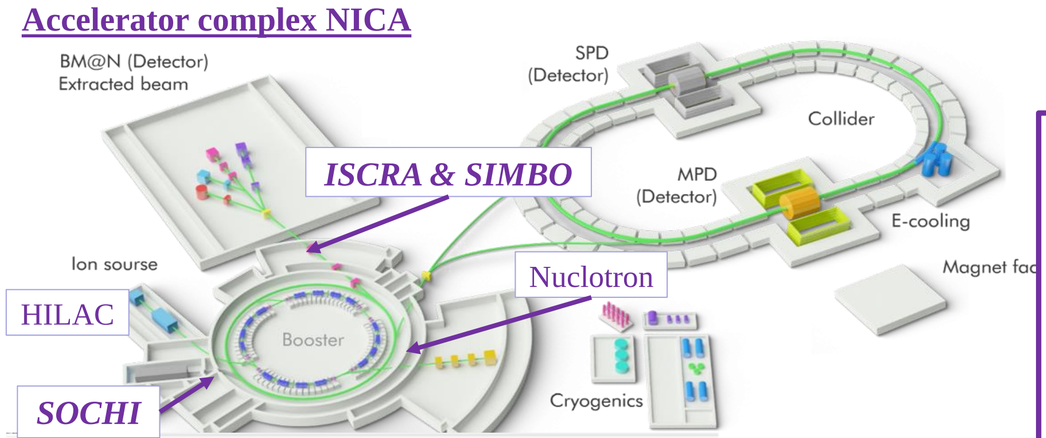
Filatov G. A.

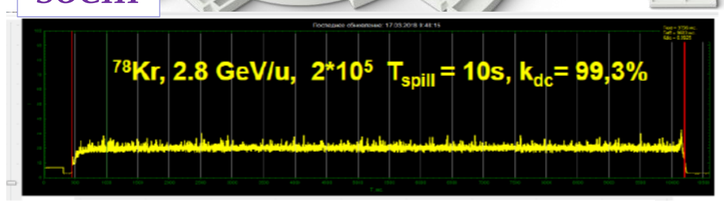
Beam lines development and construction at NICA. SOCHI beam line physical start-up.

JOINT INSTITUTE FOR NUCLEAR RESEARCH

Abstract: As part of the NICA project, an Innovation Block focusing on applied research is being set up. That requires beam shaping and transport from the accelerators to the target stations for applied research. To do this, new beam lines are being calculated and built with the engineering infrastructure (including stations, biological shielding and engineering lines). The NICA accelerator complex includes the HILAC (Heavy Ion Linear Accelerator) and the Nuclotron (superconducting synchrotron), on which the channels for applied research are based. The technical highlights of the beam lines and the SOCHI beam run results are given in this work.

Accelerator complex NICA





Spill of Kr ion beam extracted from Nuclotron

Peculiarities: long pulse duration and very good uniform extracted beam distribution in time

STATIONS:

- ***ISCRA*** — ***I****rradiation* ***S****etup for* ***C****omponents of* ***R****adioelectronic* ***A****pparature, is designed for radiation hardness testing of microelectronic products (capsulated chips);*
- ***SIMBO*** — ***S****etup for* ***I****nvestigation of* ***M****edical* ***B****iological* ***O****bjects is designed for Radiobiological Researches;*
- ***SOCHI*** — ***S****tation* ***O****f* ***Chi****p* ***I****rradiation (SOCHIis used for radiation hardness testing of microelectronic products (decapsulated chips).*
- The stations diagnostics are represented by a set of different types of detectors for setting up and monitoring the beam during the experiment (ionization chambers, scintillation-fibre detectors, microchannel plate-based detector, etc.). The detectors are movable. Object positioning systems are attached to the stations. The design of the four movable detectors allows measurement of the flux density in the beam halo for real-time monitoring of beam parameters.

