NUCLOTRON Development for NICA Acceleration Complex

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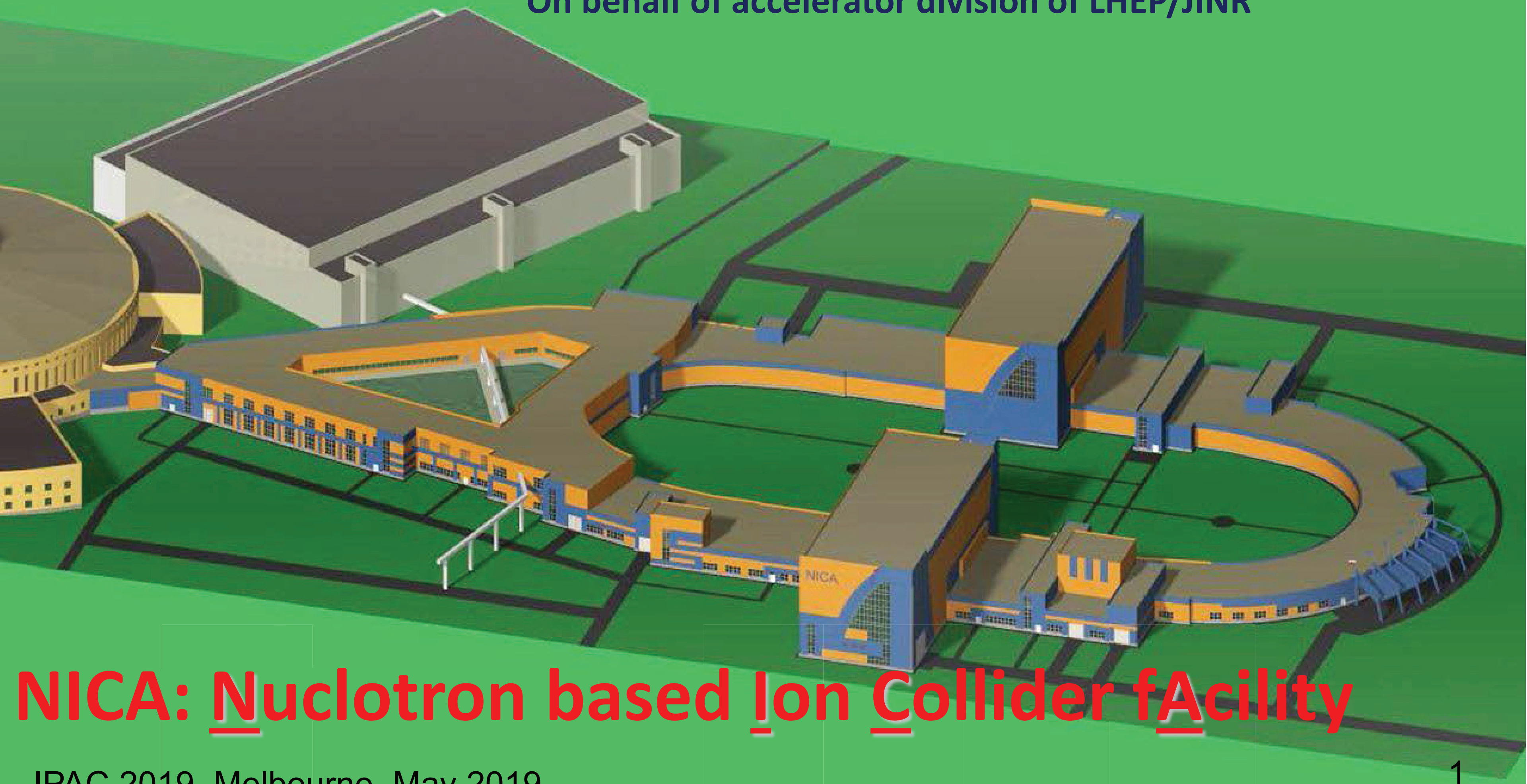
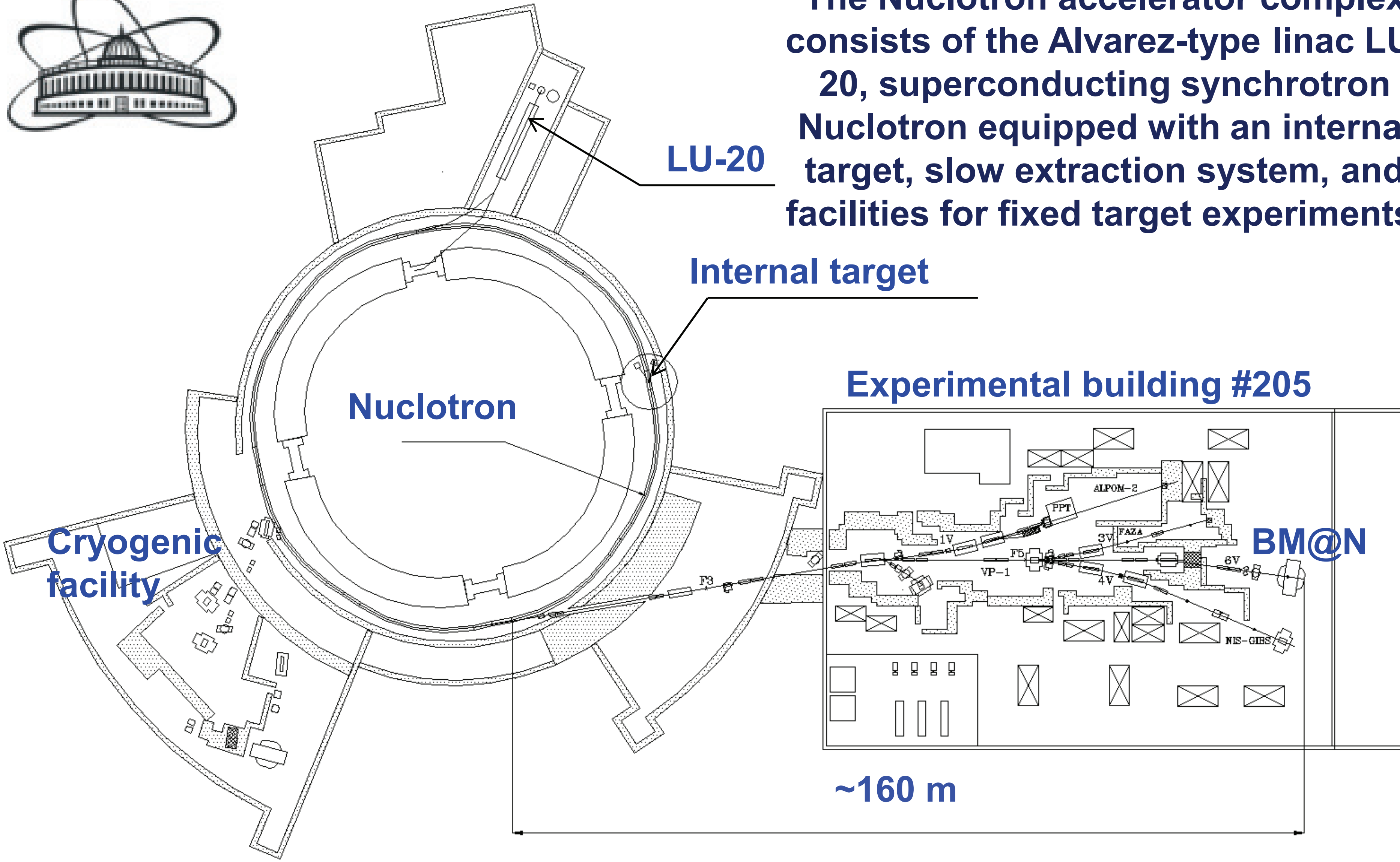


