Heavy ion collider facility NICA at JINR (Dubna): status and development.

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on behalf of the team

Joint Institute for Nuclear Research, Dubna

07 July 2012
Melbourne, ICHEP-2012
Main targets 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 $p$ to $Au$
  energy range $\sqrt{S_{NN}} = 4..11$ GeV ($Au^{79+}$)

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

Vladimir Kekelidze (JINR) Physics@NICA 06.07.12
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$^{79+}$
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

NICA Project at JINR, Grigory Trubnikov Melbourne, July 07, 2012
http://nica.jinr.ru
– superconducting accelerator for ions and polarized particle
– physics of ultrarelativistic heavy ions, high energy spin physics

Nuclotron provides now performance of experiments on accelerated proton and ion beams (up to Xe42+, A=124) with energies up to 6 AGeV (Z/A = 1/2)
<table>
<thead>
<tr>
<th>Beam</th>
<th>Nuclotron beam intensity (particle per cycle)</th>
<th>Current status</th>
<th>Ion source type</th>
<th>New ion source + booster</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>p</strong></td>
<td>$3\cdot 10^{10}$</td>
<td></td>
<td>Duoplasmotron</td>
<td>$5\cdot 10^{12}$</td>
</tr>
<tr>
<td><strong>d</strong></td>
<td>$5\cdot 10^{10}$</td>
<td></td>
<td>---, ---</td>
<td>$5\cdot 10^{12}$</td>
</tr>
<tr>
<td>$^4$He</td>
<td>$8\cdot 10^8$</td>
<td></td>
<td>---, ---</td>
<td>$1\cdot 10^{12}$</td>
</tr>
<tr>
<td><strong>d↑</strong></td>
<td>$2\cdot 10^8$</td>
<td></td>
<td>SPI</td>
<td>$1\cdot 10^{10}$</td>
</tr>
<tr>
<td><strong>7</strong>Li</td>
<td>$8\cdot 10^8$</td>
<td></td>
<td>Laser</td>
<td>$5\cdot 10^{11}$</td>
</tr>
<tr>
<td><strong>11,10</strong>B</td>
<td>$1\cdot 10^{9,8}$</td>
<td></td>
<td>---, ---</td>
<td></td>
</tr>
<tr>
<td><strong>12</strong>C</td>
<td>$5\cdot 10^9$</td>
<td></td>
<td>---, ---</td>
<td>$2\cdot 10^{11}$</td>
</tr>
<tr>
<td><strong>24</strong>Mg</td>
<td>$2\cdot 10^7$</td>
<td></td>
<td>---, ---</td>
<td></td>
</tr>
<tr>
<td><strong>14</strong>N</td>
<td>$1\cdot 10^7$</td>
<td></td>
<td>ESIS (“Krion-6T”)</td>
<td>$5\cdot 10^{10}$</td>
</tr>
<tr>
<td><strong>24</strong>Ar</td>
<td>$1\cdot 10^9$</td>
<td></td>
<td>---, ---</td>
<td>$2\cdot 10^{11}$</td>
</tr>
<tr>
<td><strong>56</strong>Fe</td>
<td>$2\cdot 10^6$</td>
<td></td>
<td>---, ---</td>
<td>$5\cdot 10^{10}$</td>
</tr>
<tr>
<td><strong>84</strong>Kr</td>
<td>$1\cdot 10^4$</td>
<td></td>
<td>---, ---</td>
<td>$1\cdot 10^9$</td>
</tr>
<tr>
<td><strong>124</strong>Xe</td>
<td>$1\cdot 10^4$</td>
<td></td>
<td>---, ---</td>
<td>$1\cdot 10^9$</td>
</tr>
<tr>
<td><strong>197</strong>Au</td>
<td>-</td>
<td></td>
<td>---, ---</td>
<td>$1\cdot 10^9$</td>
</tr>
</tbody>
</table>
Complex NICA @ JINR (VBLEP)

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 IP

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

HV e-cooler

Multi-Purpose Detector (MPD)
1a) Heavy ion colliding beams $^{197}\text{Au}^{79} + ^{197}\text{Au}^{79}$ at $\sqrt{s_{NN}} = 4 \div 11 \text{ GeV}$ (1 ÷ 4.5 GeV/u ion kinetic energy)

at $L_{\text{average}} = 1 \times 10^{27} \text{ cm}^{-2} \cdot \text{s}^{-1}$ (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:

