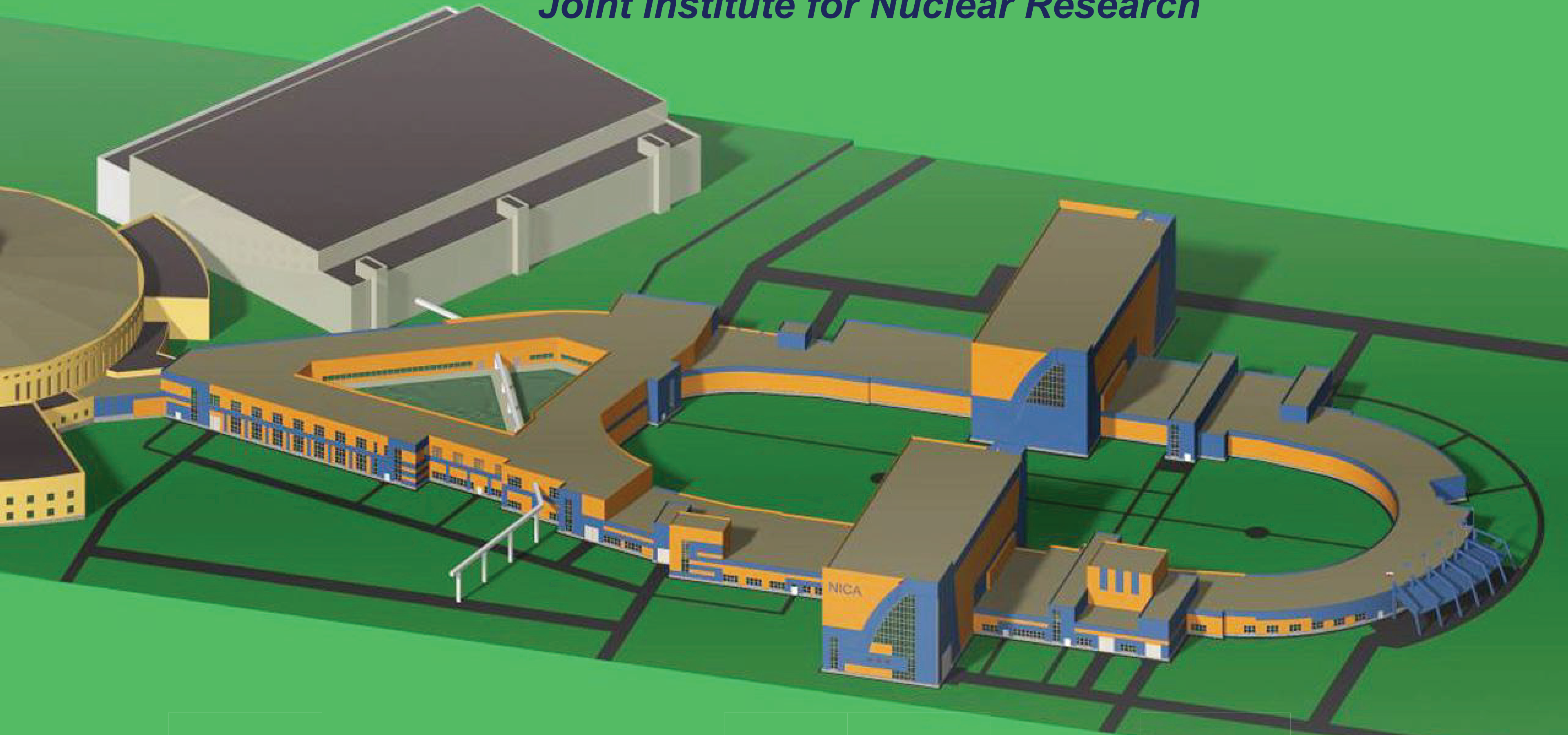
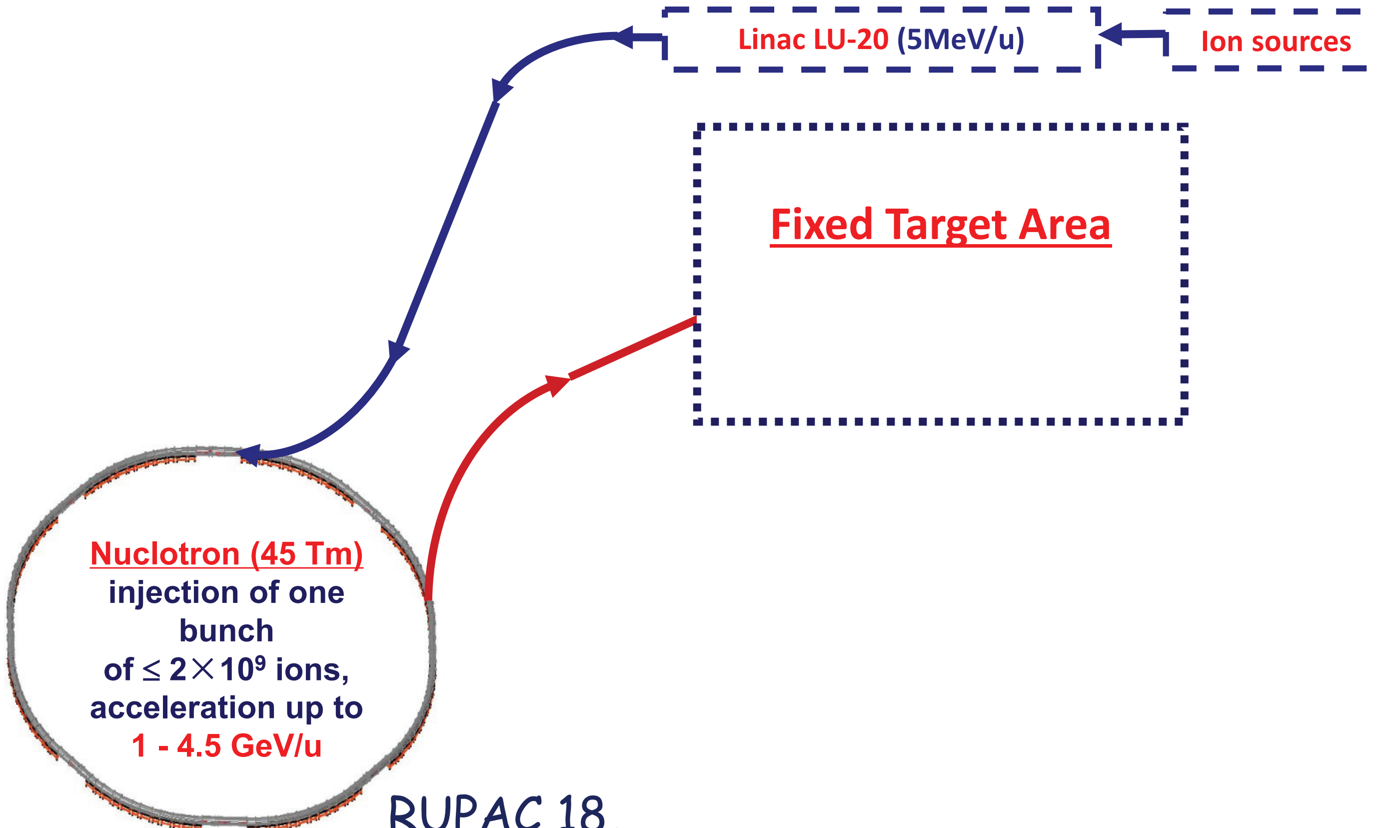
Status of Accelerated Complex NICA

Evgeny Syresin
Veksler and Baldin Laboratory for High Energy Physics
Joint Institute for Nuclear Research



NICA: Nuclotron based Ion Collider fAcility

NICA accelerator complex



RUPAC 18,
A. Martynov
WECAMH06

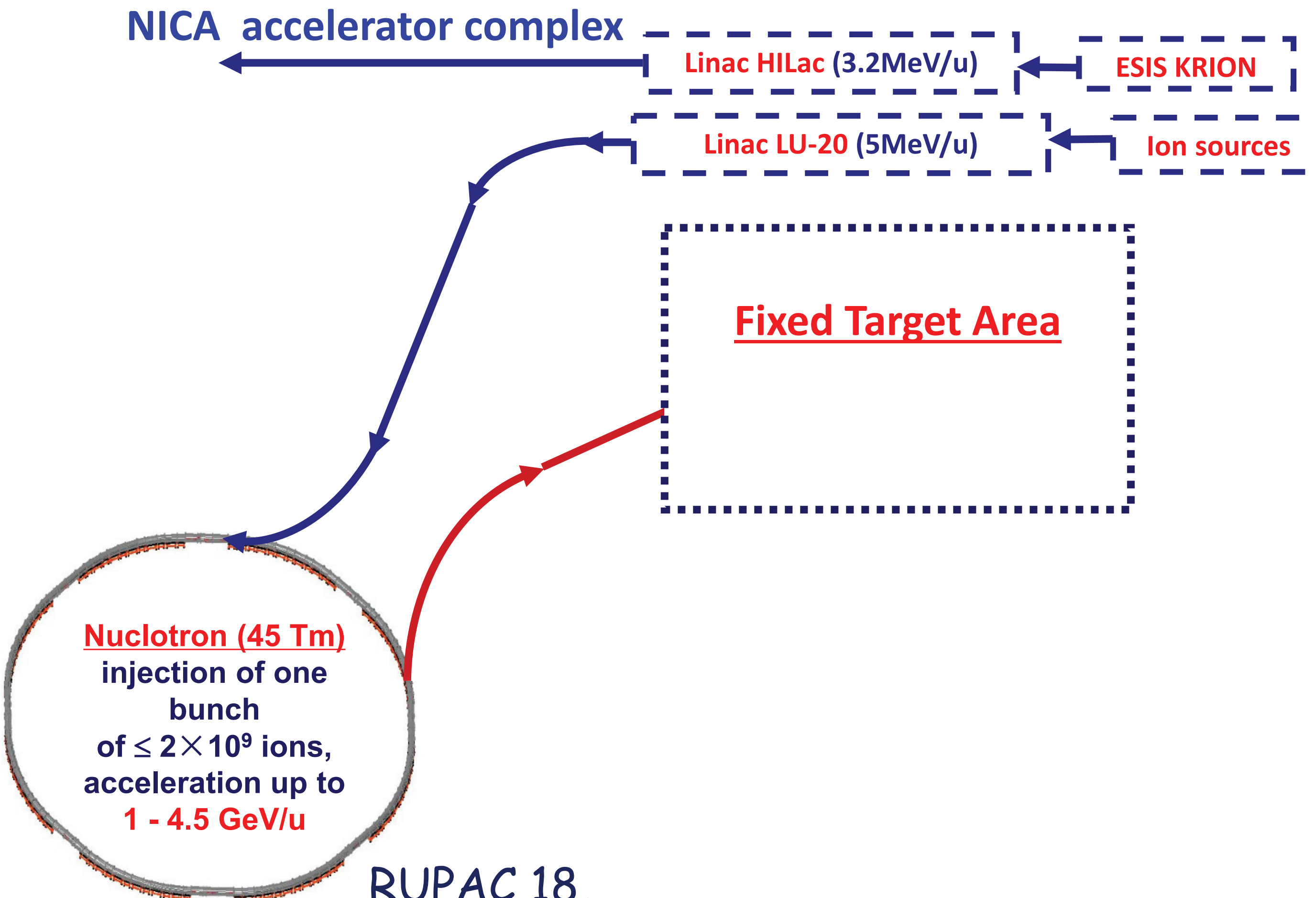
Injector Complex

Heavy ions: ESIS+HILac (Au^{31+} 3.2 MeV/n)+ Booster+Nuclotron

Polarized p↑ and d↑ beams, protons and light ions (z/A>0.3):

SPI (LIS or DP)+ Linac LU-20 (5MeV/n)+ Nuclotron

Construction of new light ion linac (LILAC at 7 MeV/n)+medium energy proton acceleration sections (13 MeV)+ SC sections (20 MeV)



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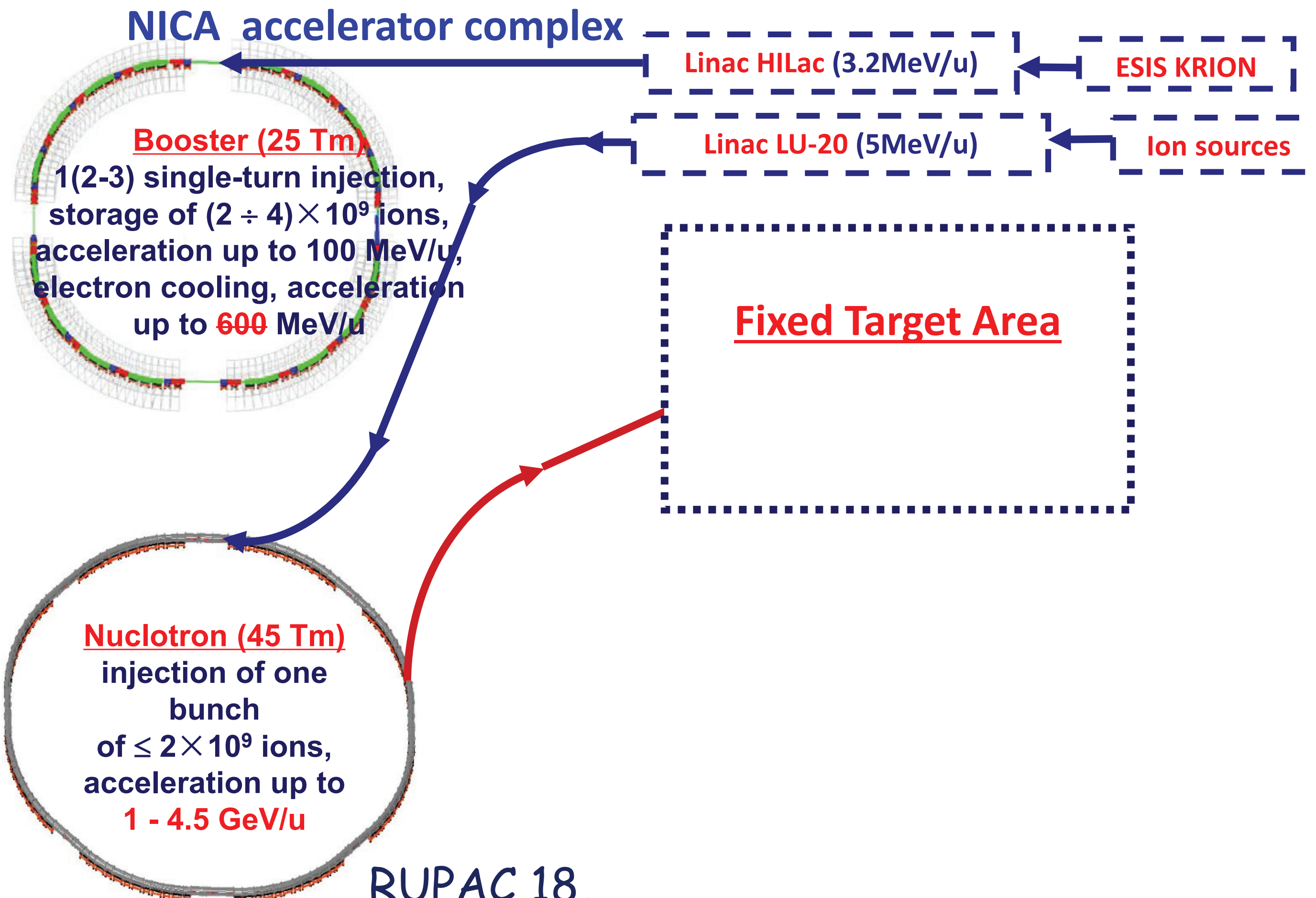

