

Strokovsky E.A.

***О работе Нуклотрона для физиков
в 2016-2017 г.г.***

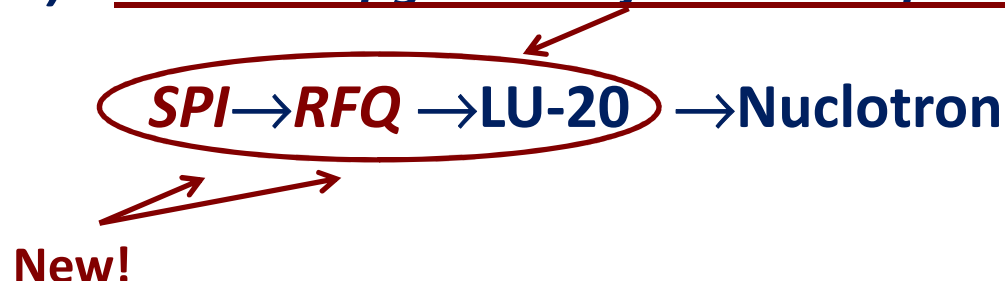
Run 52 of the Nuclotron *planned: 02.06.2016 – 08.07.2016,*
the main ring in fact: 02.06.2016 – 01.07.2016

The ultimate goal of the run was twofold:

- 1) to revive the polarized deuteron beams in the multi-GeV energy region*
(the immediate consequence is the appearance of polarized quasi-monochromatic beams of neutrons and protons in this energy region, available for users);
- 2) to revive physical measurements with polarized nucleons and deuterons*
(within the framework of the JINR topical plan (theme 1097)).

All this has to be done:

- 1) with the new Source of Polarized Ions (SPI),*
- 2) with the upgraded injection complex:*



This run was the “technical one” first of all.

Physics part of the run (in case of a good luck)

Experiments at extracted beams: **5** experiments:

Data taking for physics: **1** experiments (ALPOM-2) (polarized beam!)

R&D and calibrations: **4** experiments (FAZA, BM@N, MPD, HyperNIS)

Time requested by users (total, d): ≈ 768 hours

Time scheduled for users (total, d): ≈ 456 hours

Time obtained by users (total, d): ~ 120 hours

(including unexpected machine stops)

Good results:

SPI (unpolarized mode) \rightarrow ***RFQ*** \rightarrow LU-20 \rightarrow Nuclotron ***OK!***

Polarimeters were prepared for measurements

(the **L**ow **E**nergy **P**olarimeter (after LU-20) and the ITS polarimeter at the internal beam).

SPI (vector polarized mode) \rightarrow ***RFQ*** \rightarrow LU-20 \rightarrow LEP \rightarrow ***OK!***

(01.07.16 - 7.07.16)

vector polarization – as expected $\sim (+/- 0.5)$, but:

one sign – direct measurements,

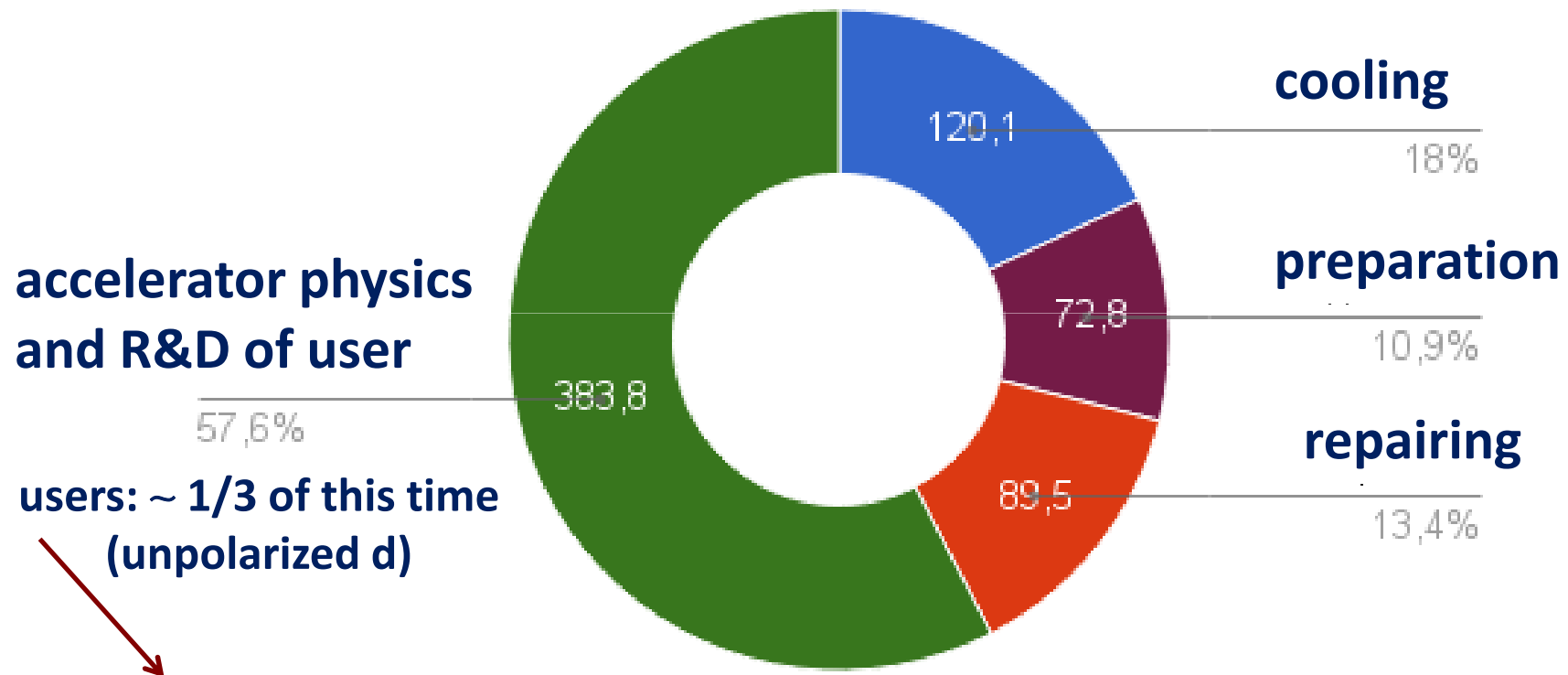
another sign: indirect measurements

(by measurements of the tensor polarization).

Run 52 of the Nuclotron (02.06.2016 – 08.07.2016)

Main ring  01.07.2016

The total run duration: ≈ 670 hours



**“ALPOM-2”, “Test-beam MPD”;
unexpected machine stop after BM@N started...**

Run 53 of the Nuclotron (27.10.2016 – 25.12.2016):

***The ultimate goal of the run was
physics with polarized deuteron beam***

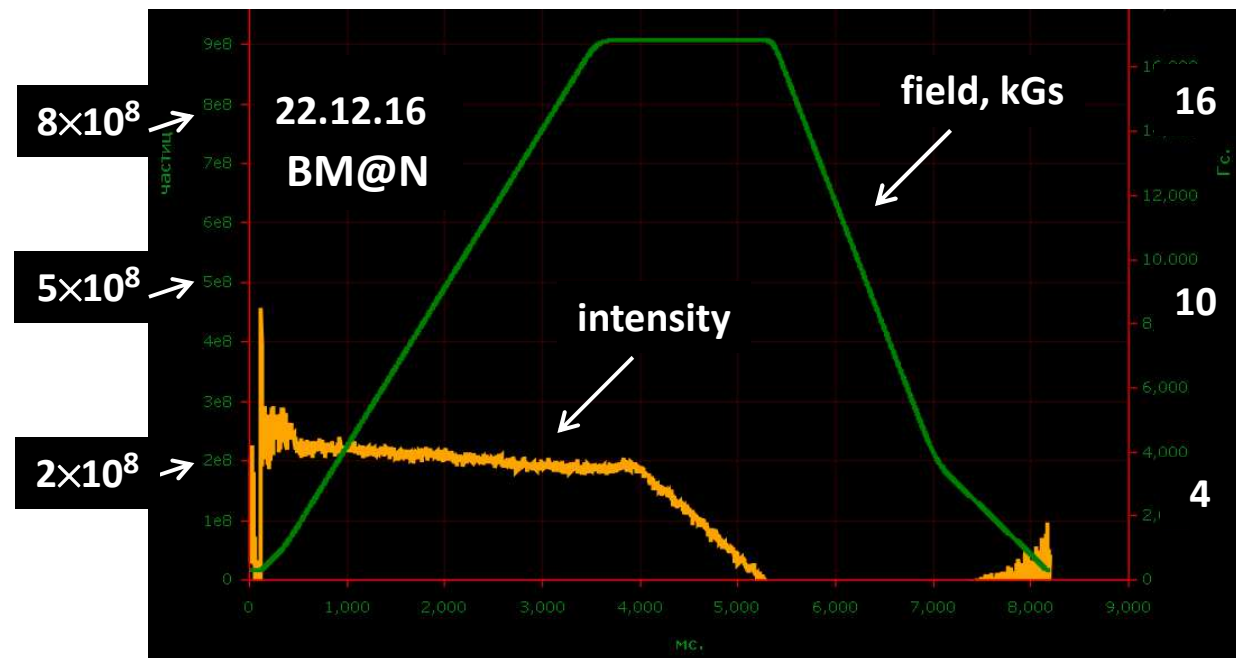
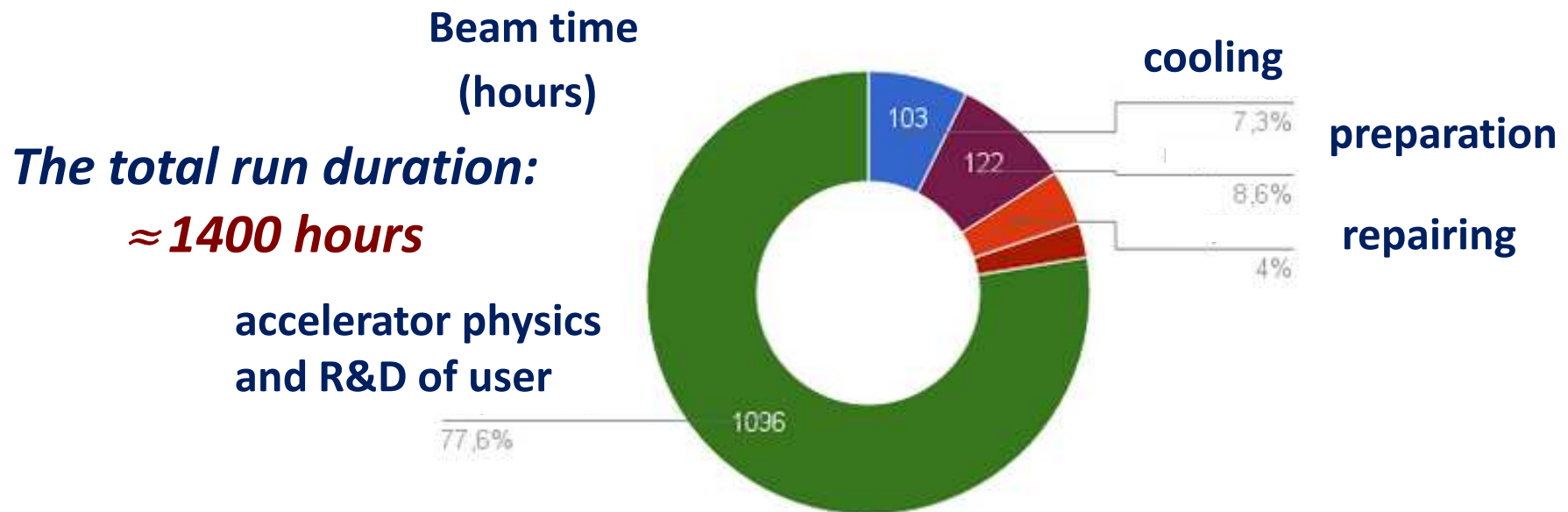
***1) ALPOM-2 with vector polarized deuteron beam:
measurements of analyzing powers for polarized protons and neutrons
in the multi-GeV energy region***