NICA: Nuclotron based Ion Collider fAcility

IPAC 2019, Melbourne, May 2019

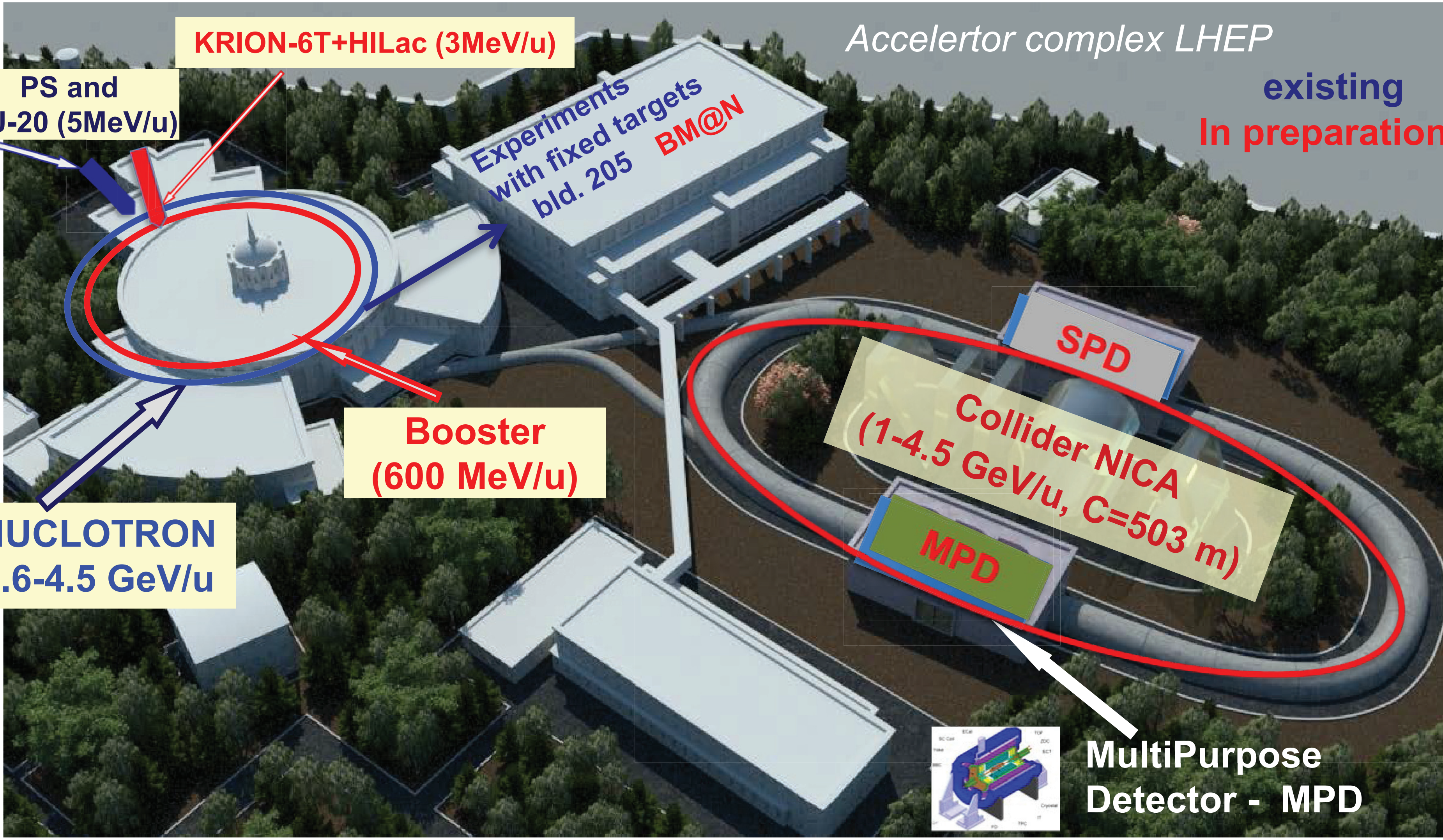
Nuclotron accelerator complex

The Nuclotron accelerator complex consists of the Alvarez-type linac LU-20, superconducting synchrotron Nuclotron equipped with an internal target, slow extraction system, and facilities for fixed target experiments.

