MØLLER POLARIMETER RECONSTRUCTION IN HALL A JEFFERSON LAB

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The Møller polarimeter reconstruction for measuring of the electron beam polarization with energies up to 11 GeV has been performed in Hall A Thomas Jefferson Laboratory (United States). This paper describes the elements of the Møller polarimeter and accelerator beamline that have been changed. The structure and characteristics of the modified data acquisition system of the polarimeter are shown. An analysis of components of systematic error of beam polarization measurement for two types of used targets is presented.

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1. MØLLER POLARIMETER

Møller polarimeter was developed in KIPT and created jointly with the National Accelerator Center. Thomas Jefferson (CEBAF, Virginia, USA) and the University of Kentucky (Lexington, USA) [1, 2]. The accelerator of Jefferson Lab [3] is a recirculation superconducting electron accelerator (Fig. 1), which consists of an injector, two of linear accelerators ("northern" and "southern") bending and extracting magnets, and is capable deliver a linearly polarized electron beam in three experimental halls (A, B, C) at the same time. The maximum average beam current of accelerator is up to 200 mA, the longitudinal polarization of the beam is up to 90%, pulse repetition frequency is 499 MHz. The range of beam energies is from 0.6 to 6 GeV.

Polarimeter designed to measure the polarization of the beam electrons in the energy range from 0.8 to 6 GeV at a beam current up to 3.0 μA and works in Hall A starting from 1998 year. The need to modernize the polarimeter is caused by the reconstruction of the Jefferson Lab accelerator and increasing the electron beam energy from 6 to 12 GeV.

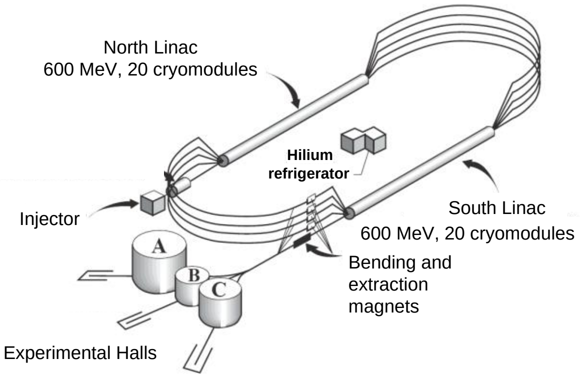

Fig. 1. Jefferson Lab accelerator before reconstruction

Møller polarimeter includes polarized electrons target (T), magnetic spectrometer and detector (Fig. 2). Møller electrons resulting from the interaction of the electron beam to the target are analyzed with a magnetic spectrometer. The spectrometer comprises three quadrupole (Q1, Q2, Q3) and one of the dipole magnets (Dipole). Scattered electrons are focused by quadrupole magnets in the horizontal plane at the entrance of the dipole magnet. The dipole magnet deflects the electrons down to the detector. Shielding insertion located in the center of the dipole magnet, through which the primary electron beam is passing without interaction with the magnetic dipole field.

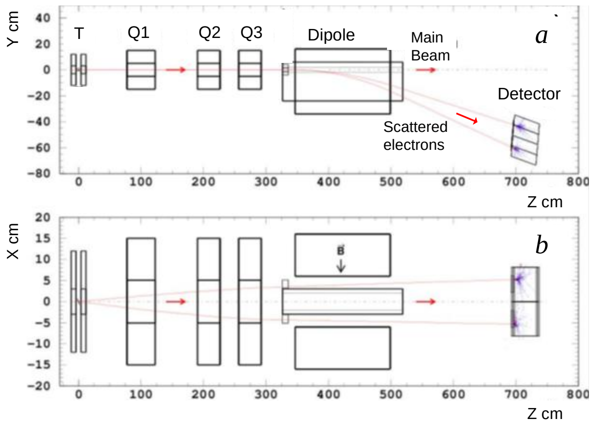

Fig. 2. Scheme of Møller polarimeter before reconstruction: a) side view, b) top view

Electron detector consists of two full absorption calorimeters, allowing register the Møller events in coincidences. Each calorimeter made from two identical blocks type of the "spaghetti", arranged vertically one above another and divided into two sections. Four photomultiplier tubes (PMTs) are located at the end of the calorimeter block. The aperture detector made of plastic scintillator and divided into four sections installed before each calorimeter.

Møller events are registered by the coincidence of signals from the left and right detectors, which can significantly reduce the contribution of background events.

