THE PROJECT NICA

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Abstract

The present flagship program of Joint Institute for Nuclear Research in Dubna assumes the experimental study of hot and dense strongly interacting QCD matter and polarization phenomena at the new home facility. This goal is proposed to be reached by (i) development of the existing 6 AGeV superconducting synchrotron – Nuclotron as a basis for generation of intense beams over atomic mass range from protons to gold and light polarized ions, (ii) design and construction of the Nuclotron-based Ion Collider fAcility (NICA) with the maximum nucleon-nucleon center-of-mass energy of $\sqrt{s_{NN}} = 11$ GeV and averaged luminosity 10^{27} cm^{-2}s^{-1} for Au+Au collisions, and (iii) design and construction of the MultiPurpose Detector (MPD) and Spin Physics Detector (SPD) at intersecting beams. Realization of the project will lead to unique conditions for research activity of the world community in the field of relativistic nuclear and spin physics.

1. Introduction

The new Nuclotron-based Ion Collider fAcility (NICA) is under construction at the Joint Institute for Nuclear Research (JINR) in Dubna [1]. The research program of the planned experiments at this facility is relevant to understanding the key astrophysical phenomena like the evolution of the early Universe after the Big Bang, formation and structure of neutron stars or the origin of cosmic rays, as well as – to clarifying the physics of relativistic heavy ion collisions and spin phenomena [2–4].

Investigation of hot and dense nuclear matter produced in relativistic heavy ion collisions is a challenging task in modern physics.

It provides information on the in-medium properties of hadrons and nuclear matter equation of state, allows for a search of possible manifestations of the deconfinement and/or chiral symmetry restoration phase transitions, mixed phase and critical end-point by scanning various excitation functions in beam energy, atomic number and collision centrality. A number of new phenomena has already been discovered: strong stopping power of colliding nuclei, strong collective flows of secondary particles pointing to a formation of a new form of matter at top RHIC energies behaving like almost ideal and rapidly expanding liquid, constituent quark number scaling of the elliptic flow, a plateau in the apparent temperature at SPS energies and a broadening of transverse momentum distributions at higher energies, irregularities in the beam-energy behavior of the K/π ratio, drastic enhancement of multistrange hyperon production, suppression of J/ψ production at SPS energies, essential broadening of the vector meson spectral functions, strong in-medium modification of produced fast hadrons and jets pointing to jet quenching during propagation through the excited nuclear matter, indications on the chiral magnetic effect from three-particle correlations and their disappearance at $\sqrt{s_{NN}} < 20$ GeV.

Different phases of strongly interacting matter are shown in the phase diagram of Fig. 1. One may see that the heavy-ion experiments at RHIC and LHC probe the region of high temperature and low net baryon density where circumstantial evidence has been obtained for a new kind of QCD matter, the strongly interacting quark-gluon plasma (sQGP), existing above a critical temperature $T_c \approx 160 - 170$ MeV and behaving as an almost ideal liquid. In the other corner of the phase diagram, at a high net baryon density, the matter is deconfined even at a low temperature and, as predicted, correlated quark-antiquark pairs form a color superconductive phase. Such phase may be created in the interior of neutron stars. A fascinating peculiarity is offered in an intermediate region of the phase diagram, where the critical end-point is expected to be located and the phase transition of the excited nuclear matter becomes of the 1st order. The position of the critical end-point is strongly model dependent, the predictions lying in the region of temperature $T_E \sim$ 160–170 MeV and baryon chemical potential $\mu_E \sim$ 200–700 MeV. The comprehension of this part of the phase diagram is far from being complete due to the

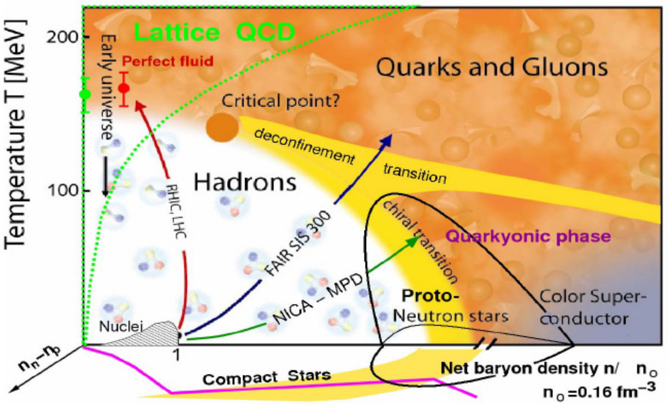

Fig. 1: The phase diagram of strongly interacting QCD matter, schematically showing the phase boundaries, critical end-point, and conjectured dynamical trajectories for an expansion stage

lack of sufficiently accurate data in the corresponding energy domain $\sqrt{s_{NN}} < 10$ GeV. Particularly, the absence of fluctuation and femtoscopic signals of the critical end-point and the onset of deconfinement is likely [4,5] due to expected dramatic decrease of the partonic phase in this energy range [6]. The search for these phenomena can thus be successful only in dedicated high statistics and precise experiments.

