Search for the Mixed Phase of Strongly Interacting Matter

at Nuclotron-based Ion Collider Facility

Dubna 2007
The Joint Institute for Nuclear Research (JINR) in Dubna is an international research organization established in accordance with the intergovernmental agreement of 11 countries in 1956. At the present time, eighteen countries are the JINR Member States. JINR has an extensive and fruitful collaboration with Germany, Hungary, Italy and the Republic of South Africa, having an Observer status at JINR and contributing their resources to projects of mutual interest.

After 50 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 and the main Laboratories of France, the USA (Fermilab, BNL, TJNL, LBL) and many other countries.

The largest number of collaborative investigations are carried out with Russian research centers.

The JINR research program in high energy particle and nuclear physics is carried out mainly at the accelerator facilities of other Laboratories: ITEP (Protvino), INR RAS (Troitsk), ITEP (Moscow), PI RAS (Moscow), BINP (Novosibirsk), Russian Research Center "Kurchatov Institute", SINP MSU (Moscow), PNPI RAS (Gatchina), CERN, FNAL and BNL (USA), GSI and DESY (Germany) and others.

The JINR basic facility for high-energy physics research is represented by the 6 AGeV Nuclotron which has replaced the old weak focusing 10 GeV proton accelerator Synchrophasotron. The first relativistic nuclear beams with an energy of 4.2 AGeV were obtained at the Synchrophasotron in 1971. Since that time the study of relativistic heavy ion physics problems has been one of the main directions of the JINR research program.
Nuclotron-based Ion Collider fAcility and MultiPurpose Detector (NICA / MPD)

- The new flagship of the Joint Institute for Nuclear Research

The main goal of the NICA/MPD project is to start in the coming years experimental study of hot and dense strongly interacting QCD matter and search for a possible manifestation of the mixed phase formation and critical endpoint in heavy ion collisions. These investigations are relevant to understanding of the evolution of the Early Universe after Big Bang, formation of neutron stars, and the physics of heavy ion collisions. The new facility makes it possible to reach a new level in studying polarization phenomena in few-body nucleon systems.

- The development of JINR basic research capabilities

Generation of intense heavy ion and polarized light nuclear beams aimed at searching for the mixed phase of nuclear matter and investigation of polarization phenomena at the collision energies up to $\sqrt{s_{NN}} = 9$ GeV is foreseen. Realization of the project will lead to unique conditions for the research activity at the JINR basic facility. The energy region of NICA is of major interest because the highest nuclear (baryonic) density under laboratory conditions can be reached there.

- The main goal is proposed to be reached by:

- Development of the existing Nuclotron accelerator facility 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 (NICA) with maximum collision energy of $\sqrt{s_{NN}} = 9$ GeV and averaged luminosity $10^{27}$ cm$^{-2}$ s$^{-1}$.

- Design and construction of multipurpose particle detector (MPD) at colliding beams.
Why a search for the mixed phase is so important

The beam energy of the NICA is particularly interesting; it is considerably lower than the region covered by the Large Hadron Collider (LHC) in Geneva but it sits right on top of the region where the baryon density at the freeze-out is expected to be the highest. In this energy range the system occupies a maximal space-time volume in the mixed quark-hadron phase (the phase of coexistence of hadron and quark-gluon matter similar to the water-vapor coexistence-phase). The net baryon density at LHC energies will be lower because of a phenomenon called nuclear transparency: at very high energies nuclei fly through each other, produce a very large number of mesons and, therefore, reach very high energy densities but due to a large number of mesons achieve fairly low baryon densities. The energy region of NICA will allow analyzing the highest baryonic density under laboratory conditions.

Water-steam transition (first-order phase transition with the latent heat) ends a critical point (second order). No difference between steam and water above the critical point.

According to modern theoretical models, quark-hadron phase transitions manifest a structure similar to water, with a crossover above the critical point ($\mu_b$ is baryon chemical potential related to the baryon density, $T$ is temperature).
Freeze-out (cease of particle interactions in the system) estimated for different colliding energies (J. Randrup and J. Cleymans, 2006). Freeze-out baryon density is maximal at collider energy \( \sqrt{s_{NN}} = (4+4) \) GeV. The blue colored numbers stand for energy in the laboratory system, the red ones - in the system of centre of mass.

