Main targets of “NICA Complex”:

- **study of hot and dense baryonic matter**

- investigation of nucleon spin structure, 
  
  polarization phenomena

- **development of accelerator facility**
  
  for HEP @ JINR providing intensive beams of relativistic ions from p to Au polarized protons and deuterons with max energy up to 
  
  $\sqrt{S_{NN}} = 11 \text{ GeV (Au}^{79^+})$ and $=27 \text{ GeV (p)}$
Synchrotron Nuclotron, in operation since 1993 – based on superconducting magnets developed in Dubna

Nuclotron provides accelerated proton and ion beams (up to $\text{Xe}^{42+}$, $A=124$) with energies up to 6 AGeV ($Z/A = 1/2$)
Collider basic parameters: $\sqrt{s_{NN}} = 4-11$ GeV; beams: from p to Au; $L \sim 10^{27}$ cm$^{-2}$ c$^{-1}$ (Au), $\sim 10^{32}$ cm$^{-2}$ c$^{-1}$ (p)
NICA – basic milestones

• The project of **NICA complex** is approved 2010

• The 1-st stage of **Nuclotron** modernization is completed 2010

  10 runs have been carried out in 2010 – 2014

• The projects: approval – completion

  ✓ **accelerator complex** 2010 – 2019

  ✓ **MPD (MultiPurpose Detector)** 2010 – 2019

  ✓ experiment with fixed target **BM@N** (I stage) 2012 - 2017

• The project preparation for **Spin Physics Detector (SPD)** is in progress
Status of the accelerator complex
NICA – Stage I

Booster

Synchrophasotron yoke

SPI & ΔY-20 (“Od” linac)

Bldg #1

Nuclotron

Fixed target experiments 2014

BM@N 2017

Nuclotron facility today

NICA – Stage I – 2017

15 September 2014

V.Kekelidze, XXII IBSHEPP, Dubna
## Nuclotron Beams

### NICA – Stage I

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Project (2017)</th>
<th>Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic field, T</td>
<td>2.0 (Bρ = 42.8 T·m)</td>
<td>2.0</td>
</tr>
<tr>
<td>Field ramp, T/s</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Repetition period, s</td>
<td>5.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy, GeV/u</th>
<th>Ions/ cycle</th>
<th>Energy, GeV/u</th>
<th>Ions/ cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Light ions</strong></td>
<td></td>
<td><strong>Heavy ions</strong></td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>6.0</td>
<td>5.6</td>
<td>1.0×10^10</td>
</tr>
<tr>
<td><strong>Heavy ions</strong></td>
<td><strong>With KRION-6T &amp; Booster</strong></td>
<td><strong>Without KRION-2</strong></td>
<td></td>
</tr>
<tr>
<td>40Ar^{18+}</td>
<td>4.9</td>
<td>3.5</td>
<td>5.0×10^6</td>
</tr>
<tr>
<td>56Fe^{26+}</td>
<td>5.4</td>
<td>2.5</td>
<td>2.0×10^6</td>
</tr>
<tr>
<td>124Xe^{48/42+}</td>
<td>4.0</td>
<td>1.5</td>
<td>1.0×10^3</td>
</tr>
<tr>
<td>197Au^{79+}</td>
<td>4.5</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Polarized beams</th>
<th>With SPI &amp; Siberian snake</th>
<th>With POLARIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>p↑</td>
<td>11.9</td>
<td>---</td>
</tr>
<tr>
<td>d↑</td>
<td>5.6</td>
<td>5.0×10^8</td>
</tr>
</tbody>
</table>
NICA – Stage III: Collider of polarized beams

Source of Polarized \( p^\uparrow \) & \( d^\uparrow \) Ions SPI

Collaboration: INR (Troitsk) & JINR

SPI test at Nuclotron with \( d^\uparrow \) is planned for winter 2015.

