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

S.N. Bazylev, Yu.P. Bushuev, A.A. Druzhinin, O.P. Gavrishchuk, V.V. Glagolev, D.A. Kirillov, N.V. Kostayeva, Yu.T. Kiryushin, 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, France

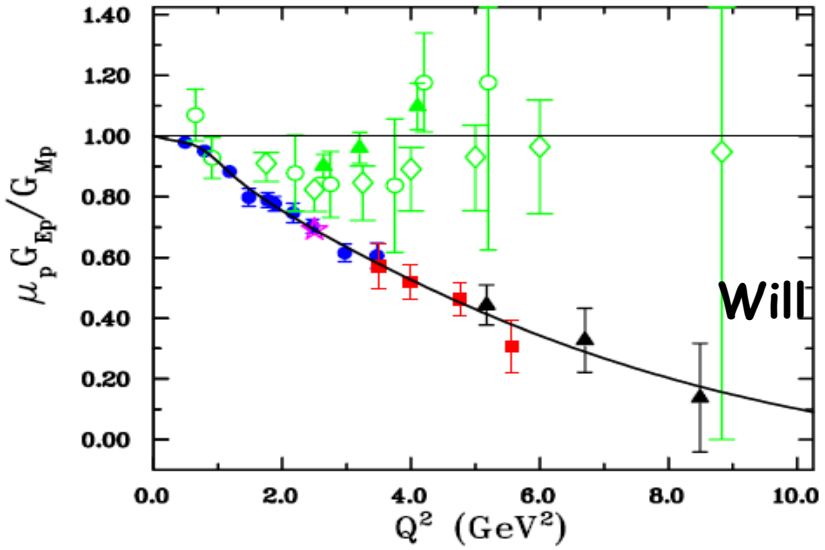
D. Marchand

IPN Orsay, 91406 ORSAY cedex, France

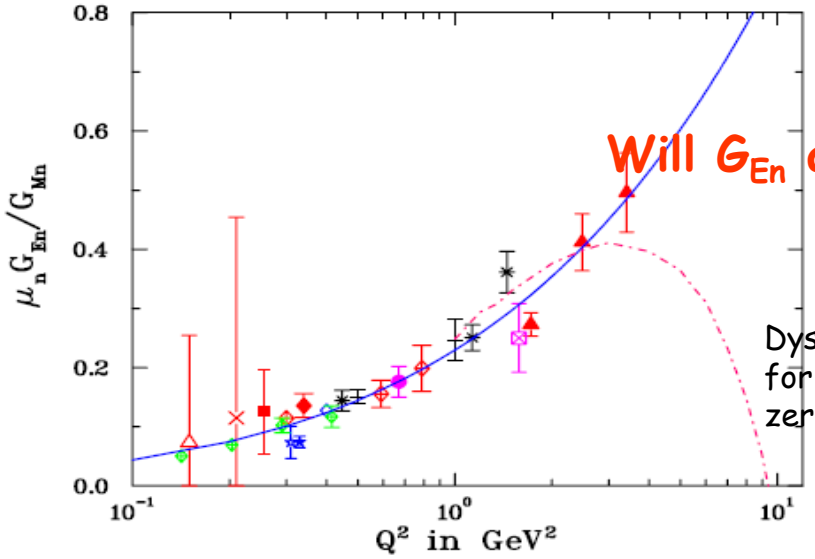
J. R.M. Annand, K. Hamilton, R. Montgomery

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

Nucleon formfactors



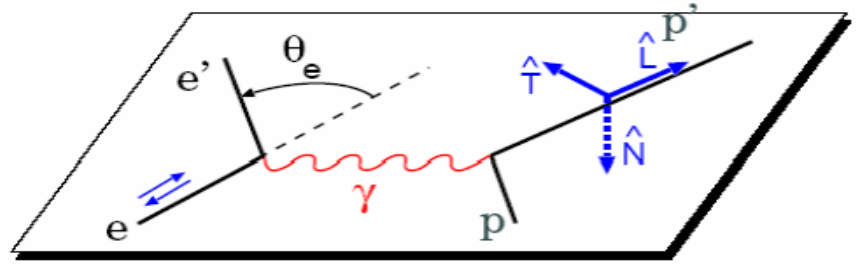
Will G_{Ep} become zero?



Will G_{En} also become zero?

Dyson-Schwinger approach for neutron predicts a (second) zero for G_{En}, also near 10 GeV^2.

Spin Transfer Reaction $^1\mathrm{H}(\vec{e}, e' \vec{p})$



Transferred polarization is: (Akhiezer & Rekalo)

$$P_n = 0$$

$$\pm h P_t = \mp h\, 2\sqrt{\tau(1+\tau)} G_E^p G_M^p \tan\left(\frac{\theta_e}{2}\right) / I_0$$

$$\pm h P_l = \pm h (E_e + E_{e'}) (G_M^p)^2 \sqrt{\tau(1+\tau)} \tan^2\left(\frac{\theta_e}{2}\right) / M / I_0$$

Where, $h = |h|$ is the beam helicity

$$I_0 = (G_E^p(Q^2))^2 + \frac{\tau}{\epsilon}(G_M^p(Q^2))^2$$

$$\Longrightarrow \frac{G_E^p}{G_M^p} = -\frac{P_t}{P_l} \frac{E_e + E_{e'}}{2M} \tan\left(\frac{\theta_e}{2}\right)$$

No error contributions from analyzing power and beam polarization measurements

Neutron polarimetry

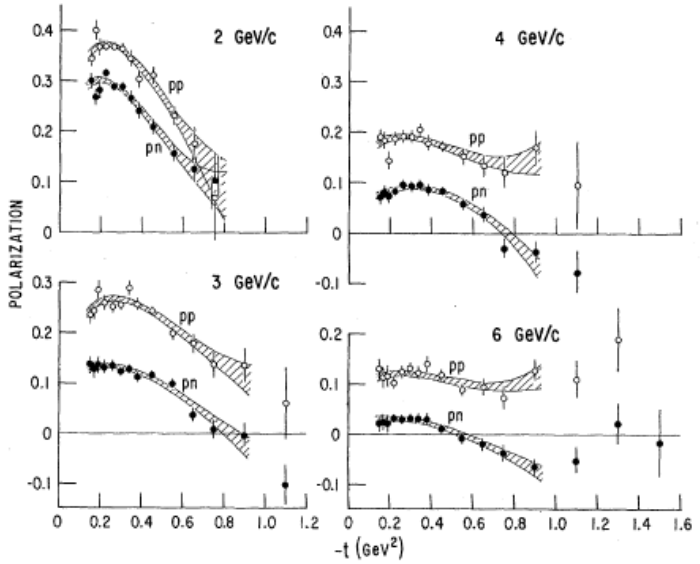
pp -> pp

pd -> pn + (p)

Phys. Rev. Lett 35 (1975) 632

A_y

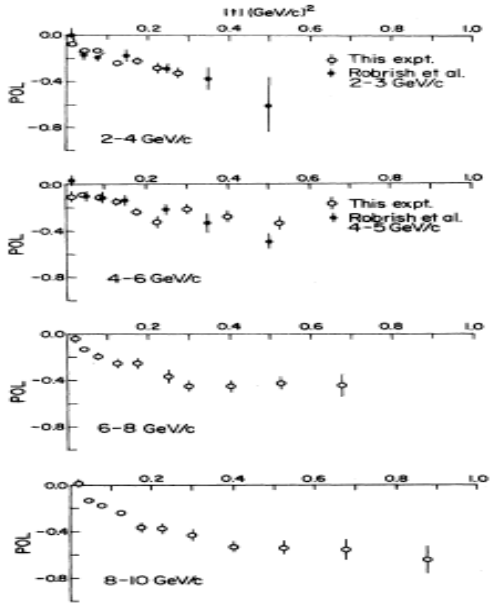
decreasing with energy



The existing data for A_y in np elastic scattering indicate that the analyzing power decreases faster than the pp analyzing power, becoming very small, then negative around 6 GeV/c neutron momentum.

