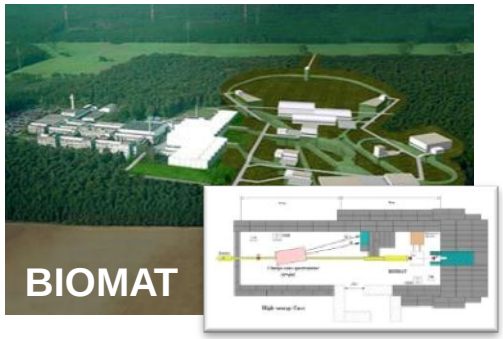
Information on plans for the development of applied research at the NICA complex

(following the International Workshop on Biophysics and Materials at NICA, 12–13 December 2016, Dubna)

Oleg Belov

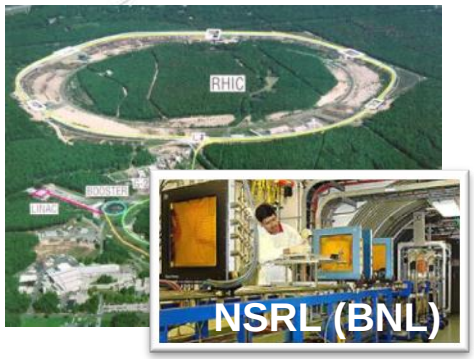
Joint Institute for Nuclear Research, e-mail: dem@jinr.ru

FAIR GSI



http://www.fair-center.eu/

BROOKHAVEN NATIONAL LABORATORY



https://www.bnl.gov/nsrl/

INFN LNS

http://www.lns.infn.it/

Applied research with particle beams

(biophysics, radiobiology, materials science, medicine, etc.)

LOMA LINDA UNIVERSITY MEDICAL CENTER

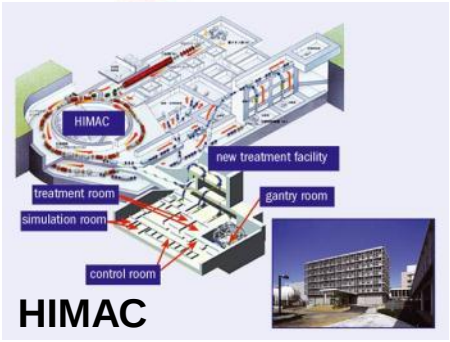
https://protons.com/

GANIL spiral2

laboratoire commun CEA/DSM CNRS/IN2P3

http://www.ganil-spiral2.eu/

NIRS



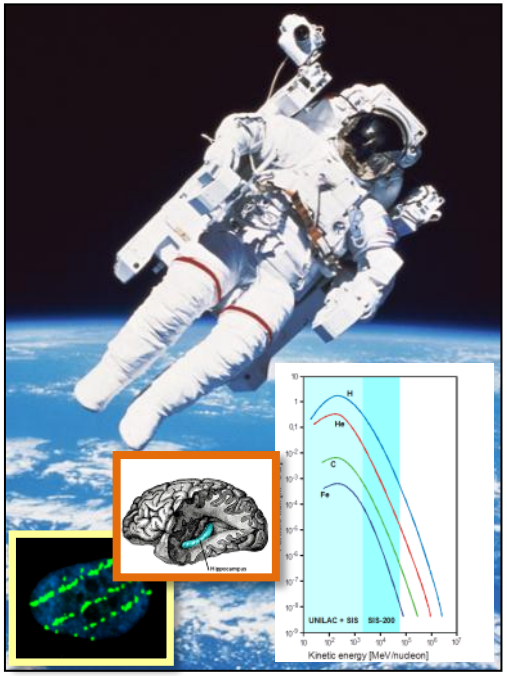
http://www.nirs.qst.go.jp/ENG/index.shtml

Area of applied research with heavy ion beams

Radiation medicine (particle therapy and diagnostics, radiation surgery, etc.)

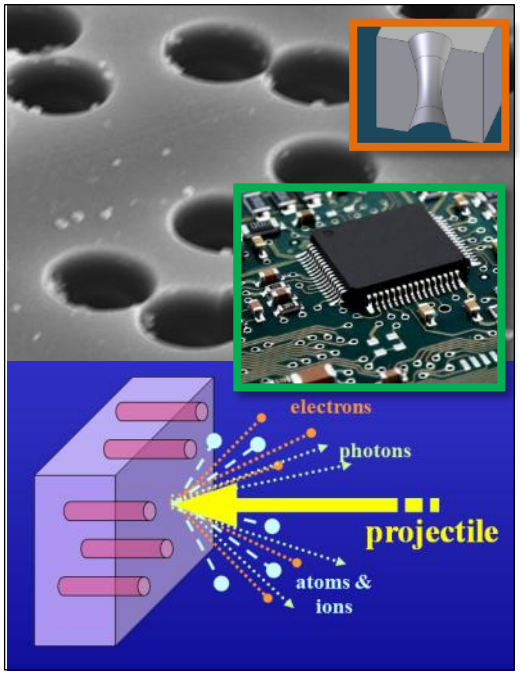
^{1}H to ^{20}Ne
70-400 MeV/n

Health in deep space, radiation risk assessment, biophysics, radiobiology, etc.



^{1}H to ^{56}Fe
100-10000 MeV/n

Materials science (radiation hardness, ion-matter interactions, ion-track nanotechnology, etc.)



Various ion species with energies from tens to hundreds MeV/u

NICA (Nuclotron based Ion Colider fAcility)

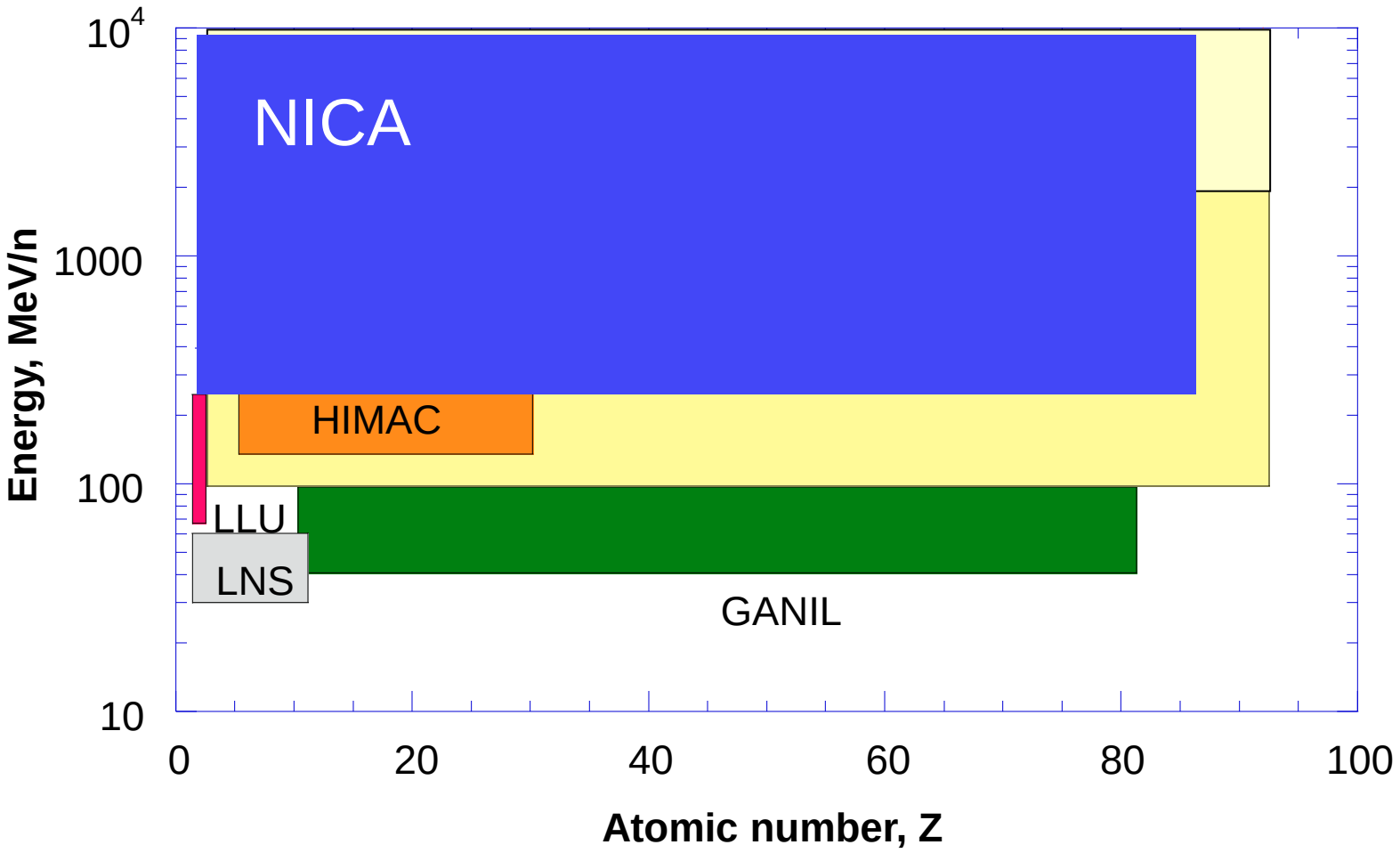
Main targets:

- *study of hot and dense baryonic matter at the energy range of max baryonic density*
- *investigation of nucleon spin structure, polarization phenomena*

- *development of accelerator facility for HEP @ JINR*
- *construction of Collider of relativistic ions from **p** to **Au**, polarized protons and deuterons with max energy up to $\sqrt{S_{NN}}$= **11** GeV (Au^{79+}) and =**27** GeV (p)*

Powerful capabilities for applied research with high-energy heavy ion beams

Heavy-ion accelerator facilities



[from A. Golubev et al.]

