March 18, 2021

Measurement of analyzing powers for the reaction p(pol)+CH2 up to 7.5 GeV/c and n(pol)+A up to 6.0 GeV/c at the Nuclotron (ALPOM2 proposal)

Prolongation for 2022-2023 years

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Summary

Accurate data for the analyzing power of CH_2, *CH* and other targets in the extension to higher energies, of experiments requiring the measurement of the polarization of protons and neutrons in nuclear reactions. Also data have been obtained in Saturn National Laboratory and Dubna, using thick analyzers, as part of a program of study of elastic and quasi-elastic dp reactions [1-6].

The form factors of elastic *eN* scattering parametrize of the charge and current structure of the nucleons. JLab has recently gone through an energy upgrade, and is starting to produce polarized beams of up to 12 GeV. This will open the way for new measurements of the four form factors of the nucleons, and therefore an extension of the analyzing power data base is urgently needed, both for protons and neutrons..

At Jefferson Lab (JLab), with polarized beams of up to 6 GeV, the four form factors of elastic *eN* scattering, G_{Ep} and G_{Mp} ,G_{En} and G_{Mn}, have been measured for both the proton and the neutron, and have produced unexpected and intriguing results. Until the late 1990's no facility was available for such experiments, as they require beams with high polarization, high intensity and duty cycle.

The use of polarization in electromagnetic physics has been discussed already in the middle fifties [7-12], as an alternate method to determine the form factors of the nucleons from elastic $\vec{e}p\rightarrow e\vec{p}$ and $\vec{e}n\rightarrow e\vec{n}$ scattering. This type of double-polarization experiments requires the measurement of the polarization of the recoiling particle in elastic *eN scattering*. It has great advantages over the traditional mean of obtaining these form factors from cross section data.

Past Double-Polarization Experiments at JLab

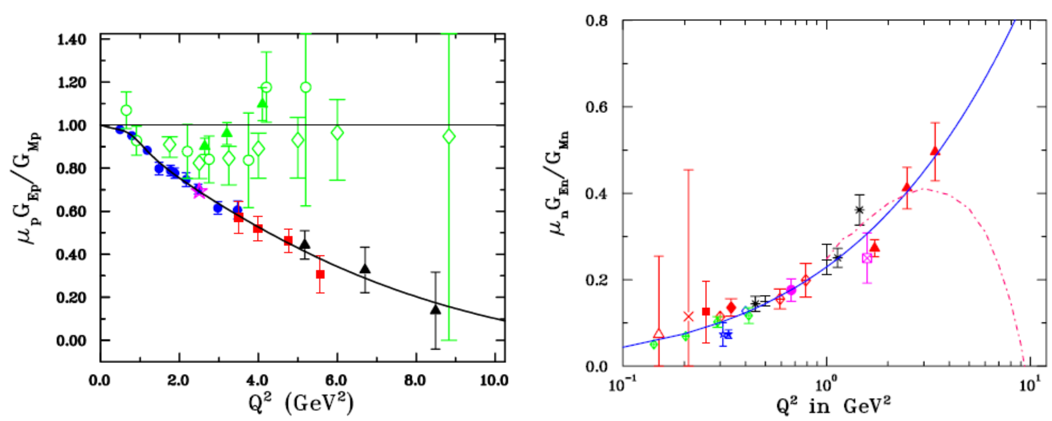

Fig. 1. Left panel, Comparison of $\mu_p G_{Ep}/G_{Mp}$ from the three JLab recoil polarization data [14-16], and Rosenbluth (cross section) separation data. The solid curve is a double polynomial fit [19]. Right panel, $\mu_n G_{En}/G_{Mn}$ data from JLab up to 3.4 GeV^2 [20], and other polarization experiments. The blue curve is a polynomial fit to the data, and pink dashed-dot curve is a Dyson Schwinger solution for the neutron form factor [21]. Details about the data in this figure can be found in the review articles [22-24].

With the CEBAF facility at the Thomas Jefferson National Accelerator Facility (JLab) coming on line in the late nineties, it became possible to use the recoil polarization technique to ever increasing transferred momentum Q^2. In 1998, the first such experiment at JLab using this technique measured the ratio of the proton form factors, G_{Ep}/G_{Mp}, to Q^2=3.5 GeV^2. The second experiment in 2000 extended the ratio measurement to Q^2 of 5.6 GeV^2. The third experiment in 2007-8 pushed the Q^2 limit to 8.5 GeV^2. All three experiments revealed a definite and entirely unexpected discrepancy when compared to the form factors results obtained by the standard, cross section based, and so-called Rosenbluth separation technique. Fig. 1 shows the results of these three experiments for the ratio G_E/G_M, and also the results obtained with the Rosenbluth technique; at the highest Q^2 the recoil polarization results are 6 times smaller than the Rosenbluth results; instead of the formerly well-known scaling, with $\mu G_E/G_M \sim 1$, we now see a linear decrease of this ratio, clearly indicating that the electric and magnetic form factor have very different Q^2-dependence, and therefore that the radial distributions of charge- and magnetization, are very different. Again, this was an unexpected result and the various papers publishing these results [13-18] have been quoted in the literature presently more than 2000.

Note that the third experiment for the proton form factor ratio [16] was depend and then approved by the JLab PAC only after the analyzing power measurements done in Dubna (with the Synchrophasotron) in 2001 [25].

Future Double-Polarization Experiments at JLab

JLab has successfully completed a project to double the beam energy from 6 to 12 GeV, providing 11 GeV in Halls A to C, 12 GeV in a new Hall D; this will open new horizons for form factor measurements.

This is an approved experiment to measure the proton form factor ratio up to 12 GeV^2 [26], currently labeled as GEp(5). The GEp(5) experiment, will run in Hall A. To do this experiment, a new spectrometer, the Super Bigbite Spectrometer (SBS) is being built with a single dipole to obtain a very large acceptance, together with a new polarimeter. This experiment will be able of reaching Q^2 values up to 15 GeV^2, but requires a very large investment, because of the extremely high particle rates in the focal plane and the polarimeter, inherent to this design (single dipole); the trigger rate will have to be lowered with the help of a hadron calorimeter downstream of the polarimeter. The tracking detectors in the focal plane and polarimeter are Gas Electron Multipliers (GEM) of large area. GEMs are being built by the Italian group of the GEp(5) collaboration for the focal plane section, and by the University of Virginia for the new polarimeter.

"The JLab Program Advisory Committee (PAC) has approved a campaign of seven experiments to run in three different experimental halls to measure the elastic, electric and magnetic form factors for both the neutron and proton. The focus of the campaign will be mapping out the quark substructure of the nucleon far beyond our current range and to test the fundamental theory of the strong force, Quantum Chromodynamics (QCD), in the non-perturbative region" [27], see Table 1 and Fig. 2 from Ref [27]..

