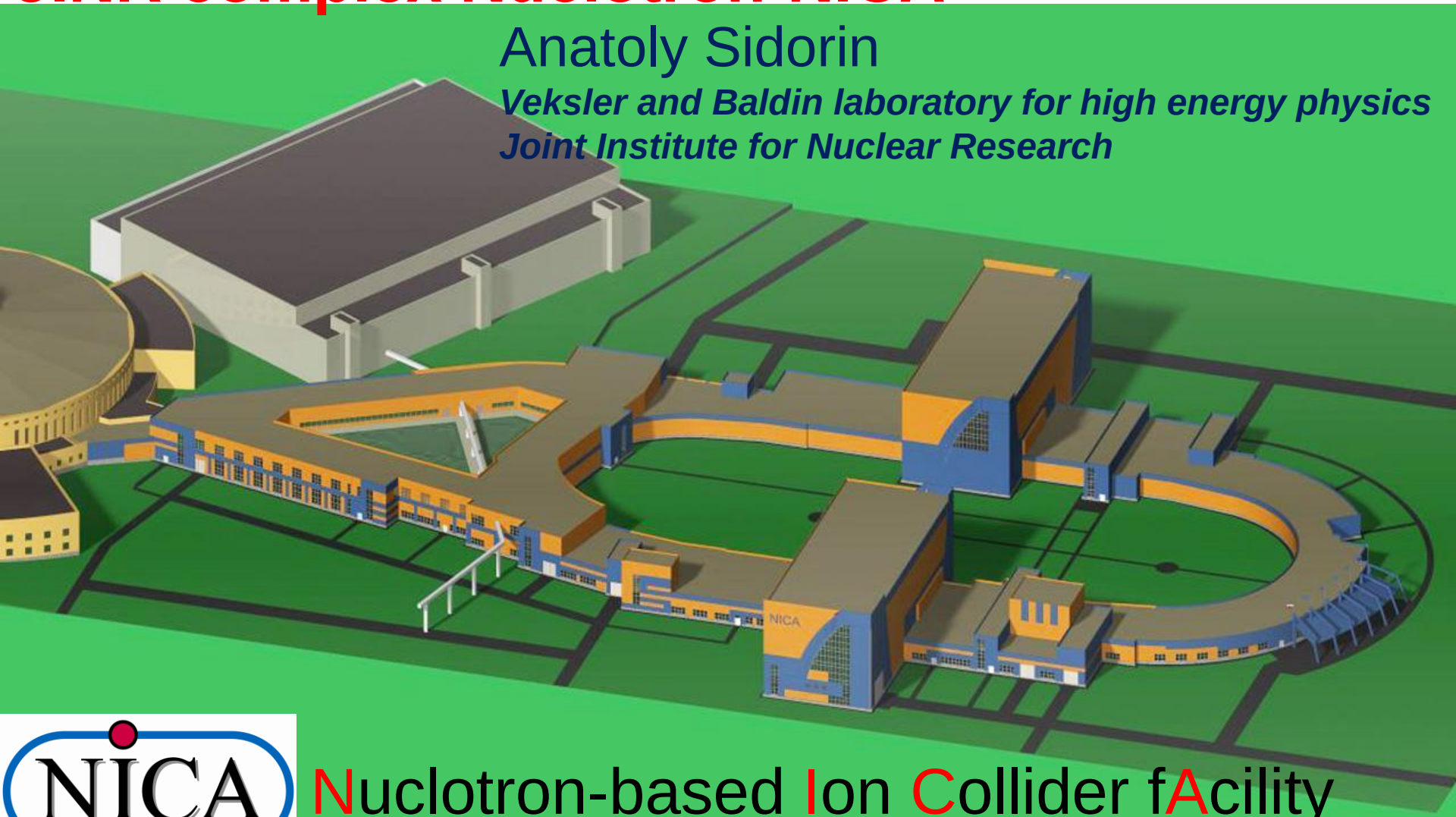
Instrumental base for physics of relativistic nuclei: JINR complex Nuclotron-NICA

Anatoly Sidorin

Veksler and Baldin laboratory for high energy physics
Joint Institute for Nuclear Research



NICA Nuclotron-based Ion Collider fAcility

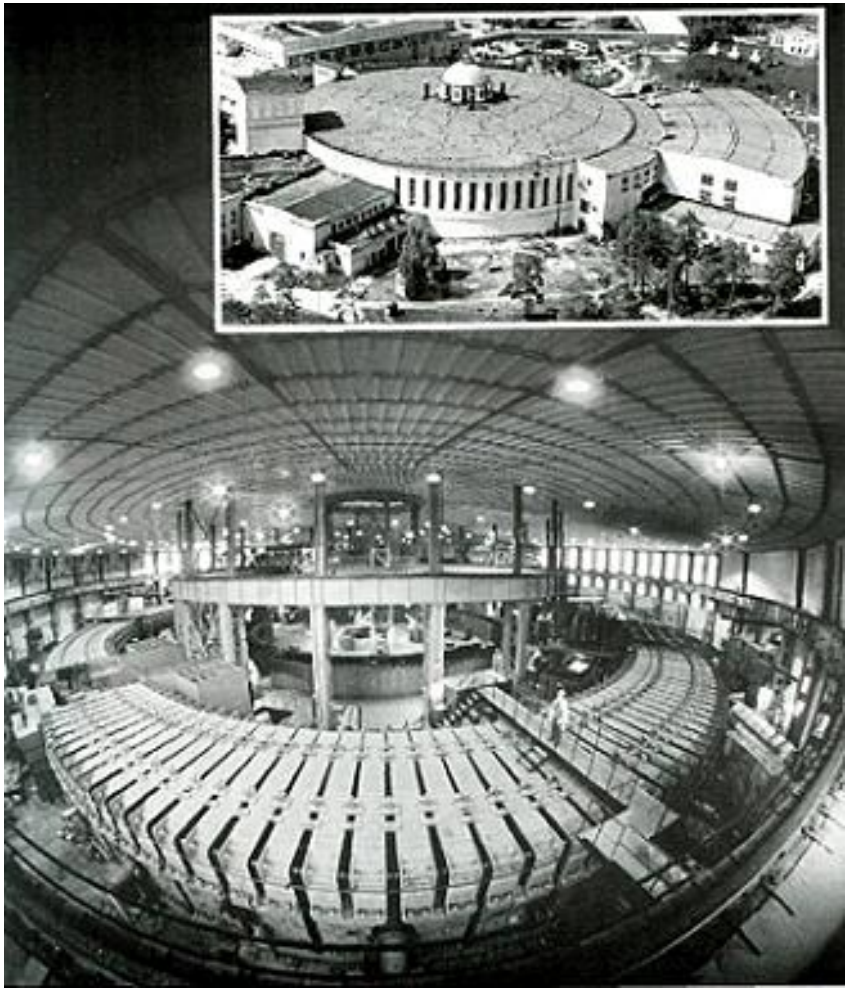
General information

NICA (**N**uclotron-based **I**on **C**ollider f**A**cility)
is an international project
realizing by international intergovernmental organization –
the Joint Institute for Nuclear Research
and brings the efforts of 19 member states and
6 associated countries.

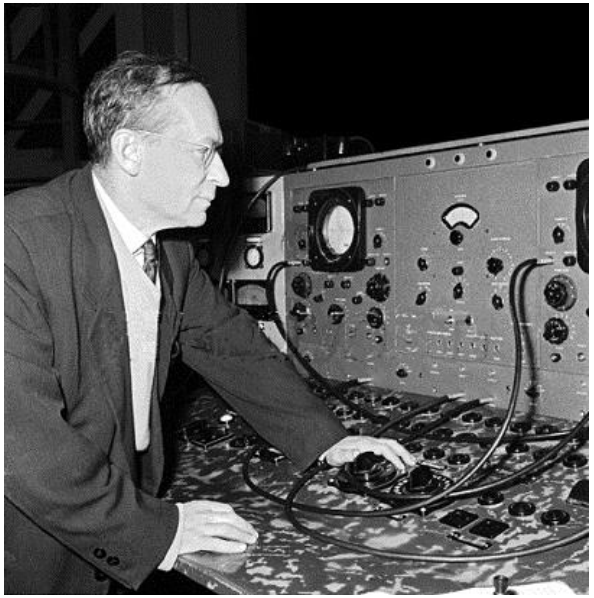
Project NICA started as a part of the JINR Roadmap for 2009-2016
was described in the JINR 7-years Program.
It was approved by Scientific Council of JINR and
the Committee of Plenipotentiaries of JINR in 2009.
NICA is a flagship project of JINR presently.

Project web-site: http://nica.jinr.ru/

Relativistic nuclear physics



End of 60-th – acceleration of ions
70-th – observation of nuclear cumulative effect

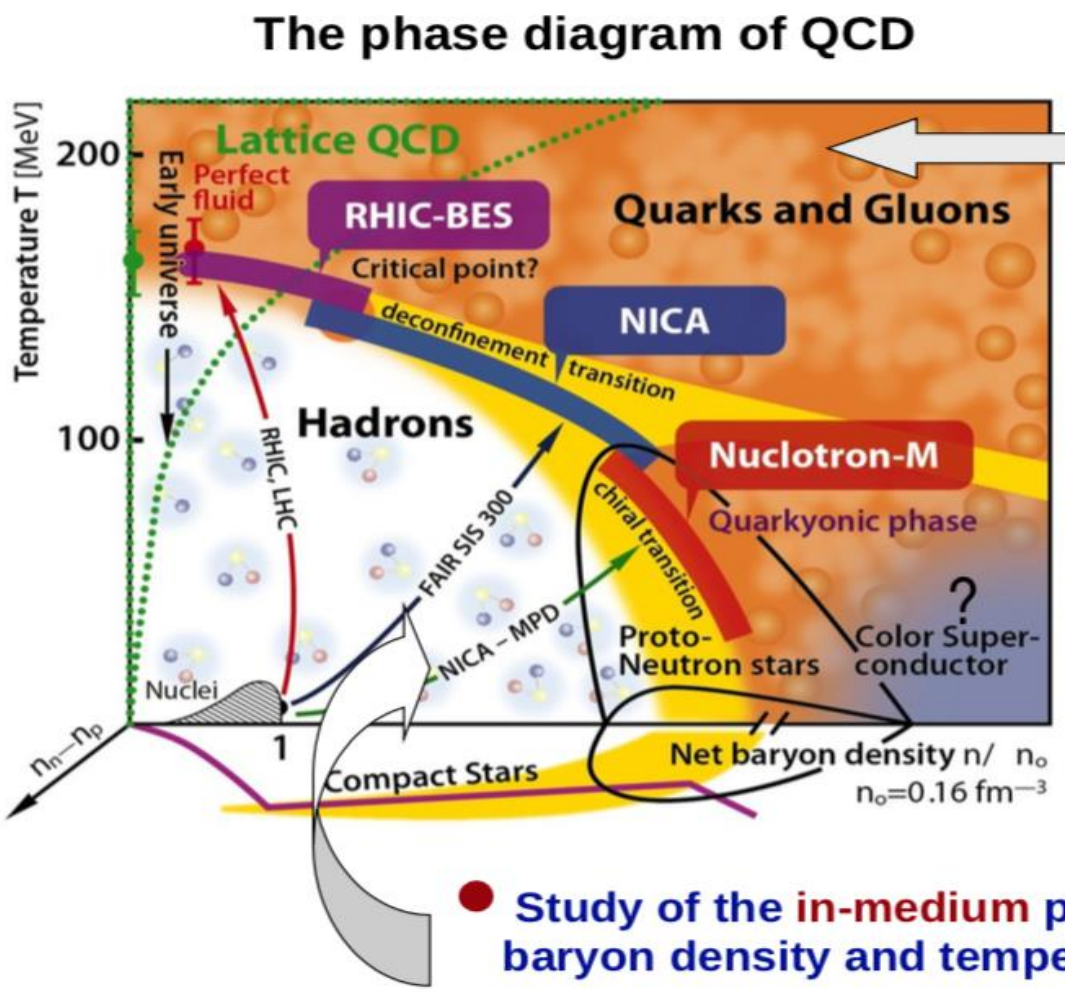


V.I. Veksler

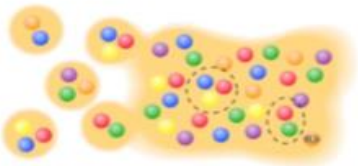
A.M.Baldin

Heavy ion collisions

The main task of heavy ion collision physics is exploration of the QCD phase diagram, in particular, transition between hadron gas and quark-gluon matter. Special interest is a phase transition at the max baryonic density, which could exist in the core of neutron stars.

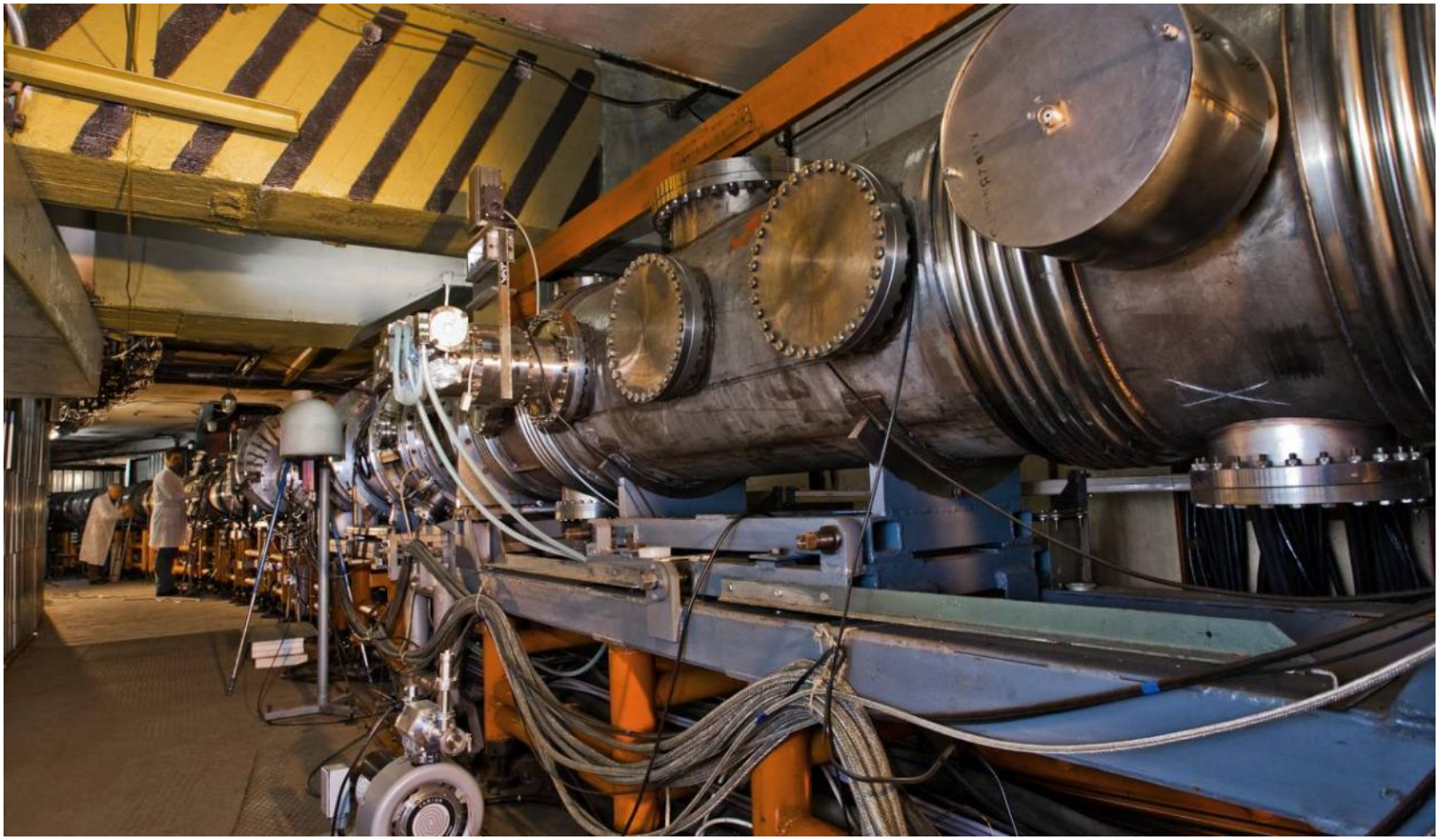


- Search for the critical point



- Study of the phase transition from hadronic to partonic matter – Quark-Gluon-Plasma
- Search for the signatures of chiral symmetry restoration
- Study of the in-medium properties of hadrons at high baryon density and temperature

First Superconducting heavy ion accelerator



Nuclotron – Superconducting Synchrotron operation since 1993

The primary purpose of the NICA construction

The project comprises experimental studies of **fundamental** character in the fields of the following directions:

- Relativistic nuclear physics;
- Spin physics in high and middle energy range of interacting particles;
- Radiobiology.

Applied researches based on particle beams generated at NICA are dedicated to test of electronics for satellites, particle beam therapy, ADS investigations and others.

Education program is one of the first priority activities at JINR, as formulated in JINR Roadmap.
The proposed NICA facility offers various possibilities for teaching and qualification procedures including practice at experimental set ups, preparation of diploma works, PhD, and doctoral theses.

Stages of the experimental program realization

Stage I

-Fixed target experiment with heavy ions (started 2018)

Stage II

-Starting configuration of the collider and detector (2022)

-Basic configuration, heavy ion collisions (2023)

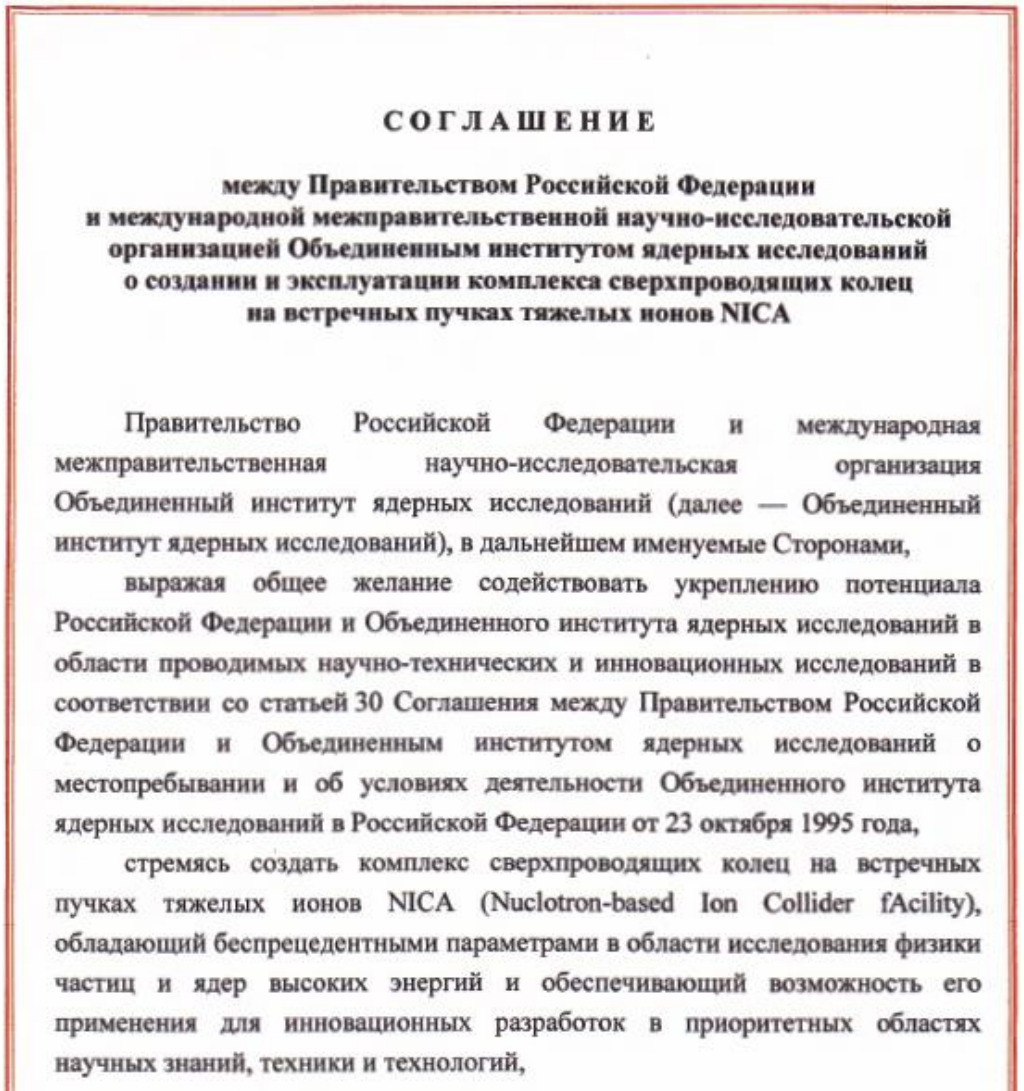
-Collisions of heavy ions with light ions (protons)

Stage III

-Spin physics program

International cooperation: Russia

In 2016 between **Russian Federation** and **JINR** was signed a contract presuming start of operation of starting configuration of the NICA complex in 2022.



