Recent Achievements in Transverse Spin-Polarisation at LEP

L. ARNAUDON, R. ASSMANN [*], A. BLONDEL [†], B. BOUCHET, J. CAMAS,
B. DEHNING, G.P. FERRI, P. GROSSE-WIESMANN, H. GROTE, R. JACOBSEN,
J.P. KOUTCHOUK, J. MANN, J. MILES, R. OLSEN, M. PLACIDI,
R. SCHMIDT, J. WENNINGER, CERN, Switzerland

Abstract

In 1993 several important achievements on transverse spin polarization at LEP were obtained. The polarization degree was improved from below 16% to almost 60%. All four experimental solenoids were successfully spin matched and polarization in close to physics conditions was established at three operational LEP energies. Regular energy calibration with resonant depolarization at the end of physics coasts was done and the beam energy was monitored over the whole year. Higher-order depolarization due to beam energy spread was measured in excellent agreement with theoretical calculations, showing that radiative polarization at LEP is at least possible up to 55 GeV.

1 INTRODUCTION

Transverse spin polarization opens the possibility to measure accurately the absolute energy scale of LEP and hence the mass and the width of the Z boson. The method is referred to as energy calibration by resonant depolarization. Regular energy calibrations on an operational basis need high transverse beam polarization in close to physics conditions. In 1992 often as much as 12 hours of optimization were needed to find a polarization degree of typically 10%. In order to improve this situation a thourough experimental and theoretical program on polarization was followed in 1993. The main results are presented in the following.

2 POLARIZATION IN PHYSICS CONDITIONS

The dominant problems in order to find polarization in close to physics conditions arise 1) from the longitudinal magnetic fields at the large experimental solenoids in LEP and 2) from the settings of the betatron tunes. All non-vertical magnetic fields cause depolarization and only an insignificant polarization degree is left with solenoids. However, the spin rotations caused by the solenoids can be compensated by a configuration of vertical closed orbit bumps [1]. The depolarizing effect of the ALEPH solenoid and the compensation of ALEPH and DELPHI are shown in fig. 1.

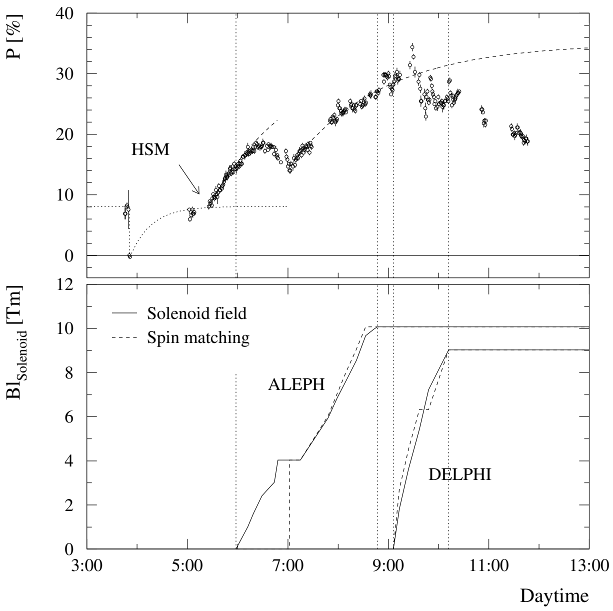

Figure 1: The first polarization measurement in 1993 is shown. The polarization could be increased from 8% to above 30% by deterministic Harmonic Spin Matching (HSM). The depolarizing effect of the unmatched ALEPH solenoid and the spin matching of ALEPH and DELPHI is shown. After spin matching some loss in polarization can be observed. The spin tune (beam energy) was 105.5 during that experiment.

The drop in polarization towards the end of the experiment is explained by side effects from the solenoids on the vertical closed orbit. Polarization up to 57% was measured with all four solenoids successfully spin matched.

The spin precession is described by the spin tune $\nu = a\gamma$. The LEP energies are always set such that the spin tune is close to the half-integer, e.g. $\nu = 101.47$. Then a maximum degree of polarization is expected. Depolarizing spin resonances arise as coupling resonances between the spin precession and the orbital motion. The resonance condition is written as

$$\nu = k \pm k_x Q_x \pm k_y Q_y \pm k_s Q_s$$

where Q_x, Q_y and Q_s are the tunes of the orbital motion and k, k_x, k_y, k_s are any integers. For the LEP standard

*Max-Planck-Institut für Physik, Werner-Heisenberg-Institut, München, Germany.
†Ecole Polytechnique, Paris, France.

