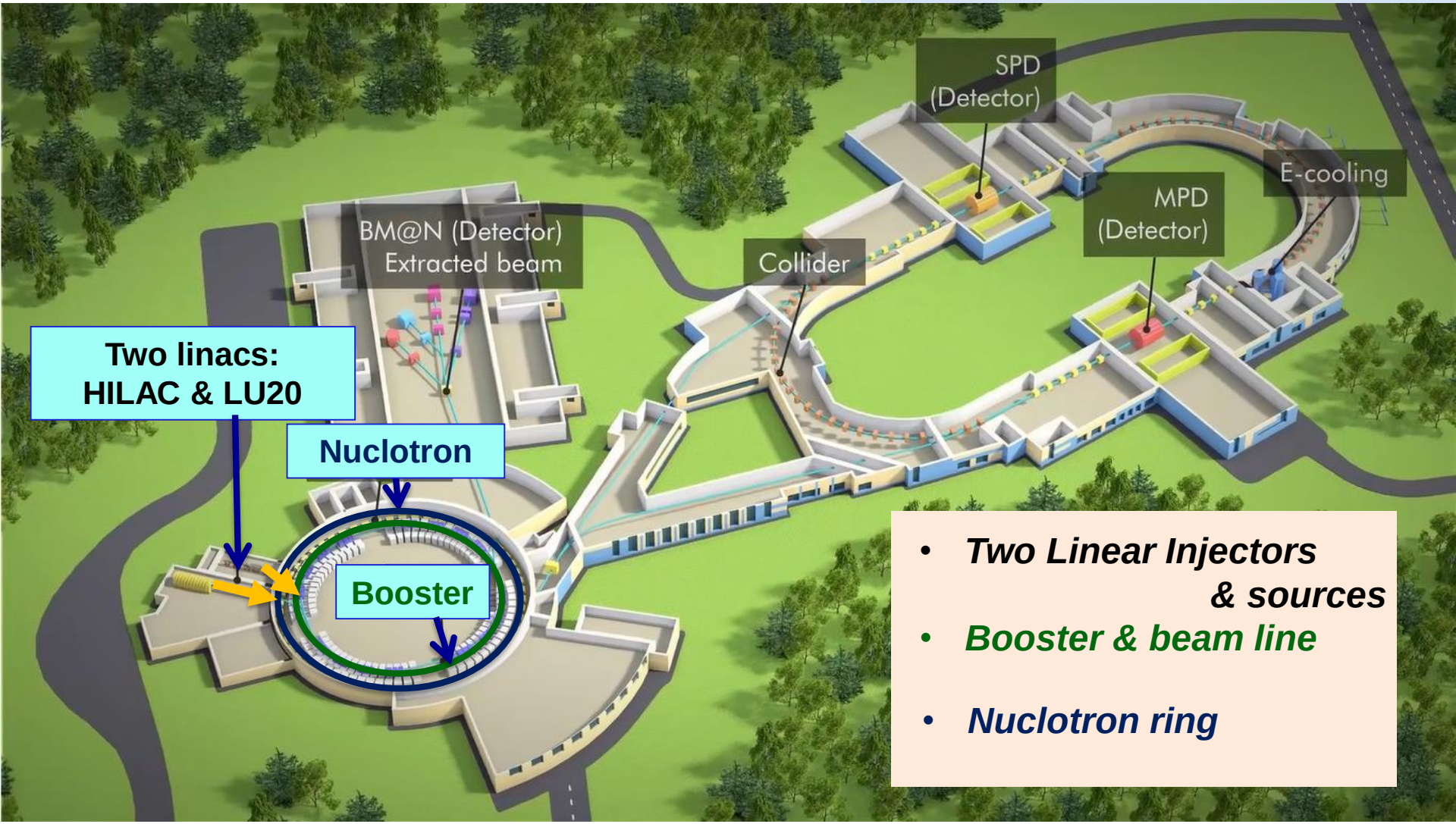
BOOSTER –NUCLOTRON-COLLIDER DEVELOPMENT

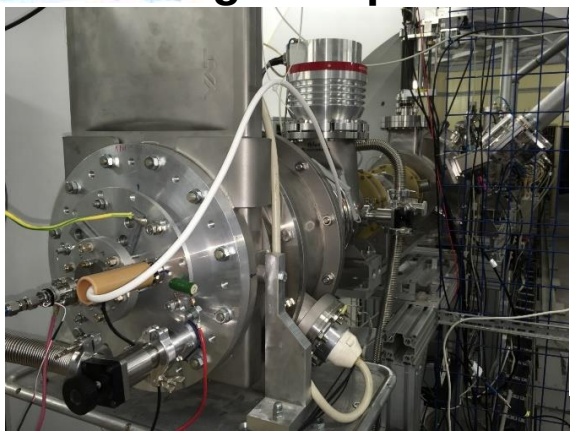
E.Syresin on behalf of the team

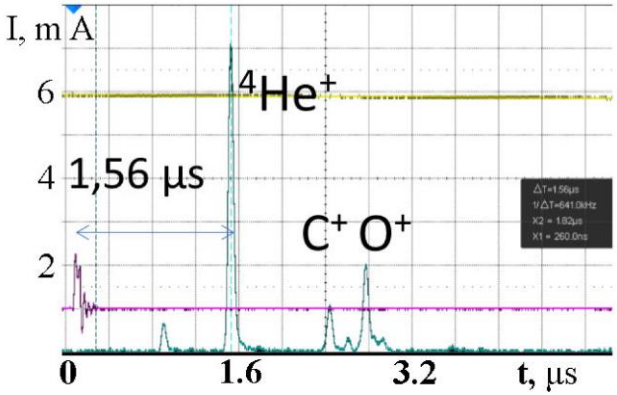


- *Two Linear Injectors & sources*
- *Booster & beam line*
- *Nuclotron ring*

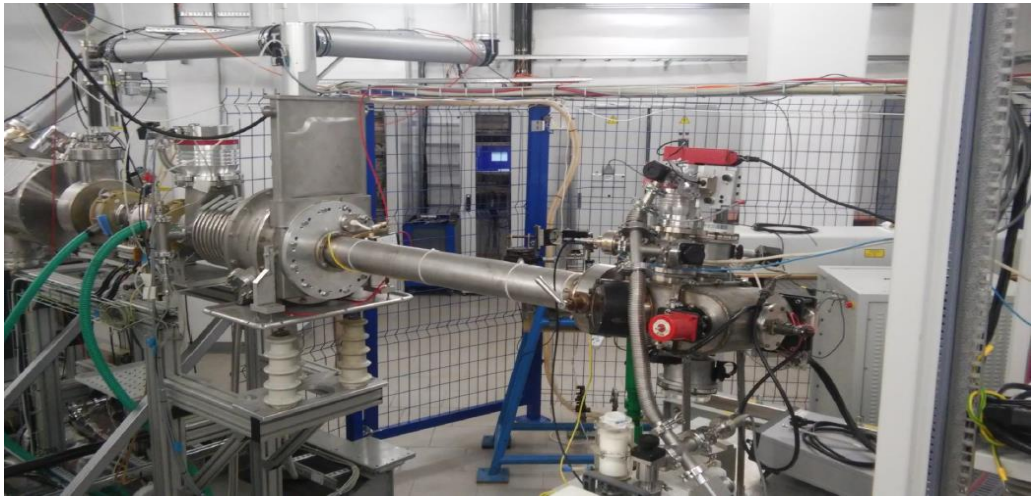
Ion sources for Booster beam commissioning

Ion source with a cold magnetron cathode and magnetic plasma compression.

