Polarised $e^{\pm}$ at Hera: experience and expectations after the Luminosity Upgrade

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Abstract. After a short summary of experience with $e^{\pm}$ polarisation at HERA, the impact of the collider Luminosity Upgrade on polarisation will be reviewed.

INTRODUCTION

HERA is a 6 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, joined the collider experiments in 1994.

The HERA performance has greatly improved over the years. In particular, although the beam currents did not reach the design values, it was possible to attain the design luminosity through a reduction of the beam sizes at the IP's.

At the request of the physics community the feasibility of higher luminosity has been studied in the last few years. The resulting Luminosity Upgrade project was approved in December 1997 and is currently being realised.

EXPERIENCE WITH POLARISATION AT HERA

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 [1]. The polarisation direction is given by the periodic solution to the Thomas–BMT equation for the spin on the closed orbit, $\hat{n}_0(s)$, which is vertical in a perfectly planar ring. 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, rotators must involve radial fields; this means that the ring is, by design, no longer planar everywhere. In a non–planar ring, where $\hat{n}_0(s)$ is not everywhere vertical and/or the beam has a finite vertical dimension, the stochastic photon emission causes the single particle spins to diffuse away from $\hat{n}_0(s)$ with a consequent decrease of polarisation. Spin rotators are therefore a source of spin diffusion; this can be partially neutralised by designing a "spin matched" optics [2,1].

Similarly, the unavoidable magnet misalignment and field errors lead to spin diffusion [1]. Simulations show that for a high energy storage ring, like HERA, even after that the closed orbit distortion has been minimised, the polarisation is very low and of no practical interest for the experiments. A dedicated minimisation of the $\hat{n}_0(s)$ distortion, $\delta\hat{n}_0(s)$, is then needed and was for the first time successfully applied at PETRA [3]. The method has been improved for HERA [4,5]; 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 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. Transverse beam polarisation was observed for the first time at HERA in November 1991 and after June 1992 [5], with dedicated machine tuning, high transverse polarisation became a routine aspect of HERA operation. This success played a decisive role in the approval of the HERMES experiment and of the installation of a first pair of spin rotators of the Buon–Steffen type [6] during the 1993–1994 shut down to provide longitudinal polarisation to HERMES. The vertical bending magnets of the rotators were turned on for the first time on May 4, 1994 [7]. High longitudinal beam polarisation was then routinely delivered to HERMES and the doubts were seen to be unfounded.

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, since 1996 while the proton current and the specific luminosity have steadily increased, a clear correlation between $e^{\pm}$ polarisation and luminosity has been observed. By careful machine tuning it has nevertheless been possible to cope with the beam–beam interaction.

HERA–e is the only high energy $e^{\pm}$ ring delivering longitudinal spin polarisation.

THE HERA LUMINOSITY UPGRADE

Impact of the new IR design on polarisation

The aim of the Luminosity Upgrade is to increase the luminosity without spoiling the polarisation for HERMES and for H1 and ZEUS, for which two more rotator pairs have been manufactured in the meantime. Since the solution adopted has been described elsewhere (see for example [8]), we here only recall the aspects which have a direct impact on polarisation. In particular:

- The new interaction regions will no longer be mirror symmetric w.r.t. the IP's.
- Due to lack of space the anti–solenoids will be removed.

- The IR quadrupoles will be stronger. So too, will those in the arcs where the FODO phase advance will be increased in both planes from 60 to 72 degrees in order to reduce the $e^{\pm}$ horizontal emittance, ϵ_x.
- It is planned to operate the machine with a RF frequency offset of about 250 Hz to get a further ϵ_x reduction.

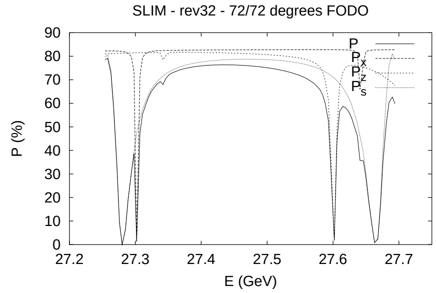
In the new design the betatron coupling resulting from the lack of anti–solenoids will be corrected by 4 independently powered skew quadrupoles per IP. Moreover, although the H1 solenoid, for example, would rotate a vertical spin by about 86 mrad at 27.5 GeV, at first sight there should be no distortion of $\hat{n}_0(s)$ since the nominal $\hat{n}_0(s)$ is longitudinal with the H1 and ZEUS spin rotators running. But we must nevertheless expect some reduction of the achievable polarisation due to the presence of two additional spin rotators and of the solenoids themselves [9].

The experiment solenoids have been treated as a perturbation and ignored when designing the new optics. However, subsequent local spin matching of the optics in the presence of the solenoids does not seem to be possible. A mutual compensation of the two solenoids is not feasible either, mainly because it would at least require the phase advance between the two IP's to be a multiple of π.

