Recommendation. The PAC supports the group's plan to pursue this experiment and recognizes that it will secure JINR's leadership in polarimetry equipment and study. The PAC notes the possible difficulties in allocating the requested 336h of polarized deuteron beam in 2022–2023, due to the strong competition for, and the limited availability of, beam time in this period. The PAC recommends continuation of the ALPOM-2 experiment till the end of 2023 with ranking A.

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 2024-2026 years

S.N. Bazylev, O.P. Gavrishchuk, A.A. Druzhinin, D.A. Kirillov, N.V. Kostayeva, Yu.T. Kiryushin, K.S. Legostaeva, A.N. Livanov, I.A. Philippov, N.M. Piskunov, 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

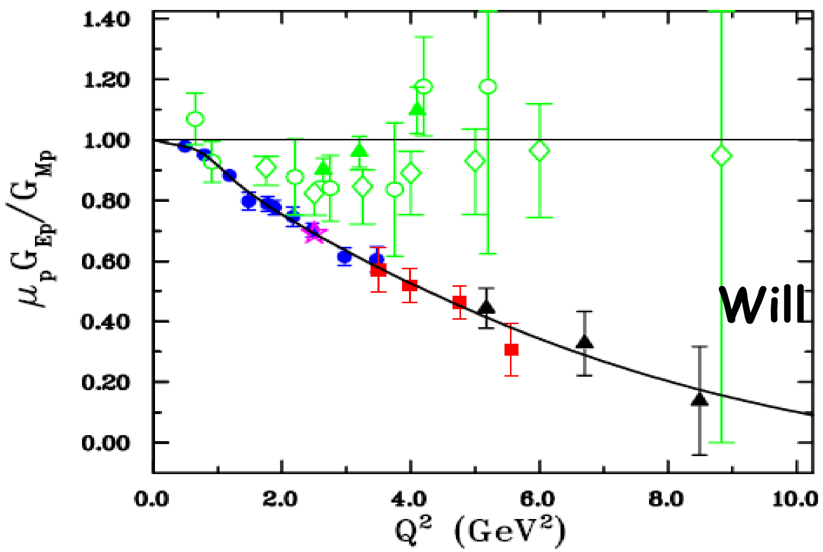
D. Marchand

IPN Orsay, 91406 ORSAY cedex, France

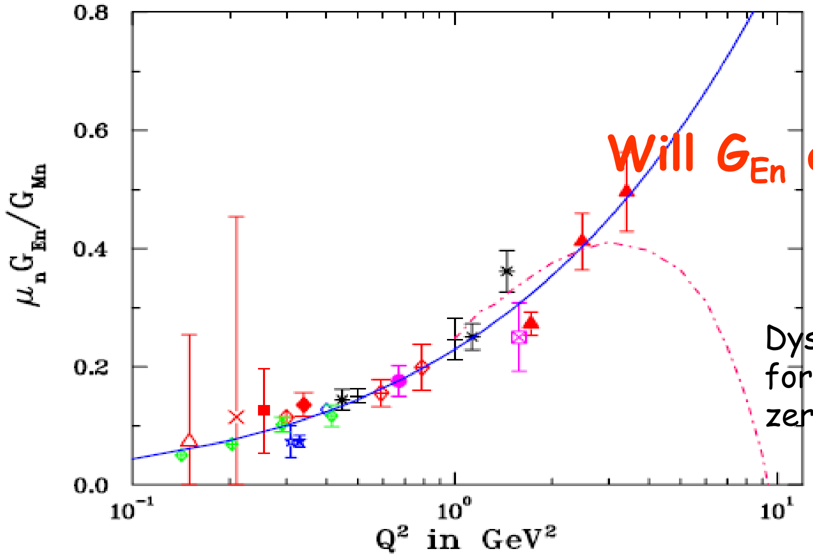
J. R.M. Annand, K. Hamilton, R. Montgomery

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

Nucleon formfactors



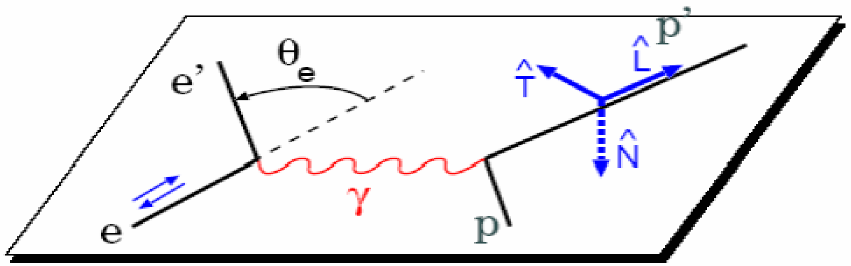
Will G_{Ep} become zero?



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

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

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

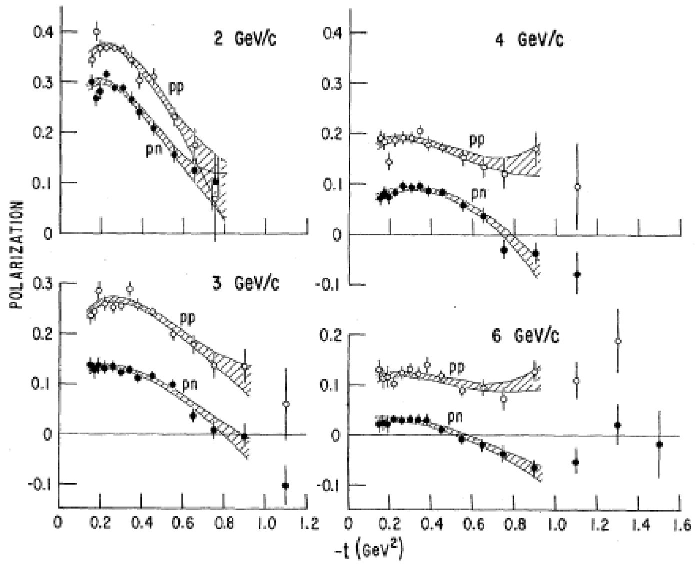
No error contributions from analyzing power and beam polarization measurements

Neutron polarimetry

pp -> pp
pd -> pn + (p)
Phys. Rev. Lett 35 (1975) 632

A_y

decreasing with energy



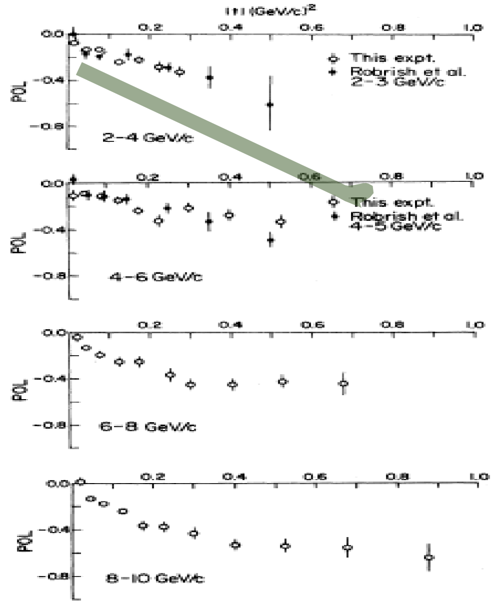
The existing data for A_y in np elastic scattering indicate that the analyzing power decreases faster than the pp analyzing power, becoming very small, then negative around 6 GeV/c neutron momentum.

Phys. Rev. Lett 30 (1973) 1183

np -> pn

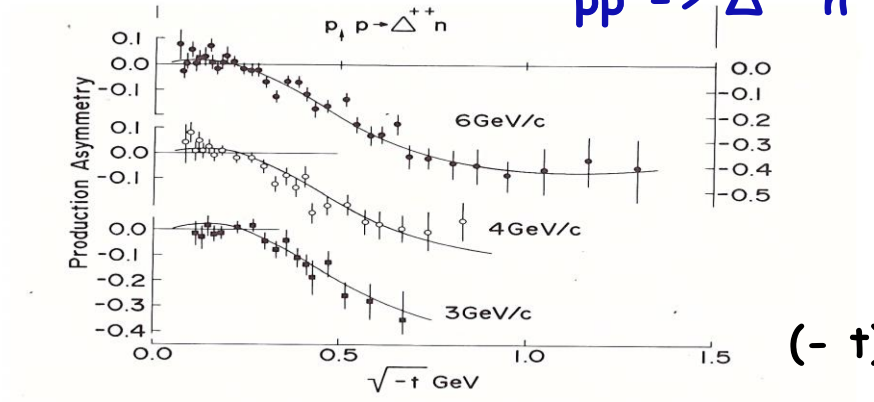
- t, GeV^2

increasing with energy



A_y

pp -> Δ^{++} n SPD ?

