Joint Institute for Nuclear Research

Development of the JINR basic facility for generation of intense relativistic heavy ion and polarized nuclear beams

Project "Nuclotron M" / NICA

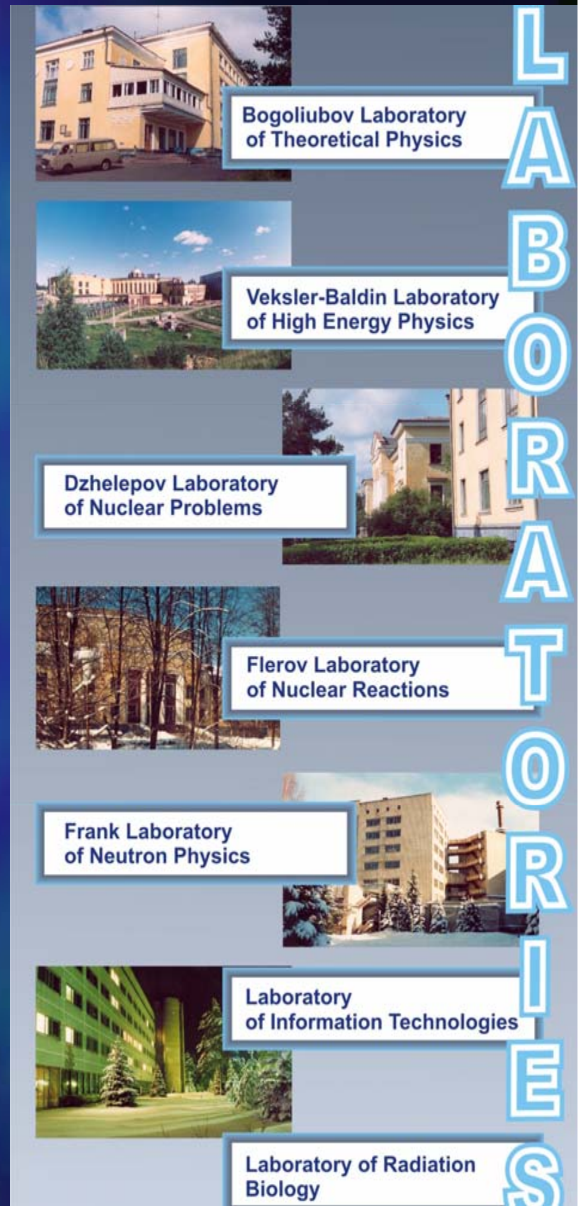
A.Kovalenko, SYMMETRIES AND SPIN, Praha, July 20-26, 2008

JINR's research niche offered by home facilities

- **Heavy-Ion Physics:**
  - at high energies (up to 5 GeV/n)
  (in future $\sqrt{s_{NN}}$ = 9 GeV, NICA facility)

  - at low and intermediate energies (5 – 100 MeV/n)

- **Condensed Matter Physics**
  using nuclear physics methods



WORLD FACILITIES

Facility	SPS	RHIC	NICA	FAIR SIS-300
Detector	NA61	STAR PHENIX	MPD	CBM
Start (year)	2010	2010	2013-2014	2015-2016
Energy (for Pb-ions) c.m. GeV	4.9-17.3	4.9-50	≤ 9	≤ 8.5
Physics	CP,OD	CP,OD	CP,OD,HDM	CP,OD,HDM

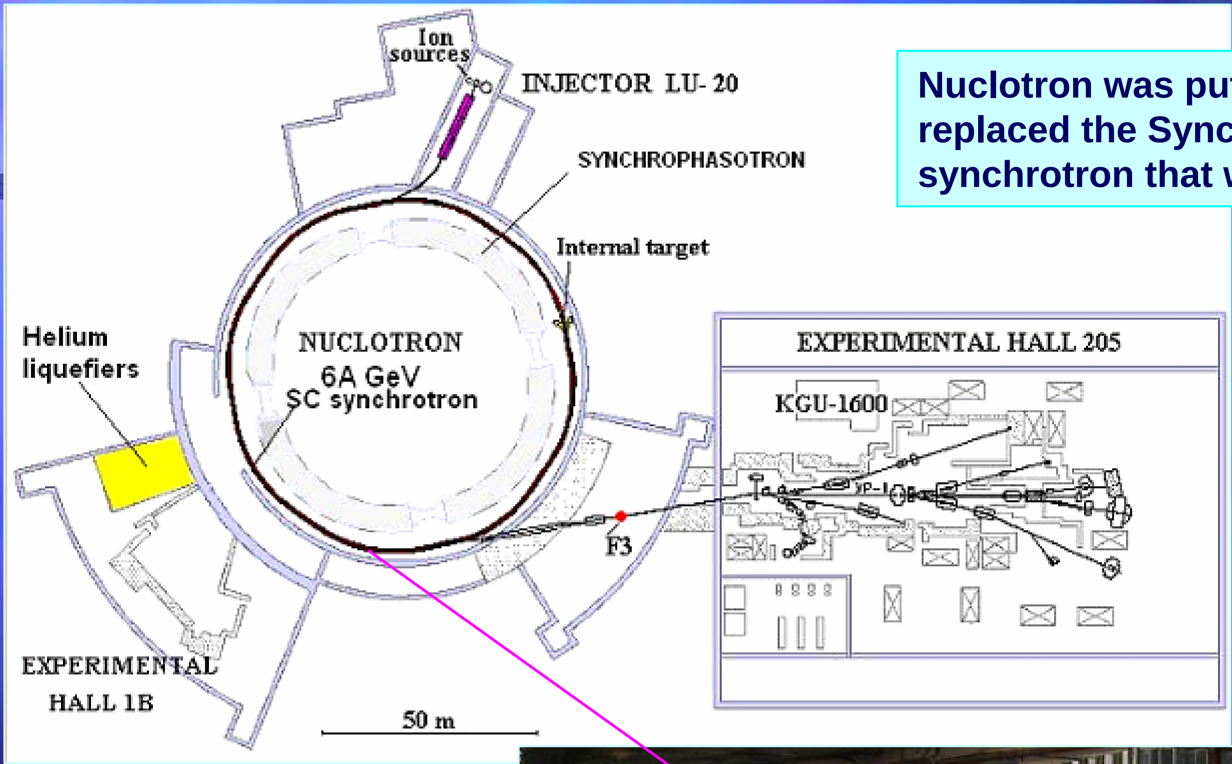
CP – critical endpoint

OD – onset of deconfinement

HDM – hadronic dense matter

JINR Veksler-Baldin Laboratory of High Energy Physics:
Accelerator buildings

Existing JINR facility: Nuclotron



Nuclotron was put into operation in 1993 and replaced the Synchrophasotron – 10 GeV proton synchrotron that was under operation since 1957

Nuclotron is based on the unique technology of fast-cycled superconducting magnets that was proposed and realized at the laboratory

