THE RESULTS OF SCIENTIFIC COOPERATION OF NSC KIPT AND TJNAF (USA)

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As a part of the spin-physics program at the Jefferson Laboratory (TJNAF), a Møller polarimeter has been developed to measure the polarization of electron beam of energies between 0.8 and 6.0 GeV. Since April 1998, regular measurements with the polarimeter are made. Kharkov scientists participated in 14 from 17 experiments, which were done in the Hall A. The most interesting published results are presented.

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1. INTRODUCTION

Since 1996 the Thomas Jefferson National Accelerator Facility (TJNAF) is the world’s premier facility for studying nuclei and nucleons via the (e,e′x) reactions with using a polarized electron beam. In the Hall A, a combination of two high-resolution spectrometers and a high-quality, high energy resolution 100% duty cycle electron beam enables one to separate electromagnetic structure functions to be made in kinematical ranges and with a precision currently unavailable at other facilities. With the added availability of the polarized electron beam and a focal plane hadron polarimeter, spin physics has a partially important component of the Hall A and TJNAF physics program.

A variety of problems in intermediate energy nuclear physics are examined including the structure of nucleons and their excited states, properties of few body systems and complex nuclei, and strange quarks and parity violating electron scattering. For the spin-physics program at TJNAF, a number of polarimeters exploiting Mott, Møller, and Compton scattering are used.

Collaboration between NSC KIPT and TJNAF began since 1992 when the “Memorandum of Understanding between NSC KIPT and TJNAF” (MOU) was signed. In accordance to the MOU, as a part of the spin-physics program at the Hall A, TJNAF, a Møller polarimeter was designed and constructed to measure the polarization of the electron beam with energies from 0.8 to 6 GeV. In 1995 the University of Kentucky (Lexington, USA) was joined to the Møller polarimeter collaboration.

2. THE HALL A MØLLER POLARIMETER

The polarimeter exploits the process of Møller scattering of polarized electrons of the beam on polarized electrons of the target [1]. Its cross-section depends on the beam and target polarizations. A set of magnets and particle detectors analyze the kinematics of the scattered electrons. The layout of the Hall A Møller polarimeter is shown in Fig. 1.

There are a some new ideas used in the design of the Hall A Møller polarimeter:

— The intrinsic momenta of the bounded target electrons as a possible source of the systematic error (now known as the Levchuk effect) was investigated and the Møller polarimeter was designed to minimize this effect [2,3] (see below).

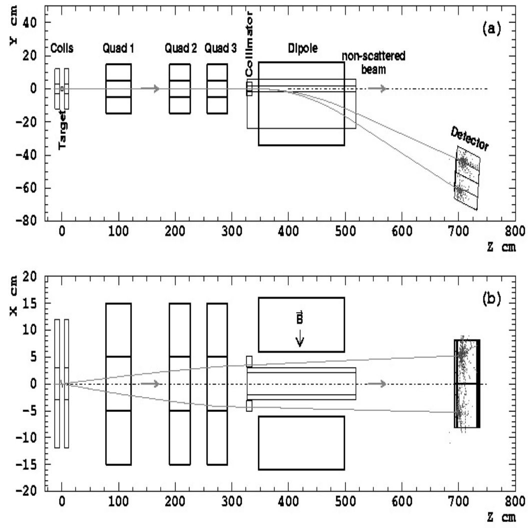

Fig. 1. *The Hall A Møller polarimeter layout, a) – side view, b) – top view*

— A set of three quadrupole magnets was used to keep the position of all polarimeter elements unchanged within the whole range of TJNAF energies. Their primary purpose is to focus the divergent trajectories aligned with the axis of the beam at the exit of the last quadrupole.

— A dipole provides the energy analysis, thus separating the Møller scattered electrons from electrons coming from the Mott scattering tail and thereby suppressing the background. It also bends the Møller electrons from the reaction plane, allowing their detection away from the electron beam. The dipole has a magnetic shielding insertion in the center of the magnetic gap. The Møller electrons pass through the dipole on the left and right sides of this shielding insertion. The primary electron beam passes through the hole bored in the shielding insertion letting its passage to the Hall A beam dump with small influence of the dipole magnetic field.

The more detailed description of the Hall A Møller polarimeter is done in [4].

