Prospects for the study of heavy-ion collisions at the NICA collider @ JINR

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(JINR)

On behalf of NICA-MPD

- NICA accelerator complex: status
- Detectors for A+A collisions @ NICA: MPD and BM@N experiments

The European Physical Society Conference on High Energy Physics
Venice, Italy, July 5-12, 2017
QCD matter at NICA:
- Highest net baryon density
- Energy range brackets onset of deconfinement
- Complementary to the RHIC/BES, FAIR, and CERN experimental programs

Energy: $\sqrt{s_{NN}} = 4-11$ GeV (Au,collider), up to 26 GeV (p+p), $E/A = 2-6$ GeV (fixed target),

Beams: from p to Au. $L \sim 10^{27}$ cm$^{-2}$ c$^{-1}$ (Au), $\sim 10^{32}$ cm$^{-2}$ c$^{-1}$ (p,d)
### NICA: Structure and Operation Regimes

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<tr>
<th>Beam</th>
<th>Nuclotron beam intensity (particle per cycle)</th>
<th>at NICA</th>
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<td><strong>Current</strong></td>
<td><strong>Ion source type</strong></td>
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<td>p</td>
<td>$3 \times 10^{10}$</td>
<td>$5 \times 10^{12}$</td>
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<td>d</td>
<td>$3 \times 10^{10}$</td>
<td>$5 \times 10^{12}$</td>
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<td>$^4$He</td>
<td>$8 \times 10^{8}$</td>
<td>$1 \times 10^{12}$</td>
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<td>d$^\uparrow$</td>
<td>$2 \times 10^{8}$</td>
<td>$1 \times 10^{10}$</td>
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<td>$^7$Li</td>
<td>$8 \times 10^{8}$</td>
<td>$5 \times 10^{11}$</td>
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<td>$^{11,10}$B</td>
<td>$1 \times 10^{9.8}$</td>
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<td>$^{12}$C</td>
<td>$1 \times 10^9$</td>
<td>$2 \times 10^{11}$</td>
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<td>$^{24}$Mg</td>
<td>$2 \times 10^7$</td>
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<td>$^{14}$N</td>
<td>$1 \times 10^7$</td>
<td>$5 \times 10^{10}$</td>
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<td>$^{40}$Ar</td>
<td>$1 \times 10^9$</td>
<td>$2 \times 10^{11}$</td>
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<td>$^{56}$Fe</td>
<td>$2 \times 10^6$</td>
<td>$5 \times 10^{10}$</td>
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<td>$^{84}$Kr</td>
<td>$1 \times 10^4$</td>
<td>$1 \times 10^9$</td>
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<tr>
<td>$^{124}$Xe</td>
<td>$1 \times 10^4$</td>
<td>$1 \times 10^9$</td>
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<tr>
<td>$^{197}$Au</td>
<td>-</td>
<td>$1 \times 10^9$</td>
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NICA infrastructure development

- **Civil Construction**
- **Service systems: water cooling, cryogenics, electric power, etc.**

“Strabag” and 7 sub-contractors:
- total number of engineers and workers – 154
- 70% of reinforced concrete and piled works done

15 kA power supply (assembled & tested)

New helium liquefier (10^3 l/h) launched at JINR
NICA elements. Construction status

3.2 MeV/u, Au^{31+}, 10 mA

NICA HILac
(in operation since 2016)

Heavy ion source: Krion-6T ESIS
(in operation since 2015)

The booster power supply
(up to 600 A, since 2016)

Electron cooling system for the Booster
(assembled, under tuning)
The facility for SC-magnets: in operation since Nov. 2016

**Working plans:**
- 40 dipoles + 48 quadrupoles for the Booster
- 80 dipoles + 86 quadrupoles for the Collider
- 175 quadrupoles for SIS100 (FAIR)

NICA booster: 33% of dipoles and 10% of doublets passed all the tests

*We plan to have 75% magnets at the end of 2017*
Detectors at NICA: Baryonic Matter at Nuclotron (BM@N)