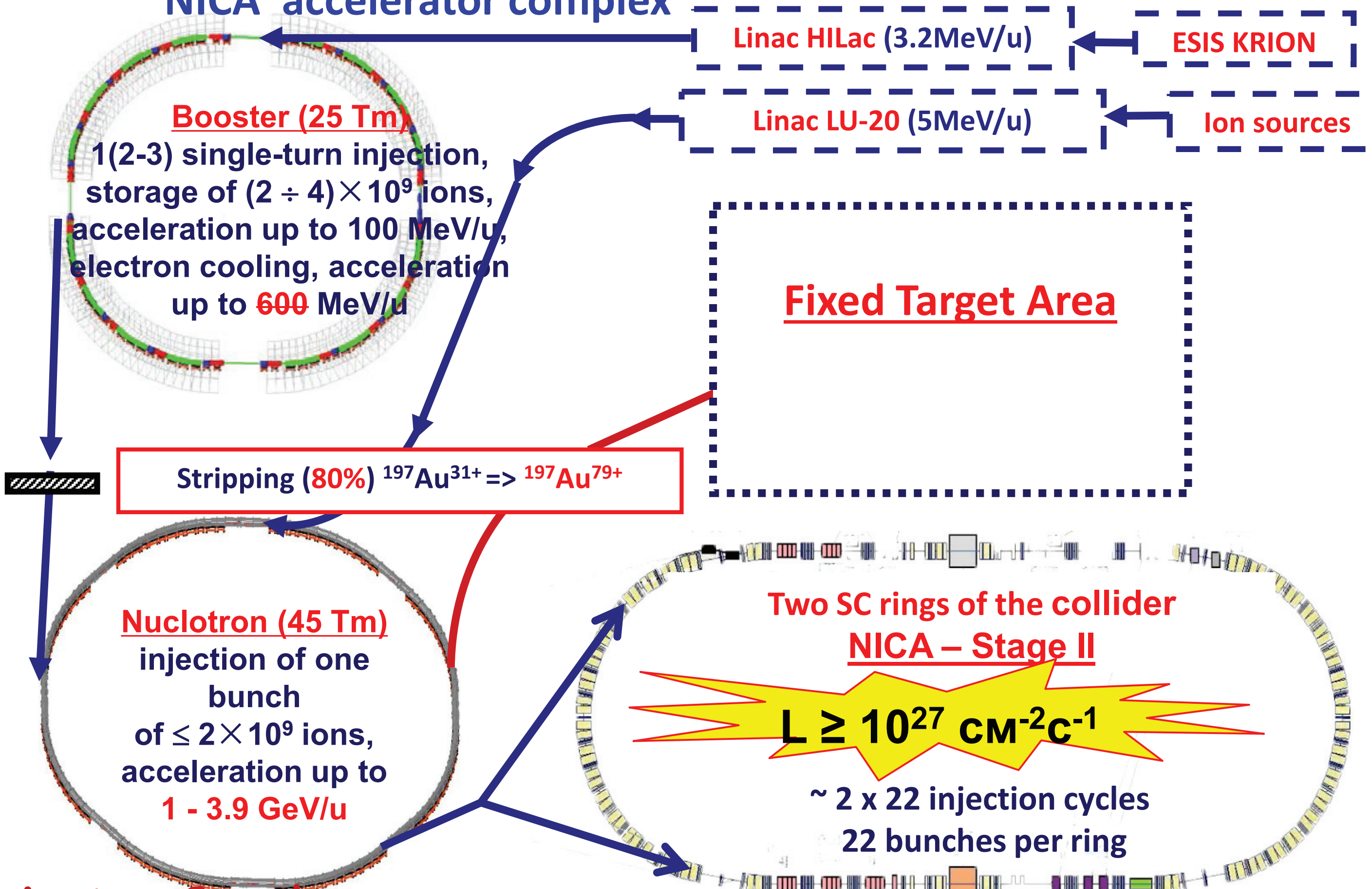


Nuclotron in operation since 1993

Complex NICA, JINR, Dubna



NICA accelerator complex



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

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.

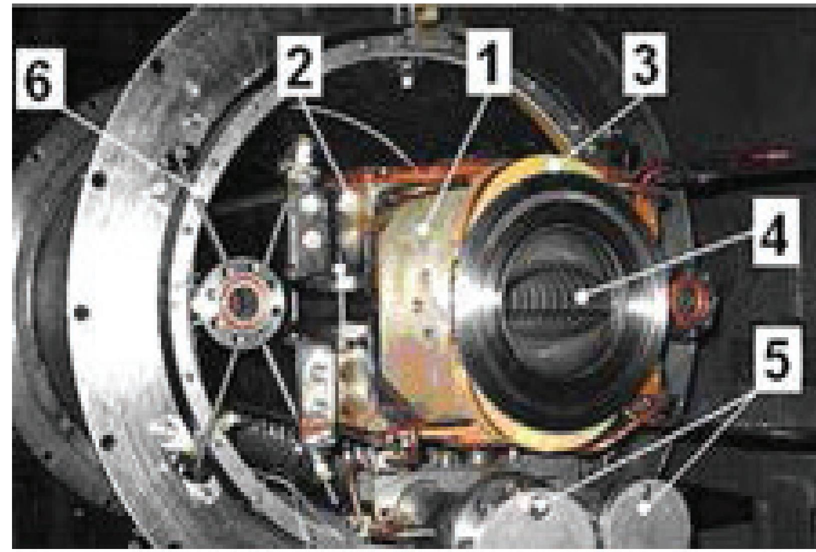
Commissioning – 2019-2020

First technological run-2021

JINR Superconducting synchrotron-Nuclotron

JINR superconducting synchrotron-Nuclotron.

Nuclotron in operation since 1993



The Nuclotron type fast cycling 3.6T/s dipole magnets with circulating two phase helium flow in superconducting cable

Maximum particle energy, 5.6 GeV/n
Perimeter, 251.5 m
Max. magnetic field, 1.8 T
Temperature, 4.5 K

The Nuclotron-type design based on a window frame iron yoke and a saddle-shaped superconducting winding has been chosen for the NICA booster and collider magnetic system as well as for the SIS100 synchrotron (FAIR project).