It will be beginning of new stage of experiments with polarized beams at Nuclotron.
Test bench in 2013:

- $B = 5.4 \, T$ reached in a robust regime;
- produced beams: Au$^{30+} \div$ Au$^{32+}$, $6 \cdot 10^8$ ppp, repetition rate 50 Hz

Project parameters: magnetic field up to 6.0 T, electron energy up to 15 keV

preparation for the run at the Nuclotron - May 2014

Krion-6T at LU-20, HV platform (Run #50)
**HILac:** high current (10 mA) heavy ion Linac, the first Linac with transistor RF amplifier

Design and fabrication by “BEVATECH OHG” Germany, Offenbach/Main, to be delivered at JINR in 2015
RFQ Tank (ready, prepared for delivery to JINR)

Gaps along cavity IH2
Stochastic Cooling System

SCS at Nuclotron - is a prototype for the NICA Collider:

\[ W = 2-4 \text{ HGz}, \]
\[ P = \text{up to 60 W} \]

Collaboration:

JINR-IKP FZJ-CERN

Experimental results (2013):

stochastic cooling of the carbon (C6+) beam, \( E = 2.5 \text{ GeV/u} \)

\[ \sigma_{\text{init}} = 0.15 \times 10^{-3} \]
\[ \sigma_{\text{final}} = 0.07 \times 10^{-3} \]
\[ \tau \approx 27 \text{s} \]

\[ \sigma_{\text{init}} = 0.2 \times 10^{-3} \]
\[ \sigma_{\text{final}} = 0.13 \times 10^{-3} \]
\[ \tau \approx 64 \text{s} \]
The Booster

Booster synchrotron: $C = 211m$, 25 $T^*m$, 600 MeV/u for Au\(^{31+}\)
ultra high vacuum, electron cooling

Dipole SC magnet

Synchrophasotron yoke

Quadrupole SC magnet

15 September 2014
V.Kekelidze, XXII IBSHEPP, Dubna
Nuclotron

Fixed target experiments

SPI & ΔY-20 (“Od” linac)

Booster

Synchrophasotron yoke

Bldg #1

Nuclotron

Fixed target experiments

NICA – Stage II - 2019

15 September 2014
V. Kekelidze, XXII IBSHEPP, Dubna
The Collider

45 T*m, 4.5 GeV/u for Au\textsuperscript{79+}

Double aperture magnets: dipole & quadrupole prototypes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring circumference, m</td>
<td>503.04 m</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>22</td>
</tr>
<tr>
<td>r.m.s. bunch length, m</td>
<td>0.6 m</td>
</tr>
<tr>
<td>(\beta), m</td>
<td>0.35 m</td>
</tr>
<tr>
<td>max. Ion Energy, Gev/u</td>
<td>4.5 Gev/u</td>
</tr>
<tr>
<td>r.m.s. (\Delta p/p), (10^{-3})</td>
<td>1.6</td>
</tr>
<tr>
<td>IBS growth time, s</td>
<td>2500 s</td>
</tr>
</tbody>
</table>
| Peak Luminosity, \(\text{cm}^{-2} \text{s}^{-1}\) | \(1 \times 10^{27}\)

Au(+79) ion mode

15 September 2014
V. Kekelidze, XXII IBSHEPP, Dubna
Electron cooling system for Collider

- $E_{\text{max}}, \text{MeV}$: 2.5
- cooling section length, m: 6.0
- electron beam current, A: 0.5-1
- electron beam radius, cm: 1
- $B$ field at cooling section, T: 0.1-0.3
Workshop at LHEP JINR for SC magnet assembly & tests

~ 450 SC magnets will be assembled & tested in the workshop for NICA & SIS-100 FAIR

Design (2012)

3 cryogenic stations with 6 arms for tests of 6 modules in parallel
The workshop starts magnet production in Dec. 2014

cable machine has been put in operation

workshop is ready for coil production

the l-st arm has been put in operation

28 Aug. 2014
Technical design project is in the final stage:
new helium liquefier-plant.
The cooling power will be doubled
up to 8 kW @ 4.5K with new plant;
2 new screw compressors
are under production

The bld. 32 will be reconstructed
to accommodate the new Cryo Complex
Experiments at NICA:

**MultiPurpose Detector (MPD)**  
*at the Collider*

and

**Baryonic Matter at Nuclotron (BM@N)**  
*at extracted Nuclotron beam*
Physics

- **Bulk properties, EOS** - particle yields & spectra, ratios, femtoscopy, flow
- **In-Medium modification of hadron properties**
- **Deconfinement (chiral), phase transition at high $\rho_B$** - enhanced strangeness production
- **QCD Critical Point** - event-by-event fluctuations & correlations
- **Strangeness in nuclear matter** - hypernuclei

QCD matter at NICA:
- **Highest net baryon density**
- **Energy range covers onset of deconfinement**
- **Complementary to the RHIC/BES, FAIR and CERN experimental programs**

**Freeze-out conditions**

---

15 September 2014

V. Kekelidze, XXII IBSHEPP, Dubna
Present and future HI machines

Fixed target: L-limited by detectors

Colliders: scale of L, in cm$^{-2}$s$^{-1}$

- $10^{23}$
- $10^{25}$
- $10^{27}$

Expected region of phase transition at max baryonic density

20??
2019
2019
2017

SIS-300 (FAIR)
SIS-100 (FAIR)
NICA (JINR)
Nuclotron-M (JINR)
Booster (JINR)

SIS-18 (GSI)
AGS (BNL)
SPS (NA-49/61, CERN)

BES

15 September 2014
V. Kekelidze, XXII IBSHEPP, Dubna
NICA White Paper – International Effort

Statistics of White Paper Contributions

111 contributions:
188 authors from 70 centers in 24 countries

Indicates wide international interest to the physics at MPD & BM@N

SEARCHING for a QCD MIXED PHASE at the NUCLotron-based ION COLLIDER FACILITY (NICA White Paper)

15 September 2014

V. Kekelidze, XXII IBSHEPP, Dubna
Tracking: up to $|\eta|<2$ (TPC)
PID: hadrons, e, $\gamma$ (TOF, TPC, ECAL)
Event characterization:
  centrality & event plane (ZDC)

Superconducting solenoid:
  $B_0=0.66$ T

high level ($\sim 10^{-4}$) of magnetic field homogeneity at the TPC position

Stage 1:
TPC, TOF, ECAL, ZDC, FD

Stage 2:
IT + Endcaps (tracker, TOF, ECAL)
MPD Solenoid

Packages:
- Support Structure
- Yoke
- Mass + Cryostat
- Vacuum System
- Cryogenic System
- Coils + Cooling
- Control System
- Packages:
- Support Structure
- Yoke

Status:
- technical design – completed
- potential producers are identified
- the first offers have been received
- preparation for the tender is in progress
- the choice of the producers by the end of 2014
Cylinder C3 manufactured in Dec. 2013

FEC-64 prototype
(ALTERA FPGA, ALTRO, PASA chips)

TPC - technical project approved, fabrication stage

Dia. = 3000 mm, L = 3400 mm, FEE = 120 000 ch, δp/p < 2%

Cylinder C2, preparation for vacuum tests

Ø 27 cm, l = 3.4 m

R 140 cm, L = 3.4 m
4 mm thickness
0.1 mm precision

15 September 2014

V. Kekelidze, XXII IBSHEPP, Dubna
Time of Flight system (TOF)

**Fast Forward Detector (FFD):**
- **Production stage**
- **Provides:** $T_0$ for TOF, beam adjustment & collision L0-trigger

**mRPC – TDR has been prepared,**
ready for mass production

The achieved time resolution is better than required


**required efficiency, rate capability & time resolution are reached**
**ECAL – TDR - in preparation**

$L \sim 35 \text{ cm} (\sim 14 X_0)$, Pb+Scint. $(4 \times 4 \text{ cm}^2)$
read-out: WLS fibers + MAPD

<table>
<thead>
<tr>
<th>Energy resolution</th>
<th>$2.5% / \sqrt{E}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time resolution</td>
<td>80 psec / $\sqrt{E}$</td>
</tr>
</tbody>
</table>

Preparation for tests with electron beams at DESY (December’13)

