論文内容の要旨

論文題目：Dynamics of non-perturbative particle production in strong gauge fields
（強ゲージ場中の非摂動論的粒子生成のダイナミクス）

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Particle pair creation from vacuum in the presence of an external field is one of the most remarkable consequences of quantum field theory. We investigate this problem as a mechanism of matter formation in the initial stage of relativistic heavy-ion collisions, especially focusing on its real-time dynamics.

Despite the great success of the perfect fluid description of a quark-gluon plasma (QGP) for relativistic heavy-ion collisions, an understanding of how produced matter reaches thermal and chemical equilibrium is still lacking. In the framework of the Color Glass Condensate, which is an effective theory to describe high-energy nuclei in saturated region, it has been shown that high density gluons which are emitted from colliding nuclei can be interpreted as coherent classical color electromagnetic fields polarized in a longitudinal beam direction. Given this situation, describing how particles emerge from the coherent fields is of prime importance in order to get an understanding of the formation process of QGP.

Because heavy-ion collisions are dynamic systems, a real-time description of pair creation is necessary. We describe the space-time evolution of the quantum state of charged particle fields in the presence of strong electromagnetic fields in terms of the mode functions of charged particles, taking into account the back reaction of the particle production to the background field. The time evolution of momentum distributions of created particles is presented, which show collective motion of plasma oscillation and quantum effects as well, such as the Bose enhancement/Pauli blocking and interference between matter fields.

Getting an understanding of how quarks are produced in a system of heavy-ion collisions is important because chemical equilibrium between light quarks and gluons is expected in QGP state, while the initial state of heavy-ion collisions is considered as a gluon-dominated state. Therefore, we investigate quark pair production under SU(3) color electric fields. By the procedure of Abelianization, we introduced a gauge-invariant parameter characterizing the direction of the color field in color space. We find that although the momentum distribution of each colored quark strongly depends on the color direction of the field, field quantities such as the color current and the total number density of created quarks are rather insensitive to it.

We also examined the role of pair creation for the isotropization of pressure. The initial state with the coherent electric field is quite anisotropic: longitudinal pressure is positive and transverse pressure is negative. At later time, created quarks are accelerated by the field and generate positive longitudinal pressure. Moreover, the field strength is weakened by the back reaction, so that pressure by the field is also weakened. As a result, anisotropy in pressure is moderated. This is a collision-less mechanism of isotropization and may assist thermalization expected in heavy-ion collisions.

Because the formation of color magnetic fields as well as electric fields in a longitudinal beam direction is predicted by the Color Glass Condensate model, We investigated the effects of a magnetic field which is parallel to the electric field. Due to emergence of the Landau levels, scalar particles become effectively heavy under the magnetic field, and thereby their pair creation is suppressed. In contrast, pair creation of spinor particles is enhanced by the magnetic field. This is because (i) spinor particles in the lowest Landau level do not become heavy because of the spin-magnetic field interaction, and (ii) the number of modes degenerating in one Landau level is proportional to the magnetic field strength. This enhanced pair creation makes the time evolution of the system faster through the back reaction. Furthermore, induction of chiral charge in the magnetic field is discussed.

In heavy-ion collisions, electric fields are generated only between two color-charged plates of Lorentz-contracted nuclei receding from each other a velocity close to the speed of light. In an ideal situation where the two nuclei run at exactly the speed of light, the electric fields span only inside the forward light cone. The dynamics of particle production in electric fields of such configuration is studied. A characteristic of this field configuration is its boost invariance in the longitudinal direction. By formulating the field quantization in a curvilinear coordinate, we show that particles are created preserving the boost symmetry of the background

and they have the same velocity distribution as the Bjorken flow from a first instant they are created. These particles are quantum-mechanical superpositions of several momentum modes. This fact brings non-trivial rapidity correlations among the particles. We calculate the two-particle correlations between these particles, and find that the correlation is short-range with respect to the transverse momentum, which originates in the Bose-Einstein/Fermi-Dirac correlation, and is long-range with respect to the longitudinal rapidity. This result is interesting in the context of the near-side ridge phenomena observed in nucleus-nucleus collisions at RHIC and recently observed also in proton-proton collisions at LHC.