Quantity	Method	Target	$Q^2(GeV^2)$	Hall	Beam Days
G_M^{p} *	Elastic scattering	LH_2	7 – 15.5	A	24
G_E^p/G_M^p	Recoil Polarization	LH_2	5 – 12	A	45
G_M^n	$E-p/e-n$ ratio	$LD_2 - LH_2$	3.5 – 13.0	B	30
G_M^n	$E-p/e-n$ ratio	LD_2, LH_2	3.5 – 13.5	A	25
G_E^n/G_M^n	Double polarization asymmetry	polarized ^{3}He	5 – 8	A	50
G_E^n/G_M^n	Recoil Polarization	LD_2	4 – 7	C	50
G_E^n/G_M^n	Recoil Polarization	LD_2	4.5	A	5

Table 1. Listing of approved experiments for measuring the elastic electromagnetic form factors.

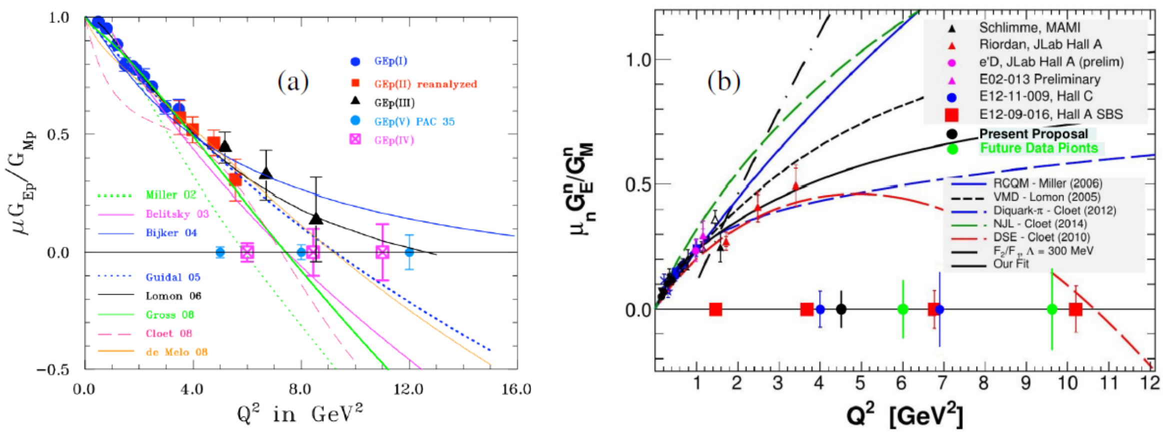

Fig.2. World's data for the proton form factor ratio $\mu_p G_{Ep}/G_{Mp}$ data using the recoil polarization method are shown in panel (a) [24, 26]. World's data for $\mu_n G_{En}/G_{Mn}$ are shown in panel (b) [28]. In both cases, the points plotted along the axis represent the anticipated Q^2 and uncertainty in future measurements.

Knowledge of nucleon analyzing powers

The future nucleon form factor experiments at 12 GeV depend on the knowledge of the actual analyzing power of CH2. Other analyzing material have been considered but for the time being ruled out because of prohibitive cost. The kinetic energy of recoil nucleons for elastic electron nucleon scattering is given by $T_N = Q^2/2m_N$. The corresponding proton momentum for $Q^2 = 14$ GeV^2 is $p_{recoil} = 8.3$ GeV/c. It was noted in ref. [25] that the maximum value of the analyzing power

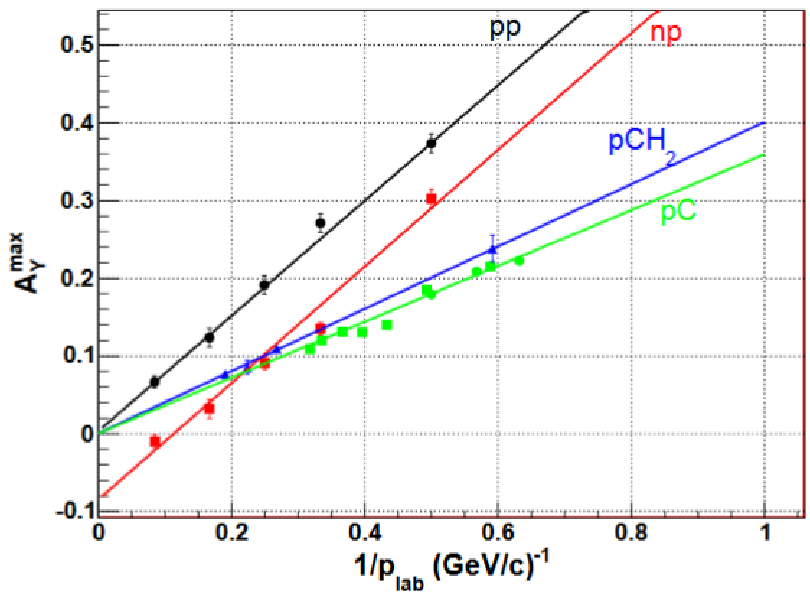

Fig. 3. The dependence of the maximum of A_Y on $1/p_{lab}$. Black circles: ANL d(p,p)n data [29, 30]; black line: linear fit. Red squares: ANL d(p,n)p data [29, 30]; red line: linear fit. Blue triangles [25]: p+ CH2→charged+X; blue line: linear fit [25]. Green squares [31] and circles [32]: p+ C→charged+X; green line: linear fit [25].

was well fitted by a straight line when plotted as a function of the inverse of the proton momentum ($1/p_{recoil}$) as shown in Fig. 3. Combined with the observation (revealed by the same data) that for proton momenta larger than 3.5 GeV/c, the shape of the angular distribution of the analyzing power multiplied by the incident proton momentum, is invariant when plotted as a function of transverse momentum transfer, allows some prediction of what the analyzing power might be at 7-8 GeV/c. However, extrapolation to momenta larger than observed in Dubna, is too chancy to justify the enormous effort that future experiments will require.

A measurement of the angular distribution of the analyzing power of CH_2 **for protons** to a momentum as high as possible, is of the greatest interest and necessary for these future experiments; a measurement at a proton momentum of 7.5 GeV/c will be most valuable. The Nuclotron in Dubna is the only facility where this reaction can be studied.