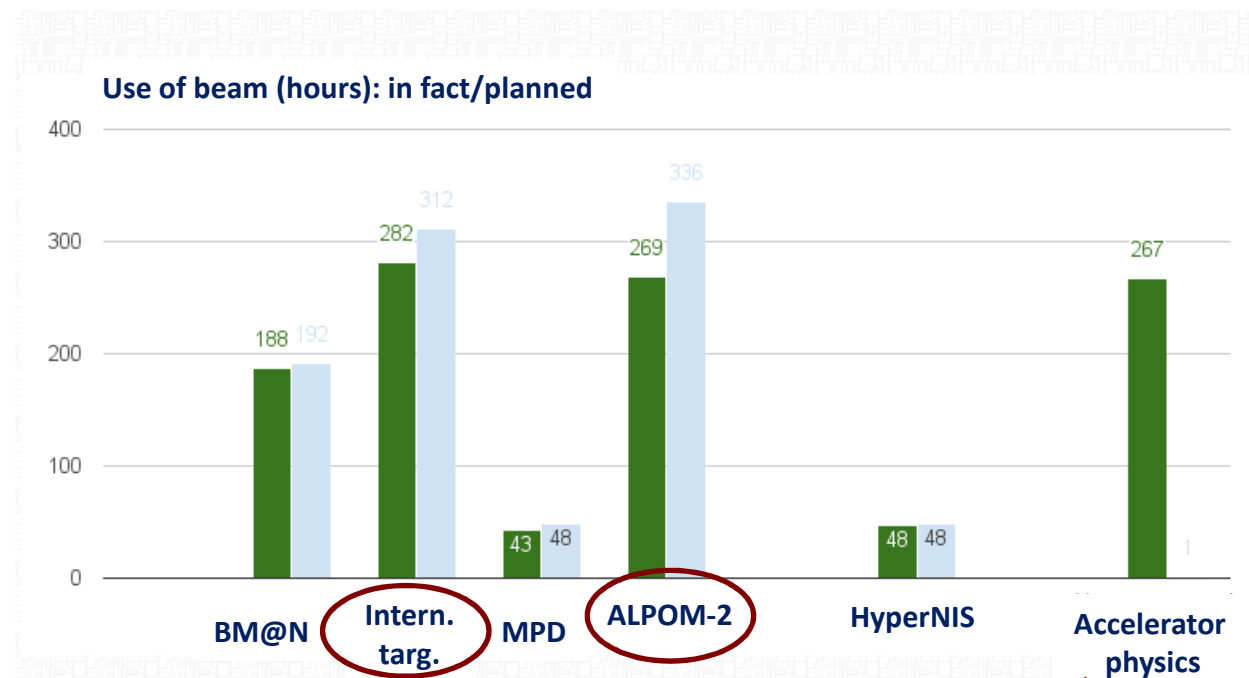
***2) measurements of cross sections and analyzing powers of
deuteron scattering at CH₂ and C targets (tensor polarized deuterons)
(the DSS project)***

3) Works with unpolarized deuteron beam (methodics)

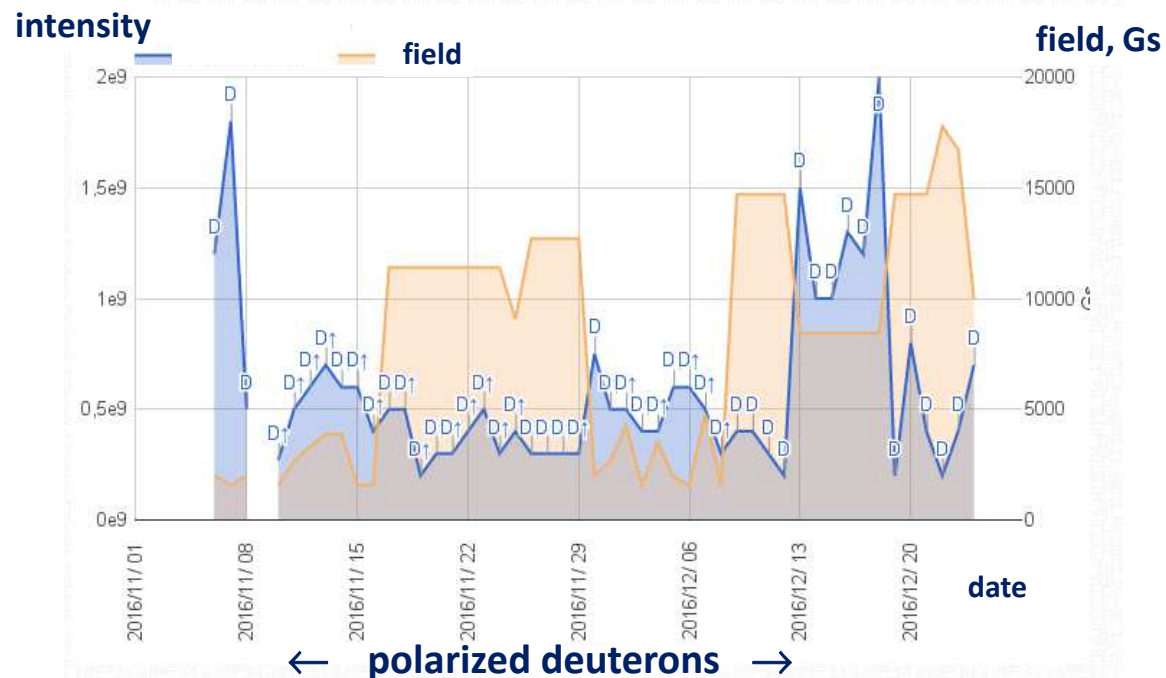
**All the works were performed according
the JINR topical plan.**

Run 53 of the Nuclotron (27.10.2016 – 25.12.2016)





↑
(including polarimetry)

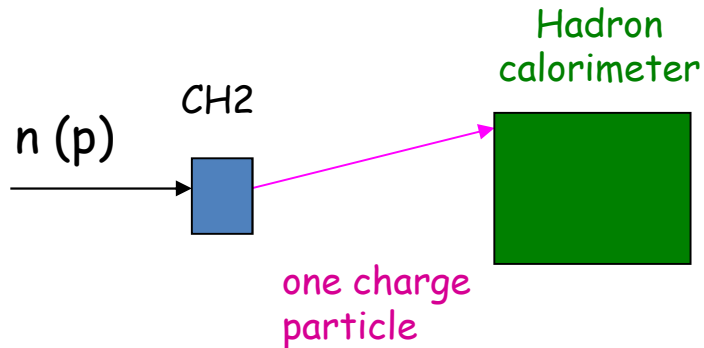


Selected results

(all the data are preliminary, data analysis is in progress)

ALPOM-2 in the run 53 Data status: preliminary; reported at DSPIN-2017

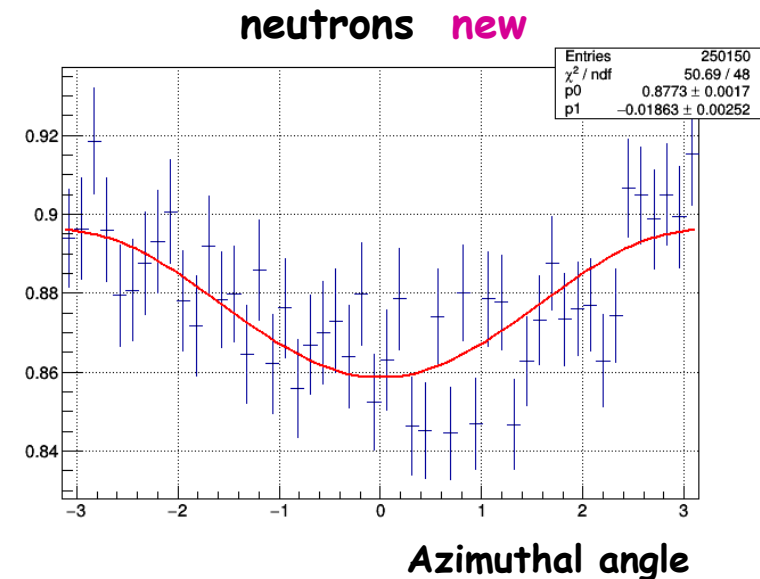
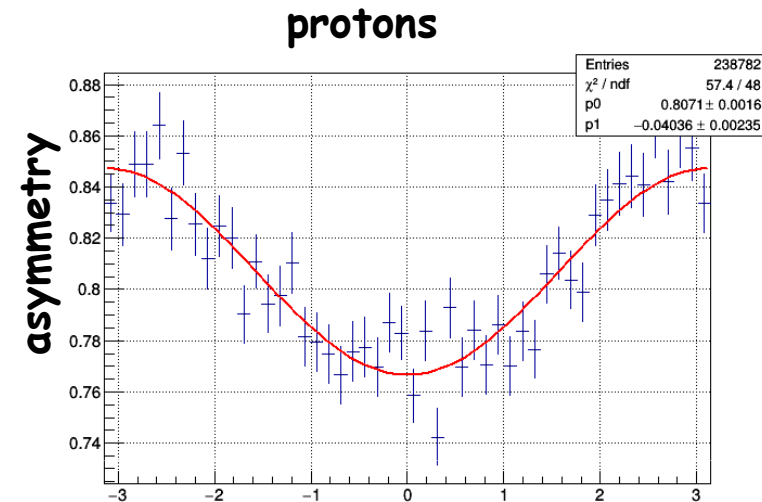
Measurement of analyzing powers for the reaction $p + \text{CH}_2$ up to 7.5 GeV/c and $n + \text{CH}$ up to 4.5 GeV/c at the Nuclotron (ALPOM2 proposal)



