MÖLLER POLARIMETER IN THE HALL A JEFFERSON LAB AFTER RECONSTRUCTION

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The Möller polarimeter in the Hall A of Jefferson Lab was reconstructed in order to expand of the energy range of the polarimeter to measure the polarization of the electron beam with an energy up to 11.5 GeV. The paper describes the main results of the Möller polarimeter testing after reconstruction. The measurements of the electrons polarization were provided by two data acquisition systems operating in parallel. The testing of the shielding insertion of magnetic dipole has been performed. The way to eliminate detected deviations in the operation of polarimeter during test is shown.

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INTRODUCTION

Jefferson Lab is one of the world's scientific centers, where the properties of nuclei and nucleons using beams of polarized electrons are being studied. The accelerator of Jefferson Lab [1] is a recirculation superconducting electron accelerator (Fig. 1) with beam energy 1…12 MeV and beam current up to 100 µA. Facililty 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 any three of four experimental halls (A, B, C, D) at the same time.

Möller and Compton polarimeter are used when conducting experimental studies with polarized electron beam in Hall A of Jefferson Lab. Hall A Möller polarimeter was created as a result of cooperation Jefferson Laboratory, KIPT and the University of Kentucky and it was commissioned since 1997 [2]. Initially, Möller polarimeter was designed to measure the polarization of the electron beam in the energy range of 0.8…6.0 GeV [3].

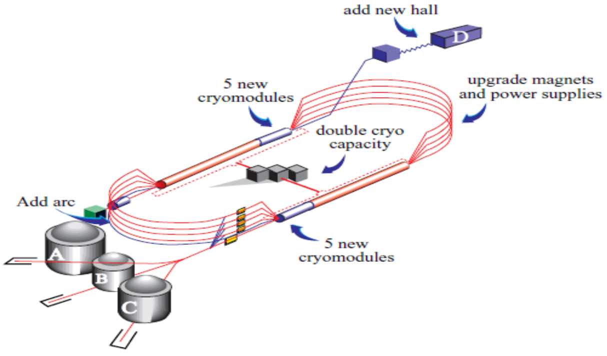

Fig. 1. Jefferson Lab accelerator after reconstruction

During 2012-2013 years Jefferson Lab accelerator was reconstructed to increase the maximum energy of the electron beam from 6 to 12 GeV. Hall A Möller polarimeter was modernized at the same time to operate with electron beams with energies up to 11 GeV.

1. ELECTRON BEAM POLARIZATION MEASUREMENT

The operating principle of the polarimeter Møller based on the use Möller scattering [4] $e^{\rightarrow}+e^{\rightarrow}\rightarrow e'+e'$. Möller scattering cross section depends on the polarization of the electron beam and target polarization:

$$\frac{d\sigma^{Moll}}{d\Omega^*} = \frac{d\sigma_0^{Moll}}{d\Omega^*} \times (1 + A_Z \cdot P^b \cdot P^t), \qquad (1)$$

where $\frac{d\sigma_0^{Moll}}{d\Omega^*}$ – Möller scattering cross section of unpolarized beam of electrons on unpolarized electrons of the target, P^b и P^t – the polarization of the beam electrons and electron targe, respectively, A_Z – analyzing power of the reaction of Möller scattering (the axis Z – along the beam).

The asymmetry of the scattering beam of polarized electrons by polarized electron target is measured with polarimeter, which is described by the formula:

$$A_{meas} = \frac{N^{\uparrow\uparrow} - N^{\uparrow\downarrow}}{N^{\uparrow\uparrow} + N^{\uparrow\downarrow}} = A_Z \cdot P^b \cdot P^t \cdot \cos\alpha, \qquad (2)$$

where $N^{\uparrow\uparrow}$ and $N^{\uparrow\downarrow}$ – detector counting rates measured in parallel and antiparallel direction of the longitudinal component of the polarization vector of the target to the direction of the longitudinal component of the polarization vector of the electron beam, respectively, α – angle of the foil target to the direction of the electron beam. The polarization of the beam is determined from the expression (2) as:

$$P^b = \frac{A_{meas}}{A_Z \cdot P^t \cdot \cos\alpha}. \qquad (3)$$

The analyzing power A_Z is also determined by the geometry of the magnetic spectrometer and polarimeter detector and it is calculated using the software toolkitt GEANT [5]. Thus, to do measure of the beam polarization, asymmetry of scattering is to be measured and the value and sign of the polarized electron target is to be known.