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

Booster magnet

Collider magnet

Status of the Nuclotron

Parameter	Project	Status
Max. magn. field, T	2	2 (1.8 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	5E10(p,d), 2E9 (A > 100)	d $4*10^{10}$ ($2*10^{10}$ routine), $^{7}Li^{3+}$ $3*10^{9}$ $^{12}C^{6+}$ $2*10^{9}$ $^{40}Ar^{16+}$ $1*10^{6}$ $^{78}Kr^{26+}$ $2*10^{5}$ $^{124}Xe^{42+}$ $1*10^{4}$

NICA accelerators

Injection chain for heavy ions

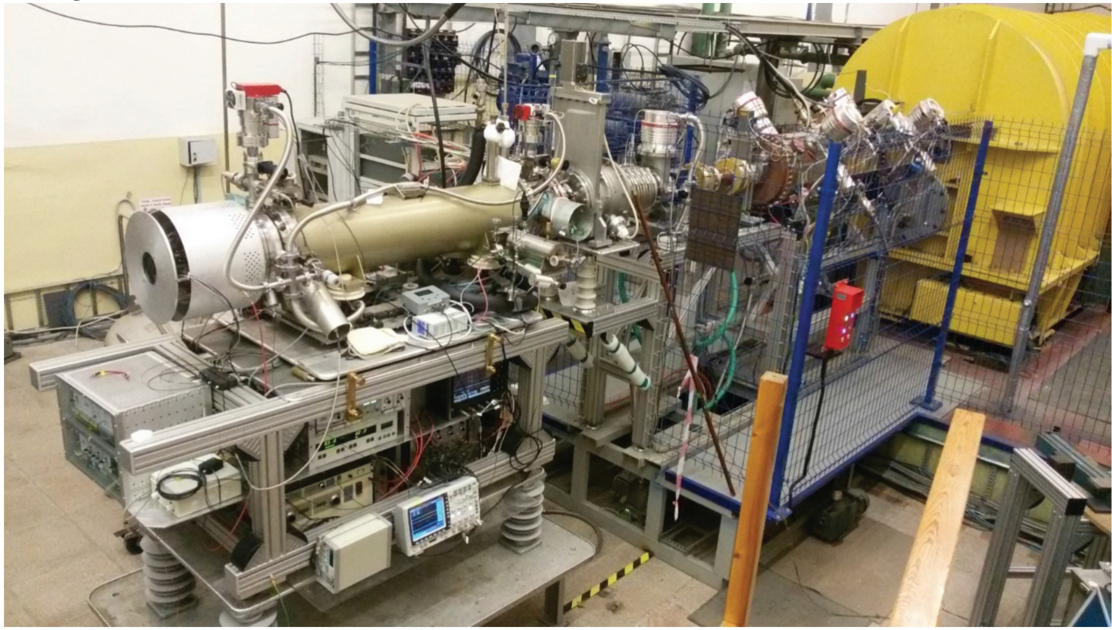
Cryogenic heavy ion source KRION

of Electron String Ion Source (ESIS) type

project up to $2 \cdot 10^9$ Au^{31+} particles per cycle

(achieved $5 \cdot 10^8$ Au^{31+})

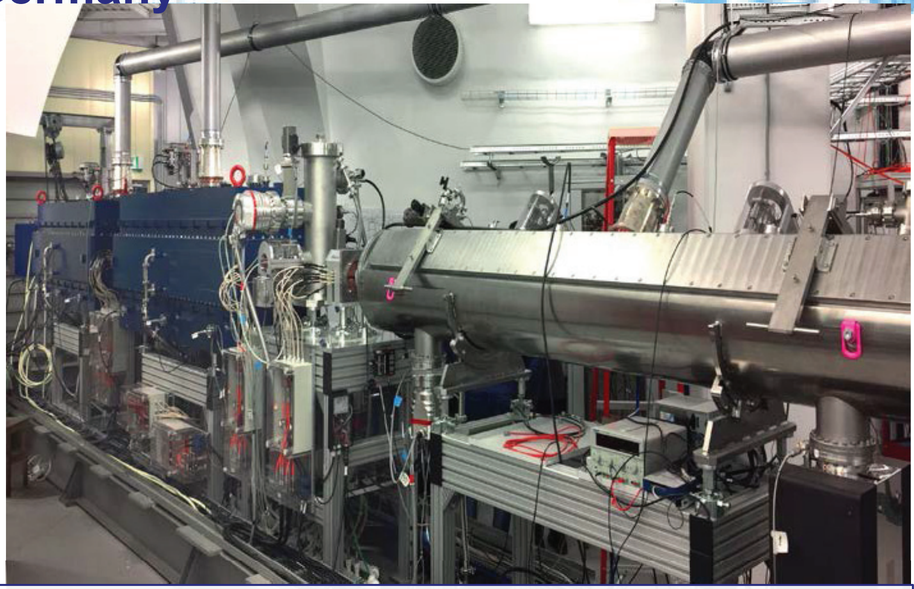
at repetition frequency up to 10 Hz



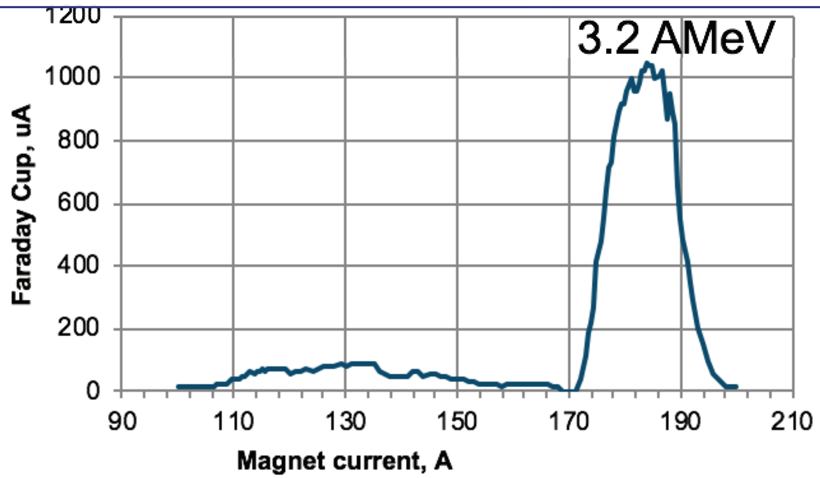
Usage of the buncher permitted to increase the Ar beam intensity at the entrance of the Nuclotron by about 5 times

