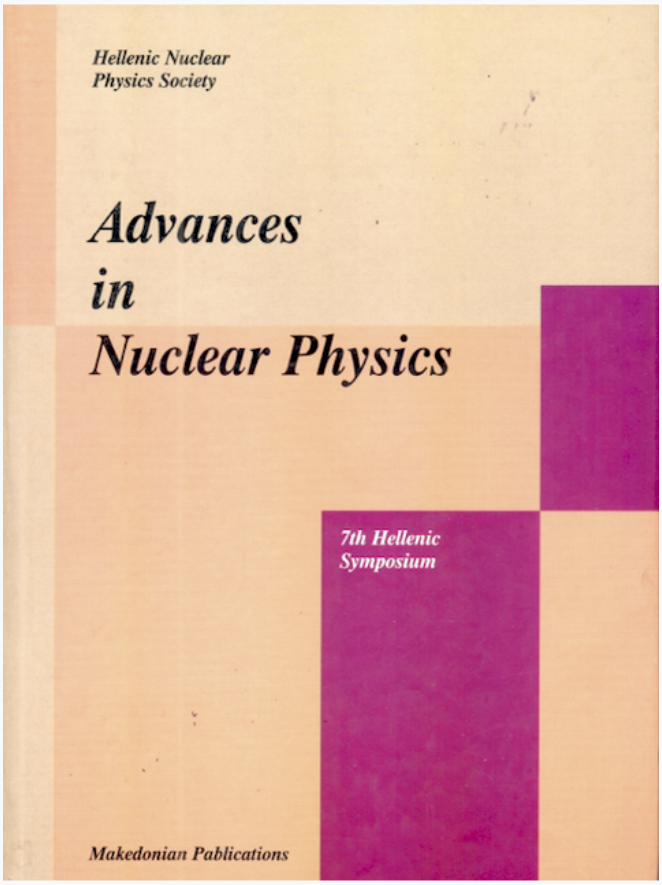
HNPS Advances in Nuclear Physics

Vol 7 (1996)

HNPS1996



A Compton Backscattering Polarimeter for Electron Beams below 1 GeV

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doi: [10.12681/hnps.2409](https://doi.org/10.12681/hnps.2409)

A Compton Backscattering Polarimeter for Electron Beams below 1 GeV

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Abstract

A recently installed polarized electron source will allow internal target experiments to be performed with polarized electrons at the *NIKHEF* Internal Target Hall. To measure the longitudinal component of the polarization vector of the stored electron beam, a polarimeter based on spin-dependent Compton scattering has been developed and successfully commissioned.

1 Introduction

Spin-dependent electron scattering is considered to be an essential tool to study the electro-magnetic structure of nuclei. To perform experiments with polarized electrons the *NIKHEF* facility has been upgraded with the necessary complex equipment to provide a intense longitudinally polarized electron beam in the Internal Target Hall of the Amsterdam Pulse Stretcher-storage ring (*AmPS*) ([1]). A polarized electron Injector has been constructed, consisting of a laser-driven photocathode electron source, a Z-shape spin rotating system, and a Mott polarimeter. Polarized electrons are accelerated and then stored in the *AmPS* ring. To compensate dynamically the depolarization effects and maintain the polarization longitudinal at the interaction region of the Internal Target Facility, during storage, a mirror-symmetric system, the so called *Siberian Snake*, consisting of two superconducting solenoids with a quadrupole in the middle and two skew quadrupoles on each end, is installed in the East straight section of the *AmPS* ring. In order to measure and monitor continuously the longitudinal polarization of the stored electron beam, during tune or performance of an experiment, a beam polarimeter was designed and constructed based on the laser Compton backscattering technique ([2]).

2 Compton Polarimetry

In the *LAB* frame the differential cross section for Compton scattering of circularly polarized light off longitudinally polarized electrons depends on the product of the longitudinal component of the electron polarization (P_z) and the circular photon polarization (S_3) as follows ([3]):

$$\frac{d\sigma_p}{dE_\gamma} = \frac{d\sigma_0}{dE_\gamma}[1 + P_z S_3 \alpha_{3z}(E_\gamma)] \tag{1}$$

where $\frac{d\sigma_0}{dE_\gamma}$ is the differential cross section for unpolarized Compton scattering, E_γ is the energy of the scattered photons, and α_{3z} is the longitudinal analyzing power of the reaction.

The analyzing power α_{3z} depends on the energy of the incoming electron and photon beams. For a given electron energy the shorter the photon wavelength the larger the analyzing power. In addition more energetic electron beams result in larger analyzing powers in polarized Compton scattering.

