International project NICA at the Joint Institute for Nuclear Research

V. Kekelidze,

JAI/PP seminar, March 17, 2016, Oxford
Joint Institute for Nuclear Research
International Intergovernmental organization
founded in 1956 by agreement of 12 countries
Located in Dubna town, Moscow region

JINR Member States

18 Member States + 6 Associated countries
from the Synchrophasotron to the Collider NICA

1957
Synchrophasotron

10 GeV proton synchrotron - the world leader in energy
the start up of high energy era

V.I. Veksler - the discovery of
Phase Stability Principle (1944)

1993
Nuclotron

the first superconducting accelerator of heavy ions based on
Dubna type SC magnets

A.V. Baldin - the pioneer of
relativistic nuclear physics

2019
NICA

The superconducting Collider
of heavy ions

study of nuclear matter at extreme conditions and spin physics

March 17, 2016
V. Kekelidze, JAI/PP seminar, Oxford
**NICA (Nuclotron based Ion Collider fAcility)**

**Main targets:**

- study of hot and dense baryonic matter
  at the energy range of max baryonic density
- investigation of nucleon spin structure, polarization phenomena
- development of accelerator facility for HEP @ JINR
- construction of Collider of relativistic ions from p to Au,
  polarized protons and deuterons

with max energy up to $\sqrt{s_{NN}} = 11$ GeV (Au$^{79+}$) and =27 GeV (p)
Asymptotic freedom of quarks

The regime of “asymptotic freedom” is reached in hard processes at sufficiently high energies, however, this regime could be available already at rather low energies in super dense nuclear matter (the distance between particles \( \sim 1/T \)).

Yukawa coupling; charge screening, de-confinement

Confinement

\[ \frac{1}{r} \sim \frac{1}{\ln(\frac{r}{r_0})} \]

\[ \sim \exp(-\frac{r}{R_0}) \]

The super dense nuclear matter could be obtained in heavy ion interactions

\( R_0 \sim 1 \text{ fm} = 10^{-13} \text{ cm} \)

March 17, 2016
V.Kekelidze, JAI/PP seminar, Oxford
Nuclear collisions and the QGP expansion

\[ \frac{\text{fm}}{c} = 3 \times 10^{-24} \text{ s} \]

* evolution in time *selection by spectators*

- collision evolution
  - expansion and cooling
- particle detectors
  - kinetic freeze-out
  - hadronization
  - distributions and correlations of produced particles

- QGP phase
  - quark and gluon degrees of freedom
- collision overlap zone
- quantum fluctuations

\[ \tau \sim 0 \text{ fm/c} \quad \tau_0 \sim 1 \text{ fm/c} \quad \tau \sim 10 \text{ fm/c} \quad \tau \sim 10^{15} \text{ fm/c} \]
Phase transition in nuclear matter

- 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
Freeze-out conditions

QCD matter at NICA:
- highest net baryon density
- energy range covers onset of deconfinement
- complementary to the RHIC, FAIR and CERN
Relativistic Heavy Ion Collider

Design energy $\sqrt{s_{NN}} = 200$ GeV

BNL 2000: RHIC ~ 4 km

PHENIX

STAR
Present and future HI collider experiments

Interaction rate [Hz]

Collision energy $\sqrt{S_{NN}}$ [GeV]

NiCA/MPD

STAR BES II

energy region of max. baryonic density

March 17, 2016 V.Kekelidze, JAI/PP seminar, Oxford
Present HI F.T. experiments

Collision energy $\sqrt{S_{NN}}$ [GeV] vs. Interaction rate [Hz]

Energy region of max. baryonic density

HADES

NA-61/SHINE

March 17, 2016

V. Kekelidze, JAI/PP seminar, Oxford
Complex FAIR: experiments with fixed target

1,0AGeV

Darmstadt, Germany
Present and future HI F.T. experiments

Interaction rate [Hz]

Collision energy $\sqrt{S_{NN}}$ [GeV]

2022 – 2025: SIS-100 FAIR

NICA/BM@N II

HADES

STAR F.T.