СОГЛАШЕНИЕ

между Правительством Российской Федерации и международной межправительственной научно-исследовательской организацией Объединенным институтом ядерных исследований о создании и эксплуатации комплекса сверхпроводящих колец на встречных пучках тяжелых ионов NICA

Правительство Российской Федерации и международная межправительственная научно-исследовательская организация Объединенный институт ядерных исследований (далее — Объединенный институт ядерных исследований), в дальнейшем именуемые Сторонами,

выражая общее желание содействовать укреплению потенциала Российской Федерации и Объединенного института ядерных исследований в области проводимых научно-технических и инновационных исследований в соответствии со статьей 30 Соглашения между Правительством Российской Федерации и Объединенным институтом ядерных исследований о местопребывании и об условиях деятельности Объединенного института ядерных исследований в Российской Федерации от 23 октября 1995 года,

стремясь создать комплекс сверхпроводящих колец на встречных пучках тяжелых ионов NICA (Nuclotron-based Ion Collider fAcility), обладающий беспрецедентными параметрами в области исследования физики частиц и ядер высоких энергий и обеспечивающий возможность его применения для инновационных разработок в приоритетных областях научных знаний, техники и технологий,

International cooperation: Germany

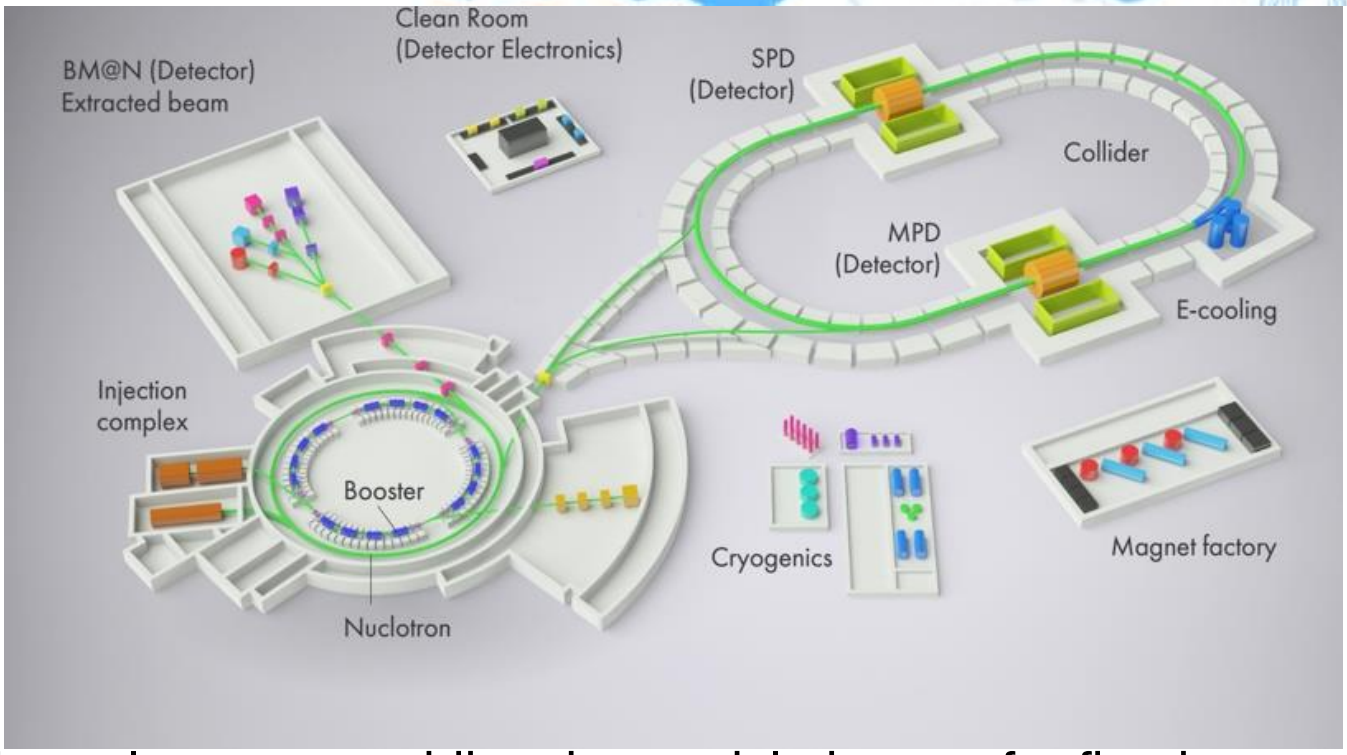
6 February 2020.

The Agreement, signed by the directors of the **GSI** and **JINR**, opened the way for the participation of German scientific organizations in the implementation of the NICA project. The work is coordinated by the GSI and **funded by the Federal Ministry of Education and Research of Germany**.

International cooperation: China

On August 26, 2020 an Agreement on the participation in the NICA was signed between the **Ministry of Science and Technology of the People's Republic of China** and the **JINR**.

The NICA complex includes:



- Set of accelerators providing the particle beams for fixed target and collider experiments,
- Experimental facilities,
- Line for assembling and cryogenic testing of SC-magnets,
- Workshops for construction of the detector elements,
- NICA innovation center,
- Required infrastructure.

Experimental facilities

Fixed target experiment

Baryonic Matter at Nuclotron (BM@N)

Collider experiments:

Multi Purpose Detector (MPD)

Spin Physics Detector (SPD)

Experimental facilities

2[d] MPD and BM@N collaboration meetings
29-30.10.2018

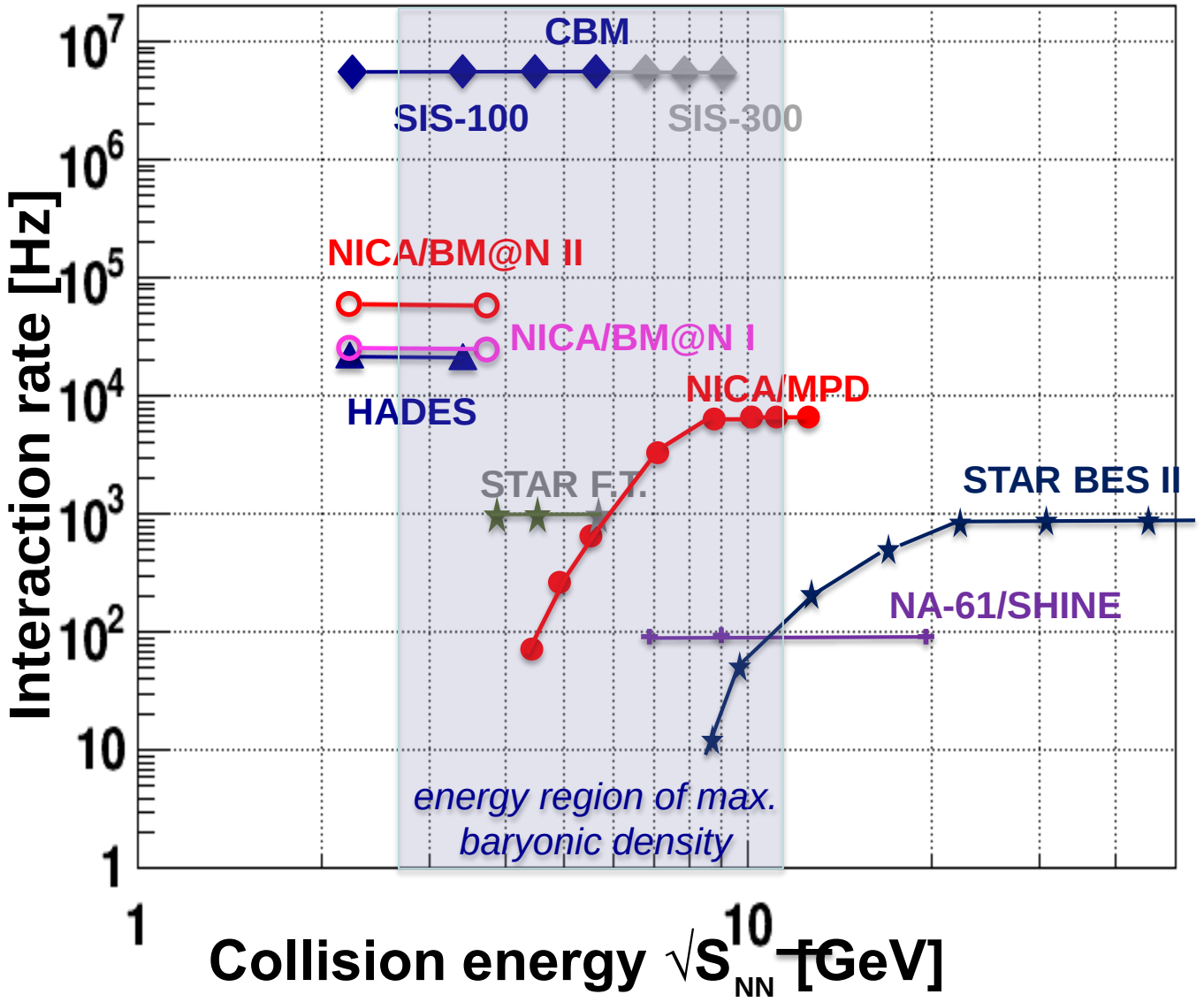
BM@N: 10 Countries, 17 Institutions, 216 Participants
(spokesperson M.Kapishin, technical coordinator A.Maksimchuk)

MPD: 10 Countries, 26 Institutions, 436 Participants
(spokesperson A.Kisiel, technical coordinator V.Golovatiuk)

The 6th Meeting of the MPD Collaboration 6th Meeting of the BM@N Collaboration took place in a videoconference format from 26 to 30 October 2020.

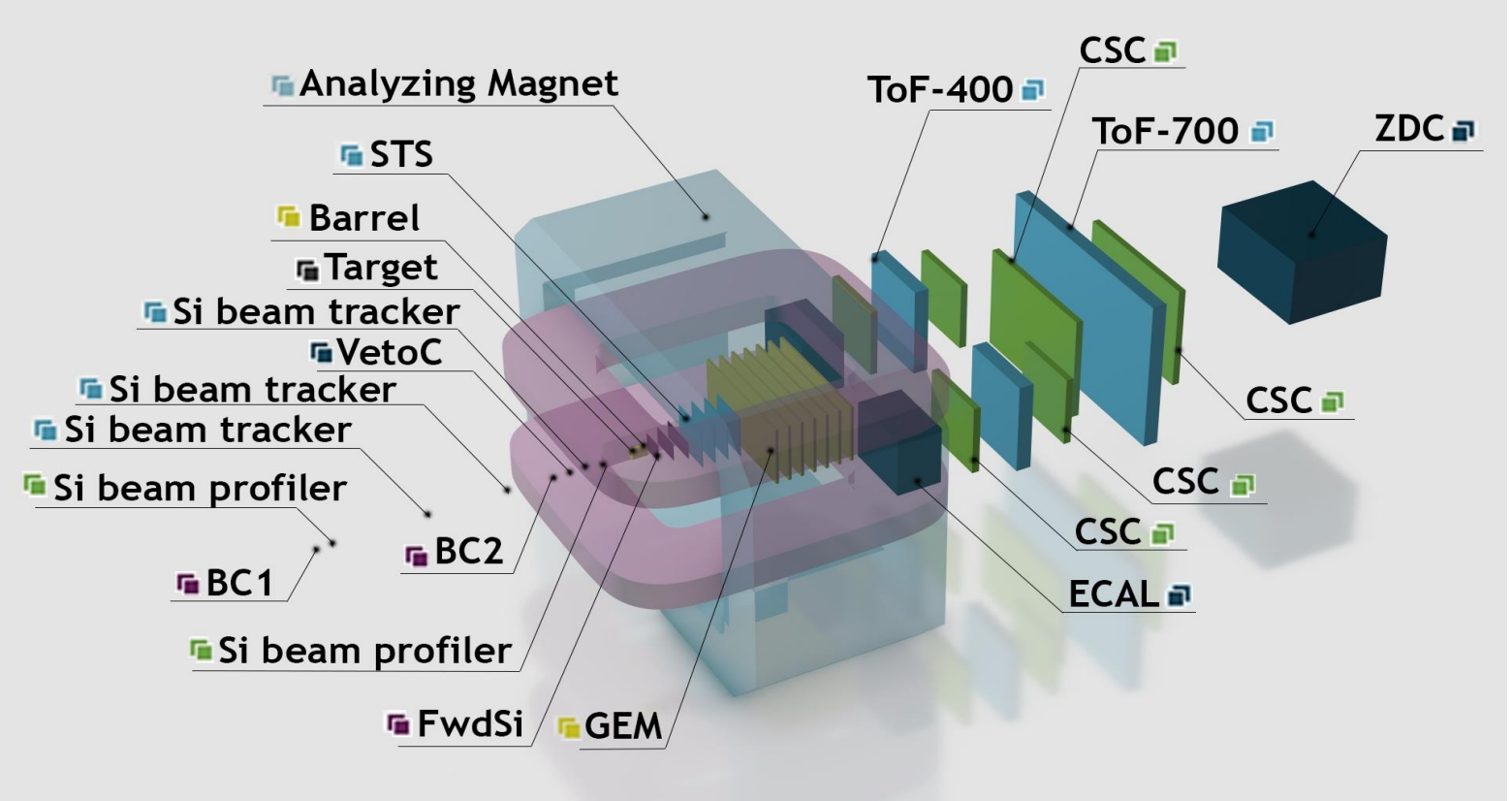
The **7th Collaboration Meeting of the BM@N Experiment at the NICA Facility - now**

Experimental status



Complementary to the RHIC/BES, CERN and FAIR programs

Baryonic Matter at Nuclotron



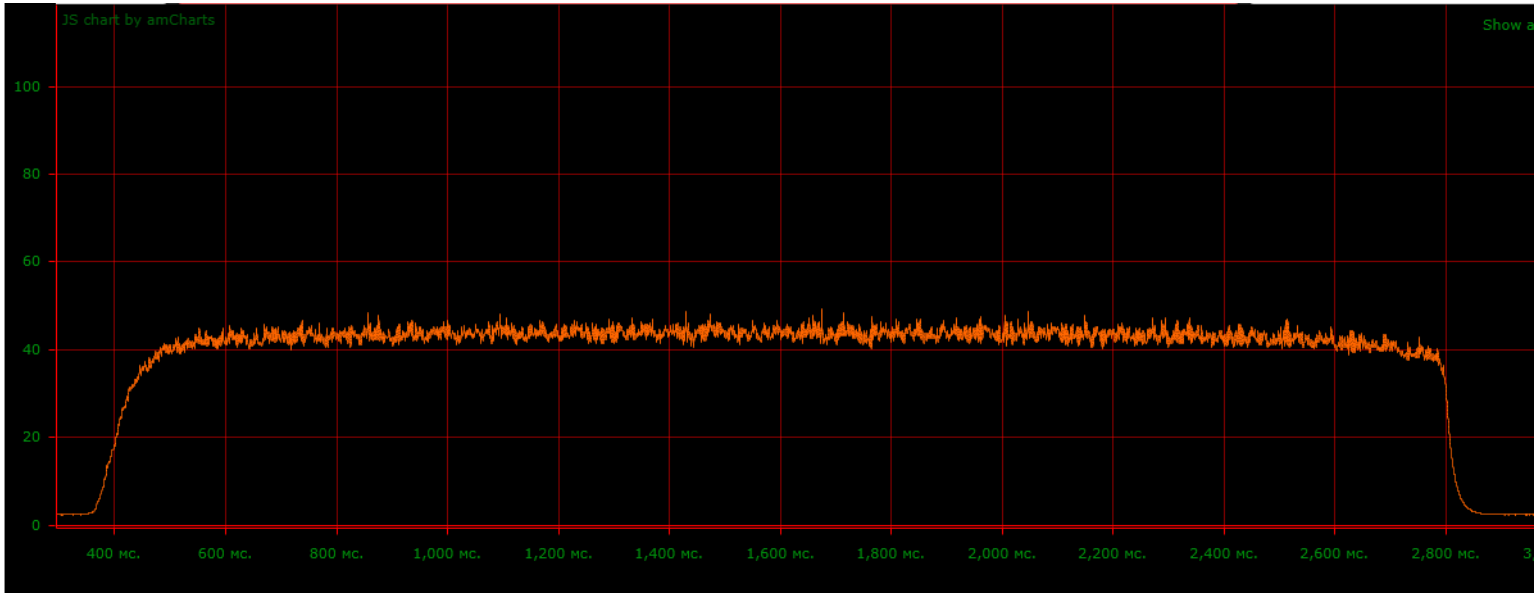
Main goals are

- investigations of strange/multi-strange hyperon, hypernuclei production and short range correlations.