- Ideally suited for exploration of reaction mechanism & in-medium properties
- Energy range of limited experimental information
- Expectation of rich structure of the QCD phase diagram @ high densities

Physics cases:
- Bulk properties, EOS
- In-medium meson-nucleon potential at high \( \rho_B \)
- Sub-threshold production of strange hadrons in A+A
- Measurement of elementary reactions

![Invariant mass: \(^3\)H \rightarrow \(^3\)He + \(\pi^-\)]

- S/B=1.6
- S/(S+B)=22.4
- Eff.=1.0%
- Peak 271.8
- Mean 2.991
- Sigma 0.0025

![Invariant mass: \(^3\)He \rightarrow \(\Lambda + \pi^-\)]

- S/B = 3.6
- S/(S+B) = 14.0
- Eff. = 0.8%
- Peak 77.53
- Mean 1.321
- Sigma 0.0027
## BM@N status and data taking plans

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<td><strong>beam</strong></td>
<td>d ( )</td>
<td>C, Ar</td>
<td>Kr</td>
<td>Au</td>
<td>Au, p</td>
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<td><strong>maximum intensity, Hz</strong></td>
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<td>1M</td>
<td>1M</td>
<td>1M</td>
<td>10M</td>
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<td><strong>trig. rate, Hz</strong></td>
<td>10k</td>
<td>10k</td>
<td>20k</td>
<td>20k</td>
<td>50k</td>
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<td><strong>central tracker</strong></td>
<td>6 GEM half pl.</td>
<td>8 GEM half pl.</td>
<td>10 GEM half pl.</td>
<td>8 GEM full pl.</td>
<td>12 GEM or 8+2Si</td>
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<td><strong>expiment status</strong></td>
<td>techn. run</td>
<td>techn. run</td>
<td>commis.&amp; physics run</td>
<td>physics stage 1</td>
<td>physics stage 2</td>
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**MPD at NICA: design and tasks**

**Experimental strategy:** measure a large variety of signals systematically changing collision parameters (energy, centrality, system size). Reference data (i.e. $p+p$) will be taken in the same experimental conditions.

**Bulk properties, EOS**
- particle yields & spectra, ratios, femtoscopy, flow
  - measure: $\gamma$, $\pi$, $K$, $p$, $\Lambda$, $\Omega$, (anti)particles, light nuclei

**In-Medium modification of hadron properties**
- onset of low-mass dilepton enhancement
  - measure: $\rho$, $\omega$, $\phi \rightarrow e^+e^-$

**Deconfinement (chiral) phase transition at high $\rho_B$**
- enhanced strangeness production
- Chiral Magnetic (Votical) effect, $\lambda$ polarization

**QCD Critical Point**
- event-by-event fluctuations and
- Strangeness in nuclear matter
- hypernuclei, exotica

**Magnet:** 0.5 T superconductor
**Tracking:** TPC, ECT, IT
**ParticleID:** TOF, ECAL, TPC
**T0, Triggering:** FFD
**Centrality, Event plane:** FHCAL

I stage (barrel) – 2020
upgraded (IT + endcaps) – 2023
Particle yields in Au+Au collisions @ $\sqrt{s_{NN}} = 8$ GeV  
(central collisions)

