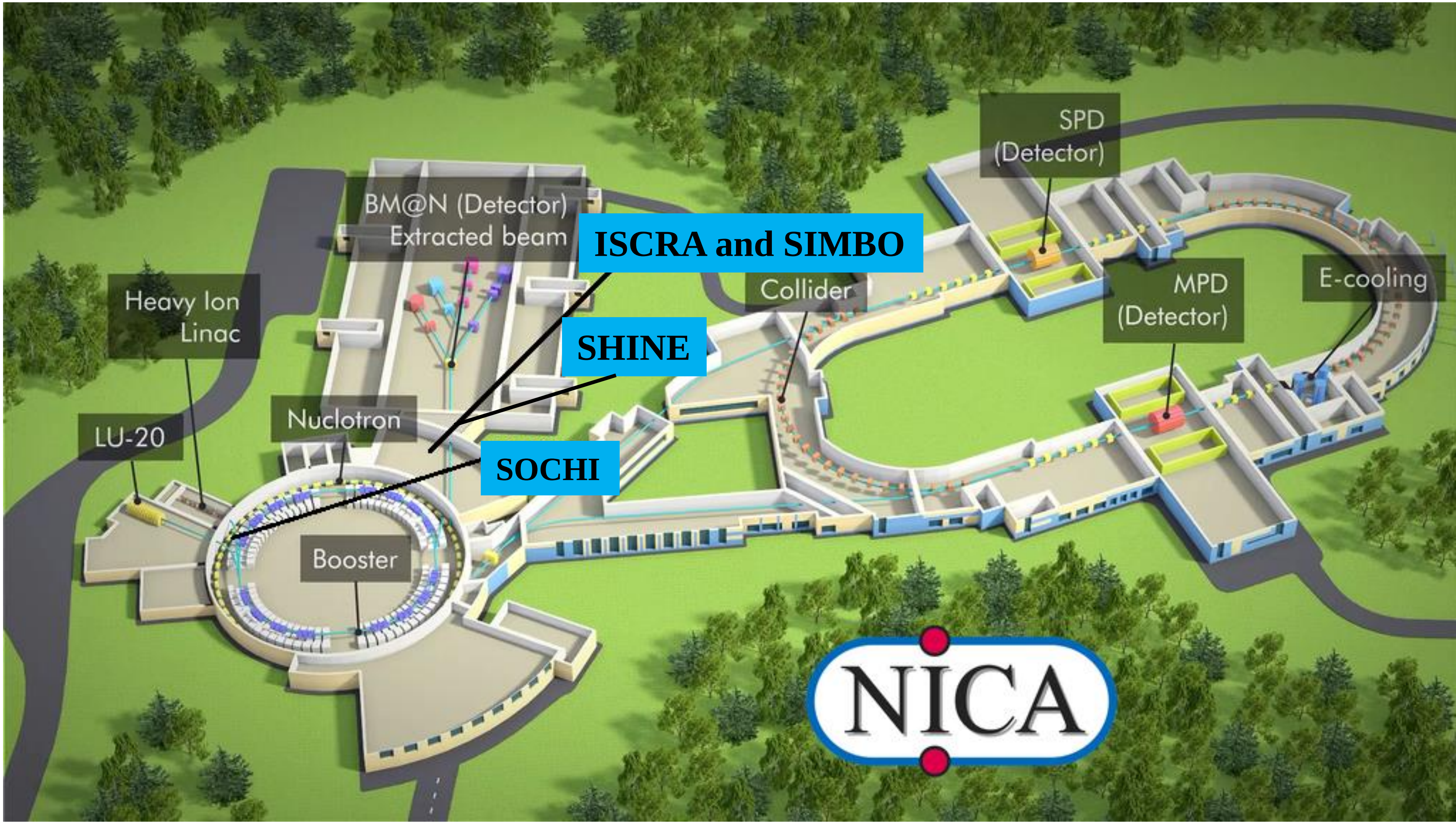
Status of areas for applied researches at the NICA complex

E.Syresin on behalf of team



Three innovation zones of NICA Accelerator complex

Zone–1. Ion beams of low energy at HILAC, 3.2 MeV/u	Zone–2. Nuclotron Ion beams of intermediate energies, 150-1000 MeV/u	Zone–3. Nuclotron Ion beams of high energies, 4.5 GeV/u
Radiation damages at microelectronic **S**tation **O**f **CH**ip **I**rradiation (**SOCHI**).	Radiation damages in microelectronic: **I**rdiation **S**tation of **C**omponents of **R**adioelectronic **A**pparatuses (**ISCRA**). Radiobiological Researches: **S**tation of **I**nvestigation of **M**edico-**B**iological **O**bjects (**SIMBO**)	Relativistic Nuclear energetic: **S**tation of **H**igh Energy **I**nvestigation in **N**uclear **E**nergetic (**SHINE**)

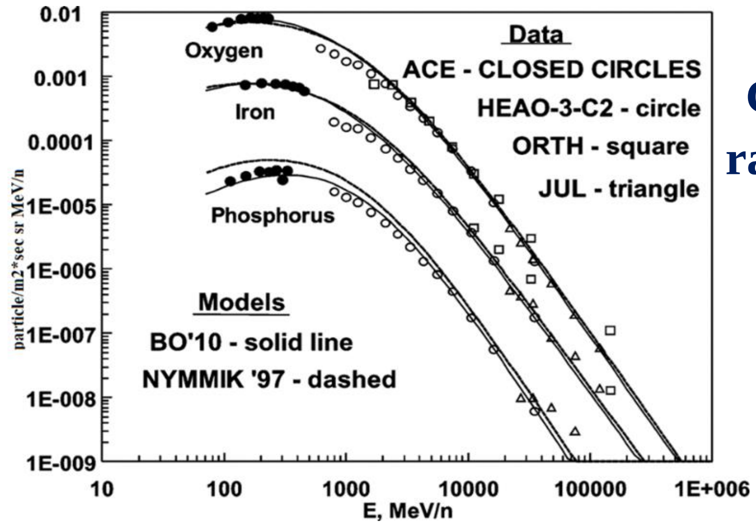
Budget and schedule of applied researches at NICA

Budget of applied researches

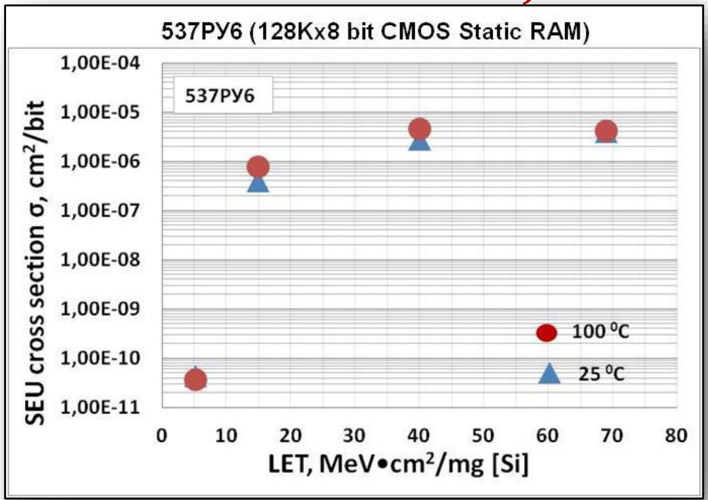
Applied researches	Total Budget, Million $	Total Budget, Million, Rub
Budget of innovation zones		
High energy ion chip irradiation, ISCRA	4.761	320.00
High energy ions, radiobiology, SIMBO	3.773	258.00
Nuclear energetic, SHINE	5.370	370.00
Total	13.904	948.00
Budget of engineering and scientific infrastructure		
Low energy ion chip irradiation, SOCHI	1.696	108.36
Total budget	15.600	1056.36

Construction – Autumn of 2019- Winter of 2022
Assembling- Autumn 2021-Summer of 2022
Commissioning- Spring -Autumn of 2022
Beam runs- Summer- Autumn 2022