CBM

NA-61/SHINE

energy region of max. baryonic density

March 17, 2016

V. Kekelidze, JAI/PP seminar, Oxford
Present and future HI experiments

NICA/MPD will provide most precise results exploring the whole phase space region in the most interesting energy range

Interaction rate [Hz]

Collision energy $\sqrt{S_{NN}}$ [GeV]

energy region of max. baryonic density

NICA/MPD

STAR BES II

STAR FT

HADES

NICA/BM@N I

NICA/BM@N II

CBM

March 17, 2016

V.Kekelidze, JAI/PP seminar, Oxford
Study of nucleon spin structure

must confirm

the sum rule:

\[
\frac{1}{2} = \frac{1}{2} \Sigma_q + \Sigma_g + L_q + L_g.
\]

**NICA** collider will provide collisions of protons and deuterons with all combinations of polarization – *transversal and longitudinal*

*It will allow to measure all 8 intrinsic-transverse-momentum dependent PDFs (at leading twist) in one experiment*

**Matveev-Muradyan-Tavkhelidze-Drell-Yan** mechanism and **SIDIS** processes – *are good tools for these measurements*

Direct photons production *(gluon polarization)*
## Experiments studying nucleon spin structure

<table>
<thead>
<tr>
<th>Experiment</th>
<th>CERN, COMPASS-II</th>
<th>FAIR, PANDA</th>
<th>FNAL, E-906</th>
<th>RHIC, STAR</th>
<th>RHIC-PHENIX</th>
<th>NICA, SPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>F.T.</td>
<td>F.T.</td>
<td>F.T.</td>
<td>collider</td>
<td>collider</td>
<td>collider</td>
</tr>
<tr>
<td>Beam/target</td>
<td>π- , p</td>
<td>anti-p, p</td>
<td>π- , p</td>
<td>pp</td>
<td>pp</td>
<td>pp, pd,dd</td>
</tr>
<tr>
<td>Polarization: b/t</td>
<td>0; 0.8</td>
<td>0; 0</td>
<td>0; 0</td>
<td>0.5</td>
<td>0.5</td>
<td>0.7</td>
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<tr>
<td>Luminosity</td>
<td>2·10^{33}</td>
<td>2·10^{32}</td>
<td>3.5·10^{35}</td>
<td>5·10^{32}</td>
<td>5·10^{32}</td>
<td>10^{32}</td>
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<tr>
<td>√s , GeV</td>
<td>14</td>
<td>6</td>
<td>16</td>
<td>200, 500</td>
<td>200, 500</td>
<td>10 - 26</td>
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<tr>
<td>x_1(beam) range</td>
<td>0.1-0.9</td>
<td>0.1-0.6</td>
<td>0.1-0.5</td>
<td>0.03-1.0</td>
<td>0.03-1.0</td>
<td>0.1-0.8</td>
</tr>
<tr>
<td>q_T, GeV</td>
<td>0.5 -4.0</td>
<td>0.5 -1.5</td>
<td>0.5 -3.0</td>
<td>1.0 -10.0</td>
<td>1.0 -10.0</td>
<td>0.5 -6.0</td>
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<tr>
<td>Lepton pairs,</td>
<td>μ-μ+</td>
<td>μ-μ+</td>
<td>μ-μ+</td>
<td>μ-μ+</td>
<td>μ-μ+</td>
<td>μ-μ+, e+e-</td>
</tr>
<tr>
<td>Data taking</td>
<td>2015</td>
<td>&gt;2025</td>
<td>2013</td>
<td>&gt;2016</td>
<td>&gt;2016</td>
<td>&gt;2020</td>
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<td>Transversity</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
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<td>Boer-Mulders</td>
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<td>YES</td>
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<td>YES</td>
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<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
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<td>Pretzelosity</td>
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<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
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<td>Worm Gear</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
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<tr>
<td>Direct γ</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
</tbody>
</table>
Statistics of White Paper Contributions:

111 contributions, 188 authors from 70 centers in 24 countries
the Laboratory hosted

the 15-th international conference SQM in July 2015
Accelerator blocks

- **Injection Complex**
- **Nuclotron**
- **Booster**
- **Collider**
Accelerator blocks

Leaders:

G. Trubnikov, I. Meshkov, A. Butenko, A. Kovalenko

Machine Advisory Committee:

- Boris Sharkov, ITEP, chairman
- Pavel Beloshitsky, CERN
- Sergei Ivanov, IHEP
- Thomas Roser, BNL
- Alexei Fedotov, BNL
- Markus Steck, GSI
- Nicholas Walker, Desy
- Sergei Nagaitsev, FNAL

- Andrei Seryi, JAI Oxford
- Alexander Zlobin, FNAL
- Takeshi Katayama, Tokyo Univ.
- Valeri Lebedev, FNAL
- Rolf Stassen, FZJ
- Yuri Senichev, FZJ
- Evgeny Levichev, BINP
- Pavel Zenkevich, ITEP

The TDR is approved
Nuclotron (45 Tm)

- Injection bunch
  - ~2 × 10⁹ ions
  - Acceleration up to 1 - 4.5 GeV/u

Linac LU-20

Linac HILac

Booster (25 Tm)

