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, SPhn, CEA Saclay, 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

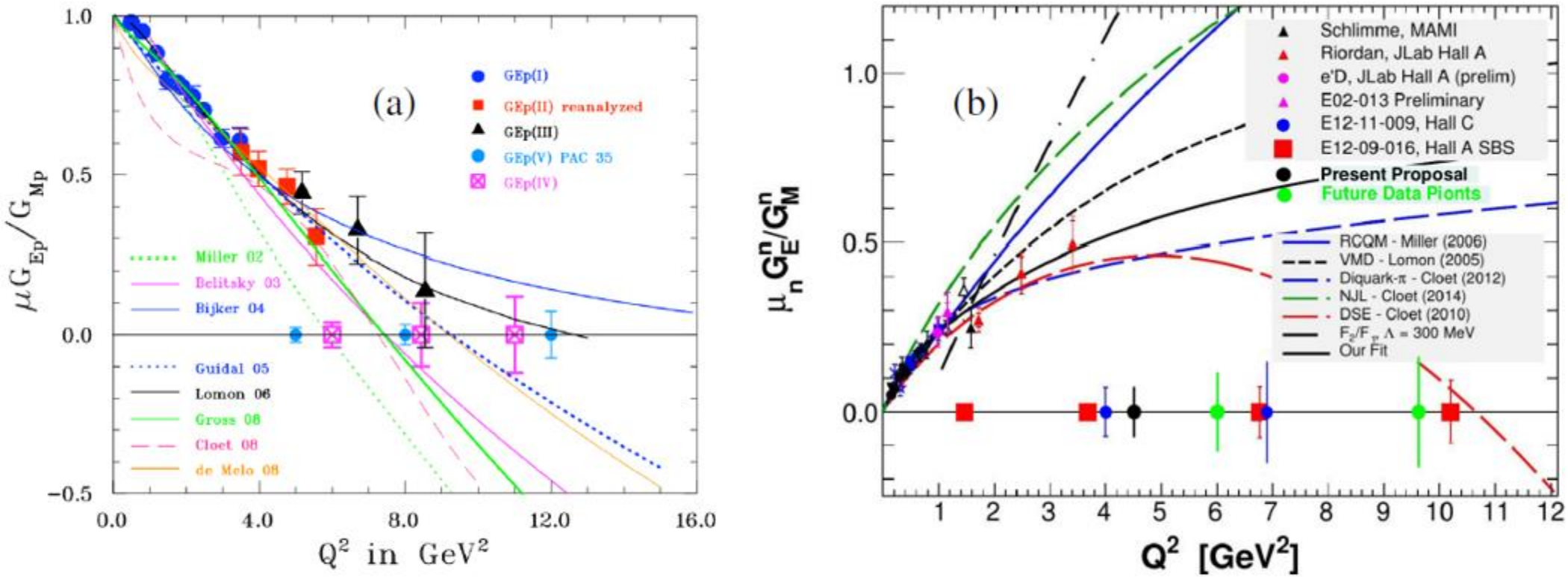


Fig.2.·World's·data·for·the·proton·form·factor·ratio·$\mu_p G_{Ep}/G_{Mp}$·data·using·the·recoil·polarization·method·are·shown·in·panel·(a)·[24,·26].·World's·data·for·$\mu_n G_{En}/G_{Mn}$·are·shown·in·panel·(b)·[28].·In·both·cases,·the·points·plotted·along·the·axis·represent·the·anticipated·Q2·and·uncertainty·on·future·measurements.¶

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.

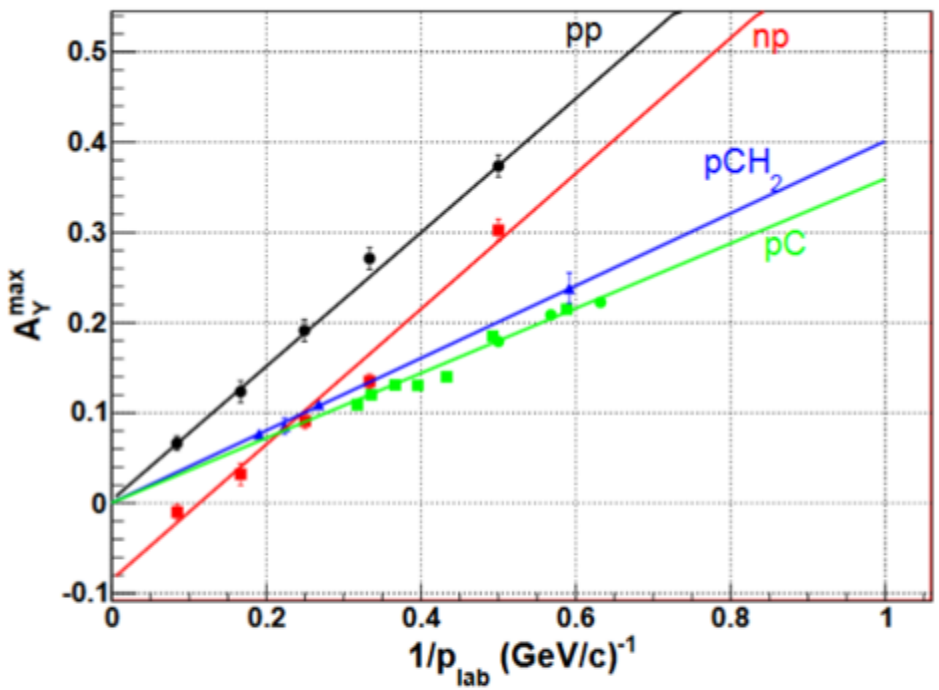


Fig. 3: The dependence of the maximum of A_Y on $1/p_{lab}$. Black circles: ANL d(p,p)n data [29, 30]; black line: linear fit. Red squares: ANL d(p,n)p data [29, 30]; red line: linear fit. Blue triangles [25]: p+CH2→charged+X; blue line: linear fit [25]. Green squares [31] and circles [32]: p+C→charged+X;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

