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Progress report on the A4 Compton backscattering polarimeter

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Abstract. The A4 collaboration at the Dept. of Nuclear Physics, University of Mainz, is conducting experiments on parity violation in the elastic electron-nucleon-scattering which require the use of polarized beams. In order to measure the absolute beam polarization, we have installed a Compton backscattering polarimeter in front of the target, using for the first time the internal cavity concept. A maximum intracavity intensity of 90 W has been measured, and in August 2003, first backscattered photons have been detected. This article describes the new design concept and the current status and results.

PACS. 29.27.Hj Polarized beams – 41.85.Qg Beam analyzers, beam monitors and Faraday cups – 42.60.By Design of specific laser systems – 42.60.Da Resonators, cavities, amplifiers, arrays and rings

1 Introduction

The A4 experiment at the Mainz Microtron (MAMI) is designed to determine the strange quark contribution to the nucleon properties by measuring the parity-violating cross-section asymmetry in the elastic electron-nucleon scattering with polarized beams. The measured asymmetry is related to the physics asymmetry via

$$A_{exp} = P_e A_{phys} \tag{1}$$

where P_e is the (longitudinal) beam polarization. For an absolute measurement of P_e, a Compton backscattering polarimeter using a new design concept has been installed in the A4 beamline.

2 Compton polarimetry

The Compton cross-section for polarized light on polarized electrons can be written as follows [1]:

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} + Q\frac{d\sigma_1}{d\Omega} - VP^e_{long}\frac{d\sigma_{long}}{d\Omega} - VP^e_{tr}\cos\varphi\frac{d\sigma_{tr}}{d\Omega} \tag{2}$$

P_{long}, P_{tr} denote the longitudinal and transverse electron polarizations, Q, V the Stokes parameters describing the light polarization and φ the azimuthal scattering angle. When using purely circular light ($Q = 0$), switching the light helicity ($V = \pm 1$) leads to an asymmetry in the spatial and energetic distributions of the backscattered photons, from which P_{long} and P_{tr} can be extracted.

The measurement time depends on the cross-section, the asymmetry, and the luminosity $\mathcal{L}$ via [2]

$$t \propto \frac{1}{\mathcal{L}\left<\sigma\right>\left<A^2\right>} \tag{3}$$

Table 1. Luminosity requirements for green light, P_e=0.8

$\Delta P_e/P_e$	$\mathcal{L}(E_e = 855 MeV)$	$\mathcal{L}(E_e = 570 MeV)$
10 %	1.15 kHz/barn	2.51 kHz/barn
5 %	4.59 kHz/barn	10.05 kHz/barn
3 %	12.76 kHz/barn	27.91 kHz/barn
1 %	114.86 kHz/barn	251.16 kHz/barn

where $\left<\sigma\right>$ is the detector efficiency-weighted average of the unpolarized cross-section over the energy range, and $\left<A^2\right>$ the cross-section- and efficiency-weighted mean-squared asymmetry. Asymmetry and cross-section are mostly fixed by kinematics and available devices, so only the luminosity can be optimized. Table 1 shows the luminosity required to achieve various accuracies within 15 min in absence of background. When calculating the expected luminosity for reasonable setup parameters (green laser light, 10 W of output power), the maximum value is about 4 kHz/barn even for optimum light focusing. It strongly depends on the crossing angle and decreases by a factor of 20 within 20 mrad. It is therefore desireable to use a collinear geometry and necessary to increase the laser intensity.

3 Polarimeter layout

One possibility to increase the available intensity is to feed the laser beam into a Fabry-Pérot resonant cavity. This concept has been reported to work successfully [3] but is difficult to build because the small bandwidth makes a frequency stabilization of the laser necessary. The A4 polarimeter implements for the first time the internal cavity concept [4]: lasers already consist of a F-P cavity with

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[a] comprises part of PhD thesis