Phase trajectories in the phase diagram calculated within the 3-fluid hydrodynamic model for central Au+Au collisions at different energies (Yu. Ivanov V.N. Russkikh, V.D. Toneev, 2005; A.N. Stesakian, A S Solin, M.K. Suleymanov V.D. Toneev, G.M. Zinovjev, 2005, 2006). Freeze-out curve is shown by dots, the shaded region is a mixed phase for baryon and strange conserved charges. For \( E_{\text{lab}} = 30 \) AGeV (\( \sqrt{s_{NN}} = 8 \) GeV) the trajectory goes near the critical end-point. Points with numbers indicate the time of the system evolution (1 fm/c ~ 3.3 \times 10^{-24} \) sec).
Relativistic 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 - 1998, pioneer experiments in the field of relativistic nuclear physics.

AGS: $E_{lab} \sim 11$ AGeV ($\sqrt{s_{NN}} = 5$ GeV)

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: $\sqrt{s_{NN}} = 5520$ AGeV ($E_{lab} \sim 6.1 \cdot 10^7$ AGeV)
2008 - planned

SIS 300 (FAIR): $E_{lab} \sim 34$ 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.
NICA general layout

Construction of the new facility is based on the existing infrastructure of the Nuclotron accelerator complex and experimental area (building 205) of the Laboratory of High Energies. Composition of the NICA/MPD main components is shown in the picture below. Basic accelerator chain includes: "Heavy ion source – Linear pre-accelerator – Superconducting booster synchrotron – Nuclotron – Superconducting collider rings. The maximum design kinetic energy of U$^{238}$ ions in the collider is limited to 3.5 AGeV. Perimeter of the collider magnetic system is chosen to satisfy the initial design conditions of the existing building. The project design presumes the use of fixed target experiments. Polarized deuteron collision mode is foreseen.

This approach allows for the following cost saving factors:

- No new buildings, no additional power lines.
- No extra heat, water cooling power.
Nuclotron facility development

- The Nuclotron, 6 A·GeV synchrotron based on unique fast-cycling superferric magnets, was designed and constructed at JINR for five years (1987-1992) and put into operation in March 1993. The annual running time of 2000 hours is provided during the last years.

- The Nuclotron cryo-magnetic ring of 251.5 m in perimeter is installed in the tunnel around the Synchrophasotron base. The necessary infrastructure for the magnet cooling to 4.5 K exists.

- Ion beams up to krypton and polarized deuterons have been accelerated and extracted from the accelerator.

- Unique technology of highly charged state ion sources (KRION-type) based on ionization by electron impact is developed. The ions up to Au have been obtained at the test bench.

- Fast-ramped superconducting magnet technology is at the highest world level.

Necessary development of the Nuclotron facility includes the following:

- The KRION ion source development
- Improvement of the Nuclotron vacuum system
- Construction of the new pre-accelerator and booster synchrotron
- Electron cooling system
- Partial modernization of beam extraction line and radiation shield
- Development of cryogenic supply and other accelerator and beam control and monitoring systems.
The experimental set-up of proposed MPD has to perform tracking of high multiplicity events and particle identification. The tracking system, both the vertex tracker based on silicon strip detectors and tracking, includes detectors - Central Tracking System and Forward Track Systems. These detectors are optimized for determination of the primary and secondary vertices and for precise tracking of low-momentum particles. All tracking detectors (SVS, TPC and FTS) are situated in the magnetic field of 1 T which is parallel to a beam direction. The detectors record the tracks of charged particles, measure their momenta and identify particles by measuring their ionization energy loss (dE/dx) with a good resolution. The TPC is an appropriate detector for reconstruction of events with high density tracks. For identification of secondary particles it is proposed to use Time of Flight Detectors. The outermost Time of Flight array provides pion, kaon and proton identification.

Simulated tracks from U+U collision with √sNN = 9 GeV energy with RQMD model.

Scheme of the MPD. TPC - Time Projection Chamber; SVS - Silicon Vertex tracking System; TOF - Time of Flight detectors; ZDC - Zero Degree Calorimeter.
The Project Milestones

- **Stage 1:** years 2007 – 2008  
  - Development of the Nuclotron facility  
  - Preparation of Technical Design Report  
  - Start prototyping of the MPD and NICA elements

- **Stage 2:** years 2008–2012  
  - Design and Construction of the Booster Accelerator  
  - Design and Construction of NICA and MPD detector

- **Stage 3:** years 2010 – 2013  
  - Assembling

- **Stage 4:** year 2013  
  - Commissioning

"...the truth is gained... from the comparison of what came to mind with what is really observed."

(Painting and sentence by D.I. Blochstok)

«...истина добыывается... из сравнения того, что придумано, с тем, что наблюдалось.»

(Рисунок и высказывание Д.И. Блохстока)
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Dubna is a town in the North of the Moscow Region. It is situated just at the place where the Moscow Canal flows into the Volga River. The distance from Moscow is 120 km. It is well known in Russia and abroad as a science town due to the Joint Institute for Nuclear Research.

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