Project of the Nuclotron-based Ion Collider fAciility (NICA) at JINR

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JINR, Dubna


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Introduction: The NICA Project Goals

The goal of the project is construction at JINR of a new accelerator facility that provides

1a) Heavy ion colliding beams $^{197}\text{Au}^{79+} \times ^{197}\text{Au}^{79+}$ at $\sqrt{s_{NN}} = 4 \div 11 \text{ GeV} \ (1 \div 4.5 \text{ GeV/u ion kinetic energy})$
   
at $L_{\text{average}} = 1E27 \text{ cm}^{-2}\text{s}^{-1} \ (at \ \sqrt{s_{NN}} = 9 \text{ GeV})$

1b) Light–Heavy ion colliding beams of the same energy range and luminosity

2) Polarized beams of protons and deuterons in collider mode:
   
   $p\uparrow p\uparrow \sqrt{s_{pp}} = 12 \div 27 \text{ GeV} \ (5 \div 12.6 \text{ GeV kinetic energy})$
   
   $d\uparrow d\uparrow \sqrt{s_{NN}} = 4 \div 13.8 \text{ GeV} \ (2 \div 5.9 \text{ GeV/u ion kinetic energy})$
   
   $L_{\text{average}} \geq 1E30 \text{ cm}^{-2}\text{s}^{-1} \ (at \ \sqrt{s_{pp}} = 27 \text{ GeV})$

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

4) Applied research on ion beams at kinetic energy from 0.5 GeV/u up to 12.6 GeV (p) and 4.5 GeV/u (Au)
1. Facility Scheme and Operation Scenario

NICA Layout

- **Nuclotron**
- **SPI & LU-20** ("Old" linac)
- **Synchrophasotron yoke**
- **Beam transfer lines & New research area**
- **Nuclotron beam transfer line**
- **Collider C = 534 m**
- **MPD**
- **Spin Physics Detector (SPD)**
- **Booster**
- **KRION-6T & HILac**

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O. Kozlov, NICA Project

RuPAC’2010

Sept. 28, 2010 IHEP, Protvino
Heavy Ion Mode: Operation Regime and Parameters

**Injector:** 2×10⁹ ions/pulse of ¹⁹⁷Au³²⁺ at energy of 6.2 MeV/u

**Collider (45 Tm)**
Storage of 26 bunches by ~ 1×10⁹ ions per ring at 1 - 4.5 GeV/u, electron and/or stochastic cooling

**Booster (25 Tm)**
1(2-3) single-turn injection, storage of 2×(4-6)×10⁹, acceleration up to 100 MeV/u, electron cooling, acceleration up to 600 MeV/u

**Stripping (80%)** ¹⁹⁷Au³²⁺ => ¹⁹⁷Au⁷⁹⁺

**Two SC collider rings**

**Nuclotron (45 Tm)**
injection of one bunch of 1.1×10⁹ ions, acceleration up to 1 - 4.5 GeV/u max.
2. NICA Collider (Contnd)

2.1. Layout (Contnd)

Collider 2T- 534m
The scheme of elements location
2. NICA Collider (Contnd)

2.2. Peak Luminosity

The main limitation of the collider luminosity are the beams space charge effects, which can be described by the following:

1. The Laslett tune shift:
   \[ \Delta Q = \frac{Z^2}{A} \cdot \frac{r_p N_i}{\beta^2 \gamma^3 4 \pi \varepsilon_\sigma} \cdot k_{\text{bunch}}, \quad k_{\text{bunch}} = \frac{C_{\text{Ring}}}{\sqrt{2 \pi \cdot \sigma_s}}. \]

2. The beam-beam parameter:
   \[ \xi = \frac{Z^2}{A} \cdot \frac{r_p N_b (1 + \beta^2)}{4 \pi \beta^2 \gamma \varepsilon}. \]

More essential is the first one. If \( \Delta Q = \text{Const} \) with energy then luminosity is scaled with energy as \( L \propto \beta^5 \gamma^6 \varepsilon_{\text{geom}} = \beta^4 \gamma^5 \varepsilon_{\text{norm}} \):

\[ L = 8 \pi^2 \beta^5 \gamma^6 \Delta Q^2 \frac{A^2}{Z^4} \cdot \frac{\varepsilon_{\text{geom}}}{r_p^2 \beta^s} \cdot \left( \frac{\sigma_s}{C_{\text{Ring}}} \right)^2 \cdot \frac{c n_{\text{bunch}}}{C_{\text{Ring}}}, \]

where \( \sigma_s \) is the bunch length,

\[ f_{HG} - \text{“the hour-glass” factor}. \]