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

Design and fabrication by “BEVATECH”, Germany HILAC



commissioning: Oct. 16

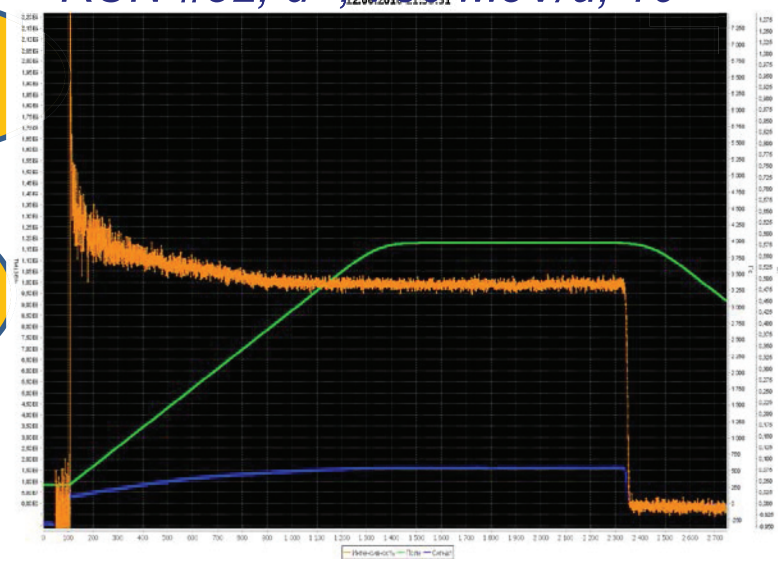


Parameter	Value HILAC
A/q (max)	6.25 for 10 mA Au^{31+}
A/q (min)	1 for ⩽ 2 mA p
Frequency	100.625 MHz
RF amplifier (RFQ/IH)	140 kW / 340 kW
Repetition rate	⩽ 10 Hz
Max. pulse length RF	200 µs
Pulse length beam	30 µs
E_{in} RFQ/E_{out} RFQ	17 AkeV/300 AkeV
Transmission RFQ	90 %
E_{out} IH-DTL (2xIH)	3.2 AMeV
Total Transmission HILac after LEBT	≥80 %
ε_{in} (trans, norm)	0.6/0.4 π mm mrad

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**

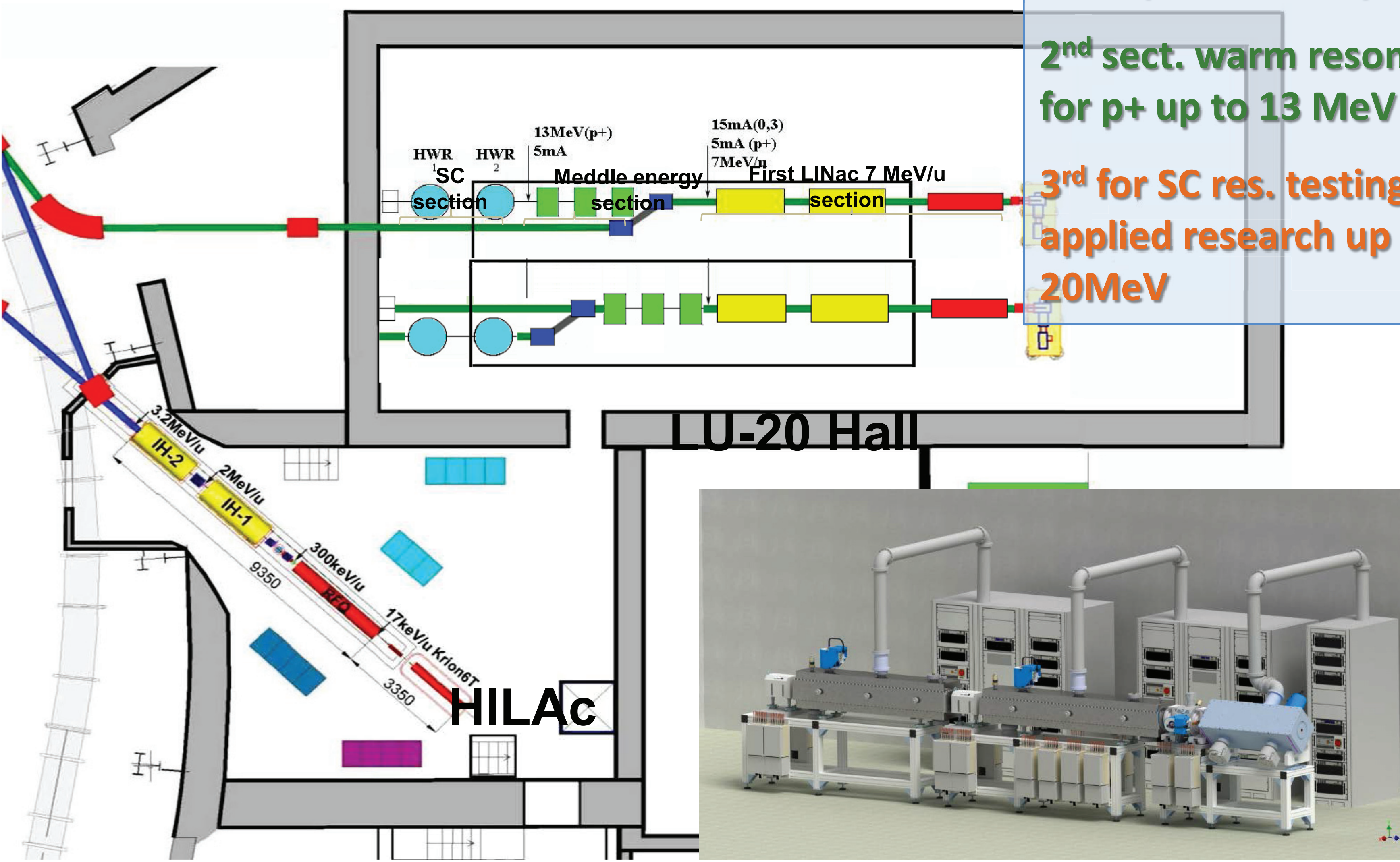
New Light Ion Linac "*LILAc*" Injector for the Nuclotron

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



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.

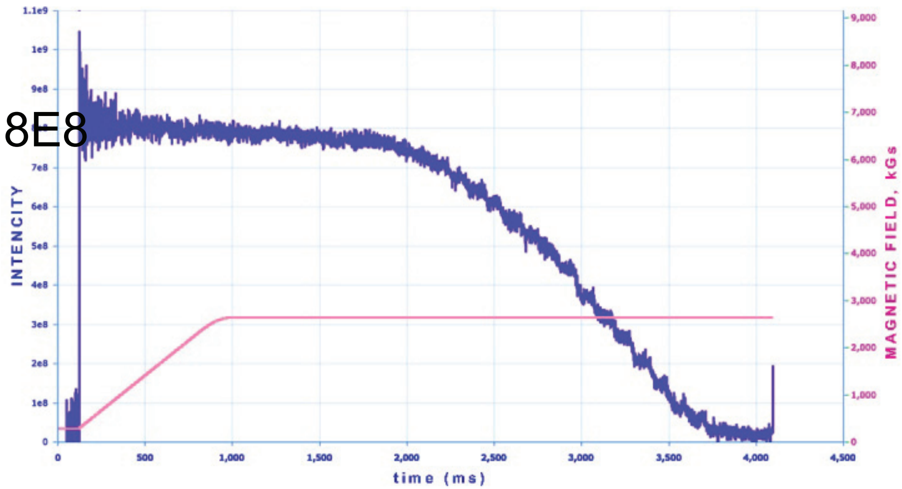
Start of assembly – September 2018.