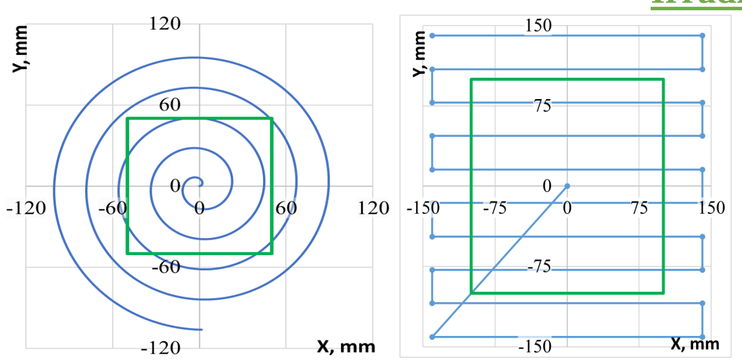
Beam parametrs	SIMBO	ISCRA	SOCHI
Ion type	$^{40}Ar^{18+}$, $^{56}Fe^{26+}$, $^{84}Kr^{36+}$		$^{12}C^{4+}$, $^{40}Ar^{10+}$, $^{131}Xe^{22+}$,
	$^{12}C^{6+}$	$^{131}Xe^{54+}$, $^{197}Au^{79+}$	$^{84}Kr^{14+}$, $^{169}Tm^{21+}$, $^{197}Au^{31+}$, $^{209}Bi^{34+}$
Ion energy, MeV/n	400-1100	150-425	3,2
Beam intensity, particles per pulse	10^6-3×10^9	3×10^4-10^8	10^8-6×10^9
Beam emittances (95%), $\varepsilon_x/\varepsilon_y$ (π·mm·mrad)	3-10/ 8-15	5-17/ 13-25	10/10
Mean particles flux density, particles/(cm^2.s) at the target	10^3-10^5	10^2-3×10^5	10^3-10^5
Pulse time	2-20 s		0.5-8 μs

Beam lines based on Nuclotron beams.

Irradiation modes

With scanning magnets

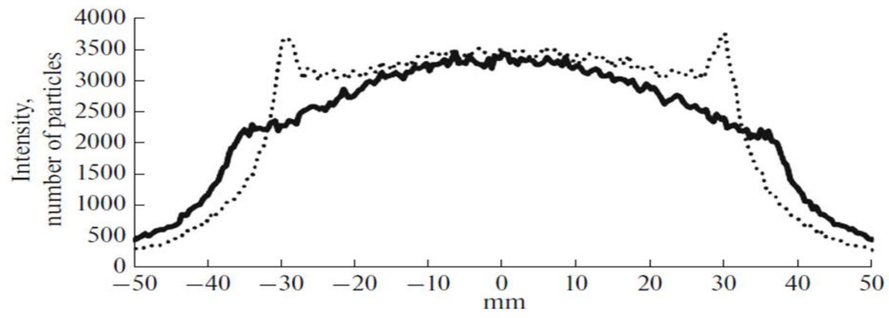
A spiral and a line scanning mode will be used. A pair of orthogonal scanning magnets produce particle distribution profile with a large target area up to 200×200 mm^2 (ISCRA) and 100×100 mm^2 (SIMBO). The beam dynamics calculations for the 3-Hz repetition frequency showed that the beam homogeneity at the targets is better than 5%.



With octupole magnets

To reach beam homogeneity on the target better than 10% two octupole magnets are required in ISCRA beam transfer line.

Transverse particle distribution in horizontal (dotted) and vertical (solid) planes on the target as a function of transverse coordinates.



