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Title: Electric charge correlators from lattice QCD

Abstract: Quark gluon plasma, that once made up the whole Universe, can be recreated in particle accelerators. The Standard Model makes precise predictions to the pattern how this fluid radiates, and about its break-up as it cooles down beyond a certain temperature. Scientists at the University of Wuppertal calculated the expected electric charge distribution as a function of temperature by simulating the strong force on Jülich supercomputers. As the experiments gain precision we will learn on the temperature and other features of the plasma at its final moment.

Outside of our planet Nature forces matter to endure extreme conditions. In the core of neutron stars, which are remainders of medium sized stars the density well surpasses those of the minuscule nuclei that we can observe on Earth. When such dead stars collide, and they do, as recently observed gravitational waves are telling us, the temperature can be tens of thousands times hotter than the center of our sun. It might be surprising to hear that such high temperatures can be created in Earth-bound laboratories. In 2012 a Guiness record was set up by the Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC) at 4 trillion degrees Celisus, only to be broken soon by the Alice experiment at the Large Hadron Collider at CERN near Geneva, Switzerland. In a tiny patch of space, imagine a sphere, about 20 femtometers across, such temperatures recreate the conditions in the Early Universe at a time when it was just a few microseconds old.

Under such extreme conditions matter assumes phases that are utterly new to human experience. This phase, the so called quark gluon plasma, is most like an ideal fluid, that radiates various particles, thereby signalling its temperature. As it is cooling down by expansion, quite analogously to our Universe, it passes a point where its phase switches back to ordinary matter, including protons, neutrons and alike. This freezing is not a sudden transition, but a cross-over. We know this from computer simulations at the University of Wuppertal, where the unterlying theory, Quantum Chromodynamics was investigated using GPU-based computer clusters back in 2006.

In fact, Quantum Chromodynamics (QCD) can be simulated very efficiently on graphics processors, like those installed at the JUWELS/Booster system at FZ-Jülich. The reason for this is that GPUs were developed for gaming, that mostly involves, fast rotations of objects and textures. QCD describes the strong interactions in terms of generalized rotations of four dimensional fields. This could be efficiently implemented on several generations of graphics cards by various research groups.

In this project the theory group in Wuppertal addressed the statistical pattern of the break-up of the Quark Gluon Plasma. These data are recorded by the leading experiments at RHIC and LHC. The distribution of the electric charge in heavy ion collisions, too, is temperature dependent, and can, in principle, be predicted by simulating the Standard Model. This, however, has been hindered by large discretization errors so far. Such discretization effets arise when the continuous space-time is viewed through a coarse mesh.

With the support of FZ-Jülich (13.8 million core hours on Juwels/Booster) the PI and his team met the challenge of eliminating the discretization errors. The computer power allowed the use fine discretizations, but it was equally important to first redesign the discretization in a novel scheme to avoid previous unrealistic assumptions on the particles that carry the strong force Thus, the Standard Model's prediction on the electric charge distribution could be recovered in a continuum for the first time.

The results have been presented at the Quark Matter conference in 2022 and the final results are prepared for publication at the moment.