Recent progress
in *experiments* with relativistic ions
at the Nuclotron

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Introduction

(to remind: what is the NICA project?)

Relativistic Heavy Ion Physics is a high priority task in many scientific centers (BNL, CERN, GSI) since last few decades

This physics is under discussion for J-PARC as well:

34th Reimei workshop

"Physics of Heavy-ion Collisions at J-PARC"

Tokai, 2016/8/8

and the corresponding LOI was submitted to the J-PARC PAC.

The JINR plans: to start in the coming 3÷5 years experimental studies of hot and dense strongly interacting QCD matter as well as search for possible manifestation of signs of the mixed phase and critical endpoint in heavy ion collisions.

Instrumental basis :

NICA collider **(including modes with polarized beams) with the multipurpose detectors: *MPD*, SPD**
Nuclotron-M (including modes with extracted polarized beams and MPPT) with *BM@N*
External facilities at CERN (SPS, LHC), FAIR, RHIC

Main directions of studies with the relativistic heavy ions:

Probing of different regions of the phase diagram for hot *and* *dense* hadronic matter:

- •Phase transitions
  - •Baryonic to hadronic and QCD (quark-gluon) matter
  - •Critical endpoint (exists or not); mixed phase
  - •Liquid-to-fog (at the condensing-hadronization stage 3)
- •Exotic nuclei (hypernuclei ; stabilizing role of strangeness implemented into a nuclear matter)

Other physics within the NICA: ***Spin and polarization phenomena***

- nucleon structure, phenomenology of the nucleon-nucleon interactions
- few nucleon systems at short distances (probe of sub-nucleonic aspects; multinucleon forces etc.)

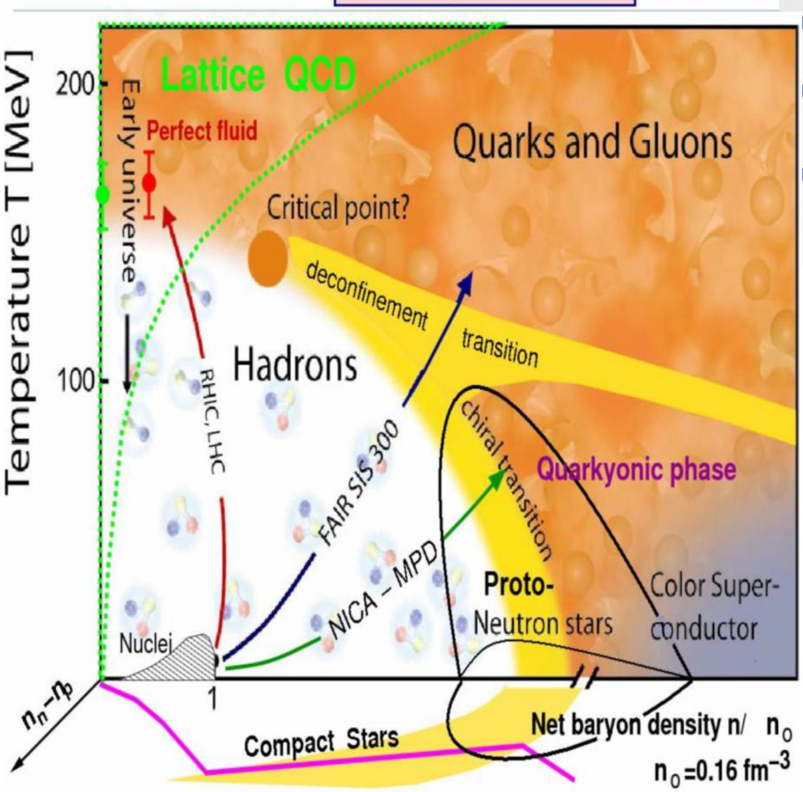
Flavour physics, **i.e.**

Fundamental symmetries **and mechanisms of their violation**

Particle structure **(constituents, quark content) in empty space and in the strongly interacting medium, exotics)**

Particle properties in medium **(cold and normal/sparse; hot and dense)**

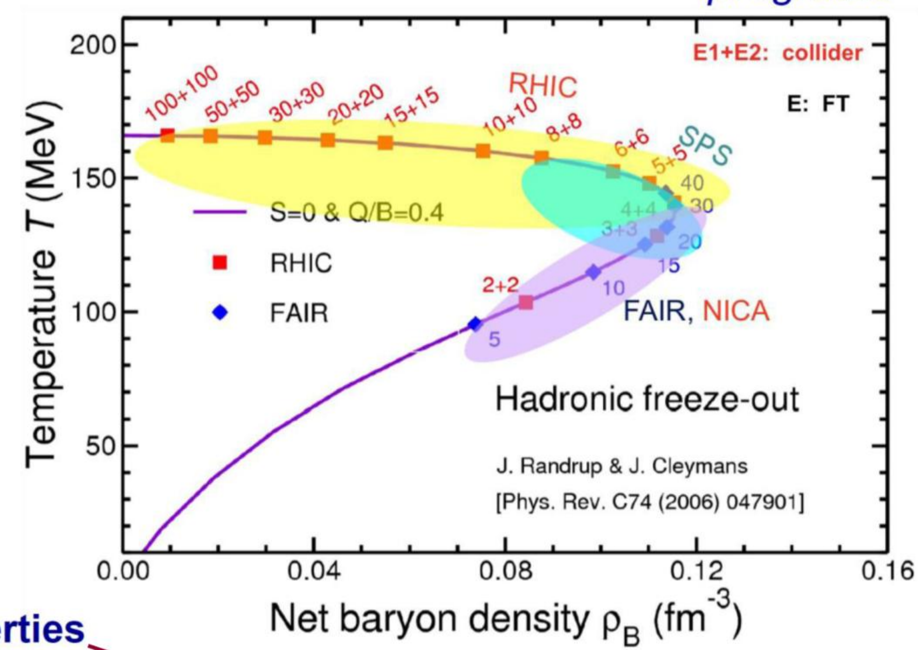
Physics



QCD matter at NICA :

- *Highest net baryon density*
- *Energy range covers onset of deconfinement*
- *Complementary to the RHIC/BES, FAIR and CERN experimental programs*

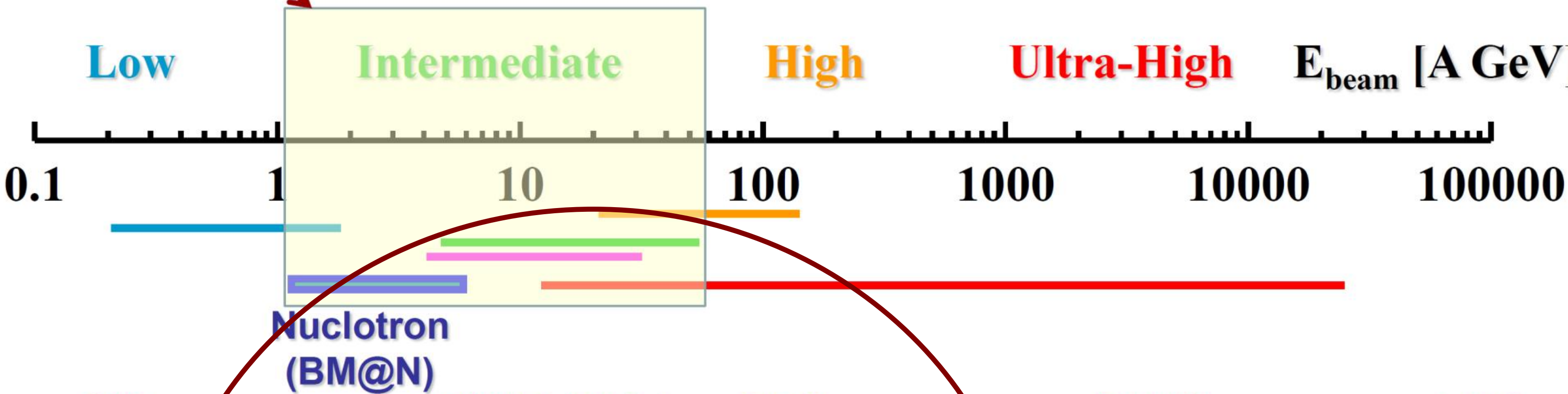
Freeze-out conditions



- **Bulk properties, EOS** - *particle yields & spectra, ratios, femtoscopy, flow*
- **In-Medium modification of hadron properties**
- **Deconfinement (chiral), phase transition at high ρ_B** - *enhanced strangeness production*
- **QCD Critical Point** - *event-by-event fluctuations & correlations*
- **Strangeness in nuclear matter** - *hypernuclei*

NOTE: a particle must live "long enough" inside the medium!

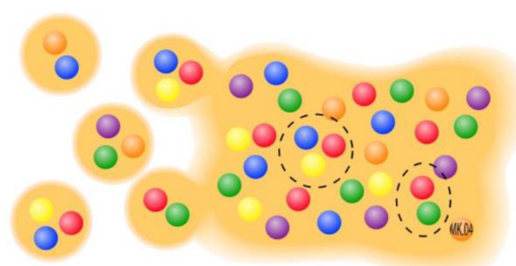
Heavy Ion Collision experiments



Baryonic matter
||
Meson and baryon spectroscopy
In-medium effects
EoS

‚Mixed‘ phase:
hadrons (baryons, mesons) +
quarks and gluons
||
In-medium effects
Chiral symmetry restoration
Phase transition to sQGP
Critical point in the QCD phase diagram

QGP: quarks and gluons
||
Properties of sQGP



The NICA Project: recent review papers

See also

https://ufn.ru/en/articles/2016/4/

Physics – Uspekhi **59** (4) 383 – 402 (2016)

60th ANNIVERSARY OF THE JOINT INSTITUTE FOR NUCLEAR RESEARCH (JINR) PACS numbers: **11.80.–m**, 13.85.Dz, 14.20.Dh

Relativistic nuclear physics at JINR: from the synchrophasotron to the NICA collider

N N Agapov, V D Kekelidze, A D Kovalenko, R Lednitsky, V A Matveev,
I N Meshkov, V A Nikitin, Yu K Potrebennikov, A S Sorin, G V Trubnikov

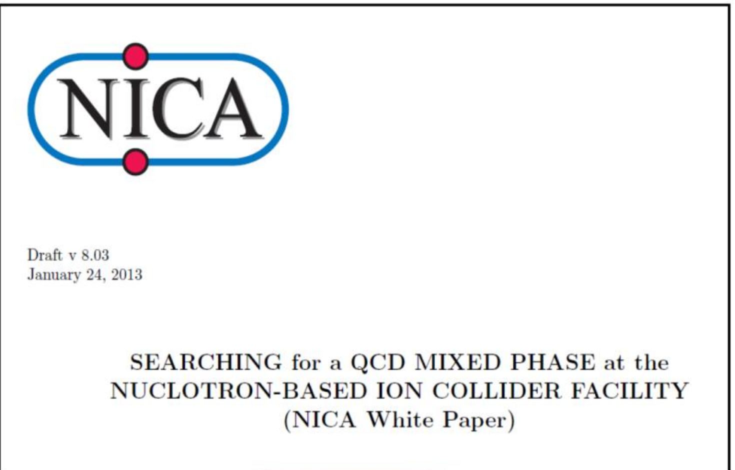
DOI: 10.3367/UFNe.0186.201604c.0405

and Eur. Phys. Journal A “Hadrons and Nuclei”, 52 N8 (2016), ed. by D.Blaschke, J.Aichelin, E.Bratkovskaya et al (special issue).

Physics: program and suggestions see in

http://theor0.jinr.ru/twiki-cgi/view/NICA/WebHome

NICA White Paper – International Effort

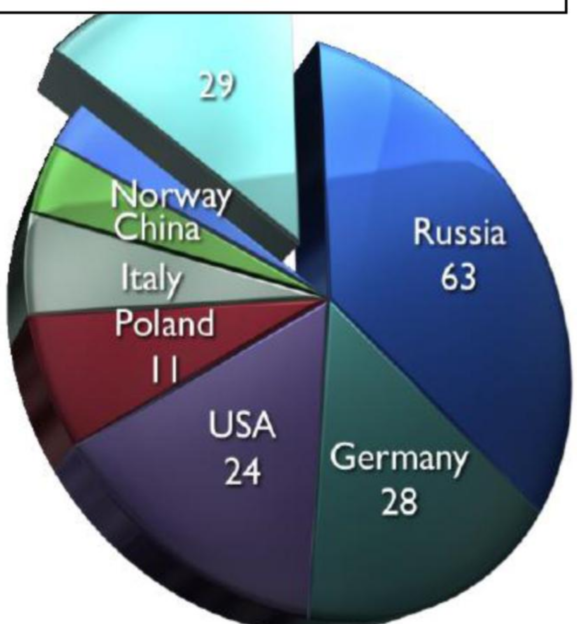

Draft v 8.03
January 24, 2013

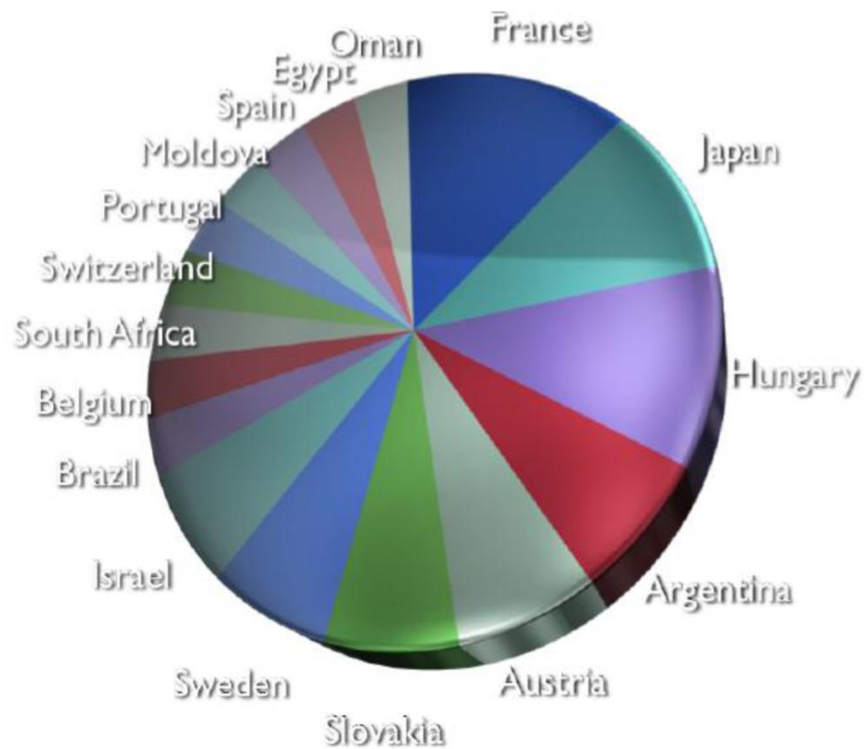
SEARCHING for a QCD MIXED PHASE at the
NUCLOTRON-BASED ION COLLIDER FACILITY
(NICA White Paper)

Statistics of White Paper Contributions (as in 2015)