Equipment and infrastructure

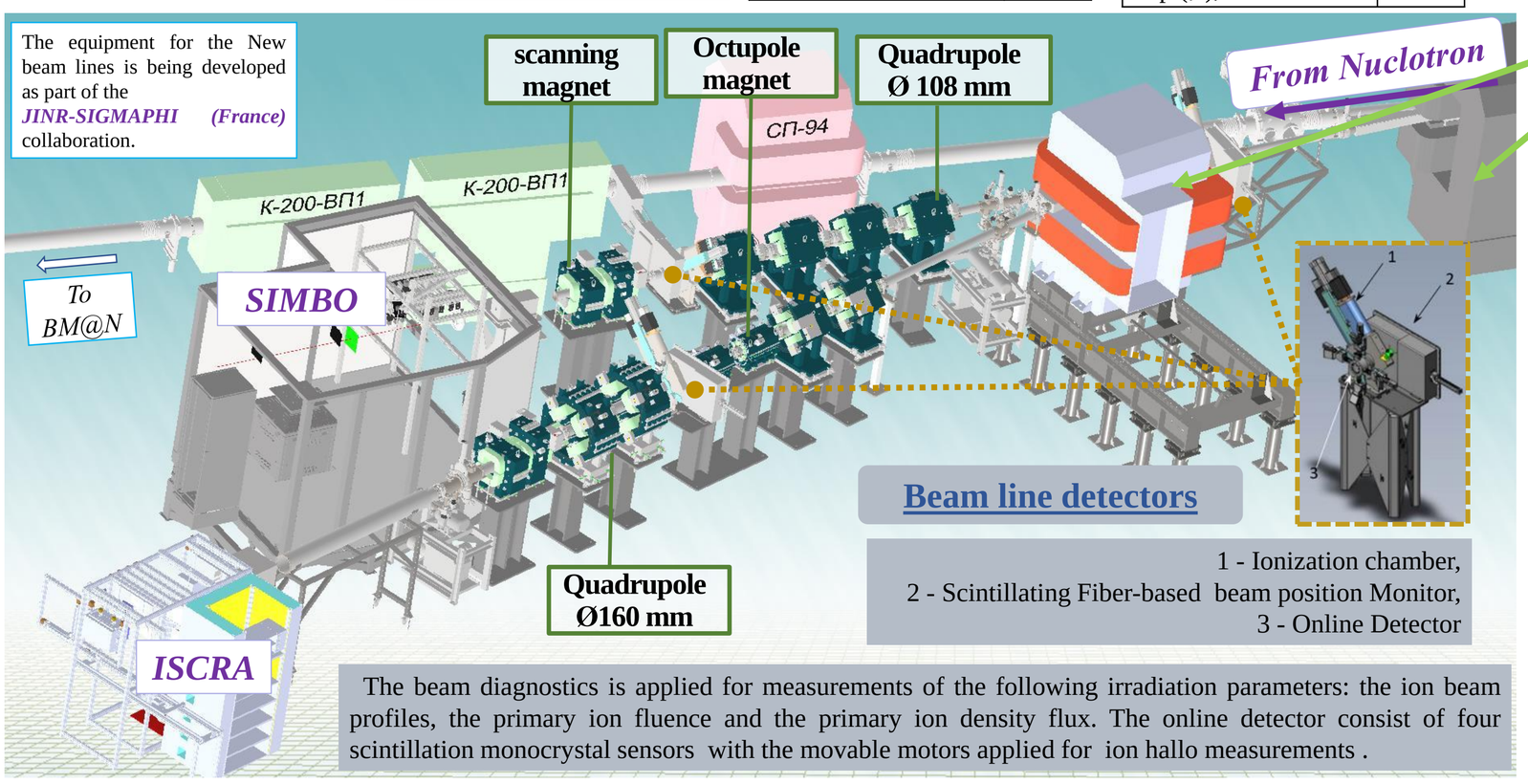
Scanning magnet	
Type of power source	0.5-3Hz
Effective length, m	0.35
Max. magnetic field, T	0.8
Gap, mm	140

Octupole	
Type of power source	DC
Effective length, m	0.5
Max. Gradient, T/m^3	1.4
Gap (Ø), mm	105

Quadrupole (Ø 108)	
Type of power source	DC
Effective length, m	0.49
Max. Gradient, T/m	5.4
Gap (Ø), mm	108

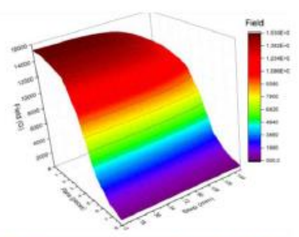
Quadrupole (Ø 160)	
Type of power source	DC
Effective length, m	0.48
Max. Gradient, T/m	1.4
Gap (Ø), mm	160

The equipment for the New beam lines is being developed as part of the ***JINR-SIGMAPHI*** ***(France)*** collaboration.