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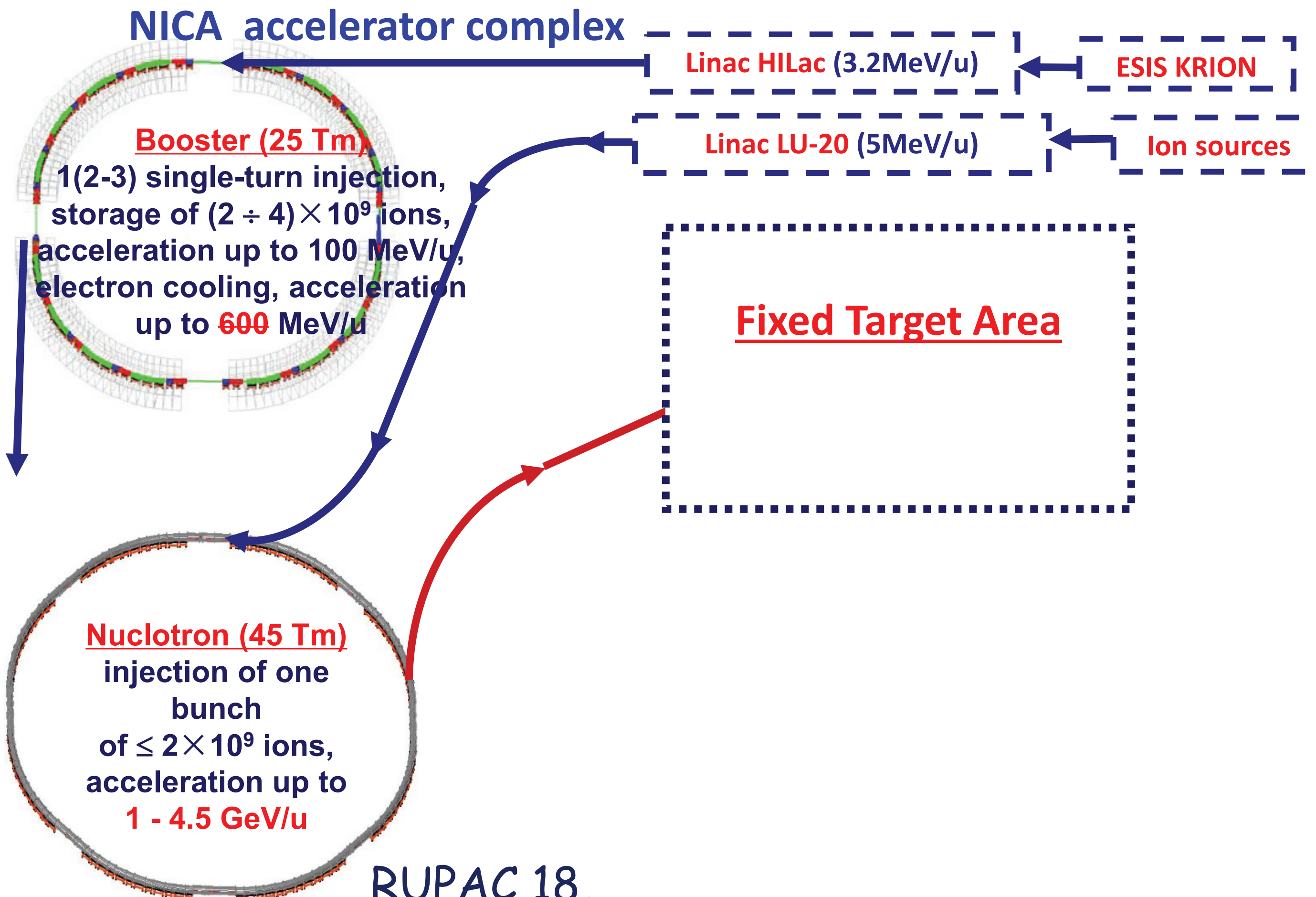

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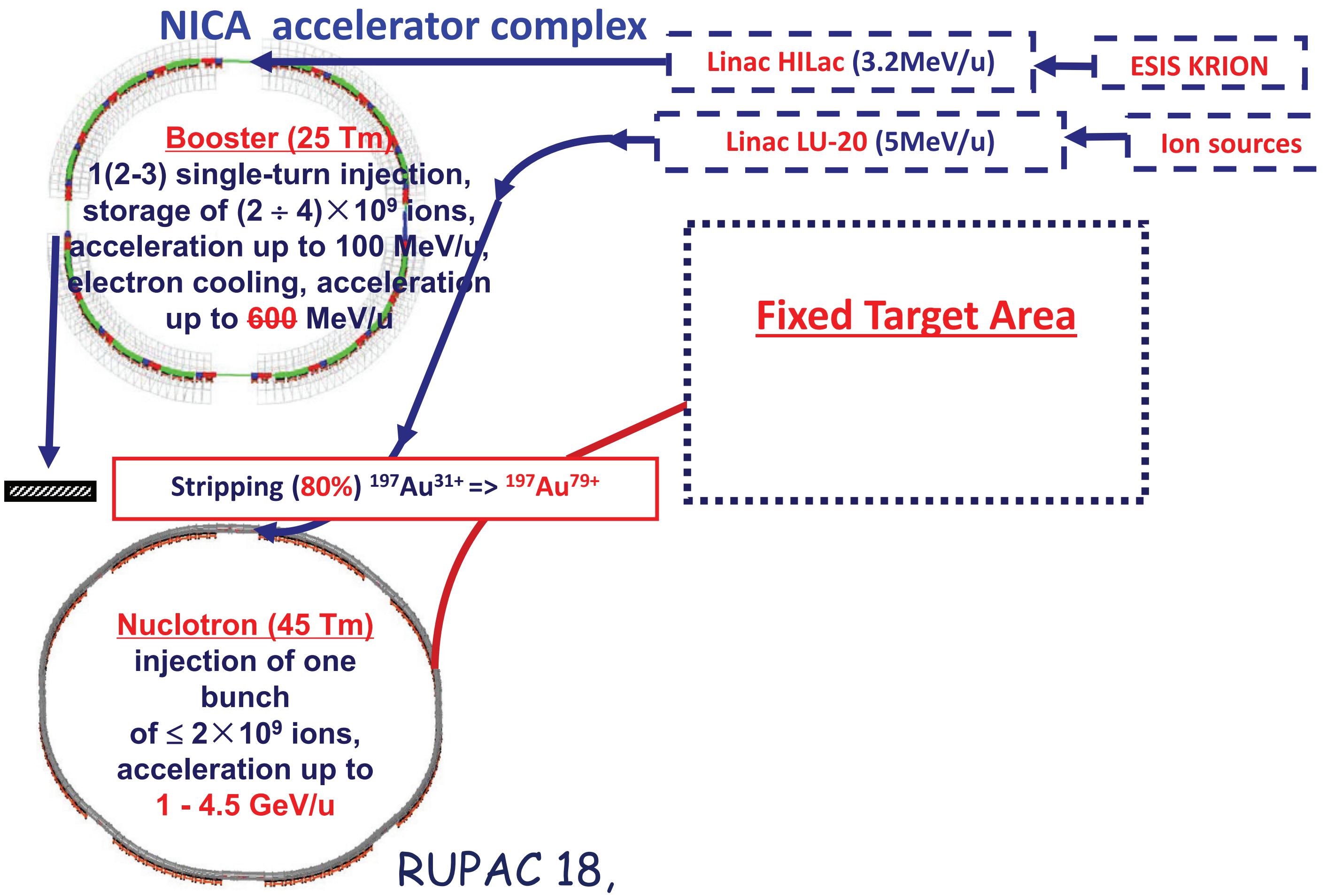

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A. Martynov
WECAMH06

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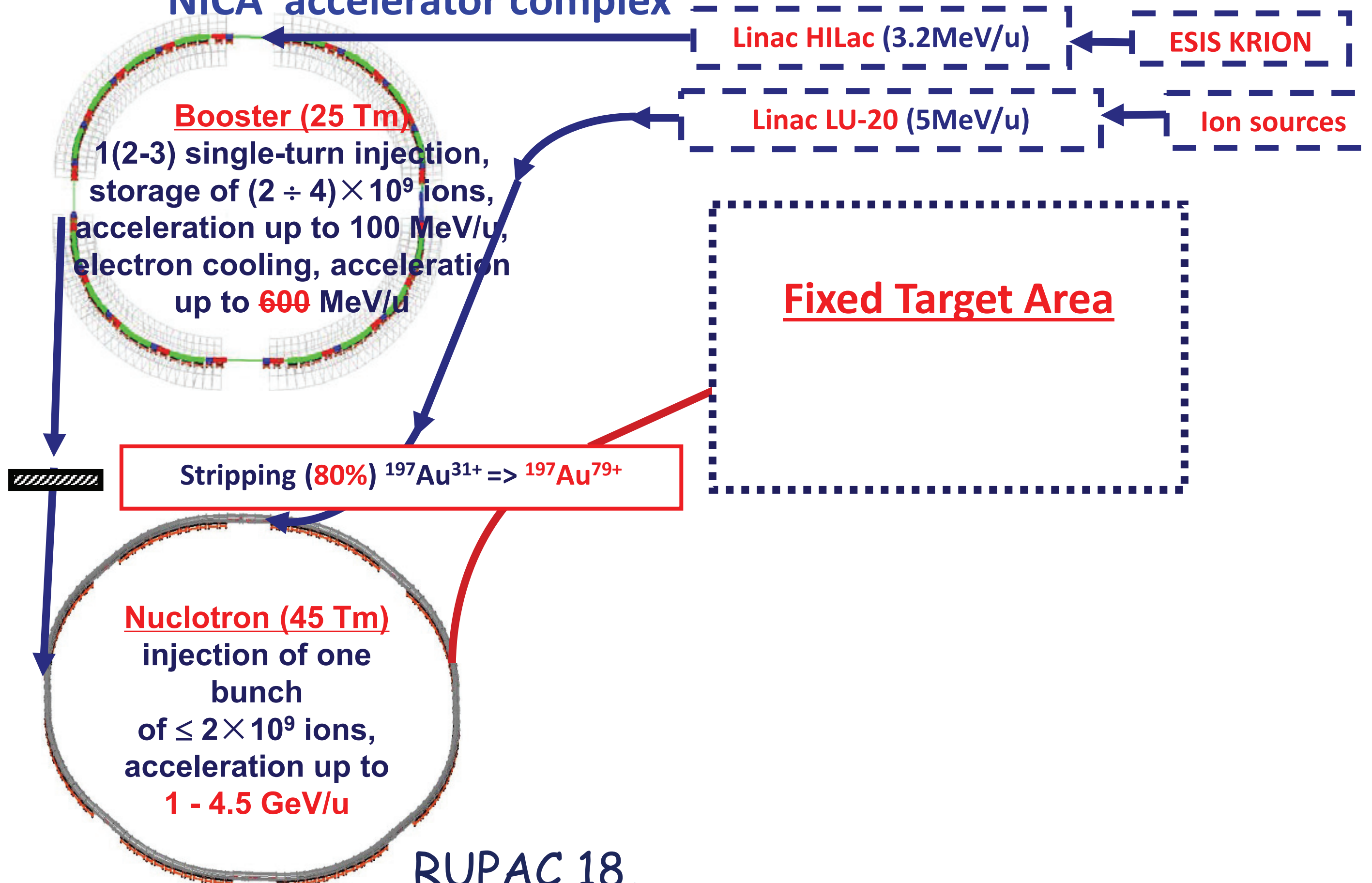

