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For a few millionths of a second, shortly after the Big Bang, the Universe was filled with an astonishingly hot, dense soup made of all kinds of particles moving at near light speed. This mixture was dominated by quarks – fundamental bits of matter – and by gluons, carriers of the strong force that normally bound quarks together into familiar protons and neutrons and other species. In those first evanescent moments of extreme temperature, however, quarks and gluons were bound only weakly, free to move on their own in what's called a quark-gluon plasma (QGP).

To recreate conditions similar to those of the very early Universe, powerful accelerators make head-on collisions between massive ions, such as gold nuclei at Relativistic Heavy Ion Collider (RHIC in operation since 2000) located at Brookhaven National Laboratory in the US or lead nuclei at the Large Hadron Collider (LHC in operation since 2010) at CERN in Switzerland. In these heavy-ion collisions the hundreds of protons and neutrons in two such nuclei smash into one another at energies of upwards of a few trillion electronvolts each. This forms a minuscule fireball in which everything “melts” into the QGP.

The fireball instantly cools, and the individual quarks and gluons (collectively called partons) recombine into a blizzard of ordinary matter that speeds away in all directions to be finally caught by enormous detectors. The debris contains a wealth of particles such as pions and kaons, which are made of a quark and an antiquark; protons and neutrons, made of three quarks; and even copious antiprotons and antineutrons, which may combine to form the nuclei of antiatoms as heavy as helium. Much can be learned by studying the angular distribution and energy of the particles within this debris.

Over the last decade scientists discovered the QGP formed in heavy-ion collisions at RHIC and later at a factor of 14 higher energy at the LHC. An early discovery at RHIC was that the QGP behaves more like a perfect fluid with small viscosity than like a gas, as many researchers had expected. The unexpected properties of the QGP have largely been confirmed by heavy-ion experiments at the LHC. But many mysteries remain about the nature of the quark-gluon interactions that hold together our visible world and how they evolved from this early Universe.

The much greater collision energies expected in 2015-2018 at the LHC push measurements to much higher energies than are accessible at RHIC, allowing new and more detailed characterization of the QGP. Theoretical understanding of these measurements is challenging, however, is one of the most important problems in quantum chromodynamics, the theory that explains how quarks and gluons can interact between themselves.

Within this project scientists from the Institute of Nuclear Physics PAS and AGH University of Science and Technology from Kraków carry out a set of high-impact measurements of heavy-ion collisions collected by the ATLAS experiment at the new unprecedented energy which will be provided for the first time in the fall of 2015 by the LHC. Our team has gained a lot of experience contributing to a number of measurements published based on analyses of lower-energy lead collisions collected in years 2010-2013 by ATLAS. This project will advance our understanding of matter in the QGP state and will allow to set the stage for the future heavy-ion explorations at yet higher luminosity at the LHC.