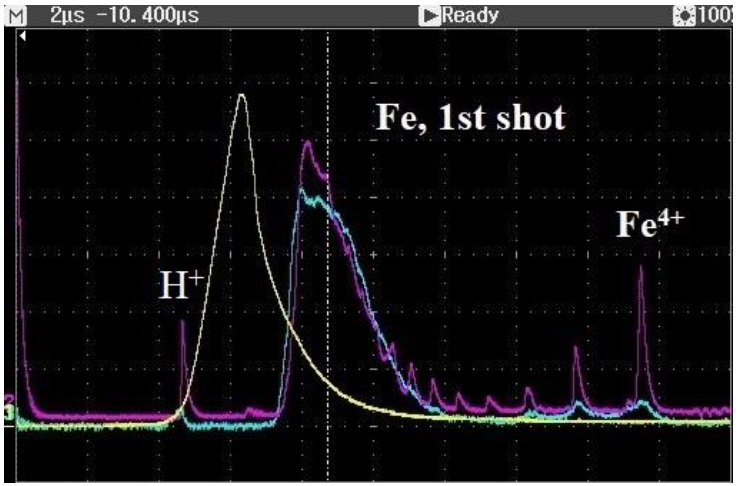




For the first Booster run the He^{1+} ion beam was used.

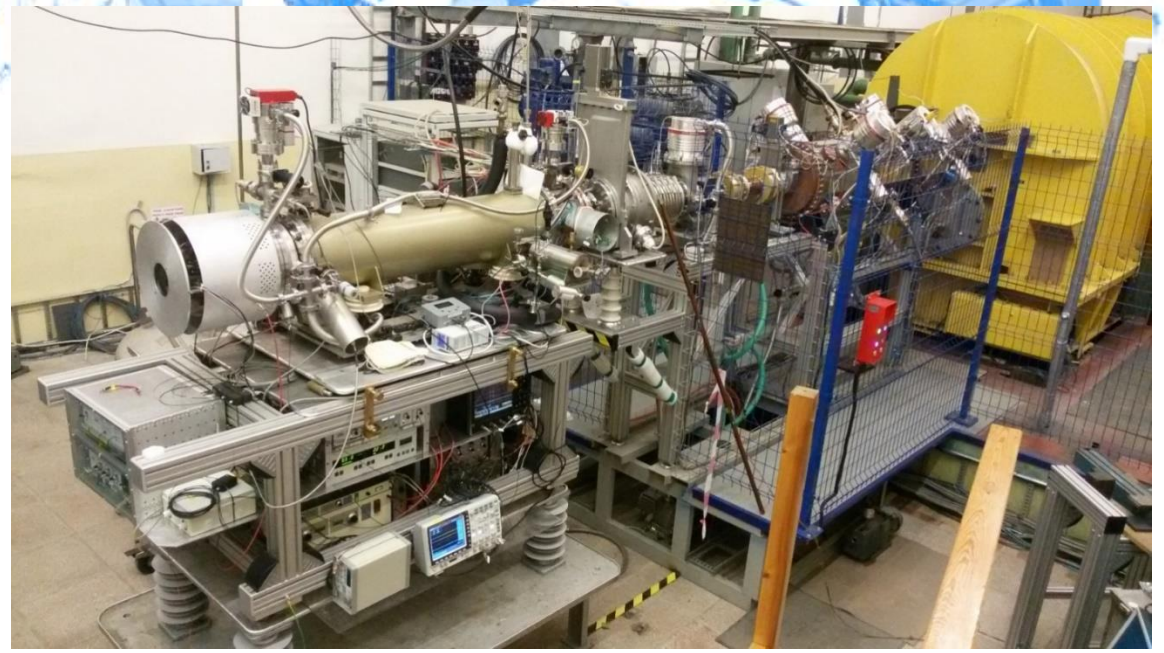


Лазерный источник ЛУТИ на основе Nd:YAG импульсного лазера.



Вертикальная пунктирная линия соответствует спектру ионов *Fe^{16+}*.

ELECTRON STRING ION SOURCE –KRION -6T



KRION -6T at linear accelerator LU20

$^{209}Bi^{35+}$ $3 \cdot 10^8$ ions/pulse

C^{6+} -10^9 ions/pulse

Ar^{16+} $-5 \cdot 10^8$ ions/pulse

Kr^{26+} - $3 \cdot 10^8$ ions/pulse

Xe^{41+} - $2 \cdot 10^8$ ions/pulse.

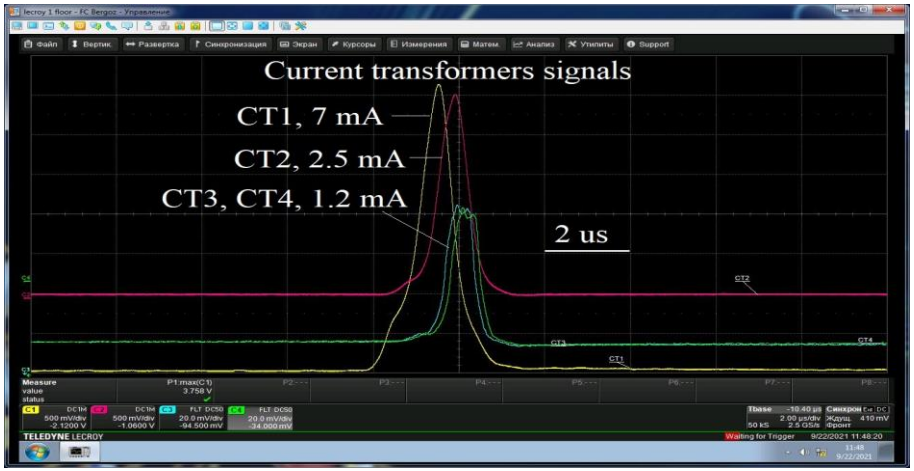
September-December 2022 Booster-Nuclotron run is planned with Xe ions

HILAc status

Stable and safe operation during Booster commissioning with He^{1+}, Fe^{14+}, C^{4+} ion beams

