

All of the known elementary particles and forces (except the gravity) are included in the so-called Standard Model. It provides a mathematical description of the interactions in terms of the quantum fields. Apart from electromagnetic interactions, known from everyday life and described in terms of electron and photon fields, and the so-called weak interactions, responsible for example for some radioactive decays, the Standard Model describes also strong interactions. They govern the structure of hadrons – particles made of quarks and gluons. The theory of quark and gluon interactions is called Quantum Chromodynamics (QCD). Quarks are somewhat similar to electrons, but, apart from smaller (fractional) electric charge, they possess additional type of a charge called color. Gluons exchange the color between quarks, meaning they are responsible for color quark interactions. Moreover, gluons can interact with each other, what makes the QCD theory very complicated. A very interesting aspects of the theory is that all observable particles that are build of quarks and gluons have no color. It is the so-called color confinement property.

Another property of hadrons that is directly connected to the topic of the following project, is their mysterious behavior during collisions at velocities close to the speed of light. Imagine a particle that probes such a speeding hadron. It can be a quark or a gluon belonging to another hadron, or for example a photon. Typically, the probe collides with just one quark or gluon, but it turns out, that the density of gluons grows rapidly with the increase of the collision energy, and, ultimately, gluons dominate and fill in the whole hadron. One can ask a question: what happens if we still increase the energy? Theoretical computations show that gluons create a sort of condensate possessing certain collective properties. When increasing the energy even further, the gluon density stops to grow – this is the so-called gluon saturation phenomenon. It is directly related to the fundamental property of gluon fields that satisfy non-linear field equations. At present, experiments with hadrons colliding at very large velocities are done at Large Hadron Collider (LHC) at CERN. However, not every collision happens with hadrons that are saturated. Such events can be filtered (or tagged) thanks to detectors (more precisely their parts called calorimeters) of particles produced at small angles with respect to the colliding beams. Some current LHC detectors are planned to be upgraded to account for such calorimeters with excellent resolution. Another crucial experiment in the context of gluon saturation physics is the Electron Ion Collider (EIC) that will be build in the USA. Despite several attempts, the gluon saturation has not been discovered yet, although there are some hints in the experimental data.

The goal of the present project is to develop new theoretical tools that will allow for precision calculations of quantities sensitive to gluon saturation, that in turn can be compared with experimental data. The new methods have to accommodate a description of the processes with elementary strong interacting particles (quarks and gluons), as well as a description of hadrons at high energies. In order to achieve that, we will extend the newest quantum field theory methods, as well as some existing methods that have not been used in the regime of gluon saturation. The goal of the project is, however, not only to develop a theoretical formalism, but also its implementation as a computer program that can be used to calculate observable effects of gluon saturation at LHC and EIC. Such computations are indispensable to make possible discovery of that fascinating state of matter.