Presentation 48

Polarimeter Performance and Operation

By M. Placidi

48.1 Introduction

The LEP laser polarimeter has been designed [1] and installed [2] to provide fast monitoring of polarisation changes. It will be used to optimise orbit correction strategies needed to improve the polarisation level presently limited by optics imperfections like betatron coupling and residual vertical dispersion [3]. The procedures adopted in the commissioning of the polarimeter have been described in detail in [4] and are briefly recalled here. The experimental results obtained from the first measurements of transverse polarisation at the end of the 1991 LEP run are presented together with the optics manipulations developed to check the consistency of the observed polarisation signal.

48.2 Spin-Dependent Compton Scattering

The differential Compton scattering cross section expressed in terms of the electron and photon polarisation states in the $e^{\pm}$-rest frame [5] [6] is:

$$\frac{d\sigma_c(\vec{\xi},\vec{P_e})}{d\Omega} = \frac{1}{2}\left(r_e\frac{k'}{k'_0}\right)^2 \left[\Phi_0 + \Phi_1\left(\vec{\xi}\right) + \Phi_2\left(\vec{\xi},\vec{P_e}\right)\right] \tag{48.1}$$

where $r_e = e^2/m_e c^2$ = classical electron radius
k'_0, k' = incident and scattered photon momenta
$\vec{P_e} \equiv (P_x, P_y, P_z) = e^{\pm}$ Polarisation vector
$\vec{\xi} \equiv (\xi_1, \xi_2, \xi_3)$ = Photon Polarisation vector in terms of the normalised Stokes parameters ($\sum_{i=1}^{3} \xi_i = 1$).

In the general case of transverse ($P_x = 0, P_y \equiv P_\perp$) and longitudinal ($P_z \equiv P_{||}$) beam polarisation, the differential cross section (1) reads:

$$\begin{aligned} \frac{d\sigma_c(\vec{\xi},\vec{P_e})}{d\Omega} = & \frac{1}{2}\left(r_e\frac{k'}{k'_0}\right)^2 \Big\{1 + cos^2\theta' + (k'_0 - k')\ (1 - cos\,\theta') \\ & + \xi_1\, sin^2\,\theta' \\ & - \xi_3\, P_\perp\, \left[(1 - cos\,\theta')\, k'\, sin\,\theta'\right]\, sin\,\phi' \\ & - \xi_3\, P_{||}\, \left[(1 - cos\,\theta')\ (k'_0 + k')\ cos\,\theta'\right]\Big\} \end{aligned} \tag{48.2}$$

Circular light ($\xi_3 \neq 0$) produces asymmetry via the Φ_2 term in presence of transverse or longitudinal beam polarisation. In both cases an asymmetry function $A(y)$ can be defined:

$$A(y) = \frac{n_R(y) - n_L(y)}{n_R(y) + n_L(y)} = \frac{\Phi_2(\vec{\xi}, \vec{P_e})}{\Phi_0} \tag{48.3}$$

where $n_{R,L}(y)$ are the γ-rates at a vertical position y for right and left circular light, or horizontal and vertical linear light.

48.3 The LEP Polarimeter

The LEP polarimeter is installed in LEP straight section at IP1 to monitor the transverse polarisation of the electron beam. A Nd-YAG laser in the Optical Laboratory generates 12 ns long, 50 mW light pulses at a $\sim$ 30 Hz repetition rate. The 532 nm wavelength light is guided over 115 m to the Laser Interaction Region (LIR) by five multilayer dielectric mirrors in a roughly evacuated transport line, steered onto the incoming electron beam by the in-vacuum Ag-coated Cu mirror M_6 and finally analyzed in the optical box outside the LIR. Photons in an energy range of 5-28 GeV are backscattered in the direction of the incoming electrons and their transverse profiles recorded $\sim$ 247 m downstream in a detector constituted of silicon strip planes behind a remotely controlled variable-thickness lead absorber.

Changes in the shape of the vertical γ-distributions originating from asymmetry properties of the Compton cross section provide the observable beam polarisation signal. The associated centre-of-gravity shift (*mean-shift*) of the distribution is proportional to the photon and electron degree of polarisation :

$$\Delta\langle Y\rangle = \kappa\, \xi_3\, P_\perp \tag{48.4}$$

In our case the "analyzing power" κ (total centre-of-gravity shift for unit electron and photon polarisation) evaluated at 46.5 GeV is :

$$\kappa = 500 \pm 30\,\mu\text{m}.$$

48.4 Results

The polarimeter was commissioned and optimised as far as possible by running in parasitic mode on physics runs and adjusting the M_6, M_6' mirror positions at the LIR to avoid any perturbation to the accelerated beams. Progress in the strategies adopted to optimise the laser-e^- beam relative alignment for the best overlap, to steer the electron orbit at the LIR for optimum transmission of the recoil photons and to define the detector parameters saved the allocated MD time for polarisation studies.

The optical section installed on a bench at the laser output provides full control of the light polarisation state. A rotating $\lambda/2$ plate and an adjustable $\lambda/4$ plate can produce any elliptical light state, from linear to circular. Linear light has proved fruitful to the setting up of the polarimeter since for ($\xi_1 \neq 0$) the Compton cross section does not depend on beam polarisation (Equ. (2)).