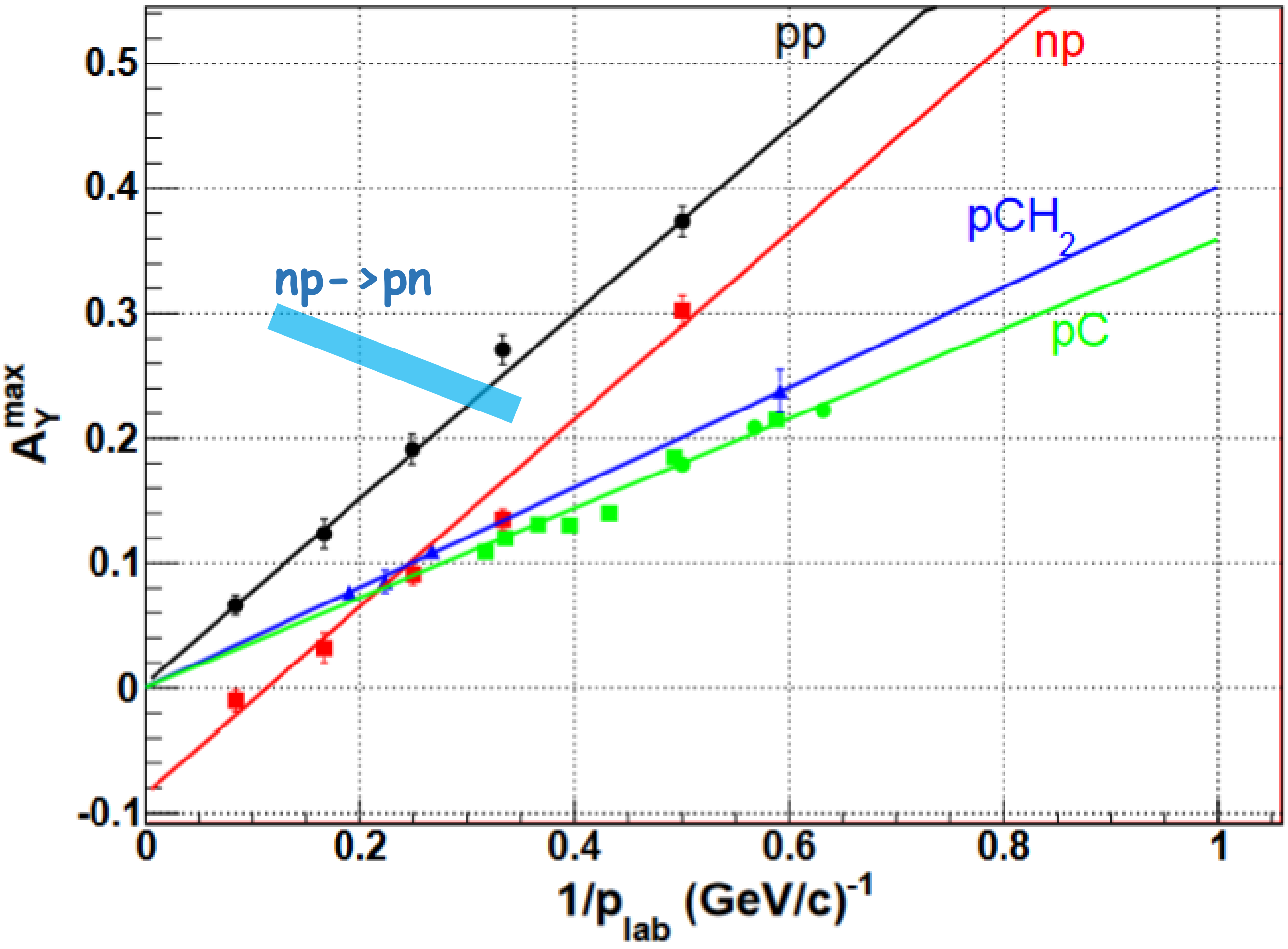


(- t)$^{1/2}$, GeV

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.

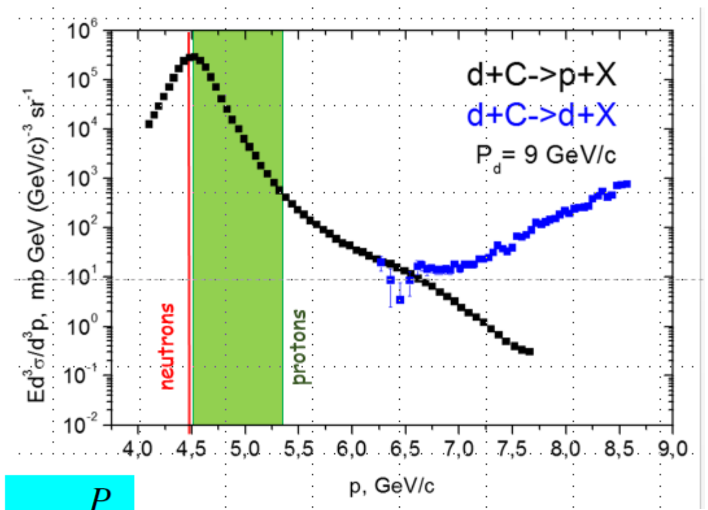
Charge exchange reaction

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

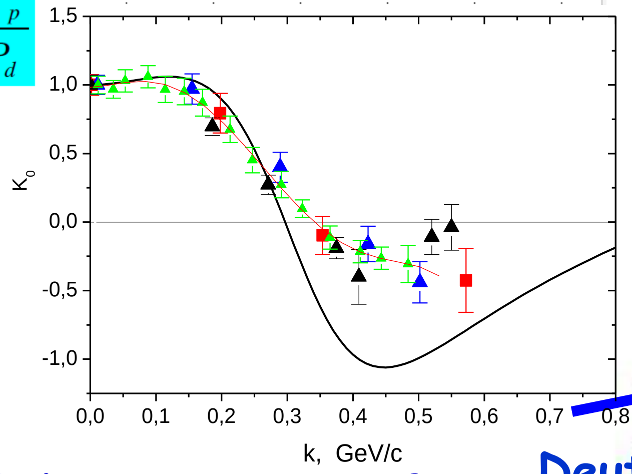


Black circles: ANL d(p,p)n data [29, 30]; black line: linear fit. Red squares: ANL d(p,n)p data [29, 30]; red line: linear fit. Blue triangles [25]: p+ CH2→charged+X; blue line: linear fit [25]. Green squares [31] and circles [32]: p+ C→charged+X; green line: linear fit [25].