JINR-Slovakia-USA-France-United Kingdom



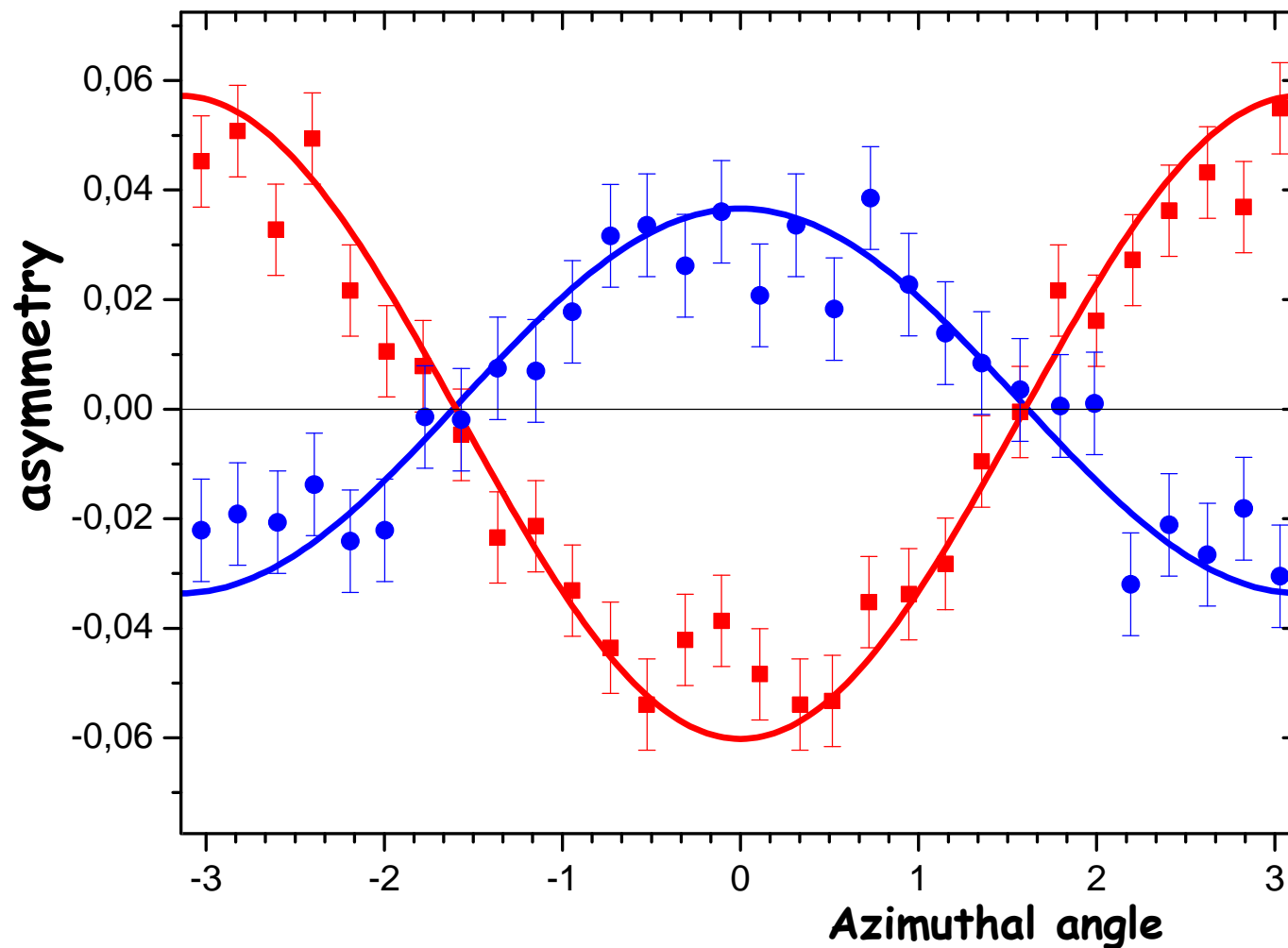
E.A.C., 5-e Сов. потреб, 05.10.2017



ALPOM-2 in the run 53. Data status: preliminary; reported at DSPIN-2017

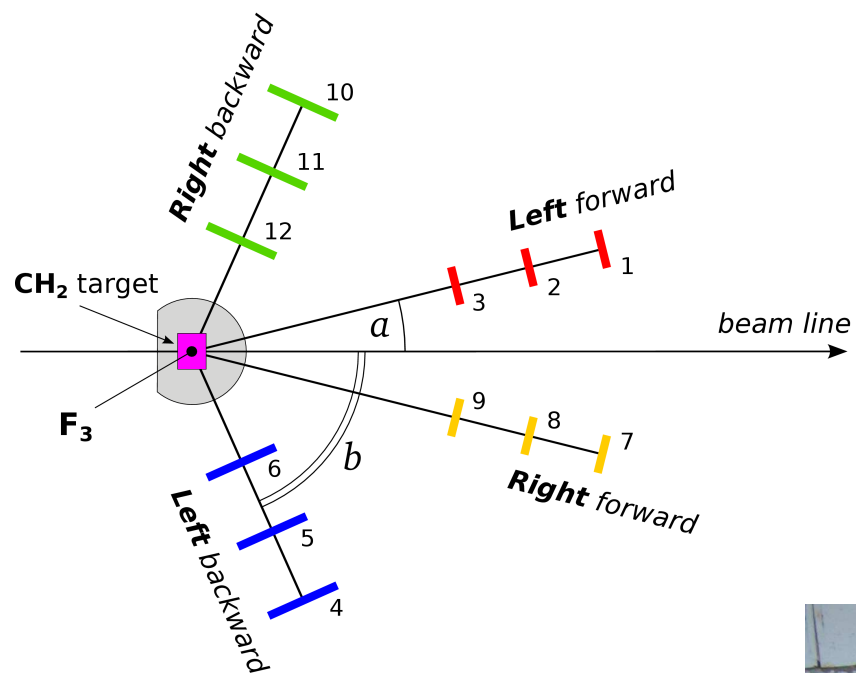
More – in talk by N.M.Piskunov

ALPOM2 p+CH2 3.75 GeV/c



Polarimeter at the extracted beam (F3 focus)

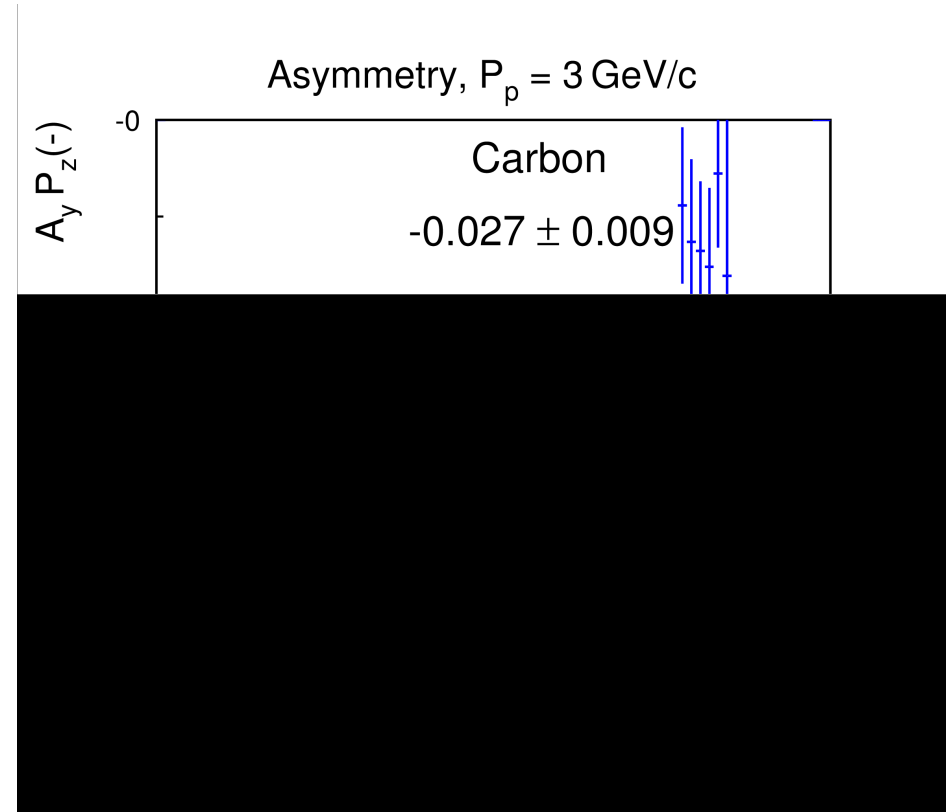
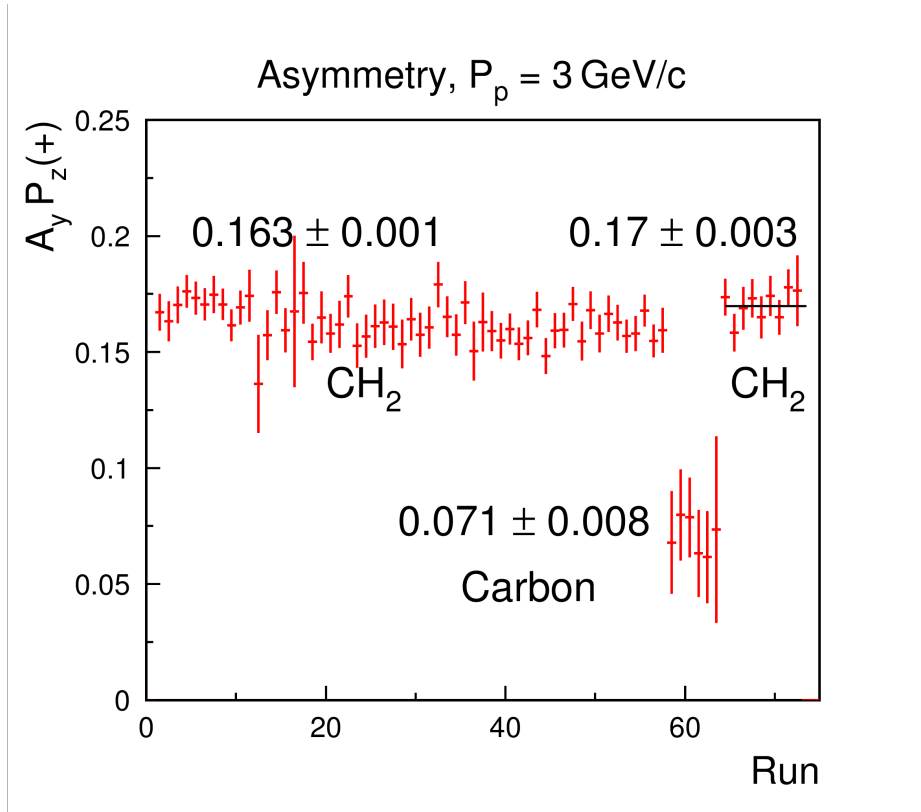
More – in talk by R.Shindin



Polarimeter at the extracted beam (F3 focus)

More – in talk by R.Shindin

Deuteron beam momentum: 3 GeV/c



Vector polarization of the beam (*preliminary!*)

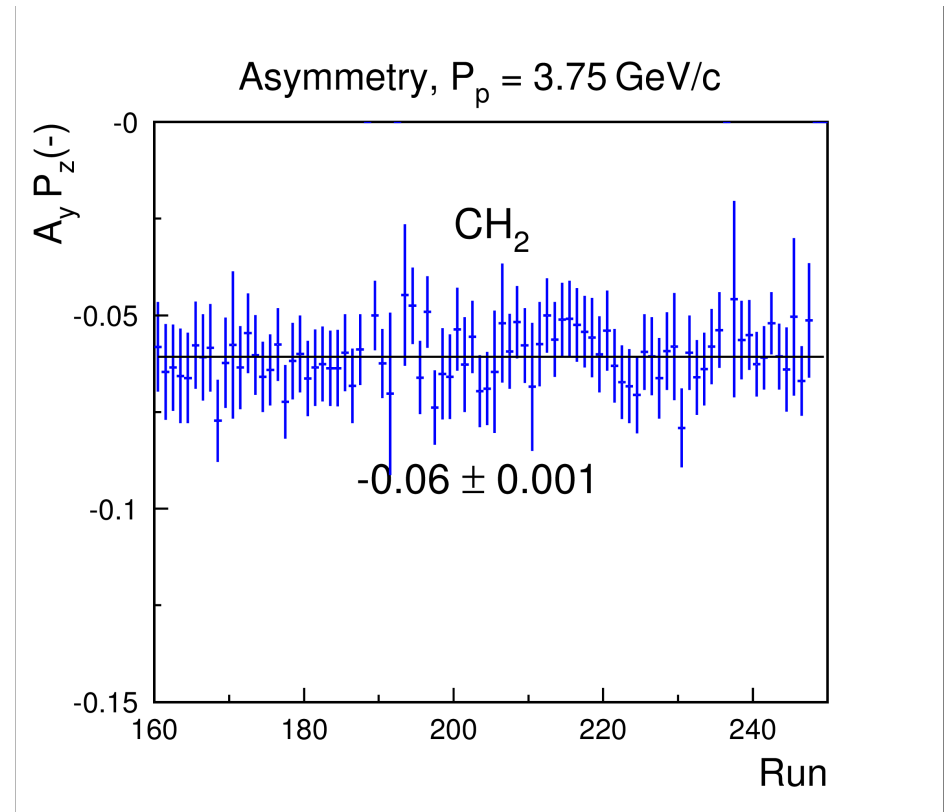
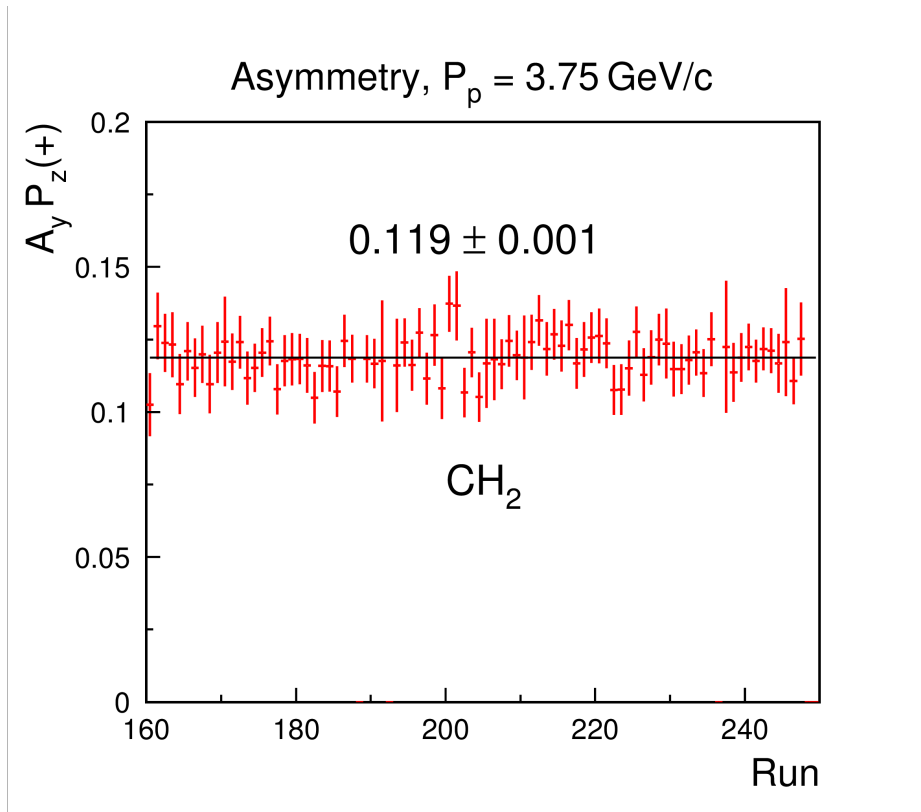
$$P_z(+) = \mathbf{0.652} \pm 0.004 \pm 0.052$$