2. POLARIMETER AFTER RECONSTRUCTION

Möller polarimeter includes polarized electrons target (T), magnetic spectrometer and detector (Fig. 2). Möller electrons resulting from the interaction of the electron beam to the target are analyzed with a magnetic spectrometer. The spectrometer after reconstruction comprises four quadrupoles (Q1, Q2, Q3, Q4) 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.

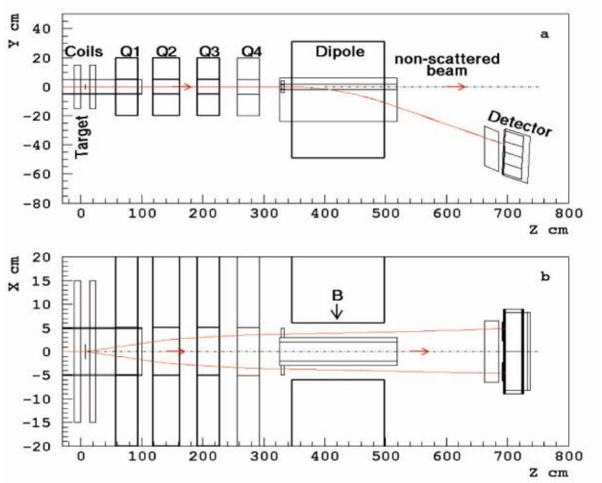

Fig. 2. Diagram of Möllerr Polarimeter after reconstruction: a – side view; b – top view

Electron detector consists of two full absorption calorimeters, allowing to register the Möller events in coincidences. Möller events are registered by the coincidence of signals from the left and right detectors, which can significantly reduce the contribution of background events.

Following elements of the polarimeter have been modified [6]:

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

2.1. MAGNETIC SPECTROMETER

The most significant changes required for a magnetic spectrometer of polarimeter. The first quadrupole magnet Q1 was moved down along the beam by 40 cm and an additional quadrupole magnet Q4 was installed in 70 cm from the target (Fig. 3).

2.2. DIPOLE

Reconstruction of the dipole magnet was performed to improve the protection of the main beam of electrons from the magnetic field of the dipole magnet. For this purpose 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 has been manufactured and installed in the dipole (Fig. 4).

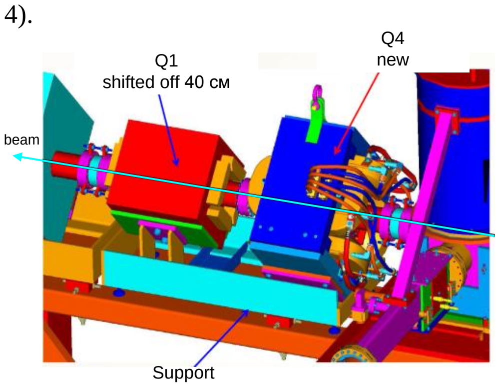

Fig. 3. New quadrupole magnet Q4 installed behind the target

The power supply provides a maximum dipole current 550 A, which is only enough for the beam energy up to 8 GeV at Möller electron deflection angle of 10°. This limitation has led to reduce the maximum deflection angle of Möller electrons from 10 to 7.3° for electron energy 11 GeV.

Fig. 4. Photo: shielding insertion of dipole

2.3. DETECTOR

As the deflection angle Möller electrons has been reduced from 10 to 7.3°, the detector with a shielding housing box was also raised to 7 cm (Fig. 5).

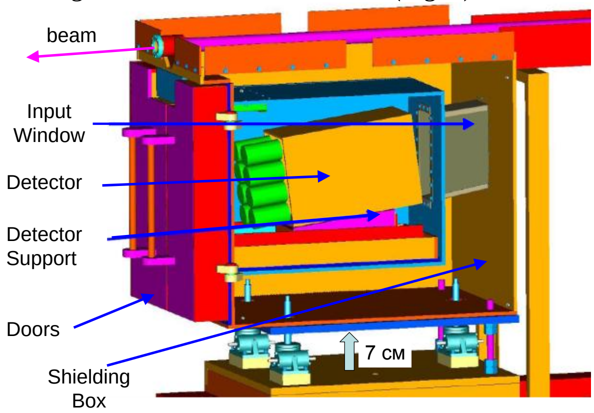

Fig. 5. Detector shielding box and detector after reconstruction

The vertical corrector to compensate the deflection of the electron beam after the dipole has been added also. An additional beam position monitor has been added for more precise positioning of the beam on the polarimeter target.