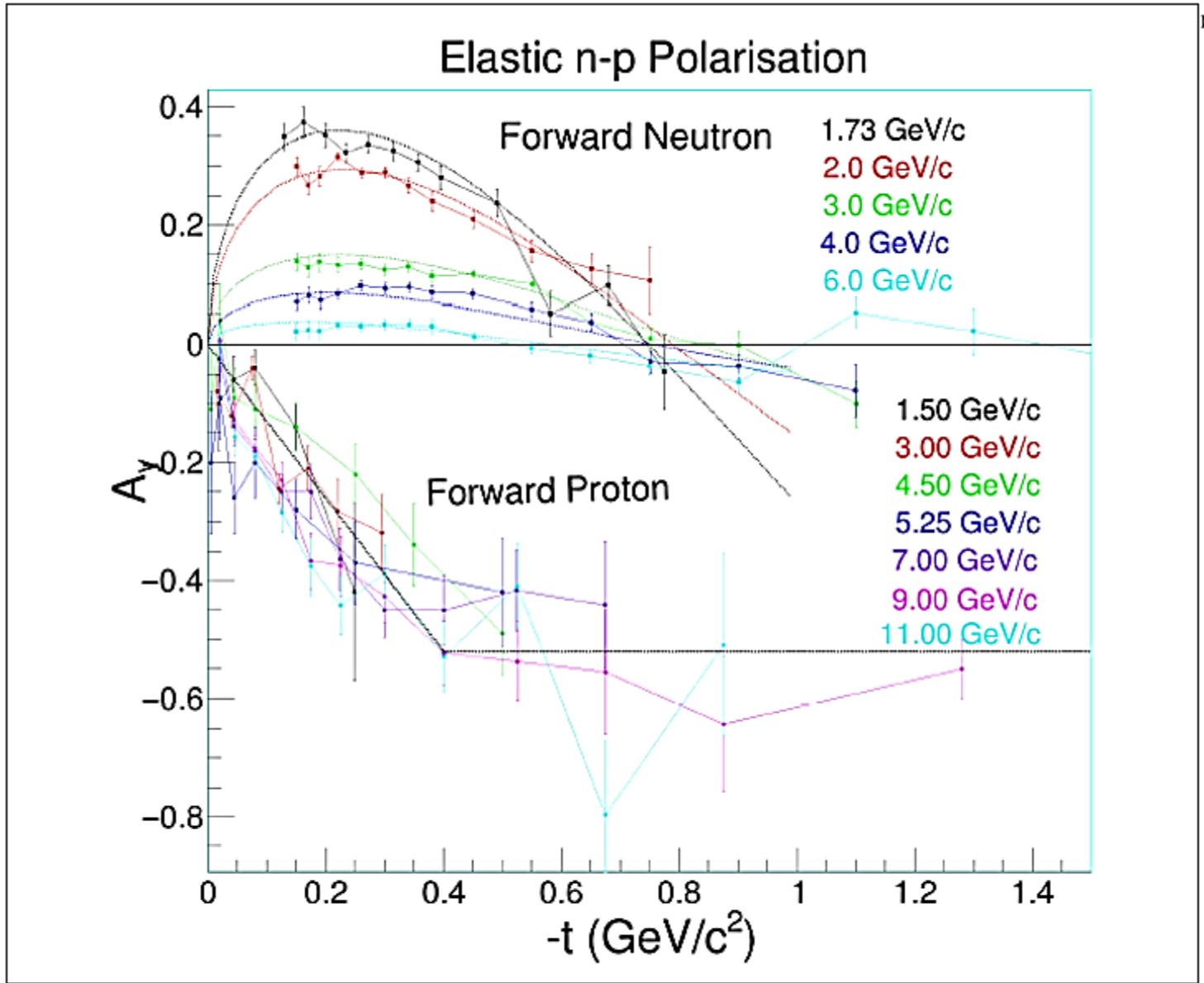
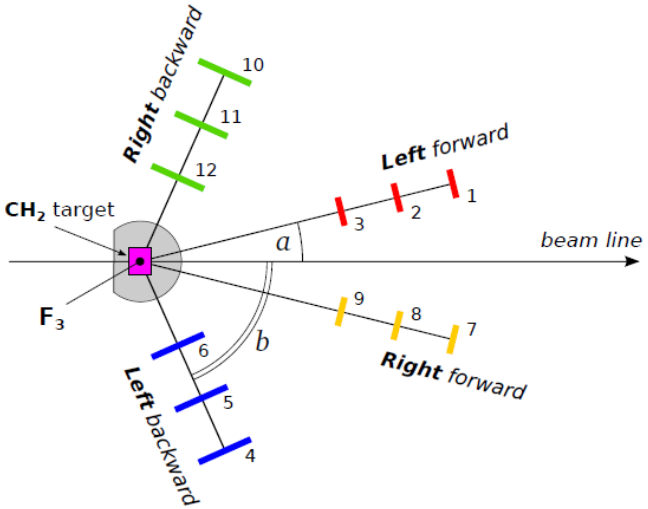
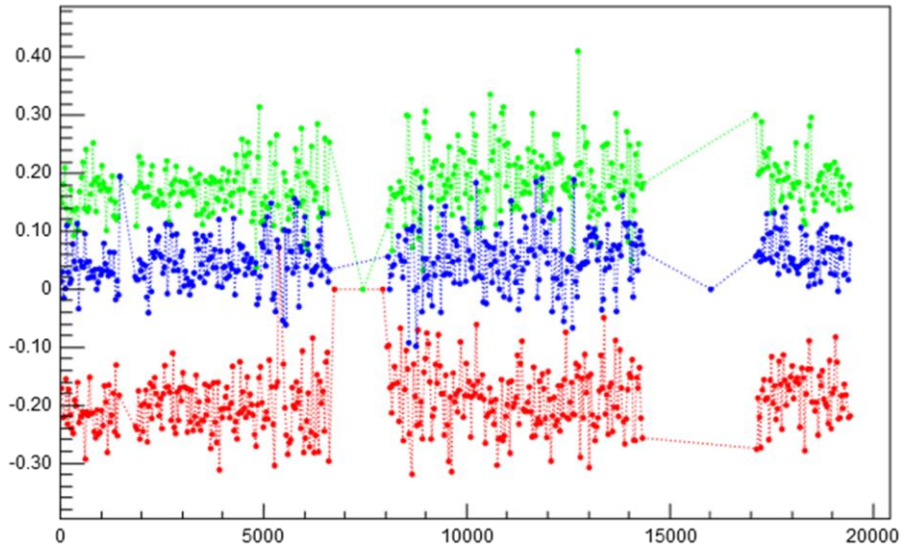


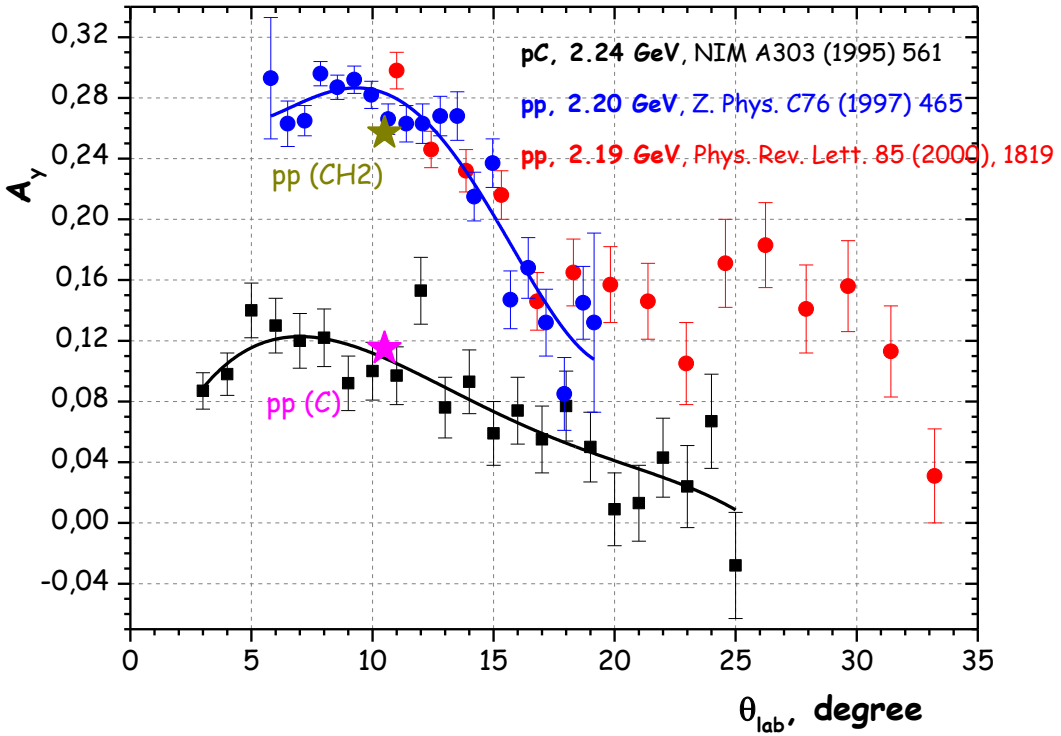
Fig. 4: Top: the p_{lab} and t-dependence of the analyzing power of elastic pn scattering [29, 30]. The smooth dotted lines show the fit of Ref. [33] to the pn data.
Bottom: the p_{lab} and t dependence of charge-exchange np scattering [34, 35].
The color-coding relates the data to momentum labels.