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

<table>
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<tr>
<th>Particle</th>
<th>Multiplicity</th>
<th>Decay mode</th>
<th>BR</th>
<th>*Efficiency %</th>
<th>Yield/10 w</th>
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<tr>
<td>$\pi^+$</td>
<td>293</td>
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<td>61</td>
<td>$2.6 \cdot 10^{11}$</td>
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<td>$K^+$</td>
<td>59</td>
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<td>50</td>
<td>$4.3 \cdot 10^{10}$</td>
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<tr>
<td>$p$</td>
<td>140</td>
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<td>60</td>
<td>$1.2 \cdot 10^{11}$</td>
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<tr>
<td>$\rho$</td>
<td>31</td>
<td>e+e-</td>
<td>$4.7 \cdot 10^{-5}$</td>
<td>35</td>
<td>$7.3 \cdot 10^{5}$</td>
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<tr>
<td>$\omega$</td>
<td>20</td>
<td>e+e-</td>
<td>$7.1 \cdot 10^{-5}$</td>
<td>35</td>
<td>$7.2 \cdot 10^{5}$</td>
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<tr>
<td>$\phi$</td>
<td>2.6</td>
<td>e+e-</td>
<td>$3 \cdot 10^{-4}$</td>
<td>15</td>
<td>$1.7 \cdot 10^{5}$</td>
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<tr>
<td>$\Omega$</td>
<td>0.14</td>
<td>$\Lambda K$</td>
<td>0.68</td>
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<td>$D^0$</td>
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<td>$K^+\pi^-$</td>
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<td>$J/\psi$</td>
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<td>e+e-</td>
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*Efficiency includes the MPD acceptance, realistic tracking and particle ID.  
Particle Yields from experimental data (NA49), statistical and HSD models.  
Efficiency estimates based on MPD simulations.
MPD magnet: construction status

MPD Solenoid production stages (AGS superconductors, Genova, Italy)

Manufacturing Jan. 2016-Aug. 2018
Final Solenoid tests by AGS Jun. 2018
Packaging and Transportation Apr. 2018-Oct. 2018
Assembly at JINR, tests Oct. 2018-Apr. 2019

Plates
Winding machine for SC solenoid
Support rings
Aluminum support cylinder blanks for SC coil during transportation
Poles
MPD tracker - TPC

- Dimensions: 4 m x 3m
- Drift Length: 170cm
- Gas: 90% Argon + 10% Methane
- Readout: 2x12 sectors (MWPC or GEM)
- Rate capability up to 7 kHz
- Spatial resolution: $\sigma_{r\phi} \sim 300 \mu m$, $\sigma_z \sim 2 mm$
- Momentum resolution: $\Delta p/p < 3\%$
- $dE/dx$ resolution: < 8\%
MPD mRPC TOF: preparation to mass-production

- Material ordering
- Equipment installation
- Personnel training

basic elements - NINO & HPTDC chips have been purchased sufficient to produce read-out electronics for the TOF + reserve (~24000 channels).
MPD Calorimetry: ECAL and FHCAL

FHCAL calorimeter for centrality & event plane determination

Transverse granularity allowing:
- the reaction plane with the accuracy ~ 30°

ECAL - high acceptance & purity e/γ identification:
- in-medium modifications in dilepton spectra
- thermal radiation from QGP

Projective geometry
Barrel ~ 43000 modules

Pb+Scint. (14 X0, 4x4 cm²)
WLS fibers + MAPD

Hadron suppression up to 10⁻⁵

2<|η|<5
## NICA schedule

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*running time*
Summary

- Construction of the NICA complex is well in progress
  (civil construction, accelerator components, service systems)

- Substantial progress in the construction of the detectors:
  - BM&N experiment – commissioning runs started
  - MPD design has optimized for Day’1 physics,
    preparation for mass-production ongoing

Thank you for your attention!
SPARES
MPD after 2023: EndCap and InnerTrackers

- A new technology developed to build straw detectors as multi-wheel structures
- ECT full size prototype: max. deviation $\Delta R < 300$ mm for a $R=1.1$ m wheel

- 4 cylindrical layers $|\eta|<2.5$
- $300 \mu$m double-sided microstrip 100 $\mu$m pitch
- Thickness/layer $\sim 0.8\% X_0$
- Resolution: $\sigma_z = 120 \mu$m, $\sigma_{rf} = 23 \mu$m

2x60 straw layers $1.3<|\eta|<2.2$
72000 straw tubes 4 mm x 60 cm

Site for module assembly

TPC+ECT tracking up to $\eta=3$

TPC+IT $\sigma_{rf},\sigma_Z < 40 \mu$m

Invariant mass $\Omega \rightarrow \Lambda K$

Integral 694
$p_0$ 76.55
$p_1$ 1.672
$p_2$ 0.002825
$p_3$ 1406
$p_4$ -1586
$p_5$ 448.8