Deuteron fragmentation

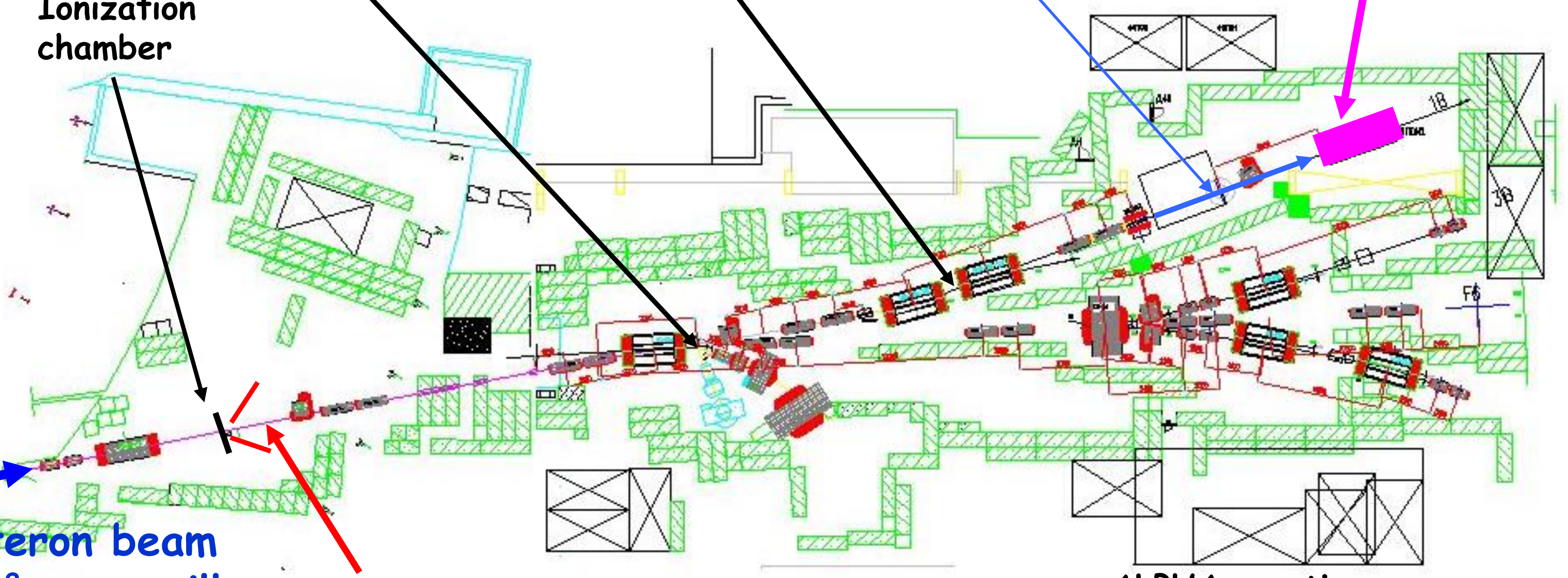


$$k_0 = \frac{P_p}{P_d}$$



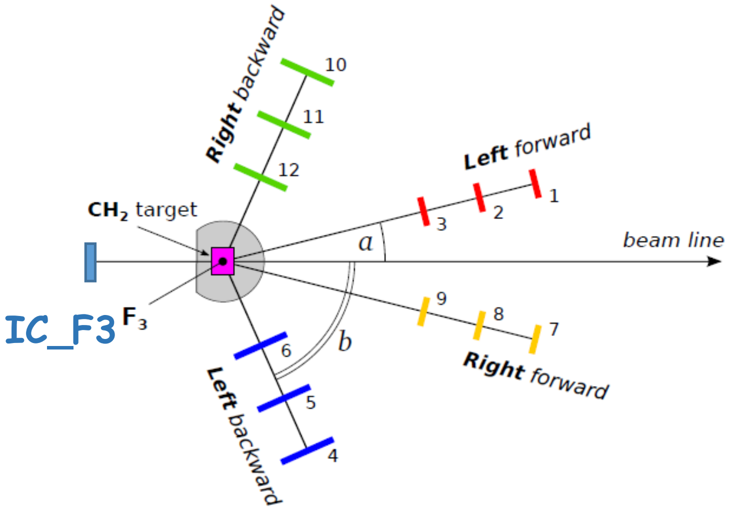
Polarization transfer

Polarized proton and neutron beams



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

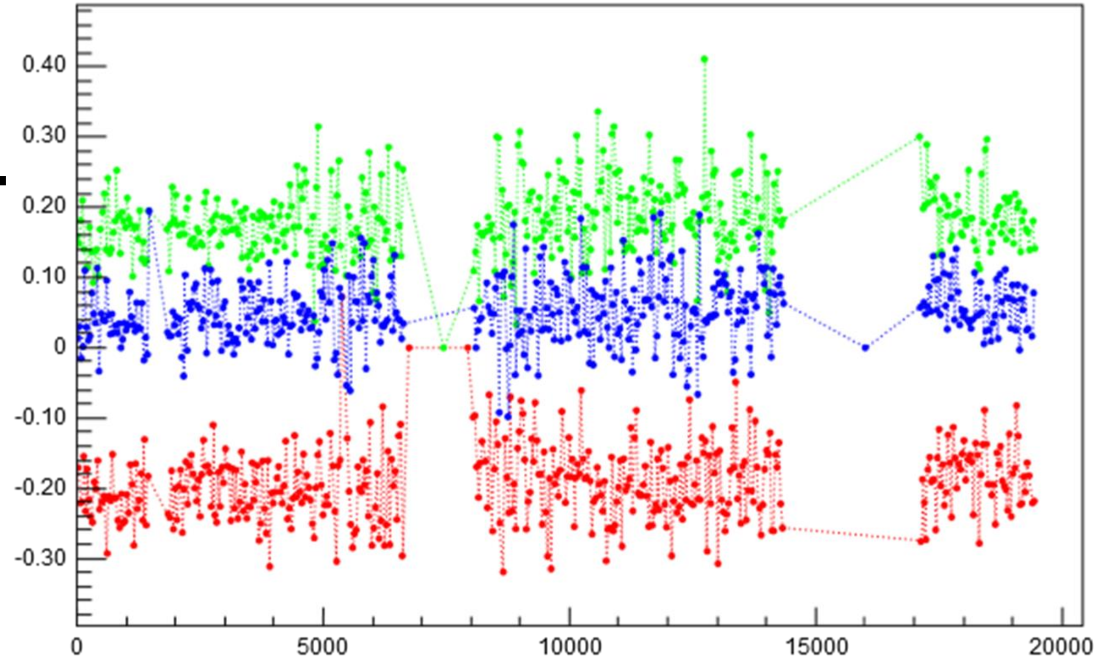
Beam polarization measurements



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

About 5 hours

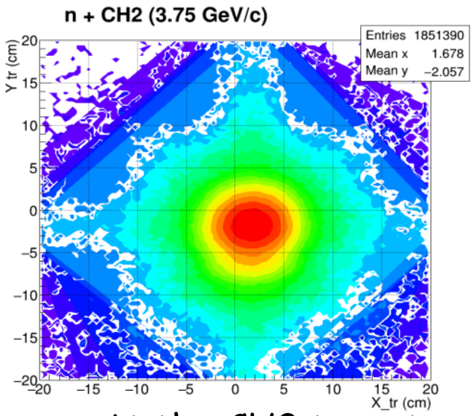
each point corresponds to one spill.



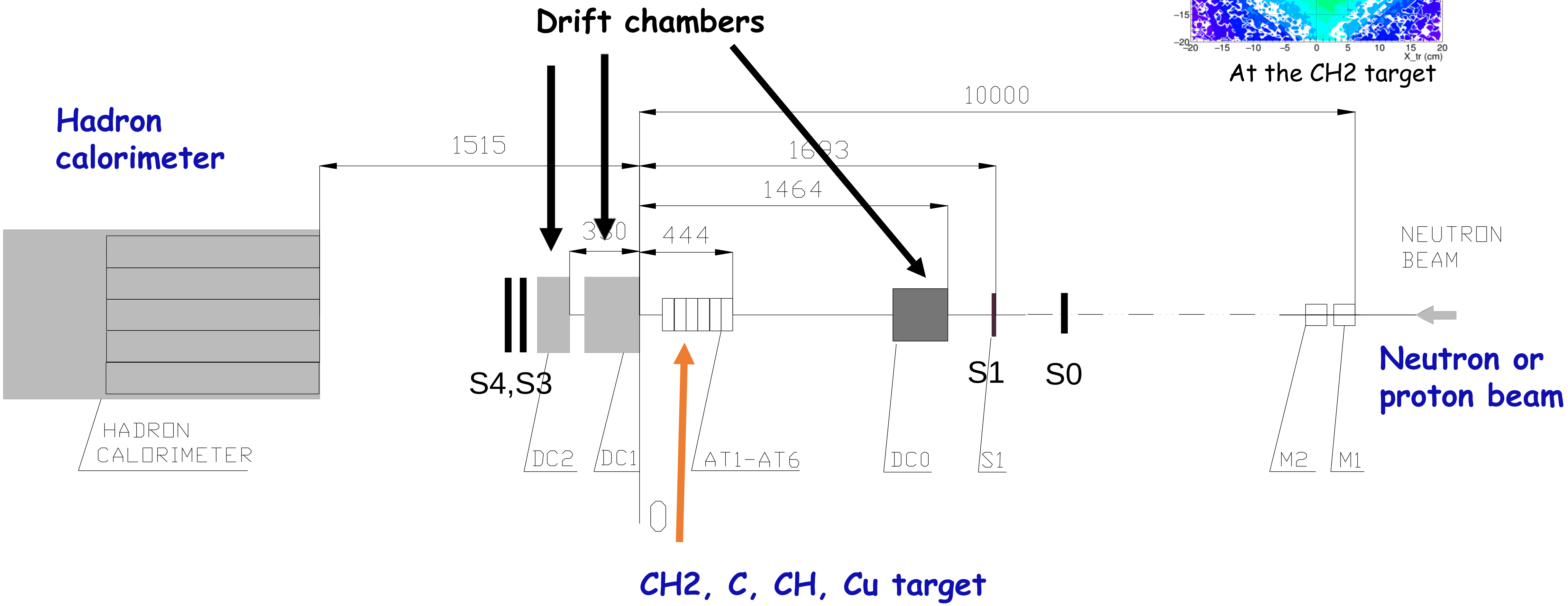
The polarization in one mode
is two times lower than
the other one

