Heavy Ion Collider Facility NICA at JINR (Dubna): Status and Development.
I.Meshkov, G.Trubnikov
for NICA team
Joint Institute for Nuclear Research, Dubna

24 September 2012
St.Petersburg, RUPAC-2012
Main goals of the **NICA accelerator facility:**

- **study of hot and dense baryonic matter** & nucleon spin structure

- **development of accelerator facility**

  for HEP in JINR providing

  intensive beams of relativistic ions from $\text{p to Au}$
  
  energy range $\sqrt{S_{NN}} = 4..11 \text{ GeV} (\text{Au}^{79+})$

  and polarized **protons and deuterons**
  
  (energy range $\sqrt{S_{NN}} = 4..26 \text{ GeV} \text{ for p}$)

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2\textsuperscript{nd} generation HI experiments

**STAR/PHENIX @ BNL/RHIC.** Originally designed for higher energies ($s_{NN} > 20$ GeV), low luminosity for LES program $L < 10^{26}$ cm$^{-2}$s$^{-1}$ for Au$^{79+}$

**NA61 @ CERN/SPS.** Fixed target, non-uniform acceptance, few energies (10,20,30,40,80,160A GeV), poor nomenclature of beam species

3\textsuperscript{rd} generation HI experiments

**CBM @ FAIR/SIS-100/300**
Fixed target, $E/A=10-40$ GeV, high luminosity

**MPD & SPD @ JINR/NICA.** Collider, small enough energy steps in the range $s_{NN} = 4-11$ GeV, a variety of colliding systems, $L \sim 10^{27}$ cm$^{-2}$s$^{-1}$ for Au$^{79+}$

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QCD phase diagram - Prospects for NICA

Energy Range of NICA
unexplored region of the QCD phase diagram:

- Highest net baryon density
- Onset of deconfinement phase transition
- Strong discovery potential:
  a) Critical End Point (CEP)
  b) Chiral Symmetry Restoration
- Complementary to the RHIC/BES, FAIR, CERN & Nuclotron-M experimental programs

NICA facilities provide unique capabilities for studying a variety of phenomena in a large region of the phase diagram

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- superconducting accelerator for ions and polarized particle
- physics of ultrarelativistic heavy ions, high energy spin physics

Nuclotron provides now performance of experiments with accelerated proton and ion beams (up to Xe$^{42+}$, $A=124$) with energies up to 6 AGeV ($Z/A = 1/2$)
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<tr>
<th>Beam</th>
<th>Nuclotron beam intensity (particle per cycle)</th>
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<td></td>
<td>Current</td>
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<tr>
<td>p</td>
<td>$3 \cdot 10^{10}$</td>
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<tr>
<td>d</td>
<td>$5 \cdot 10^{10}$</td>
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<tr>
<td>$^4\text{He}$</td>
<td>$8 \cdot 10^{8}$</td>
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<tr>
<td>$d\uparrow$</td>
<td>$2 \cdot 10^{8}$</td>
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<tr>
<td>$^7\text{Li}$</td>
<td>$8 \cdot 10^{8}$</td>
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<tr>
<td>$^{11,10}\text{B}$</td>
<td>$1 \cdot 10^{9,8}$</td>
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<tr>
<td>$^{12}\text{C}$</td>
<td>$5 \cdot 10^{9}$</td>
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<tr>
<td>$^{24}\text{Mg}$</td>
<td>$2 \cdot 10^{7}$</td>
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<tr>
<td>$^{14}\text{N}$</td>
<td>$1 \cdot 10^{7}$</td>
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<tr>
<td>$^{24}\text{Ar}$</td>
<td>$1 \cdot 10^{9}$</td>
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<tr>
<td>$^{56}\text{Fe}$</td>
<td>$2 \cdot 10^{6}$</td>
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<td>$^{84}\text{Kr}$</td>
<td>$1 \cdot 10^{4}$</td>
</tr>
<tr>
<td>$^{124}\text{Xe}$</td>
<td>$1 \cdot 10^{4}$</td>
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<tr>
<td>$^{197}\text{Au}$</td>
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Complex NICA @ JINR (VBLHEP)

FT experiment area  
Collider  
New Linac  
Booster  
Nuclotron  
Lu 20
Superconducting accelerator complex NICA
(Nuclotron based Ion Collider fAcility)

Fixed target experiments
area (b.205)
Extracted beams from
Nuclotron

KRION-6T
and HiLac
(3.5 MeV/u)

SPP and
LU-20
(5 MeV/u)

