Physics @ NICA, JINR

V. Kekelidze, A. Kovalenko, R. Lednicky, V. Matveev, I. Meshkov, A. Sorin, G. Trubnikov

XXXVI International Conference on High Energy Physics, 4-11 July, Melbourne, Australia
NICA Collider parameters:

- **Energy range:** $\sqrt{s_{NN}} = 4-11$ GeV
- **Beams:** from p to Au
- **Luminosity:** $L \sim 10^{27}$ (Au), $10^{32}$ (p)
- **Detectors:** MPD; Waiting for Proposals

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

2-nd IP - open for proposals

see details in tomorrow report of Prof. G. Trubnikov: NICA @ JINR (r.218, 10:15)

6 July 2012

V. Kekelidze, ICHEP-2012, Melbourne
Main targets of "NICA Complex":

- study of hot and dense baryonic matter & 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 deuterones with max energy up to

$$\sqrt{S_{NN}} = 11 \text{ GeV} (Au^{79+}) \text{ and } =26 \text{ GeV} (p)$$
existing & future HEP experimental facility of Joint Institute for Nuclear Research

Nuclotron-M -> NICA (SC synchrotron) extracted beams

Barionic Matter @ Nuclotron (2015)

- Gibs–NIS (FS)
- Faza-3
- polarized beams & target
- test beams
- beams for applied researches

MultiPurpose Detector (2017)

NICA Collider the 1-st IP (2017)

NICA Collider the 2-nd IP (2017) open for proposals

approved, in preparation

running experiments

6 July 2012

V.Kekelidze, ICHEP-2012, Melbourne
Bld. 205 (10 000 m²): structure of research zones with extracted beams

beam polarimeters

Baryonic Matter at Nuclotron (DBM@N)

HyperNIS

BM@N area

Polarization studies area

6 July 2012
V. Kekelidze, ICHEP-2012, Melbourne
QCD phase diagram - Prospects for NICA

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

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

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

6 July 2012
V.Kekelidze, ICHEP-2012, Melbourne
Freeze-out conditions

Hadronic freeze-out

J. Randrup & J. Cleymans
Existing & Future HI Machines

20??
2018
2017
2015

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

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

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

Fixed target: $L$-limited by detectors

$\sqrt{S_{NN}},$ GeV for Au+Au

6 July 2012
V.Kekelidze, ICHEP-2012, Melbourne
beams extracted from Nuclotron-M-NICA

covers the gap between SIS-18 and AGS (with some overlaps)

\[
\begin{array}{cccc}
Z/A & max \sqrt{s_{NN}} \ (GeV/n) & max. T_{kin} \ (GeV/n) \\
p & 1 & \approx 5.2 & \approx 12 \\
d & 1/2 & \approx 3.8 & \approx 5.7 \\
Au & 0.4 & \approx 3.5 & \approx 4.5 \\
\end{array}
\]

(including polarized deuterons)

These allow:

• study of dense baryonic matter at temperatures up to 100 MeV,
• (multi)-strangeness (open & hidden) production in dense baryonic matter,
• modification of particle properties in dense nuclear matter

The corresponding multi-purpose setup

\textit{Baryonic Matter at Nuclotron (BM@N)}
<table>
<thead>
<tr>
<th>Beam</th>
<th>Nuclotron beam intensity (particle per cycle)</th>
<th>Ion source type</th>
<th>New Injection facility + booster</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>3.10^{10}</td>
<td>Duoplasmotron</td>
<td>5.10^{12}</td>
</tr>
<tr>
<td>d</td>
<td>3.10^{10}</td>
<td>---, ---</td>
<td>5.10^{12}</td>
</tr>
<tr>
<td>^4He</td>
<td>8.10^{8}</td>
<td>---, ---</td>
<td>1.10^{12}</td>
</tr>
<tr>
<td>d↑</td>
<td>2.10^{8}</td>
<td>SPI</td>
<td>1.10^{10}</td>
</tr>
<tr>
<td>^7Li</td>
<td>8.10^{8}</td>
<td>Laser</td>
<td>5.10^{11}</td>
</tr>
<tr>
<td>^11,10^B</td>
<td>1.10^{9,8}</td>
<td>---, ---</td>
<td></td>
</tr>
<tr>
<td>^12^C</td>
<td>1.10^{9}</td>
<td>---, ---</td>
<td>2.10^{11}</td>
</tr>
<tr>
<td>^24^Mg</td>
<td>2.10^{7}</td>
<td>---, ---</td>
<td></td>
</tr>
<tr>
<td>^14^N</td>
<td>1.10^{7}</td>
<td>ESIS (&quot;Krion-6T&quot;)</td>
<td>5.10^{10}</td>
</tr>
<tr>
<td>^24^Ar</td>
<td>1.10^{9}</td>
<td>---, ---</td>
<td>2.10^{11}</td>
</tr>
<tr>
<td>^56^Fe</td>
<td>2.10^{6}</td>
<td>---, ---</td>
<td>5.10^{10}</td>
</tr>
<tr>
<td>^84^Kr</td>
<td>1.10^{4}</td>
<td>---, ---</td>
<td>1.10^{9}</td>
</tr>
<tr>
<td>^124^Xe</td>
<td>1.10^{4}</td>
<td>---, ---</td>
<td>1.10^{9}</td>
</tr>
<tr>
<td>^197^Au</td>
<td>-</td>
<td>---, ---</td>
<td>1.10^{9}</td>
</tr>
</tbody>
</table>
BМ@N Collaboration