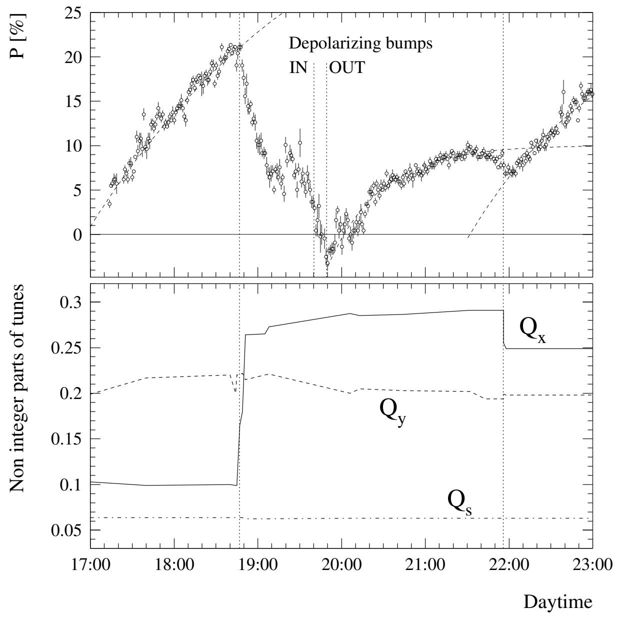

Figure 2: Polarization is shown for different tunes Q_x, Q_y and Q_s. In the beginning polarization above 20% was achieved with polarization tunes. After setting Q_x close to its value in physics coasts polarization degraded to about 8%. The beam was depolarized and the build-up of polarization was measured. When changing Q_x to some other calculated optimum point high polarization came back with a somewhat smaller asymptotic value.

betatron tunes in 1993 ($Q_x = 90.27$ and $Q_y = 76.18$), the $Q_x + Q_y$ resonance shows up at $k + .47$, i.e. just on top of the standard spin tune $\nu = 101.47$. Since this resonance is close to the half-integer depolarization cannot be avoided. Special betatron tunes were therefore chosen for polarization experiments ($Q_x = 90.10$ and $Q_y = 76.20$). Especially the horizontal betatron tune differs significantly from its standard value. Since the tunes can be changed inside a fill this did not prevent energy calibrations at the end of physics fills. The effect from the betatron tunes on polarization is shown in fig. 2.

3 OPTIMIZATION OF POLARIZATION

Radiative beam polarization [2] is observed for LEP at the highest beam energy so far. In the linear approximation the dependence of polarization P on the beam energy E can be written as [3]:

$$P = \frac{92.4\%}{1 + (\alpha E)^2} \tag{1}$$

The constant α was adjusted from SPEAR data (without HSM) and from HERA data (with HSM). Assuming equal imperfections for all storage rings the polarization

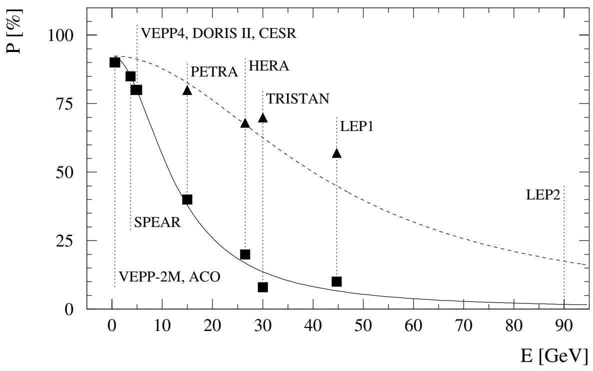

Figure 3: Maximum measured polarization degrees are compared for different storage rings with Harmonic Spin Matching (triangles) and without Harmonic Spin Matching (squares). The measurements from SPEAR and HERA are extrapolated in beam energy using eq. 1. Equal imperfections for all machines and no depolarization from the beam energy spread are assumed.

degrees measured at SPEAR and HERA can be extrapolated in beam energy. In fig. 3 the maximum observed polarization degrees are compared for different storage rings with and without HSM. The polarization degrees are taken from [4, 5, 6]. The polarization decreases as expected with the beam energy E. This shows that the linear approximation is a valid model up to the LEP energy. If higher-order spin resonances would have contributed to the depolarization, the dependence on the energy would be steeper with an exponent larger than 2. This does not mean that these resonances were not present, but that they could be avoided. Before LEP went into operation, strong depolarization by higher-order effects was indeed feared.

From fig. 3 it can be concluded that high transverse beam polarization in LEP can only be established by the use of Harmonic Spin Matching [7]. Due to the well aligned quadrupoles and the precise orbit monitors the strengths of spin resonances can be measured directly in LEP [8]. Harmonic Spin Matching can therefore be applied in an deterministic way. Its effect on polarization was already shown in fig. 1. With Harmonic Spin Matching polarization was always established beyond 35% with a measured maximum of 57% ± 3%. More details on deterministic Harmonic Spin Matching are given in [9].