LOW ENERGY ION CHIP IRRADIATION, SOCHI

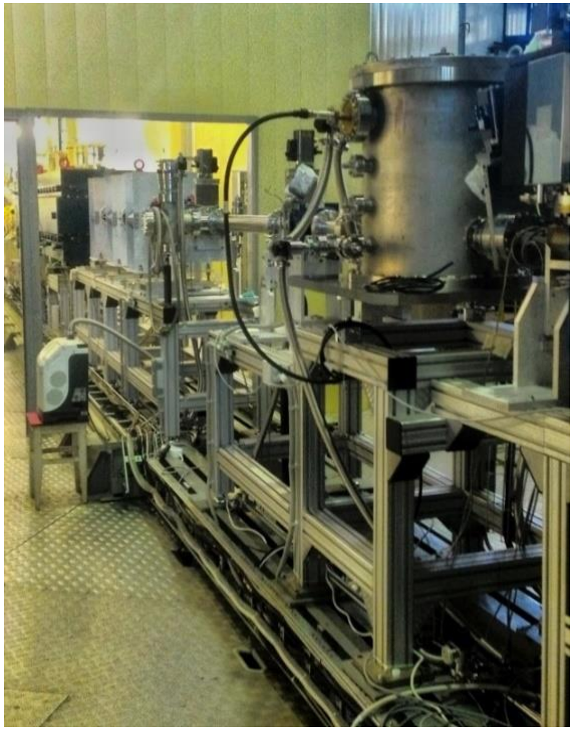


Galactic cosmic rays: protons and ions Z=2 to 92

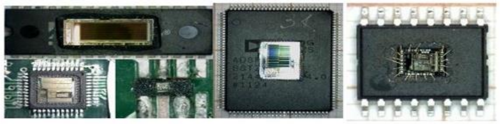


Dependence of the thyristor effect cross section in microchip on ion LET

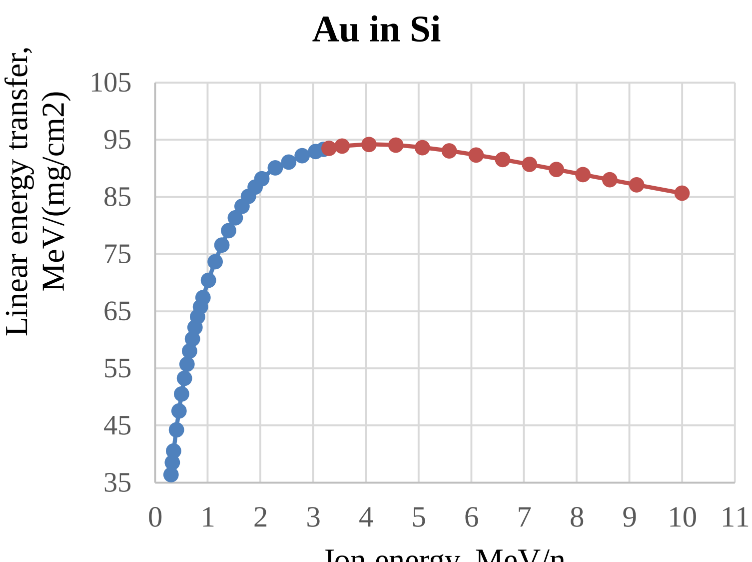
The SOCHI experimental station designed for decapculated chip irradiation by low energy ions extracted from the HILAC at energy 3.2 MeV/n



The HILAC-Booster beamline

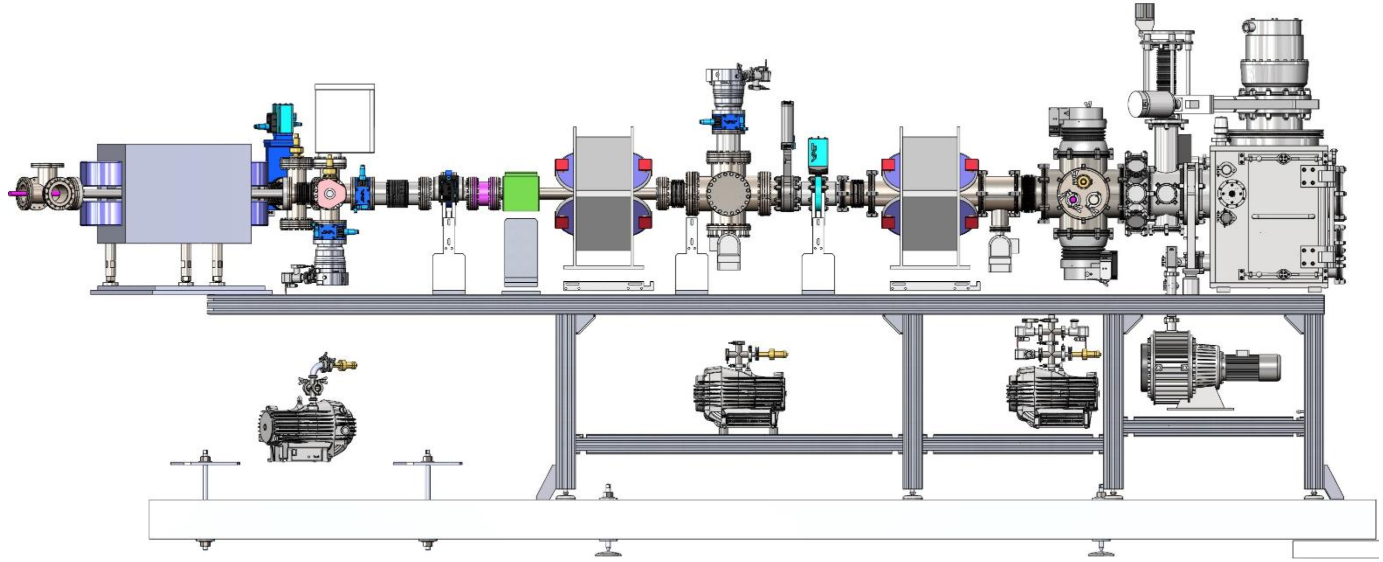


Chip decapculation



LET dependence on Au ion energy in Si chip

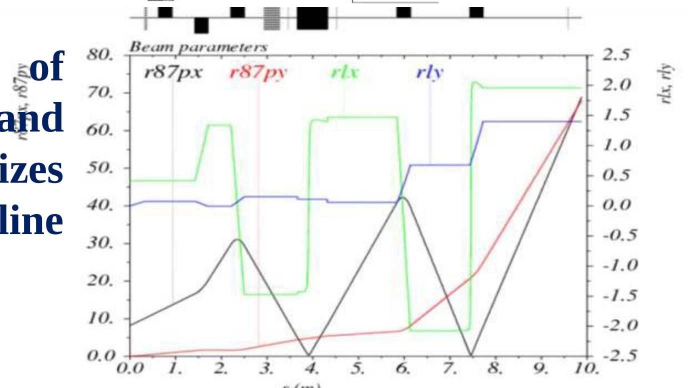
STATION SOCHI FOR LOW ENERGY ION CHIP IRRADIATION



Beam diagnostic consists of equipment operating in «tuning» and «irradiation» modes. The equipment measures ion flux density, intensity, fluence, beam profile: it involves micro channel plate detector, scintillation-fiber detectors, semiconductor detector, four on-line control scintillation detectors.

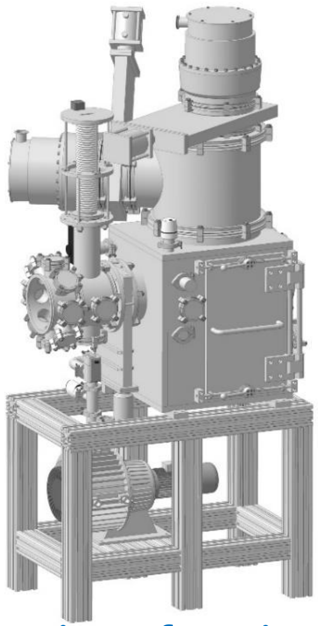
Vacuum pressure in SOCIT is 10^{-5} Torr and by 3 orders of magnitude is higher pressure in the HILAc-Booster transfer line. To solve this problem, a cryogenic traps, a pulsed diaphragms and turbo pumps will be installed.

Dependences of horizontal and vertical beam sizes on the beamline longitudinal coordinate.



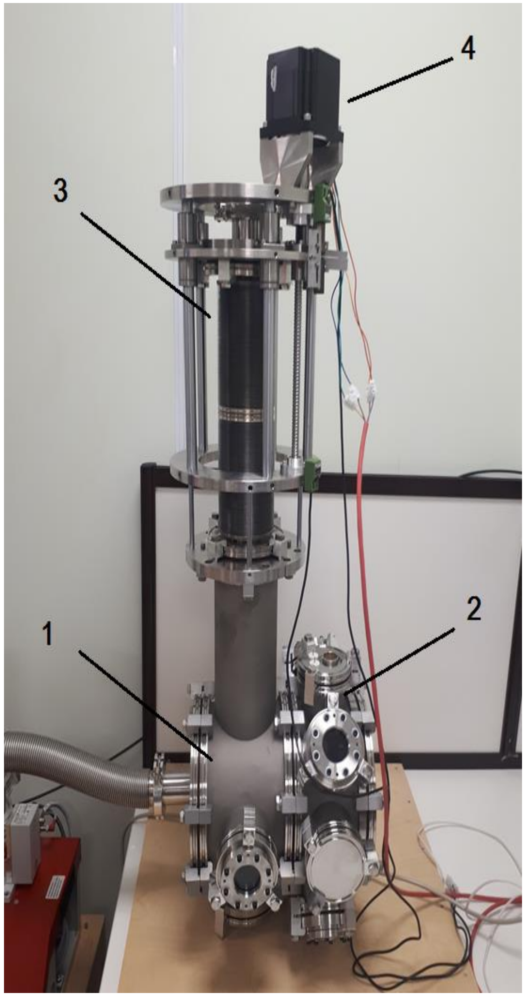
The ionization dose of HILAC beam pulse should be less than 1 rad/μs in the silicon chip. This requires to reduction of the HILAc beam current from few mA to several hundreds of nA at the chip irradiation. A diaphragm with several holes of 20 μm will be installed to reduce beam current by 4 orders of magnitude. Beam FWHM on target is 73 mm, beam density homogeneity is larger 90% on chip size of 20×20 mm.