Beam polarization measurements

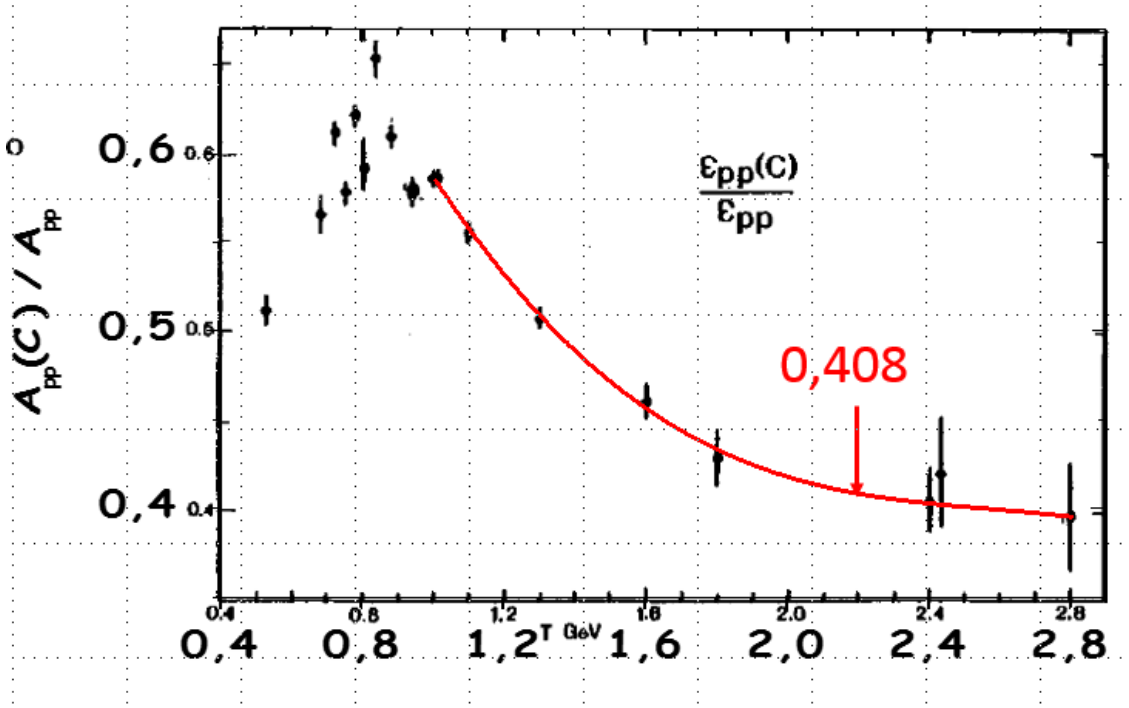


P(+) – P(-) = 0,96 ± 0,05

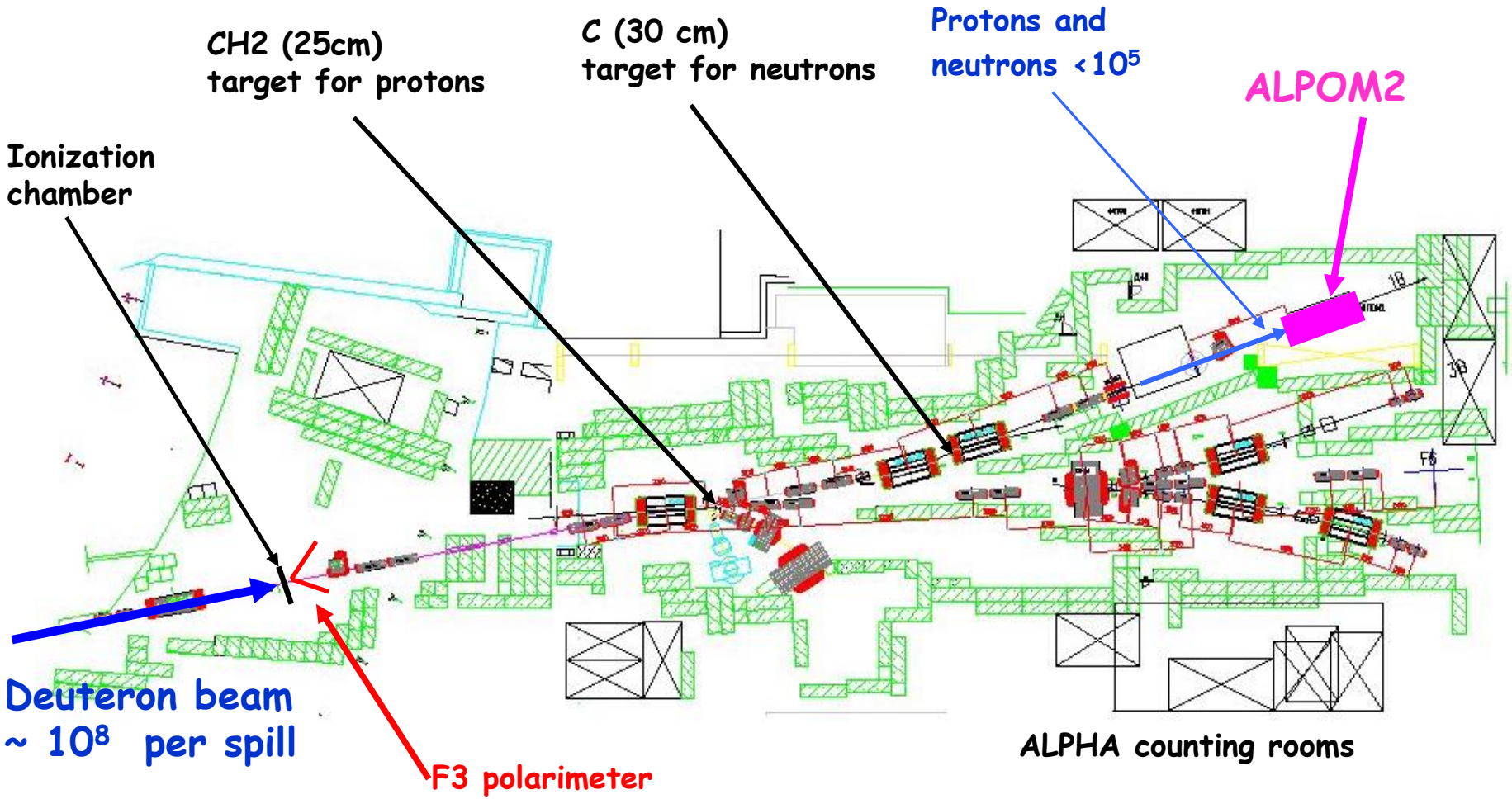




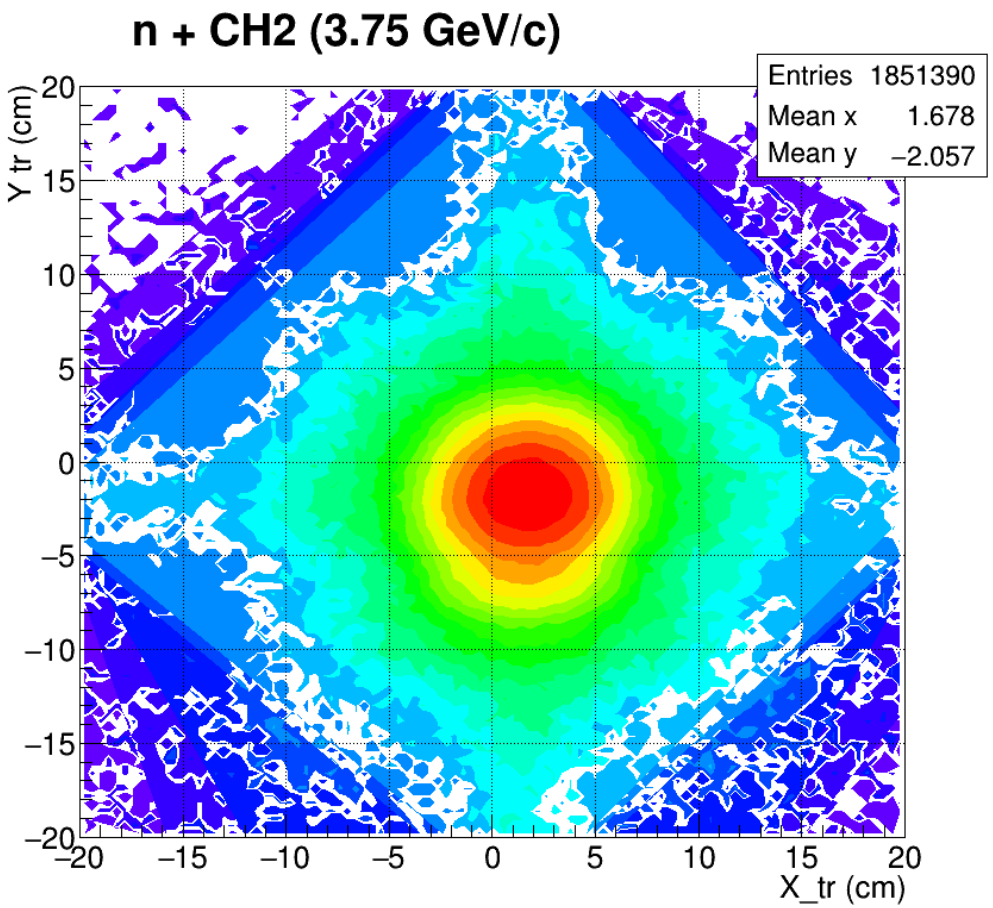
JOURNAL DE PHYSIQUE
Colloque C2, supplément au n02, Tome 46, février 1985 page C2-483