Nuclotron: status 2007

Parameter/System	Nuclotron (available) in 2007
The heaviest accelerated ions: • Mass, A • Charged state, q	 56 (iron) 24
Dipole magnetic field, T • Maximum tested in the ring • More frequently operation	 1.5 1.2 (up to)
Magnetic field ramp, T/s • Nuclotron project • Maximum operating	 2.0 (up to) 1.0
Vacuum in the ring (averaged), Torr	$\sim 2 \cdot 10^{-8}$
RF acceleration: • Number of the RF stations • Particle capture scheme	 2 non-adiabatic
Beam extraction: • Max. beam energy, GeV/u • Electrostatic septa voltage, kV • Spill duration (minimum), mks • Spill duration (maximum), s	 2.2 120 100 10
Beam intensities, (part. per cycle): • Protons, deuterons • Heavy ions (A ~ 200) • Polarized deuterons	 $\sim 3.5 \cdot 10^{10}$ not available $\sim 10^{7}$ - 10^{8}

annual operation time was at the level of 2000 hours

"NUCLOTRON-M"

- The project "Nuclotron-M" is considered as the first subproject (SP1) of the JINR future project NICA/MPD (Nuclotron-based Ion Collider fAcility and Mixed Phase Detector).
- The NICA/MPD facility is aimed at investigation of the mixed phase formation in strongly interacting nuclear matter at extremely high baryon densities and polarization phenomena in few-body nucleon systems.
- The extension of JINR research capabilities for generation of intense heavy ion and high intensity light polarized nuclear beams, including design and construction of heavy ion collider aimed at reaching the collision energies of $\sqrt{s_{NN}} = 4 \div 9$ GeV and average luminosity of $1 \cdot 10^{27}$ $cm^{-2}s^{-1}$.
- Different schemes of the NICA were considered by the present time. It was shown, the NICA specified parameters (average luminosity, c.m. collision energy, atomic mass range) can be reached.
- The main parts of the project are the following:

- *development, modernization and improvement of the Nuclotron systems,*
- *design and construction of heavy ion injector,*
- *design and construction of heavy ion booster synchrotron and*
- *design and construction of the collider rings.*

Nuclotron: status and future development

Parameter/System	Nuclotron (available) in 2007	"Nuclotron-M" (project goals) 2008-2010	Comments
The heaviest accelerated ions: • Mass, A • Charged state, q	56 (iron) 24	238 (uranium)*)	*) acceleration of gold ions (A=198, q ? 65) will be realized first
Dipole magnetic field, T • Maximum tested in the ring • More frequently operation	1.5 1.2 (up to)	2.0 2.0	**2.12 T** at the test bench before installation in the ring
Magnetic field ramp, T/s • Nuclotron project • Maximum operating	2.0 (up to) 1.0	1.2 – 1.5 1.2 – 1.5	**4.0 T/s** at test bench before installation in the ring
Vacuum in the ring (averaged), Torr	$\sim 2 \cdot 10^{-8}$	$\sim 5 \cdot 10^{-10}$	N_2 concentration at T = 300 K equivalent
RF acceleration: • Number of the RF stations • Particle capture scheme	2 non-adiabatic	3 adiabatic*)	*) better efficiency of capture (by a factor of two)
Beam extraction: • Max. beam energy, GeV/u • Electrostatic septa voltage, kV • Spill duration (minimum), mks • Spill duration (maximum), s	2.2 120 100 10	6 200 - $\sim 2.5 \cdot 10^{-8}$	(q/A= 0.5) single bunch
Beam intensities, (part. per cycle): • Protons, deuterons • Heavy ions (A ~ 200) • Polarized deuterons	$\sim 3.5 \cdot 10^{10}$ not available $\sim 10^{7}$ - 10^{8}	$\sim 1 \cdot 10^{11}$ $\sim 10^{7}$ $\sim 10^{10}$	minimization of the losses, development of the ion source KRION, new polarized ion source

The necessary set of R&D, construction and experimental work that should be done for the Nuclotron upgrade is covered by the project "Nuclotron-M".

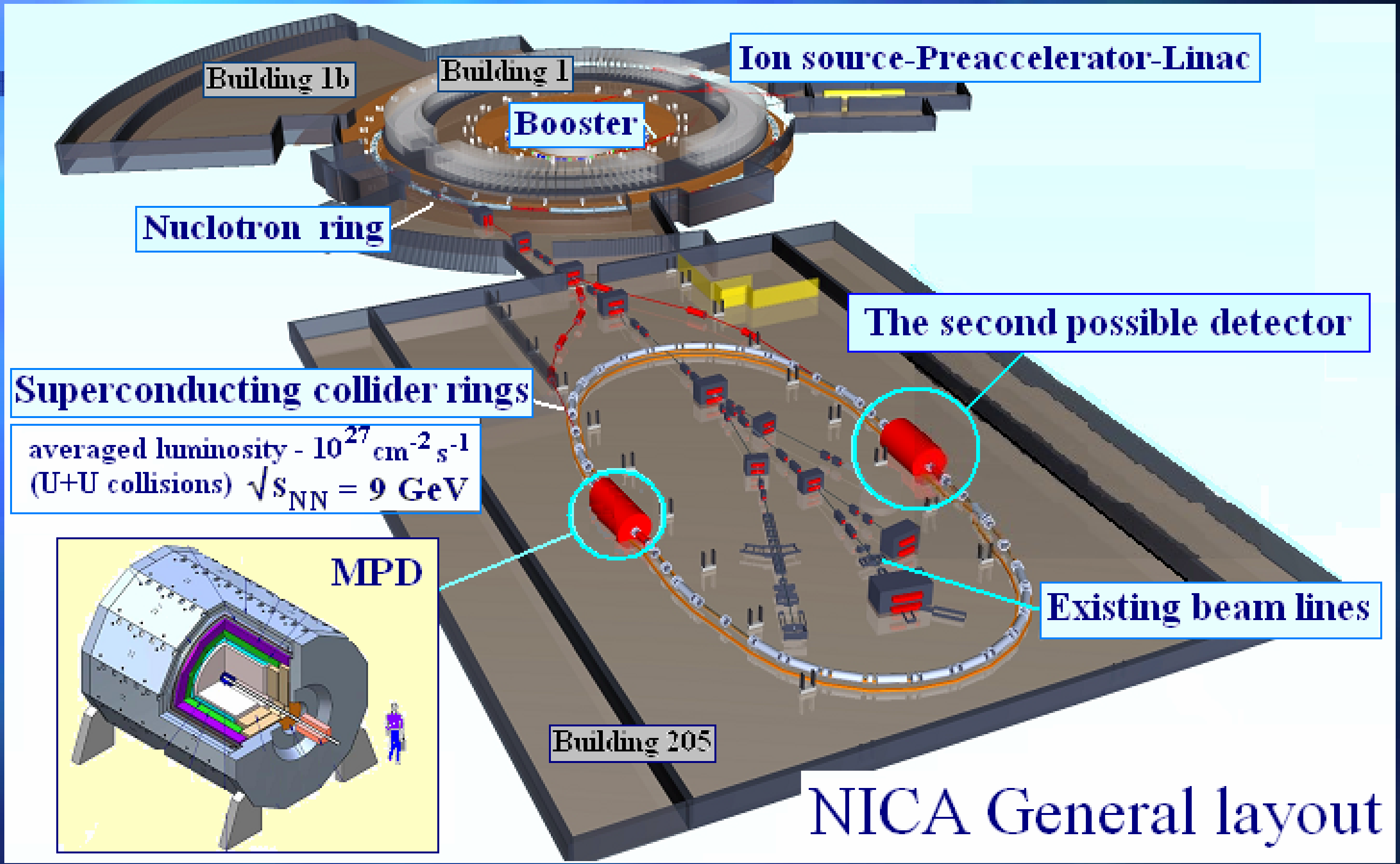
The main goal of the NICA project is an experimental study of hot and dense nuclear matter and spin physics problems

These goals are proposed to be reached by:

- development of the existing accelerator facility as a basis for generation of intense beams over atomic mass range from protons to uranium and light polarized ions; (1st stage of the NICA accelerator programme: Nuclotron-M)

- design and construction of heavy ion collider with maximum collision energy of $\sqrt{s_{NN}} = 9$ GeV and average luminosity 10^{27} cm^{-2} s^{-1} (for U^{92+}), and polarized proton beams with energy $\sqrt{s} \sim 27$ GeV and average luminosity > 10^{30} cm^{-2} s^{-1};
- design and construction of the MultiPurpose Detector (MPD).