STATION SOCHI FOR CHIP IRRADIATION BY IONS OF LOW ENERGY

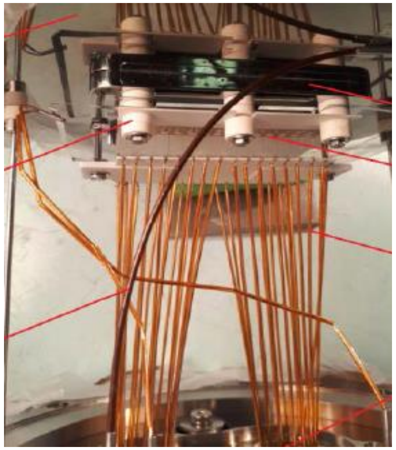


Design of station SOCHI

STATION SOCHI



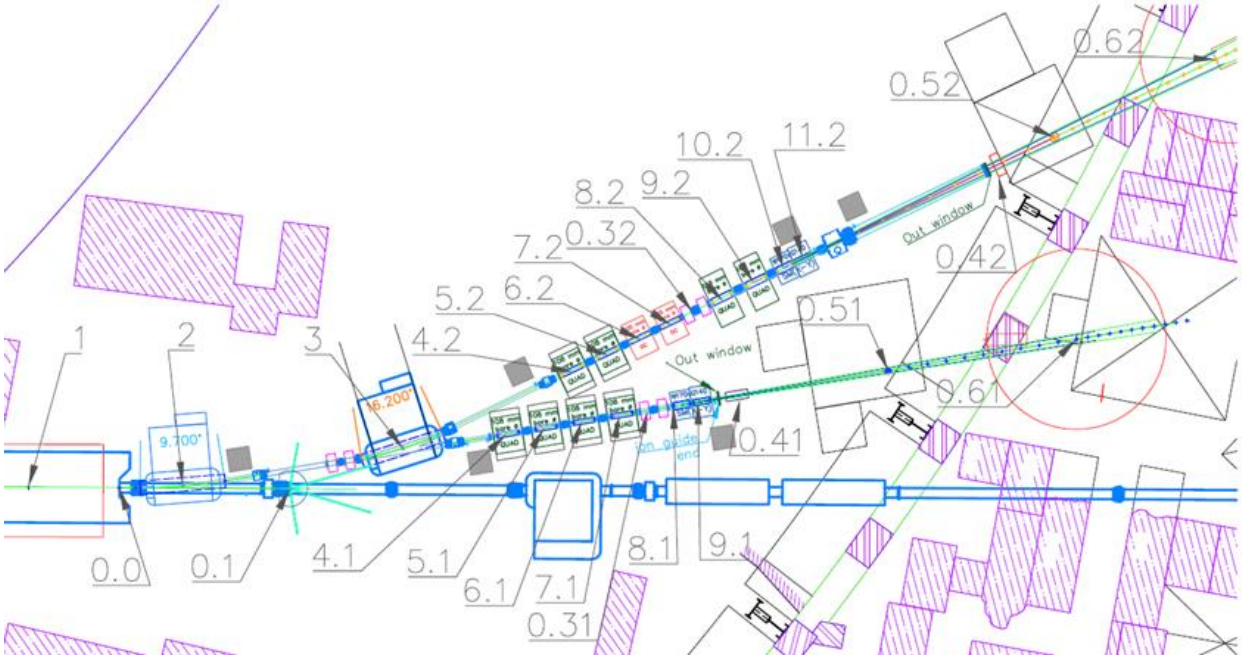
Detector vacuum chamber for installation of scintillation detectors, Micro-channel plate detector, cylinder Faraday.



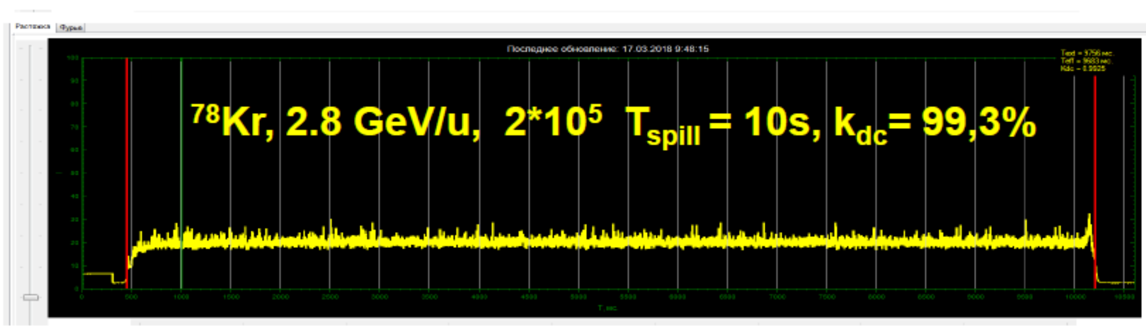
MCP detector

SOCHI equipment construction by JINR-ITEPh was started in 2020,
Assembling is planed in Autumn 2021,
Commissioning - Spring 2022,
Tests Beam Runs - Summer 2022

NEW NUCLOTRON BEAM LINES FOR ISCRA AND SIMBO STATIONS



New Nuclotron beamlines applied for radiobiological researches and chip irradiations



Spill of Kr ion beam extracted from Nuclotron

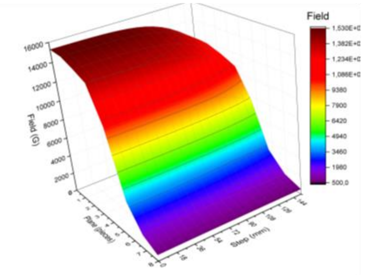
Peculiarities are: long pulse duration and very good uniform beam distribution in time

Heavy ion beams from the Nuclotron will be used for irradiation of capsulated chips. and radiobiological researches

MAGNET SYSTEM OF APPLIED CHANNELS

	Scanning	Quadrupole		Octupole
Parameter	SMX/SMY	Type 1	Type 2	
# magnets	2+2	6	2	2
Gap/bore (mm)	140	108	160	105
Field/Gradient (T, T/m, T/m^3)	±0.8	0.6-5.4	0.2-1.4	1098
L_{eff} (mm)	356±4	492±2	480±2	505±3
Good Field Region (mm)	H×V 60 x 60	Ø 100	Ø 128	Ø 90
Rel. integrated field error x10^{-3}	< ±5	< ±5	< ±5	< ±5
Operating mode	Scanning f=0.5-3 Hz	DC	DC	DC

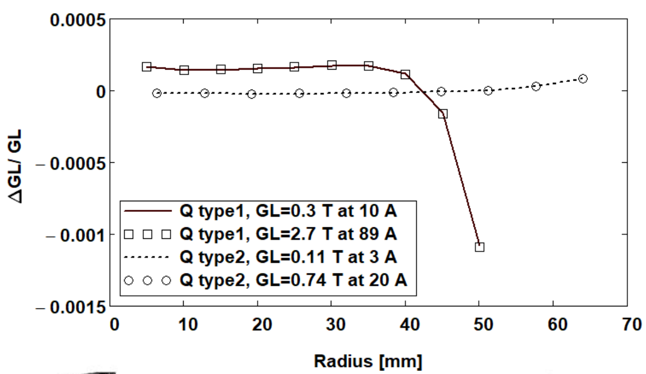
JINR Dipole Magnets



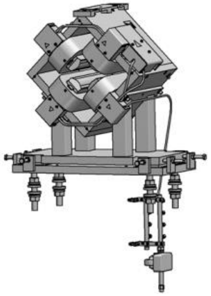
3 D magnetic field Map of dipole magnet

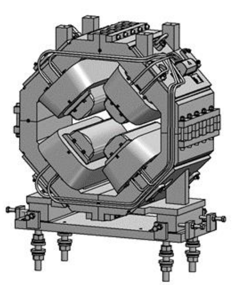
Sigma-Phi (France) starts construction of Magnetic system in June 2020

Quadrupoles

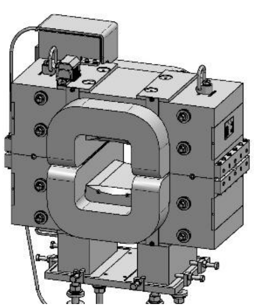


Relative errors of integrated average gradient in the median plane for type 1 and type 2 quadrupoles at min. and max. values of excitation current.