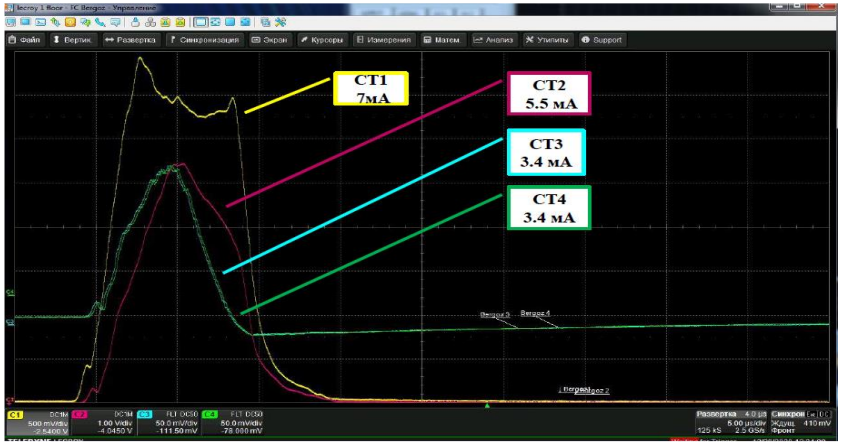
A/q (Target Ion Au^{31+})	6.25
Beam current	< 10 emA
Repetition rate	< 10 Hz
Output energy	3.2 MeV/u

Transmission of ions is about 78.5% from RFQ to the exit of linac, 3.2 MeV/u



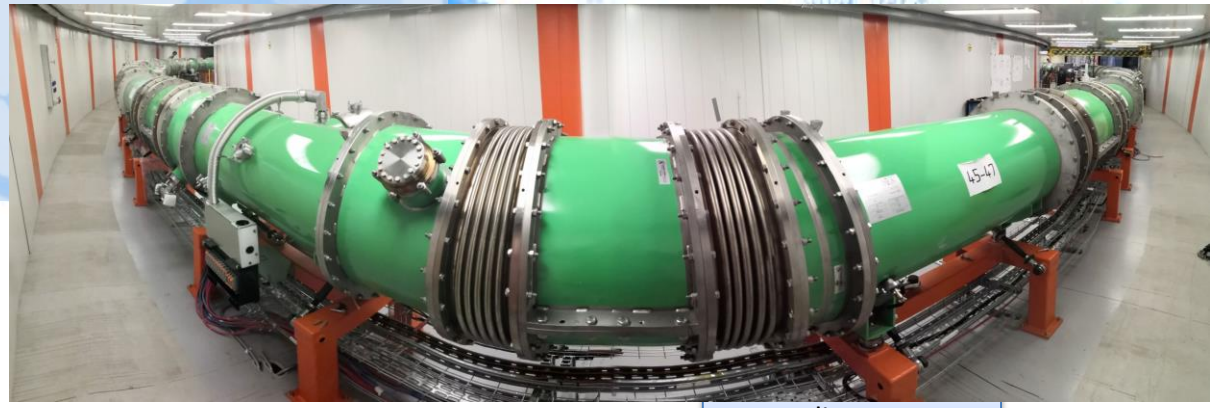
Fe $^{14+}$ ions, CT1- exit of RFQ, CT2-exit of HILAC

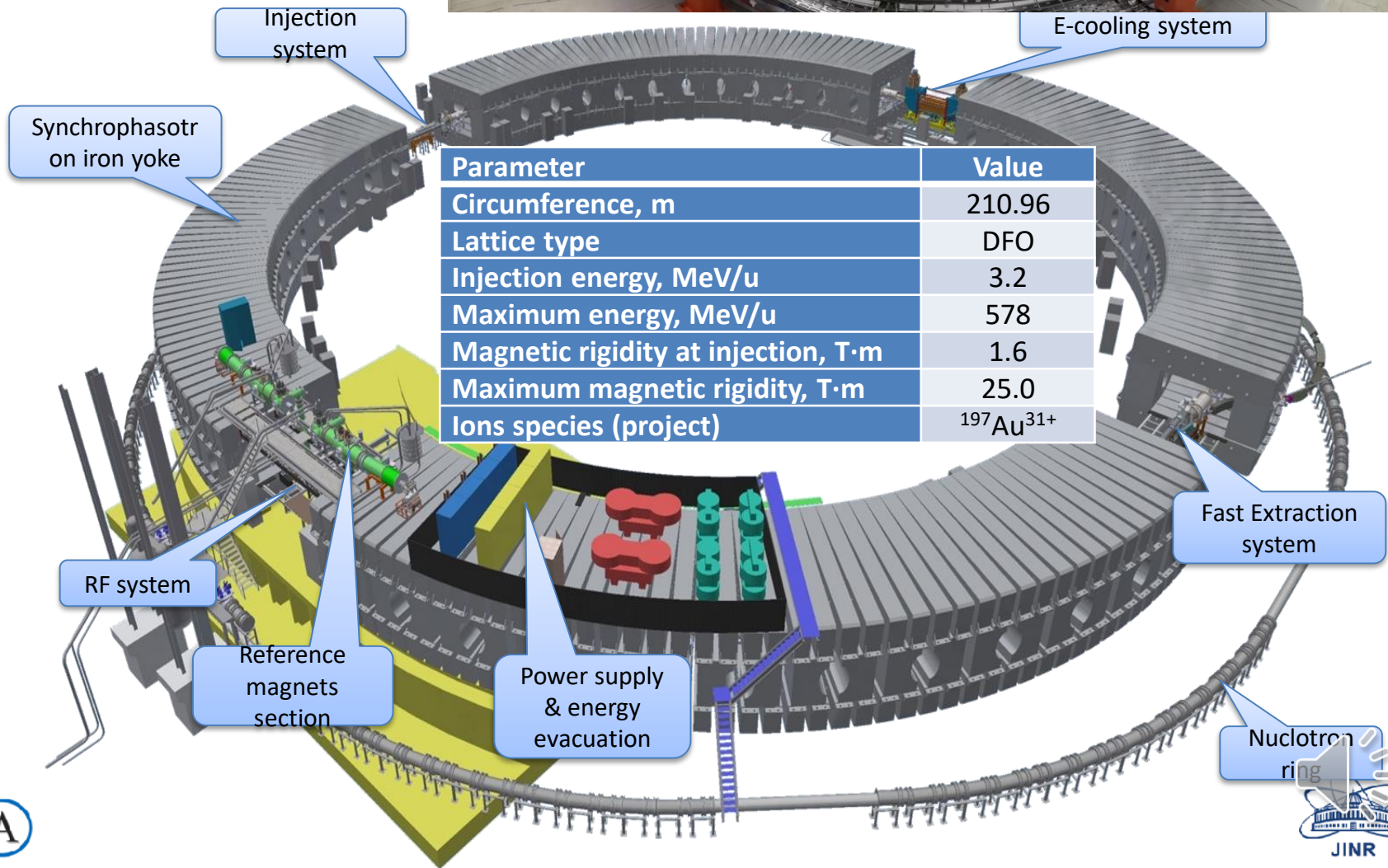
Exit HILAC project current of $^{209}Bi^{35+}$ is 1,5 mA