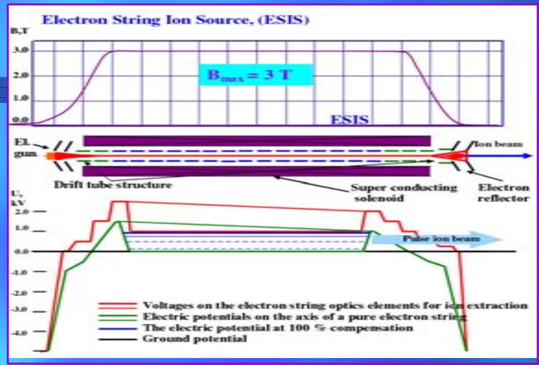
Layout of the NICA/MPD (2007)



Subproject SP1.1 "Design and construction of highly charged state heavy ion source based on the "KRION" technology"

(leaders: E.E. Donets and E.D.Donets)

- Development of heavy ion source KRION



The fist Au32+ ion beams have been obtained in October 2006. Ionization time was 100 ms. The total intensity was of $1.2*10^9$ ions/pulse.

General view of the ion source and basic operation scheme.

Construction and test of the new ion source with 6 T solenoid within the coming two years is the main goal of the SP1.1.

The new important feature of the source is capability of operation at high pulse repetition rate in the case of production heavy ions at intermediate charged states, was considered.

U^{30+} intensity of $(4\text{-}8)10^{10}$ ions/sec is reached in the case of the pulse repetition rate of 5-10 Hz.

The fundamental parameter of a KRION-type source is a factor **jτ** - product of electron current density and ionization time. The **jτ** value depends, in particular, on the applied external magnetic field. The maximum magnetic field in the existing ion source dont exceed 3 T. Ionization capability of the source and experimental results have been obtained at test bench are presented

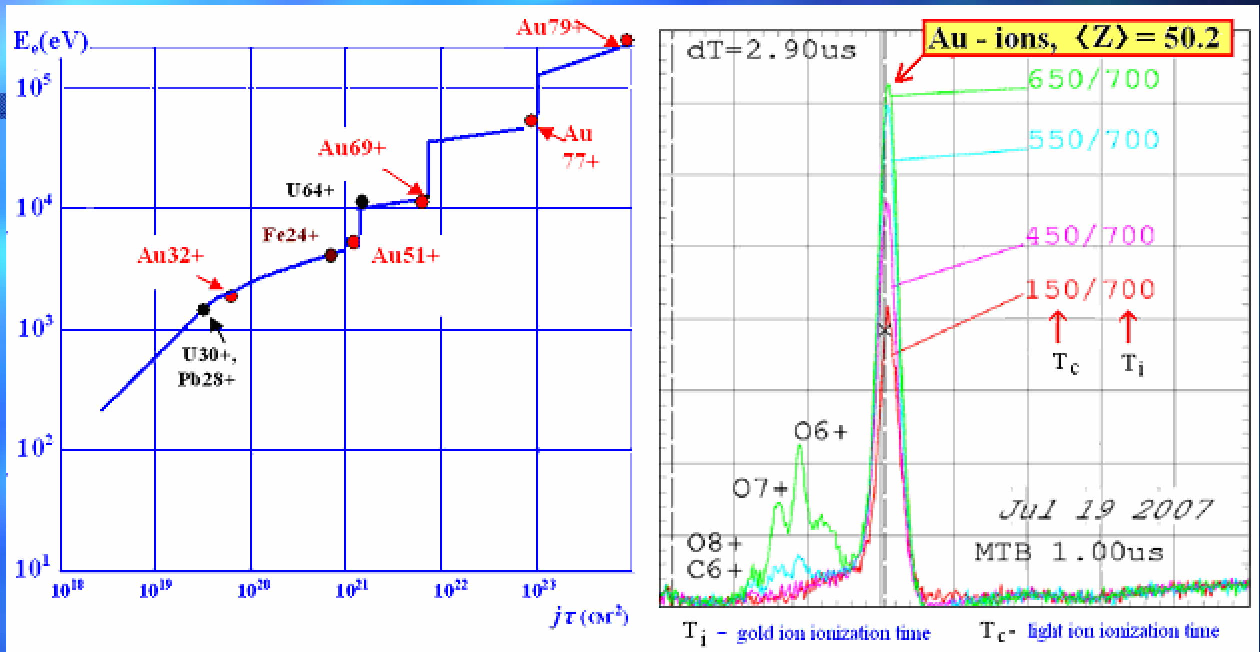


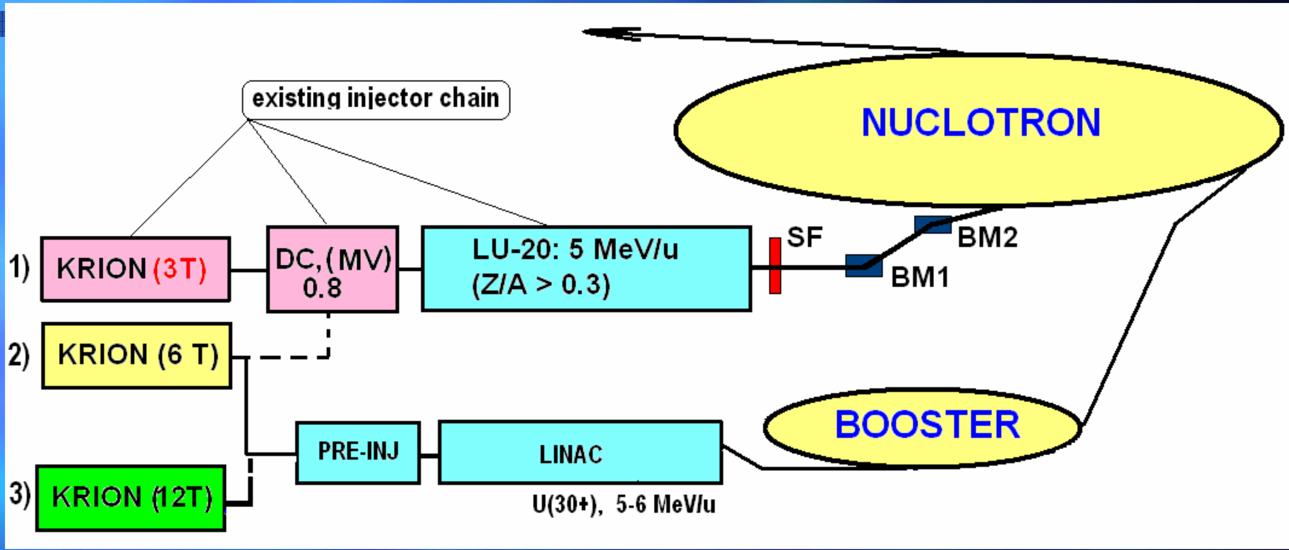
Fig. 2. Ionization capability (left plot) and experimental results from the ion source KRION-2 on generation of highly charged state gold ions.

