Precision measurement of energy at linear colliders using spin precession

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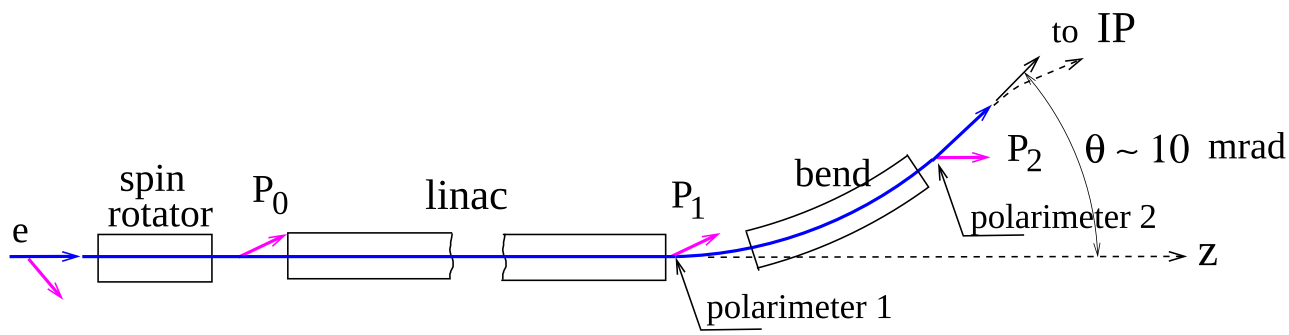
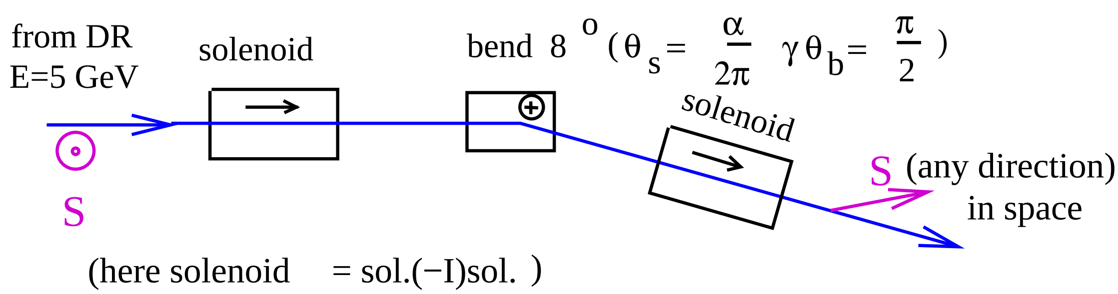
Idea of the method



Spin rotator at TESLA

(top view)



Electrons at LC have a high degree of longitudinal polarization.

Spin rotator can change (arbitrary) the direction of spin at the entrance of LC.

All LC have a big band with the angle about 10 mrad.

Using the Compton scattering one can measure the longitudinal polarization, the absolute accuracy is $< O(1\%)$, but relative accuracy can be much better.

The angle of spin in respect to direction of motion (θ_s) changes proportional to the bending angle (θ_b):

$$\theta_s = \frac{\mu'}{\mu_0} \gamma \theta_b = \frac{\alpha\gamma}{2\pi} \theta_b$$

The bending angle can be measured with a very high accuracy, then by measuring θ_s one can determine the beam energy

The accuracy

$$\frac{\Delta E}{E} = \frac{\Delta\theta_s}{\theta_s} = \frac{2\pi\Delta\theta_s}{\alpha\gamma\theta_b} \sim \frac{0.043}{E(\text{TeV})}\Delta\theta_s$$