A "push-pull" $\lambda/2$ plate positioned after the first two optical retarders introduces an additional π phase-shift, thus reversing once more the handedness. This provides a simple way to correlate the observed sign reversal in the measured mean-shift to the polarisation signal.

The ellipticity of the light at the LIR was controlled in the optical section by timing the angular position of the rotating plate with respect to the laser pulse to compensate for depolarising effects from elements in the transport line (reflections, birefringence etc.) which would spoil an initially perfect circular light.

Period	χ^2/D.F. of the fit	P_∞ (%) (fit)	P_∞ (%) (expected)	Conditions and comments
1	0.99	$9.1 \pm 0.6 \pm 1.2$		asymptotic polarisation
2	1.07	$5.1 \pm 0.6 \pm 1.6$	7.4	excitation of ν_s=106 (20 %)
3	0.74	$2.5 \pm 1.6 \pm 1.3$	0.3	excitation of ν_s=106 (100 %)
4	1.26	$11.5 \pm 3.1 \pm 2.1$	9.1	natural rise
5	4.4	$0.6 \pm 0.6 \pm 1.7$	2.1	RF trips, solenoid bumps ON
6	1.3	$1.9 \pm 0.7 \pm 1.2$	2.1	stable beam, solenoid bumps ON
7	2.36	$9.1 \pm 0.3 \pm 1.3$	9.1	asymptotic polarisation
8	0.62	$2.0 \pm 0.6 \pm 1.2$	1.2	excitation of ν_s=106 (50 %)
9	2.4	$11.7 \pm 2.4 \pm 2.7$	9.1	natural rise

Table 48.1: Summary of fits to the polarisation measurements for different optics conditions. The errors, statistical and systematic, include: a possible 5 μm systematic shift in $\Delta\langle Y\rangle$, uncertainties in the transition time between consecutive conditions (periods 2,3,4,9), and scale factor for the goodness-of-fit (periods 5,7,9). Expected asymptotic values [4] are also shown for comparison.

A good agreement has been found between simulated and measured asymmetries for linear and circular light: the predicted $\pm 11\%$ maximum asymmetry for linear light has been experimentally confirmed while measurements with circular light are found compatible with a transverse beam polarisation of $\sim 9\%$.

With an effective 85% degree of circular polarisation, measured at the optical box outside the LIR, a mean-shift $\Delta\langle Y\rangle$ of $\sim 40\,\mu$m was detected when switching from left to right circular light. The shift vanished when using linearly polarised light. The polarisation data have been collected at a beam energy of 46.5 GeV (ν_s = 105.55) and are shown in terms of the mean shift $\Delta\langle Y\rangle$. Negative $\Delta\langle Y\rangle$ values correspond to measurements with the push-pull $\lambda/2$ plate in "IN" position. The associated polarisation levels from (4) are collected in Table 48.1 and subdivided into 9 periods of time according to different optics manipulations.

48.5 Conclusions and Future Plans

The commissioning and the studies of the polarimeter with linearly and circularly polarised light produced the expected results. The centre-of-gravity shift measurements with right and left circularly polarised light indicated an asymmetry compatible with a degree of polarisation of $\sim 9\%$. In agreement with simulations, the shift vanished when illuminating the beam with linear light and no changes in the peak height and the rms width of the distributions were observed with circularly polarised light.

The LEP polarisation program for 1991 aims for an absolute beam energy calibration to an accuracy of some 10^{-5}. Improvements in the performance of the polarimeter are being implemented to cope with the polarisation studies which will be devoted to improve the level of polarisation on the present optics, to study the behaviour of the new wigglers expected to reduce the natural polarisation time ($\sim$ 5.5 h at the Z^0 energy) to about 35 min and to develop a new optics capable of producing appreciable polarisation level at the Z^0 resonance and in physics conditions.

48.6 Acknowledgements

The measurements reported here are the result of a close collaboration between IN2P3 (France), MPI (Munich) and CERN. The authors wish to acknowledge the encouragement and the strong support to the polarisation program at LEP from the SL and PPE Divisions and the LEP users community. The realisation of the polarimeter, its commissioning and the polarisation studies could never have been accomplished in a relatively short time without the active participation and the skill of colleagues in the Beam Instrumentation, Accelerator Physics and Operation groups. Credit goes to the LEP users community for having granted to the measurements the last 24 hours period of the 1990 LEP physics program.

References

[1] M. Placidi, R. Rossmanith, NIM A274 (1989) 79-94.
[2] M. Placidi *et al.*, 2nd European Particle Acc. Conf., Nice, 1990.
[3] J.P. Koutchouk, this Conference.
[4] J. Badier *et al.*, LEP Performance Note 42, December 1990.
[5] U. Fano, J. Opt. Soc. Am., (1949) 39, 859.
[6] F.W. Lipps and H.A. Toelhoek, Physica XX (1954) 85, 395.
[7] V.N. Baier and V.A. Khoze, Sov. J. Phys. 9 (1969) 238.