DESIGN AND FIRST PERFORMANCE OF THE LEP LASER POLARIMETER

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Abstract A laser polarimeter has been installed in LEP to measure the transverse beam polarization. After recalling the optimization criteria adopted in the design we describe the layout in connection with background considerations. First commissioning results with backscattered gammas are compared with the expected performance and limits to the lowest detectable $e^{\pm}$ polarization level are quoted on the basis of the sensitivity of the polarimeter.

1 Introduction

Present transverse polarization in LEP is expected to be limited by several drawbacks like betatron coupling and residual vertical dispersion. As a consequence a limited polarization level is likely to be available by the end of the first year of LEP operation and a fast polarimeter [1] [2] capable of monitoring polarization changes of a few percent is an essential tool to optimize orbit correction strategies necessary to improve the polarization level.

Absolute beam energy calibration at the Z^0 mass will be the first application of polarimetry at LEP. The expected accuracy is of the order of a few electron masses [3] since the electron gyromagnetic anomaly $a = \frac{g-2}{2} = 1.159652188 \cdot 10^{-3}$ is known to a precision of some 10^{-9} [4].

2 The Compton polarimeter

Suggested by Baier and Khoze [5] the laser polarimeter is based on spin-dependent Compton scattering of circularly polarized photons from polarized electrons or positrons (Fig.1). The spin-dependent total Compton cross section $\sigma_c(P_e, P_\phi)$ has been evaluated in [6] and is shown in Fig.2 as a function of the scattering angle θ' in the $e^{\pm}$ rest frame.

The vertical angular distribution of the recoil high energy γ-rays, as measured at a detector downstream the laser interaction region (LIR), shows an **up-down asymmetry** depending on the right-left helicity of the incident laser photons and proportional

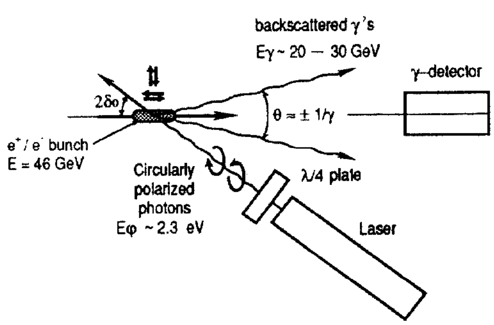

Figure 1: Principle of the laser polarimeter

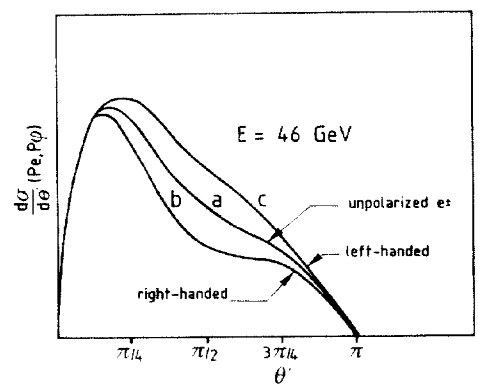

Figure 2: Spin-dependent Compton cross section vs. scattering angle θ' in the $e^{\pm}$ rest frame for right- and left-handed circularly polarized photons on 46 GeV vertically polarized leptons.

to the lepton transverse polarization level

$$A(y) = \frac{n_R - n_L}{n_R + n_L} = P_e\, P_\phi \cos\phi'\, \Pi(\theta', k_0'), \tag{1}$$

where $n_{R,L}(y)$ are the γ -rates at a vertical position y and the usual kinematic notations are those of [1].

This asymmetry property can also be expressed in terms of the **centroid shift** ΔC between the two distributions [7]

$$\Delta C = \kappa P_e\, . \tag{2}$$

related to the lepton polarization level P_e through the quantity κ proportional to the analyzing power usually defined for the asymmetry method. Simulations performed for our polarimeter geometry indicate $\kappa \sim 800\,\mu$m.

3 Optimization criteria

Asymmetry

The analyzing power $\Pi(\theta', k_0')$ in (Equ.1) has a maximum value $\Pi^*(k_0')$ around $\theta' = \pi/2$ where the largest asymmetry in the Compton cross section occurs (Fig.2).

$$\Pi^*(k_0') \equiv \Pi(\theta' = \frac{\pi}{2}) = \frac{k_0'}{1 + k_0' + k_0'^2}\, . \tag{3}$$

The condition $k_0' \sim 1$ for optimum asymmetry suggests a relationship allowing the laser wavelength to be chosen to optimize the asymmetry according to the beam energy E [GeV] :

$$k_0' = \frac{2\,E\,E_\phi}{(m_0c^2)^2} = 9.5\,\frac{E}{\lambda_\phi} \sim 1\, , \tag{4}$$

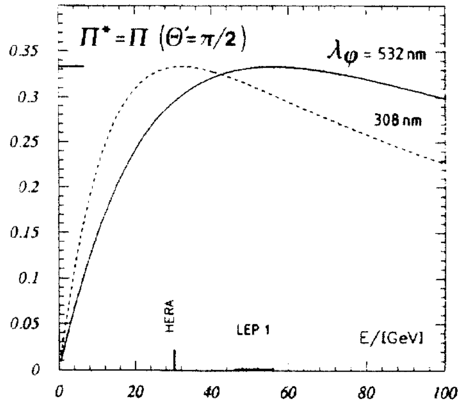

Figure 3: Energy dependence of the analyzing power $\Pi^*(k'_0)$.