He $^{1+}$ ions, CT1- exit of RFQ, CT2-exit of HILAC

Booster ring layout





Parameter	Value
Circumference, m	210.96
Lattice type	DFO
Injection energy, MeV/u	3.2
Maximum energy, MeV/u	578
Magnetic rigidity at injection, T·m	1.6
Maximum magnetic rigidity, T·m	25.0
Ions species (project)	$^{197}Au^{31+}$

NICA

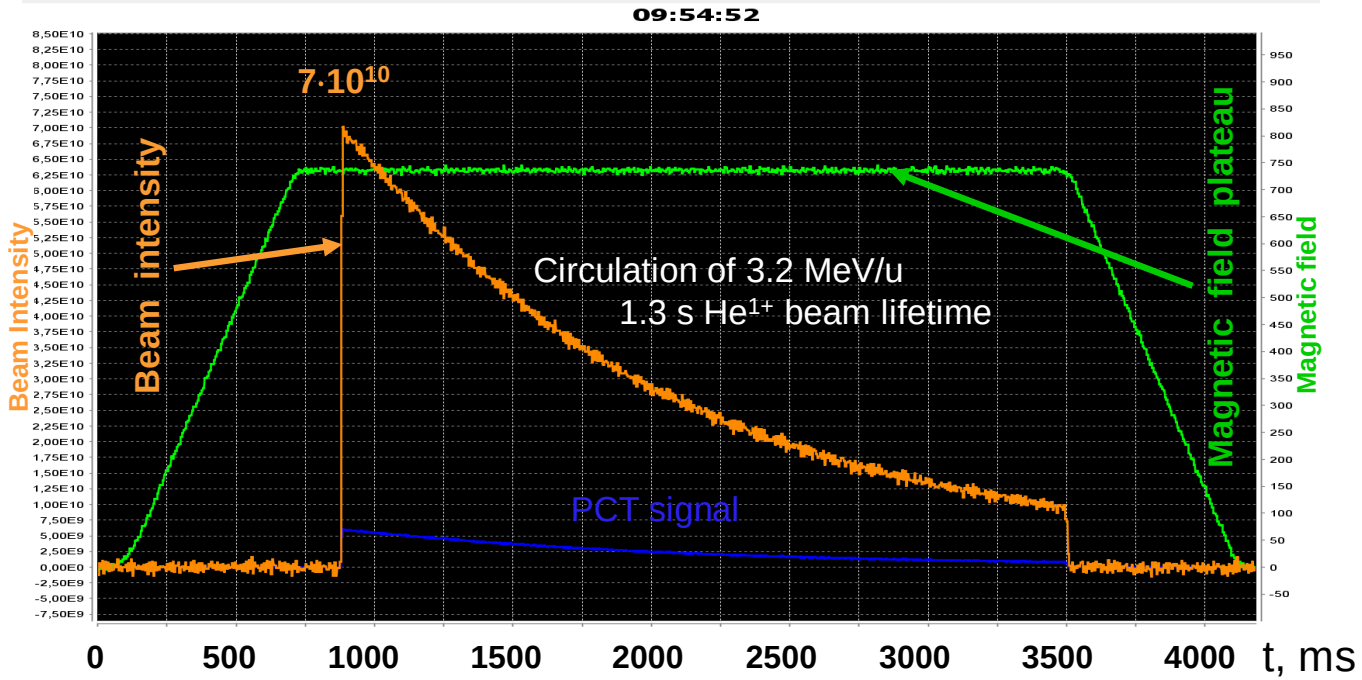
JINR

Beam current & vacuum conditions

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

Measurements of integral vacuum conditions by intensity decrement of circulating He^{1+}

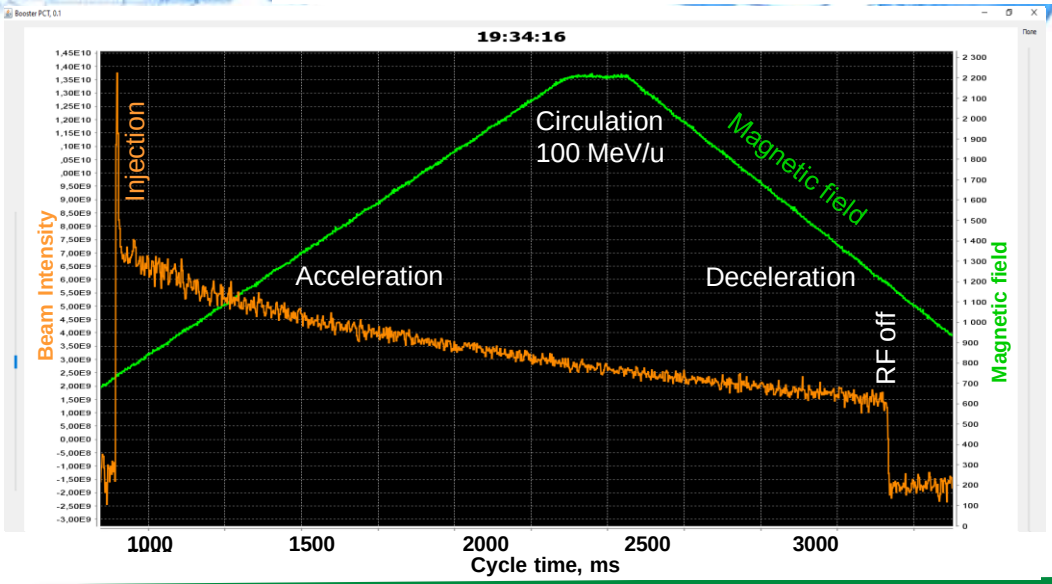
Parametric beam current transformer signal (DC mode)



- ✓ ***$7 \cdot 10^{10}$ elementary charges ~ $2 \cdot 10^9$ of Au^{31+} (design intensity)***
- ✓ ***Life-time is about 1.3 s, equivalent pressure of residual gas is $2 \cdot 10^{-8}$ Pa***

Beam acceleration

Parametric beam current transformer signal (DC mode)

