# Nonequilibrium properties of quark-gluon matter for NICA energies

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**Abstract**

Theoretical search for observable effects in pp- and AuAu-collisions at NICA energies is the main aim of studies of LPI group. The topics are widely spread from internal strucfure of colliding objects and non-equilibrium quantum fields at the very initial stages of the quark-gluon medium to anisotropic hydrodymanics and ultraperipheral processes. Analitical expressions and Monte-Carlo programs obtained in these studies will be used for experiments planning and comparison with future experimental data. Brief review is given in this talk. More details can be found in talks of Radovskaya and Kovalenko and in the published papers referred to.

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# 1 Keldysh-Schwinger diagrammatic technique for scalar $\phi^4$ and semiclassical approximation [1, 2]

The initial stage of the quark-gluon plasma formed during heavy ion collisions is subject of the intensive interaction of quantum fields. Evolution of the non-equilibrium quantum fields from a highly excited initial state is studied in two approaches: the standard Keldysh-Schwinger diagram technique and the semiclassical expansion. It is demonstrated explicitly that these two approaches coincide if the coupling constant g and the Plank constant h are small simultaneously. Thus, it is shown that these approaches are two facets of one general way to deal with nonequilibrium quantum fields. The shear viscosity for the scalar field theory is calculated at the leading semiclassical order. The new technique that unifies both semiclassical and diagrammatic approaches is developed. Numerical simulations of observables are envisaged.

# 2 Anisotropic hydrodynamics [3]

Stability of shock waves in anisotropic hydrodynamics

Hot and dense hadronic matter created in the early stages of relativistic heavy-ion collisions has strong spatial anisotropy. The rapid expansion of matter along the beam-axis in the first moments after the collision leads to a strong drop in the ratio of longitudinal and transverse pressures. One of the hydrodynamic descriptions of such a system is the anisotropic approach, in which the anisotropy parameter is explicitly introduced for the one-particle distribution function. The question of how to generate shock waves in a quark-gluon plasma is still open, but it is clear that they exist in such a medium, that is very well described by hydrodynamic equations. Shock waves are closely related to the jet quenching effect and hadronization; therefore, it is especially interesting to study them in the context of anisotropic system. Registration of shock waves in matter created in relativistic collisions of heavy nuclei directly depends on the degree of their stability. The stability of shock waves has not yet been studied for anisotropic hydrodynamics.

The purpose of this report is to highlight the problem of shock wave stability in anisotropic relativistic hydrodynamics. The influence of small perturbations on the behavior of the discontinuity surface will be considered, and the dependence of this behavior on the anisotropy parameter will also be studied.

# 3 Ultraperipheral processes [4, 5, 6, 7, 8, 9]

Large-distance ultraperipheral collisions of two relativistic ions are considered. The clouds of photons surrounding the ions are responsible for their distant electromagnetic interaction. It is argued that the cross sections of ultraperipheral interactions of heavy nuclei can become comparable in value to those of their ordinary hadronic interactions at high energies. Spectra of unbound electron-positron pairs (dielectrons, in brief) and photons from decays of parapositronia produced in ultraperipheral collisions of electrically charged objects are calculated. Their shapes at energies of the NICA collider are demonstrated. It is shown that production of low-mass e+e- pairs in ultraperipheral nuclear collisions is enhanced due to the Sommerfeld-Gamow-Sakharov (SGS) factor. This effect is especially strong near the threshold of creation of unbound e+e- pairs with low masses in the two-photon fusion. It can enlarge the outcome of 511 keV photons at NICA energies. Their observation would be important for understanding some astrophysical effects.

# 4 Further plans

It is planned to deal with such problems as:

1. Effects of baryon junctions in particle production at NICA energies
2. Developed hydrodynamic turbulence in anisotropic hydrodynamics
3. Monte-Carlo models at NICA energies and comparison with experimental data on mutiplicities, transverse momenta, pseudorapidity etc
4. Role of strings and multiparton interactions at NICA.
5. Proposal for NICA-detectors of ultraperipheral processes

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