Baryonic Matter at Nuclotron

-Three technological runs (2016 – 2017)

-**5.02 – 4.04.2018 experiments** with C, Ar, Kr beams (Short range correlations, strange production)



Intensity of extracted Kr beam.
Spill duration 2.5 sec. Up to $5 \cdot 10^5$ ions per cycle

Baryonic Matter at Nuclotron

BM@N
Wiki pages

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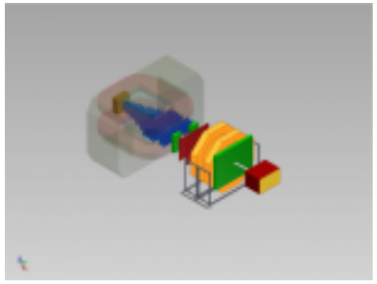
main



BMN collaboration

- BMN Experiment
- BMN Discourse

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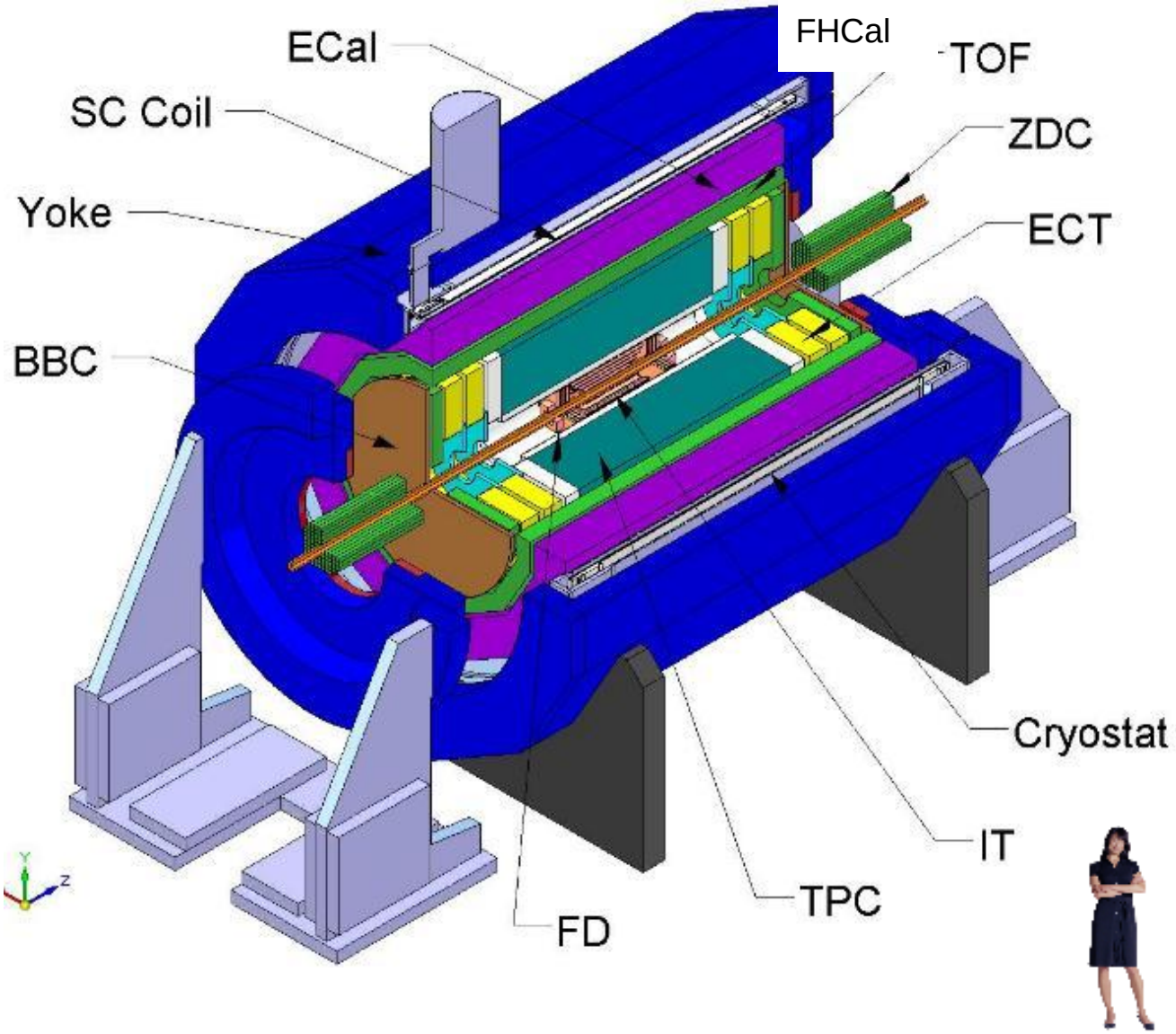
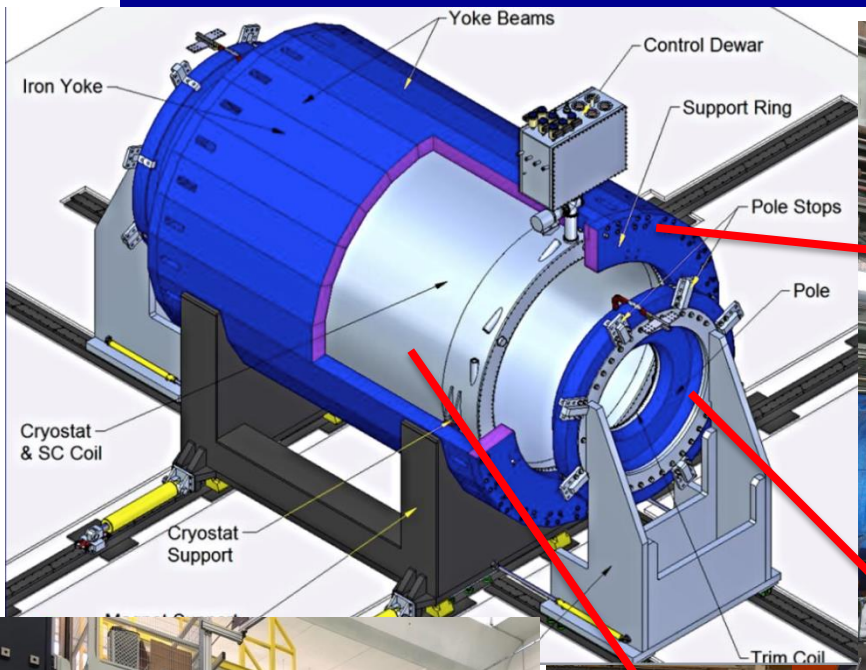
http://bmnshift.jinr.ru/wiki/doku.php

Multi Purpose Detector (MPD)



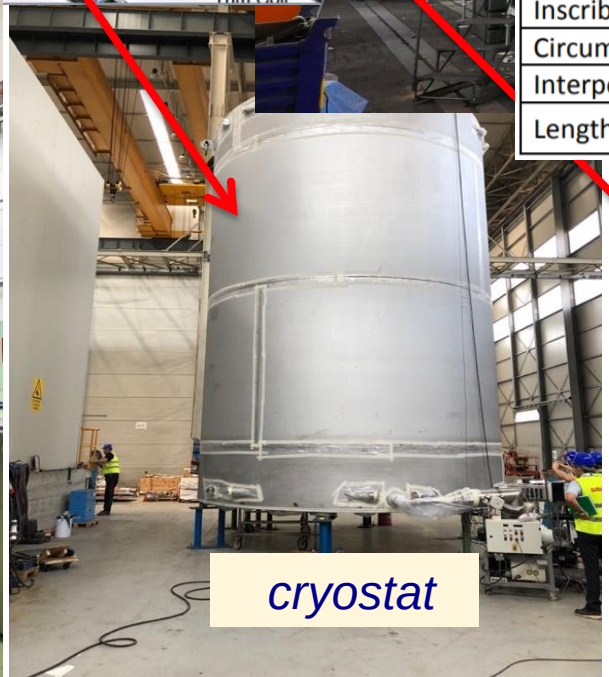
Magnet fabrication: *ASG (Genova) & Vitkovice HM*



yoke control assembly at HM Vitkovice

Cryostat	
Inner diameter (warm hole), mm	4656
Outer diameter, mm	5443
Length, mm	7910
Yoke	
Inscribed diameter, mm	5883
Circumscribed diameter, mm	6583
Interpole distance, mm	7390
Length, mm	8970

winding machine



cryostat

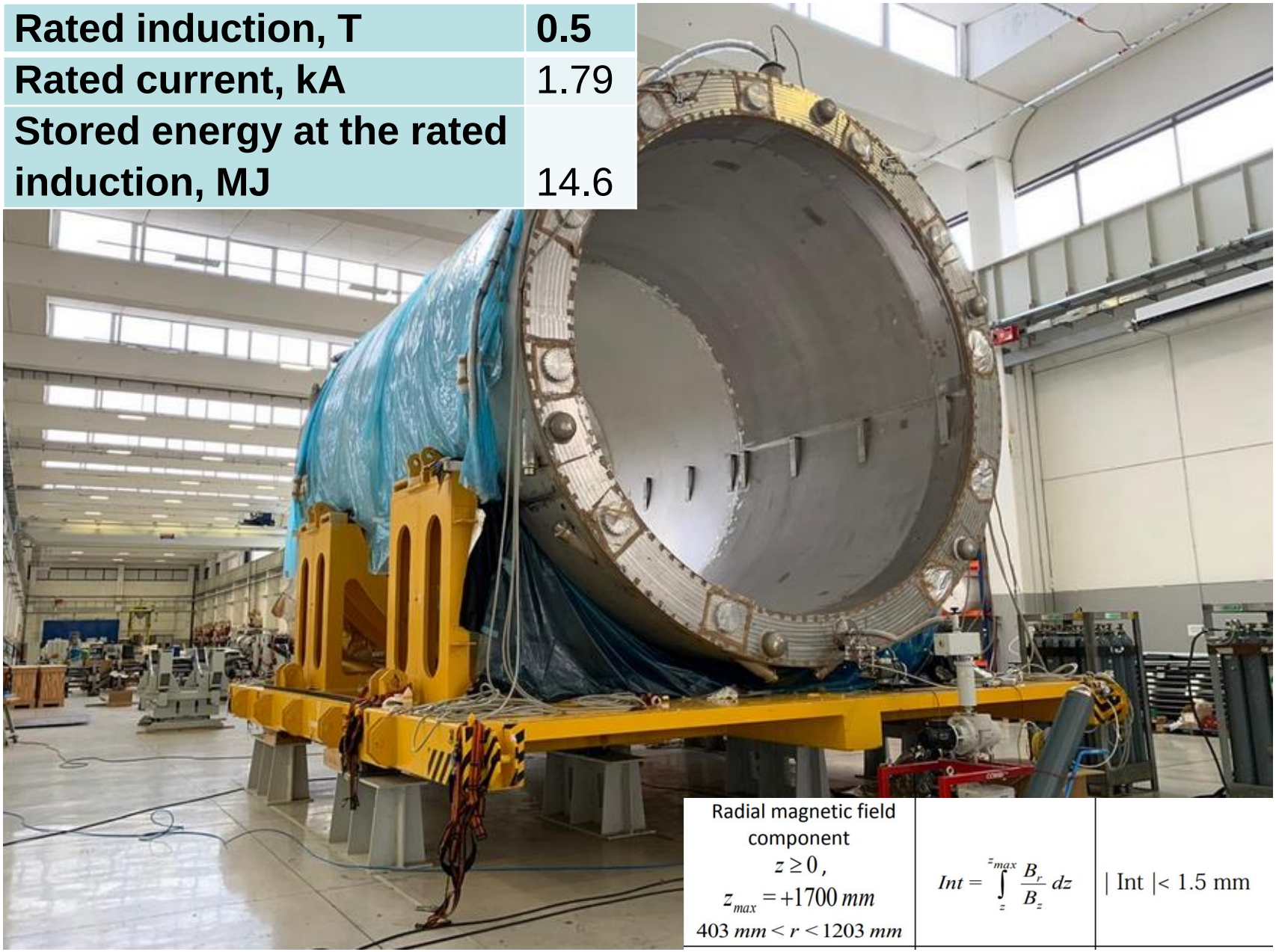
trim coil

Magnetic yoke (720 t)

On 25 December 2020, according to the preliminary work plan,
the control assembly of the magnet yoke has been successfully completed:
the final upper plate No. 28 was installed.

SC Solenoid in Genova

Rated induction, T	**0.5**
Rated current, kA	1.79
Stored energy at the rated induction, MJ	14.6



Radial magnetic field component $z \geq 0$, $z_{max} = +1700\ mm$ $403\ mm < r < 1203\ mm$	$Int = \int_{z}^{z_{max}} \frac{B_r}{B_z}\, dz$	| Int |< 1.5 mm

E la nave va – “And the Ship Sails On…”

ASG Superconductors team at the moment of sending the magnet to JINR

On September 25, the transportation of the magnet to Dubna began

… in Saint-Petersburg

... Volga river

… transported to VBLHEP

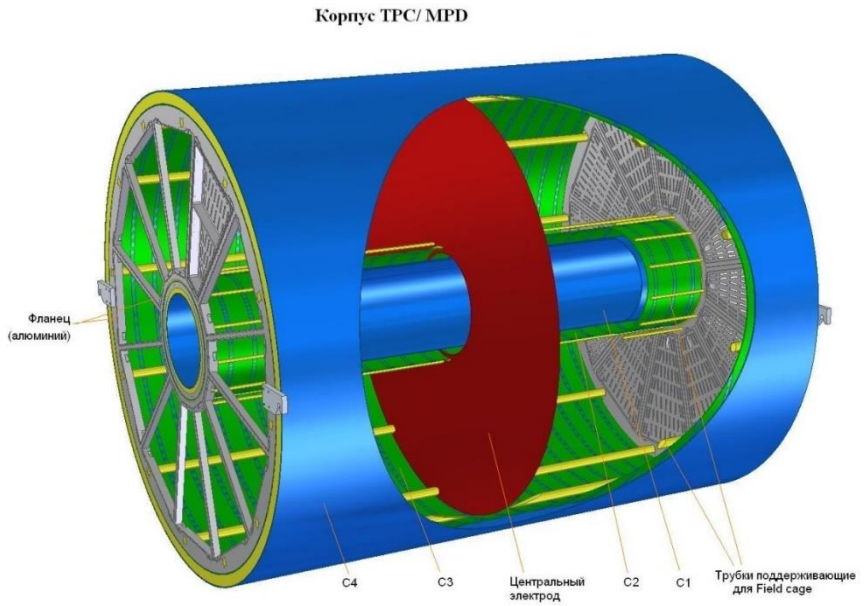
…assembled in the MPD hall

28 December 2021 – beginning of cryogenic test

MPD inner tracker

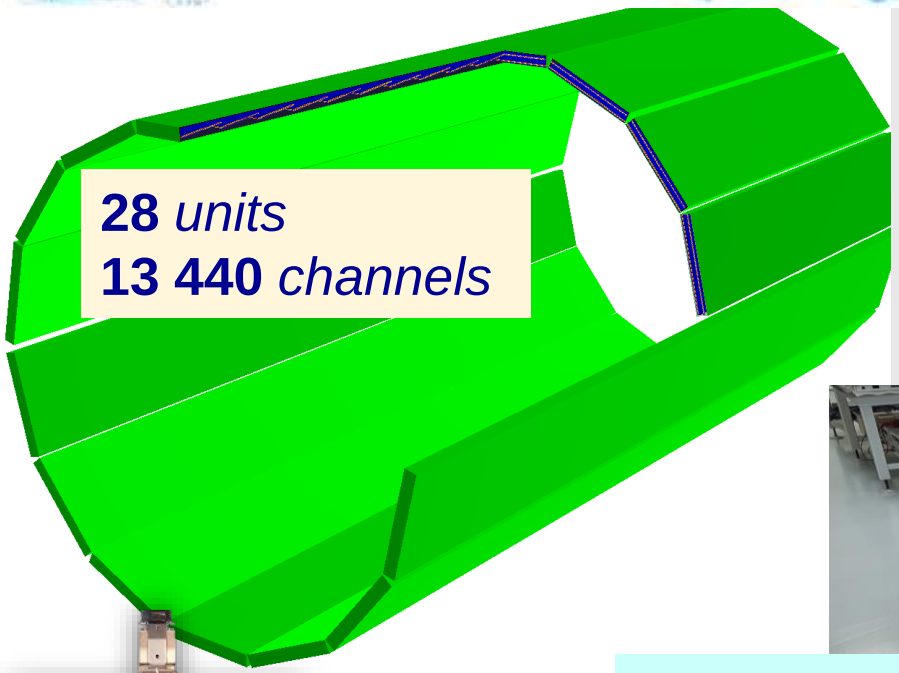
CREMLIN WP2 Working Meeting
„Exchange on Policy- and ESFRI-related Issues”, April 2016, Dubna

Time Projection Chamber (TPC)

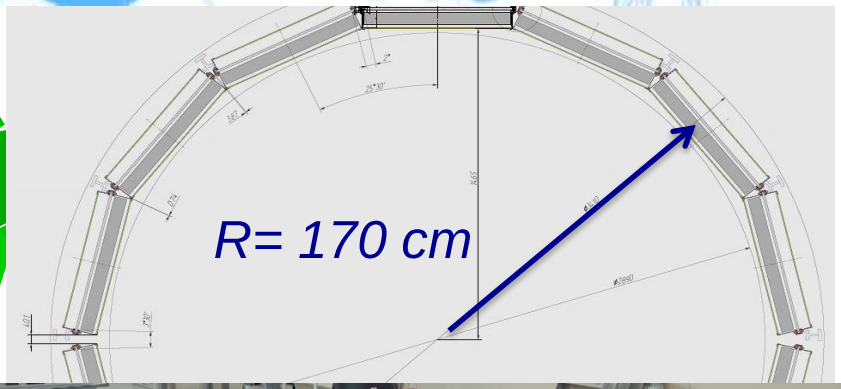


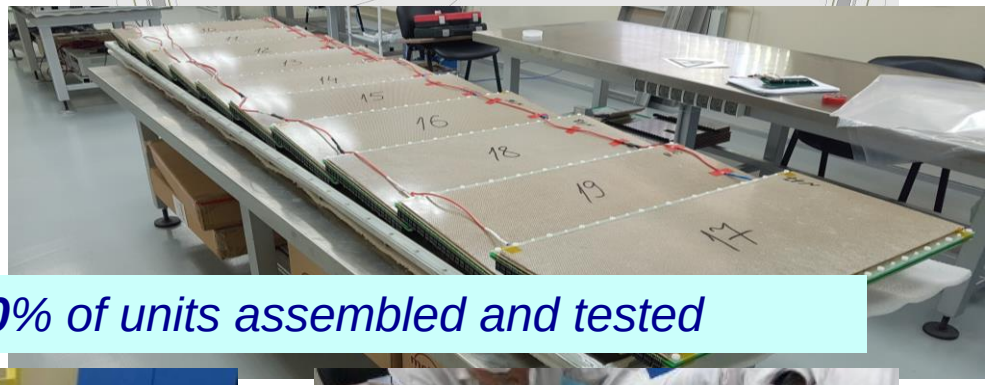
length	*340 см*
external R	*140 см*
internal R	*27см*
gas	*90% Ar+10% meth.*
Drift velocity	*5.45 см / мкс;*
Drift time	*< 30 мкс;*
N of chambers	*12 + 12*
N channels	*95232*
rate	*< 7 kHz (L= 10^{27})*

Time of Flight system (TOF)