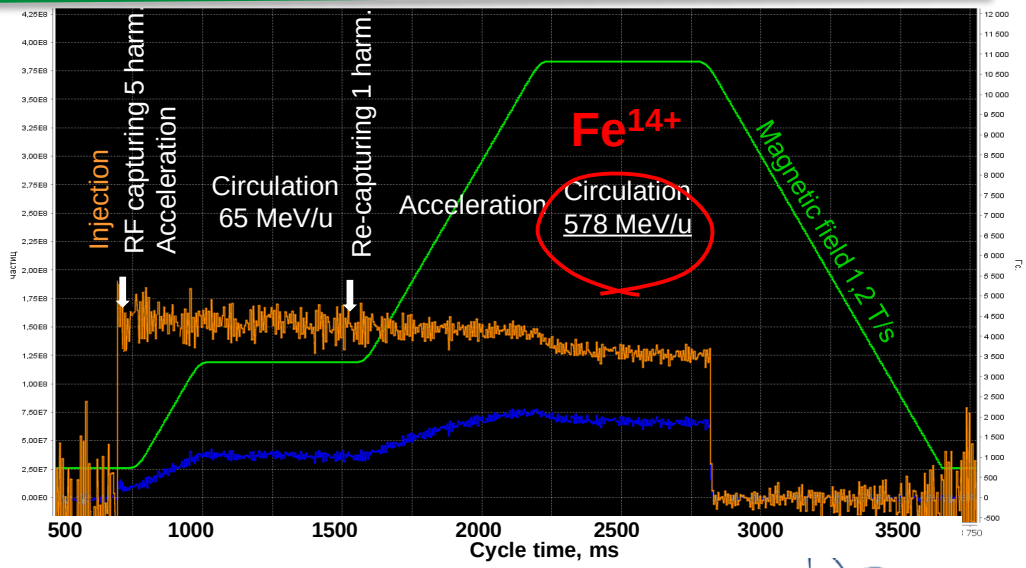


Cycle-1 of commissioning
20 of December 2020 He^{1+}

PCT signal when beam injecting into rising field, capturing (~60%), accelerating & decelerating:
no transient losses on the MF table & after.

Cycle 2 of commissioning
14-23 of September 2021 Fe^{14+}

- *Beam injection with adiabatic capturing 5 harmonic (>95%),*
- *accelerating up to 65 MeV/u,*
- *recapturing 1 harmonic (close to 100%)*
- *acceleration up to 578 Mev/u*
- *with dB/dt = 1.2 T/s*
- *Ion cooling at 3.2 MeV/n*



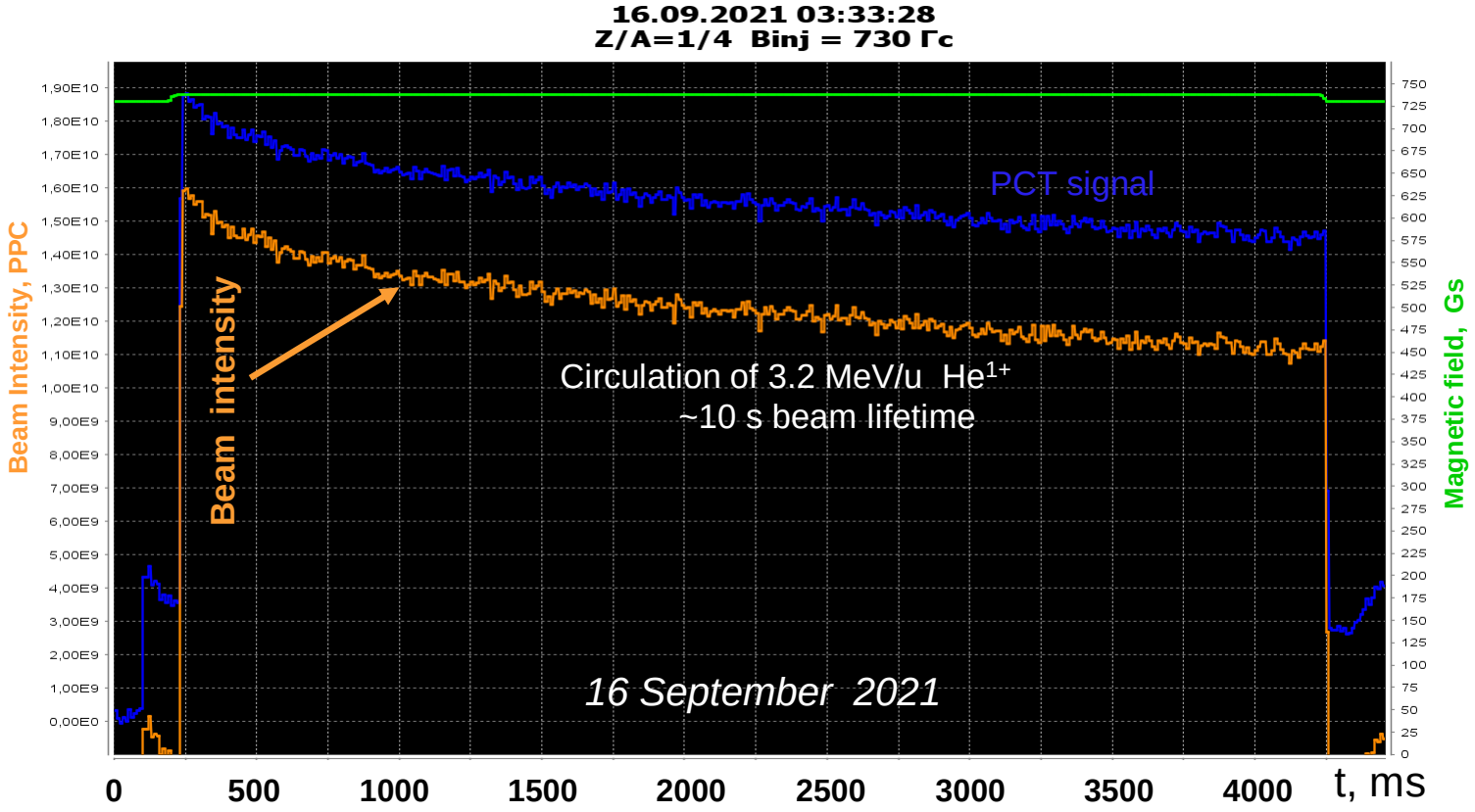
NICA

JINR

Beam current & vacuum conditions

16.09.2021: Measurements of integral vacuum conditions by intensity decrement of circulating He^{1+}

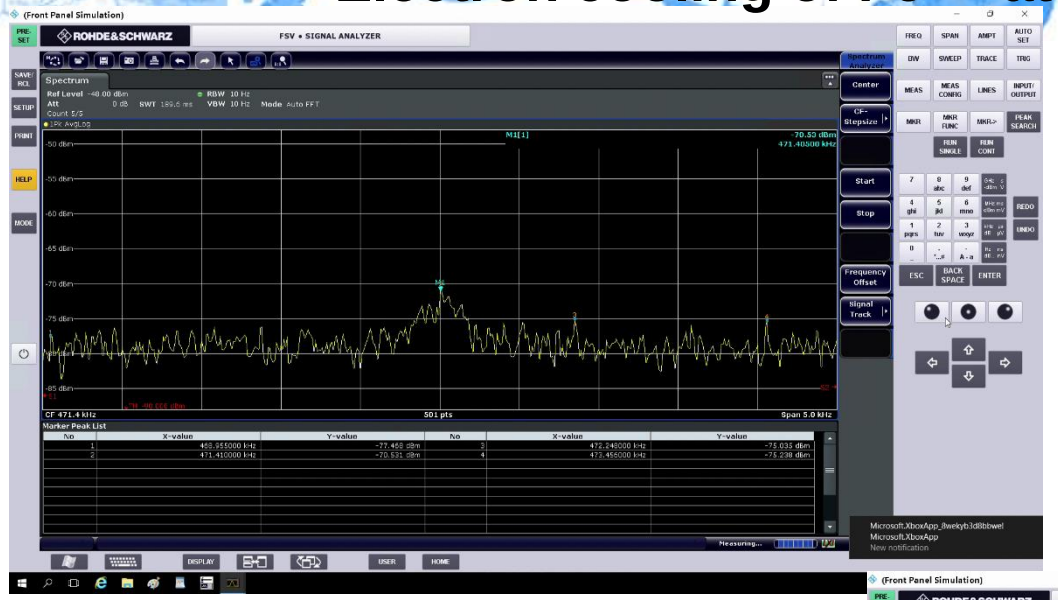
Parametric beam current transformer signal (DC mode)



