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 (p*rolongation for 2022-2023)*

Theme 02-1-1097-2010/21

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Abstract

We propose to extend at high energies the data basis for proton and neutron analyzing powers on CH2, CH and other targets. Such data are necessary for the experiments that require the measurement of the polarization of protons and neutrons in nuclear reactions. At Jefferson Lab (JLab), Virginia, with polarized electron beams of up to 6 GeV, the four nucleon form factors (electric and magnetic, for protons and neutrons, G_{Ep} and G_{Mp} ,G_{En} and G_{Mn}, respectively) have been measured and produced unexpected and intriguing results, giving rise to a revision of nucleon models and to a large number of publications with more than 2000 citations. JLab has recently gone through an energy upgrade. The availability of polarized electron beams of energy up to 12 GeV will open the way for new measurements of hadron form factors that require *the measurement of the polarization of the recoiling particle in elastic eN scattering with longitudinally polarized electrons.* The optimization of hadron polarimetry and the extension of the analyzing power database is urgently needed, both for protons and for neutrons. This is possible only in Dubna, where polarized proton and neutron beams are available, by breakup of accelerated deuterons. Our team has large expertise and has successfully worked in the area, as shown by the recently published measurement of analyzing powers up to a proton (neutron) momentum of 3.75 (4.2) GeV/c. We propose to upgrade the drift chambers and the DAQ system and install the Zero Degree Calorimeter of the BM@N setup along the neutron line in 2021-2022. The present proposal requests 336 hours of polarized deuteron beam to measure analyzing powers for protons at 5.3, 6.5 and 7.5 GeV (168 hours), and for neutrons at 5 and 6 GeV/c (168 hours) in 2022-2023. Data analysis and publication of the results are expected in 2023. The budget of 42 k$ covers the upgrade of the installation and visits.

1. Introduction

In reactions involving elementary particles, hadrons and light nuclei, polarization observables bring essential information on the structure of hadrons (protons and neutrons) and on the reaction mechanism. The structure of hadrons is conveniently parametrized in terms of form factors, that describe the distribution of charge and magnetic currents in the hadron. The program of form factor measurements at Jefferson Laboratory after the 12 GeV energy upgrade, requires to know the polarization of the outgoing nucleon in the elastic eN scattering (N is a proton or a neutron) with a longitudinally polarized electron beam. We propose to optimize the polarimetry issues and extend the data basis for analyzing powers on CH2, CH and other targets, for protons up to 7.5 GeV and for neutrons up to 6 GeV.

Conceiving, building, testing and validating polarimeters require proton and neutron polarized beams, of known polarization. Today, such beams of energy in the GeV range are available only at the Nuclotron complex of JINR, where the accelerated polarized deuteron beam can produce by breakup proton and neutron beams of known momentum and polarization.

The measurement of the polarization of outgoing hadrons (protons and neutrons) produced in a nuclear reaction requires the measurement of the azimuthal asymmetry in a secondary scattering. Such experiments are lengthy and costly, requiring therefore a thorough optimization of polarimetry for each particle and at each energy. A polarimeter is characterized by a figure of merit based on the efficiency and the analyzing powers, determined by the chosen secondary target and reaction.

The approval and planning of JLab form factor Experiments E12-07-109 and E12-17-004, are conditional to a proof of feasibility of polarization measurements. The first JLab experiments took benefit of the results obtained at 'Laboratoire National Saturne', in Saclay, and at Dubna Synchrophasotron. With polarized protons to 3 GeV/c and polarized neutrons to 1.9 GeV/c, it was shown that a thick carbon or a mylar (hydrogen rich) target with the detection of a charged particle was sufficient to build an effective polarimeter. It was also shown that analyzing powers decrease when the energy grows, because other reactions, producing several charged particles and not carrying information on the polarization, become more probable.

To compensate this effect, three major findings were highlighted in a previous measurement at Nuclotron, where the analyzing powers were measured up to a proton(neutron) momentum of 3.75 (4.2) GeV/c.

- Analyzing powers increase after a selection on the scattered particle energy deposit. This has required adding a hadron calorimeter;
- The charge-exchange reaction become interesting compared to elastic (or inelastic scattering), with an evident advantage in the neutron case where one charge particle (the proton) is detected forward;
- Heavy targets are at least as efficient as hydrogen rich light targets, what greatly simplifies the conception of a polarimeter; this is understood as the reaction carrying the information on the particle polarization is the 'quasi free' NN scattering

These concepts open the way to simpler and more efficient measurements of nucleon polarization in the region of GeV energies and will be integrated in the future experiment. In order to increase the acceptance for the detection of the scattered particles and improve the angle resolution, in particular at small angles, we plan to install the wide aperture ZDC calorimeter along the neutron beam line and to upgrade the drift chambers and the DAQ system.