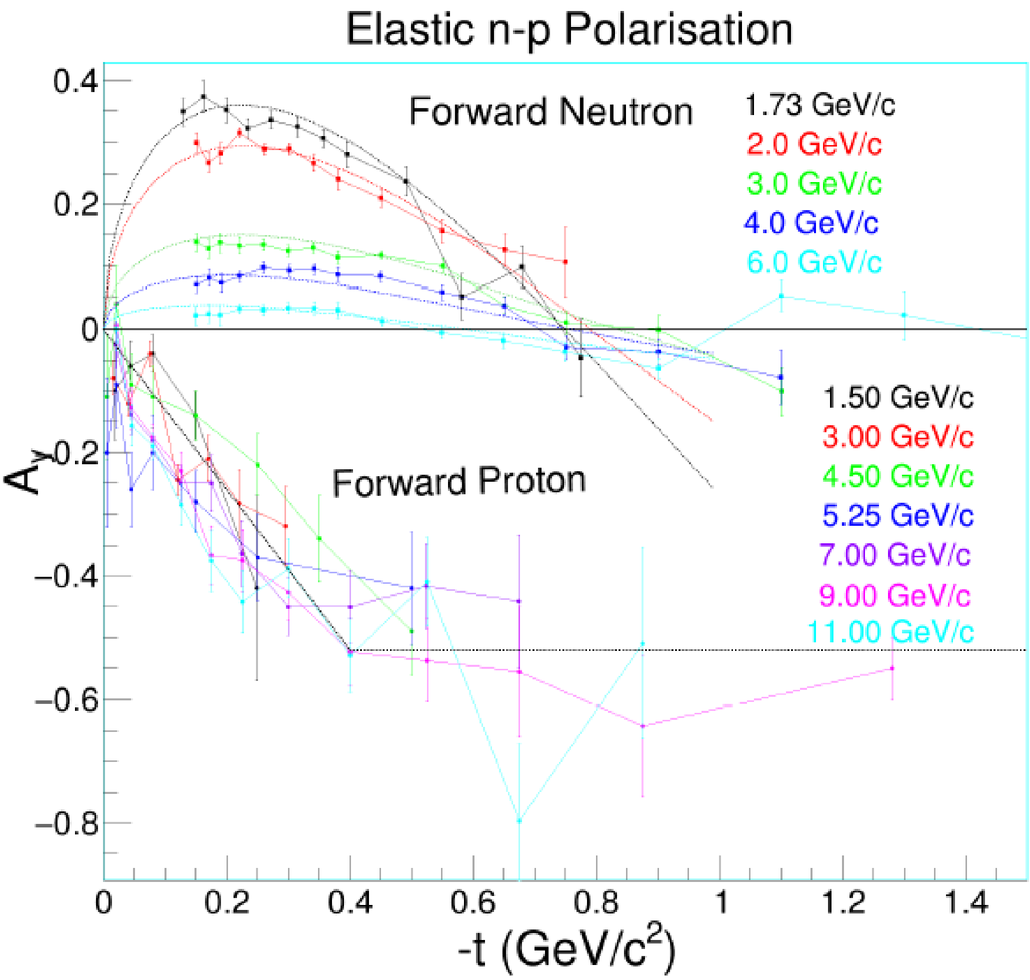

Fig. 4. Top: the p_{lab} and t-dependence of the analyzing power of elastic pn scattering [29, 30]. The smooth dotted lines show the fit of Ref. [33] to the pn data.
Bottom: the p_{lab} and t dependence of charge-exchange np scattering [34, 35].
The color-coding relates the data to momentum labels.

Analyzing powers for polarized **neutrons** exist only for thin hydrogen targets. Cross section and analyzing powers for np, for both elastic and charge exchange reactions are known up to 29 GeV/c. No data are known to exist for thick analyzers, made of scintillator material. A scintillator polarimeter target is required to make a coincidence trigger for both reactions. We propose to obtain analyzing powers for both reactions (elastic and charge exchange), up to 6.0 GeV/c, which corresponds to the largest Q^2 of the approved Hall C measurement [28]. The relevant analyzing powers for np elastic and charge exchange are shown in Fig. 4. The analyzing powers for np elastic scattering become smaller and then negative as the neutron momentum increases.

Importance of the hadron calorimeter

In the past polarimeters have been inclusive devices, without particle identification (PID) for the particle(s) emerging from the analyzer. However, as one increases the energy of the incident proton, the probability for inelastic scattering in the analyzer increases, resulting in multiparticle events. At 7 GeV/c only about 30% of the reactions in the analyzer are elastic, i.e. without production of secondary particles (mesons). If one were to detect all of the particles in the final state, one would observe no asymmetry. In the past, the event selection was basically "any charged particle". With increasing energy the probability that all the particles of the final state are detected increases; it depends on particularities of the detector, like angular resolution, ability to select the leading particle, ability to reconstruct multi-particle events and so on. One might expect that the largest analyzing power will be obtained when the particle selected has the smallest scattering angle and the largest energy; this particle is then more likely to be the scattered incident particle. This concept has now been tested with the data of GEp(3); removing the "smallest angle" condition results in a drastic decrease of the observed asymmetry. These two features are combined by adding a hadron calorimeter to the ALPOM setup. This hadron calorimeter consist of 25 of the individual "bars" built 20 years ago in Dubna, and subsequently used in COMPASS at CERN, which located downstream from the polarimeter. The response of these bars to proton energies smaller than 10 GeV (the lowest energy for which the "bars" have been calibrated [36]), has been calibrated in several test run at the JINR Nuclotron [37]. In the GEp(V) experiment with the SBS such a hadron calorimeter downstream from the polarimeter will have a dual purpose: first provide a coincidence trigger with signal from the EM calorimeter, and second to contribute to the selection of the largest energy particle emerging from the polarimeter. Of course, the selection of particular events, instead of the standard inclusive mode used so far, results in a decreased fraction of useful scatterings. However, the coefficient of merit of a polarimeter is proportional to ηA_y^2, where η is the fraction of useful scattering in the analyzer, and A_y is the average analyzing power; hence a decrease of efficiency may be more than compensated by an increase in analyzing power.

The polarized deuteron beam.

The polarized deuteron beam is provided by the Source of Polarized Ions (SPI), pre-accelerated in a potential of 100-150 keV LU-20 injector, and accelerated by the Nuclotron [41]. The SPI is an atomic beam polarized ion source with a plasma (H, D) charge exchange ionizer and a storage cell in the ionization region (Fig. 9). The parts of the polarized source CIPIOS were moved from Bloomington (Indiana, USA) and totally renewed at JINR and INR RAS [14].

On line F3 polarimeter

The accurate measurement of the secondary nucleon beam polarization is crucial to the extraction of the analyzing power in ALPOM2, as the beam-polarization uncertainty is the main source of the systematic error on the analyzing power. The polarized deuteron beam is tagged with its three polarization states, down (plus, '+', $P_z = +1$, $P_{zz} = +1$), up (minus, '−', $P_z = -1/3$, $P_{zz} = 0$), and unpolarized (zero, '0'), where the state is changed after each spill.

The beam polarimeter, see Fig. 5 denominated F3 as it is located at the focus F3 of the extracted beam line, is based on quasielastic *pp* scattering, where analyzing powers are known (within 10%) [47]. For example the analyzing power of the polarimeter at a momentum of 3.75 GeV/c is $A_y = 0.20 \pm 0.02$. F3 has an ionization chamber (IC) as a beam intensity monitor for normalization, and four arms, forward and recoil, left and right. The coincidence between forward and recoil arms (left and right) and the IC counts are collected, spill by spill, by the data acquisition system. The nucleon beam polarization is constantly monitored and the stability of the beam was excellent. The fluctuations of the polarimeter asymmetry do not exceed 2%, see Fig. 6.

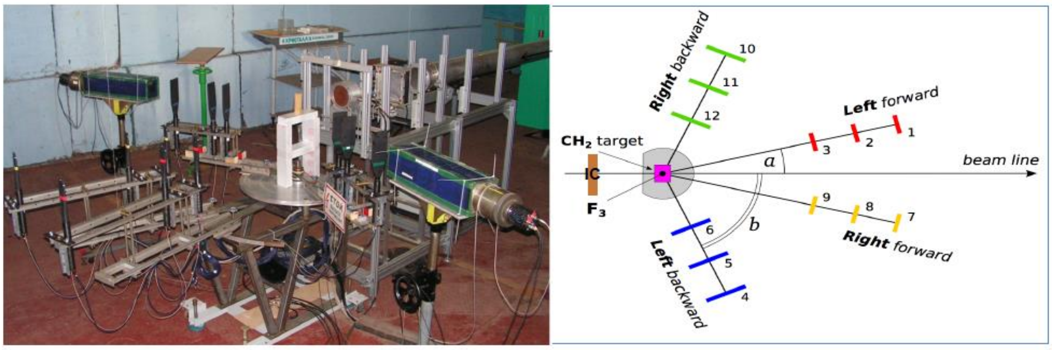

FIG. 5. The F3 polarimeter. IC is an ionization chamber. The F3 left, right forward and backward arms have three scintillation counters at angles a and b with respect to the beam-line.