NICA facility

In operation ***Under construction***

International mega-project NICA

~ 70 Russian Institutions and Universities + 26 Organizations abroad RF

МИФИ, МЭИ, МФТИ, КГТУ, СПбГУ,...

Budker INP SB RAS, Novosibirsk

NRC KI IHEP, Protvino: RFQ,beam dynamics, Feed-back systems

НПО ГЕЛИЙМАШ

КРИОГЕНМАШ

BEVATECH

НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ ЦЕНТР «КУРЧАТОВСКИЙ ИНСТИТУТ»

KI ITEP: Beam dynamics RFQ linac

INR RAS, Troitsk polarised source, Linacs, beam diagnostics

FZ Juelich (IKP)
HV Electron cooler
Stoch. cooling

South Africa Republic:
DST, iThemba, NECSA,
Universities: Capetown, Stallenbosch, etc
others (Theory, cryostats, ion source, cryogenics

CERN
SC technologies, Rad.safety, energetics, beam cooling and dynamics

GSI/FAIR
SC dipoles for Booster/SIS-100
beam cooling, diagnostics

FNAL:
HV Electron cooler
Beam dynamics,Stoch.cooling

BNL (RHIC)
Beam dynamics,
Stoch. Cooling

Rosatom: Sarov, Snezhinsk, Lesnoy

Rostex: Savelovo, etc

Status of the NICA mega-science @ JINR

ПРАВИТЕЛЬСТВО РОССИЙСКОЙ ФЕДЕРАЦИИ

РАСПОРЯЖЕНИЕ

от 27 апреля 2016 г. № 783-р

МОСКВА

О подписании Соглашения между Правительством Российской Федерации и международной межправительственной научно-исследовательской организацией Объединенным институтом ядерных исследований о создании и эксплуатации комплекса сверхпроводящих колец на встречных пучках тяжелых ионов NICA

1. В соответствии с пунктом 1 статьи 11 Федерального закона "О международных договорах Российской Федерации" одобрить представленный Минобрнауки России согласованный с МИДом России, Минфином России, Минэкономразвития России и международной межправительственной научно-исследовательской организацией Объединенным институтом ядерных исследований проект Соглашения между Правительством Российской Федерации и международной межправительственной научно-исследовательской организацией Объединенным институтом ядерных исследований о создании и эксплуатации комплекса сверхпроводящих колец на встречных пучках тяжелых ионов NICA (прилагается).

2. Поручить Минобрнауки России провести переговоры с международной межправительственной научно-исследовательской организацией Объединенным институтом ядерных исследований и по достижении договоренности подписать от имени Правительства Российской Федерации указанное в пункте 1 настоящего распоряжения Соглашение, разрешив вносить в прилагаемый проект изменения,

On 27th April 2016 the RG Prime-minister issued the Governmental Decree about establishment of the NICA mega-science on Russian territory at JINR.
Russia and JINR co-invest to the“NICA Complex”.
Agreement between RF Government and JINR (signed on 2nd June 2016) in the frame of Decree formulates basic principles of the setting and development of the International collaboration “Complex NICA”.

We assume that in coming years similar Agreements will be prepared, agreed and signed with other countries and International Scientific centers, expressed their interest to participate and contribute to NICA.

We invite new countries to join NICA (Germany, China, India, SAR, …) and leading International centers (CERN, FAIR, …), also Universities.

Possibilities for applied research with particle beams at NICA

Area - 1 Low energy beams Injector (< 5 MeV/u)	Area - 2 Medium energy beams Booster (< 600 MeV/u)	Area - 3 High energy beams Nuclotron (< 4.5 GeV/u)
Research in field of nanotechnologies	• Possibility to have cooled ion beam • study of radiation damages in microelectronics; • radiobiology for space • new materials; • R&D for elements and prototypes of the carbon beam therapy center	• Possibility to have cooled ion beam • study of radiation damages in microelectronics; • radiobiology for space • Relativistic nuclear energetics. Utilization of radioactive waste; • Remote control and monitoring of the fission substances

In order to define a roadmap for development of applied research at this facility, a special International Workshop on Biophysics and Materials at NICA was held in Dubna on 12–13 December 2016.

Joint Institute for Nuclear Research
SCIENCE BRINGING NATIONS TOGETHER

RU

JINR | SCIENCE | STUDENTS & EDUCATORS | PRESS OFFICE | FOR EMPLOYEES | EVENTS

News | World science | Organization | Education | Grants | Publications | Culture | Agenda

International Workshop «BIOMAT»

Conferences

The International Workshop on Biophysics and Materials at NICA «BIOMAT» will be held on 12-13 December 2016 in the Veksler and Baldin Laboratory of High Energy Physics JINR, Dubna.

The seminar is held for the first time, it is dedicated to applied research at the NICA complex. This is initially pertinent to radiobiology, ion beam interactions with materials, and exposure of electronic components, testing of electronic components for space applications. The seminar gathered 60 participants from Belarus, Germany, Egypt, Italy, Poland, the Czech Republic, and Russian research centers: National Research Centre "Kurchatov Institute", MEPhI, SINP MSU. On the JINR side, several reports from FLNP, FLNR, LRB, and VBLHEP will be presented. Opportunities for joint research will be discussed in the roundtable format, an excursion to the Nuclotron will be organized for participants.

Workshop webcast: http://lheplive.jinr.ru/live-streaming/

Workshop «BIOMAT» – Applied research at NICA, http://science-tv.jinr.ru/

About 60 participants from JINR and other leading scientific and technical international organizations

Germany
- FAIR, GSI Helmholtzzentrum für Schwerionenforschung

Italy
- Trento Institute for Fundamental Physics and Applications, INFN

Poland
- Institute of Nuclear Physics of Polish Academy of Sciences

Czech Republic
- Nuclear Physics Institute of ASCR

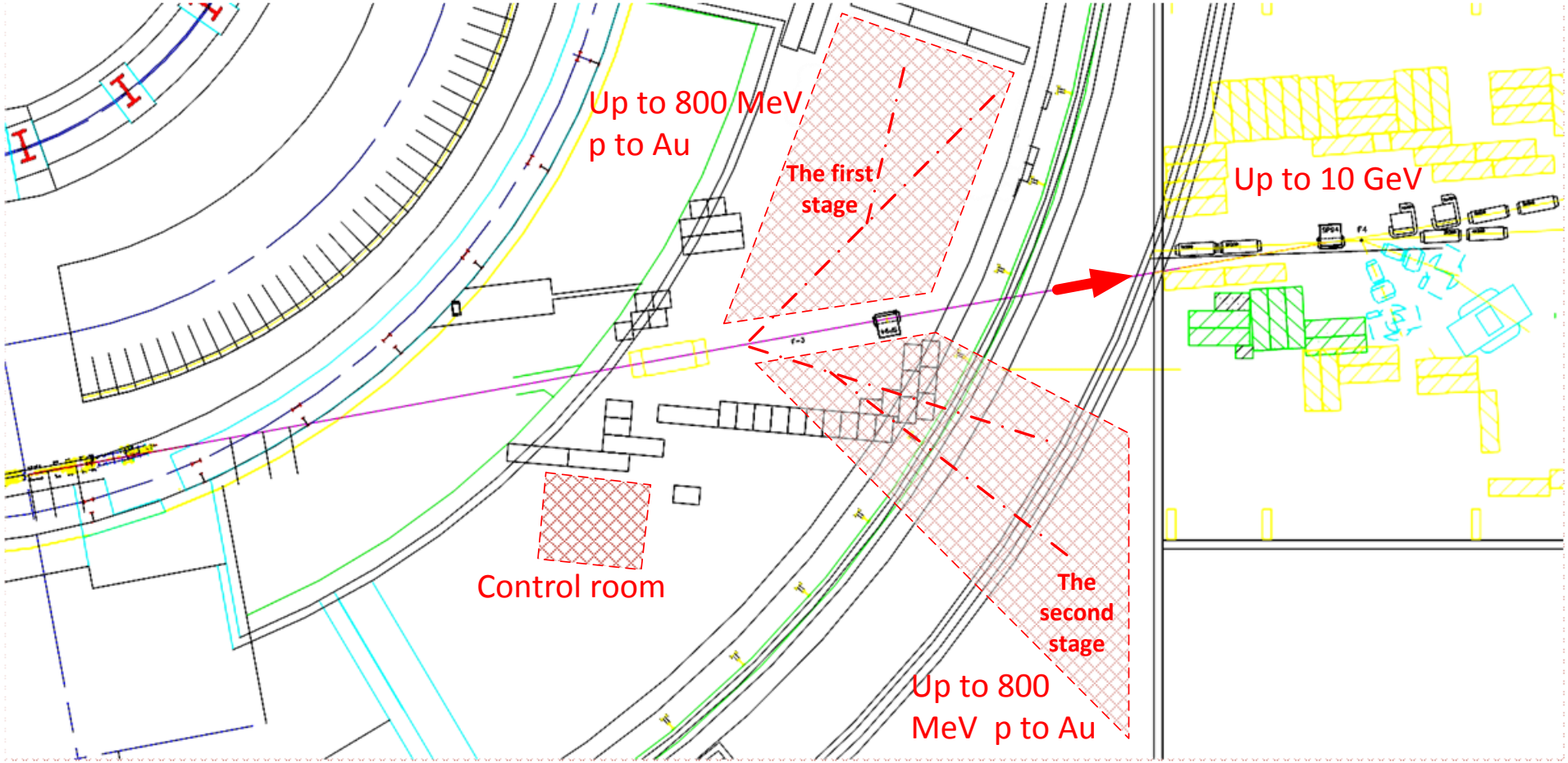
Belarus
- Belarusian State University

Egypt
- Faculty of science, Damanhour University

Russia
- FSBI “SSC RF ITEP” of NRC “Kurchatov Institute”
- Petersburg Nuclear Physics Institute of NRC “Kurchatov Institute”
- Lomonosov Moscow State University
- National Research Nuclear University “MEPhI”
- Roskosmos
- Branch of Joint - Stock Company "United Rocket and Space Corporation" - "Institute of Space Device Engineering“

