CEBAF-PR-89-010

LEP AND CEBAF POLARIMETERS

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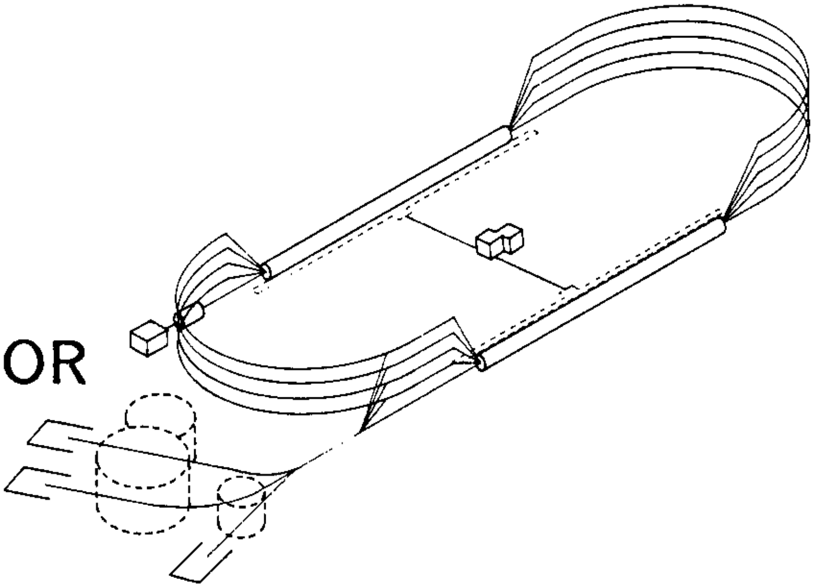

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The Southeastern Universities Research Association (SURA) operates the Continuous Electron Beam Accelerator Facility for the United States Department of Energy under contract DE-AC05-84ER40150.

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Abstract

This paper gives an overview on high energy electron (positron) polarimeters by describing in more detail the plans for the LEP polarimeter and the CEBAF polarimeters. Both LEP and CEBAF will have laser polarimeters. In addition CEBAF will be equipped with a Møller polarimeter (for currents below 1μA).

The LEP laser polarimeter[1] should take data in the second half of 1989, the CEBAF[2] polarimeter (both laser and Møller polarimeter) are needed when CEBAF will accelerate polarized electrons.

The principle of a laser polarimeter is shown in Fig. 1. A circularly polarized laser beam is directed against the electron (positron) beam and the backscattered photons are observed.

Usually the Compton cross section is described in the rest frame of the electron[1]:

$$\frac{d\sigma}{d\Omega} = \sigma_I + \sigma_{II} \tag{1}$$

where the spin dependent term σ_{II} depends on the electron and laser polarization. σ_I does not depend on the electron polarization. With circularly polarized light σ_{II} and therefore the total cross section depends on the polarization of the electron. As mentioned above, the formula describes the Compton process in the rest frame of the electron; the scattering angle is Θ^*, the azimuthal angle is φ^* (Fig. 2).

The asymmetry

$$A = \frac{N_- - N_+}{N_- + N_+} \tag{2}$$

is measured. N_- and N_+ are the backscattering rates when the light has + or - helicity. For transverse polarization A describes an azimuthal asymmetry, and for longitudinal polarization A is a counting rate asymmetry. Fig. 3 shows that both asymmetries have their maximum near 90 degree in the rest frame. The energy range shown in Fig. 3 is the energy range of CEBAF.

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* Invited paper given at the 8th International Symposium on High Energy Spin Physics, Minneapolis, September 1988. This work was supported by the U. S. Department of Energy under contract DE-AC05-84ER40150.

