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FIRST EVIDENCE OF TRANSVERSE POLARIZATION IN LEP

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Abstract

Results on first experimental evidence of transverse polarization in LEP at $E = 46.5$ GeV ($v_s = 105.55$) are reported. The polarization level associated to the significant asymmetry observed in the Compton back-scattered photon distribution when illuminating the electron beam with circularly polarized laser light is estimated to be $9\% \pm 2\%$ (systematic) $\pm 2\%$ (statistical). The validity of the polarization signal was assessed by exciting a depolarizing resonance. The measurement is consistent with the predicted polarization degree with the especially prepared polarization optics.

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ABSTRACT

Results on first experimental evidence of transverse polarization in LEP at $E = 46.5$ GeV ($\nu_s = 105.55$) are reported. The polarization level associated to the significant asymmetry observed in the Compton back-scattered photon distribution when illuminating the electron beam with circularly polarized laser light is estimated to be $9\% \pm 2\%$ (systematic) $\pm 2\%$ (statistical). The validity of the polarization signal was assessed by exciting a depolarizing resonance. The measurement is consistent with the predicted polarization degree with the especially prepared polarization optics.

1 INTRODUCTION

A fast laser polarimeter has been designed [1] and installed [2] as an essential tool to optimize orbit correction strategies expected to improve the polarization level in LEP, presently limited by optics imperfections like betatron coupling and residual vertical dispersion [3]. The procedures adopted in the commissioning of the polarimeter are described in [4] and briefly recalled here. Experimental results on the first measurements of transverse polarization at LEP are presented together with the optics manipulations developed to check the consistency of the observed polarization signal.

2 SPIN-DEPENDENT COMPTON SCATTERING

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

$$\frac{d\sigma_c(\vec{\xi}, \vec{P}_e)}{d\Omega} = \frac{1}{2} \left(r_e \frac{k'}{k_0} \right)^2 \left[\Phi_0 + \Phi_1(\vec{\xi}) + \Phi_2(\vec{\xi}, \vec{P}_e) \right] \quad (1)$$

where $r_e = e^2/m_e c^2$ = classical electron radius

k'_0, k' = incident and scattered photon momenta

$\vec{P}_e \equiv (P_x, P_y, P_z) = e^\pm$ Polarization vector

$\vec{\xi} \equiv (\xi_1, \xi_2, \xi_3)$ = Photon Polarization vector in terms of the normalized Stokes parameters ($\sum_{i=1}^3 \xi_i = 1$).

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

$$\begin{aligned} \frac{d\sigma_c(\vec{\xi}, \vec{P}_e)}{d\Omega} = & \frac{1}{2} \left(r_e \frac{k'}{k_0} \right)^2 \left\{ 1 + \cos^2 \theta' + (k'_0 - k') (1 - \cos \theta') \right. \\ & + \xi_1 \sin^2 \theta' \\ & - \xi_3 P_\perp [(1 - \cos \theta') k' \sin \theta'] \sin \phi' \\ & \left. - \xi_3 P_\parallel [(1 - \cos \theta') (k'_0 + k') \cos \theta'] \right\} \end{aligned} \quad (2)$$

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

$$A(y) = \frac{n_R(y) - n_L(y)}{n_R(y) + n_L(y)} = \frac{\Phi_2(\vec{\xi}, \vec{P}_e)}{\Phi_0} \quad (3)$$

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.

3 THE LEP POLARIMETER

The LEP polarimeter, based on spin-dependent Compton scattering of circularly polarized photons from polarized particles [7], is installed in the LEP LSS1 straight section to monitor the transverse polarization of the electron beam. A Nd-YAG laser in the Optical Laboratory (Fig. 1) generates 12 ns long, 50 mW light pulses at a ~ 30 Hz repetition rate.

Figure 1: Optical layout of the LEP laser polarimeter.

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 ~ 247 m downstream in a detector constituted of silicon strip planes behind a remote 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 polarization signal. The associated centre-of-gravity shift (*mean-shift*) of the distribution is proportional to the photon and electron degree of polarization :

$$\Delta\langle Y \rangle = \kappa \xi_3 P_\perp \quad (4)$$

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

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

Figure 2: Measured asymmetry for linear and circular laser light.

4 RESULTS

The polarimeter was commissioned and optimized mainly running in parasitic mode on physics runs by adjusting the mirror positions at the LIR to avoid any perturbation to the accelerated beams. Progress in the strategies adopted to optimize 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 could be achieved saving the allocated MD time for polarization studies.

The optical section installed on a bench at the laser output is used to control the light polarization. A rotating $\lambda/2$ plate, a $\lambda/4$ plate and a "push-pull" $\lambda/2$ plate 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 polarization (Equ. (2)). The push-pull $\lambda/2$ plate 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 polarization signal (Fig. 3).

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

In Fig. 2 an example is shown of measured asymmetries for linear and circular light. Good agreement with simulation is found in both cases: the predicted $\pm 11\%$ maximum asymmetry for linear light is obtained and measurements with circular light are compatible with a transverse beam polarization of $\sim 9\%$.

With an effective 85% degree of circular polarization, measured at the optical box outside the LIR, a mean-shift $\Delta\langle Y \rangle$ of $\sim 40 \mu\text{m}$ was detected when switching from left to right circular light. The shift vanished when using linearly polarized light. The polarization data collected at a beam energy of 46.5 GeV ($\nu_s = 105.55$) are shown in Fig. 3 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 polarization levels from (4) are collected in Table I and subdivided into 9 periods of time according to different optics manipulations.

5 CONCLUSIONS AND FUTURE PLANS

The commissioning and the studies of the polarimeter with linearly and circularly polarized light produced the expected results. The centre-of-gravity shift measurements with right and left circularly polarized light indicated an asymmetry compatible with a degree of polarization of $\sim 9\%$. According to 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 polarized light.

The LEP polarization program for 1991 contemplates the 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 polarization studies which will be devoted to improve the level of polarization on the present optics, to study the behaviour of the new wigglers expected to reduce the natural polarization time (~ 5.5 h at the Z^0 energy) to about 35 min and to develop a new optics capable of producing appreciable polarization level at the Z^0 resonance and in physics conditions.

Figure 3: Experimental results in terms of mean shift $\Delta\langle Y \rangle$. The level of transverse polarization is evaluated from (4) for $\kappa = 500 \mu\text{m}$, as resulting from simulations, and $\xi_3 = 85\%$ measured circular laser light. The expected behaviour from applied depolarizing resonances (dotted line) is compared to the experimental data fit. Negative $\Delta\langle Y \rangle$ values represent measurements with the push-pull half wave plate in "IN" position.

Period	$\chi^2/\text{D.F.}$ 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 %)
3	0.74	$2.5 \pm 1.6 \pm 1.3$	0.3	excitation of $\nu_s=106$ (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 polarization
8	0.62	$2.0 \pm 0.6 \pm 1.2$	1.2	excitation of $\nu_s=106$ (50 %)
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 $5\mu\text{m}$ 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.

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