P(+) – P(-) = 0,96 ± 0,05

Layout of the setup



At the CH2 target



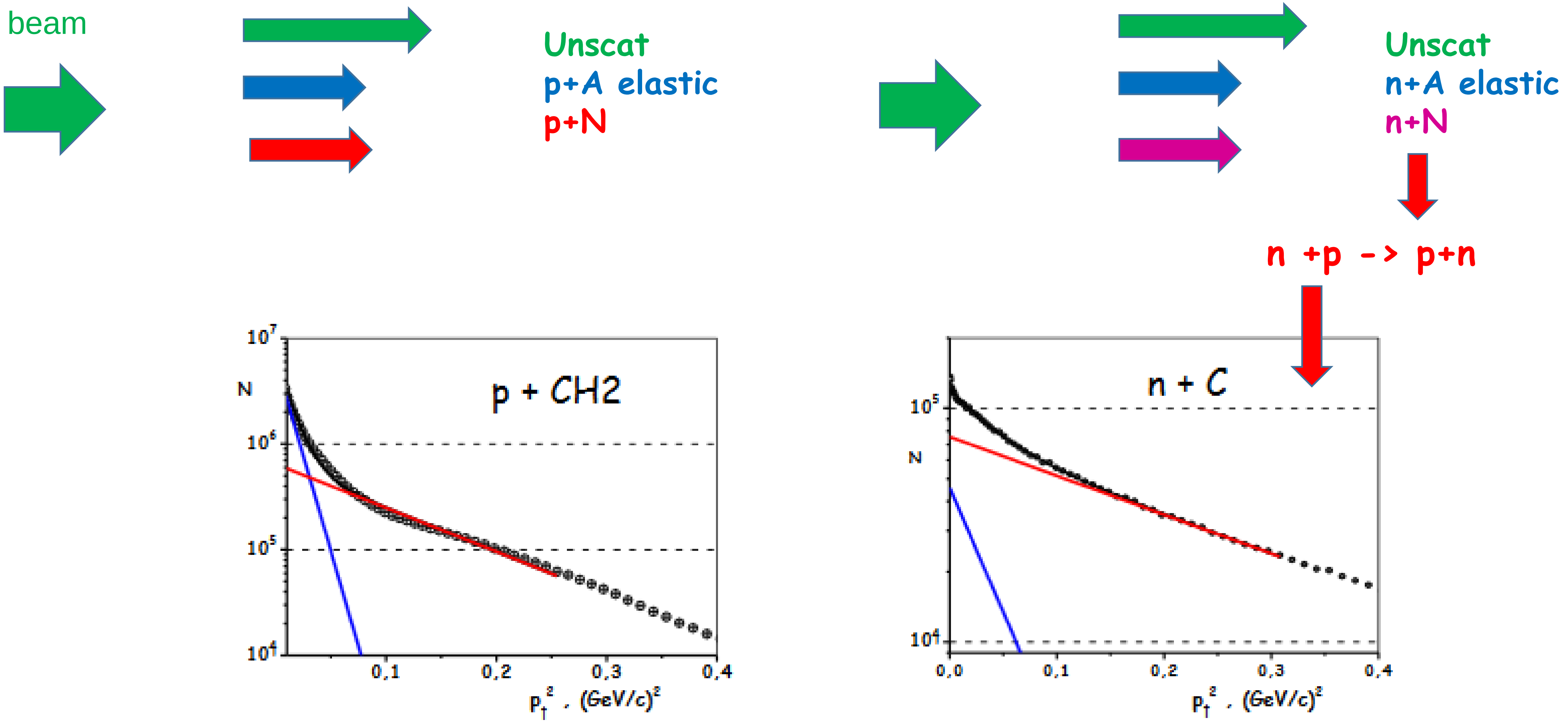
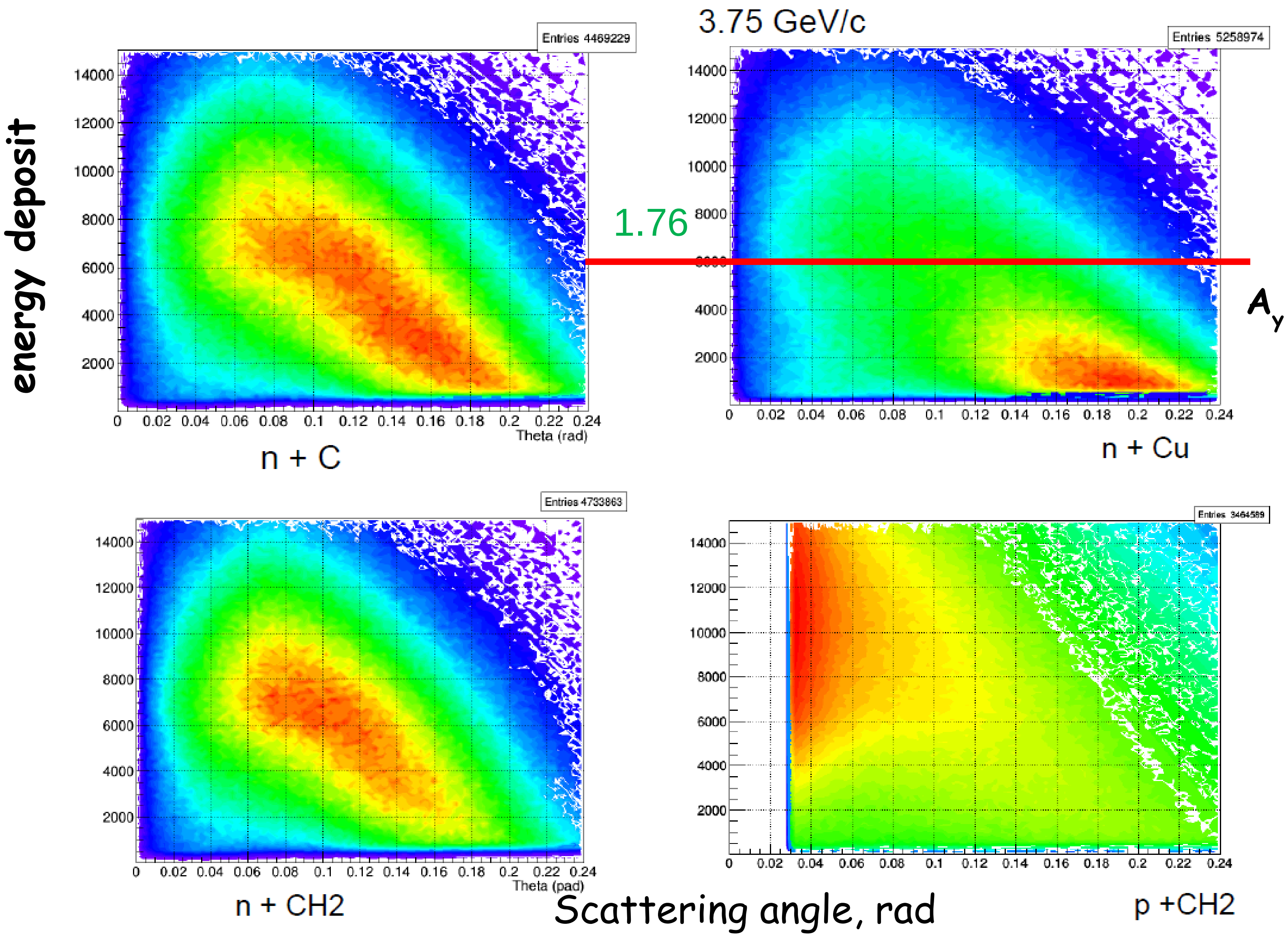


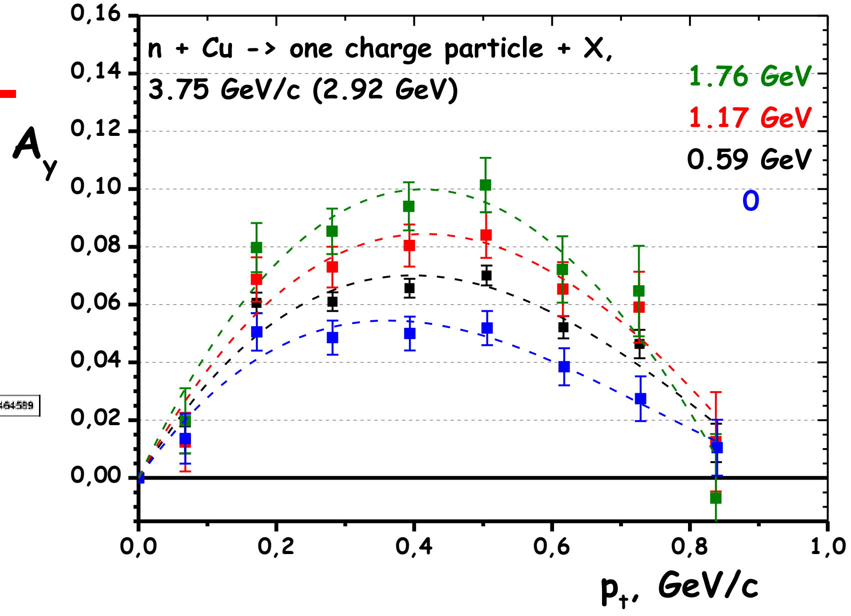
Fig. 14. pt2 -distribution for p + CH2 scattering at 3.75 GeV/c. The black curve is the sum of exponential functions with slope parameters b'1 (blue) and b'2 (red).

