POLARISED $e^{\pm}$ AT HERA*

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After a short summary of experience with $e^{\pm}$ polarisation at the pre-upgraded HERA, the impact of the luminosity upgrade on polarisation is reviewed. Polarisation tuning requires a machine in stable and reproducible conditions, which have not been established yet. Priority has naturally been given to the luminosity operation and until now no attempt has been made to measure and optimise polarisation after the upgrade, but we hope to start as soon as possible.

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1. Introduction

HERA is a 6.3 km long $p/e^{\pm}$ double ring collider located at DESY in Hamburg. The proton and $e^{\pm}$ beams are accelerated up to 920 GeV and 27.5 GeV, respectively and collide head–on at the Interaction Points (IP's) North and South, where the experiments H1 and ZEUS are located. These experiments started data taking in 1992. HERMES, which uses the longitudinally polarised $e^{\pm}$ beam on an internal polarised gas target at the IP East, joined the collider experiments in 1994.

The HERA performance greatly improved over the years and after reducing the beam sizes at the IP's the design luminosity was attained in 2000.

At the request of the physics community [1] the feasibility of higher luminosity had been studied in the last few years up to 2000. The resulting luminosity upgrade project was approved in December 1997 and realised in the period between September 2000 and July 2001. Beam operation resumed in July. The first collisions after the upgrade were observed in October. Several technical problems slowed down the recommissioning. The main

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difficulty the machine shift crew has to face is the background which must be kept at levels tolerable for the experiment components, in particular the new ZEUS micro vertex detector.

2. Experience with polarisation before the luminosity upgrade

An integral part of the original HERA design was the provision of longitudinally spin polarised $e^{\pm}$ beams for the collider experiments. In a storage ring, $e^{\pm}$ beams can become spin polarised through the Sokolov–Ternov effect [2]. The polarisation direction is given by the periodic solution, $\hat{n}_0(s)$, to the Thomas–BMT equation for the spin on the closed orbit. In a perfectly planar ring $\hat{n}_0(s)$ is vertical. To provide the experiments with longitudinal polarisation, $\hat{n}_0(s)$ must be rotated into the longitudinal direction at the experiments by special magnet insertions called "spin rotators". At high energy, they usually involve radial fields; this means that the ring is, by design, no longer planar everywhere. In a ring where $\hat{n}_0(s)$ is not everywhere vertical and/or the beam has a finite vertical dimension due to lack of planarity, the stochastic photon emission causes the single particle spins to diffuse away from $\hat{n}_0(s)$ with a consequent decrease of polarisation. This source of spin diffusion can be partially neutralised by designing a "spin matched" optics [2,3]. The unavoidable magnet misalignment and field errors lead to spin diffusion too [2]. Simulations show that for a high energy storage ring, in addition to the usual orbit correction, a dedicated minimisation of the $\hat{n}_0(s)$ distortion, $\delta\hat{n}_0(s)$, is needed. The method, for the first time successfully applied at PETRA [4], was improved for HERA [5,6]; 8 closed vertical orbit bumps ("harmonic bumps") allow the 8 most important Fourier components of $\delta\hat{n}_0(s)$ to be minimised.

There were originally some doubts in the scientific community about whether large beam polarisation could be observed in high energy storage rings and whether it could be maintained in the presence of spin rotators. However transverse beam polarisation was observed for the first time at HERA in November 1991 and after June 1992 [6], with dedicated machine tuning, high transverse polarisation became a routine aspect of HERA operation. Then the newly approved HERMES experiment and a first pair of spin rotators of the Buon–Steffen type [7] were installed around the IP East during the 1993–1994 shut down. When the vertical bending magnets of the rotators were turned on for the first time on May 4, 1994 [8] there was no substantial loss of polarisation.

In a collider such as HERA the interaction with the counter–rotating beam was also expected to be a source of trouble for polarisation. Indeed, while the proton current and the specific luminosity have steadily increased, a clear correlation between $e^{\pm}$ polarisation and luminosity was observed.

By careful machine tuning it was nevertheless possible to cope with the beam–beam interaction [9] and to deliver high longitudinal polarisation to HERMES. HERA–e is the first high energy $e^{\pm}$ ring to deliver longitudinal spin polarisation.

3. Impact of the luminosity upgrade on polarisation

Owing to the facts that the total $e^{+/-}$ current is limited by the RF power and the maximum proton density is limited by space charge effects in the low energy proton booster, DESY III, the HERA luminosity could be increased only by decreasing the beam cross section at the IP's. The solution adopted [10, 11], namely the one promising the largest specific luminosity gain, implied that the focusing elements had to be placed as close as possible to the IP's and that the synchrotron radiation emitted in the separating magnets is produced inside the experiment region.

Another aim of the luminosity upgrade was to maintain the $e^{\pm}$ polarisation for HERMES and, as planned in the HERA Proposal, provide longitudinal $e^{+/-}$ polarisation to H1 and ZEUS, by means of the two pairs of rotators which had long been awaiting installation. The aspects of the luminosity upgrade having the largest impact on polarisation are:

(a) due to lack of space the anti–solenoids, which were locally compensating the experiment solenoids, had to be removed;

(b) the IR quadrupoles became stronger, as well as those in the arcs where the FODO phase advance was increased in both planes from 60 to 72 degrees in order to reduce the $e^{\pm}$ horizontal emittance.

Currently the betatron coupling resulting from the experiment solenoids is corrected by 4 independently powered skew quadrupoles per IP.