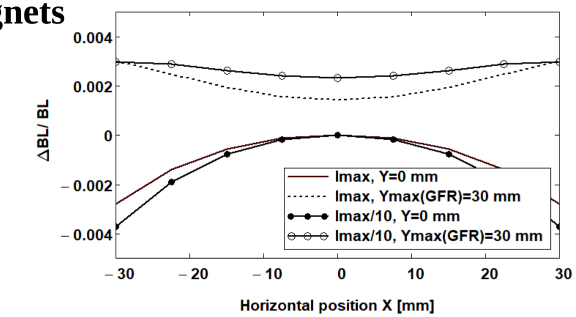




Scanning magnets



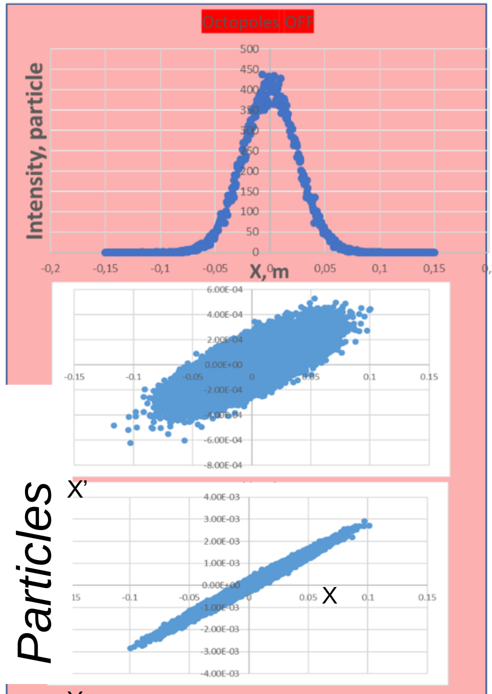
Mechanical layout of the scanning magnets

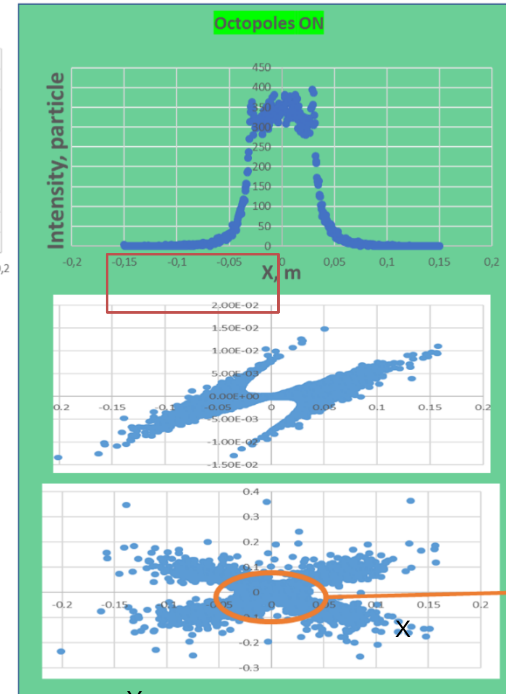


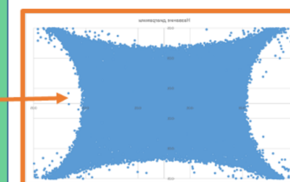
Relative integrated field errors inside the good field region for two values of excitation current

ISCRA beam line. Particle tracking. Octupoles. Uniformity.

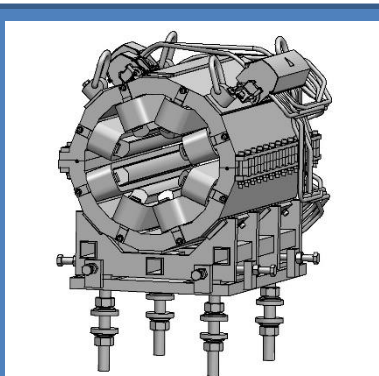
In ISCRA channel, two octupole magnets are also required to reach Beam homogeneity on the target better than 10%





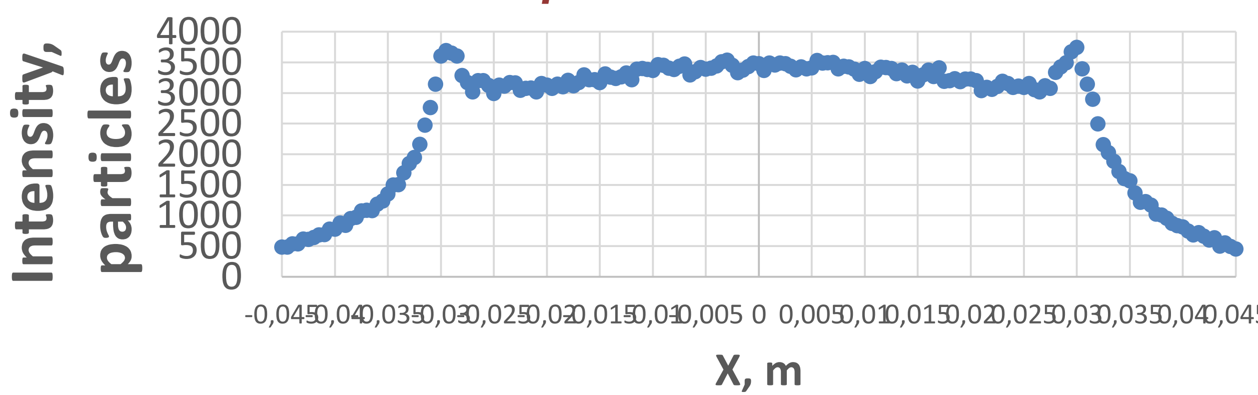


50000 Particles



Mechanical layout of **the octupole magnet**

5·10⁵ particles



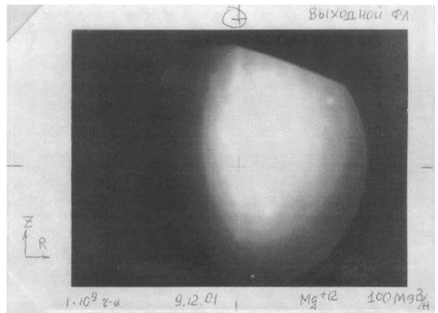
Sigma-Phi (France) plan to finish construction in Summer of 2022.
Commissioning and first beam run is planed in Autumn of 2022

RADIATION TESTS OF MICROELECTRONIC FOR ITALIAN-RUSSIAN-SHWEDEN SPECTROMETER PAMELA

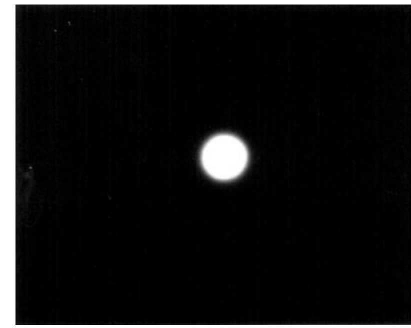
Baikonur, June, 2006
Spectrometer Pamela was launched

Spectrometer PAMELA was used for researches of antiparticles (antiprotons, positrons)

Radiation tests of Spectrometer Pamela microelectronics by extracted from Nuclotron Mg ion beams at energy 150 MeV/n in December 2001

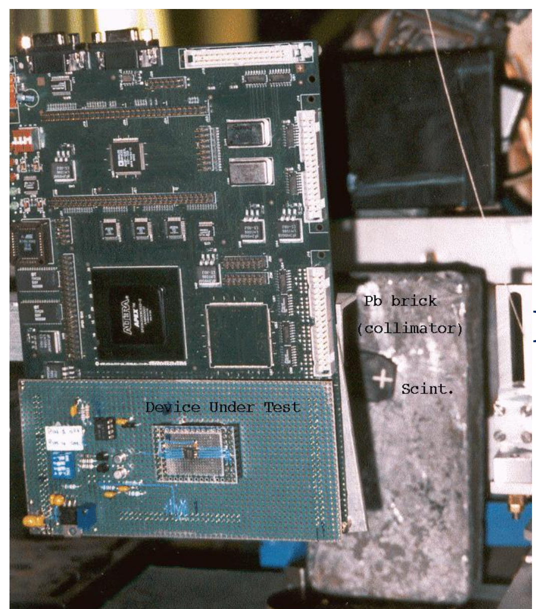


Mg ion beam before collimation



Mg ion beam after collimation

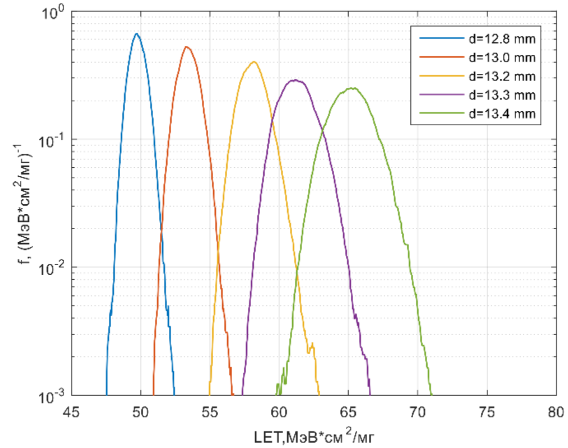
Pamela radiation test at Nuclotron



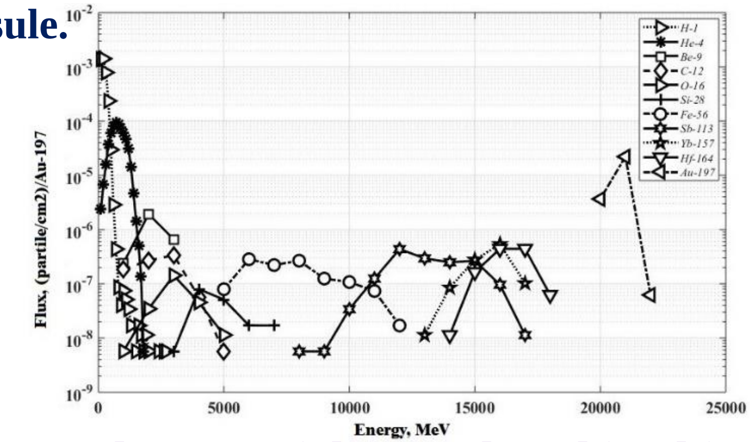
Pamela microelectronic at Nuclotron radiation test

