IL NUOVO CIMENTO Vol. 35 C, N. 4 Luglio-Agosto 2012
DOI 10.1393/ncc/i2012-11275-8

Colloquia: PAVI11

Møller (iron foils) existing techniques

O. Glamazdin
National Science Center Kharkov Institute of Physics and Technology
Kharkov 61108, Ukraine

ricevuto il 14 Ottobre 2011; approvato il 5 Maggio 2012

Summary. — In Møller polarimetry for solid targets (iron or supermendure), there are only two different techniques of electron target polarization. The first one is a "classic" technique of the Møller target polarization in a foil plane. The second one is the so-called "brute force" technique of the electron target polarization in a strong magnetic field (about 3 T) in a plane perpendicular to the foil plane. Both the techniques can be used for different experiments for electron beam polarization measurements.

PACS `13.88.+e` – Polarization in interactions and scattering.
PACS `29.27.Hj` – Polarized beams.
PACS `29.25.Pj` – Polarized and other targets.

1. – Introduction

A significant part of the physics program requires polarized electron beams. For many experiments, the error associated with the beam polarimetry makes the leading contribution to the total experiment systematic error budget. Therefore, better understanding, and any improvements, of the beam polarimetry systematic error is important. Møller polarimeters are widely used for beam polarization measurements. Typically, the dominant systematic error of the Møller polarimetry is the electron target polarization uncertainty.

2. – Solid target polarization techniques

All of the Møller polarimeters use ferromagnetic foils made of pure iron (99.85–99.99% purity) or Supermendure alloy (49%Fe, 49%Co, 2%V) as a material for polarized electron target (PET). There are two different techniques to polarized ferromagnetic foils:

1) A "classic" technique [1]. For this technique a relatively low (a few hundred Oe) magnetic field with the direction parrallel the direction of the beam is used. A ferromagnetic foil is placed in the field at an angle 20° between the foil plane and

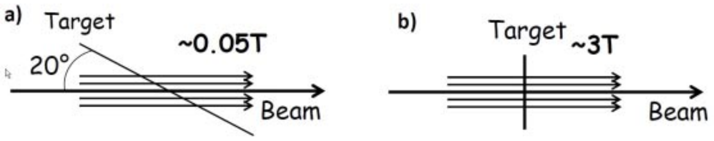

Fig. 1. – a) Scheme of "classic" technique of ferromagnetic foil polarization in the foil plane. b) Scheme of "brute force" technique of ferromagnetic foil polarization in out-of-the-foil plane.

the beam/magnetic field direction (see fig. 1a). Due to the ferromagnetic domain structure, a low outer magnetized field produces a high (of about 2 T) magnetic field inside the domains/foil. The domains line up along a direction in the foil plain and produce foil magnetization with that direction. For this reason, such technique of a foil polarization is often called "in foil plane" polarization technique. Unfortunately, a few hundred Oe magnetic field is not enough to produce a full foil magnetization saturation. Therefore the dependence of foil polarization saturation of the saturated magnetic field has to be measured before using the foils as a PET.

2) A "brute force" technique [2]. This technique exploits the idea to use a strong (larger than the magnetic field inside of the foil domains) magnetic field for a ferromagnetic foil polarization. In this case, if the magnetized field is strong enough, the "brute force" of the field has to be sufficieant to orient domains along the magnetized field, which may have any direction. A scheme of "brute force" technique is shown in fig. 1b. The magnetic field direction is the same as the beam direction. An angle between the target foil plane and the the beam/field direction usually is chosen to be 90° to reduce the magnetic field magnitude required for full foil polarization. In that case the foil polarization direction is perpendicular to the foil plane. Because the magnetization direction does not lie in the foil plain, this technique is also called the "out of foil plane" polarization technique. Because the magnetization field should be sufficiently strong to cause the full foil polarization saturation, the PET polarization measurement is not necessary as the target polarization can be calculated with using world data [3].

The Hall A Møller polarimeter [4] is the only polarimeter which has a set of both "classic" and "brute force" PETs. Accordingly, the techniques will be described and will be compared using the Hall A Møller polarimeter results.

3. – "Classic" technique

For ferromagnetic materials, the electron polarization and the resulting magnetization come from the atomic *d*-shell that is not fully populated. In iron, about 2 electrons per atom are polarized, providing an average electron polarization of about 8%. The electron polarization in ferromagnetic foil can be derived from the value of magnetization. The magnetization must be measured.

