OBSERVATION OF TRANSVERSE POLARIZATION IN LEP

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Abstract We present and discuss the experimental results on the observation of transverse polarization in LEP at 46.5 GeV/beam. The level of transverse polarization was determined by monitoring the mean shift of the vertical distributions of the backscattered photons under helicity reversal of the circularly polarized laser light. Plans for polarization studies and absolute LEP energy calibration are presented.

1 Introduction

A significant asymmetry was observed in the Compton back-scattered photon distribution when illuminating the LEP electron beam with circularly polarized light. The associated polarization level is estimated to be 9.1% ± 0.3% (statistical) ± 1.2% (systematic) [1], [2]. The validity of the polarization signal was assessed by exciting a depolarizing resonance. The measurement is consistent with the polarization degree predicted for the especially prepared optics and the amplitude of the effect is consistent with the observed polarization rise-time.
This report summarizes the results obtained during the 1990 machine physics period granted to the polarization program.

2 Compton polarimetry

Laser polarimetry is based on spin-dependent Compton scattering of circularly polarized photons from polarized charged particles [3]. The differential Compton scattering cross section in terms of the electron and photon polarization states in the $e^{\pm}$ rest frame [4] reads, for transverse ($P_\perp$) and longitudinal ($P_\parallel$) beam polarization :

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

where $r_e = e^2/m_ec^2$ = classical electron radius,
k'_o, k' = *incident* and *scattered* photon momenta,
θ', ϕ' = scattering and azimuthal angles and
$\vec{\xi} \equiv (\xi_1,\xi_2,\xi_3)$ = photon polarization vector in terms of the normalized Stokes parameters ($\sum_{i=1}^{3}\xi_i = 1$).

Circular light ($\xi_3 \neq 0$) produces asymmetry in presence of beam polarization. In the transverse case the vertical distribution $n_{R,L}(y)$ of the backscattered γ's for left (L) and right (R) photon helicity is asymmetric due to the ϕ'-dependence in (1).

A *transverse* asymmetry function $A_T(y)$ is defined the amplitude of which depends on the photon and beam polarization level through the *transverse* analyzing power Π_T and which flips sign according to the photon helicity ξ_3 :

$$A_T(y) = \frac{n_R - n_L}{n_R + n_L} = P_\perp\,\xi_3\,\Pi_T(\theta',k'_o)\,sin\,\phi'. \tag{2}$$

The asymmetry (2) is related to the *mean shift* $\Delta\langle Y\rangle$ between the center-of-gravity of the two γ-distributions produced by the helicity states $\xi_3 = \pm 1$ in (1):

$$\Delta\langle Y\rangle = \kappa\,\xi_3\,P_\perp\,, \tag{3}$$

where the *mean-shift for full electron and photon polarization* κ was simulated for our polarimeter :

$$\kappa = 500 \pm 30\,\mu\mathrm{m}. \tag{4}$$

3 Polarimeter

The LEP polarimeter [5] [6] installed in the LSS1 straight section monitors the transverse polarization of the *electron* beam. A Nd-YAG laser generates 90 mJ, 12 ns pulses at 30 Hz repetition rate from an Optical Laboratory about 15 m off the LEP tunnel. The 532 nm wavelength light is guided over a distance of 115 m to the Laser Interaction Region (LIR) in a roughly evacuated transport line including three lenses and five dielectric mirrors. Final steering onto the electron beam under an interaction angle of 2 ÷ 3 mrad is provided by $(Ag + Mg\,F_2)$-coated Cu mirrors.

In *multi-photon* operation mode hundreds of photons per laser shot are backscattered in an energy range of 5-28 GeV and their transverse profiles are recorded in a silicon strip detector installed 247 m downstream the LIR [7].

4 Dedicated machine configuration

Although the aim of the experiment was to establish polarization at the Z^0 resonance (ν_s = 103.5) the LEP *energy* was set to 46.5 GeV (ν_s = 105.53) to be far enough from the strong spin resonance "103" driven by the coupling fields and which spoils any polarization at the Z^0 for the (71/77) optics adopted in the 1990 run [8] :

$$\nu_s = Q_{int} + k\, S_b \tag{5}$$

($S_b = 8$ is the LEP lattice superperiodicity, k any integer).