111 *contributions:*
188 *authors from* **70** *centers in* **24** *countries*

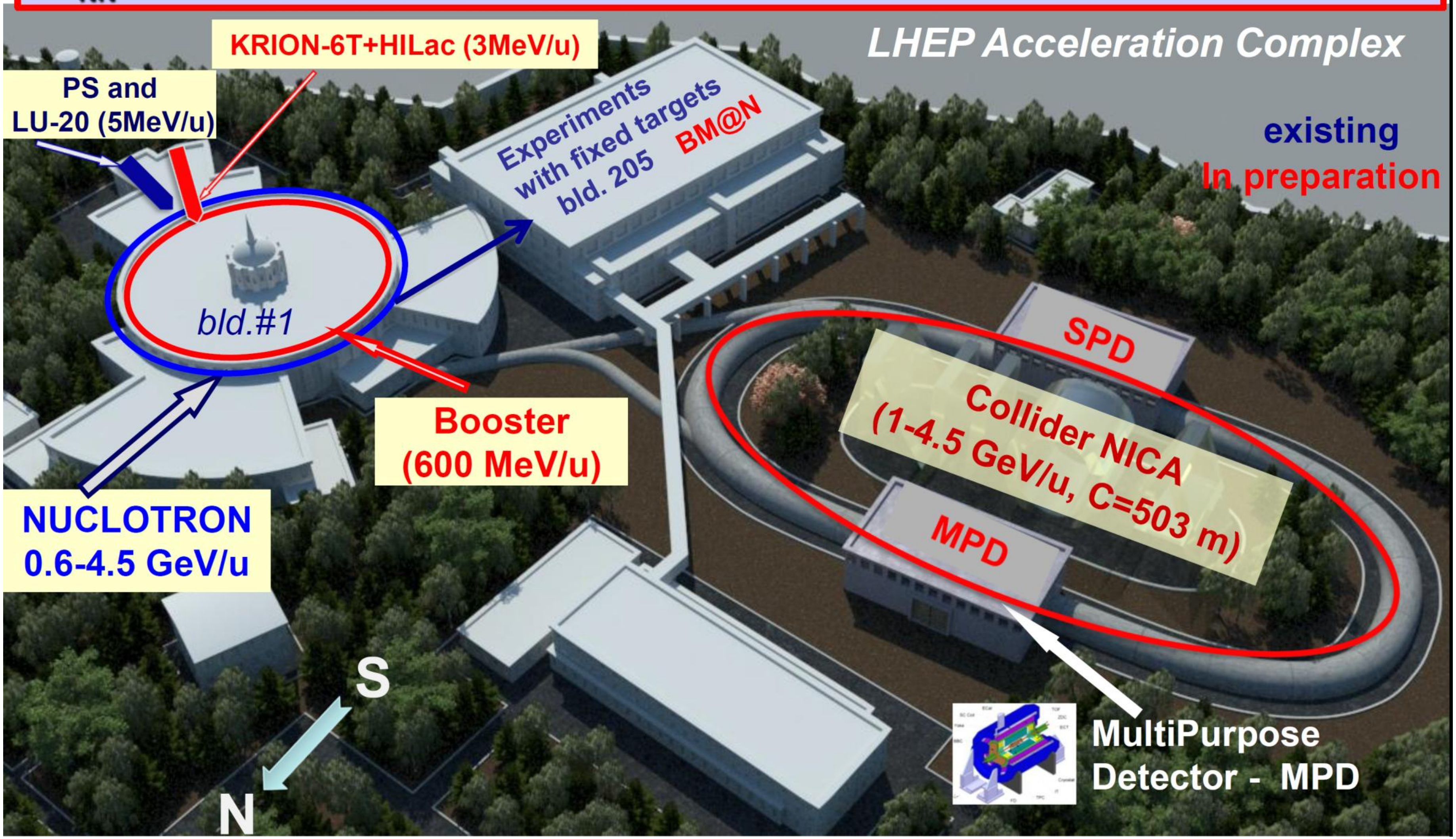
Indicates wide international interest
to the physics at MPD & BM@N



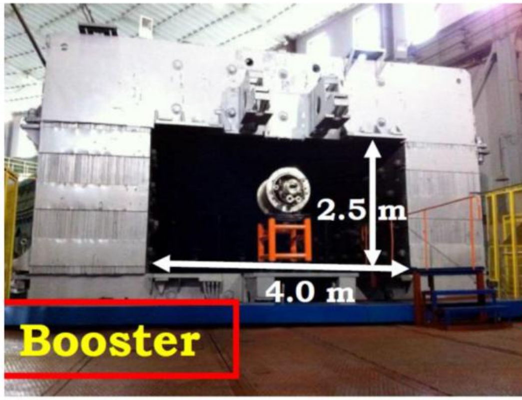


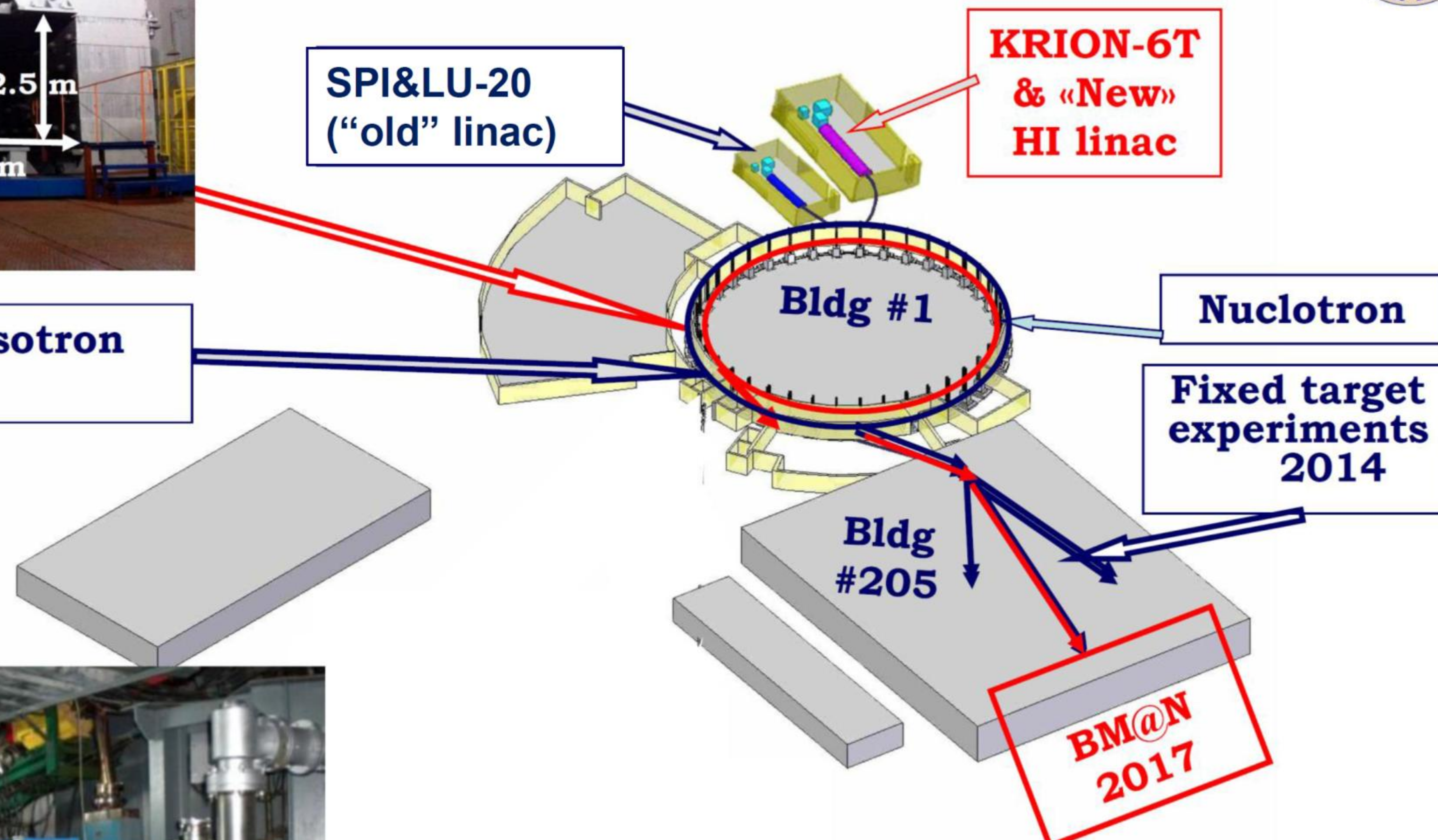
NICA complex

Collider basic parameters:
$\sqrt{s_{NN}}$ = **4-11** GeV; ***beams**: from* **p** to **Au**; **L~10^{27}** cm^{-2} c^{-1} (Au), ~**10^{32}** cm^{-2} c^{-1} (p)



NICA – Stage I

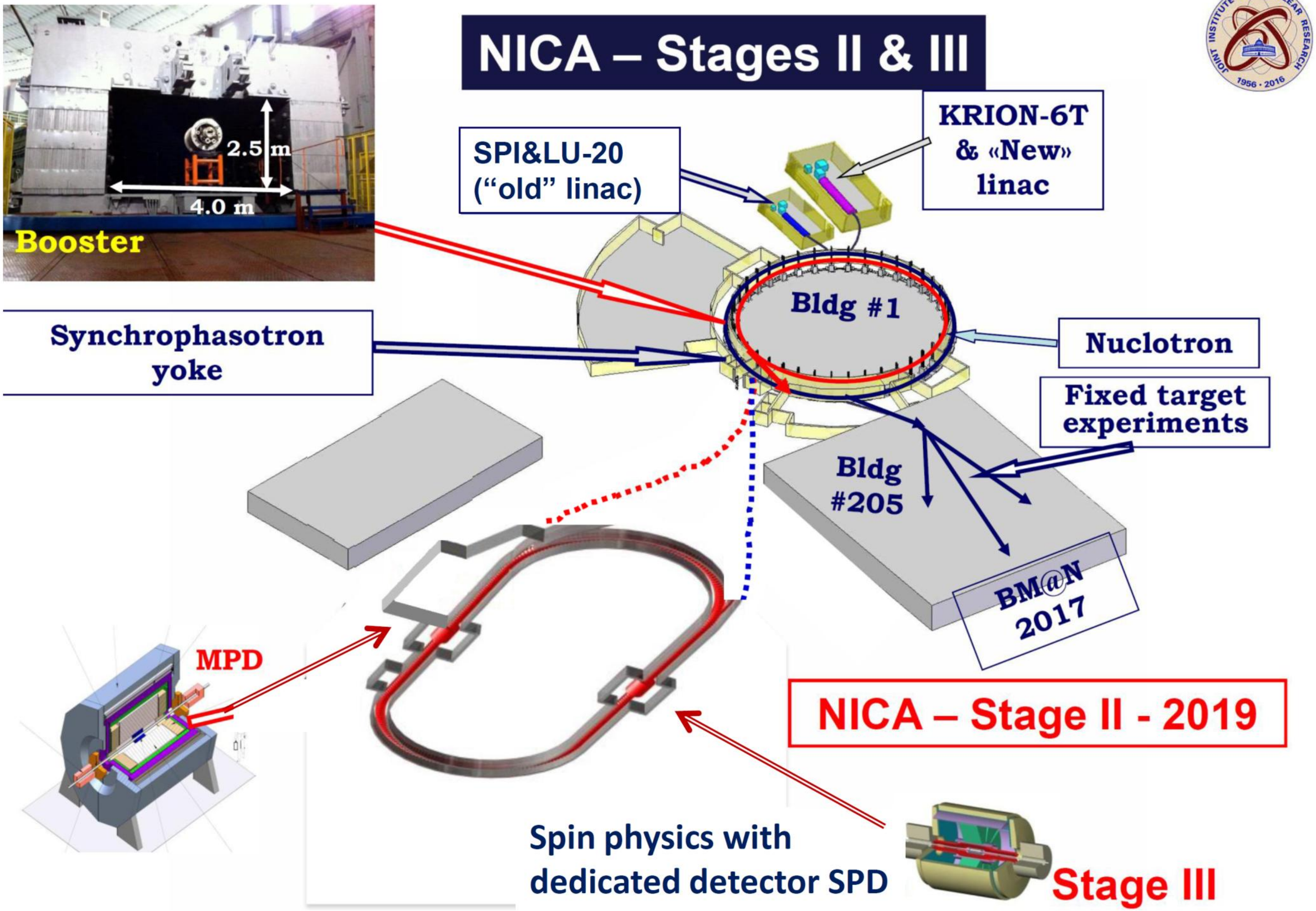




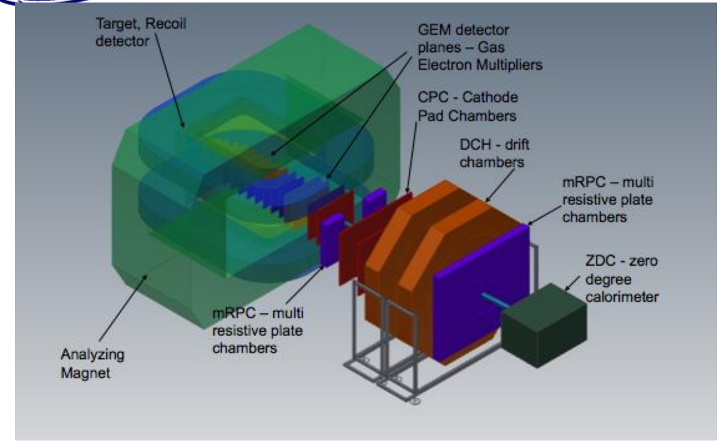
Nuclotron facility today

NICA – Stage I – 2017

Introduction



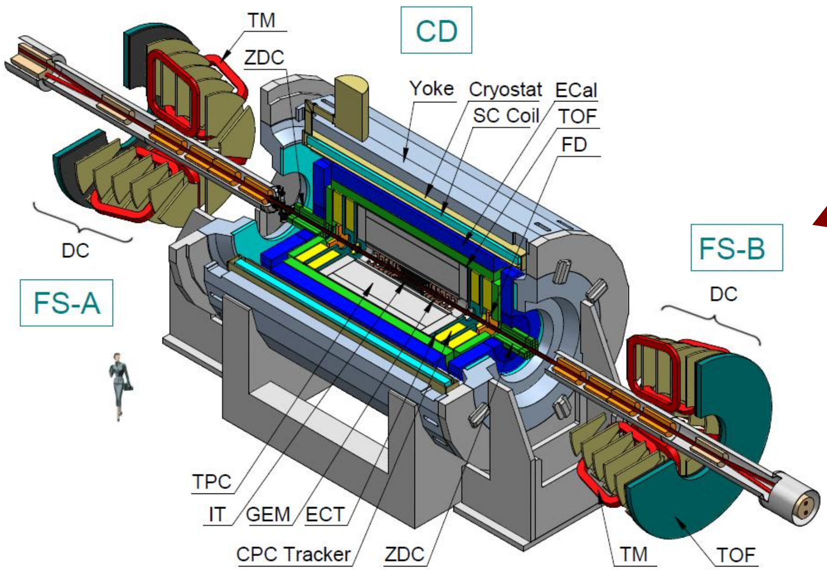
NICA DETECTORS



Baryonic Matter at Nuclotron (BM@N)

the fixed target experiment at the Nuclotron

start of Stage I - 2017



MultiPurpose Detector (MPD)

at the Collider

start of Stage I - 2019

Spin Physics Detector (SPD) start of Stage I **- 2023**

project is under preparation

Complementarity between the collider-type and fixed-target type experiments

Experiments with fixed targets (the BM@N first of all) at extracted Nuclotron beams

are important parts of the NICA project.

Collisions of elementary particles:

- **protons** ***(nucleus of hydrogen)***
- **heavy ions (for example, Au)**

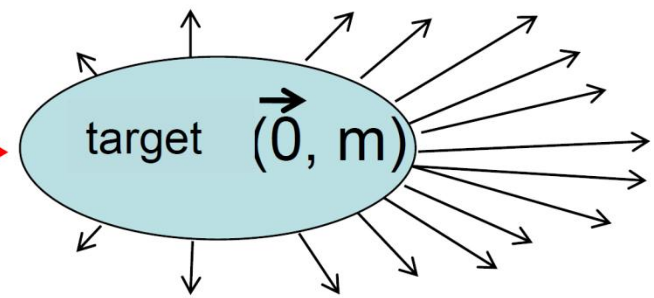
$$S_{NN} = (E_1 + m)^2 - (\vec{p} + 0)^2$$
$$\approx 2pm + 2m^2$$

Experiments:

✓ with fixed targets:

p = **10** GeV

$(\vec{p}, m)$

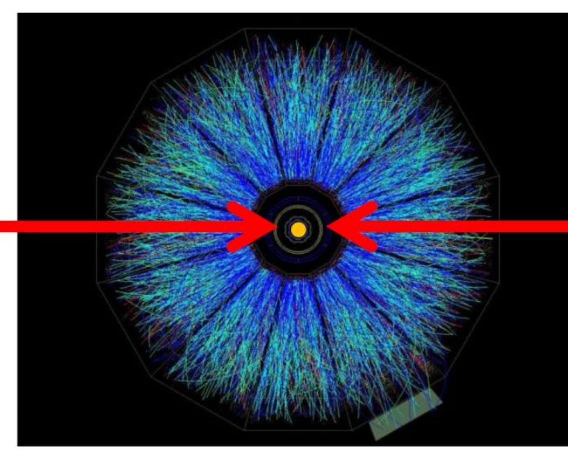


$\sqrt{S_{NN}} \approx$ **4,5** GeV

1eV	= **1.6 × 10^{-19}**J
1GeV=10^9 eV≈ m	

✓ at colliders:

