THE TRANSVERSE POLARIMETER FOR LEP

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Abstract: The design of a fast Compton-scattering laser polarimeter for LEP is outlined. Although the design is optimized for LEP at 50 GeV beam, general considerations are extended to LEP energies up to 100 GeV/beam.

Besides a recall of the physics of the polarimeter the study includes considerations on the background and consequent layout of the equipment, the optimization of the laser-electron beam interaction region, the specifications of the laser to fit the LEP energy range and an overview of the devices to be used as detectors for the high energy backscattered γ-beam.

A 50 % polarization level is expected to be measured in a few seconds with an accuracy of $\approx$ 3 %.

1. Introduction

The current knowledge of the problems connected with polarization in LEP suggests good and fast polarimetry as an essential tool for implementing orbit correction strategies to obtain polarized beams. The feasibility considerations described in previous reports [1,2] are summarized here in a proposal containing the specifications to meet these requirements.

The depolarizing effects experienced by the e^+ and the e^- beams can be different mainly due to orbit offsets in quadrupoles connected with distributed machine errors and unsymmetrically excited RF cavities. Although the final aim is to measure the polarization P_e of both beams, it is assumed in the text that the laser photons interact with the electron beam.

The absolute beam energy calibration will be the first application of polarimetry at LEP. In this procedure, already adopted at SPEAR and PETRA, changes in the degree of polarization are monitored as a function of the frequency of a time-dependent perturbing magnetic field, and the average machine energy can be determined with the accuracy of the electron rest mass [3] since the electron gyromagnetic anomaly $a \equiv (g-2)/2 = 1.159652 \cdot 10^{-3}$ is known to a precision of some 10^{-7}.

The success in overcoming the various depolarizing effects will be monitored by the measurement of the absolute level for polarization and will provide useful information for the future plans for longitudinal polarization at LEP.

2. Transverse Polarization in LEP

The radiative Sokolov-Ternov [4] polarization time at the Z_o peak, $\tau_p \approx 6$ hrs, is dissuasive. Eight asymmetric dipole wiggler magnets [5] are foreseen to control emittance, energy spread, damping and polarization times in LEP. The asymptotic polarization level and the polarization time, when all wigglers are excited to their maximum field, are at 46 and 55 GeV :

$$(P_{max})_w \approx 73\ \% \div 78\ \% \qquad (\tau_p)_w \approx 90 \div 50 \text{ min.} \tag{1}$$

A new generation of wigglers has been proposed recently [6] which could reduce even more the polarization time ($\tau_p \approx 36$ min at 46 GeV), without penalizing the asymptotic value.

3. The Laser Polarimeter

Originally suggested by Baier and Khoze [7] the laser polarimeter, based on spin dependent Compton scattering of circularly polarized photons from a high energy electron/positron beam, has become a part of the standard equipment in $e^{\pm}$ storage rings above 1 GeV. The Compton rate is

$$\dot{n}_\gamma = \mathcal{L}\sigma_c(P_e, P_\phi) \tag{2}$$

where $\mathcal{L}$ is the luminosity of the electron beam-laser interaction. The spin-dependent total Compton cross-section $\sigma_c(P_e,P_\phi)$ has been calculated by Lipps and Toelhoek [8].

The backscattered high energy γ-rays travel towards a detector which records their angular distribution, vertically shifted depending on the left-right photon polarization P_ϕ. The absolute value of the electron beam polarization can be derived from

$$P_e = A(y)/\Pi\, P_\phi \tag{3}$$

where the analyzing power Π is averaged over the kinematic region defined by the detector angular acceptance and the up-down asymmetry is

$$A(y) = \frac{n_r(y) - n_\ell(y)}{n_r(y) + n_\ell(y)} \tag{4}$$

n_r and n_ℓ being the counts of the backscattered γ's at a vertical position y, for the two helicities of the laser beam.

Introducing the spin-dependent term Φ_2 of the cross-section σ_c in the electron restframe [8], the asymmetry can be written

$$A(P_e,P_\phi) = \frac{\Phi_2}{\Phi_o} = P_e P_\phi \cos\varphi' \, F(\vartheta',k_o') \tag{5}$$

For a given kinematic situation defined by the angle ϑ' the function $F(\vartheta',k_o')$ is proportional to the incoming photon energy $E_\phi = k_o m_o c^2$

$$k_o' \approx 2\gamma k_o = 2\gamma E_\phi/m_o c^2 \tag{6}$$

The function F in (5) has a maximum around $\vartheta' = \pi/2$ and thus the strongest spin dependence occurs for angles in the laboratory $\vartheta \approx 1/\gamma$.