Phys. Rev. Lett 30 (1973) 1183

np -> pn



- t, GeV²

increasing with energy

A_y

pp -> Δ^{++} n

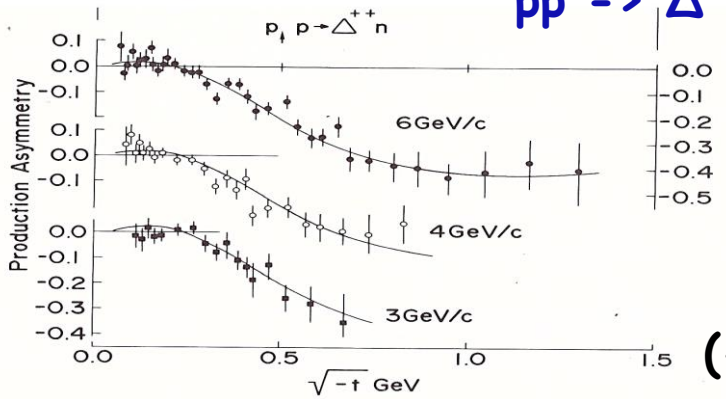
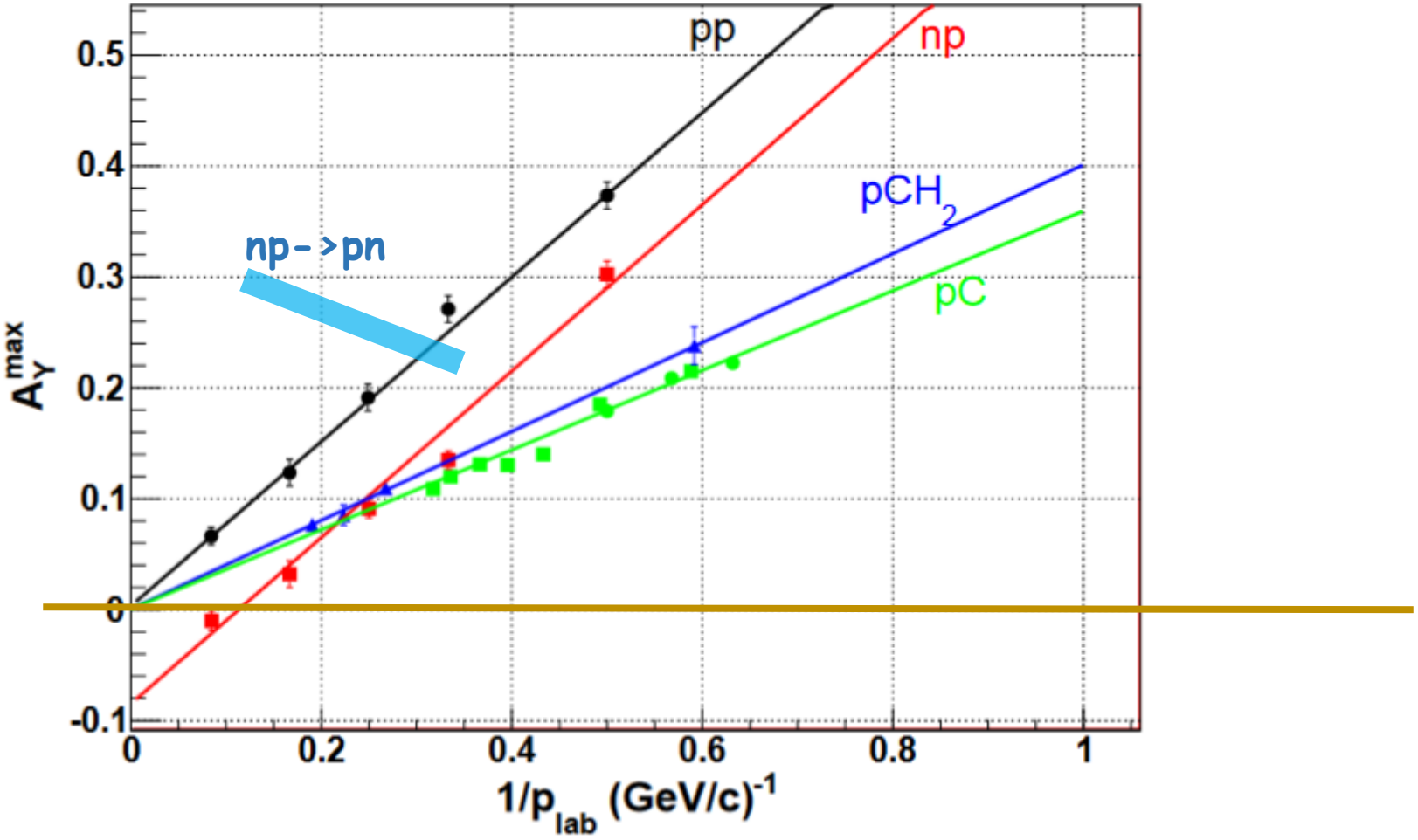


Fig. 1 Overall left-right asymmetries in $p_\uparrow p \to \Delta^{++} n$ at 3, 4, and 6 GeV/c. The curve is an eyeball interpolation of the 6 GeV/c data.

$(-t)^{1/2}$, GeV

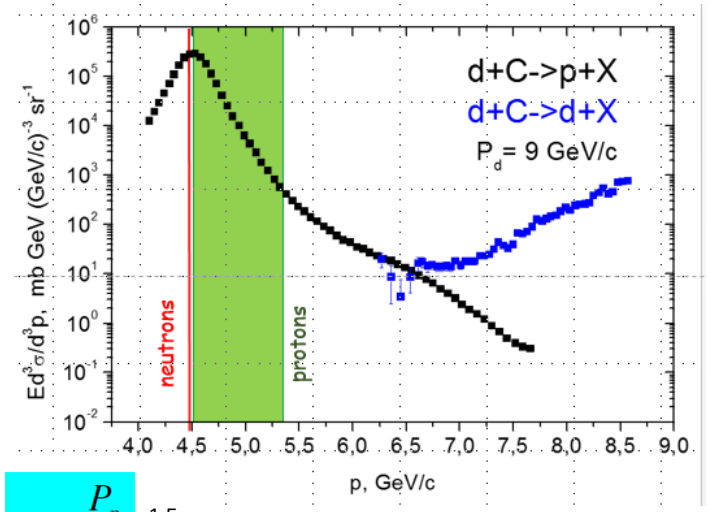
Charge exchange reaction

The dependence of the maximum of A_y on $1/p_{lab}$.