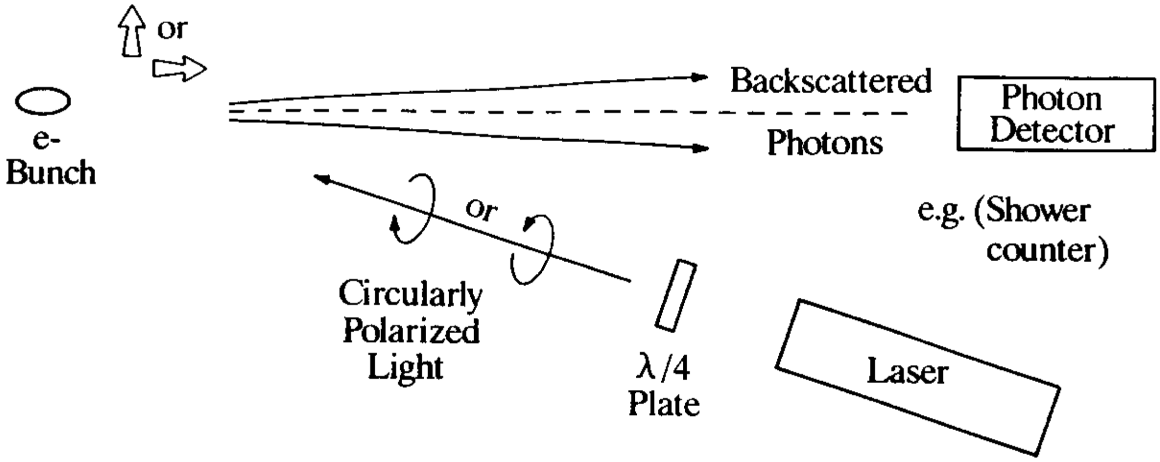
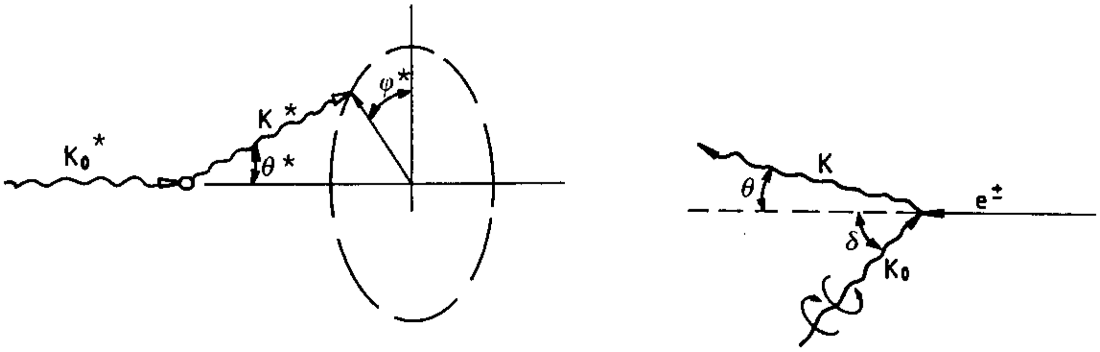


Figure 1: The principle of a laser polarimeter.



$e^\pm$ rest frame

Lab. frame

Figure 2: The Compton effect in the rest frame of the electron. Θ^* is the scattering angle and $\varphi*$ is the azimuthal angle.

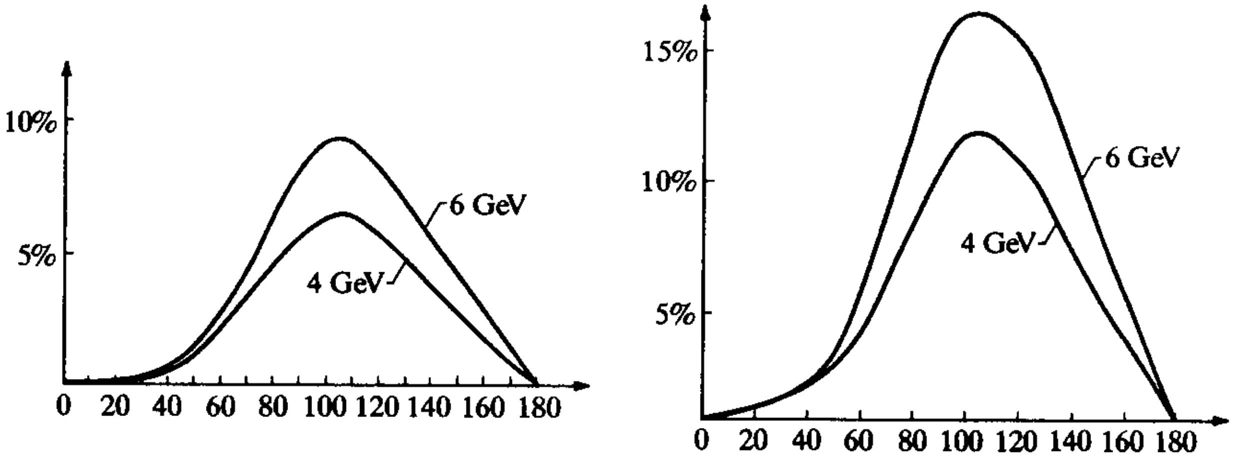


Figure 3: Asymmetries for vertical and longitudinal electron polarization versus scattering angle (in degrees) in the rest frame of the electron at 4 and 6 GeV (CEBAF energies), energy of the incident photons 2eV.