Two different methods can be adopted to illuminate the electron beam. In the single-photon method the beam is made to interact with the photons produced by a low energy, high repetition frequency laser pulse. The number of backscattered γ's is of the order of one per bunch crossing and the maximum rate is then given by the revolution frequency of the electron bunch. The multi-photon technique, instead, makes use of a high peak power laser to produce about 10^3 γ's per interaction. The maximum γ-rate is limited by the laser repetition rate but the method provides a much more efficient background rejection.

4. Background

The background consists of two components: gas bremsstrahlung and synchrotron radiation.

The total cross-section for the gas bremsstrahlung can be found in [7] :

$$\sigma_{gb}(\varepsilon_s) = 57.3\{6.37\ [\varepsilon_s - \ln(\varepsilon_s)] - 2.34\varepsilon_s^2 - 4.03\} \tag{7}$$

The rate of bremsstrahlung photons from the residual gas in LSS1 with $<Z> = 5$, av.pressure = $5 \cdot 10^{-9}$ Torr, path length = 500 m, $\epsilon_s = k/E \geq 0.2$, is of the order of two photons per interaction with 1 mA/bunch.

The number N_{sr} of s.r. photons/s/mA/m emitted above an energy u/keV as a function of the energy E and the bending radius ρ is given by [10]:

$$N_{sr} = 4.6 \cdot 10^{16} \exp(-0.45\, u\rho/E^3) \sqrt{(E^5/u\rho^3)} \qquad (8)$$

Four sources of s.r. background, namely the standard dipole magnets, the normal conducting quadrupoles, the orbit correctors and the miniwiggler system [11] installed in LSS1 are compared with the 10 % dipole for E = 55 GeV and u = 500 keV in Table I where ϵ_c is the s.r. critical energy, N_d the number of s.r. photons per interaction hitting the detector and P_d the associated deposited energy.

Table I Flux of synchrotron radiation photons with energies higher than 0.5 MeV emitted from the magnetic elements in LSS1 at 55 GeV

Source		ρ (km)	e_c (keV)	N_d 10^{12}ph/mA/s	P_d GeV/crossing
Main dipole		3.096	120	4	$1.4 \cdot 10^5$
10 % dipole		30.96	12	$5.6 \cdot 10^{-17}$	$2 \cdot 10^{-12}$
Quadrupoles		≈ 10	≤ 40	≤ $1.5 \cdot 10^{-3}$	≈ 50
Corr. dipole	100%	2	184	220	$7.5 \cdot 10^6$
	50%	4	92	5.2	$2 \cdot 10^5$
	30%	6.7	55	0.07	$2 \cdot 10^3$
Mini-wigglers		0.877	420	10^3	$3.6 \cdot 10^7$

The figures for P_d in Table I have to be compared with the energy deposited by the γ-beam.

The ≈ 25 GeV average energy of the backscattered γ's raises the signal to ≈ $2.5 \cdot 10^4$ GeV per interaction with the multiphoton technique. The s.r. from the main dipoles is still too high and the layout described in Sec. 5 has been adopted to avoid it.

5. Layout

As shown in Fig. 1 the photon beam produced by a laser installed in the Optical Laboratory in front of IP1 is directed towards the LEP tunnel through a ≈ 16 m long channel. The light is then deflected towards the electron Laser Interaction Region (LIR) located between the quadrupoles QL4 and QL5 ≈ 66 m downstream IP1 and interacts with the electron beam at an angle of 2 mrad (Fig. 2).

The backscattered γ's travel along the whole LSS1 straight section and leave the LEP vacuum chamber at the end of the dipole B4/1 to reach the γ-detector installed at about 275 m from the LIR.

6. The Laser Parameters

The adoption of the multi-photon technique, for its far better S/N ratio, implies the use of high peak power, low repetition rate lasers (50 ÷ 100 MW, ≈ 500 mJ/pulse).