INTERMEDIATE ENERGY ION CHIP IRRADIATION, ISCRA

Ion beam requirements	
Ion types	$^{12}C^{6+}$, $^{40}Ar^{18+}$, $^{56}Fe^{26+}$, $^{84}Kr^{36+}$, $^{131}Xe^{54+}$, $^{197}Au^{79}$
Ion energy, MeV/n	150-350
Ion flux density, particle/(cm²·s)	10^2 .. 1×10^5
Fluence per session, ion/(cm²)	10^7
Area of chip irradiation of 20×20 mm without scanning, mm	∅30
Flow uniformity at chip irradiation of 20×20 mm without scanning	10%
Exposure area in scan mode, mm	200×200
Flux uniformity at scan irradiation	±15%
FWHM beam diameter at target, mm	25-73
Range of LET (Si)	1…70 MeV·cm²/mg



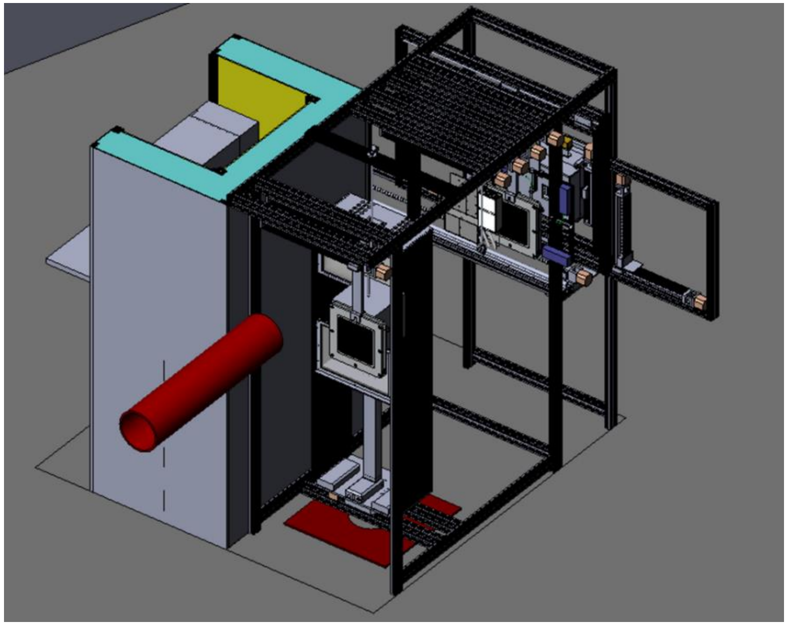
LET corresponds to 60-70 MeV×cm²/mg for ions $^{197}Au^{79}$. A reduction of maxim LET is related to effect connected with ion transition trough chip capsule.



Secondary particles produced in chip capsule give an influence on LET value

Heavy ion beams from the Nuclotron will be used for irradiation of capsulated chips. The ions like $^{197}Au^{79+}$ at the energy of 150-350 MeV/u are decelerated in the surrounded microchip capsule to the energy of 5-10 MeV/u corresponding to the Bragg peak.

ISCRA – Station of Capsulated Chip Irradiation by Heavy Ions of Intermediate Energies



Design of Station ISCRA

Technology of decapsulated chip irradiation by ions of low energy was effectively used in FLNR JINR.

Decapsulation is impossible for many modern chips caused by their technological ascepcts (Flip-chips with plastic capsule, powerful microprocesors) .

Technology of capsulated chip irradiation by high energy heavy ions was realized in RHIC. However this technology does not realized in Russian and in JINR member state countries.

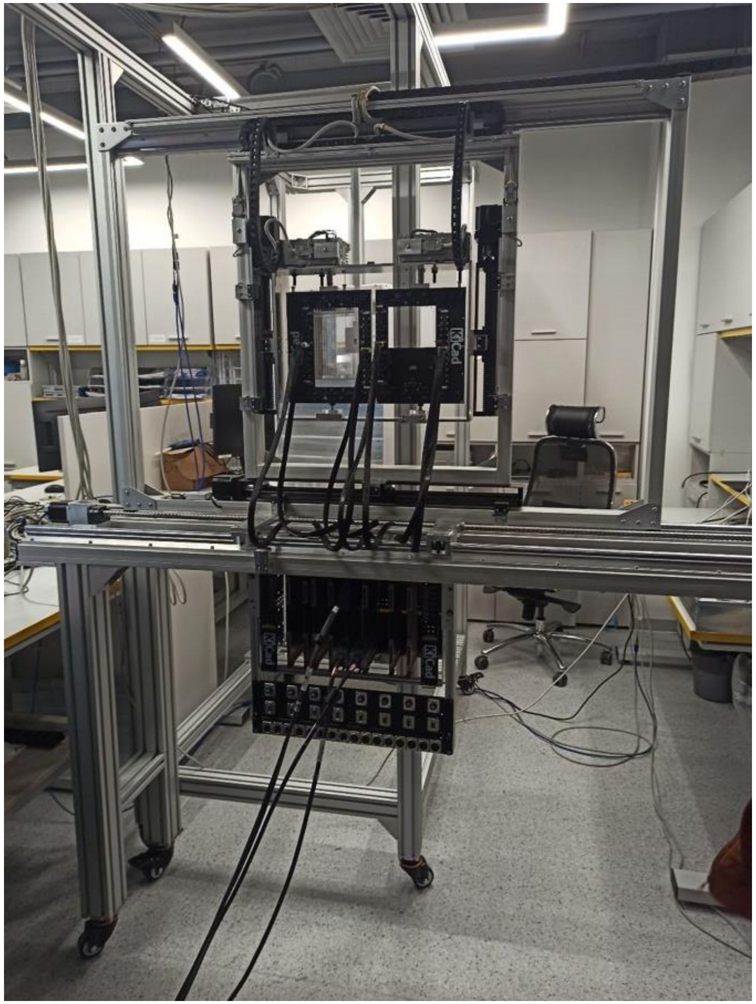
Development of technologies of capsulated chip irradiation will be realized in frame of ISCRA project

Construction of ISCRA was started by ITEPh in 2019.

Assembling of equipment are planed in Spring 2022.

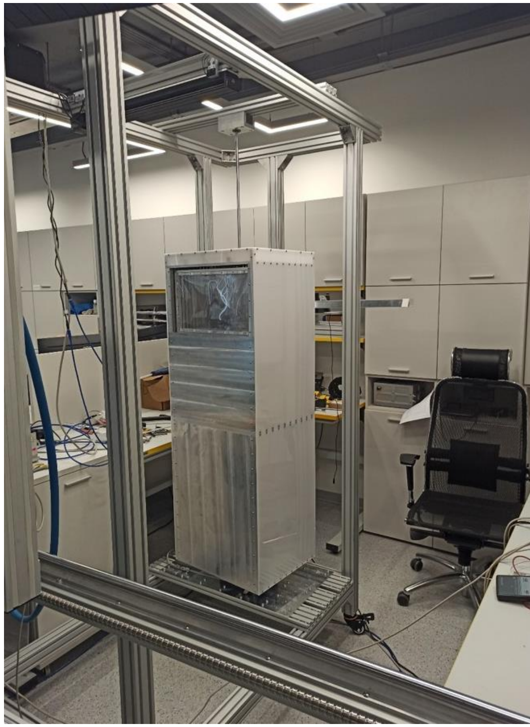
First beam experiments are planned in Autumn 2022.

