ELECTRON BEAM POLARIMETRY AT THE S-DALINAC*

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Abstract

For planned experiments with polarized electron and photon beams at the superconducting Darmstadt electron linear accelerator S-DALINAC, the absolute degree of the electron beam polarization needs to be known. We present the existing and planned polarimeters at the source of polarized electrons and the experimental sites, especially a 100 keV Mott polarimeter and a Möller polarimeter for 30-130 MeV electrons.

INTRODUCTION

Polarization degrees of freedom can provide sensitive data for understanding fundamental interactions. At low momentum transfer and energies below the pion mass, there are very little data available, but the advent of, e.g., pionless chiral effective field theory has brought significant theoretical advances in this energy region. For example, experiments to study the fifth structure function in the break-up of nuclei at low momentum transfer and parity violation in photo-induced reactions are proposed at the S-DALINAC. The uncertainty in the knowledge of the electron beam polarization is a significant contribution to the accuracy of these measurements. All methods which are developed to date to measure the electron beam polarization at the accelerators are based on measuring count-rate asymmetries by the electron scattering on nuclei, electrons or photons. Electron-nucleus scattering, so-called Mott scattering is typically employed at energies below 20 MeV. The second method is electron-electron or Möller scattering used at middle and high energy. The third technique is electron-photon or Compton scattering. All three techniques will be used for electron-beam polarimetry at the S-DALINAC.

S-DALINAC AND TEST STAND SETUP

A schematic drawing of the S-DALINAC and its experimental sites is shown in Fig. 1. The S-DALINAC provides an electron beam of about 4-130 MeV [1]. To extend the existing experimental capabilities, the S-DALINAC Polarized INjector (SPIN) has been developed. SPIN should provide an electron beam with ≥80% polarization and intensities of up to 60 μA. The locations of the polarimeters are indicated in Fig. 1. The 100 keV Mott polarimeter is located in front of the first superconducting accelerator structure. To test the main components of the new injector such as the polarized electron gun, a Wien filter, a 100 keV Mott polarimeter and a chopper/prebuncher system, an off-line test stand has been constructed [2].

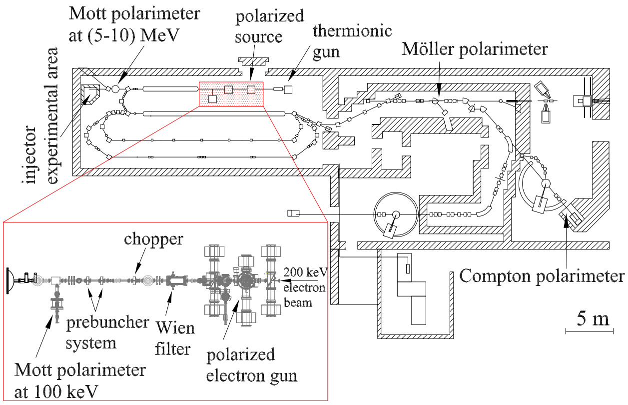

Figure 1: Schematic view of the S-DALINAC.

100 keV Mott Polarimeter

A Mott polarimeter is based on a spin-orbit interaction. The counting rate asymmetry in the elastic Mott scattering occurs if the polarization vector is not parallel to the scattering plane. The Mott scattering chamber [3] is cylindrical in shape with a diameter of 203 mm and a length of 180 mm and is manufactured from 304 stainless steel. A rotatable target wheel has 11 positions for up to 9 Au targets, a Be viewer to control the beam position and one empty target for underground measurement. The gold targets are self supporting and cover a thickness range between 42.5 and 500 nm. The upside of the Mott chamber flange is coated with colloidal graphite (Aquadag) to reduce background from scattered electrons. Electrons scattered elastically from the gold foils are detected by four silicon surface barrier detectors, located at the azimuth angles of 45°, 135°, 225° and 315°. This allows one to determine both transverse spin components. The scattering angle of $(120 \pm 1.5)^\circ$ is defined by an aluminium collimator with a hole of 2 mm diameter. At this angle the analyzing power, the so-called Sherman function, has a broad maximum for 100 keV electrons. The typical energy resolution is about 20 keV, and the peak to background ratio is 14:1 for a 122 nm Au foil. The polarization of the electrons can be switched from parallel to antiparallel to the electron momentum by changing the incident laser light from right

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to left circular polarization. This is done to eliminate instrumental asymmetries. Typical spectra for different laser polarization from a pair of detectors separated by 180 ° in azimuth are shown in Fig. 2.