6.1 The Laser Beam Wavelength λ_ϕ

The asymmetry (5) has a maximum around $\vartheta' \approx 90°$ and $k_0' = 1$. This condition states a relationship between the laser energy E_ϕ and the beam energy E for optimum asymmetry :

$$E_\phi\, E = 1.3 \cdot 10^{-7}\ \mathrm{GeV}^2 \qquad (9)$$

In the LEP energy range lasers operating in the visible region ($E_\phi \approx 2.5$ eV) provide maximum asymmetry.

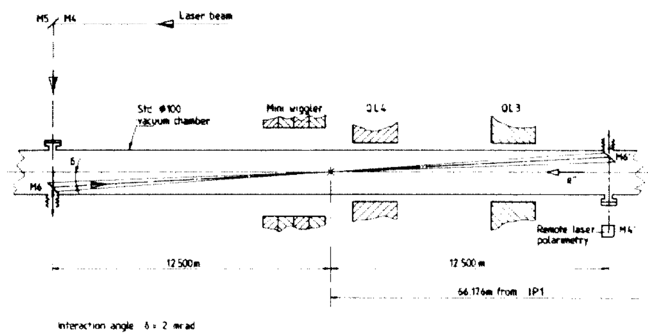

Fig. 2 LIR Layout

6.2 Collision angle and laser beam sizes

The request of providing a small collision angle to maximize the luminosity has to be balanced with the importance of reducing the sensitivity to vertical closed orbit misalignments. Small interaction angles are moreover limited by the position of the last mirror w.r.t. the electron beam. The influence on the luminosity of the laser beam size σ_ϕ at the LIR has been studied for two three-dimensional Gaussian distributions crossing at an angle $2\delta_0$. The relative luminosity is shown in Fig. 3 as a function of σ_ϕ for collision angles $2\delta_0$ = 2, 4 and 6 mrad. Requiring a 10 mm beam-to-mirror M_6 clearance and taking into account the laser beam emittance, a 2 mrad collision angle can be obtained with a nominal rms laser beam size at LIR

$$\sigma_\phi{}^* = 0.6\ \mathrm{mm}. \qquad (10)$$

A smaller size would require a larger collision angle to accommodate the increased mirror dimensions with no net advantage in the luminosity.

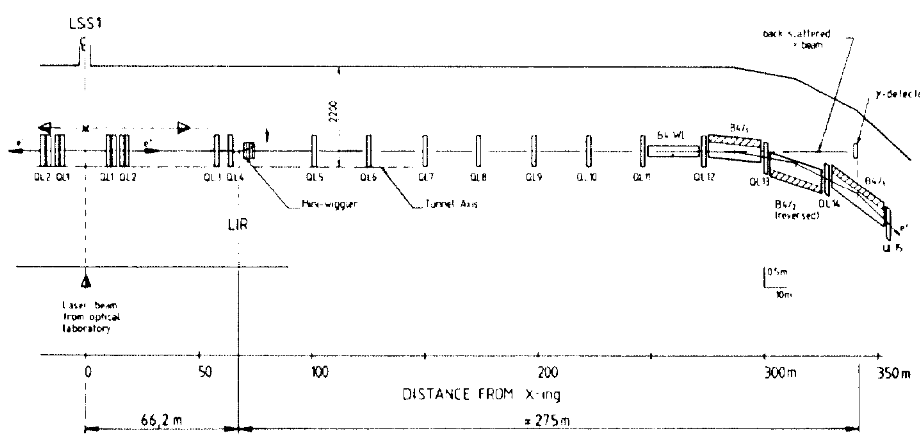

Fig. 1 Polarimeter Layout

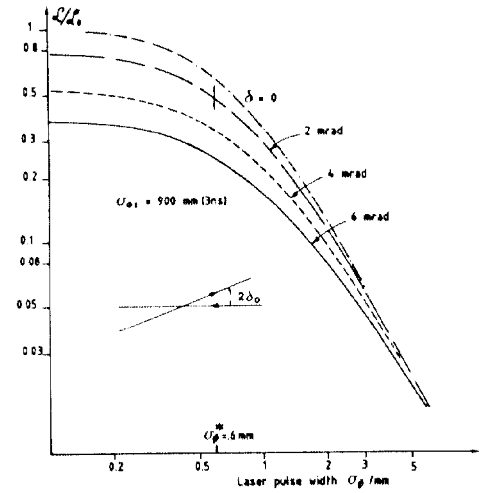

Fig. 3 Luminosity at LIR vs. laser beam width

The dependence of the luminosity on the laser pulse duration $\sigma_{\phi z}$ has been investigated for the interaction with a LEP electron bunch of ≈ 60 ps bunchlength. Figure 4 shows that a laser pulse length $\sigma_{\phi z}$ = 3 ns would provide a luminosity only 20 % below the asymptotic value, which is acceptable.