JINR
- Veksler and Baldin Laboratory of High Energy Physics
- Frank Laboratory of Neutron Physics
- Flerov Laboratory of Nuclear Reactions
- Laboratory of Radiation Biology

Proposals on construction of experimental areas for applied research



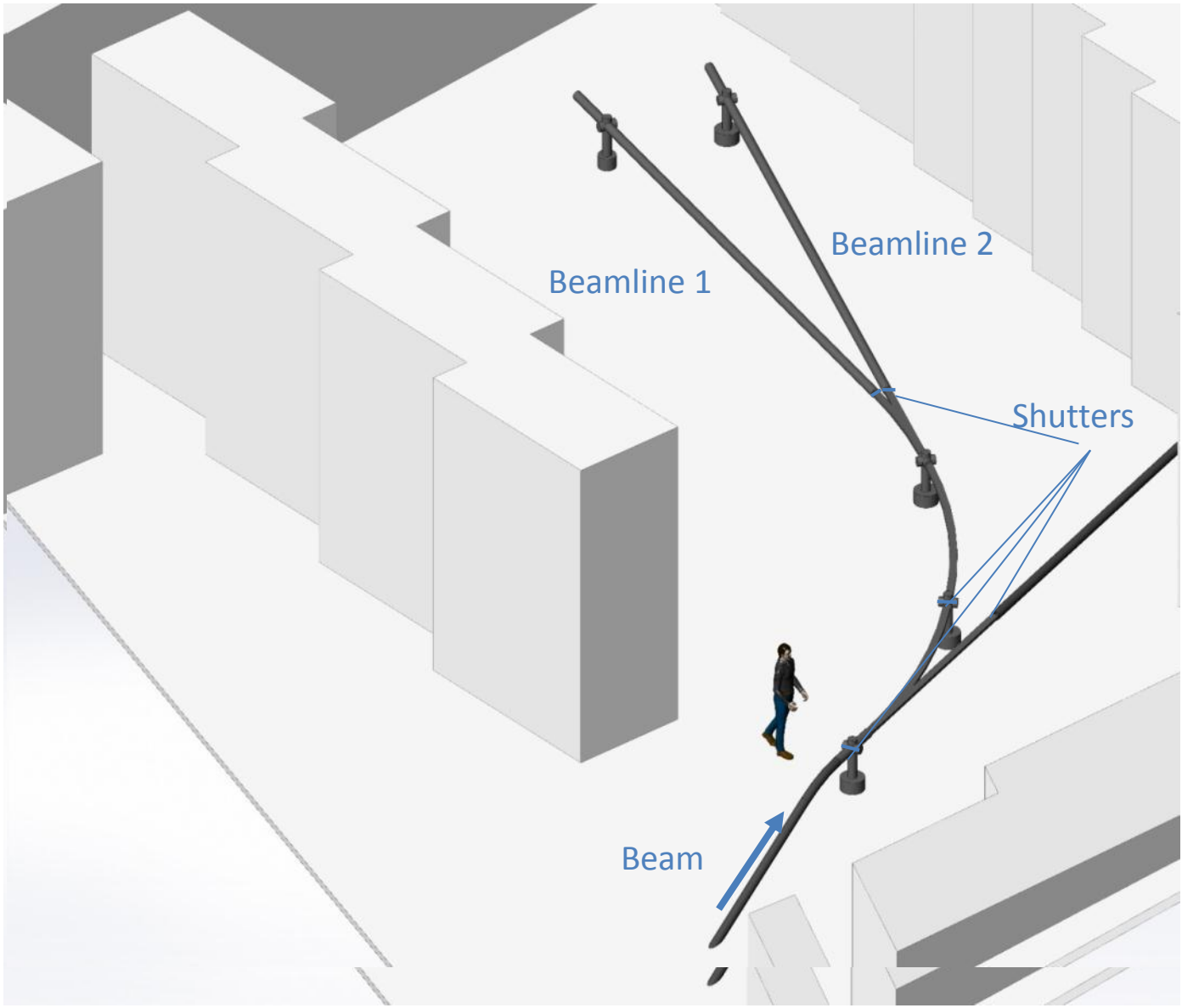
The first – the experimental setup at the gallery for the irradiation of electronics for space equipment's, materials and biological objects;

The second – the area for research applied to carbon therapy, including the high-energy proton imaging of exposed region;

The third – the biophysics research on influence high energy (up to 10 GeV/u) protons and heavy ions on biological samples.

Beamline and vacuum system

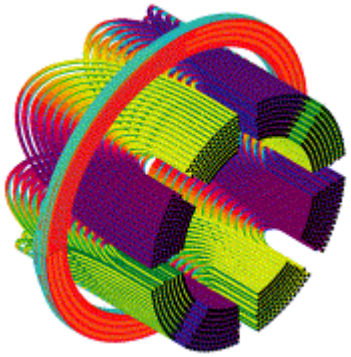
System Requirements:
Vacuum range:
10^{-7} -10^{-8} torr
Two independent beamlines
Thin vacuum windows for beam output

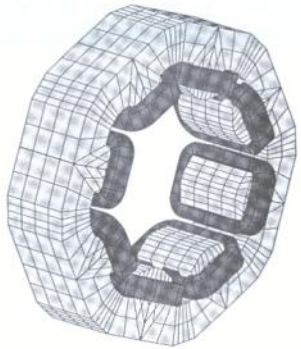


Beamline: Ion-optical system

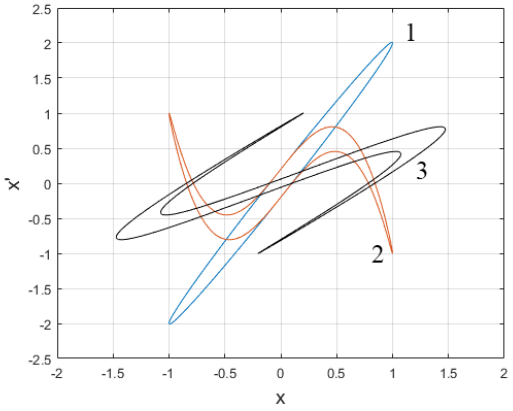
Use of nonlinear optics

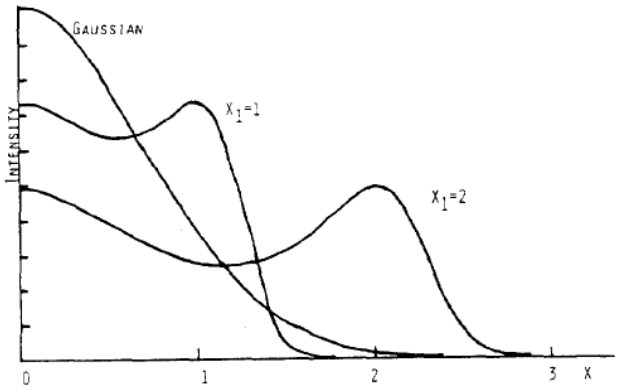
One of ways of formation of uniform distribution of density of a beam on a target is the method of application of nonlinear ion optics.

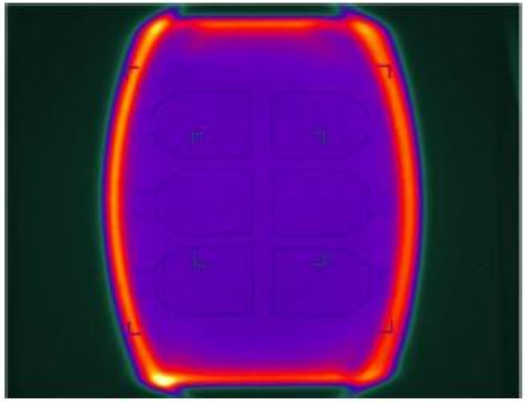




Several magnetic octupoles installed along an beamline allow to distort a phase volume of a beam in such a way that in the target plane distribution of density of a beam instead of normal Gaussian becomes similar on rectangular