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A. Martynov
WECAMH06

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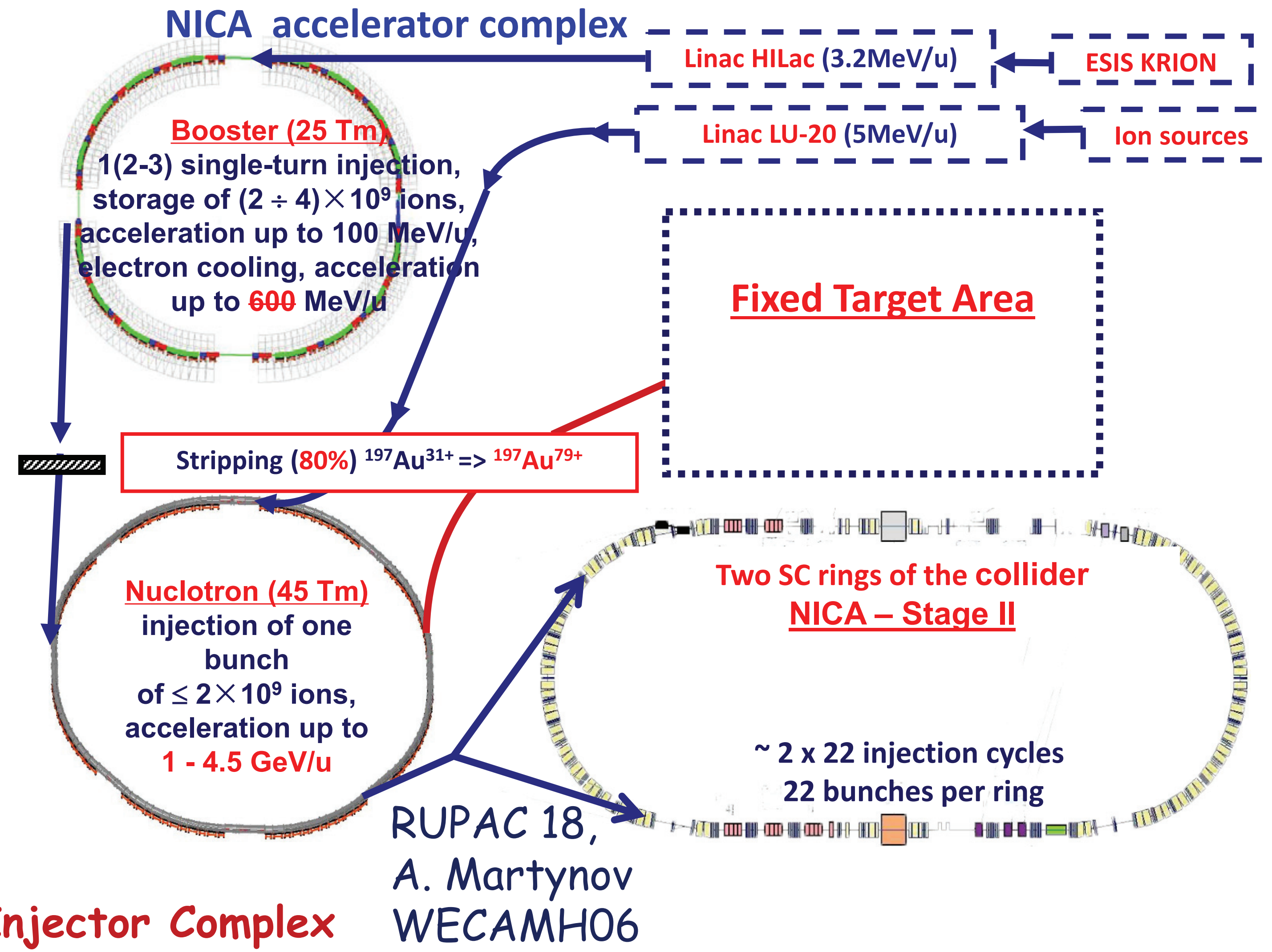

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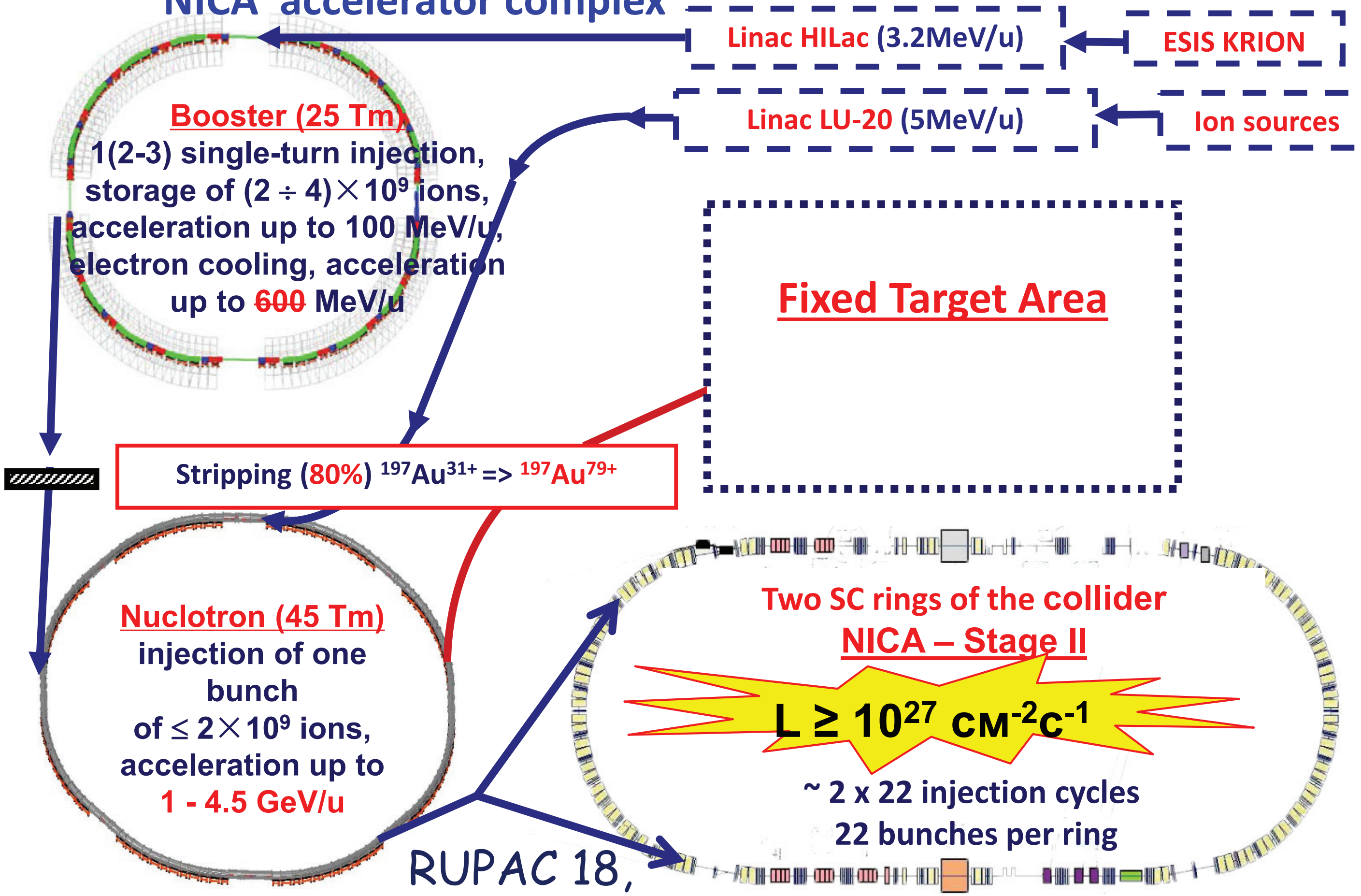

RUPAC 18,
A. Martynov
WECAMH06

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NICA accelerators

Injection chain for heavy ions

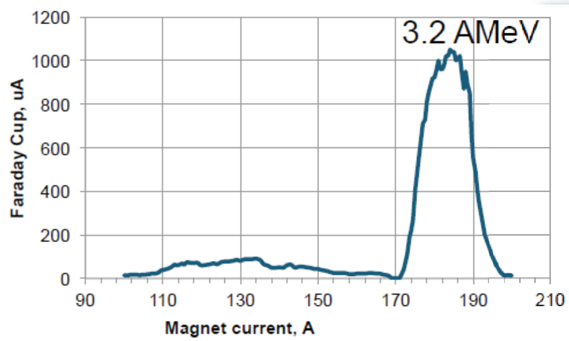
Cryogenic heavy ion source KRION
of Electron String Ion Source (ESIS) type
project up to $1.5 \cdot 10^9$ Au^{31+} particles per cycle
(achived $5 \cdot 10^8$ Au^{31+})
at repetition frequency up to 10 Hz

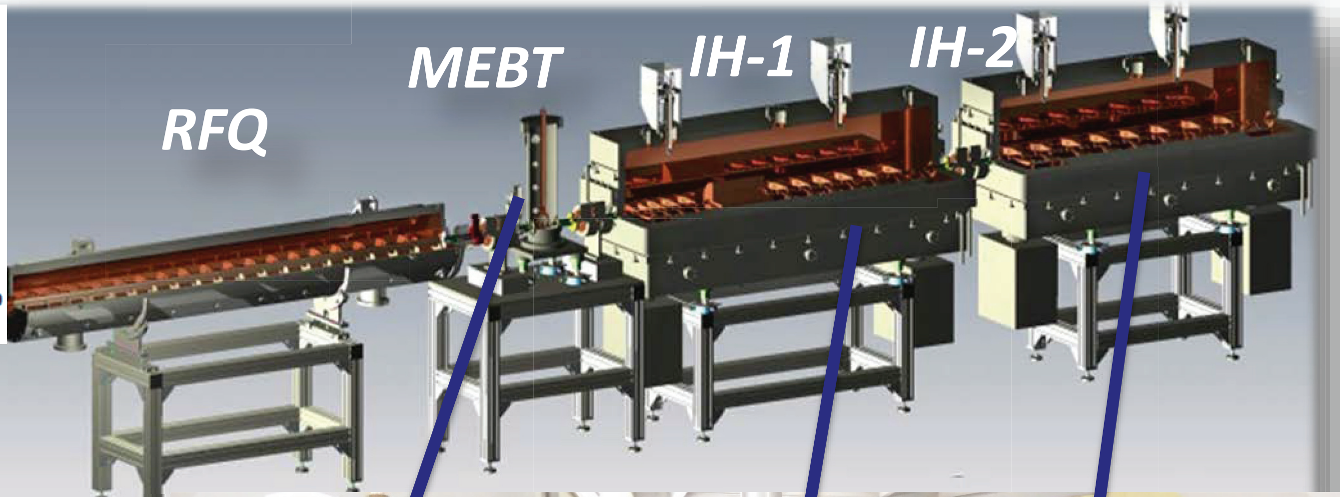
Two runs at Nuclotron (2014, 2018)
ESIS KRION -6T will be used for injection in booster in 2019
New ESIS will be constructed in 2020 for collider experiments

Heavy Ion Linear Accelerator HILAc

high current (10 mA), the first Linac with transistor RF amplifier

Design and fabrication by “BEVATECH OHG” Germany, Offenbach/Mainz



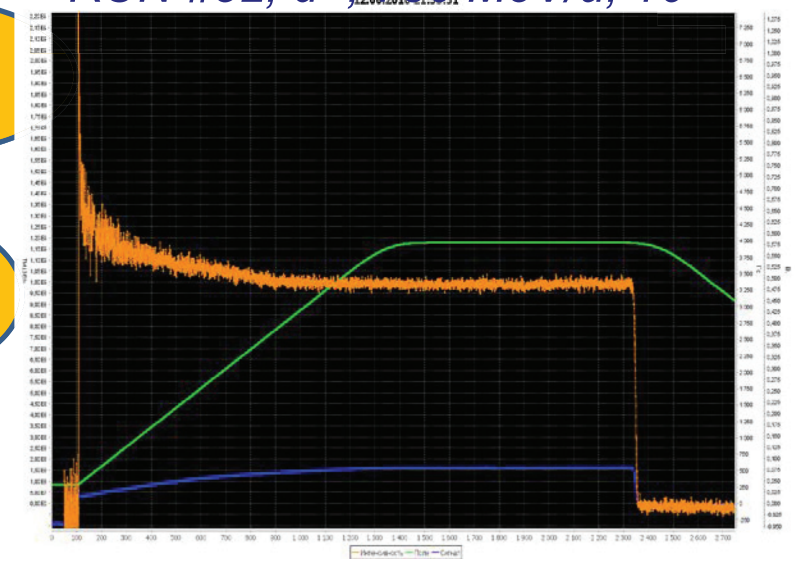


overall commissioning: Oct. 16

NICA accelerators

Injection chain for light ions

RUN #52, d+, 750 MeV/u, 10^9



New fore-injector with buncher for LU-20 + SPI

JINR, INR, ITEP, MEPHI,
Resonator is fabricated in Sneshinsk

- **May '16 – beam is accelerated in LU-20**
- **June '16 – the deuteron beam from SPI is accelerated in the Nuclotron ring**

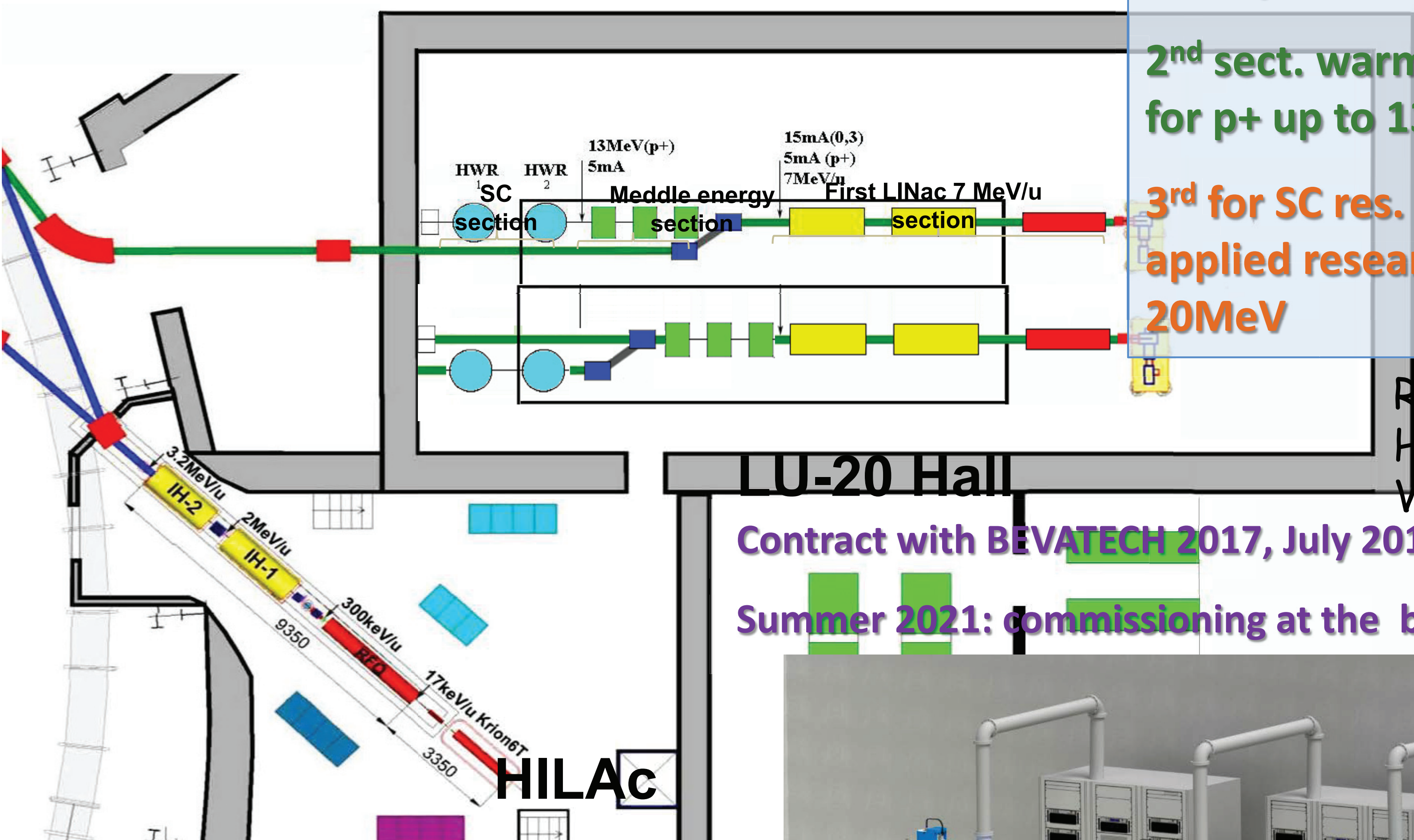
New Light Ion Linac "*LILAc*" Injector for the Nuclotron

