March 29, 2018

# *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)*


S.N. Basilev, Yu.P. Bushuev, O.P. Gavrishchuk, V.V. Glagolev, D.A. Kirillov, N.V. Kostayeva, A.D. Kovalenko, K.S. Legostaeva, A.N. Livanov, I.A. Philippov, N.M. Piskunov, A.A. Povtoreiko, P.A. Rukoyatkin, R.A. Shindin, A.V. Shipunov, A.V. Shutov, I.M. Sitnik, V.M. Slepnev, I.V. Slepnev, A.V. Terletskiy

*Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia*

C.F. Perdrisat

*the College of William and Mary, Williamsburg, VA 23187, USA*

V. Punjabi

*Norfolk State University, Norfolk, VA 23504, USA*

M.K. Jones

*Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA*

E. Brash

*Christopher Newport University and TJNAF*

G. Martinska, J. Urban

*University of P.J. Šafarik, Jesenna. 5, SK-04154 Košice, Slovak Republic*

J. Mušinsky

*Institute of Experimental Physics, Watsonova 47, SK-04001 Kosice, Slovak Republic*

E. Tomasi-Gustafsson

*IRFU, DPHN, CEA, Université Paris- Saclay, 91191 Gif-sur-Yvette, Fra*nce

D. Marchand

*IPN Orsay, 91406 ORSAY cedex, France*

J. R.M. Annand, K. Hamilton, R. Montgomery

*University of Glasgow, Glasgow G12 8QQ, Scotland, UK*

## *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*

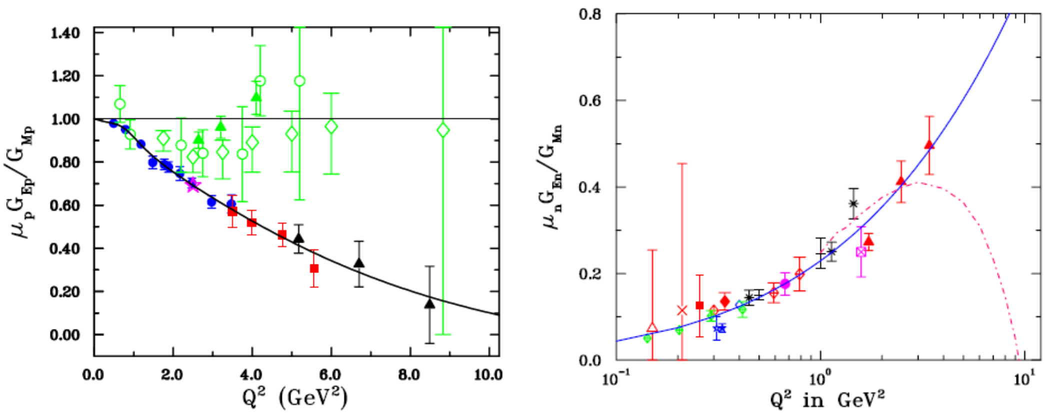



Fig. 1: Left panel, Comparison of $\mu_p G_{Ep}/G_{Mp}$ from the three JLab recoil polarization data [14-16], and Rosenbluth (cross section) separation data. The solid curve is a double polynomial fit [19]. Right panel, $\mu_n G_{En}/G_{Mn}$ data from JLab up to 3.4 GeV$^2$ [20], and other polarization 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 | $Q^2(\mathrm{GeV}^2)$ | 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.

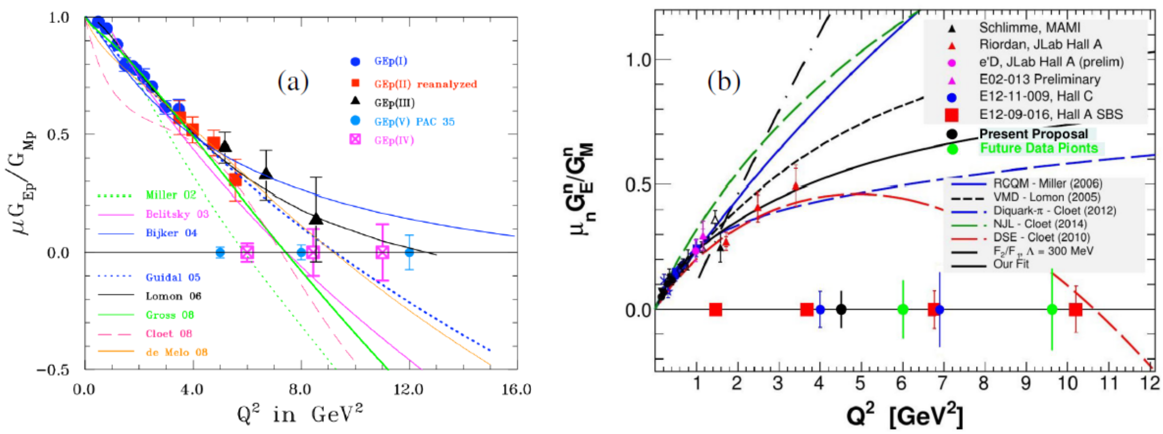



Fig.2. World's data for the proton form factor ratio $\mu_p G_{Ep}/G_{Mp}$ data using the recoil polarization method are shown in panel (a) [24, 26]. World's data for $\mu_n G_{En}/G_{Mn}$ are shown in panel (b) [28]. In both cases, the points plotted along the axis represent the anticipated $Q^2$ and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