Spin resonances in LEP are considerably large compared to the resonance spacing and lowering the fractional part of the betatron tunes helps in separating the betatron spin resonances from the half integer. A *low-tune* optics simulated with realistic lattice imperfections predicted a reasonable polarization level and was prepared for polarization studies. The working point was finally set as :

$$Q_x = 71.12,\ Q_y = 77.20,\ Q_s = 0.085 \tag{6}$$

Residual *vertical closed orbit* and *dispersion* are at the origin of many depolarizing phenomena. Special efforts were undertaken to push the orbit correction procedure to reduce the vertical closed orbit and hence the spurious dispersion to the very good result :

$$\sigma_y^{c.o.} = 0.53\,\mathrm{mm}, \qquad \langle D_y \rangle = 13\,\mathrm{cm}.$$

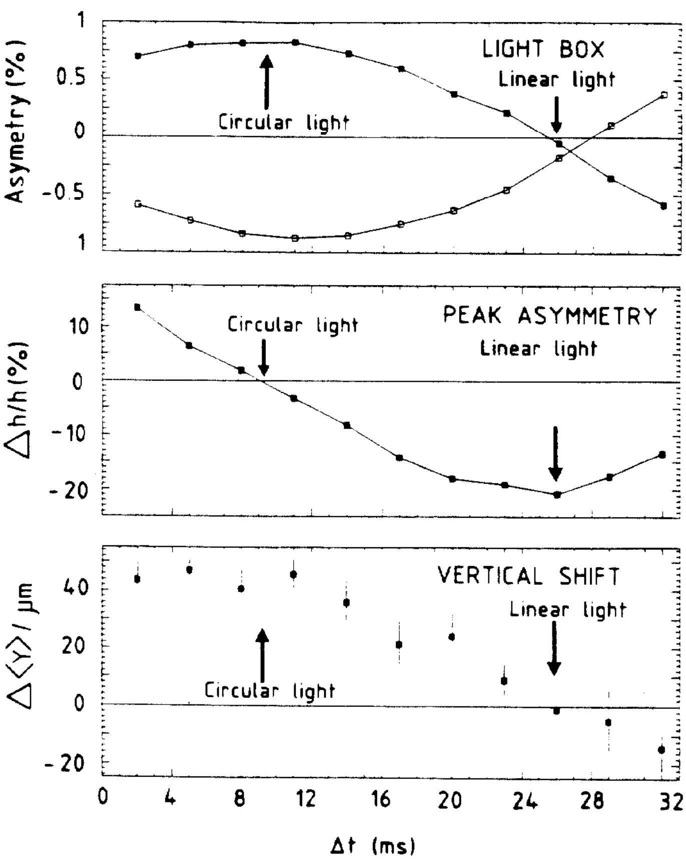

Figure 1: Optimization of the light polarization states.

5 Commissioning and results

The *Optical Section* in the laser line [7] was used to control the light polarization states. A rotating $\lambda/2$ plate and a $\lambda/4$ plate produce any elliptical light state, from linear to circular. Measurements with linear light ($\xi_1 \neq 0$) were performed for the setting up of the polarimeter since in this case the Compton cross section (1) does not depend on beam polarization.

A "push-pull" $\lambda/2$ plate was sometimes used to introduce an additional π phase-shift, thus reversing once more the light handedness and providing a cross check correlation between the sign reversal of the measured $\Delta\langle Y \rangle$ and the effective polarization signal.

The quality of the light polarization states at the interaction point was monitored with the analyzing box at the LIR and controlled from the optical section by timing the angular position of the rotating $\lambda/2$ plate w.r.t. the laser pulse arrival time (Fig. 1) to compensate for depolarizing effects from optical elements in the transport line.

Profile asymmetries measured with linear and circular light (Fig. 2) turned out to be in good agreement with simulation. The predicted $\pm 11\%$ maximum asymmetry for linear light was reproduced and the $P_\perp$-dependent asymmetry with circular light was compatible with a $\sim 9\%$ transverse beam polarization.

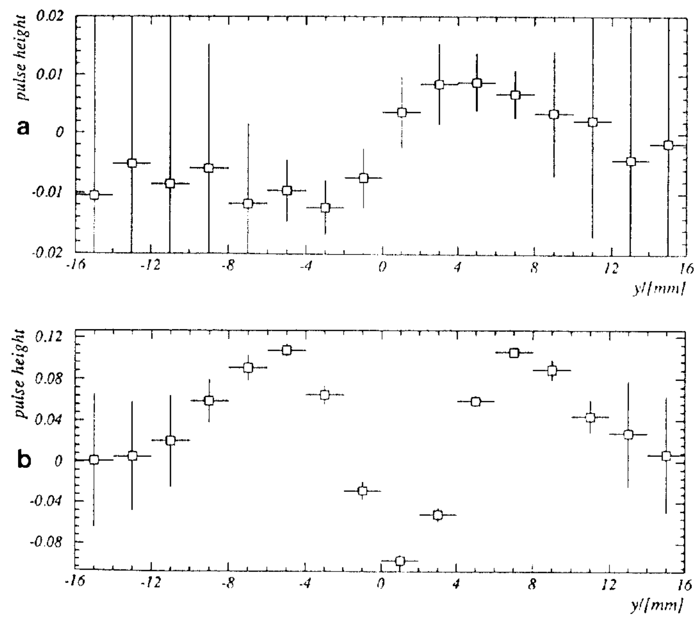

Figure 2: Measured asymmetry for circular (a) and linear (b) laser light.