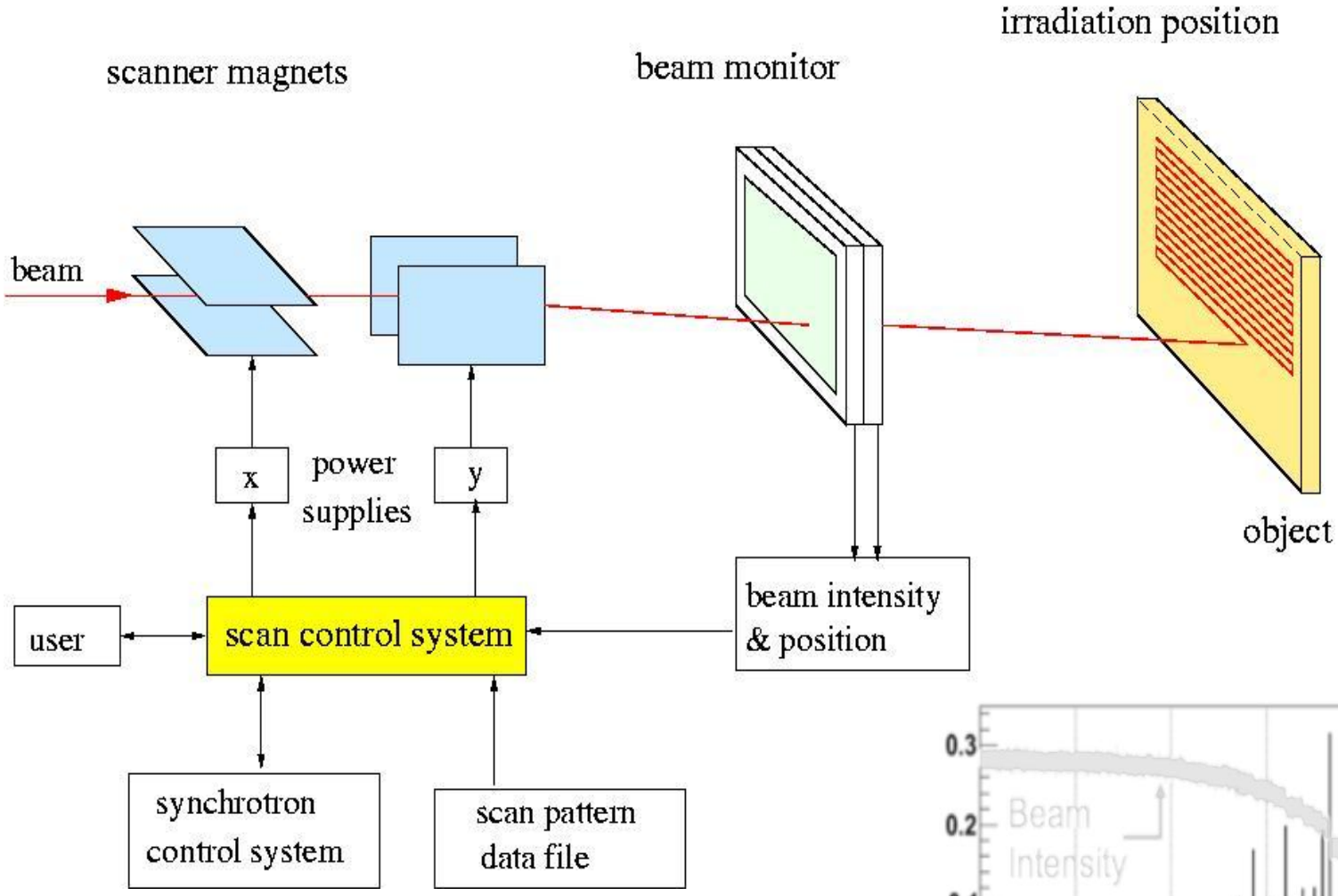


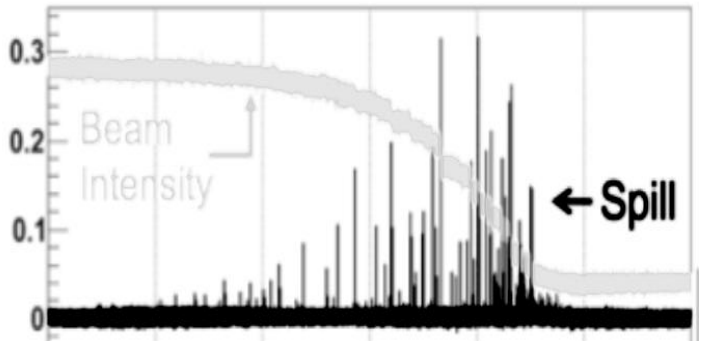


Example of such system created by NASA Space Radiation Laboratory at BNL present.

Beamline: Ion-optical system

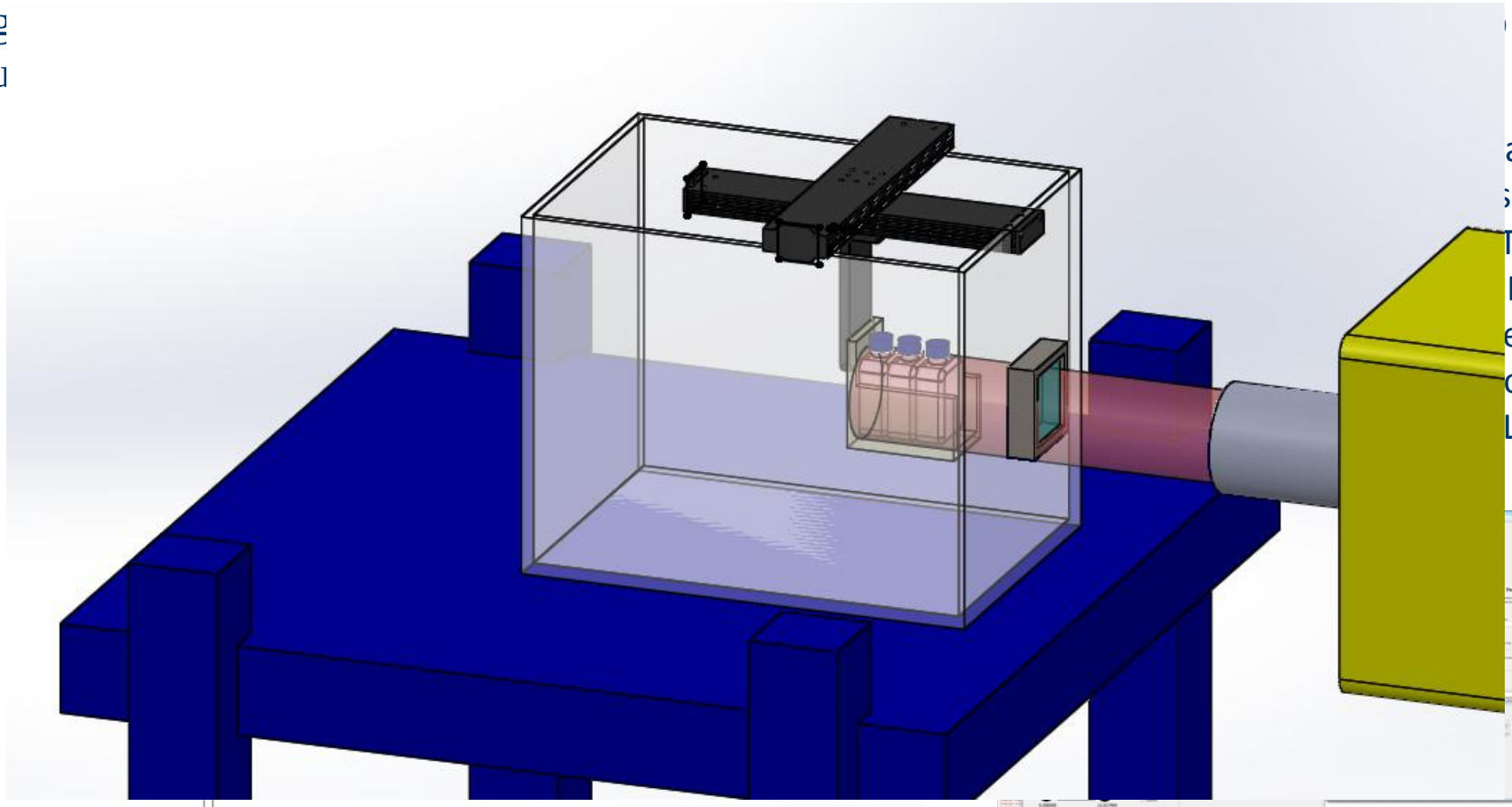
Scanning system





Target stations

The target area can include different beam-monitoring systems and different systems for manual or automatic sample positioning of the irradiation targets. The choice of the beam-monitoring system will depend on the particular experimental conditions like e.g. beam-shaping method (active scanning vs. passive scattering), ion species, energy and particle fluence. The choice of the target position system will depend on target size, target type, etc. Targ the requ ased ; VT- T-80, P-15 e is ollux Load



Aluminum profile system BLOCAN (http://rk-russia.ru/)

Software (Delphi XE2)

Data acquisition and control system

Pressure Measurements, Pfeiffer Vacuum control unit

RS232

PPRes Pressure value reading program

Target manipulator, MICOS actuators

Ethernet

Robot_HHT. Reading/ Setting position

HSM (Hardware-Software Module)