2. POLARIMETER PARTS RECONSTRUCTION

There are several key factors, which are limited energy range of polarimeter:

- the spectrometer acceptance wich determines by the position of the magnetic elements, their magnetic field and the position of the collimator;
- bending of the main beam by a magnetic field of a dipole inside the shield insertion.

The first factor limits the energy range from below to 0.8 GeV, and the second one does from the top to 6.0 GeV. To measure the polarization of the electron beam with energies up to 11 GeV, it was necessary to

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reconstructing of the main elements of Møller polarimeter. Following elements of the polarimeter have been modified:

- Magnetic Spectrometer;
- Shielding box of the detector and the detector;
- The elements of beamline;
- Data acquisition system.

The most significant changes required for a magnetic spectrometer of polarimeter. For operation of the polarimeter in the energy range 0.8…11 GeV, it was necessary to move the first quadrupole magnet Q1 (Fig. 3) along the beam by 40 cm and install an additional quadrupole magnet Q4 (see Fig. 3) in 70 cm from the target. The quadrupole magnet Q4 has been installed on beamline after testing and measurement of the magnetic field map.

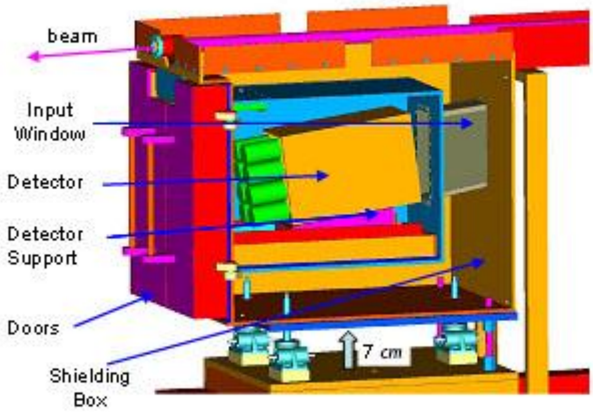

Fig. 3. New quadrupole magnet Q4 installed behind target

This configuration of the magnetic elements ensures that acceptance of the polarimeter by solid angle of θ_{cm} more than 20° (Fig. 4) in energy range from 0.8 to 11 GeV.

Reconstruction of the dipole magnet was to improve the protection of the main beam of electrons from the magnetic field of the dipole magnet. For his a additional shielding insertion type of tube made from steel AISI-1006 with an internal diameter of 2.5 cm and thickness of 0.9 cm and length of 212.4 cm (Fig. 5) has been manufactured and installed in the dipole.

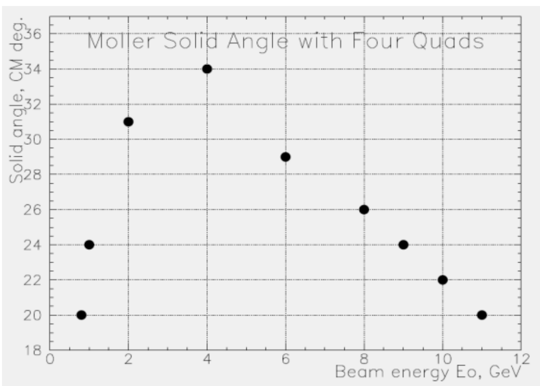

Fig. 4. Acceptance of polarimeter by solid angle θ_{cm} for configuration with four quadrupole magnets

The power supply provides a maximum dipole current 550 A, which is only enough for the beam energy up to 8 GeV at Møller electron deflection angle of 10°. This limitation has led to the need to reduce the maximum angle of deflection of Møller electron from 10 to 7.3°. Fig. 6 shows the results of the simulation by program TOSCA the displacement of the electronic beam on the physical target in the Hall A ("a" – 13 m from the center of the dipole) and the beam dump ("b" – 63 m from the center of the dipole) due to the influence of the magnetic dipole field with shielding insertion. We can see that with the maximum energy of the electron beam in Hall A 11 GeV beam displacement on the main target of not more than 2.5 mm and not more than 10 mm in the beam dump. Calculations according to the dipole magnetic field in the gap and inside the shielding insertion for different energies of the electron beam are shown in Fig. 7.