If a circularly polarized photon beam is backscattered off a polarized electron beam, the scattered intensity will depend on the helicity of the light and the electron spin according to the Compton cross section. The longitudinal degree of the polarization P_z, of the stored electron beam, is found by measuring the integrated counting rate asymmetry when one flips either the electron polarization or the photon polarization.

Spin-dependent Compton scattering of circularly polarized laser beam off polarized electrons has been traditionally used as a fast, accurate and non-destructive method for measuring the polarization of high-electron beams due to the high analyzing power of the Compton process [4]. The advent of intermediate energy electron storage rings makes realizable the application of this technique for electron beams with energy lower than 1 GeV, although the longitudinal analyzing power of the Compton process is small (for commercially available laser systems and for electron beam energies lower than 1 GeV the longitudinal analyzing power is less than 7%) ([5]).

3 The Compton beam polarimeter of $AmPS$ ring

The polarimeter consists of a laser system for producing the polarized photon beam with its associated transport optical system and a γ-ray detector for the detection of the backscattered photons. More details on the design and construction of the polarimeter are presented elsewere [2].

An Ar-ion laser system has been selected which produces a 10 W continuous and TEM_{00}-mode beam with wavelength of $\lambda = 514.5$ nm. An anti-reflection coated quarter wave ($\lambda/4$) plate is used to convert the initially linearly polarized laser light to circularly polarized light. Left-handed and right-handed polarized laser light is obtained by switching the high voltage on a Pockels cell, positioned immediately after the quarter-wave plate and operating in a half-wave ($\lambda/2$) mode. A chopper mounted on the laser support structure and immediately after the Ar-ion laser is used to block the laser light for 1/3 of the time for background measurements. The chopper, operating at 75 Hz, is also used to generate the driving signal for the Pockels cell. This ensures that the background measurement and the flipping of the laser polarization have exactly the same frequency.

The laser light is transported with single-layer coated mirrors, with a reflectivity of better than 99%, interacting with stored electrons in the straight section ($\sim$ 2.5 m long) after the first dipole, with bending angle of 11.25 deg, and before the second dipole after the Internal Target Facility. The laser beam position and orientation with respect to the stored in the $AmPS$ ring electron beam can be changed by means of remotely controlled mirrors, in order to optimize the overlap between the electron and laser beams in their interaction region. Initial tests with an unpolarized electron beam have shown an excellent performance of the laser positioning system ([6]).

4 The performance of the Polarimeter

The first commissioning tests of the polarimeter were performed with stored polarized electron beam with energy of 615 MeV, which results in backscattered photons with a maximum energy of $E_\gamma^{max} = 13.7$ MeV. During the tests a small beam current of between 2 and 5 mA was used with a storage lifetime of approximately 15 minutes and a laser power of only 3 W, to avoid rate problems and to minimize the relative contribution of background events.

The Compton scattered photons were detected with a pure CsI crystal with size of $10 \times 10 \times 24$ cm^3. A plastic scintillator is placed in front of the C-sI crystal to veto charged particles. The detector readout was done with a high speed VME-based histogramming module, which has been developed at $NIKHEF$. This module digitizes the signals from the CsI-crystal and stores ADC-values in different histograms based on the state of the chopper and the laser polarization. In this way, different energy spectra were constructed inside the module for left and right-handed polarized laser light and for background events. Thanks to the small decay time of the pure CsI crystal, an active base on the photomultiplier tube attached to the crystal and the dedicated electronics, the total setup is able to handle rates up to 1 MHz.