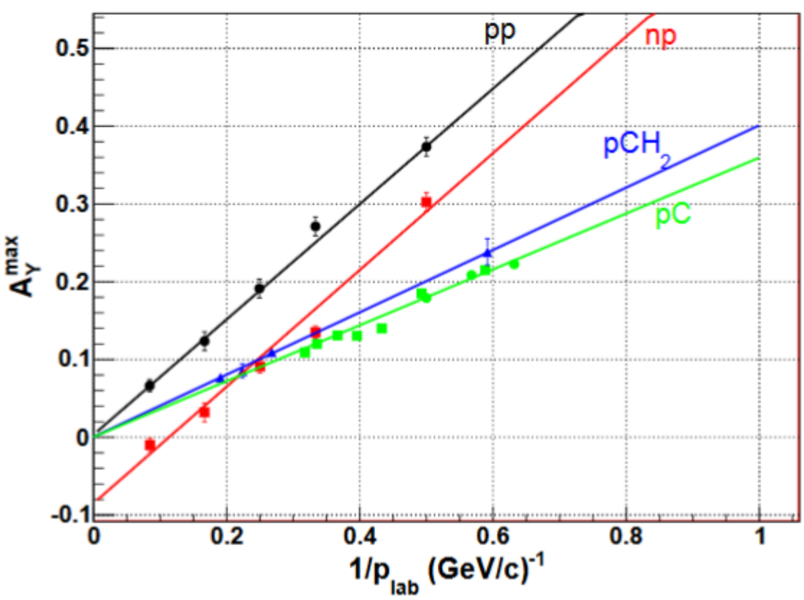



Fig. 3: The dependence of the maximum of $A_Y$ on $1/p_{lab}$. Black circles: ANL d(p,p)n data [29, 30]; black line: linear fit. Red squares: ANL d(p,n)p data [29, 30]; red line: linear fit. Blue triangles [25]: p+ CH2→charged+X; blue line: linear fit [25]. Green squares [31] and circles [32]: p+ C→charged+X;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

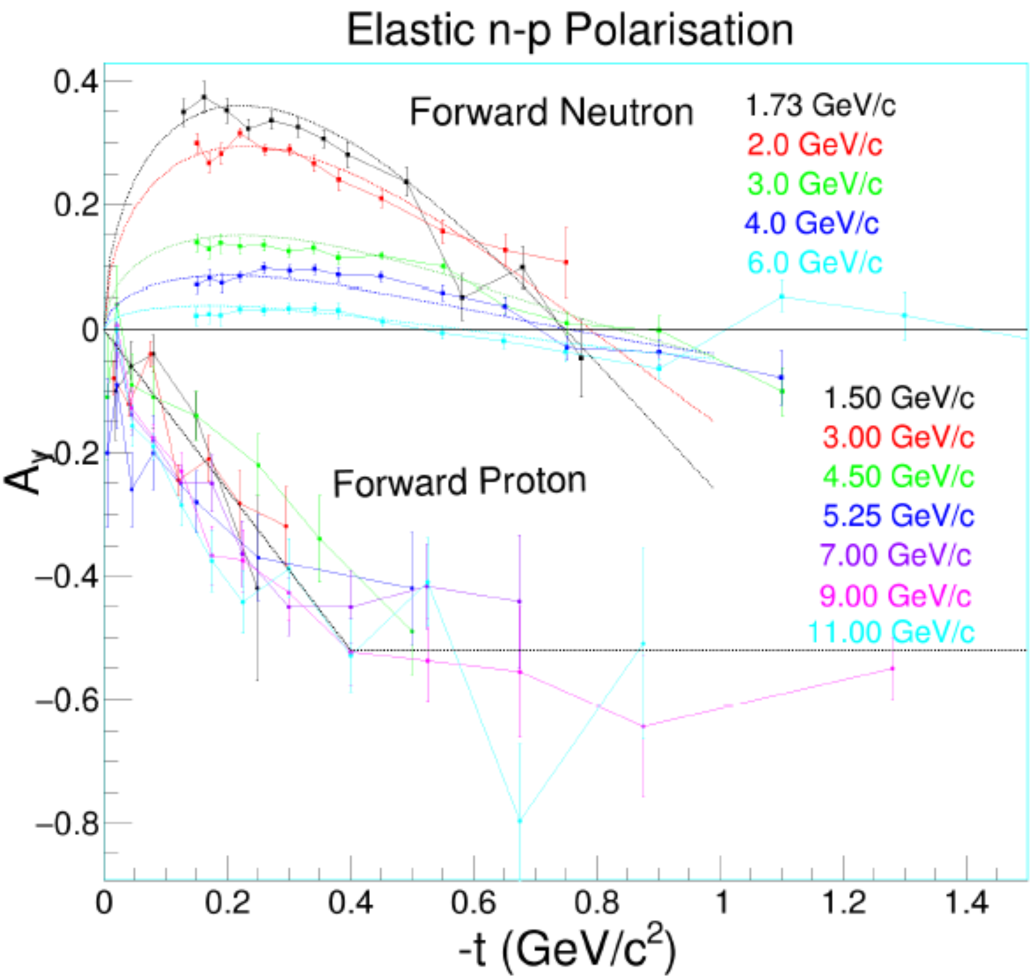



Fig. 4: Top: the $p_{lab}$ and t-dependence of the analyzing power of elastic pn scattering [29, 30].
The smooth dotted lines show the fit of Ref. [33] to the pn data.
Bottom: the $p_{lab}$ and t dependence of charge-exchange np scattering [34, 35].
The color-coding relates the data to momentum labels.

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 $\eta A_y^2$, where $\eta$ 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. 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. The parts of the polarized source CIPIOS were moved from Bloomington (Indiana, USA) and totally renewed at JINR and INR RAS.