Polarized proton and neutron beams

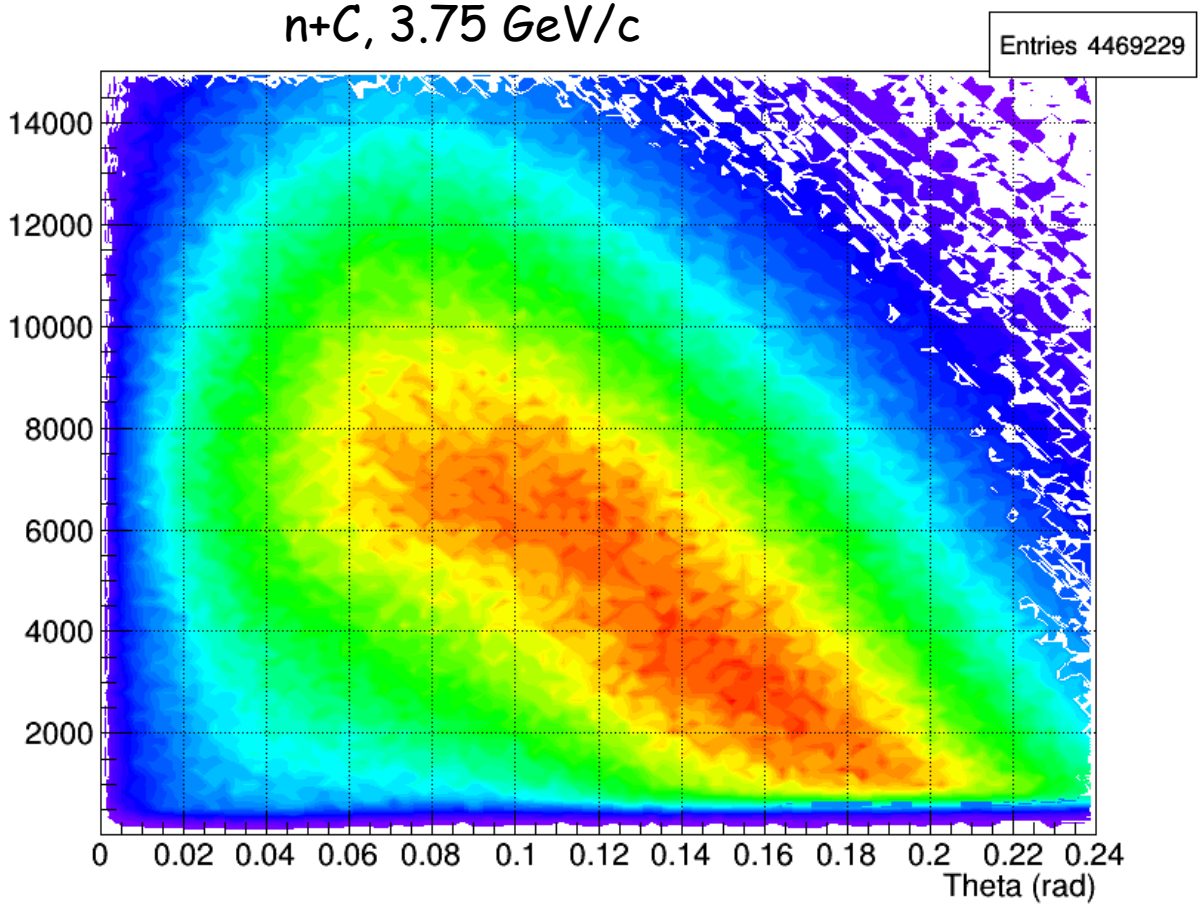


Neutron beam



At the target

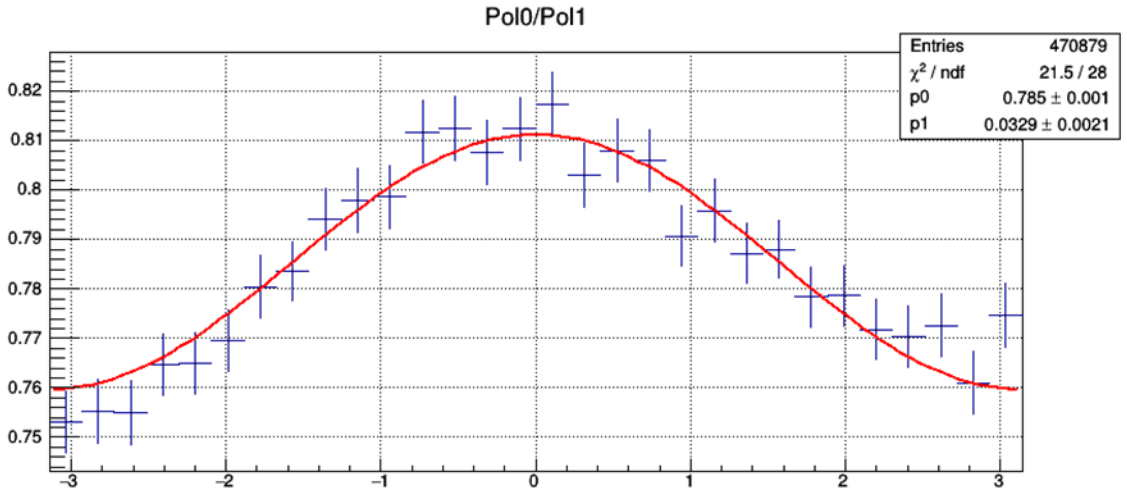
Hadcal, deposit energy
n+C, 3.75 GeV/c

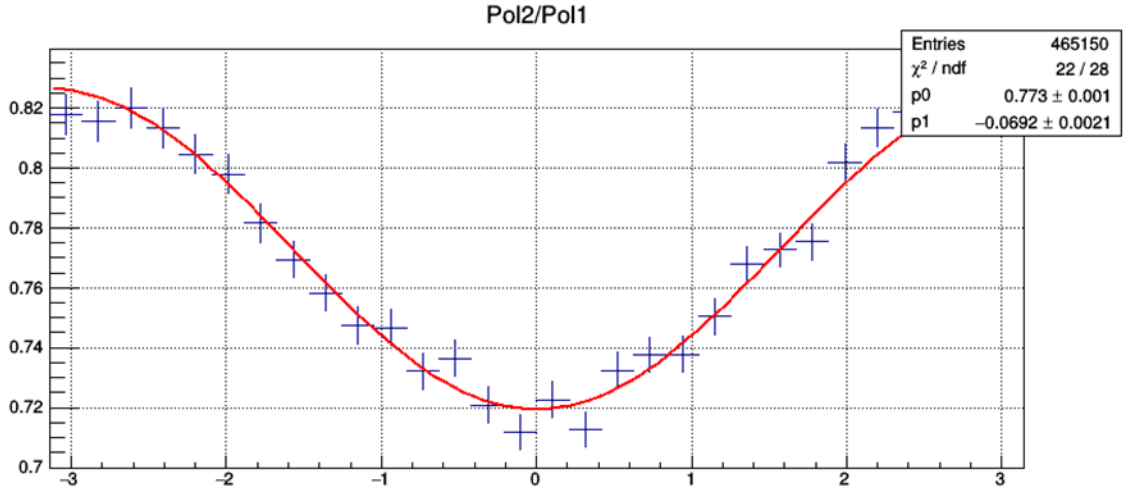


Scattering angle, rad

Measured asymmetries

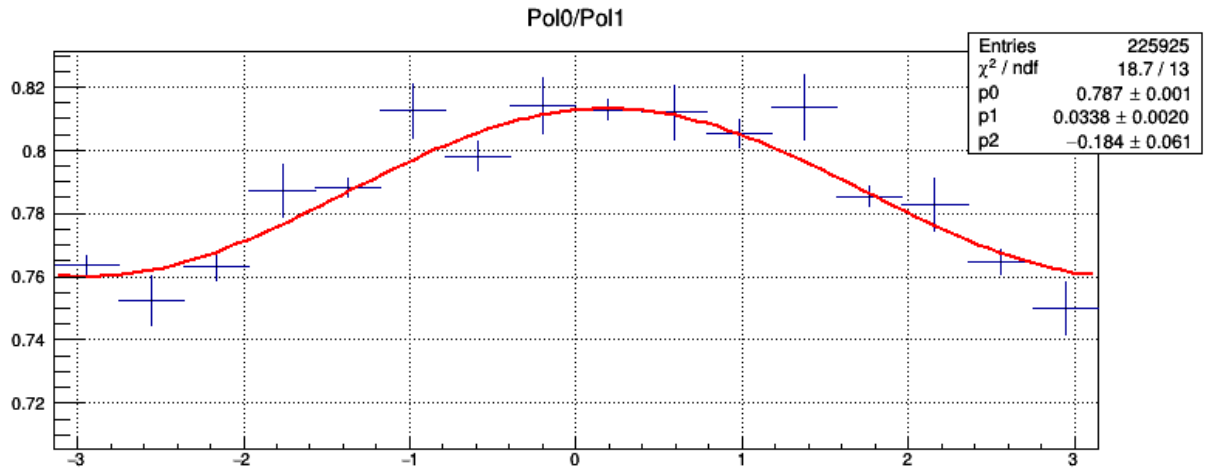
p+CH2, 3.0 GeV/c, tracks, scattering angles 0.03-0.24 rad