3.4 State-of-the-art of the science case proposed

Polarization observables are discriminative to theoretical models in particle reactions. In particular, in elastic electron-proton scattering: $\boldsymbol{e} + p \rightarrow e + \boldsymbol{p}$ **.** A polarized electron beam interacts with a proton target and the polarization in the scattering plane of the emitted proton has to be known for the measurement of proton form factors, following the Akhiezer-Rekalo polarization method [1,2]. Similarly, the polarized electron beam can be sent on neutrons within a target, and the recoil neutron polarization has to be measured.

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. Three experiments: GEPI, (in 1998, up to Q^2=3.5 GeV^2), GEPII (in 2000, up to Q^2=5.66 GeV^2), GEPIII (in 2007-8, up to Q^2=8.5 GeV^2), see Fig. 1 revealed a definite and entirely unexpected discrepancy when compared to the form factors results obtained by the standard Rosenbluth separation 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. The various papers publishing these results [3-8] have been quoted in the literature presently more than 2000 times. **Note that the GEPIII experiment [6] was deferred and then approved by the JLab PAC only after the analyzing power measurements done in Dubna (with the Synchrophasotron) in 2001 [9].**

JLab has successfully completed a project to double the beam energy from 6 to 12 GeV opening new horizons for form factor measurements.

"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" [10], see Table 1 and Fig. 2 from Ref [10].

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.

In particular an approved experiment to measure the proton form factor ratio up to 12 GeV^2 [11], currently labeled as GEp(5) will run in Hall A. A new spectrometer, the Super Bigbite Spectrometer (SBS) is being built with a very large acceptance, together with a new polarimeter and a hadron calorimeter downstream of the 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.

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 corresponding proton momentum for $Q^2 = 14$

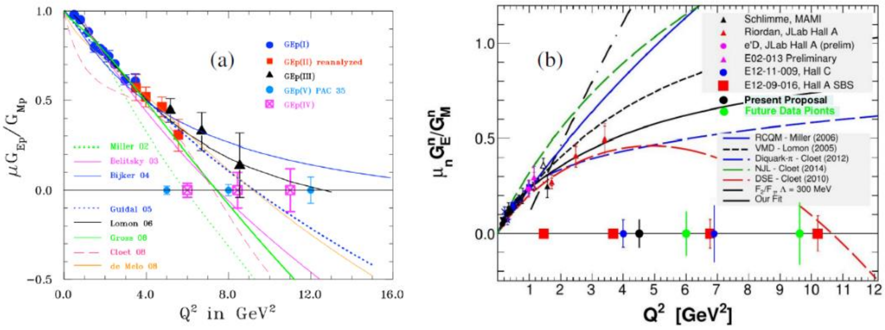

Fig. 1 World's data for the proton form factor ratio $\mu_p G_{Ep}/G_{Mp}$ data using the recoil polarization method are shown in panel (a) [12, 13]. World's data for $\mu_n G_{En}/G_{Mn}$ are shown in panel (b) [13]. In both cases, the points plotted along the axis represent the anticipated Q^2 and uncertainty in future measurements.

GeV^2 is $p_{recoil} = 8.3$ GeV/c. It was noted in Ref. [9] that the maximum value of the analyzing power 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. 2. 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 larger momenta larger momenta is too chancy to justify the enormous effort that future experiments will require.

Prior to the ALPOM2 experiment [14], cross section and analyzing powers for *np*, both for elastic (neutron forward) and charge exchange (proton forward) reactions were known only for thin hydrogen targets, and up to 29 GeV/c. No data were known to exist for thick analyzers, made of scintillator material. A scintillator polarimeter target is required to make a coincidence trigger for both reactions. The relevant analyzing powers for np