## *On line F3 polarimeter*

During the ALPOM2 experiment, mainly the high energy polarimeter F3 (Fig. 13) was used, as the information can be recorded on line, for each beam burst, and collected together with the data, insuring a continuous relative monitoring of the beam polarization. F3 is an on-line beam polarimeter to monitor the vector polarization of the deuteron beam after the accelerator and before the breakup target. The measurement of the vector deuteron polarization is based on the asymmetry of quasi-elastic pp reaction with vector beam polarization [47]. The scattered and recoil particles from the reaction on hydrogen in a polyethylene (CH2) or carbon targets are measured symmetrically in left and right arms.

The layout of the F3 polarimeter is shown in Fig. 5. A ionization chamber (IC) is set as a beam intensity monitor for normalization. The stability of the polarization during the runs is shown in Fig. 6 but the polarization in one mode is two times lower than the other one. If the analyzing power for CH2 target at proton momentum is 0.25, then the sum of the two polarization modes is equal 0.95 +/- 0.05.

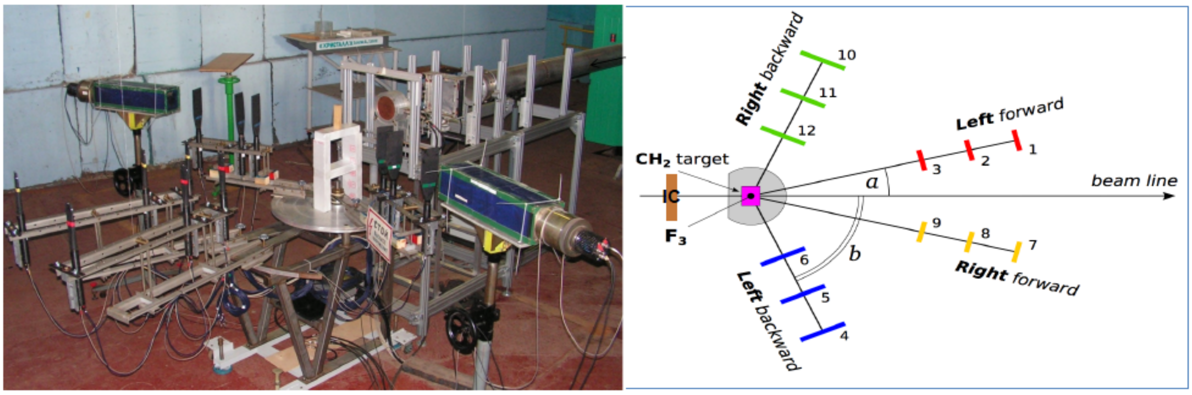



FIG. 5: The F3 polarimeter. IC is an ionization chamber. The F3 left, right forward and backward arms have three scintillation counters at  angles a and b with respect to the beam-line.

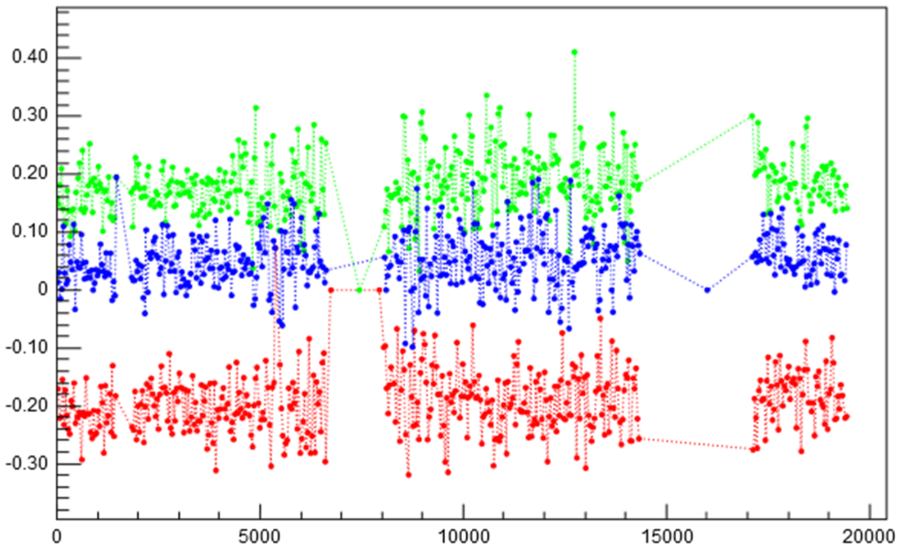



Fig. 6. A simple relation (L-R)/IC vs time, each point corresponds to one spill.

## *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.

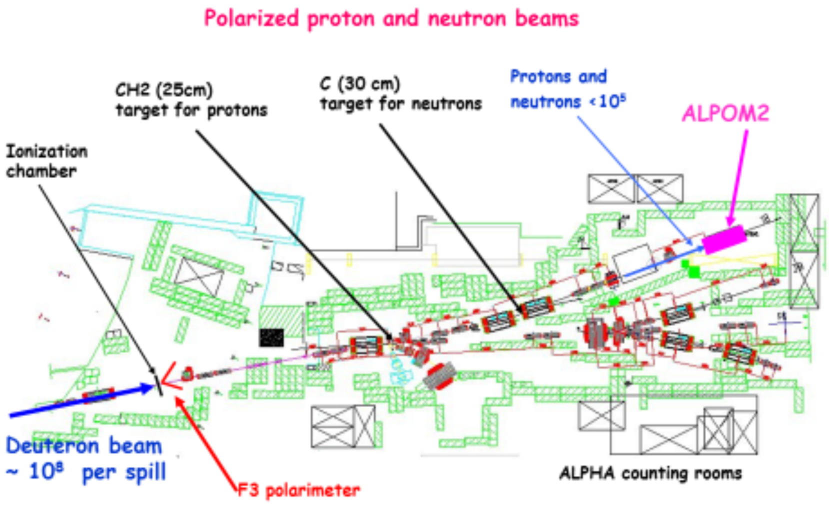



Fig. 7. Scheme of transportation polarized beams from Nuclotron to the ALPOM2 setup and the location of F3 polarimeter and production target for proton and neutron beams

## *The polarized proton beam.*

The polarized protons will be produced by fragmentation of the polarized deuteron beam on an 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.

