PRELIMINARY POLARIZATION MEASUREMENT OF TRISTAN ELECTRON BEAM

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Abstract

A fast polarimeter for electron beam has been installed in the TRISTAN 30 GeV ring. This polarimeter measures an asymmetry in the Compton scattering of circularly polarized laser beam by polarized electrons. The first polarization measurement at the beam energy 29 GeV is described .

Introduction

Natural polarization of electron beam[1] has been observed in many storage rings[2] with energy less than 25 GeV. As energy increases it is expected that the degree of polarization becomes low due to strong depolarization effects. These are crucial problems to achieve highly polarized beams in high energy storage rings exceeding the 30 GeV range. The TRISTAN covers the energy range of 25 to 32 GeV, in which the study of beam polarization provides useful information. We have developed a fast polarization monitor to measure a transverse polarization of electron beam at TRISTAN MR, based on the Compton scattering of laser light. A fast data taking and an excellent precision are crucial points to measure a low level polarization with a short buildup time, as expected in the MR. Features of our polarimeter design are to minimize a systematic error as well as a statistical error and to allow for measurement of the longitudinal polarization simultaneously.

Beam Polarization in TRISTAN

In the presence of depolarizing effects originating from magnetic field imperfections and misalignments in a real storage ring, the buildup of the beam polarization can be expressed in terms of the effective buildup time τ as

$$P_e(t) = \tau/\tau_p P_0(1 - \exp(-t/\tau)), \tag{1}$$

where P_0 is the ideal asymptotic polarization level, $P_0 = 8/(5\sqrt{3})$ = 92.38%, and τ_p is the natural polarization buildup time. The buildup time of the polarization for the beam energy E in GeV is given by

$$\tau_p = 98.66(\rho^3/E^5)(R/\rho)\,\mathrm{sec}, \tag{2}$$

where ρ is the bending radius in meters and R is the machine mean radius. In the MR the natural polarization buildup time would be $\tau_p = 2.88 \times 10^9/E^5$ sec, typically 2 minutes for 30 GeV.

An observable buildup time depends on the asymptotic degree of the polarization determined by depolarization effects. The prediction of the polarization level can be calculated by a computer code SLIM[3]. Fig. 1 shows the expected polarization of the MR in the energy range 24 to 32 GeV, calculated with simulated magnetic field imperfections. This calculation takes no account of contributions from three large solenoids for the colliding detector. The absolute polarization level is expected to be very low

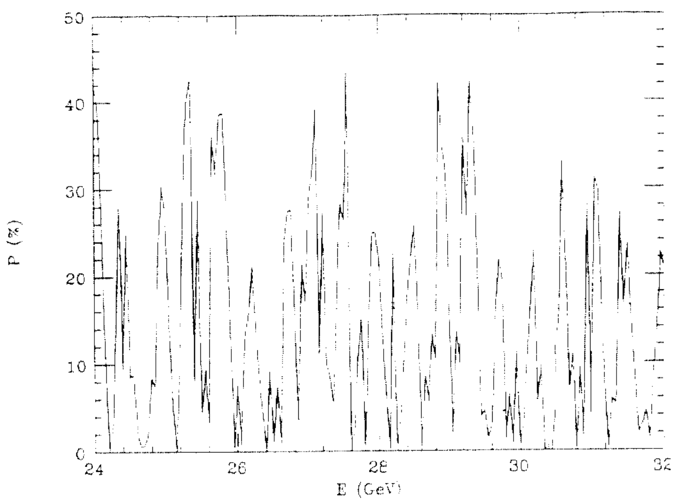


Fig. 1 Expected beam polarization of TRISTAN MR

around the depolarization resonance. It occurs when the spin tune $\nu = E/0.44065$ satisfies $\nu = n + n_x\nu_x + n_y\nu_y + n_s\nu_s$, where ν_x, ν_y, ν_s are the horizontal, vertical and synchrotron tunes, respectively and n, n_x, n_y, n_s are any integers. A polarization time will be 42 sec for a 30 % polarization level at 29 GeV in the MR.

Compton Polarimetry

The laser polarimeter is very useful to make a fast polarization measurement. The principle is based on the asymmetry in the Compton scattering of circularly polarized laser photons by an electron beam. A transversely polarized electron beam gives rise to an up-down asymmetry in the backscattered γ rate, depending on the left-right photon polarization. The differential Compton scattering cross section[4] of circularly polarized photons on transversely polarized electrons or positrons is written in the electron rest frame as

$$d\sigma/d\Omega = (r_e^2/2)(q/q_0)^2\big[(1 + \cos^2\theta) + (q_0 - q)(1 - \cos\theta) \pm P_e P_\gamma \cos\phi(1 - \cos\theta)q\sin\theta\big] \tag{3}$$

where q_0 and q are the incoming and outgoing photon energies and θ and ϕ are the scattering angles.