Multi channels digitizer Agilent Acqiris

Reading/Setting Digitazer

CCD cameras PCO DiCam Pro

ImageJ-Java based program

Oscilloscopes Tektronix, Lecroy

PTEK Program

Delay generators DG535, DG645

Delay Generator control program

Laser Control program

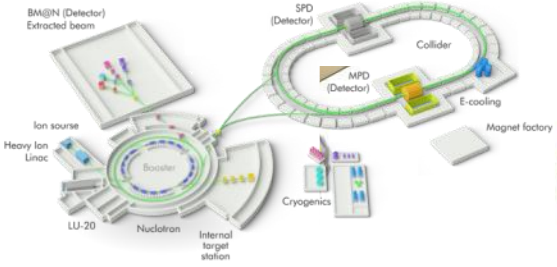
Laser, Coherent Verdi

Beam line control system

Ethernet

Experiment participants

Ser



Basic Module

Samba File Server

MySQL Database

Public Site

Internet

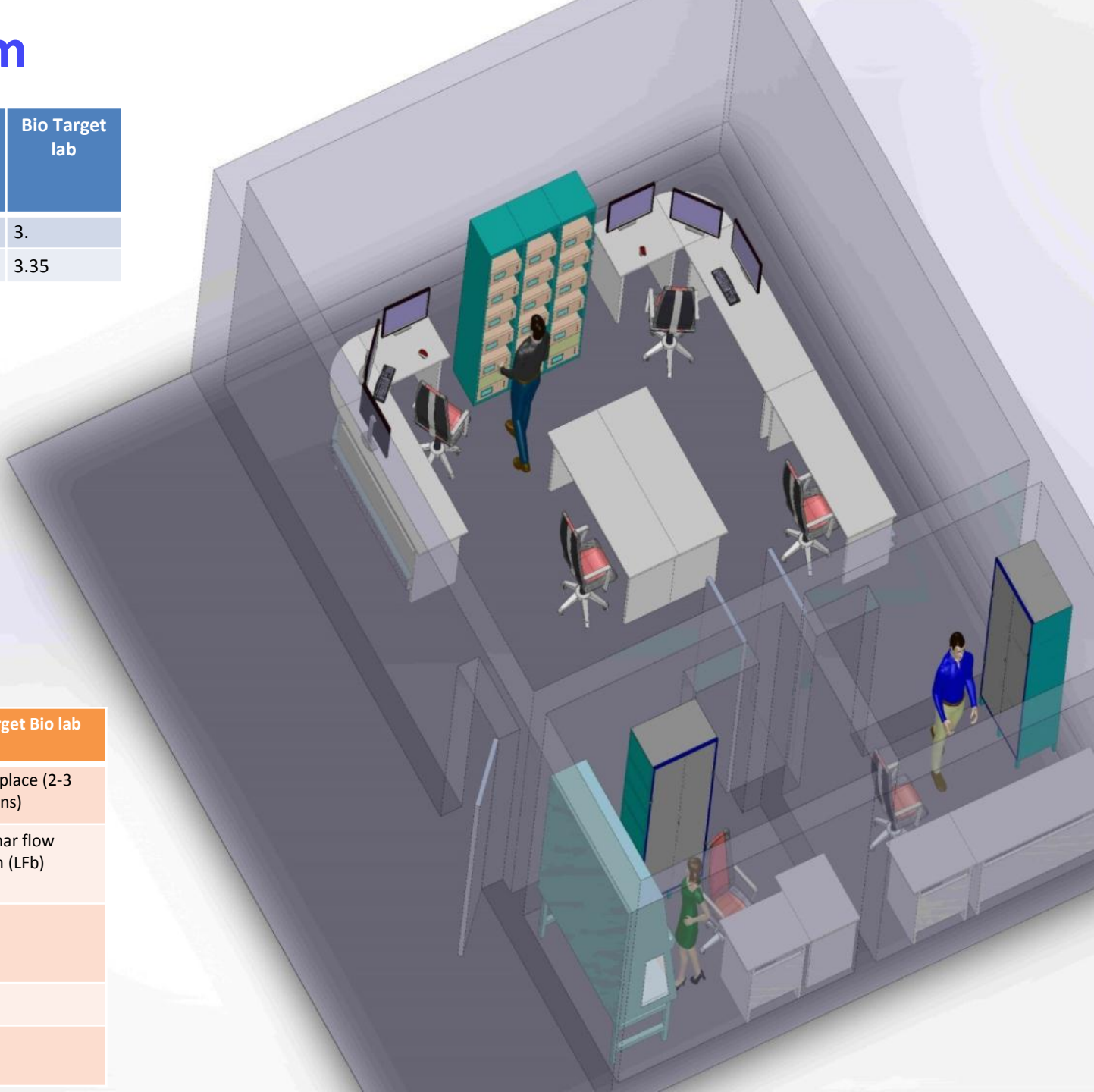
Experimental data Server + WWW Server

Beam request

File name & parameters saving

Control room

Inside dimensions (m)	Control room (main room)	Target lab	Bio Target lab
Length	7.0	3.1	3.
Width	7.7	3.35	3.35



Control room (main room)	Target lab	Target Bio lab
Beam extraction control system (3)	Workplace (2-3 persons)	Workplace (2-3 persons)
Control system for target positioning and diagnostics (1)		Laminar flow bench (LFb)
Control system for target positioning and diagnostics (2)		
Electric raceway (4)		
Workplaces (app. 12 persons)		

In order to define the design parameters of the beamlines and user requirements for the infrastructure around them, a wide range of invited talks were presented in the following fields:

- Biophysics, radiobiology and particle therapy
- Radiation testing of microelectronics for space applications
- Modeling of the cosmic ray composition
- Material studies with ion beams (radiation hardness, ion-matter interactions, ion-track nanotechnology, etc.)
- Development of accelerator driven reactors and radioactive waste transmutation
- ect. http://indico.jinr.ru/conferenceOtherViews.py?view=standard&confId=122

Prof. Marco DURANTE
(TIFPA-INFN, Italy)

Prof. Alexander GOLUBEV
(FSBI "SSC RF ITEP" of NRC "Kurchatov Institute", Russia)

Prof. Christina TRAUTMANN
(GSI and FAIR, Germany)

Dr. Daniel SEVERIN
(GSI and FAIR, Germany)

Prof. Mikhail PANASYUK
(SINP, MSU, Russia)

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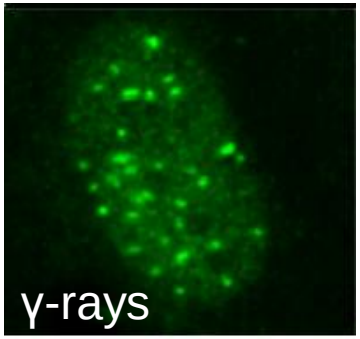
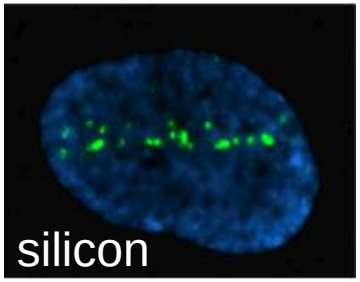
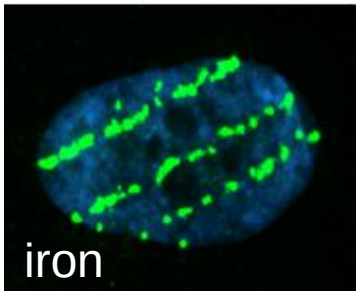
Biophysics

Investigating effects of charged particle exposure in various biological objects

Studies with cells and tissues

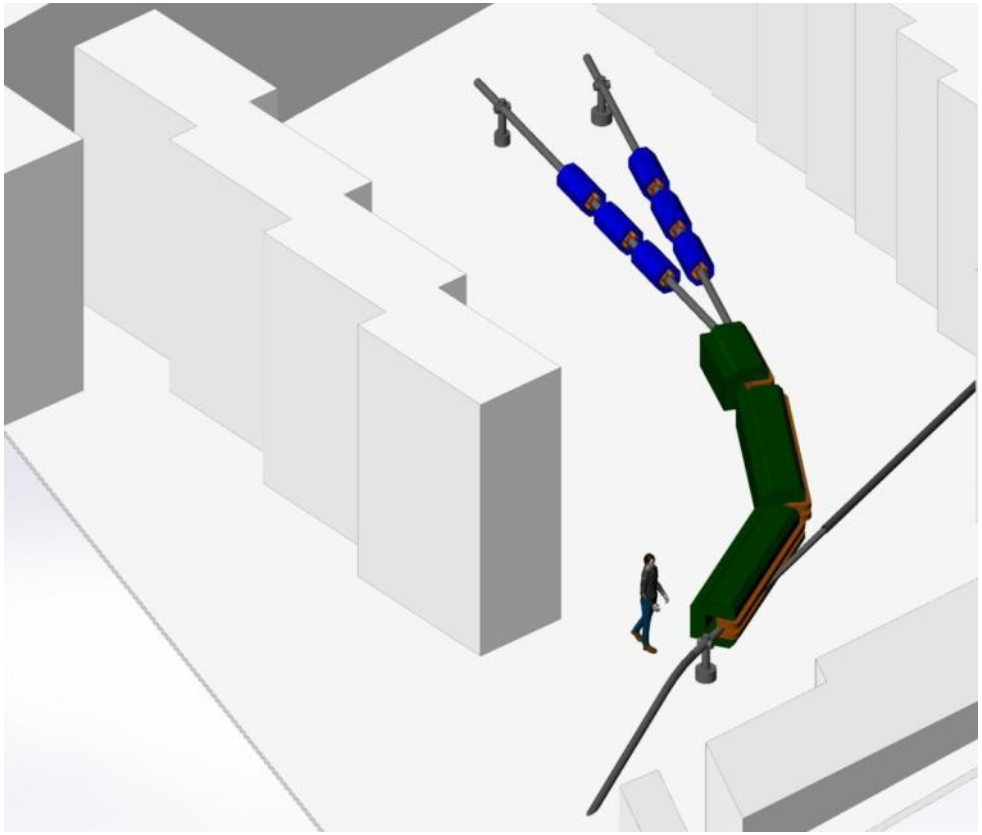




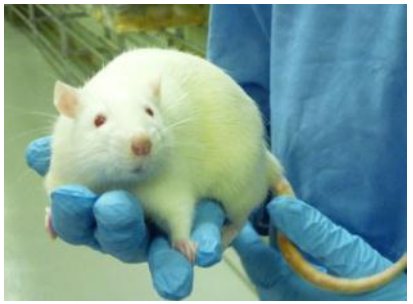


Markers of DNA double-strand breaks (γH2AX) in cells
[*Cucinotta and Durante, Lancet Oncol. 2006]*