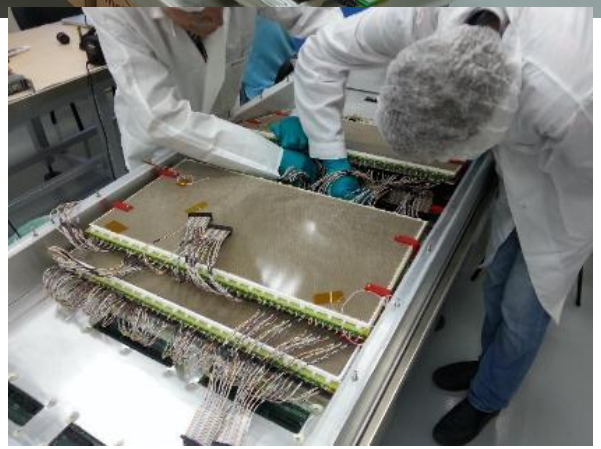


28 *units*
13 440 *channels*

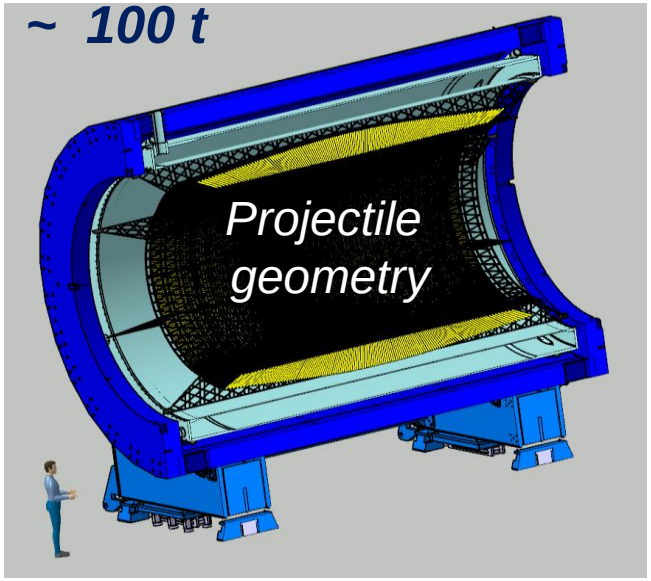


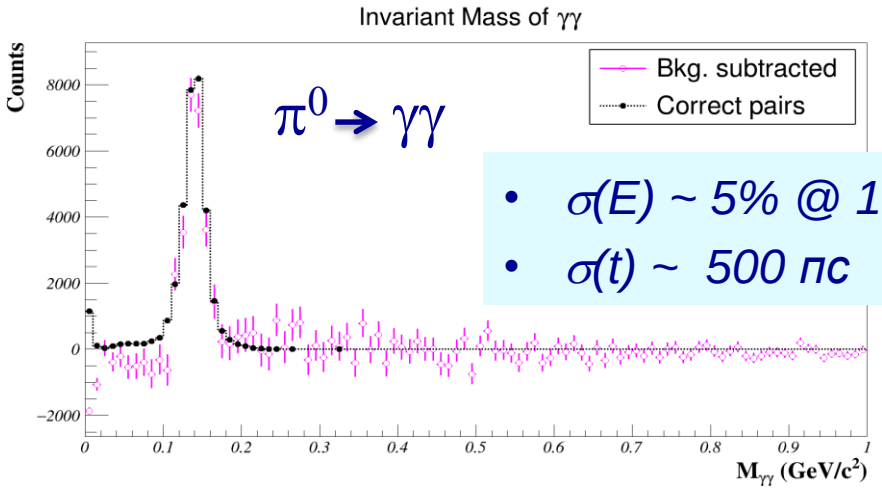


***20**% of units assembled and tested*



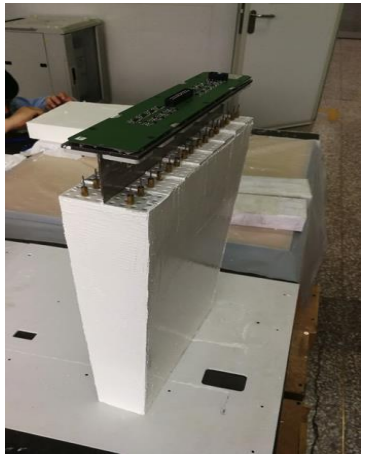
Electromagnetic calorimeter (ECal) system





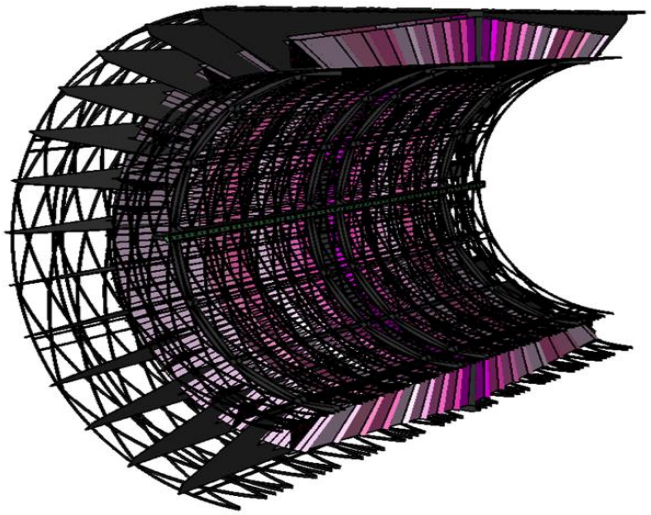
- $\sigma(E) \sim 5\%$ @ 1 ГэВ;
- $\sigma(t) \sim$ 500 пс

Support system

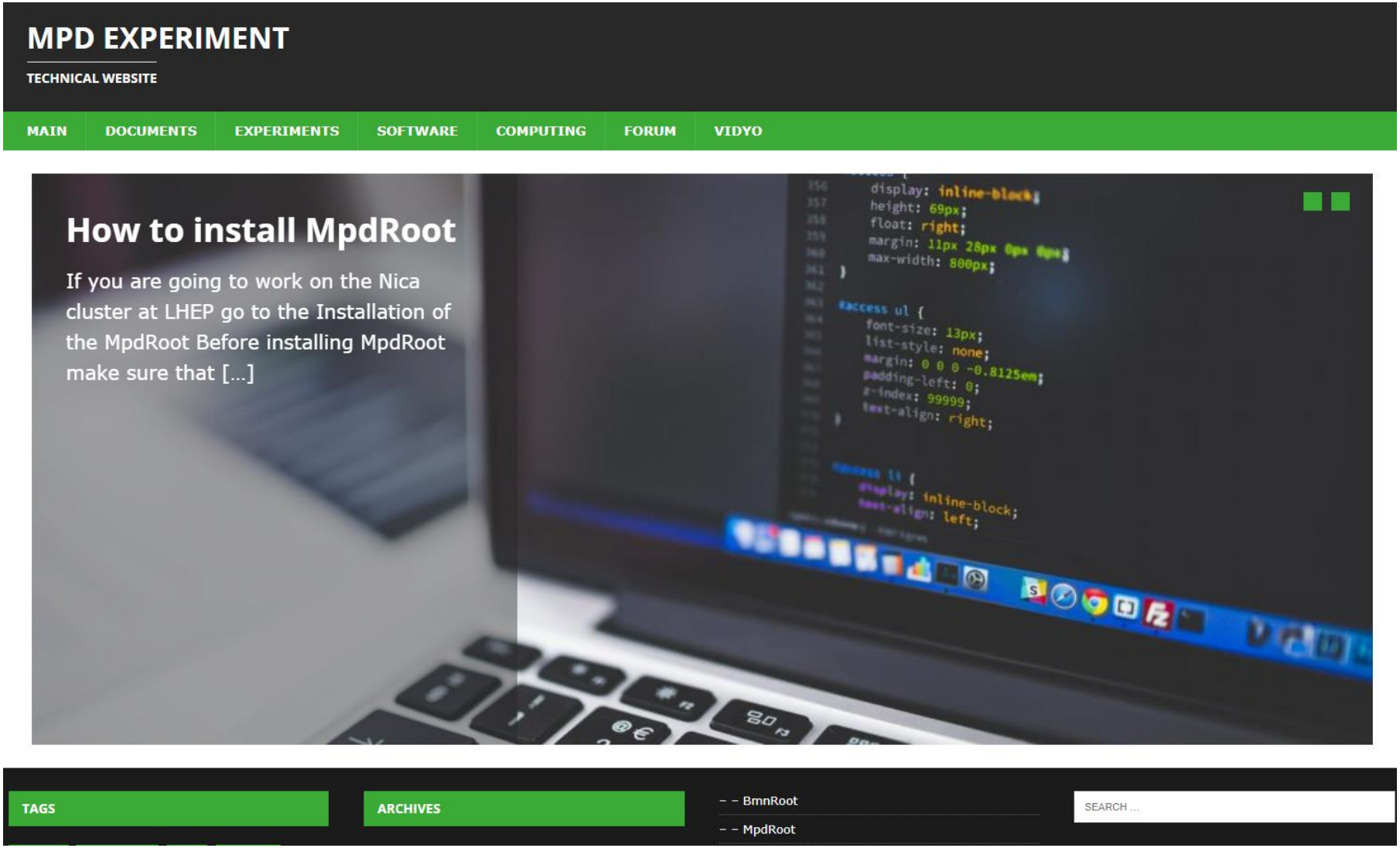


Protvino

Bejing



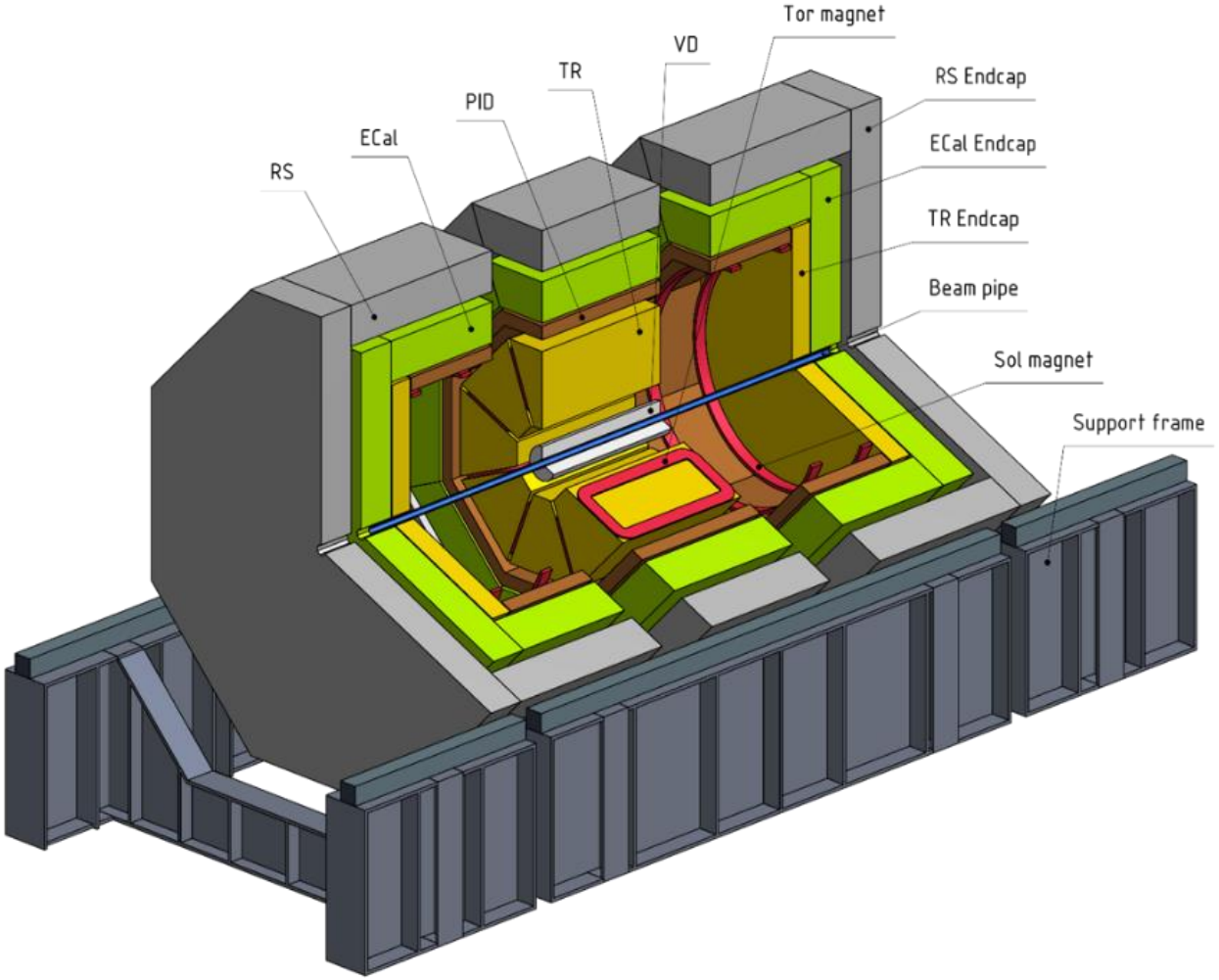
MPD experiment



http://mpd.jinr.ru/

Main experimental facilities

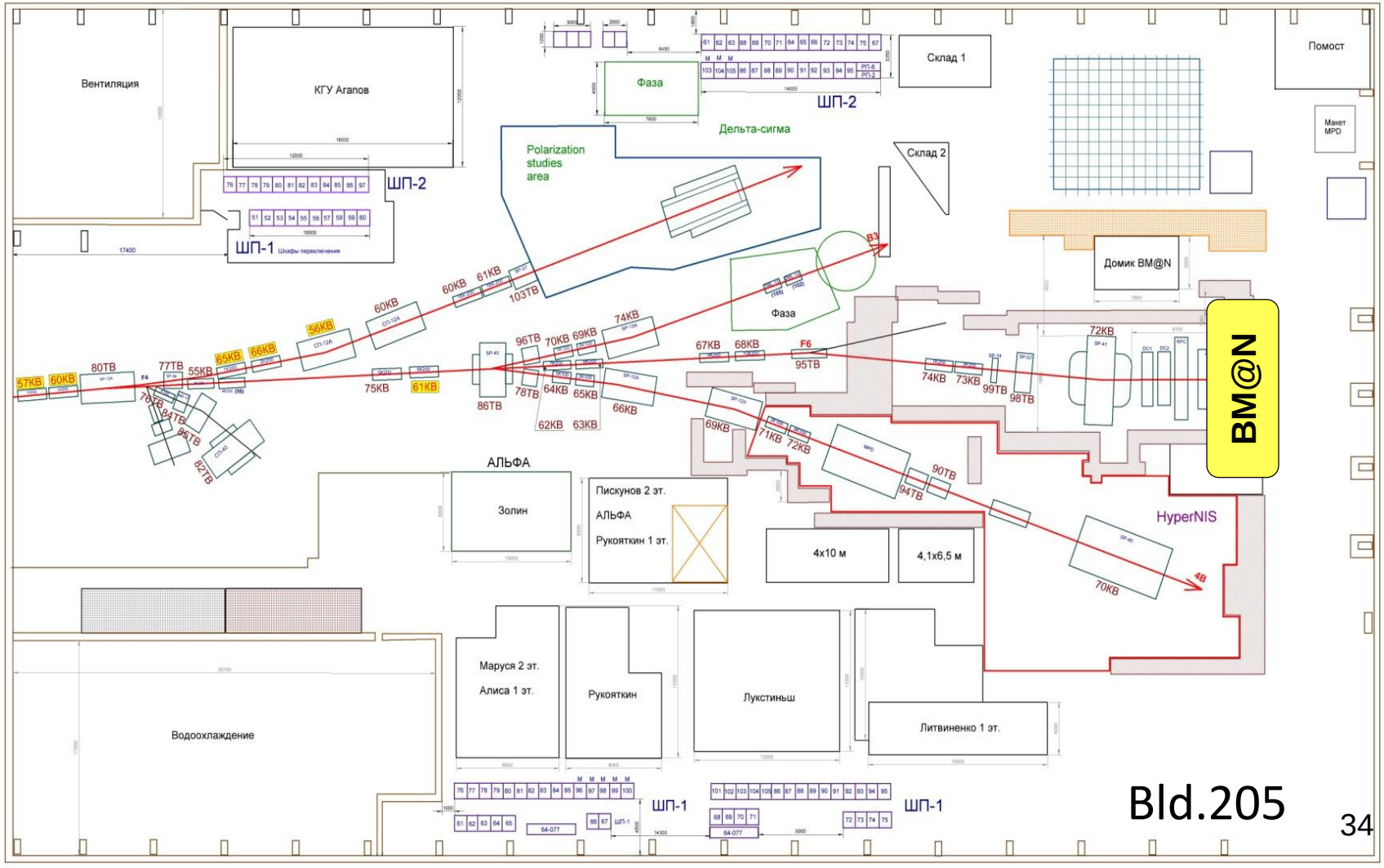
Spin Physics Detector (SPD) aiming to study of spin physics with colliding beams of polarized deuterons and protons at the energies up to 27 GeV (for protons).



Main experimental facilities

Area for radiobiology and applied research

is under development in the existing experimental building.



Innovations based on NICA technologies

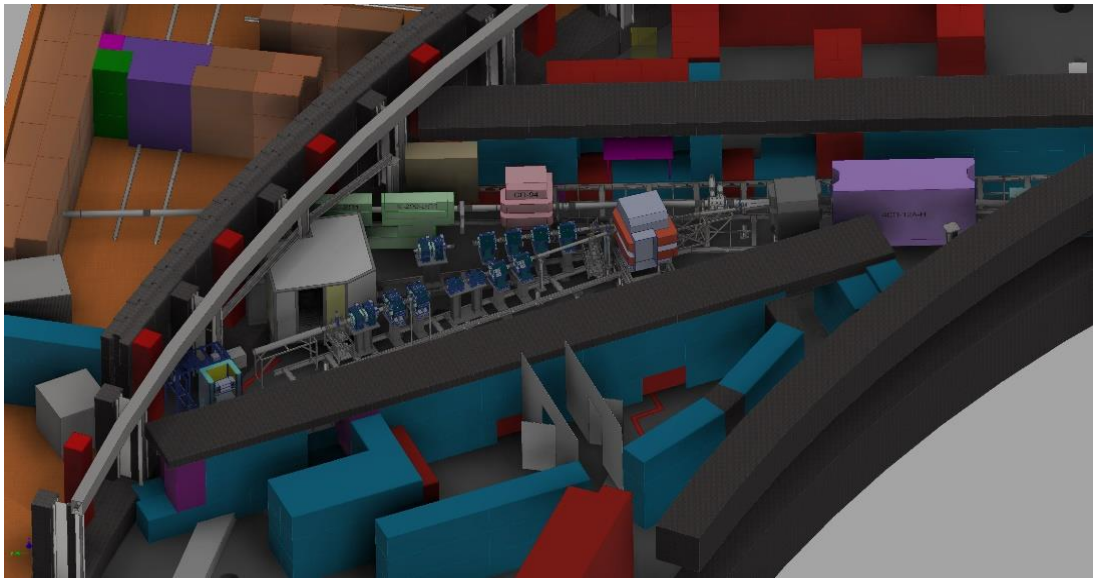
Chip irradiation and radiobiological researchers by high energy ions

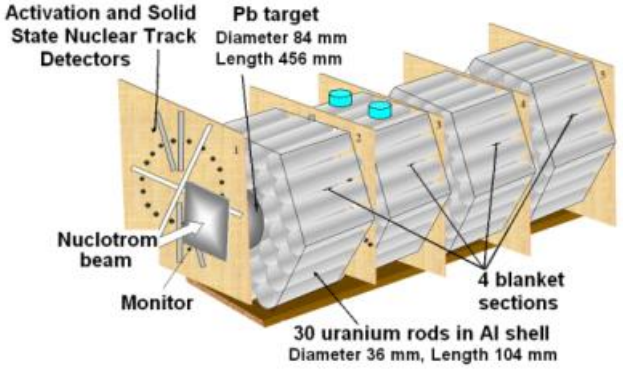
Investigations in the field of nuclear energetic and transmutation