The ratio \( C_{\text{Ring}}/n_{\text{bunch}} = l_{\text{interbunch}} = \text{Const} \) because it is limited by design of the collider lattice (a necessity to avoid “parasitic” bunch-bunch collisions in straight section). Thus

\[ L(E) \propto \left( \frac{\sigma_s}{C_{\text{Ring}}} \right)^2 / \beta^s \]
2. NICA Collider (Contnd)

2.3. Luminosity preservation

Beam life time defined by IBS

If $\Delta Q$ is fixed as before then beam life time by IBS is proportional to

$$\tau_{IBS} \propto \frac{A}{Z^2} \cdot \frac{\beta^2 \gamma^2 \varepsilon_{\text{geom}} \cdot (\Delta p / p)}{\Delta Q} \cdot f(\sigma_x, \sigma_y, \sigma_s, \text{lattice functions})$$

Collider 2T - 534

$\tau_{IBS}$ and $\tau_{\text{cool}} (I_e = 1 \text{ A})$ vs ion energy

How to resolve the problem?

$\Rightarrow$ Smooth lattice functions to increase $\tau_{IBS}$

(S.Kostromin, JINR & V.Lebedev, FNAL)

$\Rightarrow$ Stochastic cooling at

$2.5 \text{ GeV/u} < E < 4.5 \text{ GeV/u}$

(T.Katayama, G.Trubnikov, N.Shurkhno);

$\Rightarrow$ Electron cooling at

$1.0 \text{ GeV/u} < E < 2.5 \text{ GeV/u}$.
3. Status and plan of NICA elements development
3.1. Heavy Ion Source KRION-6T
(E.D.Donets, E.E.Donets)

**Status:** Construction of working prototype

Assembled vacuum and cryogenic vessels of the KRION-6T

Foreinjector scheme

Automatic tool for solenoid spooling
3. Status and plan of NICA elements development (Contnd)

3.2. Heavy Ion Linac (HILAc)

HILAC - 1 section of RFQ + 4 sections of Drift Tube Linac (DTL),

2H cavities of "Ural" RFQ (prototype)  Sector H-cavity of "Ural" RFQ DTL (prototype)

Status: Design at IHEP (Protvino) and JINR,
Construction at VNIIIEF (Sarov) - recent agreement.
3. Status and plan of NICA elements development (Cont'd)

3.3. Booster

**RF system**: working design and manufacturing

*(G. Kurkin and team, Budker INP, by contract)*
3. Status and plan of NICA elements development (Contnd)

3.3. Booster

**SC magnetic system:** manufacturing of magnet prototypes (H. Khodzhibagiyan and team)

Cross section of the Booster dipole and quadrupole lens

Booster dipole yoke at assembling

The tool for assembling a curved yoke for the Booster dipoles
3. Status and plan of NICA elements development (Contnd)

3.3. Booster

**Electron cooler: working design**

(A. Shabunov, A. Smirnov, N. Topilin, Yu. Tumanova, S. Yakovenko)

General view of the electron cooler

Electron gun

Electron collector

SC Solenoid field simulation

(R. Pivin)
3. Status and plan of NICA elements development (Contnd)

3.4. Nuclotron

Thorough upgrade since 2007 - after 14 years running

G. Trubnikov, N. Agapov, A. Bazanov, O. Brovko, A. Butenko, A. Govorov, E. Ivanov, V. Karpinsky, H. Khodzhibagiyan, V. Mikhailov, V. Monchinsky, A. Sidorin, V. Slepnev, A. Smirnov, V. Volkov
### 3. Status and plan of NICA elements development (Cont'd)

#### 3.4. Nuclotron (Cont'd)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Project</th>
<th>Status (March 2010)</th>
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<tr>
<td>Max. magn. field, T</td>
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<td>Magn. rigidity, T·m</td>
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<td>Cycle duration, s</td>
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<td>Accelerated particles</td>
<td>p-U, p↑, d↑</td>
<td>p-Xe, d↑</td>
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<td>Max. energy, GeV/u</td>
<td>12.6(p), 5.87(d)</td>
<td>5.1(d), 1.0(124Xe^{42+})</td>
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<td>Intensity, ions/cycle</td>
<td>1E11(p,d), 1E9 (A &gt; 100)</td>
<td>3E10 (p,d), 1E10 (d↑), 1E6 (Xe^{24+})</td>
</tr>
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</table>
3. Status and plan of NICA elements development (Contnd)