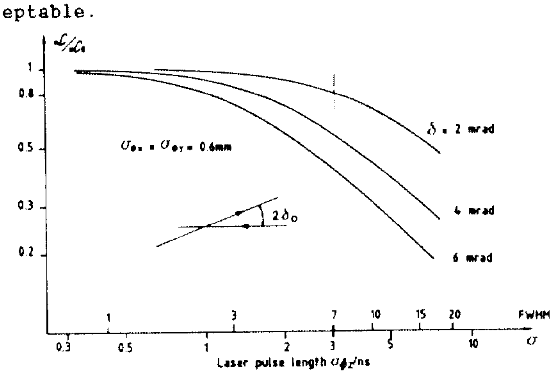

Fig. 4 Luminosity at LIR vs. laser pulse length

7. Considerations on the γ-Detector

To resolve the small vertical asymmetry of the backscattered γ's high density tungsten/silicon calorimeters similar to those developed for the Bhabha detectors [12] are best suited. A first tungsten layer will let the γ-shower develop while filtering out most of the s.r. flux. Two silicon strip planes will allow to check the profiles of the incoming γ's during the calibration phase (Fig. 5).

The detector has an horizontal plane of symmetry allowing for simultaneous recording of the γ's above and below the center of gravity of their vertical distributions. The number of counts $n_{ru,d}$ and $n_{\ell u,d}$ recorded in the upper and the lower half of the detector for right- and left-handed photon helicities are combined to give the asymmetry

$$A = \frac{n_{ru} - n_{\ell u} + n_{\ell d} - n_{rd}}{n_{ru} + n_{\ell u} + n_{\ell d} + n_{rd}} \qquad (11)$$

The asymmetry A is insensitive to systematic errors from drifts in the closed orbit at LIR. An analogous algorithm can be set up to monitor any systematic vertical offset at the detector, and this information will be used for a position feedback.

The evaluation of the analyzing power of the polarimeter gives

$$\Pi\ (P_\phi = 1) = \frac{\partial A}{\partial P_e} \approx 14\ \% \qquad (12)$$

8. Rates, Accuracies and Measuring Time

The adoption of the multi-photon technique and the availability of a laser fulfilling the recommendations of Section 6 would provide a Compton γ-rate : $r_\gamma \approx (1 \div 3)\cdot 10^4$ Hz. The measuring time in terms of P_e, Π and of the relative statistical accuracy δA/A is collected in Table II.

Table II Measuring time vs. P_e and δA/A

P_e (%)	A (%)	δA/A (%)	T_{meas} (s)
70	9.8	3	6
		10	0.5
50	7	3	11
		10	1
10	1.4	3	280
		10	25

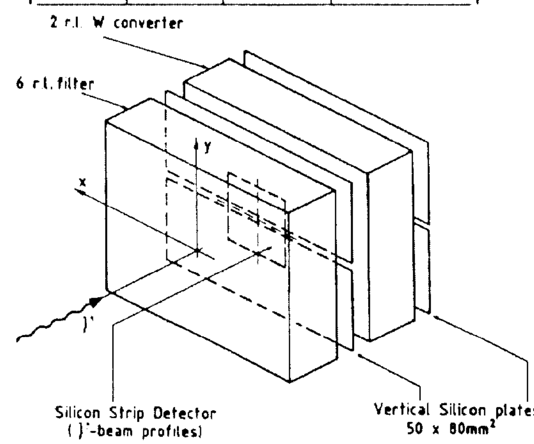

Fig. 5 Schematic of the γ-Detector

9. Conclusions

- The choice of a layout avoiding synchrotron radiation from the main dipoles and the adoption of the multiphoton method provides a favourable signal to noise ratio in the measurement of the asymmetry.
- Laser specifications fulfilling the multiphoton requirements have been defined. They can be met by commercially available devices.
- The optimization of the laser beam optics and specifically of the interaction geometry appears to provide promising performance.
- When LEP is operated at an energy of ≈ 55 GeV with the existing wigglers, the polarimeter is powerful enough to monitor the polarization build-up at a rate of about 1 % per minute.

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