2024

Return of the prodigal Goldstone-Nambu boson

Hungarian physicists from MATE Institute of Technology, Gyöngyös and Eötvös University and HUN-REN Wigner RCP Budapest, leading a paper preparation group in the PHENIX experiment at the RHIC accelerator in Brookhaven National Laboratory, USA, observed that an anomalously massive particle, the so called eta-prime boson looses about 40 % of its mass in hot and hadronic, strongly interacting matter. Furthermore, the mass of the modified eta-prime meson becomes similar to the mass of the other members of its particle family, indicating the restoration of particle symmetry, predicted theoretically more than 40 years ago but observed experimentally only in 2024.

High energy particle and nuclear accelerators – located predominantly in the USA, Europe, and recently also in Japan – provided collisions measured by cutting edge particle detectors, built and operated in large international scientific collaborations. These data suggests that in ultra-relativistic collisions of heavy ions create the so-called Little Bangs, that in many ways create circumstances that are similar to the conditions of our Universe after a few microseconds after the Big Bang. In these collisions, the strongly interacting nuclear matter melts down, and a nearly perfect fluid of quarks is observed. This hot quark soup expands and consequently cools down both in the Big Bang and in the Little Bangs and takes on its everyday, observable form.

The four experiments (BRAHMS, PHENIX, PHOBOS and STAR) operated at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory in the US summarized in 2005 the results their first few years of datataking in renowned (5000+ cited) papers. They reported the observation of a new phenomena, that can be explained with the creation of a new form of matter, and determined that this matter flows like a nearly perfect fluid, with nearly vanishing mean free path. This observation was in sharp contrast to the theoretical expectations, that suggested a gas-like behaviour, where the mean free path tends to be as large as the system size.

During 2007, PHENIX observed that the degrees of freedom of this nearly perfect fluid are the quarks, corresponding to the basic building blocks of hadrons, the strongly interacting particles. Quarks are colorful, they carry a „color charge”, that regulates their participation in color exchange, that mediates the strong interactions. Matter that consists of protons, neutrons and other, directly observable strongly interacting particles called hadrons are color-white or color-neutral. Thus the 2027 observation that the nearly perfect fluid at RHIC flows on the level of colorful quarks corresponds to color deconfinement, a theoretical prediction from the 1980-s. However, theoretical predictions of the theory of strong interactions suggested not only one, but at least two transitions. **Our results in the PHENIX experiment, that concluded a 15 year long data analysis, observed a second transition in Au+Au collisions at RHIC energies.**

In the PHENIX experiment at RHIC, we have found a signal for a nearly 40 % reduction of the so-called η’ (eta-prome) meson in hot and dense hadronic matter, illustrated in Figs. 1 and 2.

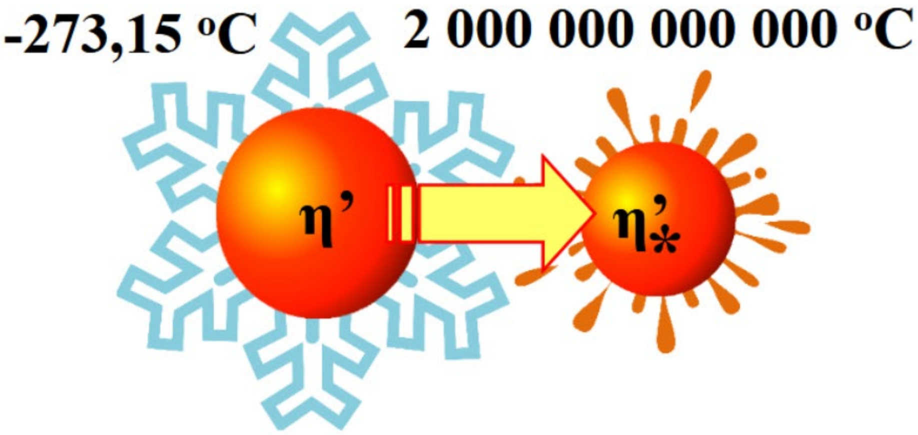

Figure 1: Reduction of the mass of the η’ meson in hot and dense hadronic matter at 2 terakelvin, below the temperature of color deconfinement.

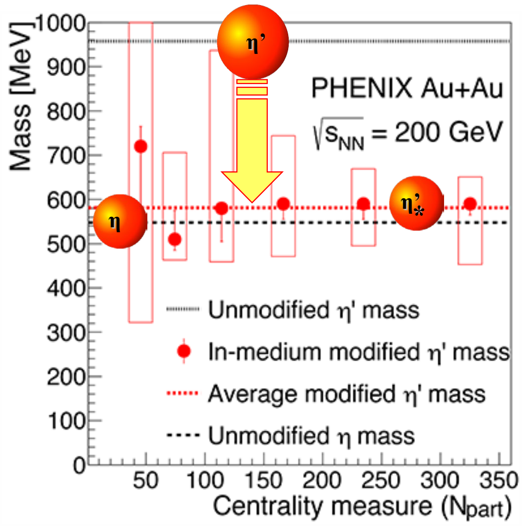

Fig. 2: PHENIX experimental results on the in-medium mass reduction and the return of a prodigal Nambu-Goldstone boson [2].

This η’ meson in earlier measurements, corresponding to measurements in the vacuum at absolute zero temperature, at – 273,15 °Celsius, was found to be anomalously heavy, with mass nearly twice as heavy as the mass of the other pseudoscalar mesons, that have the same quark content. According to the new PHENIX results [1], in hot and dense, but color confining hadronic matter, the mass of the η’ meson becomes similar to the mass of its particle-twin, the mass of the η meson. At the same time, this reduced mass of the in-medium modified η’ meson becomes similar to the mass of the kaons, the pseudoscalar particles that have strange quark content. This implies the return of a Nambu-Goldstone boson in hot and dense, color confining matter: **a second, theoretically long time predicted transition in Au+Au collisions at $\sqrt{s_{NN}}$ =200 GeV is now observed by PHENIX.**

The PHENIX paper [1], reporting an analysis of data taken in 2010, was published in December 2024 and received the honor of Editor’s Suggestion of the Physical Review C. The paper was prepared by the researchers of HUN-REN Wigner RCP, with leading contributions also from the Laboratory of Femtoscopy, MATE Institute of Technology, Gyöngyös and Institute of Physics of the Eötvös University, Budapest.

References:

1. PHENIX Collaboration (M. Csanád, T. Csörgő, G. Kasza, D. Kincses, S. Lökös, A. Ster et al): https://doi.org/10.1103/PhysRevC.110.064909
2. Suggestions by the Editors of the Physical Review C: https://journals.aps.org/prc/