New linac – 3 sections:

1st sect. from BEVATECH 7MeV/u for ions Z/A>1/3

2nd sect. warm resonators for p+ up to 13 MeV

3rd for SC res. testing & applied research up to 20MeV



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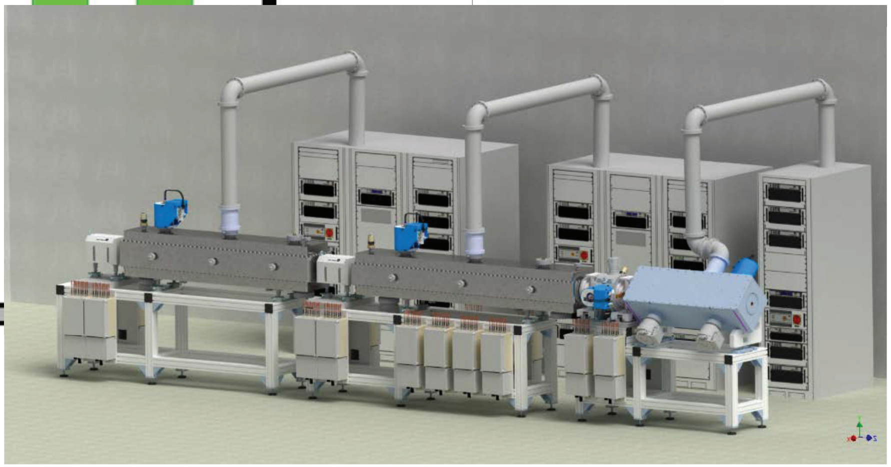
H. Hoeltermann
WECAMH02

Contract with BEVATECH 2017, July 2018: TDR

Summer 2021: commissioning at the beam tests



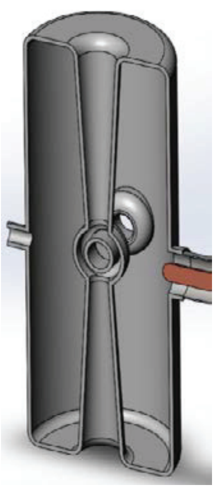
SC resonators for the "LILAc"

QWR & HWR is under design and construction

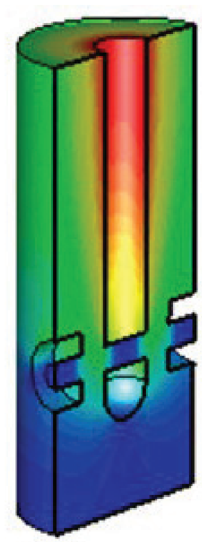
RUPAC 18,
S. Polozov
WECBMH01

JINR, MEPhI, PhTI NANB, BSTU

The simplest design with cylindrical central conductor was chosen.
For QWR: ED, thermal and mechanical design was done.
The sat-file was prepared and sent to PTI NANB for copper model design and construction.



HWR



QWR

T = 4.5 K
***F*=162.5 MHz**
β_G=0.12
E_{acc}=6.0 MV/m
ER_{sh}/Q_0=488.0 Ohm,
$G= R_{sh}\cdot Q_0$=37.0 Ohm,
***T*=88.0 %.**

3D model for copper prototype manufacturing (RF and measurement loops are not visible)

Two HWR will be delivered in JINR in 2020 From PhTI NANB

HILAC-Booster beam transport channel

Composition

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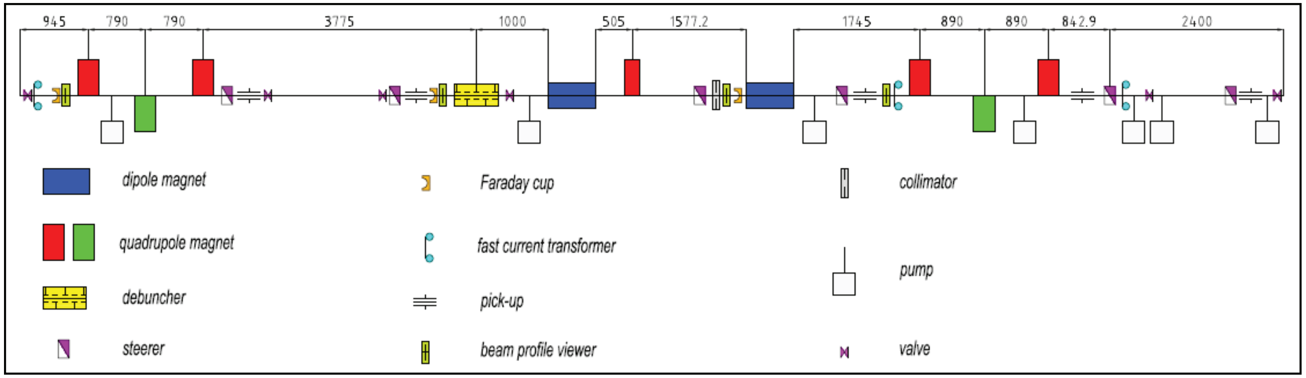
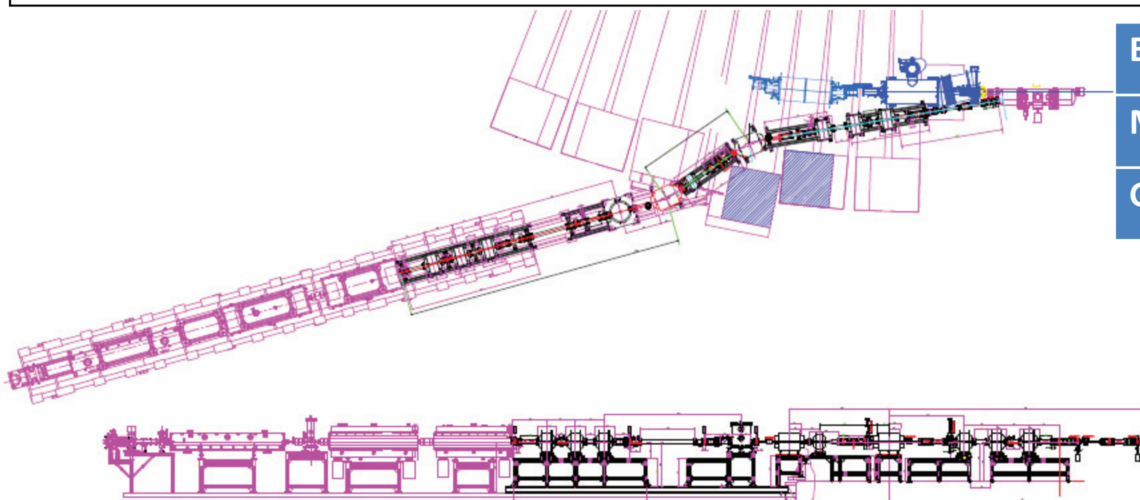
A. Tuzikov
TUCDMH01



Effective length, m	0.65
Max field, T	1
Gap, mm	45



Effective length, m	0.29 / 0.21
Max gradient, T/m	10 / 19
Gap (diameter), mm	95 / 71

Assembling – 2018.

NICA accelerators

Injection chain for heavy ions

The Booster should accelerate ions up to 600 MeV/u (for ions with *Z*/*A* = 1/6).
The magnetic ring of 211 m long is placed inside the window of the Synchrophasotron yoke.

Fabrication of the magnetic system is completed.

Start of assembly – September 2018.

First (technological) run – beginning of 2019.

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Start of assembly – September 2018.

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Line for assembling and cryogenic testing of SC-magnets

RUPAC 18,
D. Nikiforov
WECBMH04

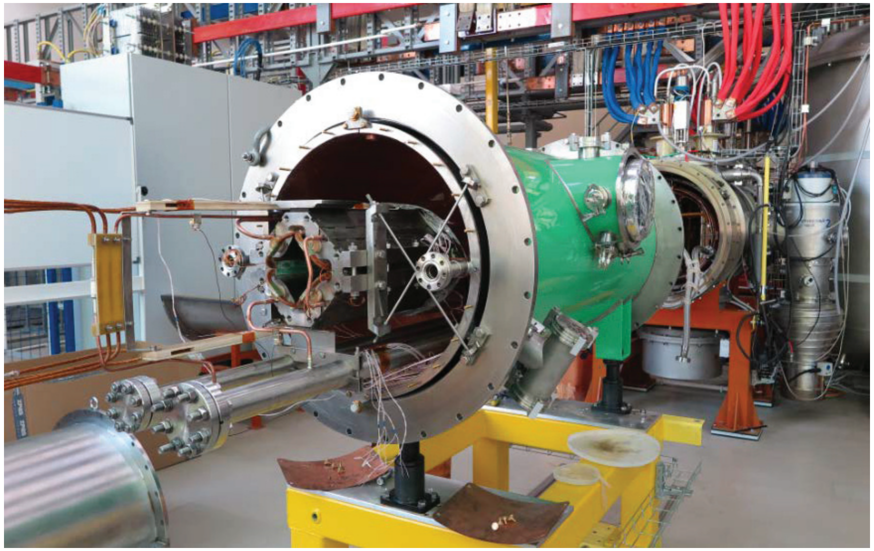
Main production areas:

- 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

Testing of SC-magnet's for NICA booster

Parameter	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



Completely manufactured: all cryostats of magnets

Successfully passed cryogenic and magnetic tests and certified for installation in the Booster

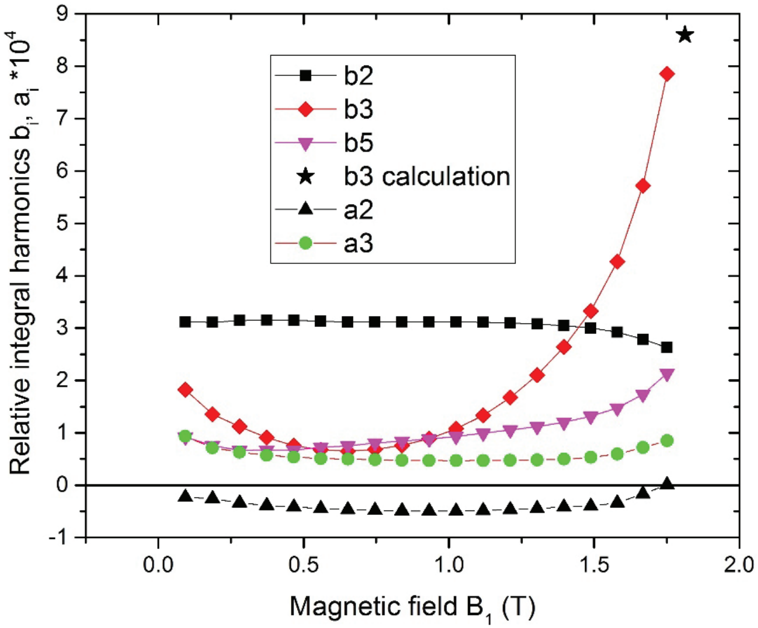
40 dipole magnets (100%)

34 lens (70%)

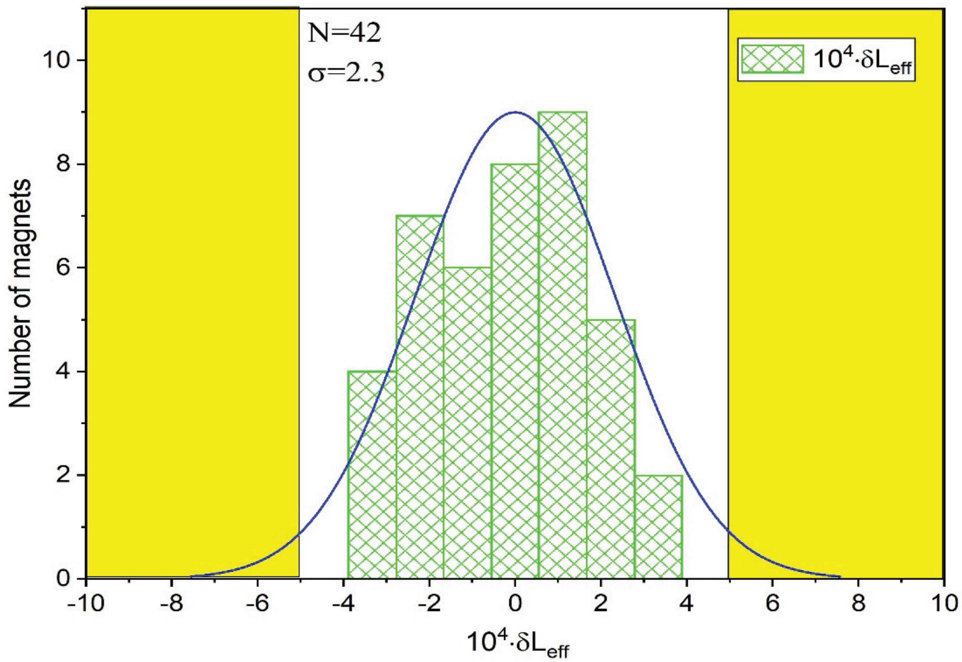
Cryogenic Test Results

RUPAC 18,
V. Borisov
WECBMH02

Magnetic measurements have good repeatability and their magnitude is within the permissible values



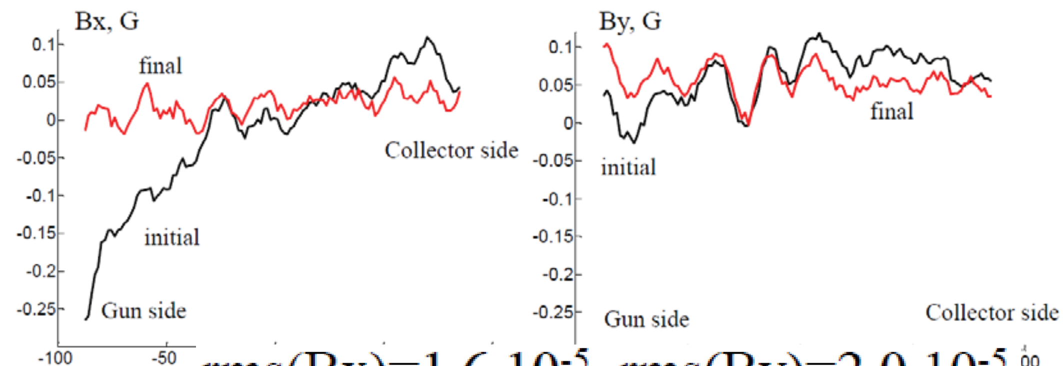
Relative integral harmonics of the magnetic field in the aperture of the NICA booster magnet at the radius of 30 mm as a function of the magnetic field in the magnet center.



