

The Status of Polarization Studies at HERA

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Abstract

In August 1992 a vertical electron beam polarization of nearly 60% at 26.7 GeV (spin tune=60.5) was obtained at HERA. This was achieved by optimizing the energy and orbit tunes and by applying harmonic corrections to the closed orbit. The polarization level was reproducible from fill to fill and the calibration of the Compton polarimeter was confirmed by measuring the polarization build up curve. The polarization measurements were made with currents of one to two milliamps. Much higher currents are expected for the 1993 luminosity run (~ 30 mA were obtained in May 1993). The high polarization level was reproduced at high current. Further polarization studies in parallel with e-p operation are planned. In 1993/94 a pair of spin rotators will be installed in the East straight section so that longitudinal polarization is available at the East interaction point. Simulations with the spin tracking program SITROS are in qualitative agreement with the measurements. Calculations with SITROS show that longitudinal polarizations of up to 50% could then still be achieved.

I. INTRODUCTION

The HERA electron-proton colliding beam facility was designed with the aim of storing polarized electrons. The beam can become polarized parallel to the main bending field through the emission of synchrotron radiation in the arcs.

Vertical polarization of the electron beam at the 8% level was observed in November 1991 at the current operating energy of 26.7 GeV. The HERA polarimeter and these first measurements are described in detail in [1]. The following steps were taken to increase the polarization:

1. the alignment of the quadrupole magnets was checked and selected magnets were realigned,
2. the tilt of the beam ellipse was corrected with orbit bumps distributed around the ring,
3. the orbital tunes were changed to increase the energy separation of the first order resonances,
4. the harmonic spin-orbit correction scheme was prepared and tested with simulations.

Parasitic measurements in April and June 1992 showed that owing to the first two steps the maximum polarization had increased to about 18%. After all optimizations of the orbit nearly 60% vertical polarization was obtained [2].

A. Theoretical Aspects

Centre of mass spin motion in electric and magnetic field is governed by the Thomas-BMT [3][4] equation:

$$\frac{d\vec{s}}{d\theta} = \vec{\Omega} \times \vec{s},$$

where $\vec{\Omega}(\vec{B}, \vec{E}, \gamma)$ is a function of the fields and energy. θ is the azimuthal coordinate.

In a flat ring with the conditions $\vec{B} \parallel \vec{e}_z$, $\vec{E} = \vec{0}$ and after transformation to a frame which is circulating with the beam, $\vec{\Omega}$ becomes:

$$\vec{\Omega} = \frac{e\vec{B}}{cm_e\gamma} \frac{R}{2\pi} \gamma a,$$

where the first part is the relativistic cyclotron frequency $\vec{\omega}$, R the circumference of the ring and γa the spin tune ν . a denotes the electron anomalous g factor.

The emission of synchrotron radiation in an electron storage ring can cause spin flip from up to down and vice versa [5]. An asymmetry in the emission rates leads to an exponential polarization buildup with time against the direction of the bending field [6]:

$$P(t) = P_\infty(1 - \exp(-t/\tau_p)), \quad \tau_p^{-1} \propto \gamma^5 \oint \frac{1}{\rho^3} d\theta$$

with ρ = modulus of bending radius, the equilibrium polarization $P_\infty = 92.4\%$ for a flat ring and the characteristic buildup time $\tau_p = 46$ min for a ring like HERA at 26.67 GeV. So far we have neglected depolarizing effects. Due to the stochastic change of momentum by photon emission betatron oscillations are excited. Especially in the quadrupoles this leads to additional fields which can act on the spin. As a result spin diffusion and hence depolarization with a characteristic depolarization time τ_d is introduced:

$$P(t) = P_\infty \frac{\tau_d}{\tau_p + \tau_d} \left(1 - \exp\left(-\frac{\tau_p + \tau_d}{\tau_p \tau_d} t\right) \right)$$

(HERA: $P_{eff} = 17\%$ corresponds to $\tau_{eff} = 7.5$ min at 26.67 GeV). Spin diffusion is particularly strong when the precession of the spins is synchronous with orbital and energy oscillations which drive the diffusion, i.e. when the spin resonance condition:

$$\nu = m + m_x Q_x + m_z Q_z + m_s Q_s$$

is fulfilled, where Q_x, Q_z, Q_s are the horizontal, vertical and synchrotron tunes and m and $m_{x,z,s}$ are integers. At