There is a special technique to measure the magnetization of a ferromagnetic foil. The ferromagnetic foil is placed inside of a pickup coil which is located in a magnetic field. The constant external magnetic field is used during the measurement and the foil

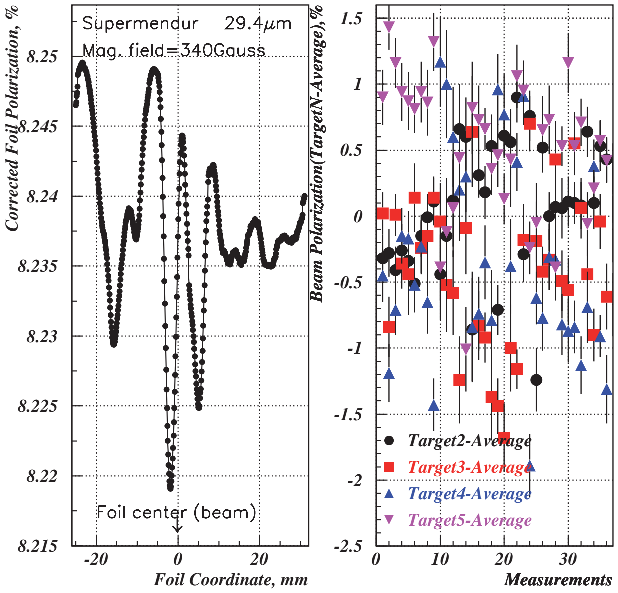

Fig. 2. – Left: the target polarization profile with all required corrections. Right: deviation of the beam polarization measurements using different PETs of average beam polarization for all four targets.

is moved through the pickup coil, changing the magnetic flux and creating an emf:

$$\int \varepsilon(t)\mathrm{d}t = \Delta\Phi = \mu_0 \Delta M \cdot S_{\text{foil}} + \mu_0 \Delta H \cdot S_{\text{coil}} + \Delta B_{\text{stray}} \cdot S_{\text{coil}}, \tag{1}$$

where H is the external field, B_{stray} is the stray (returned) field from the foil, while S_{coil}, S_{foil} are the cross-sections of the coil and the foil. As may be observed from eq. (1), the measured signal is calculated from the the foil magnetization and the foil cross-section. For thin (a few microns) foils, it is difficult to measure the foil thickness with a sub-percent accuracy, which does not allow to measure directly the cross section S_{foil} with high accuracy. The foil width can be made uniform along the length to a 0.1% level, but the thickness of thin foils may vary by more than 10%. The foil uniformity uncertainty is the dominant systematic error in the target polarization uncertainty.

In fig. 2 left the PET polarization profile with all required corrections (calculated for the particular magnetic field with subtraction of the background and the air flux, with correction on the foil thickness profile and on the magnetic field non-uniformity) in the central part of the ferromagnetic foil is shown. As fig. 2 left shows, the target polarization varies essentially along the foil. Thus, precise knowledge of the beam position on the PET is required for the accurate beam polarization calculation.

In fig. 2 right results of beam polarization measurements using a set of the PETs made of different materials and with different thicknesses are shown. The discrepancy illustrates precision of PETs polarization measurement.

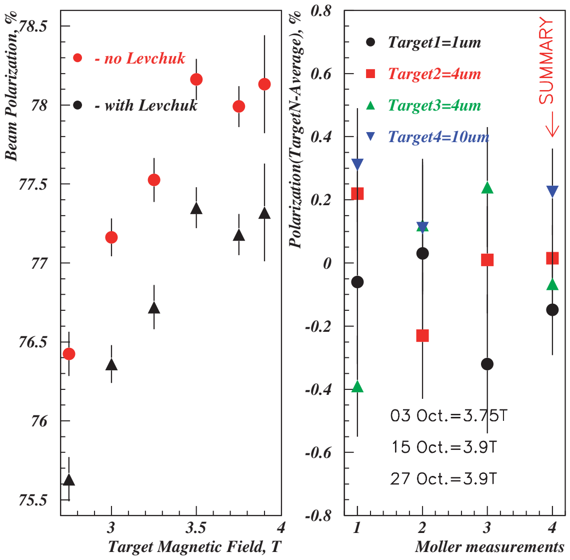

Fig. 3. – Left: the target polarization saturation curve before and after corrections on analyzing power and Levchuk effect. Right: deviation of the beam polarization measurements with using different PETs of average beam polarization for all four targets.