In the laboratory system the maximum asymmetry of the backscattered γ rate occurs in the polar angles of $\theta_L \sim 1/\gamma$, typically 20 μrad in the TRISTAN energy range. The angular divergence of the beam and the angular resolution of the detector must be smaller than θ_L so that the asymmetry of the γ ray angular distribution is not lost. The net angular resolution of the polarimeter with an rms position resolution Δ of the detector and beam emittance ϵ is given by

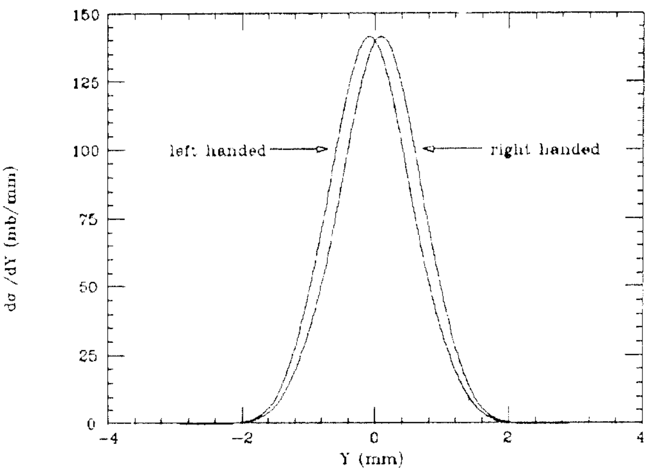


Fig. 2 Vertical distribution of γ ray at the detector

$$\delta = \left\{(\epsilon/\beta)[1 + (\alpha - \beta/L)^2] + (\Delta/L)^2\right\}^{1/2} \quad (4)$$

where L is the distance of the detector from the laser interaction point and α, β are the beam Twiss parameters at the interaction point. The parameters are chosen so as to minimize the angular resolution. This is optimized by choosing an interaction point where the β- function is its maximum value. Usually in the e^+e^- storage rings, the horizontal emittance is large enough to smear out an asymmetry of the projected profile on the detector. Therefore only vertical distribution of the γ rays is measured. The vertical β and α functions at the interaction point are 23.7 m and $\sim$ 0 m, respectively, and L is set to be 38 m because of restriction on the installation space. A typical vertical emittance is 2.5 nm for 25 GeV, assuming a 2 % of the horizontal one. The projected beam spot size on the detector is 0.46 mm. If we use the detector with the position resolution 126 μm, the net angular resolution is 12.5 μrad, sufficiently smaller than $1/\gamma$.

The degree of polarization P_e can be determined by the vertical asymmetry of the measured γ rate and the analyzing power A for 100 % photon polarization:

$$P_e = (1/A)(N_+ - N_-)/(N_+ + N_-) \quad (5)$$

where N_+ and N_- are the numbers of γ events counted at a vertical position for the two photon helicities. The vertical distribution of γ rays is calculated by integrating over the horizontal distribution and the γ energy distribution. Taking into account the angular divergence of the incident beam with a Gaussian distribution, an expected vertical profile at the detector is obtained as shown in Fig. 2. The analyzing power is defined by the ratio of the spin-dependent term σ_2 of cross section to the non spin-dependent term σ_0. It depends on bins used in the asymmetry measurement and the cutoff γ energy. Since the accuracy of the polarization measurement is given by $\Delta P_e \sim 1/(A\sqrt{N})$ with $N = N_+ + N_-$, these values should be chosen so as to optimize the quantity of $A^2N \propto \sigma_2^2/\sigma_0$.

Laser Polarimeter

Two methods have been proposed to measure the vertical asymmetry of γ rays. In the single photon counting method[2] the electron beam is illuminated by a low power, high repetition rate laser pulse. Each backscattered photon is measured by a position sensitive detector and a calorimeter. The multi-photon technique[5] uses a high peak power laser to produce numerous γ rays per interaction. The number of photon is recorded as deposited energy in the calorimeter. We adopted the single photon counting method to avoid systematic errors due to the drift of a closed orbit or a photon counting detector.

Laser

We use a cavity-dumped Ar ion laser producing the 514.5 nm(2.41eV)line. The cavity-dump pulse is synchronized with the beam revolution frequency to illuminate the electron beam at each crossing. The laser pulse has a width of 15 ns (FWHM) and a peak power of 50W. The linearly polarized laser light is converted to either right or left circularly polarized light with a KD*P Pockels cell. The laser beam is guided through the transport optics of 8 mirrors and a final focusing lens as shown in Fig. 3 The laser beam is aligned with an optical target which is remotely inserted at the interaction point. The laser beam is focused at this point with an rms spot size approximately 1 mm.