$$P_z(-) = \mathbf{-0.343} \pm 0.005 \pm 0.027$$

Polarimeter at the extracted beam (F3 focus)

More – in talk by R.Shindin

Deuteron beam momentum: 7.5 GeV/c



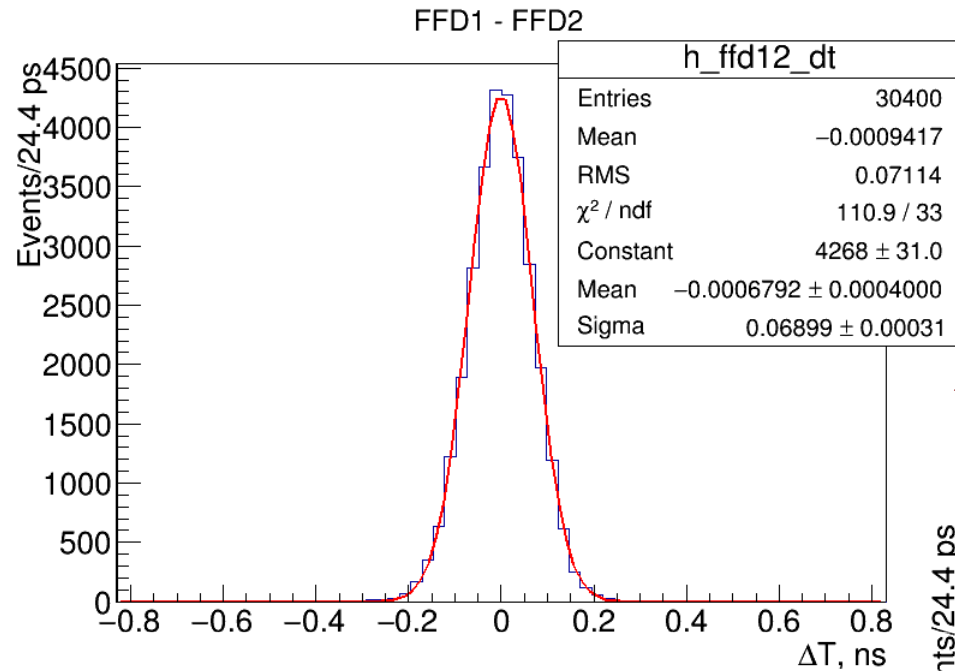
Vector polarization of the beam (*preliminary!*)

$$P_z(+)=\mathbf{0.593} \pm 0.005 \pm 0.047$$

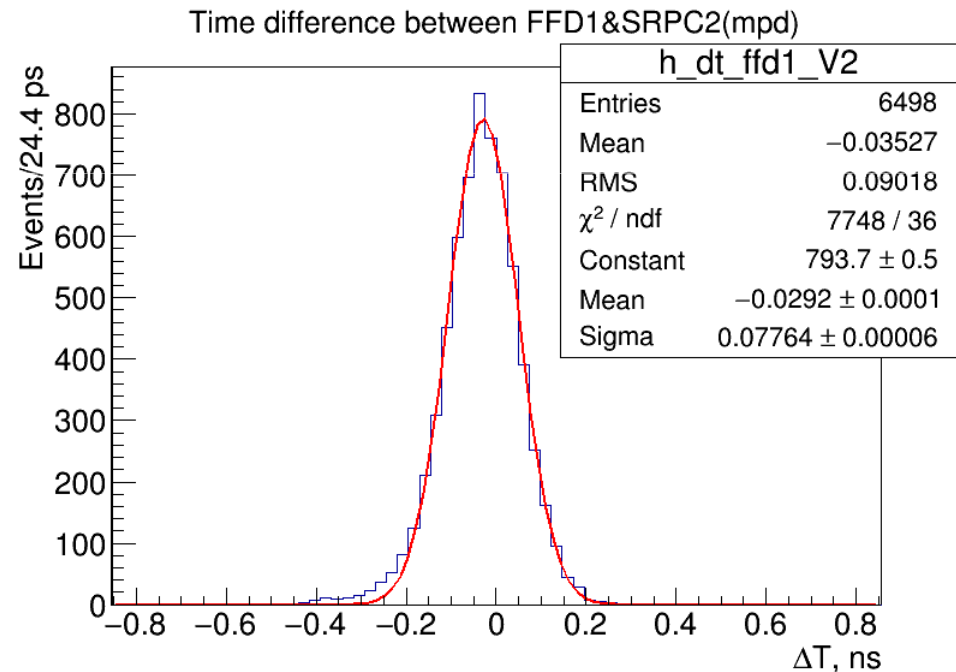
$$P_z(-)=\mathbf{-0.302} \pm 0.006 \pm 0.024$$

Some R&D results (preliminary)

“MPD test-beam” in the run 53

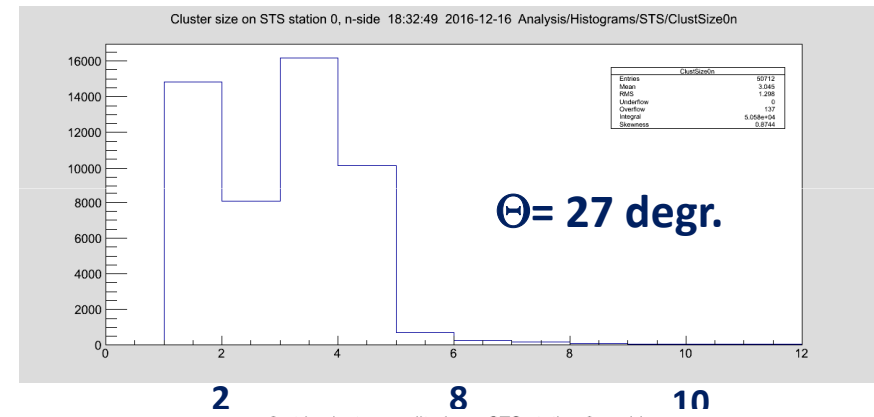
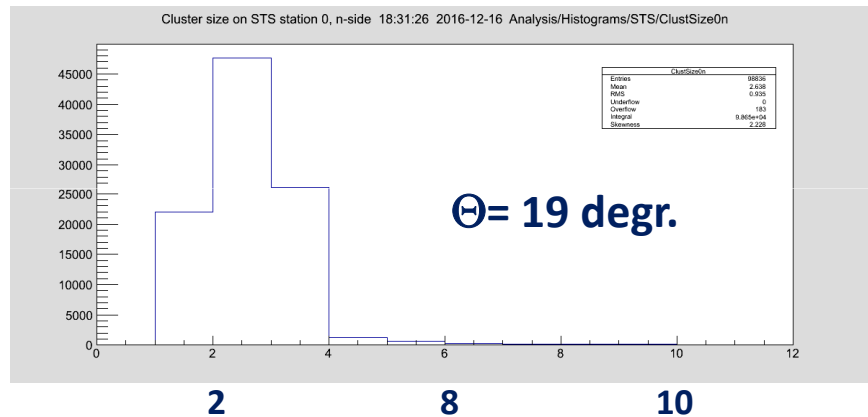
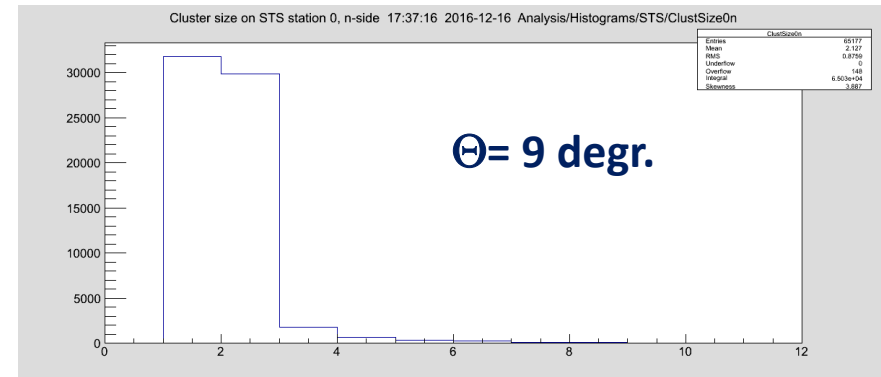
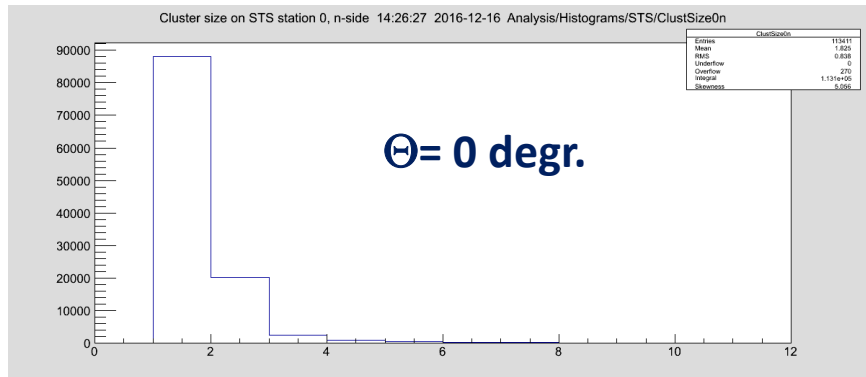


**T0 detectors tested;
achieved time resolution: 49 ps**



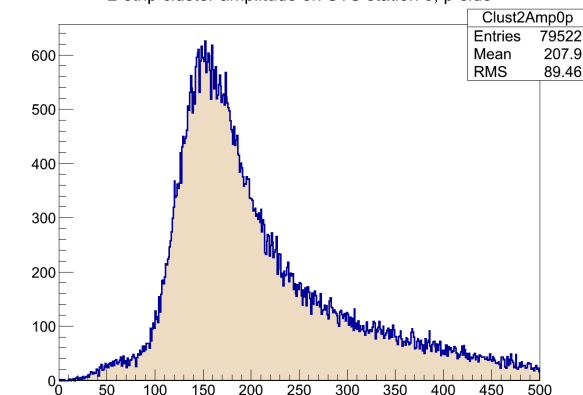
**RPC prototypes tested:
achieved time resolution: ~60 ps**

The *first beam test* of the microstrip detectors (STS) for BM@N and CBM



Dependence of the *cluster sizes* upon the *beam inclination angle* Θ

2-strip cluster amplitude on the STS station 0 (P-side)



Since the 2016 year
***JINR has again, at the LHEP Nuclotron,
the polarized deuteron beam
with kinetic energy up to 5 GeV/nucleon***

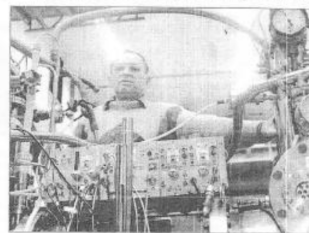
«Опять есть поляризованные дейтроны на Нуклотроне!» (2016 г.)