STATION ISCRA



Equipment of station ISCRA

Electronic equipment in radiation shielding

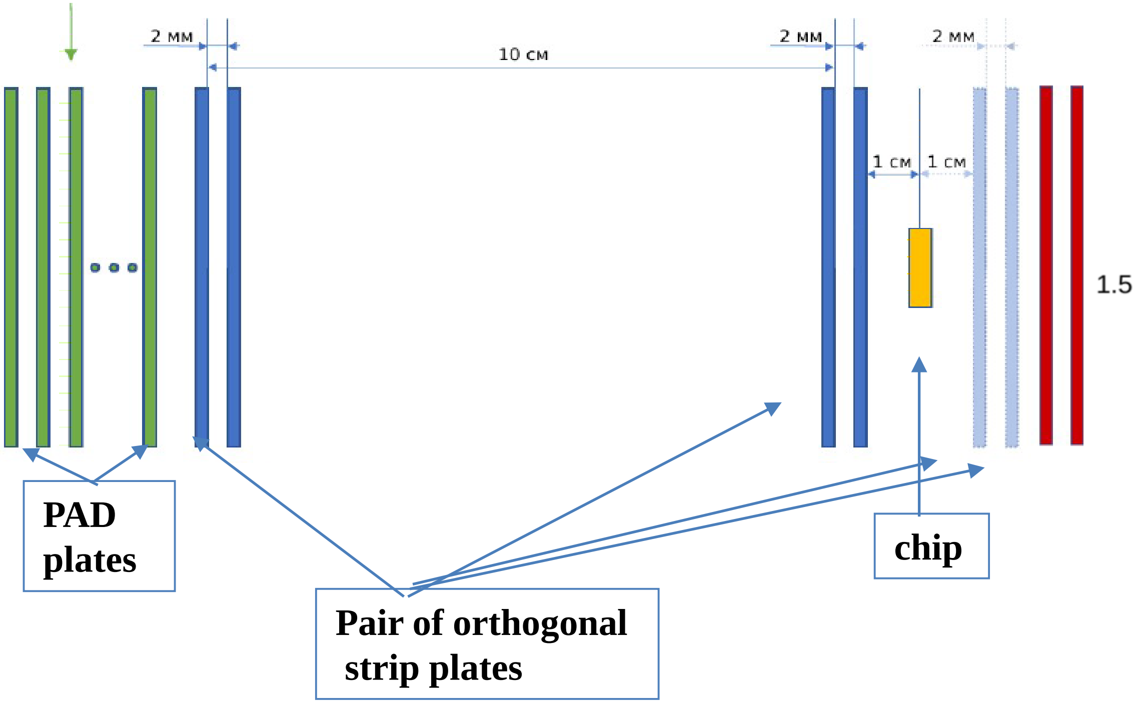


Degrader of ion beam

Beam diagnostics operate in "tuning" and "irradiation" modes. The diagnostic provides measurements of ion beam profiles, primary ion fluence, the primary ion density flux, the secondary particle density flux, the radiation dose: (three ionization chambers, scintillation-fiber detector, semiconductor detector, multi electrode cylinder Faraday, Si strip detector for individual ion detection, four on-line control scintillation detectors).

ISCRA Strip Si Detector

Mapping of radiation damages of separate microstructures inside chip (MSU, Russia)



Typical size of chip microstructure elements like power supply of flash memory is about 100 µm. Minimum space resolution of 20 µm is defined by ion scattering in chip capsule.

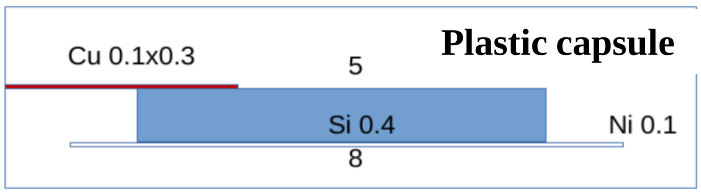
Strip Si detector

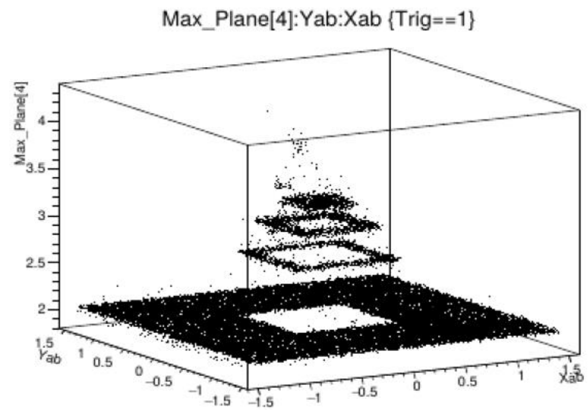
Strip size-100 µm

Ion flux- 10^2 .. 10^4

Registration of each individual ion

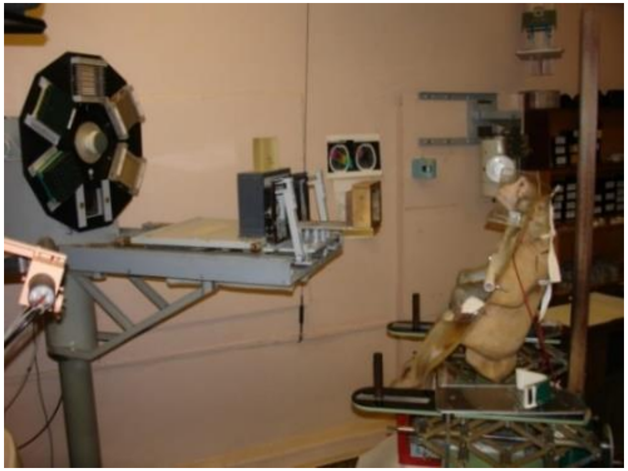
LET tomography by heavy ions

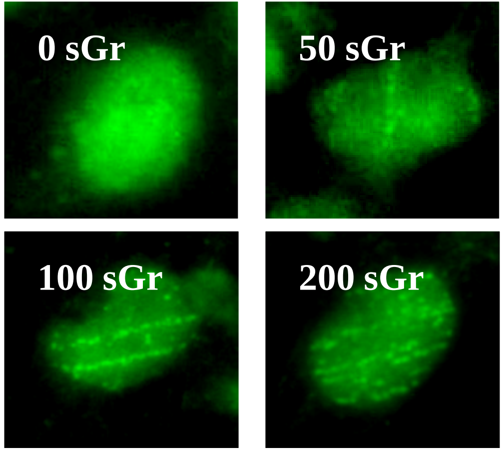




Reconstruction of transverse and longitudinal chip structures

Radiobiological experiments in JINR





Fe ion tracks in cells

Experiments with primate brain irradiation

DLNP Phasotron,
Protons of 170 MeV

Nuclotron
C6+ ions at 500 MeV/n

Ion beams extracted from Nuclotron are used for radiobiological experiments with dose 1-2 Gy.

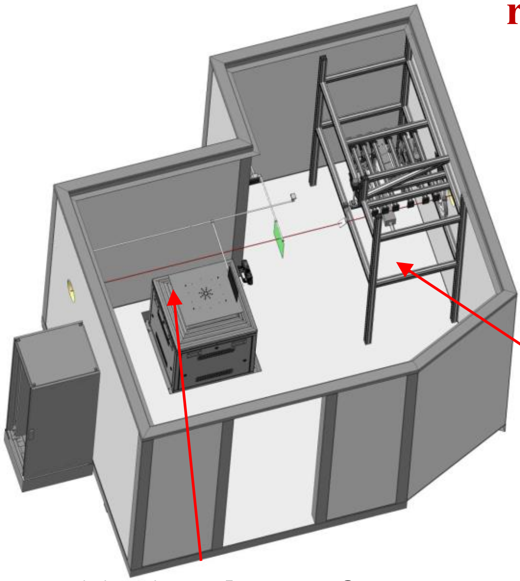
Radiobiological experiments with ion beam at intermediate energy of 0,5-1 GeV/n has goal to investigate their interaction with biological objects on cell and organism levels.

The mechanisms of geny mutation are studied at ion interaction with cells.
Morphological changes in mouse and rut tissues and primate cognitive functions are investigated at intermediate energy ions.

SIMBO-a biological station for irradiation by intermediate energy ions

General 3D view of the SIMBO station

SIMBO ─ an applied research station for space radiobiological research and modelling of influence of heavy charged particles on cognitive functions of the brain of small laboratory animals and primates (energy range 500-1000 MeV/n).