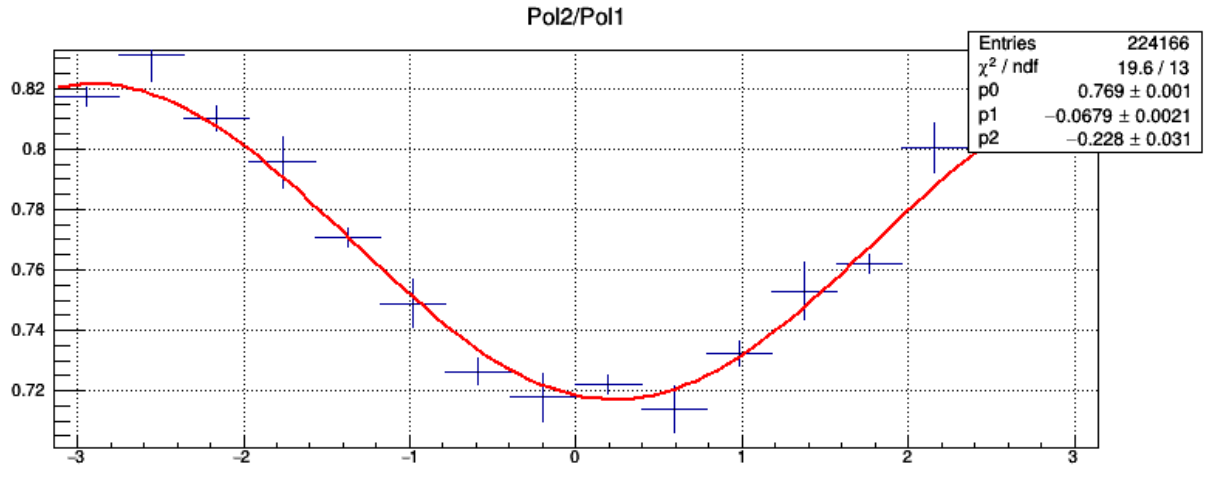




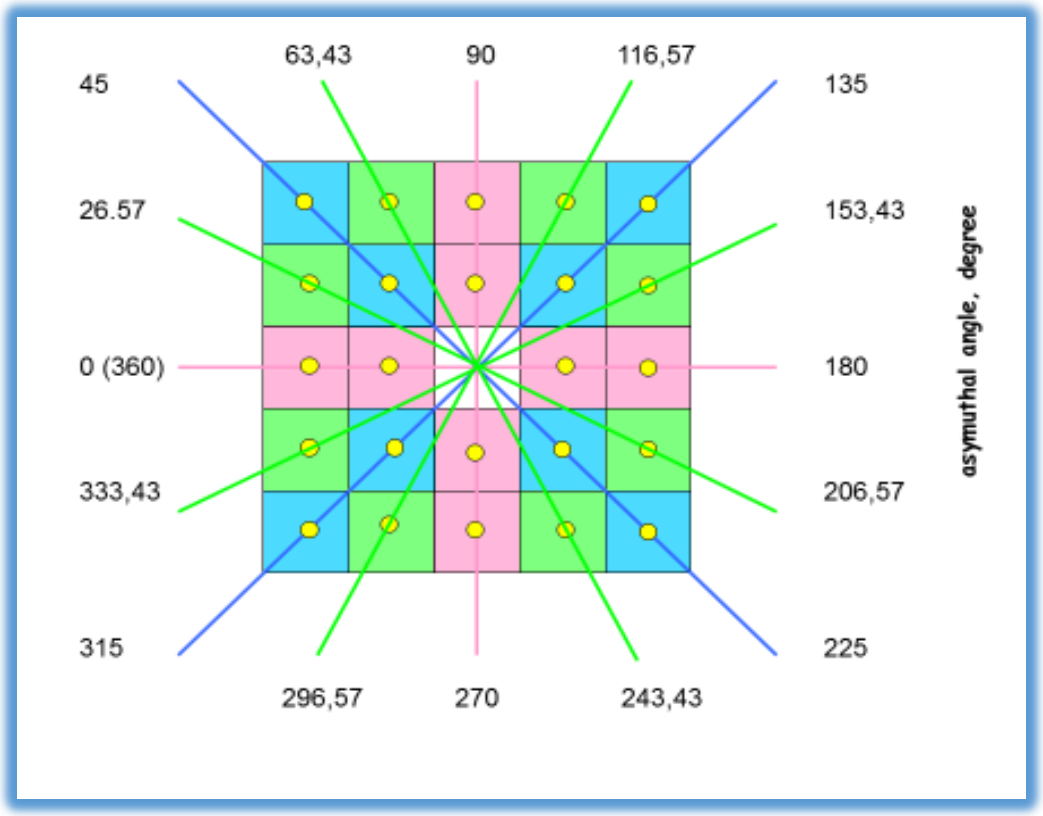
asymuthal angle, rad

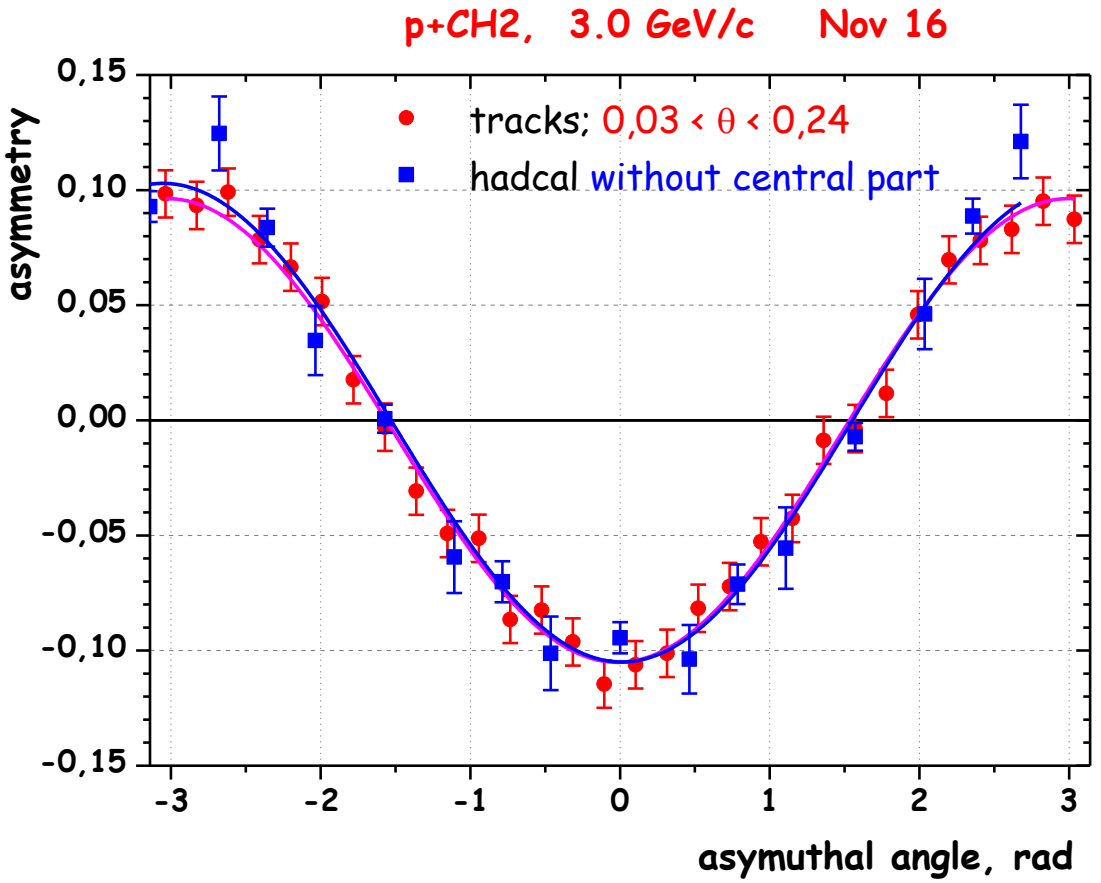
p+CH2, 3.0 GeV/c, hadcal, max amplitude without the central part

