Exp.-Nr.: A1/01–16
Eingang:

Mainz Microtron MAMI

Collaboration: A1

Spokesperson: H. Merkel

Title: Beam-normal single-spin asymmetry measurement for medium-heavy nuclei

Contactperson: A. Esser, H. Merkel, B. S. Schlimme, C. Sfienti, and M. Thiel

Abstract of physics: We propose to measure the Z-dependence of the beam-normal single-spin asymmetry (A_n) at low Q^2. The intermediate mass regime is of particular interest to study effects from Coulomb distortion and dispersion corrections. Due to the focus on the low Q^2 range (Q^2(SpecA)=0.007 GeV/c^2 and Q^2(SpecB)=0.003 GeV/c^2), the data will significantly contribute to the improvement of current theoretical calculations.

Abstract of equipment: In addition to the standard A1 set-up, two of the high resolution spectrometers (SpecA and SpecB) will be equipped with quartz Cherenkov detectors in the focal plane. The readout of the system will be performed either in counting mode (standard A1 DAQ) or in integrating mode (former A4 electronics). The beam polarization will be measured with the Møller (A1), Mott, and Compton (MAMI) polarimeters.

MAMI specifications :

beam energy:	210 MeV
beam current:	20 μA
time structure:	continuous beam
polarization:	yes (vertical)

Experiment specifications :

hall:	spectrometer hall
beam line:	standard to spectrometer hall

spectrometer:	particles:	range of angles:	out of plane:
A	e$^-$	23.5°	-
B	e$^-$	15.1°	-

special detectors:	two Cherenkov detectors placed in SpecA and SpecB
targets and chamber:	^{12}C, ^{28}Si, and ^{40}Ca

Beam time request :

set-up without beam:	48 h
set-up with beam:	36 h
data taking:	276 h

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Proposal for an experiment

Beam-normal single-spin asymmetry measurement for medium-heavy nuclei

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1 Introduction

Next generation parity-violating electron scattering experiments will measure very small asymmetries (A_{PV}) of the order of few hundreds parts-per-billion (ppb) with unprecedented accuracy. The requirements of these experiments are challenging for both detector and electronics as well as beam parameters and their stability. In this context the precise knowledge of the beam-normal single-spin asymmetry (or transverse asymmetry) A_n is of outmost importance since A_n can lead to false asymmetries [1].
The transverse asymmetry arises from the interference of the one-photon and two (and more)-photon exchange [2]. Calculating the two-photon exchange in general kinematics is challenging because such a calculation requires an account of inclusive hadronic intermediate states with arbitrary virtualities of the exchanged photons. This complication is alleviated if considering the very low Q^2 region where the leading behaviour is $\sim Q \log(Q^2/m^2)$ with m being the electron mass [3, 4]. The coefficient in front of this large logarithm is model-independent and it is obtained from the optical theorem as an energy-weighted integral over the total photoabsorption cross section on the particular target.
For the proton, calculations in this inclusive approach [3, 4], as well as models with a partial account of the excited hadronic spectrum [5, 6] are available. While the former one is limited to forward angles, the latter one is applicable to a general kinematics. Both calculations provide a good description of forward proton data [7] and reasonably good description of large angle data [8, 9, 10] with the exception of the backward data of Ref. [11]. Gorchtein and Horowitz generalized the forward inclusive model to nuclear targets upon neglecting multi-photon exchanges [12].

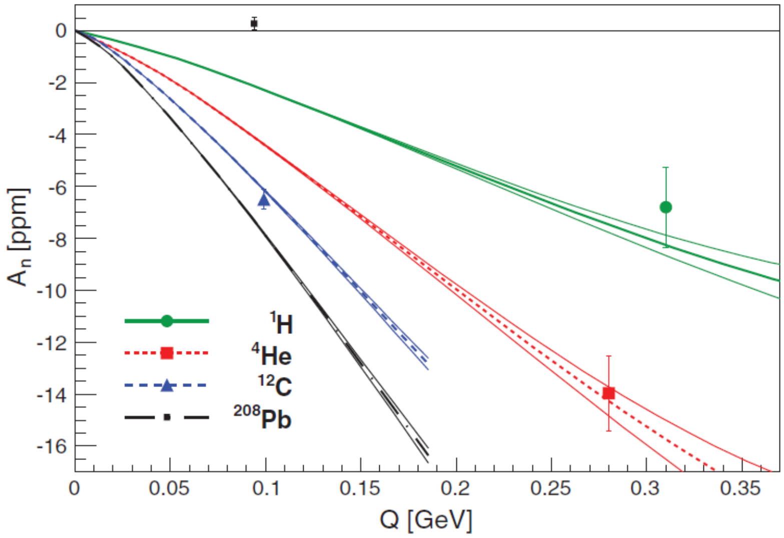

Figure 1: Extracted beam-normal single-spin asymmetries A_n versus four-momentum transfer for different nuclei [7] in comparison to theoretical predictions [12].