Positioning element for laboratory animals and biological objects

The beam diagnostics system for the SIMBO station. Side view

Technical requirements for the ion beams at the SODIB station

Ion types	$^{12}C^{6+}$, $^{40}Ar^{18+}$, $^{56}Fe^{26+}$, $^{84}Kr^{36+}$
Ion energy at the exit from the Nuclotron, MeV/n	500-1000
Ion flux density, particles/(cm^2·s)	$10^3..10^6$
Irradiation time per run, min	1-5
Radiation dose, Gy	1-3
Maximum irradiation area in the scanning mode/nonscanning mode, mm	100x100/Ø10
Flux uniformity for the maximum irradiation area in the scanning mode/nonscanning mode, %	5/10
Beam FWHM at the target, mm	25-35

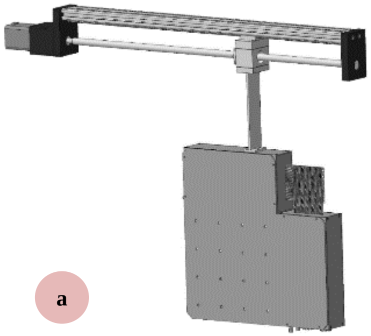
The equipment for the SODIB station is being developed as part of the *JINR-VST*(Belgorod)–OSTEC(Moscow) collaboration

Start of SIMBO construction was done in 2020

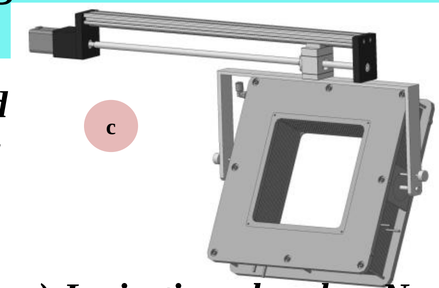
Assembling is planed in middle of 2022.

First beam experiments are planned in Autumn of 2022.

Diagnostic equipment of biological station SIMBO for irradiation by intermediate energy ions

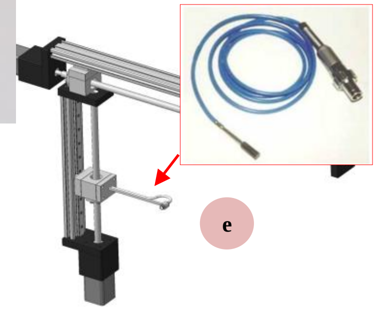


a)Diagnostic chamber No. 1 based on scintillation-fiber detectors (it is used to measure ion flux density, beam profiles in nonscanning mode before the experiment during beam adjustment).



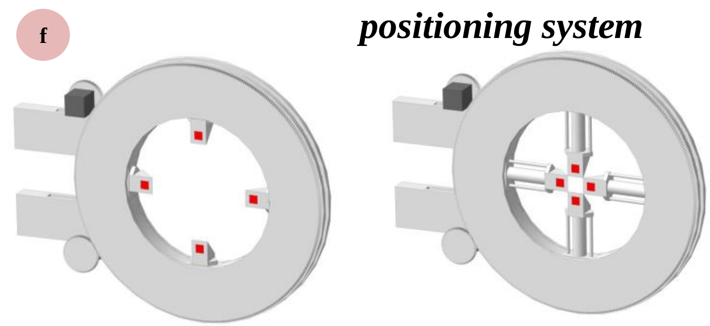
c) Ionization chamber No. 3 a slanted multi-section dosimetric ionization chamber with column recombination suppression (is used to determine the absorbed dose).

d) Ionization chamber No. 4 based on a model QIC-2S (Pyramid Technical Consultants, Inc) four-channel ionization chamber is used as a local dose detector



e) A diamond semiconductor detector (detector of the local dose and average ion energy) installed on the positioning system

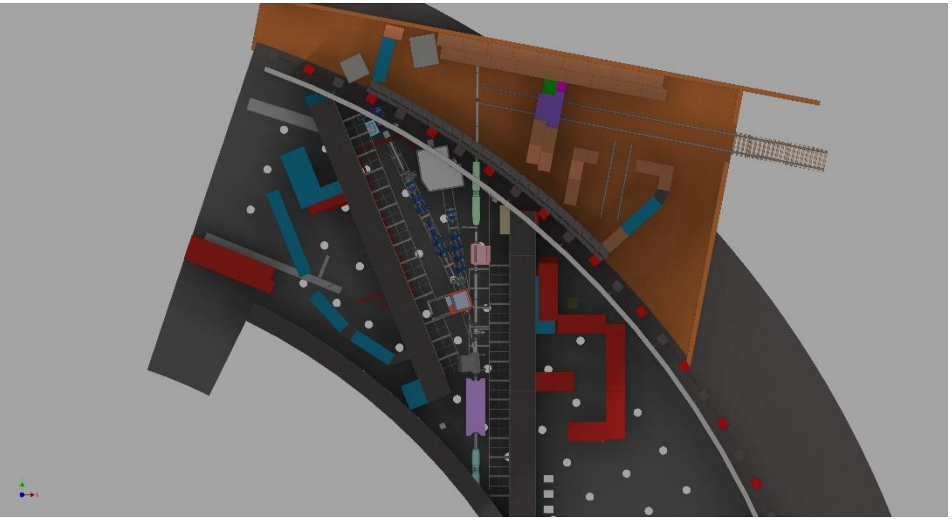
b) Diagnostic chamber 2 based on the IC64-16 (Pyramid Technical Consultants, Inc)strip ionization chamber is a duplicating chamber for ionization chamber 1 and solves similar problems

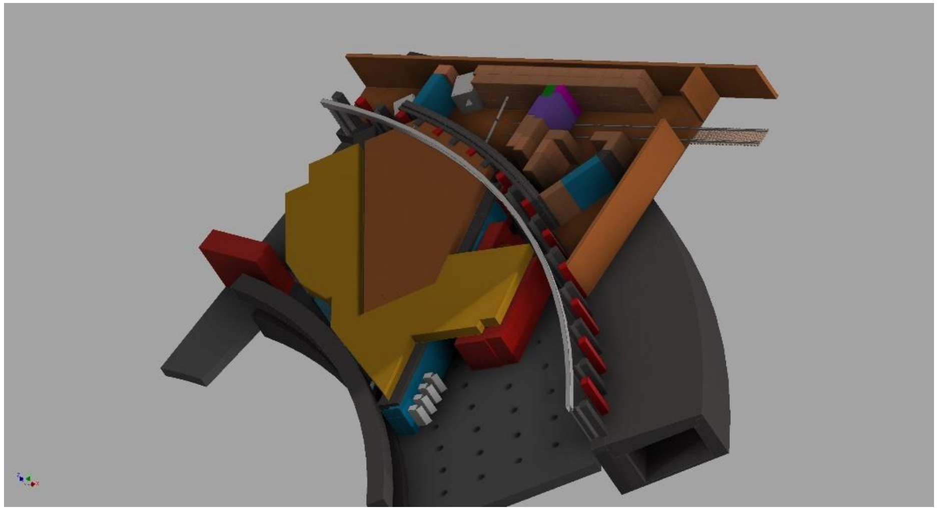


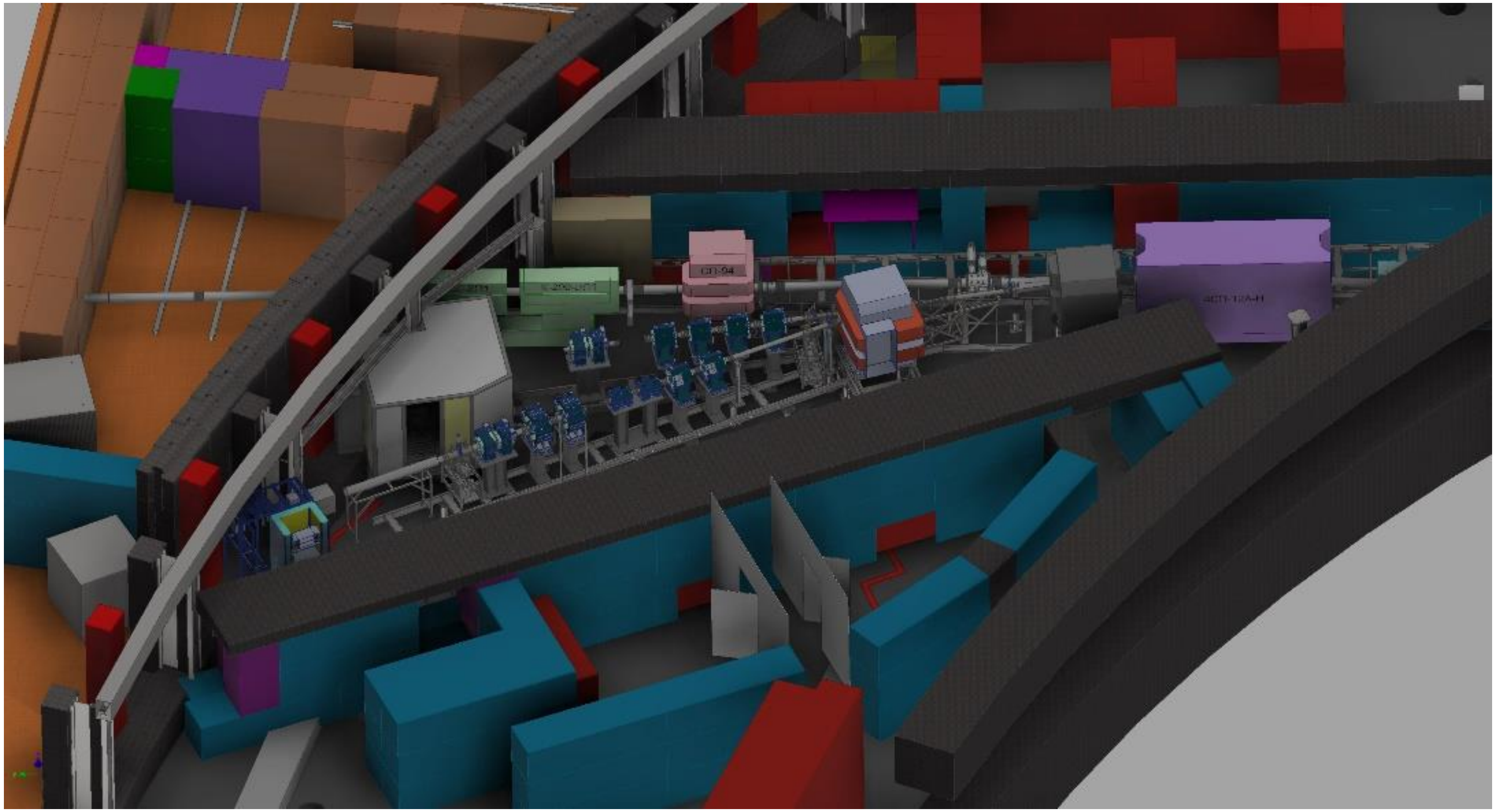
f) The system for online diagnostics and control of the peripheral ion flux density based on four scintillation detectors.