First (technological) run – middle of 2019.

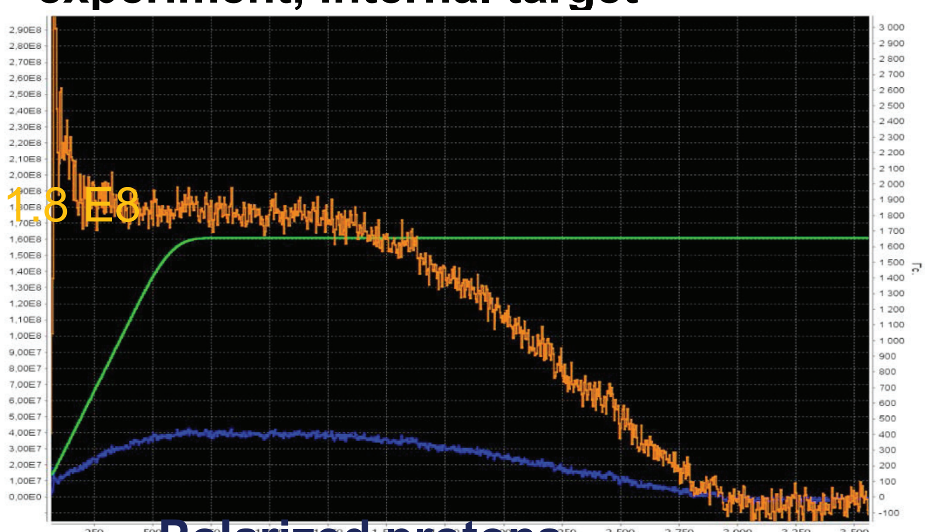
Nuclotron: polarized deuterons and protons

Routine operation of SPI and new fore-injector

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



Deuteron Spin Structure experiment, internal target



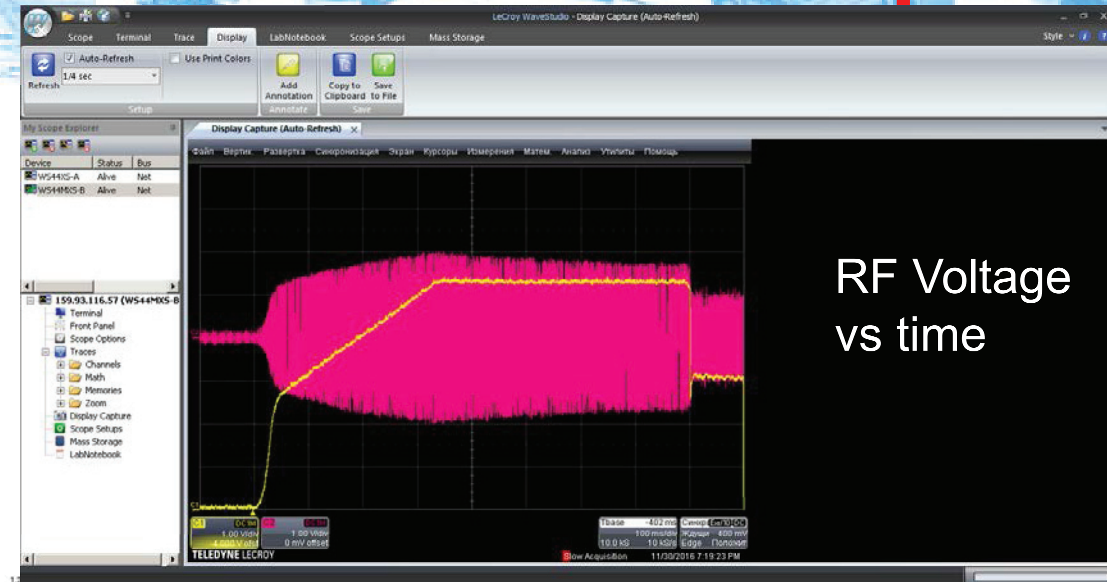
Polarized protons

The deuterons and light ions were accelerated at second harmonics Injection energy – 156 keV, output energy 5 MeV/u.

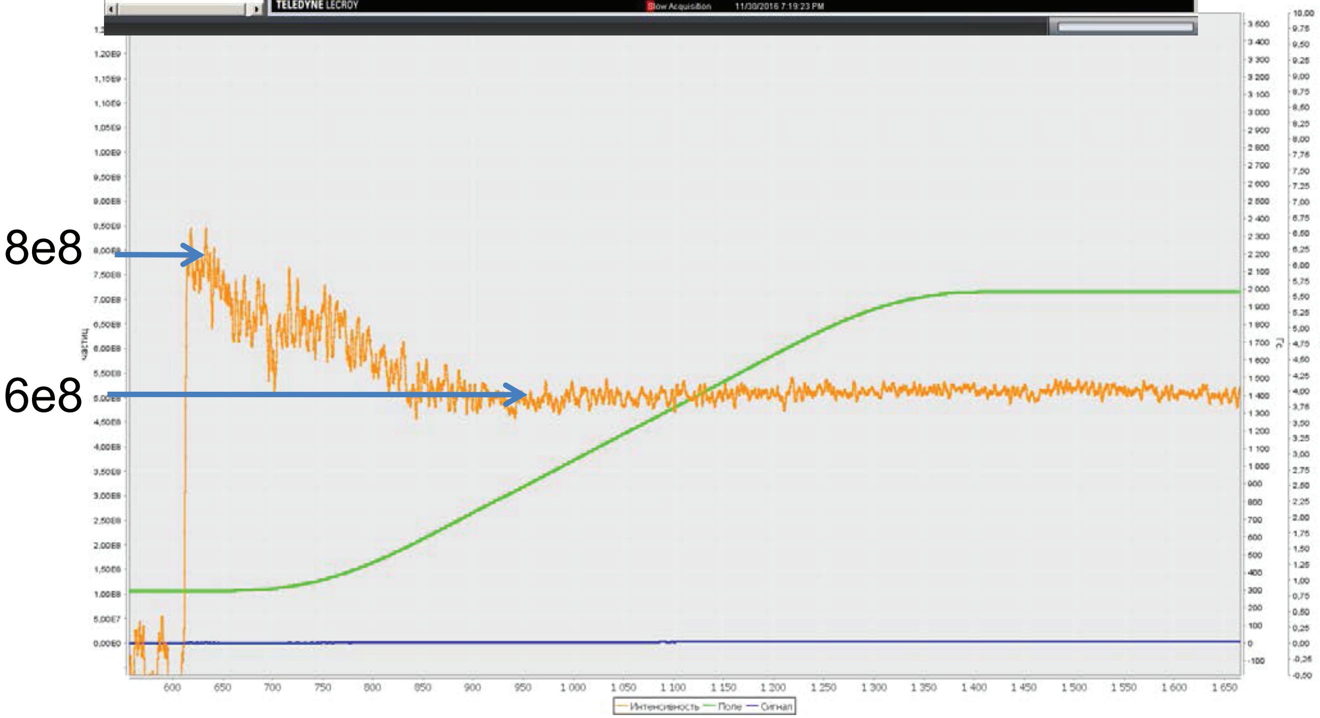
LU-20 was designed for the proton acceleration to 20 MeV Injection energy of about 625 keV was provided by HV transformer