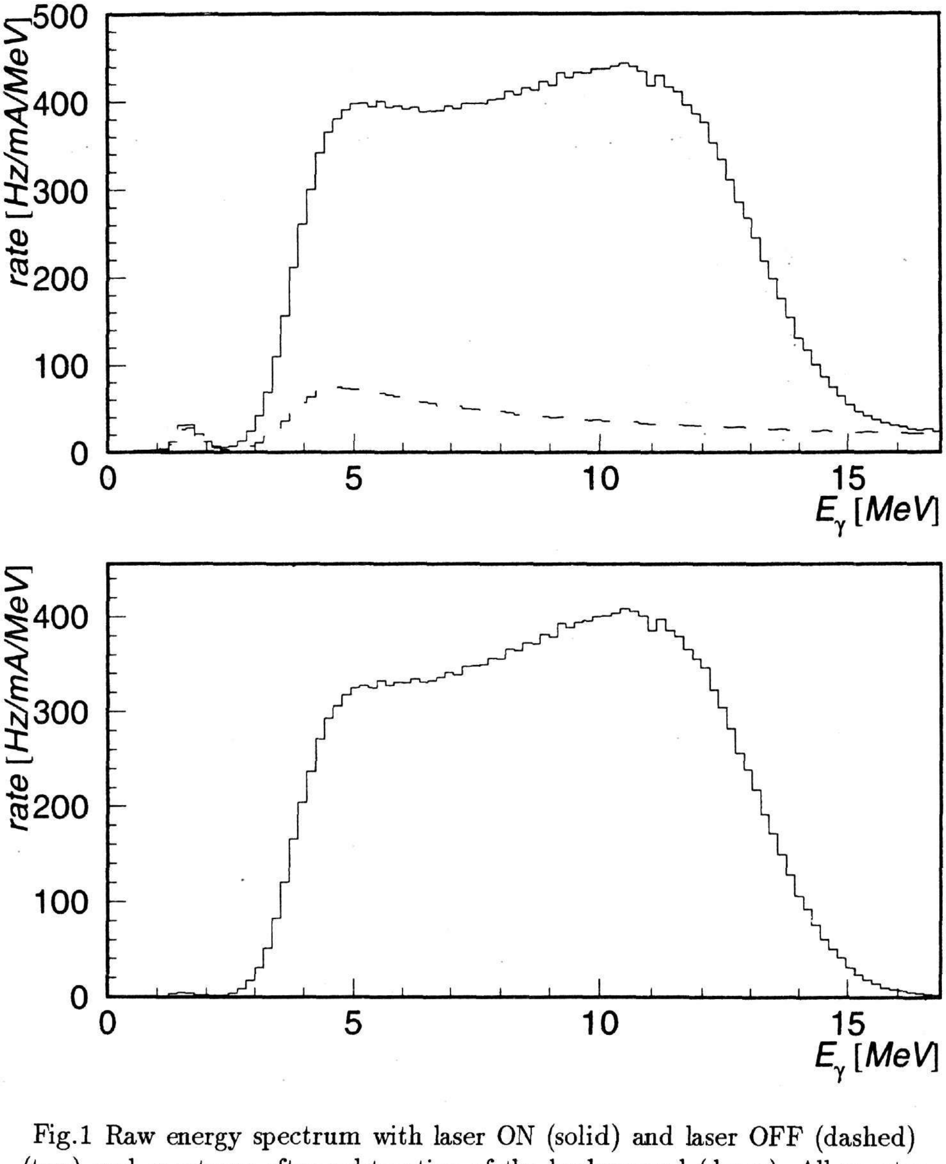

Fig.1 Raw energy spectrum with laser ON (solid) and laser OFF (dashed) (top) and spectrum after subtraction of the background (down). All spectra are normalized to the beam current.

A fraction of 88% of all detected photons were originated from Compton s-cattering, with a rate normalized to the beam current of 3.5 kHz/mA (see Fig. 1). During the experiment, an energy shift was observed between the two energy spectra for left and right-handed polarized laser light, due to ground currents. This shift of 22 keV ($\approx 10^{-3}$ of the full scale) was corrected for.

In order to measure the longitudinal polarization P_z of the electron beam the following experimental asymmetry (A_{exp}) was constructed by flipping the polarization of the incident laser photons:

$$A_{exp} = \frac{N_+(E_\gamma) - N_-(E_\gamma)}{S_+[N_-(E_\gamma) - N_b(E_\gamma)] + S_-[N_+(E_\gamma) - N_b(E_\gamma)]} = P_z < \alpha_{3z}(E_\gamma) > \quad (2)$$

where N_+ (N_-) is the energy spectrum with left (right)-handed polarized laser light, N_b is the background spectrum, S_+ (S_-) is the respective (absolute) degree of the laser light circular polarization. The electron polarization can be extracted from a measurement of N_+, N_- and N_b using this relation when the polarization of laser light is known from separate measurements.

Using Eq. 2 the experimental asymmetry A_{exp} was constructed and the magnitude of the electron polarization P_z was extracted. The experimental asymmetries A_{exp} are presented in Fig. 2 as a function of the energy of backscattered photons E_γ. A value of $P_z = 0.38 \pm 0.04$ ($P_z = -0.42 \pm 0.06$) was measured for the case of electrons having positive or negative helicity. During the experiment independent measurements were performed with the Mott polarimeter at the polarized Injector area. A value of $P_z = 0.45 \pm 0.05$ was extracted for both positive and negative helicity electrons, in agreement with the results of the Compton backscattering polarimeter.

To check for false assymetries the experimental asymmetry A_{exp} was determined for unpolarized electrons. The results are presented in Fig. 2 (inset) as a function of the energy of backscattered photons. A value of $P_z = 0.01 \pm 0.04$ was extracted for the "polarization" of the unpolarized electron beam, indicating the absence of false asymmetries in our measurements.

All errors indicated in Fig. 2 are purely statistical. Systematic errors can originate from the separate measurement of the laser circular polarization. We estimate this error to be smaller than 3%.