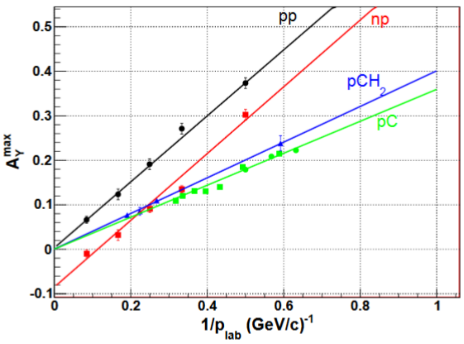

Fig. 2. The dependence of the maximum of A_Y on $1/p_{lab}$. Black circles: ANL d(p,p)n data [15, 16]; black line: linear fit. Red squares: ANL d(p,n)p data [15, 16]; red line: linear fit. Blue triangles [9]: p+ CH2 → one charged +X; blue line: linear fit [9]. Green squares [17] and circles [18]: p+ C→ one charged +X; green line: linear fit [9].

elastic and charge exchange are known from phenomenological assumptions. The analyzing powers for np elastic scattering become smaller and then negative as the neutron momentum increases. Therefore, charge-exchange gives an interesting alternative to increase the Figure of Merit. Further improvement will be expected from the use of heavier targets, as Cu and selection on the deposited signal in the hadron calorimeter.

A measurement of the angular distribution of the analyzing power of CH_2 **for protons and neutrons** 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. For **neutrons**, 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 [13] and neutron momentum of 6 GeV/c. **The Nuclotron in Dubna is the only facility where these reactions can be studied.**

3.5 Description of the proposed research

The aim of the present proposal is to optimize polarimetry for proton and neutrons in the GeV region and extend the data basis of analyzing powers at the largest available energies.

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* [14].

3.5.1. Polarization measurement features

Data on analyzing powers were previously obtained at Los Alamos, Saturne National Laboratory and Dubna, using thick analyzers, as part of a program of study of elastic and quasi-elastic dp reactions [19-24] (Fig. 2). They were accompanied by studies of optimization of polarimeter geometry and target and limited by the available beam energy below 3 GeV.

The recoil particles cross the polarimeter, usually set at the focal plane of a spectrometer. A polarimeter is constituted by a detection system of the trajectories before and after a secondary target. The precise reconstruction of these trajectories allows to measure the left/right (top/down) asymmetries of the secondary reaction products, more exactly the azimuthal asymmetry (with an unpolarized beam, the reaction products would be emitted with a cylindrical symmetry around the beam axis). Therefore, the polarization is measured by the asymmetry of the azimuthal distribution in a secondary reaction. The nature of the secondary target, its thickness, as well as the geometry of the polarimeter, has to be optimized at each energy. 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 the future experiments, in particular a measurement at a proton momentum of 7.5 GeV/c will be most valuable.

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 were known to exist for thick analyzers, made of scintillator material, prior to ALPOM2 experiment. A scintillator polarimeter target is required to make a coincidence trigger. 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 [13]. The relevant analyzing powers for *np* elastic and charge exchange are known from phenomenological assumptions. The analyzing powers for *np* elastic scattering become smaller and then negative as the neutron momentum increases. Analyzing powers for charge exchange reactions improve the figure of merit compared to elastic scattering [14].

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. One expects that the largest analyzing power will be obtained when the particle selected has the smallest scattering angle and the largest energy. These two features are combined by adding a hadron calorimeter downstream: it will provide a coincidence trigger and 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 Ay is the average analyzing power; hence a decrease of efficiency may be more than compensated by an increase in analyzing power.

3.5.2. The latest results

The dependence of Ay on the target material shown in Fig. 3 is very weak, there is no significant difference between the data for C, CH, CH2 and Cu, and this consistent with the assumption that 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. 4 (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.

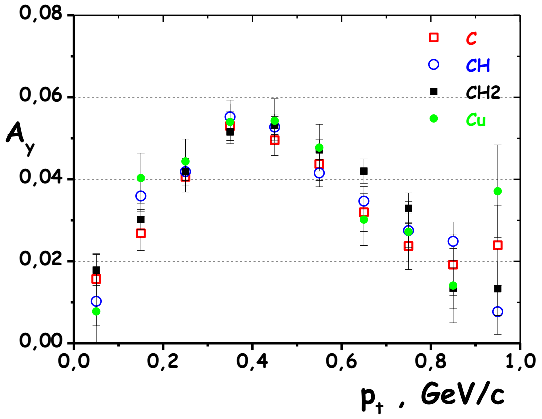

Fig. 3. Analyzing power Ay as a function of pt for 3.75 GeV/c neutrons scattering on carbon (red), scintillator (blue), polyethylene (black), and copper (green).