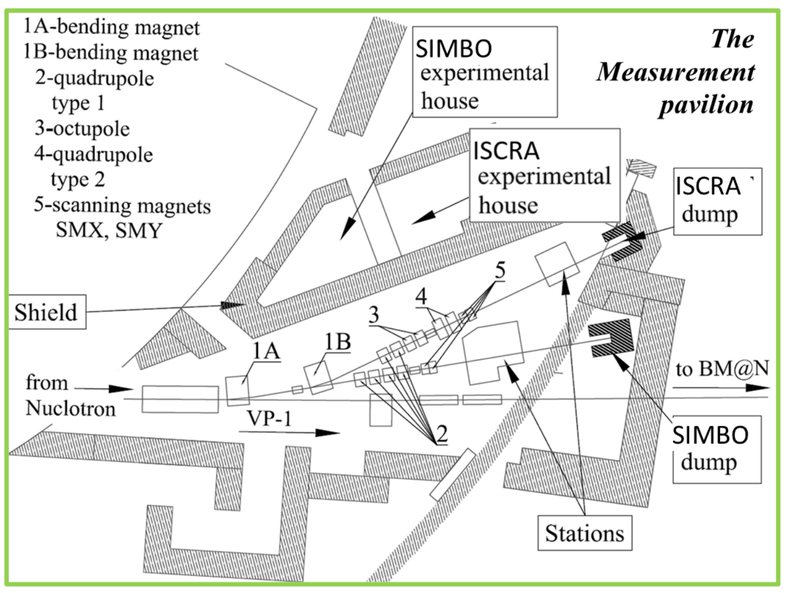
The beam diagnostics is applied for measurements of the following irradiation parameters: the ion beam profiles, the primary ion fluence and the primary ion density flux. The online detector consist of four scintillation monocrystal sensors with the movable motors applied for ion hallo measurements .

JINR Dipole Magnets



3 D magnetic field Map of dipole magnet

Infrastructure scheme



✓ **All power supplies for the SIMBO and ISCRA magnets (except those used for the scanning magnets) will be delivered to JINR at the end of 2021.**

SOCHI PHYSICAL START-UP

SOCHI BEAM DESIGN

❑ **high beam current** of few mA coming from the HILAC-Booster channel

different foil (50 μm stainless**) target holes:**

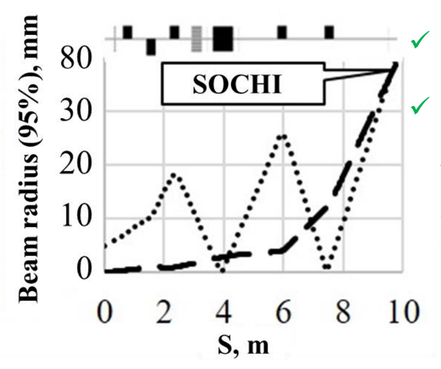
- ❖ 20; 234 holes ⌀ 30; 30x15 μm; Step: 700; 150 μm
- ❖ 35x0.26;
- ❖ 35x0.03 mm

by means of collimator

✓ **beam currents of nA**

the dose rate should not exceed 1 rad/μs to not distort test results

❑ **Leads to small beam size (30 μm)**



✓ **target area 20×20 mm**

✓ **homogeneity 10%**

beam size is more 70 mm (In radius)