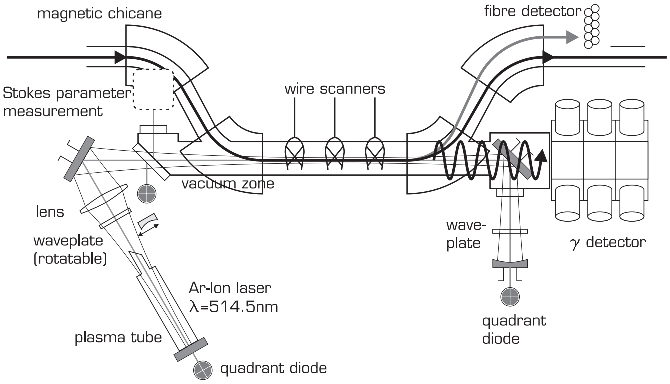

Fig. 1. Schematic view of the laser resonator. It is installed in a magnetic chicane in front of the A4 target

a lasing medium, and the output light is only a fraction of the internally circulating light. Our method is to extend the cavity length, use high-reflecting mirrors on both ends and guide the electron beam through the laser resonator where it interacts with the high intra-cavity power. Since the laser medium will adapt to cavity length fluctuations, no frequency stabilization is necessary; however, the achievable maximum power is lower than with an external cavity.

Figure 1 shows an overview drawing. The laser is an Ar-ion laser delivering 10 W at 514.5 nm in factory configuration. The lens is used to preserve the original beam profile in the medium while optimizing it in the interaction region. The cavity is now 7.8 m long and therefore vulnerable to vibrations of the optical elements. Since the influence of vibrations to the beam axis depends on the optics spacing and the vulnerability of the luminosity to beam axis fluctuations depends on the focusing, Monte-Carlo simulations of the effective luminosity as a function of vibration amplitude have been performed for various focusings. The final value is a focusing of $z_R = 2.5$ m with a maximum luminosity of 2.1 kHz/barn per 10 W of power. Also, a stabilization system for the laser beam position has been designed. The position is measured with quadrant diodes and stabilized using piezo-actuated mirrors [5]. In the interaction region, three wire scanners measure the positions of both beams simultaneously to establish overlap. The backscattered photons are detected in a NaI calorimeter. The electrons involved in the scattering lose energy and are displaced with respect to the main beam. A scintillating fibre array behind the chicane is used to detect them in coincidence with the photons to improve the data quality.

The circular polarization of the light is created using two quarter waveplates, one being rotatable to select the helicity. Two waveplates are necessary because the polarization optics is installed inside a resonator. One of the vacuum windows is used as a beam splitter to measure the polarization state. The extracted light (0.6%) is transmitted through a rotating quarter waveplate and a Glan-Laser prism; the intensity is thereby modulated with modulation amplitudes proportional to the beam's Stokes parameters.

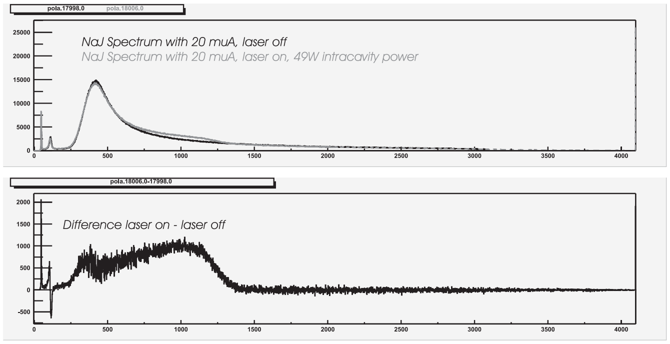

Fig. 2. ADC spectra in the NaI calorimeter with and without laser beam. The intracavity power was 49W

4 Status and results

The magnetic chicane has been set up in December 2002. It does not affect the beam quality on the target. The laser system has also been installed and works reproducibly. After installation of the polarization optics, intra-cavity intensities of up to 90 W have been measured in single-line (514.5 nm) configuration. Procedures to bring electron and laser beem to overlap have been established, and backscattered photon spectra have been recorded with the NaI calorimeter. A calibration procedure for the detector has been established which uses muons from cosmic radiation with trigger-defined track lengths inside the detector. The fibre array detector has been commissioned, and the data quality was improved by imposing a coincidence condition between electrons and photons. The signal-to-noise ratio was increased from 1:7.1 to 1:2.1. The laser beam stabilization system has been installed, and tests have shown a significant reduction of beam axis fluctuations [5]. The measurement device for the laser Stokes parameters has been installed and tested. The next steps will comprise the improvement of the vacuum and an analysis of stress birefringence in the vacuum windows. The NaI calorimeter is φ-averaging and the polarimeter therefore only sensitive to longitudinal polarization. It is planned to install a position-sensitive detector to measure also the transverse polarization.

With this setup, a statistical accuracy of 2.5% without and about 5% with background seems to be achievable in 15 min. Systematic uncertainties can arise from detector response and the Stokes parameter measurement. We are currently working to control and minimize them.

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