Status of the NICA project at JINR

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Abstract. The status of the new flagship Project Nuclotron-based Ion Collider fAcility (NICA) at the Joint Institute for Nuclear Research, its main parameters, construction details and physics program is reported. The generation of intense heavy ion and polarized light nuclear NICA beams is aimed at searching for the phase transitions, mixed phase and critical phenomena of nuclear matter and investigation of polarization phenomena at the collision energies up to $\sqrt{s_{NN}} = 11$ GeV.

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Joint Institute for Nuclear Research International Intergovernmental Organization

Nuclotron-based Ion Collider fAcility (NICA) at JINR: New Prospect for Heavy Ion Collisions and Spin Physics

A.N.Sissakian, A.S.Sorin

Dense Matter in Heavy Ion Collisions and Astrophysics JINR, Dubna, July 17 2008

JINR is an international research organization established in accordance with the intergovernmental agreement signed in 1956. At the present time, eighteen countries are the JINR Member States. JINR has an extensive and fruitful collaboration with Germany, Hungary, Italy, Serbia, and the Republic of South Africa having an Observer status at JINR.

- After 52 years of scientific activity the Institute plays a world leading role in a number of branches of fundamental physics.
- Long-term scientific cooperation is established with CERN, Germany (GSI, DESY), France (GANIL, IN2P3), USA (FNAL, BNL, TJNL, LBL, LNL), Switzerland (PSI), Japan (RIKEN, KEK) and many other countries.
- The largest number of collaborative investigations are carried out with Russian research centers: IHEP (Protvino), INR RAS (Troitsk), ITEP (Moscow), Lebedev PI RAS (Moscow), BINP (Novosibirsk), Russian Research Center "Kurchatov Institute", SINP MSU (Moscow), PNPI RAS (Gatchina) and others.

JINR's research niche offered by home facilities

- **Heavy-Ion Physics:**
 - at high energies (up to 5 GeV/n)
(in future $\sqrt{s_{NN}} = 9$ GeV, NICA facility)
 - at low and intermediate
energies (5 – 100 MeV/n)
- **Condensed Matter Physics
using nuclear physics methods**

10^0 h

10^4 h

10^5 h

The n^{th} order phase transition:

$$\frac{\partial^n}{\partial x_i^n} F(x_1, x_2, \dots, x_n) \text{ is discontinuous}$$

x_k - thermodynamic variables

F - thermodynamic potential

A mixed phase in different representations

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Discontinuity of
 $A = A_{II} \lambda + A_{II} (1 - \lambda)$
originates from
discontinuity of
 $\lambda = V_{II} / V$

Critical end-point $\Rightarrow$ critical end-line $\Rightarrow$ critical end-boundary hypersurface !?

Dynamical trajectories

Skokov V., 2008

Ivanov Yu., Russkikh V., Toneev V., 2005

Experimental programs

Facility	SPS	RHIC	NICA	SIS-300
Detector	NA61	STAR PHENIX	MPD	CBM
Start (year)	2010	2010	2013-2014	2015-2016
Energy (for Pb-ions) c.m. GeV	4.9-17.3	4.9-50	≤ 9	≤ 8.5
Physics	CP,OD	CP,OD	CP,OD,HDM	CP,OD,HDM

CP – critical endpoint

OD – onset of deconfinement

HDM – hadronic dense matter

Un missionnaire du moyen âge raconte qu'il avait trouvé le point
où le ciel et la Terre se touchent...

Nikola Camille Flammarion (1888)

Heavy Ion Accelerators

SIS

BEVALAC
(shut down)

NUCLOTRON

SPS

RHIC
AGS (shut down)

Synchrophasotron
(shut down)

	E (GeV)	S ^{1/2} (GeV)
AGS BNL Au+Au 1985 – 1990	2 + 11	2.3 ♦ 4.7
SPS CERN Pb+Pb		
2003	20	6.3
2002	30	7.6
2000	40	8.3
2000	80	12.3
1994 – 2000	160	17.4
RHIC BNL Au+Au 2000 – ?	2.1•10 ⁴	200

Relativistic Heavy Ion Facilities
from Synchrophasotron and AGS to NICA and FAIR

Over the last 30 years a lot of efforts have been made to provide the conditions for searching for new states of strongly interacting matter under extreme conditions.