Technical project – in preparation

19 scientific centers: INR, SINP MSU, IHEP + 2 Universities (Russia);
GSI, Frankfurt U., Gissen U. (Germany):
+ CBM-MPD IT-Consortium,
+ .... expressed an interest

6 July 2012

V. Kekelidze, ICHEP-2012, Melbourne
Kinematic thresholds

for Au beam

maximal mass $M_x$ of created system, GeV/c^2

kinetic beam energy at fixed targets, $T_{kin}^{lab}$, GeV/nucleon

Forbidden region

target: $^{12}$C nucleus

target: deuteron

target: proton

Permitted region

$D_c$

$\Omega + 3K$

$\phi$
Physics is complementary to the MPD program & will be actual even after start of the MPD runs:

- **AA interactions:**
  - particle production, incl. sub-threshold processes;
  - particle (collective) flows, event-by-event fluctuations, correlations;
  - multiplicities, phase space distributions of p, n, π, K, hyperons, light nuclear fragments, vector mesons, hadronic resonances, direct light hypernuclei production in central AA collisions.

- **pA, nA, dA interactions in direct & inverse (Ap, Ad) kinematics:**
  - to get a “reference” data set for comparison with AA interactions,
  - to look for polarization effects in particle production off nuclear targets by polarized d, p, n.
MultyPurpose Detector (MPD)

1-st IP @ NICA Collider

$4 \text{ GeV} < \sqrt{S_{NN}} < 11 \text{ GeV} \ (\text{for Au}^{79+})$
MultiPurpose Detector (MPD) @ 1st IP

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

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

3rd stage
F-spectrometers (optional ?)

FS-A

DC

FD

ECT

ZDC

GEM

TPC

IT

Ecal

TOF

Yoke

Cryostat

TM

Multi Purpose Detector (MPD)
MPD Observables

I stage: mid rapidity region (good performance)
- Particle yields and spectra ($\pi, K, p, \text{clusters}, \Lambda, \Xi, \Omega$)
- Event-by-event fluctuations
- Femtoscopy involving $\pi, K, p, \Lambda$
- Collective flow for identified hadron species
- Electromagnetic probes (electrons, gammas)

II stage: extended rapidity + IT

....
- Total particle multiplicities
- Asymmetries study (better reaction plane determination)
- Di-Lepton precise study (ECal expansion)
- Exotics (soft photons, hypernuclei)

measurements regarded as complementary to RHIC/BES, CERN/NA61 & FAIR
MPD/NICA advantage is Scan of the QCD phase diagram

Strategy:

detailed energy & system size scan

with a step ~ $10 \text{ MeV/u}$ in selected regions

with a high $L$ aimed in a search for anomalies:

- in particle production in the vicinity of the critical point,

- signatures of in-medium modification

  of the vector-spectral functions,

- study of the properties of the mixed phase

  of strongly interacting matter.
MPD

progress in R&D
**Straw full scale prototype for EC tracking**

**Technological TPC prototype**

**Material:**
- **Kevlar** laminated by Tedlar film
- Diameter - 950 mm
- Length - 900 mm
- Wall thickness - 2 mm
- Weight ~ 10 kg
Fast Forward Detector (FFD)

RPC prototype time resolution < 100 ps.

ffc tests of full scale RPC prototype

Beam line

MPD center

FFD array

FFD prototype time resolution < 100 ps.

FFD array 24 mm

Beam pipe 240 mm

FFD L

FFD R

175

175

V. Kekelidze, ICHEP-2012, Melbourne

beam tests at Nuclotron; groups from JINR, Beijing & Hefei (China)

6 July 2012
MPD
feasibility study
simulation with MPDROOT
### Particle Yields, Au+Au @ $\sqrt{s_{NN}} = 8$ GeV (central collisions)

Expectations for 10 weeks of running at $L = 10^{27}\text{cm}^{-2}\text{s}^{-1}$ (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>$4\pi$</td>
<td>293</td>
<td>y=0</td>
<td>----</td>
<td>---</td>
<td>61</td>
</tr>
<tr>
<td>$\pi^+$</td>
<td>59</td>
<td>20</td>
<td>----</td>
<td>----</td>
<td>50</td>
</tr>
<tr>
<td>$K^+$</td>
<td>140</td>
<td>41</td>
<td>----</td>
<td>----</td>
<td>60</td>
</tr>
<tr>
<td>$\rho$</td>
<td>31</td>
<td>17</td>
<td>e+e-</td>
<td>4.7 $\cdot 10^{-5}$</td>
<td>35</td>
</tr>
<tr>
<td>$\omega$</td>
<td>20</td>
<td>11</td>
<td>e+e-</td>
<td>7.1 $\cdot 10^{-5}$</td>
<td>35</td>
</tr>
<tr>
<td>$\phi$</td>
<td>2.6</td>
<td>1.2</td>
<td>e+e-</td>
<td>3 $\cdot 10^{-4}$</td>
<td>35</td>
</tr>
<tr>
<td>$\Omega$</td>
<td>0.14</td>
<td>0.1</td>
<td>$\Lambda K$</td>
<td>0.68</td>
<td>2</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>0.038</td>
<td>20</td>
</tr>
<tr>
<td>J/$\psi$</td>
<td>8 $\cdot 10^{-5}$</td>
<td>6 $\cdot 10^{-5}$</td>
<td>e+e-</td>
<td>0.06</td>
<td>15</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)