Beamlines' infrastructure should enable experiments with a wide range of biological objects

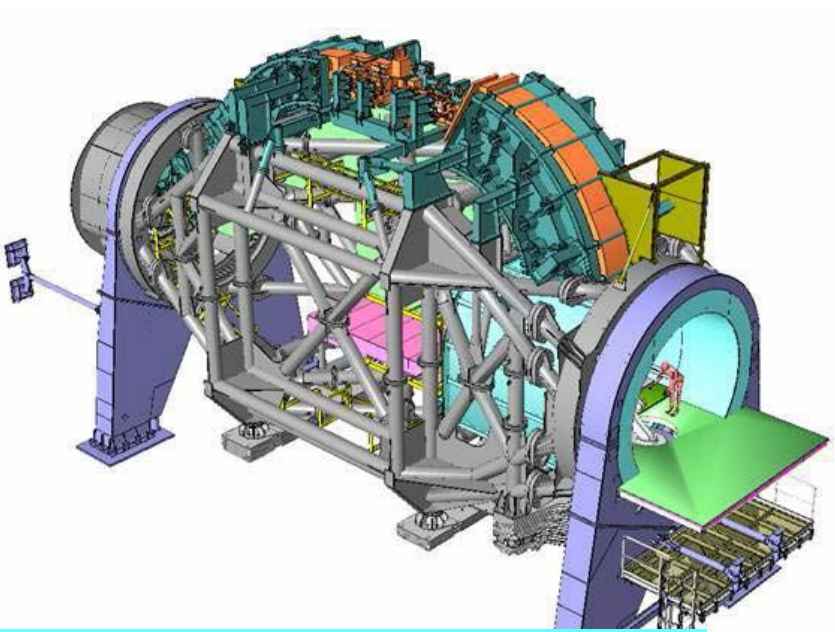


Physiological studies with laboratory animals



Particle therapy

Prototype of a carbon nuclei beam at Nuclotron

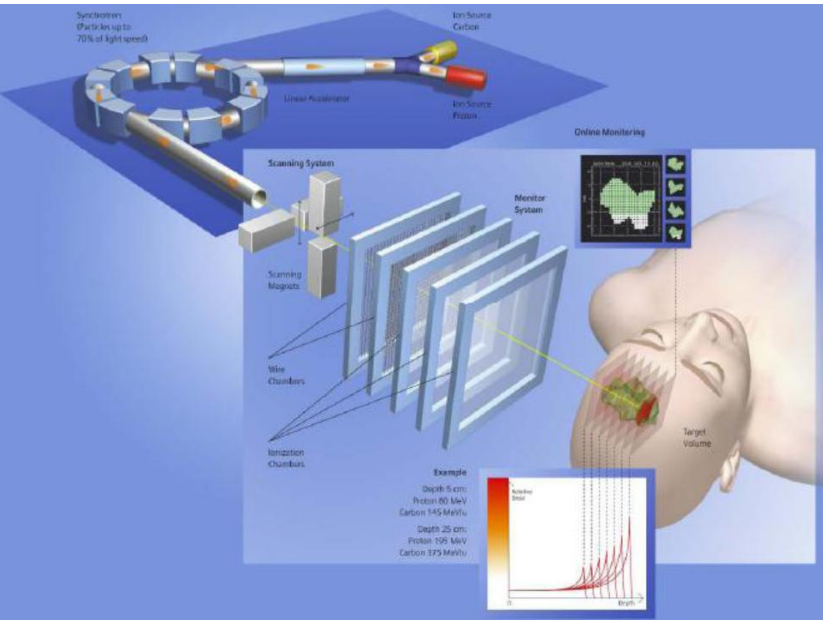


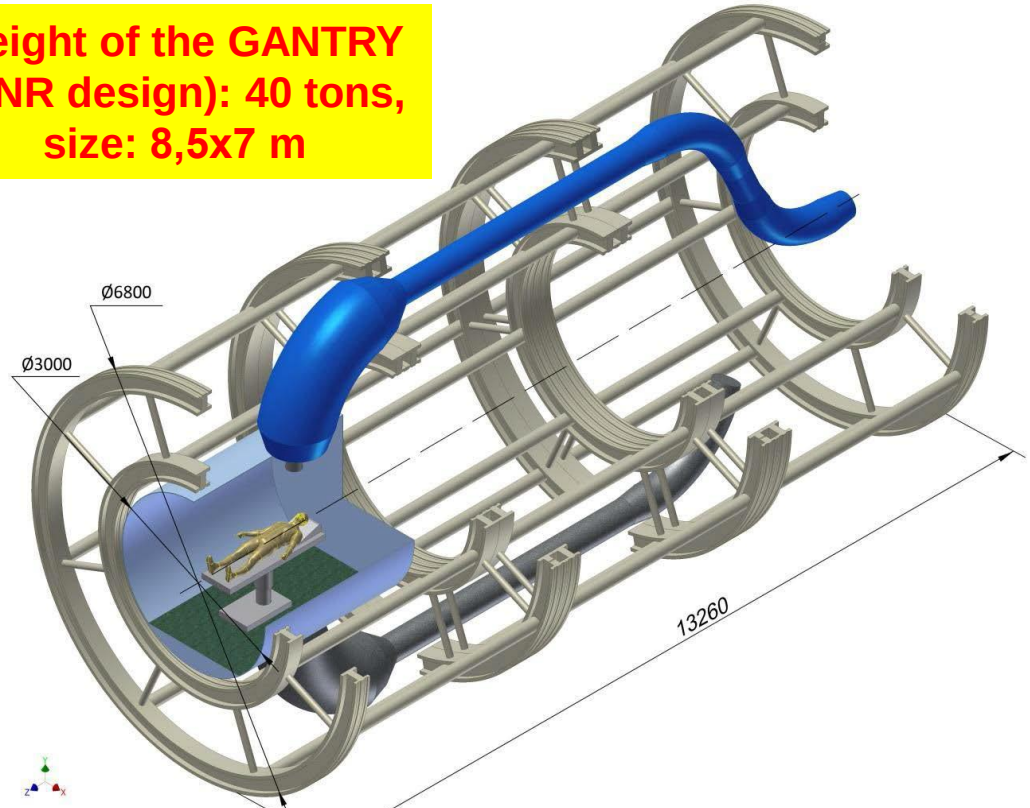
Energy-saving, for proton and carbon ions (Energy from 200 to 600 MeV/u) – synchrotrons for beam therapy

Systems of carbon-beam GANTRY and beam transportation channels

Weight of HIT GANTRY - 600 tons, size: 19 x 12 meters

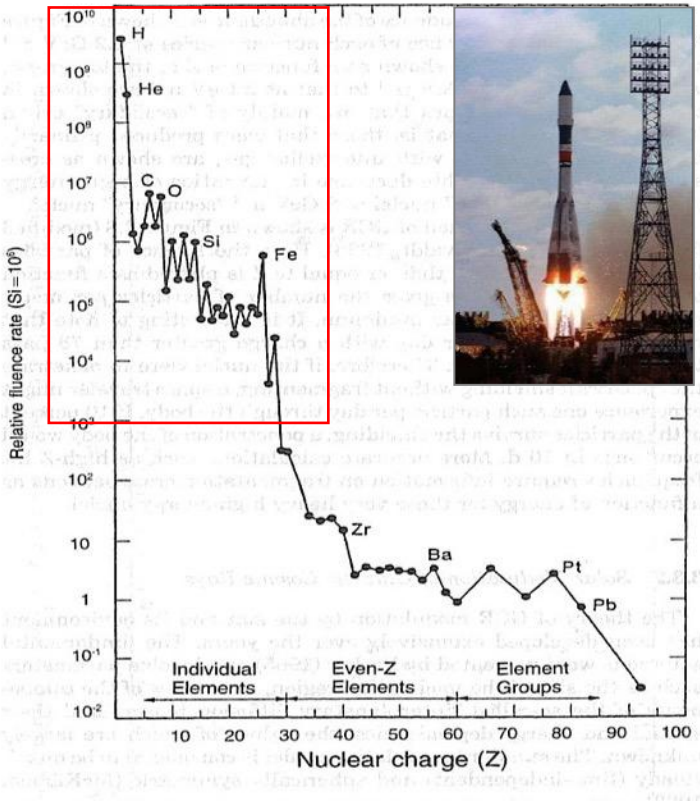
Weight of the GANTRY (JINR design): 40 tons, size: 8,5x7 m