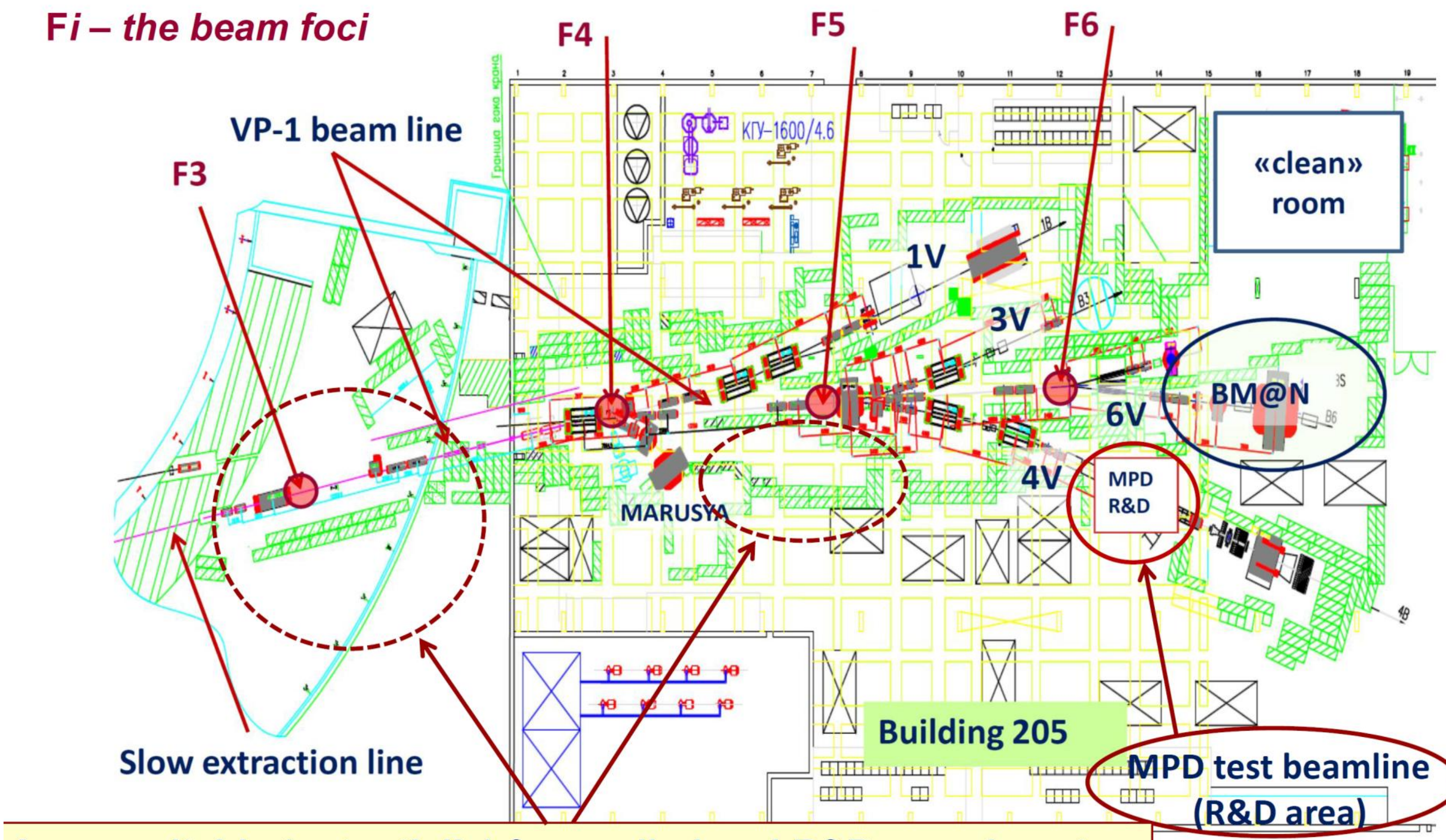
$(\vec{p}, m)$ $(-\vec{p}, m)$



$\sqrt{S_{NN}} \approx 2p =$ **20** GeV

Extracted beams.

Map of beam lines for fixed target experiments at Nuclotron beams



Areas suitable (potentially) for applied and R&D experiments

NICA Collider area (Jan. 2017)

NICA Collider area (May 2017)

NICA Collider area (May 2017)

NICA Collider area (June 2017)

Some last year news concerning realization of the NICA project (fixed targets part):

(1)

Renewal of the polarized deuteron beam at the LHEP of JINR (results of the year 2016)

↙

Runs 52 and 53 of the Nuclotron (total duration: ≈2070 hours)

Run 52 of the Nuclotron

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:***

SPI→RFQ **→LU-20 →Nuclotron**

New!

This run was the "technical one" first of all.

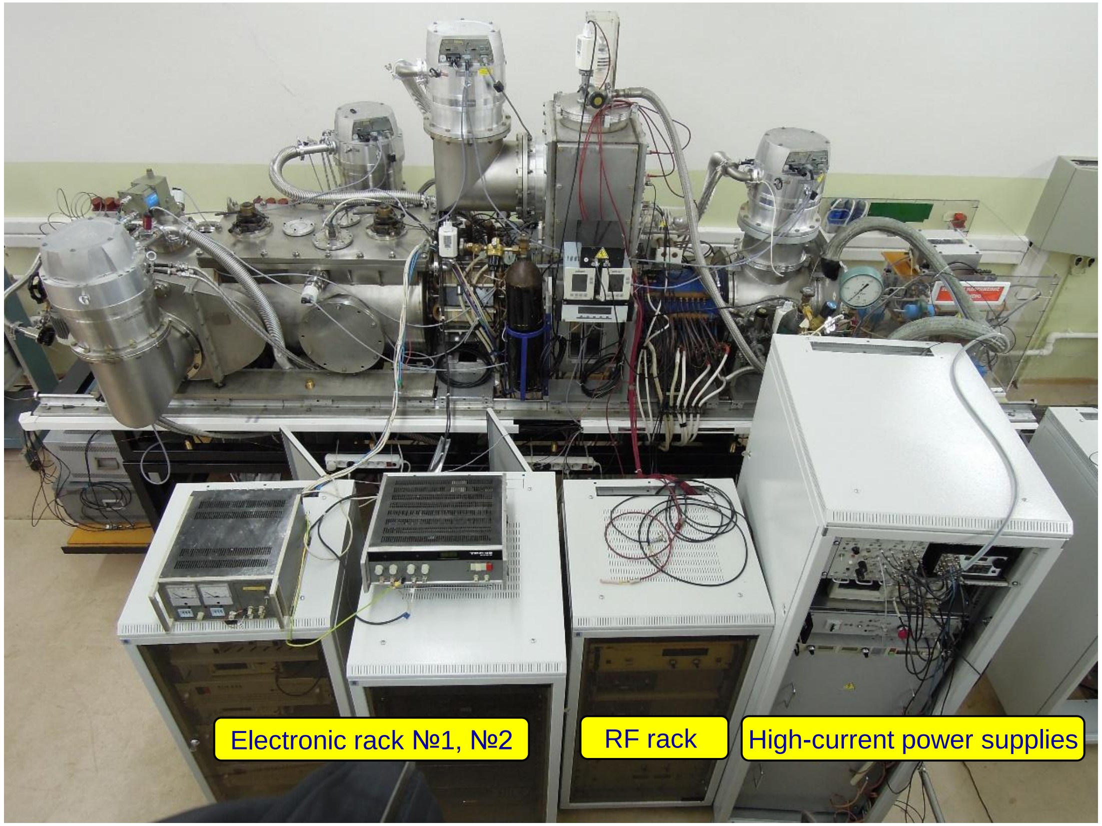
Source of Polarized Ions (the project)

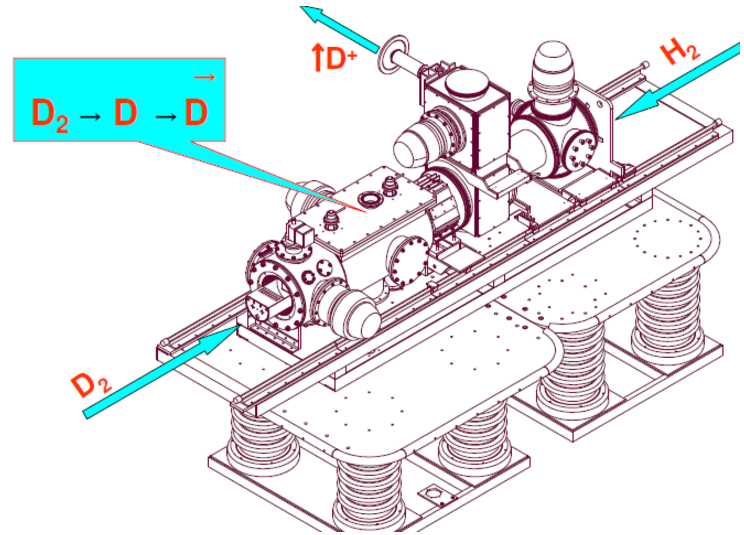
The SPI-project includes the following stages:

- development of the high-intensity Source of Polarized Ions
- complete tests of the SPI
- modification of the Linac pre-accelerator platform & power station
- SPI matching with Low Energy Beam Transfer (LEBT), RFQ & Linac
- remote control system (console of Linac) of the SPI under the high voltage
- SPI & Linac runs with polarized beam and polarization measurements at the NUCLOTRON

SPI – the Source of Polarized Ions (p, d, H); JINR+INR RAS

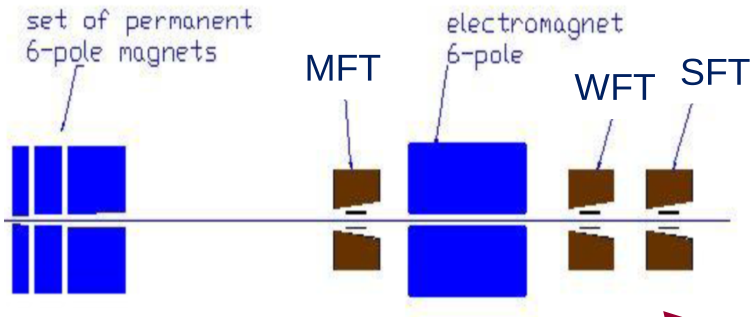
V.Fimushkin
A.Belov

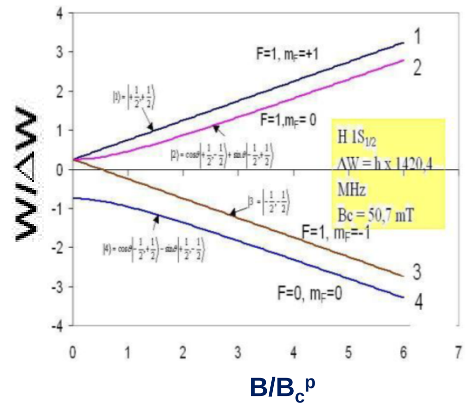




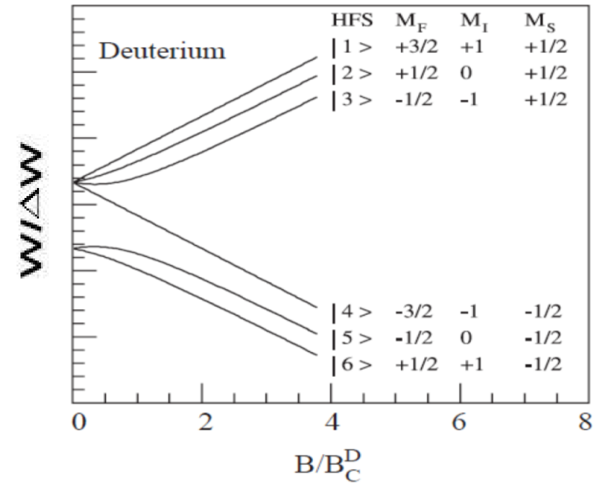
- In August 2012, the ABS was transported from the INR of RAS (Moscow) and assembled at JINR
- All-inclusive SPI-tests are carried out in 2014-2015 at JINR
- ~ 2 mA deuteron beam current was achieved in July 2015

Principle of the SPI operation





Energy diagram of hfs of hydrogen atom in ground state $1S_{1/2}$



deuterons

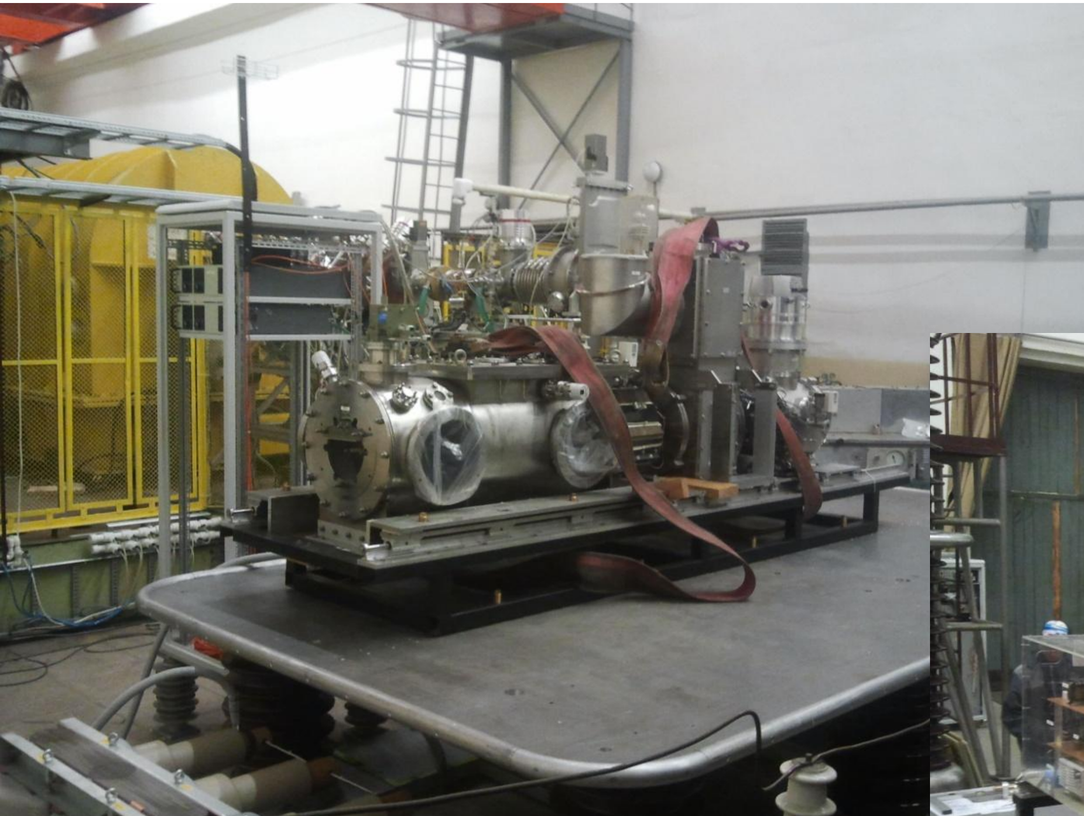
HFT between 6poles	HFT after 6poles	Final D hfs	P_Z	P_{ZZ}
MFT 3 → 4	WFT 1,2 → 3,4	3,4	-1	+1
MFT 3 → 4	SFT 2 → 6	1,6	+1	+1
MFT 1 → 4	SFT 3 → 5	2,5	0	-2
MFT 1 → 4	SFT 2 → 6	3,6	0	+1