16.12.2002

Есть поляризованные дейтроны на нуклотроне!

7-9 декабря состоялся сеанс работы нуклотрона с источником ПОЛЯРИС. Впервые ускорен до энергии более 2 ГэВ нуклон и выведен из нуклотрона пучок поляризованных дейтронов. Максимальная интенсивность пучка $1.35 \cdot 10^4$ частиц в цикле ускорения. Поляризация пучка измерена физическими установками СФЕРА (внутренняя мишень), ПОЛЯРИМЕТР (измерительный павильон); АЛПОМ (корпус 205). Коэффициент поляризации более 0.5.



Директору ЛВЭ имени В. И. Векслера и А. М. Балдина профессору А. И. Малахову. Примите самые сердечные поздравления с замечательным результатом – ускорением и выведением из нуклотрона пучка поляризованных дейтронов. Это важный шаг на пути освоения нуклотрона как пользовательской базовой установки ОИЯИ и его стран-участниц. Мы уверены, что научная общественность с большим вниманием отнесется к новым возможностям, открытым для исследований на нуклотроне. Искренняя благодарность и поздравления всему коллективу лаборатории. Шлем всем наши новогодние поздравления и добрые пожелания.

В. Г. КАДЫШЕВСКИЙ,
А. Н. СИСАКЯН

Поздравляю с первым ускорением поляризованных дейтронов на нуклотроне. Я очень счастлива. Наилучшие пожелания, Фрэнтишек ПЕГАР

На снимках: В. П. Еризов, ведущий инженер научно-исследовательского криогенного отдела ЛВЭ (снимок сверху) и начальник НИКО Ю. К. Пилипенко в сеансе ускорения поляризованных дейтронов. Фото ЛВЭ.



**Dubna newspaper about acceleration
of polarized deuterons in the Nuclotron**

Статистика о работе Нуклотрона за 5 лет

Год	Сеанс	Даты	Всего часов	в т.ч. охлаждение	Подготовка + ремонт	Физика потребителей, ускорительная физика
2012	45	22.02-24.03	700	15%	25%	60%
	46	15.11-24.12	940	13%	18%	69%
всего за год			1640	14%	21%	65%
2013	47	20.02-28.03	870	14%	18%	68%
	48	14.11-27.12	1060	10%	16%	74%
всего за год			1930	12%	17%	71%
2014	49	10.02-9.03	640	18%	23%	59%
	50	20.05-16.06	650	18%	22%	60%
всего за год			1290	18%	22%	60%
2015	51	26.01-15.03	1150	11%	19%	70%
всего за год			1150	11%	19%	70%
2016	52	2.06-1.07	670	18%	24%	58%
	53	27.10-25.12	1400	7%	13%	80%
всего за год			2070	11%	17%	73%
всего за 5 лет			8080	13%	19%	68%

Run 54 of the Nuclotron
(total duration: \approx 1008 hours)
10.02.2017 – 24.03.2017

Run 54 of the Nuclotron (10.02.2017 – 24.03.2017):

1. Works with SPI:

- ☐ **Data taking** (to complete measurements started in the run 53):
 - **DSS project**
 - **ALPOM-2 project**
- ☐ **Accelerator physics: acceleration of polarized protons in the Nuclotron.**

2. Works with the Laser Source (nuclear beams: C and Li)

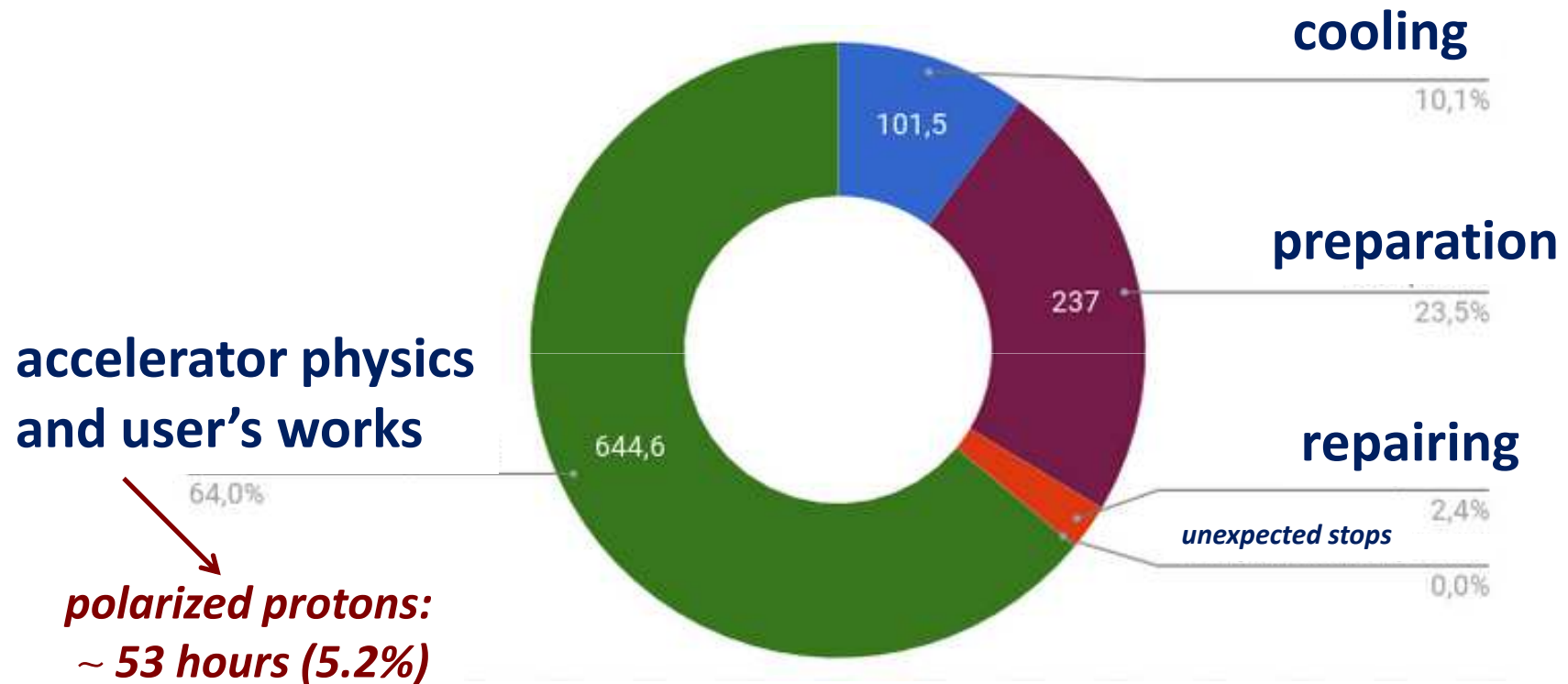
- ☐ **Carbon beam**
 - **BM@N: start of data taking for commissioning (and R&D for other users)**
- ☐ **^7Li beam**
 - **HyperNIS: start of data taking for commissioning (and R&D for other users)**

All the works are included in the JINR topical plan.

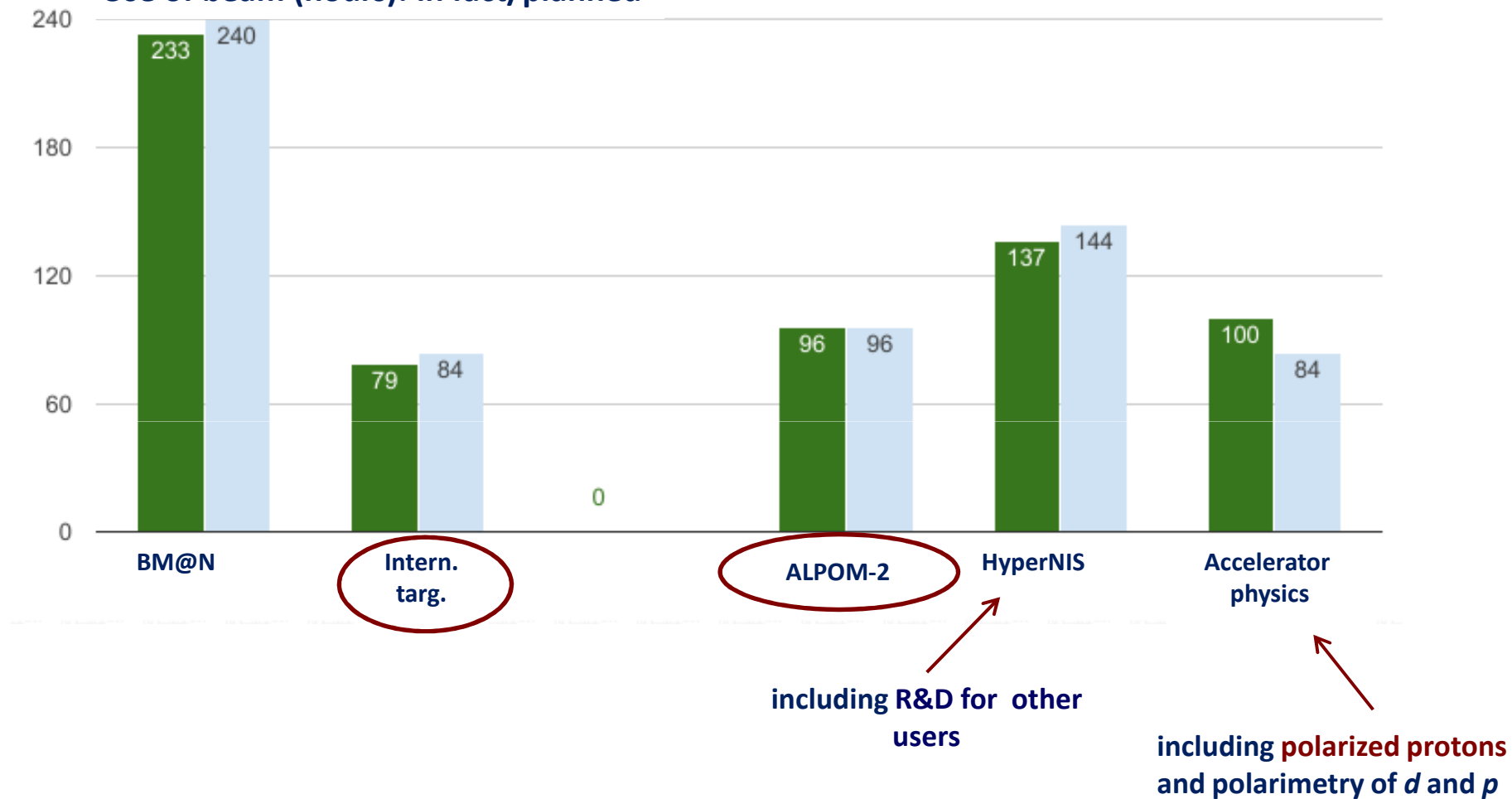
In parasitic mode: R&D works for accelerator physics and other approved projects (SCAN-3 etc.) at MARUSYA setup.

Run 54 of the Nuclotron (10.02.2017 – 24.03.2017)

The total run duration: ≈ 1008 hours



Use of beam (hours): in fact/planned



In general, users are satisfied by the machine work.

