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Report on the PhD thesis of Ing. Jakub Cimerman

Dear Madams and Sirs,

I was asked to provide my expert opinion on the PhD thesis of Ing. Jakub Cimerman, entitled "Fluid Dynamical Models for Relativistic Nuclear Collisions". In his thesis, Ing. Cimerman, investigates strongly interacting matter (i.e. matter governed by the theory of Quantum ChromoDynamics, QCD) as it is currently produced and explored in relativistic heavy ion collisions or is present in Neutron Stars or the early Universe. The thesis is divided into eight Chapters and followed by an Appendix.

Chapter 1 provides a very short introduction and summary of the thesis.

Chapter 2 then turns to the most important features of the Quark-Gluon-Plasma (QGP). It gives a short introduction to the quark model and the idea of asymptotic freedom, and then moves over to current days heavy ion program and its relation to the phase transitions of QCD.

Chapter 3 introduces the main observables studied in heavy ion reactions. Ing. Cimerman begins with the space-time rapidity and the eigen-time (sometimes called Milne coordinates) and the rapidity and transverse momentum distributions. From their he continues with a description of the collective flows (v1, v2, .., vn) and extensively discusses the event-plane and (higher order) cumulant methods to estimate the n-particle reaction plane.

The next Chapter begins with a historical introduction and then presents the hydrodynamic equations of motion for an ideal fluid and a viscous fluid followed by a short discussion of the shear viscosity and its extraction from data.

In Chapter 5, the thesis focuses on the initial state for the hybrid simulations. Here, Ing. Cimerman compares three different approaches for the calculation of the initial state of the hydrodynamics evolution: UrQMD, Glissando and TRENTO. Then the vHLLE code is used to evolve these initial conditions to the particlization surface,

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followed by UrQMD to obtain final states that can be compared to experimental data. Ing. Cimerman shows that the rapidity spectra provide substantial information on the initial state and can distinguish between the different fits and the UrQMD calculation. On the contrary (and surprisingly), transverse momentum spectra and elliptic and triangular flow do not seem to be sensitive to different implementations of the initial state. This (non-)effect is however to a certain extend artificial, because the UrQMD and Glissando initial states are both strongly Glauber MC like and the chosen TRENTO initial conditions are rather similar for the specific symmetric system. However, for the longitudinal structure and the AFTER@LHC experiment Ing. Cimerman can nicely demonstrate that there is a large discrimination power between the different initial conditions.

In Chapter 6, he turns to the three-fluid hydrodynamical model. Here he starts from the definition of the initial conditions, this time chosen as a slightly different version of the Glauber MC initial conditions. Then he describes the evolution and coupling of the multiple fluids, which are the main building blocks of the multi-fluid model. Finally, Ing. Cimerman provides the Equations-of-State, which is needed to close the system of equations. Finally, particlization happens on a constant energy density surface via a Cooper-Frye prescription. To obtain individual hadrons in events the SMASH hadron sample is used. Generally, such an approach is state-of-the-art, however, I had hoped that Mr. Cimerman would have been a bit more critical about the used implementation of the SMASH sampler.

Chapter 7 shows the large body of results of the three fluid hydrodynamical simulations. Here he starts with the centrality determination and continues with first results on the rapidity spectra of charged hadrons at various energies and centralities. Then he turns to the baryon stopping and also here the three fluid model shows a good description of the data. Unfortunately, the transverse momentum spectra of protons and especially anti-protons seem to be more difficult to describe with the current set of parameters. The mismatch between simulation and data seems most pronounced towards very central collisions which might indicate a too strong absorption in the SMASH afterburner. Further problems seem to emerge when exploring the elliptic flow, especially at lower energies, which might also be related to the freeze-out prescription.

Chapter 8 summarizes the thesis and provides final conclusions.

The thesis of Ing. Cimerman addresses topics at the front of todays physics research, combining viscous relativistic hydrodynamics and (non-abelian)QCD matter. He applied a multitude of complicated (state-of-the-art) numerical methods to solve large sets of coupled (integro-)differential equations. The obtained results are very valuable and can be (or have already been) published in top international journals. The goal of the thesis has been reached and the obtained results are presented in a clear and structured way.

Therefore, I recommend to accept this thesis for presentation and defense.

Your sincerely,

Univ.-Professor Dr. habil. Dr. h.c. Marcus Bleicher