A mean-shift $\Delta\langle Y \rangle$ of $\sim 40\,\mu$m was detected when illuminating the beam with left or right circularly polarized light with an effective 85% degree of polarization. The signal vanished when using linear light.

The polarization data in terms of the mean shift $\Delta\langle Y \rangle$ are shown in Fig. 3 and the associated polarization levels from (3) and (4) are collected in Table I for 9 periods of time corresponding to different optics manipulations.

6 Conclusions and future plans

The measurement of the centre-of-gravity shift of the recoil γ-distributions with right and left circularly polarized

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 polarization
2	1.07	$5.1 \pm 0.6 \pm 1.6$	7.4	excitation of $\nu_s = 106$ (20% level)
3	0.74	$2.5 \pm 1.6 \pm 1.3$	0.3	excitation of $\nu_s = 106$ (100% level)
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 polarization
8	0.62	$2.0 \pm 0.6 \pm 1.2$	1.2	excitation of $\nu_s = 106$ (50% level)
9	2.4	$11.7 \pm 2.4 \pm 2.7$	9.1	natural rise

Table 1: Summary of fits to the polarization 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 [1] are also shown for comparison.

light indicated an asymmetry compatible with a degree of polarization of $\sim$ 9%. Changes in the peak height and in the rms of the distributions were observed, in agreement with simulations, when running the polarimeter with linear light. The use of the push-pull half-wave plate caused the mean shift to invert sign confirming that the observed polarization signal was consistent with the nature of the laser light and not artificially generated in the data acquisition system or in the light control optical section.
The polarimeter reacted as expected when the beam was deliberately depolarized: the amplitude of the mean shift decreased and came back to the previous level after switching off the depolarizing source. The polarization signal followed the expected optical manipulations in a way that could not be explained by systematic or random effects.

Application of polarimetry to absolute beam energy calibration has been given priority for the 1991 LEP run. A new (70/76) optics has been prepared which is expected to provide a promising polarization level at the Z^0 energy.

References

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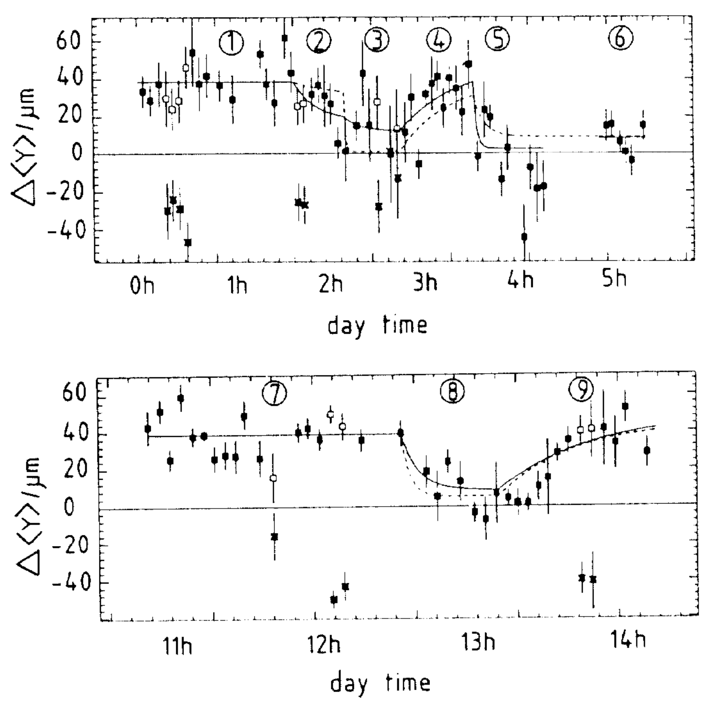

Figure 3: Experimental results in terms of mean shift $\Delta\langle Y\rangle$ at a beam energy of 46.5 GeV (ν_s = 105.53). Expected behavior from applied depolarizing resonances (dotted line) is compared to the experimental data fit. Negative $\Delta\langle Y\rangle$ values represent *check measurements* with the push-pull $\lambda/2$ plate in "IN" position.