Figure 1 shows the experimental measurements of A_n for four different target nuclei (^{1}H, ^{4}He, ^{12}C, and ^{208}Pb) by the PREX and HAPPEX collaborations at JLab in comparison with the theoretical predictions of [12]. While the data of the lighter target nuclei are in very good agreement with the calculation, the experimental point for lead cannot be explained by the theory, hence raising the question of the importance of multi-photon exchanges, e.g. Coulomb distortion and indicating the need for new calculations that involve simultaneously Coulomb distortion and dispersion corrections.

To verify the theoretical predictions with respect to open questions like Q^2-dependence and Z-dependence, new data, especially in the intermediate mass range between carbon and lead, are needed. Motivated by this, we have proposed a systematic study of A_n within the Collaborative Research Centre 1044.

2 Preparatory Work

To measure the transverse asymmetry A_n with the existing spectrometer set-up in the A1 hall, the electron beam has to be polarized normal to the scattering plane. Since MAMI was originally not designed to run with a vertically polarized beam, some minor (reversible) modifications to the operation mode of a double solenoid had been made. It had to be verified, that the beam polarization was purely vertical. Unfortunately, the Møller polarimeter in the experimental hall is only sensitive to the longitudinal component. Therefore, a sophisticated method had been worked out to determine the magnitude as well as the orientation of the polarization using all available polarimeters [13]: the Mott [14] and Compton [15] polarimeters sitting close to the polarized source in combination with the Møller polarimeter [16] in the experimental hall. The degree of the vertical polarization was deduced from a measurement of the total polarization "minus" the horizontal polarization components. The result of the horizontal beam polarization measurements is shown in figure 2.

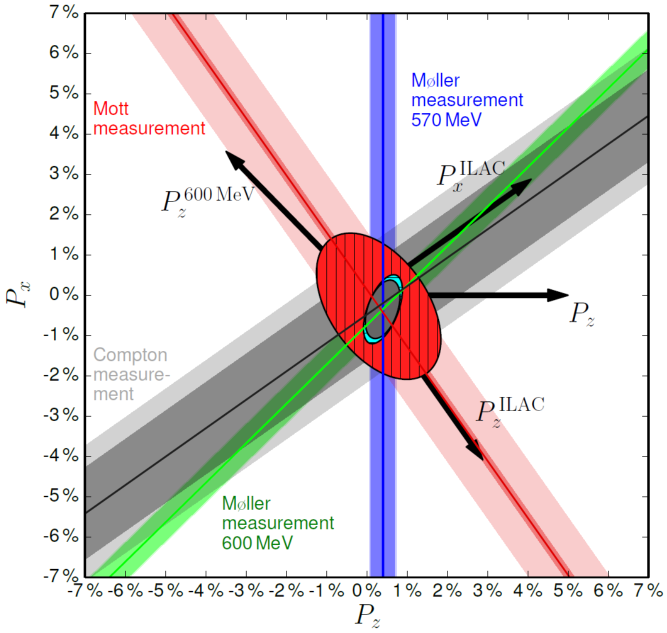

Figure 2: Reconstructed horizontal beam polarization components. The result of a maximum likelihood fit when combining all available polarimeter data is shown as solid ellipse (grey). Consideration of only the Mott and Compton result gives the vertically hatched (red), combination of the two Møller measurements the horizontally hatched ellipse (blue) [13].

According to the success of this commissioning beam time together with the former feasibility study of such type of experiments at A1 (as explained in detail in the Continuation Proposal of the CRC 1044), we performed an experiment to study the Q^2-dependence of A_n. Carbon was chosen as target material due to its high sublimation point ($T_{sub} = 3642°\mathrm{C}$) and the large separation energy to the first excited state ($\Delta E = 4.4\,\mathrm{MeV}$).

Regarding the chosen kinematics, it was of utmost importance that the first Q^2 data point was determined in a symmetric spectrometer configuration (double-arm measurement) to enable an identification of possible false asymmetries caused by variations of the beam which are correlated to the direction of the polarization.