Distribution of effective lengths of the booster dipole magnets relative variations for maximum RSD.

Electron cooling system commissioning

Designed, fabricated by BINP and commissioning in booster 2017 by JINR and BINP Teams



rms(Bx)=$1.6\cdot10^{-5}$, rms(By)=$2.0\cdot10^{-5}$

Vacuum pressure, Pa	3×10^{-9}

Beam test at 17 June 2018

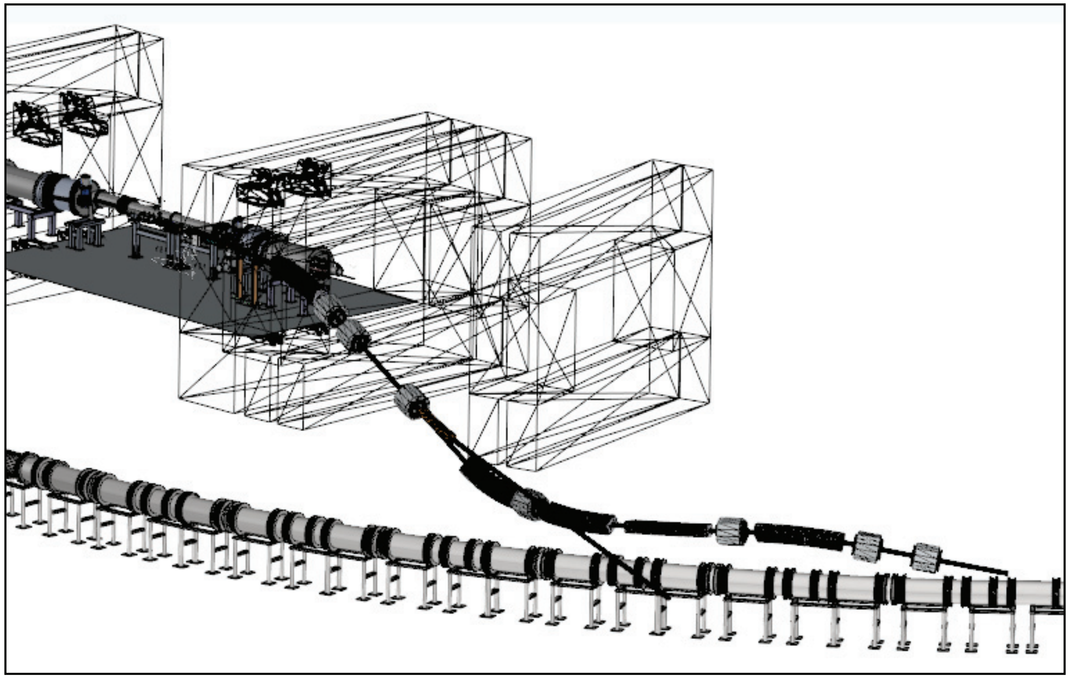
Electron energy – 5 keV,

Beam current -300 mA.

Booster-Nuclotron beam transport channel

- The beam transport with minimal ion losses.
- Separation of neighbor charge states. Estimates of ion stripping at energy of 580 MeV/u: 100% Au^{31+} → 80% Au^{79+}, ~20% Au^{78+}. Due to high intensity of Au^{78+} ions they have to be extracted to an absorber.

RUPAC 18,
A. Tuzikov
TUCDMH01

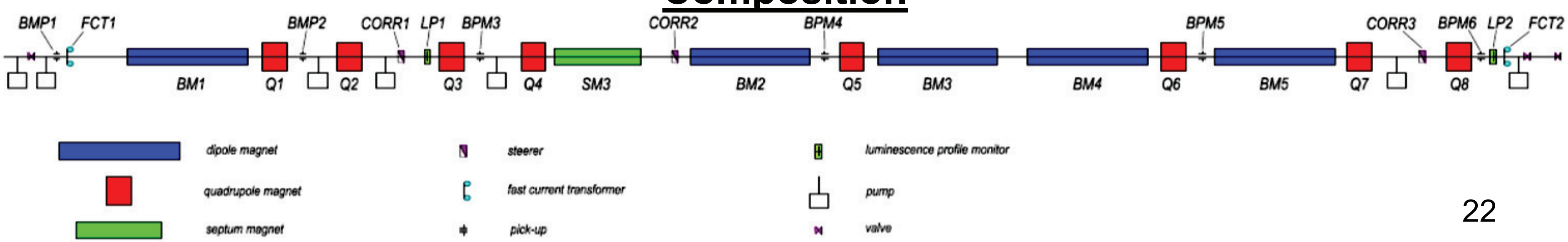


3D model

BINP fabrication

Commisioning in JINR November 2019

Composition

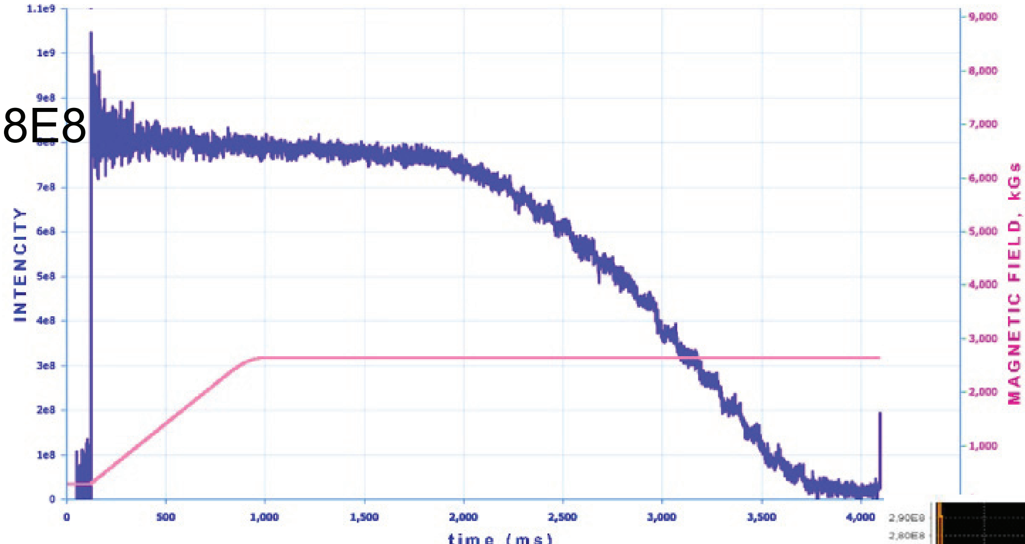


Nuclotron: polarized deuterons and protons

Routine operation of SPI and new fore-injector

Polarized deuteron acceleration: Intensity up to 2*10^9 per cycle

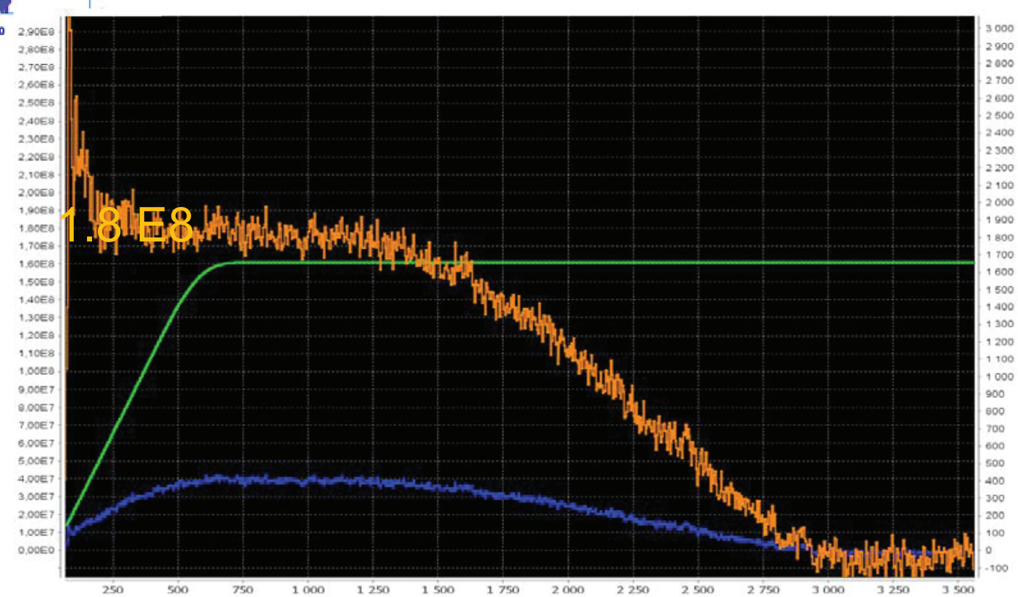
RUPAC 18,
A. Sidorin



Deuteron Spin Structure experiment, internal target

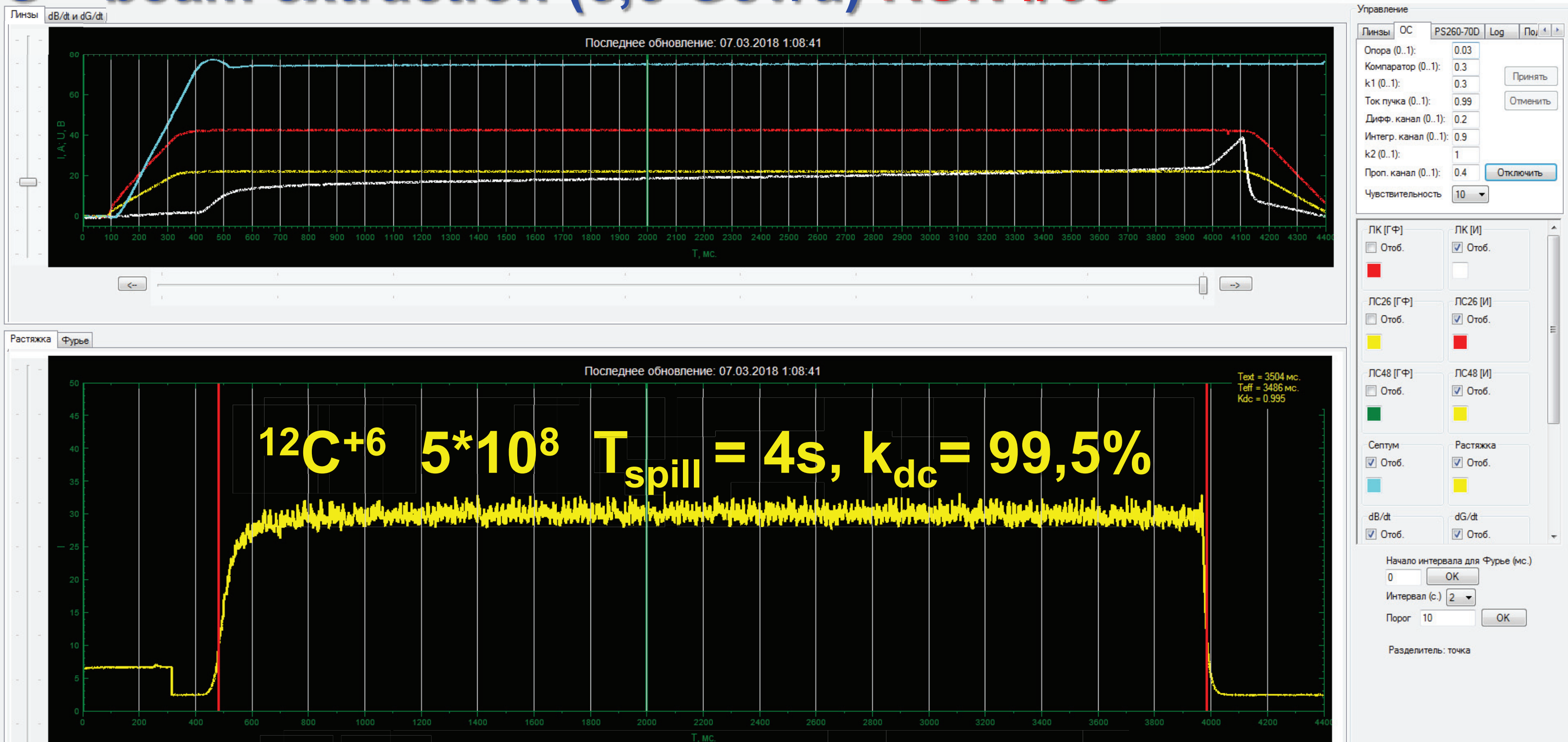
Nuclotron in operation since 1993

Polarized protons

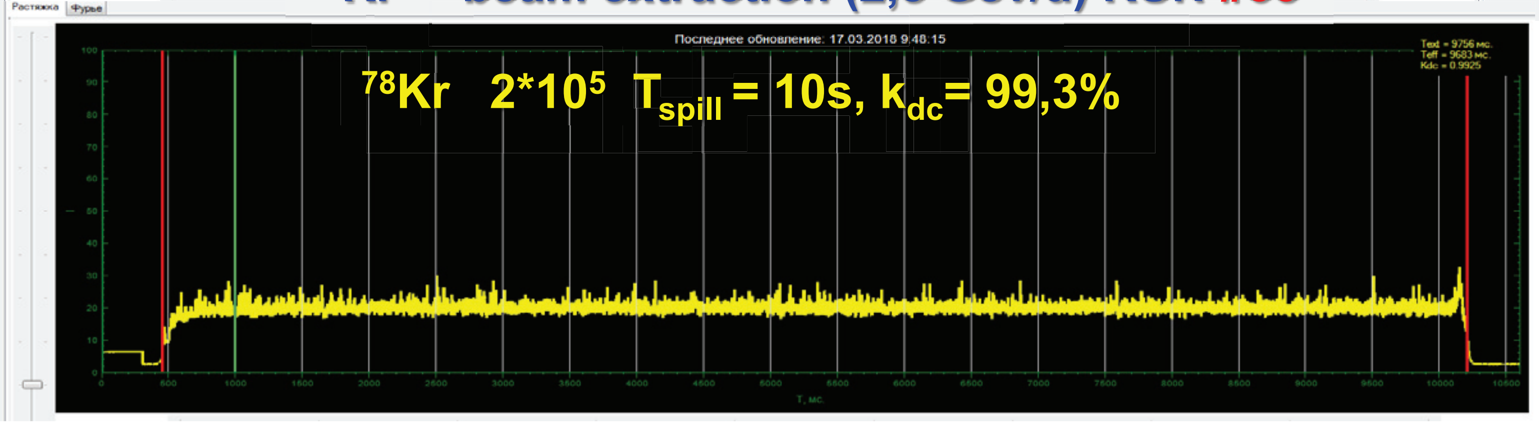


Nuclotron: slow extraction

$^{12}C^{+6}$ beam extraction (3,5 Gev/u) RUN #55



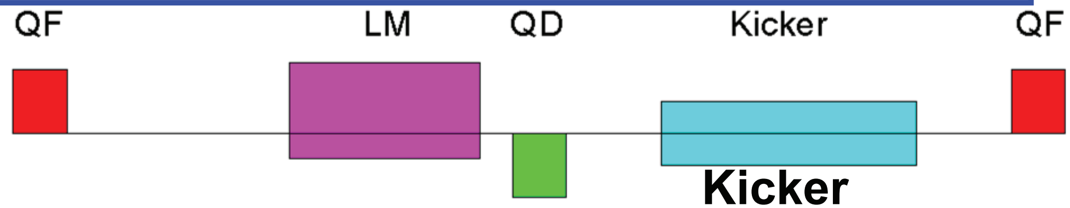
$^{78}Kr^{+26}$ beam extraction (2,8 Gev/u) RUN #55