1.Design and construction of the new electron-string highly-charged state heavy ion source KRION-6T aimed at generation of heavy ion beams with q/A up to 0.33 (for example Au65+ ÷ Au69+).
2.Study of the electron string phenomenon at different conditions in the source working volume (magnetic field range up to 6 T, energy of electron beam up to 25 keV). Development and optimization of heavy atoms injection into the string and ion-ion cooling process. The further investigation of tubular electron-string ion source
3.Preparation of the existing source KRION-2 to the next run at the Nuclotron aimed at acceleration of the ion beams over atomic mass range of A ~ 100 **(the last decision is xenon Xe(44+).**

•Design and construction work on heavy ion pre-accelerator chain with injection and extraction beam lines

The existing complex will be used for protons, deuterons, polarized deuterons and light ions (Z/A > 0.3).

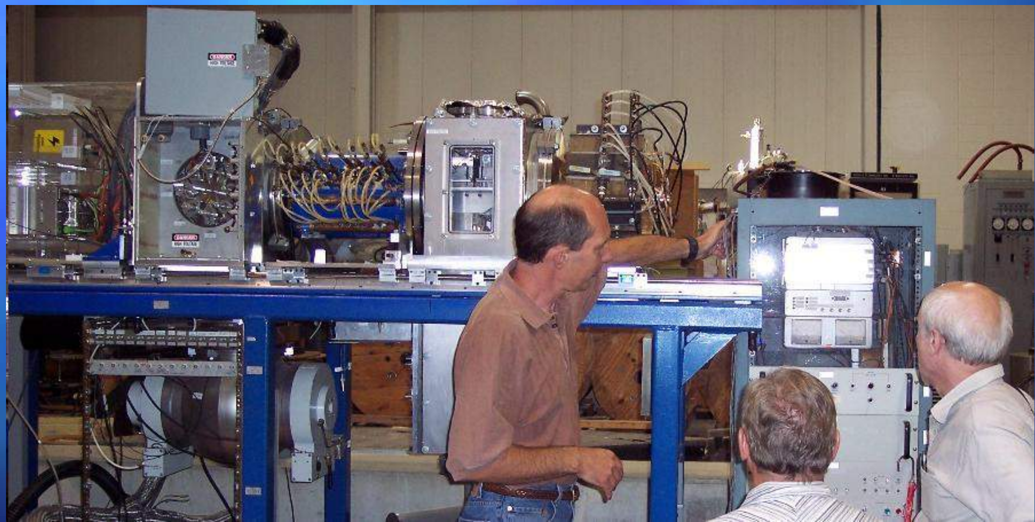
The new heavy ion source KRION-6T, upgrade of pre-accelerators and improvement of vacuum in LU-20 and injection line is supposed within the project "Nuclotron-M".



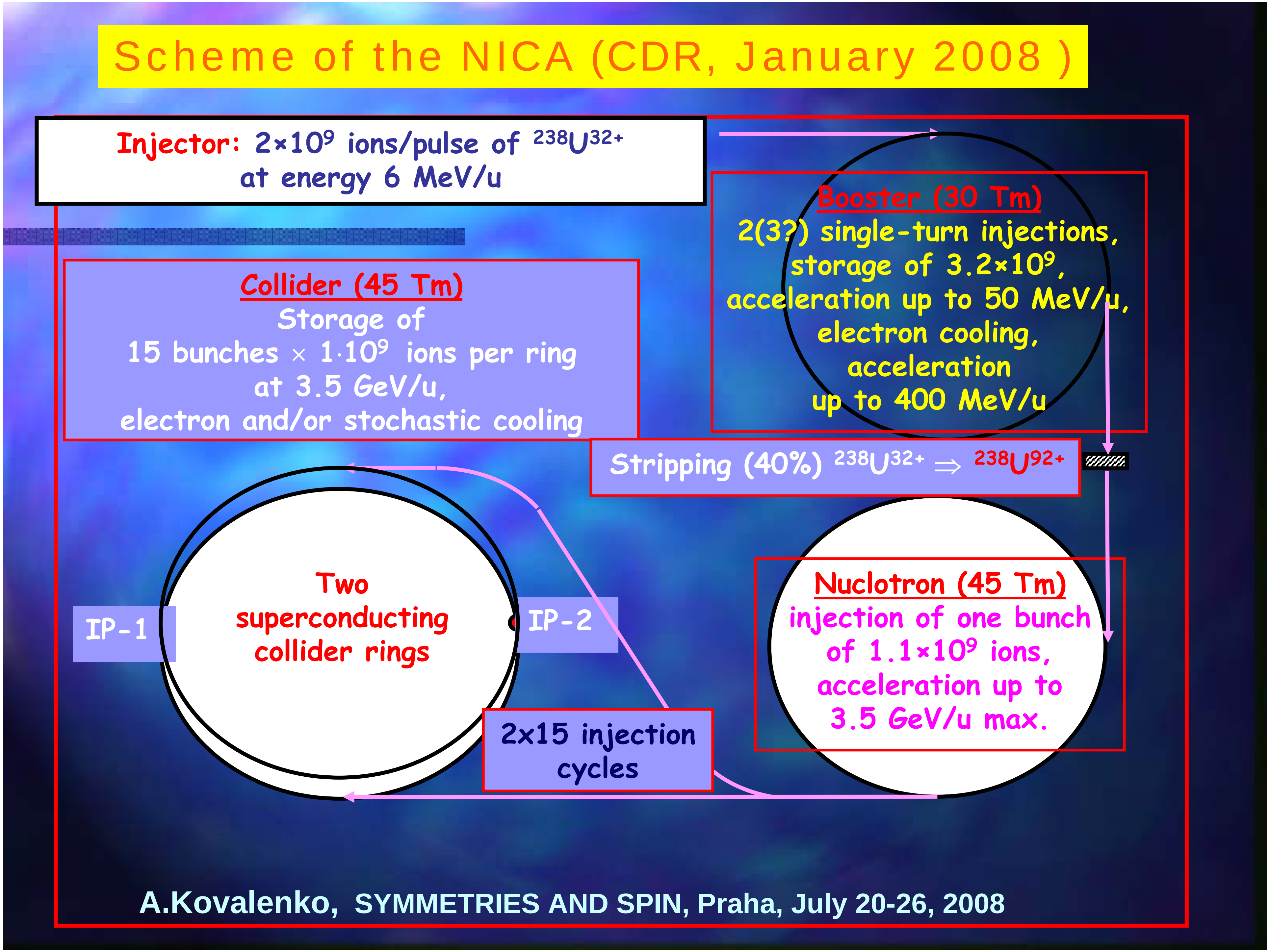
The limiting charge-to-mass ratio of ion accelerated in the LU-20 is $q/A \geq 0.3$. As it follows from the SP1.1 sub-project description, the possibility of the KRION-type ion source with the magnetic field of 3 T and energy of the electron beam up to 6 keV (existing version of the source) can provide ion beam of $^{130}Xe^{44+}$, i.e. ions with $q/A \approx 0.34$. Thus, it is possible to perform a test acceleration of heavy ion beam with atomic mass of 130 at the Nuclotron after completion of the work on improvement of vacuum in the accelerator chamber. Acceleration of gold ions will be performed after construction of KRION-6T ion source.