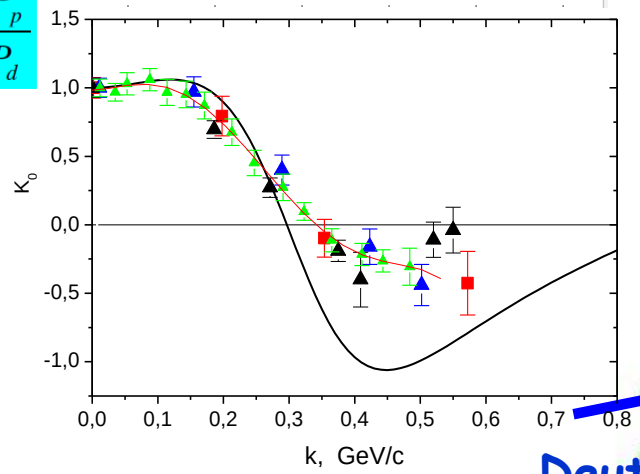


Black circles: ANL d(p,p)n data [29, 30]; black line: linear fit. Red squares: ANL d(p,n)p data [29, 30]; red line: linear fit. Blue triangles [25]: p+ CH2→charged+X; blue line: linear fit [25]. Green squares [31] and circles [32]: p+ C→charged+X; green line: linear fit [25].

Deuteron fragmentation

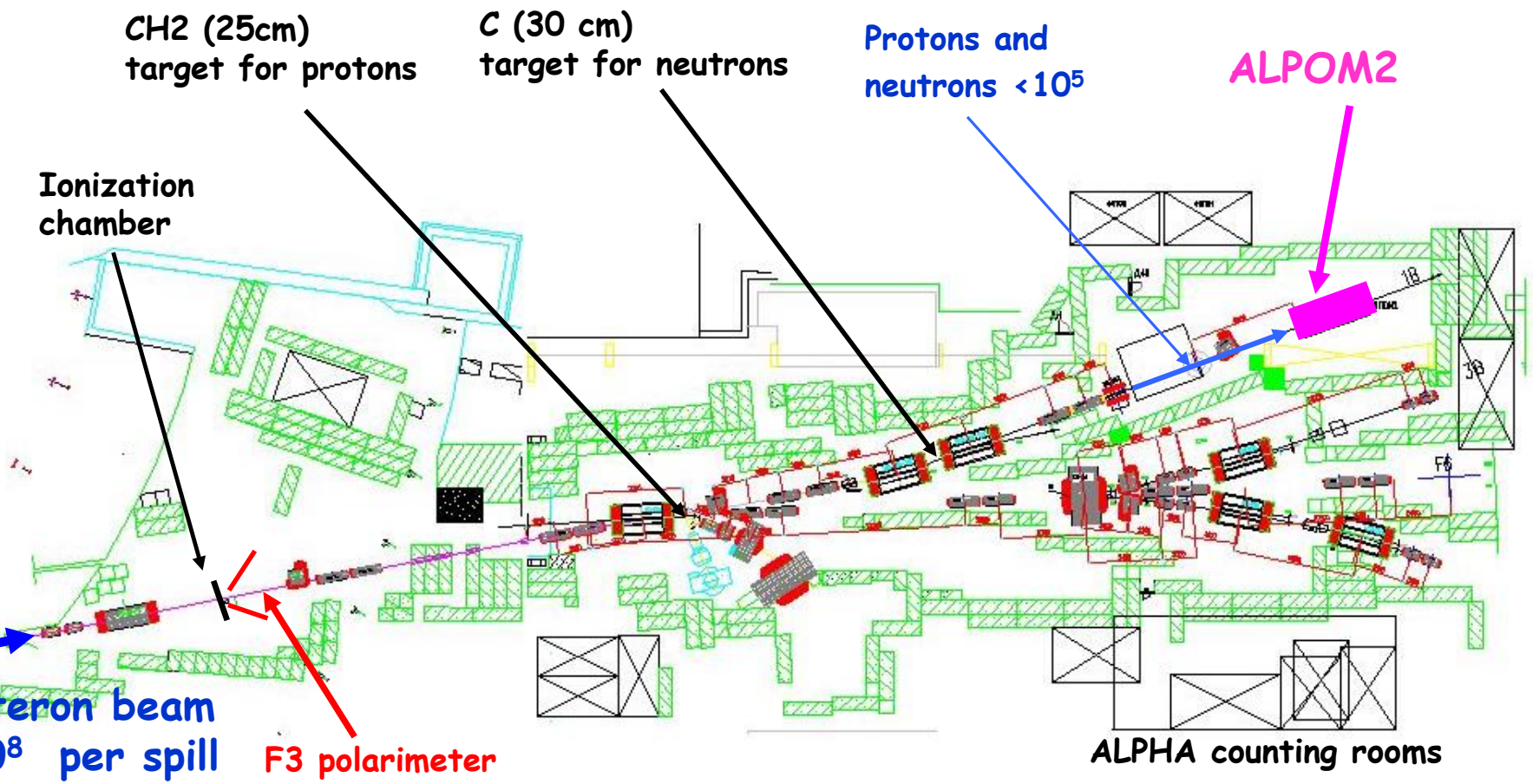


$$k_0 = \frac{P_p}{P_d}$$



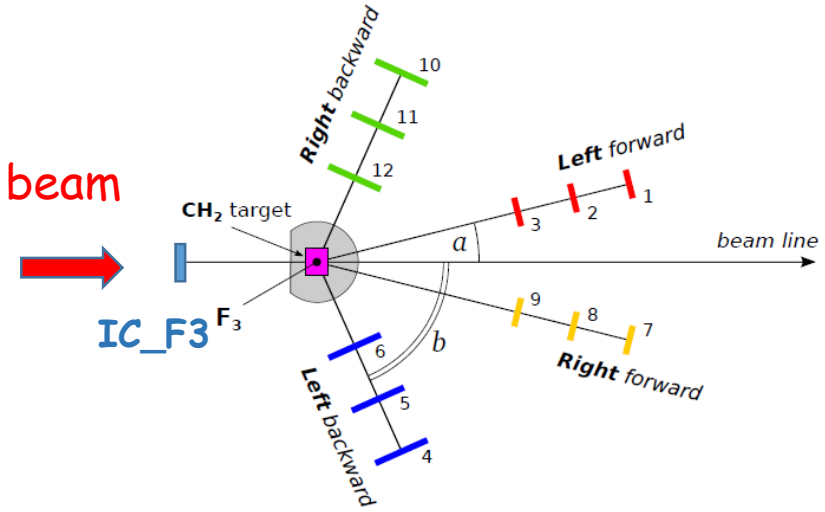
Polarization transfer

Polarized proton and neutron beams



Scheme of transportation polarized beams from Nuclotron to the ALPOM2 setup and the location of on-line F3 polarimeter and production targets for proton and neutron beams