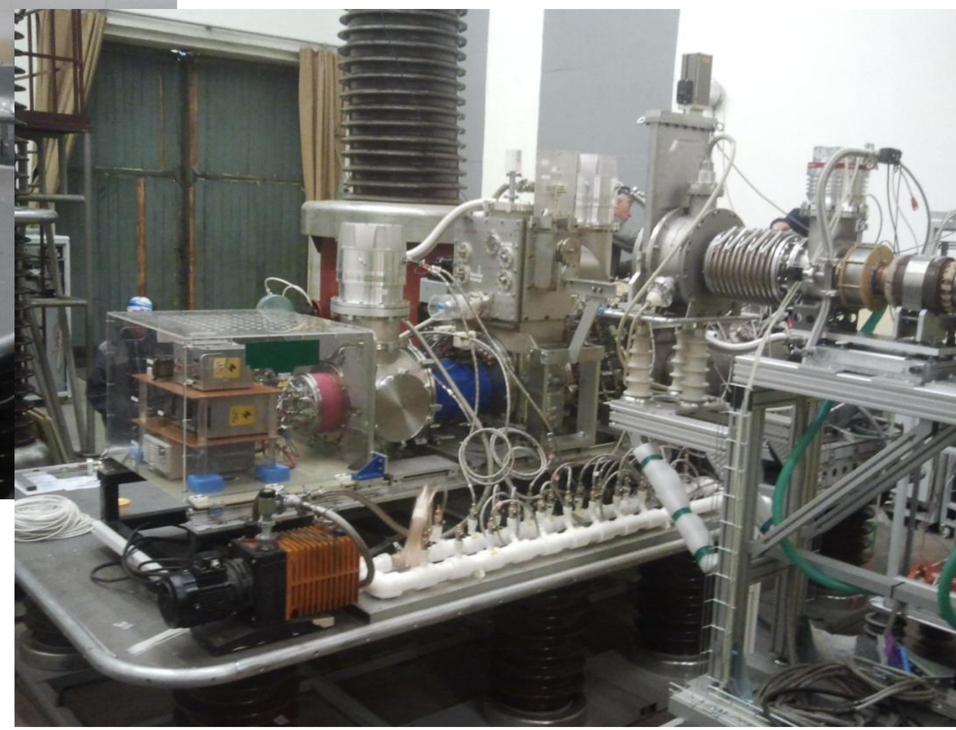
protons

		Final H hfs	
MFT - off	WFT 1→ 3	2,3	-1
MFT - off	SFT 2→ 4	1,4	+1

SPI – the Source of Polarized Ions (p, d, H); JINR+INR RAS

V.Fimushkin
A.Belov



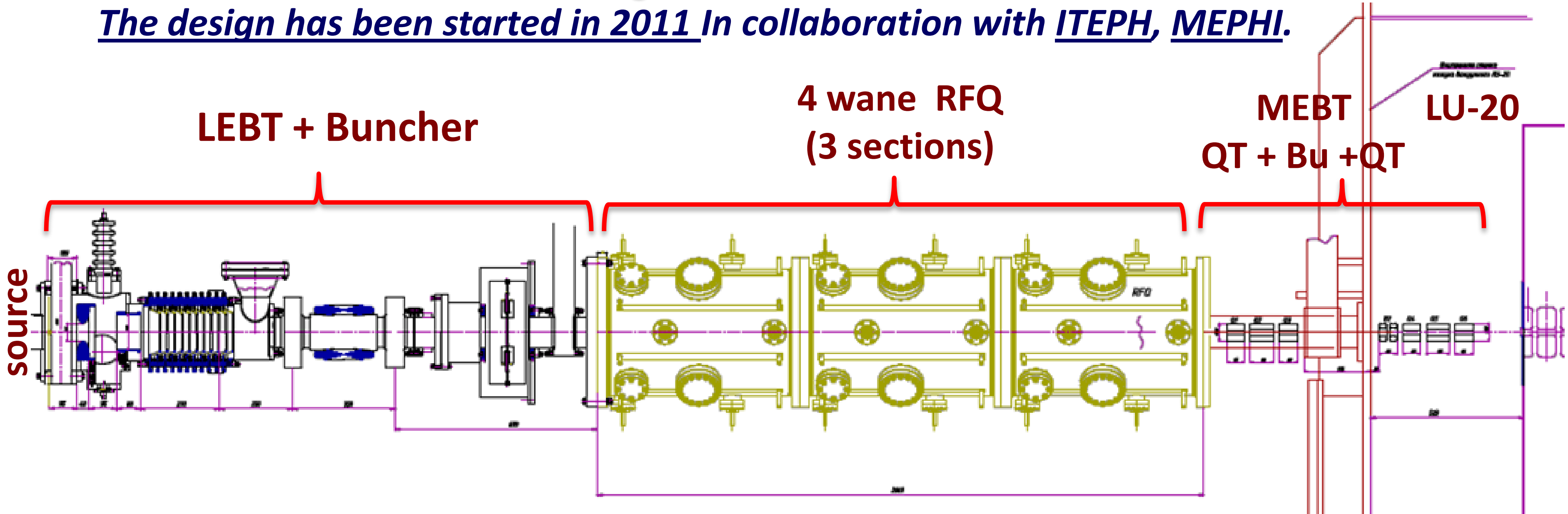


SPI transportation and assembly at the LU-20

The control system of the SPI is under the high voltage

New fore-injector for LU-20

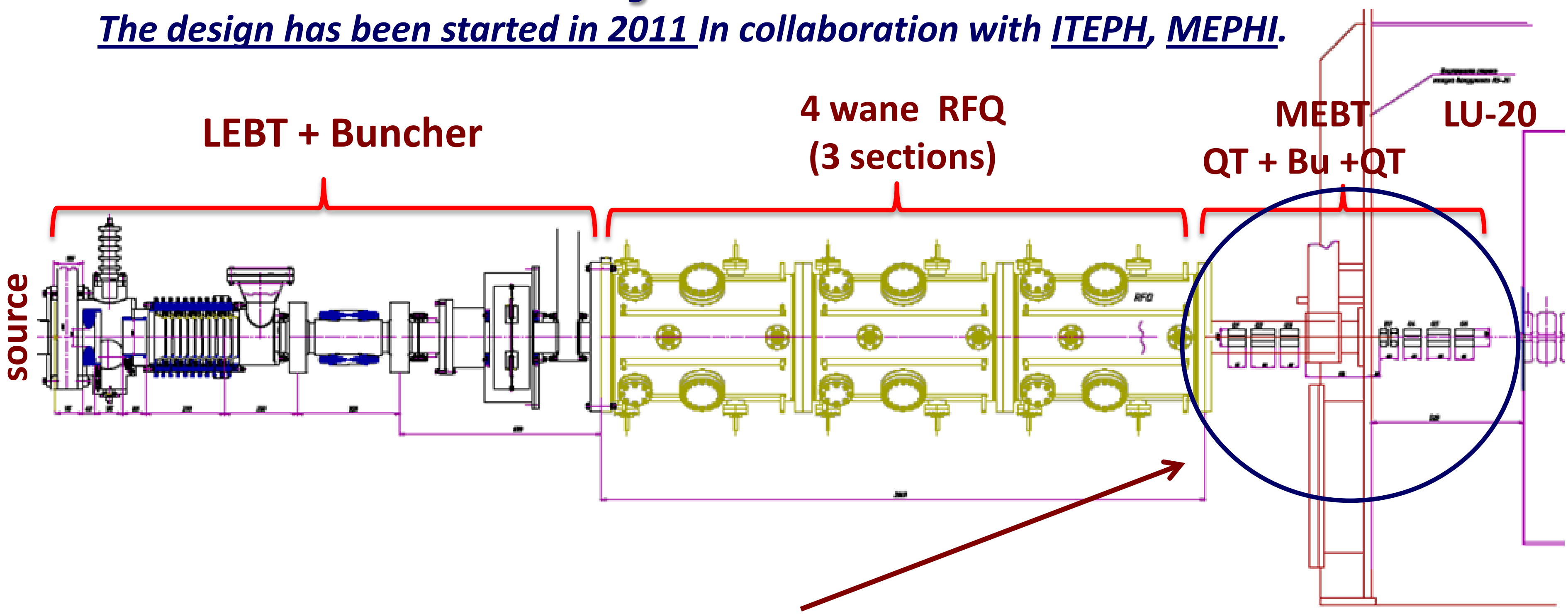
The design has been started in 2011 In collaboration with ITEPH, MEPHI.



q/A	1.0	0.5	≥ 0.3
Injection energy, [keV]	31	61.8	103
Max current, [mA]	10	20	10
Output energy [MeV/u]	0.156		
Norm emittance (output) [π·cm·mrad]	≤ 0.5		
RFQ length, [m]	2.2		
Transmition, %	> 85%	> 89%	> 93%
In LU-20 acceptance	70 %	71 %	80 %

New fore-injector for LU-20

<u>The design has been started in 2011</u> In collaboration with <u>ITEPH</u>, <u>MEPHI</u>.



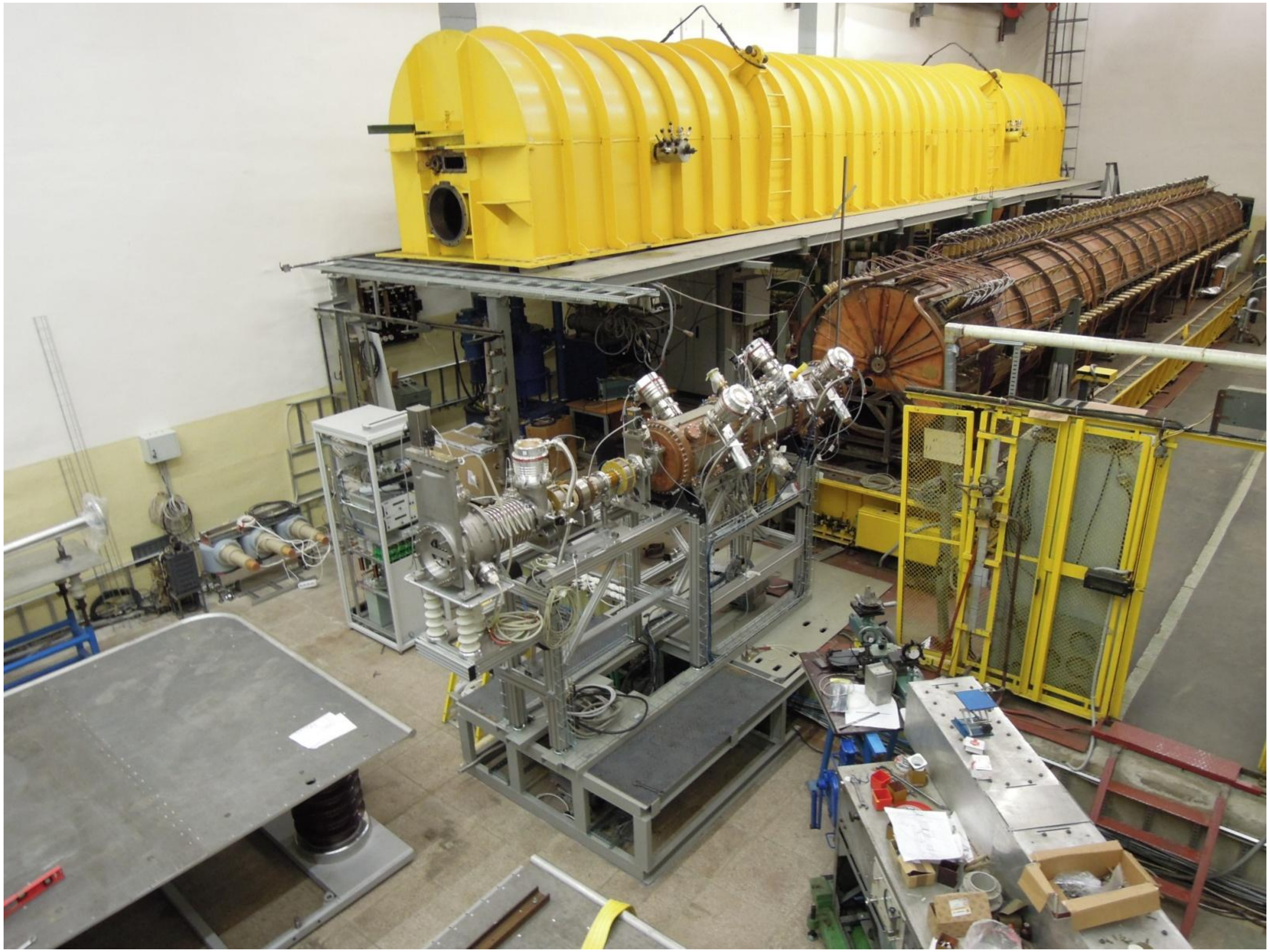
The LEBT, RFQ and Medium energy beam transport (MEBT) were assembled in March – May 2016

The MEBT includes two triplets of quadrupole lenses and Buncher

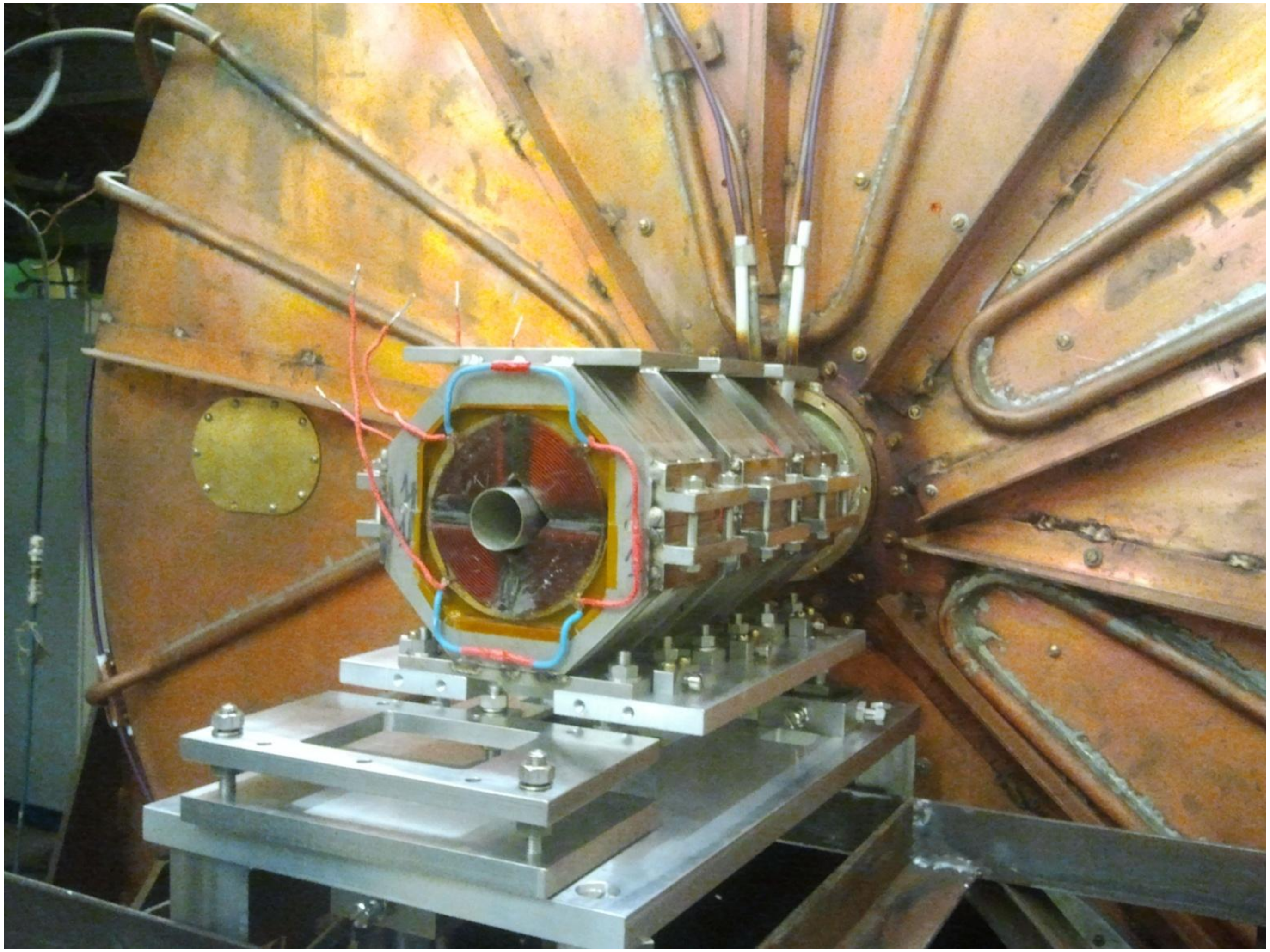
In the current configuration the Buncher is absent (Transmission ~ 20%)

The new High-Voltage platform was assembled

New fore-injector for LU-20



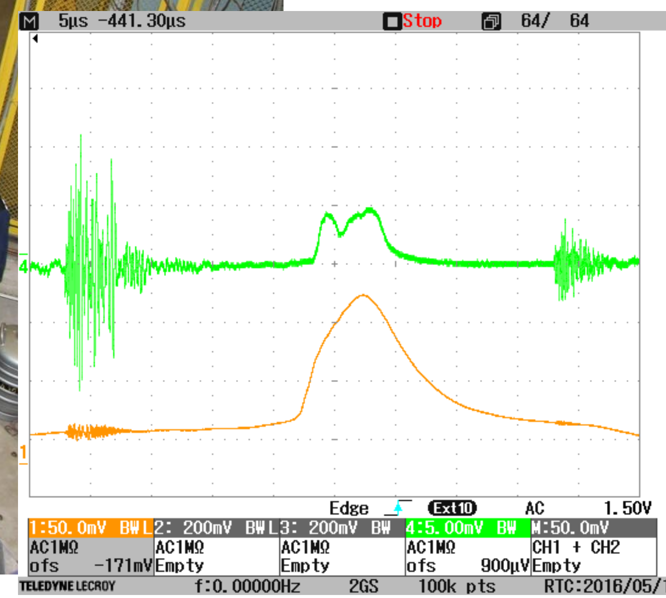
New fore-injector for LU-20



Triplet inside the LU-20 resonator

New fore-injector for LU-20

G.Trubnikov,
A.Butenko,
A.Govorov,
V.Monchinsky,
T.Kulevoy,
S.Polozov
…



16 of May 2016 – beam from the laser source was accelerated in the LU-20

Run 52 (technical)

Good results:

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

Polarimeters were prepared for measurements
(the Low Energy Polarimeter (after LU-20) and the ITS polarimeter
at the internal beam).

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

(01.07.16 - 7.07.16)

vector polarization – as expected ~ (+/- 0.5), but:
one sign – direct measurements,
another sign: indirect measurements
(by measurements of the tensor polarization).