- Storage of (2 ÷ 4) × 10⁹ ions
- Acceleration up to 600 MeV/u

Fixed Target Area

Ion sources

Stripping (80%) ¹⁹⁷Au⁴⁺ → ¹⁹⁷Au²⁺

Two SC collider rings

- ~2 x 22 injection cycles
- 22 bunches per ring

IP-1

IP-2

March 17, 2016

V. Kekelidze, JAI/PP seminar, Oxford
~ 2 mA deuteron beam current was achieved at the end of 2015

the first beam with Nuclotron run is foreseen in May 2016
Assembly of the LEBT and ion source  

A. Butenko, V. Monchinsky, A. Govorov, K. Levterov, A. Sidorin, T. Kulevoy, S. Polozov  

JINR, ITEP, MEPHI  

March 17, 2016

V. Kekelidze, JAI/PP seminar, Oxford

<table>
<thead>
<tr>
<th>Parameter</th>
<th>q/A</th>
<th>1.0</th>
<th>0.5</th>
<th>≥ 0.3</th>
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<tbody>
<tr>
<td>Injection energy, [keV]</td>
<td></td>
<td>31</td>
<td>61.8</td>
<td>103</td>
</tr>
<tr>
<td>Max current, [mA]</td>
<td></td>
<td>10</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Output energy [MeV/u]</td>
<td></td>
<td></td>
<td></td>
<td>0.156</td>
</tr>
<tr>
<td>Norm emittance (output) [π·cm·mrad]</td>
<td></td>
<td></td>
<td></td>
<td>≤ 0.5</td>
</tr>
<tr>
<td>RFQ length, [m]</td>
<td></td>
<td></td>
<td></td>
<td>2.2</td>
</tr>
<tr>
<td>Transmission, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In LU-20 acceptance</td>
<td></td>
<td>&gt; 85%</td>
<td>&gt; 89%</td>
<td>&gt; 93%</td>
</tr>
</tbody>
</table>
New preinjector for LU-20 first beam, *JINR, ITEP, MEPHI*

A.Butenko, V.Monchinsky, A.Govorov, K.Levterov, A.Sidorin, T.Kulevoy, D.Donets, B.Golonevsky

**November 2015,**

- RF amplitude
- HV tube voltage
- Beam current

**test with deuteron and carbon beams from laser source**

March 17, 2016

V.Kekelidze, JAI/PP seminar, Oxford
Nuclotron development

✧ Stable and safe operation up to maximum design energy
✧ Beam time for users > 70%
✧ Time losses < 8%
✧ Development of cryogenic facility
✧ Modern automatic control system based on TANGO
✧ Test of stochastic cooling
✧ New RFQ fore-injector for LU-20

2 – 4 GHz bandwidth, the cooling of bunched and coasting deuteron and carbon beams was achieved
The 3rd Workshop of the Nuclotron beam users “Perspectives of Experimental Research at the Nuclotron beams” was held at the Laboratory on 8 – 9 September, 2015.
**Krion-6T (Electron String Ion Source)**

*E.D. Donets, E.E. Donets, D. Donets, A. Ramzdorf, A. Boytsov, V. Shutov, D. Ponkin, V. Salnikov*

Stand prototype for Krion-N(ica) ion source.

*the electron string current density \( J \sim 1400 \, \text{A/cm}^2 \) has been obtained*

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>design</th>
</tr>
</thead>
<tbody>
<tr>
<td>magnetic field, T</td>
<td>5,4</td>
<td>6,0</td>
</tr>
<tr>
<td>e energy, keV</td>
<td>12</td>
<td>25</td>
</tr>
<tr>
<td>ion</td>
<td>( \text{Au}^{51+} )</td>
<td>( \text{Au}^{31+} )</td>
</tr>
<tr>
<td>intensity, ppp</td>
<td>((1-3) \times 10^8)</td>
<td>((1-4) \times 10^9)</td>
</tr>
<tr>
<td>repet. rate, Hz</td>
<td>3-5</td>
<td>50</td>
</tr>
<tr>
<td>t extraction, s</td>
<td>((8-30) \times 10^6)</td>
<td></td>
</tr>
<tr>
<td>RMS emitt.</td>
<td>0,6 - 0,15 ( \pi )</td>
<td></td>
</tr>
<tr>
<td>peak current, ma</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>
HILac:

*high current (10 mA), the first Linac with transistor RF amplifier*

Design and fabrication by “BEVATECH OHG” Germany, Offenbach/Mainz

RFQ - 1\(^{st}\) section under commissioning:

A. Butenko, V. Monchinsky, K. Levterov, V. Kobets, A. Bazanov

*HILac in the new hall*
RF amplifier commissioning (3 units)

100MHz; 120 / 340 /320 kW in RFQ section

A. Butenko, K. Levterov, V. Kobets

September 2015
HILAC RFQ first beams: acceleration of $D$ and $He$ beams, December 2015
A. Butenko, V. Monchinsky, K. Levterov, V. Kobets, A. Sidorin, D. Donets
The Booster

Booster synchrotron:  
C = 211 m  
ultra high vacuum  
electron cooling

Dipole SC magnet

Quadruple SC magnet
In May **2014** 2 RF stations were assembled and tuned in **BINP** (Novosibirsk) in coop. with JINR specialists.