Fig. 5. Photo: additional shielding insertion of dipole

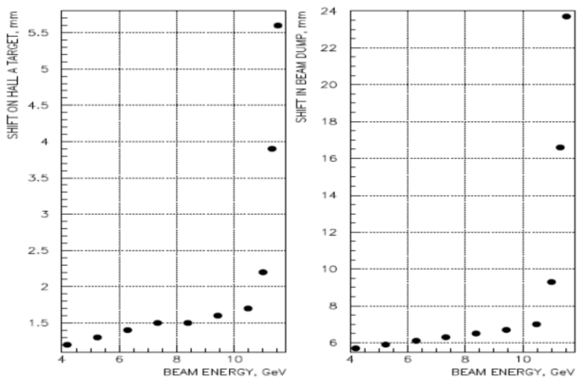

Fig. 6. Beam displacement on the physical target (left) and beam dump (right) due to magnetic field of dipole with shielding insertion

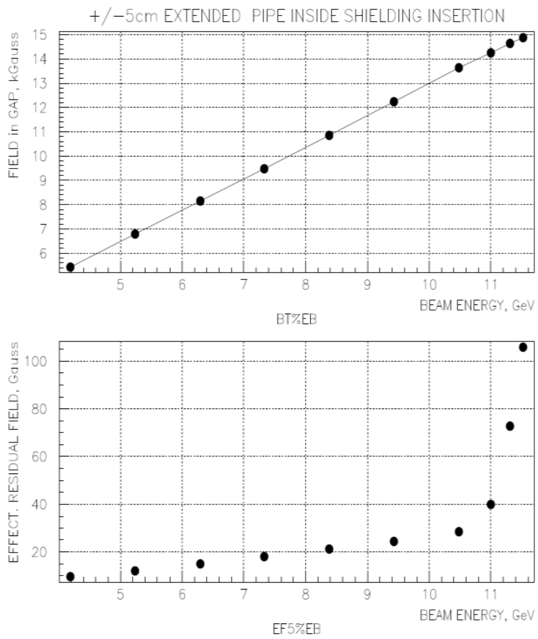

Fig. 7. Calculation of dipole magnetic field in gap (upper) and inside shielding insertion for different electron beam energies

As the deflection angle Møller electrons has been reduced from 10° to 7.3°, the detector with a shielding housing box was raised to 7 cm. A new shielding housing box of detector is designed and manufactured with improved design of input windows, doors, and the possibility of placing additional protection at the top of box near beamline. Support that provides tilt of detector, has also been replaced for an angle of 7.3°. Aperture counters modification is performed: added test LEDs, improved light protection and the connection to the PMT.

Elements of beamline after a dipole magnet have also been modified (Fig. 8). Vertical corrector to compensate the bending of the electron beam after the dipole has been added. An additional beam position sensor has been added for more precise positioning of the beam on the target of polarimeter.

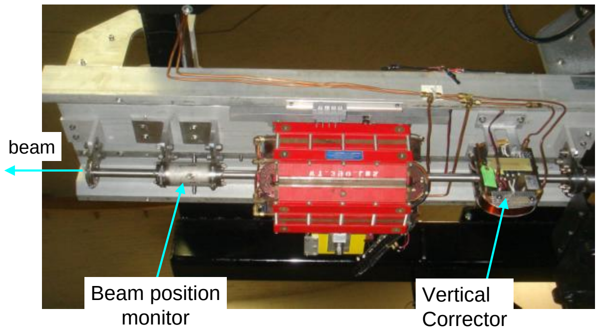

Fig. 8. Additional elements of beam line after dipole

3. POLARIZED ELECTRON TARGET

Two types of polarized targets are used in Møller polarimeter for measurements of the polarization of the beam: 1) the target with a low magnetic field (0.03 T) and polarization along the plane of the target ("Low Field") [5]; 2) target with a large magnetic field (4 T) and polarization-zation across the plane of the target ("High Field") [6].

"Low Field" target of polarized electrons comprises ferromagnetic foil set (Table 1) that inclined at an angle of 20.5° to the direction of the electron beam and the magnetic field. The foils have a different thickness and made of pure iron (99.95%) or supermendur (49% Fe, 49% Co, 2% V).

Table 1

Set of ferromagnetic foils as target of polarized electrons. (SM – supermendur; Fe – iron; Al – aluminum)

Position	6	5	4	3	2	1	0
Material	park	SM	Fe	Fe	SM	SM	Al
Thickness, μm	–	6.8	9.3	14.3	29.4	13.0	16.5

The design of the target chamber is shown in Fig. 9. The design of the camera allows one to move the foil target in two directions across the beam (from the foil to the foil), and along the long sides of the foil.