***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)

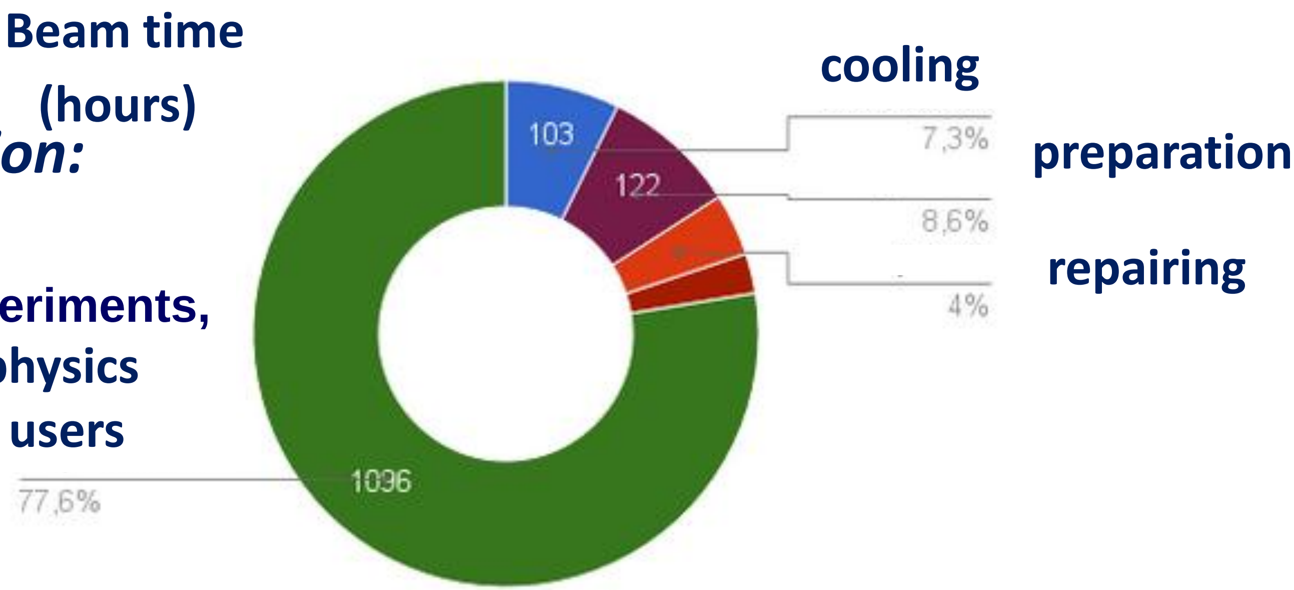
All the works were performed according
the JINR topical plan.

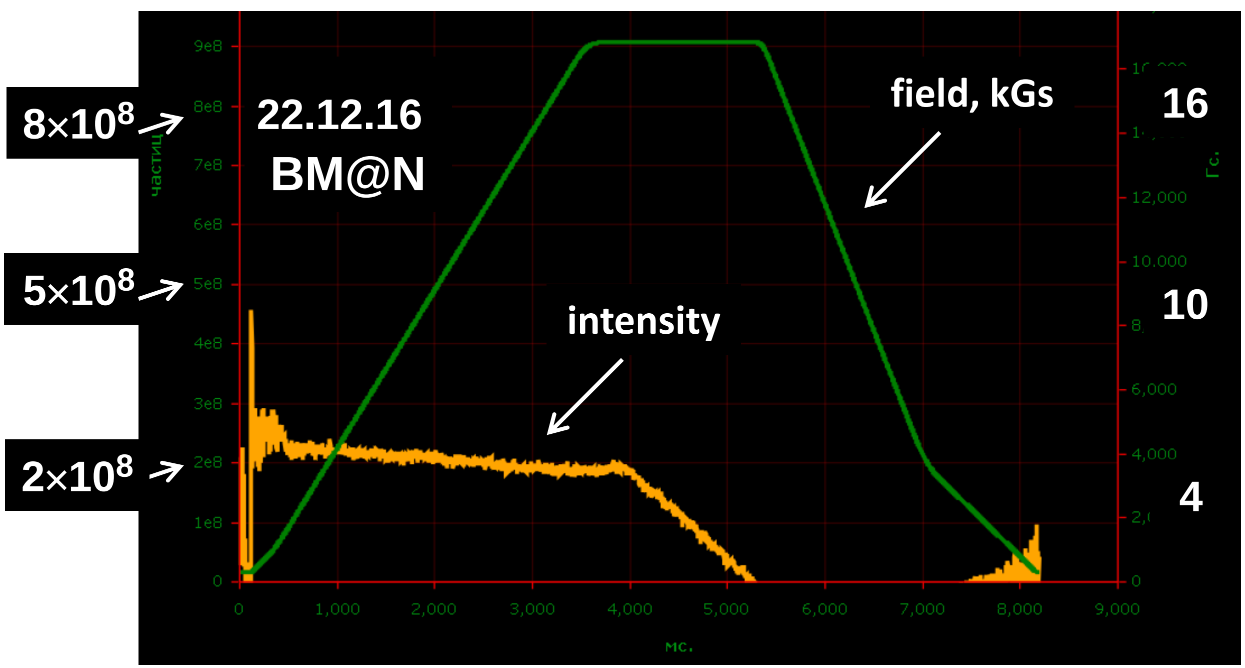
Run 53 of the Nuclotron (27.10.2016 – 25.12.2016)

The total run duration:

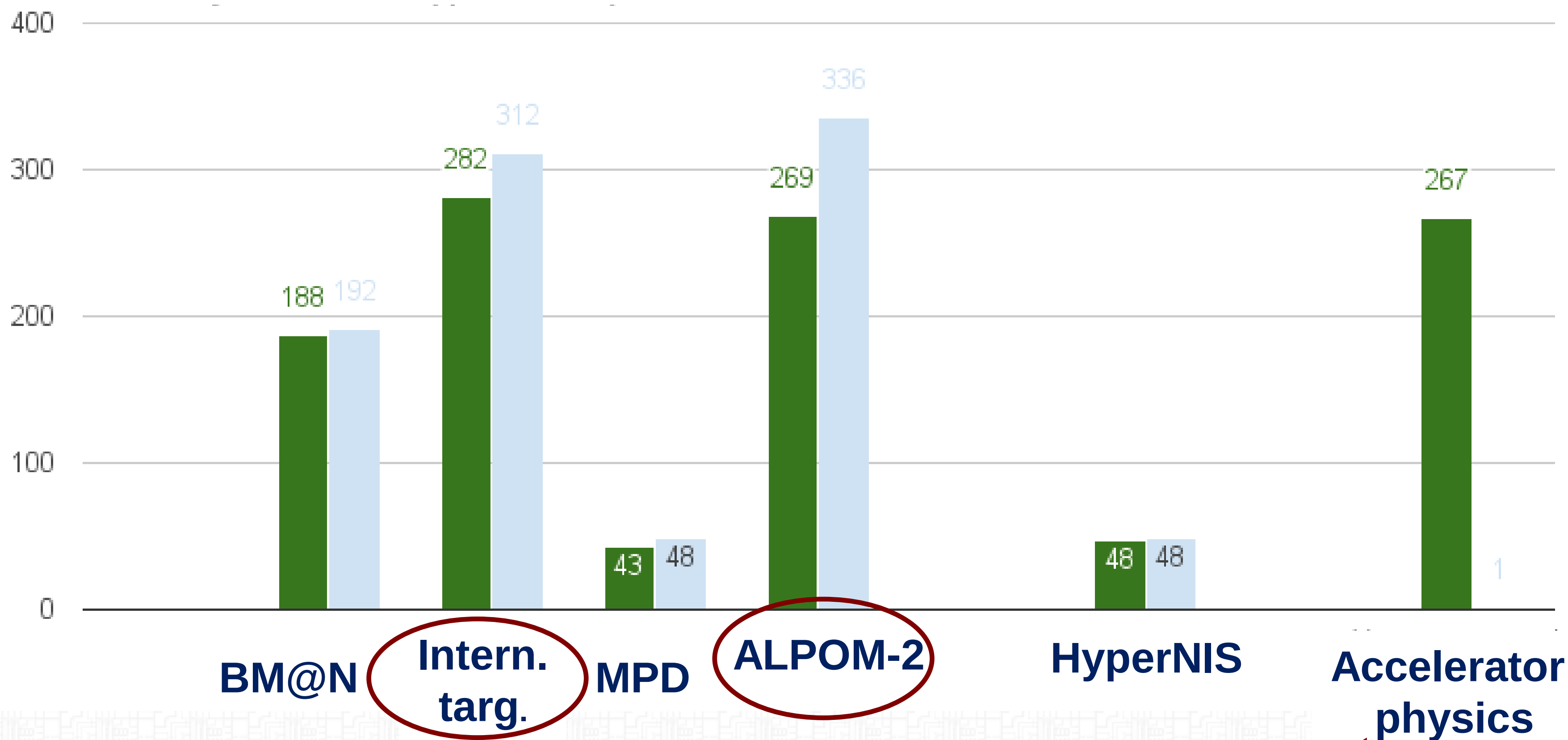
≈1400 hours

Physics experiments, accelerator physics and R&Ds of users





Use of beam (hours): in fact/planned



(including polarimetry)

Selected results (ALPOM-2 in the run 53)

all the data are preliminary,

data analysis is in progress,

reports are being expected at the DSPIN Conference (Sept. 2017)

Jefferson Lab's upgrade has doubled the electron beam energy to 12 GeV:

The doubling of the energy will allow measurements of the electric and magnetic form factors of the neutron and proton to significantly higher Q^2.

From talk by V.Punjabi at JINR PAC for particle physics, session 43

Continuing the form factor ratio measurements for proton and neutron by the recoil polarization method to as high a Q^2 as possible is a priority at JLab.

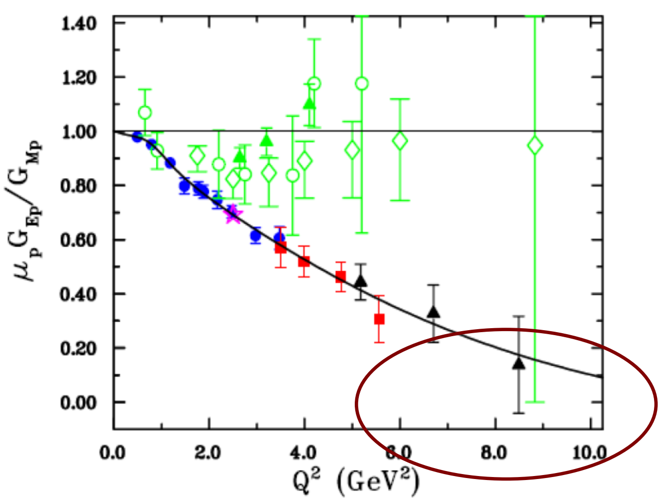
Current Status of G_{Ep}/G_{Mp} and G_{En}/G_{Mn}

Current situation for G_{Ep}/G_{Mp}, showing unbridgeable discrepancy between cross section (green) and polarization (blue/red/black). Curve is double-polynomial fit.

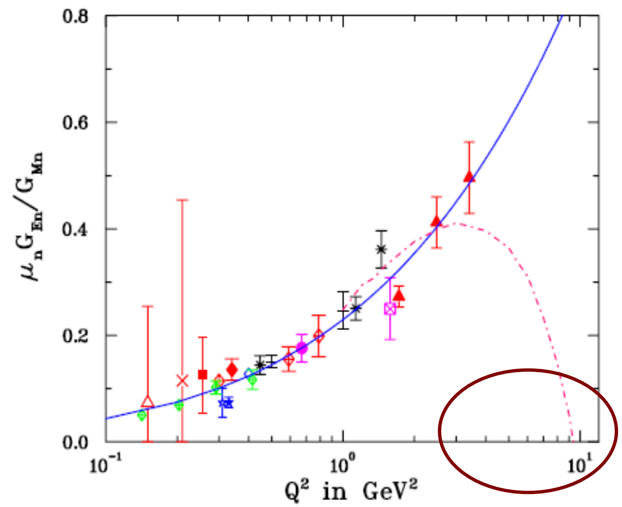
Dyson-Schwinger approach for neutron predicts a (second) zero for G_{En}, also near 10 GeV^2.

ALPOM-2 is for this!

Will G_{Ep} become zero?



Will G_{En} also become zero?

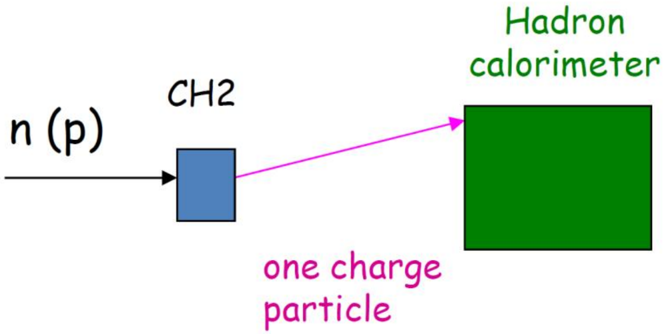


References: http://www.scholarpedia.org/article/Nucleon_Form_factors, and arXiv:1503.01452v4 and Prog. Part. Nucl. Phys. 59 (2007) 694-764

ALPOM-2 in the run 53 Data status: *preliminary*; analysis is in progress

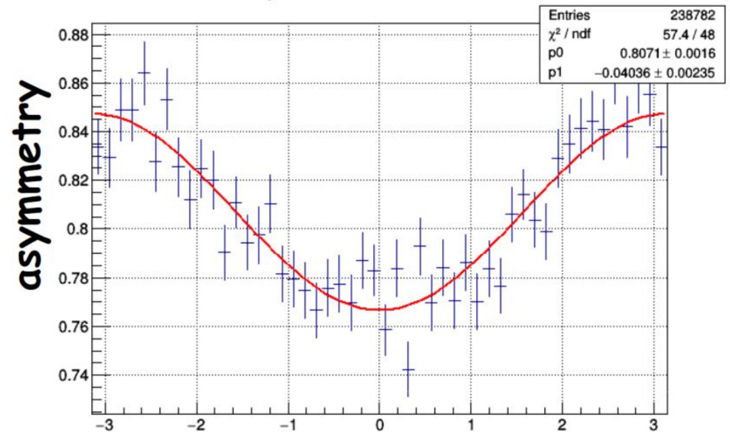
Measurement of analyzing powers for the reaction p + CH2 up to 7.5 GeV/c and n + CH up to 4.5 GeV/c at the Nuclotron (ALPOM2 proposal)

(From N.M.Piskunov)