In October **2014** the stations were delivered to Dubna, assembled and tested.

**Project status:**
all the works are performed in accordance with the plans.

The Booster RF station during commissioning at test bench at JINR

Commissioning at Booster is planned in **2017**
Electron cooling system for booster, BINP

There are purchased 90% of materials
~ 80% of items are produced in workshop

delivery to JINR – 2016
Commissioning is planned in 2017

Project status: on schedule
The Collider

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

<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. int. Energy, Gev/u</td>
<td>11.0 Gev/u</td>
</tr>
<tr>
<td>r.m.s. (\Delta p/p), (10^{-3})</td>
<td>1.6 (10^{-3})</td>
</tr>
<tr>
<td>IBS growth time, s</td>
<td>1800 s</td>
</tr>
<tr>
<td>Luminosity, (cm^{-2} s^{-1})</td>
<td>(1 \times 10^{27})</td>
</tr>
</tbody>
</table>

Double aperture magnets: dipole & quadrupole prototypes

Au(+79) ion mode

March 17, 2016

V. Kekelidze, JAI/PP seminar, Oxford
SC Magnets for Booster, Collider & SIS-100/FAIR workshop at VBLHEP JINR (bld. 217)

3 of 6 cryo-test benches are mounted

serial production of Booster magnets has started!
## Magnet production plan

**H. Khodzhiba**  
**S. Kostromin**

**Status on 14.02.2016**

<table>
<thead>
<tr>
<th>Booster</th>
<th>Collider</th>
<th>dipole correctors</th>
<th>quadrupole correctors</th>
<th>multipole correctors</th>
<th>nonstructurals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Booster</strong></td>
<td><strong>Collider</strong></td>
<td><strong>total</strong></td>
<td><strong>schedule</strong></td>
<td><strong>delivered yokes</strong></td>
<td></td>
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<tr>
<td>dipoles</td>
<td>dipoles</td>
<td>40</td>
<td>16</td>
<td>5</td>
<td></td>
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<tr>
<td>quadrupoles</td>
<td>quadrupoles</td>
<td>48</td>
<td>24</td>
<td>24</td>
<td></td>
</tr>
</tbody>
</table>

**Magnet production plan**

**H. Khodzhiba, S. Kostromin**

**Status on 14.02.2016**

<table>
<thead>
<tr>
<th>Booster</th>
<th>Collider</th>
<th>dipole correctors</th>
<th>quadrupole correctors</th>
<th>multipole correctors</th>
<th>nonstructurals</th>
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<tbody>
<tr>
<td><strong>Booster</strong></td>
<td><strong>Collider</strong></td>
<td><strong>total</strong></td>
<td><strong>schedule</strong></td>
<td><strong>delivered yokes</strong></td>
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<tr>
<td>dipoles</td>
<td>dipoles</td>
<td>40</td>
<td>16</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>quadrupoles</td>
<td>quadrupoles</td>
<td>48</td>
<td>24</td>
<td>24</td>
<td></td>
</tr>
</tbody>
</table>
Cryogenics general view for the NICA complex

LHe Liquefier OG-1000 (the final stage of commissioning): (2010-2016) ADB2-5.2.1

Gaseous He purification system:
25% completed (2016-2017) ADB2-5.2.2

He satellite refrigerators for Collider:
5% completed (2014-2018) ADB2-5.2.3

LN2 Re-condensation (liquefier + 2 compressors)
50% completed (2012-2018) ADB2-5.1.1

LHe 40m3 reservoir:
20% completed (2016-2017) ADB2-5.2.4

Two He screw compressors (delivered):
95% completed (2011-2016) ADB2-5.4.1

Construction of the new compressor station:
(2015-2017) ADB2-5.4.4

The cooling power should be doubled from 4 kW to 8 kW @ 4.5K

Objects:
5.1: Nitrogen system
5.2: He system
5.3: Control system
5.4: Infrastructure