$p \uparrow p \uparrow \sqrt{s_{pp}} = 12 \div 27 \text{ GeV}$ (5 ÷ 12.6 GeV kinetic energy)

d$\uparrow$d$\uparrow \sqrt{s_{NN}} = 4 \div 13.8 \text{ GeV}$ (2 ÷ 5.9 GeV/u ion kinetic energy)

$L_{\text{average}} \geq 1 \times 10^{30} \text{ cm}^{-2} \cdot \text{s}^{-1}$ (at $\sqrt{s_{pp}} = 27 \text{ GeV}$)

3) The beams of light ions and polarized protons and deuterons for fixed target experiments:

$\text{Li} \div \text{Au} = 1 \div 4.5 \text{ GeV } /\text{u ion kinetic energy}$

$p, p \uparrow = 5 \div 12.6 \text{ GeV kinetic energy}$

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 ($\text{Au}$)
Superconducting Booster synchrotron, \( E = 3..600 \) MeV/u, \( C=211 \) m

Heavy Ion Linac (RFQ+RFQ DTL) 3MeV/u
Unique low energy (1 - 4.5 GeV/u) collider with extremely high luminosity $L=1e^{27}$

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

The collider dynamic aperture in the horizontal phase space.

Luminosity @ NICA as function of particle number (to avoid incoherent tune shift) and energy

http://nica.jinr.ru
Proposed scheme of RF cycle in collider

Barrier RF system (1-st RF)

accumulation

barriers are switched off

coasting beam

2-nd RF system (h=C/21.5m)

1/3

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

NICA Project at JINR, Grigory Trubnikov  Melbourne,  July 07, 2012                  http://nica.jinr.ru
Facility structure and operation regimes

The problems and the solutions

<table>
<thead>
<tr>
<th>The problems:</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Beam space charge effects</td>
</tr>
<tr>
<td>✓ Beam-beam effects</td>
</tr>
<tr>
<td>✓ IntraBeam scattering (IBS) - ➞ luminosity degradation</td>
</tr>
<tr>
<td>✓ Recombination in e-cooler</td>
</tr>
<tr>
<td>✓ Bunch halo formation - ➞ parasitic collisions, background growth</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>The solutions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Electron cooling application</td>
</tr>
<tr>
<td>➢ Stochastic cooling application</td>
</tr>
<tr>
<td>➢ Beam parameters choice</td>
</tr>
<tr>
<td>➢ Operation scenario optimisation</td>
</tr>
</tbody>
</table>

Scrappers and collimators
Beam stacking with electron cooling @1.5 GeV/u

Beam stacking with stochastic cooling @3.5 GeV/u

Simulations by T.Katayama (GSI)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>SC dominated</th>
<th>IBS dominated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring circumference, m</td>
<td>503.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of bunches</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rms bunch length, m</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta-function in the IP, m</td>
<td>0.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ring acceptance (FF lenses)</td>
<td>40 (\pi\cdot\text{mm}\cdot\text{mrad})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long. acceptance, (\Delta p/p)</td>
<td>(\pm 0.010)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma-transition, (\gamma_{tr})</td>
<td>7.091</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ion energy, GeV/u</td>
<td>1.0, 3.0, 4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ion number per bunch</td>
<td>2.75(\cdot)10^8, 2.4(\cdot)10^9, 2.5(\cdot)10^9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rms momentum spread, 10^{-3}</td>
<td>0.62, 1.25, 1.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rms beam emittance, h/v, (unnormalized), (\pi\cdot\text{mm}\cdot\text{mrad})</td>
<td>1.1/1.01, 1.1/0.89, 1.1/0.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luminosity, cm(^{-2})s(^{-1})</td>
<td>1.1e25, 1e27, 5e27</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SC dominated (\(\Delta Q < 0.05\))
Strategy of the cooling at experiment

IBS dominated mode, Scool +Ecool

SC dominated, ECool

Effective stacking with ECool

IBS is calculated for equal rates in 3 degrees of freedom, \( I_e = 0.5 \) A

NICA Project at JINR, Grigory Trubnikov Melbourne, July 07, 2012 http://nica.jinr.ru
Unique SC Heavy Ion Source KRION with 3T and 6T SC solenoid

