MÖLLER AND COMPTON POLARIMETRY

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In this short review, we describe techniques used for measuring electron beam polarization at GeV energies. We focus on Möller and Compton polarimeters and describe the experimental set-ups, the systematic errors and future possible developments for both techniques.

Introduction

The field of the structure of the nucleon has received much attention thanks to the development of highly polarized electron beams. Parity violation experiments [1] have extensively used these beams and the measured experimental asymmetry depends on the electron polarization P_e through :

$$A_{exp} = P_e(A_{th} + A_{new})$$

where A_{th} is the asymmetry one can calculate using known theories and A_{new} is the footprint of new physics. Thus, one understands that the beam polarization is an important quantity. As parity experiments are becoming more ambitious, the error arising from the determination of the beam polarization is becoming of major concern.

1. Möller polarimetry

1.1. *Principle*

This first type of polarimeter is based on Möller scattering off polarized electrons : $\vec{e}+\vec{e} \rightarrow e+e$ This process presents an asymmetry of the cross-section when the helicity of the target electrons are reversed. The asymmetry depends on the orientation of the polarization vector. In the frame where the z-axis is along the beam and the y-axis is normal to the scattering plane the different asymmetries read [2]:

$$A_{zz} = -\frac{(7+\cos^2\Theta_{CM})\sin^2\Theta_{CM}}{(3+\cos^2\Theta_{CM})^2}$$

$$-A_{xx} = A_{yy} = \frac{\sin^4\Theta_{CM}}{(3+\cos^2\Theta_{CM})^2}$$

$$A_{xz} = A_{yx} = A_{yz} = A_{zy} = 0$$

Therefore Möller polarimeters are often operated at an angle of 90 degrees in the CM frame. Under these conditions, A_{zz} reaches a maximum of -7/9 and polarimeters are thus designed to maximize longitudinal polarizations.

1.2. ***Experimental Set-up***

Möller polarimeter setups are designed to detect either one (single arm) or the two scattered electrons (double arm) as for the JLab Hall A Möller (see figure 1). The indiscernible scattered particles are focussed and bend onto an electromagnetic calorimeter.

1.2.1. *Magnetized target*

Most of the Möller polarimeters use a target made of a thin foil of Supermendur which is a Ferromagnetic alloy of Fe-Co-Va (49-49-2). The application of an external magnetic field using Helmholtz coils produces a magnetization of the material. The electrons spins tend to be anti-aligned with the field resulting in a net polarization of the order of 8 %. The foil is then inclined at an angle of 15 degrees from the beam axis.

The magnetization is derived from the measurement of the flux variation induced in a pick-up coil wrapped around the target when the applied magnetic field is reversed. The electron polarization is : $P_e = \frac{g_e}{g_e-1}\cdot\frac{g'-1}{g'}\cdot\frac{M}{\rho_e\mu_0\mu_B}$ where g' is the magneto-mechanical ratio of the alloy determined through Einstein-De Haas solid state physics experiments. The reproducibility of the magnetization measurements, the thickness dispersion and the lack of knowledge on g' lead to a systematic error of the order of 2 % on the target electron polarization.

1.2.2. *"Levchuk" effect*

Electrons from the inner shells of the atoms of the target material have momenta up to k_e =50 keV/c. This momentum results in a smearing of

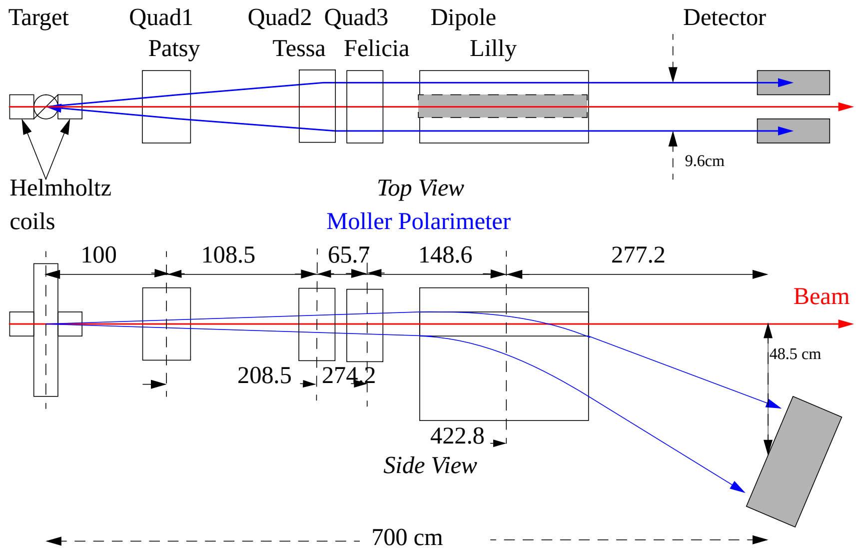

Figure 1. Experimental setup of the JLab Hall A double arm Möller polarimeter.

the scattering angle $\Delta\theta = \theta(1 \pm \frac{k_e}{m_e})$. Due to finite acceptance, this changes the analyzing power of the polarimeters. Effect of the order of 15% has been observed [3] leading to its discovery and was explained by Levchuk [4]. Recent polarimeters[5] where designed using Monte-Carlo simulation and the effect is kept below 3% with an error of 0.3 %.

1.3. *Breakthrough*

A new type of polarimeter has been built for the Jefferson Lab Hall C. The design addresses most of the drawbacks of existing polarimeters. The magnetizing field is applied along the beam axis using a SC-magnet [6] and a pure Iron target minimizing false asymmetries and error in the target polarization. It also uses the electro-optical Kerr effect to monitor the relative variation of the target polarization allowing high current running of the polarimeter. This type of polarimeter shows a total error below 1 % (instead of 2 %) and displays many of the possible improvements.