**3 detectors**

**Baryonic Matter at Nuclotron (BM@N)**

*the fixed target experiment at the Nuclotron*

- **Stage I** 2017
- **MultiPurpose Detector (MPD)** at the Collider
  - **Stage I** 2019

**SPD (Spin Physics Detector) at the Collider**

*the project - in preparation*
**Multi Purpose Detector (MPD)**

the observables in AA, pA and pp collisions:

- multiplicity of produced hadrons ($\pi$, $K$, $p$, $\Lambda$, $\Xi$, $\Omega$)
- electromagnetic probes: electrons, gammas, vector meson decays,
- event-by-event fluctuations
- femtoscopy of $\pi$, $K$, $p$, $\Lambda$
- .....
Collision of relativistic nuclei

Elliptic flow of central fireball matter (*collective motion*)

\[ e = y^2 - x^2 \]
\[ y^2 + x^2 \]

*initial coordinate-space anisotropy*

\[ \nu_2 = \left( \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \right) \]

*final momentum-space anisotropy*

\[ \frac{dN}{d\phi} \propto 1 + 2\nu_2 \cos[2(\phi - \Psi_R)] + 2\nu_4 \cos[4(\phi - \Psi_R)] + \ldots \]

elliptic flow establishes there is strongly interacting matter at \( t \sim 0 \)
Lepton pair production

- In-medium modification of vector meson properties may signal on partial chiral symmetry restoration in heavy ion collisions
- Dileptons as penetrating probes of the fireball interior – no FSI

The detector relevant features:

- Low material budget;
- Electron reliable ID & hadron extra suppression by ECAL;
- High event rate allowing study of dielectron continuum at high $p_T$.

\[
\begin{align*}
\omega: c\tau &= 23 \text{ fm} & M &= 783 \text{ MeV}, \Gamma &= 8 \text{ MeV} \\
\Phi: c\tau &= 44 \text{ fm} & M &= 1019 \text{ MeV}, \Gamma &= 4 \text{ MeV} \\
\rho: c\tau &= 1.3 \text{ fm} & M &= 768 \text{ MeV}, \Gamma &= 149 \text{ MeV}
\end{align*}
\]

Required mass resolution $\sim 10 \text{ MeV}$
a subject of research:

to measure charge asymmetry w.r.t. reaction plane as a possible signature of strong P violation

Electric dipole moment of QCD matter!

excess of positive charge

excess of negative charge

Multi Purpose Detector (MPD)

Coordinator: V. Golovatyuk

Detector Advisory Committee:

Hans Gutbrod, GSI - chairman
Itzhak Tserruya, Weizmann Institute
Hans Rudolf Scmidt, Tubingen Uni.
Jean Cleymans, Cape Town Uni.
Nu Xu, BNL

TDRs for most sub-detectors have been prepared and now are under evaluation by DAC
MPD detector for Heavy-Ion Collisions @ NICA

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

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

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

Status: 
- technical design and detector R&D – completed;
- Preparation for the mass production

March 17, 2016
V.Kekelidze, JAI/PP seminar, Oxford
MPD superconducting Solenoid

$B_0 = 0.66 \text{ T}$

weight ~ 900 t

Control Dewar, pipe lines

Cryostat

SC coil

Trim Coil

TPC region

high level ($\sim 3 \times 10^{-4}$) of magnetic field homogeneity

ASG superconducting (Genova, Italy):
- Cold Mass + Cryostat
- Vacuum System
- Trim Coils
- Control System
- PS
- General responsibility

Contract - signed; works – in progress
VITKOVICE Heavy Machinery (Czech Rep.) – JINR:
Yoke + supports + assembly tools
*contract - signed*

- N.D. Topilin

ООО ПП "СПЕЦМАШ" - MORANDINI (Milano, Italy):
*forged steel for the Yoke;*
*all bars produced, 4 rings - production in progress*
Schedule for MPD Magnet fabrication & commissioning

<table>
<thead>
<tr>
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<td>IV</td>
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<td>- final design report</td>
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<td>- SC cable, cryostat, coils</td>
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<td>- delivery to Dubna</td>
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<td>- tests &amp; overall commission</td>
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<tr>
<th>NKMZ+ Mjrandini: Raw material for Yoke</th>
<th>2015</th>
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<td>- production forged bars and rings</td>
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<td>- delivery to VHM</td>
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<th>Vitkovice Heavy Machinery: Yoke</th>
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<td>- production &amp; delivery to Dubna</td>
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<th>STU (Georgia): system of movement</th>
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<th>2016</th>
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<td>- technical design</td>
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<td>- production and delivery to Dubna</td>
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<td>CERN: the field measurement system</td>
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<th>Readiness for MPD integration</th>
<th>2015</th>
<th>2016</th>
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<td>the MPD Hall is available</td>
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March 17, 2016 V.Kekelidze, JAI/PP seminar, Oxford
Time Projection Chamber

TPC Prototype

Sketch of TPC

-~ \( 3400 \) mm
diameter \( \varnothing 2800 \)

HV-electrode ~ 28 kV

~ 110 000 readout channels

12 Readout chamber

Project status:
- basic R&D finished, (cont. alternative RO Ch.);
- assembly workshop in preparation (readiness – IIq., 2016)

Leaders: S. Movchan, Yu. Zanevsky

Works are going in accordance with the schedule
The barrel consists of 12 super-modules (two modules connected together).