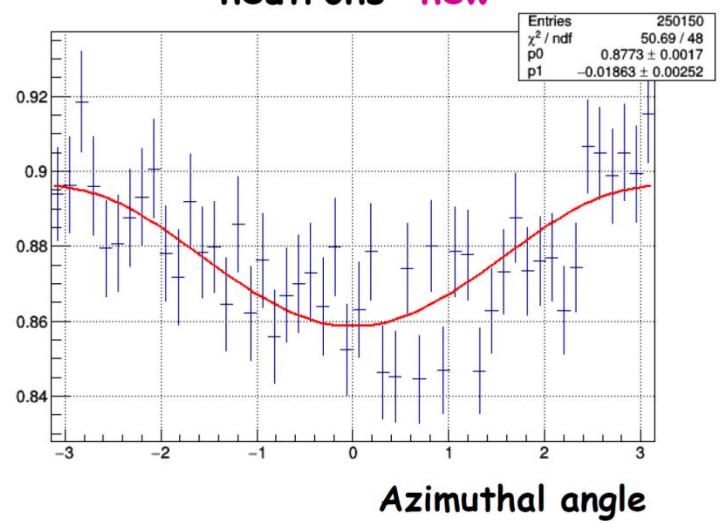


JINR-Slovakia-USA-France-United Kingdom

protons

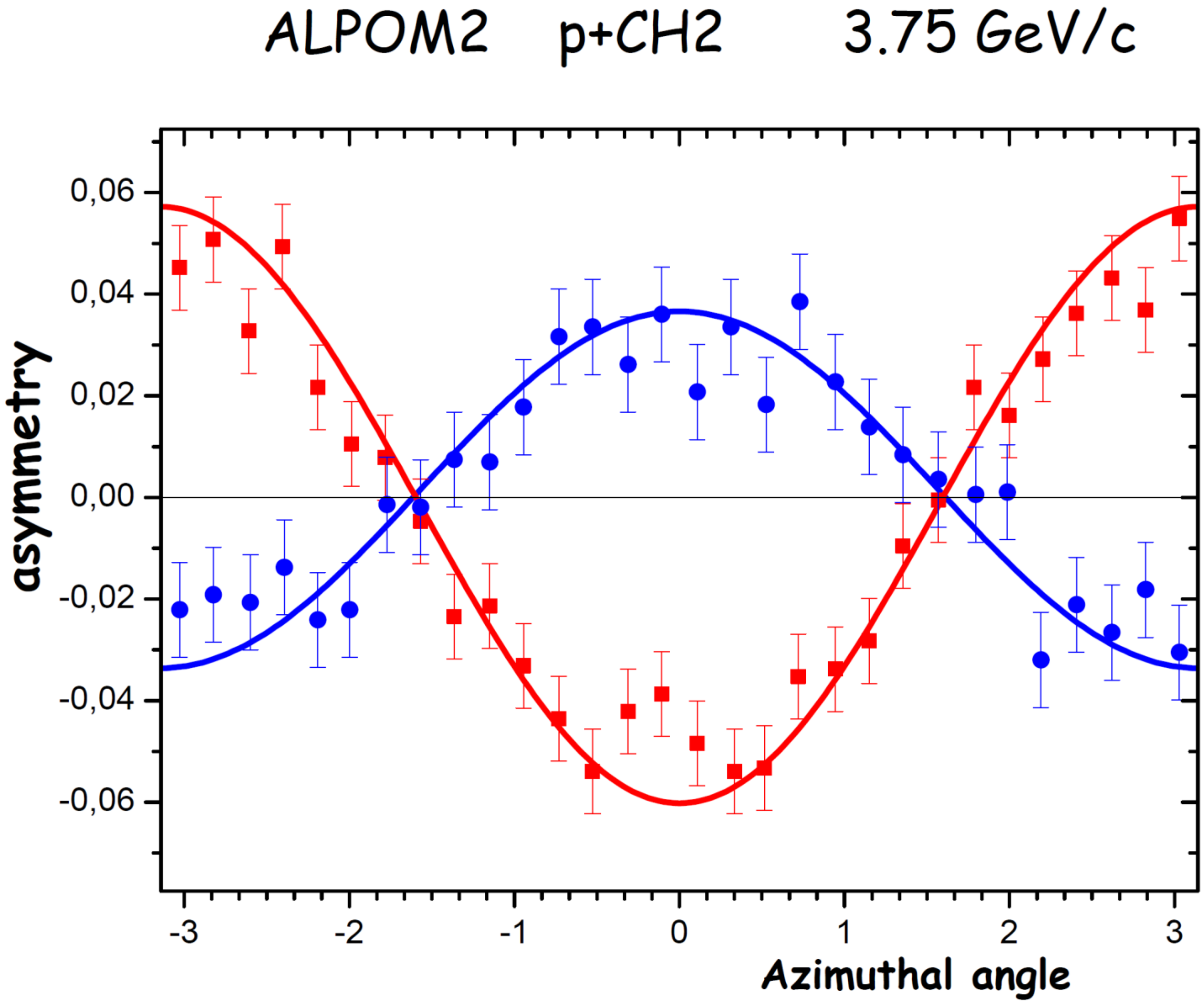


neutrons **new**



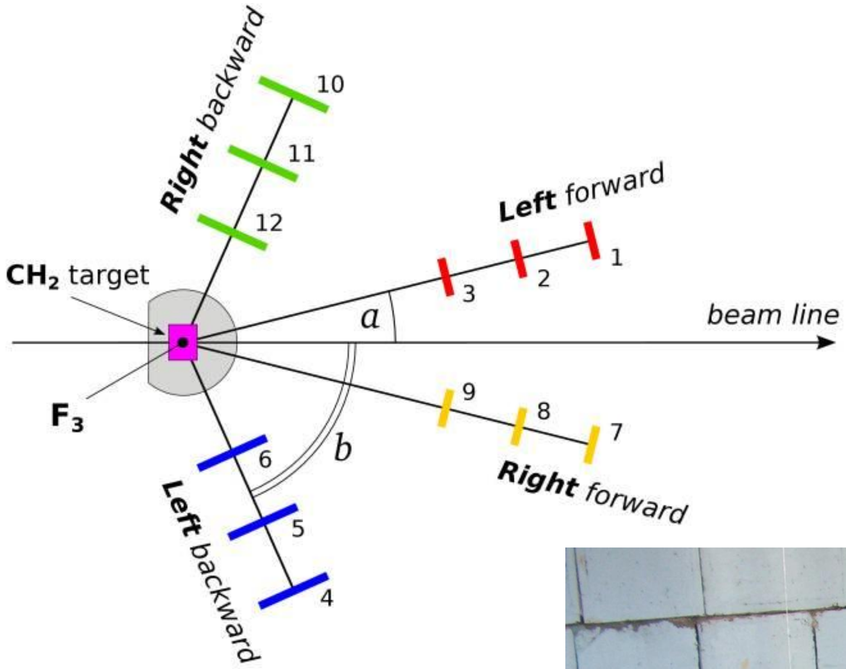
(From N.M.Piskunov)

ALPOM-2 in the run 53. Data status: ***preliminary***; analysis is in progress



Polarimeter at the extracted beam (focus F3)

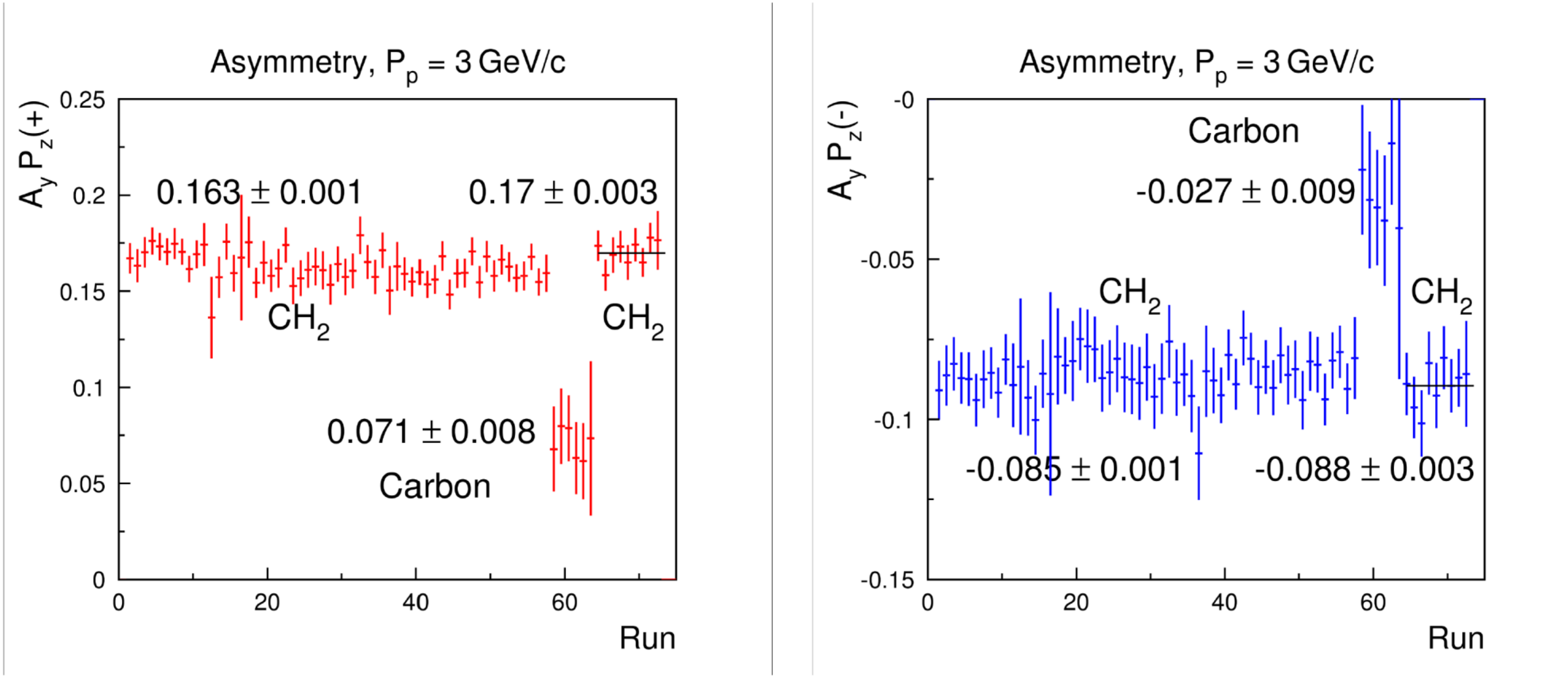
(From N.M.Piskunov and R.A.Shindin)



(From N.M.Piskunov and R.A.Shindin)

Polarimeter at the extracted beam (F3 focus)

Deuteron beam momentum: 3 GeV/c



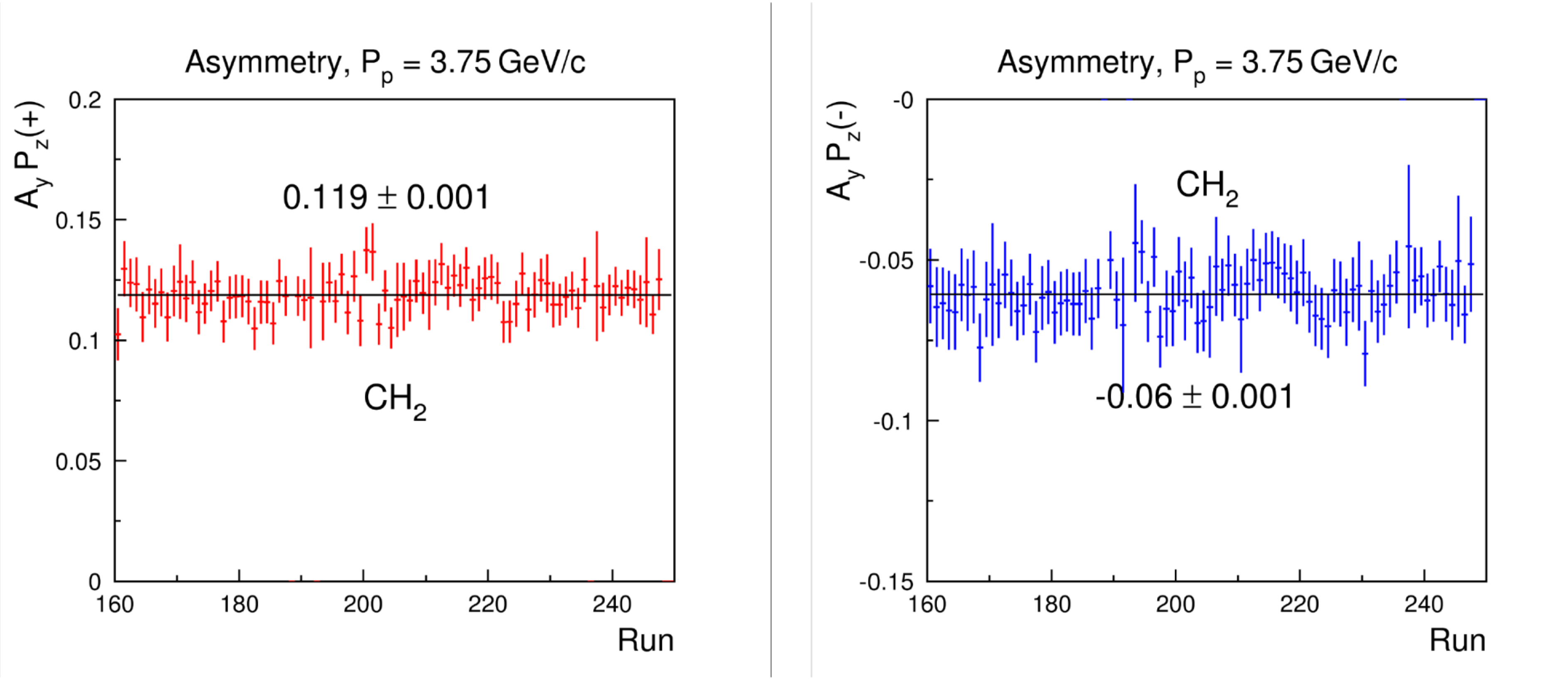
Vector polarization of the beam *(preliminary!)*

$P_z(+) = 0.652 \pm 0.004 \pm 0.052$ $P_z(-) = -0.343 \pm 0.005 \pm 0.027$

(From N.M.Piskunov and R.A.Shindin)

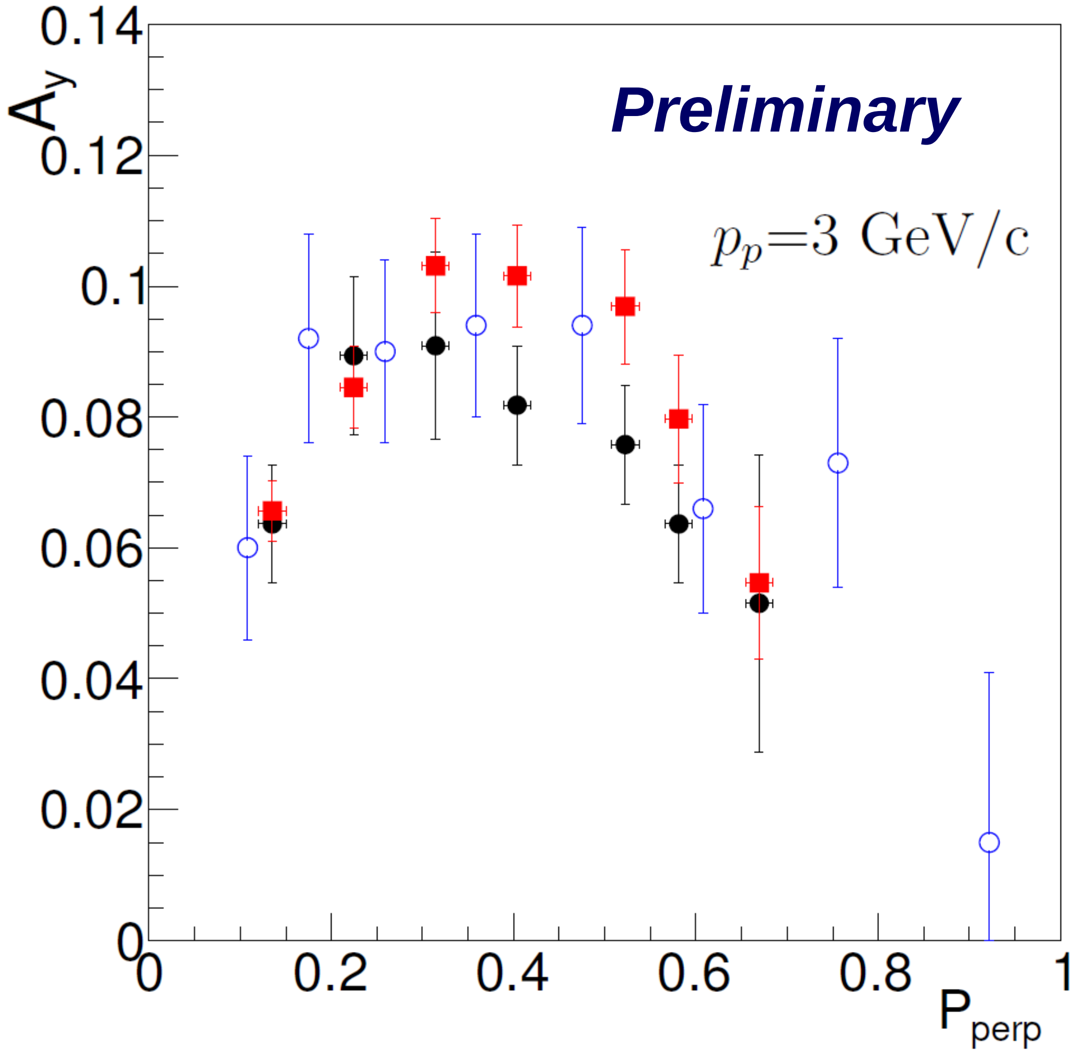
Polarimeter at the extracted beam (F3 focus)

Deuteron beam momentum: 7.5 GeV/c



Vector polarization of the beam *(preliminary!)*

$P_z(+) = \mathbf{0.593} \pm 0.005 \pm 0.047$ $P_z(-) = \mathbf{-0.302} \pm 0.006 \pm 0.024$



Analyzing powers of the $p + CH_2 \to 1$ charged particle+X, at p_p=3 GeV/c, with a 30 cm thick target, for polarization state +1 (red solid squares) and -1 (black solid squares), compared to the existing values from Azhghirey *et al.*, at p_p=3.7 GeV/c [NIM. A 538 (2005) 431441] (blue open circles).

(From N.M.Piskunov)

Data on the neutron asymmetry were obtained with

CH and CH2 targets at neutron momentum p_n=3.75 GeV/c

at the first time.

Data analysis is in progress.

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

Some last year news concerning realization of the NICA project *(fixed targets part):*

(2)

Run 54 of the Nuclotron
(total duration: ≈1008 hours)

10.02.2017 – 24.03.2017

One of the important results of this run is:

at first time, JINR has got the relativistic polarized proton beam, accelerated in the Nuclotron (up to 2 GeV kin. energy).