Furthermore, to reach a reasonable high count rate, the detectors have to be placed in forward direction. Here, we are limited by the distance between the exit beamline and the quadrupole of SpecA. Therefore, SpecA was placed at its minimum angle of 23.5 degree which corresponds to $Q^2 = 0.04$ GeV$^2/c^2$, running at a beam energy of 570 MeV. To cover the same momentum range with the smaller acceptance of SpecB, it was placed at 20.61 degree. Both spectrometers measured the same asymmetry within error bars, indicating negligible contributions from false asymmetries. Therefore the decision was made to move the two spectrometers to different angles to cover a larger four-momentum range. Three more points, running single-arm, were measured: SpecA at $Q^2 = 0.05$ GeV$^2/c^2$ and SpecB at $Q^2 = 0.02$ GeV$^2/c^2$ and $Q^2 = 0.03$ GeV$^2/c^2$. Table 1 summarizes the running conditions of the beam time.

beam energy	570 MeV
beam current	20 μA
beam polarization	vertical (80%)
target	^{12}C (2.27 g/cm^2)
Q^2	0.02 - 0.05 GeV$^2/c^2$
scattering angle θ (SpecA)	23.5°, 25.9°
scattering angle θ (SpecB)	15.11°, 17.65°, 20.61°

Table 1: Beam time conditions.

To handle the expected high count rate, two Cherenkov detectors consisting of quartz plates read out with photomultiplier tubes have been built. According to the different focal plane geometries of SpecA and SpecB where the Cherenkov detectors were mounted, the quartz plates had the dimensions (300 x 70 x 10) mm^3 and (100 x 70 x 10) mm^3 respectively. During the experiment, two different operation modes have been used. For an optimum positioning of the detectors with respect to the elastic line, the Cherenkov detectors have been read out in coincidence with the vertical drift chambers of the spectrometers. In this so called “counting mode”, the beam current was reduced to approximately 50 nA. Figure 3 (left panel) illustrates how well the elastic events, detected with the Cherenkov detectors, are separated from the events of the first excited state.

In the integrating mode, only the Cherenkov detectors have been read out with parts of the former A4 experiment data acquisition system [17]. In this mode, where the beam current was increased up to 20 μA, the electron beam has to be extraordinary stable with respect to energy, intensity, and position over the entire running time of the experiment in order to constrain the systematic uncertainties. A new AC (fast component) and DC (slow component) stabilization system had been developed and has been successfully checked during this beam time as illustrated in figure 3 (right panel). Several beam monitors, placed in the A1 beamline, have been read out in combination with the detector using ADCs which integrate the charge over periods of 20 ms. A gate generator provides the integration windows where the polarization is reversed in patterns like $\uparrow\downarrow\downarrow\uparrow$ or $\downarrow\uparrow\uparrow\downarrow$ in a pseudo random sequence. In addition, the integration windows were synchronized to the power grid frequency to minimize any effect from ground noise.

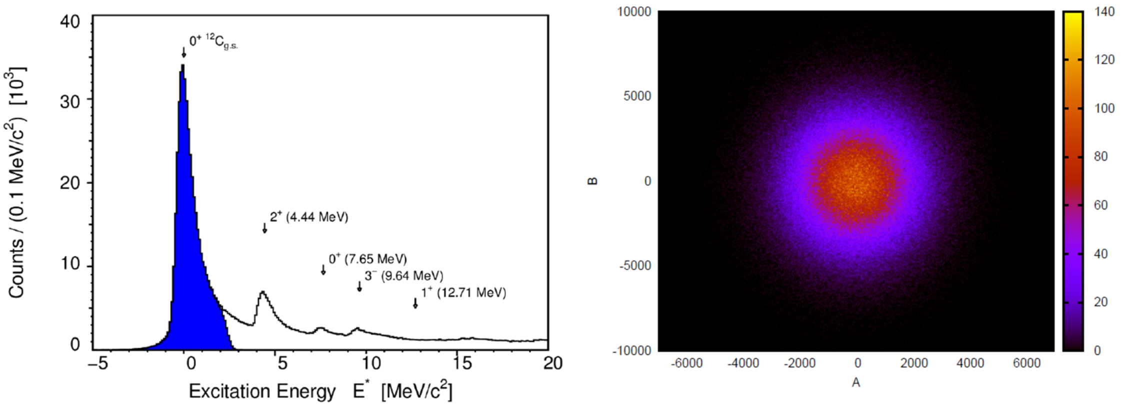

Figure 3: *Left:* Counting mode data to verify the position of the Cherenkov detectors. Black line shows the response of the complete spectrometer for SpecB. The filled area corresponds to the response of the Cherenkov detector only. It perfectly covers the elastic peak (around zero MeV) in the excitation energy spectrum shown. *Right:* Correlation of the measured transverse asymmetries with the two Cherenkov detectors in SpecA and SpecB. The circular shape indicates that contributions from false asymmetries are negligible because of a well stabilized beam.

