

Experimental study of matter under the influence non-abelian gauge theory

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Abstract. Physical phenomena, which are observed in our daily life, are dominated by electromagnetic interaction, an abelian gauge theory. In the region of highest experimentally reachable temperature and density, the strong interaction or QCD dominates. In this region, nuclear matter displays exotic properties which arise due to the non-abelian nature of QCD. In this talk I will illustrate some theoretical predictions of QCD using recent results from the ALICE Experiment.

1. Asymptotic freedom in quantum chromodynamics

Quantum chromodynamics (QCD) is the currently accepted theory that describes the phenomena of strongly interacting particles. It is a non-abelian gauge theory based on $SU(3)$ symmetry group. A particular feature of non-abelian gauge theory is asymptotic freedom [1, 2]. The origin of this feature is that the running behavior of coupling constant in non-abelian gauge theories is not only due to the fermion loops, but also due to gauge boson loops. The two kinds of diagrams produce opposite effects: the fermion loop diagrams tend to screen the pole charge, while the gauge boson loop diagrams tend to augment (antiscreen) the pole charge.

In QCD, the lowest-order beta function for the strong coupling α_3 is given by

$$\beta_3(\alpha) = \frac{\alpha_3^2}{\pi} \left(-\frac{33}{6} + \frac{n_f}{3} \right) \quad (1)$$

where n_f is the number of quark flavors. If the beta function is negative, the theory is asymptotically free. For QCD, it is asymptotically free as long as the number of quark flavors is less than 16. Experimentally, the number of quark flavors is 6, thus QCD is asymptotically free.

The thermodynamic property of strongly interacting matter is shown in the QCD phase diagram as shown in figure 1. A particular region in the phase diagram is the quark-gluon plasma region, which is the QCD analogy of electromagnetic plasma. In this region, the quarks are deconfined and together with the gluons, they form the quark-gluon plasma.

In order to study the property of matter under the influence of QCD in the asymptotic (short-distance) region, nuclei are accelerated and are collided at high energy to create highly compressed nuclear matter, as shown in figure 2. The quark-gluon plasma is behaving like a perfect liquid of strongly interacting matter. As this drop of perfect liquid expands and cools down, it hadronizes into the more well-known hadrons (mesons and baryons), which can be observed experimentally.



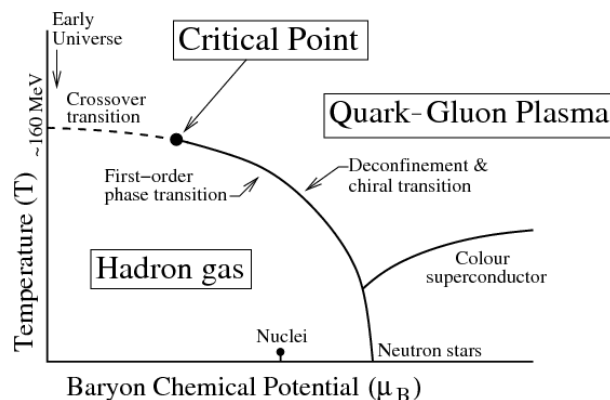


Figure 1. The thermodynamics phase diagram of QCD matter. Figure is taken from [3].

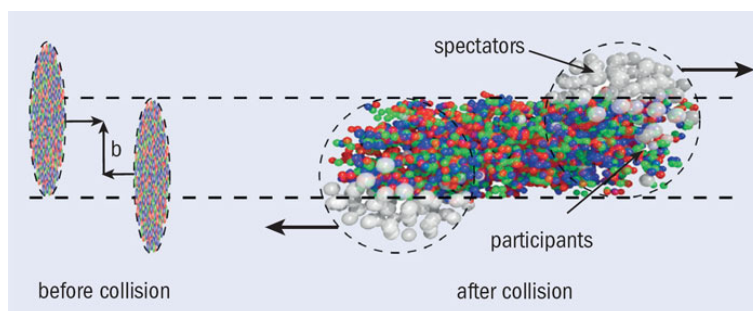


Figure 2. Collisions of two heavy nuclei in relativistic heavy ion collisions. The collisions are not always head-on, thus sometimes some of the nucleons become spectators while the rest become participants. Figure is taken from [4].

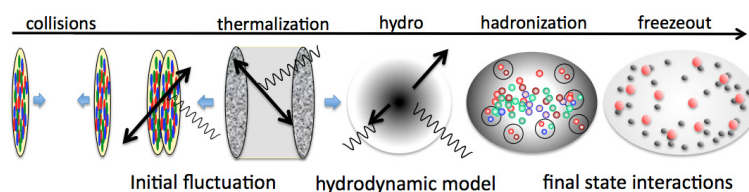


Figure 3. The expanding quark-gluon plasma cools down and hadronizes into the known hadrons. Figure is taken from [5].