Status of the Nuclotron 2018

Parameter	Project	Status (June 2018)
Max. magn. field, T	2	2 (1.7 T routine)
B-field ramp, T/s	1	0.8 (0.7 routine)
Accelerated particles	p–U, d↑	p↑, d↑, p – Xe
Max. energy, GeV/u	12 (p), 5.8 (d) 4.5($^{197}Au^{79+}$)	5.6 (d, ^{12}C), 3.6 ($^{40}Ar^{16+}$)
Intensity, ions/cycle	1E11(p,d), 2E9 (A > 100)	d $4*10^{10}$ ($2*10^{10}$ routine), $^{7}Li^{3+}$ $3*10^{9}$ $^{12}C^{6+}$ $2*10^{9}$ $^{40}Ar^{16+}$ $1*10^{6}$ $^{78}Kr^{26+}$ $2*10^{5}$ $^{124}Xe^{42+}$ $1*10^{4}$

Nuclotron high energy beam injection system

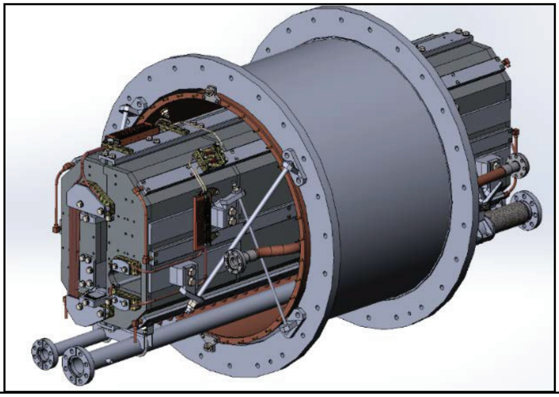


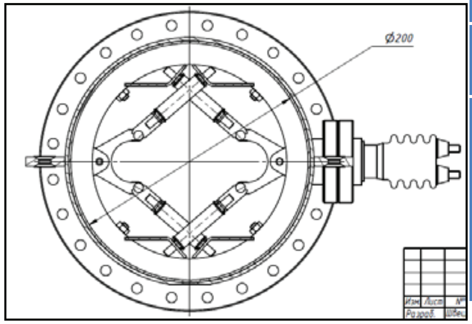
Lambertson magnet

Length, m	1.5
Max magnetic field, T	1
Septum thickness, mm	7
Power supply	DC

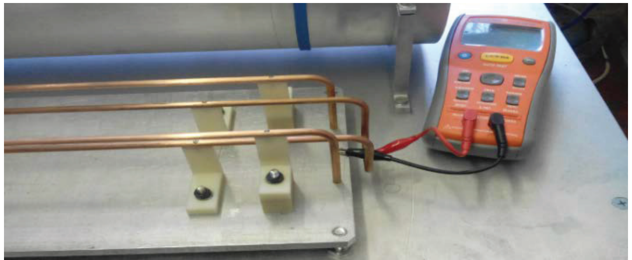
Kicker

Length, m	2
Max magnetic field, T	0.1
Max current, kA	15
Aperture, mm×mm	86 × 44
Pulse duration, μs:	
rise	free
plateau	≥ 0.5
fall	≤ 0.5

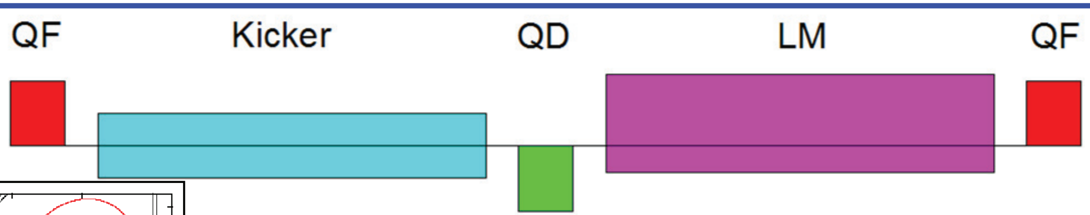


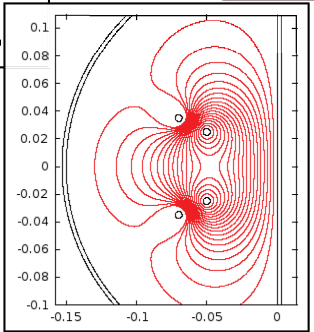


- Lambertson magnets are based on existing spare yokes for slow extraction system of Nuclotron.
- Concept has been developed.



Nuclotron fast extraction system





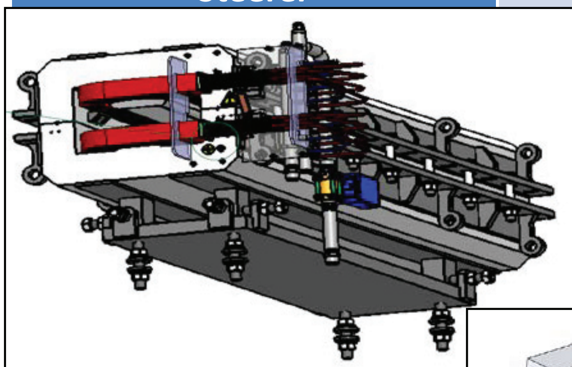
- Design of a cold kickers is in progress.
- Warm prototype for mechanical tests has been manufactured.

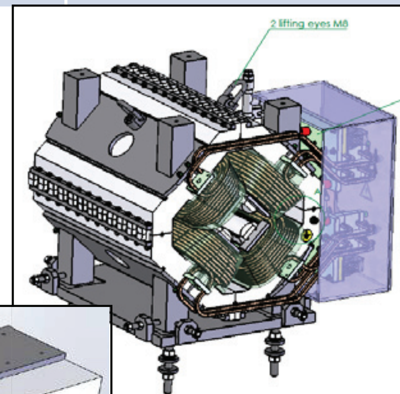
Nuclotron-Collider beam transport channel

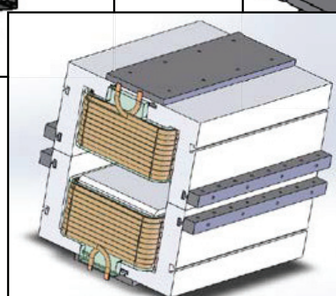
RUPAC 18,
A. Tuzikov
TUCDMHO

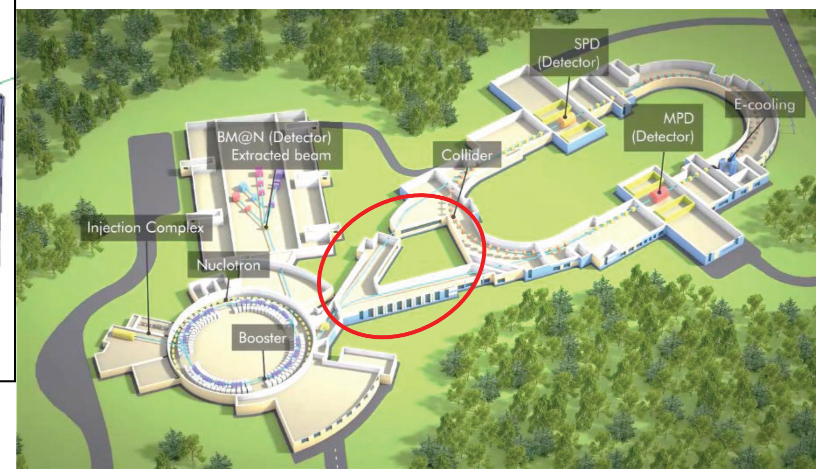
Parameters of pulsed magnet elements

Magnetic element	Number	Effective length, m	Max. magnetic field (gradient), T (T/m)
Long dipole	21	2	1.5
Short dipole	6	1.2	1.5
Quadrupole Q10	22	0.353	31
Quadrupole Q15	6	0.519	31
Steerer	33	0.466	0.114









Magnets of the Nuclotron-Collider channel are in development by SigmaPhi.

Start of channel commissioning – Summer 2019

NICA accelerators

Collider

The Collider ring 503.04 m long has a racetrack shape and is based on double-aperture (top-to-bottom) superconducting magnets at maximum dipole field 1.8 T;

The major parameters of the NICA Collider are the following:
- magnetic rigidity = 45 T·m;
-ion kinetic energy range from 1 GeV/u to 4.5 GeV/u for Au^{79+};
-energy of polarized deuterons is 6 GeV/u, protons – 12 GeV,

- vacuum in a beam chamber: 10^{-11} Torr;
- zero beam crossing angle at IP;
- 9 m space for detector allocations at IP's;

Average luminosity 10^{27} $cm^{-2}\cdot s^{-1}$ for gold ion collisions at $\sqrt{s_{NN}} = 9$ GeV.
The luminosity in the polarized mode is up to 10^{32} $cm^{-2}\cdot s^{-1}$.

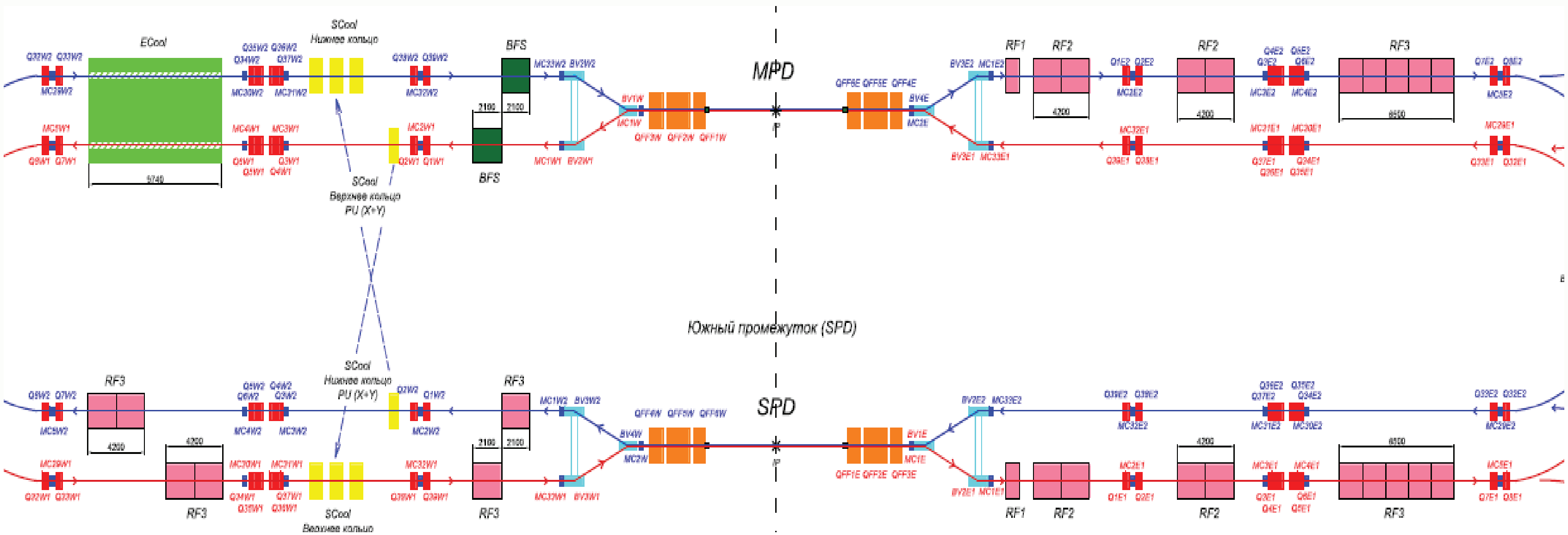
Commissioning – 2019-2020
First technological run-2021

NICA Stage II-a (basic configuration):

1. Injector chain: KRION => Booster => BTL BN => Nuclotron
2. BTL Nuclotron => Collider
3. Collider equipped with

- RF-1 (barrier voltage system) for ion storage
- RF-2 in a reduced version: 2 cavities per ring instead 4 (50 kV RF amplitude instead 100 kV)
- 1 channel of S-cooling per ring (cooling of longitudinal deg. of freedom)

Result: 22 bunches of the length $\sigma \sim 2$ m per collider ring that 5e25 $cm^{-2} \cdot s^{-1}$.