The polarimeter covers the energy from 0.8 to 6 GeV and can be used for measurements with beam currents from 0.1 to 2 μA. It takes about 20 minutes of the 0.5 μA electron beam for the polarization measurements with a statistical error of 0.2% and a detector dead time of about 1.8%. A pair of Helmholtz coils provides a 26 mT magnetic field in the region of the electron beam striking the target. The experimentally measured target polarization is 0.0798 for the 13.7 μm Supermendur foil. The background in coincidence mode is negligible. The typical detector acceptance angle in the reaction plane for an energy range from 2 to 5 GeV is $\Delta\Theta^{moll} \approx \pm 14°$ in c.m. and an analyzing power is of about 0.76. Total systematic error is equal to 2.4%.

Although the polarimeter quadrupole magnets are a part of the regular Hall A beam transport, it is not necessary to change the magnets settings or the primary beam trajectory in switching from data taken with the Hall A physics target to a beam polarization measurements. Also, the polarization measurements can be done with the Hall A fast raster on.

The Hall A Møller polarimeter design and results were presented on a several international conferences [4-6].

In accordance with the TJNAF plan of the accelerator upgrade up to the 12 GeV the design of the Hall A Møller polarimeter upgrade was developed [7].

The first polarization measurement with the Hall A Møller polarimeter was done in June 1997. Since April 1998, regular measurements with the polarimeter are made. Kharkov scientists participated in 14 from 17 experiments, which were done in the Hall A. The most interesting published results are presented below.

3. THE LEVCHUK EFFECT

It was shown in Ref. [2] that the beam polarization measured with the Møller polarimeters can be essentially overestimated, if motion of bound target electrons is not taken into account. This observation rests upon the following approximate relationship

$$\Theta^2 = \Theta_0^2 \cdot \left(1 - \frac{p_t}{m_e}\cos\Theta_{12}\right), \qquad (1)$$

were Θ is the lab. angle of scattering of a beam electron on an electron bound in a target atom, Θ_0 is the angle of scattering on a free target electron at rest, p_t is the intrinsic atomic momentum of the target electron, m_e is the electron mass, and Θ_{12} is the angle between the beam and target electron momenta. Thus, to the first approximation, the binding effects (the second factor in Eq. (1)) smear the angle Θ_0 by quantity $\sim p_t/m_e$ which is independent of the beam energy. This correction varies from one scatterer atomic shell to another, can be as large as several per cent and is different for different polarimeter target materials.

Typical targets used in Møller polarimeters are manufactured from pure iron or Supermendur (49% Fe, 49% Co and 2% V). In these materials the (unpolarized) K- and L-shell electrons have average momenta ~90 keV/c and ~30 keV/c, respectively. The polarized electrons occupying the outer shells can be considered as free and motionless. Therefore, in case of polarimeters with acceptances tuned to the two-body kinematics of the Møller scattering, an effective increase of the target polarization can occur due to the partial loss of electrons scattered from the target K- and L- shell electrons. Thus, thorough calculations of the polarimeter acceptance are necessary in order to have estimates of the effect, which can result in a substantial overestimate of the beam polarization measured.

The influence of Levchuk effect on the accuracy of electron beam polarization measurements with Møller polarimeters operating in a double-arm mode was analysed in Ref. [3]. It was demonstrated that the effect could result in either increase or decrease of the measured polarization depending on the detector position and acceptance.

An analysis aimed at the minimization of the correction in question has been accomplished for the Hall A Møller polarimeter. A detailed simulation of the polarimeter optical system for accurate calculation of the polarimeter acceptance was done with using RAYTRACE and GEANT codes. The result of GEANT simulation of the correction for the Hall A Møller polarimeter is shown on Fig. 2.

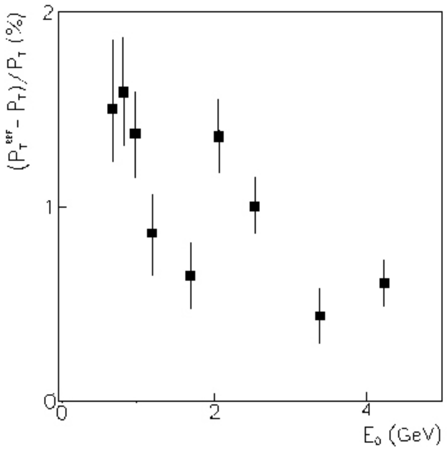

Fig. 2. *Simulations of the effective increase of the target polarization due to the binding effects for the Hall A Moller polarimeter*

For 4.255 GeV (the beam energy at which a measurement of the effect was accomplished), the Møller polarimeter acceptance is ±20° in c.m., and the calculated increase of the beam polarization due to the target binding effects is 0.5±0.1%.