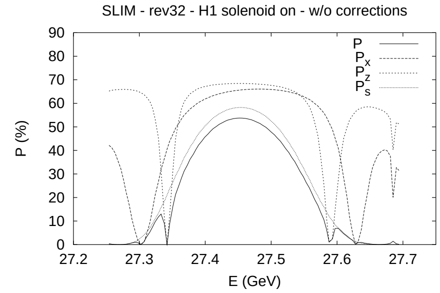
While the ZEUS solenoid ($B_{sol}L$=4.4 Tm) fits physically into the 3.9 m free space between the machine magnets, the H1 solenoid ($B_{sol}L$=7.6–8.3 Tm, L=7.3 m) overlaps with the machine magnets, namely with the long combined function superconducting magnet GO. Moreover it is longitudinally shifted by 1.1 m. Therefore the nominal particle velocity and $\hat{n}_0$ are not perfectly parallel to the solenoid field when entering it. The overlap produces a (mainly vertical) orbit distortion (Δz_{rms}=1.2 mm) and the longitudinal offset produces a residual $\hat{n}_0$ distortion ($\delta\hat{n}_{0,rms}$=8.8 mrad). The distortions due to the H1 solenoid were computed initially by solving the equations of particle motion for the transverse coordinates and the Thomas–BMT equation for the spin in a general 3–dimensional field. Later on symplectic/orthogonal maps produced by numerical integration of the equations of particle/spin motion in the measured fields were introduced into the existing codes SLIM/SLICK [10] and SITF/SITROS [11]. In parallel we also used interleaved slices of combined function magnets, solenoids and vertical correctors — the "sandwich" model. This approach does not need code changes, but of course leads to unphysical non–cancelling solenoid end fields. Nevertheless, the results of these different approaches are in reasonable agreement.

The orbit will be locally corrected by using the vertical dipole windings of the two closest machine magnets. The residual $\hat{n}_0$ distortion will be compensated by slightly asymmetric settings of the vertical bending magnets of the rotators on the left and on the right side of the IP North.

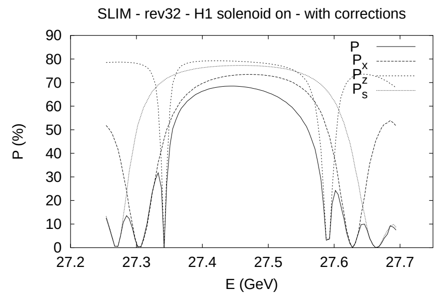
Fig. 1 shows polarisation vs. energy for the optics with 3 rotator pairs (linear calculations with SLIM): (a) ideal optics; (b) optics with H1 solenoid turned on ("sandwich" model); (c) with H1 solenoid turned on, after correcting the orbit, the coupling and the $\hat{n}_0$ distortion ("sandwich" model).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



(a)



(b)



(c)

FIGURE 1. Polarisation vs. energy (linear spin motion calculations).

TABLE 1. Expected $\delta\hat{n}_0$ and polarisation in presence of random errors

after usual orbit correction			with harmonic bumps in addition		
$\delta\hat{n}_0$(mrad)	P(%)	P_x(%) P_z(%) P_s(%)	$\delta\hat{n}_0$(mrad)	P(%)	P_x(%) P_z(%) P_s(%)
35.6±11.1	12.3±11.8	73.5±4.1 72.5±4.4 11.3±11.9	16.9±3.7	67.5±4.8	71.5±4.1 70.8±5.3 67.6±5.8

Effects of random distortions

The impact of the unavoidable random alignment errors has been studied for the optics with 3 rotator pairs and, initially, without experiment solenoids. The assumed rms value of the horizontal and vertical quadrupole displacement is 0.3 mm with a 3 σ cut. In some cases a roll–angle error (0.35 mrad rms value) has also been introduced.

In Table 1 the expected rms value of $\delta\hat{n}_0$ and the polarisation, after usual orbit correction and after additional optimisation of the harmonic bumps, are quoted; the values are averaged over 6 seeds. The orbit has been corrected down to x_{rms}=0.76±0.06 mm and z_{rms}=0.81±0.14 mm.

In comparison with the old optics there is a larger $\hat{n}_0$ perturbation and the closed orbit must be better corrected (down to $\simeq$ 0.7 mm) to ensure $P \geq 60\%$, after harmonic bump optimisation. We have also noticed that in some cases the polarisation is limited by the large horizontal dispersion around the IP's. Therefore it is sensible for the future to have a dispersion correction algorithm.

Recent polarisation studies

After the Luminosity Upgrade, routine running with longitudinal polarisation is expected to be more difficult than in the past. Therefore studies aiming to explore some of the issues were carried out before shutting down the machine last September. A spin matched $72°/72°$ optics was established and it was possible to get about 60% polarisation within 24 hours. Afterwards, the dependence of the polarisation on the RF frequency shift, at constant particle energy (by tuning the main dipole current), was measured. A slight drop of polarisation was observed but the effect of the RF shift was not as large as predicted by the corresponding preliminary calculations with SITROS to include nonlinear spin motion.

A dispersion correction algorithm based on singular value decomposition was also tested and the results look encouraging.

SUMMARY AND OUTLOOK

HERA demonstrated the possibility of getting longitudinal polarisation in a high energy electron ring. Machine tuning for polarisation required care, but was feasible and high longitudinal beam polarisation was routinely delivered to HERMES together with luminosity for H1 and ZEUS. The Luminosity Upgrade will have a large impact on HERA–e and on polarisation. The orbit will have to be very well corrected. The increase of the vertical incoherent beam–beam tune shift by about 24% will be quite challenging. Machine commissioning for polarisation will in practice be more difficult than in the past.

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