For head on collision, or nearly head on collision, the incoming photon energy k_0^* in units of the $e^{\pm}$ rest mass is

$$k_o^* = \frac{2(E_e E_{ph})}{(mc^2)^2}. \tag{3}$$

E_e is the electron energy, E_{ph} the photon energy. Fig. 4 shows the asymmetry for transverse electron polarization for a wide E_e range. At 46 GeV (around the Z_o resonance) the asymmetry achieves a maximum of 33 percent when E_{ph} is in the visible range. The ideal laser for LEP is therefore a laser in the visible range (e.g. a frequency doubled Nd-Yag laser). For the much lower CEBAF energies an Excimer laser could be the right choice.

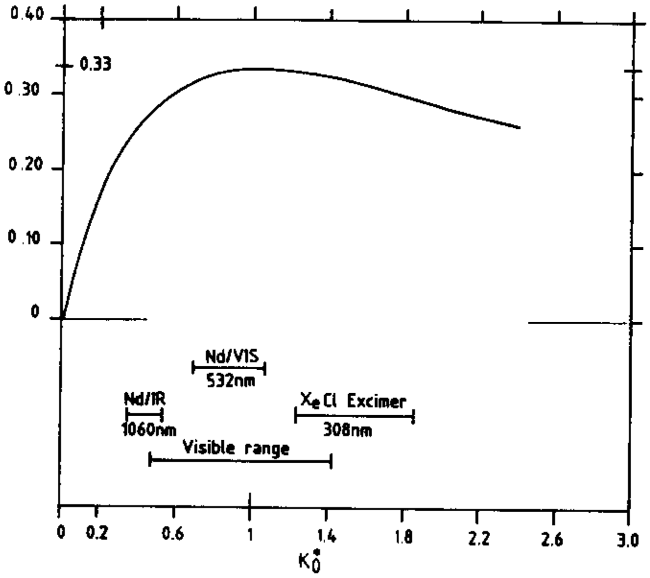


Figure 4: Asymmetry versus k_0^* for transverse polarization. The lines mark the range of k_0^* for LEP between 45 and 55 GeV for various lasers.

Transformed into the laboratory frame the scattering angle Θ^* becomes Θ

$$\Theta = \frac{cot(\Theta^*/2)}{\gamma} \tag{4}$$

and the backscattered γ energy

$$E_\gamma \approx (\gamma m_o c^2)\frac{(1 - cos\Theta^*)}{1 - cos\Theta^* + 1/k_o^*} \tag{5}$$

With this formula the energy spectrum of the backscattered γ's as a function of the scattering angle in the rest frame for various beam energies in LEP is shown in Fig. 5.

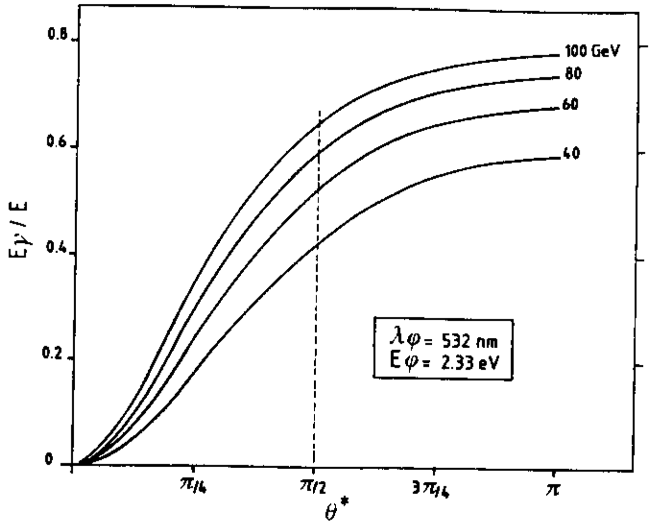


Figure 5: Normalized energy of the backscattered photons versus rest frame angle for different electron energies.