- **Active area of TOF barrel**: $\sim 56 \text{ m}^2$
- **Number of channels**: 13,824

**Project status:**
- 90% readiness for the mass production

**Leader:** V. Golovatyuk
New beam test results

Efficiency and time resolution of the MRPC versus HV

Time resolution in dependence from the position along strip

Time resolution in dependence of rotation in surface YZ
Fast Forward Detector (FFD)

Leader: V. Yurevich

JINR + Radium Institute (St.Petersburg).

Provides:
T0 for TOF, beam adjustment & collision L0-trigger

Status:
- procurement of necessary elements;
- production in accordance with the schedule.

the achieved time resolution fits the requirement

Fig. 3

<table>
<thead>
<tr>
<th>dt_FFD1_FFD2_ch0</th>
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<tbody>
<tr>
<td>Entries</td>
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<tr>
<td>Mean</td>
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<td>RMS</td>
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<td>$\chi^2 / \text{ndf}$</td>
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<tr>
<td>Constant</td>
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<tr>
<td>Mean</td>
</tr>
<tr>
<td>Sigma</td>
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</tbody>
</table>
ECAL – shashlyk type

Leaders: I. Tyapkin, A. Ol’shevsky

$L \sim 35 \text{ cm} (\sim 12 \text{ } X_0), \text{ Pb+Scint. } (4 \times 4 \text{ cm}^2) \text{ read-out: WLS fibers + MAPD}

Energy resolution: $2.5\% / \sqrt{E}$ fits the requirement

ECAL module:
- 220 layers
- 25 kg

Sector: 4 modules x 23 rows = 92 modules

Barel ECal: 56 sect. x 92 mod. = 5152 modules

Design of integration with the MPD magnet is in progress
End Cap ECal: 712 modules each side
In total: ~ 1500 modules
to be produced by 2022
Zero Degree Calorimeter (ZDC)

Leaders: A. Ivashkin, A. Kurepin, F. Guber

structure of module

- 60 lead/scintillator sandwiches (sampling ratio 4:1)
- 10 longitudinal sections
- 6 WLS-fiber/MAPD per section
- 10 MAPDs/module

\[ \sigma(E)/(E) = 56.1%/\sqrt{E}({\text{GeV}}) + 2.1\% \]
Centrality determination

energy vs barrel track multiplicity

Heavy fragment escape in beam hole for peripheral collisions. Comparison of ZDC response with charged particle multiplicity helps to resolve ambiguity.

Reaction plane reconstruction

\[ \sin(\varphi_i) = \frac{y_i}{\sqrt{x_i^2 + y_i^2}} \]
\[ \cos(\varphi_i) = \frac{x_i}{\sqrt{x_i^2 + y_i^2}} \]

\[ \Psi_{1,\text{EP}} = \text{acrtg} \sum \frac{E_i \sin(\varphi_i)}{E_i \cos(\varphi_i)} \]

\[ \Delta \Psi = \left| \Psi_{\text{EP}} - \Psi_{\text{RP}} \right| \]

**March 17, 2016**

V.Kekelidze, JAI/PP seminar, Oxford
CBM-MPD consortium structure for R&D and production of IT modules (since 2008)
Workshop for microstrip detector assembly & test

CBM-MPD Consortium

Leader: Yu. Murin

The clean workshop has started operation in 2015.

CERN & JINR have signed MoU for manufacturing the STS carbon fiber frames for NICA (BM@N & MPD) and FAIR (CBM).

Project is supported by the CREMLIN grant (in the framework of HORIZON-2020).

March 17, 2016

V. Kekelidze, JAI/PP seminar, Oxford
MPD IT comprises MAPS - DSSD layers of new ALICE ITS MAPS and CBM-like modules DSSD with new ASIC (system currently simulated and optimized)

2 layers of ALICE ITS
(MAPS inner layers of double length)
4 layers of DSSD
with readout through long (< 100 cm) cable (a call for ASIC development)

MAPS budget: 0.3% $X_0$
DSSD budget: 0.3% - 1.2% $X_0$
Simulation & analysis framework

✓ Software repositories
✓ Software tests
✓ Forum
✓ Information, etc.