3D positioner of biological objects and its control system

Infrastructure and Radiation shielding of 2-3 innovation zones

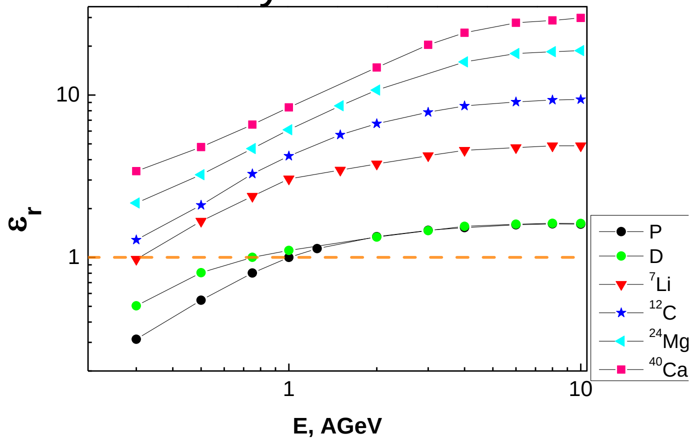




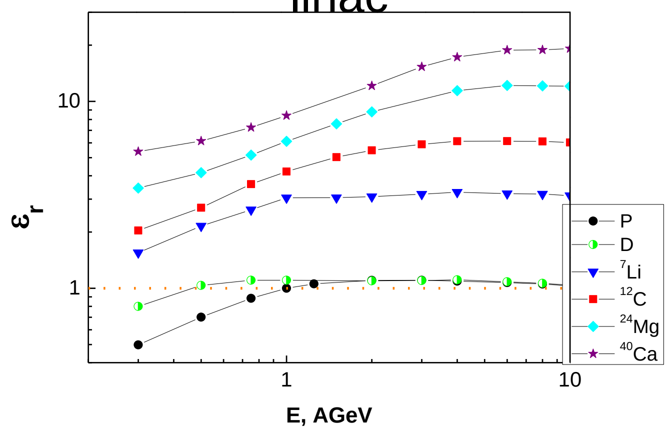


ADS CONCEPT WITH LIGHT ION BEAMS

synchrotron



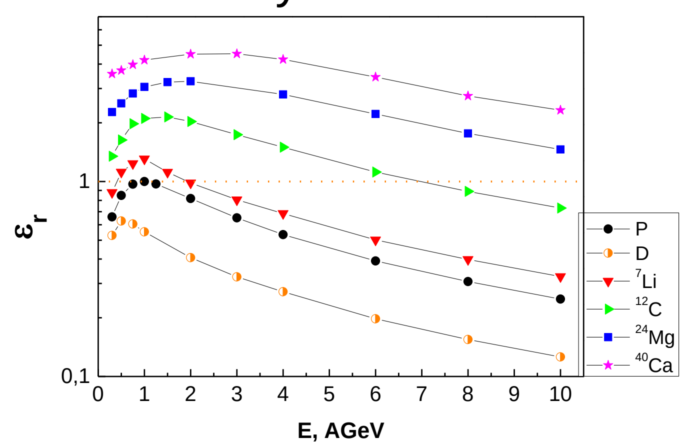
linac



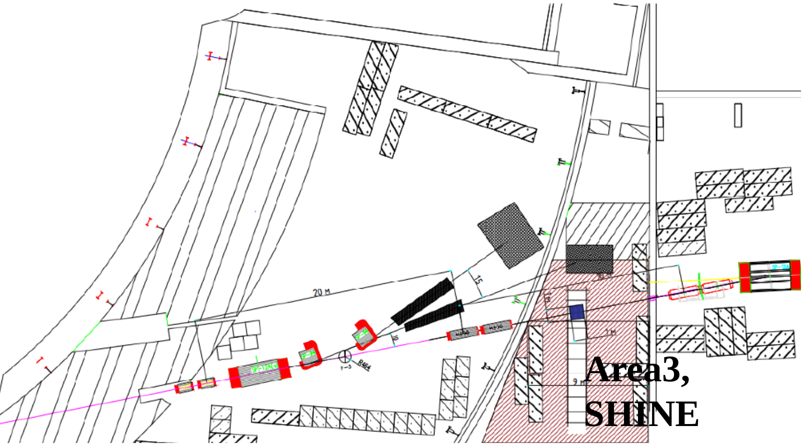
The key element of ADS is an accelerator. A study of the energy efficiency of proton beams with an energy from 0.5 GeV to 4 GeV and light ion beams (^{7}Li, ^{9}Be, ^{11}B, and ^{12}C) with energies from 0.25 AGeV to 1 AGeV showed that the best solution for ADS from the point of view of energy gain and miniaturization is ^{7}Li or ^{9}Be beams with an energy of 0.35 – 0.4 AGeV .

Experimental verification of this idea is under preparation as a part of applied research at NICA accelerator complex.

cyclotron

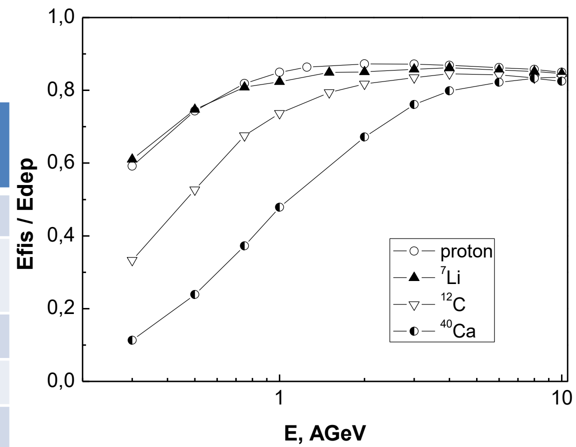


STATION SHINE FOR RELATIVISTIC NUCLEAR ENERGETIC



The SHINE station is created for relativistic nuclear energetic and ADS. Light ion beams at energy of 0.3-4 GeV/n are planned to be used for these research program on the Nuclotron. Light ions have a short path in the target, which reduces the probability of inelastic nuclear interactions and the required beam power for ADS.

Ions	$^{12}C^{6+}$, $^{40}Ar^{18+}$, $^{7}Li^{3+}$, $^{1}P^{1+}$, $^{2}D^{1+}$
Ion energy, GeV/n	0.3-4.0
Ion intensity, 1/s	$^{1}P^{1+}$, $^{2}D^{1+}$ - 10^{10} $^{12}C^{6+}$, $^{7}Li^{3+}$ - 10^{9}
Nuclear impurities with non goal Z, %	5
Field of irradiation, мм	∅ 20-50
Fluece at irradiation of one object	$>10^{14}$



Dependence of relative energy input in uranium target on kinetic energy per nucleon for different nucleus.

Equipment of SHINE involves: targets from C up Pb at length up 1.5 m and diameter up 35 cm, thin targets from Be to U at thickness 0.05-50 mm; beam diagnostic system; target diagnostic system on base of activation and track analysis; target position system; thermometry system; synchronization system; radiation control system; data acquisition system.

Beam diagnostic system involves ionization chambers; target diagnostic consists of 100 fusion chambers on base U, Ag, Au, Al and others, scintillations detectors, total number of target detectors 150, 3 gamma spectrometers for activation analyses, 1000 samples for activation analysis (from Al to Th), track automatic measuring with accuracy of 1 µm, 100 channels of thermometry system, data acquisition system with 1000 signals, system of transfer date with 1 Gb/s.

SHINE Technical project was realized by IPhTP (Rosatom) in 2020. Equipment construction was started in 2021. Assembling and first beam run is planed in end 2022.

THANKS FOR YOUR ATTENTION