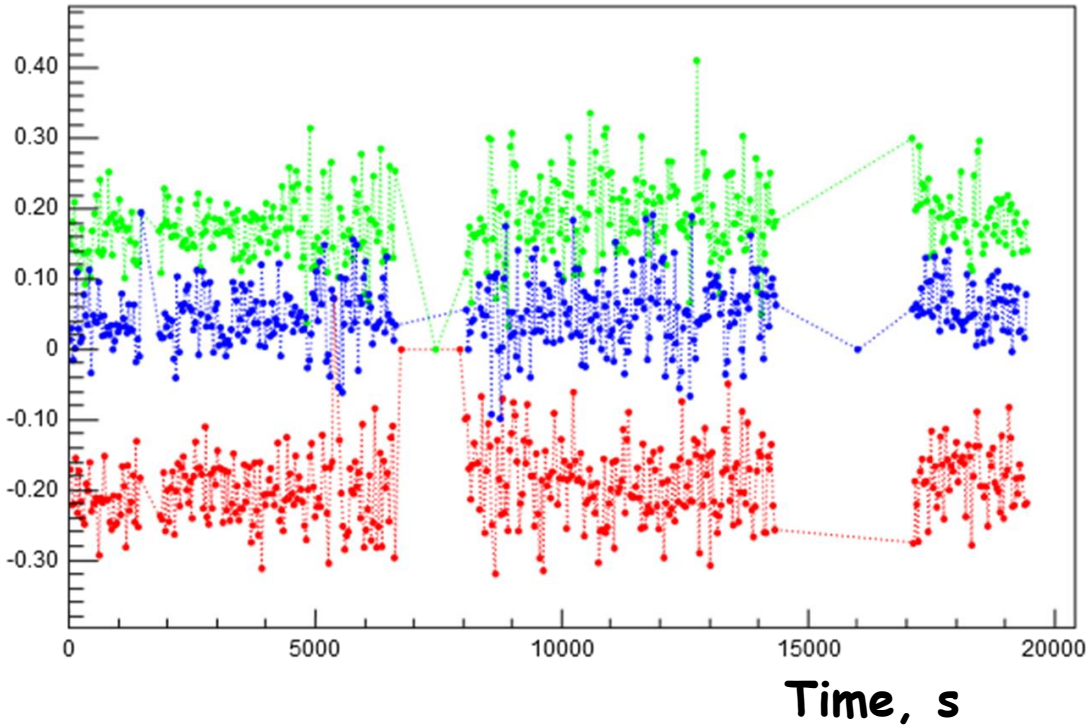
On-line beam polarization measurements



About 5 hours

each point corresponds to one spill.

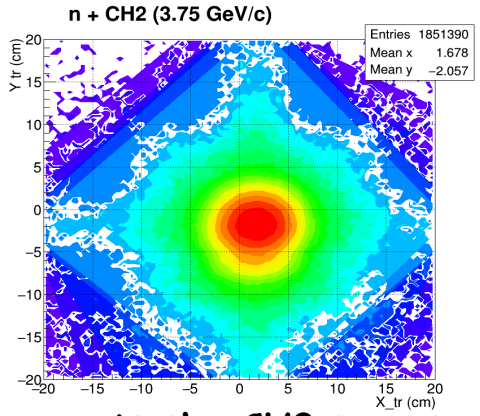
$$\frac{\text{Left-Right}}{\text{IC\_F3}}$$