2.4. POLARIZED ELECTRON TARGETS

Two types of polarized targets are used in Möller polarimeter for measurements of the beam polarization: 1) the target with a low magnetic field (0.03 T) and polarization along the plane of the target ("Low Field") (Fig. 6) [7]; 2) target with a large magnetic field (4 T) and polarization across the plane of the target ("High Field") (Fig. 7) [8].

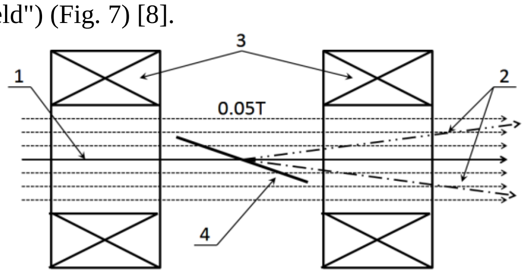

Fig. 6. The schematic diagram of the target with polarization along the longitudinal plane of the target: 1 – polarized electron beam; 2 – electrons scattered by the target; 3 – magnetic coil with field of 0.05 T; 4 – target (foil)

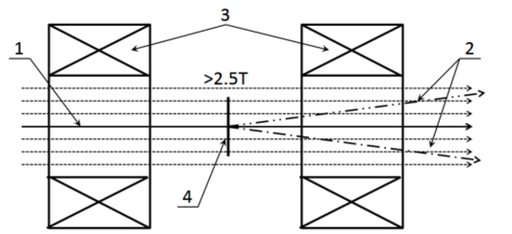

Fig. 7. The schematic diagram of the target with the polarization transverse plane of the target. The notation is the same as in Fig. 6

"Low Field" target of polarized electrons comprises ferromagnetic foil set 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 (7…10 μm) and made of pure iron (99.95%) or supermendur (49% Fe, 49% Co, 2% V) (Fig. 8).

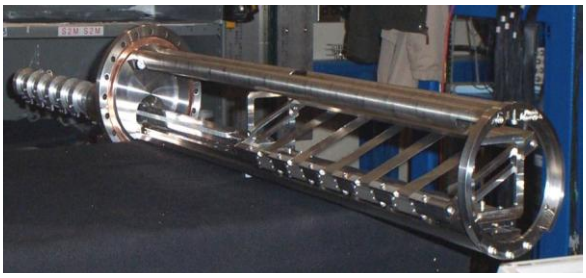

Fig. 8. Holder of polarized electrons target ("Low Field")

The design of "High Field" target of polarized electrons of Möller polarimeter in the Hall A is shown in Fig. 9. The target consists of:

- Superconducting magnet with a maximum field up to ± 4 T;
- Target holder 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.

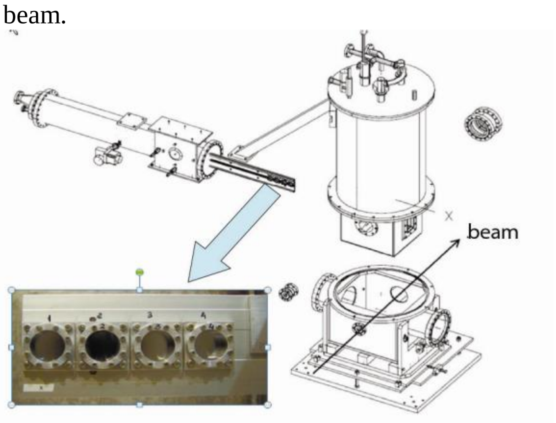

Fig. 9. The scheme of polarized electrons target of Hall A Möller polarimeter. The diagram shows: superconducting magnet, the target unit and the target chamber. The photo shows the target holder with a set of iron foils

2.5. DATA ACQUISITION SYSTEM

Hall A Møller polarimeter has two data acquisition and data processing systems:

1. The old system, based on the modules in the standard CAMAC, VME and NIM, since 1997.
2. A new system VME-based flash-ADC module F-250, commissioned since 2009.

The old data acquisition system of Möller polarimeter is used more than 15 years [9]. It is fully functional for all targets polarimeter and well studied. At the same time it has a low rate of events logging, system modules occupy several racks, as well as a large number of connections and interconnect cables, which reduces the reliability of the data acquisition system. In addition, some modules of the system are out from production and can not be replaced in case of failure.

The main goal of introduction of the new data acquisition system is to reduce systematic errors of polarization measurement by increasing the rate of events and reduce the dead time.