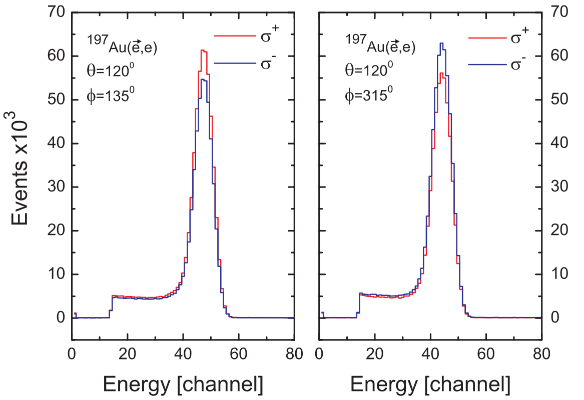

Figure 2: Energy spectra measured with two opposite Si-detectors for electrons scattered on a 122 nm gold target at 120°.

A high cross section of electron scattering at low energy leads on the one hand to high counting rates, and on the other hand to significant plural and multiple scattering even in thin foils, which reduce the effective Sherman function. The uncertainty of the foil-thickness extrapolation to target thickness zero is one of the main uncertainties by the determination of the beam polarization (Fig. 3). Gay et al. [4] discuss various forms for extrapolation of asymmetry. Table 1 summarizes the results of extrapolation using various fitting curves (for the linear fit only two foils with thickness 42.5 and 60 nm were included). Data have been taken using an electron beam produced from a bulk GaAs photocathode. The best fit is given by an exponential function (χ^2/d.o.f.=1.38). The average value of asymmetry extrapolated to zero thickness is $(13.8 \pm 0.4)\%$. The theoretical value of the Sherman function at $120°$ for single atom scattering is -0.391 [5] with an uncertainty of 1%, for our acceptance -0.3904. From this a degree of polarization $P = (35.5 \pm 1.4)\%$ for bulk GaAs was obtained. The degree of polarization of $(72.1 \pm 2.1)\%$ was measured for superlattice photocathode.

Table 1: Extrapolated values of the asymmetry A_0 to zero thickness for different fit functions

Fit function	**A$_0$**	**χ^2/d.o.f.**	**r^2**
$A(t) = a - bt$	0.1373	-	-
$A(t) = a/(1 + bt)^2$	0.1363	7.05	0.995
$A(t) = a/(1 + bt)$	0.1428	2.46	0.997
$A(t) = a + be^{-t/c}$	0.1370	1.38	0.998

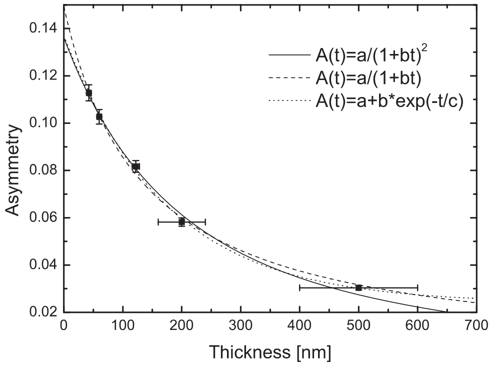

Figure 3: Experimental asymmetry as a function of the gold foil thickness and foil-thickness extrapolation.

Orientation of the Beam Polarization

The electrons emitted from the GaAs photocathode by illumination with circular polarized light have longitudinal polarization. Because of spin motion in the electromagnetic field the spin is not parallel to the velocity of the particle at the experimental areas, so a spin manipulator is necessary. Since spin manipulation at low energy is easier than at high energy, a Wien filter was installed and tested at 100 keV. The Wien filter consists of crossed homogenous electric and magnetic fields perpendicular to the particle momentum and each other [6]. The spin is rotated in the plane of the electric field. The electron beam can pass through the Wien filter undeflected, while the spin is rotated, if the Lorentz force equilibrium condition $|E/B| = \beta c$ is satisfied. The Wien filter focuses an electron beam in one plane and acts as a drift in another. The focal strength is given by $k = \gamma\varphi \sin(\gamma\varphi)/L$, where φ is the spin rotation angle and L is the effective length of the Wien filter, resulting in focal strengths between 0 and 4.6 m^{-1}. This effect can be minimized: the focus was chosen inside of the Wien filter.

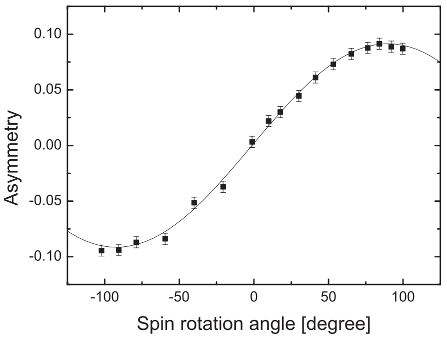

Figure 4: Measured Mott scattering asymmetry as a function of the spin rotation angle.

