Title: Nuclotron-based Ion Collider Facility at JINR (NICA Complex)

Contact person: Prof. V.Kekelidze, kekelidze@jinr.ru

Abstract

The NICA (Nuclotron-based Ion Collider fAcility) project is now under realization at the Joint Institute for Nuclear Research (JINR) - international intergovernmental scientific research Laboratory established in 1956 in Dubna town near Moscow. The main goal of the project is extension of the existing relativistic ion facility Nuclotron to the world level research infrastructure facility NICA aimed at study of hot and dense nuclear and baryonic matter in heavy ion collisions and spin physics research with polarized proton and deuteron beams. The centre-of-mass energies $\sqrt{s_{NN}}$ from 4 to 11 GeV will be available in heavy ion research mode. Polarized proton collisions can be studied over energy range up to $\sqrt{s_{NN}} = 27$ GeV. Physics detector setups MPD, SPD and BM@N are under design and construction. An average luminosity in the collider mode is expected to reach 10^{27} cm^{-2} s^{-1} for Au (79^{+}) collisions and 10^{32} cm^{-2} s^{-1} in pp mode. Extracted beams of various nucleus species with maximum momenta of up to 13 GeV/c (for protons) will be available. The proposed program allows to search for possible signs of phase transitions and critical phenomena as well as to shed light on the problem of the nucleon spin structure. The particle beams of the NICA complex will be used not only for fundamental research but also for innovation and technological activities aimed at obtaining of new knowledge in modern areas of nuclear and space technologies; medical and biological technologies; higher education and information technologies as well.

Comprehensive overwiew

Scientific context

The NICA complex is aimed at performing study of hot and dense baryonic matter that should shed light on in-medium properties of hadrons and the nuclear matter equation of state, existence of mixed phase and critical phenomena. Heavy ion collisions at $\sqrt{s_{NN}}$ = 4-11 GeV allow to attain the highest baryon density. The problem of the origin of the nucleon spin and study of polarization phenomena in polarized protons and light ion interactions are also among the targets.

Objectivites and methodology

The research at NICA aims at obtaining new data and knowledge that should shed light on: in-medium properties of hadrons and the nuclear matter equation of state (EOS); the onset of deconfinement (OD) and/or chiral symmetry restoration (CSR); phase transition (PT), mixed phase and the critical end-point (CEP); possible local parity violation in strong interactions (LPV). The NICA research domain is attractive as being the expected region for searching for the new phenomena at the maximum baryon density including possible phase transitions. The study of the nucleon spin origin ("spin puzzle") and polarization phenomena in polarized proton and deuteron interactions is also a target of research. The high intensity and high polarization (>50%) of the colliding beams provide unique possibilities for this study. The new spectrometers are: the Baryonic Matter at the Nuclotron (BM@N) for fixed target experiments with heavy ion and polarized deuteron and proton beams extracted from the Nuclotron; the MultiPurpose Detector (MPD) at the colliding beams with a primary goal to study heavy ion collisions; Spin Physics Detector (SPD) aimed to study spin physics.

The BM@N experiment has several goals:

1) in heavy-ion (A+A) collisions these are: study of the dense nuclear (dominantly baryonic) matter with strangeness including: a) production mechanisms and modifications of hadron properties in dense nuclear matter (“in-medium effects”) using the following probes: strange

mesons, strange and multi-strange baryons; vector mesons via hadronic or dilepton/photon mode); b) study of the EoS with strangeness, c) hyper-matter production: search for light hypernuclei and multi-strange metastable objects;
2) study of elementary reactions: pp, pn(d) as "reference" to pin down nuclear effects;
3) search for ‚cold' nuclear matter in pA – collisions.

The BM@N at the first stage can study the *in-medium effects on strangeness* measuring of a variety of observables for different energies and impact parameters in heavy-ion collisions in order to find an *"anomalous"* behavior in comparison with the theory. The observables sensitive to in-medium effects include: particle yields and ratios, $p_T(m_T)$ spectra, rapidity and angular distributions, collective flow. Measurement of in-medium effects for vector mesons (V = ρ, ω, φ) could be possible in perspective. An optimal way for that is investigation of the dilepton ($V \rightarrow e{+}e^-$) or photon ($\omega \rightarrow \gamma\, \pi^0$) modes. Possible alternative is the $\varphi \rightarrow K^+K^-$ decay.

The MPD experimental program is directed to investigate both hot and dense baryonic matter and polarization phenomena. A preliminary list of the first priority physics tasks to be performed includes:
1) measurement of a large variety of signals over a range of collision conditions (energy, centrality, system size) using as bulk observables 4π geometry particle yields (OD, EoS); multi-strange hyperon yields and spectra (OD, EoS); electromagnetic probes (CSR, OD); azimuthal charged-particle correlations (LPV); event-by-event fluctuation in hadron productions (CEP); correlations involving π, K, p, Λ (OD); directed and elliptic flows for identified hadron species (EoS, OD); reference data (i.e. p + p) will be taken at the same experimental conditions;
2) study of hyperon polarization and other polarization phenomena including possible study of the nucleon spin structure via the Drell-Yan (DY) processes after the MPD upgrade. The MPD is a typical collider detector based on a superconducting solenoid with magnetic field of 0.5 T (~ 5 m in diameter and ~ 8 m in length). It will be installed in the IP-1 of the collider ring. The evaluated rate in Au + Au collisions at the maximum energy (10% central interactions) will be up to 7 kHz at the design luminosity of $L = 1{\cdot}10^{27}\ cm^{-2}\ s^{-1}$.