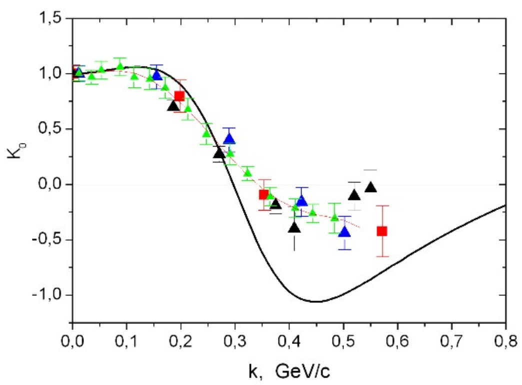



Fig. 8 World data of p(d,p)X and C(d,p)X reactions for the polarization transfer coefficient versus k; the curve is calculated in framework of IA, using the Paris N-N potential.

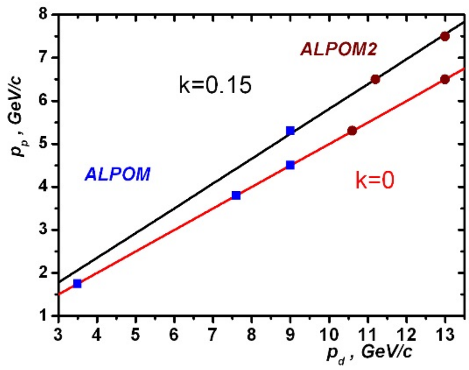



Fig. 9 Dependence of proton momentum at which the proton polarization is equal to the deuteron polarization (k=0.15) versus the primary deuteron momentum. Blue points: old measurements; red points: future measurements.

## *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.

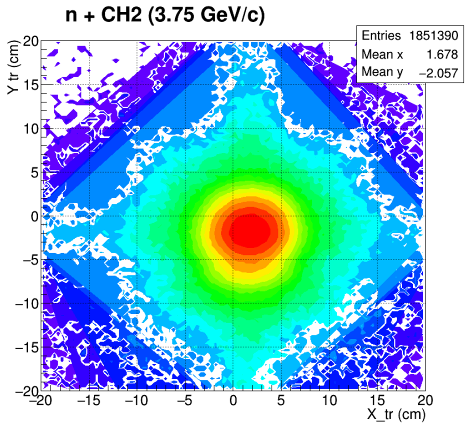



Fig.10. Position of neutron beam at the CH2 target.

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.

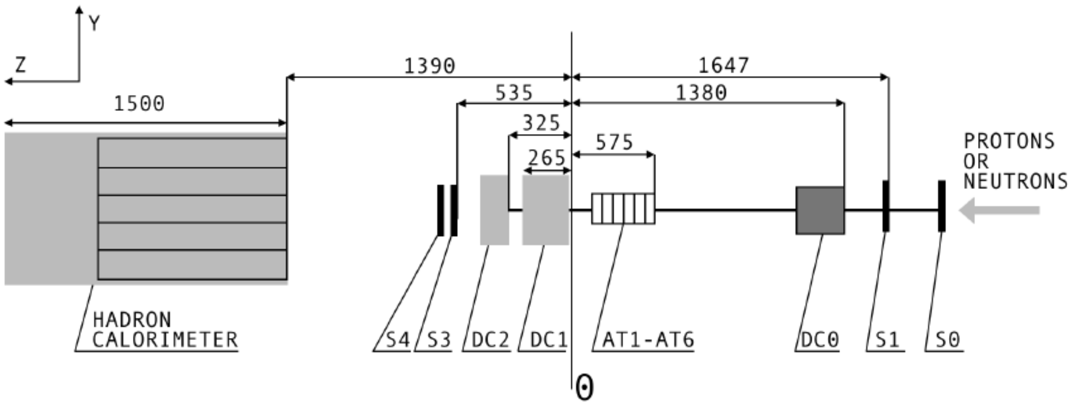



Fig. 11. Side view scheme of the ALPOM2 set up positioned on the secondary proton/neutron beam line, including scintillation counters (S0, S1, S3, S4); drift chambers (DC0, DC1, DC2); hadron calorimeter. The analyzing materials of the polarimeter were located between DC0 and DC1. Here a CH active target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