Collaboration with INR RAS: high intensity polarized particle source: up to $10^{11}$ particles/pulse

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

Assembly of the charge-exchange plasma ionizer

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http://nica.jinr.ru
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

Slot-coupler RF structure (by IKP FZJ)

Kicker station

Pick-Up station

HV Generator prototype U=250 kV, I=1mA
RF stations for booster – manufacturing is under completion (BINP)
RF stations for collider – under design (BINP)
HV generator for collider HV e-cooler – tested up to 250 kV
Cryostats – first prototypes are tested at JINR

Barrier Bucket cavity (preliminary design, BINP)

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

Booster RF stations manufactured at BINP

Curved vacuum chambers for booster
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
Magnets for the Booster

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

Sextupole corrector prototype (for SIS100 and NICA booster) at assembly

Quadrupole lense
Cryo-tests (autumn 2012), magnetic measurements, new cryo-plant at b.217 (power convertors, cryogenics, etc.) serial production…
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.
Thank you for your attention!

http://nica.jinr.ru
Hadronic freeze-out

J. Randrup & J. Cleymans

MultiPurpose Detector (MPD)

3 stages of putting into operation

2-nd stage
IT, EC-subdetectors, Forward tracking chamber (GEM, CPC)

3-d stage
F-spectrometers (optional ?)

1-st stage
barrel part (TPC, Ecal, TOF) + ZDC, FFD, BBC, magnet, ...

6 July 2012
V. Kekelidze, ICHEP-2012, Melbourne
### Particle yields, Au+Au @ $\sqrt{s_{NN}} = 8$ GeV (central collisions)

Expectations for 10 weeks of running at $L = 10^{27}$ cm$^{-2}$s$^{-1}$ (duty factor = 0.5)

<table>
<thead>
<tr>
<th>Particle</th>
<th>Yields</th>
<th>Decay mode</th>
<th>BR</th>
<th>*Effic. %</th>
<th>Yield/10 w</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+$</td>
<td>293</td>
<td>97</td>
<td>----</td>
<td>61</td>
<td>$2.6 \cdot 10^{11}$</td>
</tr>
<tr>
<td>$K^+$</td>
<td>59</td>
<td>20</td>
<td>----</td>
<td>50</td>
<td>$4.3 \cdot 10^{10}$</td>
</tr>
<tr>
<td>$p$</td>
<td>140</td>
<td>41</td>
<td>----</td>
<td>60</td>
<td>$1.2 \cdot 10^{11}$</td>
</tr>
<tr>
<td>$\rho$</td>
<td>31</td>
<td>17</td>
<td>e+e-</td>
<td>35</td>
<td>$7.3 \cdot 10^{5}$</td>
</tr>
<tr>
<td>$\omega$</td>
<td>20</td>
<td>11</td>
<td>e+e-</td>
<td>35</td>
<td>$7.2 \cdot 10^{5}$</td>
</tr>
<tr>
<td>$\phi$</td>
<td>2.6</td>
<td>1.2</td>
<td>e+e-</td>
<td>35</td>
<td>$1.7 \cdot 10^{5}$</td>
</tr>
<tr>
<td>$\Omega$</td>
<td>0.14</td>
<td>0.1</td>
<td>$\Lambda K$</td>
<td>2</td>
<td>$2.7 \cdot 10^{6}$</td>
</tr>
<tr>
<td>$D^0$</td>
<td>$2 \cdot 10^{-3}$</td>
<td>$1.6 \cdot 10^{-3}$</td>
<td>$K^+\pi^-$</td>
<td>20</td>
<td>$2.2 \cdot 10^{4}$</td>
</tr>
<tr>
<td>$J/\psi$</td>
<td>$8 \cdot 10^{-5}$</td>
<td>$6 \cdot 10^{-5}$</td>
<td>e+e-</td>
<td>15</td>
<td>$10^{3}$</td>
</tr>
</tbody>
</table>

*Efficiency includes the MPD acceptance, realistic tracking and particle ID. Particle Yields from experimental data (NA49), statistical and HSD models. Efficiency from MPD simulations. Typical efficiency from published data (STAR)