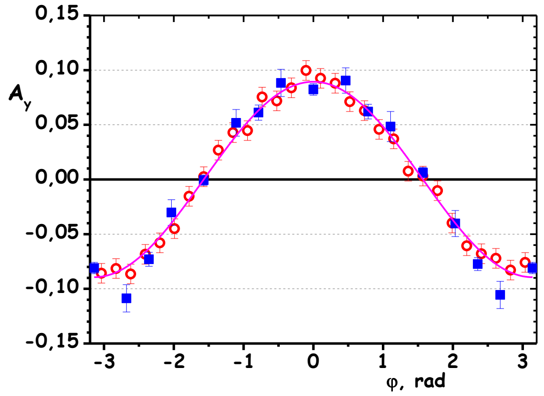

Fig. 4. Azimuthal dependence Ay for p + CH2 scattering at a momentum of 3.0 GeV/c, obtained from the triggered modules of the hadron calorimeter (blue squares) and from the tracks (red circles)

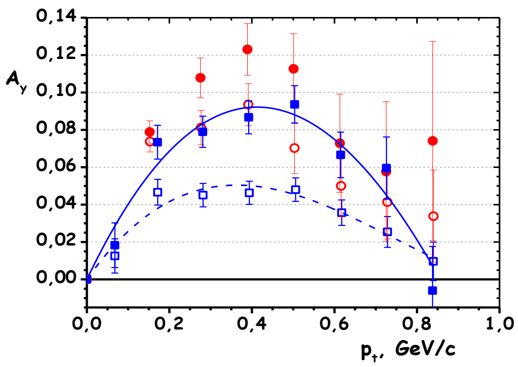

Fig. 5. Dependences of Ay on pt for n + Cu (blue) and for p + Cu (red). Open points - without sampling by the calorimeter, filled ones - with sampling with a threshold above 1.76 GeV.

The analyzing capabilities with polarized protons and 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 is given in Fig. 5 that 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 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, 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.

3.5.3. Setup description

A detailed description of the setup elements can be found in our previous publication [14]. The main elements are briefly recalled here.

-The polarized deuteron source. The polarized deuteron beam is provided by the new Source of Polarized Ions (SPI), pre-accelerated in a potential of 100-150 keV LU-20 injector, and accelerated by the Nuclotron [25]. SPI is composed from parts of the polarized source CIPIOS, moved from Bloomington (Indiana, USA) and totally renewed at JINR and INR RAS [26].
-The on line F3 polarimeter for the accurate measurement of the secondary nucleon beam polarization is based on quasielastic *pp* scattering.
-The polarized deuteron beam: 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.
-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 polarized neutron beam. The production target will be positioned close to one focal point of the deuteron beam line. Protons and deuterons are removed from the neutron beam by a bending magnet.
-Experimental setup. A schematic view of the experimental setup used during the last measurements is shown in Fig. 6.

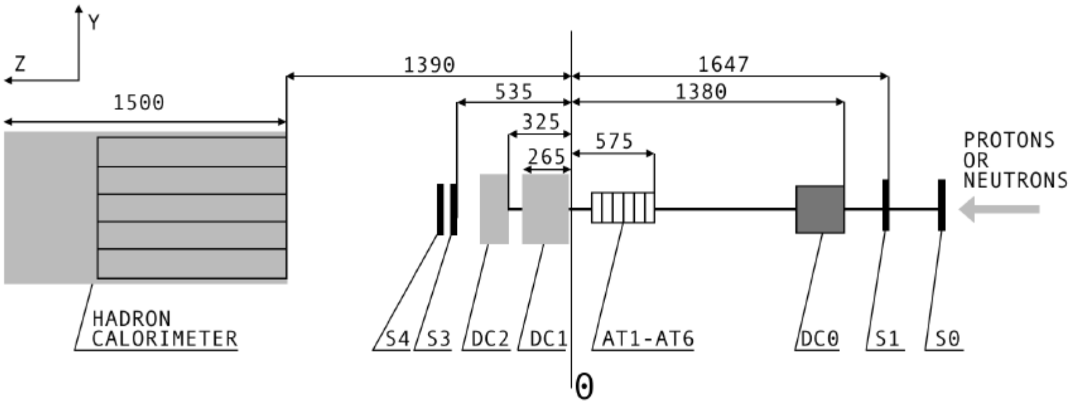

Fig. 6. Side view scheme of the ALPOM2 set up positioned on the secondary proton/neutron beam line, including scintillation counters (S0, S1, S3, S4); drift chambers (DC0, DC1, DC2); hadron calorimeter. The analyzing materials of the polarimeter are located between DC0 and DC1. Here a CH active target (AT1 -AT6), is shown as an example. Dimensions are in mm.