Cryogenics

Nuclotron
0.6-4.5 GeV/u

Booster (3-660 MeV/u)
inside Synchrophasotron
yoke

2nd IR

NICA Collider
(1-4.5 GeV/u, C-500 m)

HV
e-cooler

Multi-Purpose
Detector (MPD)

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NICA goals

1a) Heavy ion colliding beams $^{197}$Au$^{79+}$ x $^{197}$Au$^{79+}$ at
$$\sqrt{s_{NN}} = 4 ÷ 11 \text{ GeV} \ (1 ÷ 4.5 \text{ GeV/u ion kinetic energy })$$
$$\text{at } L_{\text{average}} = 1 \times 10^{27} \text{ cm}^{-2} \cdot \text{s}^{-1} \ (\text{at } \sqrt{s_{NN}} = 9 \text{ GeV})$$

1b) Light-Heavy ion colliding beams of the same energy range and $L$

2) Polarized beams of protons and deuterons in collider mode:
$$p^{\uparrow}p^{\uparrow} \sqrt{s_{pp}} = 12 ÷ 27 \text{ GeV} \ (5 ÷ 12.6 \text{ GeV kinetic energy })$$
$$d^{\uparrow}d^{\uparrow} \sqrt{s_{NN}} = 4 ÷ 13.8 \text{ GeV} \ (2 ÷ 5.9 \text{ GeV/u ion kinetic energy })$$
$$L_{\text{average}} \geq 1 \times 10^{30} \text{ cm}^{-2} \cdot \text{s}^{-1} \ (\text{at } \sqrt{s_{pp}} = 27 \text{ GeV})$$

3) The beams of light ions and polarized protons and deuterons for fixed target experiments:
$$\text{Li} ÷ \text{Au} = 1 ÷ 4.5 \text{ GeV/u ion kinetic energy}$$
$$p, p^{\uparrow} = 5 ÷ 12.6 \text{ GeV kinetic energy}$$
$$d, d^{\uparrow} = 2 ÷ 5.9 \text{ GeV/u ion kinetic energy}$$

4) Applied research on ion beams at kinetic energy
from $0.5 \text{ GeV/u}$ up to $12.6 \text{ GeV (p)}$ and $4.5 \text{ GeV/u (Au)}$
NICA injector chain

Cascade transformer up to 0.7 MeV
Booster Synchrotron, $C = 211 \text{ m}$

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**SC Booster-Synchrotron**

**Booster Parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
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<tbody>
<tr>
<td><strong>Particles</strong></td>
<td>ions A/Z≤3</td>
</tr>
<tr>
<td><strong>Injection energy, MeV/u</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>Maximum energy, GeV/u</strong></td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Magnetic rigidity, T·m</strong></td>
<td>1.55 ÷ 25.0</td>
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<tr>
<td><strong>Circumference, m</strong></td>
<td>211.2</td>
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<tr>
<td><strong>Fold symmetry</strong></td>
<td>4</td>
</tr>
<tr>
<td><strong>Quadrupole periodicity</strong></td>
<td>24</td>
</tr>
<tr>
<td><strong>Betatron tune</strong></td>
<td>5.8/5.85</td>
</tr>
</tbody>
</table>
To reach maximum peak luminosity:
- minimum beta function in the IP;
- maximum bunch number;
- maximum bunch intensity;
- minimum beam emittance;
- minimum bunch length.

Circumference 503 m
Twin SC magnets

O.Kozlov’s poster on Tuesday
Proposed Scheme of Ion Stacking and Bunch Formation in The Collider

**Barrier RF system (1-st RF)**
- Accumulation
- Barriers are switched off
- Coasting beam

**2-nd RF system (h=C/21.5m)**
- Bunching with adiabatic RF increase
- Stop at length of 1/3 of bucket

**3-d RF system (h=h2x3)**
- Rebucketing adiabatic RF increase
- Bunch has final parameters

All stages are provided with cooling

A. Eliseev’s talk on Monday

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Facility Structure and Operation Regimes

Two regimes and cooling methods

1. Ion acceleration in Linac – Booster – Nuclotron up to experiment energy \( 1 \leq E_{\text{ion}} \leq 4.5 \text{ GeV/u} \), injection and storage in Collider at experiment energy;

2. Ion acceleration in Linac – Booster – Nuclotron up to “certain” energy, injection and storage in Collider, then acceleration in Collider up to the experiment energy.