The new data acquisition system is based on the flash-ADC F250, which was developed in the Jefferson Laboratory [10]. This data acquisition system allows to register and record the data flow at speeds up to 50 MB/s for events rate in the coincidence of the left and right arms of detector is about 160 kHz.

Detailed description of the structure and operation of both data acquisition systems is given in [11].

Software for analysis and processing of measured data is built on the package ROOT (package object-oriented programs and libraries developed by the European Center for Nuclear Research (CERN)) [12].

The software package consists of programs for online monitoring of the data and the program for offline processing. The monitoring program allows one to control the quality of incoming information by displaying the current values of the coincidence scalars, the digitized analog signals from each detector unit, amplitude spectra of signals from the detector. Program offline processing allows to convert data files from the CODA format to root file format, perform data analysis and obtain results of the beam polarization measurements.

The both data acquisition systems operated in parallel during measuring of the polarization. Thus, that allows an additional study of systematic errors of the measurements.

3. DIPOLE TESTING

Testing of the dipole shielding insertion was performed using the beam position monitor, which is located behind the dipole magnet and a polarimeter detector. Three measurements of the vertical beam position were done:

- with disabled dipole and vertical corrector;
- dipole is ON and vertical corrector is OFF;
- dipole and vertical corrector are both ON.

The test results are shown in Fig. 10. One can see that the switch on of dipole leads to a displacement of the vertical beam position of about 1.4 mm. This value agrees well to the estimated value for the beam energy of 6.05 GeV and dipole with a shielding insertion.

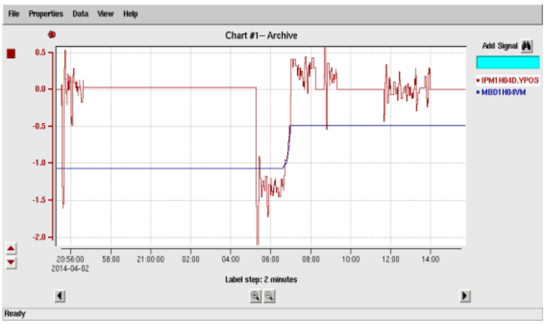

Fig. 10. Test of operation of dipole shielding insertion

Fig. 11 shows the results of simulation with TOSCA software the displacement value of the primary electron beam on the physical target of Hall A (the left – 13 m from the center of the dipole) and at the beam dump (right – 63 m from the center of the dipole) due to the influence of the dipole magnetic field with shielding insertion. Turning on the vertical corrector is fully compensate the deflection of the beam due to the dipole magnetic field. Thus this test is checked the operation of dipole shielding insertion.

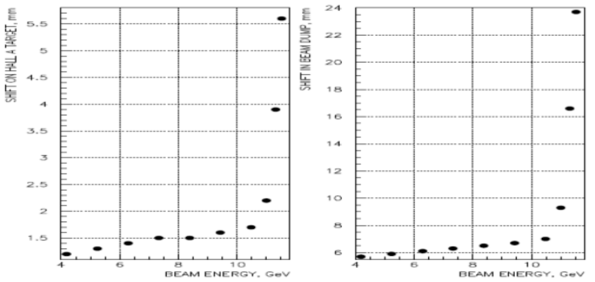

Fig. 11. Main electron beam deflection at the target (left) and at the beam dump (right) due to magnetic field of dipole with shielding insertion

Also, operation dipole tests, with maximum current of 500 A were conducted. During these tests it was found that the dipole power supply instability appears at current of 450 A (Fig. 12). Further research of operation of the power supply has shown that stable operation of the power supply is provided only with a maximum current up to 440 A. It was planned during the reconstruction of the polarimeter that the operation of the polarimeter with a maximum energy of electron beam of 11 GeV the dipole current has to be set at 500 A. It was decided to reduce the angle of deflection of the electron by dipole from 7.3 to 6° to provide the operation of the polarimeter with a maximum beam energy and with a maximum dipole current of 440 A. This requires to lift up the detector with a shielding box for another 3.5 cm.

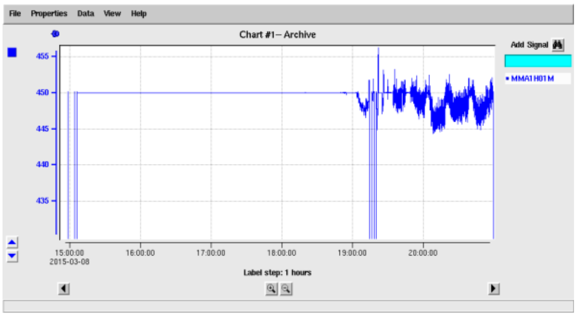

Fig. 12. Instability of dipole power supply with current set at 450 A

4. OPTIMIZATION OF POLARIMETER OPERATION

All tests of the polarimeter and tuning its systems were carried out using target with low magnetic field and the polarization along the plane of the target.

