Final Report Summary - HILHC (Heavy Ion Collisions: from RHIC to LHC)

The Large Hadron Collider (LHC) is the world’s most important project in high energy physics. With its dedicated experiment on heavy ion (HI) physics, the LHC focuses on the unique possibility of creating and studying a new state of matter, quark gluon plasma (QGP), at energy densities similar to those of the early Universe. The quest for QGP is also the driving force behind the currently operating (though at much smaller energies) Relativistic Heavy Ion Collider (RHIC). The fundamental theory underlying the proton structure as well as the one responsible for nuclear forces is Quantum ChromoDynamics (QCD), the theory of strong interactions.

The study of QCD under extreme conditions of high energies, temperatures and densities has been for long one of the most challenging problems in physics, capturing increasing experimental and theoretical attention. Understanding QCD at high energies is an essential ingredient for success of the LHC program. It is also one of the most active frontiers both in particle phenomenology and nuclear physics and one of the topics where both fields clearly profit from close collaboration.

In particular, a theoretical description of HI collisions and the formation of QGP from first principle calculations is still missing. This project is aimed at achieving a qualitatively new level of understanding of HI collisions, both theoretically and phenomenologically, through the development of a new QCD-based description of these processes.

Both searches for new physics at the LHC in proton-proton and investigations of high energy medium effects in HI collisions require a solid understanding of multiple gluonic interactions. The same effects should be present, though less pronounced, at currently operating accelerators.

Gluon densities rise rapidly with energies as has been discovered by Hadron-Electron Ring Accelerator (HERA) at German Electron Synchrotron DESY.

When probed at very high energies, proton appears like a very dense cloud of gluons. Part of this project is to develop a new theory for high energy collisions of dense objects.

This is an essential problem for LHC especially for its heavy ion program, where the effects of high gluonic densities get enhanced not only by very high energies but also by the number of nucleons in nuclei.

The prime objective of our research project is to develop QCD-based effective theory for the initial (pre-thermalization) phase of high energy collisions of heavy nuclei, as well as to reach systematic phenomenological description of certain class of measurements which are of particular importance for HI program at the LHC. Contrary to previous approaches largely based on models, we intend to derive this theory from the first principle calculation within the fundamental theory. Achieving our phenomenological objectives requires not only understanding of initial conditions encoded in the QCD wavefunctions of the colliding particles, but also to follow evolution of the dense gluonic system first through non-equilibrium and then QGP phases.

One of the main goals of our research program is to use perturbative resummation techniques to derive an effective field theory valid at high energies and high gluonic densities. We are to study the total cross section, multiplicities, momenta distributions and various correlations of particles produced in the collision.
These results shall be used as initial conditions for subsequent time evolution through the plasma phase. The plasma evolution is to be modeled by means of a new hydrodynamic description, which is to be developed using string/gravity-inspired methods.

Major progress has been achieved in understanding the QCD at high energies. An effective field theory of QCD was derived and explored in various limits. New degrees of freedom, reggeons, relevant at high energies were introduced and transition vertexes between various types of the reggeons were studied. The theory was also refined towards increasing its accuracy via a set of works in which next-to-leading corrections in the coupling constant were computed. The results obtained during this project involve a thorough understanding of two-particle correlations produced in high multiplicity proton-proton and heavy ion events at the LHC.

New, all order hydrodynamic model of QCD plasma inspired by the fluid/gravity correspondence was proposed. It’s relevance for the total multiplicity of produced particles at the LHC was established.

The list of publications which came out from this research project is:


Tolga Altinoluk, Néstor Armesto, Alex Kovner, Eugene Levin, Michael Lublinsky, "KLWMlj Reggeon Field Theory beyond the large Nc limit", Accepted to JHEP.