***BM@N results will be presented in the talk by
M.Kapishin;***

***results from ALPOM-2 and DSS projects
were presented at the DSPIN-2017 Conference
and will be reported in respective talks;***

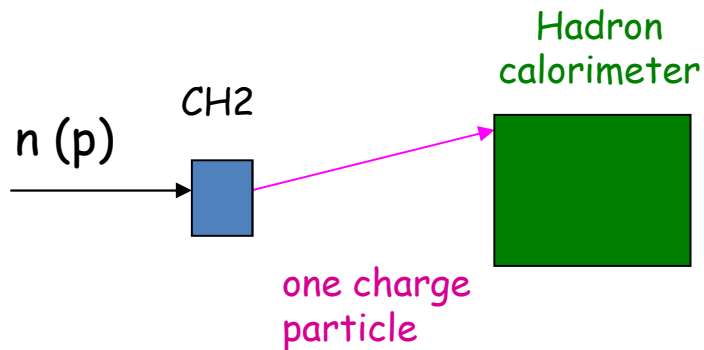
***Some results about beam polarization (in the run 54):
few next slides.
(all the data are still preliminary, data analysis is going on)***

ALPOM-2 in runs 53 and 54:

reminder

(from N.M.Piskunov)

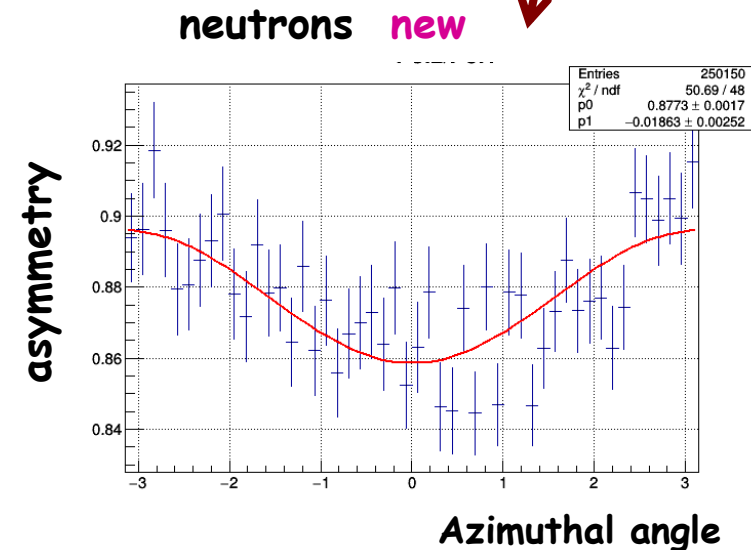
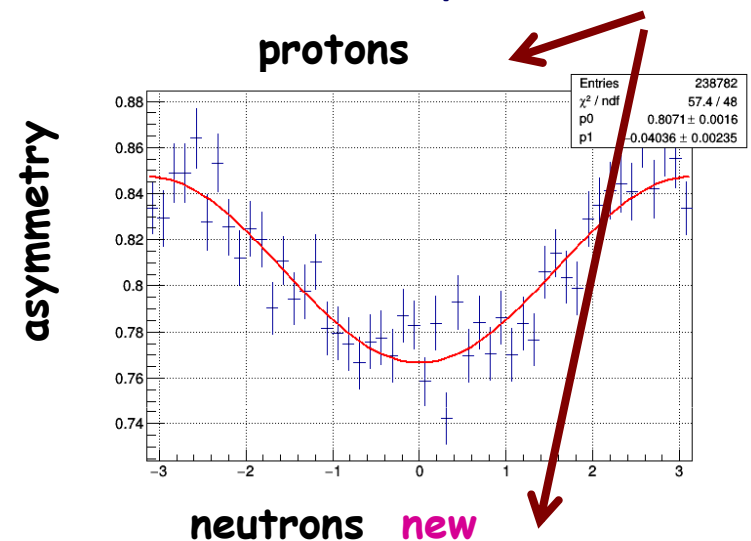
Measurement of analyzing powers for the reaction $p + CH_2$ up to 7.5 GeV/c and $n + CH$ up to 4.5 GeV/c at the Nuclotron



JINR-Slovakia-USA-France-United Kingdom



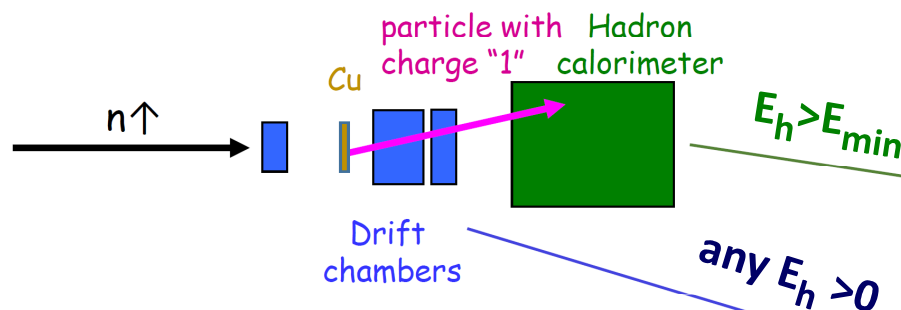
(From the run 53)



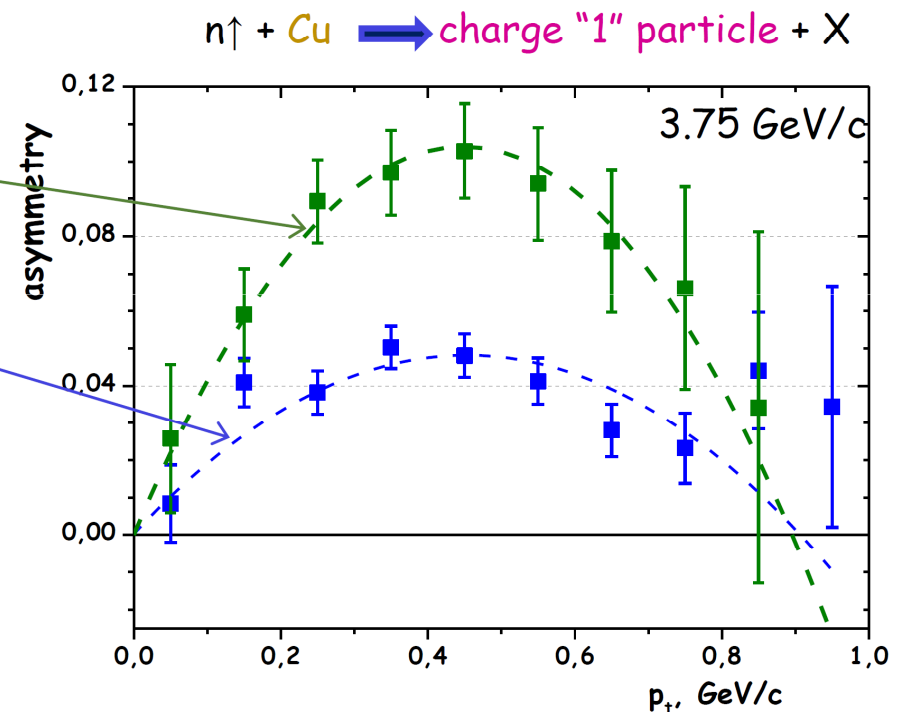
unique result, observed at first time in the world:

Measurement of analyzing powers for the reaction $p + \text{CH}_2$ up to 7.5 GeV/c and $n + \text{CH}$ up to 4.5 GeV/c at the Nuclotron
(ALPOM2 proposal)

JINR-Slovakia-USA-France-United Kingdom



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



The inverse reaction $p + \text{Cu}$ (W), with detection of a neutron in the forward direction by a hadron calorimeter, can be used for measurements of the proton polarization at the NICA collider.

SPI performance for deuterons was investigated. In particular, the tuning of the SPI in the “tensor” mode was studied (using polarimetry at the Internal Target Station for monitoring of the tensor polarization of deuterons) and value of $P_{zz} \approx -1.5$ was observed.

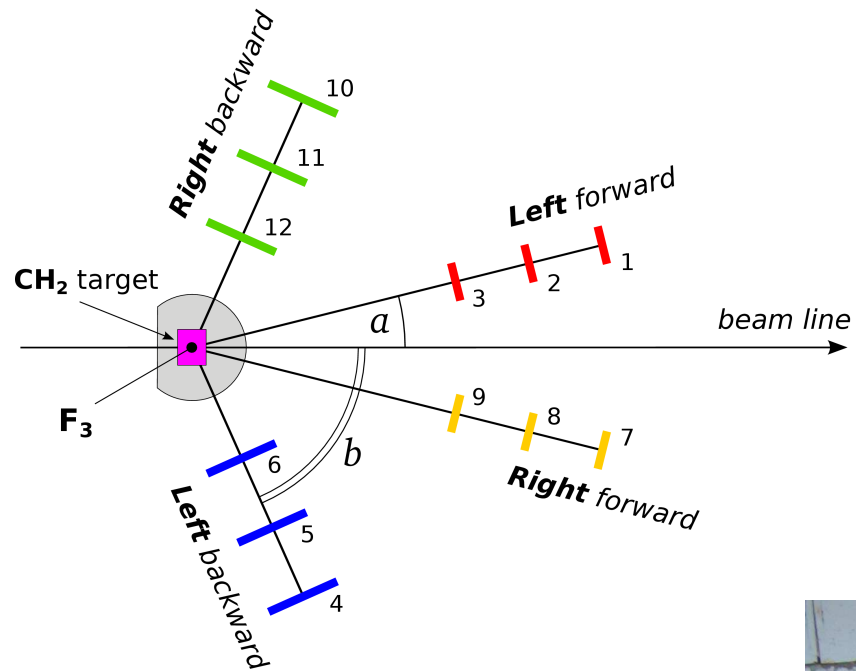
The capability of the Nuclotron to accelerate polarized protons was investigated at first time in JINR.

Polarization of the internal beam of polarized protons was measured at 500 MeV.

*Polarimeter at the extracted beam (F3 focus):
Polarization of extracted polarized protons was seen at the level of $|P| \approx (0.1 \div 0.15)$ at $T_p = 1$ and 2 GeV (kinetic energy) (very preliminary estimation!).*

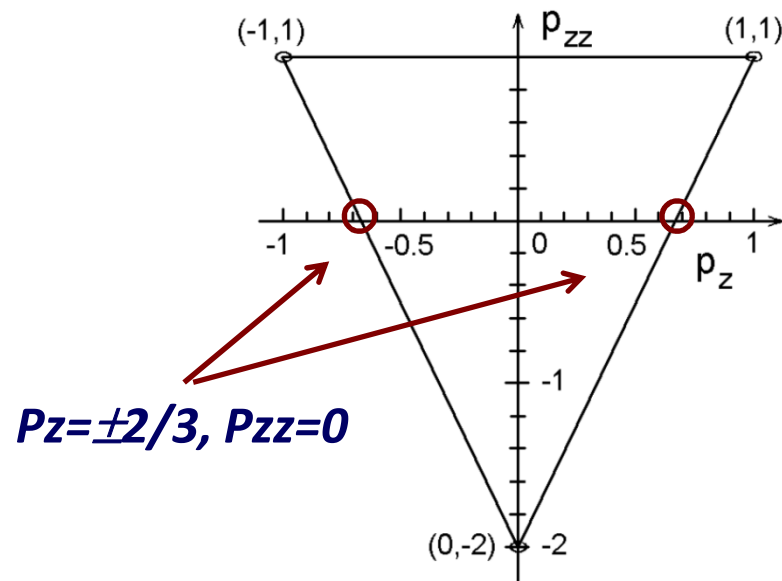
Polarimeter at the extracted beam (F3 focus)

reminder



Polarimeter at the extracted beam (F3 focus)
Deuteron beam momentum: 7.5 GeV/c
(preliminary, Nuclotron run 54)