The polarization in one mode is two times lower than the other one

$$P(+) - P(-) = 0{,}96 \pm 0{,}05$$

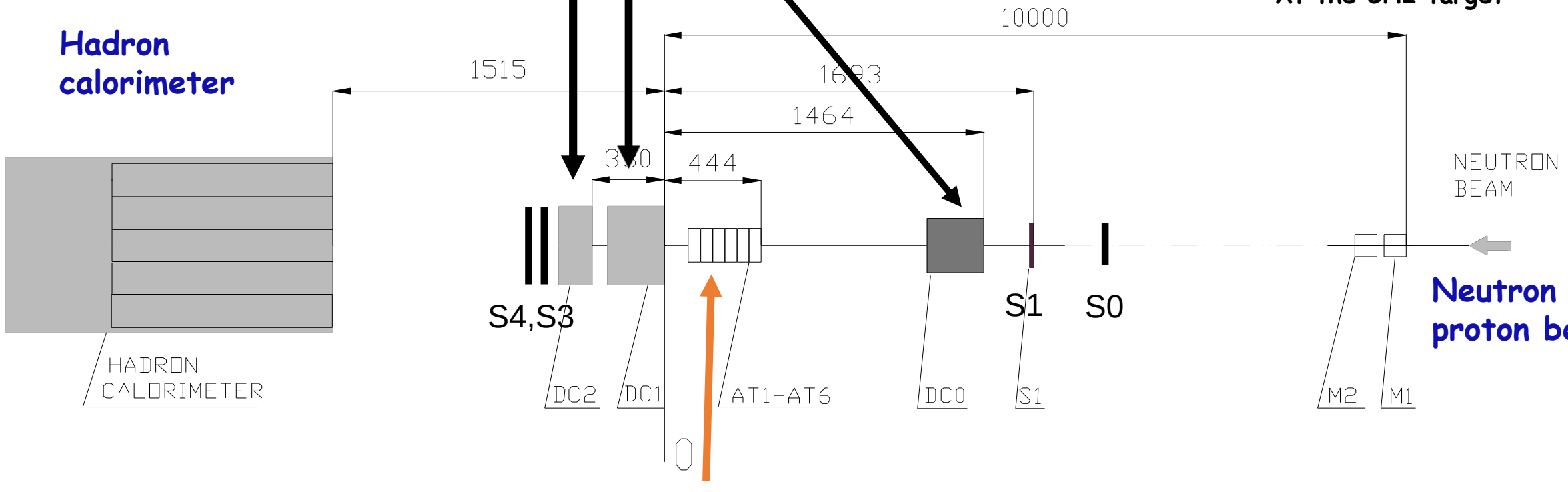
Layout of the setup



At the CH2 target

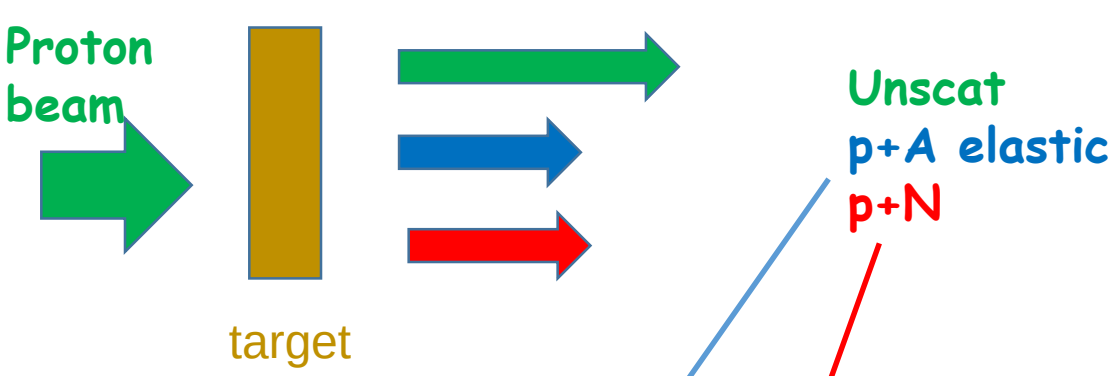
Drift chambers

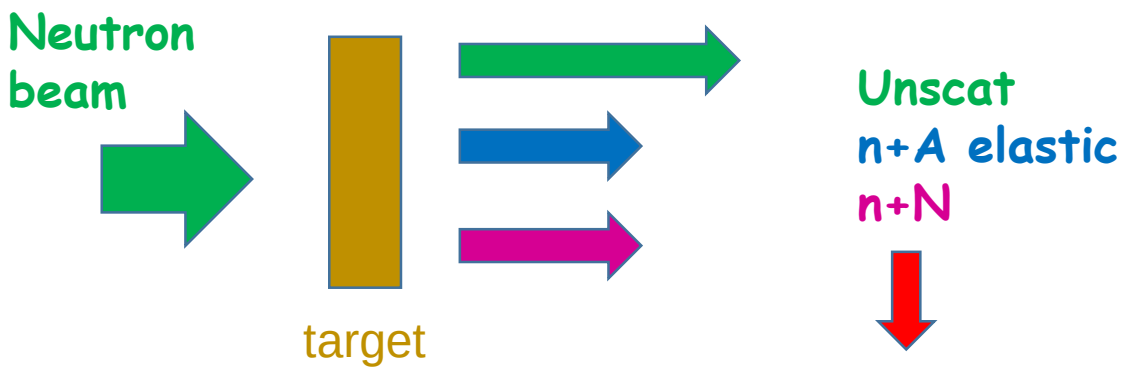
Hadron calorimeter



Neutron or proton beam

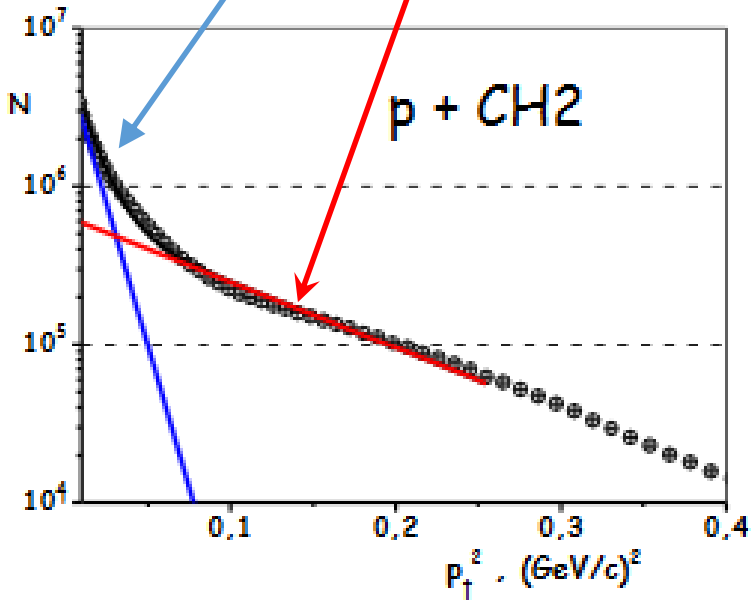
CH2, C, CH, Cu target





n +p -> p+n

One charged particle is detected



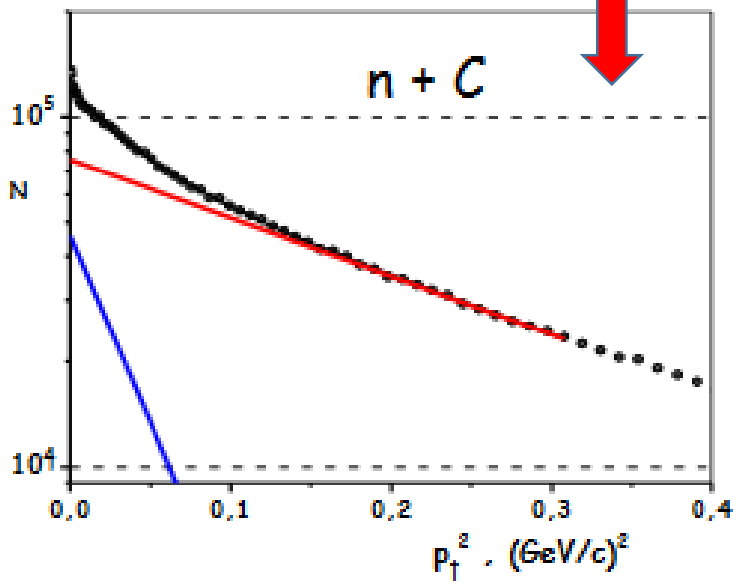
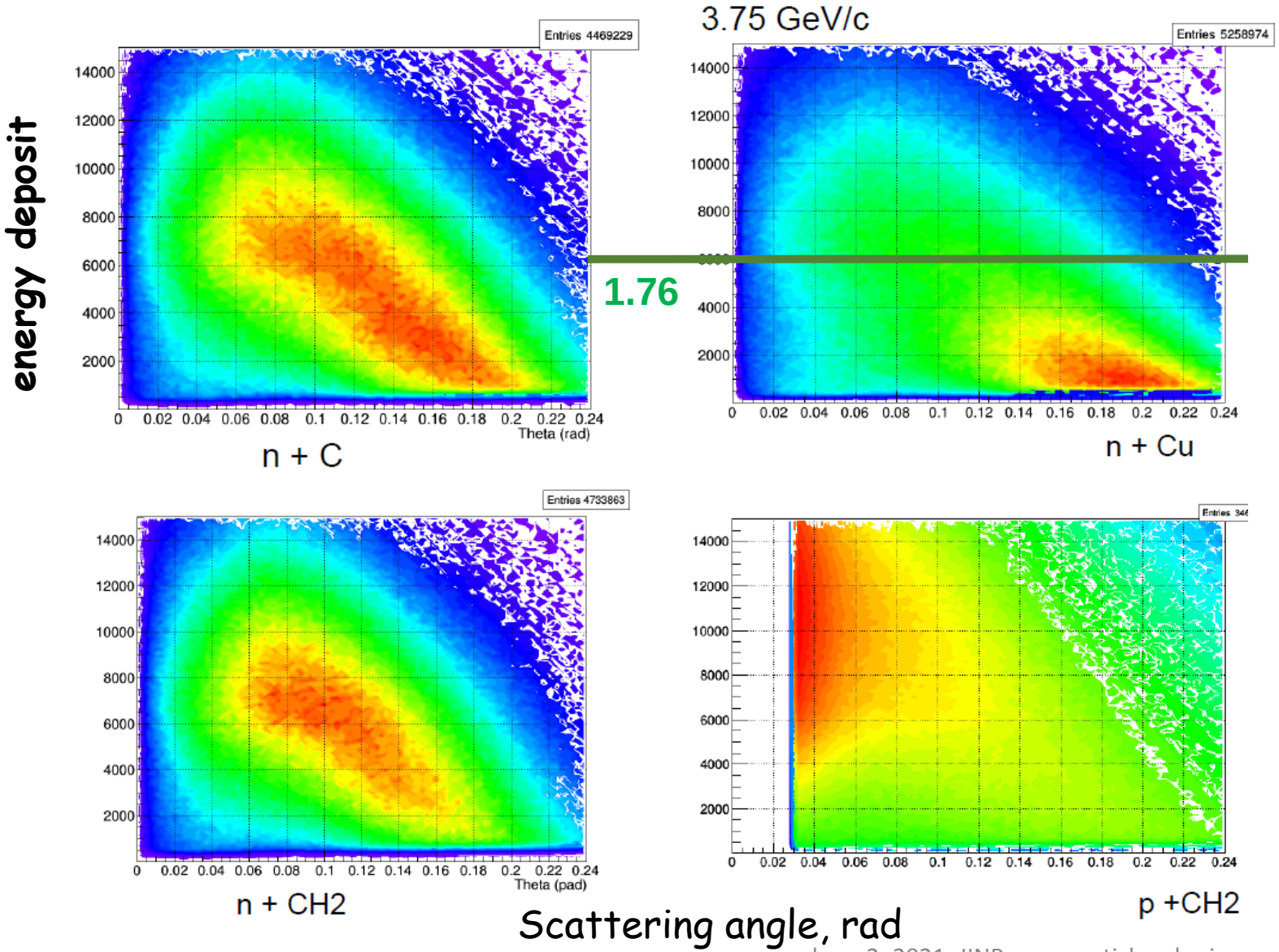