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

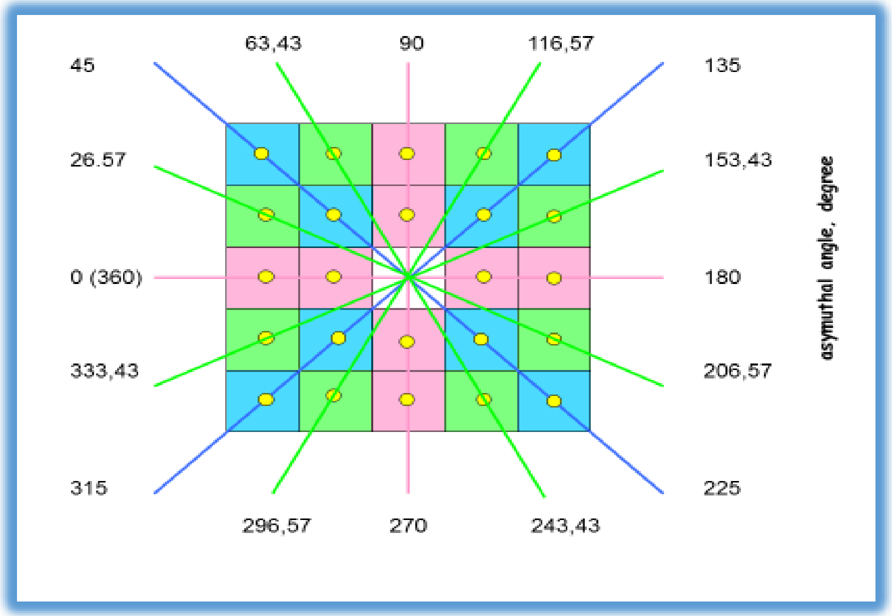




Hadron calorimeter 2

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

Azimuthal segmentation available from the hadron calorimeter for asymmetry measurements



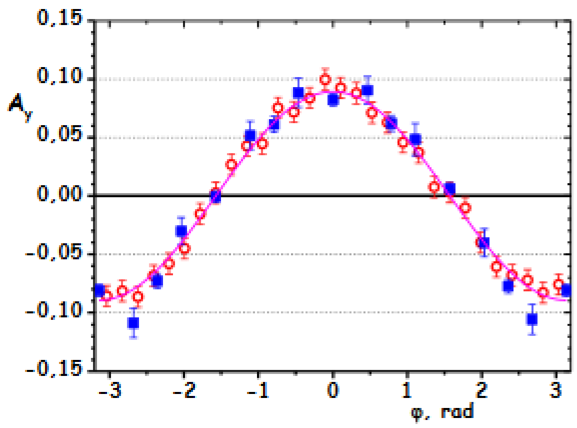


Fig. 17. Azimuthal dependence Ay for p + CH2 scattering at a momentum of 3.0 GeV/c, obtained from the triggered modules of the hadron calorimeter (blue squares) and from the tracks (red circles)

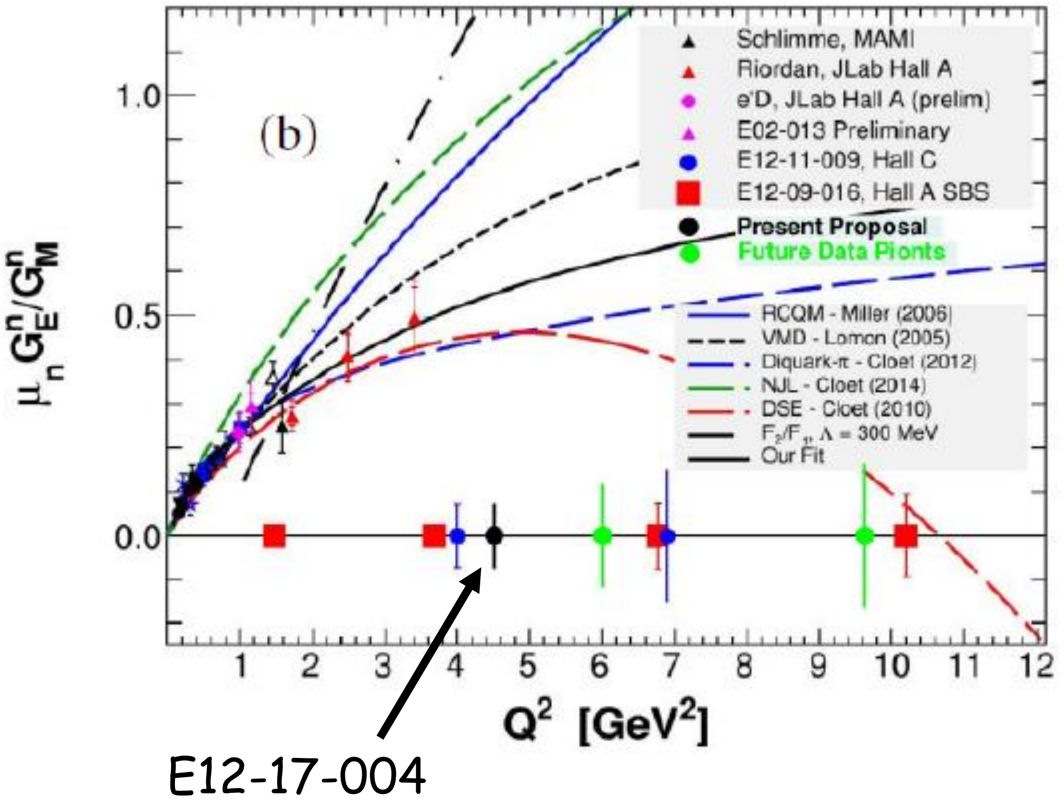
The asymmetry as a function of the azimuthal angle from the calorimeter (blue squares) and from the drift chambers (red circles)

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, see Appendix 1 and Figure. , which presents the current state and planned measurements of neutron electromagnetic form factors.



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

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.

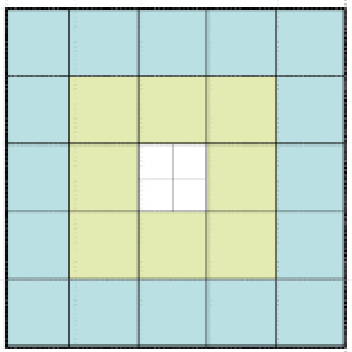


Fig. 12. ALPOM2 calorimeter layout: central part consist of 4 modules with sizes 7.5×7.5 cm^2, peripheral part contains 24 modules of 15×15 cm^2