Synchrophasotron: $E_{lab} \sim 4.2$ AGeV ($\sqrt{s_{NN}} = 3$ GeV)
1971 - 1999, pioneering experiments in the field of relativistic nuclear physics.

AGS: $E_{lab} \sim 11$ AGeV ($\sqrt{s_{NN}} = 5$ GeV)
1986 – 1992, study of compressed baryonic matter.

SPS: $E_{lab} \sim 158$ AGeV ($\sqrt{s_{NN}} = 18$ GeV)
1986- up to now,
study of compressed baryonic matter.

RHIC: $\sqrt{s_{NN}} = 200$ GeV ($E_{lab} \sim 80000$ AGeV)
1996 - up to now.

LHC: $\sqrt{s_{NN}} = 5600$ AGeV ($E_{lab} \sim 6.3 \cdot 10^7$ AGeV)
2009 - planned

SIS 300: (FAIR GSI) $E_{lab} \sim 34$ AGeV
($\sqrt{s_{NN}} = 8.5$ GeV),
full performance will be reached in 2015,
study of compressed baryonic matter.

NICA: $\sqrt{s_{NN}} = 9$ GeV ($E_{lab} \sim 40$ AGeV).
full performance will be reached in 2013,
search for the mixed phase of strongly
interacting matter.

BNL Brookhaven National Laboratory

CERN European Organization for Nuclear Research

AGS (BNL) Alternative Gradient Synchrotron

SPS (CERN) Super Gradient Synchrotron

RHIC (BNL) Relativistic Heavy Ion Collider

LHC (CERN) Large Hadron Collider

JINR NUCLOTRON

**Project parameters: maximum energy
5 GeV/nuc. for nuclei with $A \sim 200$.**

The main goal of the NICA project is an experimental study of hot and dense nuclear matter and spin physics

These goals are proposed to be reached by:

- development of the existing accelerator facility (1st stage of the NICA accelerator programme: Nuclotron-M subproject) as a basis for generation of intense beams over atomic mass range from protons to uranium and light polarized ions;

- design and construction of heavy ion collider with maximum collision energy of $\sqrt{s}_{NN} = 9$ GeV and average luminosity $10^{27} \text{ cm}^{-2} \text{ s}^{-1}$ (for U^{92+}), and polarized proton beams with energy $\sqrt{s} \sim 25$ GeV and average luminosity $> 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$;
- design and construction of the MultiPurpose Detector (MPD).

Scheme of the NICA complex

NICA parameters

Circumference	m	225	1. Circumference, m	224
Number of collision points		2	2. β^* , m	0.5
Beta function in the collision point	m	0.5	3. $\Delta p/p$ (one σ)	$1 \cdot 10^{-3}$
Rms momentum spread		0.001	4. Bunch length (σ), m	0.3
Rms bunch length	m	0.3	5. Beam emittance (σ), $\pi \cdot \text{mm} \cdot \text{mrad}$	0.26
Number of ions in the bunch		10^9	6. Bunch intensity	$(1-2) \cdot 10^9$
Number of bunches		15	7. Bunch number per ring	15
Incoherent tune shift		0.05	8. Average luminosity for UU at 3.5 GeV/u	$1.1 \cdot 10^{27} \text{ cm}^{-2} \cdot \text{s}^{-1}$
Rms beam emittance at 1 GeV/u / at 3.5 GeV/u	$\pi \text{ mm mrad}$	3.8 / 0.26	for pp at 12.5 GeV	$3 \cdot 10^{31} \text{ cm}^{-2} \cdot \text{s}^{-1}$
Luminosity per one interaction point at 1 GeV/u at 3.5 GeV/u	$\text{cm}^{-2} \cdot \text{s}^{-1}$	$6.6 \cdot 10^{25}$ $1.1 \cdot 10^{27}$		

NICA – Collaboration

- Joint Institute for Nuclear Research
- Institute for Nuclear Research Russian Academy of Science
- Institute for High Energy Physics, Protvino
- Budker Institute of Nuclear Physics, Novosibirsk
- MoU with FAIR is under preparation
- *Open for extension ...*

Design and Construction of
Nuclotron-based Ion Collider Facility (NICA)

Conceptual Design Report

Dubna 2008

<http://nica.jinr.ru>

The NICA Project Milestones

- **Stage 1: years 2007 – 2009**

- Upgrade and Development of the Nuclotron facility
- Preparation of Technical Design Report of the NICA and MPD
- Start prototyping of the MPD and NICA elements