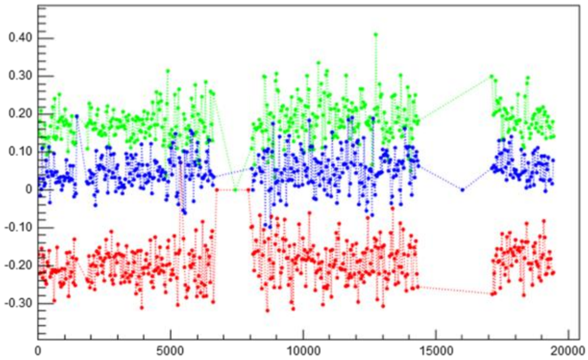

Fig. 6. A simple relation (L-R)/IC vs time, each point corresponds to one spill.

Polarized proton and neutron beams

After acceleration up to 7.5 (6.0 or 8.4) GeV/c in the Nuclotron, the slowly extracted deuteron beam is transported to the focus F3, where the F3 polarimeter is located, and, then, to the production target, see Fig. 7.

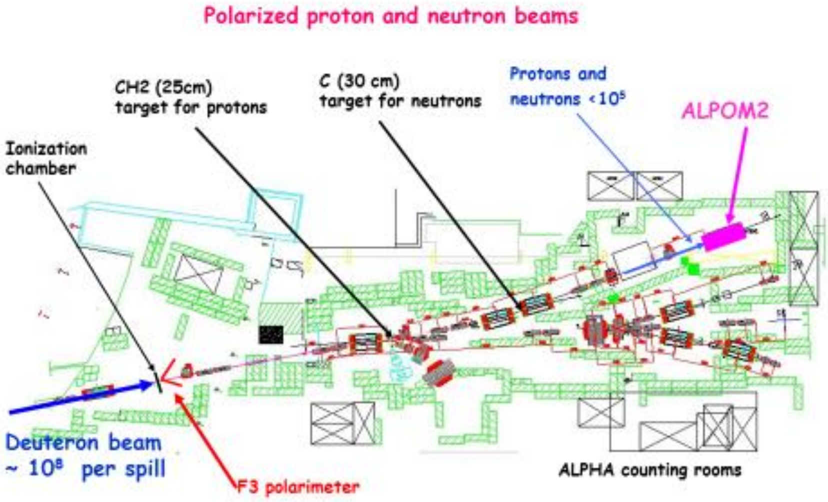

Fig. 7. Scheme of transportation polarized beams from Nuclotron to the ALPOM2 setup and the location of F3 polarimeter and production target for proton and neutron beams

The polarized proton beam.

The polarized protons will be produced by fragmentation of the polarized deuteron beam on a 25 cm thick CH2 target, installed about 40 m upstream of the polarimeter. Two dipoles of the beam transport line separate the break-up protons at zero angles from the deuteron beam. The angular and momentum acceptances of the beam transport line are about $\Delta\Omega \sim 10^{-4}$ sr and $\Delta p_p/p_p \sim 3\%$, respectively.

Experiments on polarization transfer from deuteron to proton show that the proton polarization is equal to the polarization of the primary deuteron beam and is constant up to deuteron internal momentum k=0.15 GeV/c, as seen in Fig. 8. This feature allows us to get polarized protons with momentum higher than half of deuteron momentum in the fragmentation reaction. In order to have proton momentum of 7.5 GeV/c we need deuteron with momentum of 13 GeV/c, see Fig. 9.

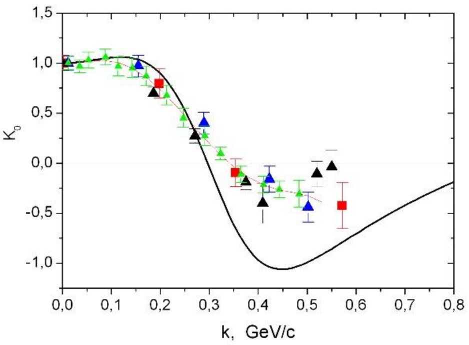

Fig. 8. World data of p(d,p)X and C(d,p)X reactions for the polarization transfer coefficient versus k; the curve is calculated in framework of IA, using the Paris N-N potential.

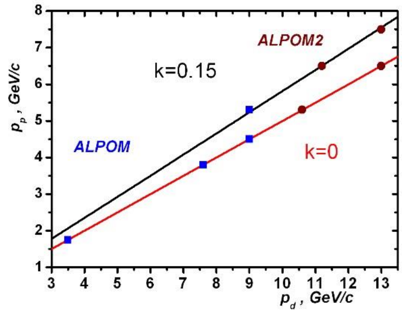

Fig. 9. Dependence of proton momentum at which the proton polarization is equal to the deuteron polarization (k=0.15) versus the primary deuteron momentum. Blue points: old measurements; red points: future measurements.

The polarized neutron beam.

The neutron momentum distribution in the forward break-up reaction, due to the Fermi motion of the nucleons in the accelerated deuterons, has a Gaussian-like shape with FWHM ~5% of the neutron momentum. The production target was positioned close to one focal point of the deuteron beam line. Protons and deuterons were removed from the neutron beam by a bending magnet. Neutrons were collimated by 6 m iron and brass in a path of 17 m upstream from the ALPOM2 set-up. The neutron angular divergence was ~1.5 mrad. The collimators and efficient shielding of the experimental area decreased the low energy tail of the neutron spectrum to about 1%. The dimension of neutron beam is presented in Fig. 10.

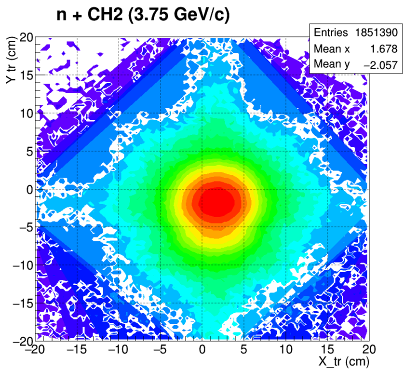

Fig.10. Position of neutron beam at the CH2 target.

The polarization of the incident deuterons is oriented perpendicularly with respect to the beam momentum, along the vertical axis. The polarization of the produced neutrons has the same direction and the same value as the vector deuteron polarization.

Experimental setup

A schematic view of the experimental setup used during the test measurements is shown in Fig. 11, see also Fig. 12.