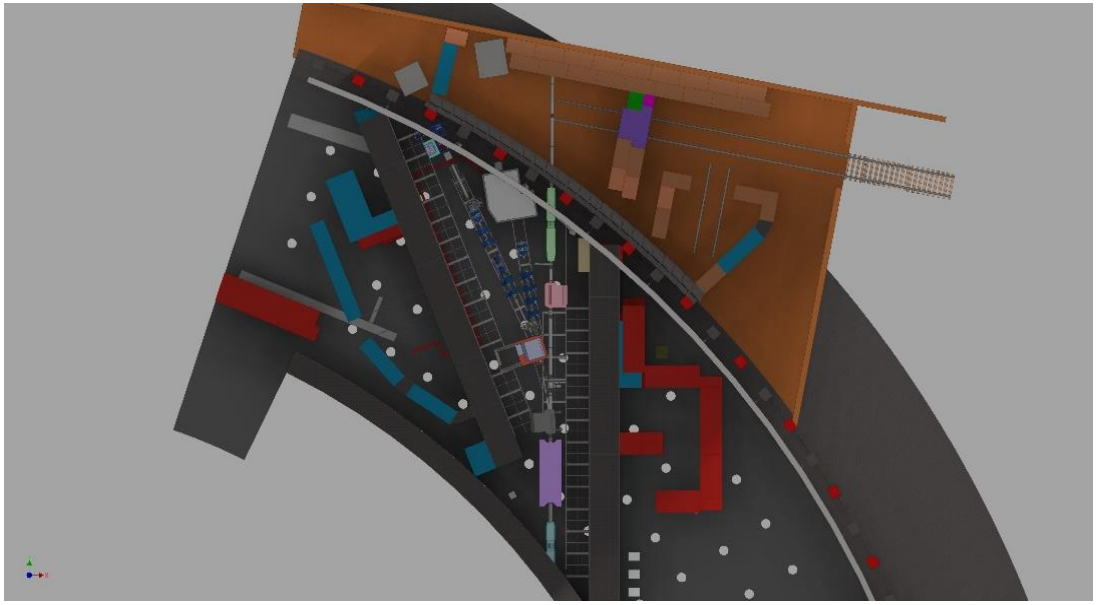
Chip irradiation by low energy ions

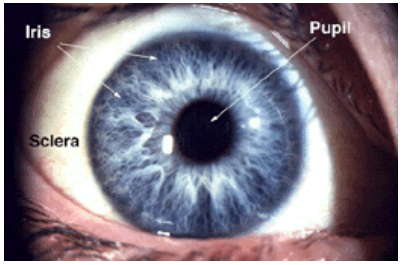
Design and Development of accelerator and detector technologies for medicine

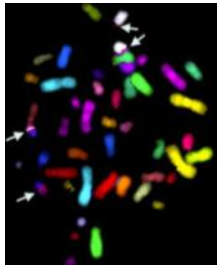
Area 1,2 of innovation zone





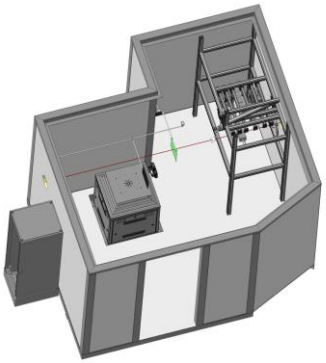




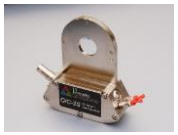


Areas 1,2 of innovation zone

SIMBO (Station of Investigations of Medico-Biological Objects)



Special chair for monkey 3D positioning
with accuracy better than 1mm + beam diagnostics

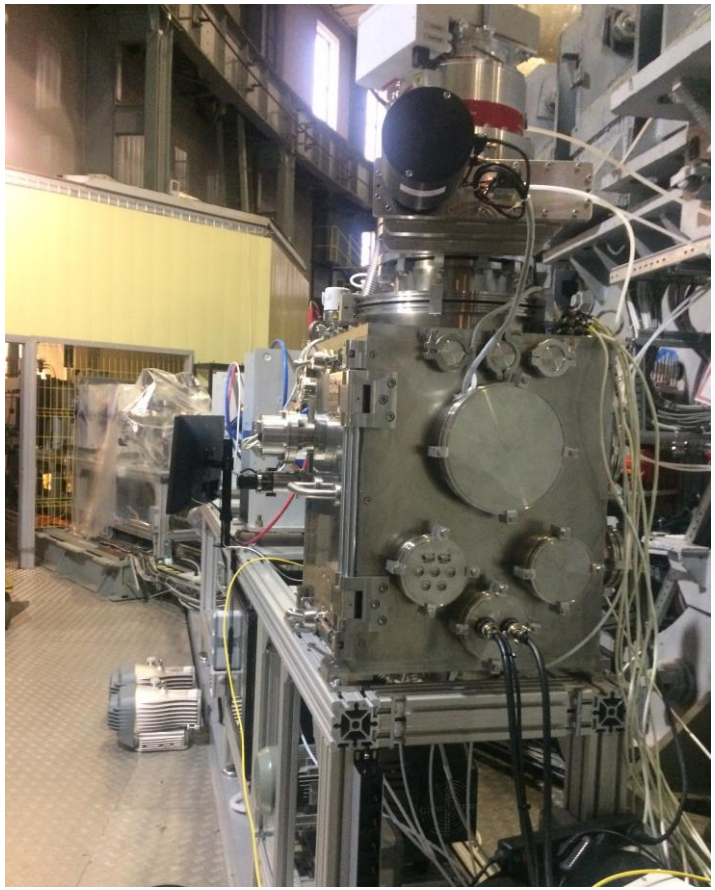


ISCRA (Irradiation Station of Components of Radioelectronic Apparatuses)

Station for investigation in the field of nuclear energetic and transmutation **SHINE** (realising by Institute of Physic-Technical Problems - SK Rosatom)

SOCHI (Station of Chip Irradiation)

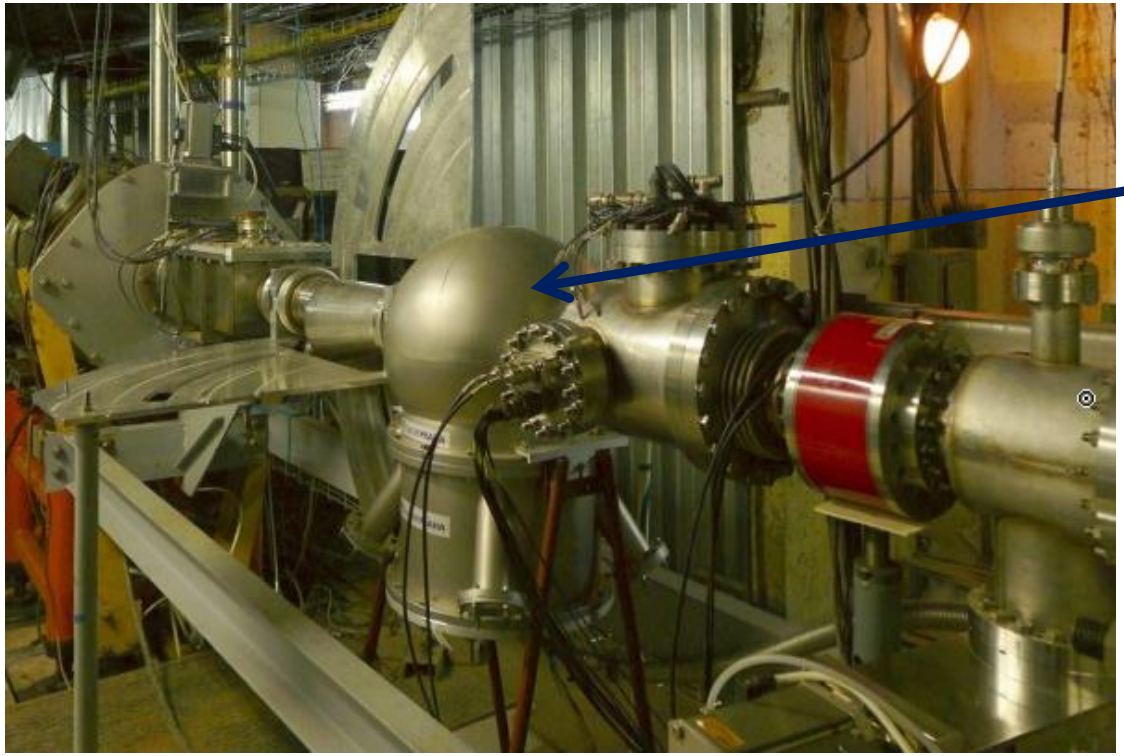
Night of 22 – 23 December 2021:
The first commissioning of equipment and the beam transportation channel.

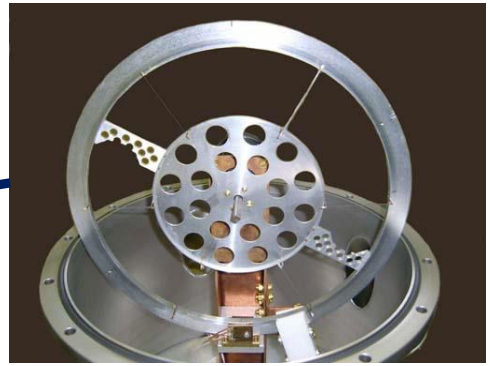


The carbon beam of the energy of 3.2 MeV/n
was transported through the channel and reached the target.

Main experimental facilities

The Nuclotron internal target station equipped with six different targets: wire, strip and film with material from hydrogen to tungsten dedicated for particle physics, spin physics, relativistic atomic physics experiments.





NICA accelerators

Main accelerator of the NICA complex is **the Nuclotron** –
superconducting ion synchrotron at magnetic rigidity of about 42 T·m
equipped with two injection chains: for heavy and for light ions.

Injection chain for heavy ions consists of:
the ion source (KRION-6N), heavy ion linear accelerator (HILac),
superconducting booster synchrotron (Booster) and required beam transport lines.

Injection chain for light ions includes:
Laser ion source (LIS), Source of polarized ions (SPI), Duoplasmatron,
RFQ accelerator as a foreinjector, Drift tube linac of Alvarec type (LU-20)
and required beam transport lines.

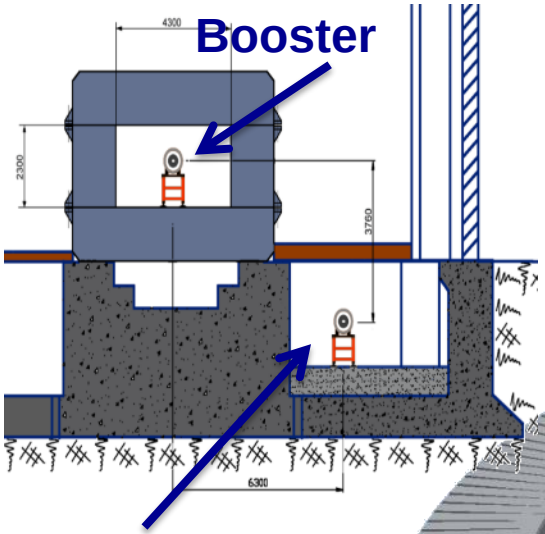
The collider experiments will be provided at two storage rings
with two interaction points (IP).

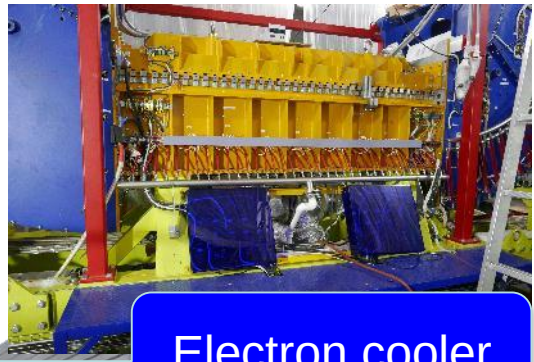
Heavy ion injection chain

KRION 6T
used in two runs

Heavy ion linear accelerator (HILAc)
Commissioned – October 2016

Booster





Electron cooler

injection

Reference section

Power supply

extraction

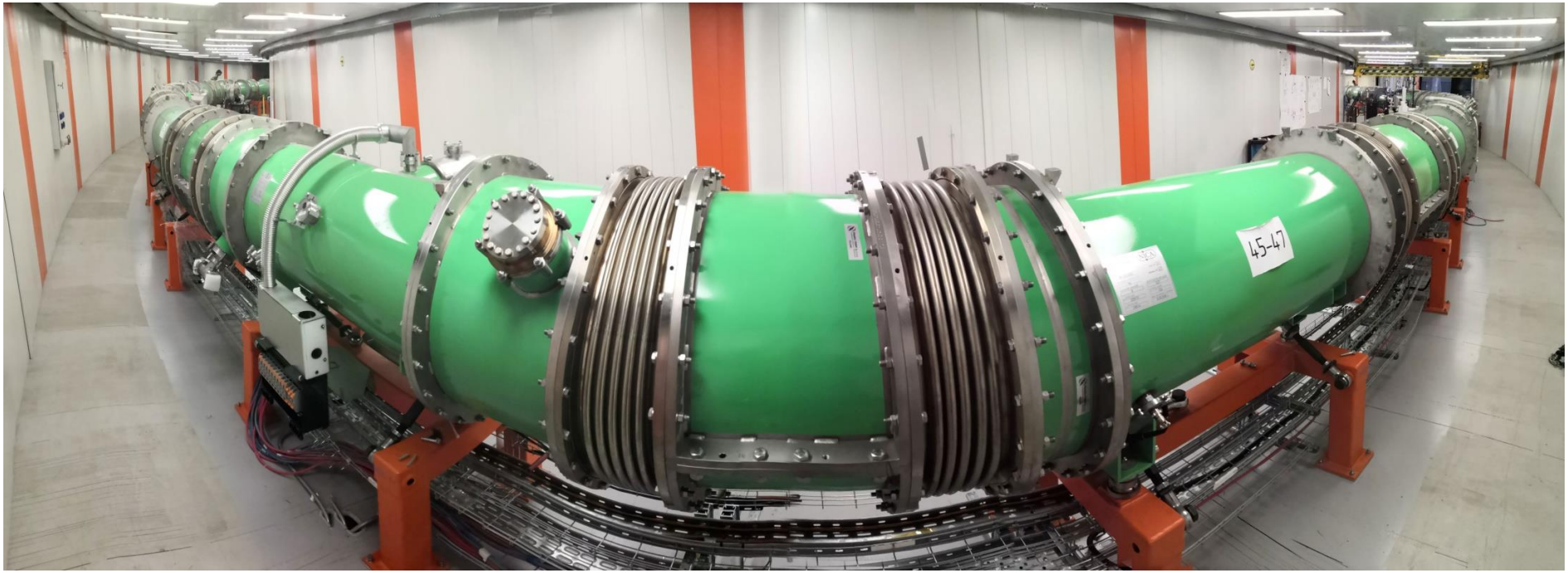
RF stations

Nuclotron

Booster

Official start of the commissioning

Booster

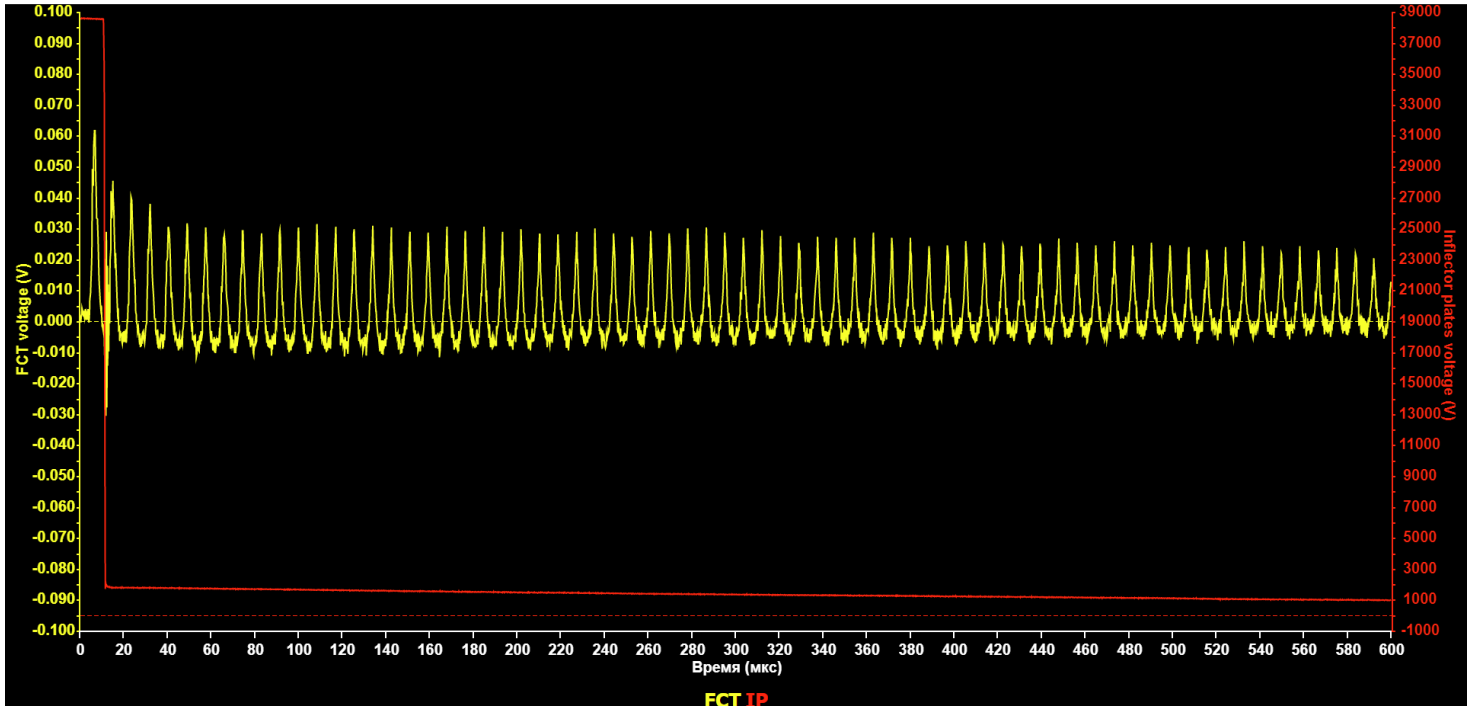


Cryo-magnetic system in assembly
12 November – 30 December 2020 – technological run

First run of the Booster

12.11 – 03.12: assembly and test of vacuum system
04.12 – 11.12: cooling, thermometry commissioning
12.12 – 18.12: commissioning of quench protection system, tuning of power supply, tuning of the HILAC – Booster transfer line
19.12: first circulating beam He^{1+}