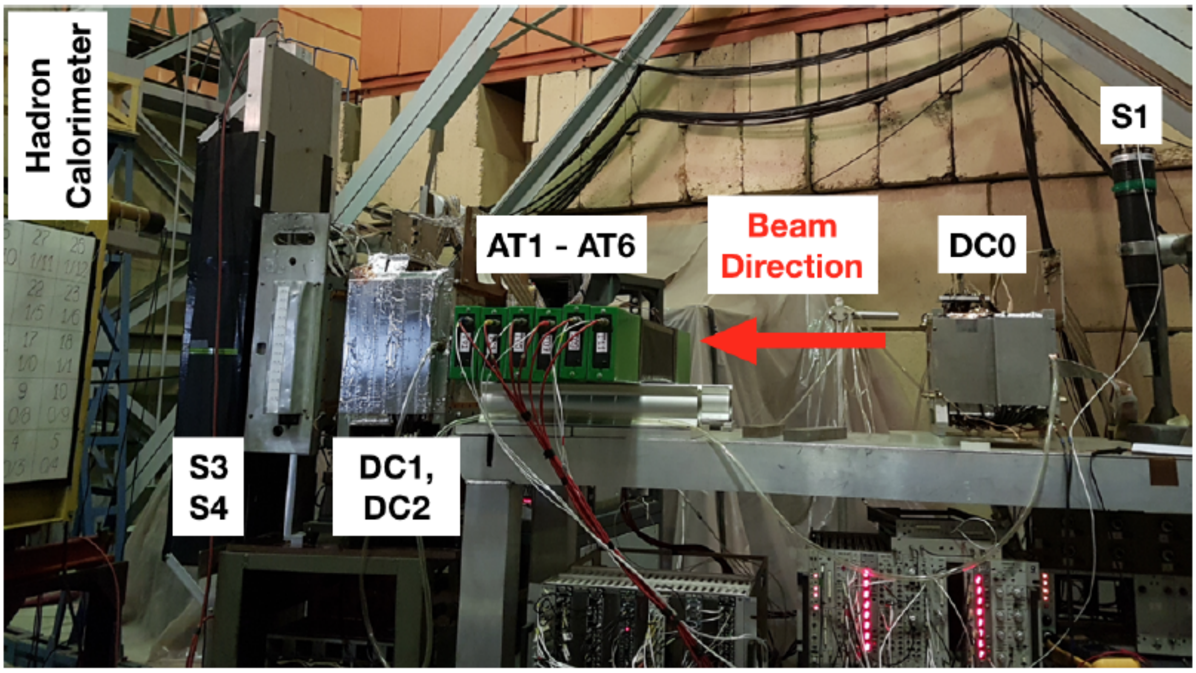



FIG. 12: Photograph of the ALPOM2 set up with the CH active target analyzer, which was used for a subset of neutron polarimetry measurements, in place.

## *Drift chambers*

Chambers of two sizes, 12.5x12.5cm$^2$ (DC0) and 25 x 25 cm$^2$ (DC1 and DC2), will be used in the future experiments. Individual planes are combined in modules, each module containing 4X and 4Y (or 2X and 2Y) planes in one gas enclosure. The small chambers are located before the target, the large ones after the target. 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 21 mm to resolve the left-right ambiguity. The total material in an eight planes (4X and 4Y) module is 0.141 g/cm$^2$ (0.008 radiation lengths) in the sensitive area.

All drift chambers have been tested with Nuclotron deuteron beams. Their spatial resolution is lower than 0.1 mm [34]. Using the drift chambers allows us to get angle resolution better than 0.4 mrad.

## *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)*

The hadron calorimeter, as used in the ALPOM2 set up, is composed by 28 "bars" (Fig. 13). Four bars were used in the central region, at smaller scattering angles with dimensions 75 mm x 75 mm, where higher counting rates were experienced. At larger scattering angles, 24 bars with dimensions of 150mm x 150mm were used. It is a sampling calorimeter, with different bars having different arrangements of iron (Fe), lead (Pb) and scintillator (Sc) layers, as shown (Figure 20). The azimuthal binning available from the hadron calorimeter geometry, and and subsequently used for asymmetry measurements, is given in Fig. 13. Immediately before the ALPOM2 data taking, the response of all bars and readout electronics of the hadron calorimeter

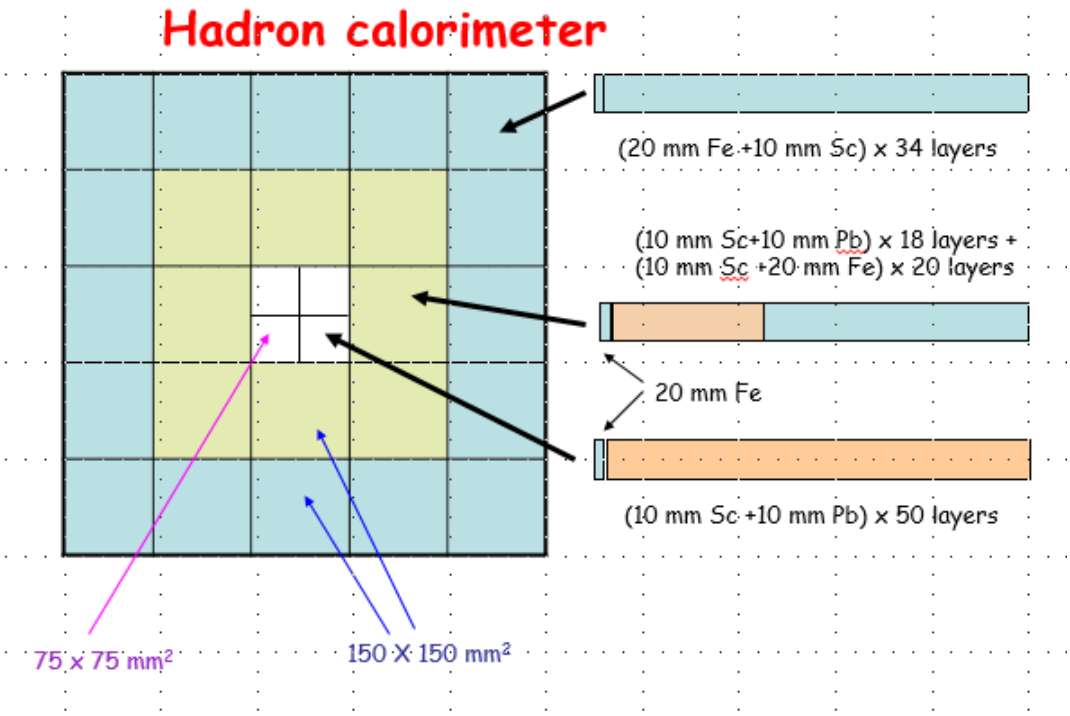



FIG. 13: Design of the different bars of the hadron sampling calorimeter used in the ALPOM2 setup.

were calibrated using dedicated runs with cosmic particles. The trigger for cosmic measurements was provided by additional scintillation counters positioned above and below the calorimeter.