6 July 2012
V.Kekelidze, ICHEP-2012, Melbourne
Reaction plane determination & flow study

- $v_2$ in TPC & $v_1$ at high vapidities
  
  *(a possibility for improvement)*

- $v_2$ in TPC by a ‘two sub-events’
  
  to avoid autocorrelations

- Measurement of spectators of both colliding nuclei;
  centrality determination by track multiplicity
  & spectator energy deposit

---

**Event plane resolution for “central events”**

- Extended ZDC detector ($2<\eta<5$)
  improves RP resolution
  at low & medium $b$

  - $L = 120 (60)$ cm
  - $5 < R < 71$ cm, $1<\theta<14^\circ$ ($2<\eta<5$)

---

V. Kekelidze, ICHEP-2012, Melbourne
Particle IDentification in MPD

(realistic detector simulation)

- **PID:** Time Of Flight
  - Separation: e/h – 0.1..0.35 GeV/c
  - \(\pi/K\) – 0.1..1.5 GeV/c
  - K/p – 0.1..2.5 GeV/c

- **PID:** Ionization loss \((dE/dx)\)
  - Separation: e/h – 1.3..3 GeV/c
  - \(\pi/K\) – 0.1..0.6 GeV/c
  - K/p – 0.1..1.2 GeV/c

- **Coverage:** \(|\eta| < 1.4, p_t=0.1-2\ \text{GeV/c} \quad \text{barrel} \quad |\eta| < 2.6, p_t=0.1-2\ \text{GeV/c} \quad \text{barrel+EC}

- **Matching eff.:** > 85% at \(p_t > 0.5\ \text{GeV/c}\)

- **PID:**
  - \(2\sigma \quad \pi/K \sim 1.7\ \text{GeV/c}, \quad (\pi,K)/p \sim 2.5\ \text{GeV/c}\)
V0 performance (TPC+IT)

Central Au+Au @ 9

Improved Sg-to-Bg ratio (S/B) with the vertex IT detector

\[ \sigma_{\text{vertex}} < 60 \, \mu m \]

6 July 2012  V.Kekelidze, ICHEP-2012, Melbourne
Dileptons: $e^+e^-$

Input: central Au+Au at 7 GeV, Pluto + RQMD
- track selection and e-conversion suppression
- PID by $dE/dx$ & TOF, hadron suppression $\sim 10^{-5}$
- Extra suppression by ECAL

Efficiency: 35%
MisID contamin.: -19.0% (w/o cut on ECAL signal)
- 1.4% (w cut on ECAL signal)

Selection: $|\eta| < 1.2$; $0.2 < P < 2.0$ GeV/c

Pion suppression

$\sigma_\varphi = 17$ MeV
$\sigma_\omega = 14$ MeV
Cooperation @ Nuclotron-M / NICA experiments

- Joint Institute for Nuclear Research
- Institute for Nuclear Research, RAS, RF
- Nuclear Physics Institute of MSU, RF
- Institute Theoretical & Experimental Physics, RF
- St. Petersburg State University, RF
- Bogolyubov Institute for Theoretical Physics, NAS, Ukraine
- Institute for Scintillation Materials, Kharkov, Ukraine
- State Enterprise Scientific & Technology Research Institute for Apparatus construction, Kharkov, Ukraine
- Institute of Applied Physics, AS, Moldova
- Particle Physics Center of Belarusian State University, Belarus
- Physics Institute Az.AS, Azerbaijan
- Institute for Nuclear Research & Nuclear Energy BAS, Sofia, Bulgaria
- Aristotel University of Thessaloniki, Greece
- GSI, Germany
- Institute of Physics & Technology of MAS, University of Mongolia
- Department of Engineering Physics, Tsinghua University, Beijing, China
- University of Science and Technology of China, Hefei, China
- Osaka University, Japan
- RIKEN, Japan
- The University of Sidney, Australia
- TJNAF (Jefferson Laboratory), USA
- University of Cape Town, RSA

6 July 2012  V.Kekelidze, ICHEP-2012, Melbourne
Concluding Remarks

- The **BM@N** TDR preparation & Collaboration formation - are going on
- The **MPD** R&D's are well progressing;
- The **MPD** final design - close to completion - under the permanent supervision by the external referee's
- New participants are welcomed to join to **BM@N** &/or **MPD** projects
- The second Interaction Point is waiting for Your PROPOSALS!
Thank you
spare