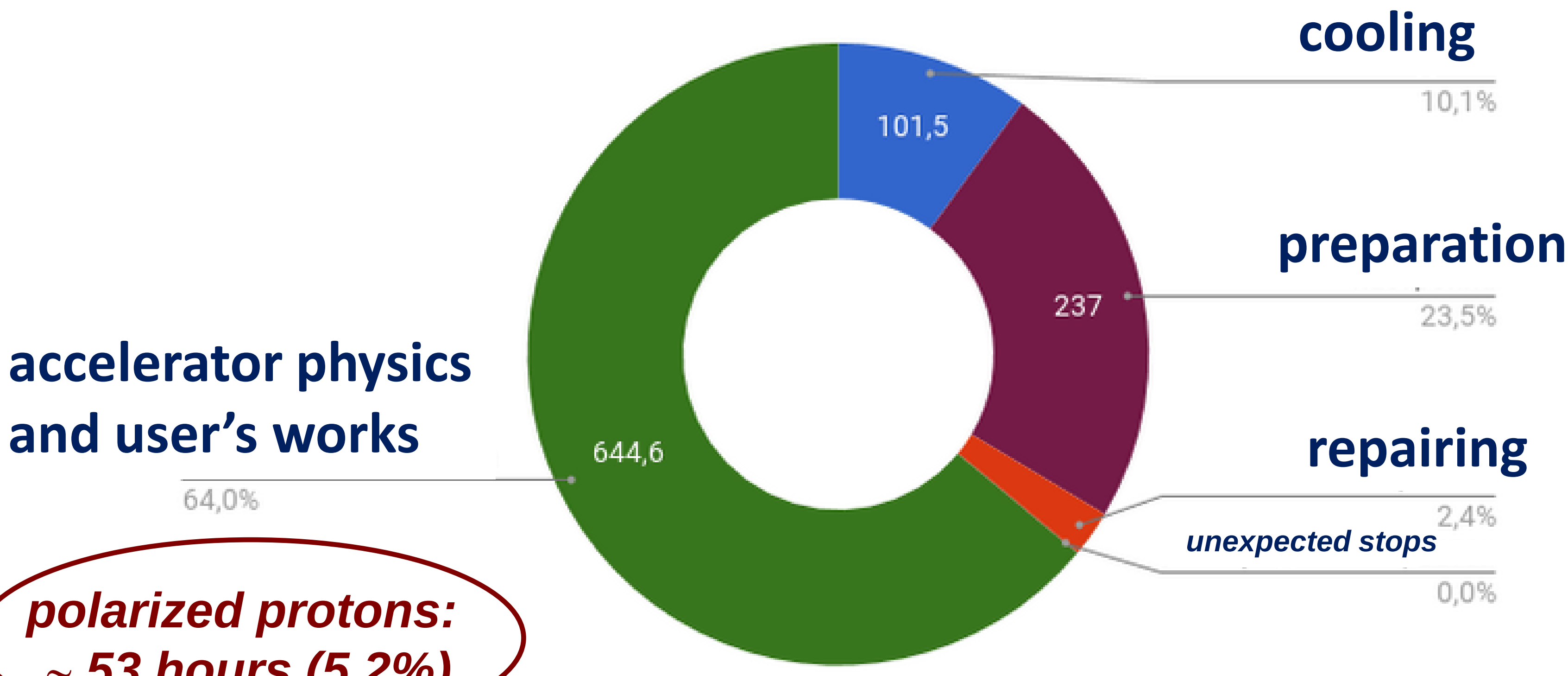
Run 54 of the Nuclotron (10.02.2017 – 24.03.2017):

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)***

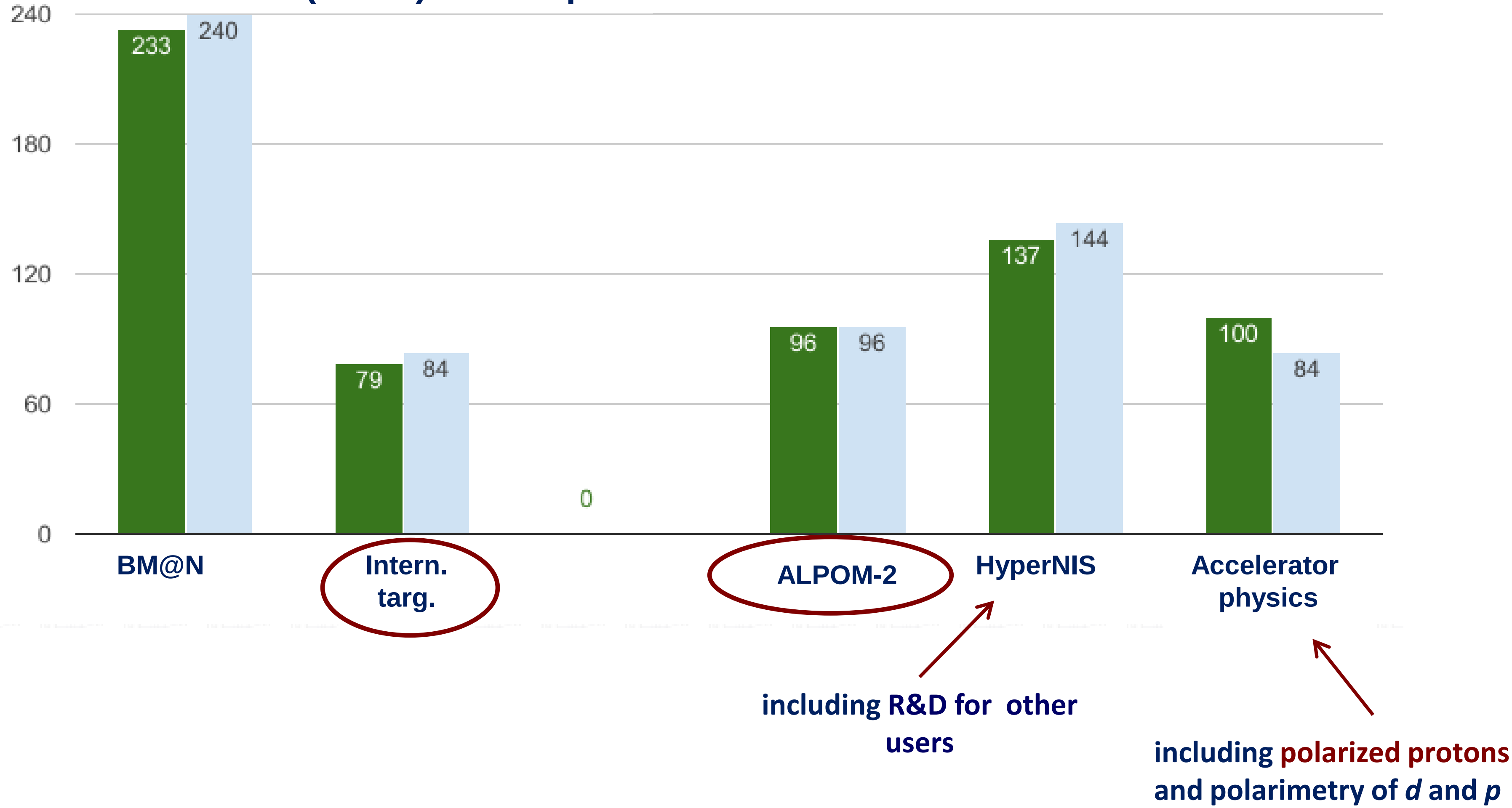
All the works are included in the JINR topical plan.

The total run duration: ≈1008 hours



polarized protons:
~ 53 hours (5.2%)

Use of beam (hours): in fact/planned



In general, users are satisfied by the machine work.

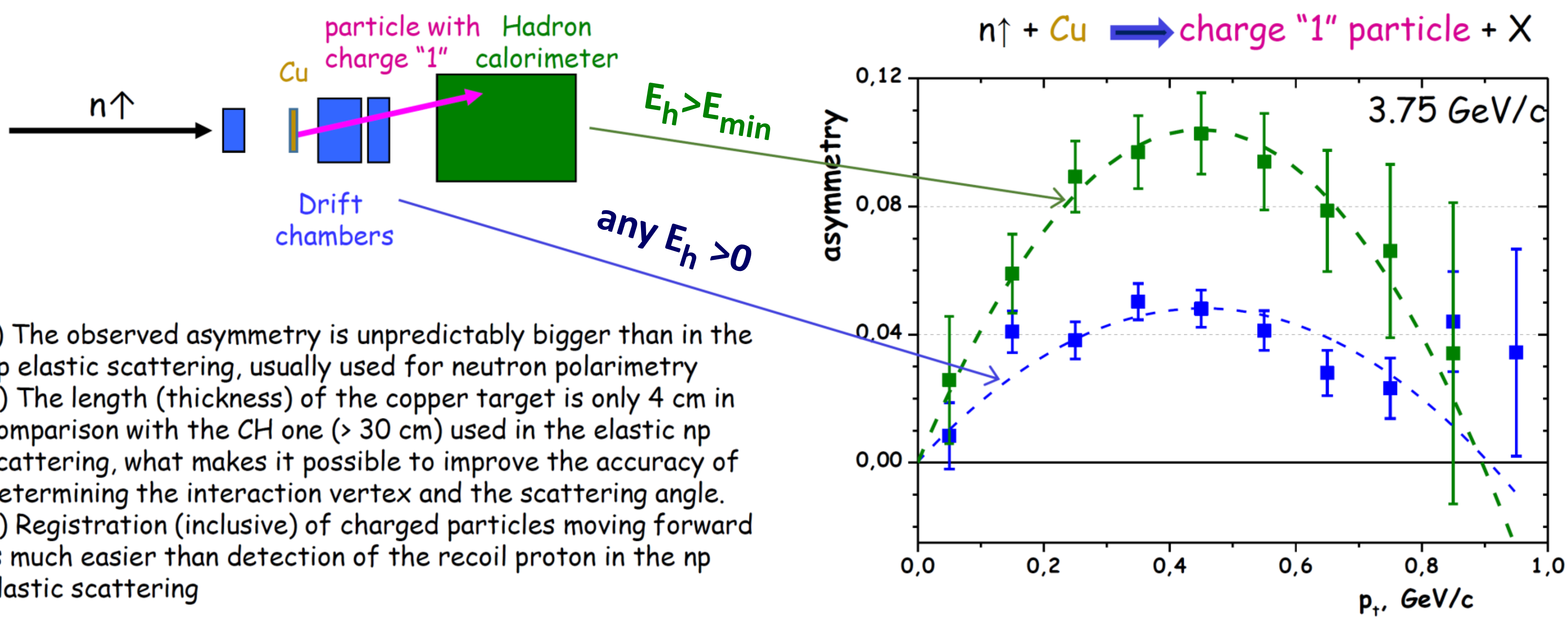
(From N.M.Piskunov)

ALPOM-2 in the run 54: unique result, observed at first time in the world:

new

Measurement of analyzing powers for the reaction p + CH2 up to 7.5 GeV/c and n + 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+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 particlular, 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 Pzz ≈ -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|≈(0.1÷0.15) at T_p = 1 and 2 GeV (kinetic energy) (very preliminary estimation!).

For acceleration of polarized proton beam a spin-rotator in the LU-20 - Nuclotron transfer channel is necessary

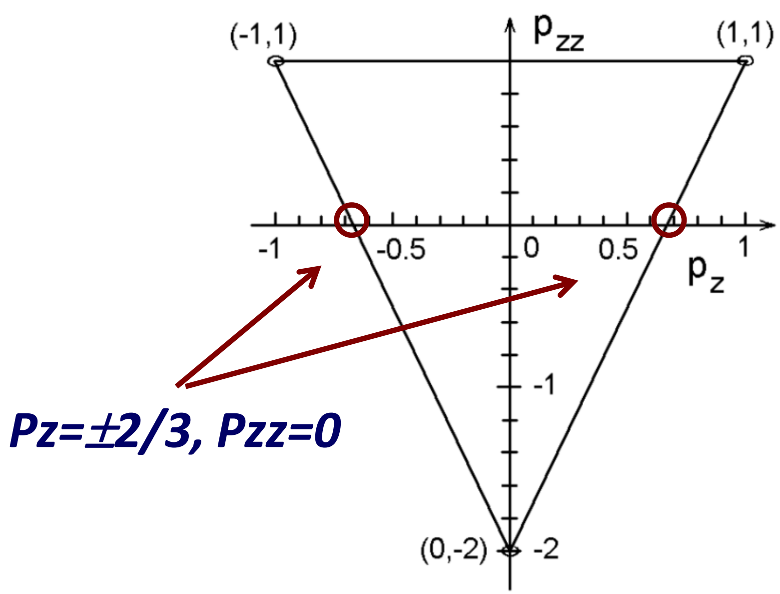
(From R.A.Shindin)

Polarimeter at the extracted beam (F3 focus)

Deuteron beam momentum: 7.5 GeV/c

(preliminary, Nuclotron run 54, SPI in the P_{zz}=0 mode)

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



- **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…***

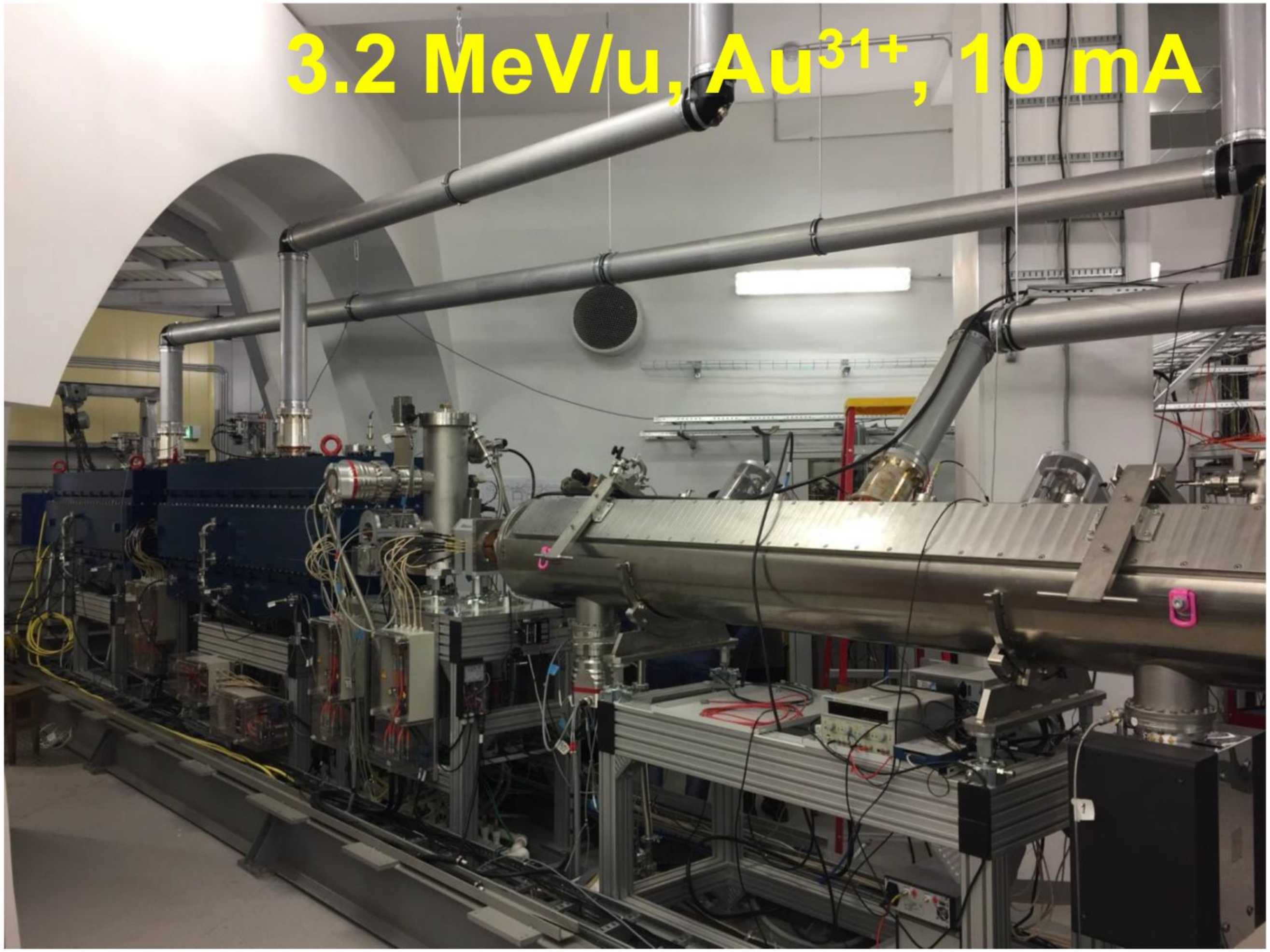
Reports are being expected at the DSPIN Conference (Sept. 2017)

Other last year news concerning realization of the NICA project *(instrumentation part):*

(3)

(A) HILac commissioning

V.Butenko,
A.Govorov,
V.Monchinsky



October 2016 –
carbon beam from laser source was accelerated up to design energy

Acceleration structure
BEVATECH (Germany)

Power amplifier
TOMCO (Australia)

Low level RF
ITEP

Diagnostics
INR RAS

Vacuum system
Vaccum Praha

Building preparation,
Ion source,
LEBT,
Lens power supply, …
JINR

The next nearest step – the Booster

SC magnets for Booster:

The Nuclotron-type design based on a cold, window-frame iron yoke and a winding of the hollow superconductor was chosen for the NICA Booster.