From these formulae it can be seen that the scattering angle depends also on the energy of the electron. Fig. 6 shows the asymmetry as a function of laboratory scattering angle Θ. According to Fig. 6 a rest frame angle of 90 degree is converted into $\approx 5\mu$rad in the laboratory system at an electron energy of 100 GeV.

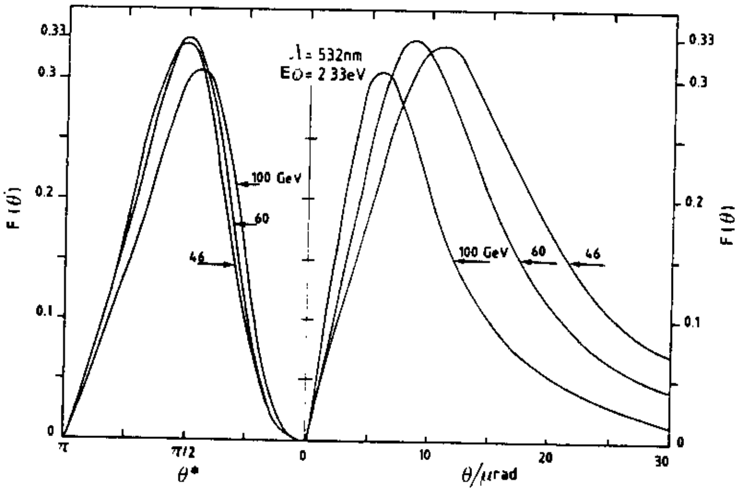


Figure 6: Asymmetry versus laboratory angle (μ rad) and rest frame angle for different electron energies in GeV (transverse electron polarization).

In principle, the measurement can be performed in the following two ways:

- The intensity of the backscattered photons is so low that a detector can measure the energy of each photon. Only photons emitted in the rest frame near to 90 degree are taken into account (single photon method).
- Several photons per bunch are backscattered. The energy of each individual photon cannot be measured anymore (multiphoton method[3]). Since photons with different energies hit the detector the overall asymmetry is reduced.

Which method is the best has to be chosen for each machine individually. Although at the first glimpse the second method seems to have many disadvantages that have to be taken into account; the maximum obtainable asymmetry is reduced by the finite emittance of the beam. In addition, background considerations have to be taken into account; the background (gasbrems- and synchrotron radiation) is negligible in the multiphoton case.

For LEP, a Nd-Yag laser with several 10's of MW pulse power, a pulse length of ≈ 3 nsec rms and a repetition rate of 30 Hz was chosen. For CEBAF the use of an excimer laser is discussed.

Fig. 7 shows the overall arrangement for the LEP polarimeter. The laser beam is directed from an optical laboratory via a ≈ 100 m long optical path against the electron and/or positron beam in one of the straight sections. The backscattered photons travel ≈ 300 m downstream until they hit the detector. At the detector, the distribution of the backscattered photons with right- and lefthanded polarized light is shown in Fig. 8 (for 100 percent electron beam polarization). The detector is either a position sensitive shower counter and/or a position sensitive silicon strip detector.