New RFQ fore-injector provides output energy of 156 keV for all ions:
-the protons can be accelerated in LU-20 at the second harmonics only
-the output proton energy is 5 MeV
-the Nuclotron magnetic field at injection has to be about 150 G (instead of 300 G for other ions)

Adiabatic capture

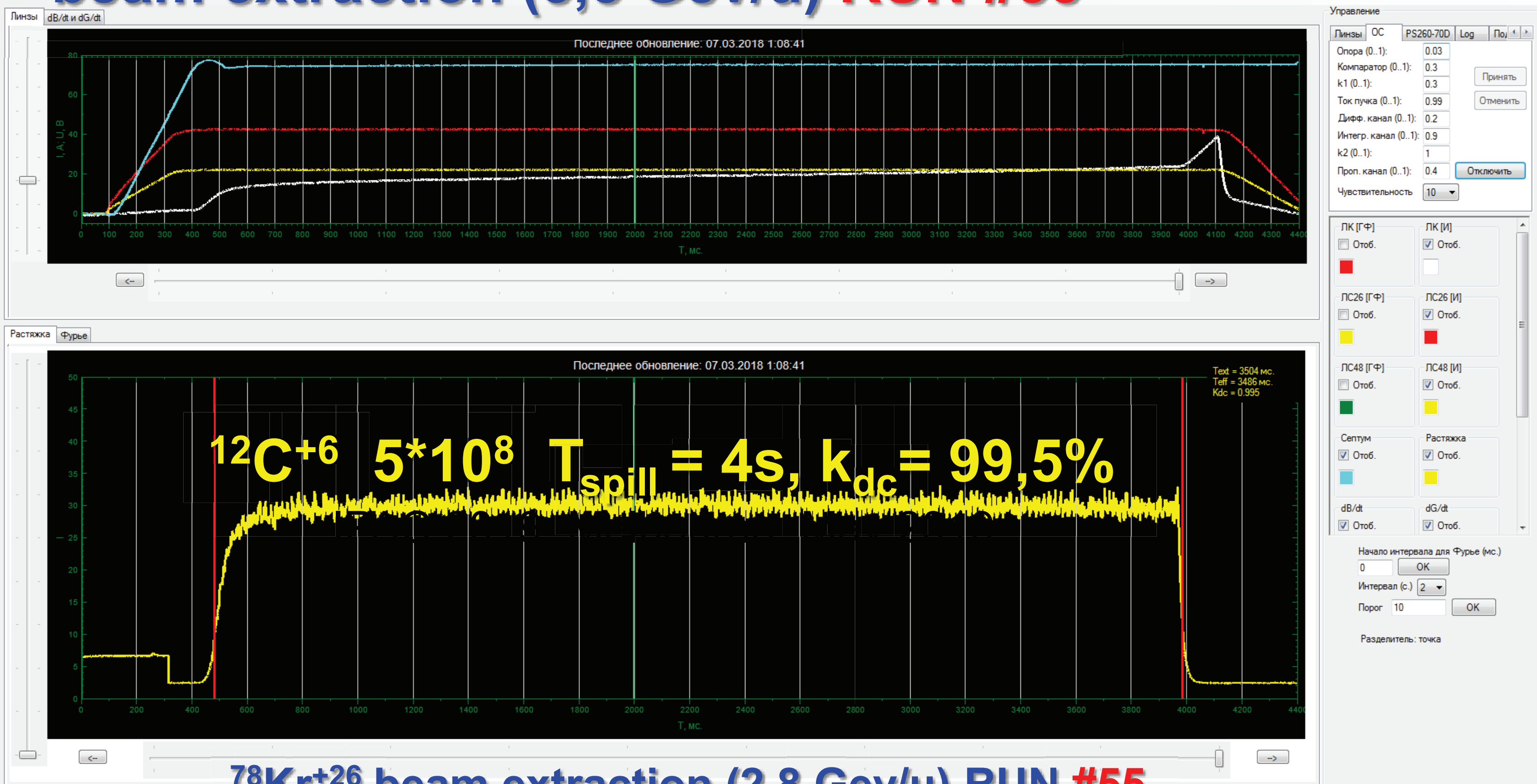


Capture efficiency ~ 75%



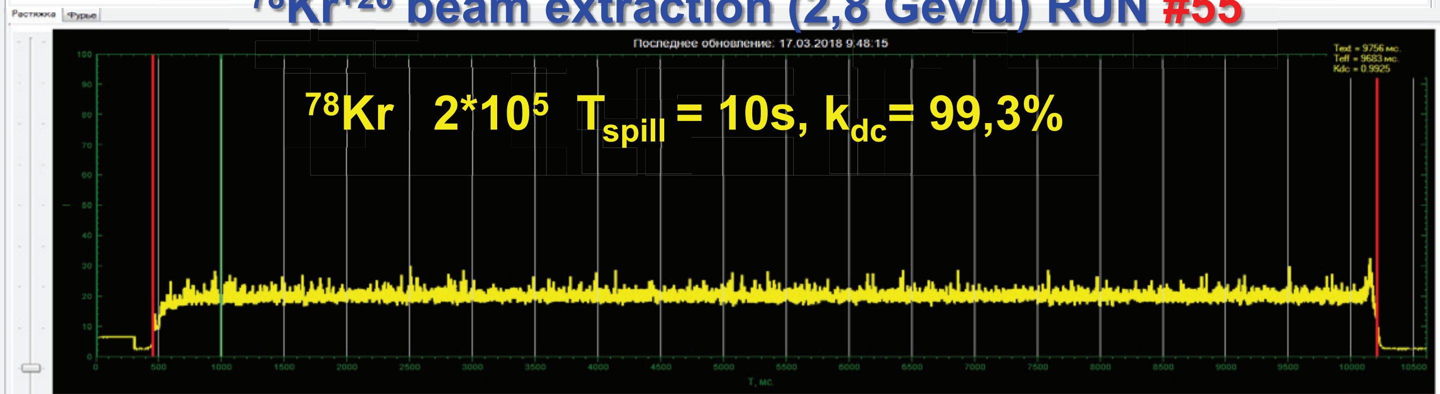
Nuclotron: slow extraction

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



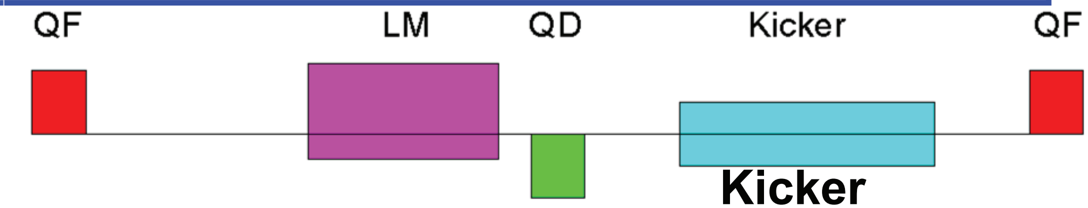
$^{12}C^{+6}$ $5*10^{8}$ $T_{spill} = 4s$, $k_{dc} = 99,5\%$

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



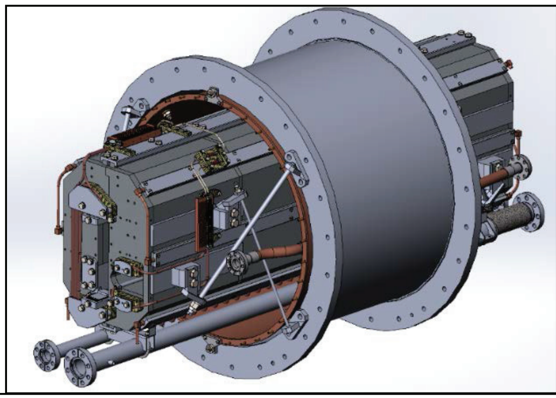
^{78}Kr $2*10^{5}$ $T_{spill} = 10s$, $k_{dc} = 99,3\%$

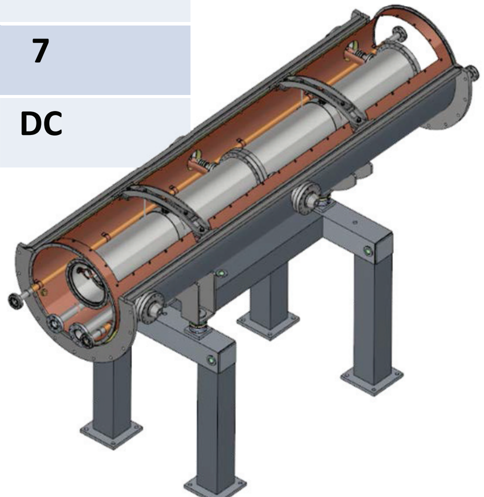
Nuclotron high energy beam injection system



Lambertson magnet

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