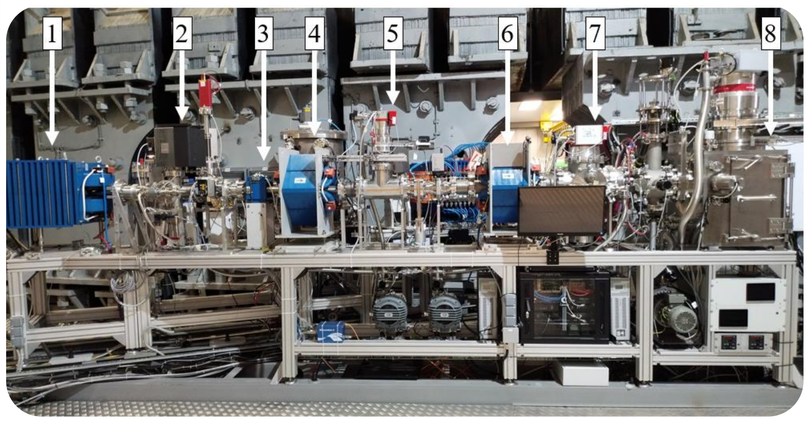
horizontal (dotted) and vertical (solid) planes

by means of optics setting

○ The volume with microchips samples have a high level of gas flow and low vacuum level

• Vacuum system in the SOCHI station and(or) beam lines

✓ **prevent spoiling the vacuum condition in the HILAC-Booster beam line**



1 - dipole magnet, 2 - third vacuum post, 3 - corrector, 4 - first quadrupole lens, 5 - second vacuum post, 6 - second quadrupole lens, 7 - first vacuum post, 8 - SOCHI station.

Dipole magnet (1)	
Effective length, m	0.65
Max. magnetic field, T	1
Gap, mm	45

Steerers (3)	
Effective length, m	0.25
Max field, T	0.05
Gap, mm	125 × 110

Quadrupole lenses (4, 5)	
Effective length, m	0.29
Max. gradient, T/m	10
Gap (diameter), mm	95

✓ **the residual gas pressure is lower than the pressure in the HILAc-Booster channel (10^{-6} Pa)**

✓ **The magnet pulsed operating mode reduces the rms current density**

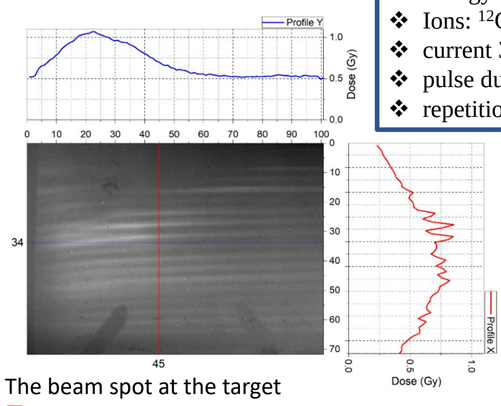
✓ **therefore the air-cooling of the magnet coils**

✓ **A power supply cabinet was assembled for the magnets.**

December 2021

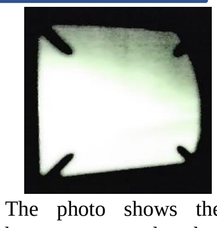
Beam from HILAc:

- ❖ Energy: 3.2 MeV/n
- ❖ Ions: $^{12}C^{4+}$
- ❖ current 3.5 mA,
- ❖ pulse duration 3 μs,
- ❖ repetition frequency 4 s.



The beam spot at the target

❑ **nonuniform structure of the striped character**

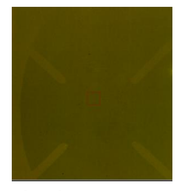


The photo shows the beam spot on a phosphor detector. Shadows from the system for online.

October 2022

Beam from HILAc:

- ❖ Energy: 3.2 MeV/n
- ❖ Ions: $^{40}Ar^{12+}$
- ❖ current 60 μA,
- ❖ pulse duration 5 μs,
- ❖ repetition frequency 4 s.



The beam spot at the target

✓ **Essentially improved beam structure**

✓ **The microchip was irradiated**

Conclusion

In December 2021, the physical start-up of the beam line and SOCHI station was carried out. In October 2022, the start-up of SOCHI station was continued. The new SIMBO and ISCRA application channels are planned to start testing at the end of 2023.