As a response to this quest, GSI declared construction of a big accelerator complex FAIR with the extracted heavy-ion beams at $E_{\rm lab} = 4$–35 AGeV, $\sqrt{s_{NN}} = 3$–8 GeV; the first stage SIS-100 ($E_{\rm lab} <$ 11 AGeV) to be available in 2019 and the second one SIS-300 – after 2020. At the BNL-RHIC, the pilot experiments have already been performed at the collider energies reduced from $\sqrt{s_{NN}} = 200$ GeV to 7.7, 11.5, 19.6 and 39 GeV despite the loss in the luminosity by 2-3 orders in magnitude at the lowest energies; the low energy scan program at RHIC will continue in 2012 by taking the data at the energy $\sqrt{s_{NN}} = 27$ GeV.

The NICA energy range $\sqrt{s_{NN}} = 4$–11 GeV is very much lower than those of the RHIC and the LHC, and partly overlaps with the lowest energies available in the RHIC energy scan and the energies of the fixed-target experiments at SPS and FAIR. It sits right on top of the region where the net baryon density is expected to be the highest achievable in terrestrial experiments. In this energy range, the excited nuclear matter occupies the maximum space-time volume in the mixed quark-hadron phase (similar to that of the water-vapor coexistence phase).

Besides the heavy ion beams, the NICA will also provide the polarized proton and deuteron beams up to the c.m.s. energy of 27 GeV for pp collisions with the luminosity higher than 10^{30} cm^{-2}s^{-1}. The high intensity and high polarization ($> 50\%$) will provide a unique possibility for spin physics research, which is of crucial importance for the solution of the nucleon spin problem ("spin puzzle") – one of the main tasks of the modern hadron physics. Particularly, a study of the Matveev-Muradyan-Tavkhelidze-Drell-Yan (MMT-DY) processes, not requiring the input from the poorly known fragmentation functions, can be done in the kinematic region not available in other experiments.

2. NICA Layout

The NICA collider complex is shown on Fig. 2. The construction of this facility is based on the existing buildings and infrastructure of the Synchrophasotron/Nuclotron of the JINR Veksler-Baldin Laboratory of High Energy Physics. The accelerator chain includes heavy-ion and polarized particle sources (KRION-6T and SPP), RFQ injector, heavy- and light-ion linacs (HILac and LU-20), booster ring, Nuclotron and superconducting collider rings. The peak design kinetic energy of gold ions in the collider is 4.5 AGeV. Beam cooling and bunching systems are foreseen to achieve the average luminosity of 10^{27} cm^{-2} s^{-1} in the Au+Au collisions. The project design presumes the continuation of some of the fixed-target experiments, including those with polarized beams from the Nuclotron. The concept of the NICA project was first presented and discussed at the round table discussion in October 2006, the present project status is available in the Conceptual Design Report [2] and the Technical Design Report is close to its completion. Two interaction points are foreseen at the NICA collider, thus providing a possibility for two detectors to operate simultaneously. The MultiPurpose Detector (MPD) is optimized

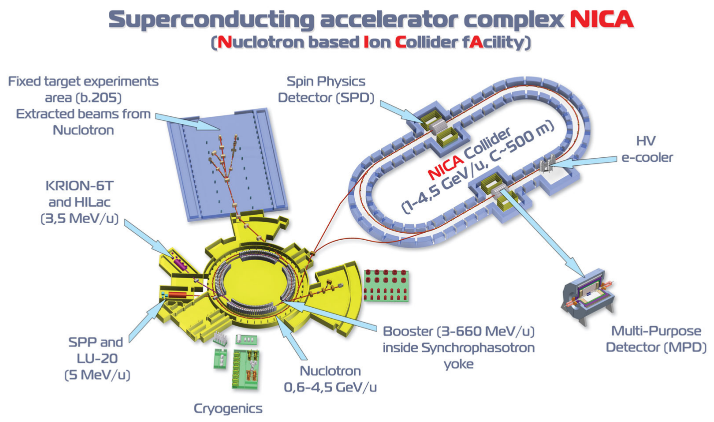

Fig. 2: Location of the NICA collider in the JINR accellerator complex area

for the study of properties of hot and dense nuclear matter produced in heavy-ion collisions and the Spin Physics Detector (SPD) – for the study of spin phenomena in the collisions of light polarized ions.

