REPORT to the

Directorate of the Joint Institute of Nuclear Research on the

Physics Justification to Study Nuclear Collisions at the Nuclotron Energies

On July 7-9, 2005 the workshop "Searching for the mixed phase of strongly interacting matter at the JINR Nuclotron" was held at the Joint Institute of Nuclear Research in Dubna. The aim of this meeting was to discuss the prospects of the new experimental activity devoted to the study of nuclear collisions at the JINR Nuclotron. Having heard all talks, remarks and suggestions, taking into account ideas expressed in the discussions, we came to the clear opinion that future experiments at the Nuclotron energy range are important and interesting. Therefore, we strongly support the idea to establish the new experimental program at the Dubna Nuclotron.

In this report, following the request of the JINR Directorate, we state our opinion on a physics justification to study nuclear collisions at Nuclotron energies. We start from a brief review of the nuclear high energy physics today and continue with our list of the most important physics problems which can be addressed by the new measurements at the Dubna Nuclotron.

Since the first acceleration of deuterons in the Dubna Synchrophasotron in 1971, the relativistic nuclear collisions have been studied experimentally at several scientific centers all over the world. The broad research program is devoted to the investigation of properties of strongly interacting matter at high densities. Rich results obtained at the CERN-SPS [1] and BNL-RHIC [2] are suggestive for the creation of a new state of dense matter at the early stage of central collisions of heavy nuclei. The detailed study of the properties of this new state at vanishing baryon density is the main goal of the future heavy-ion LHC program. The rapid changes of the energy dependence of hadron production observed recently at the low SPS energies [4] may indicate that the phase transition is located in this energy range [5]. Further analysis of the transition region as well as a search for the critical end-point will be the focus of the future program at the CERN SPS. At lower energies ($<15A$ GeV) the data on nuclear collisions were taken at JINR Synchrophasotron, LBL-Bevalac, BNL-AGS and GSI-SIS-18. The heavy ion programs at Synchrophasotron, Bevalac and AGS were finished many years ago. The maximum energy of SIS-18 is only $2A$ GeV. A planning of the new accelerator complex FAIR with SIS-100 and

SIS-300 machines is in progress. They should deliver heavy ion beams with the maximum energy of about $35A$ GeV starting from 2013 onward.

The JINR Nuclotron has a possibility to accelerate heavy ions (up to A$\simeq$200) to a maximal energy of $5A$ GeV in about a year. This gives the unique possibility to address experimentally many recent problems within the next several years before the FAIR accelerators will come into operation. Possible new program at the Nuclotron may be considered as a pilot study preparing for the detailed investigations at SIS-100/300 [6] and as an integral part of the world scientific cooperation to study the energy dependence of hadron production properties in nuclear collisions.

The rapid experimental progress at high energies (SPS, RHIC) as well as new theoretical developments rise numerous important questions which can be answered only by new data at low energies ($<15A$ GeV). The most important subjects which in our opinion should be studied theoretically and experimentally at the Nucleotron energies are listed below.

1. **Modification of hadron properties in the dense phase of strongly interacting matter.** The masses and the widths of hadrons are expected to change significantly in the vicinity of the phase transition boundary[8, 9]. More precisely, the *spectral function* with the same quantum number as the hadrons can be modified in association with a change of the QCD vacuum. For short-lived low mass vector mesons and σ meson, their spectral functions can be measured directly via their decays into di-leptons and photons[8, 10]. Dilepton and photon pairs from these decays are very difficult to measure due to the small branching ratios and the very large combinatorial background (Dalitz decays, γ conversions as well as π and K decays). Typical experimental requirements are: a good momentum resolution, unambiguous identification of electrons, muons and/or photons produced at the interaction vertex, and a high event collection rate leading to high statistics data samples. Due to these challenging requirements only very few experimental results exist and new high quality measurements are very important.

2. **Mechanisms of equilibration in high energy nuclear collisions.** Existing data indicate a large degree of equilibration of the matter [7]. The mechanisms of equilibration are still unclear. In particular, a large difference between dynamical and statistical models is observed for heavy baryons (e.g. for multi-strange hyperons, Ξ and Ω and resonances) measured at high energies [11]. The corresponding data for the Nuclotron energies are missing. We are expecting that future Nuclotron measurements will give a strong input for a further development of dynamical and statistical approaches and help to distinguish between these two types of models.

The multi-strange hyperons are measured via their cascade-type decay process into charged hadrons. The experimental identification of these decays requires a large acceptance hadron tracking detector with a good momentum resolution and precision measurements of secondary vertexes. The multiplicity of heavy hadrons, and in particular anti-baryons, is very low in low energy nuclear collisions and thus high statistics data samples are needed.

3. **Fluctuations in relativistic strongly interacting matter.** The experimental study of event-by-event fluctuations (e.g. multiplicity fluctuations) in nuclear collisions gives a unique possibility to test recent predictions concerning fluctuations in relativistic strongly interacting matter [12].

   The measurements require a large (ideally full) acceptance tracking detector and a precise control of collision centrality by event-by-event measurements of the number of projectile spectators. It is also recommended to identify charged hadrons (pions, kaons and protons) on an event-by-event basis, which would allow to study baryon number and strangeness fluctuations. From the experimental point of view the Nuclotron energy range seems to be ideal for these measurements. This is because a moderate particle multiplicity and their relatively broad angular distribution simplifies efficient detection of all produced charged particles. In addition the fixed target configuration of experiments at the Dubna Nuclotron allows measurements of the number of projectile spectators. Up to now only results in a very limited acceptance at high energies are available, thus the new measurements at the Nuclotron energy are of particular importance.

4. **The energy dependence of hadron production properties.** Production of heavy hadrons, fluctuations and long range correlations, are measured only at SPS and RHIC energies. The corresponding measurements below $15A$ GeV are missing. They are necessary for physical understanding of the current detailed measurements at higher energies. Thus measurements of these quantities at the Nuclotron energies should be seen as a necessary continuation of the global effort to establish the energy dependence of hadron production properties in search for the signals of deconfinement and the critical point.

Our proposal is in general compatible with the main goals of the research program developed by the working group and appended to this report.

Clearly the ambitious physics goals of the research program and our report should now be confronted with the available technical, manpower and financial resources. This requires quantitative evaluation of the experimental requirements based on model predictions for the relevant quantities. Due to large theoretical uncertainties it is important to perform critical tests of the models used against existing experimental data.

The general opinion is that the detector facilities available now at the Nuclotron are not enough and a close cooperation and coordination of experimental efforts between different national and international centers (CERN, FAIR, BNL, FNAL) are needed.

Marek Gazdzicki
(University of Frankfurt, Germany and Swietokrzyska Academy, Poland)
Mark I. Gorenstein
(Bogolubov Institute of Theroretical Physics, Ukraine)
Teiji Kunihiro
(Yukawa Insitute for Theoretical Physics, Kyoto University, Japan)
Viatcheslav D. Toneev
(Joint Institute for Nuclear Research, Dubna)

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