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Subj: Report on the Habilitation Thesis "Heavy ion collisions: a femtometer laboratory for studies of the nuclear matter phase diagram and hadron-hadron interactions from SIS18 to LHC energies" by Dr Georgui Kornakov Van

Dr Kornakov has submitted a Habilitation Thesis consisting of a cycle of ten articles [H1-H10] published in leading refereed journals with high impact factor (6) and in renowned Proceedings journals (4). These works are based on his main contributions as an experimentalist to the goals of the three collaborations to which he belongs as a member: HADES at GSI Darmstadt [H1, H5-H10], ALICE [H2, H4] and AEgIS [H3] at CERN Geneva. The HADES and ALICE experiments are situated at the low- and high-energy limits of the global effort to explore the phase diagram of nuclear matter within systematic beam energy scan programs. These investigations are performed in order to delineate the phase border between hadronic matter and the quark-gluon plasma and to study the phenomena that are related with the hadron-to-quark matter transition. Hereby the state of matter probed in these terrestrial laboratory experiments bears similarities with very different extreme states of matter in the evolution of the cosmos:

- ALICE studies matter at high temperatures that is approximately symmetric in the abundances of particles and their antiparticles like in the early universe. It recreates the big bang at a femtoscopic scale (Little Bang).
- HADES achieves high baryon densities and low temperatures similar to those occurring in the merger of two neutron stars or during a core-collapse supernova, again on the femtoscale (Femto-Nova).

The achievements of Dr Kornakov that are described in the Thesis have contributed to reaching the very different goals of these experiments which are performed as a multinational effort of mankind to deepen our understanding of the fundamental laws of nature that govern the phases of strongly interacting matter and the transitions between them. In the following, I shall review more in detail these contributions to the success of the experiments and the results that were obtained, as outlined in the habilitation Thesis.

At SIS18 energies (HADES) the works were focused on hadronic [H1, H6, H7, H8, H9, H10] and electromagnetic probes [H5]. At LHC energies (ALICE), two particle correlations were used to measure the duration of the final hadronic stages of the fireball [H2] and the strong interaction between baryons and antibaryons [H4]. An

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alternative path to study the interaction between the lightest baryons (protons) and their antimatter partners (antiprotons) is presented in [H3].

Dr Kornakov has contributed new analysis methods to the experiments. In HADES, he contributed to the particle identification by his development of the time-of-flight calibration as described in [H10], the enhancement of the electron-positron pair identification outlined in [H5] and the new iterative method of reconstruction of short-lived resonances detailed in [H6] which was essential in obtaining the results described in the HADES publication [H1] to which the author contributed with a dominant fraction of the work (75%). This new iterative method is a key achievement of Dr Karnakov which alllows to identify signal and background contributions without the use of input models or normalization constants. The publication [H6] in EPJA on the iterative method, coauthored with Tetyana Galatyuk, can be considered like a single-authored paper of Dr Kornakov because his contribution to it amounts to 90%. In situations with a large combinatorial background the application of this method allows to reconstruct broad resonances which are important for understanding the dynamics of heavy-ion collisions.
For the ALICE experiment, Dr Kornakov developed the basics of the femtoscopic analysis technique that was used in the publications [H2] and [H4] in Physics Lett. B.

The calibration methods developed by Dr Karnakov in [H10] allowed to improve the timing of the Resistive Plate Chamber detector from 100 ps to 64 ps. Furthermore, he has developed a position-sensitive calibration method that led to an improvement of the precision of the time measurement by 20%. The new techniques and calibration strategies developed by Dr Karnakov had a direct impact in the works [H1, H5, H7-H9] and the HADES publications that were using the Time-of-Flight method as a particle identification method starting from 2014.

Dr Karnakov coordinated and supervised the realisation of the RICH backtracking algorithm to enhance the di-electron signal in HADES. A precise determination of the di-electron spectrum is essential for diagnosing the matter properties in early stages of the heavy-ion collision.
The hadronic signals and the related particle identification on the other hand are essential for the analysis of the hot and dense hadronic matter at the later stages of the heavy-ion collision, at the chemical and kinetic freezeout, as illustrated in Fig. 1.

After having reviewed the contributions of Dr Kornakov to the development of new methods in heavy-ion collision experiments, a few remarks on the scientific results obtained with them are in order.

A striking result which was broadly accepted in the heavy-ion physics community, is the measurement of the true temperature of the fireball produced in Au+Au collisions

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at the SIS18 of the GSI Darmstadt. For a center-of-mass energy 2.42 GeV in the nucleon-nucleon system, the fit to a blackbody spectral distribution of the di-electron pairs emitted from the fireball stage of the collison which is opaque to hadrons gives an inverse slope parameter (temperature) kT=71.8 +/- 2.1 MeV.
This can be compared to the freeze-out temperature kT_fo =50 MeV for the Δ++ resonance in the most central events which was reconstructed from the analysis of the transverse momentum spectrum of the π+p pairs. These impressive scientific reesults are of great importance for the ongoing search for the existence and location of the critical endpoint (CEP) in the QCD phase diagram. Together with the information from lattice QCD that the temperature of the CEP should be below 130 MeV, one can now focus in the search on experiments with energies below √s ~ 6 GeV, as was oulined by Peter Senger [Phys. Scripta 96 (2021) 054002].

The Thesis presents a rich body of frontier research work in a well structured and logic manner. It is formulated in very good English language with only a few typos.

Beyond the excellent scientific results, made possible due to the new contributions to the analysis techniques of heavy-ion collision experiments that were introduced by Dr Kornakov, he has an impressive activity as a scientific leader in the planning and conduction of the experiments as well as in the conceptual development of new collaborations like the AegIS experiment. This is an important aspect of the habilitation as an independent scientist, qualified to lead a scientific group.

Summarizing, I conclude that the Habilitation Thesis and the scientific activity of Dr Karnakov fulfil all necessary criteria for promoting him to a habilitated doctor in the physical sciences. I recommend the Thesis to the Faculty for its acceptance.

David Blaschke

Wroclaw, 12.08.2022

Prof. dr hab. Dr h.c. David Blaschke