The NICA complex is aimed at the basic science research, yet beams of particles intended for physics experiments may find another applications. In particular, JINR has already accumulated essential experience in conducting biomedical research and in performing cancer therapy. The proton and ion beams from the linacs, booster and Nuclotron are well suited for applications and will greatly enhance the JINR capability in many important areas of applied sciences, radiation technology and medicine.

3. The Detectors: MPD and SPD

Due to the high complexity of the search for the critical end-point and mixed phase in relativistic heavy ion collisions and large uncertainties in the predicted signals, an accurate scanning of the considered phase diagram domain in the collision energy, impact parameter and system size is utterly needed. In this respect, it is important to provide a uniform detector acceptance over the whole energy range of interest. The operation in the collider mode, as proposed in the NICA project and in the low-energy RHIC program (however, with the luminosity by several orders of magnitude lower than planned in the NICA project), naturally satisfies this demand and has an advantage as compared with the fixed-target mode (SPS, FAIR).

The MPD setup [2] is designed to explore the phase diagram of strongly interacting matter produced in heavy-ion collisions at NICA. It has to cover a large phase space, be functional at high interaction rates and comprise high efficiency and excellent particle identification capabilities in a high track multiplicity environment and allow for a controlled selection of the event centralities. The MPD detector concept matching these requirements comprises the central detector and two optional forward spectrometers, the latter covering the pseudorapidity region $2 < |\eta| < 3$.

The central detector consists of a barrel part and two end-cap trackers located inside the magnetic field. The latter are aimed for precise tracking over pseudorapidity range $1.2 < |\eta| < 2$. The barrel part covers the pseudorapidity region of $|\eta| \leq 1.2$. It consists of a tracker and particle identification system. The principal tracker is the time projection chamber (TPC) supplemented by the inner tracker (IT) surrounding the interaction region. Both IT (silicon strip detector as a baseline) and TPC have to provide precise track finding, momentum determination, vertex reconstruction and pattern recognition. The energy loss (dE/dx) measurements in the TPC gas will provide an additional capability for particle identification in low momentum region. The high performance time-of-flight (TOF) system must be able to identify charged hadrons and nuclear clusters in the broad rapidity range and up to total momentum of 2 GeV/c. The fast forward detectors will provide the TOF system with the start signal. In addition, the electromagnetic calorimeter will identify electrons, photons and measure their energy with high precision. Its high granularity together with excellent energy resolution and good timing performances will enhance the overall efficiency and particle identification capabilities of the MPD detector. Particles emitted in very forward/backward directions will be detected by fast forward detectors, beam-beam counters and zero degree calorimeters. They will be used for trigger definition, centrality determination and reconstruction of the position of the interaction point.

The following measurements will be done in the first stage: multiplicity and spectral characteristics of identified hadrons probing entropy production and system temperature at freeze-out; event-by-event fluctuations in multiplicities of various particle species, multiplicity ratios, charges and particle transverse momenta as generic properties of critical phenomena; collective flow effects, particle correlations and femtoscopy with identified particles characterizing collective phenomena and space-time evolution of the excited matter. In the second stage, the electromagnetic probes (photons and dileptons) will be measured.

The NICA facility will also give unique possibilities for spin physics. For this, the SPD setup [3] at the second interaction point is designed similar to the PAX setup at FAIR. It assumes nearly 4π acceptance, minimal radiation length to provide an effective detection of lepton pairs and a good angular resolution to allow for a measurement of azimuthal spin asymmetries in a wide kinematic region. The basic SPD parts are: a toroid magnet system with the integrated field of ~ 0.4 T·m, inner tracker (Silicon or MicroMega), main tracker (drift chambers or straw tubes), Cherenkov counter, electromagnetic calorimeter, trigger counters and EndCap detectors. Also considered is the possibility of so-called beam-dump muon detector.

The following measurements are assumed: MMT-DY and J/ψ production processes with longitudinally and transversally polarized proton and deuteron beams for the extraction of unknown or poorly known parton distribution functions; spin effects in baryon, meson and photon production; spin effects in various exclusive reactions and diffractive processes; spin-dependent cross sections, helicity amplitudes and double spin asymmetries (Krisch effect) in elastic reactions; spectroscopy of quarkonia; polarimetry.

4. Conclusions

The project of the Nuclotron-based Ion Collider fAcility, NICA, is being realized in JINR. It will make it possible to study very important unsolved problems of the physics of strongly interacting matter and spin phenomena. The design and organizational work on this project started in 2006, and its realization assumes several stages: upgrade of the Nuclotron facility, preparation of the NICA technical design report, start of the prototyping of the NICA, MPD and SPD elements (2007-2012); design, construction and assembling (2012-2016); commissioning (2017). Worldwide cooperation is anticipated at all stages of the project as well as – in the elaboration of the scientific program.

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