4 ENERGY CALIBRATION

Due to the achievements in transverse beam polarization the beam energy could be routinely measured at the end of physics coasts. In 1993 a 3-point scan of the Z resonance was done in LEP. About one third of the integrated off-peak luminosity was taken in calibrated fills. Experimental and theoretical studies showed that the average

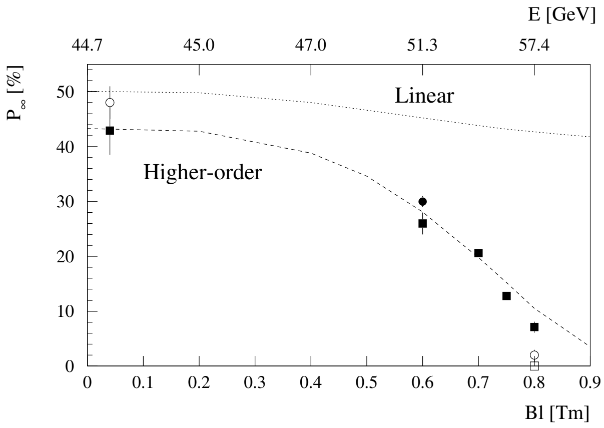

Figure 4: Equilibrium polarization P_∞ as a function of the integrated magnetic field Bl at all damping wigglers. The different symbols indicate results from different experiments. The measurements are compared to calculations in linear and higher-order theory. The upper horizontal scale gives the beam energy needed to get the same energy spread as from the wigglers.

beam energy in LEP can be determined with a precision of much better than 1 MeV. Thus the absolute energy scale of LEP could be determined accurately on three points of the Z resonance, yielding a significant improvement in the knowledge of the mass and width of the Z boson. More details on energy calibration by resonant depolarization in LEP can be found in [10].

5 DEPOLARIZATION DUE TO ENERGY SPREAD

The damping wigglers in LEP vary the beam energy spread without changing the closed orbit in first approximation. They were used to measure the depolarization due to beam energy spread which arises from higher-order spin resonances. This long expected effect was measured in very good agreement with analytical calculations [11, 12] and a prediction by the polarization program SODOM [13]. It was feared that polarization already at LEP1 with 45.6 GeV would be heavily affected from this kind of depolarization. The results, however, show that radiative beam polarization in LEP can be maintained at least up to about 55 GeV.

6 CONCLUSION

1993 was a very successful year for transverse spin-polarization in LEP. Linear and higher-order depolarizing effects were studied in detail and were found in excellent agreement with theoretical calculations. A high beam polarization of $57\% \pm 3\%$ was measured and regular energy calibrations were performed with a precision better than 1 MeV. Transverse beam polarization during physics can be foreseen and would allow almost continuous monitoring of the beam energy. The high transverse polarization level opens the possibility to operate LEP with longitudinally polarized beams in the future.

7 ACKNOWLEDGEMENTS

We would like to thank K. Yokoya for providing us with his program SODOM and Y. Eidelman and D. Barber for helpful discussions.

8 REFERENCES

[1] A. Blondel: "Compensation of Integer Spin Resonances Created by Experimental Solenoids". LEP Note 629 (1990).

[2] A.A. Sokolov and I.M. Ternov: "On Polarization and Spin Effects in the Theory of Synchroton Radiation". Sov. Phys. Dokl. 8(1964)1203.

[3] A.W. Chao: "Latest on Polarization in Electron Storage Rings". SLAC-PUB-3081 (1983).

[4] Yu.M. Shatunov: "Polarized Beams of High Energy Electrons and Positrons". Part. Acc. 32(1990)139.

[5] D.P. Barber. Private communication.

[6] K. Nakajima: "Polarization Study in TRISTAN". Proc. of the 3rd European Particle Accelerator Conf., Berlin, March 1992. H. Henke et al. (eds), Edition Frontieres 1993.

[7] R. Rossmanith and R. Schmidt: "Compensation of Depolarizing Effects in Electron Positron Storage Rings". Nucl. Instr. Meth. Phys. Res., A236(1985)231.

[8] R. Assmann: "Transversale Strahlpolarisation und ihre Anwendung für Präzisionsmessungen bei LEP", Ludwigs-Maximilians-Universität, München, Germany, 1994.

[9] R. Assmann et al.: "Deterministic Harmonic Spin Matching in LEP", in Proc. of the EPAC94, London, Great Britain, June 1994.

[10] R. Assmann et al.: "Energy Calibration with Resonant Depolarization at LEP in 1993", in Proc. of the EPAC94, London, Great Britain, June 1994.

[11] K. Yokoya: "Spin Chromaticity for Higher-Order Synchroton Resonances". Part. Acc. 13(1983)85-93.

[12] C. Biscari, J. Buon and B.W. Montague: "Depolarizing Effects of Quantum Fluctuations and the Action of Non-linear Wigglers on Equilibrium Polarization Level". Nuovo Cimento 81B(1984)128-142.

[13] K. Yokoya: "Non-perturbative Calculation of Equilibrium Polarization of Stored Electron Beams". KEK Report 92-6.