γ detector

The backscatterted γ rays travel along with the electron beam, then leave the beam pipe and finally reach the γ detector. A schematic diagram of the γ detector is shown in Fig. 4. The detector measures both the position and the energy distribution of

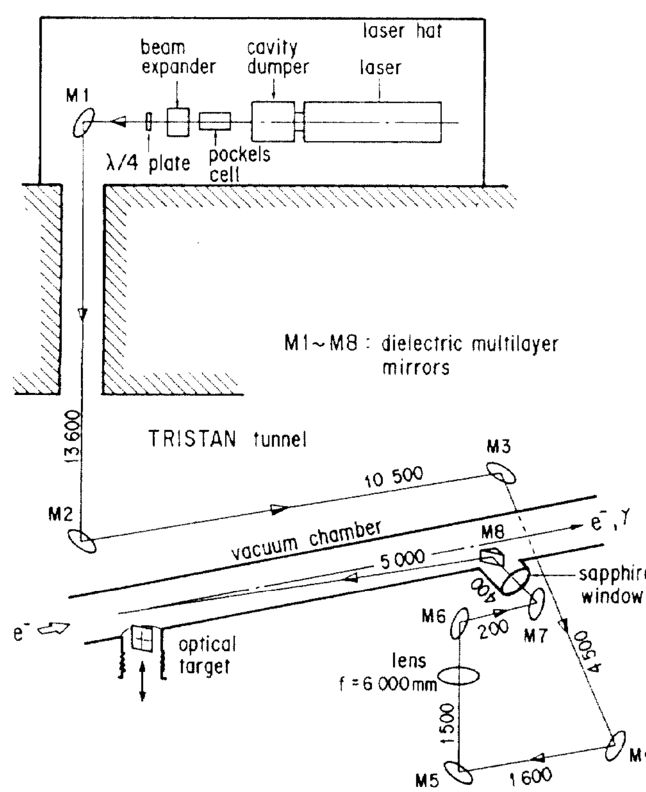


Fig. 3 Laser system of TRISTAN polarimeter

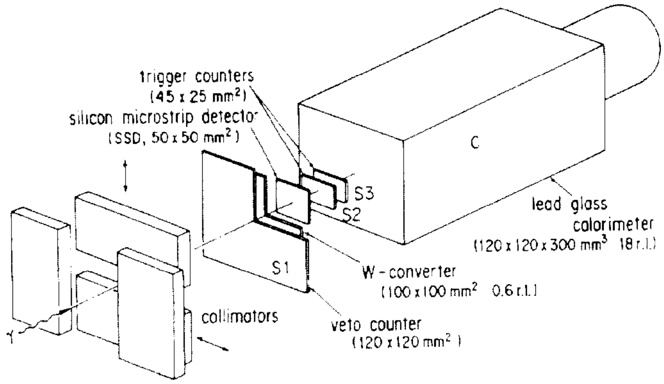


Fig. 4 Layout of γ detector

γ rays. The photon trigger is provided by 3 scintillation counters S1, S2, S3 and a lead glass calorimeter. The counter S1 vetoes charged particles. A 2 mm thick (≈ 0.6 r.l.) tungsten converter is followed by the trigger counters S2, S3 and the lead glass counter with ≈ 18 r.l. for the energy measurement of a $e^- - e^+$ pair created in the converter. The vertical position of a converted photon is determined from hit channels of the silicon microstrip detector (SSD) with a 50 mm×50 mm sensitive area. The SSD is composed of P-N junctions formed on a silicon substrate with 42 μm pitch. A capacitive charge divided pulse is read out every three strips. It is possible to detect a charged particle with position resolution of 42 μm. We use 160 readout channels over a 20 mm vertical width.

Pulse height signals generated in the SSD and the lead glass calorimeter are digitized by fast ADC CAMAC modules (LeCroy FERA) in coincidence with the trigger gate. A FERA ECL bus transfers encoded data to either of two 16K words memory module. Then data are read out through CAMAC bus by the computer each time a memory module is filled with data. This system allows for fast data acquisition at the maximum rate of 80 kHz.