- **Stage 2: years 2008 – 2012**

- Design and Construction of NICA and MPD

- **Stage 3: years 2010 – 2013**

- Assembling

- **Stage 4: year 2013 - 2014**

- Commissioning

NICA provides unique possibility for the heavy ion physics program:

1. Heavy ion beams in **wide** energy range:

$$\sqrt{s} = 4 - 9 \text{ AGeV}$$

2. Possibility to perform atomic mass and centrality **scan**

3. Few intersection points for detectors with large energy-independent acceptance

4. High luminosity $L \sim 10^{27} \text{ cm}^{-2}\text{s}^{-1}$

High baryonic densities

Maximal baryonic densities on freeze-out curve! $\Rightarrow$ High densities on interaction stage!?

Critical points

◆ Models

◆ Lattice QCD

○ Chemical freeze-out for different energies $\sqrt{s}$

NICA/MPD physics problems

Study of in-medium properties of hadrons and nuclear matter **equation of state** including a search for possible signs of deconfinement and/or chiral symmetry restoration **phase transitions** and **QCD critical endpoint**

Experimental observables:

Scanning in beam energy and centrality of **excitation functions** for

- ♣ Multiplicity and global characteristics of identified hadrons including multi-strange particles
 - ♣ Fluctuations in multiplicity and transverse momenta
 - ♣ Directed and elliptic flows for various identified hadrons
 - ♣ particle correlations
 - ♣ Dileptons and photons

What to measure

♣ **Multistrange hyperons.** The yields, spectra and collective flows of (multi) strange hyperons are expected to provide information on the early and dense phase of the collision. Therefore, these particles are promising probes of the nuclear matter **equation-of-state** at high baryon density.

♣ **Event-by-event fluctuations.** The hadron yields and their momenta should be analyzed event-wise in order to search for **nonstatistical fluctuations** which are predicted to occur in the vicinity of **the critical endpoint** and when penetrating **the coexistence phase of the first order deconfinement phase transition**.

♣ **HBT correlations.** Measurement of short range correlations between hadrons π , K, p, Λ allows one to estimate the **space-time size of a system** formed in nucleus-nucleus interactions. Along with the increase of fluctuations, the spatial size of the system **is expected to be getting smaller** near the deconfinement phase transition due to **softening of the equation of state** (the "softest point" effect).

♣ **Penetrating probes.** Measurements of dilepton pairs permit to investigate the **in-medium spectral functions** of low-mass vector mesons which are expected to be modified due to effects of chiral symmetry restoration in dense and hot matter. Specific properties of the **σ meson, the order parameter of chiral symmetry restoration**, may be in principle detected near the phase boundary via particular channel of σ -decay into dileptons or correlated $\gamma\gamma$ -pairs.

HBT identical particle correlations

NA49 and CERES data are contradictory

NICA/MPD provides a possibility to repeat measurements in this region

Increase of the lifetime =>
Softening of the equation of state due to phase transition?!

B.Back et al., 2006

Excitation functions of particle ratios

HSD, UrQMD, GiBUU

Experimental data:
E896, NA49, STAR, PHENIX,
BRAHMS

Exp. data (particularly a maximum at **E~30 AGeV**) are not well reproduced within the hadron-string picture => evidence for **nonhadronic degrees of freedom**

E.Bratkovskaya et al.,(2004)

Inverse slopes of transverse mass spectra

E.Bratkovskaya et al., (2004)

$$dN/m_T dm_T \sim \exp(-m_T/T)$$

Hadronic rescattering has only a small effect on the kaon slope in UrQMD and HSD models

The hadron-string picture fails? => New degrees of freedom are missing (collectivity?)

The beginning of flattening correlates with the position of maximum in K^+/π^+ ,
E~20-30 AGeV

Directed v_1 and elliptic v_2 flows

Small wiggle in v_1 at midrapidity is not described by HSD and UrQMD

Too large elliptic flow v_2 at midrapidity from HSD and UrQMD for all centralities !