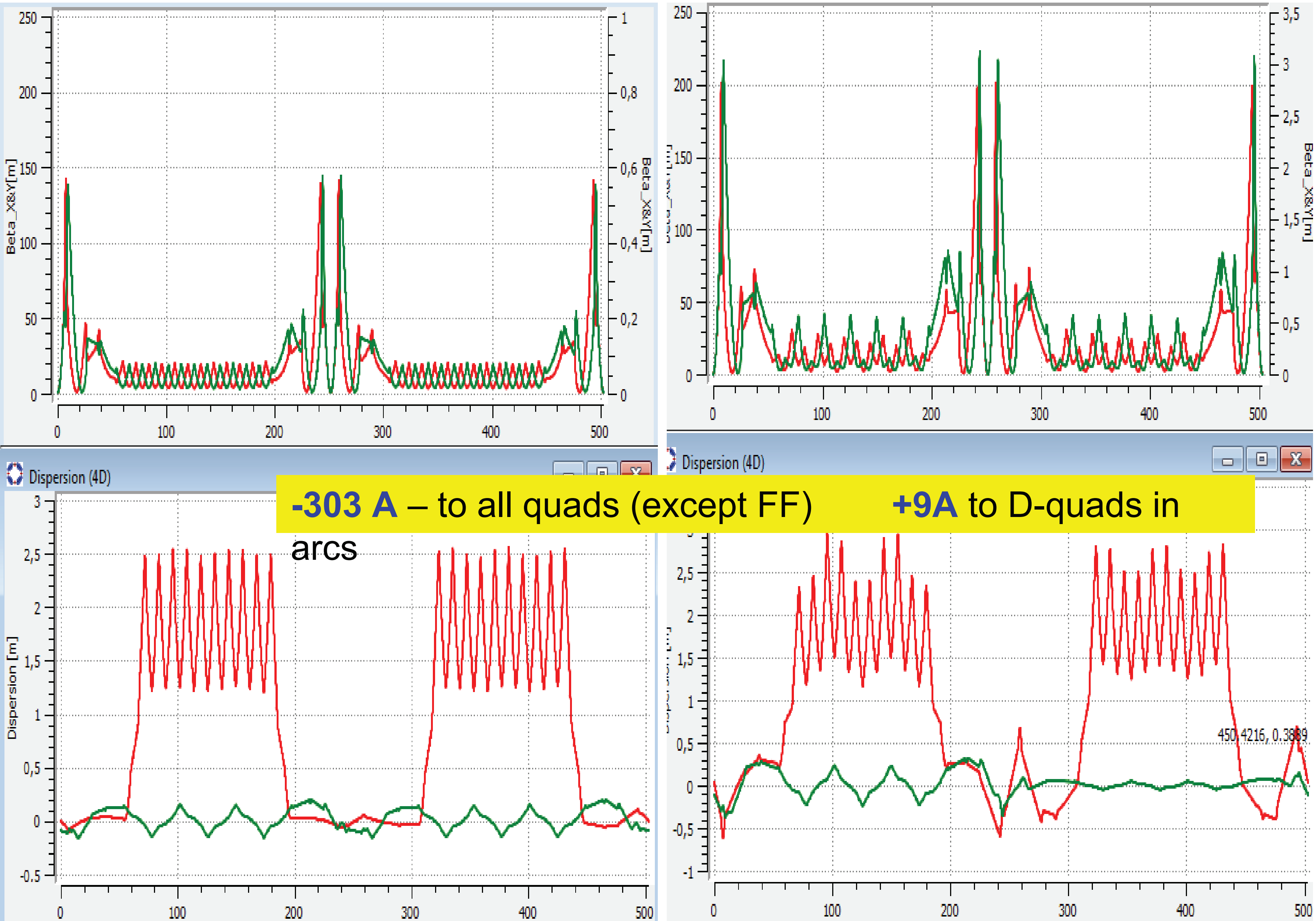
NICA Stage II-b (full configuration):

Collider

+ RF-2 systems in the project version
+ RF-3 systems in the project version
+ S-cooling (transverse)
+ E-cooling

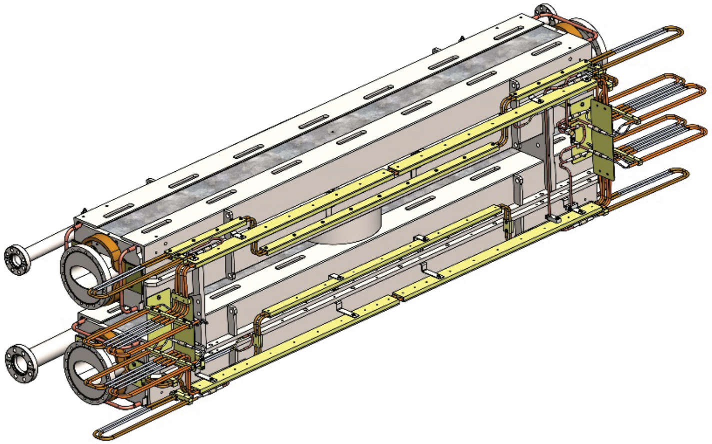
Result: 22 bunches of the length $\sigma \sim 0.6$ m per collider ring that 1e27 $cm^{-2} \cdot s^{-1}$.

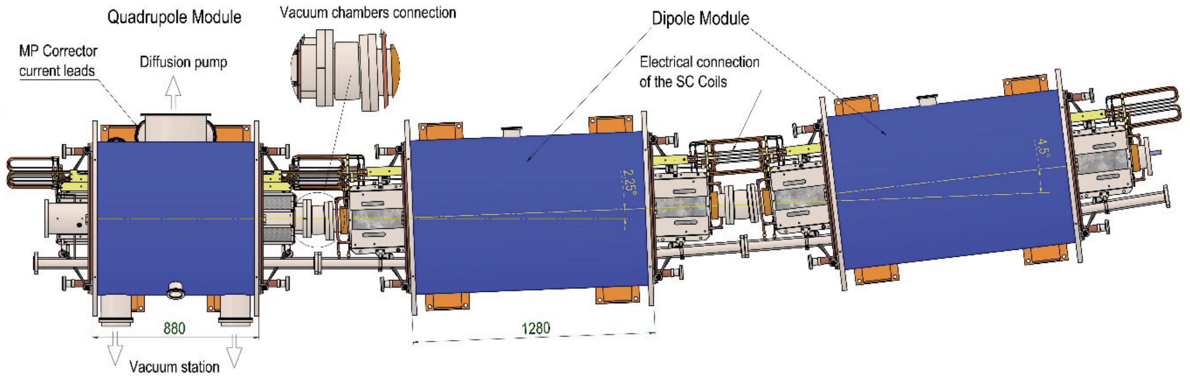
❑ **Optics** 9.44 → 9.10 Ring tune



-303 A – to all quads (except FF) **+9A** to D-quads in arcs

Joining of the magnets

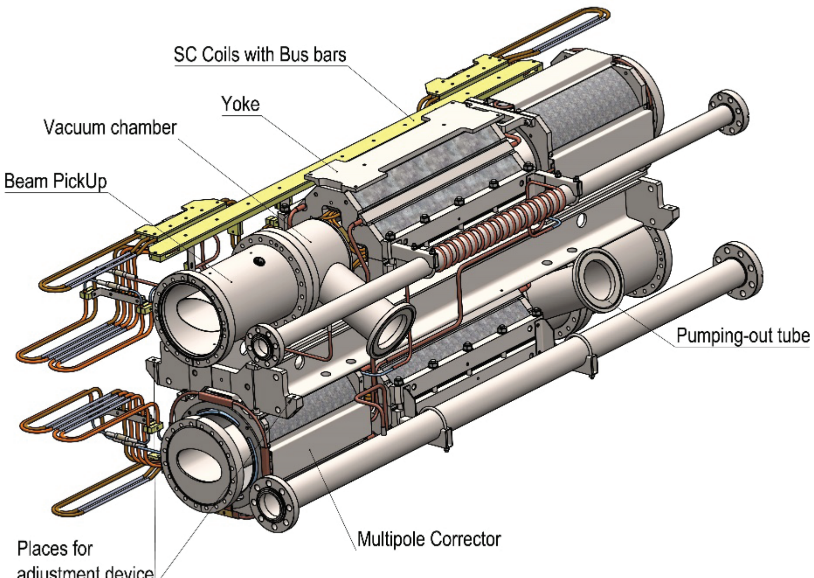




Parameter	Dipole	Lens
Number of magnets	80+8*	86+12**
Max. magnetic field (gradient)	1.8 T	23.1 T/m
Effective magnetic length	1.94 m	0.47 m
Beam pipe aperture (h/v)	120 mm / 70 mm	
Distance between beams	320 mm	
Overall weight	1670 kg	240 kg

*- the magnets for the vertical movement of the beams

**- the final focus lens.



Construction of magnets and doublet lenses 2018-2020

Commissioning –end of 2020.

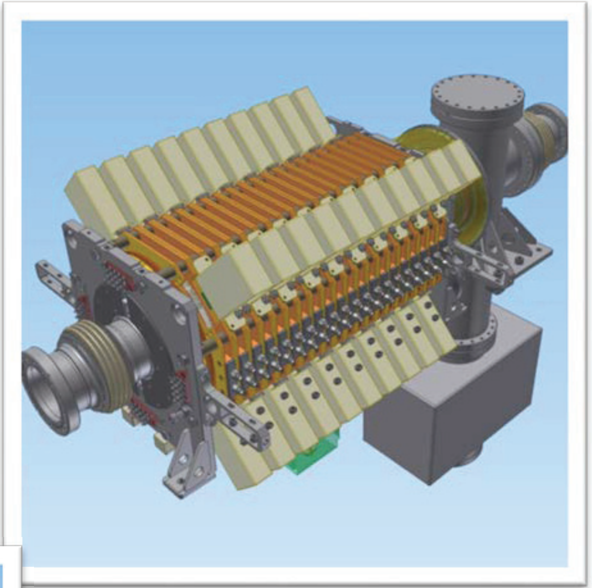
NICA Magnets Production Status

Work	num ber	% perfor med works.
External JINR production		
Yoke of dipole magnet	80+1	25%
Yoke of quadrupole lens	86+1	10%
Yoke of corrector	124	5%
Yoke of vertical dipole magnet	8	11%
Yoke of final focus lens	12	12%
Vacuum chamber of dipole	160	25%
Vacuum chamber of lens	172	10%
Chamber with PU	86	2%
Vacuum cryostats of dipoles	80+1	60%
Vacuum cryostats of lenses	86+1	20%
Cryostat of cryogenic bypass	4	2%
Cryostat of measured period	2	0%
Devided and corner cryostats	336	0%
Bellow cryostat compensators	350	100%
Suports of dipoles/doublet lenses	81/87	48%

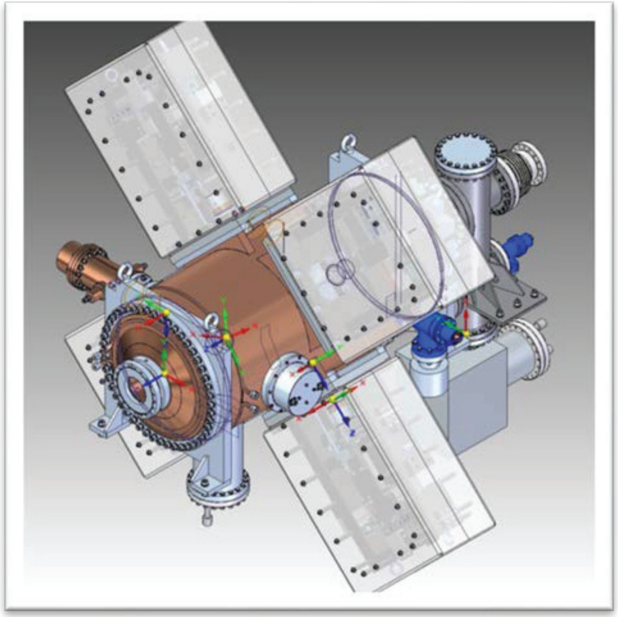
Work	Num ber	%
Internal JINR productionИзготовление в ЛФВЭ		
SC coil of dipole magnet	80+1	10%
SC coil of quadrupole lens	86+1	5%
Coil of multipole corrector	124	0%
Coil of final focus lens	12	10%
Coil of vertical dipole magnet	8	10%
Thermal screen of dipole	80+1	15%
Thermal screen of lens	86+1	10%
Thermal screen of gap between magnets	41	0%
Thermal screen between dipole and lens	80+1	0%
Thermal screens of cryogenic bypass	2	0%
Thermal sceens of measured period	2	0%
Counter of cryogenic temperature	900	70%

Construction by BINP of RF stations

RF system for basic configuration is under construction at BINP – 2020
RF system for project configuration is under development at BINP – 2021



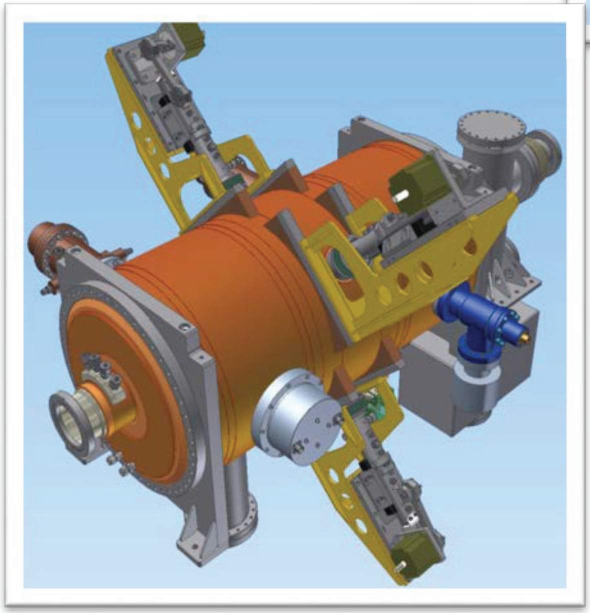
3 D model of RF1 station



3D model of RF2 station

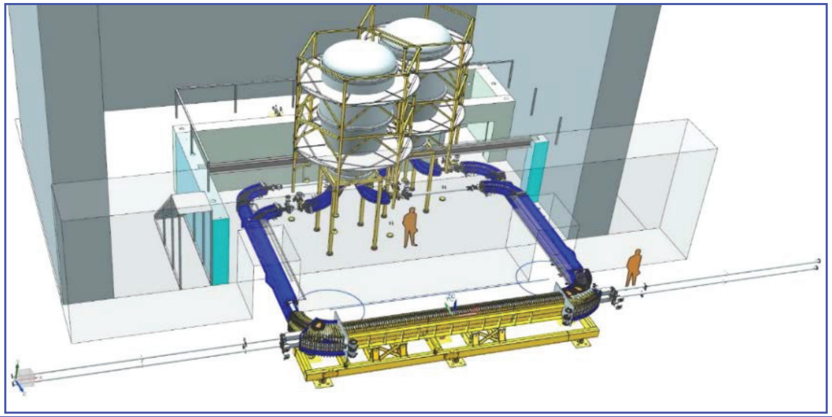
Parameters of RF2 and RF3 cavities

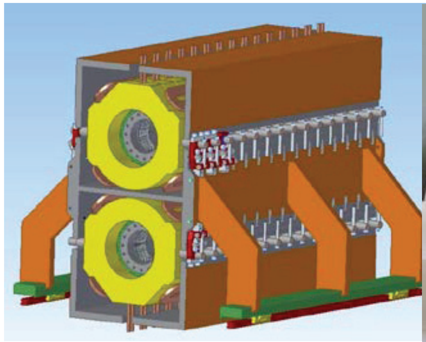
	RF2	RF3
harmonic	22	66
Frequency, MHz	11.484÷12.914	34.452÷38.742
Rsh,Ohms	$3.12 \cdot 10^{5}$	$2.68 \odot 10^{6}$.
Q	3900	6700
Rate of cavity frequency variation, kHz/s	14.7	25.7
RF voltage, kV	25	125
Number of cavities per ring	4	8