γ-Rate and Background

The luminosity of the electron beam- laser interaction with a horizontal crossing angle α is given by

$$L(\mathrm{kHz/mb}) = 257.1 I_e W_L \{\sigma_{ey}^2 + \sigma_{Ly}^2\}^{-1/2} \times \{\cos^2(\alpha/2)(\sigma_{ex}^2 + \sigma_{Lx}^2) + \sin^2(\alpha/2)(\sigma_{ez}^2 + \sigma_{Lz}^2)\}^{-1/2} \quad (6)$$

where I_e is the electron beam current in A, W_L the laser energy per pulse in μJ. $\sigma_{ex}, \sigma_{ey}, \sigma_{ez}$ and $\sigma_{Lx}, \sigma_{Ly}, \sigma_{Lz}$ are the rms dimensions of the electron bunch and of the laser beam in mm. If a 1.88 μJ laser pulse with a round profile $\sigma_{Lx} = \sigma_{Ly} = 1$ mm collides the electron beam at an angle 8 mrad, the expected luminosity is 62.2 Hz/mb for a 1 mA TRISTAN beam. The total cross section of the Compton scattering is 385 mb for 2.41 eV photons on a 25 GeV electron beam. Thus an estimate of the backscattered γ rate is 24 kHz/mA.

The background for the Compton γ events is high energy γ rays produced from the gas bremsstrahlung. The total cross section of the bremsstrahlung in a gas with average atomic number Z=5 is given by $\sigma_{brem}(> k/E) = 57.3\{6.37[(k/E) - \ln(k/E)] - 2.34(k/E)^2 - 4.03\}$ mb, where k is the emitted photon energy and E is the electron beam energy. The γ rate from a 1 mA electron beam on the residual gas of a pressure $p \times 10^{-9}$ Torr in a 200 m MR straight section leads to $1.1p$ kHz/mA for $0.19 < k/E < 0.48$.

In a real measurement the bremsstrahlung background may become comparable to the Compton events. Its background can be subtracted from the collected data if we take only the backgrounds in the laser-off run besides the up -down asymmetry run. The polarization can be corrected with the background events N_B as

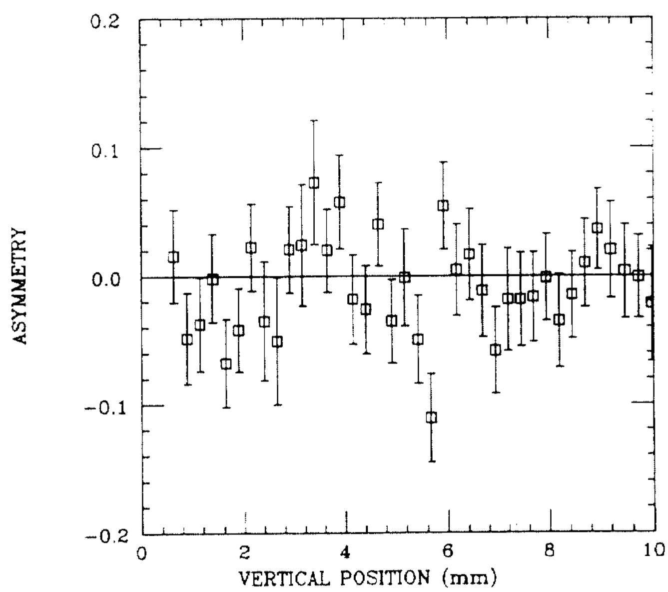
$$P_e = (1/A)(N_+ - N_-)/(N_+ + N_- - 2N_B) \quad (7)$$

where N_+ and N_- are the up and down asymmetry events including the background.

Result of Measurement

We had some difficulty in finding the backscattered Compton γ ray signal. One reason was that background level was very high since all the gas bremsstrahlung from the 200m long straight section contribute to the background. The other reason was that the laser beam power at the collision point was very often much lower than 50 W because both the tuning of the laser source and the transport of the laser beam were not adequate. After the readjustment of the laser system, Compton signal was observed as the increase of calorimeter output by about 20 % when the laser was turned on.

Fig. 5 shows the result of the asymmetry measurement . We need to accumulate more events to see if there is any structure in the data. We hope to have machine time to make energy scan and to try orbit correction or other strategy to obtain finite polarization. Authors thank Professor Kimura for his interest and encouragement.



Fig, 5 Asymmetry (Eq(7)) of Compton γ

References

1. A.A. Sokolov and I.M. Ternov, Sov. Phys. Dokl. 8 (1964) 1203.
2. D.B. Gustavson et al., Nucl. Instr.Meth. 165 (1979) 177. D.P. Barber et al., Physics Letters 135B (1984) 498. W.W. MacKay et al., Physics Review D29 (1984) 2485.
3. A. Chao, PEP note 263, 1978. SLAC-PUB-2564, 1980.
4. F.W. Lipps and H.A. Toelhoek, Physica XX (1954) 85, 395.
5. M. Placidi and R. Rossmanith, CERN/LEP-BI/86-25, 1988.