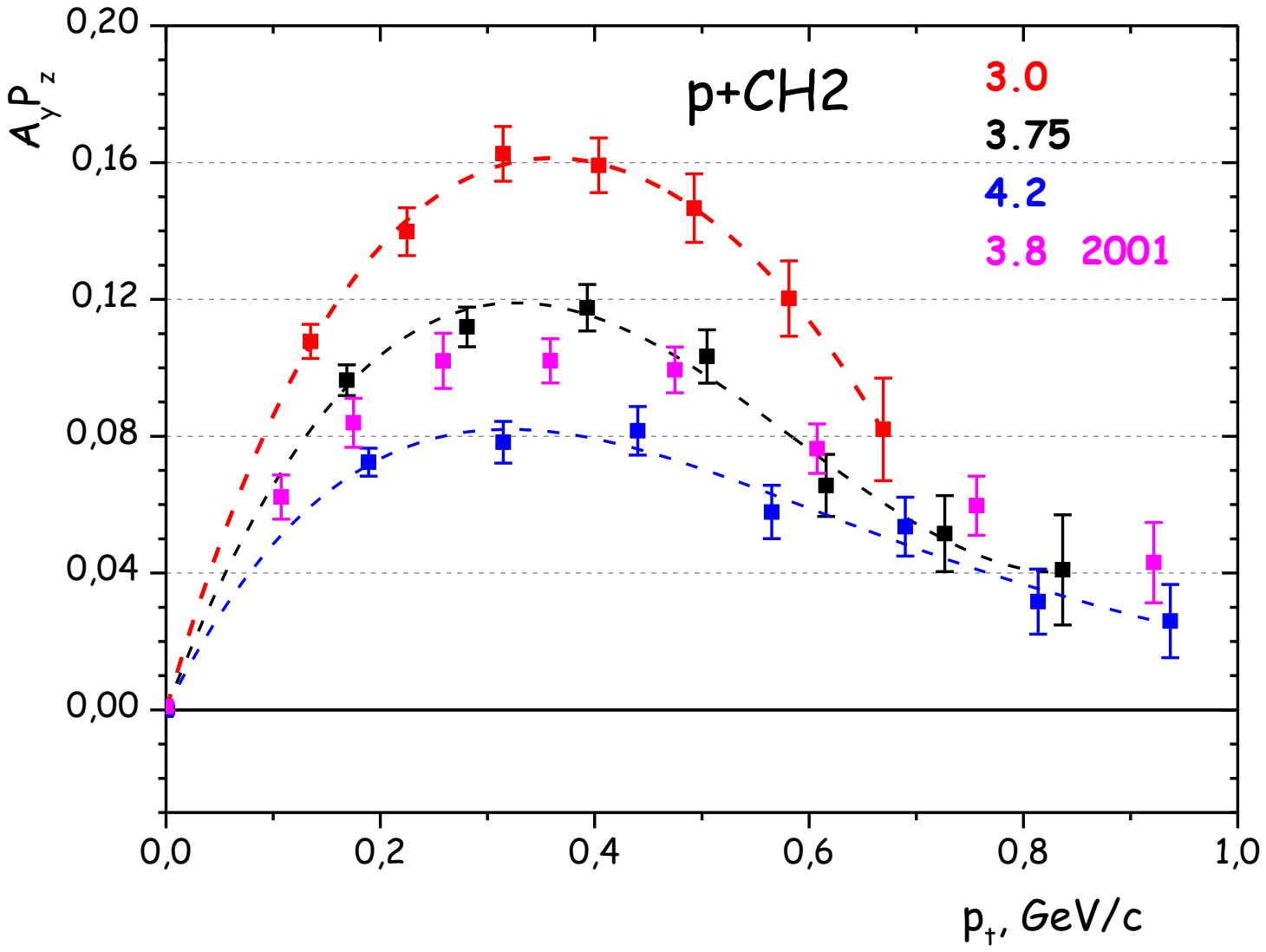


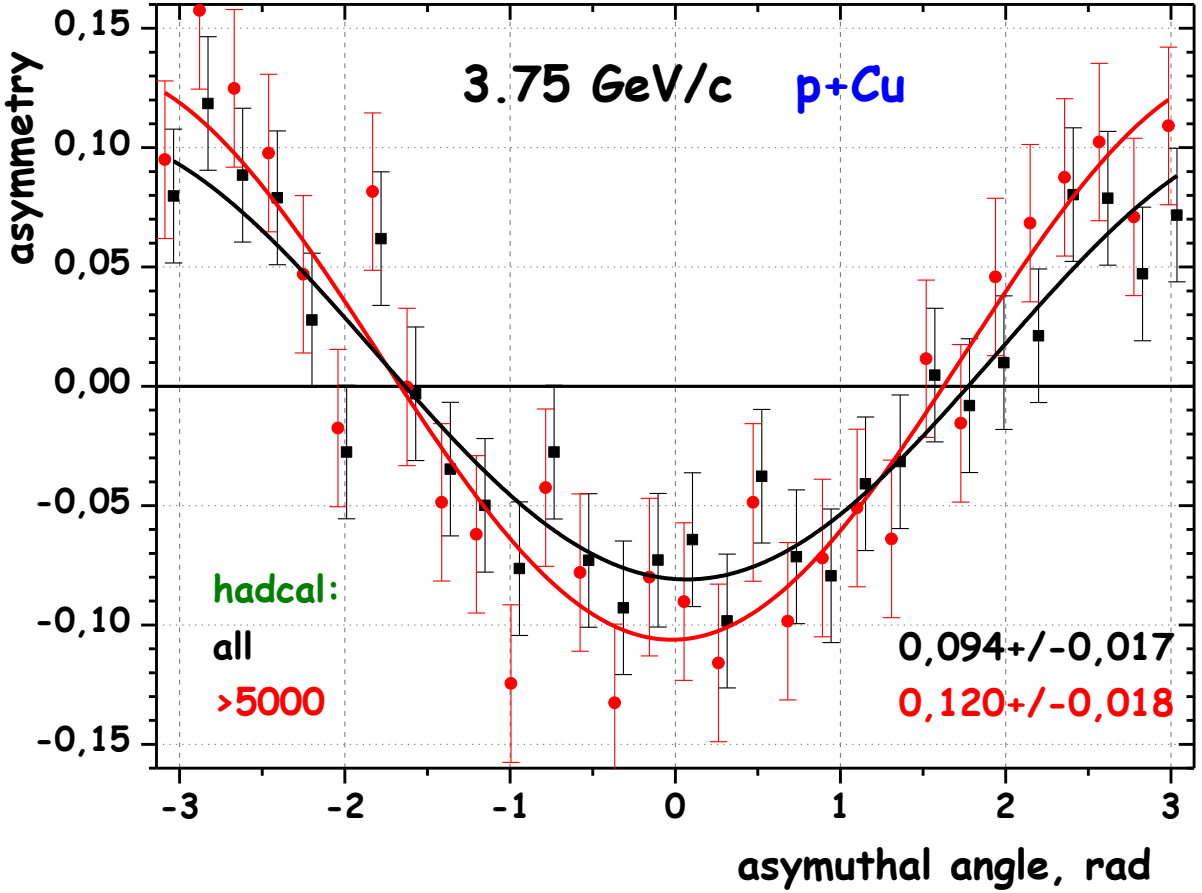


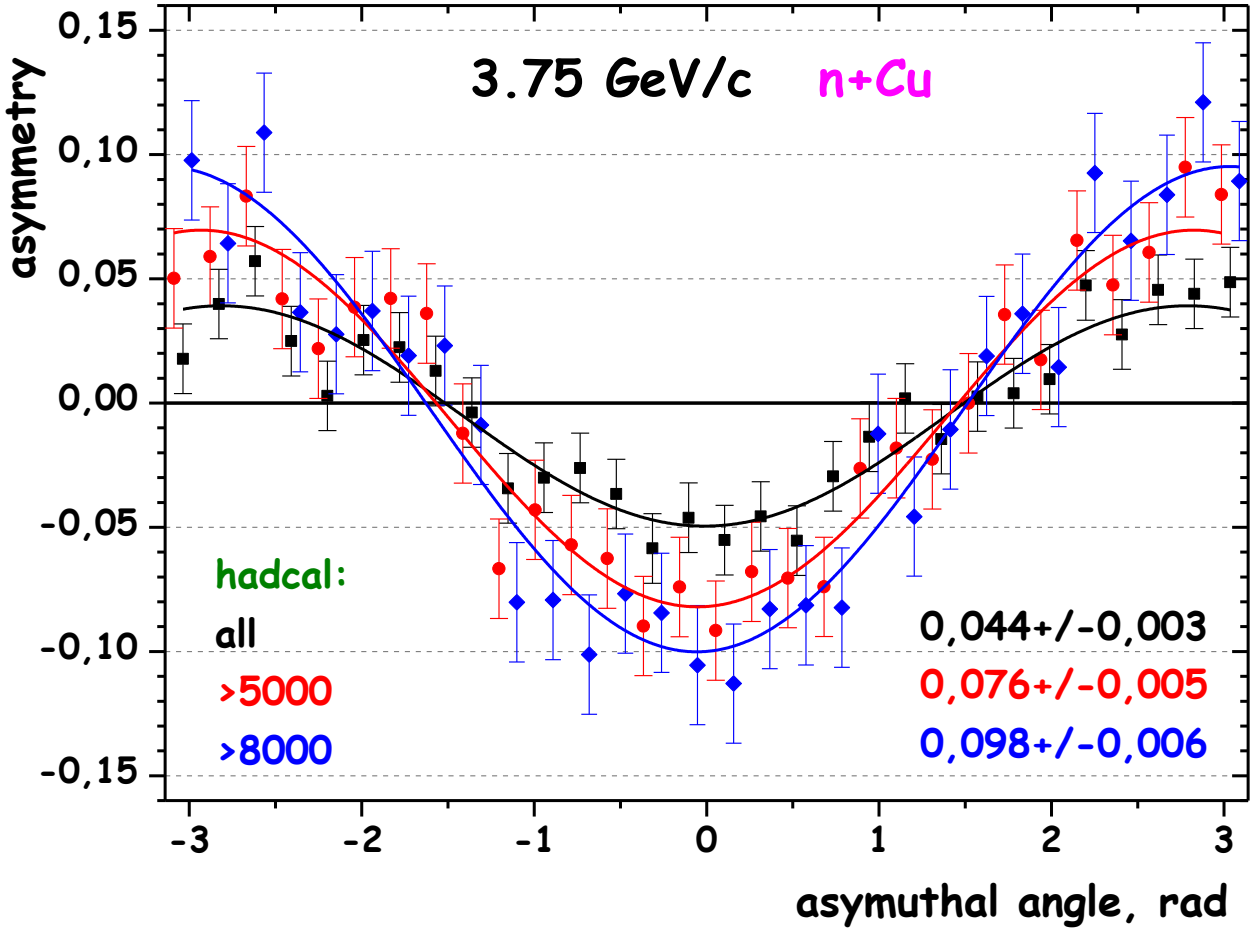
asymuthal angle, rad

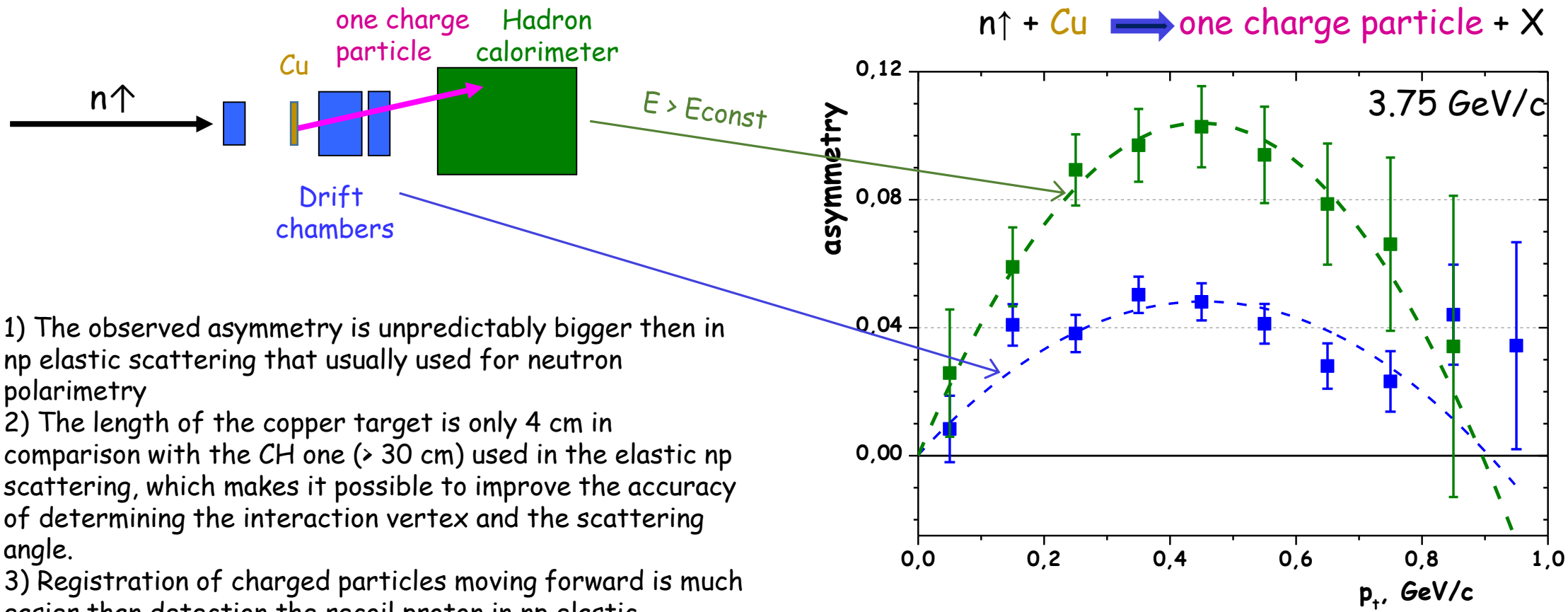

63,43
90
116,57
45
135
26.57
153,43
0 (360)
180
333,43
206,57
315
225
296,57
270
243,43
asymuthal angle, degree


p+CH2, 3.0 GeV/c Nov 16
tracks; 0,03 < θ < 0,24
hadcal without central part
asymmetry
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-3
-2
-1
0
1
2
3
asymuthal angle, rad


p+CH2
3.0
3.75
4.2
3.8 2001
$A_y P_z$
0,20
0,16
0,12
0,08
0,04
0,00
0,0
0,2
0,4
0,6
0,8
1,0
p_t, GeV/c


3.75 GeV/c p+Cu
asymmetry
asymuthal angle, rad
hadcal:
all
>5000
0,094+/-0,017
0,120+/-0,018


3.75 GeV/c n+Cu
asymmetry
asymuthal angle, rad
hadcal:
all
>5000
>8000
0,044+/-0,003
0,076+/-0,005
0,098+/-0,006



1) The observed asymmetry is unpredictably bigger then in np elastic scattering that usually used for neutron polarimetry
2) The length of the copper target is only 4 cm in comparison with the CH one (> 30 cm) used in the elastic np scattering, which makes it possible to improve the accuracy of determining the interaction vertex and the scattering angle.