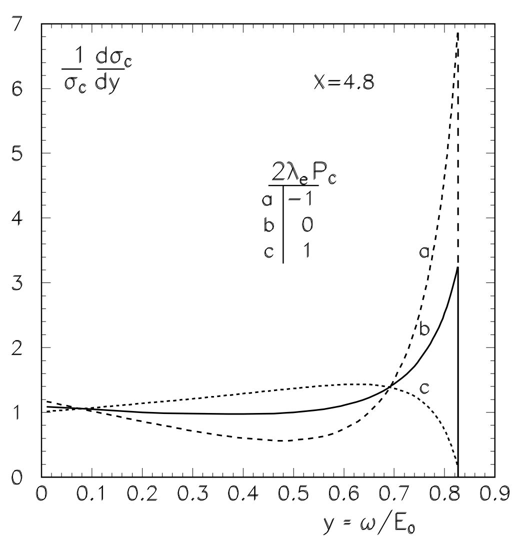
Measurement of the spin angle

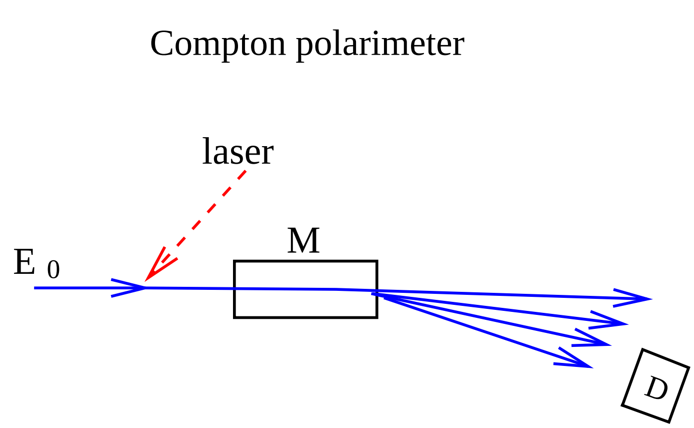
Longitudinal polarization of electrons is measured by scattering of laser photons on the electrons. After scattering of 1 eV laser photon the 100–1000 GeV electron loses up to 85 % of its energy, namely these low energy electrons are detected for measurement of the polarization

At the low energy edge of the scattered electron spectra the Compton cross section

$$d\sigma_c \propto (1 - P_e P_c) + \mathcal{O}(0.1)$$

P_e is the longitudinal polarization of electrons ($\sim 80\%$)
P_c is the circular polarization of laser photons (100%)





P_c is the helicity of laser photons

$2\lambda_e = P_e$ is the longitudinal polarization of electrons

There are two polarimeter, before the bend (1) and after (2). Changing the initial angle by spin rotator one can measure maximum value of signal corresponding to forward (or backward) electron spin direction.

For intermediate cases (i)

$$\cos\theta_1(i) = P_1(i)/P_1(max)$$

$$\cos\theta_2(i) = P_2(i)/P_2(max)$$

$$\theta_2(i) = \theta_1(i) + \theta_s$$

Each such measurement gives θ_s. Having many measurements at different initial spin angle (the accuracy strongly depends on the local spin angle) one can measure θ_s with a high accuracy.

At TESLA polarimeter expected counting rate is 10^7 Hz, that is more than 10^{10} events per hour, so relative statistical accuracy can be $\mathcal{O}(10^{-5})$.

Possible (very optimistic) accuracy for the energy

$$\frac{\Delta E}{E} \sim \frac{0.04}{E_0(\text{TeV})} \times 10^{-5} \times (1-10\ ?) = \left(\frac{10^{-6}}{E(\text{TeV})}\right) \times (1-10\ ?)$$

Systematic errors

1. For measurement of the beam energy by spin precession the electron spin at the point P1 should lay in the horizontal plane (the plane of the bending magnet). This condition could be achieved by careful study of spin rotator + accelerator system using signal in the polarimeter P1. As a test of correct knowledge one can put the spin in the plane perpendicular to the direction of motion and rotate it in this plane, in this case the signal in the polarimeter should not depend on the helicity of laser photons. Also one can create a certain angle θ_s at the point P1 and check that the signal is equal to $P = \cos\theta \times P_{max}$. The angle θ_y should be kept zero with an accuracy about $\theta_y < 10^{-2}$.

2. Knowledge of the bending angle. It should be known with an accuracy higher than the required accuracy of the beam energy.

Conclusion

1. The method is very promising, the accuracy improves with increase of the energy

2. Additional element is only the second Compton polarimeter

3. Careful study of technical aspect and systematic errors is needed