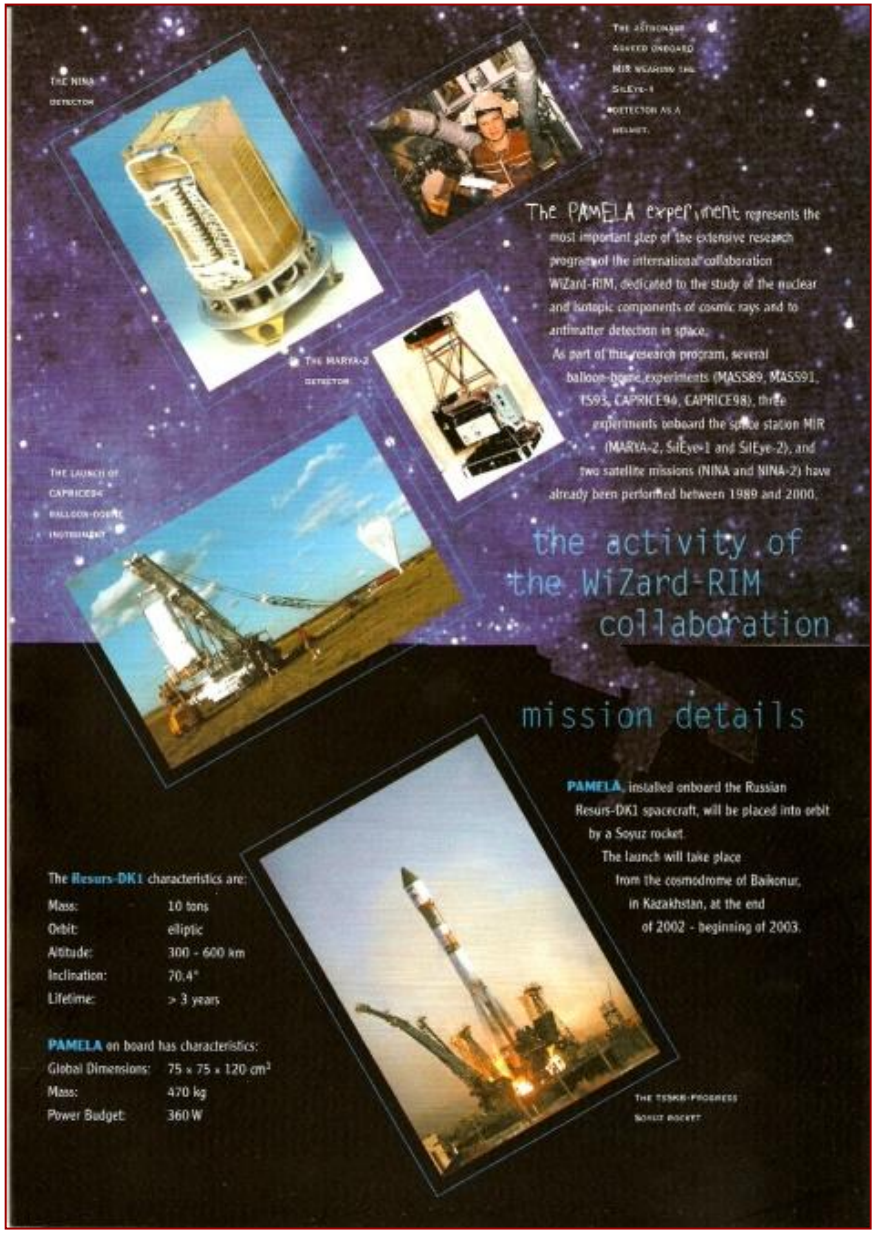




Radiation damage to electronics: Research at Nuclotron

Relativistic heavy ion beams at Nuclotron are unique instrument for test of microelectronics for space program

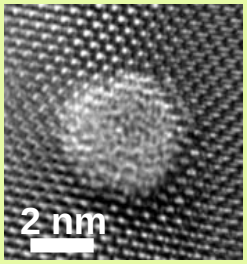


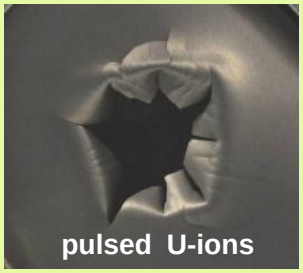


Wide range of materials research with ion beams

Radiation effects

- track formation
- beam-induced changes
- radiation hardness
- desorption processes
- sputtering





Requirements

important

Irradiations

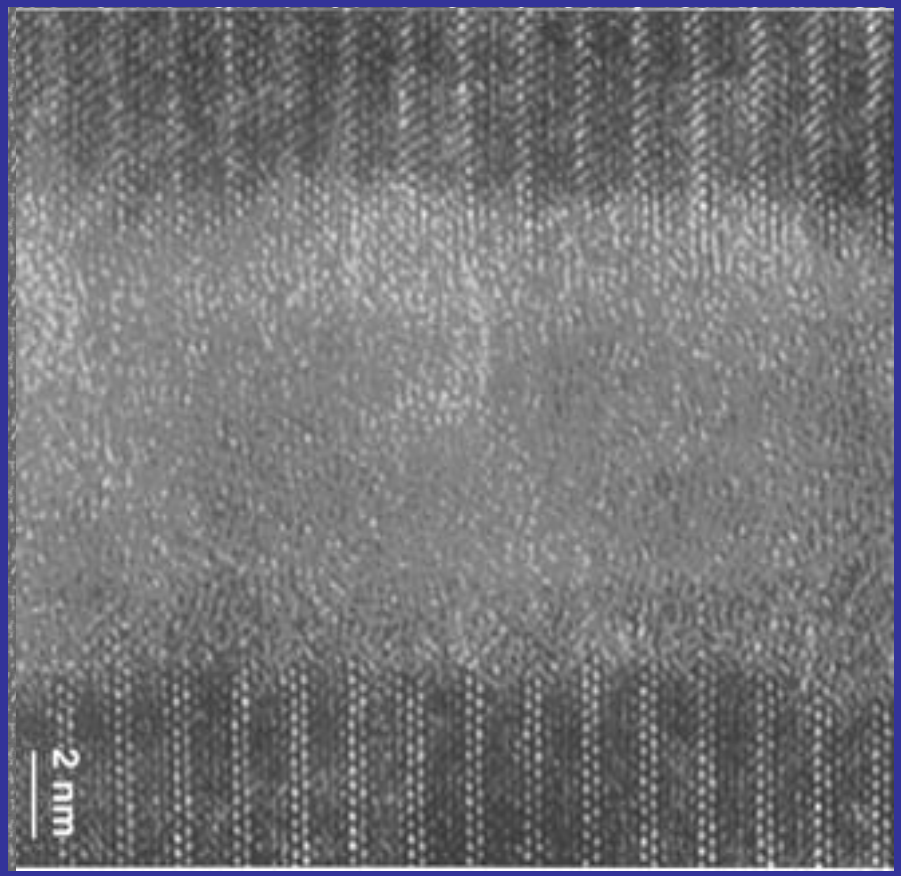
- different ion species
- different energies
- different conditions

Characterization

- microscopy
- spectroscopy
- in-situ / on-line

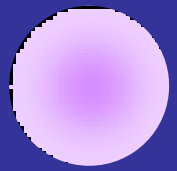
Formation of ion tracks

high-Tc superconductor



ion projectile of 1 GeV

10% velocity of light

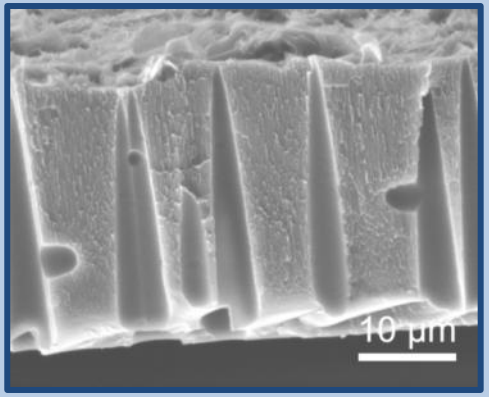


track length ~100 µm

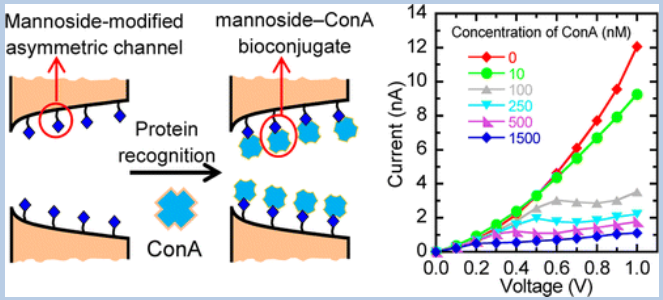
J. Wiesner et al., Physica C 268 (1996) 161

Ion-track nanotechnology

Nanochannels



Biomolecular recognition and gating of synthetic ion channels

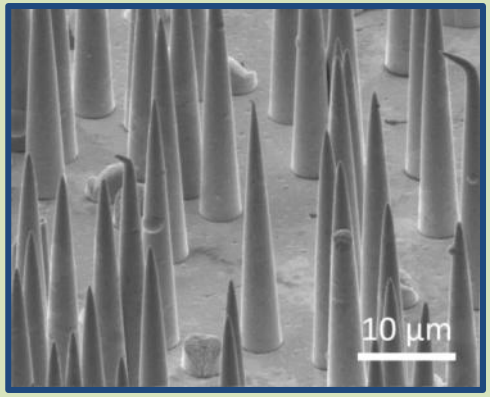


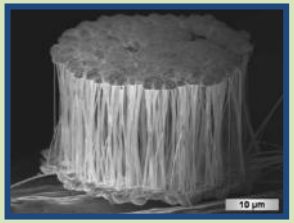
Ali, Nasir, Ramirez, Cervera, Mafe et al *J. Phys. Chem. C*, **2013**, *117* (35), 18234

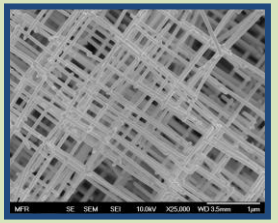
Applications as membranes, filters, model systems for biochannels , chemical- and bio-sensors, templates

