POLARIZATION OF BEAMS IN LEP

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Abstract

Plans are presented for the implementation of polarized beams in LEP Phase 1 up to about 50 GeV. They include polarimeters, enhancement of polarization rate, error correction methods.

1. Introduction

The feasibility of obtaining polarized beams in the Large Electron Positron (LEP) storage ring [1] has been under regular review since the early days of the design studies [2]. In recent years the greatly improved understanding of spin motion in storage rings has given us confidence that highly polarized e^+-e^- beams can be obtained in LEP up to energies in the 50 GeV range and even higher.

The measures that have to be taken to achieve this are similar to those that have been successfully used in PETRA and in other storage rings. However, in this high-energy region the strengths of depolarizing resonances are particulary sensitive to machine imperfections, and the error correction procedures, whilst mainly conventional in principle, require further refinement in their practical application. An important requirement will be fast, high-resolution polarimeters, in order to minimize the time required for the correction process.

Although the size of LEP corresponds to a maximum energy of about 100 GeV, the earlier operation in Phase 1 is likely to be dominated by the physics around the Z^0. Here, polarized beams could be valuable in testing for deviations from the standard model or the existence of right-handed neutral currents, as well as enhancing a number of other measurements [3]. Our plans have therefore concentrated on energies up to 55 GeV. This brings the advantage that depolarizing effects should be somewhat easier to control than at higher energies but the disadvantage that the natural polarization rate from the Sokolov-Ternov effect is rather low. Means must therefore be provided to enhance this rate.

In this paper we outline the plans for implementation of polarized beams in LEP and the means foreseen to avoid depolarization, see also Ref. 4. For a detailed discussion of these topics the reader is referred to the general review paper by one of the present authors [5].

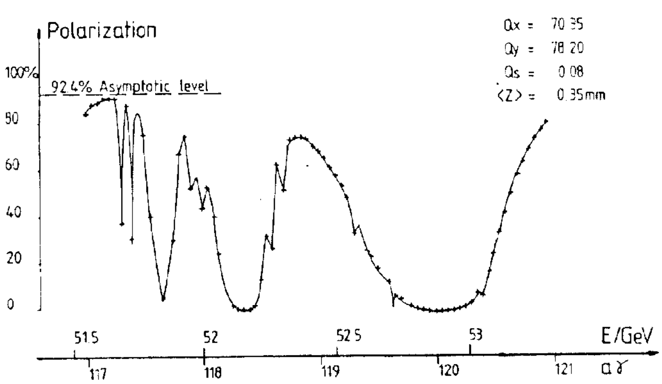

Fig. 1 - Depolarizing effects due to closed orbit distortions as evaluated with the SLIM program. This pattern repeats modulo 4 in the aγ scale.

1) on leave of absence from DESY

2. Depolarizing resonances

The natural polarization in an electron storage ring resulting from the Sokolov-Ternov effect is in competition with the depolarizing action of the spin resonances, which have the general form

$$\nu=\gamma a=k_0+k_xQ_x+k_yQ_y+k_sQ_s.$$

Here $a = (g-2)/2$ is the anomalous part of the gyromagnetic ratio, Q_x, Q_y are the betatron oscillation tunes, Q_s is the synchroton oscillation tune and γ the Lorentz energy factor.

Integers k_x, k_y and k_s, as well as k_0, are related respectively to Fourier components of the closed orbit distorsions, vertical betatron oscillations and dispersion.

The polarization reached in presence of linear spin resonances has been evaluated by means of the program SLIM [6]: and Fig. 1 shows the degree of polarization resulting for LEP with a random vertical closed orbit of 0.35 mm rms. The pattern shown on Fig. 1 is periodic modulo 4 on $a\gamma$ scale. It is clear that a polarization of say 50 % will be obtained only with an extremely well corrected vertical closed orbit and at a suitably selected energy.

Once detected the polarization can be enhanced by a careful tuning of of the closed orbit harmonics n and n+1, around the spin tune $a\gamma$.

Non-linear effects, on the polarization, from closed orbit distorsions and betatron oscillations can be evaluated with the help of the code SITROS [7]. Some preliminary results obtained sofar [8] indicate that the influence of non-linear spin resonances will not be dramatic. Various correction schemes to minimize such effects have been tested at PETRA [9] and they can be adapted to further improve the degree of polarization in LEP.