The target chamber is provided with flanges and bellows for mounting on beamline. Magnetic coils are mounted on the camera symmetrically on either side of the target.

The target chamber is mounted on slides (see Fig. 9), inclined at an angle of 20.5° to the direction of the electron beam. These rails allow a longitudinal movement of the target relative to the electron beam in the range from -25 to +30 mm.

The longitudinal position of the target is controlled by the position sensors and the ree switches. Both mechanisms moving target are used stepper motors. Since only a thin target foils can get on the beam, the change of the target position does not require interruption of the electron beam.

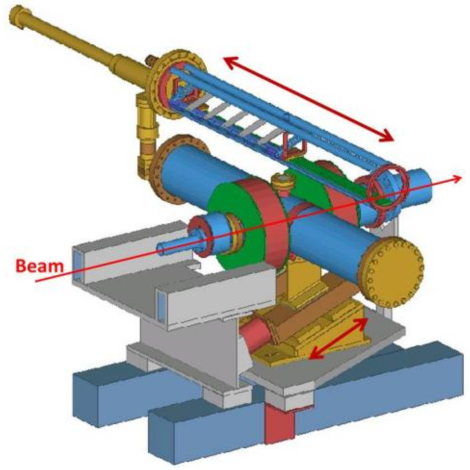

Fig. 9. The target chamber of Møller polarimeter. Structure of target holder is shown at above. Direction of target movement is shown by arrow

The design of "High Field" target of polarized electrons of Møller polarimeter in the Hall A is shown in Fig. 10. The target consists of:

- Superconducting magnet with a maximum field up to ± 4 T;
- Target device with a set of four targets. All targets are made of pure iron with a purity of 99.85% and 99.99% and thicknesses of 1, 2, 4, and 10 μm to the study of possible systematic errors;
- Adjustment mechanism for the orientation of the plane of the target relative to the direction of the magnetic field;
- Unit for movement and control targets position;
- The target chamber with orientation mechanism to the direction of the magnetic field along the electron beam.

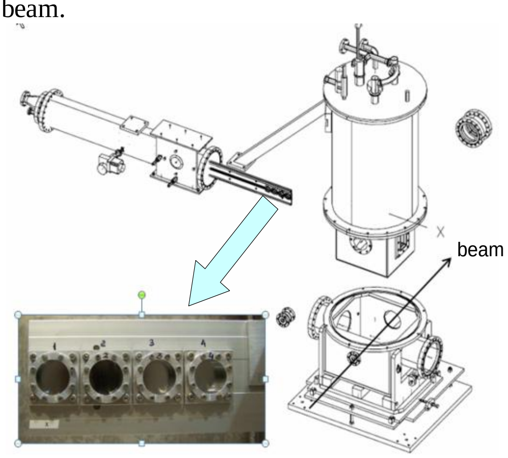

Fig. 10. The design of "High Field" target of polarized electrons of Møller polarimeter in the Hall A. The diagram shows: a superconducting magnet, the target device and the target camera. The photo shows the target holder with a set of iron foils

Adjustment mechanisms allow set of the target device and the magnetic field with linear precision ± 0.2 mm and angular accuracy of ± 0.2 mrad.

4. DATA ACQUISITION SYSTEM

The data acquisition system of the Møller polarimeter used over 15 years [4]. Some of the electronic modules are already discontinued. Acquisition system was modified to increase readout rate and reduce dead time. Basic electronic modules have been replaced with modern one, with more high integration and a high frequency bandwidth.

The module type of CAEN V1495 is used as programmable logic unit: bandwidth input/output of up to 200 MHz, 2×32-bit input ports, 1 output port, 32-bit, type of signal - LVDS; programmable logic (Fig. 11).