-Polarimeter targets. Various target materials, length and density will be tested, for several proton and neutron momenta, to determine the optimal analyzing material, for different scattering interactions. The longitudinal dimensions of the targets are chosen to provide as similar as possible corresponding proton density for each target. The C and Cu targets are monolithic, whereas the CH2 targets are constructed by packing together several smaller blocks in the longitudinal direction, leaving minimal dead space between each element. The CH analyzer, used for a sub-set of neutron measurements, is incorporated into an active target. The active target comprises six individual detector elements (AT1 -AT6). Each CH block has dimensions 500mm x 150mm x 50 mm, and both ends of each block are coupled to photomultiplier tubes. Differences in signal charge and time distributions readout at either side of each block, measured by the TQDCs, will be 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 will be included in the trigger.
-Drift chambers. Two chambers (DC0 and DC1) of size, 25 x 25 cm^2 will be reconstructed for the future experiments. Each module instead of 2X+2X +2Y+2Y will contain 3X + 3Y + 3X + 3Y planes in one gas enclosure. Their spatial resolution is lower than 0.1 mm. The angle resolution will be better than 0.3 mrad.
-Hadcal (hadron calorimeter). Instead of the ALPOM2 hadron calorimeter (Fig. 7), it is planned to use the ZDC of the BM@N setup (Fig. 8) in order to increase acceptance of detecting scattering particles and improve angle resolution at small angles.

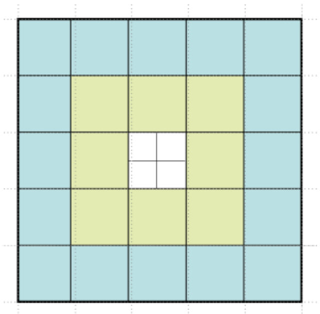

Fig. 7. ALPOM2 calorimeter layout: the central part consists of 4 modules with sizes 7.5×7.5 cm^2, the peripheral part contains 24 modules of 15×15 cm^2.

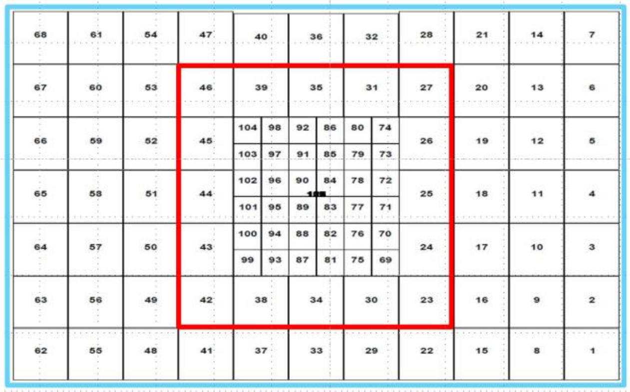

Fig. 8. ZDC layout**:** the central part consists of 36 modules with sizes 7.5×7.5 cm^2, the peripheral part contains 68 modules of 15×15 cm^2.

The response of all calorimeter bars and their associated electronics will be calibrated in dedicated cosmic-ray runs, where the hadron calorimeter is rotated by 90^o so that the bars are aligned vertically. Further calibrations with the calorimeter in standard alignment will be performed with the proton beam.

3.5.4 Beam time request

The extraction of the analyzing powers. After the reconstruction of the incident and outgoing trajectories the polar(θ) and azimuthal(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:

$$\boldsymbol{N}^{\pm}(\boldsymbol{\theta},\boldsymbol{\varphi}) = \boldsymbol{N}_0(\boldsymbol{\theta})(1 \pm \boldsymbol{P}_y \boldsymbol{A}_y(\boldsymbol{\theta}) \cos \boldsymbol{\varphi}),$$

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

$$\boldsymbol{R}(\boldsymbol{\theta},\boldsymbol{\varphi}) = \frac{\boldsymbol{N}^{+} - \boldsymbol{N}^{-}}{\boldsymbol{N}^{+} + \boldsymbol{N}^{-}} = \boldsymbol{P}_y\, \boldsymbol{A}_y(\boldsymbol{\theta}) \cos \boldsymbol{\varphi}$$

The statistical error for A_y is:

$$\Delta \boldsymbol{A}_y = \frac{1}{\boldsymbol{P}_y} \sqrt{\boldsymbol{A}_y^2\, \Delta \boldsymbol{P}_y^2 + \frac{4\boldsymbol{N}^{+}\boldsymbol{N}^{-}}{\left(\boldsymbol{N}^{+} + \boldsymbol{N}^{-}\right)^3}}.$$

The dependence of Ay on the target material shown in Fig. 6 is very weak, there is no significant difference between the data for C, CH, CH2 and Cu, and this consistent with the assumption that the charge exchange reaction is the same on both free protons and protons in the nucleus.