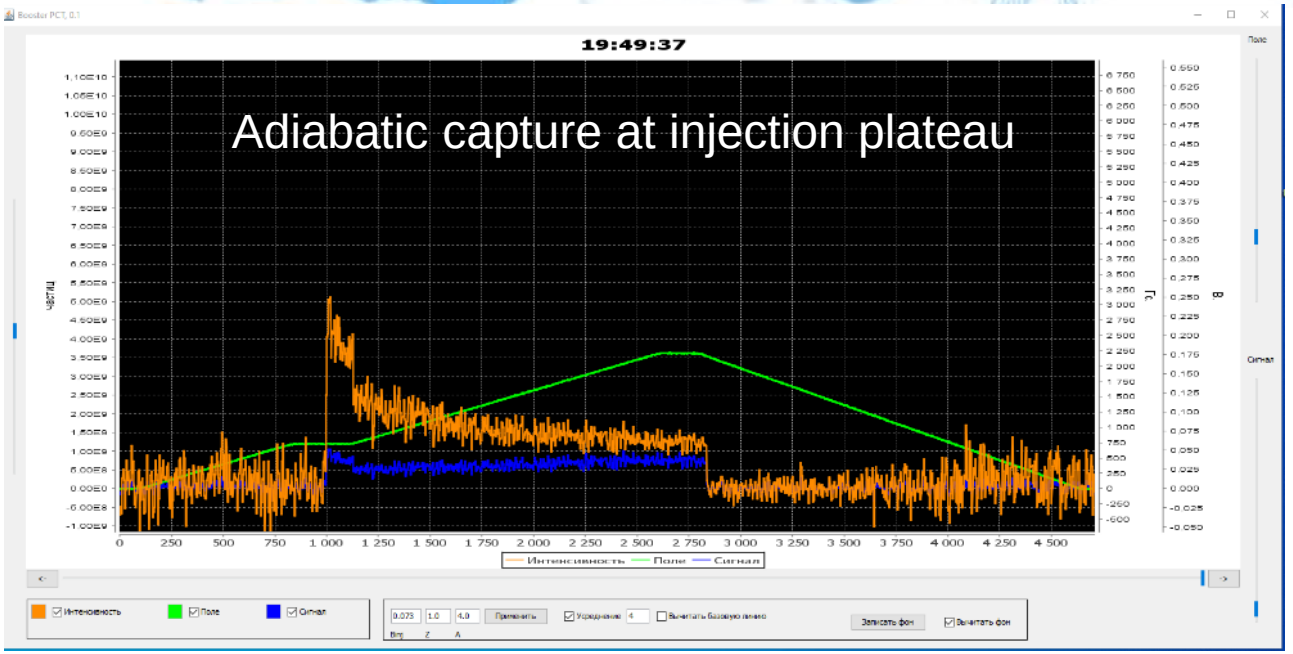
Fast current transformer

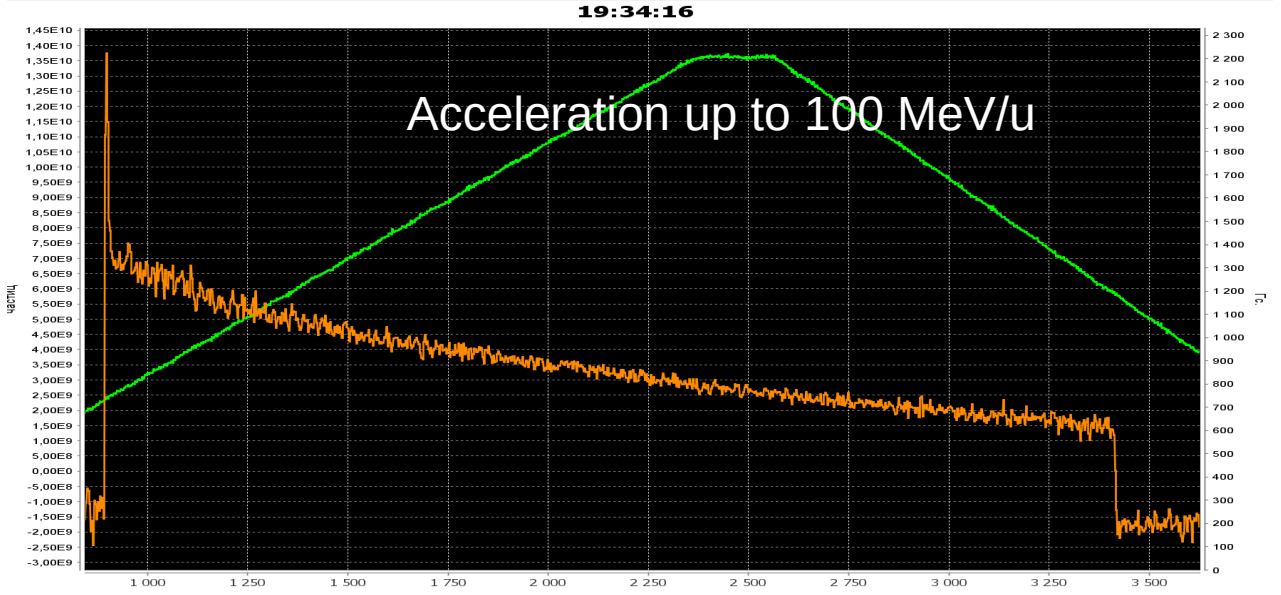


600 μs

First run of the Booster

24.12:
Beam acceleration



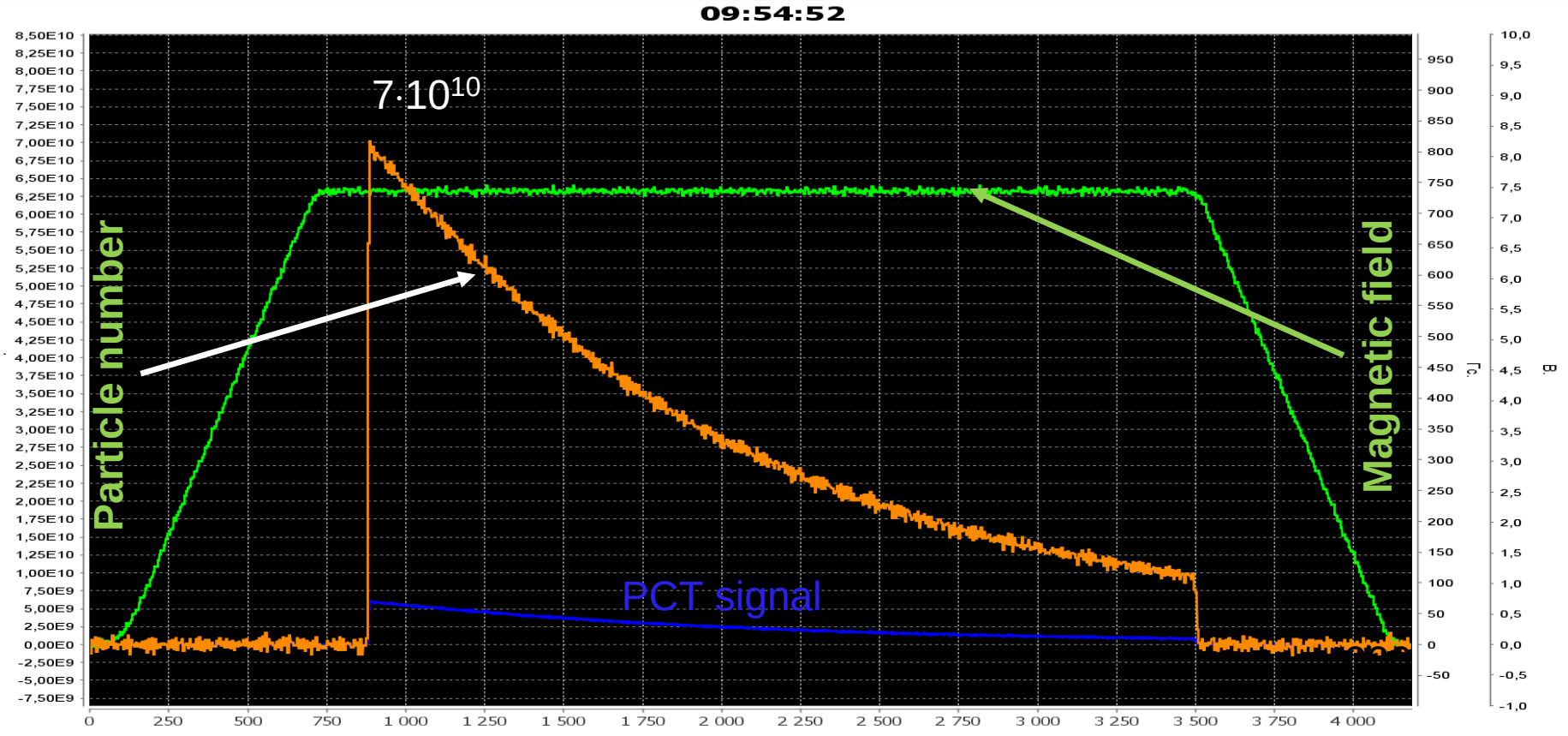


Parametric
current transformer

First run of the Booster

26.12: Orbit correction, Injection optimization – design current of circulating beam

Parametric current transformer

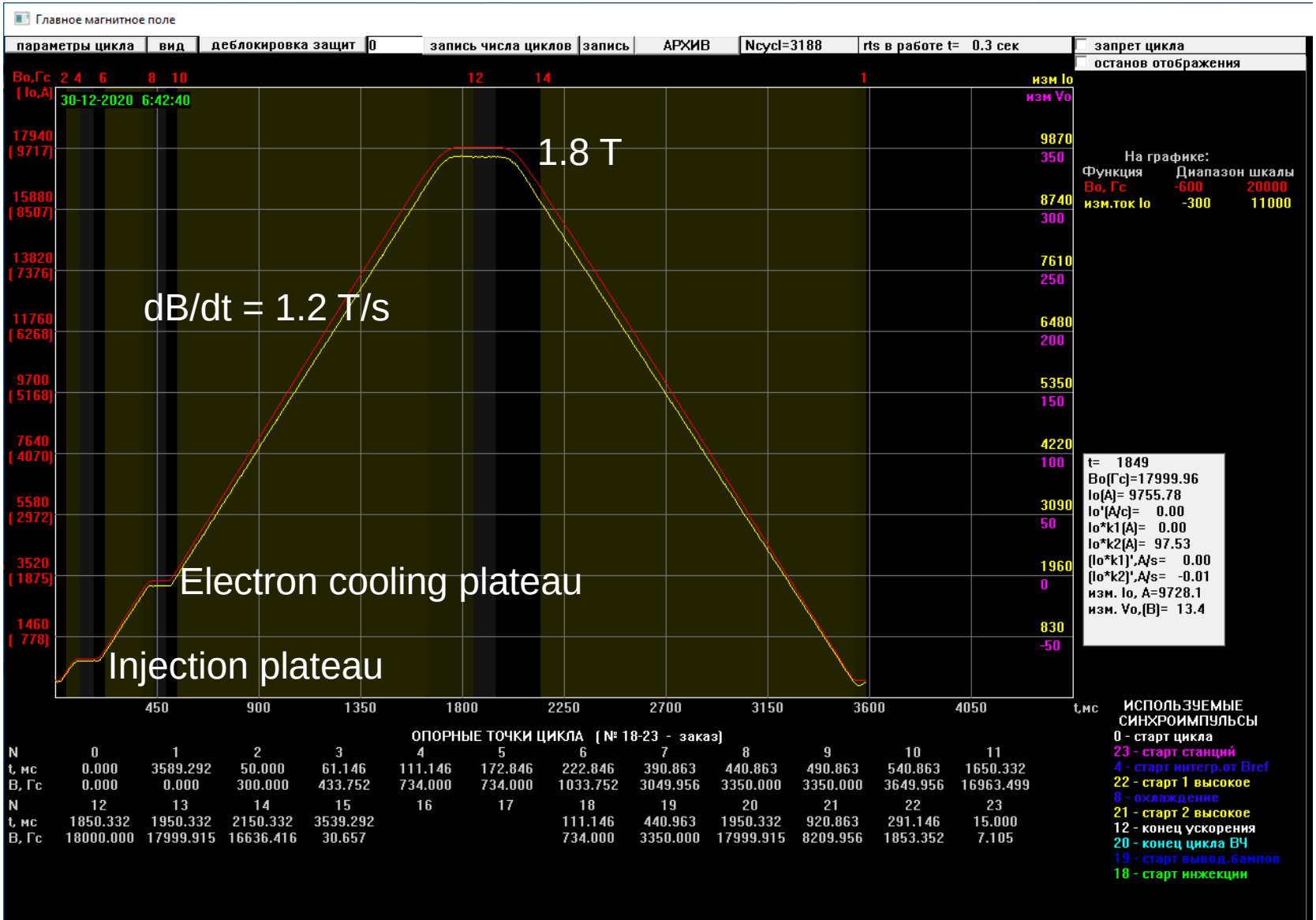


$7 \cdot 10^{10}$ elementary charges ~ $2 \cdot 10^{9}$ Au^{31+}

Life-time is about 2 s, equivalent pressure of residual gas is $3 \div 6 \cdot 10^{-8}$ Pa

First run of the Booster

30.12: design magnetic field cycle



Second run of the Booster

The Booster run was performed during the period from 6 to 24 September

Total duration - about 450 h.

Ions He^{+} (plasma source) and Fe^{14+} (laser source)

Maximum energy - 578 MeV/u.

General goal:

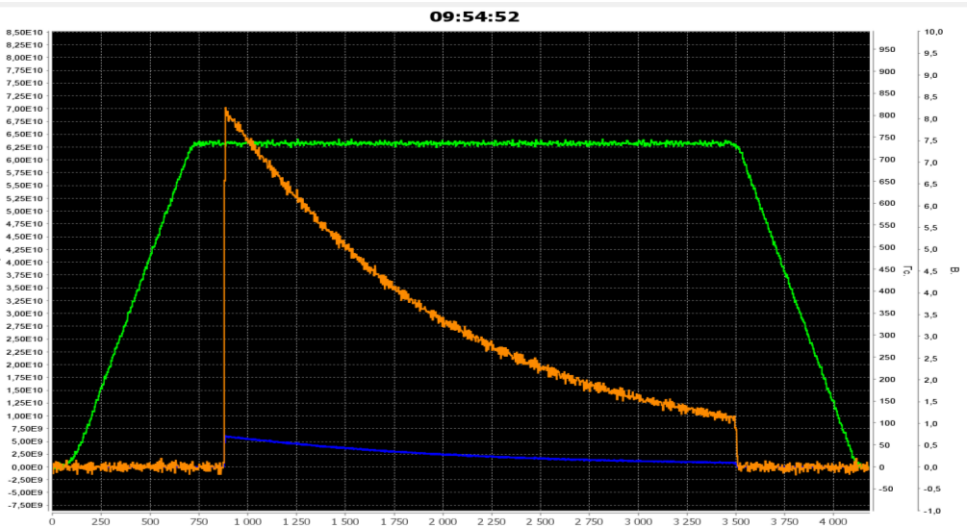
- test of the Booster systems in working regime and Booster- Nuclotron transfer line.

HILAC linear accelerator and the beam transport line to the Booster were tuned for generation of Fe^{14+} beams

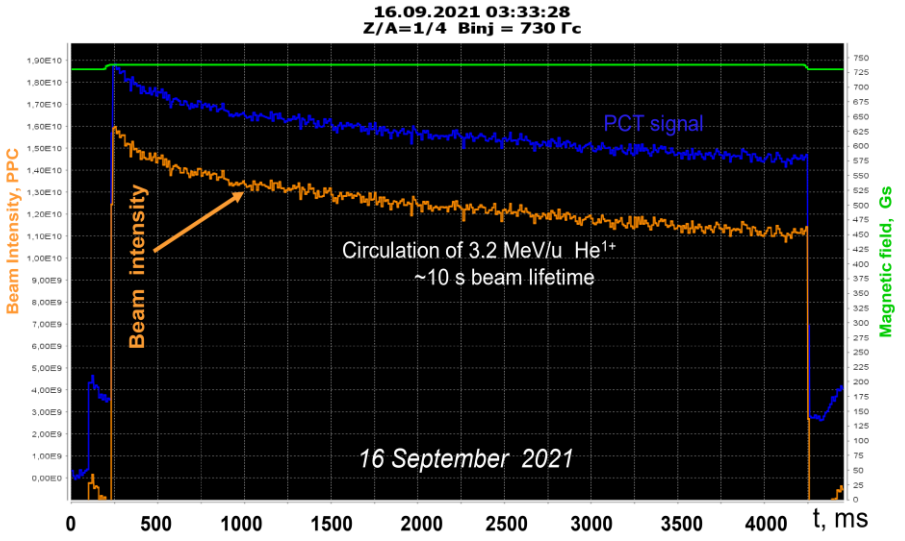
Second run of the Booster

Improvement of the vacuum conditions

First run (December 2020)

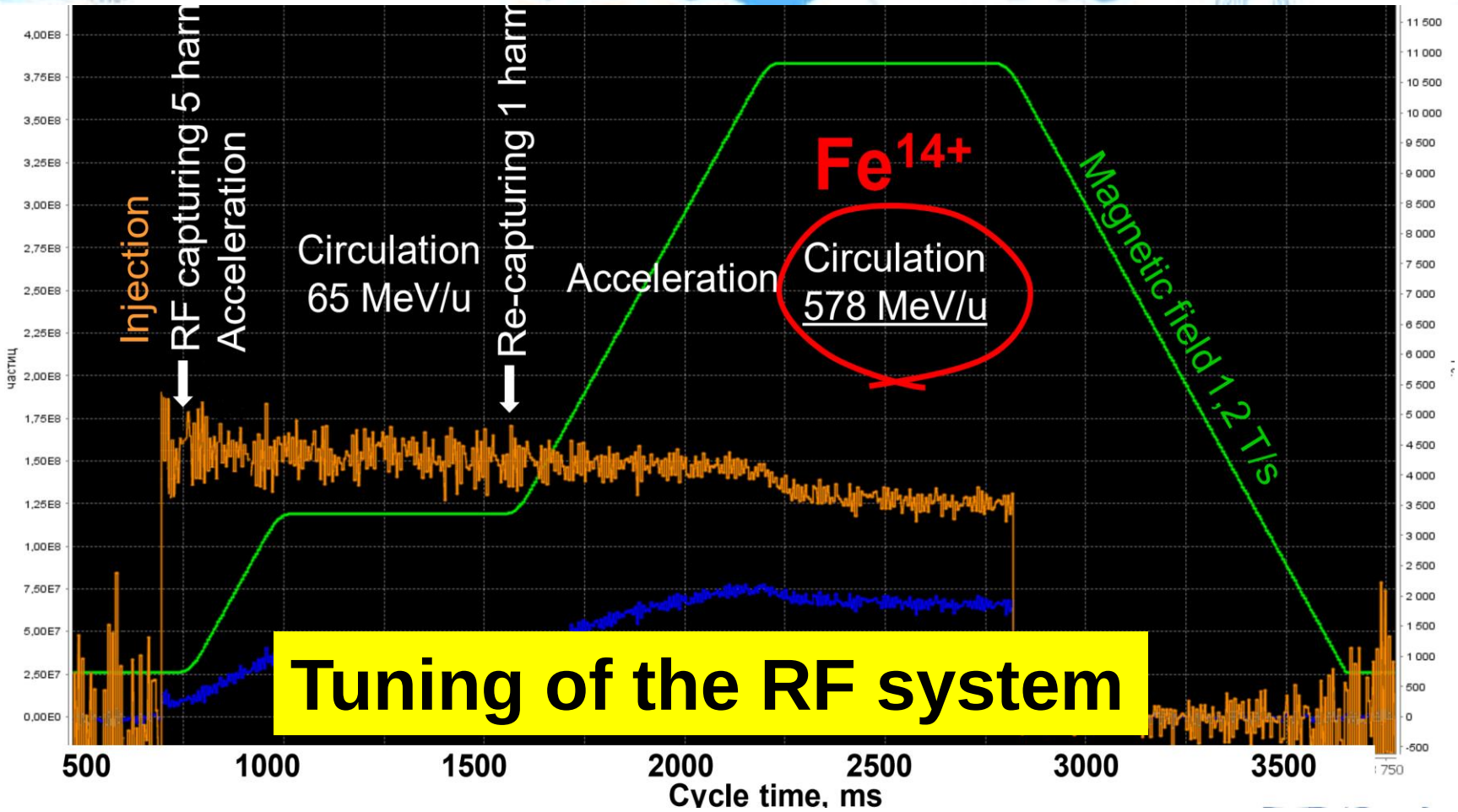


Second run (September 2021)