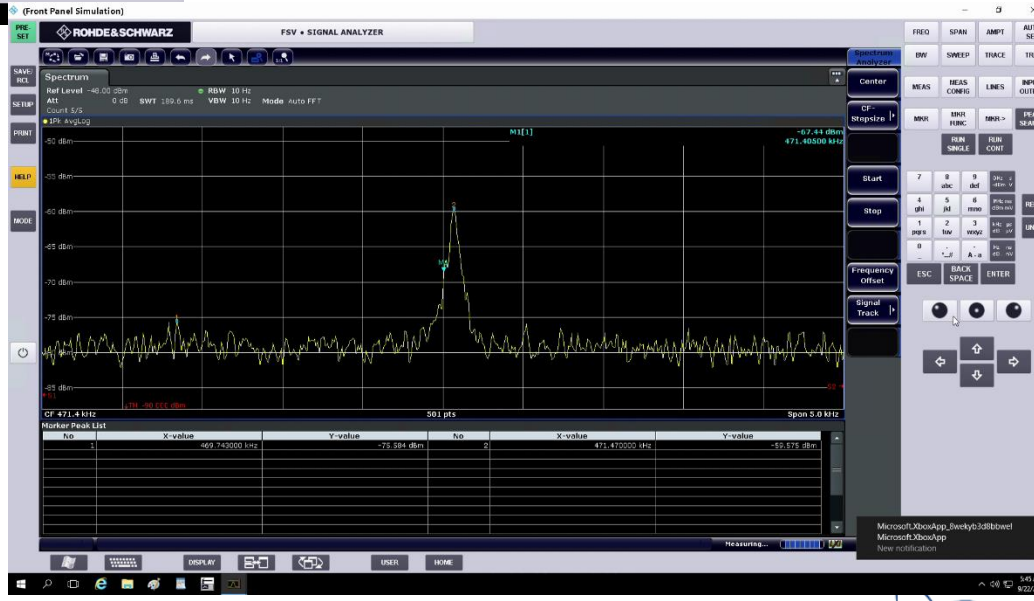
✓ ***Life-time up to 10 s (8x more), equivalent pressure of residual gas is about $5 \cdot 10^{-9}$ Pa***

Electron cooling section

Electron cooling of Fe^{14+} at 3.2 MeV/u during 2 s



Schottky spectrum at 4-th harmonics
WFHM dp/p=1.2E-3



Schottky spectrum, WFHM dp/p=4E-4

Design magnetic field amplitude & ramping rate

30.12.20: design magnetic field cycle

Nuclotron status

The project approved in 1986 year

Circumference ~251m, Br<43 Tm

Commissioning & fist beam March 1993 year

Slow extraction 2000 year

The last RUN #55 Feb. - April 2018

Booster-Nuclotron RUN January - March 2022

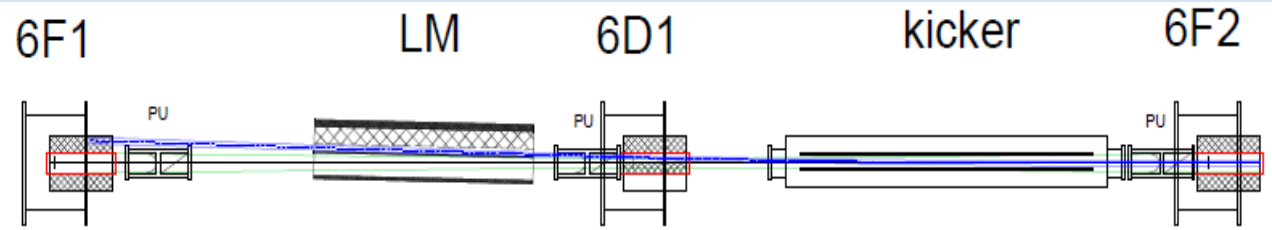
Accelerated:
Ions from p to Xe (C, Mg, Fe, Ar, Kr)
Polarized p & d beams

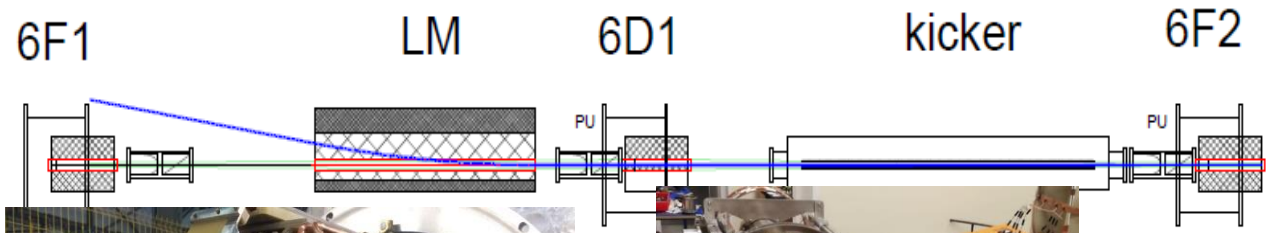
Proton energy	max 12 GeV
Light ions	max 6 GeV/u
Heavy ions	max 4.5 GeV/u

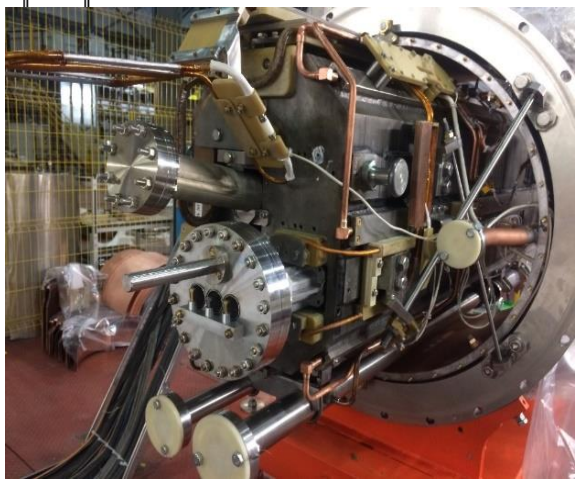
NICA

JINR

Beam injection system (Nuclotron)