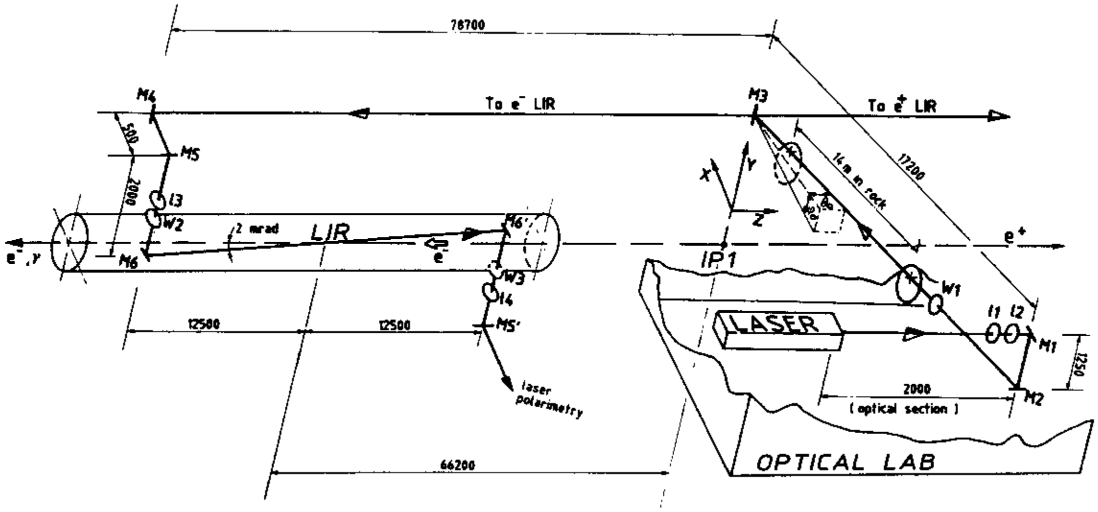


Figure 7: The optical part of the LEP polarimeter. The laser is installed outside the tunnel in an optical laboratory. The laser beam is blown up by a lens system so that the power density at the surface of the different mirrors is small. The mirrors are arranged in such a way that they do not affect the circular polarization of the laser.

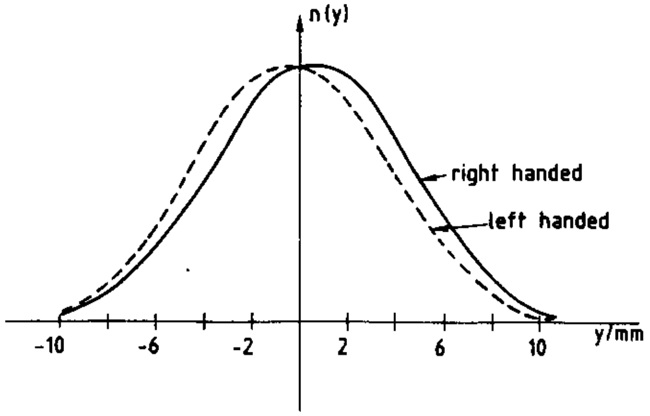


Figure 8: The vertical distribution in mm of the backscattered laser beam at the detector (for LEP) for both helicities. It is assumed that the beam has its nominal vertical size.

The laser-electron (positron) interaction region in LEP is optimized in such a way that at nominal beam currents the backscattered rate is of the order of 10^4 photons per bunch. The measuring time for polarization is shown in Fig. 9. In the interesting range, the measuring time is a few seconds for an accuracy of a few percent. With such a fast polarimeter the polarization can be optimized very fast.

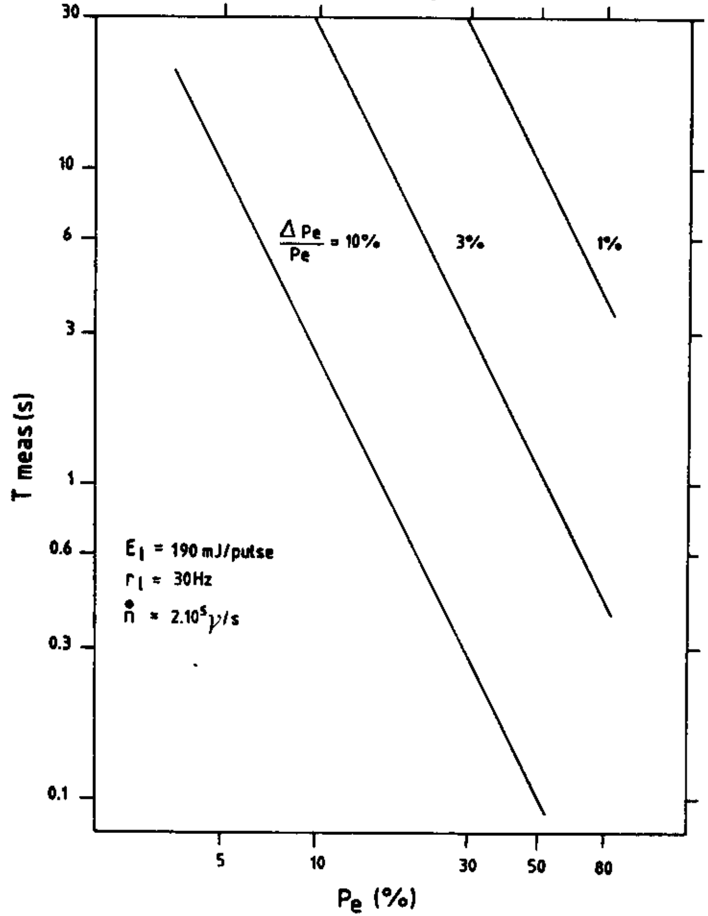


Figure 9: The measuring time of the LEP multiphoton polarimeter as a function of the degree of polarization.