Another possibility to get rid of the systematic error on the target polarisation and to run at high current would be to use atomic hydrogen gas stored in a ultra-cold magnetic trap. Studies on this issue are in progress [7].

2. Compton Polarimetry

2.1. *Principle*

This type of polarimeters is based on polarized Compton scattering : $\vec{e} + \vec{\gamma} \rightarrow e + \gamma$. This process presents an asymmetry of the cross section when the helicity of the electron is reversed (integrated over ϕ):

$$A_L(\rho) = \frac{\sigma^+ + \sigma^-}{\sigma^+ - \sigma^-} = \frac{(1 - \rho(1+a))(1 - \frac{1}{(1-\rho(1-a))^2})}{\rho(1-a)\frac{\sqrt{4a\rho(1-\rho)}}{1-\rho(1-a)}} \qquad (1)$$

where $\sigma^{+(-)}$ refers to the cross section when the spin of the electron and the photon are aligned (anti-aligned) and ρ is the ratio between the energy of the scattered photon and the maximum allowed In this process, there is a maximum for the energy of the scattered photon $k'_{max} = 4ak\frac{E^2}{m^2}$ with $a = \frac{1}{1+\frac{4kE}{m^2}}$.

2.2. *Experimental Setup*

In Compton polarimeters [8,9,10] the electron beam scatters off a "photon target". Therefore, the measurement of the polarization is non-destructive and a continuous monitoring can be performed during the course of an experiment. Both the scattered electron and the backscattered photon can be used to determine the kinematics of the reaction. The photon are separated from the electrons using a dipole magnet and are detected in an electromagnetic calorimeter of known response function. The electrons are detected in position-sensitive detectors (Cerenkov or silicon detectors).

2.2.1. *Photon target*

In most polarimeters the photon target is simply a circularly polarized laser beam. The major difficulty results in monitoring the position and polarization of the beam at the interaction point. High power (100 W) lasers need to be used in order to maximize the luminosity, implying high maintenance cost.

An elegant alternative is to use a Fabry-Perot cavity for the photon target [11]. In such a device the photon beam is trapped between two highly reflective mirrors. This was performed for the first time for the JLab Hall A

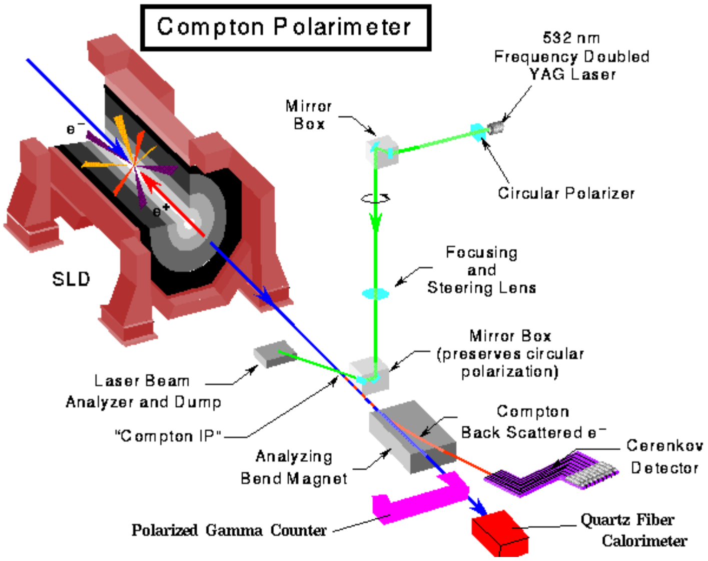

Figure 2. Layout of the SLD Compton Polarimeter at SLAC. Three types of particle detectors were used: Cerenkov counter for electrons, calorimeter, polarized γ counter.

Compton polarimeter [9] and is foreseen for Hera [12]. The laser is frequency locked to the frequency of the cavity using a feed-back loop. The monolithical design of the mechanical piece forces the photon beam to remain at the same location. It is then easier to maintain an optimal crossing of the beams. The circular polarization is not affected in the cavity because intrinsic birefringence of the mirrors is low enough. Using a 300 mW Nd:YAg laser, a power of 1700 W was routinely achieved under beam conditions.

2.2.2. *Systematic errors*

The Compton polarimeter of the SLD (see figure 2) running at 50 GeV has reached the level of 0.6 % total error after a careful analysis. It shows that there is no real blocking piece in this technique. At lower beam energy, where the experimental asymmetry is lower (the figure of merit goes like E^2), a total error of 1.4 % was reached at 4 GeV [13].

Among the systematic effect, the determination of the analyzing power taking into account the experimental conditions is contributing the most.

Measuring the polarization of the laser beam to better than 0.4% is also challenging. False asymmetries arising from helicity correlated beam differences can be large due to the fact that the photon and electron beam are small (150 microns). This effect can be minimized using techniques developed for electron scattering parity violation experiments [14]. The remaining challenge for Compton polarimetry is to reach the 1 % level at energies below 1 GeV as required for the JLab Hall A lead parity experiment.

3. Conclusions

We have described in this review the techniques and Möller an Compton polarimetry. Möller polarimetry can be performed at all beam energies but it is destructive whereas Compton polarimetry can be performed continuously during an experiment. In the past, the comparison of both techniques on the same beam as led to the discovery of the Levchuk effect. Presently, at JLab Hall A , they agree within errors bars.

The breakthroughs happened in the past five years consisting in the use of a Fabry-Perot cavity for the photon target for the Compton polarimeters and consisting in the use of a superconducting magnet to magnetize a pure Iron foil for the Möller polarimeters. Even more aggressive physics programs [15] can now be undertaken with these equipments.

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