In modern physics, there are four fundamental interactions: gravitational, electromagnetic, weak and strong. This project is devoted to the study of the latter one. The theory of strong interactions is called quantum chromodynamics (QCD). The strong interactions are responsible for elementary building blocks, called quarks and gluons, binding together into protons, neutrons and other particles. The same interaction creates the nuclear forces, which bind protons and neutrons into atomic nuclei, which are the centres of the atoms, which in turn are the building blocks for everything that we can see around in everyday life. Interestingly, the mass of the proton or neutron constituents is only 2% of the mass of the particle. It means that the mass of these particles is generated by strong interactions and, therefore, even almost all mass of each of us is generated by strong interactions! That is why, QCD is an important part of the Standard Model of particle physics. However, there is no full understanding of the QCD, because the first-principle and analytical results are not yet available due to the complexity of this theory. One of the most interesting open questions is whether we can find free quarks and gluons. And it seems that the answer is no. But under extreme conditions of very high temperature and pressure it is possible to create a special state of matter which is formed from the deconfined quarks and gluons – quark-gluon plasma (QGP). The only ab-initio studies of the strongly interacting matter properties predict the smooth change from the gas of particles to the QGP. However, these studies are quite limited due to numerical problems. Nevertheless, the studies of QCD matter properties in the effective models suggest that under strong compression the QCD matter may exhibit a so-called first-order phase transition with the critical endpoint, which is somehow similar to the water boiling. This and other predicted effects may result in a highly nontrivial phase structure of the theory.

At the same time, one of the key goals of nuclear collision experiments at high energies is to study the QCD phase diagram. Comparing experimental data with different model calculations, one can conclude about some properties of strongly interacting matter under extreme conditions, where existing theoretical approaches are not applicable. But, due to the absence of definite predictions made by the first-principles calculations, even to interpret the experimental data, it is necessary to use effective and phenomenological models.

One of such state-ot-the-art methods to describe heavy-ion collisions is a simulation of such a process with hybrid models based on the hydrodynamical simulation of the hot and dense matter evolution. But these models require the physical input in the form of the equation of state, which contains all information about the thermodynamical properties of the system that affect its evolution.

This project is devoted to the problem of the construction of the effective equation of state of QCD matter, applicable for hydrodynamic simulations of heavy-ion collisions at finite temperature and density region of the QCD phase diagram. Such an equation of state is necessary to model heavy-ion collisions in the range of moderate center of mass energies. This is a subject of particular interest for future and ongoing experiments whose primary aim is the determination of the QCD phase structure (NA61, STAR, MPD, CBM). Using a hybrid model, we will simulate heavy-ion collisions with different equations of state and perform an a-posteriori data-driven analysis of the QCD matter properties in the unsolvable regions of the phase diagram to constrain the location of the critical point and the first-order phase transition line.

As the result of this work, we will provide the community with a set of reliable equations of state for hydrodynamical simulations of heavy-ion collisions in a wide range of centre of mass energies, as well as with predictions and baselines for key observables for future and ongoing experiments.