The state of the early universe: The beginning was fluid

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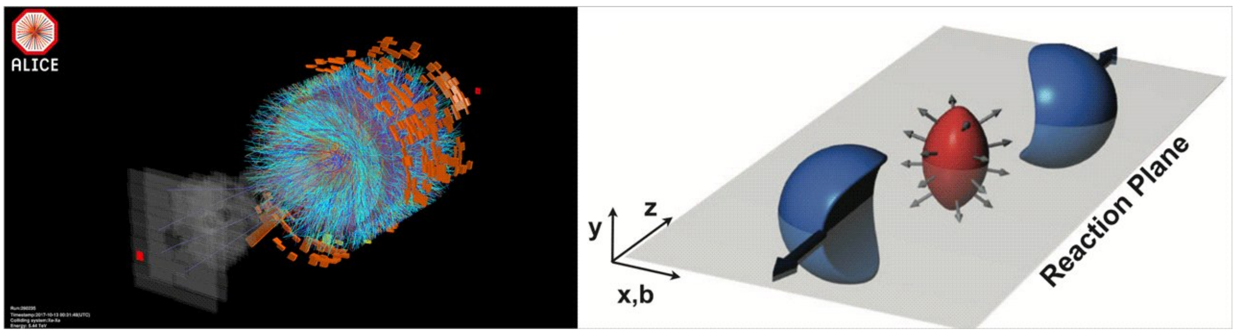

[Left] An event from the first Xenon-Xenon collision at the Large Hadron Collider at the top energy of the Large Hadron Collider (5.44 TeV) registered by ALICE [credit: ALICE]. Every colored track (The blue lines) corresponds to the trajectory of a charged particle produced in a single collision; [right] formation of anisotropic flow in relativistic heavy-ion collisions due to the geometry of the hot and dense overlap zone (shown in red color). Credit: University of Copenhagen

Scientists from the Niels Bohr Institute, University of Copenhagen, and their colleagues from the international ALICE collaboration recently collided xenon nuclei in the superconducting Large Hadron Collider in order to gain new insights into the properties of the quark-gluon plasma (QGP). The QGP is a special state consisting of quarks and the gluons that bind the quarks together. The results were published in *Physics Letters B*.

The researchers replaced the lead ions usually used for collisions with xenon ions. Xenon is a smaller atom with fewer nucleons in its nucleus. When colliding ions, scientists create a fireball that recreates the initial conditions of the universe at temperatures in excess of several thousand billion degrees. In contrast to the universe, the lifetime of the droplets of QGP produced in the laboratory is ultra-short, a fraction of a second (about 10^{-22} seconds). Under these conditions, the density of quarks and gluons is very high, and a special state of matter forms in which quarks and gluons are quasi-free, in the strongly interacting QGP state. The experiments reveal that in the instant before atoms formed in the universe, primordial matter behaved like a liquid that can be described in terms of hydrodynamics.

"One of the challenges we are facing is that, in heavy ion collisions, only the information of the final state of the many particles which are detected by the experiments are directly available—but we want to know what happened in the beginning of the collision and first few moments afterward," says You Zhou, postdoc in the research group Experimental Subatomic Physics at the Niels Bohr Institute. "We have developed new and powerful tools to investigate the properties of the small droplet of QGP that we created in the experiments."

The researchers studied the spatial distribution of the many thousands of particles that emerged from the collisions when the quarks and gluons were trapped into the particles that the universe consists of today. This reflects not only the initial geometry of the collision, but is sensitive to the properties of the QGP. It can be viewed as a hydrodynamical flow. "The transport properties of the quark-gluon plasma will determine the final shape of the cloud of produced particles after the collision, so this is our way of approaching the moment of QGP creation itself," You Zhou says.

The degree of anisotropic particle distribution—the fact that there are more particles in certain directions—reflects three main pieces of information: The first is the initial geometry of the collision. The second is the conditions prevailing inside the colliding nucleons. The third is the shear viscosity of the quark-gluon plasma itself. Shear viscosity expresses the liquid's resistance to flow, a key physical property of the matter created. "It is one of the most important parameters to define the properties of the quark-gluon plasma," You Zhou explains, " because it tells us how strongly the gluons bind the quarks together."

"With the new xenon collisions, we have put very tight constraints on the theoretical models that describe the outcome. No matter the initial conditions, lead or xenon, the theory must be able to describe them simultaneously. If certain properties of the viscosity of the quark gluon plasma are claimed, the model has to describe both sets of data at the same time," says You Zhou. The possibilities of gaining more insight into the actual properties of the "primordial soup" are thus enhanced significantly with the new experiments. The team plans to collide other nuclear systems to further constrain the physics, but this will require significant development of new LHC beams.

More information: S. Acharya et al, Anisotropic flow in Xe–Xe collisions at sNN=5.44 TeV, *Physics Letters B* (2018). DOI: 10.1016/j.physletb.2018.06.059

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