With the H1 and ZEUS spin rotators running, at first sight there is no distortion of $\hat{n}_0(s)$ due to the solenoids since the nominal $\hat{n}_0(s)$ is longitudinal at the IP's. However due to the presence of two additional spin rotators and of the solenoids themselves [12] the maximum achievable polarisation is lower than in the pre-upgrade design. Moreover, while the ZEUS solenoid ($B_{\rm sol}L = 4.4$ Tm) fits physically into the 3.9 m free space between the machine magnets, the H1 solenoid ($B_{\rm sol}L = 7.6$–8.3 Tm, $L = 7.3$ m, longitudinally shifted by 1.1 m) overlaps with the long combined function superconducting magnet GO. The nominal particle velocity and $\hat{n}_0$ are therefore not perfectly parallel to the solenoid field when entering it. The overlap produces a (mainly) vertical orbit distortion ($\Delta z_{\rm rms} = 1.2$ mm) and the longitudinal offset produces a residual $\hat{n}_0$ distortion ($\delta\hat{n}_{0,\rm rms} = 8.8$ mrad). To enable polarisation calculations with the existing codes SLIM/SLICK [13] and SITF/SITROS [14], symplectic/orthogonal spin-orbit maps for the experiment solenoids were produced by numerical integration of the equations of particle/spin motion in the measured fields [15].

Fig. 1 shows polarisation *vs.* energy for the optics with 3 rotator pairs (linear calculations with SLIM): (a) ideal optics; (b) optics with H1 solenoid turned on; (c) with H1 solenoid turned on, after correcting the orbit, the coupling and the $\hat{n}_0$ distortion. The three dashed lines correspond to the polarisation related to each of the three degrees of freedom of the motion.

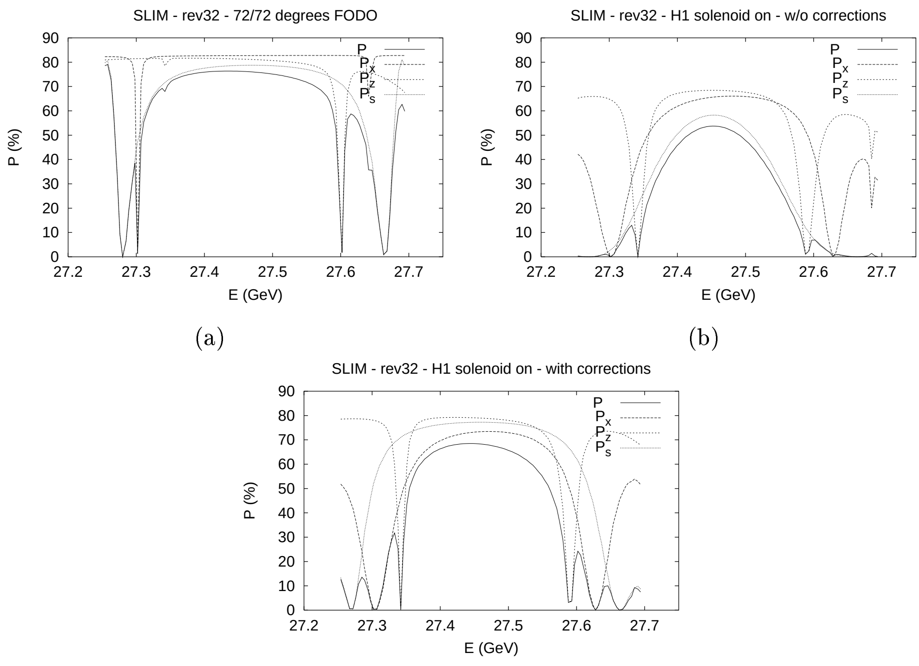

Fig. 1. Polarisation *vs.* energy (linear spin motion calculations).

The effect of the random alignment errors for the upgraded 3-rotator optics including the experiment solenoids is summarised in Table I. The assumed rms value of the horizontal and vertical quadrupole displacement is 0.3 mm with a 3 σ cut. The results are averaged over 6 seeds. The orbit has been corrected down to $x_{\rm rms} \simeq z_{\rm rms} \simeq 0.8$ mm.

In comparison with the pre-upgrade optics a larger $\hat{n}_0$ perturbation is expected and the closed orbit must be better corrected to ensure $P_{\rm lin} \geq 60\%$, after harmonic bump optimisation.

TABLE I

Expected $\delta\hat{n}_{0,\mathrm{rms}}$ and polarisation in presence of random errors (linear and non-linear calculations).

after usual orbit correction			with harmonic bumps in addition			
$\delta\hat{n}_{0,\mathrm{rms}}$ (mrad)	P_{lin} (%)	P_x(%) P_z(%) P_s(%)	$\delta\hat{n}_{0,\mathrm{rms}}$ (mrad)	P_{lin} (%)	P_x(%) P_z(%) P_s(%)	P_{nonlin}
32.9 $\pm$7.6	10.3 $\pm$5.5	66.6$\pm$4.4 74.2$\pm$3.1 10.8$\pm$6.2	14.8 $\pm$3.7	63.8 $\pm$2.1	67.1$\pm$3.8 72.7$\pm$3.7 71.5$\pm$1.5	57.0 $\pm$3.2

4. Summary and outlook

The pre-upgraded HERA has routinely delivered longitudinal beam polarisation for HERMES together with luminosity for H1 and ZEUS. After the luminosity upgrade, machine commissioning for polarisation is expected to be more difficult. The increase of the vertical incoherent beam–beam tune shift by about 24% is quite challenging too.

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