3) Registration of charged particles moving forward is much easier than detection the recoil proton in np elastic scattering

The inverse reaction p+Cu (W) with detection neutron in forward direction by the hadron calorimeter can be used for measurement of the proton polarization at the NICA collider.

The ALPOM2 setup was designed to measure analyzing powers from different analyzer targets, for protons and neutrons. It includes a large size calorimeter to help eliminate 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 point in 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, that the beam polarization, intensity and stability are appropriate for this

Schedule of the experiment:

2019 year	**Modification of neutron channel upto 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 kS
Constructing of mechanical support, gases	5 k$
Reception and sending of the experts	15 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$

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

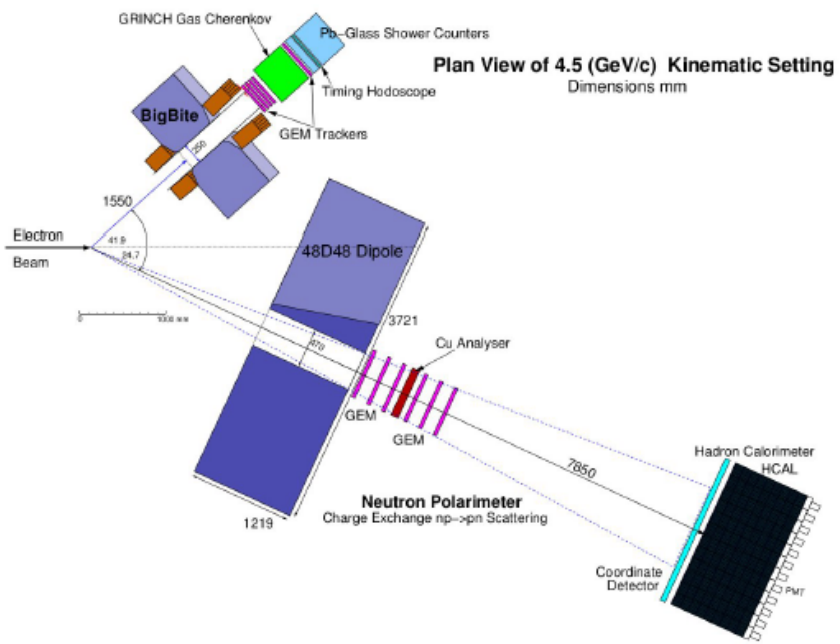
Slovak Republic grants – 22 k$, HV supply, computers, electronic modules