The SPD detector will be designed and installed in the IP-2 to study spin physics. The processes, which could be studied with this detector are as follows:
1) DY processes with longitudinally and transversally polarized p and d beams; extraction of unknown (poorly known) spin dependent parton distribution functions (PDF);
2) PDFs from J/ψ production processes;
3) spin effects in various exclusive and inclusive reactions; cross section measurements of diffractive processes;
4) study of helicity amplitudes and double spin asymmetries (Krisch effect) in elastic reactions;
5) spectroscopy of quarkonia via different decay modes.

The studies could be extended into kinematical regions not available for other experiments.

The NICA project has a long term (approximately 30 years) research program in the field of heavy ion collisions and spin physics. It involves well-established scientific community. The project addresses a multidisciplinary scientific frontier by opening a novel possibility in studies of the fundamental properties of nuclear matter under extreme conditions (high baryonic densities and temperatures); hadron physics study; study of the nucleon spin structure and polarization phenomena; nuclear and atomic physics, biophysics and astrophysics. It aims to cover the gap in the current research infrastructure panorama in Europe by construction of an accelerator complex and experimental facilities for studies of the fundamental properties of the baryonic matter:
1) new forms of baryonic matter, not observed before;
2) understanding of the nature of bounds between quarks in the nucleon;
3) various symmetry violations in strong interactions that may give hints to explain the existence

of our matter dominated Universe.

According to the current understanding, all this requires rather low energies, much lower than available in the existing accelerator complexes LHC (CERN) and RHIC (BNL).

To conduct such experiments with high precision in the most interesting energy range, the NICA and FAIR accelerator complexes are being constructed.

The NICA and FAIR projects, while having similar tasks, differ fundamentally in the approaches to its solving. Thus, FAIR promotes measurements in fixed target experiments with high-intensity ion beams. On the opposite, the heart of the NICA project is the construction of a heavy ion collider in addition to the fixed target experiments, i.e. experiments with colliding beams. It makes it a unique facility in the European landscape.

The NICA complex adds into the European research capacity in the following fields: fundamental study of matter with extreme densities and temperatures; hadron physics study; study of the nucleon spin structure and polarization phenomena; nuclear and atomic physics, biophysics and astrophysics studies, as well as innovations in medicine, energy saving, microelectronics, etc.

The following components of the NICA complex will be put into operation:

Accelerator block:

- Ion and polarized particle sources;
- Linear accelerators;
- Superconducting (SC) synchrotron Nuclotron;
- SC synchrotron-booster;
- SC collider rings for heavy ions and polarized particles

Experimental set-ups:

- BM@N - for research with the Nuclotron extracted heavy ion beams;
- MPD – for research at the NICA collider with heavy ion beams;
- SPD – for research at the NICA collider with polarized particle beams;

Production and technological block:

- Technological line for assembling and sertifying of SC magnets;
- Consortium for microstrip detector production;

Innovative block:

- beam channels for innovation and applied research by exploiting of the linear accelerators and Nuclotron extracted beams;
- beam channels for innovation and applied research on the booster and Nuclotron beams;

Infrastructure block:

- NICA user's center;
- IT complex for data storage and analysis.

Readiness of the facility

The relativistic ion synchrotron – 10 GeV Nuclotron, is under operation at the JINR for 25 years. This superconducting accelerator based on the unique cryomagnetic system originally proposed, designed and manufacturing at LHEP JINR was put into operation in 1993. It was upgraded during 2008-2010 and provides ion beams from deuterons to xenon in energy range from 500 MeV/u to 5.3 GeV/u for the users.

The new ion sources (KRION-6T for heavy ions and SPI for polarized deuterons and protons) and the new heavy ion linac – HILAC are put in operation.

The upgrade of the existing linac LU-20 is complited. The TDR for a new linac for light polarized particles has been prepared and the contract for the manufacturing has been signed. Polarized deuterons were successfully accelerated in the Nuclotron during runs in years 2016-2017.

A facility for manufacturing and testing of superconducting fast cycling magnets is in operation; all the magnets for the booster synchrotron have been produced already and the construction of the booster is going on.
The TDRs for the all main subsystems of the NICA collider have been prepared.
The cryogenic facility is in operation and its modernization and expansion is in progress.
Almost all TDRs for the BM@N set-up and MPD have been prepared and their construction has started. Experiments with the basic configuration of the BM@N set-up were started at the beginning of 2018. BM@N and MPD collaborations have been formed. The work on the CDR and TDR for the SPD has started.