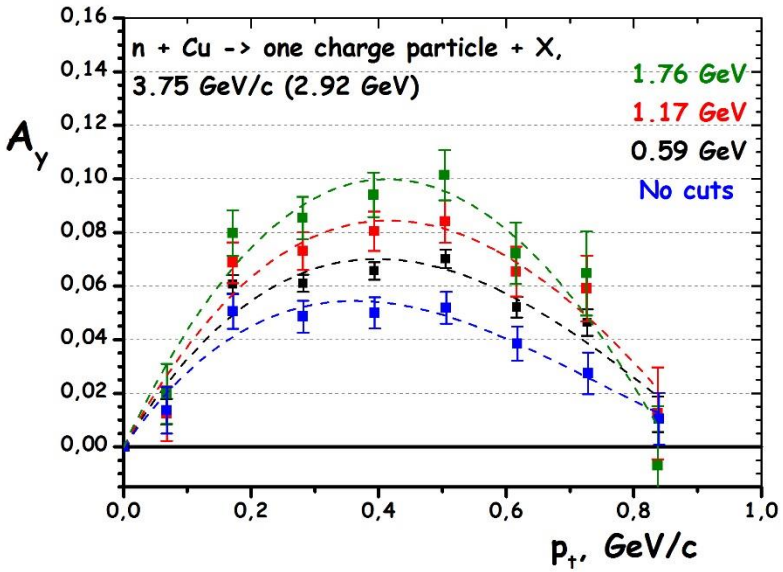
Fig. 14. pt2 -distribution for p + CH2 scattering at 3.75 GeV/c. The black curve is the sum of exponential functions with slope parameters b'1 (blue) and b'2 (red).

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).

Hadron calorimeter 1

Energy deposit measurements in the hadron calorimeter, 3.75 GeV/c

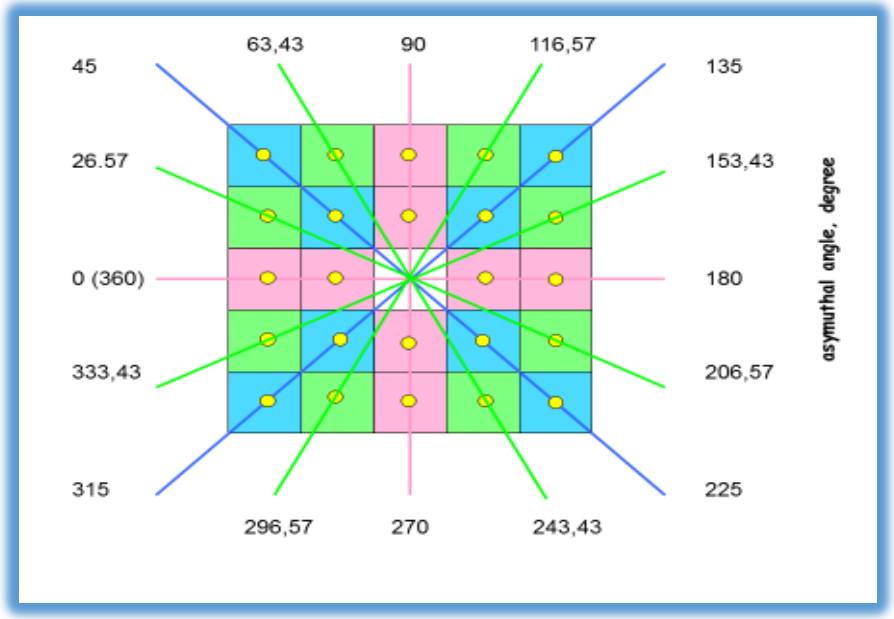




Ay is increased after the energy deposit cuts in 2 times for neutrons and 1.5 times for protons

Hadron calorimeter 2

Azimuthal segmentation available from the hadron calorimeter for asymmetry measurements



A very good agreement between tracking and energy deposit data allow us in future experiments used one of these methods

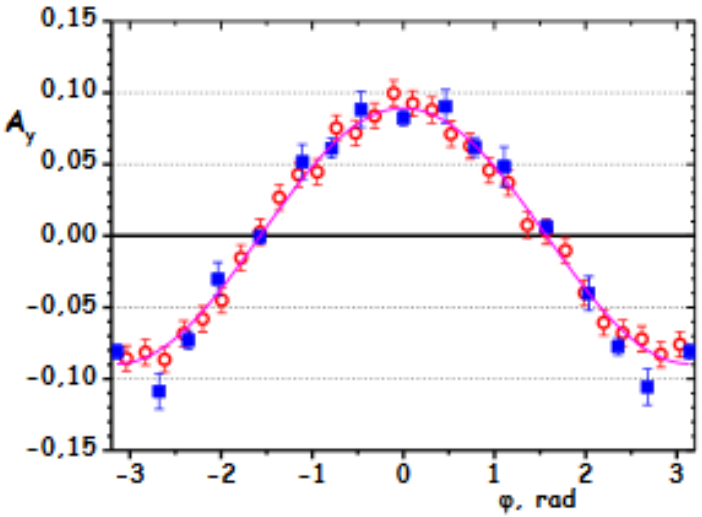


Fig. 17. Azimuthal dependence Ay for p + CH2 scattering at a momentum of 3.0 GeV/c, obtained from the triggered modules of the hadron calorimeter (blue squares) and from the tracks (red circles)

The asymmetry as a function of the azimuthal angle from **the calorimeter (blue squares)** and from **the drift chambers (red circles)**

Publication

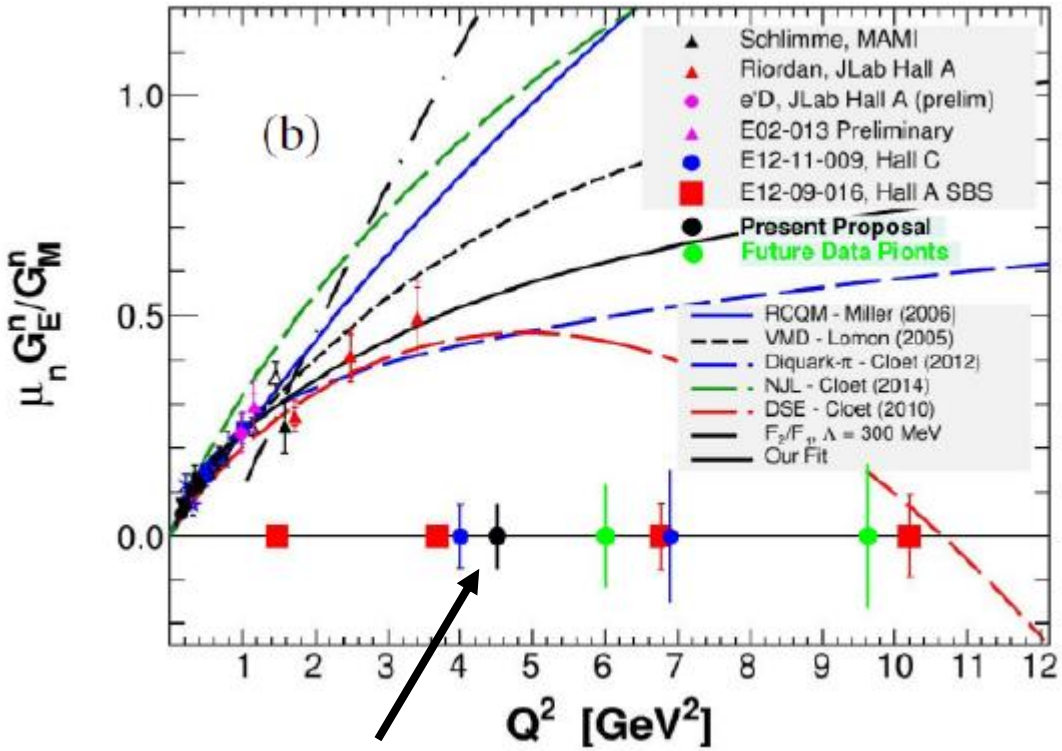
The experimental data obtained in 2016 and 2017 were analyzed and the article **Measurement of neutron and proton analyzing powers on C, CH, CH2 and Cu targets in the momentum region 3-4.2 GeV/c** was published as a *Special Article - New Tools and Techniques* in *Eur.Phys.J.A 56 (2020) 26*

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,



E12-17-004, the data taking in September, 2021

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

Upgrading the ALPOM2 setup

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.