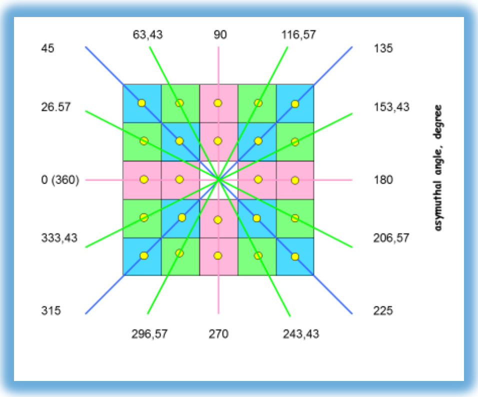



Fig. 14: Azimuthal segmentation available from the hadron calorimeter for asymmetry measurements.

In addition to providing information about polar and azimuthal scattering angles, the hadron calorimeter used energy deposit measurements, see Fig.15, to discriminate the reactions of interest (for example p +CH2 -> p+X) and reduce the contamination from events where either the primary nucleon did not interact with the analyzer, or inelastic scattering was suspected to have taken place.

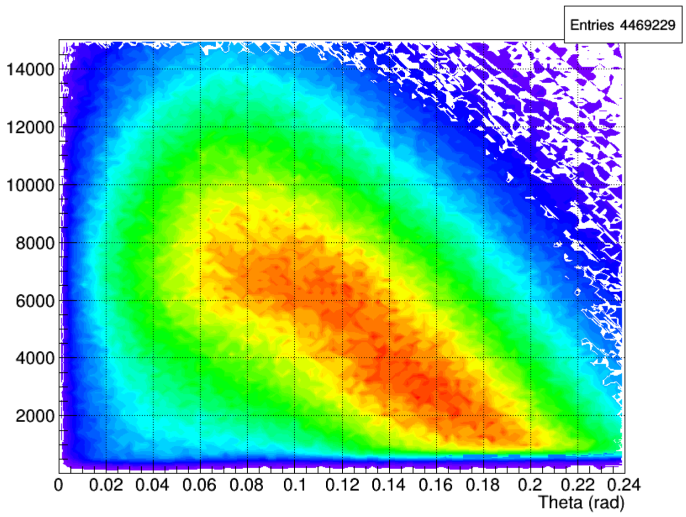



Fig.15. The energy deposit vs scattering angle for neutrons of 3.75 GeV/c on C target.

## *The extraction of the analyzing powers and beam time request*

After reconstruction of the incident and outgoing trajectories; 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 2016 - 2017 runs*

Polarized deuteron beams with intensity (1-3) x $10^8$ particles per spill were accelerated on fragmentation targets for the production of polarized protons (or neutrons).

The deuteron vector polarization was flipped at each beam spill, one spill over three being unpolarized. The deuteron vector polarization, Pd, was constantly measured by the F3 polarimeter.

The main goals of the measurements were:

a) Measure analyzing powers for the charge exchange (pol)n+CH2 ->n+X reactions, as well as for C, CH (scintillator) and Cu analyzers.
b) Investigate the use of a large size calorimeter to discriminate multi-particle final states, and correspondingly increase the analyzing power.

During the run the azimuthal asymmetries were measured with polarized proton and neutron beams on four polarimeter analyzing targets, see Table 2.

The azimuthal distribution integrated over scattering angle and normalized on the unpolarized mode for two polarized modes are presented in Fig. 16 (proton momentum is 3.0 GeV/c, CH2 target). The left panel presents the distributions calculated from the tracks reconstructed in the drift chambers at scattering angles from 0.03 till 0.24 rad. The right panel presents the assigned azimuthal angle of the hadron calorimeter module that has the maximum amplitude (the central part of the hadron calorimeter is eliminated).