Design and construction of high intensity polarized deuterons and protons ion source."

The main direction of work aimed at increase of polarized beam intensity at the Nuclotron is connected with the design and construction of the new high current polarized ion source (IPSN) based on the equipment of CIPIOS polarized proton and deuteron ion source from Bloomington The work is carried out in collaboration with INR (Troitsk). The ion source equipment (not completed) was transported to Dubna from IUCF (Indiana University, Bloomington, USA). Some parts of a suitable equipment for the new source were presented from DAPNIA (Saclay).



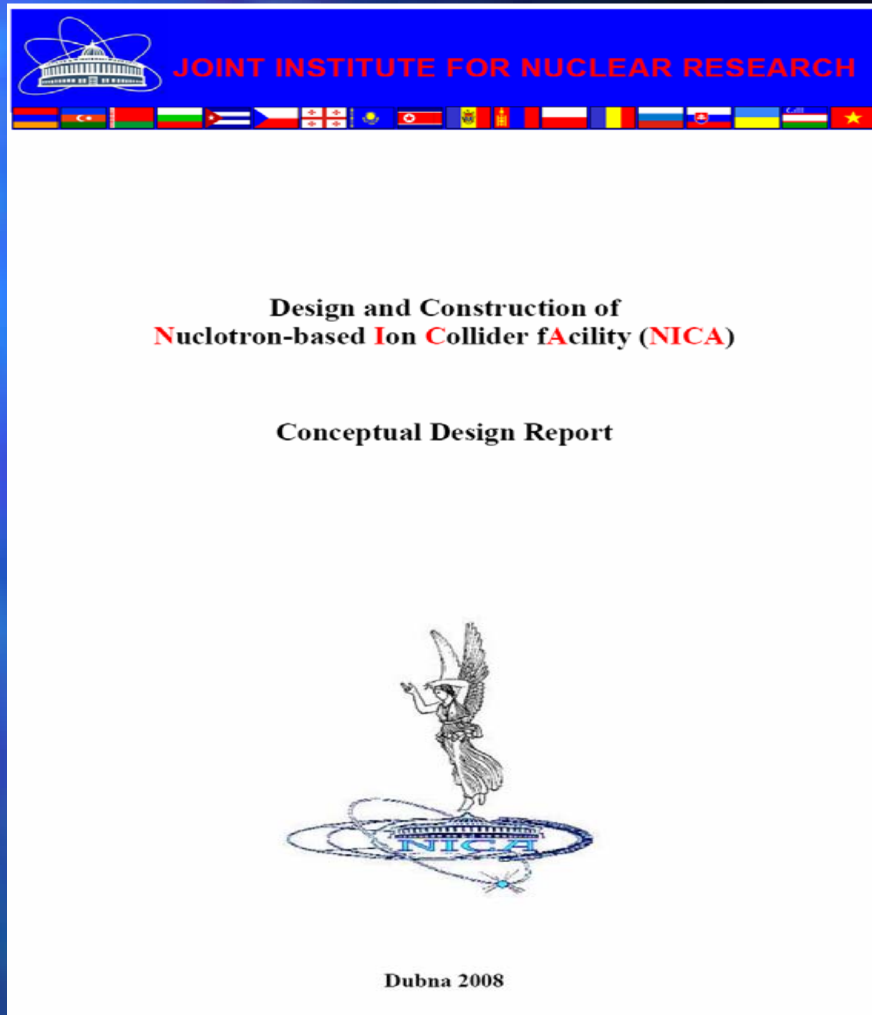
See presentation by V.Fimushkin at this workshop for more details


Scheme of the NICA (CDR, January 2008)
Injector: $2{\times}10^9$ ions/pulse of $^{238}U^{32+}$
at energy 6 MeV/u
Booster (30 Tm)
2(3?) single-turn injections,
storage of $3.2{\times}10^9$,
acceleration up to 50 MeV/u,
electron cooling,
acceleration
up to 400 MeV/u
Collider (45 Tm)
Storage of
15 bunches $\times$ $1{\cdot}10^9$ ions per ring
at 3.5 GeV/u,
electron and/or stochastic cooling
Stripping (40%) $^{238}U^{32+} \Rightarrow$ $^{238}U^{92+}$
Two
superconducting
collider rings
IP-1
IP-2
2x15 injection
cycles
Nuclotron (45 Tm)
injection of one bunch
of $1.1{\times}10^9$ ions,
acceleration up to
3.5 GeV/u max.
A.Kovalenko, SYMMETRIES AND SPIN, Praha, July 20-26, 2008

1. Circumference, m	224
2. β^*, m	0.5
3. $\Delta p/p$ (1σ)	$1 \cdot 10^{-3}$
4. Bunch length (σ), m	0.3
5. Beam emittance (σ), $\pi \cdot$mm$\cdot$mrad	0.26
6. Bunch intensity	$(1-2) \cdot 10^9$
7. Bunches per ring	15
8. Average luminosity, $cm^{-2} \cdot s^{-1}$ for UU: at 3.5 GeV/u at 1.0 GeV/u for pp: at 12.5 GeV dd: at 6 GeV/u	 $1.1 \cdot 10^{27}$ $6.6 \cdot 10^{25}$ $3 \cdot 10^{31}$ $1 \cdot 10^{31}$

NICA – Collaboration

- Joint Institute for Nuclear Research
- Institute for Nuclear Research Russian Academy of Science
- Institute for High Energy Physics, Protvino
- Budker Institute of Nuclear Physics, Novosibirsk
- MoU with FAIR is under preparation
- *Open for extension …*


JOINT INSTITUTE FOR NUCLEAR RESEARCH

Design and Construction of
Nuclotron-based Ion Collider fAcility (NICA)

Conceptual Design Report

Dubna 2008

http://nica.jinr.ru

The NICA Project Milestones

Proposal 2006

• **Stage 1: years 2007 – 2009**

- Upgrade and Development of the Nuclotron facility
- Preparation of Technical Design Report of the NICA and MPD
- Start prototyping of the MPD and NICA elements

• **Stage 2: years 2008 – 2012**

- Design and Construction of NICA and MPD

• **Stage 3: years 2010 – 2013**

- Assembling

• **Stage 4: year 2013 - 2014**

- Commissioning

The NICA/MPD (2008)

• NEW REALITY:

• request for 4 collision points (2 for the Mixed Phase Detector (hadron observables and lepton observables) and 2 for spin physics research – more space is needed

The NICA/MPD (2008)

• NEW REALITY:

• request for 4 collision points (2 for the Mixed Phase Detector (hadron observables and lepton observables) and 2 for spin physics research – more space is needed

• SOLUTION?:

The NICA/MPD (2008)

• NEW REALITY:

• request for 4 collision points (2 for the Mixed Phase Detector (hadron observables and lepton observables) and 2 for spin physics research – more space is needed

• SOLUTION?:

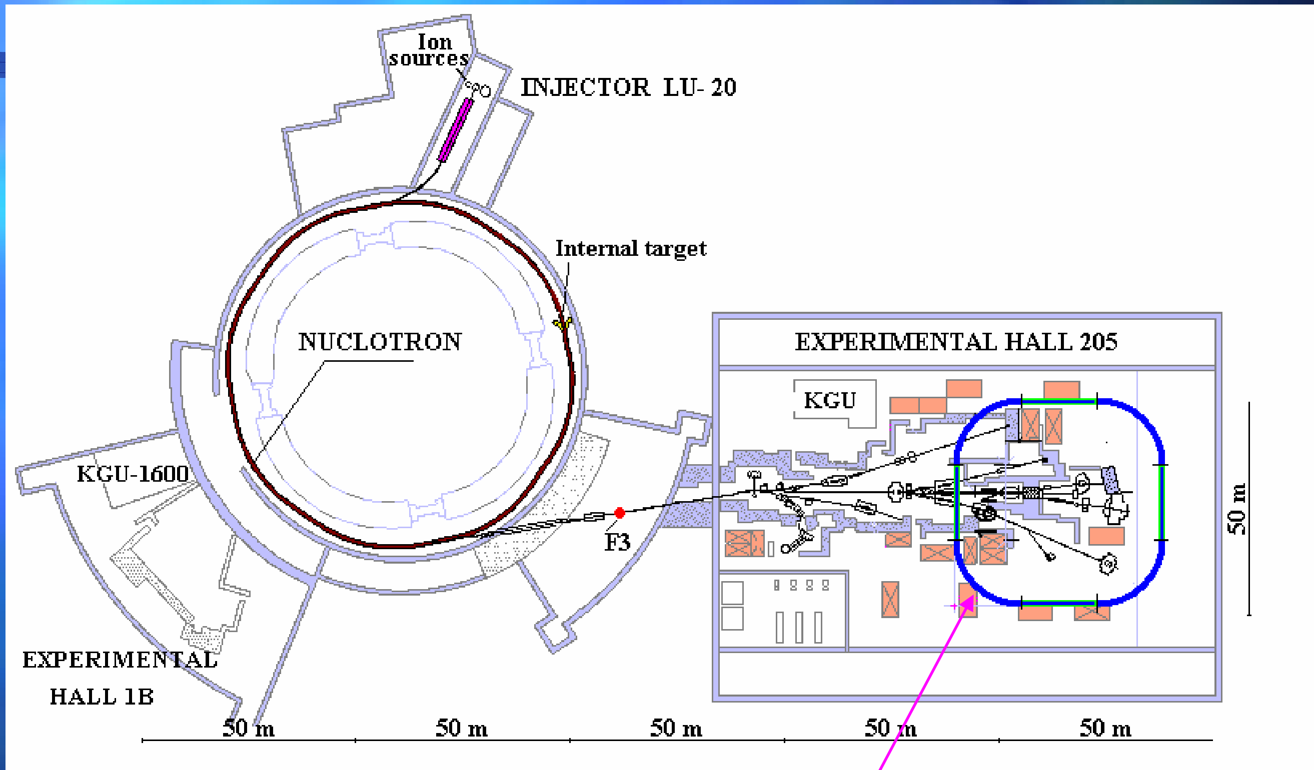
build the collider facility in the new tunnel?

to find feasible option of the collider rings for the existing building?

NICA collider facility in the new tunnel

The necessary space is available

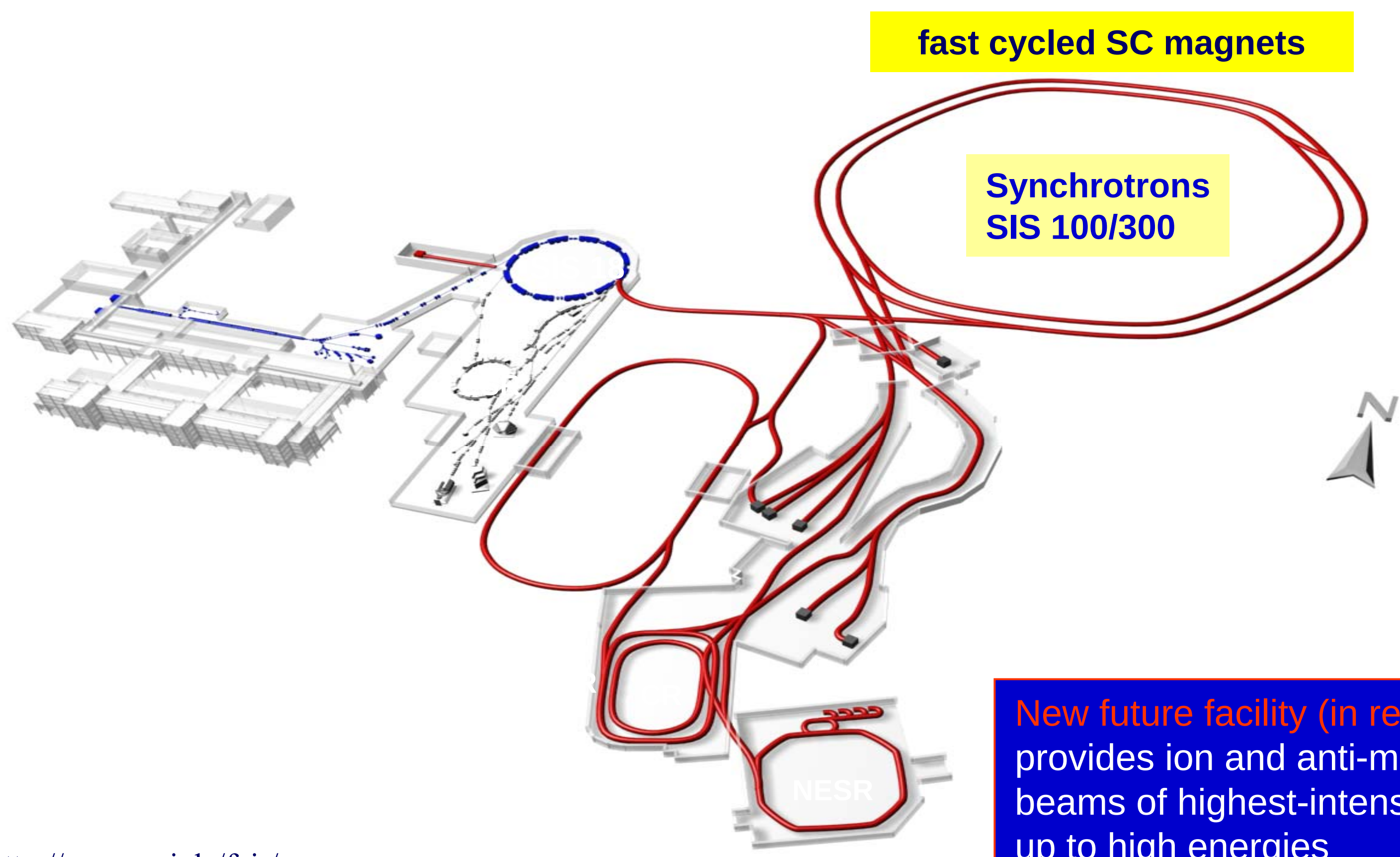
feasible option of the collider rings for the existing building?