Experiment (NA49): **breakdown of elliptic v_2 flow at midrapidity !**

Signature for a first order phase transition

H.Stoecker et al., 2005

Fluctuations: theoretical status

Lattice QCD predictions: **Fluctuations of the quark number density (susceptibility) at $\mu_B > 0$** (C.Allton et al., 2003)

$$\frac{\chi_q}{T^2} = \left[\frac{\partial^2}{\partial (\mu_q/T)^2} \frac{P}{T^4} \right]_{T_{fixed}}$$

← χ_q (quark number density fluctuations) will diverge at the critical end point

Experimental observation:

- Baryon number fluctuations
- Charge number fluctuations

Collective flows

Non-central collisions

Interactions between constituents lead to a **pressure gradients** => spatial asymmetry is converted in asymmetry in momentum space
=> **collective flows**

$$\frac{dN}{dp_T dp_T d\varphi} = \frac{dN}{dp_T dp_T} \frac{1}{2\pi} (1 + 2v_1 \cos(\varphi) + 2v_2 \cos(2\varphi) + \dots)$$

directed flow

elliptic flow

Correlation femtoscopy of identical particles

$$\mathbf{q} = \mathbf{p}_1 - \mathbf{p}_2, \quad \Delta \mathbf{x} = \mathbf{x}_1 - \mathbf{x}_2$$

$$C_2 = 1 + (-1)^S \langle \cos \mathbf{q} \Delta \mathbf{x} \rangle \rightarrow 1 + \lambda \exp(-R_{long}^2 q_{long}^2 - R_{side}^2 q_{side}^2 - R_{out}^2 q_{out}^2 - 2R_{out}^2 q_{out} q_{long})$$

Signals of chiral symmetry restoration

MPD conceptual design

MPD – Collaboration

- Joint Institute for Nuclear Research
- Institute for Nuclear Research Russian Academy of Science
- Bogolyubov Institute of Theoretical Physics, NASUK
- Skobeltsyn Institute of Nuclear Physics of Lomonosov MSU, RF
- Institute of Applied Physics, Academy of Science Moldova
- *Open for extension ...*

A consortium involving GSI, JINR & other centers for IT module development & production is at the organizational stage

Version 1

The **MultiPurpose Detector (MPD)**
to study Heavy Ion Collisions at NICA

Letter of Intent

Dubna, 2008

<http://nica.jinr.ru>

On the Spin Program at NICA

$$S_z^N = \frac{1}{2} = \frac{1}{2} \left[\underbrace{\Delta u + \Delta \bar{u} + \Delta d + \Delta \bar{d} + \Delta s + \Delta \bar{s}}_{\text{EMC, 1987}} + \underbrace{\Delta G}_{\text{Spin Nucleon Structure}} + \underbrace{\Delta L_g + \Delta L_q}_{\text{Spin Nucleon Structure}} \right]$$

EMC,

1987

$$\Delta \Sigma = 0.12 \pm 0.17$$

Spin Nucleon Structure

Polarization data has often been the graveyard for fashionable theories. If theorists had their way they might well ban such measurements altogether out of self-protection.

J.D. Bjorken, 1987

NICA could provide unique possibilities for the spin program :

1. Accelerate at NUCLOTRON polarized high energy proton and deuterons
2. Have high luminosity ($> 10^{30} \text{ cm}^{-2}\text{s}^{-1}$)
3. Have high polarization ($> 50\%$)
4. Rotate spin L/T
5. Polarization measure $\sim 3\%$
6. Construct adequate (4π geometry) detector

Spin program

Studies of Drell-Yan (MMT-DY) processes with polarized p and D beams
Extraction of unknown PDFs from J/ψ production processes

Spin effects in baryon and meson productions.

Studies of spin effects in various exclusive reactions

Diffractive processes studies

Cross sections and double spin asymmetries in elastic reactions

Spectroscopy of quarkoniums with any available decay modes

On the Spin Program at NICA

Preliminary estimations of the MMT-DY processes feasibility (first stage)

DY cross sections (nb) in comparison with PAX (GSI, FAIR) and possibility to increase the statistics (month of data taking)