Electrodeposition

Nanowires





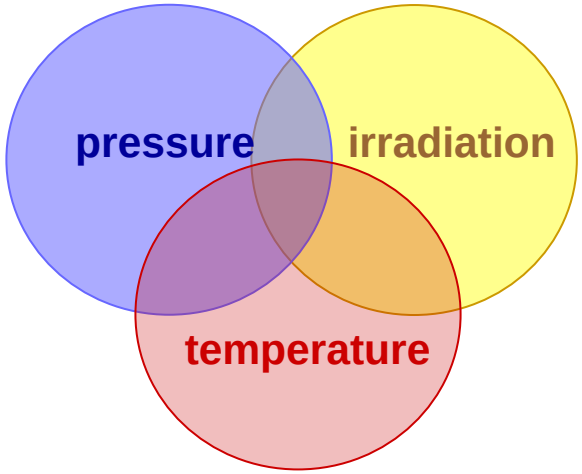


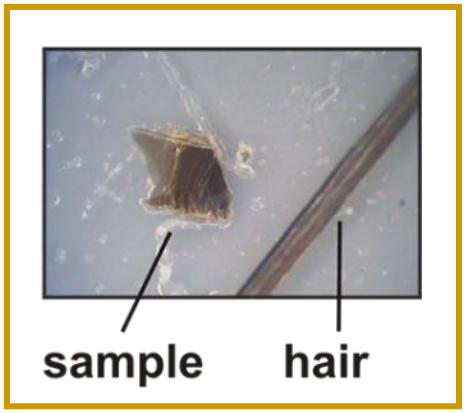
Metals: Au, Ag, Pt, Co, Ni, Cu...
Semimetals: Bi, Sb
Semiconductors: Bi_2Te_3, Cu_2O, ZnO

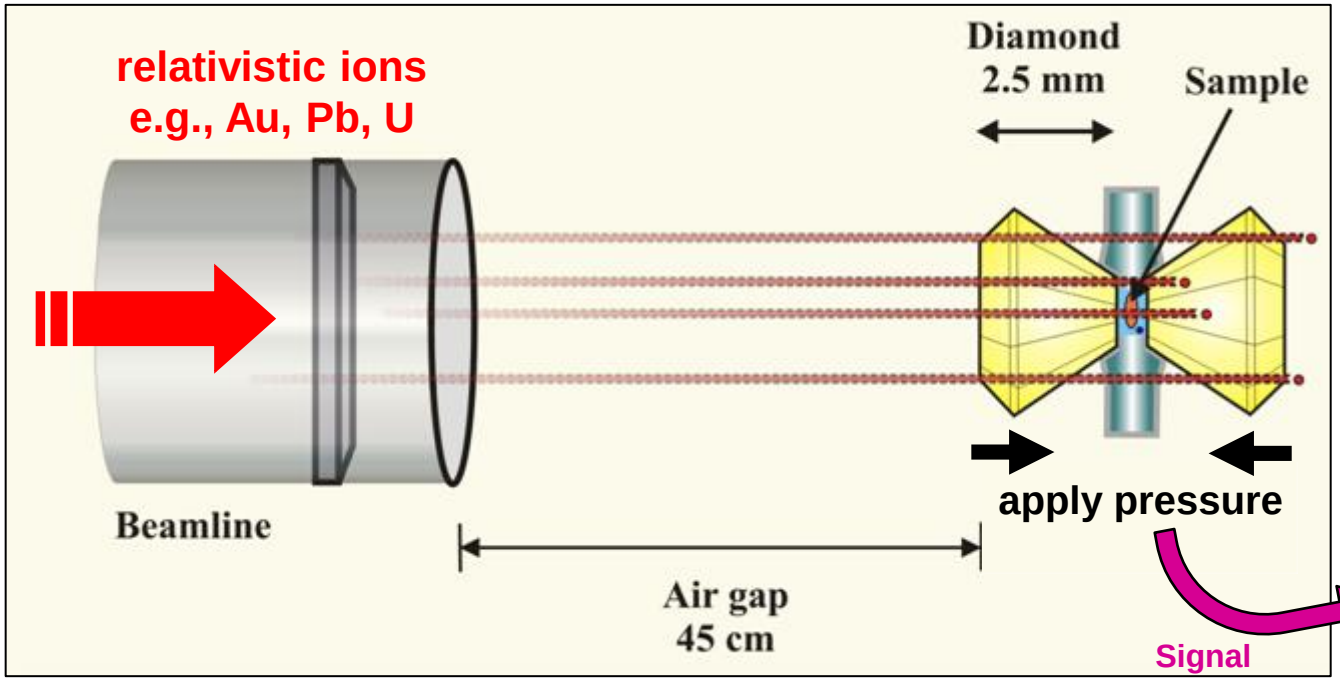
Applications in field emission, electronics, plasmonics, sensorics, thermoelectrics, water splitting...

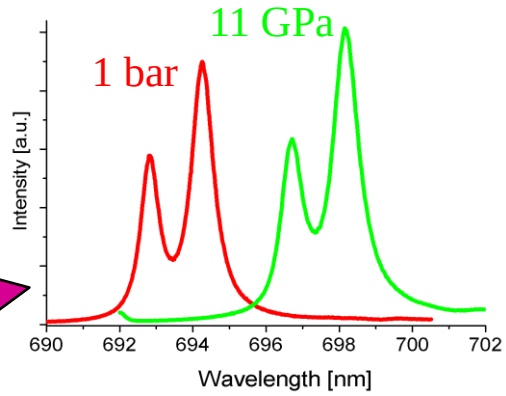
Materials under multiple extreme conditions

Exposure:
simultaneously
or sequential

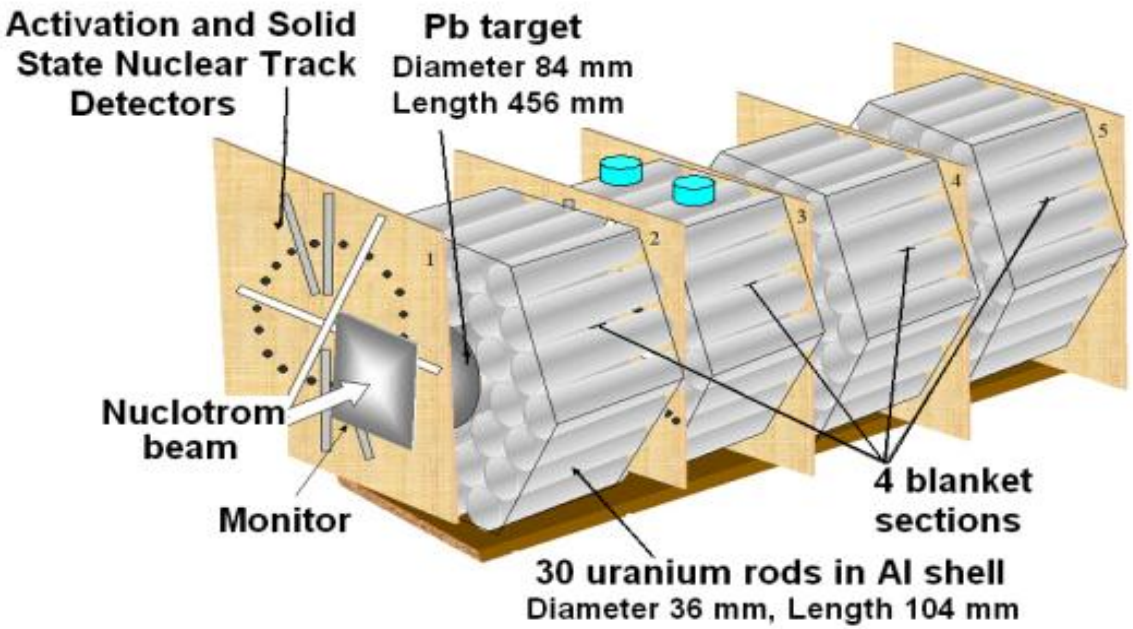








Study of irradiation of sub-critical uranium assembly + lead target. International collaboration “Energy+Transmutation” at Nuclotron



Getting new basic nuclear-physics data with relativistic proton, deutron and light ion beams **(1 - 4.5 GeV/u)**
for modeling and design of the active core of the prototype for close-to-industrial setup of the radioactive waste processing

Workshop Round Table

- The results of the Workshop indicate that heavy ion beams to be available at the NICA complex are in high demand both for JINR and for international user community as a whole.

- Considering that NICA will serve as the basis for a variety of fundamental and applied research, the Workshop participants expressed intents to set up scientific collaboration with JINR for the purpose of formulating the programme of applied research at this facility and its further implementation.

Draft programme of applied research at NICA

- Development and construction of the beamlines and experimental setups for applied research at NICA.
- Radiobiological investigations with ions at the particle energy range of 250–800 MeV/u.
- Modeling the cosmic ray irradiation of space shuttle crews in long-term flights.
- Irradiation of electronics hardware with NICA ion beams and modeling of cosmic ray irradiation of electronic components.
- Radiation hardness of materials at the interaction with NICA ion beams.
- Development of diagnostic technique and instrumentation that is applied for irradiated materials and biological objects.

Conclusion

- ✓ Development of facilities for biophysics and materials science research at NICA is at the phase of beginning, and therefore, any suggestion and comments are welcomed.
- ✓ Establishing the close cooperation with international scientific community is essential for defining the user requirements for irradiation setups going to be constructed.
- ✓ Development of applied research at NICA contributes to visibility and promotion of this mega-science project.
- ✓ Concentration of applied research around flagship projects like NICA increases the quality and impact of these studies.

Thank you for your attention