Storage \( \Rightarrow \) with Barrier Bucket method + Electron cooling \( (E_{\text{kin}} < 2.5 \text{ GeV/u}) \) or Stochastic cooling \( (E_{\text{kin}} > 2.5 \text{ GeV/u}) \)

Acceleration in the collider:
if necessary – with Barrier Buckets RF system
Role of Beam Cooling
Beam Stacking with BB System and Cooling

1. Beam stacking using BB system: Injection repetition is 10s, the cooling times has to be short enough
2. Longitudinal cooling during beam bunching
3. During experiment:
   - in IBS dominated mode - Suppression of IBS;
   - in SC dominated mode – providing optimum phase volume

E > 2.5 GeV/u: stacking with Stochastic cooling
The cooling time is proportional to the bunching factor for “almost” coasting beam in BB the cooling times ~ 10 sec
E < 2.5 GeV/u: Stacking with Electron cooling
Problem – cooling time strongly depends on energy and does not depend on bunching factor. The cooling power sufficient for experiment can be insufficient for effective stacking

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Beam stacking with electron cooling @1.5 GeV/u

Simulations by T.Katayama (GSI), Talk on Tuesday

Beam stacking with stochastic cooling @3.5 GeV/u

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# Beam Cooling at Experiment

Two modes of the collider operation

<table>
<thead>
<tr>
<th>IBS dominated mode</th>
<th>Space charge dominated mode</th>
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<tbody>
<tr>
<td>Cooling time is comparable with IBS times</td>
<td>Cooling time is sufficiently shorter IBS times</td>
</tr>
<tr>
<td>Emittance and momentum spread are related to each other in accordance with “equi-partitioning”: $\tau_{IBS,\text{long}} = \tau_{IBS,h} = \tau_{IBS,v}$</td>
<td>Emittance and momentum spread are optimized independently, The bunch relaxation is suppressed by cooling</td>
</tr>
<tr>
<td>In opposite case – fast bunch relaxation</td>
<td></td>
</tr>
<tr>
<td>At the large energy, where required luminosity can be obtained at small tune shift</td>
<td>At small energy, where luminosity is limited by space charge effects</td>
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http://nica.jinr.ru
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<tbody>
<tr>
<td>Ring circumference, m</td>
<td>503.04</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>24</td>
</tr>
<tr>
<td>Rms bunch length, m</td>
<td>0.6</td>
</tr>
<tr>
<td>Beta-function in the IP, m</td>
<td>0.35</td>
</tr>
<tr>
<td>Ring acceptance (FF lenses)</td>
<td>40 π·mm·mrad</td>
</tr>
<tr>
<td>Long. acceptance, Δp/p</td>
<td>±0.010</td>
</tr>
<tr>
<td>Gamma-transition, γ_{tr}</td>
<td>7.091</td>
</tr>
<tr>
<td>Ion energy, GeV/u</td>
<td>1.0</td>
</tr>
<tr>
<td>Ion number per bunch</td>
<td>2.75·10^8</td>
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<tr>
<td>Rms momentum spread, 10^{-3}</td>
<td>0.62</td>
</tr>
<tr>
<td>Rms beam emittance, h/v,</td>
<td>1.1/</td>
</tr>
<tr>
<td>(unnormalized), π·mm·mrad</td>
<td>1.01</td>
</tr>
<tr>
<td>Luminosity, cm^{-2}s^{-1}</td>
<td>1.1e25</td>
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**SC dominated** | **IBS dominated**

(ΔQ < 0.05)
Unique SC Heavy Ion Source KRION with 3T and 6T SC solenoid

Highly charge ion state for heavy ions with high intensity, f.e.: Kr 28+, Xe 44+, Au 52+

Excellent and modern SC technologies + unique accelerator physics

Measured critical current for different prototypes of solenoids

E. Donets’s talk on Friday
Heavy Ion Linac (HILac) 3MeV/u
Design and fabrication under contract with “BEVATECH OHG”
Germany, Offenbach/Main (IAP, Frankfurt University)
to be delivered at JINR September 2013.
Stochastic cooling system installed at Nuclotron – prototype for Collider: W = 2-4 GHz, P = 60 W. (collaboration JINR - IKP FZJ - CERN)

HV Electron cooling system design and prototyping: Collaboration JINR – AREI - BINP

Kicker station

Pick-Up station

Poster N.Shurkhno, Tuesday

Slot-coupler RF structure (by IKP FZJ)

