

Popular science summary of the project

Asymptotic freedom at the earliest stage of relativistic heavy-ion collisions

Soon after the Big Bang when the Universe was young, small and hot, matter was in the form of *quark-gluon plasma*. Using currently available laboratory facilities, physicists are able to create drops of the plasma colliding heavy nuclei which are accelerated almost to the speed of light. Quark-gluon plasma reveals various amazing features but the most puzzling is a plasma's behavior just after its birth. The aim of the project is to study properties of such a nonequilibrium quark-gluon plasma.

Quarks and gluons are constituents of elementary particles – *hadrons* which interact strongly. These forces are responsible, in particular, for binding together *neutrons* and *protons* into atomic nuclei. Quarks and gluons carry *color charges*, which are similar to electric charges, but in contrast to the latter, color charges can exist only in color neutral (white) configurations. This is the *confinement hypothesis* which forbids nature to isolate any color quark or gluon. Therefore, quarks and gluons are always constituents of bigger objects like protons, neutrons or macroscopic quark-gluon plasma which are all neutral as a whole.

Quantum Chromodynamics – the theory which governs the behavior of the quarks and gluons that carry color charges – reveals the unique property that forces acting among quarks and gluons become weaker and weaker, or color charges become smaller and smaller, when distances between interacting particles decrease. One says that the system becomes asymptotically free or non-interacting.

Since a quark-gluon plasma can be created by squeezing or heating up nuclear matter, there are no doubts that the plasma was present in the early Universe. It might well be that a plasma is present today in the dense cores of massive neutron stars. The most exciting, however, is a possibility to create a plasma in terrestrial laboratories by colliding relativistic heavy ions. This is an objective of large scale experimental programs. Theoretical physicists are responsible for providing an adequate description of the collisions.

The earliest stage of relativistic heavy-ion collisions is the least known part of the collision scenario because there are hardly any experimentally accessible direct signals of the phase and its characteristics are “forgotten” in the subsequent temporal evolution of quark-gluon system during which it reaches local thermodynamic equilibrium, evolves hydrodynamically, experiences a transition to the hadron phase and finally decouples into free hadrons which are ultimately registered in particle detectors.

The goal of this project is to study two rather general theoretical problems related to the physics of quark-gluon plasma from the earliest stage of relativistic heavy-ion collisions. The first and main problem is whether the plasma is a strongly or weakly interacting system, whether it resembles an ideal gas or if color forces present in the system dominate its behavior. More technically we ask whether the regime of asymptotic freedom regime is reached at the earliest stage of relativistic heavy-ion collisions, or whether the coupling constant is small.

The second problem we address concerns properties of non-equilibrium quark-gluon plasma which is assumed weakly coupled but populated with strong chromodynamic fields. In analogy to electromagnetic plasmas we call such a quark-gluon plasma *turbulent* and we ask how the turbulent plasma evolves in time and how heavy quarks, like charm and beauty, interact with it. We intend to study how a transient state of turbulent plasma influences characteristics of heavy quarks which fly across it.