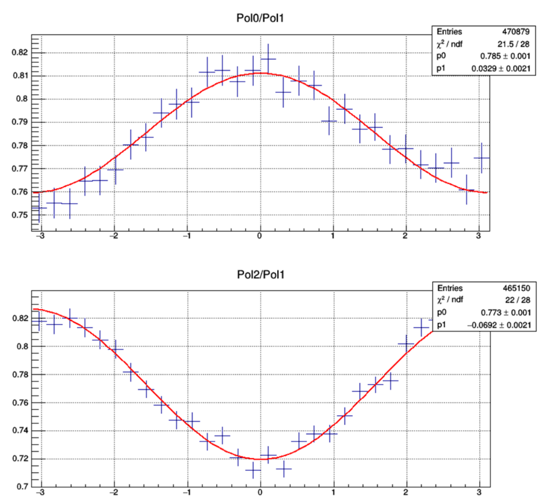



Fig. 16a. Tracks, scattering angles 0.03-0.24 rad

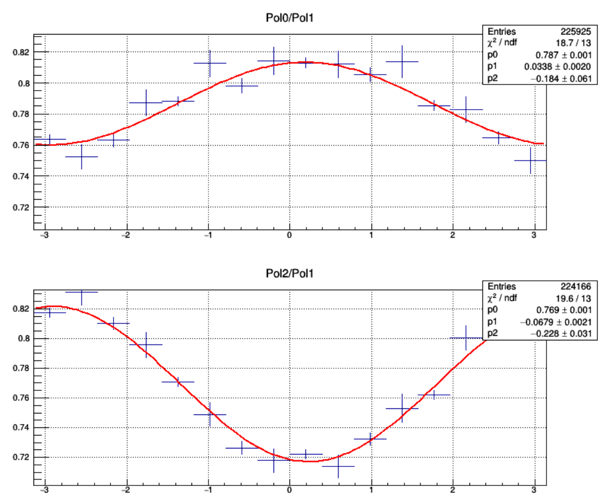



Fig. 16b. Hadcal, maximum amplitude, without the central part

If the azimuthal distributions for the two polarization modes of the deuteron beam are combined taking into account the average direction corresponding to the azimuthal angle for the modules of the hadron calorimeter, the results for the asymmetry are consistent (see Fig.17).

Fig. 18 shows the results of measurements of the asymmetries by drift chambers (red points) and modules of hadron calorimeter (blue points) without the central part of scattering that corresponds mostly unscattered particles. A very good agreement between tracking and energy deposit data allow us in future experiments one of these methods.

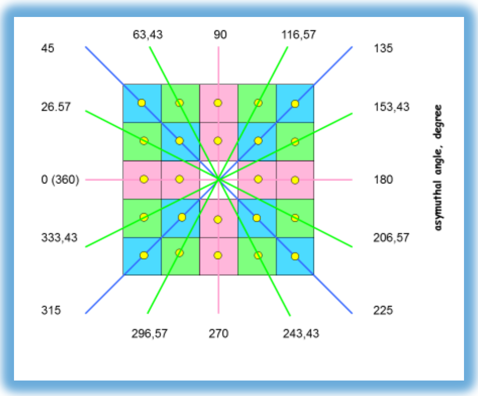



Fig.17. Azimuthal segmentation of the hadron calorimeter for the asymmetry measurements.

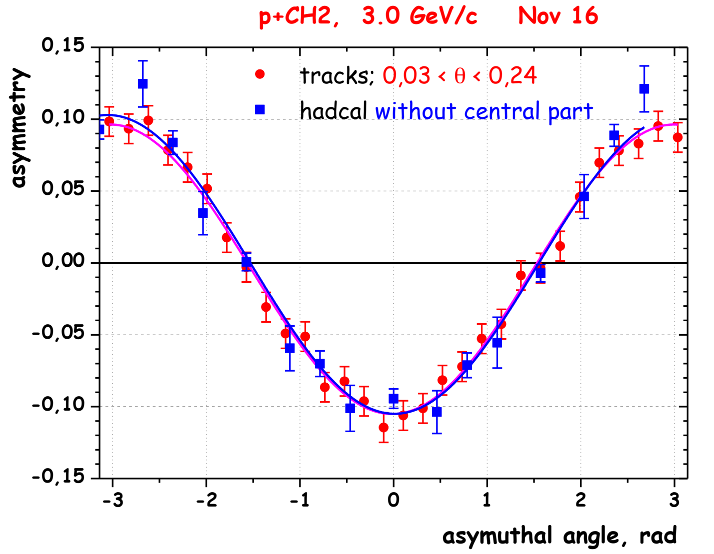



Fig.18. The asymmetry as a function of the azimuthal angle from the calorimeter (blue squares) and from the chambers (red circles).

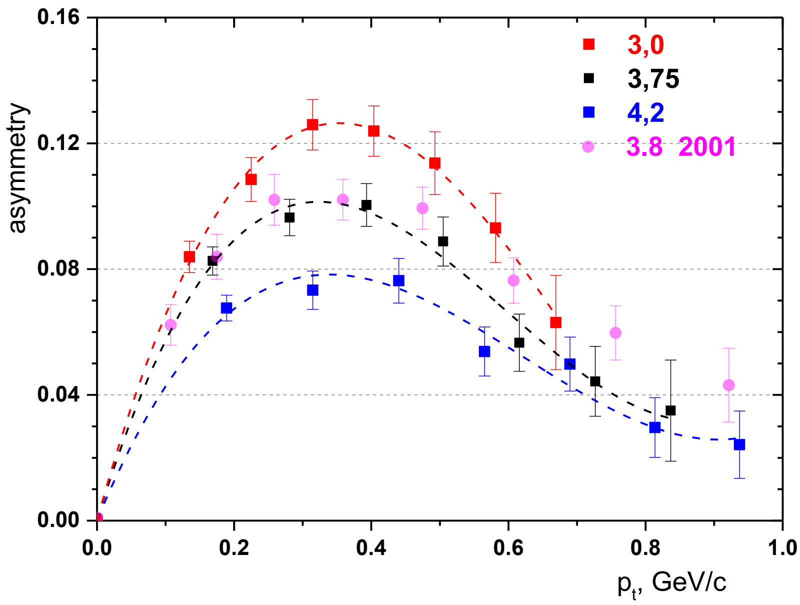
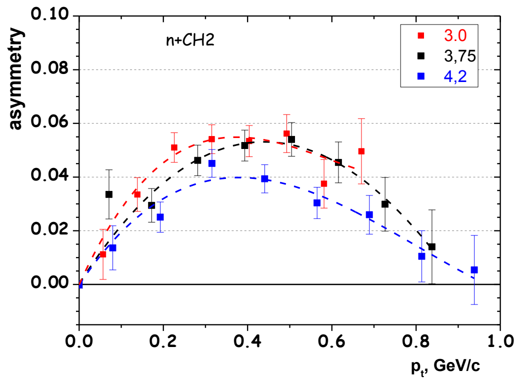



Fig.19. Energy dependence of the asymmetry of polarized protons on CH2 target, the magenta points from Ref. [25].