HV Generator prototype U=250 kV, I=1mA

S.Yakovenko’s talk on Tuesday
RF stations for booster – manufacturing is under completion (BINP)
RF stations for collider – under conceptual design (BINP)

Barrier Bucket cavity (preliminary design, BINP)

RF-2 and RF-3 resonators preliminary design (BINP)

Booster RF stations (2 p.) under manufacturing at BINP

A. Eliseev’s talk on Monday

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Transfer channels

Nuclotron

Collider
LHEP has unique the most powerful He liquifier complex in Europe:

Cooling power 4 kW at 4.5 K (1000 litre/sec). With new liquid He plant, cooling power for NICA will be doubled up to 8 kW at 4.5K
The best method to measure phase space size is currently implemented using a Booster Synchrotron for NICA. Vladimir I. Veksler and colleagues from the NICA Project at JINR, I. Meshkov, and G. Trubnikov have contributed to this project. For more information, visit http://nica.jinr.ru.
Magnets for the Booster

Booster dipole at cryo-test (9690A) and magnetic measurements

Quadrupole lens

Sextupole corrector prototype for SIS100 at assembly

Beampipe for booster magnet

NICA Project at JINR, I.Meshkov, G.Trubnikov
http://nica.jinr.ru
Magnets for the Collider

Cryo-tests (autumn 2012), magnetic measurements, new cryo-plant at b.217 (power convertors, cryogenics, etc.) serial production…

H. Khodzhibagiyan’s talk on Thursday
Стенд для сборки и испытаний сверхпроводящих магнитов

Стенд предназначен для круглогодичной сборки и серийных краткосрочных испытаний сверхпроводящих магнитов следующих типов:

- Дипольный магнит Бустер NICA - 40 шт.
- Магнитный магнит Бустер NICA - 40 шт.
- Дипольный магнит Колоссий NICA - 80 шт.
- Надиритный магнит Колоссий NICA - 180 шт.
- Магнитный магнит SIS100 проект PARIS - 175 шт.

При параллельной работе на 6 тягачей стенд планируется проводить до 11 испытаний магнитов в месяц.
Запуск стенда в эксплуатацию намечен на 2013 г.

**Test facility for the assembling and testing of superconducting magnets**

The test facility is designed for round-the-clock assembling and cryogenic testing of superconducting magnets of the following types:

- Dipole magnet for the NICA Booster - 40 pcs.
- Quadrupole magnet for the NICA Booster - 48 pcs.
- Dipole magnet for the NICA Collider - 80 pcs.
- Quadrupole magnet for the NICA Collider - 84 pcs.
- Quadrupole magnet for the SIS100 Project PARIS - 175 pcs.

The test facility will allow testing of up to 11 magnets per month, when operating in parallel on 6 benches.
Commissioning of the test facility is scheduled for 2013.
Technological part of the TDR (main equipment, engineering systems, etc), radiation and environmental safety, architecture had been fulfilled. Now – the final stage: capital spending sights. Plan – to submit all documents to the State Expertise – end of 2012.
NICA TDR:
- Call is opened
- JINR Expertise 1 month
- Tender – until December

Late autumn 2012:
- Start of the preparational civil construction.
- State expertise
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<td><strong>ESIS KRION</strong></td>
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<td><strong>LINAC + channel</strong></td>
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<td><strong>Booster + channel</strong></td>
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<td><strong>Nuclotron-M</strong></td>
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<td><strong>Nuclotron-M → NICA</strong></td>
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<td><strong>Channel to collider</strong></td>
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**Legend:**
- **R&D**
- **Design**
- **Manufacturing**
- **Mount.+commis.**
- **Commis/opr**
- **Operation**
NICA Collaboration

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

- IHEP (Protvino)
  - RFQ, beam dynamics, RF, Feed-back systems

- Budker INP
  - Booster RF system, e-cooler
  - Collider RF system
  - HV e-cooler for collider
  - Electronics

- FZ Juelich (IKP)
  - HV Electron cooler
  - Stoch. cooling

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

- INR RAS, Troitsk
  - polarised source, Linacs, beam diagnostics

- All-Russian Inst. for Electrotechnique
  - HV Electron cooler

- FNAL
  - HV Electron cooler
  - Beam dynamics, Stoch. cooling

- Corporation “Powder Metallurgy” (Minsk, Belorussia):
  - Technology of TiN coating of vacuum chamber walls for reduction of secondary emission

- BNL (RHIC)
  - Beam dynamics, Stoch. Cooling

- ITEP
  - Beam dynamics in the collider, RFQ linac
Thank you for your attention!

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