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. To have the largest impact, the results should be made available in 2023.

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 charge exchange reaction), 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.

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 analysis and publication of the results.

3.5.5. Publications, presentations at conferences and award

Two journal papers [14, 27] have been published and two reports were presented at the international conferences [28,29].

A series of scientific works *“Measurement of analyzing powers for nucleon-nucleus scattering at momentum range from 1.75 to 5.4 GeV/c” was awarded* a first JINR prize (2020) in the nomination of Physics Instruments and Methods.

A future experiment at Jefferson Lab, requiring recoil neutron polarimetry, has already integrated the results into the approved experiment E12-07-109 [13] measuring neutron electromagnetic form factors.

4. Estimation of human resources

The following Table lists ALPOM2 JINR group members with their roles and participation.

№	Name	Responsibilities	FTE
1	Piskunov N.M.	Project leader, analysis, data taking	0.8
2	Kirillov D.A.	Analysis, data taking	0.8
3	Sitnik I.M.	Analysis, data taking	1.0
4	Gavrishchuk O.P.	ZDC, data taking	0.2
5	Shindin R.A.	ZDC, polarimeter, data taking	0.8
6	Livanov A.N.	ZDC, polarimeter, data taking	0.1
7	Druzhinin A.A. (25 years)	ZDC, polarimeter, data taking	0.8
8	Kiryushin Yu.T.	Drift chambers, data taking	0.2
9	Kostayeva N.V.	Drift chambers, data taking	1.0
10	Legostaeva K.S. (27 years)	Data taking	1.0
11	Bushuev Yu.P.	ZDC, data taking	0.5
12	Povtoreiko A.A.	Counters, data taking	0.2
		TOTAL FTE	**7.4**

Other authors take part in the implementation of the project as needed.

5. Schedule proposal and resources required (Form 26)

Form No. 26

Schedule proposal and resources required for the implementation 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)

Expenditures, resources, financing sources			Costs (k$) Resource requirements	Proposals of the Laboratory on the distribution of finances and resources				
				1st year	2nd year	3rd year	4th year	5th year
Expenditures		Main units of equipment, work towards its upgrade, adjustment etc.	14.0	7.0	7.0			
		Construction/repair of premises						
		Materials	8.0	4.0	4.0			
Required resources	Standard hour	Resources of – Laboratory design bureau; – JINR Experimental Workshop; – Laboratory experimental facilities division; – accelerator Nuclotron; – computer. Operating costs.	1000 336	1000 168	168			
Financing sources	Budgetary resources	Budget expenditures including foreign-currency resources. Contract paying	42.0 14.0 6.0	21.0 7.0 3.0	21.0 7.0 3.0			
	External resources	Contributions by collaborators. Grants. Contributions by sponsors. Contracts. Other financial resources, etc.						

PROJECT LEADER

6. Estimated expenditures (Form 29)

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

7. Strengths, weaknesses, opportunities, threats

Strengths: The results will complete and extend data on analyzing powers, in frame of a coherent program, recently performed in Dubna, and earlier at other laboratories, in particular in France, USA, and Japan. The experiment will use polarized deuteron beam that is present only in Dubna. No competition is expected from other laboratories, because GeV energy polarized proton and neutron beams are available only in Dubna. The results are of great interest for all those experiments that need to measure the polarization of protons and neutrons in the GeV range, at hadron and electron accelerators worldwide.

Weaknesses: In connection with the construction of the NICA collider, there is currently no beam schedule for the Nuclotron. The last session on a polarized beam was in the spring of 2017.

Opportunities: When carrying out measurements, it will be possible for the first time to measure the analyzing powers simultaneously for forward scattering and charge exchange scattering; in the case of the interaction of polarized protons with a target, the asymmetries of forward scattering of both one charged particle and a neutral particle will be measured. The obtained results will contain significant material for the defense of PHD thesis by young participants in the experiment.

Threats: The highly professional level of the participants in the experiment, the previous experience of the team, the available equipment and the presence of polarized proton and neutron beams of GeV energies limits essentially the risks. However, the pandemic could limit the number of participants in the experiment from abroad.

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