To be sure in our measurements with neutron beams, control measurements on CH2 target with a proton beam at different momenta were done, see Fig. 19. It is well seen that the asymmetry becomes smaller when momentum of protons increases so the measurements at the momentum at 7.5 GeV/c is strongly needed. The agreement with our old data at momentum 3.8 GeV/c is also good.



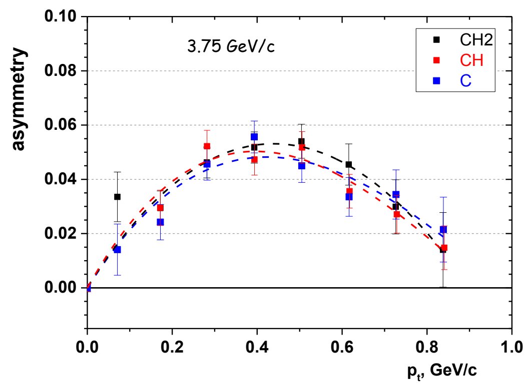




Fig.20a. Energy dependence of the neutron asymmetry on CH2 target.

Fig.20b. Neutron asymmetry dependence of different target material .

Fig. 20 shows the results of the asymmetry measurements with neutron beams at different momenta and on different (C,CH,CH2) targets. The asymmetry becomes smaller with increasing momentum of the neutron beam (left panel). A weak dependence exists for different targets at the neutron momentum of 3.75 GeV/c (slightly larger for the CH2 target).

The results with the Cu-target on proton and neutron beams are shown in Fig. 21. A surprising large value of the neutron asymmetry is observed.

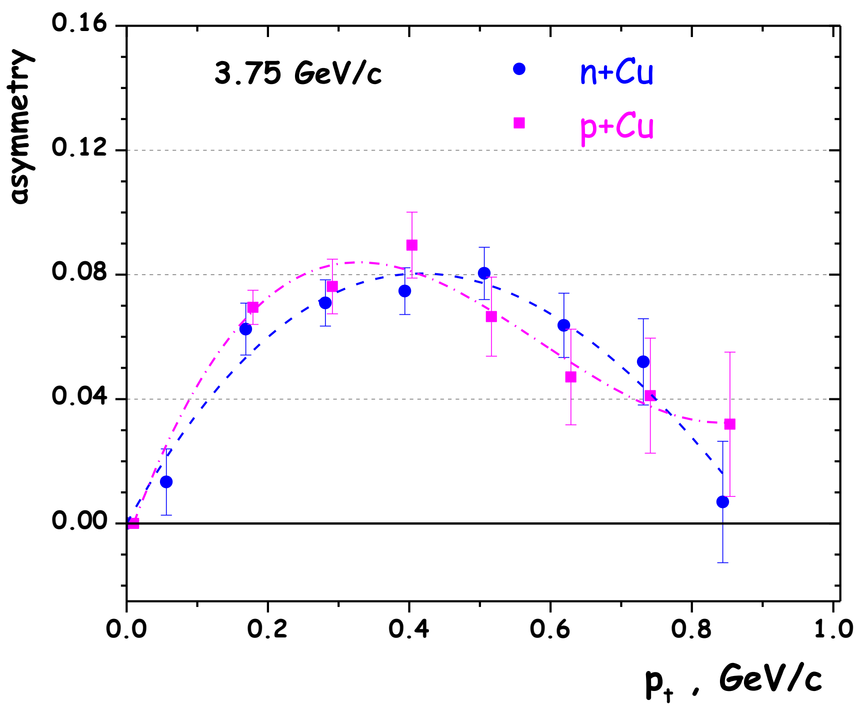



Fig.21. The asymmetry vs transfer momentum for neutron and proton scattering on Cu-target at 3.75 GeV/c.

The ALPOM2 setup was designed to measure analyzing powers from different analyzer targets, for protons and neutrons in the GeV range. It includes a large size calorimeter to discriminate multi-particle final states, and correspondingly increase the analyzing power. So far protons and neutrons of 3.0, 3.75 and 4.2 GeV/c momentum have been used. Polarized protons of up to 7.5 GeV/c should become available in the near future.

The proton data in the momentum range available at this time are in general agreement with data from various laboratories.

We now have, for the first time, analyzing power data for the charge exchange (pol)n+CH2->n+X reactions, as well as for C, CH (scintillator) and Cu analyzers. Based on the available (and ancient) charge exchange analyzing power data for np->pn, the expectation was that the same reaction channel for the complex target available (C, CH, CH2 and Cu) would be significantly larger than for the forward process, np->np. The new data fully support this expectation.

The consistency of these data clearly indicates that the experimental setup is adapted to the challenge, and that the beam polarization, intensity and stability are appropriate for this aim.

## *Schedule of the experiment:*

2019 year — Modification of neutron channel up to 6 GeV/c

2020-2021 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 .

2021 year — Data analyzes and publication of the results.

## *Expenses*

*The following expenses are requested:*

| | |
|---|---|
| Modernization of the neutron channel | 22 k $ |
| Constructing of mechanical support, gases | 5 k $ |
| Reception and sending of the experts | 15 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 – 22 k$, HV supply, computers, electronic modules

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