The Wien filter rotation angle is given by the equation

$$\varphi = \frac{eLB}{mc\beta\gamma^2}$$

where e and m electrons charge and rest mass. For a

100 keV beam a 90° spin rotation requires B=5.4 mT. The Wien filter was tested at E=1.07 MV/m (17.1 kV over 16 mm gap), so that it provides a 100 degree spin rotation. Figure 4 presents the measured Mott scattering asymmetry as a function of the spin rotation angle and a fit function $A = A_m \sin(k\varphi + \varphi_0)$. The χ^2 per degree of freedom is 1.3 with a correlation coefficient of 0.9975.

5-10 MEV MOTT POLARIMETER

To support experiments at the injector experimental area, it is planned to measure the beam polarization at energies between 5 and 10 MeV with a Mott polarimeter. Mott scattering at this energy has also a number of advantages. The differential cross section is smaller, but multiple and plural scattering are reduced. This makes the results of the foil thickness extrapolation less uncertain. Furthermore, small cross sections allow measuring the beam polarization at much higher currents. Examples for such devices are given in [7].

MÖLLER POLARIMETER

The scattering of two polarized electrons is called Möller scattering, and the spin-spin interaction leads to an asymmetry. The Möller polarimeter consists of a polarized electron target, a momentum selecting dipole magnet and detectors to detect the scattered and recoiling electrons in coincidence. The polarimeter uses a Vacoflux target (49% Fe, 49% Co, 2% V) which is polarized “in plane“ by a weak longitudinal magnetic field created by Helmholtz coils. The mesured polarization is (8.22±0.12)% at 80 Gs. The target is 20 μm thick and mounted at an angle of 25^0 with respect to the beam, giving an effective target thickness of 47.3 μm. The scattered and recoiling electrons leaving the target in vertical direction are selected by a collimator and momentum analyzed by a dipole magnet. The electron pairs are detected by plastic scintillators in coincidence for background suppression. The layout of the polarimeter is shown in Fig. 5.

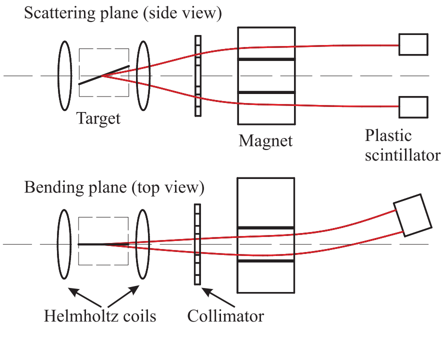

Figure 5: Schematic view of the Möller polarimeter.

For the energy range between 30 and 130 MeV a center-of-mass (CM) scattering angle of 90° (where the asymmetry coefficient reaches a maximum of about 7/9) corresponds to a laboratory angle between 5 and 10.4 degrees, if the target electrons are at rest. The electron orbital motion of the target electrons affects the laboratory scattering angle and can constitute a large systematic uncertainty for Möller scattering [8]. A dominant effect comes from electrons scattered on unplarized electrons from K and L shells, that leads to an overestimation of the beam polarization. To avoid it, a large angular acceptance is required. Figure 6 shows the dependence of the scattering angle from center-of-mass scattering angle. For monitoring the beam polarization during electron scattering experiments, a Compton transmission polarimeter [9] will be used. We also study the feasibility of Mott scattering at electron energies between 15 and 50 MeV.

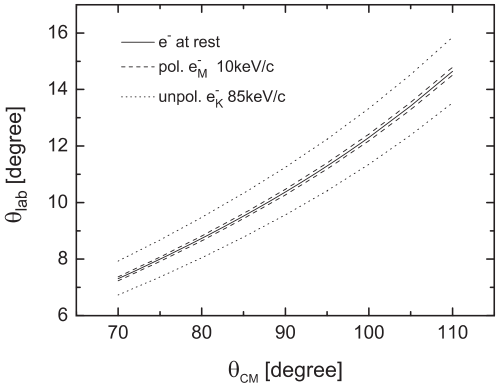

Figure 6: The Möller scattering angle as a function of the CM scattering angle for 30 MeV. The solid line is for target electrons at rest. The dashed and the dotted lines are for electrons from M and K shells having the momentum of 10 and 85 keV/c respectively.

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