3D model of RF3 station

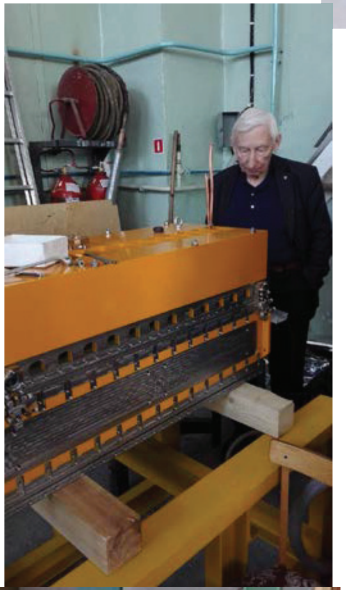
Electron Cooling System of NICA Collider, Ions $^{197}Au^{79+}$

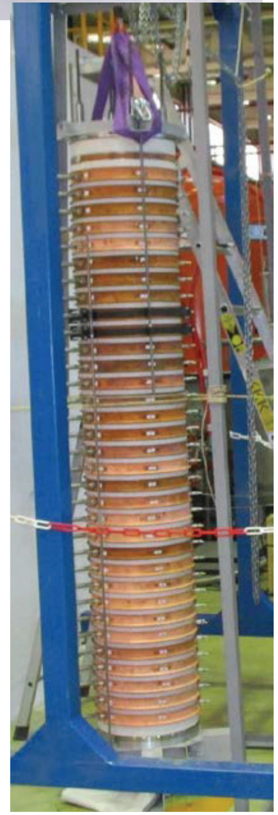




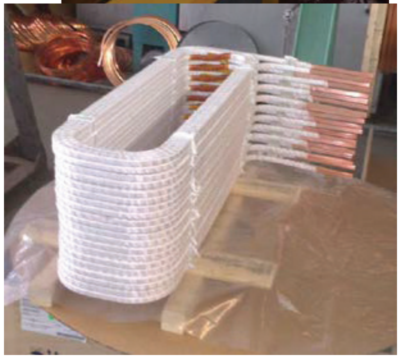
RUPAC 18,
M. Bryzgunov
TUCBMH02

HV Electron Cooler for NICA Collider
Design and construction at BINP
Installation at NICA in 2021
together with 4 RF2 and 16 RF3 stations
on 2 year early than it is planed for extended version





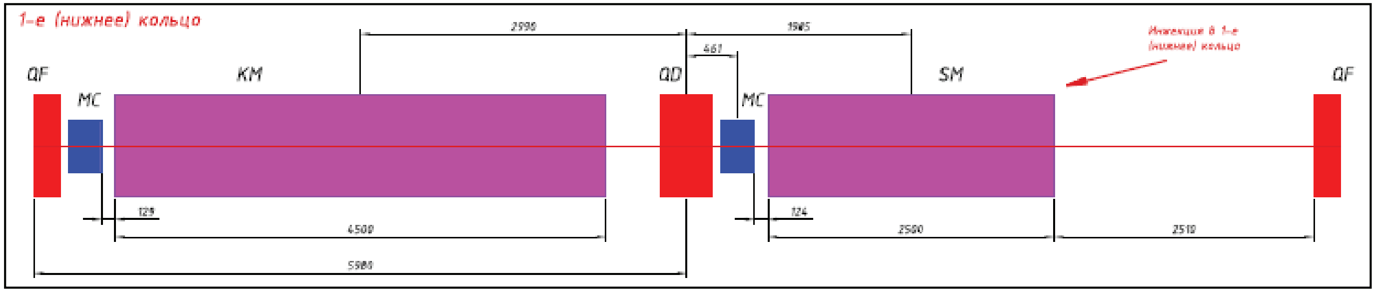
Parameter	Value
Electron energy, MeV Energy instability, $\Delta E/E$	0.2 – 2.5 $\leq 1 \cdot 10^{-4}$
Electron beam current, A	0.1 – 1.0
Cooling section length, m	6.0
Solenoid magnetic field, T Field inhomogeneity, $\Delta B/B$	0.05 – 0.2 $\leq 1 \cdot 10^{-5}$



JINR

NICA

Collider injection system

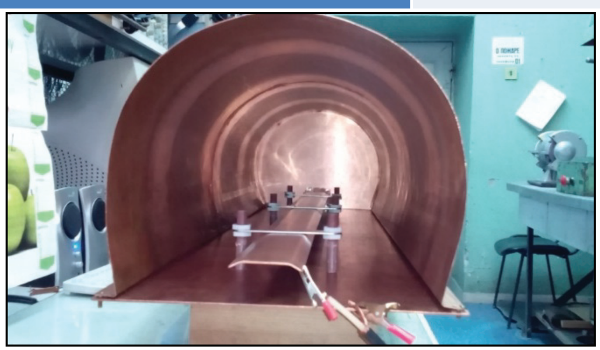


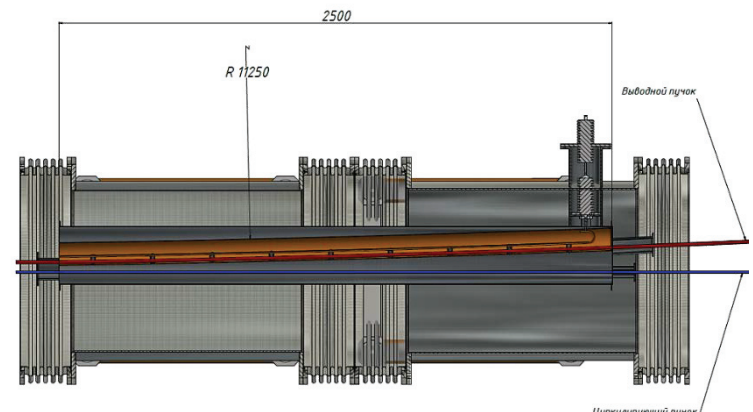
RUPAC 18,
A. Tuzikov
TUCDMH0

Length, m	2.5
Max magnetic field, T	1
Aperture, mm×mm	45×45
Septum thickness, mm	3
Pulse shape	semisinusoidal
Pulse duration, μs	~ 10

Septum

- **Technical design development is in progress.**
- **Concept of power supply has been developed.**





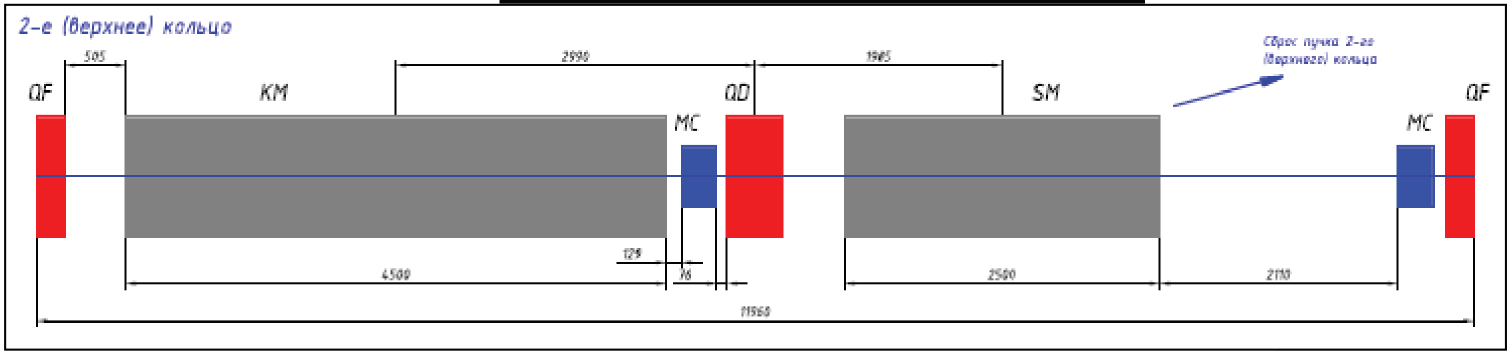
JINR invites collaborators for construction of injection system

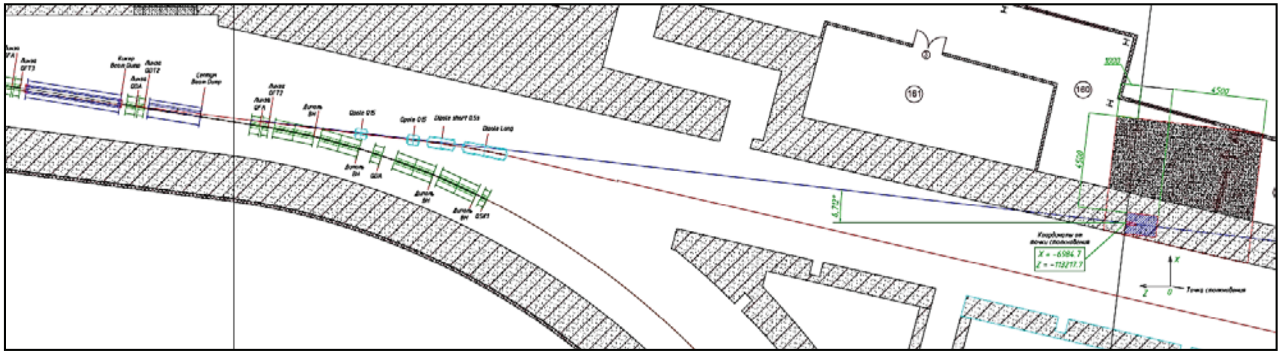
Construction 2018-middle of 2020

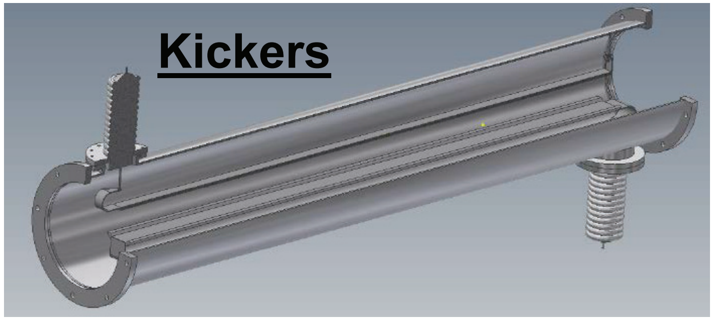
Commissioning -2020

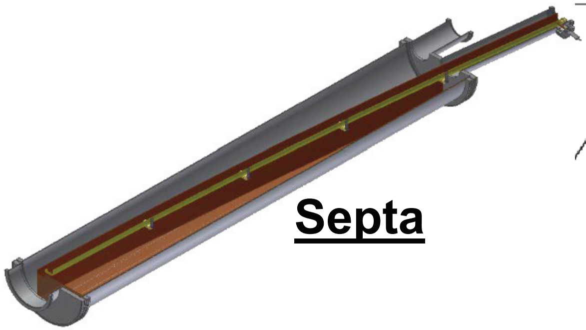
Collider beam dump system

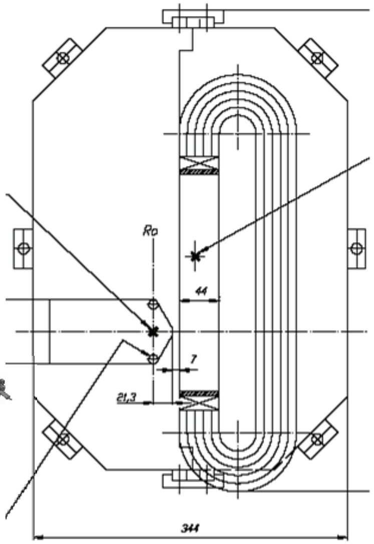
Beam dump from upper ring











Lambertson magnet

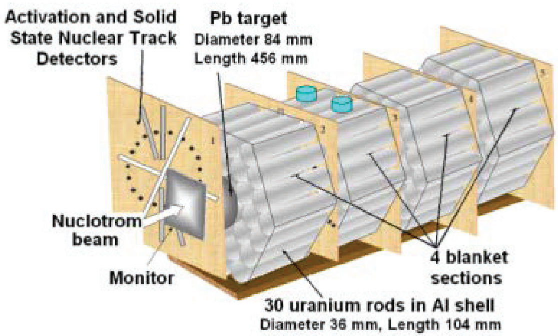
JINR invites collaborators for construction of beam dump system

Construction time- 2018-2020

Commissioning -2021

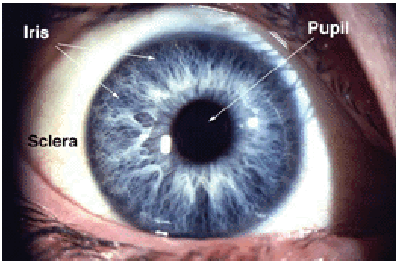
Innovations based on NICA technologies

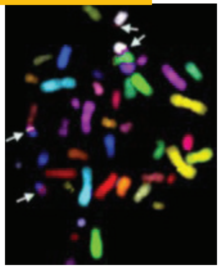
Transmutaion of nuclear fuel waste



Testing of space craft elements and electronics

Radiobiology





JINR invites collaborators for construction of beam transport channel and station for electronic irradiation and radiobiological stations (project JINR, ITEP)

Construction 2018-middle of 2020
Commissioning -2020

Collider building

Thank you for your attention!