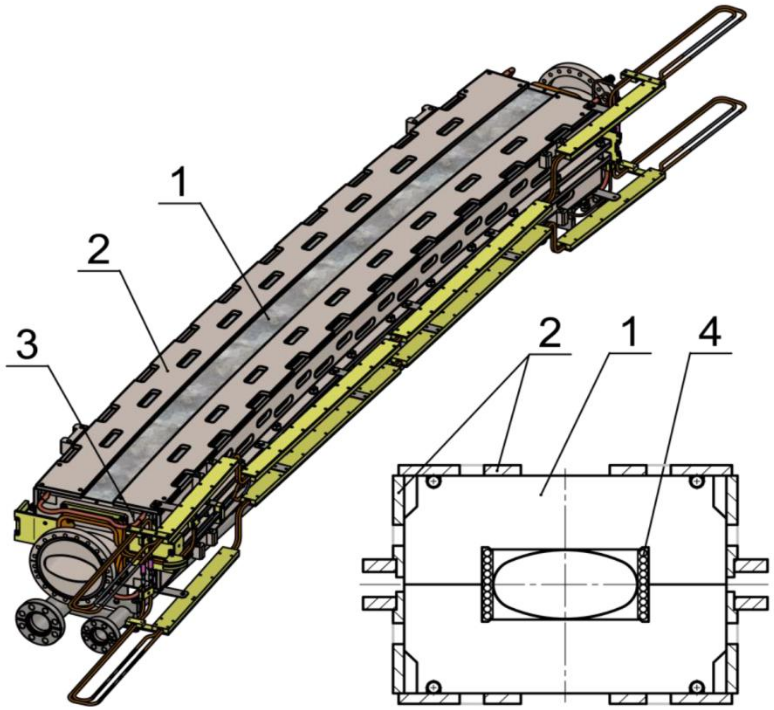


Figure 1: View of the dipole magnet. 1 – lamination, 2 - side plate, 3 - end plate, 4 – SC coil.

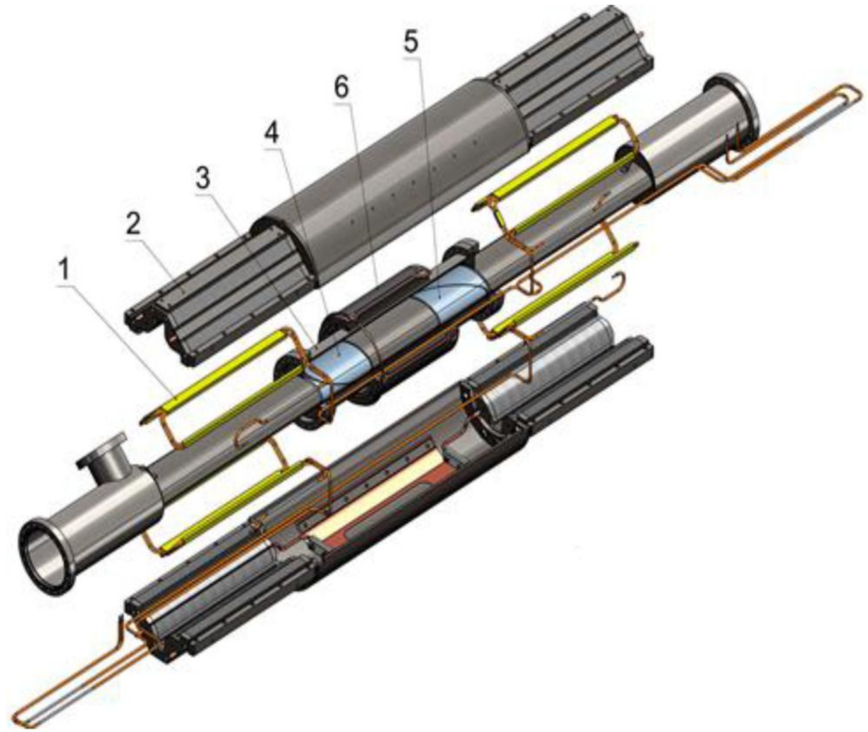


Figure 2: View of the doublet of the lenses. 1 – half-coil, 2 – half-yoke, 3 – beam pipe, 4, 5 – beam position monitors, corrector magnet

The official ceremony of launching of the high-technology line for assembling and testing of SC magnets has taken place on Nov. 28.

The ceremony was attended by leaders of the NICA and FAIR projects .

(B)

Facility for SC Magnets Assembling and Cryogenic Tests

H.Khodzhibagiyan
A.Kostromin

The facility for assembling and cryogenic tests of superconducting magnets for NICA and FAIR projects was commissioned 28 November 2016.

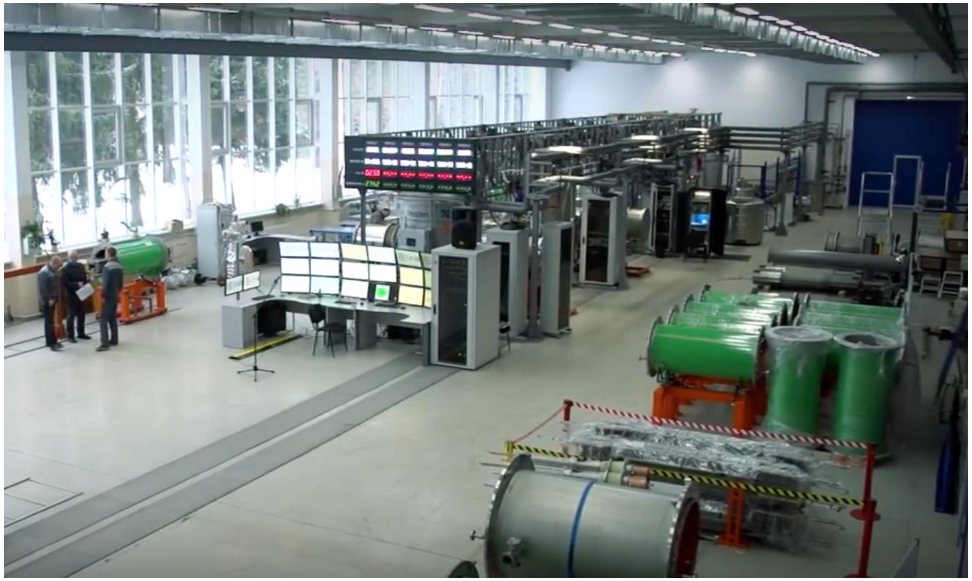
The main production area includes:

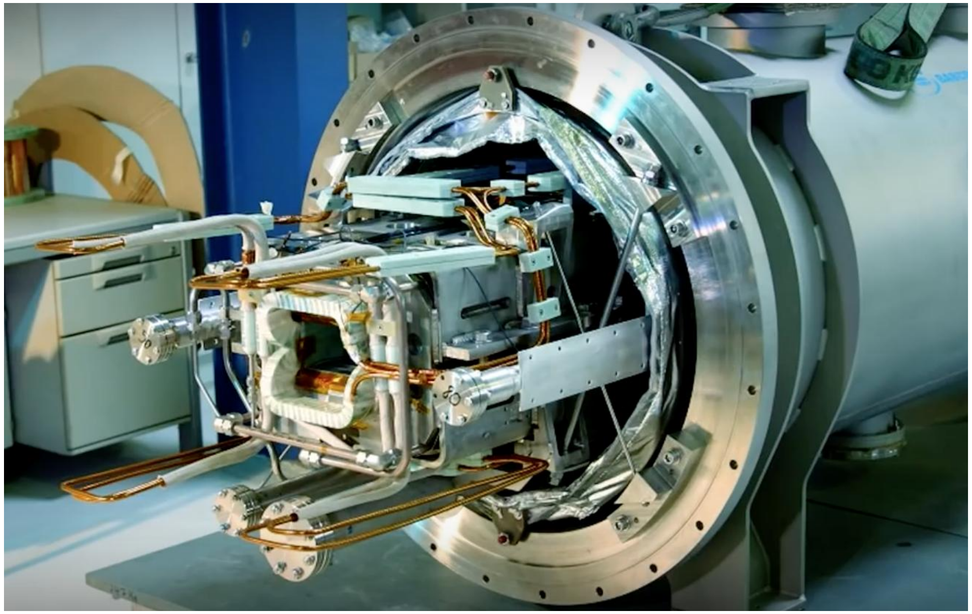
- Incoming inspection zone
- SC cable production hall
- SC coils production hall
- Area for assembling of the magnets
- Area for magnetic measurement under the room temperature
- Bay for leakage tests
- Area for mounting SC-magnets inside cryostats
- Cryogenic test benches

Production plans:

40 **dipole magnets for the NICA Booster**
48 **quadrupole magnets with multipole correctors for the NICA Booster**
80 **dipole magnets for the NICA Collider**
86 **quadrupole magnets with multipole correctors for the NICA Collider**
175 **quadrupole magnets with multipole correctors for the SIS100 synchrotron (FAIR project)**

Total 429





Final remarks
(instead of conclusions)

It should be taken into account, that
interest to the intermediate energy physics problems is being renewed and new experimental opportunities are being opened for polarization phenomena studies (JINR, first of all) and are suggested for meson beams …

Eur. Phys. J. A (2015) **51**: 129 DOI 10.1140/epja/i2015-15129-5

Physics opportunities with meson beams

William J. Briscoe, Michael Döring, Helmut Haberzettl, D. Mark Manley, Megumi Naruki, Igor I. Strakovsky and Eric S. Swanson

❖ ***The restoration of the accelerated polarized deuteron beam with kinetic energy up to 5 GeV/nucleon is very important result for the NICA project (spin physics part as in the collider mode, as in the fixed target mode).***

❖ ***The acceleration of polarized protons in the Nuclotron is another very important result for the NICA project (spin physics part as in the collider mode, as in the fixed target mode).***

SPD (Spin Physics Detector) at NICA

Collider provides both:
transversally & longitudinally
polarized ***p*** & ***d***
with energy up to $\sqrt{S}$ *=* ***27 GeV***

The issues to be studied:

- *MMT-DY processes*
- *J/Ψ production processes*
- *Spin effects in inclusive high-*p_T *reactions*
- *Spin effects in one and two hadron production processes*
- *Polarization effects in heavy ion collisions*

The Collaboration is being formed

The Project is under preparation

Nearest plans

2017:

Run #55: October – December
KRION source: C, Ar^{16+} and Kr^{26+}

Due to importance of the physical program we plan to prolong the Nuclotron operation

2018:

February-March
Laser source: d, Li, C

After completion: **start of the Booster assembly**

(From talk by A.O.Sidorin at **JINR PAC for Particle Physics, 26.06.2017)**

These plans will be discussed once more at the 5-th Beam User's Workhop (Oct. 5-6, 2017)

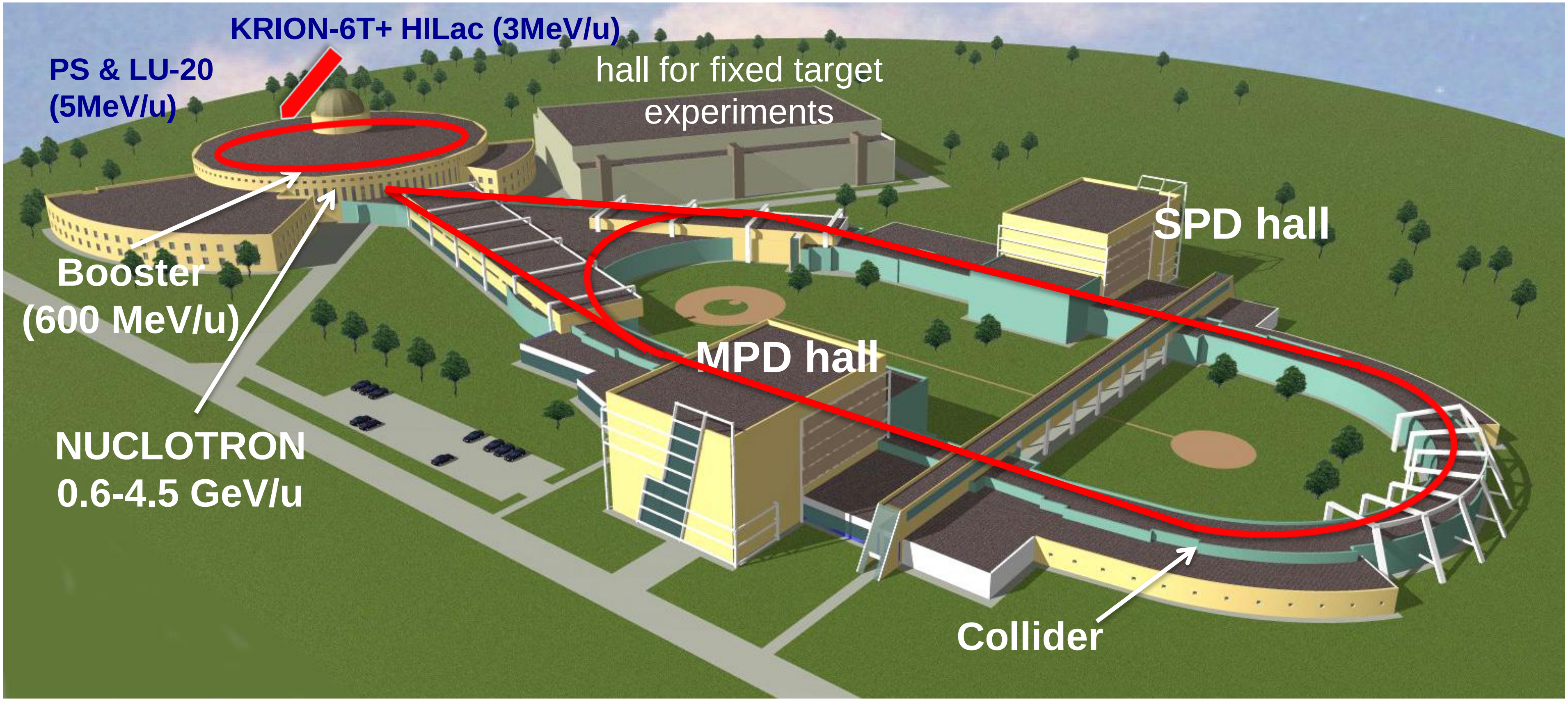
Thank you very much for your attention!

Backups…

The NICA Complex

existing facility

In red: to be constructed



(Planned future)

NICA collider major parameters

Ring circumference, m	**503.04**
heavy ions	
β, m	**0.35**
energy range for ***Au^{79+}****: $\sqrt{S_{NN}}$, GeV*	**4 - 11**
r.m.s. Δp/p, 10^{-3}	**1.6**
Luminosity for ***Au^{79+}****, cm^{-2} s^{-1}*	**1x10^{27}**
polarized particles	
max. energy for polarized ***p****, Gev*	**27**
Luminosity for ***p****, cm^{-2} s^{-1}*	**1x10^{32}**

Nuclotron Beams

Parameter	*Project (2017)*	
Magnetic field, T	2.0 (Bρ = 42.8 T·m)	
Field ramp, T/s	1.0	
Repetition period, s	5.0	
	Energy, GeV/u	Ions/ cycle
Light ions ⇒ d	7.0	$5 \cdot 10^{10}$
Heavy ions	*With KRION-6T & Booster*	
$^{40}Ar^{18+}$	5.9	$2 \cdot 10^{10}$
$^{56}Fe^{26+}$	6.4	$1 \cdot 10^{10}$
$^{124}Xe^{48/42+}$	5.0	$2 \cdot 10^{9}$
$^{197}Au^{79+}$	5.5	$2 \cdot 10^{9}$
Polarized beams	*With SPI*	
p↑	12.9	$1 \cdot 10^{10}$ *)
d↑	6.6	$1 \cdot 10^{10}$

*) *With the Siberian snake*

Characteristics of the magnets for Booster:

Characteristic	Dipole	Lens
Number of magnets	40	48
Max. magnetic field (gradient)	1.8 T	21.5 T/m
Effective magnetic length	2.2 m	0.47 m
Beam pipe aperture (h/v)	128 mm/ 65 mm	
Radius of curvature	14.09 m	-
Overall weight	1030 kg	110 kg

Status of manufactoring of the Booster magnets:

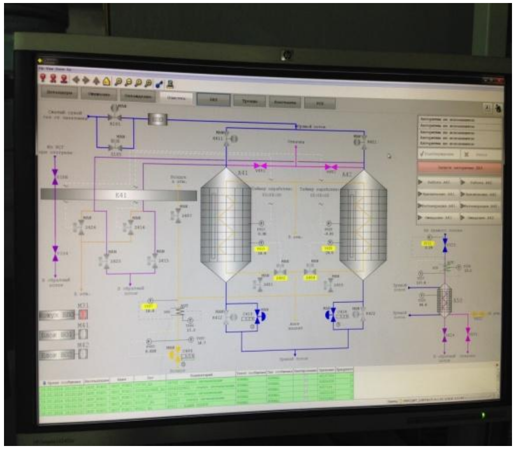
H.Khodzhibagiyan
A.Kostromin

- Yoke of the Dipole Magnets – 27 or 68%
  Coil of the Dipole Magnets - 16 or 40%
- Yoke of the Quadrupole Magnets – 48 or 100%
  Coil of the Quadrupole Magnets - 38 or 79%
- Yoke of the Corrector Magnets – 8 or 25%
  Coil of the Corrector Magnets - 2 or 6%
- Cryostat for magnets – 71 or 100%

We plan to have 75% magnets at the end of 2017

In upgrade of the cryogenic complex: (C)

Successful first run of the 1000 l/h helium liquefier



The most powerful helium liquefier unit (in Russia) was installed and successfully launched at JINR