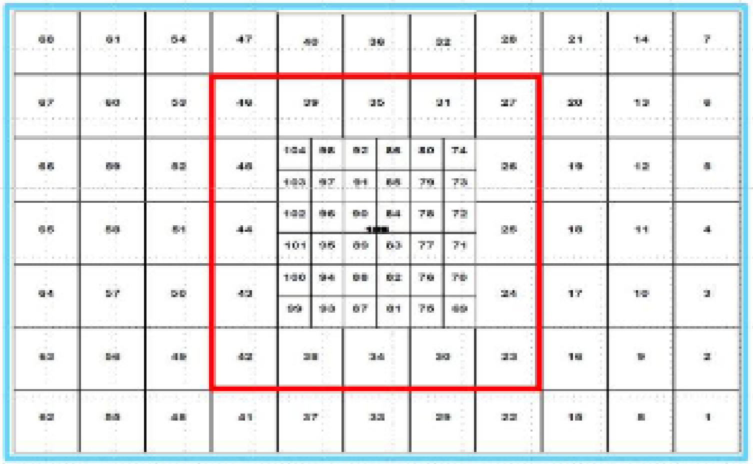
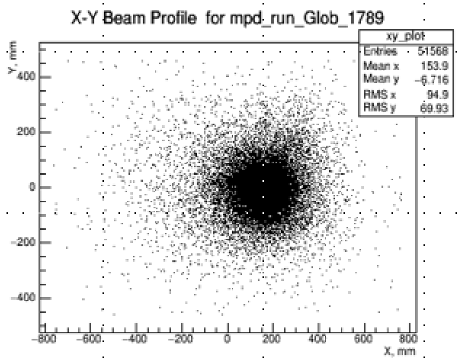
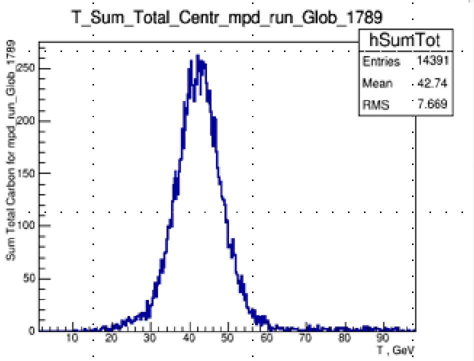


Fig. 13. ZDC layout: central part consist of 36 modules with sizes 7.5×7.5 cm^2, peripheral part contains 68 modules of 15×15 cm^2





Drift chambers (plane configuration)

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

New drift chambers

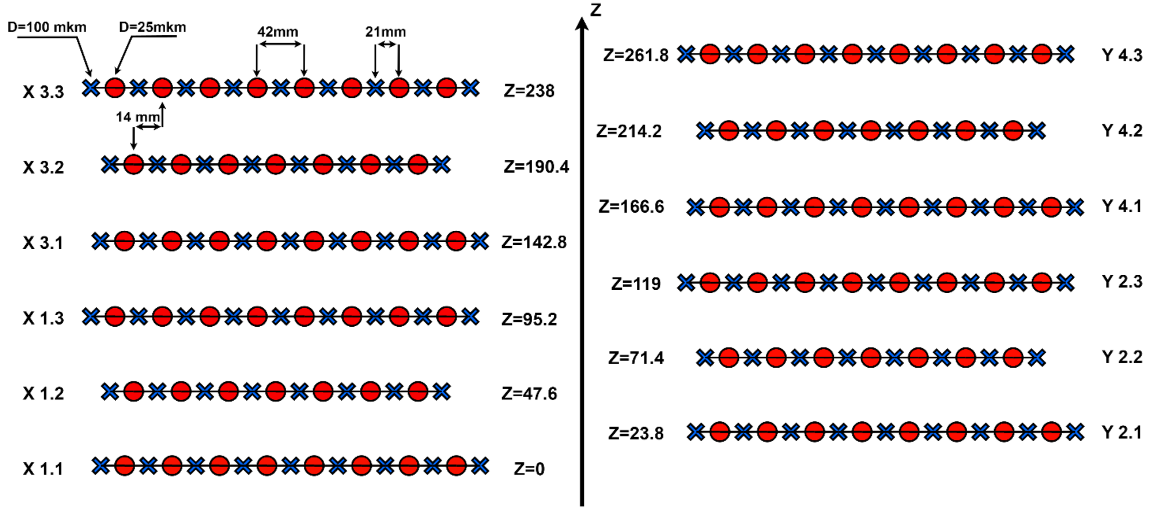
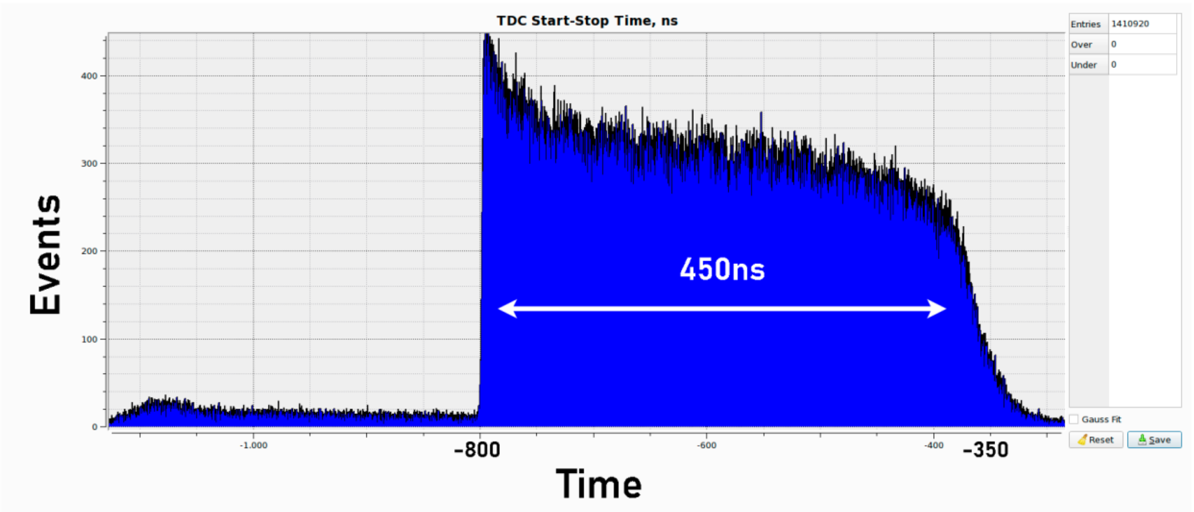
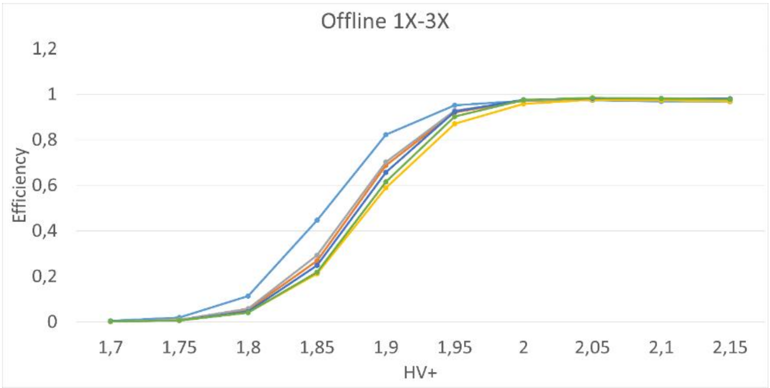


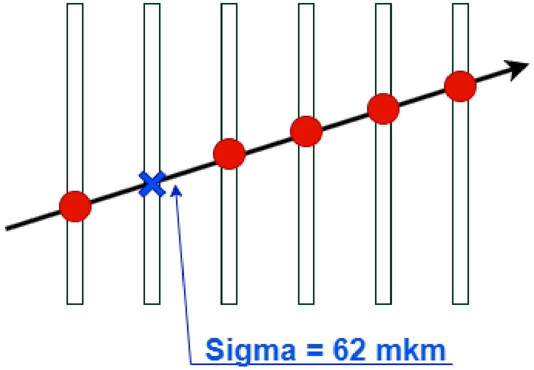
Схема расположения сигнальных и потенциальных проволочек в X и Y-плоскостях

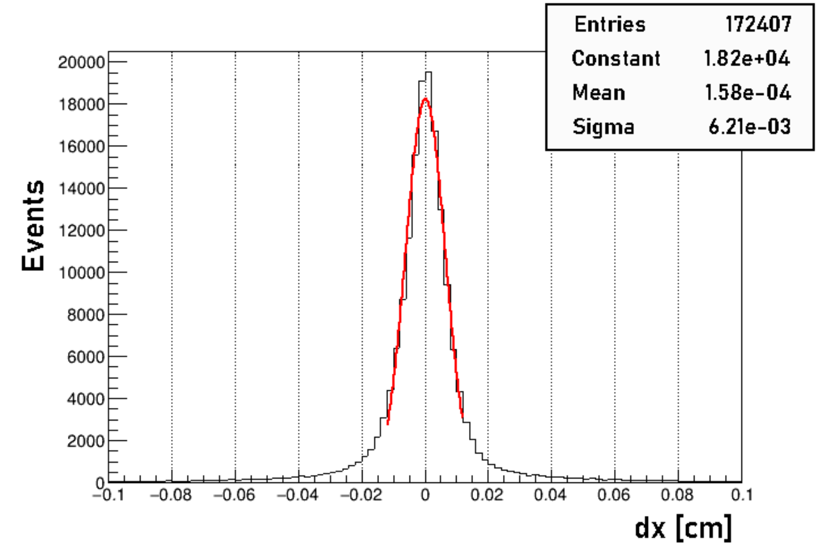


Распределение по времени дрейфа, ширина составляет 450 ns, что соответствует дрейфовому промежутку 21 mm.