Detector setup, optimization of the magnetic elements of the spectrometer were performed during test trials of polarimeter. The polarization of the electron beam with an energy of 6.05, 7.375, and 9.57 GeV was measured. Both data acquisition systems operated in parallel at the time of tests and measurements of the polarization.

The detector tuning carried out in several stages. Initially, setting of the high voltage supply for the PMT was performed to provide that the amplitude of the signal for all channels was the same and corresponded to the middle of the input range of the ADC. Then the thresholds of discrimination signals from the detector were determined to provide optimum rate of events and minimize random events for data acquisition systems of polarimeter. The detector tuning process was controlled in on-line mode using the amplitude spectrum of signals from the detector (Fig. 13).

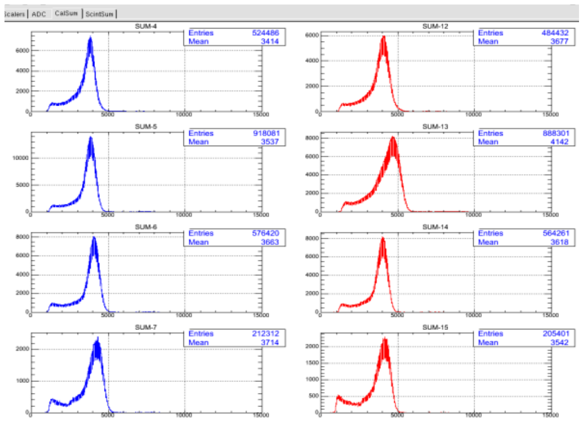

Fig. 13. Amplitude spectrum of left and right calorimeters (flash-ADC)

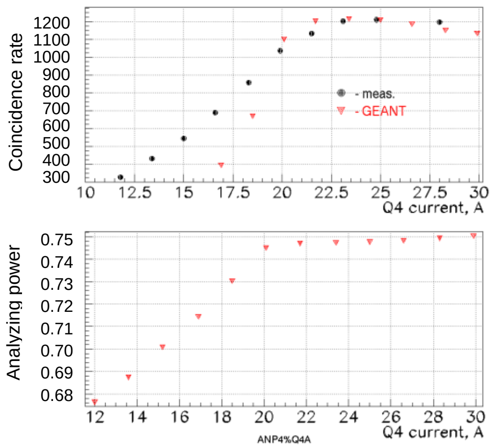

Fig. 14. Quadrupole magnet Q4 current scan (top) and calculated analyzing power of polarimeter (bottom)

Optimization of the magnetic elements of the spectrometer was carried out by measuring the dependence of the frequency of events in the coincidence of the left and right arms of the detector from the set magnetic field (current) of the magnetic element. The measurements were performed for the quadrupole magnets Q1, Q2, Q4, and the dipole. The obtained data were compared with calculations made in the GEANT. Fig. 14 (at the top) shows the measurement of the Q4 quadrupole magnet, and at the bottom is the calculated values of the analyzing power of polarimeter for the given currents in the magnetic element Q4. Optimization was performed to set such magnetic current of element that would correspond to the maximum rater of events in coincidence.

Measurements of the polarization of the electron beam were carried out for several sets of the electron energy. As noted previously, both data acquisition systems operated in parallel during the measurements. Fig. 15 shows the results of measurements of the asymmetry of polarized electron beam with an energy of 6.05 GeV made with four polarimeter targets.

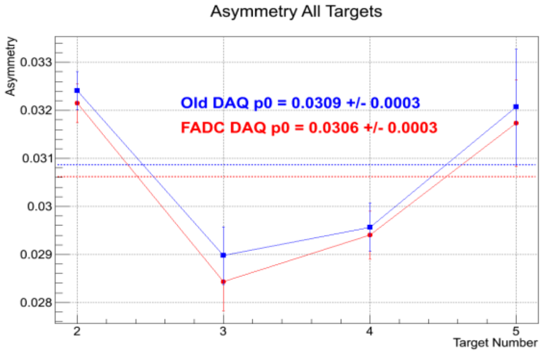

Fig. 15. The asymmetry of polarized electron beam for four targets, as measured by two data acquisition systems of the polarimeter

Measurements of the beam polarization for given energy was (-55±0.11)%.