**Zero Degree Calorimeter (ZDC):**
TDR stage

**ZDC coverage:** $2.2 < |\eta| < 4.8$

$\text{Pb-scintillator sampling (5}\lambda)$
Read-out: fibers + AvalanchePD

**Energy resolution**

$$\sigma(E)/(E) = 55\% / \sqrt{E(\text{GeV})} + 2\% +16\% / 4\sqrt{E(\text{GeV})}$$

ZDC provides required resolution
MPD performance for dileptons

Hadron suppression up to $10^{-5}$

Yields, central Au+Au st $\sqrt{s} = 8.8$ GeV/u

<table>
<thead>
<tr>
<th>Particle</th>
<th>Yields</th>
<th>Decay mode</th>
<th>BR</th>
<th>Effic. %</th>
<th>Yield/1 w</th>
</tr>
</thead>
<tbody>
<tr>
<td>$4\pi$</td>
<td>$31$</td>
<td>$e^+e^-$</td>
<td>$4.7 \cdot 10^{-5}$</td>
<td>35</td>
<td>$7.3 \cdot 10^4$</td>
</tr>
<tr>
<td>$\omega$</td>
<td>$20$</td>
<td>$e^+e^-$</td>
<td>$7.1 \cdot 10^{-5}$</td>
<td>35</td>
<td>$7.2 \cdot 10^4$</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>$2.6$</td>
<td>$e^+e^-$</td>
<td>$3 \cdot 10^{-4}$</td>
<td>35</td>
<td>$1.7 \cdot 10^4$</td>
</tr>
</tbody>
</table>

$\sigma_\omega \approx 14$ MeV/c$^2$
Hypernuclei production enhanced at high baryon densities (NICA)

\[ ^3\Lambda H \rightarrow ^3\text{He} + \pi^- \]

S/S+B = 8.4
S/B = 2.9
Eff. = 0.8%

\[ ^3\Lambda H \rightarrow p + d + \pi^- \]

S/S+B = 10.9
S/B = 11.8
Eff. = 1.0%

\( \sim 10^6 \, ^3\Lambda H \) are expected for 10 weeks @ 5A GeV

15 September 2014
V. Kekelidze, XXII IBSHEPP, Dubna
BM@N (Baryonic Matter at Nuclotron): the 1st stage

Physics:

- in-medium effects for strangeness & vector mesons
- hyperon production
- hadron femtoscopy
- electromagnetic probes (optional)

Collaboration of scientific centers:
INR, SINP MSU, IHEP + S-PSUniversity (Russia);
GSI, Frankfurt U., Gissen U. (Germany):
+ CBM-MPD IT-Consortium,
12 GEM stations:
- 1-4 stations strip pitch 0.4 мм
- 5-12 stations - 0.8 мм
- strip angles for odd stations: 0, +15°

momentum resolution

modernized magnet СП-41

area prepared for detector allocation

GEM station tracking

$\Lambda \rightarrow p^+ \pi^-$

(entries: 26866)

$p_0$: 2421
$p_1$: 1116
$p_2$: 0.002293
$p_3$: 302.6
$p_4$: -2686
$p_5$: -4841

S/B (2$\sigma$) = 4.8
eff. = 6.3%
Collider provides both: transversally & longitudinally polarized $p$ & $d$ with energy up to $\sqrt{S} = 27$ GeV

The issues to be studied:

- **MMT-DY processes**
- **$J/\Psi$ production processes**
- **Spin effects in inclusive high-$p_T$ reactions**
- **Spin effects in one and two hadron production processes**
- **Polarization effects in heavy ion collisions**

The Collaboration is forming

**Project is under preparation**
NICA Complex Civil Engineering

Preparatory works completed - 2014
1-st contract with General Contractor – 2014

The State Expertise – Oct. 2013
International tender – 2013

Civil construction will be completed by 2018
Start up version of NICA Collider:
commissioning is foreseen in 2019
NICA complex has a potential for competitive research in the fields of dense baryonic matter and spin physics.

Construction of the accelerator complex and its elements are in progress.

Constructions of both detectors BM@N & MPD are progressing as well.

The SPD project is in preparation.

The international collaboration around the NICA is growing.

New partners are invited to join NICA.
Thank you!