of 2 m. The main part of the cavity is a cylindrical vacuum vessel made of stainless steel, with a wall thickness of around 0.3 cm. The optical elements (mirrors) of the cavity are mechanically decoupled from the beam pipe and are rigidly fixed to a stable optical table. The latter is isolated from the HERA tunnel through pneumatic isolators. 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 bellows, acting as a vibration filter, block thus vibrations in the machine from reaching the mirrors.

In addition to the Fabry-Pérot cavity, there are a few other optical components mounted on the optical table, in particular the infrared laser source of 0.7 W (Nd:YAG, $\lambda = 1064$ nm). The role of the these external optical elements is twofold: the laser beam after having been highly circularly polarized has to be transported into the

[3] Three different modes of operation can be distinguished for a polarimeter detecting the backscattered photons: (1) single-photon mode: The probability to scatter a photon is very low (0.01 for the existing TPOL), so that at most one phone per interaction is detected in the calorimeter), (2) few-photon mode: The probability is high enough that on average one photon per bunch crossing is observed, (3) multi-photon mode: Per bunch crossing a large number of photons is scattered into the calorimeter (e.g. around 1000 for the actual LPOL).

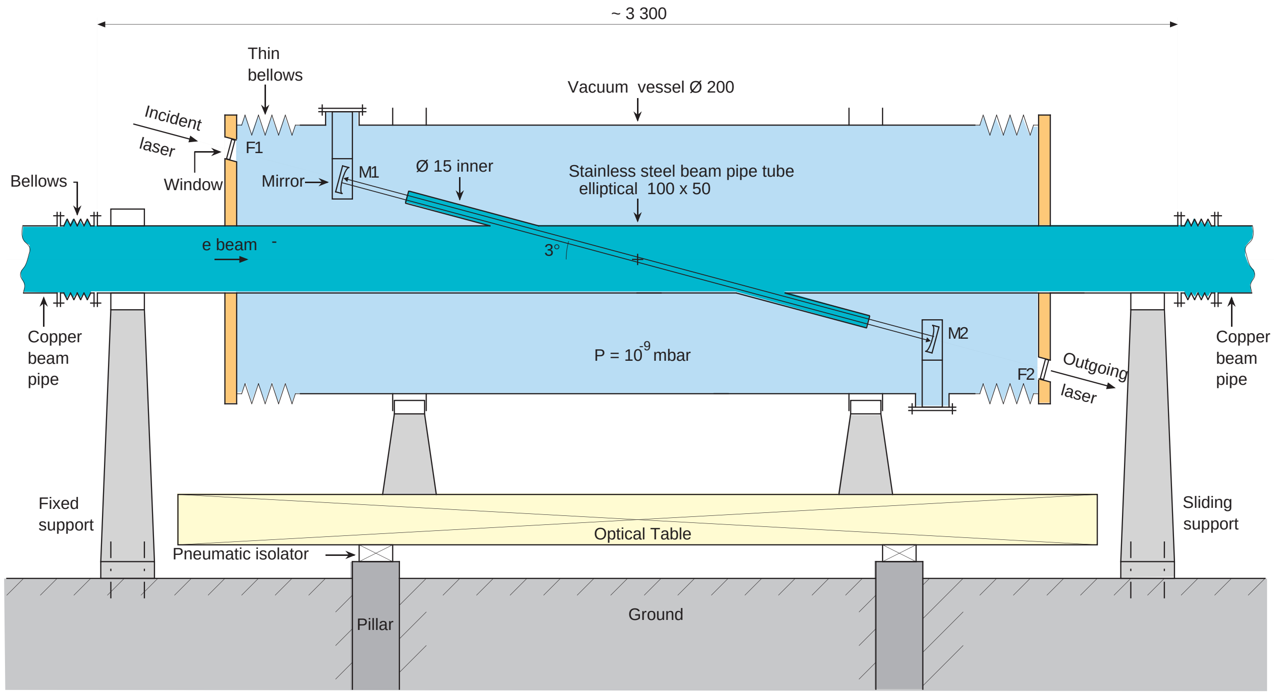

Figure 2: Schematic layout of the new longitudinal polarimeter.

cavity, and the properties of the laser beam have to be measured and monitored.

The whole system is placed in a hut maintaining a stable temperature within 1°C so that the resulting mechanical deformation of the cavity can be handled by an electronic feedback system acting on the frequency of the tunable laser.

To estimate the precision with which the polarization can be measured with the new device, a number of systematic effects have been studied: 1) the energy scale and energy linearity of the calorimeter, 2) the fluctuations of the laser power inside the cavity, 3) the dead material in front of the polarimeter, 4) the properties of the electron beam, and 5) the polarization precision of the laser light. Based on the simulations and the experience obtained from the similar cavity at CEBAF, all considered effects can be controlled such that the systematic uncertainty of the electron polarization would be measured at per mill level. In particular, a precise in-situ energy calibration is possible under the few-photon operation mode, in contrast with the multi-photon mode, since the Compton spectra of one or two photons are still visible in the measured energy distribution.

4 Summary

The new longitudinal polarimeter being constructed will use a Fabry-Péroy cavity to significantly gain the effective power of a laser light. The increased power will enable us to operate the polarimeter in the few-photon mode, and still reaching a high statistical precision of $\mathcal{O}(0.1)\%$. The new polarimeter has a number of important advantages over the existing ones:

- The polarimeter can be calibrated using the same data as for the polarization measurement.
- Systematic uncertainties can be tracked and controlled based on the information obtained from the data.
- Fast and reliable feedback can be given to the machine, helping to optimize the polarization.

The precision that the device is expected to reach will be around $0.2 - 0.4\%$ on the polarization. This will guarantee that the physics potential of HERA is not limited by the polarimetry, and that high precision measurements for the study of neutral and charged currents are possible.

References

[1] A. A. Aokolov and I. M. Ternov, *Sov. Phys. Doklady* **8** (1994) 1203.

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

[3] Proceedings the 1987 HERA Physics Workshop, ed. R. D. Peccei (DESY, Hamburg, 1988); Proceedings of the 1991 HERA Physics Workshop, ed. W. Buchmüller and G. Ingelman (DESY, Hamburg, 1992); Proceedings of the 1995/1996 Future Physics at HERA Workshop, ed. G. Ingelman, A. De Roeck and R. Klanner (DESY, Hamburg, 1996).

[4] Z. Zhang, LAL Preprint 01-70, hep-ph/0110231.