Residual gas pressure inside the beam pipe was sufficiently reduced down to the value required for heavy ion acceleration

Second run of the Booster

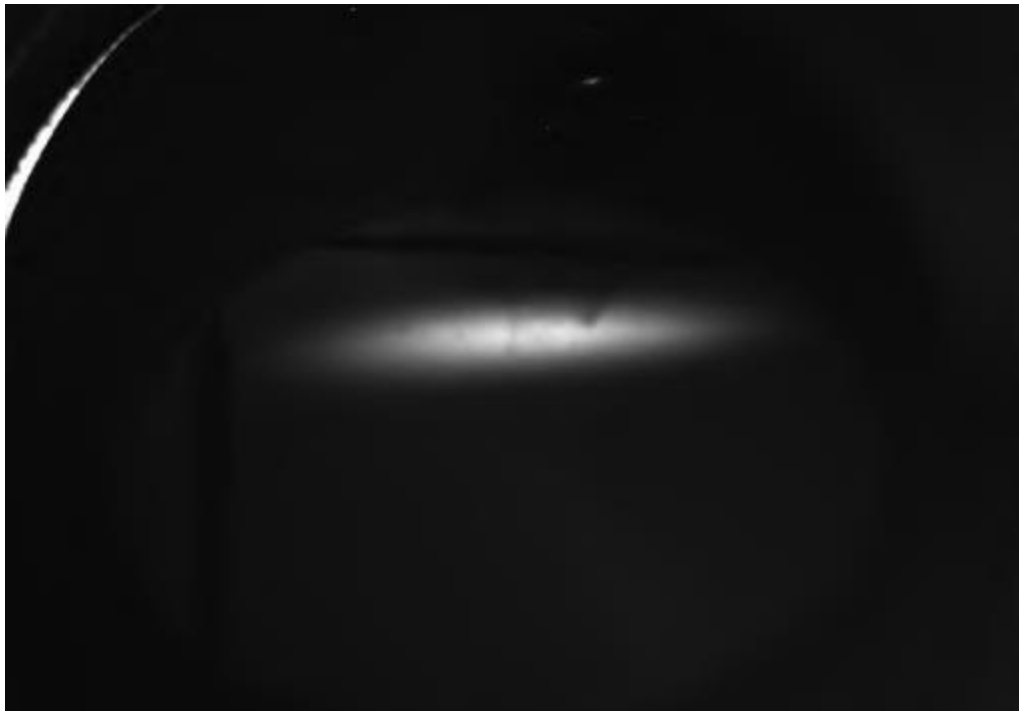


Adiabatic capture of the beam into acceleration was fulfilled
at 5-th harmonics of the acceleration field,
The beam was recaptured into 1-st harmonics at 65 MeV/n energy,
The iron ion beam was accelerated up to design energy of 578 MeV/u

Second run of the Booster

Beam transport from Booster to Nuclotron

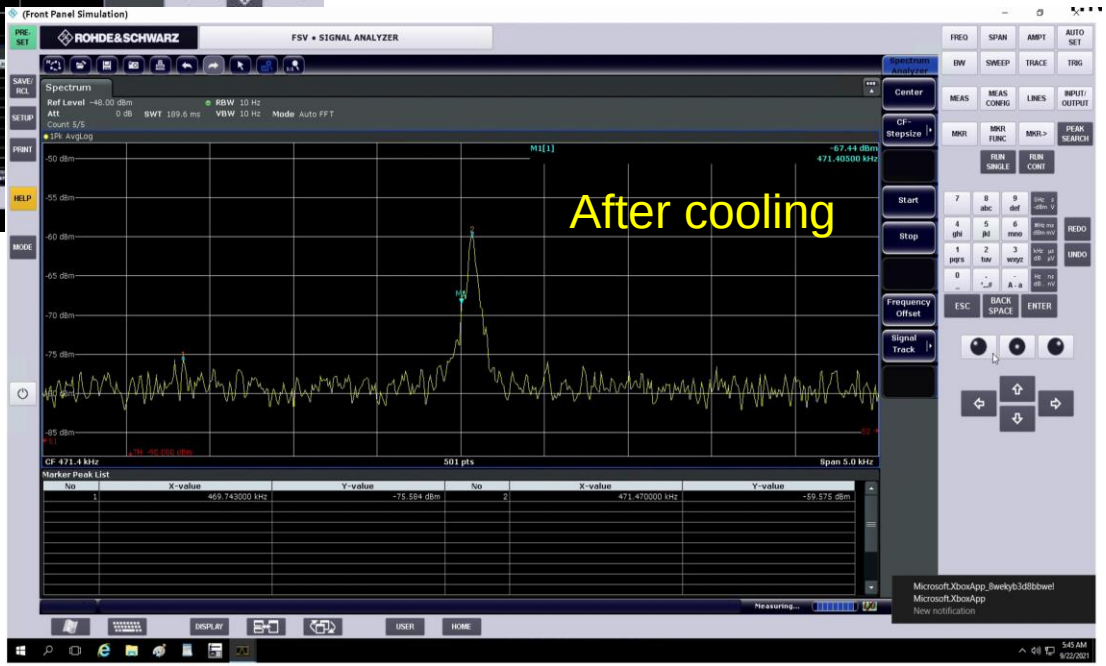
The orbit bump system was tuned at the beam extraction,
The systems for the beam extraction from the Booster and transport line to the Nuclotron were put into operation and tuned,
Helium beam and then the iron $^{56}Fe^{14+}$ beam were transported through the beam transfer line.



Beam of Fe ions on the phosphor screen
at the end section of the Booster-Nuclotron transport line

Second run of the Booster

Electron cooling of Fe ions



Schottky spectrum at 4-th harmonics

First run of the NICA

The Run has been started: 2.01.2022

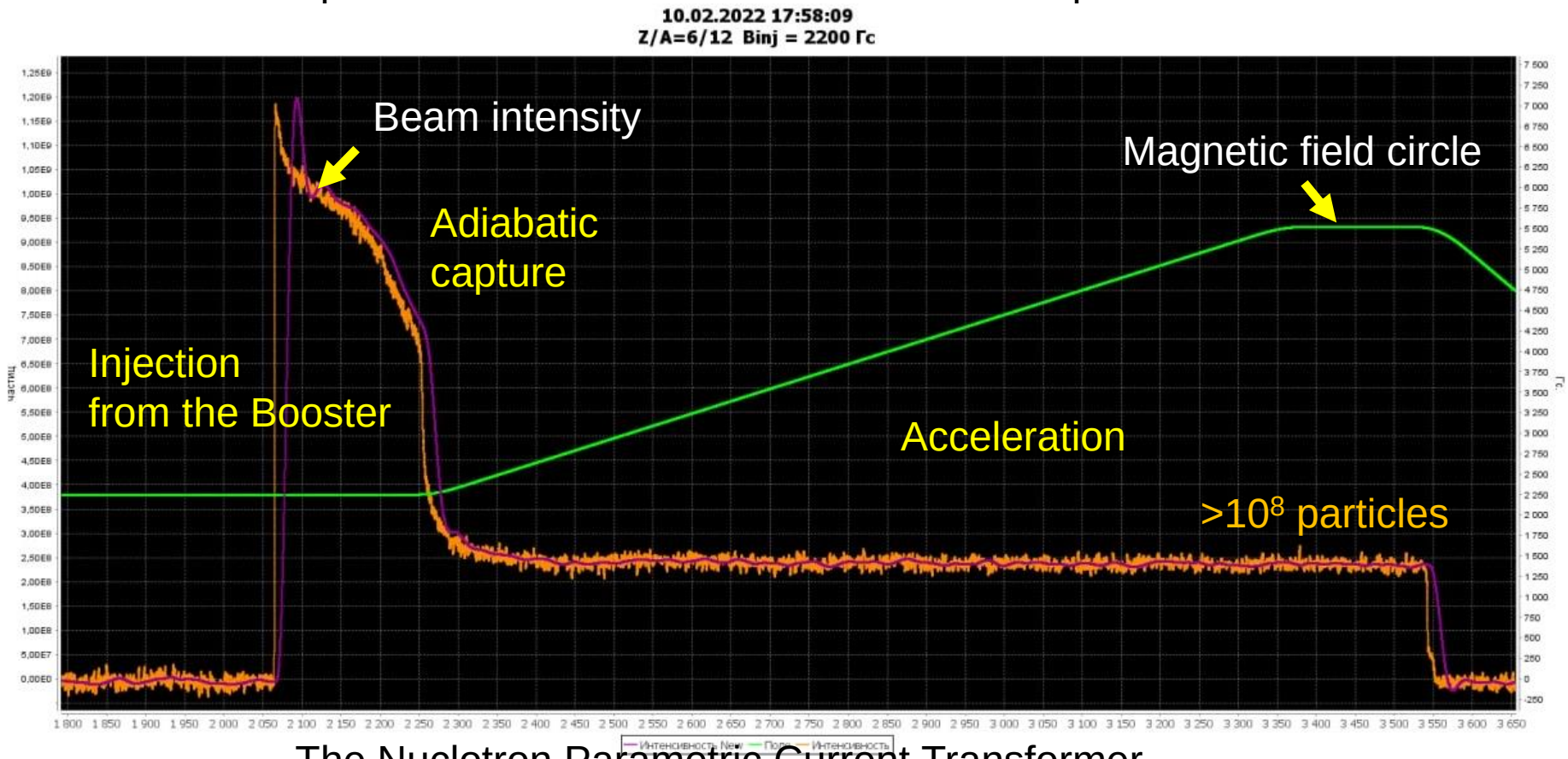
Goals:

- Tuning of the common work of HILAC, Booster and Nuclotron
- Test of new power supply system of the extracted beam optics

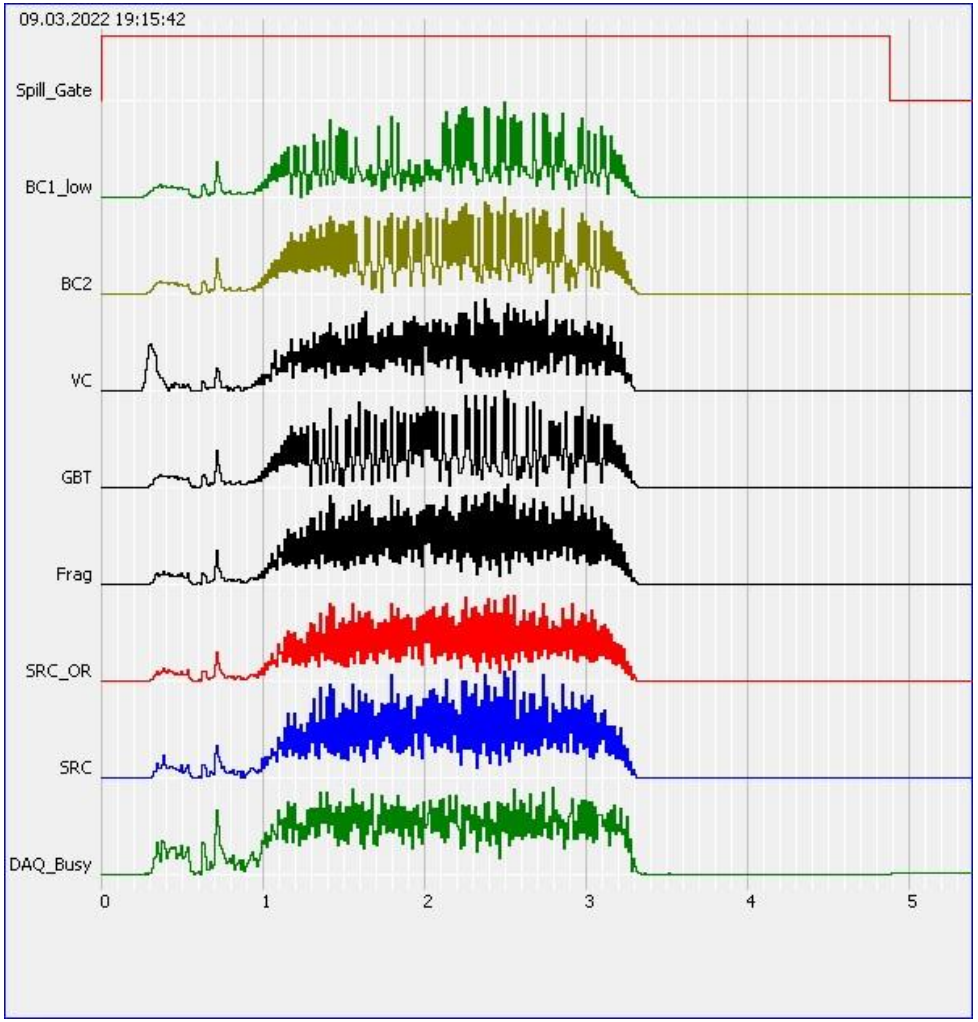
6.01 – Beginning of the Nuclotron cooling
12.01 - Beginning of the Booster cooling
24.01 – Beginning of operation with beam
28.01 – C^{+4} transported to the Nuclotron
06.02 – C^{4+} beam circulation in the Nuclotron
07.02 – C^{+6} beam circulation in the Nuclotron
10.02 - C^{+6} beam accelerated in the Nuclotron up to 1.1 GeV/u

First run of the NICA

The beam (C^{4+}) generated by laser source
accelerated in the HILAC, transported to the Booster,
accelerated in the Booster (C^{4+}),
striped in the Booster-Nuclotron beam transport line (C^{6+}),
transported to the Nuclotron,
captured and accelerated in the Nuclotron up to 1.1 GeV/u

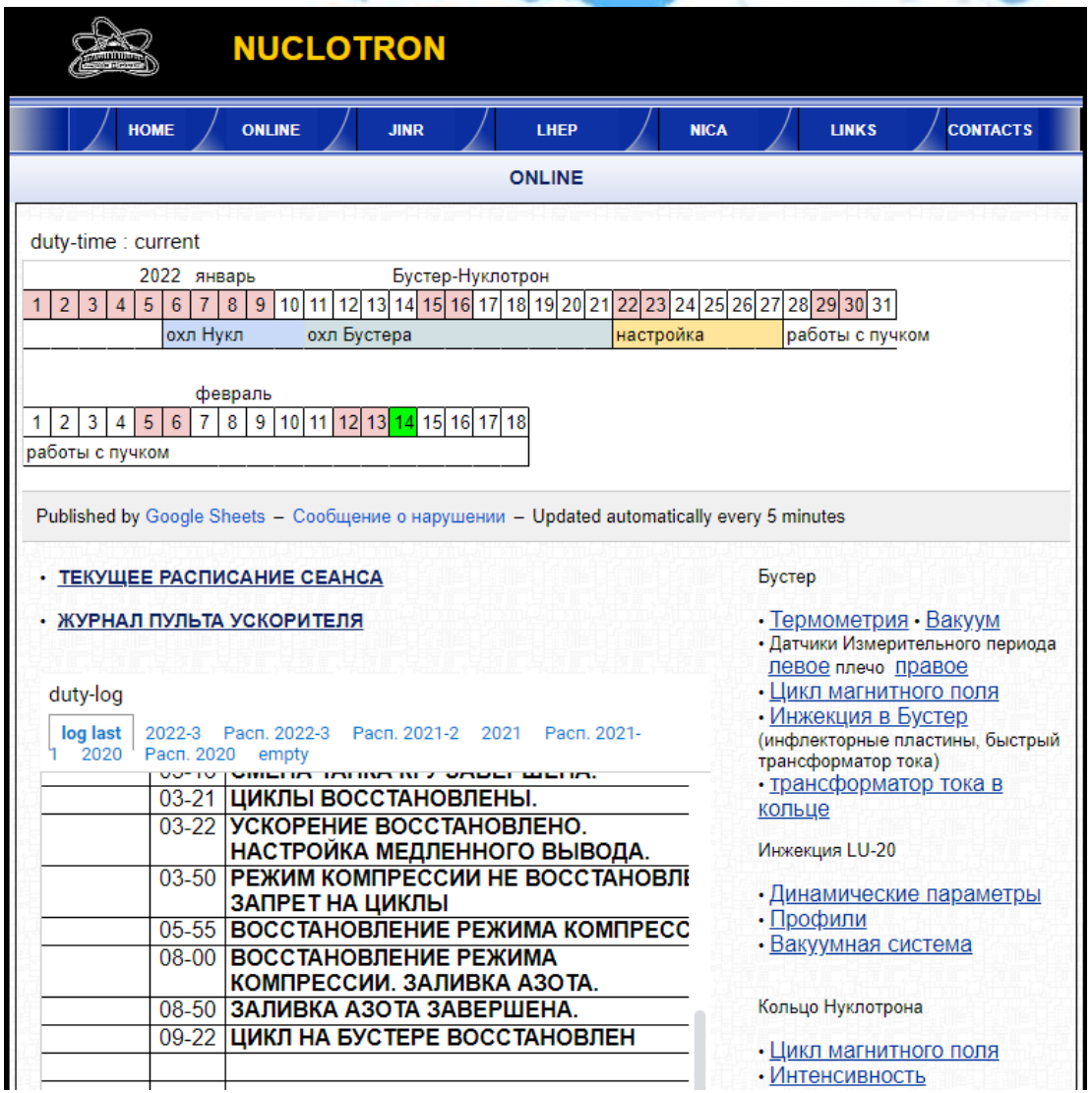


The Nuclotron Parametric Current Transformer



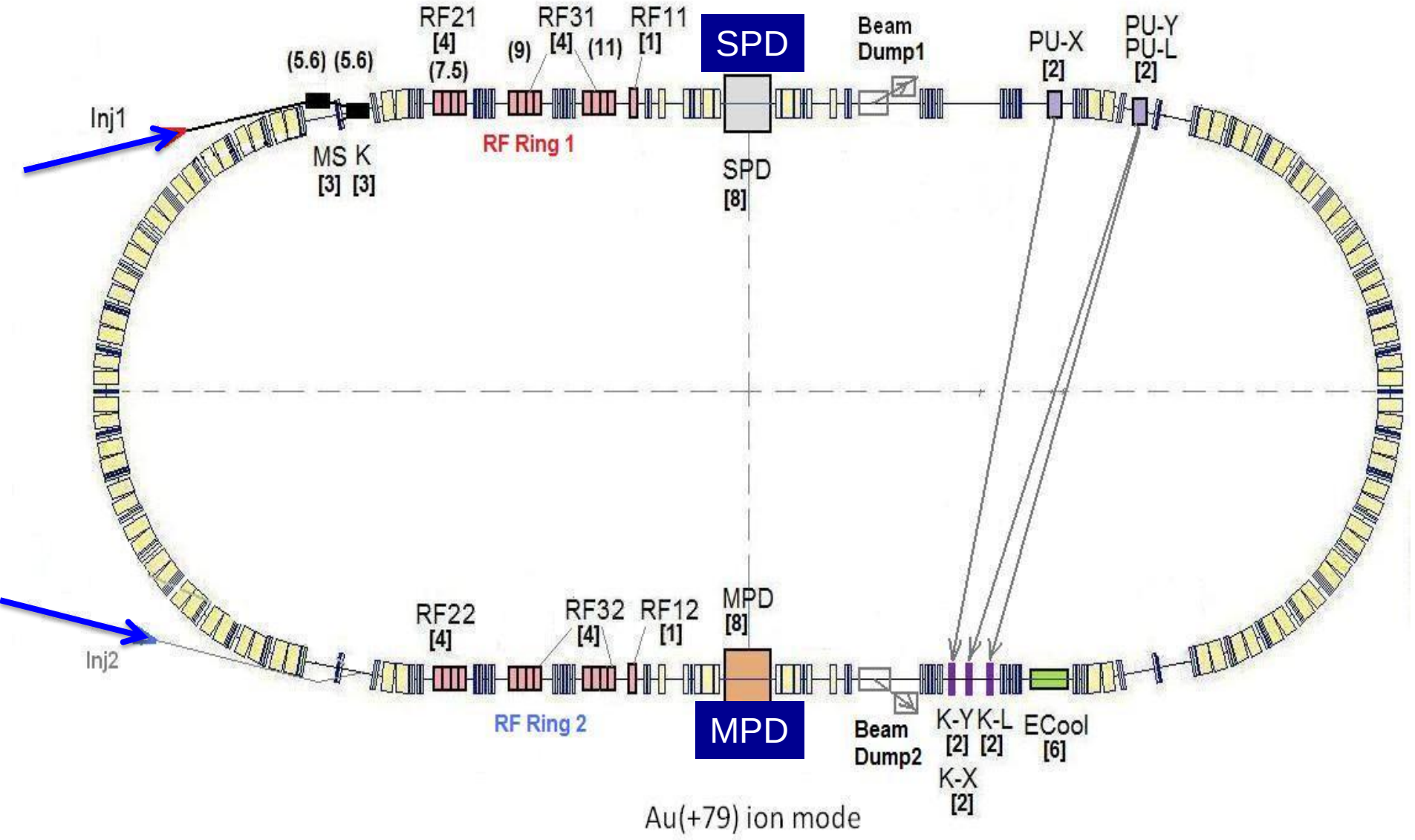
Intensities of the 3 GeV/u carbon beam as a function of time measured at the BM@N setup (SRC experiment) for one spill.
X axis shows time in seconds.
Colors indicate different trigger module channels, which correspond to some scintillator counters and combinations of those used as triggers.
The beam intensity at the BM@N area was around 10^6 ions per spill.

