Recent Achievements in Transverse Spin-Polarisation at LEP


Abstract

In 1993 several important achievements on transverse spin polarization at LEP were obtained. The polarization degree was improved from below 15% 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 coast 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 thorough 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.

![Diagram showing polarization measurement and compensation](image)

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 \( \nu = \alpha \gamma \). 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

\[
\nu = k \pm k_x Q_x \pm k_y Q_y \pm k_z Q_z,
\]

where \( Q_x, Q_y \), and \( Q_z \) are the tunes of the orbital motion and \( k, k_x, k_y, k_z \) are any integers. For the LEP standard
Deplarizing bumps

Figure 2: Polarization is shown for different tunes \(Q_z\), \(Q_y\) and \(Q_x\). In the beginning polarization above 20% was achieved with polarization tunes. After setting \(Q_x\) close to its value in physics coats 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 \(k = 4.47\), 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]:

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

(1)

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

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8 REFERENCES