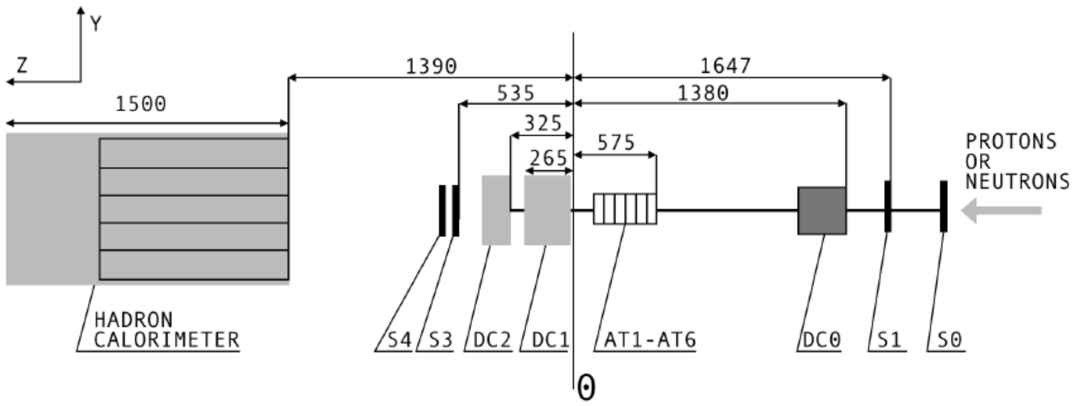

Fig. 11. Side view scheme of the ALPOM2 set up positioned on the secondary proton/neutron beam line, including scintillation counters (S0, S1, S3, S4); drift chambers (DC0, DC1, DC2); hadron calorimeter. The analyzing materials of the polarimeter were located between DC0 and DC1. Here a CH active target (AT1 -AT6), is shown as an example. Dimensions are in mm.

Drift chambers

Two chambers (DC0 and DC1) of size, 25 x 25 cm^2, will be changed in the future experiments. Each module containing 3X + 3Y + 3X + 3Y planes in one gas enclosure. The spacing of signal wires is 42 mm, so that the maximum drift length is 21 mm. The signal wires of adjacent planes are shifted by 14 mm to resolve the left-right ambiguity. The total material in an eight planes module is 0.141 g/cm^2 (0.008 radiation lengths) in the sensitive area. Their spatial resolution is lower than 0.1 mm [34]. Using the drift chambers allows us to get angle resolution better than 0.3 mrad and improve track reconstruction.

Polarimeter targets

Various target materials were tested, for several proton and neutron momenta, and their corresponding analyzing powers were compared. The aim was to determine the optimal analyzing material, for different scattering interactions, as a function of the nucleon momentum. Table IV details the tested target materials, their length and density, the momentum and type of primary particle incident on the polarimeter. The approximate scattering angle acceptances provided by the different target lengths, in the region sensitive to studying the target analyzing powers are also given.

TABLE 2: Different analyzer materials tested and their corresponding lengths.

target	g/cm^3	L, cm	N_A /cm^3	GeV/c
CH2	0,919	30 (40)	15.75	3,0; 3,75; 4,2
CH	1.06	30	17.12	3,75
C	1.68	20	16.8	3,75; 4,2
Cu	8,96	4	16.36	3,75

The longitudinal dimensions of the targets were selected to provide as similar as possible corresponding proton density for each target. This was confirmed by inspecting the event yields obtained for scattering from the different materials as a function of the nucleon transverse momentum. The C and Cu targets were monolithic, whereas the CH2 targets were constructed by packing together several smaller blocks in the longitudinal direction, leaving minimal dead space between each element. The blocks had dimensions 300mm x 300mm x 50mm each. The CH analyzer, used for a sub-set of neutron measurements, was incorporated into an active target. The active target comprised six individual detector elements (AT1 -AT6). Each CH block had dimensions 500mm x 150mm x 50 mm, and both ends of each block were coupled to photomultiplier tubes. Differences in signal charge and time distributions readout at either side of each block, measured by the TQDCs, were used to provide information about the neutron hit positions on the blocks and, consequently, on the amount of scattering taking place. For neutron measurements with CH, the active target was included in the trigger.

Hadcal (hadron calorimeter)

Instead of the ALPOM2 hadron calorimeter (Fig.12), it is planned to use the ZDC of the BM@N setup (Fig. 13) in order to increase acceptance of detecting scattering particles and improve angle resolution at small angles.

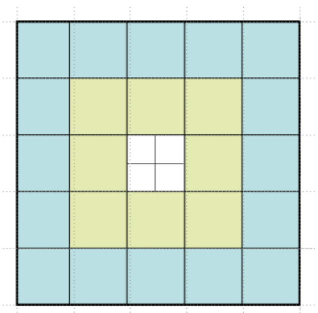

Fig. 12. ALPOM2 calorimeter layout**:** central part consist of 4 modules with sizes 7.5×7.5 cm^2, peripheral part contains 24 modules of 15×15 cm^2

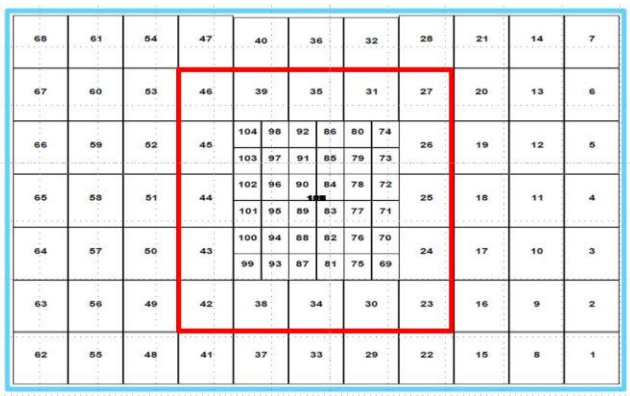

Fig. 13. ZDC layout**:** central part consist of 36 modules with sizes 7.5×7.5 cm^2, peripheral part contains 68 modules of 15×15 cm^2

The extraction of the analyzing powers and beam time request

After reconstruction of the incident and outgoing trajectories; the θ,φ bi-dimensional plots are built, with granularity 10 x 10. The number of counts is normalized to the incident beam intensity.

The number of counts for each θ,φ bin, $N(\theta,\varphi)^{\pm}$ can be written as:

$$N^{\pm}(\theta,\varphi)=N_0(\theta)(1\pm P_y A_y(\theta)\cos\varphi),$$

where the sign ± refers to the spin orientation of the incident protons. The determination of the analyzing power A_y follows from the ratio:

$$R(\theta,\varphi)=\frac{N^{+}-N^{-}}{N^{+}+N^{-}}=P_y\,A_y(\theta)\cos\varphi$$

The statistical error for A_y is:

$$\Delta A_y=\frac{1}{P_y}\sqrt{A_y^2\,\Delta P_y^2+\frac{4N^{+}N^{-}}{\left(N^{+}+N^{-}\right)^3}}.$$

In order to get the required statistical uncertainty on the analyzing powers, (which are expected to be of the order of 0.05 for *p* and *n* elastic scattering, but 3-4 times larger for *n* charge exchange), we need for each measurement ~ 10^8 incident particles (*p* or *n*). The average acquisition rate being 7500 events/s, the time needed is of the order of 24 hours per measurement.

Main results of the 2018 - 2021 years

No beam time was available from 2018 year until the present time.