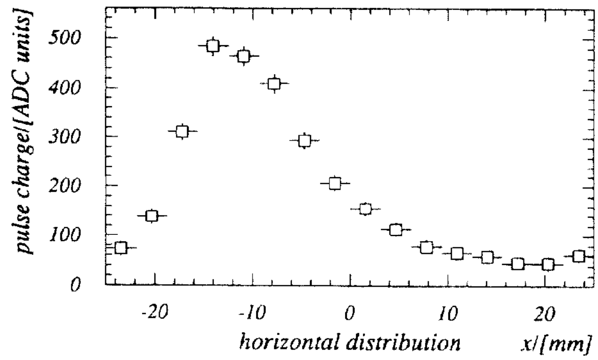

Figure 5: Horizontal profile of the backscattered photons

where $E_\phi\,\lambda_\phi\ =\ 1.24 \cdot 10^3$ eV nm.

The energy dependence of Π^* shown in Fig.3 indicates that the use of a laser in the visible range ($\lambda_\phi\ =\ 532$ nm) provides optimum asymmetry conditions for LEP phase 1 and suggests what the best wavelength should be adopted to operate near the optimum in other energy ranges.

Luminosity

The **luminosity per interaction** for bunched beams assumed to have three-dimensional Gaussian distributions and colliding under an angle $2\delta_0$ is

$$L^* = \frac{N_e N_\varphi}{\Sigma} = 2.8 \cdot 10^{21}\, \frac{I_b[\mu\mathrm{A}]\ E_L[\mathrm{mJ}]\ \lambda_\phi[\mathrm{nm}]}{\Sigma}\ [\mathrm{cm}^{-2}] \qquad (5)$$

where N_e is the $e^\pm$ bunch population, $N_\phi = 5.035 \cdot 10^{12}\, E_L \lambda_\phi$ the number of photons per pulse for a laser of energy E_L, I_b the bunch current and Σ the interaction area defined as a function of the rms dimensions of the colliding bunches and of the interaction angle $2\delta_0$ [1].

The contribution to Σ from the laser pulse length can be reduced by choosing a small interaction angle compatible with the dimensions and the position of the last mirrors in the vacuum chamber relative to the circulating beam.

Once the photon wavelength is chosen to optimize the asymmetry the laser power defines the luminosity of the interaction.

4 Layout

Quantitative considerations on background from gas bremsstrahlung and synchrotron radiation have been accounted for in [1] and led to the choice of the layout shown in Fig.4.

The light of a 50 mJ Nd-YAG laser operated in the visible range ($\lambda_\phi\ =\ 532$ nm) with a repetition rate of 30 Hz and installed in an Optical Laboratory $\sim$ 15 m from the LEP tunnel, is guided, after a divergence reduction with a beam expander, over $\sim$ 125 m in a roughly evacuated beam pipe to the LIR with ϕ = 80 mm multilayer dielectric mirrors $M_1 \cdots M_5$. The final deflection onto the e^- beam under an angle $2\delta_0\ =\ 2 \div 3$ mrad is provided by ($Ag + MgF_2$)-coated Cu mirrors [8] the position of which can be adjusted to allow the operation of the polarimeter in parasitic mode on the physics runs without affecting the beam life time nor their reflectivity. The backscattered γ's reach the detector 247 m downstream the LIR through a 50 × 20 mm^2, 2 mm thick Al window built in the modified vacuum chamber in the B1 main dipole. The upstream 10% BW dipole prevents the synchrotron radiation from B1 from reaching the detector.

5 Detector

Silicon strip planes behind a remote controlled variable thickness lead absorber constitute the active part of the detector to measure the profiles of the electromagnetic shower. The ion-implanted silicon detectors are 300 μm thick and the 50 V bias voltage can be adjusted to vary the depletion depth according to the saturation level. A first plane with 16 horizontal strips with 2 mm pitch measures the vertical profiles while a second plane (16 vertical strips / 3.1 mm pitch) is used to center the detector on the γ -beam.

6 Rates and measuring time

For our polarimeter a measurement of polarization to ΔP requires a number of backscattered photons

$$2N_\gamma = \frac{10^6}{(P_\phi\, \Delta P\,[\%])^2} \qquad (6)$$

where N_γ is the number of photons at each laser helicity.

If $P_\phi = 1$, 10^6 recoil γ's are reqired to measure the LEP beam polarization to $\Delta P = \pm 1\%$.