In the data analysis the transverse asymmetry A_n^{meas} is calculated and corrected for beam variations:

$$A_n = A_n^{meas} - \frac{I^{\uparrow} - I^{\downarrow}}{I^{\uparrow} + I^{\downarrow}} - \left(\Delta X \frac{d\sigma}{dX}\right) - \left(\Delta Y \frac{d\sigma}{dY}\right) - \left(\Delta X' \frac{d\sigma}{dX'}\right) - \left(\Delta Y' \frac{d\sigma}{dY'}\right) - \left(\Delta E \frac{d\sigma}{dE}\right).$$

Here, I is the beam current, X and Y are the horizontal and vertical positions of the beam, X' and Y' belong to the corresponding beam angles and E is the beam energy. Table 2 shows an overview of the applied correction factors.

source of false asymmetry	**correction [ppm]**
beam current (I)	-0.83
beam energy (E)	-0.0090
horizontal beam position (X)	0.10
vertical beam position (Y)	-0.00082
horizontal beam angle (X')	0.010
vertical beam angle (Y')	0

Table 2: Applied corrections to the measured asymmetry for a chosen set-up [18].

The preliminary results for the transverse asymmetry A_n for carbon in the Q^2-range 0.02 GeV^2/c^2 to 0.05 GeV^2/c^2 are presented in figure 4. A comparison of the shown statistical errors with the preliminary estimate of the systematic uncertainties of about 0.5 ppm indicates that the achievable experimental accuracy is still limited by statistics. The data points in figure 4 are compared to a theoretical calculation [12], limited at the time to small Q^2 values. Hence, a measurement of an additional point at lower Q^2 to verify the Q^2-dependence of the theoretical prediction seems to be mandatory.
Moreover, as pointed out in section 1, to study the impact of Coulomb distortion effects on A_n new data for medium-heavy mass nuclei are mandatory.

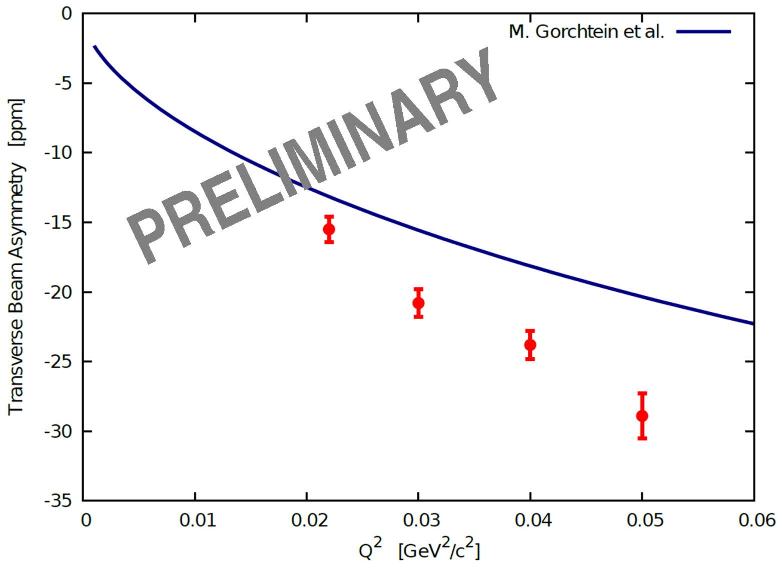

Figure 4: Preliminary results for A_n for ^{12}C [18] in comparison to theoretical calculation [12]. The data points at $Q^2 = 0.02$ GeV$^2/c^2$ and $Q^2 = 0.03$ GeV$^2/c^2$ were measured with SpecB, the data point at $Q^2 = 0.05$ GeV$^2/c^2$ was measured with SpecA and the data point at $Q^2 = 0.04$ GeV$^2/c^2$ was a double-arm measurement with SpecA and SpecB. Only the statistical error is shown.