The polarimeter detector consists of two identical parts (left and right arms) for the measurements in coincidence mode. Each part of the detector consists of four lead glass blocks. The measurement of the effect was carried out for three different geometry layouts of the detector with different angular acceptances.

- Coincidence of four left arm blocks and four right arm blocks. The measured polarization was (70.29±0.17 (stat.))%.

- Coincidence of one left arm block (the 2-nd block) with four right arm blocks. The measured polarization was (69.91±0.17 (stat.))%.
- Coincidence of one left arm block (the 2-nd) and one right arm block (the second). The measured polarization was (70.66± 0.19 (stat.))%.

The measurement confirmed that the Levchuk effect correction is small for the Hall A Møller polarimeter, and its result is in a good agreement with the simulation.

4. E-91-010 "PARITY VIOLATION IN ELASTIC SCATTERING ON THE PROTON"

This experiment was divided into two runs. The first run was completed in 1998 and the results (see Fig. 3) were published in 1999 [8]. The parity-violating electroweak asymmetry in the elastic scattering of polarized electrons from a proton was measured.

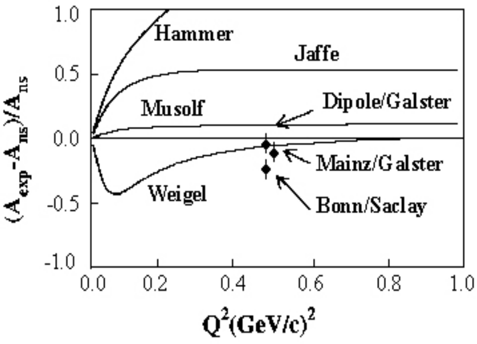

***Fig. 3**. Experimental $\delta A/A$ assuming $\delta G^n_E=0$, together with representative theoretical calculation*

During the second run in 1999, additionally ~80 C were obtained, doubling the experiment total charge. However, for this data, the electrons were originated from a strained GaAs crystal and polarization was ~70% as compared to ~40% for the first run. The higher polarization implies that the new sample has effectively three times the statistics.

The kinematic point [$\langle\Theta_{lab}\rangle$ =12.3° and $\langle Q^2\rangle$ = 0.477 (GeV/c^2)] was chosen to provide sensitivity, at a level that is of a theoretical interest, to the strange electric form factor G^s_E. The result, A = -15.05 ± 0.98(stat) ± 0.56(syst) ppm, is consistent with the electroweak standard model and no additional contributions from strange quarks. In particular, the measurement implies (G^s_E + 0.392G^s_M) = 0.025 ± 0.020 ± 0.014, where the first error is experimental and the second uncertainty arises from the uncertainties in electromagnetic form factors [10].

5. E-97-027 "ELECTRIC FORM-FACTOR OF THE PROTON BY RECOIL POLARIZATION"

The ratio of the proton's elastic electromagnetic form factors, G_{Ep}/G_{Mp}, was obtained by measuring P_t and P_l, the transverse and the longitudinal recoil proton polarization, respectively. For elastic $\vec{e}p\rightarrow e\vec{p}$, G_{Ep}/G_{Mp} is proportional to P_t/P_l. Simultaneous measurement of P_t and P_l in a focal plane polarimeter provides a good control of the systematic uncertainty. The results for the ratio G_{Ep}/G_{Mp} show (see Fig. 4) a systematic decrease with Q^2 increasing from 0.5 to 3.5 GeV^2, indicating for the first time a definite difference in the spatial distribution of charge and magnetization currents in the proton [10]. In the end of 2000 the experiment E-99-007, as extension of E-97-027 up to Q^2 = 5.6 GeV^2 was done. The results of E-97-027 will be available in a few months.