Fig. 16 shows the results of measurements of the beam polarization with an energy of 7.375 GeV for the three polarimeter targets. The value of the beam polarization (average) was (86.1±0.25)%.

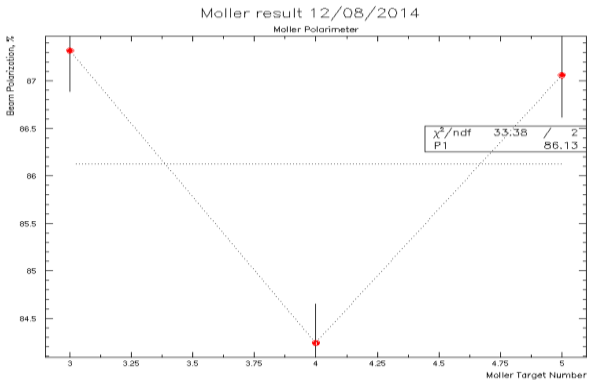

Fig. 16. Polarization of electron beam with energy 7.375 GeV for different polarimeter targets

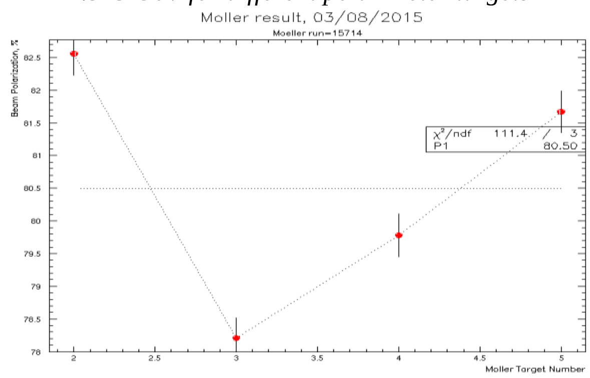

Fig. 17. Polarization of electron beam with energy 9.573 GeV for different polarimeter targets

Fig. 17 shows the results of measurements of the beam polarization with an energy of 9.573 GeV for different polarimeter targets. The beam polarization averaged over the four targets was (80.5±0.16)%.

CONCLUSIONS

The paper presents the main results of the Møller polarimeter testing after reconstruction. Operation and tests of polarimeter with electron beam showed that all systems and polarimeter generally working well. The measurements of the electron beam polarization with energies of 6.05, 7.375, and 9.573 GeV have been performed. The polarimeter is a unique setup with two different types of polarized targets, and two types of data acquisition systems working in parallel. Measurements with two data acquisition systems showed quite good agreement with each other. The slight difference in the data is due to the different in thresholds set of signal discrimination from the detector and the difference in the analyzing software for each data acquisition system.

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МЁЛЛЕРОВСКИЙ ПОЛЯРИМЕТР ЗАЛА А ЛАБОРАТОРИИ ДЖЕФФЕРСОНА ПОСЛЕ РЕКОНСТРУКЦИИ

Р.И. Помацалюк

В лаборатории им Т. Джефферсона (США) проведена реконструкция мёллеровского поляриметра зала А с целью расширения энергетического диапазона поляриметра для измерения поляризации пучка электронов с энергией до 11,5 ГэВ. Рассмотрены основные результаты тестирования мёллеровского поляриметра после реконструкции. Измерения поляризации электронов обеспечивали две системы сбора данных, работающие параллельно. Проведено тестирование защитной магнитной вставки диполя. Намечены возможные пути устранения отклонений в работе поляриметра, выявленных в процессе тестирования.

МЬОЛЛЕРІВСЬКИЙ ПОЛЯРИМЕТР ЗАЛУ А ЛАБОРАТОРІЇ ДЖЕФФЕРСОНА ПІСЛЯ РЕКОНСТРУКЦІЇ

Р.І. Помацалюк

У лабораторії ім Т. Джефферсона проведена реконструкція мьоллерівського поляриметра залу А з метою розширення енергетичного діапазону поляриметра для вимірювання поляризації пучка електронів з енергією до 11,5 ГеВ. Розглянуті основні результати тестування мьоллерівського поляриметра після реконструкції. Вимірювання поляризації електронів забезпечували дві системи збору даних, які працюють паралельно. Проведено тестування захисної магнітної вставки диполя. Намічено можливі шляхи усунення виявлених у процесі тестування відхилень у роботі поляриметра.