- Lambertson magnet
10-11.2021
- 4-rod kicker
10-11.2021
- Testing & mounting
Nov.-Decem. 2021

- Peculiarity of Nuclotron injection system test

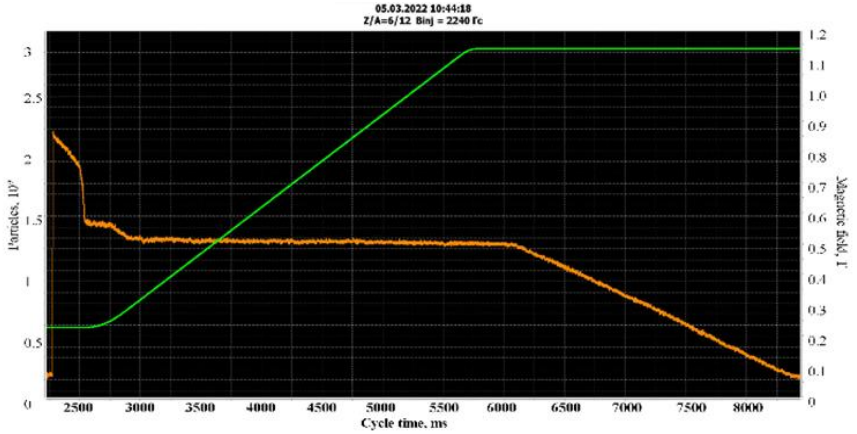
$$\Delta\theta = eB_p l_k / \beta\gamma m_p c^2$$

Power supply only for one kicker module

$B_{kick}=0,6B_{nom}$ $E_{inj}=300$ MeV/n, Ar, Kr bare nucleus

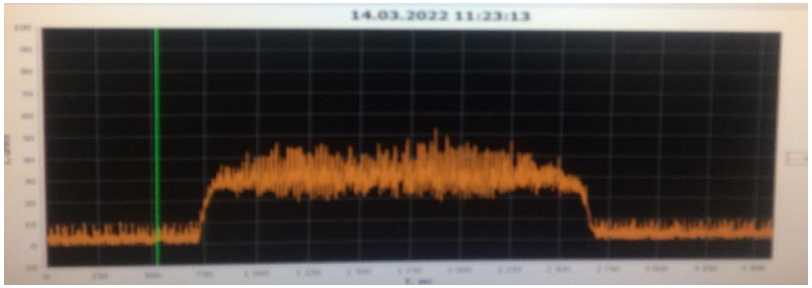
JOINT BOOSTER-NUCLOTRON RUN

January-March 2022 Booster-Nuclotron Run



The Booster intensity of $^{12}C^{4+}$ ion beam is equal to 3×10^9 particles. The $^{12}C^{4+}$ ions were accelerated up to the energy of 263 MeV/n, extracted, fully stripped and directed to the new Booster-Nuclotron transfer line.

Ions were injected to Nuclotron and accelerated up to the energy of 2.8 GeV/n. Finally, the ions were extracted with slow extraction and directed to the fixed target of the Short-Range Correlation experiment which studied collisions of $^{12}C^{6+}$ nuclei with the hydrogen target in BM@N.



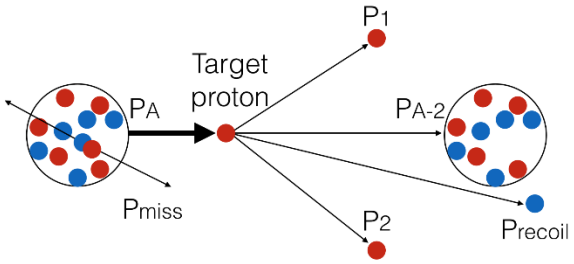
Extracted carbon ion beam for SRC experiment

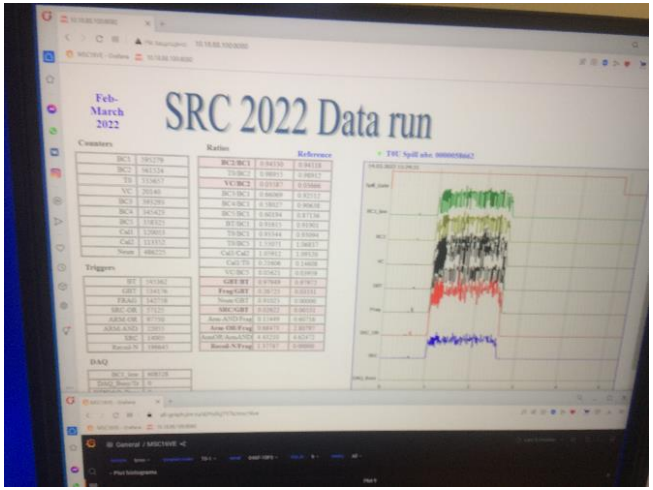
SRC Experiment at BM@N

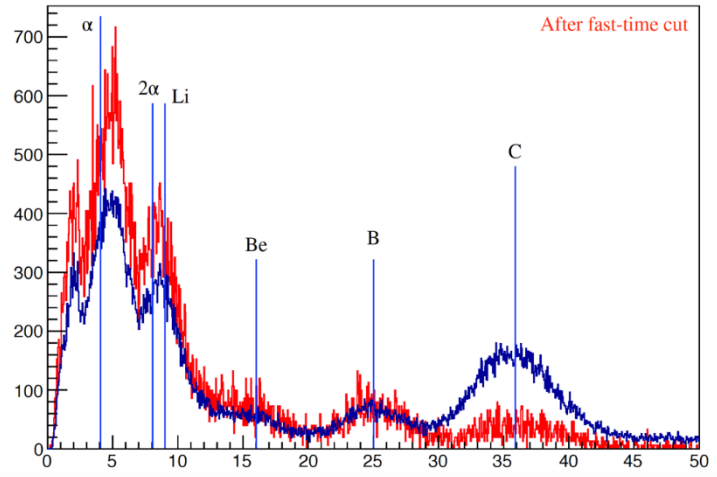
C^{6+} run Booster-Nuclotron-BM@N
February-March 2022.

Baryonic Matter at the Nuclotron

Short Range Correlation Experiment in inverse kinematics
185 mln. Trigger events in 3,5 times larger than in 2018.







Results of SRC run in 2018.
Dependence of number events on square charge.
Blue line for all events, red line - for events with pair of scattered protons.