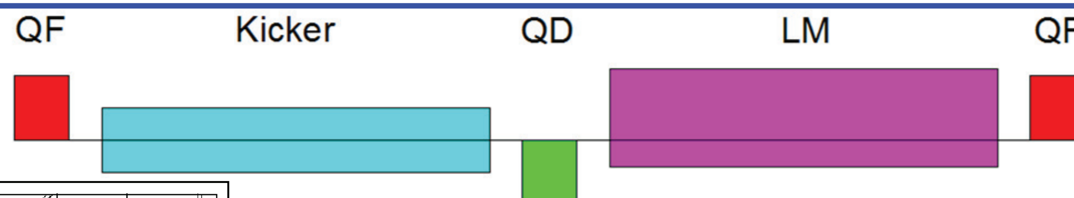


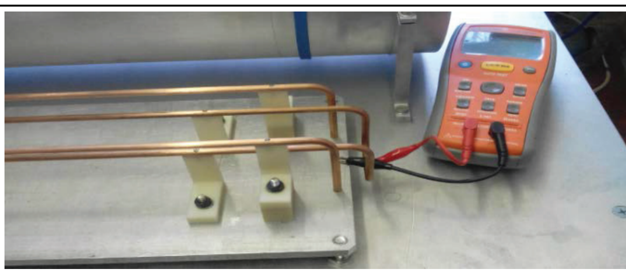
Kicker

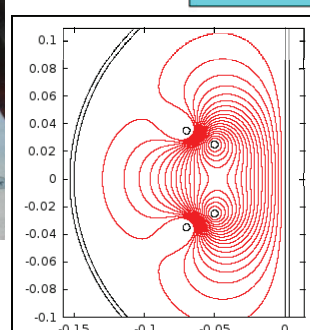
Length, m	2
Max magnetic field, T	0.1
Max current, kA	15
Aperture, mm×mm	86 × 44
Pulse duration, μs:	
rise	free
plateau	≥ 0.5
fall	≤ 0.5

- **Lambertson magnets are based on existing spare yokes for slow extraction system**

Nuclotron fast extraction system







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

Conclusions

- Adiabatic capture is used in routine operation
Capture efficiency ~ 75%

- Slow extraction system provides required beam quality
At Magnetic field up to 1.85 T
At the intensity range from 10^4 to 10^{10} particles/sec

-Possibility of the polarized proton acceleration
was demonstrated

-Assembly of the NICA Booster was started.
Technological run is scheduled for the middle of 2019

-HILAc, Booster, Nuclotron run is planed in middle 2020.

Thank you for your attention!