Superconducting 4.2 T dipoles are necessary for the collider rings, i.e. R&D.

Our Laboratory has a long term experience in a superferric 2 T magnets design and operation

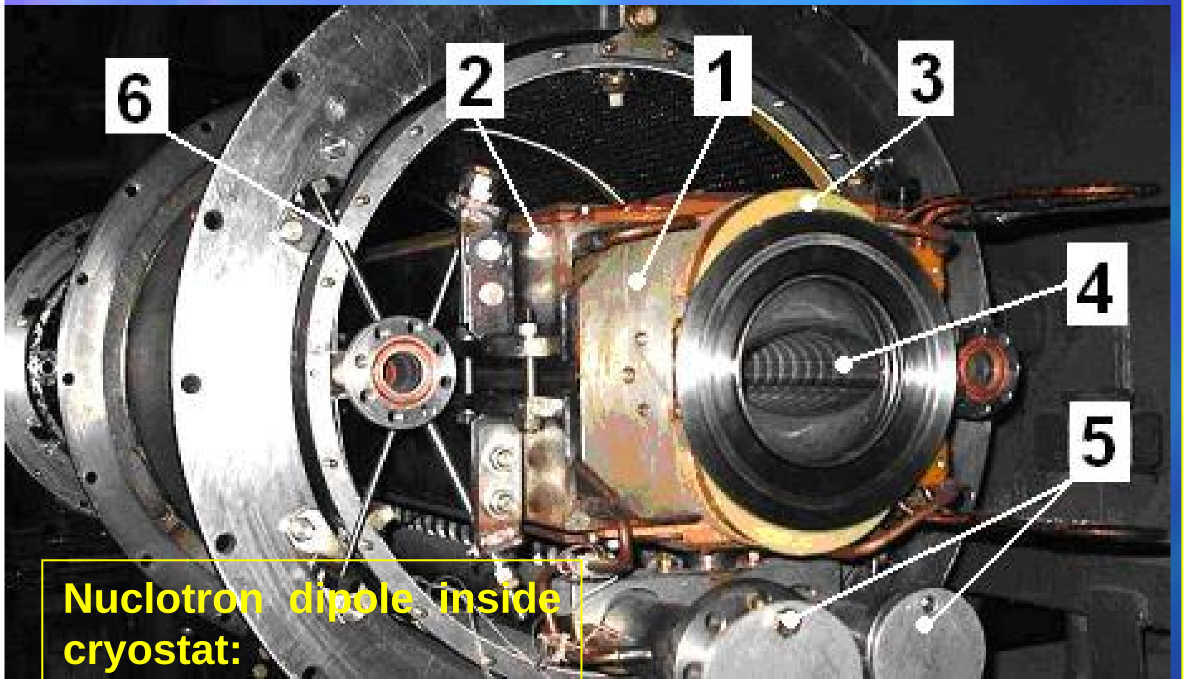
FAIR: Facility for Antiproton and Ion Research

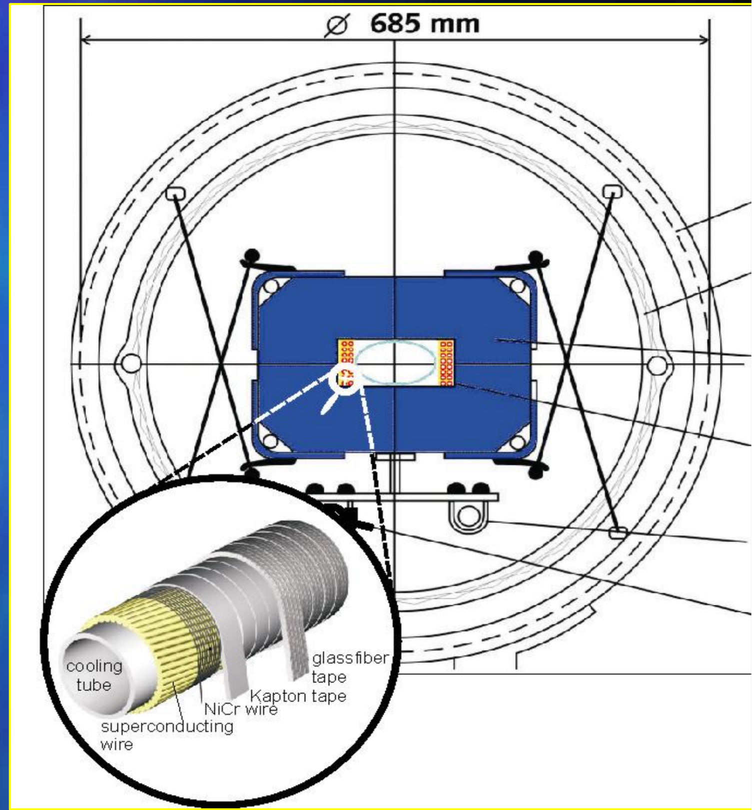


http://www.gsi.de/fair/

New future facility (in red):
provides ion and anti-matter beams of highest-intensity and up to high energies