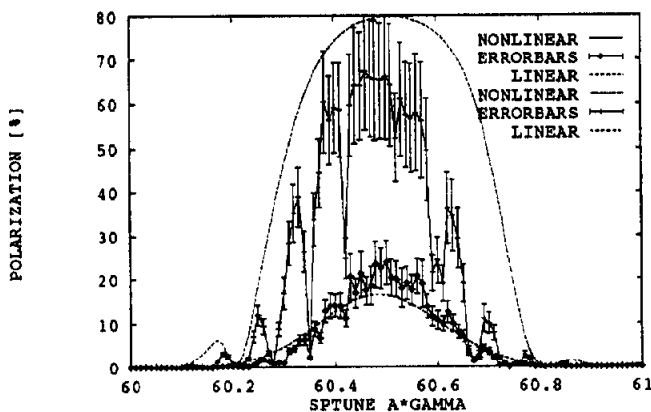


Figure 1: Monte-Carlo simulations (solid curves) of polarization vs. spin tune between two integer resonances (440 MeV). The maximum polarization attained with standard orbit corrections is $\sim 23\%$. After the corrections with the special bump scheme a value of $\sim 70\%$ is reached. The linear calculations (dashed curves) are shown for comparison

high energy and large energy spread not only the first order resonances ($|m_x| + |m_z| + |m_s| = 1$) are important. The synchrotron sidebands ($\nu = Q_{x,z,s} + m_s Q_s$) can also be strong. The spin diffusion can be controlled by a proper alignment of the ring elements (especially the quadrupoles) and with a special orbit correction scheme which minimizes the coupling between the orbital and spin motion for a given (but unknown) error distribution of the magnets by empirical optimization of the measured polarization [7]. The scheme used for HERA consists of 8 vertical orbit bumps at “strategic positions” in the arcs of the ring. Using these bumps we are able to control the most important contributions to the spin orbit coupling. The Monte-Carlo calculations with SITROS [8][9] show how effective these bumps should be (Figure 1).

II. THE HERA POLARIMETER

The vertical component of the electron polarization is measured using the asymmetry of the Compton cross section for the scattering of vertically polarized electrons off circularly polarized photons [10]. Laser light of 514 nm is directed against the electron beam and the energy E_γ and vertical position y of the backscattered photons are measured. The polarization P_y is obtained from the difference Δy in the mean vertical positions $\langle y \rangle$ of the distributions measured with left and right circularly polarized light:

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

with $\Delta S_3 = (S_{3,L} - S_{3,R})/2$ where $S_{3,L}$ and $S_{3,R}$ are the degrees of circular polarization of the laser light and Π_y the analyzing power, is derived from the polarization dependent cross section. The maximum value of Π_y is $180\mu\text{m}$ at $E_\gamma = 8$ GeV. In practice ΔS_3 is nearly 1, and the vertical

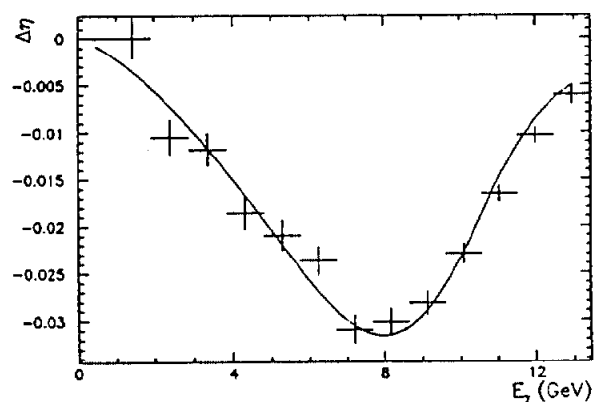


Figure 2: The polarization measurement for a typical run: $\Delta\eta$ is plotted vs. E_γ . The fit gives $\Delta S_3 P_y = 53.1\%$

component of the electron beam polarization is proportional to Δy . The HERA polarimeter has been described in detail in [1].

A. The Calorimeter

The energy and vertical position of the backscattered photons are measured using a tungsten-scintillator sampling calorimeter. The calorimeter is split in the middle, and can thus be considered to consist of two calorimeters, one on the top of the other. The energy of an incoming photon is the sum of the energies in the two halves $E_\gamma = E_{up} + E_{down}$ and the vertical position is measured using the asymmetry of the energies:

$$\eta(y) = \frac{E_{up} - E_{down}}{E_{up} + E_{down}}.$$

Figure 2 shows an example of the measured variation of

$$\Delta\eta(E_\gamma) = \frac{\langle \eta \rangle_L - \langle \eta \rangle_R}{2} = P_y \Delta S_3 \Pi_\eta(E_\gamma) \quad (1)$$

with E_γ together with the result of a fit to (1) using the Monte-Carlo program EGS4 [11] for the calculation of the normalized shower distribution dE/dy which is needed for the derivation of Π_η . The agreement is excellent. For $\Delta S_3 = 1$ the fit corresponds to $\sim 53\%$ polarization.

III. THE MEASUREMENTS

The measurements were made at beam energies near 26.7 GeV (spin tune $a\gamma=60.5$). The chosen working point was at $Q_x = 47.12$ and $Q_z = 47.20$ which has the advantage of an increased energy separation between the first order resonances and higher polarization around the half-integer spin tune (expected by simulations) compared with the old working point at $Q_x = 47.22$ and $Q_z = 47.35$. During the measurements the total circumferential voltage ranged between 140 and 165 MV leading to a synchrotron tune Q_s from 0.061 to 0.082 at 26.67 GeV. This choice of the tunes satisfies $Q_z \approx Q_x + Q_s$ which puts the sidebands to the orbital resonances on top of each other. The rms distortion