	σ_{DY} total, nb	$L, \text{cm}^{-2}\text{s}^{-1}$	K events
PAX, $\sqrt{s} = 14.6 \text{ GeV}$	~ 2	$\sim 10^{30}$	~ 10
NICA, $\sqrt{s} = 20 \text{ GeV}$	~ 1	$\sim 10^{30}$	~ 5
NICA, $\sqrt{s} = 26 \text{ GeV}$	~ 1.3	$\sim 10^{30}$	~ 7

cut on Q , GeV	1.5	1.6	1.7	1.8	1.9	2.0
NICA, $\sqrt{s} = 20 \text{ GeV}$						
σ_{DY} total, nb	2.54	1.94	1.59	1.32	1.1	0.9
N events for a month, K	14.1	10.5	8.8	7.3	6.1	5
NICA, $\sqrt{s} = 26 \text{ GeV}$						
σ_{DY} total, nb	3.3	2.7	2.3	1.9	1.6	1.3
N events for a month, K	18	15	13	10	9	7
PAX, $\sqrt{s} = 14.6 \text{ GeV}$						
σ_{DY} total, nb	5.1	4.33	3.5	2.9	2.46	2.09
N events for a month, K	24.4	20.7	16.7	13.9	11.8	10

PAX background estimations

On the Spin Program at NICA

Preliminary estimations of J/Ψ statistics in comparison with MMT-DY statistics

$\sqrt{s}$, GeV	20	26	$\sqrt{s}$, GeV	20	26
$\sigma_{J/\Psi} \cdot B_{e^+e^-}$, nb	10	16	σ_{DY} , nb	0.9	1.3
N events for a month, K	55	88	N events for a month, K	5	7

Experiments on DY measurements

Experiment	Status	Remarks
E615	Finished	Only unpolarized MMT-DY
NA10	Finished	Only unpolarized MMT-DY
E886	Running	Only unpolarized MMT-DY
RHIC	Running	Detector upgrade for MMT-DY measurements (collider)
PAX	Plan > 2016	Problem with $\bar{p}$ polarization (collider)
COMPASS	Plan > 2010	Only valence PDFs
J-PARC	Plan > 2011	low s (60-100 GeV ²), only unpolarized proton beam
SPASCHARM	Plan?	$s \sim 140$ GeV ² for unpolarized proton beam $s \sim 670$ GeV ² for polarized proton beams,
NICA	Plan 2014	high luminosity (collider)

Preliminary scheme of the experimental set-up for MMT-DY and J/Ψ measurements

Important advantages of the detector :

- 2) 4π geometry – increase of DY statistics
- 3) Minimal X_0 – effective detection of $e+e^-$ pairs
- 3) Good angular resolution – very important for azimuthal spin asymmetries measurements in the wide kinematical region

Main parts of the detector (preliminarily):

- Silicon or MicroMega (inner tracking)
- Drift chambers or straw (for tracking)
- Cherenkov counter (for PID and trigger)
- EM calorimeter
- Trigger counters
- EndCap detectors

Similarly to the PAX set-up (hep-ex/0505054)

Set-up for muon pairs detection is also under consideration

Applied research at NICA

Booster-synchrotron application to nanostructures creations:

Design and parameters of booster, including wide accessible energy range, possibility of the electron cooling, allow to form dense and sharp ion beams. System of slow extraction provides slow, prolonged in time ion extraction to the target with space scanning of ions on the target surface and guaranty **high controllability** of experimental conditions.

Ion-track technologies:

Ion tracks in a polymer matrix (GSI, Darmstadt)

Topography and current of a diamond-like carbon (DLC) film. The 50 nm thick DLC film was irradiated with 1 GeV Uranium ions.

Production of nanowires, filters, nanotransistors, ...

Further realization of NICA project, as to both theory and MPD setup construction, suffers a deficit of qualified people, young scientists and engineers. The planned steps:

- **More close collaboration with Russian institutes and JINR Member States**
- **Strengthening the relations with FAIR, RHIC and CERN where similar works are carried out (MoU)**
- **Profiling students of the Dubna University with orientation towards NICA/MPD problems**
- **Organization of student Schools and Meetings for young scientists on problems of NICA/MPD**

Round Table Discussions

Round Table Discussion I

Searching for the mixed phase of strongly interacting matter at the JINR Nuclotron

July 7 - 9, 2005

<http://theor.jinr.ru/meetings/2005/roundtable/>

Round Table Discussion II

Searching for the mixed phase of strongly interacting matter at the JINR Nuclotron: Nuclotron facility development

JINR, Dubna, October 6-7, 2006

<http://theor.jinr.ru/meetings/2006/roundtable/>

Round Table Discussion III

Searching for the mixed phase of strongly interacting QCD matter at the NICA/MPD

JINR (Dubna), end 2008

<http://nica.jinr.ru>

Welcome to the collaboration!

Thank you for attention!

Welcome to Dubna!