5 Summary

The results from the operational tests of the Compton backscattering polarimeter of the $AmPS$ ring for the measurement of the longitudinal polarization of the stored electron beam were presented. Experimental data are in agreement with the measurements at the Injector site and are indicative of the absence of false asymmetries.

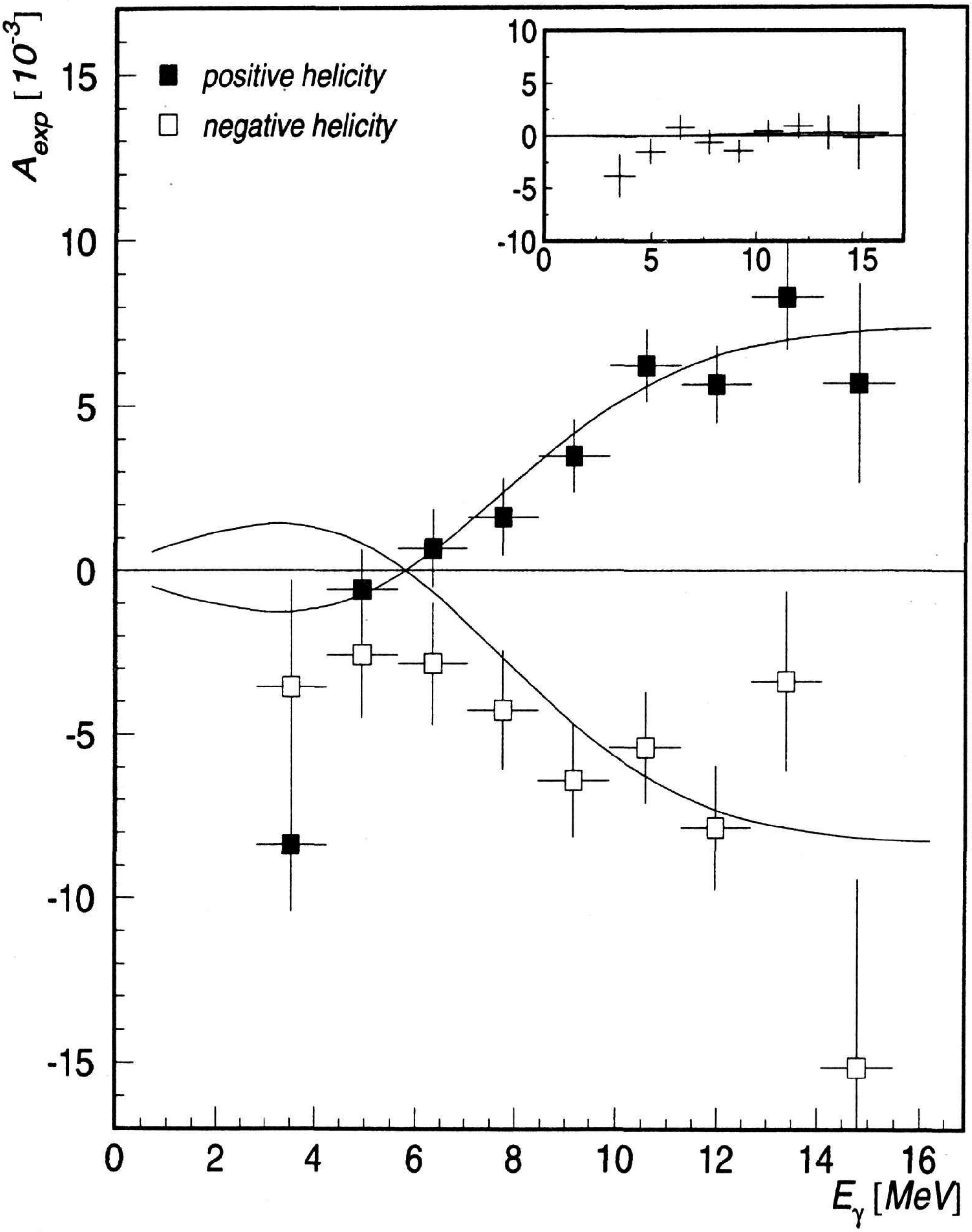

Fig.2 Experimental asymmetries A_{exp} as a function of the energy of the backscattered photons (E_γ) for positive and negative electron helicity and for unpolarized electrons (inset). The line is the best fit of $P_z < \alpha_{3z}(E_\gamma >$ to A_{exp}.

We would like to thank Dr. C. L. Morris from Los Alamos National Laboratory (LANL) for the supply of the CsI crystal. This work was supported in part by the Stichting voor Fundamenteel Onderzoek der Materie (FOM), which is financially supported by the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO), and HCM Grant Nrs. ERBCHBICT-930606 and ERB4001GT931472.

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