NICA

JINR

Nuclotron - BM@N beam line

►Upgrade of Nuclotron - BM@N transport channel for heavy ion program:

→ replace air intervals / foils with vacuum beam pipe along 160 m of BM@N transport line to get minimum dead material

►Replacement of transformers, 35 power supplies and cables to power magnetic elements of the transport channel

Reconstruction of old cables in 205

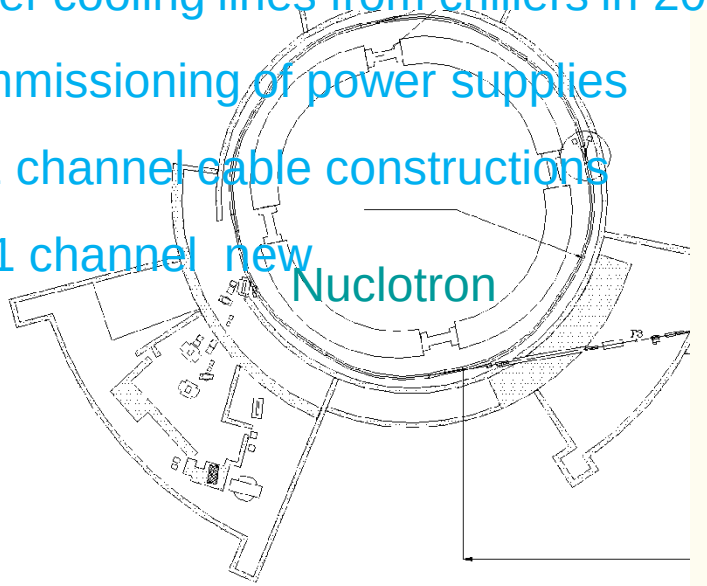
Cabling between 108 and 111 rooms in 205

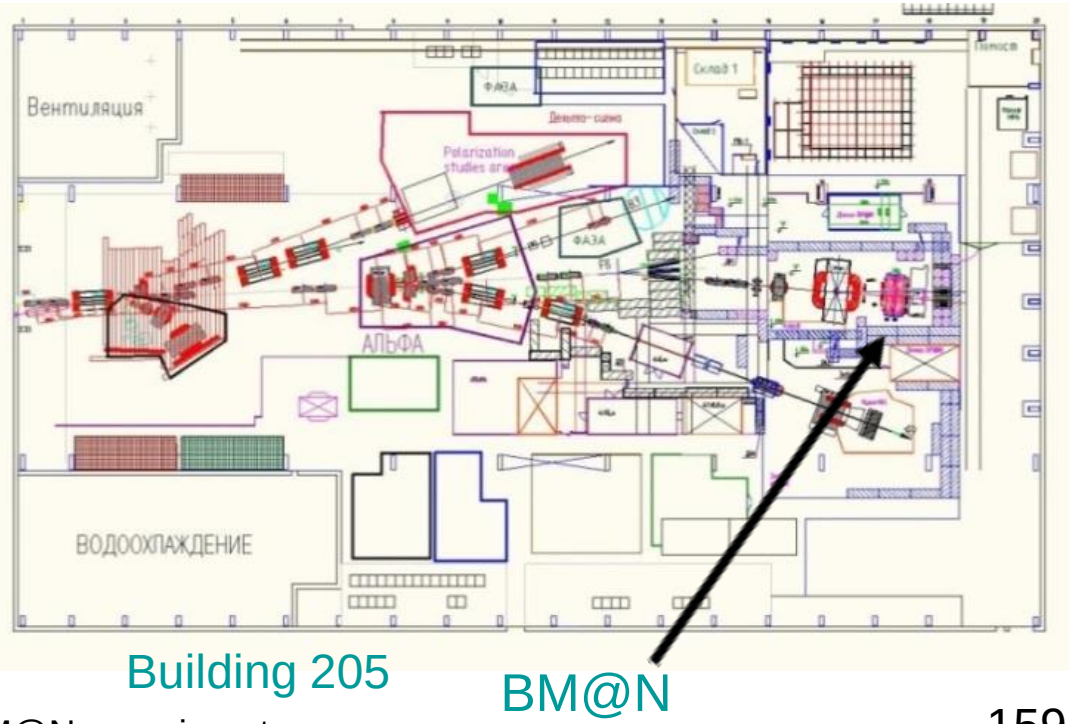
Water cooling lines from chillers in 205

Commissioning of power supplies

BV1 channel cable constructions

BV1 channel new





NICA Collider

Collider parameters:

Circumference -503.04 m, Magnetic regidity - 45 T·m; B=1,8 T

-Ion Bi^{83+}, kinetic energy 1-4,5 GeV/u, polarized deuterons - 6 GeV/u/н, protons – 12 GeV

Luminosity 10^{27} $sm^{-2}\cdot s^{-1}$ for ions Bi^{83+} at $\sqrt{s_{NN}}$ = 9 GeV, polarized protons -10^{32} $sm^{-2}\cdot s^{-1}$.

All 80 dipole magnets were constracted

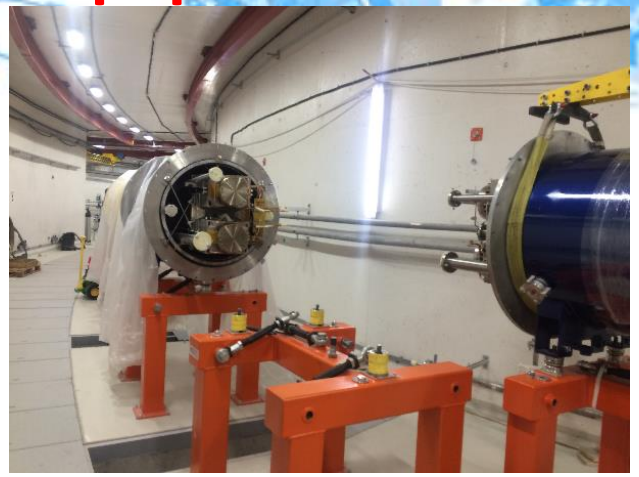
Start of mounting – December 2021.

Technological run- August 2023:

Magnetic field -1 T, vacuum - 10^{-10} Torr

RF and Electron cooling system in BINP

Mounting of Collider equipment



Mounting of Collider magnets in Kollider tunnel was started in December2021

MPD mounting

To provide technological Collider run all magnets, 8 RF2 stations, 2 RF1 stations, vacuum system should be installed.

The next systems should be under operation

Control system

Thermometry and monitoring system

Detection system of transition from superconducting to normal phase

Cycling system

Power supplies of magnetic elements

Evacuation of energy

Vacuum system

RUNS 2022-2023

1. Booster-Nuclotron Run, January –March 2022
Laser source-HILAC-Booster- Nuclotron
Short Range Correlation -C ions

2. Booster-Nuclotron Run, September-December 2022,
KRION-6T-HILAC-Booster-Nuclotron,
BM&N- Xe ion beams

3.May-June 2023, KRION-6T-HILAC-Booster-Nuclotron
BM&N- Xe ions
or
August 2023, Technological run of Collider

4.December 2023, HILAC-Booster-Nuclotron-Collider beam run

THANKS FOR YOUR ATTENTION

NICA

JINR