3 Proposed Experiment

We propose a study of the Z-dependence of the transverse asymmetry A_n for the low Q^2-range. The selection of the target material is based on its specific properties like melting temperature and the separation energy ΔE of the first excited state. Furthermore, the costs for isotopic pure material have been taken into account. Table 3 summarizes the most important parameters of the chosen target materials.

target material	**melting temperature**	$\boldsymbol{\Delta E}$
^{12}C	3642°C	4.4 MeV
^{28}Si	1410°C	1.78 MeV
^{40}Ca	842°C	3.4 MeV

Table 3: Properties of the chosen target materials. For carbon the sublimation point is given instead of the melting temperature.

Similarly to the pilot experiment we performed with ^{12}C, we will use two of the high resolution spectrometers (SpecA and SpecB) placed in forward direction to identify the reaction $X(\vec{e}, e')X$ with X being ^{12}C, ^{28}Si, or ^{40}Ca. The same Cherenkov detectors, as described in section 2, will be placed in the focal plane of the two spectrometers. At a beam energy of 570 MeV a measurement at Q^2 lower than the one previously measured is not possible since both spectrometers were already running at their minimum angle setting: SpecA at 23.5 degree ($Q^2 = 0.04$ GeV$^2/c^2$) and SpecB at 15.11 degree ($Q^2 = 0.02$ GeV$^2/c^2$). Therefore we will decrease the beam energy and take the lowest possible stabilized energy of 210 MeV. Keeping the minimum angle of the spectrometers, we will measure the transverse asymmetry A_n at $Q^2 = 0.007$ GeV$^2/c^2$ (SpecA) and $Q^2 = 0.003$ GeV$^2/c^2$ (SpecB).

3.1 Beam time Estimate

We request 360 hours of beam time, according to the following schedule.

Set-up without beam: 48 h

The Cherenkov detectors have to be placed inside the focal plane of the high resolution spectrometers. Especially in SpecA this is critical because of the limited space between the vertical drift chamber and the scintillators. Moreover, the switching between counting and integrating mode has to be set-up. A test of the counting mode requires typically one night data taking with cosmic rays. The integrating mode can be tested only with beam. The Møller polarimeter has to be cooled down: this is a two step process involving a pre-cooling with liquid nitrogen on the first day and the final cooling with liquid helium on the second day.
The target ladder has to be installed and calibrated.

Set-up with beam: 36 h

The stabilization system and the correponding monitors of MAMI have to be tested.
For each target, the Cherenkov detectors have to be positioned exactly on the elastic line. Therefore the momentum of the spectrometers has to be changed successively.

Data taking: 276 h

An important part of the data taking time has to be spent for polarization and calibration measurements. 76 hours are foreseen for polarization measurements involving the Møller, Mott, and Compton polarimeters. Especially at the beginning of the beam time we need to verify carefully that the beam is polarized normal to the scattering plane. Therefore an adjustment of the double solenoid as well as of the Wien filter has to be performed. During the data taking the polarization will be checked only with Mott measurements once a day.
To keep the source of false asymmetries as small as possible, careful calibrations of the beam current and energy, as well as of the horizontal/vertical position and angle have to be performed at the beginning of the beam time. Finally, the response of the photomultiplier tubes has to be calibrated once a day. In total 20 hours are foreseen for calibration measurements.
The estimate of the running time is based on the experience gained during the Q^2 - dependence measurement. Regarding the preliminary analysis of the data point at $Q^2 = 0.02$ GeV$^2/c^2$ (SpecB at 15.11 degree), we have a 6% statistical uncertainty of the transverse asymmetry A_n within 30 hours of data taking. With the new measurement we will decrease Q^2 by nearly one order of magnitude by going from 570 MeV beam energy down to 210 MeV. As an estimate for the size of the transverse asymmetry of carbon we can only rely on the theoretical calculation we have so far, for which at lower Q^2 the leading behaviour gets $\sim Q \log(Q^2/m^2)$. Therefore we can estimate that A_n for carbon is approximately a factor five smaller going from $Q^2 = 0.02$ GeV$^2/c^2$ to 0.003 GeV$^2/c^2$. This decrease will be partly compensated by the cross section increase of about a factor ten. For the heavier targets we will gain an additional factor of two in count rate compared to the carbon target at $Q^2 = 0.003$ GeV$^2/c^2$. Assuming the same systematic uncertainty as obtained in the former Q^2 measurement (about 0.5 ppm), we estimate the running time to determine the transverse asymmetry A_n to be 60 hours per target material to achieve a comparable statistical uncertainty of at least 0.5 ppm.

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