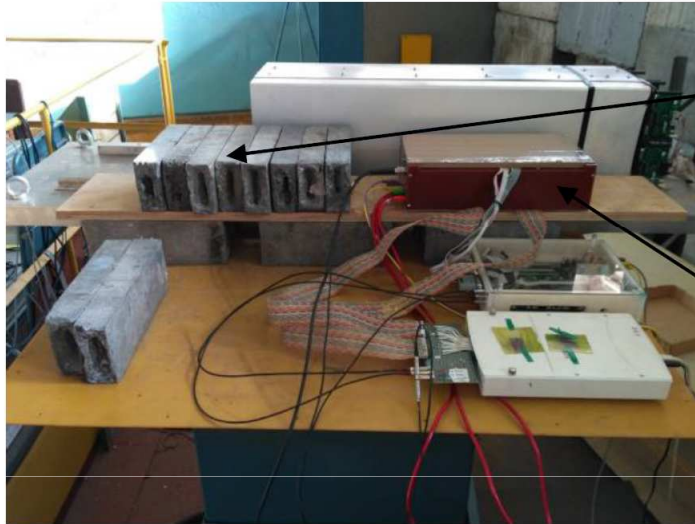
RUNs	Tar	$P_z(+)$	$P_z(-)$
35–62	CH ₂	$+0.642 \pm 0.008$	-0.508 ± 0.007
63–69	CH ₂	$+0.644 \pm 0.011$	-0.497 ± 0.009
71–78	CH ₂	$+0.656 \pm 0.012$	-0.519 ± 0.01
80–89	CH ₂	$+0.648 \pm 0.011$	-0.522 ± 0.009
90–141	CH ₂	$+0.632 \pm 0.008$	-0.515 ± 0.007
152–164	CH ₂	$+0.746 \pm 0.01$	-0.567 ± 0.009



Few R&D results

“NUCLEON-2” project: tests of the Si-Calorimeter prototype
(26 layers, thickness of the layer ≈ 1 mm)

*Carbon beam,
 $T \approx 2$ GeV/nucleon*

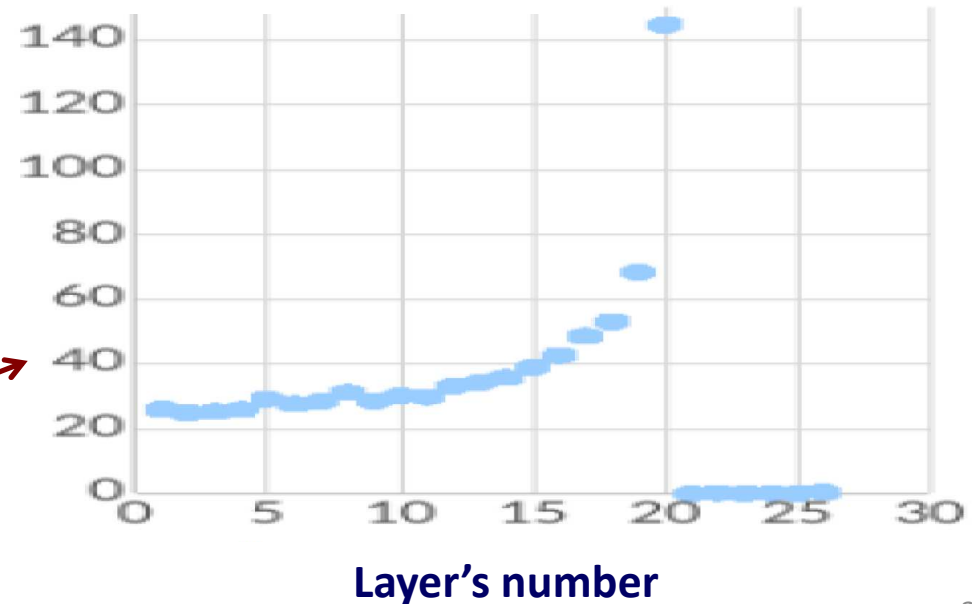


Degrader (Pb)

Detector prototype

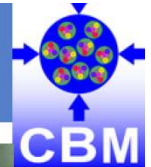
Signal
amplitude (mV)
in the layer

Example of event with
detected Bragg peak
(carbon beam)

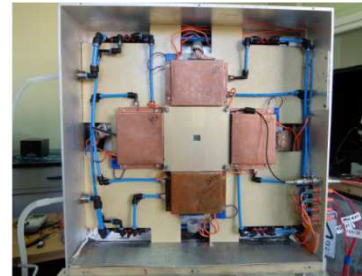


Next *beam test* of the microstrip detectors (STS) for BM@N and CBM

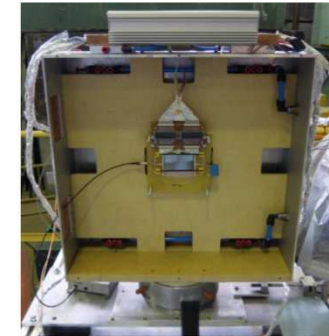
Test setup



- One STS test station
- Trigger system based on two scintillators counters
- 3 FEBs with nXYTER v.2.0 ASIC
- SysCore v.2 based readout
- Online Analysis based on DABC & Go4



Test station with “baby” sensor

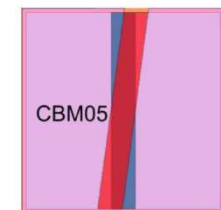


Test station with CBM06C4-DM



Two types of demonstrators were tested:

- With “baby” sensor Hamamatsu
- With CBM06C4-DM by CiS

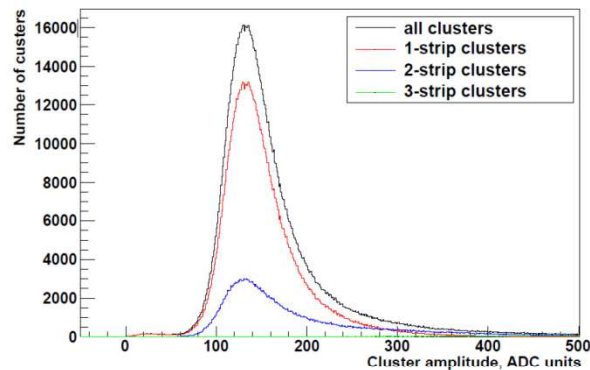


red – p-side
blue – n-side

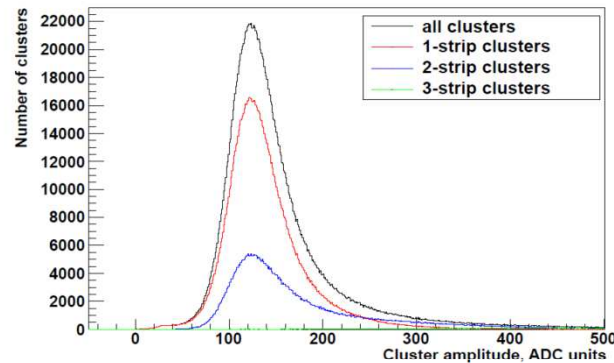
Dementev Dmitrii, CBM workgroup meeting at JINR 22.05.2017

Next *beam test* of the microstrip detectors (STS) for BM@N and CBM

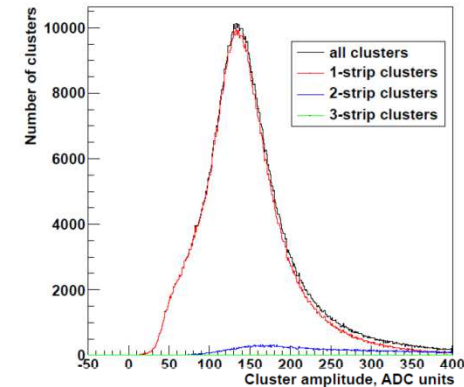
Clusters amplitudes measured with the *d* beam



Clusters amplitudes on the **P side** of baby sensor



Clusters amplitudes on the **N side** of baby sensor



Clusters amplitudes on the **P side** of CBM06C4-DM sensor

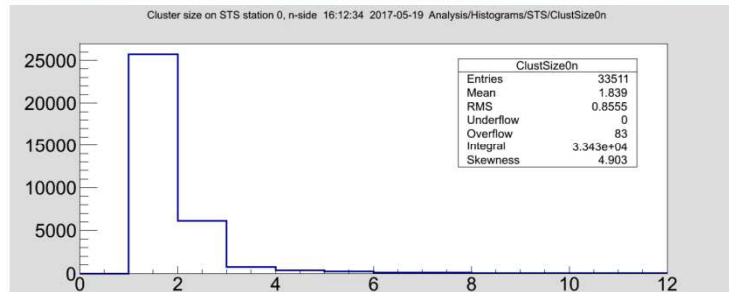
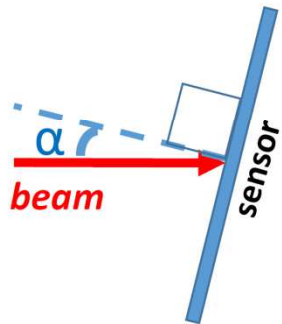
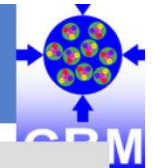
Areas with no masked and noisy channels was selected.
Coincidence with trigger was applied

Deficiency of 2-strip clusters for the CBM06C4-DM is due to high value of comp. threshold (reg 18 val 42)

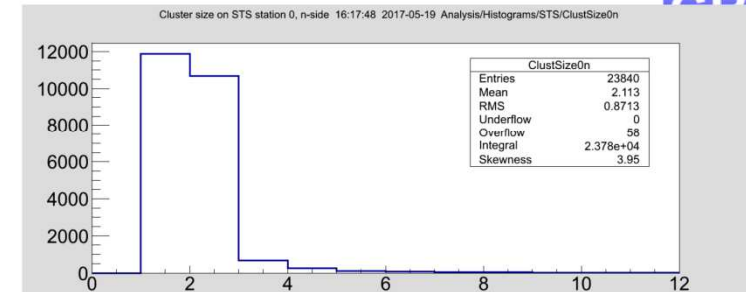
Dementev Dmitrii, CBM workgroup meeting at JINR 22.05.2017

Next *beam test* of the microstrip detectors (STS) for BM@N and CBM

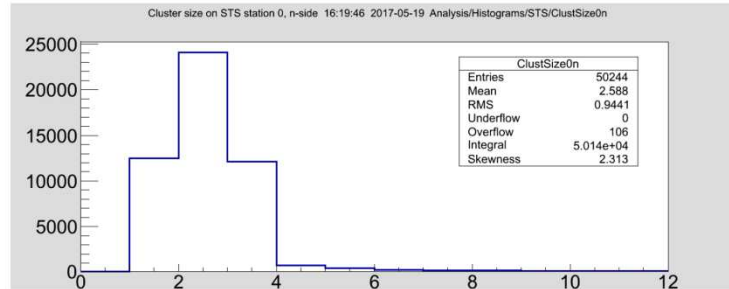
Cluster size dependence on the angle



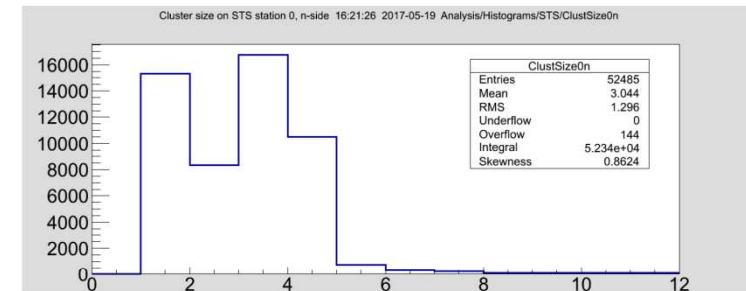
Cluster size for $\alpha = 0^\circ$



Cluster size for $\alpha = 9^\circ$



Cluster size for $\alpha = 19^\circ$



Cluster size for $\alpha = 27^\circ$

Dementev Dmitrii, CBM workgroup meeting at JINR 22.05.2017

- New physical results were obtained, important for intermediate energy polarimetry of neutrons (above pion production threshold) .