The experimental data obtained in 2016 and 2017 were analyzed and the article **Measurement of neutron and proton analyzing powers on C, CH, CH2 and Cu targets in the momentum region 3-4.2 GeV/c** was published as a *Special Article - New Tools and Techniques in Eur.Phys.J.A 56 (2020) 26*.[38]

The distribution of the nucleon yield as a function of pt2 is shown in Fig. 5 for p + CH2 scattering and in Fig. 6 for n + C scattering at a momentum of 3.75 GeV/c. These distributions represent a convolution of physical processes and effects of the final resolution of the registration system. The pt2 distribution for p + CH2 scattering is described by the sum of three exponential functions. The first, the shape of which is associated with multiple small-angle Coulomb scattering, convoluted with the experimental angular resolution, is not shown in Fig. 5. The slope parameter for the second function is $b'2 = 71.3\ (\mathrm{GeV/c})^{-2}$, which is close to the slope parameter for elastic scattering p + C. The third component $b'3 = 7.4\ (\mathrm{GeV/c})^{-2}$ corresponds to the slope pp -elastic scattering. In turn, the Pt2 distribution for n + C scattering is described by the sum of only two exponential functions with slope parameters $b1 = 24.5\ (\mathrm{GeV/c})^{-2}$ and $b2 = 3.2\ (\mathrm{GeV/c})^{-2}$, corresponding to the exchanges π and ρ mesons.

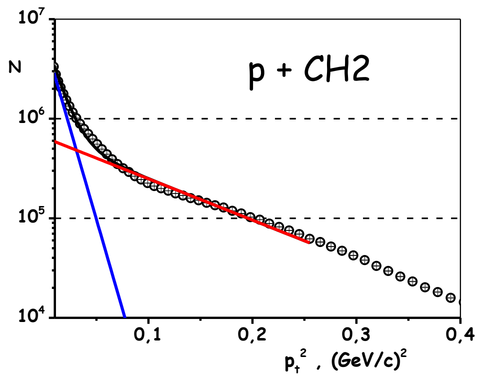

Fig. 14. pt2 -distribution for p + CH2 scattering at 3.75 GeV/c. The black curve is the sum of exponential functions with slope parameters b'1 (blue) and b'2 (red).

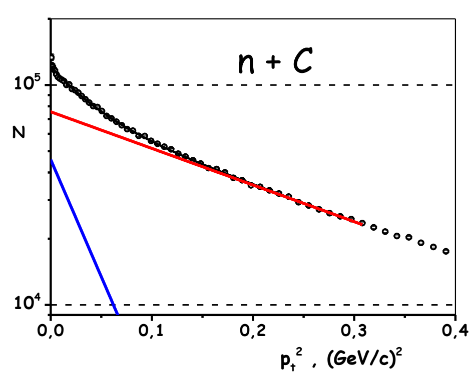

Fig. 15. pt2 -distribution for n + C scattering at 3.75 GeV/c. The black curve is the sum of exponential functions with slope parameters b1 (blue) and b2 (red).

The dependence of Ay on the target material shown in Fig. 7 is very weak, there is no significant difference between the data for C, CH, CH2 and Cu, and this is not surprising, since the charge exchange reaction is the same on both free protons and protons in the nucleus.

The scattering symmetry can be obtained independently: both from the tracks from the drift chambers and from the triggered modules of the hadron calorimeter; the results for p + CH2 at a momentum of 3.0 GeV/c are shown in Fig. 8 (filled squares). Excellent agreement between both asymmetry measurements makes it possible to use the calorimeter for proton polarimetry both together with track detectors and in the case when track detectors are absent.

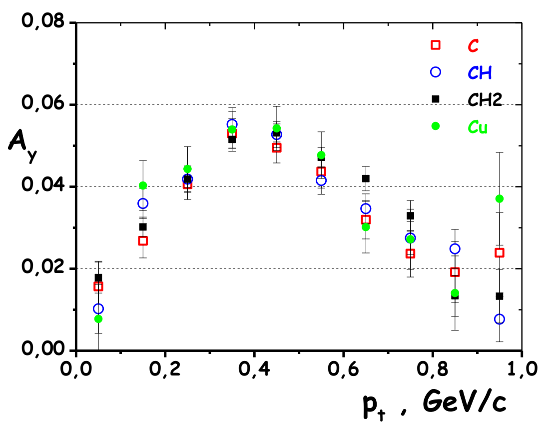

Fig. 16. Analyzing power Ay as a function of pt for 3.75 GeV/c neutrons scattering on carbon (red), scintillator (blue), polyethylene (black), and copper (green).

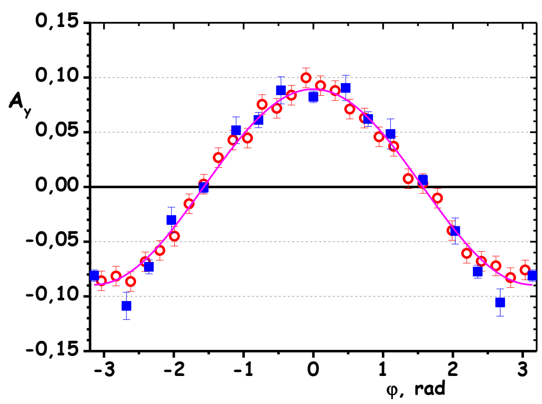

Fig. 17. Azimuthal dependence Ay for p + CH2 scattering at a momentum of 3.0 GeV/c, obtained from the triggered modules of the hadron calorimeter (blue squares) and from the tracks (red circles)

The response of all calorimeter bars and their associated electronics was calibrated in dedicated cosmic-ray runs, where the hadron calorimeter was rotated by 90° so that the bars were aligned vertically. Further calibrations, with the calorimeter in standard alignment, were performed with the proton beam. The results are shown in Fig. 18.