Nuclotron Dipole – prototype of the FAIR SIS100 magnet



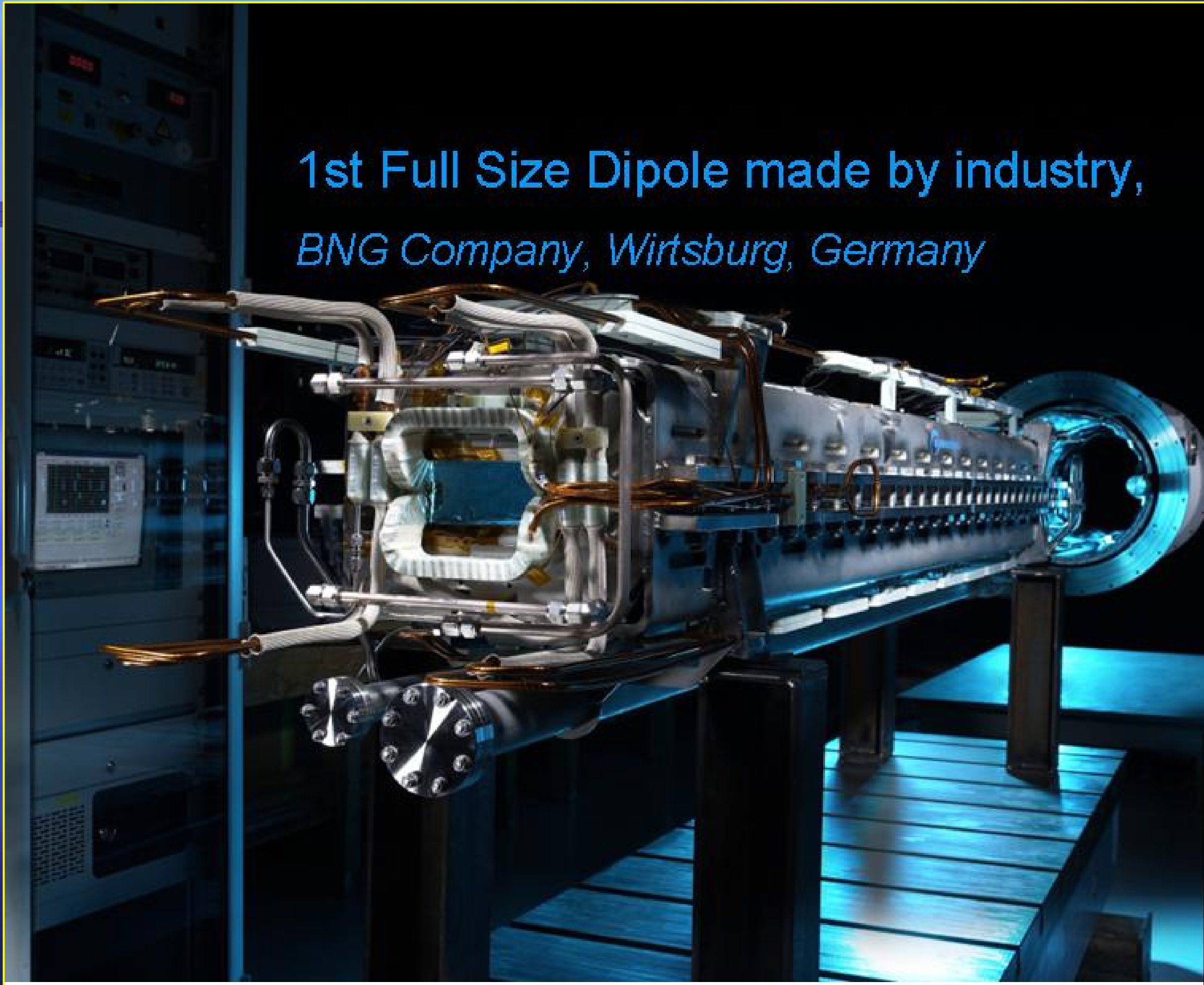


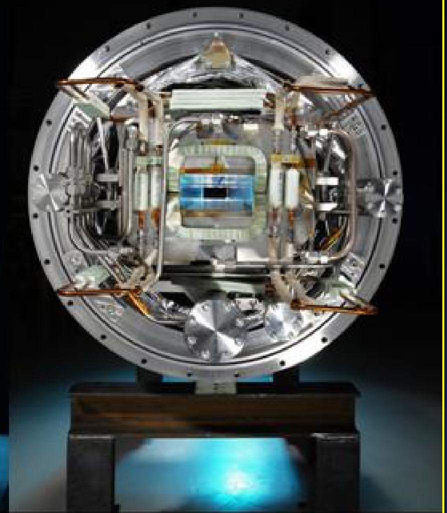
Nuclotron dipole inside cryostat:

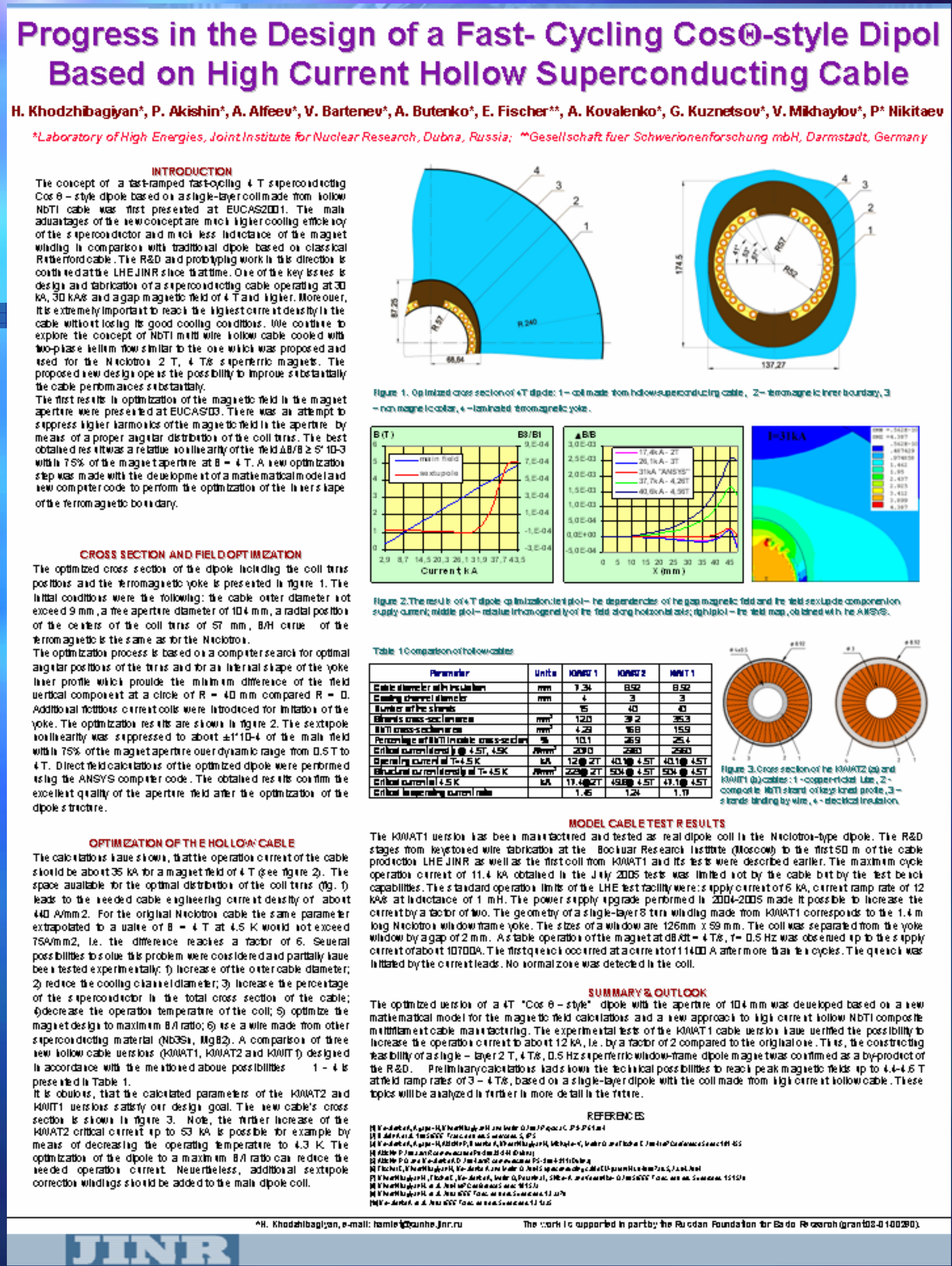
1 - yoke end plate
2 - brackets
3 - coil end loop
4 - beam pipe
5 - helium headers
6 - suspension
7 - laminated yoke

- **Superferric design (window frame type)**
- **Maximum magnetic field: 2 T, Ramp rate: 4 T/s**
- **Hollow superconducting cable**
- **Two-phase helium cooling**

FAIR SIS100


1st Full Size Dipole made by industry,
BNG Company, Wirtsburg, Germany





A.Kovalenko, SYMMETRIES AND SPIN, Praha, July 20-26, 2008

Realization of the NICA project at JINR will make it possible to obtain the unique data on the interaction of both as heavy ion and light polarized nuclear beams. The FAIR CBM at SIS300 and MPD at NICA are complementary facilities.