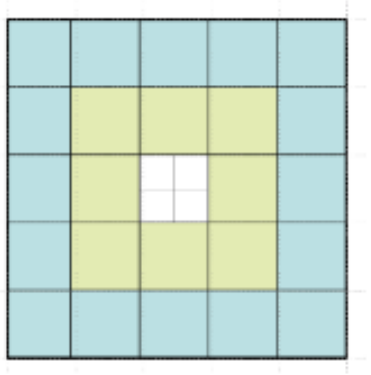


Fig. 12. ALPOM2 calorimeter layout: central part consist of 4 modules with sizes 7.5×7.5 cm^2, peripheral part contains 24 modules of 15×15 cm^2

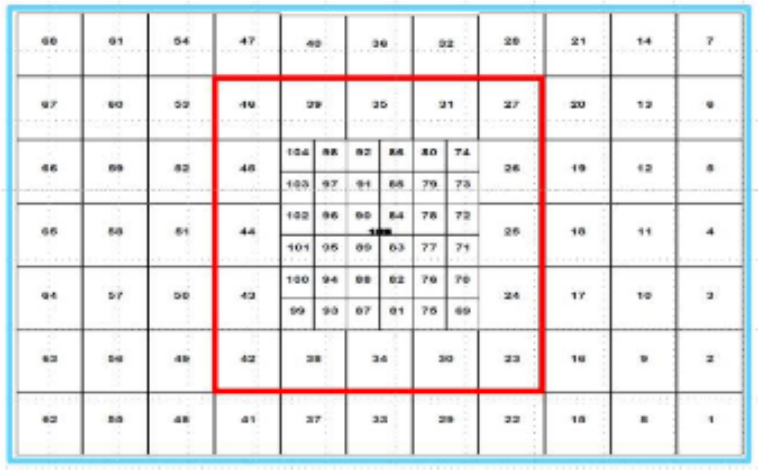
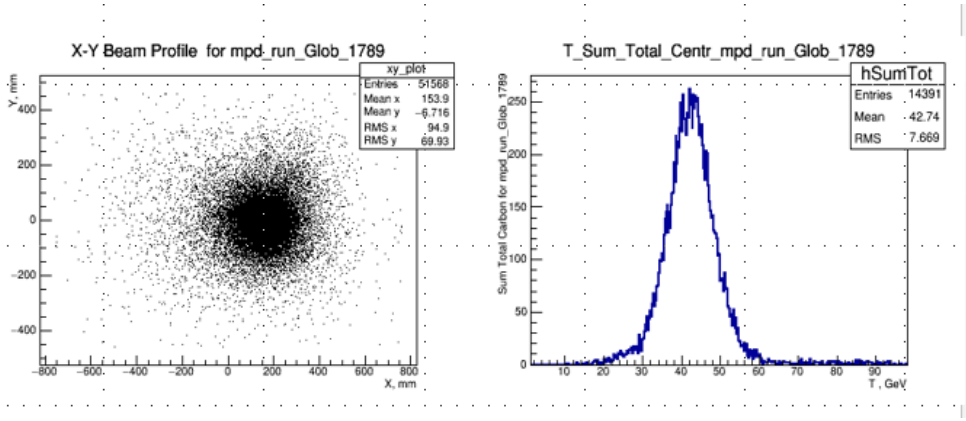


Fig. 13. ZDC layout: central part consist of 36 modules with sizes 7.5×7.5 cm^2, peripheral part contains 68 modules of 15×15 cm^2

ZDC at BM@N setup
carbon beam, 4.5 GeV/n



Beam profile
σ_x ~ σ_y ~ 2 cm

~ 14%

Drift chambers (plane configuration)

Now **2X+2X+2Y+2Y** → **Future** **3X+3Y+3X+3Y**

Schedule of the experiment:

2021-2022 years	Installation of the ZDC at the neutron beam line
2022-2023 years	Data taking during 336 hours at the deuteron intensity about 5*10**9 per spill. 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.

Expenses

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

Contributions in previous years from collaborators

USA side – crate VME – 8.5 k$; HV supply – 2 k$, .2 TQDC – 8 k$, hadcal modules – 10 k$, HV system SY5527 (Caen) – 14.6 k$ Polarized ion source parts from Indiana Univ.

French side – PM XP2020 – 2 items and several electronic modules – 5 k$

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

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

The collaboration includes 35 people from 10 Laboratories and 5 countries.

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

PhD is completed:
Ying Wang (Paris-Saclay) 2018

On going PhD to be completed within two-three years:
R.A. Shindin
A.A. Druzhinin

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.

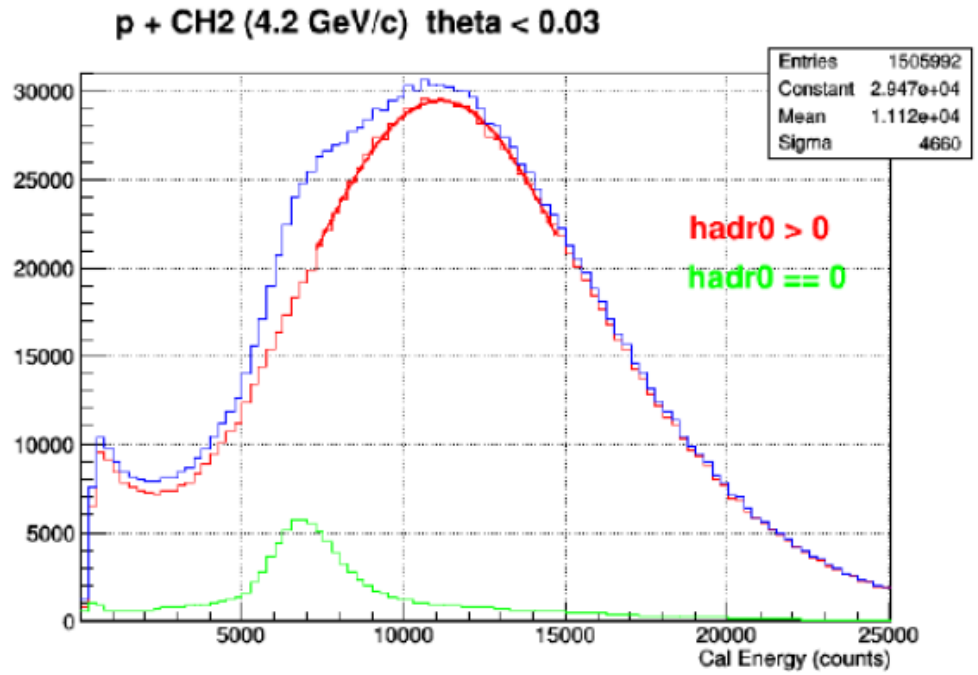
Opportunities: When carrying out measurements, it will be possible for the first time to measure the analyzing powers simultaneously for forward scattering and charge exchange scattering; in the case of the interaction of polarized protons with a target, the asymmetries of forward scattering of both 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.