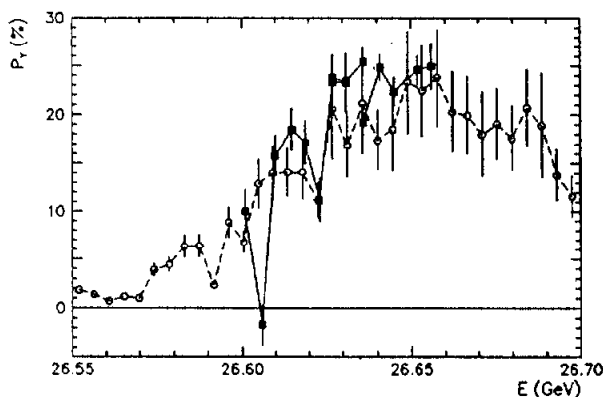


Figure 3: Overlay of simulation results (circles) and measured values (squares) of polarization vs. energy. The data have been shifted in energy by -64 MeV

of the vertical closed orbit achieved by standard orbit corrections was ~ 0.8 mm. The proton ring and the solenoids of the experiments were turned off. The total current had been limited to about 2 mA in 10 bunches with lifetime of about 5 hours. These conditions gave a statistical error of $\Delta P_y \sim \pm 0.03$ for a 1 minute measurement consisting of 40 sec Compton-scattering measurements switching the laser polarization between left and right circular polarizations at 90 Hz, followed by 20 sec background measurements. An energy scan followed by an RF voltage scan was performed to find the maximum polarisation leading to a value of 25.5% at 26.70 GeV. A comparison between measurement and simulation for the scan is made in Figure 3 taking into account the uncertainty in the energy scale of HERA. By application of the special bump scheme the polarization increased to nearly 60%. Figure 4 shows a buildup time measurement at $\sim 50\%$. The measured polarization values ($45.6 \pm 5.3\%$) and the polarization calculated by fitting the buildup time are consistent showing that the systematic error of the calorimeter measurement is small.

IV. CONCLUSIONS

An electron polarization of 8% was observed in November 1991. After the realignment of misaligned quadrupoles a maximum polarization of about 18% was observed in spring of 1992. During dedicated beam time in August and September 1992, special orbit correction schemes were successfully tested. After all corrections a maximum polarization of $56.0 \pm 1.6 \pm 5\%$ (systematic) was achieved. The short and long-term stability of the HERA ring concerning polarization was excellent. Comparisons between measurements and simulations using the Monte-Carlo program SITROS show the predictive power of the program. In forthcoming measurements the aim will be to achieve polarization during luminosity operation (solenoids and compensators of the experiments, multi-bunch feedback and proton ring turned on). An accurate beam energy measurement will be made using resonant depolarization. Spin rotators are

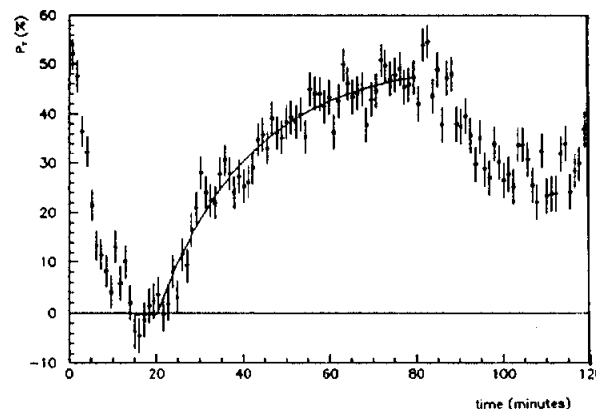


Figure 4: The buildup of polarization after depolarization (Results of the fit: $P_{max} = 50.6 \pm 1.9\%$)

ready for installation in the East area of HERA during the 1993/94 shutdown. Simulations with SITROS indicate that a high degree of polarisation can also be achieved with spin rotators [12].

V. REFERENCES

- [1] D.P. Barber, et. al., *DESY Report* 92-136, October 1992.
- [2] D.P. Barber, et. al., *DESY Report* 93-038, April 1993.
- [3] L. Thomas, *Philos. Mag.*, vol.3, p.1, (1927).
- [4] V. Bargmann, L. Michel, V.L. Telegdi, *Phys. Rev. Letts.*, vol.2, p.435, (1959).
- [5] A.A. Sokolov, I.M. Ternov, *Sov. Phys. Doklady*, vol.8, p.1203, (1964).
- [6] A. W. Chao, *Nucl. Inst. Meth.*, vol.180, p.29, (1981).
- [7] E. Gianfelice-Wendt, in: F. Willeke (editor), *DESY HERA* 92-07, p.202, (1992).
- [8] J. Kewisch, T. Limberg, R. Rossmanith, *Phys. Rev. Letts.*, vol.62, N^o4, p.419, (1989).
- [9] M. Böge, in: F. Willeke (editor), *DESY HERA* 92-07, p.211, (1992).
- [10] U. Fano, *J. Op. Soc. Am.*, vol.39, p.859, (1949).
- [11] W.R. Nelson, H. Hirayama, D.W.O. Rogers, *SLAC* 265, (1985).
- [12] E. Gianfelice-Wendt, M. Böge, 10th Int. Symp. on High Energy Spin Physics, Nagoya, Nov. 1992