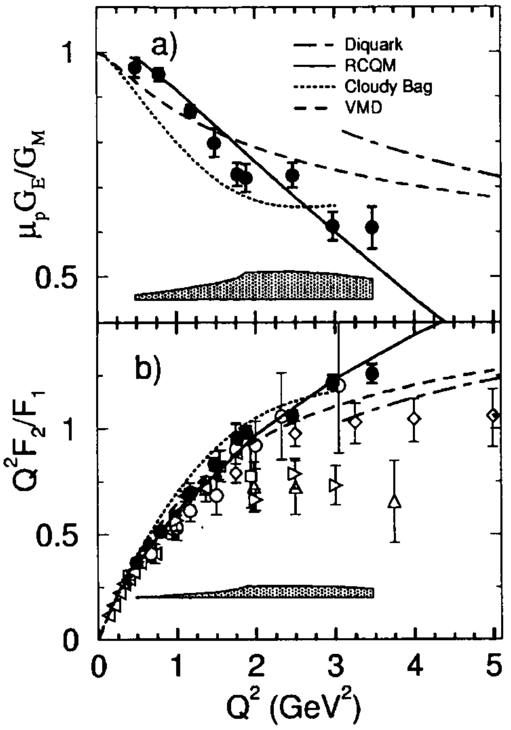

***Fig. 4**. (a) Ratio $\mu_p G_{Ep}/G_{Mp}$ from E-97-027, compared with theoretical calculations. (b) The ratio Q^2F_{2p}/F_{1p} for the same data, compared to the same theoretical models as in (a) and to world data. In (a) and (b) the absolute value of systematic error from this experiment is shown by the shaded area*

The data from these two experiments have dramatically improved our knowledge of the proton electromagnetic form factors up to Q^2 = 5.6 GeV^2. However, it should be pointed out that precision measurements of all our elastic form factors of the nucleon are required to test theories of the strong interaction.

6. THE HALL A MØLLER POLARIMETER AS A SMALL ANGLE SPECTROMETER

In addition to being a part of the standard beamline instrumentation in Hall A, the small scattering angle capabilities of the Møller polarimeter, coupled with the momentum analyzing capabilities of its dipole, present unique opportunities to do physics in the very low Q^2 regime [11]. The QQQD design of the Møller spectrometer will enable one to do electron scattering experiments at electron scattering angles ranging from about three degrees to less than one degree with $\Delta p'/p'$ of about 10^{-3}. As an initial area of investigation, we intend to measure the neutral pion form factor, $F\gamma^*\gamma\pi^\circ$, at low Q^2 via the virtual Primakoff effect [11], i.e. π° electroproduction in the Coulomb field of a heavy nucleus. The slope of this form factor in a low Q^2 range to be measured, 0.005 to 0.04 $(GeV/c)^2$, gives a measure of the mean square $\gamma^*\gamma\pi^\circ$ interaction radius and is sensitive to the constituent quark mass. Such an experiment can be performed by removing the third quadrupole magnet, installing position sensitive detectors in the focal plane, and placing a series of lead glass photon detectors upstream of the dipole to measure the π° decay photons from the $Pb(e,e'\pi^\circ)Pb$ reaction. The Hall A E-97-009 experiment "Measurement of $F\gamma^*\gamma\pi^\circ$, at low Q^2 via the virtual Primakoff effect" is conditionally approved.

7. E-99-014 "A PRECISION MEASUREMENT OF THE NEUTRAL PION LIFETIME VIA THE PRIMAKOFF EFFECT"

Also NSC KIPT scientists take part in the Hall B experimental activity. Preparation of the experiment E-99-014 [12] is an example of such a kind cooperation. This experiment proposes to perform a precise measurement of the neutral pion lifetime using the small angle coherent photoproduction of π° in the Coulomb field of a nucleus, i.e. the real Primakoff effect. The $\pi^\circ\to\gamma\gamma$ decay proceeds primarily via the chiral anomaly and represents one of the most definitive tests of low energy QCD. This measurement will be a state-of-the-art experimental determination of the lifetime with a precision of best than 1.5%, which is commensurate with the theoretical uncertainty. The π° photoproduction cross-section will be measured for three nuclei (^{12}C, ^{116}Sn, and ^{208}Pb) at photon energies from 4.6 to 5.7 GeV and at angles from zero to four degrees. High precision measurements over a range of Z's, photon energies, and angles will ensure a clean separation of the Primakoff production mechanism from competing photoproduction processes. The improved precision is enabled (1) by the use of quasimonochromatic photons from the TJNAF Hall B tagged photon facility and (2) by the development of a hybrid π^o detector consisting of a multichannel lead glass detector with a high-resolution insertion.

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