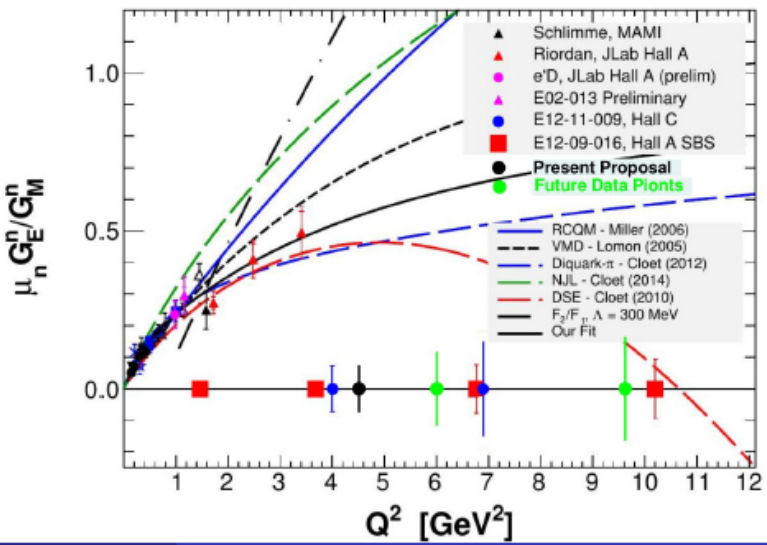
Neutron Form Factor Ratio G_E^n/G_M^n - 3

- E12-17-004 in Hall A (Annand, Bellini, Kohl, Psikunov, Sawatzky, Wojtsekhowski).
- Polarization transfer using $^2\mathrm{H}(\vec{e}, e'\vec{n})p$:

$$\frac{G_E^n}{G_M^n} = -\frac{P_t}{P_l}\frac{E+E'}{2M}\tan\left(\frac{\theta_e}{2}\right)$$

- Electron arm: Super Big Bite Spectrometer.
- Neutron arm: HCal, neutron polarimeter, CDet coordinate detector, scintillation counter.
- Kinematics: $\mathrm{Q}^2 = 4.5\ (\mathrm{GeV/c})^2$.
- Beamtime: 5 days.
- Systematic uncertainties about 3%.
- Statistical uncertainties about 8%.
- Will test extension of neutron polarimetry to high Q^2.
- Expected in the next 2-3 years.





Форма № 29

Смета затрат по проекту: **Измерение анализирующих способностей реакций p+CH2 до 7.5 ГэВ/с и n+A до 6.0 ГэВ/с на Нуклотроне (проект АЛПОМ2).**

№№ пп	Наименование статей затрат	Полная стоимость	1 год	2 год	3 год
	Прямые расходы на Проект	42.0	16.0	16.0	10.0
1.	Ускоритель, Нуклотрон	336		168	168
2.	ЭВМ (тип)				
3.	Компьютерная связь				
4.	КБ				
5.	ООЭП	1000	1000		
6.	Материалы	7.0	3.0	2.0	2.0
7.	Оборудование	10.0	3.0	4.0	3.0
8.	Оплата НИР, выполняемых по договорам	10.0	5.0	5.0	
9.	Командировочные расходы в т.ч.	15.0	5.0	5.0	5.0
	а) в страны нерублевой зоны	9.0	3.0	3.0	3.0
	б) в городах стран рублевой зоны				
	в) прием иноспециалистов	6.0	2.0	2.0	2.0

Руководитель Проекта Н.М. Пискунов

Директор Лаборатории В.Д. Кекелидзе

Ведущий инженер-экономист Лаборатории Г.Г. Волкова

Reference on the ALPOM2 project

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

Main goal of the ALPOM2 project is measurements of analysing powers for nucleon (proton and neutron) scattering on different targets at polarized nucleon momentum up to 7.5 GeV/c at the JINR VBLHE accelerating complex. These investigations became available after completion of construction of the new polarized ions source, modernization of the LINAC and increasing energy of slow extraction beam.

Upgrade of the setup includes replacement of proportional chambers by drift chambers tubes in a head part of a track system and modernisation of registration electronics and data acquisition system. The new track detectors allow improving accuracy of scattered angle measurements. In order to reject low energy hadrons scattered from the target the hadron calorimeter was integrated in the experimental setup.

During beam runs in 2016-2017 years new experimental data of the analysing powers at neutron momentum 3.0, 3.75 and 4.2 GeV/c were obtained with different targets by registration a charged particle in forward direction. Unexpected significant asymmetries in np charge-exchange reaction on Cu that increase two times when the hadron calorimeter response applied are observed.

Taking into account this result a new proposal "Measurement of the Ratio G_{En}/G_{Mn} by the Double-polarized ^2H (e(pol), e' n(pol)) Reaction" has been approved.

It is planned to measure the vector analysing power of reaction p+CH2 at polarized proton momentum of 7.5 GeV/c which was postponed by low intensity and polarization of primary deuteron beam.

After modification of the head part of neutron channel increasing neutron momentum upto 6 GeV/c a new data will be obtained for the highest possible neutron analysing powers.

The funding required from JINR (42 k$) for modernization of the neutron chaneel and support of collaboration contacts should be considered as feasible.

I would recommend this proposal for prolongation for 2018-2021 years with the 1st priority.

Anatoli V. Zarubin, PhD, VBLHEP JINR

Anatoli.Zaroubin@cern.ch

April 2, 2018

Reference on the APLOM2 project
Measurement of analyzing powers for the reaction p(pol)+CH2 up to 7.5 GeV/c and n(pol)+A up to 4.5 GeV/c at the Nuclotron

Elastic electromagnetic form factors of the nucleon at high transferred momenta Q^2 contain an unique information on the radial distribution of electric charge and magnetic moment inside the nucleon. At Jefferson Lab (JLab), four nucleon form factors have been measured up to Q^2=8 GeV^2 with polarized electron beam up to 6 GeV and have demonstrated very interesting features widely discussed in current literature and many conferences. Knowledge of the all four nucleon form-factors allows to separate contribution of quarks of different flavor. On the whole, this experimental data provide a test of QCD, and several theoretical models based on non-perturbative approaches have been developed to explain the JLab data on the form factor ratio. The Jlab proposal for double-polarization measurements up to 12 GeV with transferred momentum Q^2 up to 12-15 GeV^2 is approved by the Jlab PAC. Since polarization of the recoil nucleon has to be measured in this experiment, one has to know analyzing powers of the suitable reactions with polarized initial proton and neutron at corresponding higher energies that is the aim of the APLOM2 project.

Within the APLOM2 project, the analyzing powers for polarized proton and neutron beam at different targets (C, CH, CH2 and Cu) were measured at momenta 3.0, 3.75 and 4.2 GeV/c. These measurements show the valuable asymmetries when the charge-exchange np reaction is registered. In new measurements drift chambers were used that provides a high accuracy of the scattered angle measurements, and hadron calorimeter used in order to reject low energy hadrons scattered off the target. All equipment required to make this experiment is available at VBLHEP/JINR. The required funds, some part of which is provided by foreign partners, are necessary mainly for reconstruction of magnetic channel in order to increase the neutron momentum that in its turn will be important for new measurements of the analyzing power of the reaction {\vec p}+CH2-> p+X at proton momentum 7.5 GeV/c and for measurement of asymmetries in the charge-exchange p+A(CH2)-> n+X reactions.

Realization of this project will allow one to obtain new data on analyzing powers for the reactions induced by protons and neutrons on C, CH2, Cu that is required for the Jlab experiment aimed for measurement of electromagnetic proton and neutron form factors up to Q^2=12-15 GeV^2 . Furthermore, it will offer a possibility to perform at JINR Nuclotron other polarization experiments at the corresponding energies.

I would recommend this project for realization with the first priority.

Yuriy N. Uzikov, doctor of science,
leading researcher of DLPN, JINR
uzikov@jinr.ru
April 4, 2018