3. Enhancement of polarization rate

The rate of radiative polarization from the Sokolov-Ternov effect is a very steep function of the energy, varying as γ^5. Whilst in LEP at 100 GeV the polarization time-constant is only seven minutes, at 55 GeV it is about 2 hours. This time can be reduced by increasing the quantum excitation rate with the aid of high-field wigglers [10], i.e. dipole magnets of alternating polarity arranged such that the closed orbit outside the region is unchanged. Such wigglers will be required in LEP for reducing the damping time at injection energy, and also possibly for adjusting the beam dimensions in luminosity optimization. However, if in the wiggler magnets the alternating sections were of equal magnetic field strength, the asymptotic polarization level would be substantially reduced below the theoritical 92.4 %. What is required is an "asymmetric wiggler", in which short strong magnets alternate with long weak magnets, the strong magnets having the same polarity as the normal bending magnets of the machine. In this way the polarization is strongly enhanced in the right direction and only weakly diminished by the magnets of opposite sign.

As a first step in polarization enhancement the LEP damping wigglers have been designed to have a useful degree of asymmetry [11]. Each unit consists of a strong centre pole flanked by two end poles with 30 % of the central field, these ends providing the return flux path for the centre. With this field ratio of 2.5 and the eight wiggler units foreseen, the polarization time at 55 GeV can be reduced from 130 minutes to 50 minutes or less, with an asymptotic polarization level still as high as 77 %. The build-up time as a function of energy is shown in Fig. 2.

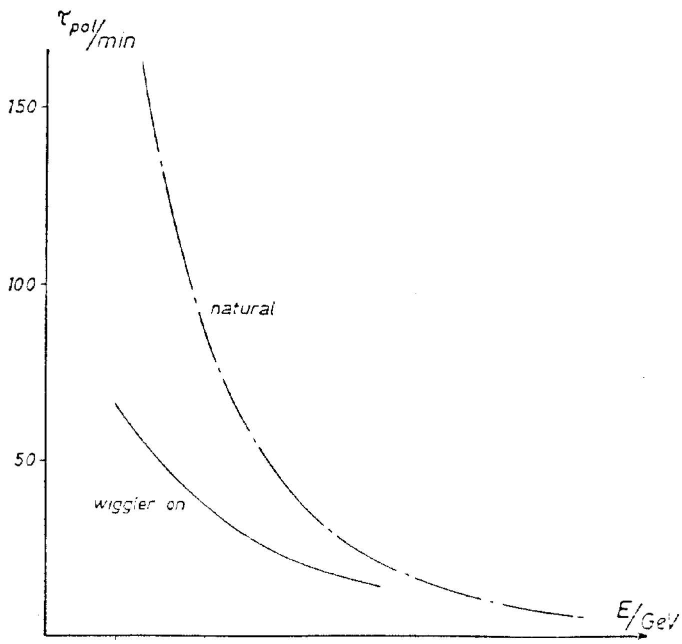

Fig 2 - LEP polarization time constant with and without wiggler action.

4. Laser polarimeters

The most practical means available for measuring the polarization state of e^+ - e^- beams in storage rings makes use of the spin dependence in Compton scattering of laser photons. A circularly-polarized laser beam incident on a vertically-polarized electron beam is back-scattered with an up/down asymmetry in the cross-section, which is greatest for photons scattered at around 90° in the electron rest frame, corresponding to an angle of about $1/\gamma$ to the electron beam in the laboratory. The method has been described in detail by Gustavson et al. [12], together with its embodiment in SPEAR. It has also been used successfully in PETRA [13], VEPP4 [14], DORIS II [15] and CESR [16]. Later at PETRA a laser polarimeter especially designed for high beam energies was installed [17]. In LEP the asymmetry is quite large, see Fig. 5, corresponding to a back-scattered photon energy of around 25 GeV for 50 GeV electrons.

Experience has shown that the laser should be accessible during machine operation, because of the fine optical adjustments required, and it will therefore be located in an optical laboratory near the bottom of Pit 1 outside the machine tunnel. In order to minimize synchrotron radiation background from the arcs, which cannot be filtered out later on because of the high critical energy generated in LEP the interaction point between the laser and electron beams is located in the straight section, so that back-scattered photons emerge from the machine at the beginning of the arc. Good resolution of the $1/\gamma$ (~ 10 μrad) up/down separation requires that the scattering take place in a region where the electron beam has minimum divergence in the vertical plane, i.e. near a vertically-focusing quadrupole.

The schematic layout is shown in Fig. 3. The laser beam from the optical laboratory can be directed towards either of e^+- or e^-- beam.