Зависимость эффективности регистрации трека частицы (космического мюона) от высокого напряжения на сигнальных проволочках. Плато эффективности 200 V идет от 1.95 до 2.15 kV.





Schedule of the experiment:

2023 year	Installation of the ZDC at the neutron beam line
2024-2025 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 .
2025-2026 year	Data analyzes and publication of the results.

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

Proposed schedule and resource request for the Project

Expenditures, resources, funding sources			Cost (thousands of US dollars)/ Resource requirements	Cost/Resources, distribution by years				
				1st year	2nd year	3rd year	4th year	5th year
		International cooperation	60	20	20	20		
		Materials	30	10	10	10		
		Equipment, Third-party company services	270	90	90	90		
		Commissioning						
		R&D contracts with other research organizations	30	10	10	10		
		Software purchasing						
		Design/construction						
		Service costs (*planned in case of direct project affiliation)*						
Resources required	**Standard hours**	Resources						
		– the amount of FTE,						
		– accelerator/installation,	336	168	168			
		– reactor,…						
Sources of funding	**JINR Budget**	JINR budget *(budget items)*	390	130	130	130		
	Extra fudning (supplementary estimates)	Contributions by partners Funds under contracts with customers Other sources of funding						

Project Leader__________/_________________/

Laboratory Economist __________/_________________/

3. Manpower

3.1. Manpower needs in the first year of implementation

3.2. Available manpower

3.2.1. JINR staff

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	0.9
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	0.9
6	Livanov A.N.	ZDC, polarimeter, data taking	0.1
7	Druzhinin A.A. (25 years)	ZDC, polarimeter, data taking	0.9
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	0.5
11	Lyubimtsev D.		1.0
		TOTAL FTE	**7.5**

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

Научный опыт авторов

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

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

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

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

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

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

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

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

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

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

Оценка кадровых ресурсов

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

Таблица 1. Участники проекта из ЛФВЭ:

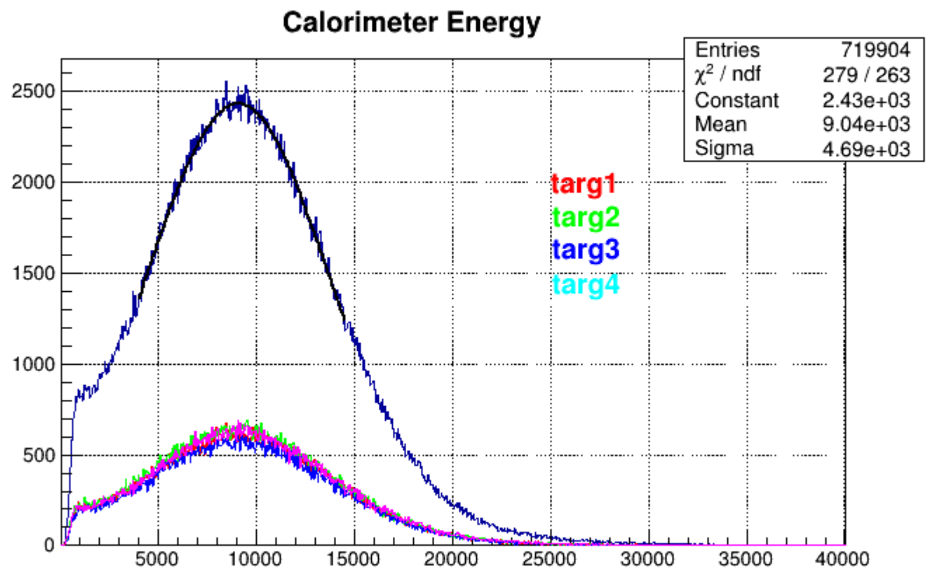
№	Фамилия	Обязанности	FTE
1	Пискунов Н.М.	Анализ, набор данных	0.8
2	Кириллов Д.А.	Анализ, набор данных	0.8
3	Ситник И.М.	Анализ, набор данных	1.0
4	Гаврищук О.П.	ZDC, набор данных	0.2
5	Шиндин Р.А	ZDC, поляриметр, набор данных	0.8
6	Ливанов А.Н.	ZDC, поляриметр, набор данных	0.5
7	Рукояткин П.А.	Пучки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

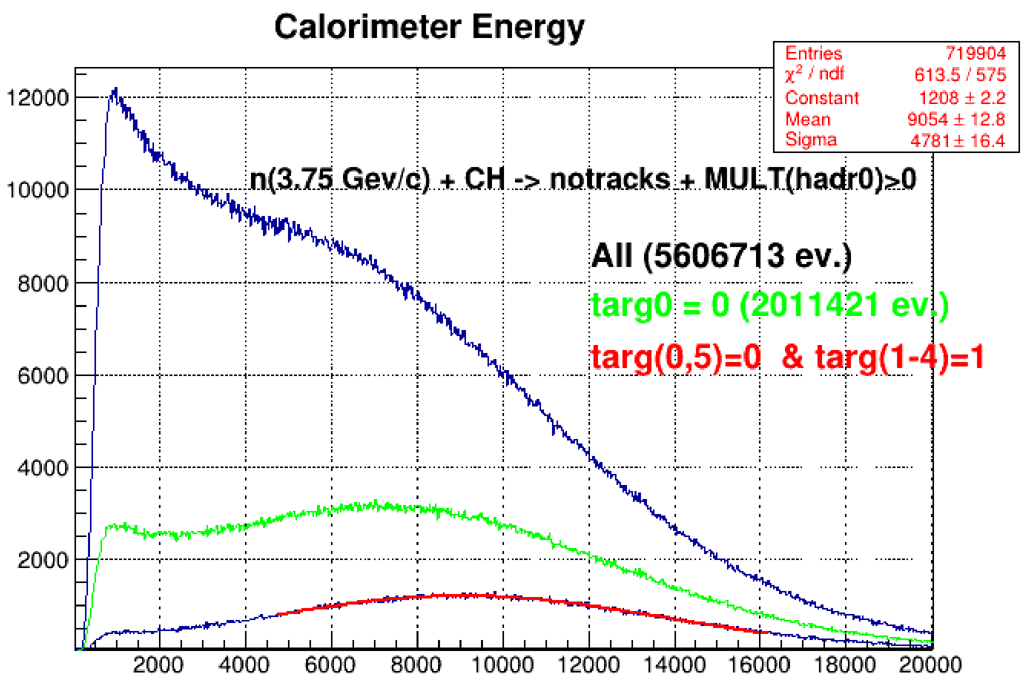
Таблица 2. Возраст молодых участников проекта.

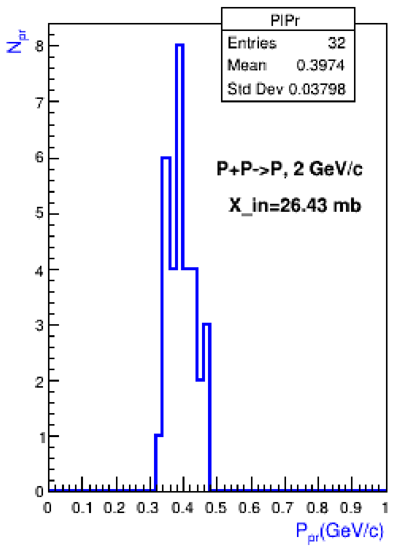
№	Фамилия	Возраст (лет)
1	Легостаева К.С.	27
2	Шипунов А.В.	34
3	Филиппов И.А.	36
4	Терлецкий А.В.	35

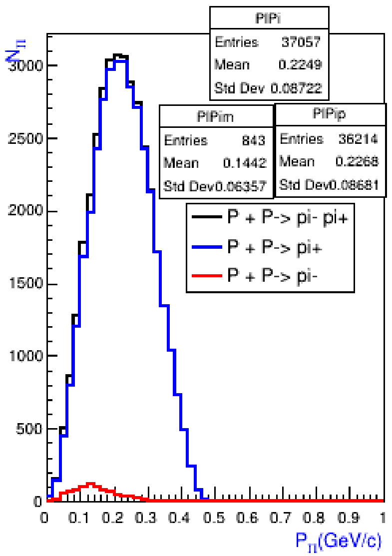
We are planning to continue the measurements at higher proton and neutron energies