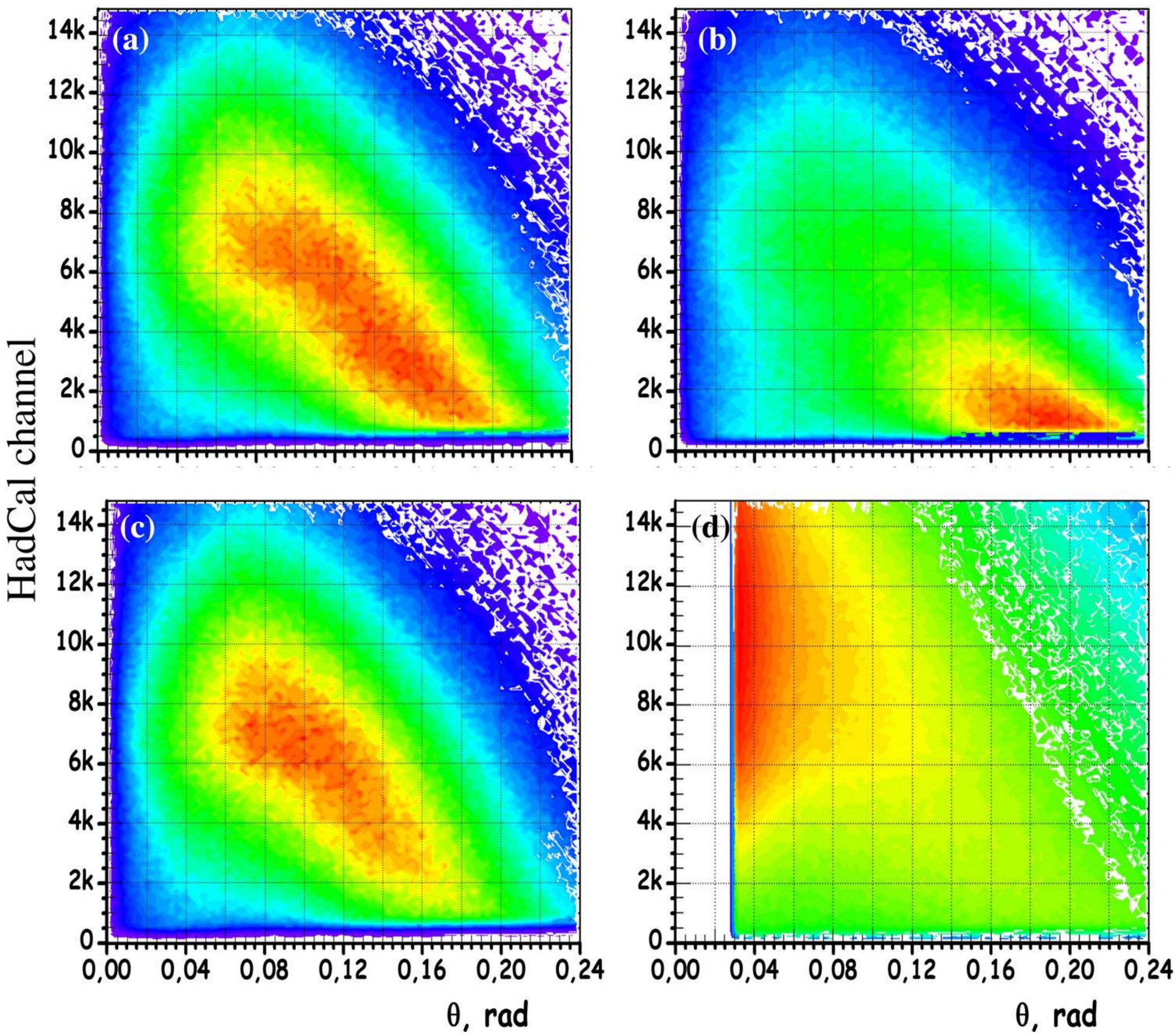

Fig. 18 Hadron calorimeter summed energy deposit vs. particle angle for (**a**) *n + C*, (**b**) *n + Cu*, (**c**) *n + CH2*, and (**d**) *p + CH2*. In subfigure (**d**) the events corresponding to the unscattered beam are removed by a small-angle cut. The value 6k on the ordinate corresponds to energy deposit of 1.76 GeV.

For the first time, data were obtained on the analyzing capabilities with polarized protons and neutrons with a momentum of 3.75 GeV/c, incident on a copper target, with the registration of one charged particle flying forward, and at different values of the energy thresholds of the calorimeter. In fig. 19 compares Ay for the charge exchange reaction n + Cu → p + X with quasi-elastic scattering p + Cu → p + X. If we disregard the energy release in the calorimeter, then Ay for p + Cu is approximately twice as large as for n + Cu. However, after the selection of events with an energy deposit exceeding 6k [channels] or 1.76 GeV, Ay for n + Cu increases by a factor of ~ 2, while the increase for p + Cu is ~ 1.3. This leads to an increase

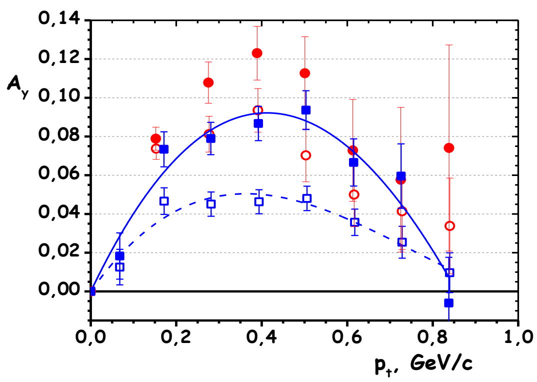

Fig. 19. Dependences of Ay on pt for n + Cu (blue) and for p + Cu (red). Open points - without sampling by the calorimeter, filled ones - with sampling with a threshold above 1.76 GeV.

in the FOM for the n + Cu charge exchange reaction by almost 40%. For a copper target 4 cm thick, the FOM is 8.0 x 10-5, and when selecting events with a calorimeter, the FOM increased to 1.1 x 10^{-4}.

Three new approaches to the development of polarimetry, namely: a) turning on the calorimeter to select high-energy nucleons in the final state, b) using the charge exchange reaction, and c) replacing the hydrogen-rich light target with heavier nuclei, open the way to simpler and more efficient measurements of nucleon polarization in the region of GeV energies. Future experiments at Jefferson Lab, requiring recoil polarimetry, have already integrated these concepts in approved experiment E12-17-004, see Appendix 1 and Fig. 2, which presents the current state and planned measurements of neutron electromagnetic form factors.

The measurements of analyzing powers in nucleon-nucleus scattering at higher energies available only in Dubna now are very important for future experiments in Jlab and JINR.

Schedule of the experiment:

2021-2022 years — Installation of the ZDC at the neutron beam line

2022-2023 years — Data taking during 336 hours.

It includes: **for proton beam 168 hours**

a) measurement A_y at proton momentum of 5.3 GeV/c (control point)
b) two measurements of transfer polarization, check conservation polarization at k=0.15 GeV/c at deuteron momentum of 11.2 GeV/c (proton momentum 6.5 GeV/c) and deuteron momentum of 13.0 GeV/c (proton momentum 6.5 GeV/c)
c) measurement at deuteron momentum of 13.0 GeV/c (proton momentum 7.5 GeV/c)

for neutron beam 168 hours

measurement A_y at neutron momenta of 5.0 and 6.0 GeV/c .

2023 year — Data analyzes and publication of the results.