4. – "Brute force" technique

As was mentioned above, for the "brute force" technique a strong magnetic field ($> 2.5\,\mathrm{T}$) has to be applied for the PET polarization. An angle of 90° between the foil plane and the beam/magnetic field direction is required to minimize the saturated magnetic field. If the angle is not 90°, a transverse component of the target polarization can appear. It reduces a longitudinal component of the target polarization. Thus, for the "brute force" technique a precise alignment of the target plane and magnetic field is required. The target foil warping also can be a reason of the transversal component of target polarization. A stronger saturated magnetic field has to be applied to eliminate the possible transverse component of the target polarization. Thus, a dependence of the target polarization saturation of the magnetic field has to be measured in order to find a region of magnetic field where the target is fully saturated and the beam polarization measurements can be done. As fig. 3 left shows, the PET becomes saturated at the magnetic field of about 3.5 T. Thus, correct beam polarization measurements can be done with the magnetic fields $> 3.5\,\mathrm{T}$.

If a strong (3–4 T) magnetic field is used for the target polarization, it is corresponds to the integral magnetic field $Bdl \approx 2\,\mathrm{Tm}$ along the beam. The Bdl can be large enough to change acceptance of the polarimeter. Non-ideal alignment of the target magnetic field along the electron beam direction can increase this effect. The acceptance changes can affect the Møller polarimeter analyzing power and Levchuk effect [5] (see fig. 3 left). The measured beam polarization has to be corrected for these possible effects. In comparison to fig. 2 right the beam polarization results obtained using a set of the PETs with "brute force" technique (see fig. 3 right) shows the same beam polarization magnitude within statistical error. It proves that for the used magnetic field the target polarization is fully saturated and the PETs polarization is the same for all the targets.

Table I. – *Systematic errors for the Møller polarimeter with "classic" and "brute force" PETs.*

Variable	"Classic"	"Brute force"
Target polarization	1.5%	0.35%
Analyzing power	0.3%	0.3%
Levchuk effect	0.2%	0.3%
Background	0.3%	0.3%
Dead time	0.3%	0.3%
High beam current	0.2%	0.2%
Others	0.5%	0.5%
Total	1.7%	0.9%

5. – Conclusion

Comparison of systematic error budgets for the Møller polarimeter with "classic" and "brute force" polarized electron targets is shown in table I. As is shown in table I, the Møller polarimeter with the "brute force" technique can be twice more precise than the polarimeter with the "classic" technique due to a better knowledge of the PET polarization. Both the PET types can be successfully used for different kind of experiments.

The PET with "classic" technique is less precise but it is cheaper to build and to operate because a cryogenics line and a superconductive magnet are not needed. But the "classic" PET requires additional time and manpower to measure the dependence of target polarization from the magnetic field. Low Bdl of such a target produces negligible influence on the beam optics (important for low energy experiments), the polarimeter analyzing power and Levchuk-effect.

The PET with "brute force" technique is more precise but more expensive. It does not require additional manpower and time before an experiment for the target polarization measurement. But additional beam time to measure the target polarization saturation is needed. Also, precise alignment of the PET magnetic field along the beam is required.

Møller polarimeters with both types of PET require a specially dedicated time for the beam polarization measurements. A maximal beam current for solid PET is a few μA.

* * *

The author thanks the organizers for the wonderful workshop. This work was supported in part by the U.S. National Science Foundation, and by DOE contract number DE-AC05-06OR23177.

REFERENCES

[1] Kessler J., *Polarized Electrons* (Springer-Verlag) 1985, pp. 1-367.
[2] Steiner P., Feltham A., Sick I. *et al.*, *Nucl. Instrum. Methods A*, **419** (1998) 105.
[3] Scott G. G., *Phys. Rev.*, **184** (1969) 490.
[4] Glamazdin A. V., Gorbenko V. G., Levchuk L. G. *et al.*, *Fizika B (Zagreb)*, **8** (1999) 91.
[5] Levchuk L. G., *Nucl. Instrum. Methods A*, **345** (1994) 496.