First run of the NICA

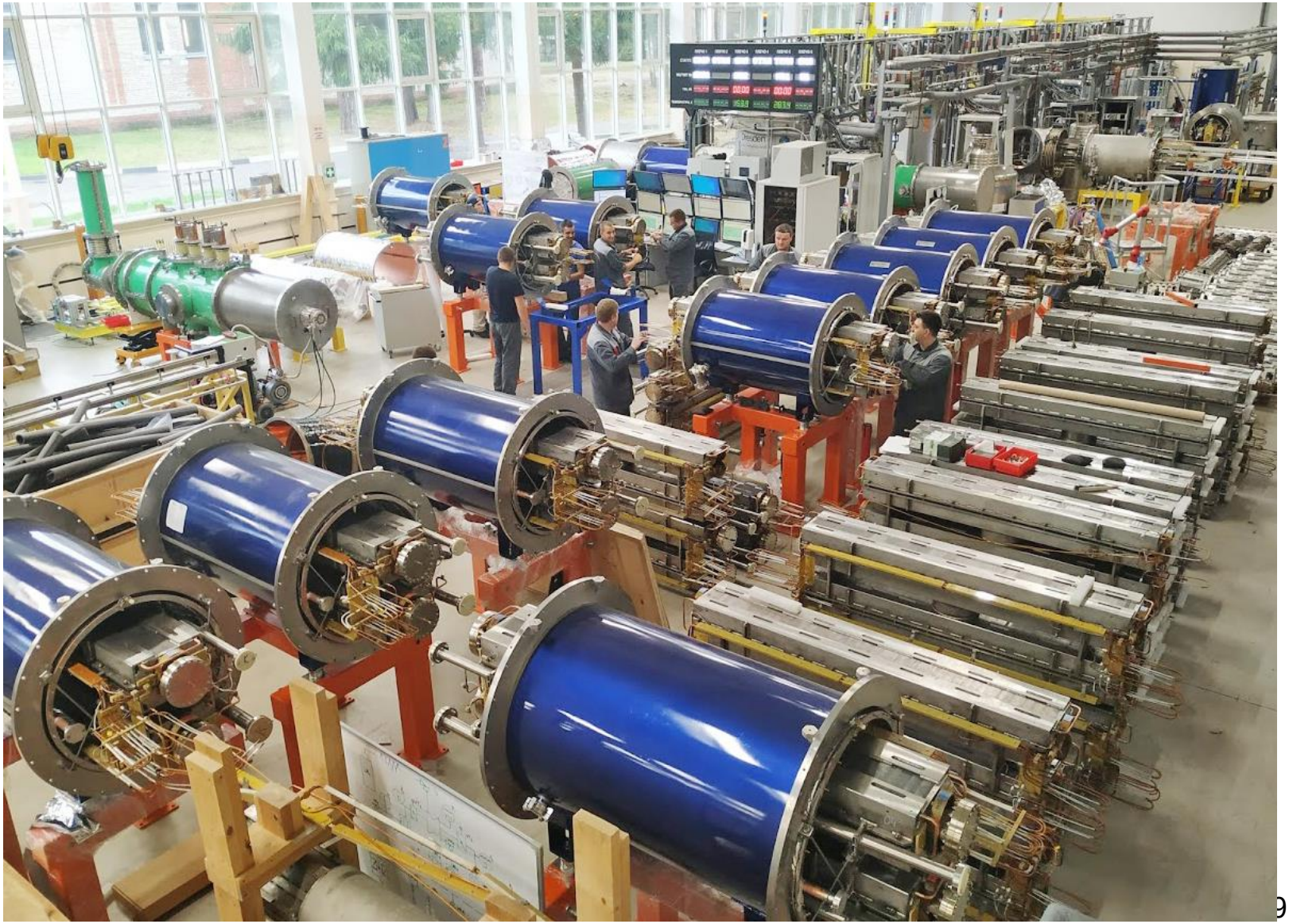


http://nucloweb.jinr.ru/nucloserv/online.htm

NICA collider



Serial production of the collider magnets



Line for assembling and cryogenic testing of SC-magnets

Main production areas:

- Incoming inspection zone
- SC cable production hall
- SC coils production hall
- Area for assembling the magnets
- Area for the magnetic measurements under the room temperature
- Leakage test area
- Area for mounting the SC-magnets inside cryostats
- Cryogenic tests bench

450 magnets for NICA and FAIR projects

Official start up

28 November 2016

Collider building

Official start up of the construction 25 March 2016

Collider building

2017

Collider building

September 2018

Collider building

November 2020

Collider building

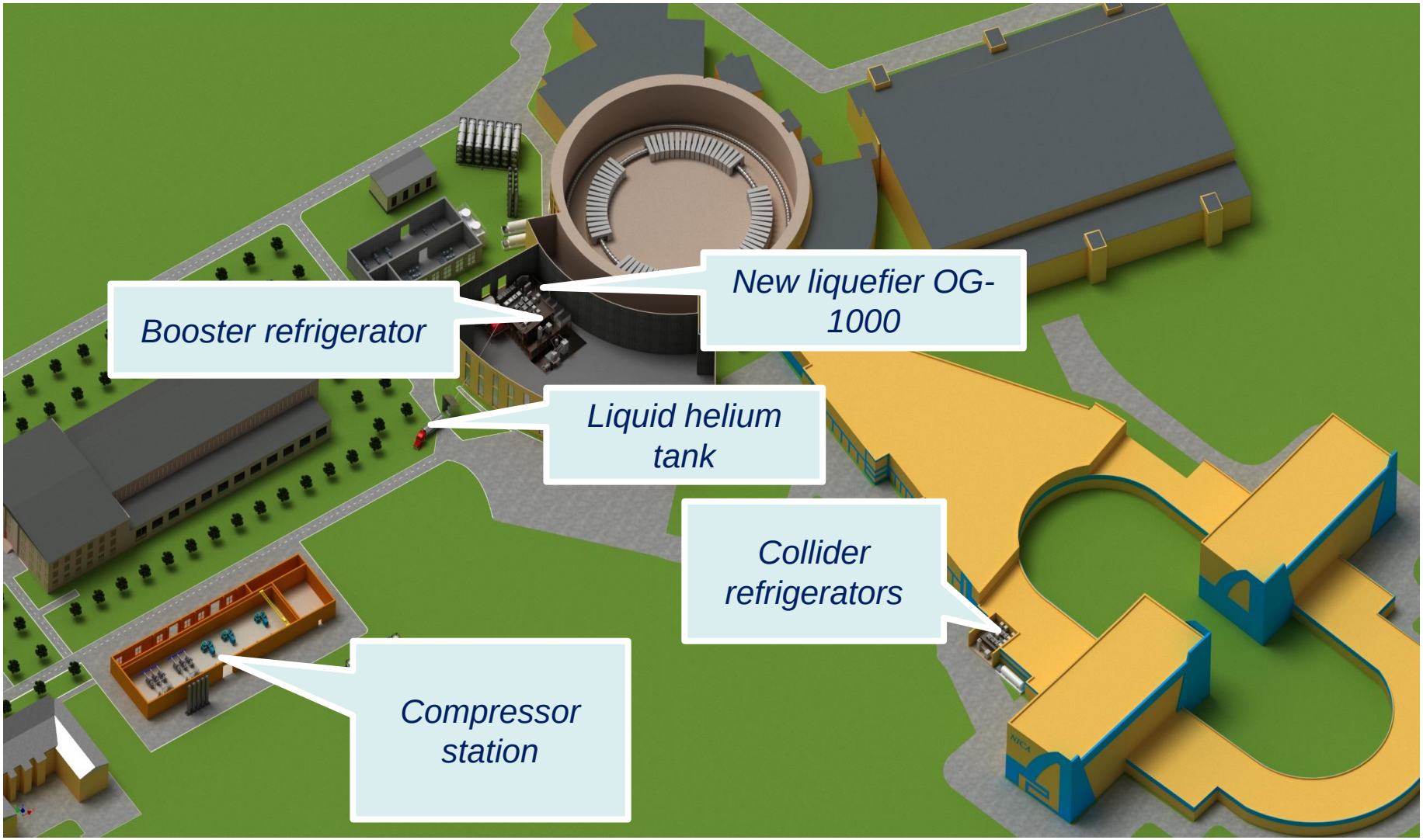
http://nucloweb.jinr.ru/

Collider building

First collider magnet in the tunnel

On 28 December, the first dipole magnet was installed in the tunnel of the collider

NICA cryogenic complex



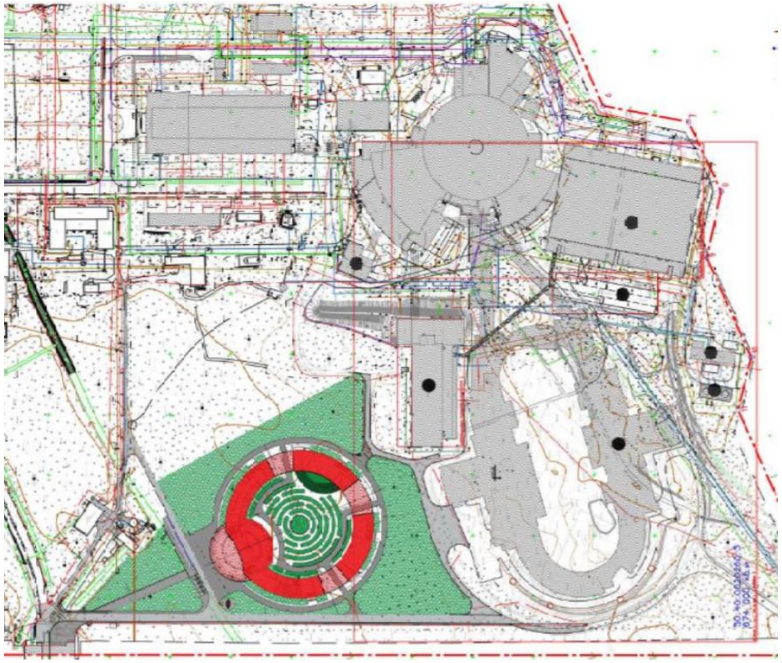
Total power 8 kW at 4.5 K

NICA cryogenic complex

New helium liquefier OG-1000
Put into operation – may 2016

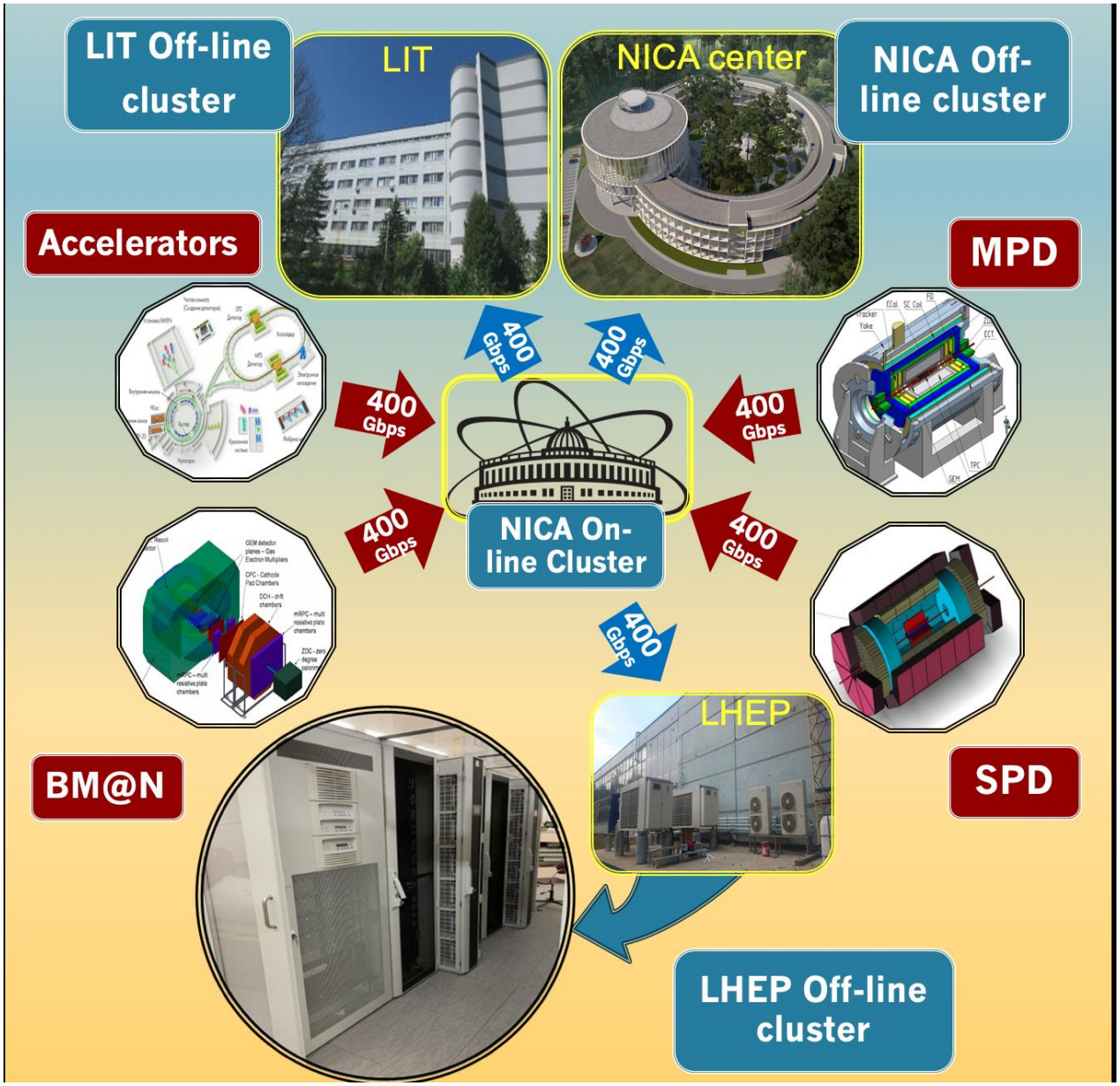
NICA innovation center

NICA innovation center



- cluster of JINR computer center dedicated to collect and process the data from NICA detectors,
- 500 offices for scientists,
- laboratory rooms for preparation of experimental equipment and fast analysis of results,
- conference hall

NICA Network and Computing



LIT

Data storage:

- 2017: 1 PB RAW /year
- plan: 10 PB RAW/year

Fast memory at supercomputer ***«Govorun»***

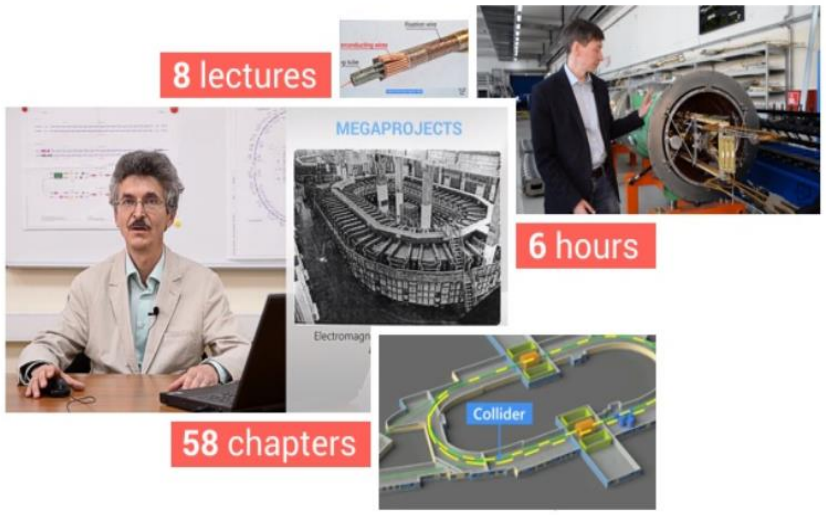
NICA Computing

LHEP off-line cluster -
put into operation
19 September 2019

Education program

JINR educational portal targets students and schoolchildren of the JINR Member States, young specialists and science teachers.
The portal hosts courses in the MOOC format on priority JINR activities.
The first courses have already been created and published:

- on the topics of the NICA megaproject,
- on heavy ions and the synthesis of new elements,
- fundamental and applied research of nanostructures and condensed matter using neutrons.



New video course: Megascience project NICA

We are pleased to present you **the first video course about megascience project NICA and collider technology**! This course consists of 8 sections and talks about scientific mega-projects, particle accelerators at JINR, structure and tasks of the NICA complex, factory of superconducting magnets and cryogenic complex.

The staff of the Veksler and Baldin Laboratory of High Energy Physics (Anatoly Sidorin, Sergey Kostromin, Anton Konstantinov, Sidorov Nikita, Marina Osmachko) and the Development and creation of educational programs department (Anna Komarova, Caren Rossouw, Oleg Smirnov) prepared this online course.

The course is available in both English and Russian.

https://edu.jinr.ru/

NICA milestones

2009
Start of the project
2013
Nuclotron modernization
2015
Technical project completion
2016
Start of the collider building construction
2018
BM@N I
2020
Completion of the Booster commissioning

Plans:

2021
BM@N II
2022
Creation of the collider in starting configuration permitting to provide experiments with colliding ion beams up to Bi^{+83}
at mean luminosity of $L = 5 \cdot 10^{25}$ см$^{-2}$ с$^{-1}$ in the energy range $\sqrt{s_{NN}} = 8 - 11$ GeV/u

Accelerator division

NICA project

A.Sidorin, VBLHEP, JINR, Dubna