3.4. Nuclotron (Contnd)

Conceptual scheme of the accelerator complex development

Polarized \( p \uparrow \) and \( d \uparrow \) beams and protons for \( p \times Au \) collisions are planned to be accelerated with existing Linac LU-20.
3. Status and plan of NICA elements development (Contnd)

3.4. Nuclotron (Contnd)

Injector (LU-20) modernization

- Upgrade of the power supply system for injection channel;

- Upgrade of vacuum system for fore-injector.
3. Status and plan of NICA elements development (Contnd)

3.4. Nuclotron (Contnd)

- Upgrade of Nuclotron vacuum system
- Upgrade of Nuclotron beam diagnostics system

- Beam slow extraction system at maximum energy
- Upgrade of the power supplies and energy evacuation system of the SC magnets
- Upgrade of Nuclotron RF (acceleration) system
- Upgrade of the cryogenic supply system (towards NICA)
3. Status and plan of NICA elements development (Contnd)

3.4. Nuclotron (Contnd)

To be designed, constructed and commissioned:

1. Injection system (to accept Booster beam)
2. RF system – new version with bunch compression
3. Dedicated diagnostics
4. Single turn extraction with fine synchronization
5. Polarized protons acceleration in Nuclotron*)

*) Can be postponed

To be commissioned in 2014
3. Status and plan of NICA elements development (Contnd)

3.4. Nuclotron (Contnd)

Test experiment on stochastic cooling at Nuclotron

Collaboration JINR / FZ Jülich

Stochastic cooling system prototype at Nuclotron for HESR/NICA

Slot-coupler structure

2 ÷ 4 GHz (~10 sec)

Vacuum tank with slot-coupler (FZJ)
3. Status and plan of NICA elements development (Contnd)

3.5. Collider

SC magnetic system: manufacturing of magnet prototypes
(H. Khodzhibagiyan and team)

“Twin” magnets of NICA collider:
Max. field - 2T, super-ferric (Nuclotron-like), double aperture
3. Status and plan of NICA elements development (Contnd)

3.5. Collider (Contnd)

HV Electron cooler: working design

A. Shabunov, A. Smirnov, N. Topilin, Yu. Tumanova, S. Yakovenko - JINR
A. Filippov, M. Pashin, L. Fisher - All-Russian Institute for Electrotechnique

Electron energy 0.5 ÷ 2.5 MeV
Electron beam current 0.5 ÷ 1 A
3. Status and plan of NICA elements development (Contnd)

3.5. Collider (Contnd)

- **Stochastic cooling system**: conceptual design, test experiment
  G. Trubnikov, N. Shurkhno, V. Seleznev - JINR, T. Katayama - Tokyo univ., R. Stassen - FZJ, L. Thorndahl - CERN

- **RF systems (Barrier Bucket system, bunching and maintaining RF systems)**: working design and manufacturing
  A. Eliseev, JINR
  G. Kurkin and team, Budker INP, by contract
3. Status and plan of NICA elements development (Contnd)

3.7. NICA construction schedule

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Legend:
- R&D
- Design
- Manufacturing
- Mount. + commis.
- Commis/opr
- Operation
3. Status and plan of NICA elements development (Contnd)

3.7. NICA construction schedule (Contnd)

The main tasks for the NICA project

In 2010:
- Conceptual / working design of the collider,
- Preparation of the project for the state expertise in accordance with regulations of Russian Federation (under preparation in The State Specialized Project Institute, Moscow),
- Construction of SC magnets prototypes.

In 2011:
- Passing through the state expertise,
- Beginning of construction of the HILAC, KRION (working version),
  Booster, the Collider elements,
- Stochastic cooling experiment at Nuclotron.
Conclusion

The NICA design passed the phase of concept formulation and is presently under

✓ detailed simulation of accelerator elements parameters,
✓ development of working project,
✓ manufacturing and construction of prototypes,
✓ preparation of the project for state expertise in accordance with regulations of Russian Federation.

The project realization plan foresees a staged construction and commissioning of accelerators forming the facility. The main goal is the facility commissioning in 2015.
Thank you for your attention!