The luminosity from a 50 mJ laser hitting a 100 μA $e^\pm$ bunch is $4 \cdot 10^{28}\,\mathrm{cm}^{-2}$/crossing (Equ. 5) and a rate $N_\gamma \sim 8 \cdot 10^3$ γ's per interaction is expected from the Compton cross section in the laboratory system [7]. A 30 Hz repetition rate laser should allow to measure a change in ΔP of $\pm 1\%$ in about 4 s.

7 First commissioning results

First evidence of backscattered photons has been observed in the Si detector after e^- closed orbit correction around the LIR.

The optimum thickness of the lead absorber to reduce the synchrotron radiation flux from quadrupoles and orbit correctors in the LSS1 straight has first been determined with LEP running at 45.6 GeV.

The overlap between the two beams at the LIR has been optimized by varying the photon horizontal position against the incoming electrons with mirror M_5 and adjusting the synchronization between the laser pulse and the e^- bunch to the maximum signal in the two Si planes of the detector.

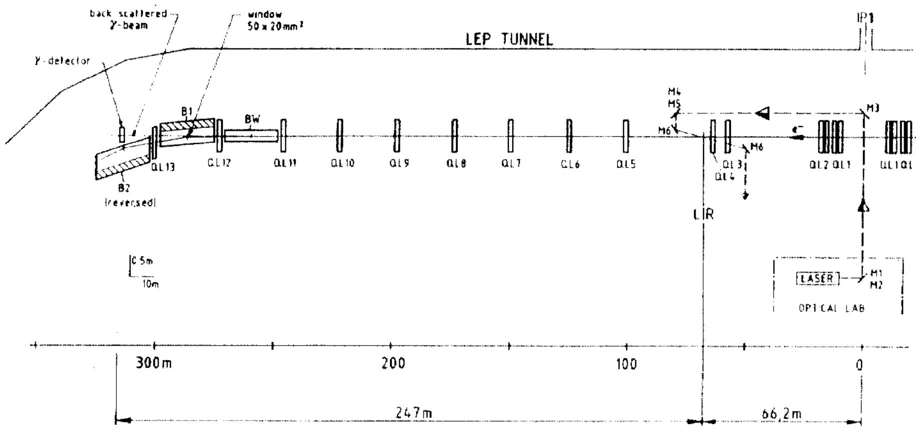

Figure 4: General layout of the LEP laser polarimeter in LSS1.

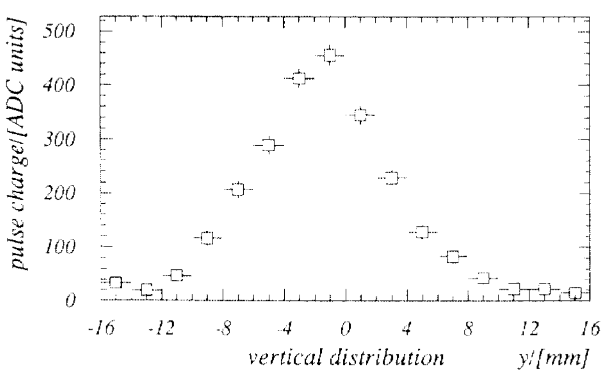

Figure 6: Vertical profile of the backscattered photons

Backscattered γ profiles in the two Si planes of the detector are shown in Figs.5 and 6. The cut from the window due to insufficient aligment of the orbit is clearly visible from these first results and suggests the use of a closed bump to adjust the slope of the e^- beam at the LIR to better steer the recoil photons towards the detector.

The signal-to-background ratio is $\sim$ 80 and the number of backscattered γ's has been estimated to about 30 per laser shot to be compared with a figure of $\sim$ 1600 expected from the evaluations of Sec.6, scaled for a laser pulse intensity of $\sim$ 10 mJ presently measured at the LIR light exit port.

The missing factor of $\sim$ 50 is mainly due to substantial losses in the transmission of the recoil photons and a better control of the orbits at the LIR will certainly improve the situation. The optimization of the optics and of the transmission of the laser beam line would also help in reaching the design figure for the number of recoil photons.

From Equ.6 a measurement of $\Delta P = \pm 2\%$ in $\sim$ 100 s is possible with about 100 recoil photons per laser shot, i.e. a factor of 3 more than the presently measured value.

8 Conclusions

The installation of a laser polarimeter on the LEP straight section LSS1 has been completed in 1989. The light of a Nd-YAG laser operated in the visible (λ_ϕ = 532 nm) intalled in the Optical Laboratory near the LEP tunnel is transported over $\sim$ 125 m to the laser interaction region (LIR) with a spot size of 0.6 mm rms, reproducible to $\pm$0.1 mm.

First evidence of backscattered photons has been observed in the γ-detector 247 m downstream the LIR after proper adjustment of the e^- beam orbit at the interaction point.

The polarimeter has been operated parasitically on some physics runs and, although not yet optimized, the number of recoil photons detected presently is estimated to about 30 per laser shot.

9 Acknowledgments

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