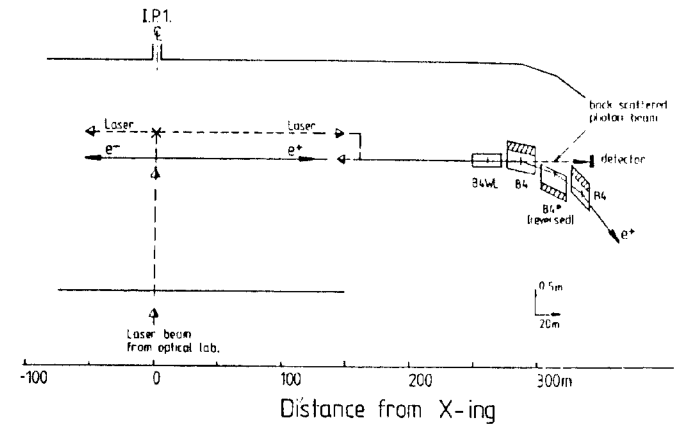

Fig. 3 - Schematic layout of a polarimeter showing the laser path from the optical laboratory and the gamma detector inside the LEP tunnel

Two types of laser are under consideration, an argon-ion laser of around 100 W peak and a Nd-YAG laser of 80 MW peak. The argon laser is capable of operating at the high repetition rate of individual bunch passages, 40 kHz, permitting the detector to measure both position and energy of individual photons. The Nd-YAG laser can only be pulsed at a relatively slow rate and the detector must therefore rely on a calorimeter with only spatial resolution, provided by a collimator slit, because of the high instantaneous photon rate.

In order to make the interaction length as long as possible for improving the scattering rate and minimizing the fluctuations due to synchronization, the beams cross at zero angle. This is made possible, for instance, with the help of a hollow laser beam [18] reflected on axis by a hollow mirror, see Fig. 4.

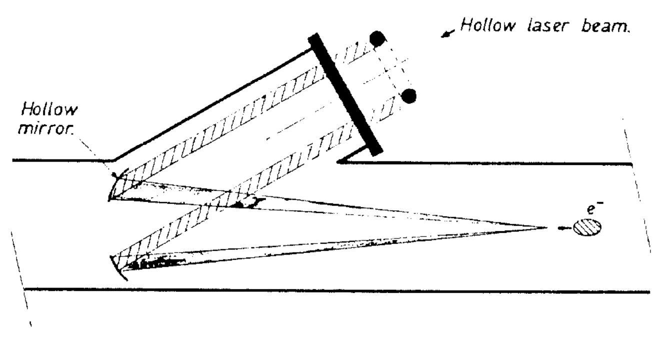

Fig.4 - On axis deflection of a hollow laser beam to provide head-on collision with e^+, e^- bunches.

Polarization is assessed by measuring the vertical asymmetry:

$$A = 2\ (n_+ - n_-)/(n_+ + n_-).$$

n_+ is the number of photons generated with a circularly polarized laser beam of one helicity, n_- with opposite helicity.

The magnitude of A varies with the vertical position. The vertical profile of the backscattered photons and the asymmetries are shown in Fig. 5. In calculating this curve it was assumed that the photons have a wavelenght of 0.5 μm (green light).

In order to provide a free path for the back scattered photons, some modifications are required to the standard design of vacuum chamber in this region. In addition, the second B4 bending magnet must be installed with the yoke reversed, as can be seen in Fig. 3.

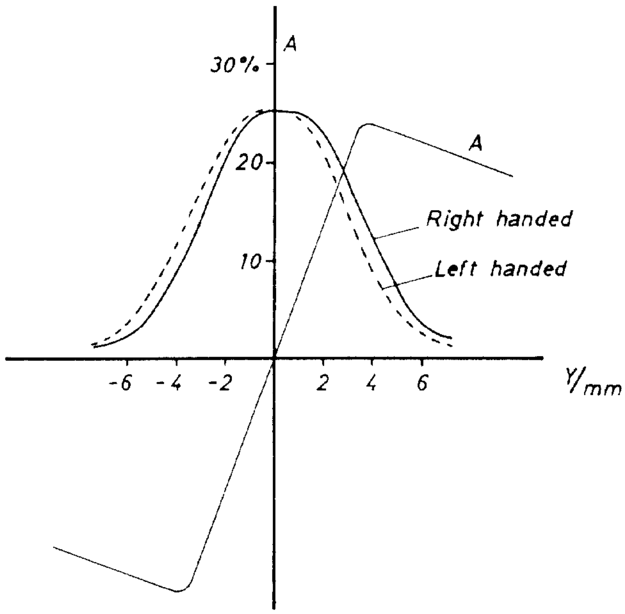

Fig. 5 - Vertical profiles of the backscattered γ beams and related asymmetry for two laser beam helicities.

5. Polarization tests

With these provisions and operating LEP under suitable conditions, as discussed in Ref. 4, we expect to observe polarized beams at an early stage in Phase 1 and to bring the polarization up to a useful level. The first use of this would most likely be the precise measurement of LEP energy.

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