Event generators

- UrQMD 2.3; LA QGSM; SHIELD on fly
- pHSD; UrQMD 3.4; 3FD + particlization

- inherits basic properties from FairRoot, C++ classes;
- extended set of event generators for heavy ion collisions;
- detector composition & geometry;
  - particle propagation by GEANT3/4;
- advanced detector response functions,
  - realistic tracking and PID included.

March 17, 2016
V.Kekelidze, JAI/PP seminar, Oxford
Good probes to indicate medium modifications of spectral functions due to chiral symmetry restoration in A+A collisions; effect is proportional to baryon density

\[ \sigma_\omega \approx 14 \text{ MeV/c}^2 \]

MPD performance for dileptons

Hadron suppression up to \(10^{-5}\)

Yields, central Au+Au st \(\sqrt{s_{\text{NN}}} = 8.8\) GeV/u

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<tr>
<th>meson</th>
<th>Yields</th>
<th>Yield/1 w</th>
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<tbody>
<tr>
<td>(4\pi)</td>
<td>(y=0)</td>
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<tr>
<td>(\rho)</td>
<td>31</td>
<td>17</td>
</tr>
<tr>
<td>(\omega)</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td>(\varphi)</td>
<td>2.6</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Hypernuclei production enhanced at high baryon densities (NICA)

Hypertritons (central Au+Au @ 5A GeV (DCM-QGSM))

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

$S/B = 2.9$

eff. = 0.8%

$S/S+B = 8.4$

$\sim 10^6$ $^3\Lambda H$ are expected in 10 weeks

$^3\Lambda H \rightarrow p + d + \pi^-$

$S/B = 11.8$

eff. = 1.0%

$S/S+B = 10.9$
Baryonic Matter at Nuclotron (BM@N)

Leader: M. Kapishin

Detector Advisory Committee:

Hans Rudolf Schmidt, Tubingen Uni. - chairman
Hans Gutbrod, GSI
Itzhak Tserruya, Weitzmann Institute
Peter Hristov, CERN
Karlheinz Hiller, DESY
**BM@N: the 1st stage**

Participants from:

**Russia:** INR, MEPhi, SINP, MSU, IHEP, S-Ptr Radium Inst.

**Bulgaria:** Plovdiv University;

**China:** Tsinghua University, Beijing;

**Poland:** Warsaw Tech.Uni.

**Israel:** Tel Aviv Uni.

**Germany:** Frankfurt Uni.

+ expression of interest from CBM

---

**Physics:**

✓ strange / multi-strange hyperon and hypernuclei production *at the threshold*

✓ hadron femtoscopy

✓ in-medium modifications of strange & vector mesons *in dense nuclear matter*

✓ electromagnetic probes, states decaying into $\gamma$, $e$ (with ECAL)
**BM@N status and milestones**

**BM@N schematic view**

---

**BM@N configuration**

<table>
<thead>
<tr>
<th></th>
<th>DAQ</th>
<th>GEM <em>(CERN)</em></th>
<th>ST</th>
<th>TOF</th>
<th>Outer tracker</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016, IV:</td>
<td>basic config.</td>
<td>6 half planes</td>
<td>1 small plane</td>
<td>half config.</td>
<td>DCH</td>
</tr>
<tr>
<td>2017, III:</td>
<td>complete</td>
<td>10 h/pl.</td>
<td>2 s/pl.</td>
<td>basic</td>
<td>DCH</td>
</tr>
<tr>
<td>2019, I:</td>
<td>-”-”-</td>
<td>8-10 full pl.</td>
<td>2 s., 2 large pl.</td>
<td>complete</td>
<td>Straw+DCH</td>
</tr>
</tbody>
</table>
BM@N ST comprises four first stations of CBM STS

CBM STS: 8 stations
BM@N ST: 4 stations

1220 sensors:
- 252 single
- 324 daisy-pairs

900 / 220
6.2 × 6.2 cm²

260 / 216
6.2 × 4.2 cm²

60 / 60
6.2 × 2.2 cm²

Sensor:
- 0.3% X₀
- r/o cables: 2 × 0.11% X₀

+ a number of “half” sensors

Double-sided-double-metalized sensors from Hamamatsu and CiS
(pitch 58 um, stereo angle 7.5 degrees)

March 17, 2016
V.Kekelidze, JAI/PP seminar, Oxford
Tasks for test run:

- trace $d, C^{12}$; beam profile/structure
- test detector response: ToF400/700 (part), DCH-1,2 (part), ZDC (part), $T_0 T$, BM
- test integrated DAQ / trigger based on $T_0 T$ in magnet

$T_0$ beams, $T_0 = 3.5 - 4.2$ GeV

ZDC on movable platform
BM@N status and milestones

BM@N plan

technical runs with $d$, $Li$, $C$ beams: 2016 – 2017;

physics run BM@N (I stage) with $Kr$ int rate 20 kHz: IV q., 2017;

physics run BM@N (II stage) with $Au$ int rate 50 kHz: 2019.

next technical run in 2016: commissioning of GEM & Si inside magnet

Simulation

A.Zinchenko, V.Vasendina

$UrQMD$ & $DCM-QGSM$, $Au+Au$, $E_{kin.} = 4.5A$ GeV, $2 \times 10^6$ events;

March 17, 2016

V.Kekelidze, JAI/PP seminar, Oxford
Computing

Data processing pipeline

On-line prototype & network rack

160 × 3 GHz CPU cores, 1024 GB RAM, 8.5 TB Flash Memory, 2 × 10 Gb Ethernet
4 × 10 Gb Ethernet

all prototypes are constructed and tested;
design of the whole NICA cluster is in progress

Leader: Yu. Potrebenikov

15 servers: 4 interactive, 11 batch hosts, 350 CPU cores
130TB disk space (replicated)

Data storage (LIT):
> 10 PB RAW data p/y after 2020

Needs:
- Comp. CPU – 5 000 GHz
- CPU cores – 1600
- Comp. RAM – 10 000 GB
- Disc storage – 2 200 TB
- Mass storage – 20 PB/year

LHEP off-line cluster (prototype)
Civil Construction of NICA Complex

General Contract (duration 43 months) - signed!, Sept. 2015

STRABAG – General contractor; КометА – designer

The preparatory works are completed (area ~60 000 m²!)

The whole Complex comprises several Objects to be commissioned:

- MPD Hall, I q., 2018
- SPD Hall, II q., 2019
- West semi-ring, III q., 2018
- East semi-ring, IV q., 2018
- Beam extraction, I q., 2019
- Bld.#1 reconstruction, I q., 2019
the area is prepared for the construction
### NICA schedule

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<td><strong>BM@N</strong></td>
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*Running time*
All basic parts of the **NICA complex** are at the stages of fabrication or **TDR** approval.

The major milestones for the commissioning:

<table>
<thead>
<tr>
<th>Accelerator Complex</th>
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<tbody>
<tr>
<td><strong>Start-up configuration</strong></td>
<td>– 2019</td>
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<tr>
<td><strong>The design configuration</strong></td>
<td>– 2023</td>
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<thead>
<tr>
<th>BM@N</th>
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<tbody>
<tr>
<td><strong>The I stage</strong></td>
<td>– 2017</td>
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<tr>
<td><strong>The II stage</strong></td>
<td>– 2019</td>
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<th>MPD</th>
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<td><strong>The I stage</strong></td>
<td>– 2019</td>
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<tr>
<td><strong>Upgraded (IT + end-cups)</strong></td>
<td>– 2023</td>
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<th>SPD</th>
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<tr>
<td><strong>Project is under preparation</strong></td>
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</table>
Earned Value Management System (EVM)

– successful cooperation with CERN
- essential contribution to the management of the NICA project

D. Mathieson (CERN), G. Trubnikov, V. Korenkov, Yu. Potrebenikov, S. Kunyaev (JINR)

at present the Project comprises 374 objects
NICA complex plans and fulfilments

JINR annual funding plans (accumulated)

actual funding

earned value

Jan. 2010
In the medium-term prospect the NICA complex will be the only facility in Europe providing unique high intensity ion beams (from $p$ to $Au$, $p\uparrow$ and $d\uparrow$) in the energy range from $2 – 27$ GeV (c.m.s.), which could be used for both fundamental and applied researches.

Researches at the NICA complex will contribute to

• discovery and study of new forms of nuclear matter;
• comprehensive study of nucleon spin structure;
• applied researches, like irradiation of biological objects by heavy ion beams (space mission program) etc.

ESFRI initiated a hearing of the NICA project in Brussels on September 7, 2015, in order to consider its inclusion as a Landmark to the ESFRI Roadmap

“… ESFRI encourages to work closely together and to pay special attention to developing NICA as a Global Research Infrastructure concept…”
Concluding remarks

- NICA complex has a potential for competitive research in dense baryonic matter and spin physics.

- The construction of accelerator complex and both detectors BM@N & MPD is going close to the schedule.

- New collaborators are invited to join the NICA project.
Thank you!