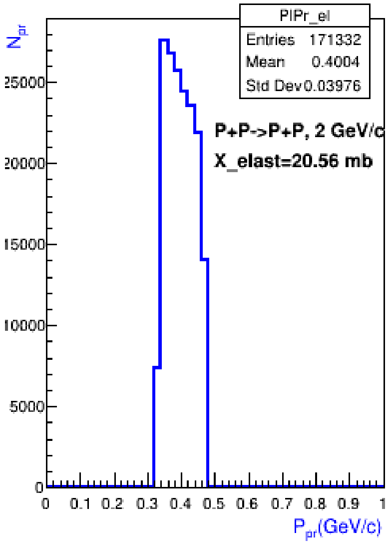
Thank you

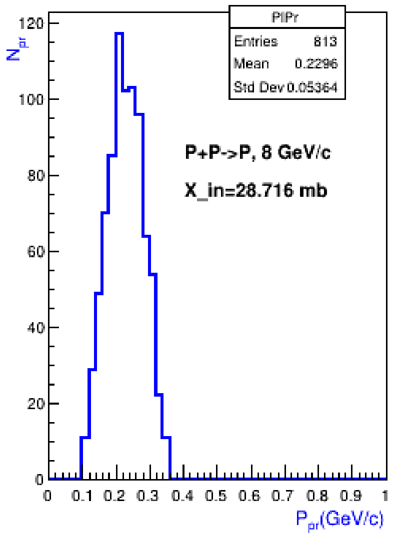

Calorimeter Energy
Entries 719904
χ² / ndf 279 / 263
Constant 2.43e+03
Mean 9.04e+03
Sigma 4.69e+03
targ1
targ2
targ3
targ4
2500
2000
1500
1000
500
0
5000
10000
15000
20000
25000
30000
35000
40000

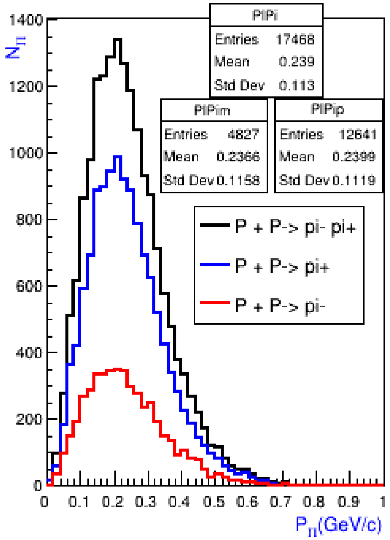

Calorimeter Energy
Entries 719904
χ² / ndf 613.5 / 575
Constant 1208 ± 2.2
Mean 9054 ± 12.8
Sigma 4781 ± 16.4
n(3.75 Gev/c) + CH -> notracks + MULT(hadr0)>0
All (5606713 ev.)
targ0 = 0 (2011421 ev.)
targ(0,5)=0 & targ(1-4)=1
12000
10000
8000
6000
4000
2000
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000

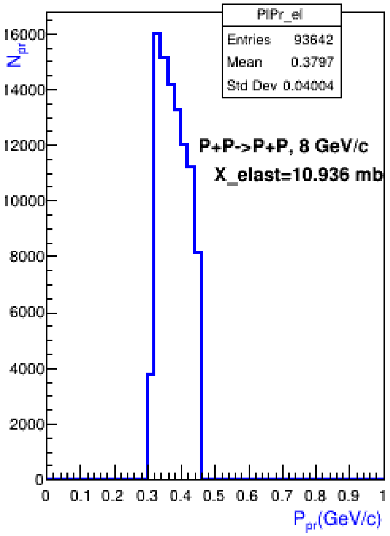

PIPr
Entries 32
Mean 0.3974
Std Dev 0.03798
P+P->P, 2 GeV/c
X_in=26.43 mb
N_{pr}
P_{pr}(GeV/c)

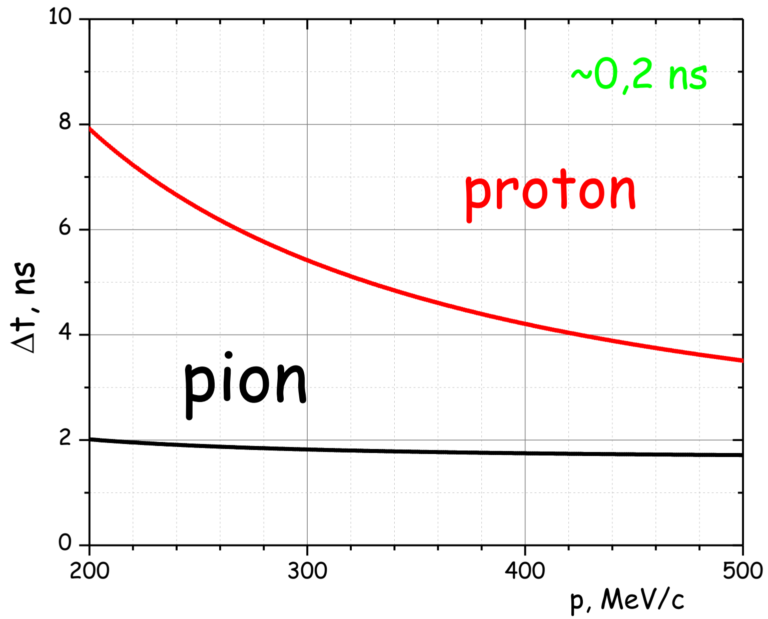

PIPi
Entries 37057
Mean 0.2249
Std Dev 0.08722
PIPim
Entries 843
Mean 0.1442
Std Dev 0.06357
PIPip
Entries 36214
Mean 0.2268
Std Dev 0.08681
P + P-> pi- pi+
P + P-> pi+
P + P-> pi-
N_{π}
P_{π}(GeV/c)

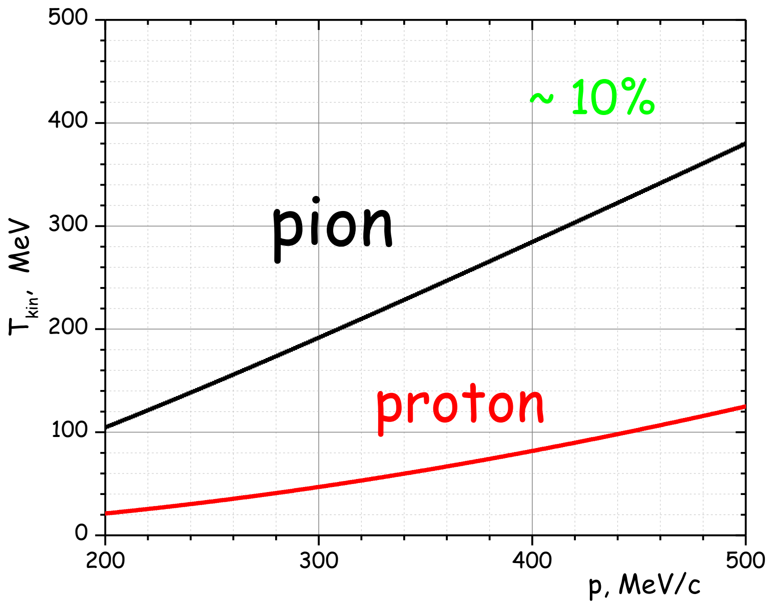

PIPr_el
Entries 171332
Mean 0.4004
Std Dev 0.03976
P+P->P+P, 2 GeV/c
X_elast=20.56 mb
N_{pr}
P_{pr}(GeV/c)


PIPr
Entries 813
Mean 0.2296
Std Dev 0.05364
P+P->P, 8 GeV/c
X_in=28.716 mb
N_{pr}
P_{pr}(GeV/c)


PIPi
Entries 17468
Mean 0.239
Std Dev 0.113
PIPim
Entries 4827
Mean 0.2366
Std Dev 0.1158
PIPip
Entries 12641
Mean 0.2399
Std Dev 0.1119
P + P-> pi- pi+
P + P-> pi+
P + P-> pi-
N_{π}
P_{π}(GeV/c)


PIPr_el
Entries 93642
Mean 0.3797
Std Dev 0.04004
P+P->P+P, 8 GeV/c
X_elast=10.936 mb
N_{pr}
P_{pr}(GeV/c)


~0,2 ns
proton
pion
Δt, ns
p, MeV/c


~ 10%
pion
proton
T_{kin}, MeV
p, MeV/c