- JINR has restored (in 2016, run 53) polarized deuteron beam with kinetic energies up to 5 GeV/nucleon;

□ *now, at first time, JINR has also the relativistic polarized **proton** beam, accelerated in the Nuclotron.*

This is the most important result of the run 54 for external users, taking into account that *accelerated polarized proton beams of intermediate energies do not exist at other world centers at present.*

❖ *The acceleration of polarized protons in the Nuclotron is very important result for the NICA project as well...*

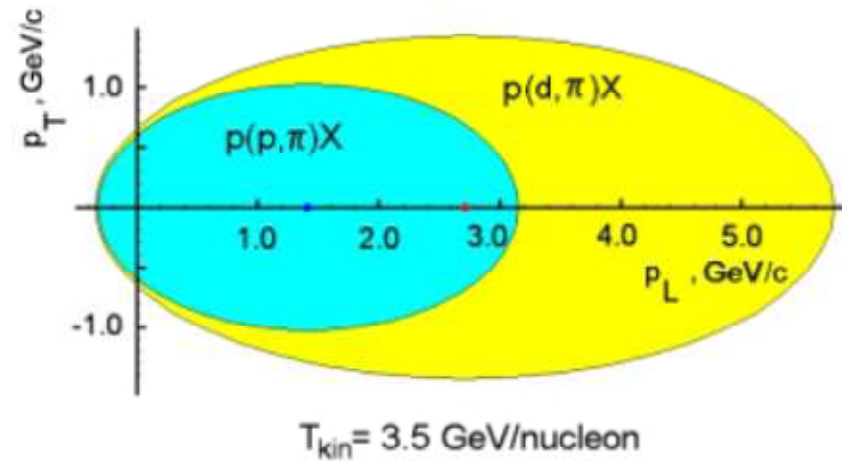
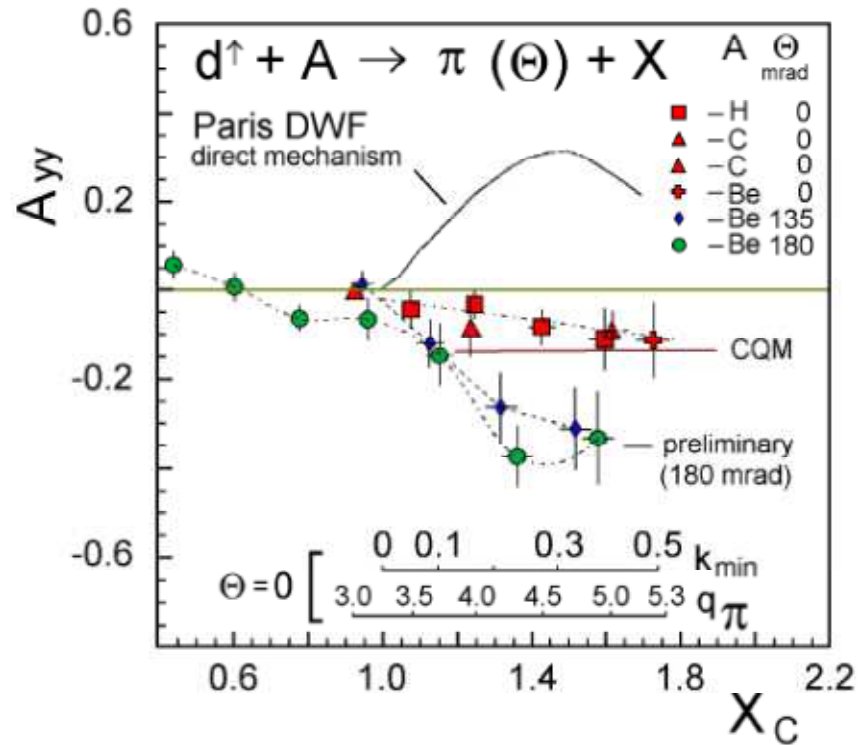
for discussion

(I)

***Few examples and some remarks
about polarization observables:
what has been done and might be done in future
for physics of few nucleon systems
and
“short range correlations” in nuclei...***

Polarization effects in cumulative particle production.

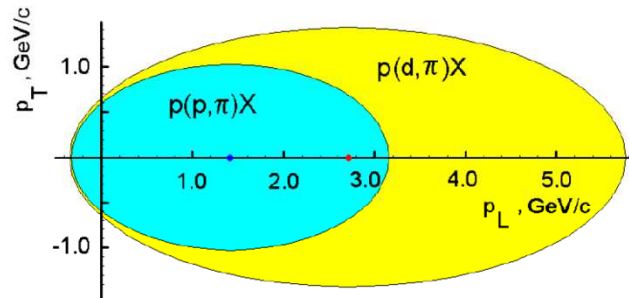
Example: pion production by polarized deuterons. L.Zolin et al, Nucl. Phys. A689 (2001) 414c



$$X_c = \frac{(P_{targ}P_\pi - m_\pi^2/2)}{(P_{targ}P_{beam}) - m_N^2 - (P_{beam}P_\pi)}$$

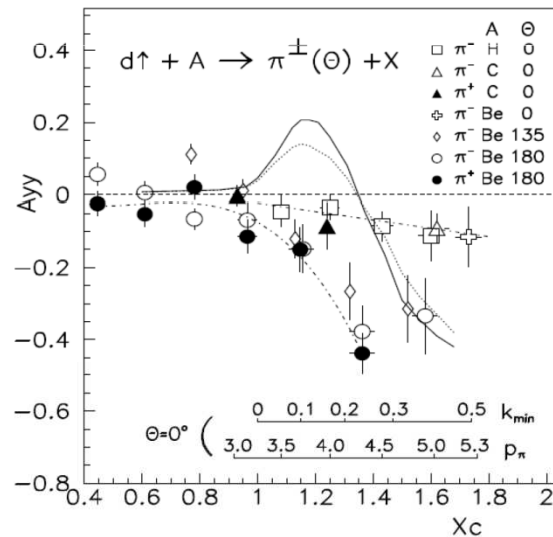
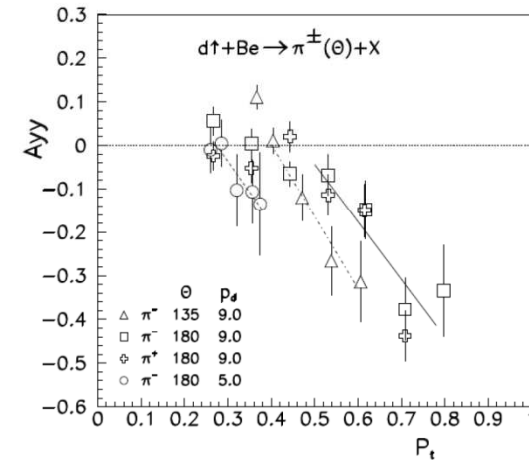


Cumulative mesoproduction by polarized d (example)

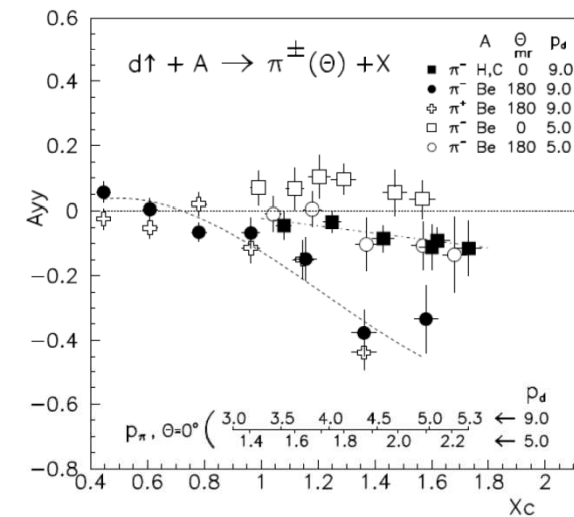


$T_{\text{kin}} = 3.5$ GeV/nucleon

Ellipses of momenta for pion production.
In yellow: cumulative region in $p(d, \pi)X$



9 GeV/c deuterons



5 and 9 GeV/c deuterons; pion lab. angles
0 and 180 mrad.

Data by L.S. Zolin et al.

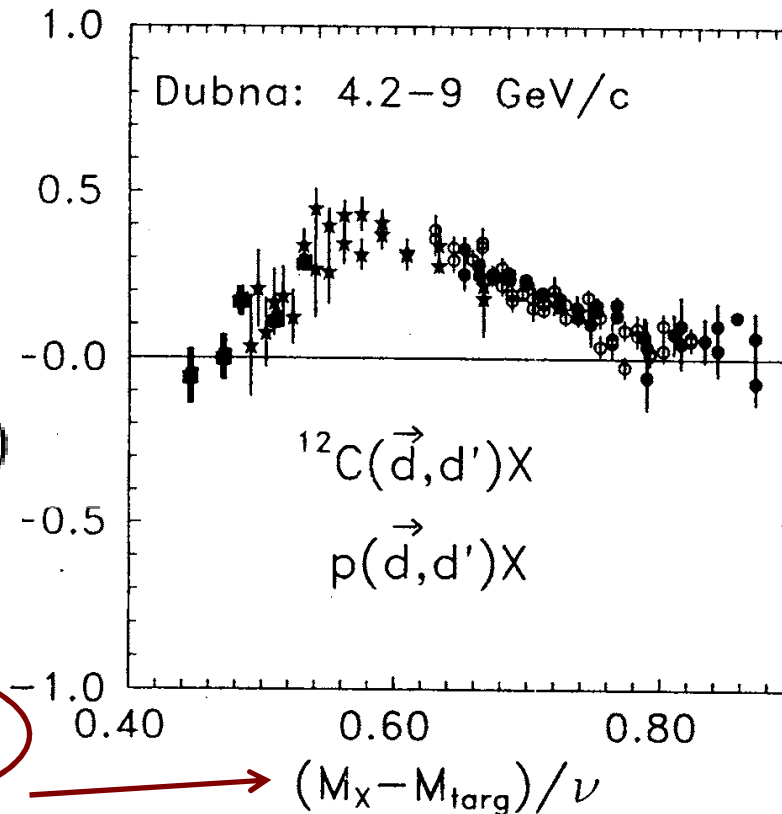
SCALING BEHAVIOUR OF TENSOR ANALYZING POWER (A_{yy}) IN THE INELASTIC SCATTERING OF RELATIVISTIC DEUTERONS

P. P. Korovin¹, L. V. Malinina, E. A. Strokovsky

$$\mathcal{R} = \frac{\Delta m_X}{\nu}, \quad \nu = \frac{1}{m_t} \mathcal{P}_t (\mathcal{P}_d - \mathcal{P}_{d'})$$

in the target rest frame

$$\mathcal{R} = \frac{\Delta m_X}{Q} = 1 - \frac{T_X}{Q}$$



- 1) Разные углы вылета рассеянной частицы (дейтрона): как 0^0 , так и 85 мрад;
- 2) Разные энергии снаряда...

Независимо от начальной энергии и **независимо** (?) от угла рассеяния,
максимум тензорной анализирующей способности – когда примерно 60% потерянной
снарядом энергии уходит в эфф. массу «отдачи» X... Почему?



Structure of lightest nuclei: general conclusions

- Good and well recognized data set was obtained.
- LFD seems to be an adequate framework for theoretical interpretation.
- In all 3 cases (d , τ , α) disagreements with simplest theory occur at distances when constituents start to touch each other.
- Best studied is the deuteron case.
- First polarization observables were measured for the τ case.
- “Meson content” of deuteron was probed by polarization.
- There is an impressive similarity with results obtained by electromagnetic probes.
- Significant influence for theory of relativistic composite systems has taken place.

New possible perspectives for future

(new source of polarized ions is available now; beams of 4He and 3He are needed!)

- Measurements of polarization transfer in d case by other method (check energy dependence)
- Polarization transfers from target to projectile fragments (d , τ , α cases): in QIA must be absent
- Verification of data-to-data correlations
- Backward elastic scattering (τ , α cases) including spin-spin correlations
- Spin-dependent observables in cumulative production of strange and vector mesons etc.....

$\alpha \equiv 4\text{He}$

$\tau \equiv 3\text{He}$

for discussion

(II)

***Polarized proton target
should be exploited again!***

This is a call to user's community ...