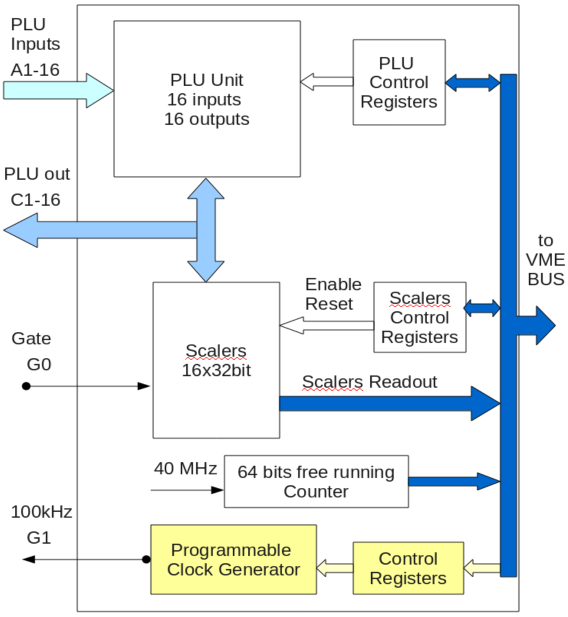

Fig. 11. Diagram of programmable logic unit based on module type of CAEN V1495

The module contains a programmable logic for event selection (16 inputs, 16 outputs), 16 counters (32-bit), trigger logic, control registers, and timer-generator.

Discriminator P / S 708: 8 channels, 300 MHz signal type - NIM, modified for remote setup of thresholds using the digital to analog converter (DAC).

Analog-to-digital converter (ADC) type of CAEN V792: 12 bit, 32 channel, memory 32 events, the conversion time is 5.7 μs.

The time to digital converter module (TDC) type of CAEN V1190B: 64 channels, the resolution is 0.1 ns, the signal type - LVDS.

Test of new modules has been performend and software developing for data processing is underway.

5. MØLLER POLARIMETER SYSTEMATIC ERRORS

The main components of the systematic errors of polarimeter for the two types of targets that affecting the accuracy of measurements of the beam polarization are shown in Table 2. It can be seen that the main contribution to the target with a low field gives a measurement error of the target polarization. For target with a large field, this error is greatly reduced, due to a stronger magnetisation of foil that close to saturation. At the same time, the Levchuk effect is increased for this type of target due to the stronger magnetic field.

Table 2

Systematic errors of Møller polarimeter for two types of target

Variable	"Low Field" target, %	"High Field" target, %
Target Polarization	1.5	0.35
Analyzing power	0.3	0.3
Levchuk effect	0.2	0.3
Dead Time	0.3	0.3
Background	0.3	0.3
High Beam Current	0.2	0.2
Others	0.5	0.5
Total	**1.7**	**0.9**

CONCLUSIONS

Møller polarimeter in Hall A of Jefferson Laboratory (USA) was reconstructed in the period 2012-2013 for measurements of electron beam polarization with energies up to 11 GeV. This paper describes the elements of the Møller polarimeter and accelerator beamline, which have been modified. The polarimeter is a unique facility with two different types of polarized targets and the two types of data acquisition systems working in parallel. This allows us to investigate the systematic uncertainty and improve the accuracy of measurements of electron beam polarization.

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МОДЕРНИЗАЦИЯ МЁЛЛЕРОВСКОГО ПОЛЯРИМЕТРА ЗАЛА А ЛАБОРАТОРИИ им. Т. ДЖЕФФЕРСОНА

Р.И. Помацалюк, В.В. Верещака, А.В. Гламаздин

В лаборатории им. Т. Джефферсона (США) проведена реконструкция мёллеровского поляриметра зала А для обеспечения измерений поляризации пучка электронов с энергией до 11 ГэВ. В работе описаны элементы мёллеровского поляриметра и электронопровода ускорителя, которые были изменены. Приведены структура и характеристики модифицированной системы сбора данных поляриметра. Проведён анализ величины систематической ошибки измерения поляризации пучка для двух типов используемых мишеней.

МОДЕРНІЗАЦІЯ МЬОЛЛЕРІВСЬКОГО ПОЛЯРИМЕТРА ЗАЛУ А ЛАБОРАТОРІЇ ім. Т. ДЖЕФФЕРСОНА

Р.І. Помацалюк, В.В. Верещака, О.В. Гламаздін

У лабораторії ім. Т. Джефферсона (США) проведено реконструкцію мьоллерівського поляриметра залу А для забезпечення вимірювань поляризації пучка електронів з енергією до 11 ГеВ. У роботі описані елементи мьоллерівського поляриметра та електронопровода прискорювача, які були змінені. Наведено структуру та характеристики модифікованої системи збору даних поляриметра. Проведено аналіз величини систематичної помилки вимірювання поляризації пучка для двох типів мішеней, що використовувались.