2. Phenomenology and experimental results of heavy-ion collisions physics

One of the dedicated experiments to study quark-gluon plasma is A Large Ion Collider Experiment (ALICE) [6] at the Large Hadron Collider (LHC) [7]. The ALICE detector, shown in figure 4 is the only detector at the LHC that is designed specifically to optimally study the phenomena of quark-gluon plasma. The core of ALICE consists of tracking detectors, which provide three-dimensional tracking capability in busy environments, and particle identification detectors, which is used to separate protons, pions and kaons.

The ALICE detector is also capable of studying physical phenomena in proton-proton

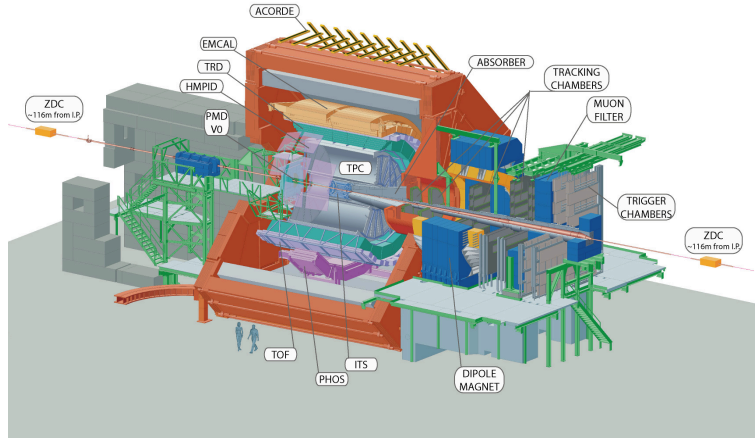


Figure 4. The ALICE Detector. Figure taken from [6].

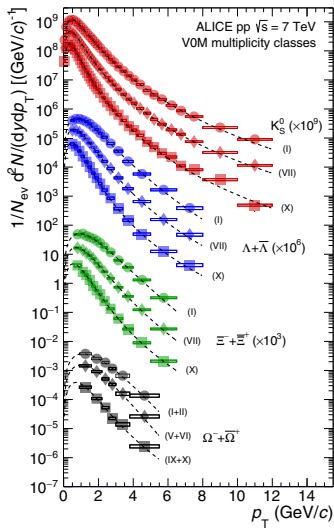


Figure 5. Production spectra of strange meson and baryons in proton-proton collisions. Figure from Ref [8].

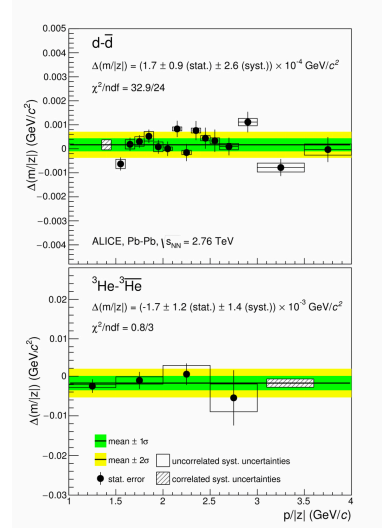


Figure 6. The mass difference of nuclei-antinuclei measured by ALICE. Figure from Ref [9].

collisions, in complementary of ATLAS and CMS. In 2016, ALICE reported the observation of enhancement in strangeness production measured in the spectra of kaons, Λ s, Ξ s and Ω s in proton-proton collisions as shown in figure 5 [8]. This enhancement is interpreted as formation of quark-gluon plasma in proton-proton collisions, and thus opens new possibilities to study quark-gluon plasma in a system smaller compared to ion-ion collisions.

The environment of heavy-ion collisions also provides the opportunity to observe and measure the property of antinuclei. ALICE has reported the first measurements of mass differences between deuteron-antideuteron, and between He^3 and $\bar{\text{He}}^3$ as shown in figure 6 [9].

3. The future of ALICE Experiment

ALICE is planned to undergo major upgrade during the Long-Run Shutdown 2 (LS2) of the LHC [10]. The inner tracking systems will be completely rebuilt [11], the time projection chamber readout pads will be replaced with new pads made using gaseous electron multiplier [12], and the data acquisition system and offline computing will be merged into one [13].

ALICE is expected to run for a data-taking period of 6 years beyond LS2, providing even more opportunities for probing the property of strongly interacting matter under QCD. The future is surely rich with new possibilities of physics topics to be studied with ALICE.

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