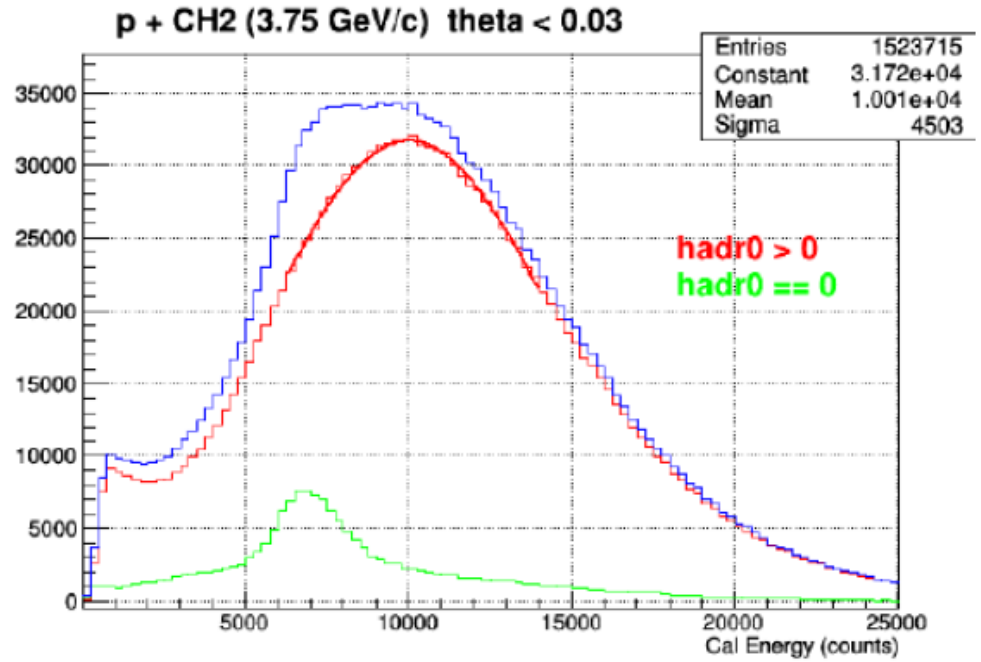
Threats: The highly professional level of the participants in the experiment, the previous experience of the team, the available equipment and the presence of polarized proton and neutron beams of GeV energies limits essentially the risks. However, the pandemic could limit the number of participants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

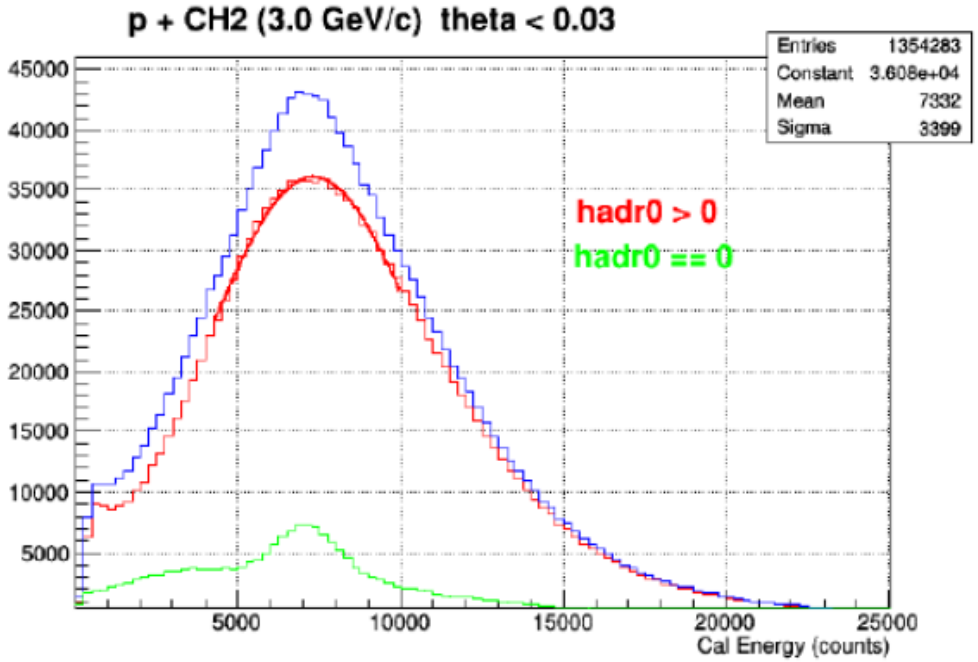
We are planning to continue the measurements at higher proton and neutron energies
The Nuclotron in Dubna is the only facility where these measurements can be performed.

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.

Thank you


p + CH2 (4.2 GeV/c) theta < 0.03
Entries 1505992
Constant 2.947e+04
Mean 1.112e+04
Sigma 4660
hadr0 > 0
hadr0 == 0
Cal Energy (counts)


p + CH2 (3.75 GeV/c) theta < 0.03
Entries 1523715
Constant 3.172e+04
Mean 1.001e+04
Sigma 4503
hadr0 > 0
hadr0 == 0
Cal Energy (counts)


p + CH2 (3.0 GeV/c) theta < 0.03
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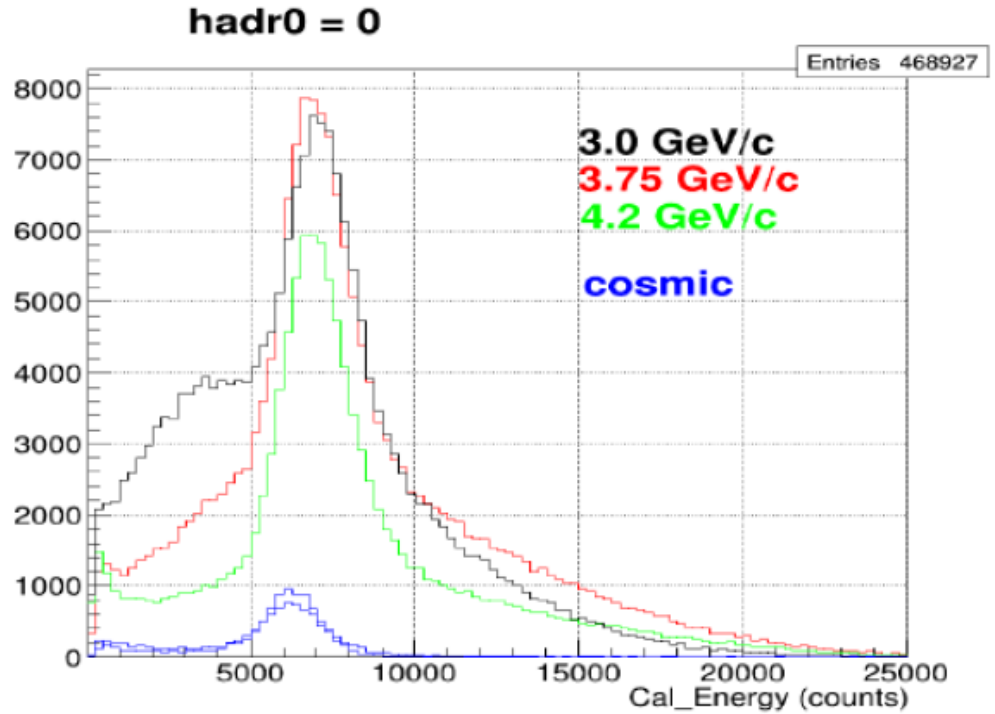
Mean 7332
Sigma 3399
hadr0 > 0
hadr0 == 0
Cal Energy (counts)


hadr0 = 0
Entries 468927
3.0 GeV/c
3.75 GeV/c
4.2 GeV/c
cosmic
Cal_Energy (counts)

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.