The beam currents in CEBAF can be varied within a wide range. Several experiments will run with the highest possible current of $200\mu A$. Experiments using polarized solid state targets will run with a maximum current of 100 nA. The backscattering rate of a laser polarimeter will be 1 kHz/Watt/$200\mu A$ calculated for a cw laser. This rate can only be obtained when the laser electron backscattering rate is optimized. At currents near or below 100 nA the above described multiphoton technique has to be used in order to reduce the background.

For measuring the polarization at low currents a Møller polarimeter appears to be advantageous. The Møller scattering cross section ($e^- + e^- \rightarrow e^- + e^-$) has a strong polarization sensitivity and can therefore be used to measure electron polarization at high energies.

The asymmetry for anti-parallel and parallel alignment of the beam and target helicities is in the high energy limit ($E >> m_e$).

$$A = \frac{\sigma(\uparrow\downarrow) - \sigma(\uparrow\uparrow)}{\sigma(\uparrow\downarrow) + \sigma(\uparrow\uparrow)} = \frac{\sin^2\theta}{(4-\sin^2\theta)^2}\{p_x p'_x \sin^2\theta - p_y p'_y \sin^2\theta + p_z p'_z (8 - \sin^2\theta)\}$$

where θ is the cms scattering angle, p is the polarization of the electron beam and p' is the polarization of the target electrons (z – beam direction, y – perpendicular to k scattering plane, x perpendicular to y and z). The incident electron beam hits an approximately $50\mu m$ thick ferromagnetic foil. About 8% of the atomic electrons are polarized, by means of an external magnetic field of $\simeq$ 100 Gauss. The maximum asymmetry occurs at a center of mass angle of 90 degree and corresponds to laboratory angles of 10 and 20 mrad for energies of 4 and 2 GeV, respectively. Two septum magnets are used to separate the Møller scattered electrons from the primary beam. The electrons are measured in coincidence in a symmetrically arranged magnetic spectrometer setup, consisting of a C type magnet and a simple electron detection system. The degree of polarization is measured by reversing the electron polarization.

$$A_c = \frac{N(\uparrow\downarrow) - N(\uparrow\uparrow)}{N(\uparrow\downarrow) + N(\uparrow\uparrow)} = \frac{7}{9} \cdot P_e^B \cdot P_e^T$$

The scattering rate is about 10^5 Hz per $1\mu A$.[4] Figure 10 shows the principle layout of the Møller polarimeter for CEBAF energies.

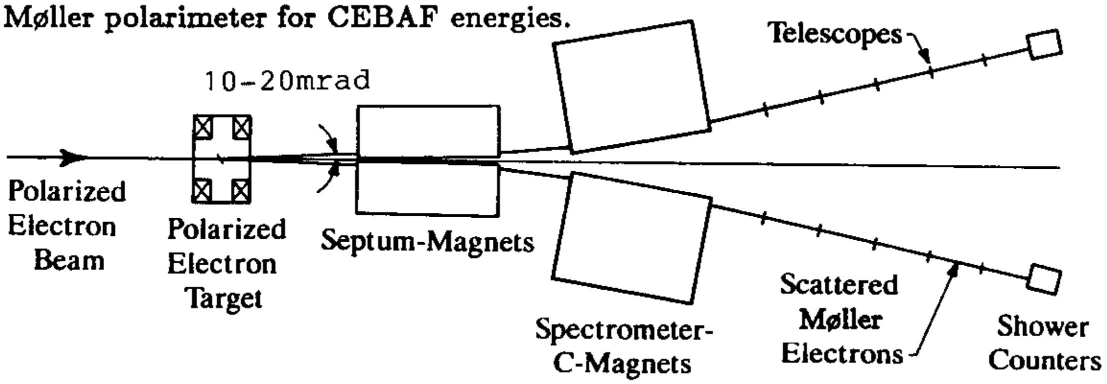


Figure 10: Principal layout of the CEBAF Møller polarimeter.

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