Expenses

The following expenses are requested:

Installation of the ZDC and upgrading DAQ system	20 k $
Constructing of mechanical support, gases	8 k $
Reception and sending of the experts	14 k $
Total:	42 k $

Contributions in previous years from collaborators

USA side – crate VME – 8500 $; HV supply – 2000 $, .2 TQDC – 8000 $, hadcal modules – 10000 $, HV system SY5527 (Caen) – 14600 $

French side – PM XP2020 – 2 items and several electronic modules – 5000 $

Slovak Republic grants – 45 k$, HV supply, computers, electronic modules, drift chambers

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Приложение 1

REPORT
OF THE 45th PROGRAM ADVISORY COMMITTEE
(PAC45) MEETING

July 10 – 14, 2017

PR12-17-004

Scientific Rating: A-

Recommendation: Approve for Five Days

Title: Measurement of the Ratio G^n_E/G^n_M by the Double-polarized 2H(e,e'n) Reaction

Spokespersons: J. Annand (Contact), V. Bellini, M. Kohl, N. Piskunov, B. Sawatzky, B. Wojtsekhowski

Motivation: Measurements of the neutron electromagnetic form factors are a cornerstone of the physics program at JLab12, providing unprecedented insight into the structure of the neutron and QCD dynamics. Present data on G^n_E/G^n_M run out at Q^2=3.4GeV^2. There is much interest in extending the Q^2 regime to higher values, in order to confront theoretical calculations, to probe the possible onset of scaling behavior predicted by perturbative QCD, and to combine with existing and forthcoming proton data to obtain a quark flavor decomposition of the form factors. Given the experience with proton form factor extractions, it is crucial to employ various different methods, either based on cross section measurements with Rosenbluth separation, or on polarization. The proposed experiment will scatter a longitudinally polarized electron beam off a deuterium target, measuring the polarization of the neutron recoiling from the interaction. *Compared to the previously approved experiment E12-11-009 that will use the same general technique, the present experiment uses a different method for neutron polarimetry that also provides access to the charge-exchange channel np→pn. As the latter dominates at high neutron energy and hence at higher Q^2, the proposed method would provide an avenue for future high-Q^2 measurements of the form factor ratio via recoil polarimetry.*

Measurement and Feasibility: The proposed measurement will be carried out in Hall A. It will make use of all apparatus required for the already approved G^n_E/G^n_M experiment E12-09-019 (LD2 target, BigBite spectrometer for electron detection, 48D48 dipole in hadron arm, HCAL hadron calorimeter), and operate at the same settings. It would hence prefer to run immediately following E12-09-019. A new neutron recoil polarimeter will be added, consisting mainly of a copper polarization analyzer with GEM chambers. The 48D48 dipole magnet will be used to process the spin of the recoil neutron from longitudinal to vertical direction. The form factor ratio G^n_E/G^n_M may then be obtained directly from the polarization ratio P_x/P_z. The analyzing power cancels in this ratio. The focus is on detecting forward protons from the charge-exchange process np→pn, although there is also potential for seeing large angle, low energy protons from the channel np→np, which would provide valuable information for E12-11-009.

The proposed experiment requests 5 days of running. It plans to access a single value of Q^2=4.5 GeV^2, which is sufficient for exploring and validating the new recoil polarimetry method. A precision of about 0.1 (absolute value) on the ratio G^n_E/G^n_M is anticipated.

Issues: *The case for polarimetry via np→pnhas recently been strengthened significantly by preliminary data from JINR/Dubna showing a sizable analyzing power for n+A→p+X. Since most of the equipment is standard Hall-A equipment and the polarimeter mainly consists of a simple copper analyzer, no technical issues are foreseen*. The TAC report raises the issue of a high DAQ data volume, which has been addressed by the collaboration and does not appear to be a reason for concern. Running consecutively with E12-09-019 appears to be a must.

Form № 29

Estimated cost of the project: ***Measurement of analyzing powers for the reaction p+CH2 up to 7.5 GeV/c and n+A up to 6.0 GeV/c at the Nuclotron (ALPOM2 proposal)***

№№	Cost item	Full price	1 year	2 year
	Direct costs for the Project, kUSD	42.0	21.0	21.0
1.	Accelerator, Nuclotron, hours	336	168	168
2.	Computer (type)			
3.	Computer connection			
4.	Design department			
5.	Workshops, hours	1000	1000	
6.	Materials	8.0	4.0	4.0
7.	Equipment	14.0	7.0	7.0
8.	Payment of research carried out under contracts	6.0	3.0	3.0
9.	Travel expenses including:	14.0	7.0	7.0
	a) non-Russian ruble zone in the country	10.0	5.0	5.0
	b) in the cities of the ruble zone			
	c) reception collaborators	4.0	2.0	2.0

Project Manager N. Piskunov

Director of the Laboratory V. Kekelidze

Leading engineer-economist of the Laboratory G. Volkova

Научный опыт авторов

Авторы проекта имеют большой опыт в проведении измерений на поляризованных пучках:

- Пискунов Н.М., Ситник И.М. участвовали в экспериментах на ускорителях ОИЯИ, Сатурн (Сакле, Франция), Лаборатории им Джефферсона (Ньюпорт-Ньюз, США) и КОЗИ (Юлих, Германия);

- Кириллов Д.А. участвовал в измерениях на ускорителях ОИЯИ, Лаборатории им Джефферсона (Ньюпорт-Ньюз, США) и КОЗИ (Юлих, Германия).

Гаврищук О.П. является высококлассным специалистов в области создания адронных калориметров и их использования в экспериментах.

Рукояткин П.А. первоклассный специалист в области создания пучков на Нуклотроне.

Шиндин Р.А. и Ливанов А.Н. уже обладают большим опытом в проведении измерений.

Кирюшин Ю.Т. имеет громадный опыт в создании трековых детекторов и их использования в измерениях на пучках.

Базылев С.Н. и его команда на самом высоком уровне обеспечивают работу систем контроля функционирования детекторов и сбора данных.

Участвующие в эксперименте ученые: Пердрисат Ч., Пунджаби В (США); Томази-Густафссон Э. (Франция) – обладают огромным опытом в проведении экспериментальных исследований на различных ускорителях в мире и в том числе на ускорителях ОИЯИ.

Мушински Я. (Словакия) – прекрасный специалист в области анализа данных, полученных в опытах на установках с трековыми детекторами.

Оценка кадровых ресурсов

В таблице 1 представлены участники эксперимента АЛПОМ2 с указанием направлений исследований и долей их участия. В таблице 2 указан возраст молодых сотрудников.

Таблица 1. Участники проекта из ЛФВЭ:

№	Фамилия	Обязанности	FTE
1	Пискунов Н.М.	Анализ, набор данных	0.8
2	Кириллов Д.А.	Анализ, набор данных	0.8
3	Ситник И.М.	Анализ, набор данных	1.0
4	Гаврищук О.П.	ZDC, набор данных	0.2
5	Шиндин Р.А	ZDC, поляриметр, набор данных	0.8
6	Ливанов А.Н.	ZDC, поляриметр, набор данных	0.5
7	Рукояткин П.А.	Пучки нуклонов	0.2
8	Кирюшин Ю.Т.	Дрейфовые камеры, набор данных	0.2
9	Костяева Н.В.	Дрейфовые камеры, набор данных	1.0
10	Легостаева К.С.	Набор данных	1.0
11	Бушуев Ю.П.	ZDC, набор данных	0.5
12	Повторейко А.А.	Набор данных	0.5
13	Глаголев В.В.	Набор данных	0.5
14	Базылев С.Н.	DAQ, набор данных	0.1
15	Слепнев В.М.	DAQ, набор данных	0.1
16	Слепнев И.В.	DAQ, набор данных	0.1
17	Шипунов А.В.	DAQ, набор данных	0.1
18	Шутов А.В.	DAQ, набор данных	0.1
19	Терлецкий А.В.	DAQ, набор данных	0.1
20	Филиппов И.А.	DAQ, набор данных	0.1
			8.4

Таблица 2. Возраст молодых участников проекта.

№	Фамилия	Возраст (лет)
1	Легостаева К.С.	27
2	Шипунов А.В.	34
3	Филиппов И.А.	36
4	Терлецкий А.В.	35